Models RGA120, RGA220, RGA320
Residual Gas Analyzer

User Manual

Revision 1.04 (6/6/2024)

Certification

Stanford Research Systems certifies that this product met its published specifications at the time of shipment.

Warranty

This Stanford Research Systems product is warranted against defects in materials and workmanship for a period of one (1) year from the date of shipment.

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Safety and Preparation for Use

WARNING!

Dangerous voltages, capable of causing injury or death, are present in this instrument. Use extreme caution whenever the instrument cover is removed. Do not remove the cover while the unit is plugged into a live outlet.

Line Cord

The RGA built-in power module option (Opt02) has a detachable, three-wire power cord for connection to the power source and to a protective ground. The exposed metal parts of the instrument are connected to the outlet ground to protect against electrical shock. Always use an outlet which has a properly connected protective ground.

Service

Do not attempt to service or adjust this instrument unless another person, capable of providing first aid or resuscitation, is present.

Do not install substitute parts or perform any unauthorized modifications to this instrument. Contact the factory for instructions on how to return the instrument for authorized service and adjustment.

Fan

The fans in the RGA are required to maintain proper operation. Do not block the vents in the chassis or the unit may not operate properly.

Specifications

Operational

Mass Range:	
RGA120	1 to 120 amu
RGA220	1 to 220 amu
RGA320	1 to 320 amu
Mass filter type	Quadrupole (Cylindrical rods, rod diameter: 0.25”, rod length: 4.5”)
Detector type	Faraday cup (FC) - standard Electron multiplier (CDEM) - optional
Resolution (per AVS standard 2.3).	Better than 0.5 amu @ 10% peak height Adjustable to constant peak width throughout the entire mass range.
Sensitivity (A/Torr)*	$2 \cdot 10^{-4}$ (FC) <200 (CDEM). User adjustable throughout high voltage range.
Minimum detectable partial pressure (MDPP)*	$5 \cdot 10^{-11}$ Torr (FC). $5 \cdot 10^{-14}$ Torr (CDEM).
Operating pressure range	10^{-4} Torr to UHV (FC) 10^{-6} Torr to UHV (CDEM)
Max. bakeout temperature (without ECU)	300°C
Operating Temperature	70 °C (max.)
Recommended bakeout temperature	200 °C (O100HJR Heater Jacket recommended)
Total press. measurement	Available with FC ion current measurements

* Measured with N_2 @ 28 amu with 1 amu full peak width @ 10% height, 70 eV electron energy, 12 eV ion energy and 1 mA electron emission current.

Ionizer

Design	Open ion source, cylindrical symmetry.
Operation	Electron impact ionization.
Material	Stainless steel, type 304.
Filament	Thoriated Iridium (dual) with firmware protection. Field replaceable.

Degas	1 to 8 W Degas ramp-up.
Electron energy	25 to 110 V, programmable.
Ion energy	4 to 16 V, programmable.
Focus voltage	0 to 110 V, programmable.
Electron emission current	0 to 4.0 mA, programmable.

Analog Output

Function Emission Current, RTD Temperature, Flange Temperature, Total Pressure, Mass Ion Current, Analog Scan Ion Current, or User Value

Range	**Voltage**	0 to 20 V
	Current	4 to 20 mA
Resolution	**Voltage**	0.3 mV
	Current	0.4 µA
Accuracy[1]	**Voltage**	±0.1 % + 5 mV
	Current	±0.1 % + 10 µA

[1]Output accuracy specifications are for User values. For linked output values, the accuracy is determined by the measured parameter being output

Max Output Current (Voltage Out) 50 mA

Max Load Resistor (Current Out) 750 Ω

Analog Input

Functions User Value or Overpressure Indicator

Range	**Voltage**	0 to 10 V
	Current	4 to 20 mA, 4 to 20 mA with Loop Power
Resolution	**Voltage**	1 µV
	Current	1 nA
Accuracy	**Voltage**	±0.1 % + 5 mV
	Current	±0.1 % + 10 µA
Input Impedance		
	Voltage	10 kΩ each lead to ground
	Current	100 Ω nominal
Absolute Maximum		
	Voltage	24 V
	Current	25 mA

Loop Power Voltage

Range	0 to 20 V
Resolution	0.005 V
Max Current	50 mA

Event Relay

Function	configurable DPDT relay that can be set to switch on an event or set by user
Events	Analog Input Current or Voltage Limits, Mass Ion Current Limit, Communications Idle Timer

Relay Contact Rating

Max Switching Power	60 W, 75 VA
Max Switching Voltage	125 VDC, 150 VAC
Max Switching Current	2 A

GPIO

Function	configurable digital output or digital input. Digital output can be set to switch on an event or set by user.
Output Events	Analog Input Current or Voltage Limits, Mass Ion Current Limit, Communications Idle Timer
Output Voltage Limits	Lo 0 V, Hi 3.3 V
Input Voltage Limits	0 to 3.3 V
Absolute Maximum	3.3 V
Transition Voltage	Programmable. Default 1.65 V

RTD Input

Nominal Pt RTD Resistance	100 Ω (at 0 C)
Nominal Lead Resistance	0.25 Ω
Voltage Out Maximum	3 V
Current Out Maximum	1 mA

Trigger Input

Voltage Limit	0 to 3.3 V
Absolute Maximum	3.3 V
Transition Voltage	Programmable. Default 1.65 V

Computer Interface

Ethernet

Connector	RJ45
Speed	10/100 Base-T
Protocols	TCP, UDP and DHCP

USB

Connector	USB Type B
Speed	USB 2.0 Full speed (12 Mbps)
Chipset	FTDI230XQ
Device Class	USB communication device class (CDC)
Software Drivers	Virtual COM Port (VCP) driver from FTDI
Baud rate	115200

RS-232

Connector	9 pin D-Sub Female Connector
Format	8 Bits, 1 Stop Bit, No Parity, CTS/RTS hardware flow control
Baud Rate	28800

General

Probe dimension	8.75” from flange face to top of ionizer
Probe insertion	2.0”
Probe mounting flange	2.75” CF
Minimum port I.D.	1.375”
ECU dimensions	9.1” x 4.1”x 3.1”. Easily separated from the probe for bakeout.

LED indicators	Power (ON/OFF), Filament (ON/OFF), CEM (ON.OFF), Degas (ON/OFF), Communication Activity (Busy signal), Communication Error, Pressure Error, and System Error.
Software	Windows OS based application.
Power Requirement	24 VDC @ 2.5 Amps. Standard barrel connector, 5.5mm OD, 2 mm ID. Optional 110/120/220/240 VAC (50/60 Hz) built-in power module.
Weight	6 lbs.
Warranty	One year parts and labor on materials and workmanship.

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Chapter 1

Getting Started

This chapter describes the process of unpacking, checking and installing the SRS RGA on a vacuum system.

Please read and follow all installation instructions to ensure that the optimum performance of the instrument is not compromised during the installation process.

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Unpacking

Before You Open the Box

1. To reduce the chance of contamination, do not remove the RGA probe from its plastic shipping container until moments before it is ready to be installed in the vacuum system.

2. Follow good high vacuum practice. Set aside a clean, dust free, work area next to the vacuum port before installation begins.

3. Please read and follow all installation instructions in this chapter to insure that the optimum performance of the instrument is not compromised during the installation process.

4. Do not power up the instrument until it is instructed in the installation procedure.

5. Take a moment at this time to read the CDEM Handling and Care section of the RGA Maintenance chapter if your unit includes the electron multiplier option (Option 01).

6. Do not operate the RGA if the pressure in the chamber is greater than 10^{-4} Torr. Consult Appendix B for information on Pressure Reduction Systems.

7. Read the RGA General Operation chapter of this manual for an overview of the instrument and its functions.

8. Inspect all components of the SRS RGA System upon unpacking. Report any damage to Stanford Research Systems immediately. Compare the contents of the shipping container with the Checklist below and report any discrepancies.

Checklist

Standard Equipment / Supplies

1. One RGA Probe (in sealed plastic container)

2. One Electronics Control Unit box

3. One USB cable (6’ or 1.6 m long)

4. Three Terminal Block Plugs for analog I/O (6 positions), RTD (8 pos.) and relay (3pos.) connections

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Optional Equipment

1. Option 01 Electron multiplier. Preinstalled at the factory.

2. Option 02 Built-in power module for AC line operation (Option 02). Preinstalled at the factory. Includes one power cord.

3. Option 03 Electron Multiplier Ion Counting Output (must also have Option 01.)

Accessories

1. O100RF Replacement Thoriated Iridium Filament Kit.
2. O100RI Replacement Ionizer Kit (includes filament).
3. O100EM Replacement Electron Multiplier.
4. O100HJRW 200 °C Heater Jacket for RGA (cannot be used with O100MAX)
5. O100MAX Maximum Insertion nipple with 4.5" ConFlat (CF) Flange (Factory installed; standard nipple not supplied when this option is ordered).
6. O120C Cable (10 ft.) for user-supplied +24 VDC power supply, locking
7. MRGAX20 Replacement manual for RGA120 family

Related Equipment

1. UGA100/200/300 Universal Gas Analyzer system.
2. PPR100/200/300 Vacuum Process Monitoring system.
3. CIS100/200/300 Closed Ion Source quadrupole mass spectrometer.
4. IGC100 Ionization Gauge Controller

Installation

Introduction

The standard SRS RGA System consists of:

1. RGA Probe
2. Electronics Control Unit (ECU)
3. RGA Software (RGASoft)

Specific hardware requirements and installation instructions are needed for each one of the components**.**

Important

- Follow the installation steps in the strict order in which they are presented in this chapter.

- Do not power up the instrument until it is indicated in the procedure.

- Read the hardware requirements before installation begins. Do not start the installation procedure until all requirements are met.

- Please read and follow all installation instructions to ensure that the optimum performance of the instrument is not compromised during the installation process.

Probe Installation

The RGA probe can be mounted on any standard 2 3/4" CF port of the vacuum chamber that provides enough clearance for the ionizer's outer cage.

A stainless steel tube (RGA Cover Nipple) covers the probe assembly with the exception of the ionizer. The ionizer is the only component of the probe that protrudes into the vacuum system (see Figure 1-1.)

Warnings:

- Do not remove the probe from its plastic shipping cover until it is ready to be installed in the vacuum system.

- Do not remove the RGA Cover Nipple from the probe. The stainless steel tube is an integral part of the quadrupole assembly and the RGA will not operate properly without it. Please consult the Hardware Modifications section in the RGA Quadrupole Probe chapter of this manual for information on operating the RGA probe without its factory provided cover nipple.

- Do not disassemble or modify the quadrupole probe in any way without reading first the Hardware Modifications section of the RGA Quadrupole Probe chapter.

- Use proper vacuum procedures while installing the probe:
  Set aside a clean, dust free, work area next to the vacuum port.
  Wear gloves!
  Do not talk or breathe directly into the probe's ionizer.
  Use clean tools during the installation procedure!

- Protect the integrity of the Vacuum seals:
  Do not use nonmetal seals.
  Avoid scratching the metal seals.

- Verify that the vacuum port is electrically grounded before attempting the installation of the RGA Probe on the vacuum system.

Hardware Requirements

1. Do not operate the SRS RGA in corrosive gas environments. If the presence of corrosive gases in the vacuum environment is known or suspected, consult SRS before installing the probe in the vacuum chamber.

2. Do not operate the SRS RGA in the presence of strong magnetic fields. Magnetic fields, such as those caused by superconducting magnets or cold cathode total

pressure gauges (i.e., Penning type), can affect the ion trajectories through the quadrupole filter resulting in very unreliable measurements. If the presence of magnetic fields in the vacuum environment is known or suspected, consult SRS before mounting the probe on the vacuum chamber.

3. The maximum operating pressure of the RGA is 10^{-4} Torr. A pressure reduction system is required if the operating pressure of the vacuum chamber is greater than 10^{-4} Torr. Consult Appendix B of this manual for details.

4. The probe can be mounted directly onto any standard 2 3/4" CF port of a vacuum chamber provided the following placement requirements are met:

   - The vacuum port must have at least 1.375" internal diameter and 2.5" depth to provide enough clearance for the ionizer (The insertion volume is comparable to that required by a nude Bayard-Albert ion gauge).

   - Any mounting orientation of the probe may be used.

   - The ionizer is the only component of the probe that protrudes into the vacuum system and it must be located close to the point where partial pressures are to be measured. If placed near a pump, the pressure in the ionizer may be considerably lower than in the rest of the system. If placed near a gas inlet or source of contamination, the pressure in the gauge may be much higher. Long tubulation or other constrictions between the ionizer and the rest of the vacuum system can cause large errors in the partial pressure readings.

   - The probe must be distanced or shielded from all other instruments that could potentially affect the RGA readings. For example, cross-talk with hot-cathode ion gauges is possible but easily eliminated by proper shielding or changes in the relative placement of the gauges.

   - The probe must be protected from evaporation sources that could coat the ionizer.

   - Enough clearance must be allowed for the ECU box that attaches directly to the probe's feedthru flange.

   - Choose the orientation of the ECU box prior to the installation of the probe. Six different orientations can be obtained rotating the probe about its axis and lining up the bolt holes of the 2 3/4" CF flanges.

   Note: The ECU will operate in any orientation, but limited space, free access to the rear panel connectors and visual access to the LED's might limit the orientation options in your vacuum system.

5. The following equipment must be available before the installation procedure starts:

   - One standard OFHC copper gasket for 2 3/4" CF flange. New and clean!

   - Six high-strength stainless steel bolts for 2 3/4" CF flanges: Use six 1/4-28 x 1 3/8" bolts, with one nut and two washers per screw, for flanges with through

holes; or six 1/4-28 x 7/8" bolts, with one washer per screw, to attach the probe's flange to a tapped vacuum port. Both standard hex and 12-point bolt heads are compatible with the RGA's flange.
Use silver-plated bolts instead of messy anti-seize lubricants whenever available.

- Wrenches: One or two wrenches will be needed to tighten the six bolts and compress the copper gasket. Use a 7/16" 12-point wrench for standard hex head bolts and nuts, or a 1/4" 12-point wrench for 12-point bolt heads.

- Optional adapter flanges: Install an adapter flange in the vacuum system if no 2 3/4" CF ports are available. Zero-Length Adapter flanges, with a 2 3/4" CF flange on one side and a bigger size flange on the other, are an economical alternative to reducing nipples.

Procedure

1. Determine the placement of the probe in the vacuum chamber following the instructions listed in step 3 of the Hardware Requirements section.

2. Remove the probe from its plastic container.
Avoid contamination following good high vacuum practices. Do not touch with bare fingers any part of the probe that will be exposed to the vacuum. Do not talk directly at an open vacuum port.

3. Hold the probe in a secured upright position and do a thorough visual inspection of the part. Check for loose, damaged or misaligned components. Minor misalignments of the ionizer's outer cage (i.e., repeller) can occur during shipping and must be corrected before the ionizer is inserted into the vacuum chamber. Check the integrity of the metal seals in all CF flanges.
Important: Abort the installation procedure and contact SRS immediately if the probe appears damaged in any way.

4. Position the copper gasket and insert the probe's ionizer into the vacuum system. Rotate the probe about its axis and align the holes on the CF flanges, as necessary to achieve the desired orientation for the ECU box. Avoid scratching the vacuum seals and do not use non-metal gaskets.
Important: Avoid touching the internal walls of the vacuum port with the repeller cage during the installation procedure, since that could lead to serious misalignment

of the ionizer. Get an extra hand from a co-worker if necessary.

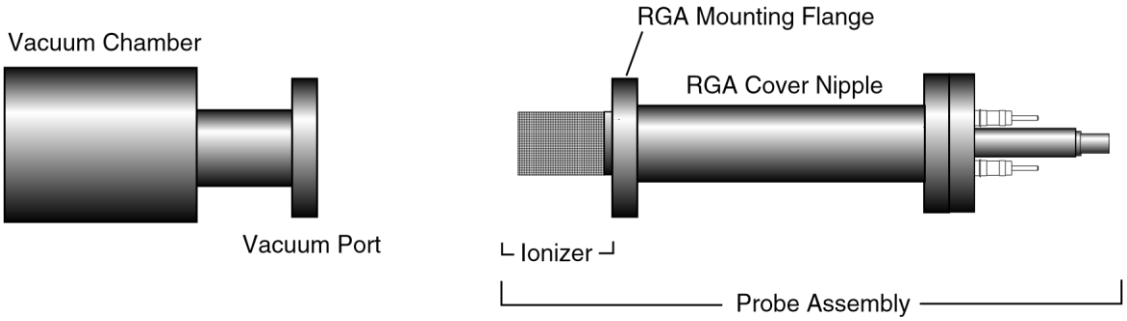

Figure 1-1 RGA Probe Installation

5. Insert the 6 bolts through the holes in the flanges and finger-tighten them. Tighten the bolts according to the standard tightening procedure for 2 3/4" CF flanges. Use 1/8 turns in crisscross order: 1, 4, 2, 5, 3, 6, 4, 1, 5, 2, 6, 3, 1.... until the flanges are in contact, and finish the tightening process with an extra 1/16 of a turn on each bolt.

6. Start pumping down the vacuum chamber as soon as the flange connection is sealed. The RGA probe is pre-cleaned and leak tested at the factory and should only contribute to the base pressure of the vacuum system through regular outgassing (i.e., mostly water) from its walls. If available, use the vacuum system's total pressure gauge to leak test the probe's connection and monitor the chamber's pressure as a function of time.

Important:

- Redo the metal seal if a leak in the vacuum system is detected after the probe is installed. Inspect the integrity of the seals before positioning the new copper gasket.

- Contact SRS immediately if a leak in the feedthru flange is detected or even suspected.

- Consult the Probe Bakeout instructions of the RGA Maintenance chapter if a bakeout is needed prior to exposing the probe to the vacuum system's main chamber.

- An overnight pump-down is needed in instruments with the electron multiplier option (Option 01). Consult the CDEM Pre-conditioning section of the RGA Maintenance chapter before applying any voltage across the CDEM.

- If available, use an ohmmeter to check for shorts between the feedthru flange connectors and the walls of the vacuum chamber. Vacuum ports with severely misaligned CF Flanges and/or large internal weld joints are not uncommon, and can result in a short between the ionizer and the inside walls of the vacuum port tube. If a short is detected, use the Feedthru Flange Connector Schematic in the RGA Probe Assembly chapter to identify the probe electrode that is causing the short. If the short is in the repeller, remove the probe from the vacuum system and correct the alignment of the outer repeller cage before reattaching the flanges (Correct alignment is best assured when the two small holes on the side of the repeller cage line up with

the filament screws). If the vacuum port is severely misaligned, and the short cannot be eliminated, consider replacing the vacuum port, using a different port or operating the RGA without the repeller (See Hardware Modifications in the RGA Quadrupole Probe chapter for instructions on operating without a repeller cage.)

Electronics Control Unit Installation

The Electronics Control Unit (ECU) attaches directly to the probe's feedthru-flange. Its correct alignment to the probe is very important during installation. Carefully follow the instructions below to insure proper alignment.

Warning:
Failure to follow the installation instructions below could result in damage to the ceramic feedthru connectors of the probe's flange, and would require sending the entire unit back to Stanford Research Systems for a complete flange replacement.

Hardware Requirements

1. External Power source:
   Standard ECU boxes require an external 24 V DC power supply @ 3 Amps (i.e. 72 Watt) to power its electronics.
   Units with the optional built-in power module (Option 02) plug directly into a wall AC outlet and require no extra power sources.

2. Power cables:
   External 24V power supplies must have a cable with a standard barrel connector (5.5 mm OD, 2.1 mm ID) on the free end.

   RGA units with the optional built-in power module (Option 02) are connected directly to a wall outlet using the three wire power cord provided by SRS.

3. Communication cable:
   The ECU can be connected to a computer using either an Ethernet, USB, or RS232 cable. Select one of the communication type and make sure the computer has the communication interface available.

4. The probe must be installed in the vacuum chamber before the ECU box is mounted on its flange.

Procedure

1. Begin by inspecting the front panel of the ECU box. Use the following diagram as a reference during installation.

2.

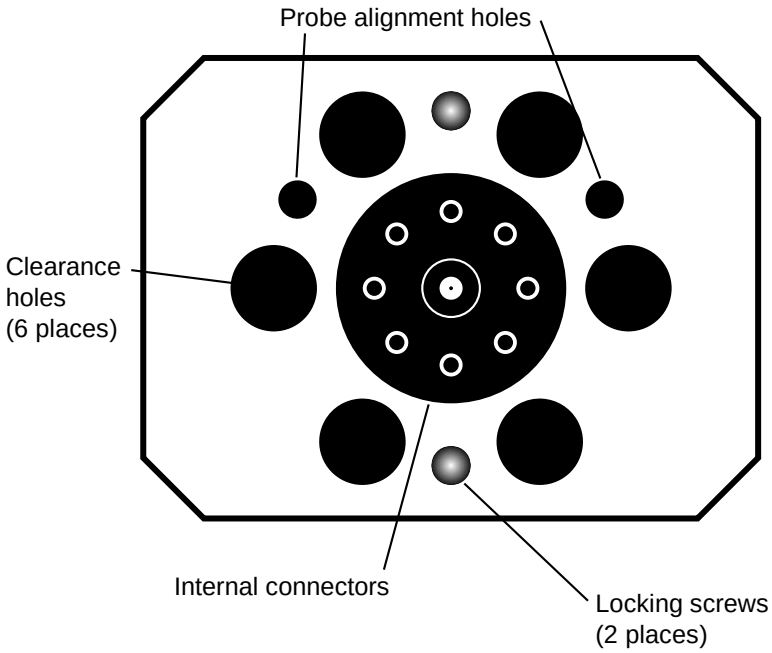

Figure 1-2 ECU Front Panel

3. Next, inspect the probe's feedthru flange:
   Eight ceramic feedthru connectors on a 1" diameter circle surround a center tube terminated by a coaxial connector. Two alignment rods (1/4" diameter) insure the correct alignment of the ECU box to the probe during installation and two threaded holes (1/4-28) line up with the locking screws of the ECU box.

4. Push the locking screws of the ECU box as far as they will go into the box.

5. Orient the ECU so that the two small alignment holes (1/4" diameter) on its front panel and the alignment rods of the flange line up. Note that there is only one correct way to do this!

6. Slide the ECU into the probe using the alignment rods as a guide, and until physical contact is made between the probe and the ECU's internal connectors.

7. Using **gentle pressure** on the back of the box, push the probe's conductors into the ECU's connectors until the front surface of the ECU rests flat against the back of the feedthru flange.

   Warning:
   The alignment of the probe/ECU connections is checked at the factory, for each

individual RGA system and only slight resistance should be experienced during this step. If significant resistance is noted while sliding the ECU onto the probe do not exert excessive force since that might damage the ceramic-to-metal seals of the feedthrus. Instead, rock the ECU box up and down, while gently pushing on its back, until the connectors line up. Once the connectors are all lined up, push the box in the rest of the way.

8. Once the ECU is in place, use the knobs on the back panel of the ECU box, to turn the locking screws and lock the assembly in place. Do not over tighten! (Hand tighten.)

9. ECU Power Connection:
   Important: Do not power up the RGA at this time.
   Standard ECU boxes must be connected to the external 24 VDC power supply. Insert the barrel connector into the ECU connector marked +24 VDC @ 2.5A on the back panel of the ECU box.
   Units with the optional built-in power module (Option 02) plug directly into an AC outlet and require no extra power sources: Use the power entry module on the back panel of the ECU box to power the RGA directly from an AC outlet. Use the three-wire power cord provided by SRS to connect the RGA directly to a properly grounded wall outlet.

10. ECU communication cable connection:
    Connect a communication (RS232, USB, or Ethernet) cable to connect the computer to the RGA.

    With a USB cable (type A to type B), insert the type B connector into the ECU connector marked as “USB”, and the type A connector to a USB port on the computer or a USB hub.

    With an Ethernet cable (Cat 5 or 6), insert a connector into the ECU connector marked as “LAN”, and insert the other connector into an Ethernet switch. The computer should be connected to the same network with the switch.

    With an RS232 cable (straight-through, DB9 Female to DB9 male), insert the 9 pin, type D male connector into the ECU connector marked as “RS232 DCE/28.8k/N/8/1”, and the 9 pin female connector to an RS232 port on the computer. For a computer without a RS232 port, you may have to use a RS232-to-USB adapter.

RGA Software Installation

Minimum System Requirements (Single RGA Operation)

- Computer running with Microsoft Windows 10 (64-bit version) or later
- USB, Ethernet, or RS232 port available on the computer.
- USB (type A to type B), Ethernet (Cat 5 or 6), or RS-232 (Straight through, DB-9 to DB-9) cable.

- 200 Mbytes of free hard disk space (more disk space is required for scan data).
- RGASoft software downloaded from the SRS website at www.thinkSRS.com.

Procedure

1. Turn on the computer and start Microsoft Windows.
2. Run the RGASoft installer program (file *RGASoft-<version>-x64.exe*).
3. The software is automatically and completely installed by the RGASoft Setup Wizard. Read and follow all instructions.
4. An "SRS RGASoft" program group with the "RGASoft" icon is automatically created at the end of the installation process. The "Documentation" link provides the online help on a web browser.
5. Take a moment at this time to read the RGA Software Chapter of this manual.

Turning on the RGA

1. Power up the RGA:
   Standard RGA units are powered up by turning on the external 24V power supply. Units with a built in power module (Option 02) have a power switch on the back panel of the ECU box.
2. When power is applied to the ECU, a firmware routine automatically checks the external voltage level and turns on the green Power LED if the voltage is within the acceptable range of 24 +/-2 V DC. The SRS RGA is now ready to communicate with the computer.

Running the SRS RGA System

This section describes how to launch the RGASoft program and start acquiring data from the RGA. An analog scan from 1 to 65 amu is executed as an example.

Important: The following steps assume that all the installation instructions described in the previous section were completed. The RGA should be mounted on the vacuum system, powered up and connected to the RS232 or USB port of the IBM compatible PC computer. RGASoft program should be installed in the computer and ready to run.

Warning:
Do not operate the RGA if the pressure in the chamber is greater than 10^{-4} Torr.

1. Turn on the computer and start MS Windows.
2. Start the RGASoft program:
   To start the RGASoft simply double-click on the RGASoft icon in the "SRS RGASoft" program group or the desktop icon created by the RGASoft installation program.

3. Connect to the RGA:
   - Upon launching, the RGASoft will show the Connections dialog box. Serial connections are automatically detected and displayed on the table.
   - Select the COM port to which the RGA is connected, and where the status shows *Available*.
   - Press the Connect button.
   - The connection is made when the status column shows *Connected* and the control panel is enabled. The program will attempt to read the RGA status when the connection is established.
4. Close the Connections dialog box when the RGA status query is completed.
5. Turn on the filament:
   - Select menu **Probe** > **Turn On Filament**.
   - The ionizer is biased with default voltage values and the filament is turned on to the default emission current. It takes a few seconds for the filament wire to warm up during which a small informative dialog box is active. The Filament status icon on the side panel stays lit (in green color) as long as the filament is emitting electrons.
   - The filament emission can be toggled on/off whenever the system is idle by selecting menu Probe > Turn On/Off Filament. The ionizer settings can be changed selecting Ionizer Settings from the Probe menu. A green status LED on the back panel of the ECU box indicates the emission status of the filament at all times and it provides the fastest way to verify if the filament is emitting electrons.
6. Perform an analog scan under the current scan conditions:
   Analog mode is the spectrum analysis mode common to all Residual Gas Analyzers. Its scan data is presented on an analog scan plot which consists of an X-Axis representing the mass range and a Y-Axis representing the measured ion current amplitudes of each mass increment. Note that the ion current amplitudes are often converted and showed in a pressure unit. The RGASoft program starts with a single-step scan sequence by default where the step is an Analog scan mode. The scan range defaults to 1 to 65 amu.
   - Select **Run** from the Scan menu, or simply click on the sidebar's ▶ Run button, to trigger an analog scan.
   - After a short delay, the analog scan data starts to be displayed on the analog plot.

Please refer to the RGA Software chapter of this manual, and the RGASoft On-Line Help files, provided with the program disks, for detailed information on all the features, procedures, and commands available in the RGASoft program. Consult the RGA General Operation chapter of this manual for a general overview of the SRS RGA and its basic operating modes.

Remote Interface Configuration

With a computer running Windows 10 or greater, the RGA can be controlled through the RGASoft Windows PC Application. However, the RGA can also be controlled directly by remote commands over the RS-232, USB, or Ethernet interfaces on the back panel.

The RGA communications interfaces can be configured most easily using RGASoft. However, some customer networks may require more advanced configuration.

RS-232

The RS232 RGA interface does not require any configuration. As stated earlier, an RS232 connection can be made with a standard RS232 straight-through DB9 female to DB9 male cable. The RGA will connect via RS232 to any host computer terminal program at 28.8kbaud, 8 bits, 1 stop bit, and no parity. If the host computer does not have a corresponding RS232 port, an RS232 to USB host adapter may be used.

USB

A USB type B connector is located on the back panel of the RGA. The interface is USB 2.0, Full Speed compatible. USB 2.0 is specified for a maximum cable length of 5 meters.

The RGA comes equipped with an FTDI FT230X USB to UART bridge chip. This may require installation of driver software to allow the USB interface on the RGA to communicate with the host computer.

When first connecting an RGA to a host computer running Microsoft Windows OS, you may be prompted with a “New Hardware Found” message and an invitation to search for the USB Driver. Depending on the version and configuration, Windows may either automatically install the drivers or prompt you to search for them. Allow it to install the drivers if you plan to configure or control the RGA over USB using this computer.

If there are difficulties installing the driver, you may need to manually install the driver. In this case, refer to Appendix F for more information on how to download and install the USB driver.

Ethernet

The RGA can be controlled over a TCP/IP connection through the Ethernet port. The Ethernet port supports communication over 10/100 Base-T Ethernet through an RJ45 connection.

If you want to configure the Ethernet connection within the RGASoft application, refer to Ethernet Setup Tools section in the Chapter 5.

Connect a standard Ethernet cable (Cat 5 or higher) between the RJ45 connector on the RGA and your network. When the RGA is powered on, the activity LED should be on or flashing green. If the LED is not responding in this way, check your Ethernet cable connection to your network.

IP Address Configuration

To use the RGA Ethernet interface, the RGA must first be assigned an IP Address.

DHCP Assignment

From the factory, the instrument is configured to accept an IP address from a DHCP server if one is available. After an Ethernet cable is connected between the RGA and a network with a DHCP server, the RGA will request an IP address. If successful, the RGA will automatically accept an IP address assigned by a DHCP server on the connected network.

To determine the IP address that has been assigned to the RGA, you can use the RGASoft PC application. The application can search for all RGAs on your local network and will offer the IP address of all RGAs that are discovered.

Optionally, you may connect to the RGA via RS232 or USB to query the instrument directly for its IP address. This is done with the following command:

```
ETHERNET:IP?
```

The command should return an IP address in standard IPv4 format of xxx.xxx.xxx.xxx.

For example:

```
172.25.70.93
```

If DHCP has failed to provide an IP address, the RGA will return:

```
0.0.0.0
```

In that case, follow the guidelines below to assign an IP address manually.

Manual IP Address Assignment

If there is no DHCP server available, or if you wish to assign an IP address manually, this must be done over an RS232 or a USB connection.

After connecting to the RGA via USB or RS232, first disable DHCP on the RGA.

```
ETHERNET:DHCP:ENABLE 0
```

Or:

```
ETHERNET:DHCP:ENABLE OFF
```

Then set the IP address with the following command:

```
ETHERNET:IP xxx.xxx.xxx.xxx
```

Where `xxx.xxx.xxx.xxx` is a standard IPv4 format address, 4 fields of integers between 0 and 255. Each field should be separated by a ‘.’ character.

IMPORTANT: When assigning a specific address to the RGA, make sure that there are no other devices already using that IP address. If another device on the local network is assigned the same address, it will cause an IP conflict. Ethernet traffic meant for the RGA at the assigned IP may not operate as expected.

Optionally, you can set the Ethernet DNS, Gateway, and Netmask with the following commands:

```
ETHERNET:DNS xxx.xxx.xxx.xxx
ETHERNET:GATEWAY xxx.xxx.xxx.xxx
ETHERNET:NETMASK xxx.xxx.xxx.xxx
```

NOTE: As the RGA acts as a server, it will only respond when a TCP/IP telnet connection is opened directly from a host computer. The DNS, Gateway, and Netmask fields are not used for Ethernet access.

The RGA will save the settings to non-volatile memory during the next Autosave cycle. However, the changes may be immediately saved with the following command:

```
SETUP:SAVE
```

Operation

Once the RGA IP address has been assigned, a telnet connection can be opened to the RGA to the IP address at port 818.

When the connection is established, there will be a prompt for a login name and a password to log into the RGA.

The default login name and password set at the factory is:

Name:	admin
Password:	admin

The login name and password can be changed with the following commands:

```
ETHERNET:LOGIN @name
ETHERNET:PASSWORD @password
```

Both `@name` and `@password` can be a string from 0 to 15 bytes long, starting with a '@' character.

The RGA will save the settings to non-volatile memory during the next Autosave cycle. However, the changes may be immediately saved with the following command:

```
SETUP:SAVE
```

The telnet connection has an automatic timeout feature in case the host computer does not close the telnet connection cleanly. This is important as only one Ethernet connection can be made to the RGA. If the host computer drops the telnet connection, the RGA will be unreachable for the time of the timeout.

If there is no activity from the host computer for the duration of the timeout timer, the RGA will close the telnet connection.

By default, the timeout is 30 seconds. This can be changed by the following command:

```
ETHERNET:TIMEOUT x
```

where x is the timeout value in seconds. The value must be between 30 seconds and 86400 seconds.

In cases where the Ethernet connection is locked out, the RGA may either be power cycled, or the following command can be sent via USB or RS232 interface:

```
ETHERNET:TELNET:CLOSE
```

This command will reset the telnet connection and make the RGA open for a new telnet connection.

Chapter 2

RGA General Operation

This chapter describes the basic properties of the Stanford Research Systems Residual Gas Analyzer (SRS RGA).

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The SRS RGA 2-3
Basic Operating Modes of the SRS RGA 2-5
The SRS RGA as a Mass spectrometer 2-5
The SRS RGA as a Single Gas monitor 2-6
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What is an RGA?

Complete characterization of a vacuum environment requires the detection of all the component gases present, as well as measurement of the total pressure. The instruments used for this purpose are called Residual Gas Analyzers or Partial Pressure Analyzers.

A **Residual Gas Analyzer (RGA)** is a mass spectrometer of small physical dimensions that can be connected directly to a vacuum system and whose function is to analyze the gases inside the vacuum chamber.

The principle of operation is the same for all RGA instruments: A small fraction of the gas molecules are ionized (positive ions), and the resulting ions are separated, detected and measured according to their molecular masses.
RGA's are widely used to quickly identify the different molecules present in a residual gas environment and, when properly calibrated, can be used to determine the concentrations or absolute partial pressures of the components of a gas mixture.

The SRS RGA

The SRS RGA is a mass spectrometer consisting of a **quadrupole probe**, and an Electronics Control Unit (**ECU**) which mounts directly on the probe's flange, and contains all the electronics necessary to operate the instrument.

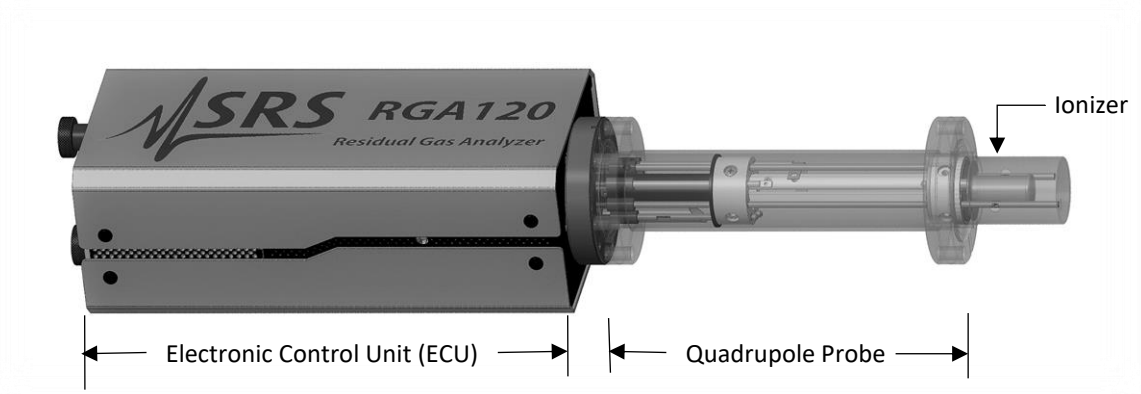

Figure 2-1 Quadrupole Head Components

The **probe** is a specially engineered form of quadrupole mass spectrometer sensor that mounts directly onto any standard 2 3/4" CF port of a vacuum chamber. It is described in detail in the RGA Probe chapter of this manual. The total probe equipment consists of three parts: the **ionizer** (electron impact), the **quadrupole mass filter** and the **ion detector**. All of these parts reside in the vacuum space where the gas analysis measurements are made. The detector measures the ion currents directly (Faraday Cup) or, using an optional electron multiplier detector (Option 01), measures an ion signal proportional to the ion current. A stainless-steel tube (CF Full nipple) covers the probe assembly except for the ionizer.

The **ECU** is a densely packed box of electronics (3" x 4" x 9") that connects directly to the probe's feedthru-flange and also to a host computer. It is described in detail in the "RGA Electronics Control Unit" chapter of this manual. It includes several regulated power supplies, a microcontroller, control firmware, and multiple communications ports for Ethernet, USB, and RS232, along with auxiliary I/Os, and relay closures. It is powered by either an external 24 VDC (@2.5 Amps) power supply or an optional built-in power module (Option 02) which plugs directly into an AC outlet. A unique, temperature-compensated picoammeter built into its box measures the ion currents collected by the Faraday cup (FC), or electron multiplier (CDEM). The electrometer is completely auto-ranging and measures both positive and negative currents with the same accuracy and resolution. Its operating range covers current magnitudes between 10^{-6} and 10^{-15} A, providing six orders of magnitude dynamic range during single mass measurements and scans, and detectable partial pressures better than 10^{-13} Torr during electron multiplier detection.

The instrument is completed with the RGA software package that runs on Windows computers. The intuitive graphical user interface allows measurements to be made and displayed in a variety of modes. The program is interactive and measurements are set up quickly and easily with the click of a mouse. The software can run in multiple instances

to support multiple RGA units. Please refer to the RGA Software chapter of this manual, and the RGASoft On-Line Help files for detailed information on the features, procedures, and commands available in the RGA software program.

Intelligent firmware, built into the RGA Head, completely controls the operation of the instrument, and provides four basic modes of operation of the mass spectrometer:

- **Analog scanning**
- **Histogram scanning**
- **Single mass measurement**
- **Total pressure measurement**.

RGASoft program provides fast access to all the RGA functions without the need for any computer programming; however, the instrument can also be programmed directly using the RGA Command Set supported by its communication interfaces. Consult the RGA Programming chapter of this manual for information on the programming options and a complete listing of the RGA Command Set.

The SRS RGA is available in three different models with mass ranges of 1 to 120 (RGA120), 1 to 220 amu (RGA 220), and 1 to 320 amu (RGA320). All models operate in the "Constant Resolution" or "Constant Δm" mode, with $\Delta M_{10\%}$ preset to one amu at the factory.
The operating pressure is UHV to 10^{-4} Torr for all models.
A complete product specifications listing is included in the introductory sections of this manual.

Basic Operating Modes of the SRS RGA

The SRS RGA is a mass spectrometer that analyzes residual gases by ionizing some of the gas molecules (positive ions), separating the resulting ions according to their respective masses and measuring the ion currents at each mass. Partial pressure measurements are determined with the help of previously calculated sensitivity (i.e. calibration) factors by reference to the abundance of the individual mass numbers attributed to each gas type.

During analysis, positive ions are formed within the ionizer and directed towards the spectrometer's **quadrupole mass-filter**. The mass filter determines which ions reach the detector at any given time. It is operated by a combination of RF and DC voltages and the filtering action is based on the mass-to-charge dependency of the ion trajectories on the RF and DC fields. The magnitude and frequency of the RF determine the **mass-to-charge ratio** of the ions that can pass through the filter without striking the rods (i.e. with stable oscillations). The RF/DC ratio determines the filter selectivity. Ions that successfully pass through the filter are focused towards the **detector** and the resulting analog current is measured by the very sensitive electrometer.

A brief note on Mass Units in Mass Spectrometry:

Since molecules are so small, it is convenient to define a special type of mass units to express the masses of individual ions. The **atomic mass unit, amu**, defined as 1/12 of the mass of a single carbon atom, isotope 12 (i.e. ^{12}C), is the unit of molecular mass most commonly used in mass spectrometry (**1 amu = 1.660 540 x 10^{-27} kg**). To a very accurate approximation, the mass of a molecule in atomic mass units (amu) is equal to its **mass number M**, defined as the sum of the number of protons and neutrons in the molecule.

Mass spectrometers do not actually measure the molecular mass directly, but rather the mass-to-charge ratio of the ions. The mass-to-charge ratio, **M/Q**, is defined as the ratio of the mass number M of the ion to its charge Q, measured in units of the electron charge e^-. For example: doubly charged ions of argon isotope 36 ($^{36}Ar^{2+}$) and singly charged ions of water, $^1H_2{}^{16}O^{1+}$, have M/Q = 18, and cannot be differentiated from each other with most mass spectrometers.

For singly charged ions, the mass to charge ratio is numerically equal to the mass of the ion in atomic mass units (amu).

RGA users often use the term "mass of an ion" when they really mean the mass-to-charge ratio. This convenient way of speaking is strictly valid for singly charged ions only.

The SRS RGA as a Mass spectrometer

The SRS RGA can perform both analog and histogram scans over its entire mass range. Residual gas analysis relies on the interpretation of the spectral data generated by these two modes to completely characterize, both qualitatively and quantitatively, a vacuum environment.

RGASoft program uses the two modes to generate the data for the Analog and Histogram Scan Modes.

Analog scanning is the most basic operation of the RGA as a quadrupole mass spectrometer. During analog scanning the quadrupole mass spectrometer is stepped at fixed mass increments through a pre-specified mass-range. The ion current is measured after each mass-increment step and transmitted to the host computer over RS232, USB or Ethernet. Analog scanning allows the detection of fractional masses and provides the only direct view of the peak shapes and resolution of the instrument.

A **Histogram (Bar Mode) Scan** consists of a succession of individual peak-height measurements over a pre-specified mass range. A single value is used to represent the peak heights at each integer mass within the range. The peak height measurements are made with the **Peak-locking** scanning procedure described in the next section. Histogram scanning is one of the most commonly used modes of operation for the RGA. Its two main advantages are a faster scan rate than analog scans, and a reduced amount of data being exchanged during the scan.

The SRS RGA as a Single Gas monitor

The SRS RGA can measure individual peak heights at any integer mass within its mass range.

This mode of operation is used to generate data for leak testing measurements, and to track changes in the concentrations of several different components of a mixture as a function of time. The outputs provided by a set of single mass measurements are often used in process control programs to control alarms, analog and digital outputs, and relays.

RGASoft program uses this mode to generate its data for the Pressure vs time, and Leak Detection modes.

Peak Locking procedure: During a Single Mass Measurement the RGA performs a Miniscan around the mass requested, and the **maximum current value** measured is sent out over RS232, USB, or Ethernet. The scanning procedure, referred to as **Peak-Locking**, is designed to measure peak currents for individual masses in a mass spectrum without being affected by drifts in the mass-axis calibration. The Miniscan covers a 0.6 amu range centered at the mass requested, and selects the maximum current from 7 individual measurements performed at 0.1 amu mass increments.

The SRS RGA as a Total Pressure Gauge

The SRS RGA can measure total pressures using the Faraday Cup detector.

The RGA might be thought of as a Total Pressure Ionization gauge with a mass analyzer interposed between the ionizer and the detector. Thus, by disabling the mass-filtering action of the analyzer section, it is possible to detect the total ion current from the ionizer and perform total pressure measurements. A total pressure sensitivity factor, stored in the non-volatile memory of the RGA, is used by RGASoft program to convert total current measurements into total pressures.

Important: The RGA's sensitivity factor for total pressure measurements is highly mass dependent. Some residual mass discrimination takes place in the filter that results in the mass dependence of the RGA readings being different from that of the Bayard-Alpert gauges. **Expect to see deviations between the two gauges as the composition of the residual gas changes.**

Do not rely on the RGA total pressure measurement for critical applications where accurate total pressure measurements are required. A high precision IGC100 controller connected to a calibrated Bayard-Alpert ionization gauge is recommended instead.

Residual Gas Analysis Basics

The SRS RGA can perform both qualitative and quantitative analysis of the gases in a vacuum system. Obtaining spectra with the SRS RGA is very simple. Interpreting the spectra, that is, understanding what the spectra is trying to tell you about your vacuum system requires some work.

The following sections will introduce some basic concepts of Spectral Analysis emphasizing the main aspects of Residual Gas Analysis. Consult Appendix A of this manual for specific examples on the application of the SRS RGA to vacuum diagnosis

For additional information on the subject of Residual Gas Analysis refer to:

1. J. Drinkwine and D. Lichtman, Partial Pressure Analyzers and Analysis, AVS Monograph Series published by the Education Committee of the American Vacuum Society

2. Basford et. al., J. Vac. Sci. Technol. A 11(3) (1993) A22-40 "Recommended Practice for the Calibration of Mass Spectrometers for Partial Pressure Analysis. Update to AVS Standard 2.3".

For information on multiple linear regression analysis consult:

1. William H. Press, et. al., 1992, Numerical Recipes in C, The Art of Scientific Computing, Second Edition, Cambridge Univ. Press, section 15.4, page 671.

2. Bevington, P.R., 1969, Data Reduction and Error Analysis for the Physical Sciences, New York, McGraw-Hill, Chapters 8-9.

How Mass Spectra are Interpreted

A mass spectrum, taken in a real system, will almost always contain signals from a mixture of various gases. Careful and complete interpretation of the spectrum (i.e. a complete spectral analysis) should reveal the identity, as well as the concentrations, of the various components which have produced the spectrum.

The first step in the spectral analysis process is to correctly identify the mass-to-charge ratio of all the peaks in the mass spectrum. A well calibrated mass scale is essential to this task. See the RGA Tuning Chapter for a detailed description of the mass scale calibration procedure.

Once all the peaks have been labeled, the next step is to identify the residual gases that have produced the spectrum. A knowledge of the recent history of your system may provide very valuable clues as to the possible gases that may be residuals in the vacuum chamber. A familiarity with the standard spectra of commonly expected gases will generally help to determine the major and minor components in the system. Any peak in the spectrum may consist of contributions from molecular ions and/or fragment ions, or multiply ionized species. **The qualitative spectral analysis is completed when all the peaks in the spectrum have been "uniquely assigned" to the components of a gas mixture, in complete agreement with the known fragmentation patterns of the components.**

In cases where only the major components are of interest, some of the minor peaks of the spectrum will remain unassigned. If only a few species are being monitored, only the peaks corresponding to the substances of interest need to be assigned and monitored.

Notes on Fragmentation Patterns: The electron impact type of ionizer used in modern RGA's almost always causes more than one kind of ion to be produced from a single type of gas molecule. Multiple ionization, molecular fragmentation and changes in the isotopic composition of the molecule are responsible for the effect. All ions formed contribute to the mass spectrum of the molecule and define its **fragmentation pattern**. The identification and interpretation of mass spectra must begin with a knowledge and understanding of the standard fragment patterns of atoms and molecules that may exist in the system. The standard fragment patterns of most molecules commonly encountered in residual gas analysis are well established and listed in the general RGA Literature. A very complete library can also be accessed through the Gas Library of the RGA software. The Gas Library Editor supports importing mass spectra from the NIST Chemistry WebBook, or a mass spectrum from the RGA scan data.

Residual Gas Analysis Tip: Virtually every vacuum system will have detectable amounts of hydrogen (2 amu), water (18 amu), carbon monoxide (28 amu) and carbon dioxide (44 amu). Become familiar with these species and their fragmentation patterns, and use their peaks to verify the correct performance of the instrument (i.e. mass scale calibration and mass resolution) while operating the RGA.

Partial Pressure Measurement

Once the different components of a mixture have been identified it is possible to use the SRS RGA to obtain quantitative values for the various partial pressures. This section describes the basic steps needed to perform quantitative measurements with the instrument. The formalism presented assumes multiple gas analysis, but is equally valid for single gas measurements. Please consult the suggested references for details and examples of these procedures.
The entire mathematical formalism used to derive the partial pressures of a mixture based on a single mass spectrum is based on one assumption:

The total spectrum is a linear combination of the spectra of the different species that are present in the mixture. In other words, the total spectrum is equal to the sum of the individual peaks that would be observed if each constituent were alone in the system.

In mathematical terms, the assumption stated above can be written as the following linear equation:

$$H_M = \Sigma_g h_{Mg} \qquad (1)$$

where:

g is an integer variable that represents the gases present (i.e. assign an integer to each gas starting with one)
M is an integer variable that represents the mass numbers for the entire mass range of the spectrum.
H_M= total peak height (amps) of the spectrum at mass number M.
h_{Mg}= peak height contribution (amps) from gas g at mass M.

h_{Mg} is related to the fragmentation pattern, the RGA's sensitivity and the partial pressure of gas g by the equation:

$$h_{Mg} = \alpha_{Mg} S_g P_g \qquad (2)$$

where:

α_{Mg} = Fragmentation factor of gas g at mass M: Ratio of ion signal at mass M to the ion signal at the principal mass peak for gas g.
S_g = RGA's partial pressure sensitivity factor for gas g, in amp/Torr (see Partial Pressure Sensitivity Factor below)
P_g = Partial pressure of gas g in the system.

Equations (1) and (2) are combined to obtain the system of equations:

$$H_M = \Sigma_g (S_g \alpha_{Mg}) P_g \qquad (3)$$

Since all gases have more than one peak in their fragmentation pattern, the number of peaks (M) in a real spectrum is generally larger than the number of gases (g). As a result, the system of equations (3) usually has more equations than unknowns. This situation is sometimes simplified eliminating some of the extra equations; however, the best results are obtained using all the equations and a multiple linear regression procedure to calculate the best possible fit to the data.

Obviously, accurate results can only be obtained if the constants α_{Mg} and S_g are well known for the RGA being used.

Note: The Scan Analysis utility of RGASoft program uses a Least Squares Fitting algorithm to automatically calculate the composition of a "typical residual gas environment" at the end of any spectral scan. Please see the RGASoft On-Line Help files for details.

Standard fragmentation patterns (for example, the fragmentation patterns included in the Gas Library of RGASoft program) can be used as a source of α_{Mg} values in moderately quantitative determinations. However, when very precise numbers are desired, one should obtain the appropriate fragment patterns by introducing pure gas into the RGA being used. The fragment patterns must be obtained under the same conditions that will be used during regular spectral

analysis since they depend on many instrumental parameters, including: electron energy, emission current, ionizer design, mass filter settings, detector type, multiplier gain, etc. The principal mass peak of a fragmentation pattern is simply the most intense peak of the spectrum, and the intensity of all the other peaks in the pattern are normalized to its height for the calculation of fragmentation factors. **Note that by our definition the α_{Mg} value for the principal mass peak of any gas is equal to one.** Principal mass peaks are used in the calculation of the sensitivity of the SRS RGA to different gases as shown below.

Partial Pressure Sensitivity Factors

The partial pressure sensitivity of the RGA to a gas g, S_g, is defined as the ratio of the change $(H-H_0)$ in principal mass peak height to the corresponding change $(P-P_0)$ in total pressure due to a change in partial pressure of the particular gas species. H_0 and P_0 are background values.

$$S_g = (H-H_0) / (P-P_0)$$

The units of S_g are of ion current per unit pressure (amp/Torr, for example).

The sensitivity of the RGA varies with different gases, changes with time due to aging of the head, and is a strong function of the operating conditions of the instrument. Careful quantitative analysis requires that the sensitivity factor, S_g, be determined for every gas which may be a component gas in the system being analyzed. The sensitivity factors must be obtained under the same operating conditions that will be used during general partial pressure analysis since they depend on many instrumental parameters, including: ionization energy, emission current, mass filter setting, type of detector, etc.

In order to separate the gain of the electron multiplier from the intrinsic sensitivity of the RGA head, the sensitivity factors of the SRS RGA are defined for Faraday Cup detection. A separate Electron Multiplier Gain Factor, is used to correct the ion signals when the electron multiplier is turned on. See the Sensitivity and Electron Multiplier Tuning sections of the RGA Tuning Chapter for details.

The basic procedure for determining the sensitivity of a particular gas in the RGA is the following:

- Introduce the pure gas into the vacuum system, at a known or calculable pressure (typically around 10^{-6} Torr).
- Measure the output signal from the RGA for the principal mass peak of that gas using the Faraday cup detector.
- The ratio of this output signal to the pressure of the gas is the sensitivity factor, S_g.

During these measurements it is very important to insure that the partial pressures of all other gases in the system are small enough so that they may be neglected. The sensitivity factors calculated can only be applied to situations where the RGA is used with the same

operating parameters. See the Sensitivity Tuning section in the RGA Tuning chapter of this manual for more details on this calibration procedure.

A **total pressure sensitivity factor** is also needed by the SRS RGA to convert the ion currents obtained during total pressure measurements into total pressures. Total pressure sensitivity factors vary with different gases and share many of the properties of the partial pressure factors. They are determined by a procedure identical to the one described above, but with the partial pressure measurements replaced by total pressure measurements.

The underlying assumption when using sensitivity factors in quantitative calculations is that there is a linear relation between the partial pressure and the corresponding RGA signals of the gases. Deviations from linearity are to be expected above 10^{-5} Torr due to space charge effects in the ionizer and ion-neutral scattering interactions in the filter. A more thorough check of the RGA's sensitivity involves measuring the RGA signals over several orders of magnitude of partial pressure to determine the range over which a linear relationship exists. The sensitivity factor for the gas is calculated as the slope of the "signal vs. partial pressure" response over the linear range.

RGASoft uses two sensitivity factors stored in the non-volatile memory of the RGA. The sensitivity factors, one for total pressure and one for partial pressure, are used as conversion factors between the ion currents received from the RGA and the pressure units selected by the user. The sensitivity factors are measured with the Faraday Cup detector and can be updated or changed very easily using the Sensitivity Tuning command in the Probe menu. A separate Electron Multiplier Gain Factor, stored in the non-volatile memory of the RGA, is used to correct the ion signals for the gain of the electron multiplier. The gain of the electron multiplier is highly mass dependent and defined relative to the corresponding FC signal. An automatic Electron Multiplier Gain Adjustment command, built into the program, can adjust the CDEM voltage for any gain between 10 and 10^6. Consult the RGASoft On-Line Help Files for details on the automated tuning procedures built into the RGASoft program. Also see the Sensitivity and Electron Multiplier Tuning sections of the RGA Tuning Chapter for more general information.

The Mass Table of RGASoft program offers scaling factors for all of its gas masses eliminating the limitations imposed by the single sensitivity factor on multiple partial pressure calculations. For example, the scaling factors can be used to display correct partial pressure for all the species in a table if the ratios between the partial pressure sensitivities of the different components are known and only principal mass peaks are used to monitor them. The scaling factors can also be adjusted to correct against the mass discrimination of the electron multiplier's gain.

Important: Following current industry standards, the partial pressure sensitivity factor stored at the factory corresponds to N_2 measured at 28 amu with $\Delta m_{10\%}$=1 amu, default ionizer settings and Faraday Cup Detection.

Single gas measurement example:
Monitoring the concentrations of one or few components in a system is easy in the absence of severe spectral interference.

Suppose a system where argon is measured at 40 amu (principal mass), in the absence of any other gases that contribute a signal at that mass value. The sensitivity to argon was previously measured at $S_{Ar}=10^{-4}$ amps/Torr, and the electron multiplier is biased and its gain at mass 40 was previously measured at $g_{CDEM}=1.02\cdot10^3$ relative to the FC signal.

The partial pressure of argon, P_{Ar}, is easily calculated measuring the intensity (i.e. peak height) of the ion current at mass 40, I_{40}.

$$P_{Ar} = I_{40} / (g_{CDEM} \cdot S_{Ar}) , \text{ units of Torr} \qquad (4)$$

The peak value, I_{40} , can be extracted from a spectral scan or measured directly using the single mass measurement mode of the SRS RGA. For example, a 10^{-9} amp peak value corresponds to $9.8 \cdot 10^{-9}$ Torr of Ar. Note that equation (4) is a particular case of equation (3), and that the fragmentation factor for the principal peak of Ar is one by definition.

Chapter 3

RGA Quadrupole Probe

This chapter describes the design and principles of operation of the components of the RGA Quadrupole probe.

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Introduction

The SRS RGA is a mass spectrometer consisting of a **quadrupole probe**, and an Electronics Control Unit (**ECU**) which mounts directly on the probe's flange and contains all the necessary electronics for operating the instrument.

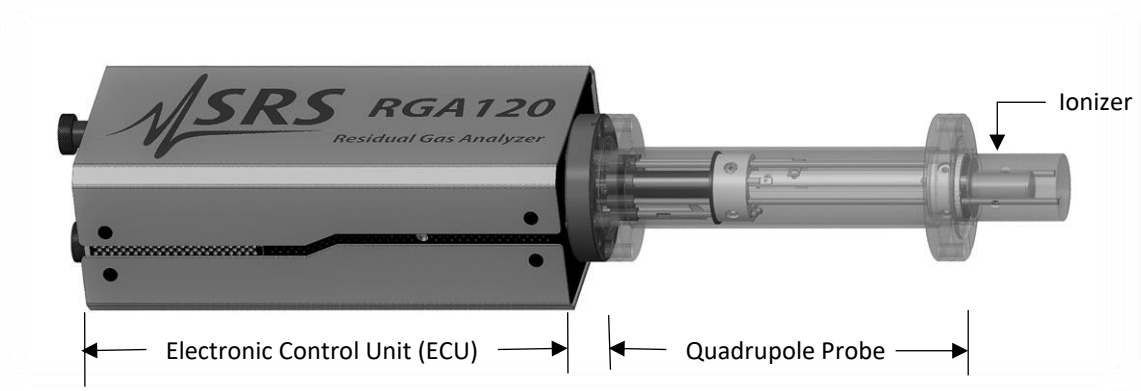

Figure 3-1 Quadrupole Head Components

The probe is a specially engineered form of quadrupole mass spectrometer sensor. It is mostly constructed out of type 304 stainless steel and high purity alumina, and mounts directly onto any standard 2.75" CF port of a vacuum chamber. It analyzes residual gases ionizing some of the gas molecules (positive ions), separating the resulting ions according to their respective masses and measuring the ion currents at each mass.

The total probe equipment consists of three parts: the **ionizer**, the **quadrupole filter** and the **ion detector**. All of these parts reside in the vacuum space where the gas analysis measurements are made.

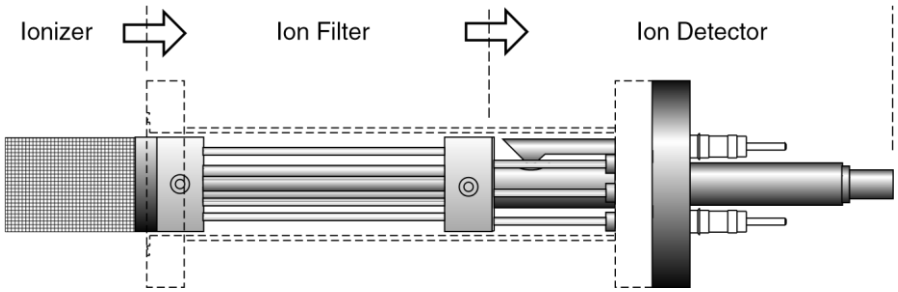

Figure 3-2 Probe Components

A stainless steel tube (RGA Cover Nipple) covers the probe assembly with the exception of the ionizer. A 2.75" CF port with at least 1.375" inside diameter and 2.5" depth is needed to provide clearance for the insertion of the ionizer into a vacuum system. This insertion volume is comparable to that taken by a regular Bayard-Albert ion gauge.
A high vacuum environment (10^{-4} Torr or less) is required for operation.

Ionizer

Positive ions are produced in the ionizer by bombarding residual gas molecules with electrons derived from a heated filament. The ions are then directed toward the entrance of the ion filter where they are separated based on their mass-to-charge ratio.

Description

The SRS RGA ionizer is of an open design (wire mesh construction) with cylindrical symmetry and mounted co-axially with the filter assembly. The open configuration provides unrestricted communication between the vacuum environment and the ionizing region. The entire assembly is built out of type 304 stainless steel for complete vacuum compatibility. The simple mesh design is very clean (low outgassing) and easy to service.

The principle parts of the ionizer are: the repeller, the anode grid, the filament and the focus plate.

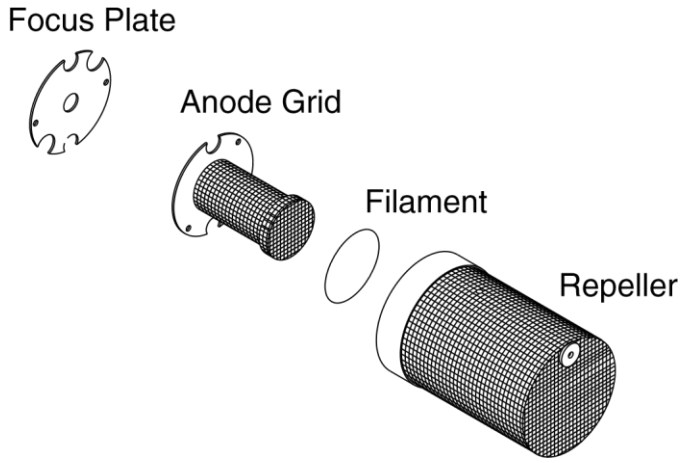

Figure 3-3 Ionizer Components

The filament is made out of oxidation-resistant thoria coated iridium wire, which operates at low temperature and can be exposed to atmosphere without the risk of burn-out. The circular construction consisting of two ThO_2/Ir wires surrounding the anode grid preserves the cylindrical symmetry of the ionizer. Both filaments operate simultaneously under normal operation, and service is not interrupted if a single filament burns out (i.e. the emission regulator automatically readjusts the temperature of the remaining filament to restore the electron emission current). Once they wear out, the filaments can easily be replaced in the field (Please see the RGA Maintenance chapter for details). A firmware driven filament-protection feature constantly monitors (675 Hz) for overpressure. If overpressure is detected the filament is immediately shut off, preserving its life.

Principle of operation

The principle of operation of the ionizer is similar to the Bayard-Alpert gauge, except there is no central wire collector, and the electron repeller has been added.

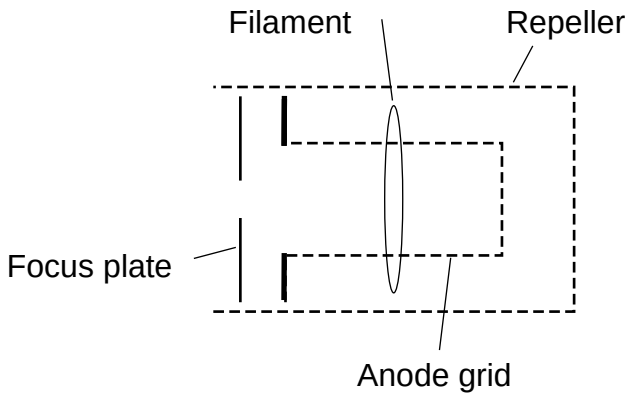

Figure 3-4 Ionizer Schematic

The filament is the source of the electrons used in ionizing the gas molecules. It operates at a negative potential relative to ground and is resistively heated to incandescence with an electrical current from the emission regulator. The thermionically emitted electrons are accelerated towards the anode grid which is positively charged with reference to the filament and ground. Because of the open (i.e. wire mesh) design of the anode grid cage, most electrons do not strike the anode immediately, but pass through the cage where they create ions through electron impact ionization. Electrons which do not strike a grid wire or ionize any molecules, pass through the grid volume into the region between the anode grid and the repeller. There they decelerate and re-accelerate back toward the grid because of the electric field created between the repeller and the anode grid. Electrons continue circulating in this fashion until they are collected by the grid or are lost by recapture. The multiple passes increase the ionization efficiency of the electron current relative to single pass configurations. Within the anode grid volume, ions are attracted to the center by the negative potential produced by an increasing electron density toward the center. Hence, the ions, once formed, tend to stay within the anode grid structure, and the ion distribution is more localized along the axis. The ions formed within the anode grid volume, are extracted from the ionizer by the electric field produced by the difference in voltage bias between the anode grid and the focus plate. The focus plate is kept at a negative potential (relative to ground) and its function is to draw the ions out of the anode cage and focus them into the filter section. The repeller, which completely encloses the ionizer, is biased negative relative to the filament and prevents the loss of electrons from the ion source. **The Repeller Grid and the Focus Plate are only biased while the filament is emitting electrons.**

The technique of electron impact ionization requires low pressure for the efficient production of electrons and the subsequent formation of ions. The ionizer is best suited for operation in the high and ultrahigh vacuum range (10^{-4} to 10^{-14} Torr). Non-linearities in the ion currents, attributed mostly to space charge effects, are to be expected at pressures above 10^{-5} Torr. Non-linearity effects can be minimized operating at reduced electron emission current settings.

Parameter Settings

The parameters that affect the ionization efficiency of the ionizer are: electron energy, ion energy, electron emission current and focusing voltage. The general principles by which they affect the performance of the source are well understood.
The ECU contains all the necessary high voltage and current supplies needed to bias the ionizer's electrodes and establish an electron emission current. The ionizer settings can be directly controlled and monitored by the user through the RGA's high level command set.
The following table summarizes the ionizer settings available to the user, including default factory values, parameter ranges and minimum acceptable increments:

Ionizer settings:

	Units	Default	Range	Min. Incr.
Ion Energy	eV	12	4 to 16	1
Electron Energy	eV	70	25 to 110	1
Focus Voltage	V	-90	0 to -110	1
Emission Current	mA	1.00	0 to 4 mA	.02

Table 3-1 Ionizer settings

The average **electron energy**, expressed in eV, is equal to the voltage difference between the filament and the anode grid and can be set anywhere in the range of 25 to 110 eV. For electrons to produce ionization of gas molecules by bombardment, they must have a certain minimum kinetic energy. This minimum energy is called the **ionization potential** and is different for every molecule. Above the threshold, the ionization efficiency increases linearly with the electron energy until a maximum is reached. For most molecules, this maximum is in the range of about 50 -100 eV, and for electron energies above the maximum, the ionization efficiency slowly decreases with electron energy.

The kinetic energy of the ions as they move down the ion filter, simply referred to as the **ion energy,** and expressed in eV, is equal to the voltage biasing of the anode grid. The ion energy (i.e., anode grid voltages) can be set between 4 and 16 eV. The ion energy setting affects the magnitude of the ion signals collected (i.e., sensitivity of the spectrometer) and limits the ultimate resolution of the mass filter. Newly formed ions are attracted by the negative potential of the focus plate and passed to the ion filter where they are decelerated by the ground potential at the central axis of the quadrupole rod assembly. Hence, the anode grid voltage defines the kinetic energy of the ions as they enter the ion filter. Ion energy determines the time spent by the ions in the filter and hence, limits the resolution that can be obtained. It is well established that the resolution limit is governed by the number of cycles of RF field to which the ions are exposed before they reach the detector. In practice, the minimum resolution, $\Delta m_{10\%}$, is mass independent, linearly related to the ion energy, and inversely proportional to the square of the product of the quadrupole length and frequency. The available ion energy settings correspond to ultimate resolutions of approximately 0.2 and 0.6 amu (well under the 1 amu factory default setting). Ion energy also determines the time spent by the ions in the fringing fields at the entrance and exit points of the filter. Ions passing through the fringing fields can collect high transverse velocities and are more likely to collide with the quadrupole rods and never be collected at the detector. As a result, ion signals (i.e., sensitivity) generally increase with ion energy.

The **focus plate** negative potential can be adjusted to any value within the range of 0 to -110 V. In general, the voltage is selected so as to optimize the ion signals. The plate serves the double purpose of drawing the ions away from the anode grid, and containing the ionizing electrons inside the source. Electron leakage into the filter is only detectable at low mass settings (1 to 10 amu) and can easily be eliminated biasing the focus plate at least 30V more negative than the repeller.

The **electron emission current** is the electron current from the filament to the grid. The available emission current range is 0 to 4 mA.

When an electron emission current is requested, the RGA biases the ionizer's electrodes and activates the filament's heater until the desired emission current is achieved. A "**Background Filament Protection"** Mode is automatically enabled to monitor the performance of the filament while it is emitting electrons. The Filament LED remains on as long as the filament is emitting electrons. If a problem is detected in the operation of the filament (i.e., burnt filament or overpressure), the heater is immediately shut down and the problem is prompted by the LED's. If a current of 0 mA is requested, the filament's heater is shut down, the repeller and focus plate are biased to ground, the CDEM is turned off (if necessary), and the Filament LED is turned off to indicate the absence of emission in the ionizer.

The electron emission current is very tightly regulated by a feedback control loop which dynamically adjusts the operating temperature of the filaments to keep the total emission current constant. The emission of electrons from the filaments is limited by space-charge effects (Child's Law limitations). The maximum current attainable is a function of the grid-to-repeller spacing and its potentials. Ideally, the rate of formation of ions should be proportional to the electron emission current. In practice, the exact dependence between ion signal and electron emission current in small ion sources is complicated by space-charge effects and only general trends can be predicted. Greater ionization efficiency is to be expected as the electron emission current increases.

Quadrupole mass filter

Positive ions are transferred from the ionizer into the quadrupole where they are filtered according to their mass-to-charge ratios. Ions that successfully pass through the quadrupole are focused towards the detector by an exit aperture held at ground potential.

Description

The quadrupole mass filter is an electrodynamic quadrupole operated by a combination of DC and RF voltages. It is constructed of four electrically-conducting, cylindrical rods accurately held in place by a set of two high-purity alumina insulators.

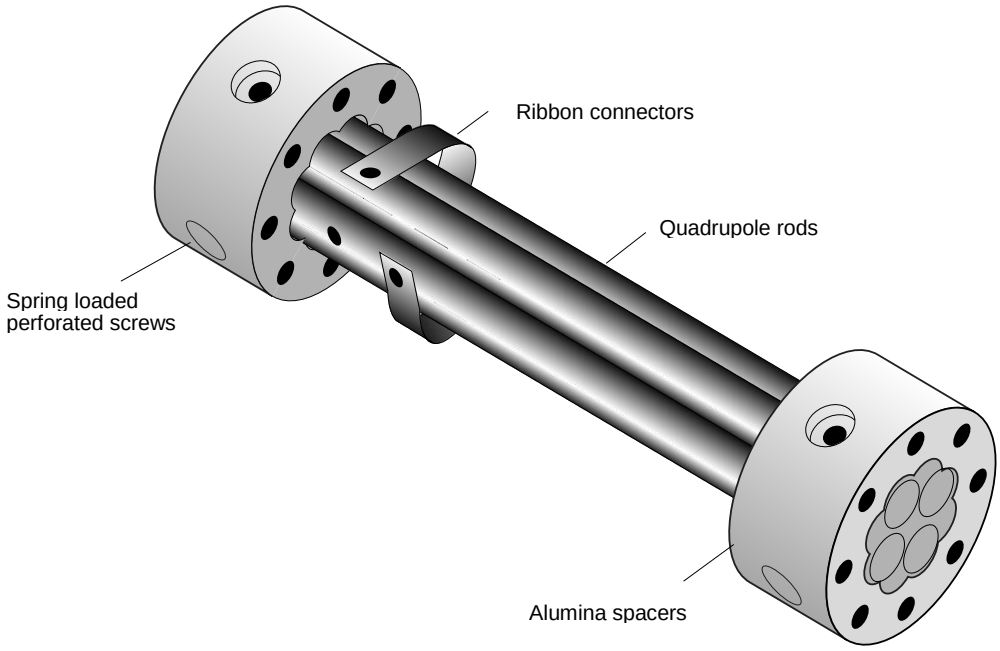

Figure 3-5 Quadrupole Mass Filter Components

Round electrodes are a common replacement for hyperbolic ones in modern RGA's and result in reduced cost and ease of construction. The stainless steel (type 304) rods are 4.5" long, have a 0.250" diameter (100 μin tolerance) and are held in quadrature and parallel to each other, to tolerances better than 300 μin, by the precision ground alumina spacers. Spring-loaded, perforated screws fasten the rods to the spacers. The whole assembly is self-aligning, can easily be taken apart for cleaning and it can withstand repeated cycling to 300°C for bakeout. The exact placement of the rods is optimized to minimize the distortion of the electrodynamic quadrupole field by canceling higher order (multipole) potential terms. The radius of the circle inscribed by the rods is 0.109". The frequency of operation is is about 2.7 MHz.

Principle of operation

The following figure schematically represents the quadrupole mass filter and its connections.

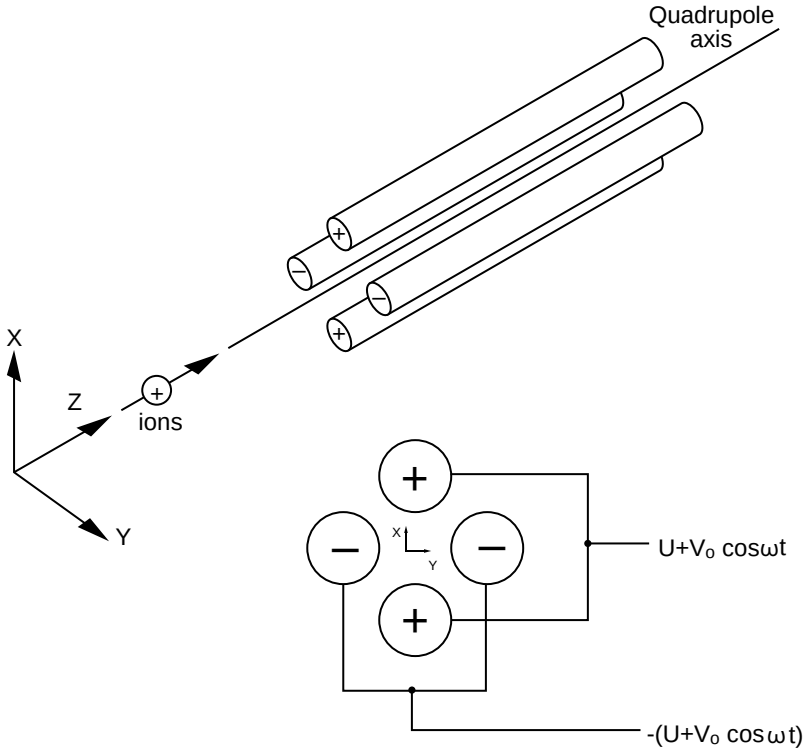

Figure 3-6 Quadrupole Connections

During operation, a two-dimensional (X-Y) quadrupole field is established between the four cylindrical electrodes with the two opposite rods connected electrically.
Ions enter the filter along the Z-axis and start oscillating in the X- and Y- directions. The ions are separated based on their mass-to-charge ratio by lateral forces resulting from the electric potentials applied to the rods. A combination of DC and RF voltages control the quadrupole filter operation. Successful separation of a specific mass species requires setting the RF and DC values such that only the ions of interest have stable trajectories down the quadrupole rod assembly. By simultaneously varying the amplitude of the DC and RF voltages an entire mass spectrum can be scanned.

The RGA is completely calibrated at the factory so that the ECU automatically programs the RF and DC voltages on the rods to the necessary levels during scans or individual mass measurements. The calibration parameters can be accessed and modified by the user in case recalibration or a change in resolution is required. (Please see the RGA Tuning chapter for details.)

The quadrupole mass filter must be operated in a vacuum. Linear operation can be expected up to pressures of the order of 10^{-4} Torr. In general quadrupoles can be operated at relatively high pressures compared to other types of analyzers. The upper limit of useful operation is determined by the collisions between the ions and the neutral gas molecules. In order to avoid collisional scattering, it is necessary to maximize the mean free path of the ions.

The general principle of operation of the filter can be visualized **qualitatively** in the following terms: One rod pair (X-Z plane) is connected to a positive DC voltage upon which a sinusoidal RF voltage is superimposed. The other rod pair (Y-Z plane) is connected to a negative DC voltage upon which a sinusoidal RF voltage is superimposed, 180 degrees out of phase with the RF voltage of the first set of rods. The potentials are represented by the expression:

$V_{x/y}$= +/- (U + V_0 cos ωt)
where,

U is the magnitude of the DC voltage applied to either pair of rods,
V_0 is the amplitude of the RF voltage applied to either set of rods, and
ω is the angular frequency (=2πf) of the RF.

Light ions (low mass-to-charge ratio) are able to follow the alternating component of the field. For the **X direction**, those ions will stay in phase with the RF drive, gain energy from the field and oscillate with increasingly large amplitudes until they encounter one of the rods and are discharged. Therefore, the X direction is a **high-pass mass filter**: Only high masses will be transmitted to the other end of the quadrupole without striking the X electrodes. On the other hand, in the **Y direction**, heavy ions will be unstable because of the defocusing effect of the DC component, but some lighter ions will be stabilized by the alternating component if its magnitude and amplitude are such as to correct the trajectory whenever its amplitude tends to increase. Thus, the Y direction is a **low-pass mass filter**: Only low masses will be transmitted to the other end of the quadrupole without striking the Y electrodes.

The two directions together give a **mass filter suitable for mass analysis**: By a suitable choice of RF/DC ratio the filter can be made to discriminate against both high and low mass ions to the desired degree.

The RF voltage magnitude and frequency determine the mass of the ions that undergo stable trajectories down the filter. As the RF amplitude increases, heavier ions start to oscillate in phase with the RF and collide with the rods. The DC/RF ratio determines the filter selectivity. As the DC increases (at constant RF) heavier ions are defocused by the negative DC component.

The attractive features of the quadrupole as a mass analyzer are evident from the above discussion: **The quadrupole provides a convenient filter which can be tuned to the desired mass by varying the amplitude of the RF voltage; the mass selectivity (i.e., resolution) can also be varied electronically by simply adjusting the DC/RF ratio.** Simultaneously varying the amplitude of the DC and RF voltages allows entire mass spectra to be scanned.

Mass Range, Resolution and Throughput

The most important characteristics of a quadrupole are the **mass range,** its **ultimate resolution** and its **throughput** characteristics**.**

The **mass range** is the range of masses defined by the lightest and the heaviest singly charged ions which can be detected by the mass spectrometer. The SRS RGA is offered in three different models with mass ranges of 1 to 120 (RGA120), 1 to 220 amu (RGA 220) and 1 to 320 amu (RGA320). The main difference between the three models is given by the maximum supply voltage available to the rods.

The terms **Resolution** and **Resolving Power** are often used by mass spectroscopists to express the ability of a mass filter to **resolve** ions having different masses:

> **Resolution, or Absolute Resolution = $\Delta M_{10\%}$:** The width **ΔM** of the pass band of the filter, defined as the full width at which the ion current falls down to 10% of the maximum value. Units = amu.
> **Resolving Power: $R = M/\Delta M_{10\%}$:** Ratio between a particular mass **M** and the resolution, **$\Delta M_{10\%}$** , at that mass. Dimensionless ratio.

It is common practice in modern RGA's to keep $\Delta M_{10\%}$ constant at a value which ensures adequate separation of masses that are 1 amu apart. The SRS RGA quadrupole operates in that "Constant Resolution" or "Constant Δm" mode. $\Delta M_{10\%}$ is preset at the factory to 1 amu, but it can easily be adjusted by the user all the way to the theoretical ultimate resolution of the filter.

The following figure illustrates the resolution concepts explained above, using a Krypton mass spectrum as an example. The different isotopes of the gas are well separated from each other, and a 1 amu peak width (= $\Delta m_{10\%}$) is measured on the ^{86}Kr peak at 10% of its peak height. Also notice the 20% valley between the ^{82}Kr and ^{83}Kr peaks.

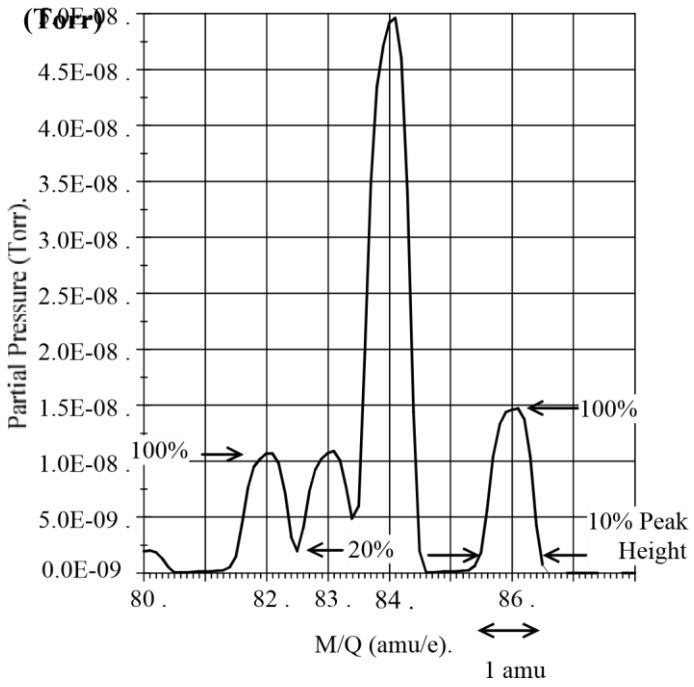

Figure 3-7 Peak Width Measurement

It is well established that the resolution attainable by a quadrupole is limited by the number of cycles of RF field to which the ions are exposed before they reach the detector. In practice, the minimum resolution ($\Delta M_{10\%}$) value attainable is mass independent, linearly related to the ion energy, and inversely proportional to the square of the product of the quadrupole length and frequency. The available ion energy range of the RGA correspond to **ultimate resolution** values of approximately 0.2 amu (4 eV) and 0.6 amu (16 eV) which are well under the factory default setting, and more than adequate to separate ions which differ in mass by 1 amu or less.

The resolving power, R, at a mass M is strictly related to the DC/RF voltage ratio. An increase in the resolving power usually results in a decrease in the effective **throughput** of the filter. As the DC/RF ratio is increased the amplitude of the ion oscillations within the filter increase and a greater fraction of the ions are lost to collisions with the analyzer rods. The throughput of the quadrupole affects the overall **sensitivity** of the spectrometer to the mass being filtered. The exact relationship between resolution and sensitivity is very complex as it depends on the concentration and divergence of the ion beam leaving the source. It is complicated further by the defocusing action of the fringing fields between the ion source and the rods. However, as a general rule of thumb **Sensitivity decreases at 1 to 1.5 times the rate of resolving power increase.**

The inverse relationship between sensitivity and resolving power is also responsible for a very important feature of quadrupole mass filters operated at constant resolution: **The throughput of the analyzer decreases with mass.** (Since $\Delta M_{10\%}$ is constant, the resolving power, $R = M/\Delta M_{10\%}$, increases with mass reducing the effective throughput of

the filter for high masses. This effect must be taken into account when calculating partial pressure sensitivities from ion currents.)

Zero Blast Suppression

When the applied potentials are small (or zero) as at the beginning of a scan, ions entering the filter may be transmitted even though their trajectories are mathematically unstable. This gives rise to an output signal at the beginning of mass scans called the "Zero Blast". In the SRS RGA the Zero Blast is suppressed preventing the DC voltage from reaching zero under 1.5 amu. Zero Blast suppression is standard practice in all commercially available RGAs and is responsible for the lack of reliable readings for hydrogen at 1 amu.

Ion Detector

Positive ions that successfully pass through the quadrupole are focused towards the detector by an exit aperture held at ground potential. The detector measures the ion currents directly (Faraday Cup) or, using an optional electron multiplier detector, measures an electron current proportional to the ion current.

Description

The following figure describes the detector assembly including the electron multiplier option.

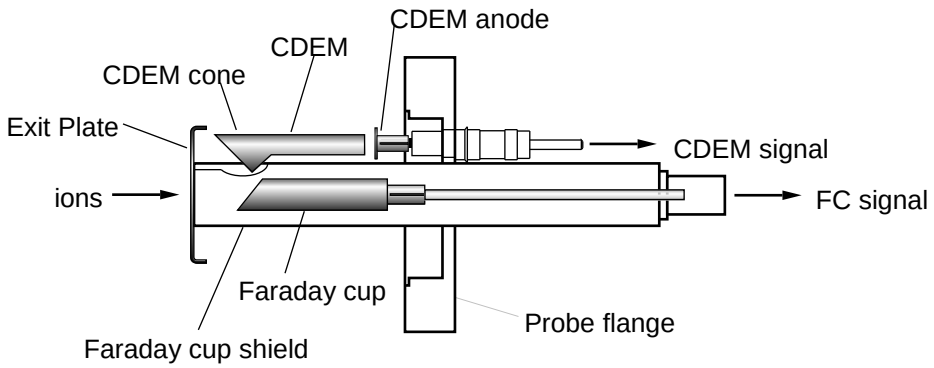

Figure 3-8 Detector Components

The **Faraday Cup (FC)** is a small stainless-steel (type 304) metal bucket located on-axis at the end of the quadrupole. It is shielded from the intense RF and DC fields of the quadrupole by the grounded **exit plate**, which also provides some focusing of the ions into the detector. A cylindrical tube (**FC Shield**) encloses the FC, protecting it from the strong electrodynamic potentials of the adjacent rods and from collecting ions originated at sources other than the ionizer. The signal is carried to the electrometer through a coaxial feedthru which extends into the ECU box and efficiently shields the small ion currents. The FC is attached to the center feedthru with a push-on connector and can easily be pulled out for cleaning or modification.

Notice that an electron suppressor electrode (commonly found in several commercially available RGA's) is not part of this detection setup since the large aspect ratio (length-to-diameter) of the FC assures efficient recapture of secondary electrons.

The **electron multiplier** is a state-of-the-art **Macro Multi-Channel Continuous Dynode Electron Multiplier (CDEM).** It consists of a straight, four or six channel tube made out of a special resistive glass (i.e., high secondary electron emission yield) with a cone of the same material attached to the front end. It is placed upright, next to the FC, and away from the axis of the analyzer (**off-axis configuration**). It is held safely in position by a clamp and a clip. The clamp is connected to the neighboring rod that carries the voltage from the High Voltage power supply, and is responsible for biasing the cone as well as assuring its correct placement next to the FC. A hole on the side of the FC Shield allows space for mounting the CDEM cone very close to the top of the FC. The clip anchors the

CDEM glass tube to the side of the FC Shield and holds the lower end of the tube at ground. Chrome electrical coatings, deposited at both ends of the tube provide the necessary electrical contacts. A plate (CDEM Anode) mounted at the exit of the CDEM collects the secondary electrons. The resulting electron current flows into the electrometer through a separate feedthru of the flange.

The entire setup is **self -aligning** and easily serviced by the user in the field. For example, removing the screw that fastens the clamp to the HV rod is all that is needed to replace the CDEM (Please see the Maintenance chapter for details.)

FC detection is standard in all RGA probes. All FC-only units can be upgraded to electron multiplier detection without the need to replace the probe. When the electron multiplier is not turned on, multiplier systems operate exactly like the FC-only systems. The same electrometer is used to measure the ion (or electron) currents under both detection schemes. The ECU automatically connects the necessary electrode to the electrometer depending on the type of detector being used.

Faraday Cup operation

The Faraday Cup (FC) detector, measures the incident ion current directly. Positive ions enter the grounded detector, strike a metal wall, and are neutralized by electron transfer from the metal to the ion. The electrons given up in this process establish an electrical current that has the same intensity as the incoming ion current.

Since the nominal sensitivity of the RGA is in the order of 10^{-4} Amps/Torr, the currents measured are very small: 10^{-9} to 10^{-15} Amps for pressures in the order of 10^{-5} to 10^{-11} Torr, respectively. Minimum-detectable-partial pressures as low as $5 \cdot 10^{-11}$ Torr are possible with the FC. However, in real-time applications, FC detectors are rarely used to measure partial pressures below 10^{-9} Torr. At pressures below that value, the CDEM option becomes a much better alternative allowing for faster scan rates and improved signal-to-noise ratios.
The best characteristics of FC detection are: simplicity, stability, large dynamic range, and lack of mass discrimination**. All ions are detected with the same efficiency regardless of their mass**.

The ECU automatically connects the FC electrode to the electrometer input upon power-on reset, and whenever the electron multiplier is not turned on.

Electron Multiplier Operation

An Electron Multiplier upgrade (Option 01) to the standard Faraday Cup (FC) detection setup is recommended when the SRS RGA is routinely used at pressures under 10^{-9} Torr. The detection upgrade consists of a state-of-the art Macro Multi-Channel Continuous Dynode Electron Multiplier (CDEM), and a negative high voltage power supply (0 to -2500V).

Macro Multi-Channel Continuous Dynode Electron Multipliers are used in the SRS RGA models with the electron multiplier option (Option 01). They consist of a straight four or six channel tube made out of a special resistive glass (i.e. high secondary electron emission yield) with a cone of the same material attached to the front end. The extruded channels run along the length of the device and are twisted at the time the part is drawn to eliminate ion feedback. Each CDEM is placed upright next to the FC and away from the

line of sight of the ionizer (i.e. off-axis configuration). When the cone is biased negatively (-1000 to -2500V) relative to the back end, positive ions are very efficiently attracted away from the FC and strike the cone at high velocity producing electrons by secondary electron emission. The secondary electrons are subsequently accelerated down the four channels and produce more secondary electrons. For each ion entering the cone of the CDEM, and depending on the bias voltage applied, up to 10^7 electrons come out at the back end and are picked up by a grounded plate (the CDEM anode). The resulting electron current is proportional to the ion current and is measured by a separate electrometer from the one used in the FC measurements. The sign of the electron multiplier currents is reversed before the current value is sent to a host computer so that the computer does not need to do any sign flipping on the currents received when the CDEM is activated.

The gain of the electron multiplier in the RGA is a function of the bias voltage and is measured relative to the FC signal. The following figure shows a typical **"gain characteristic**" (i.e., gain vs bias voltage) curve obtained for H_2O^+ ions at 18 amu.

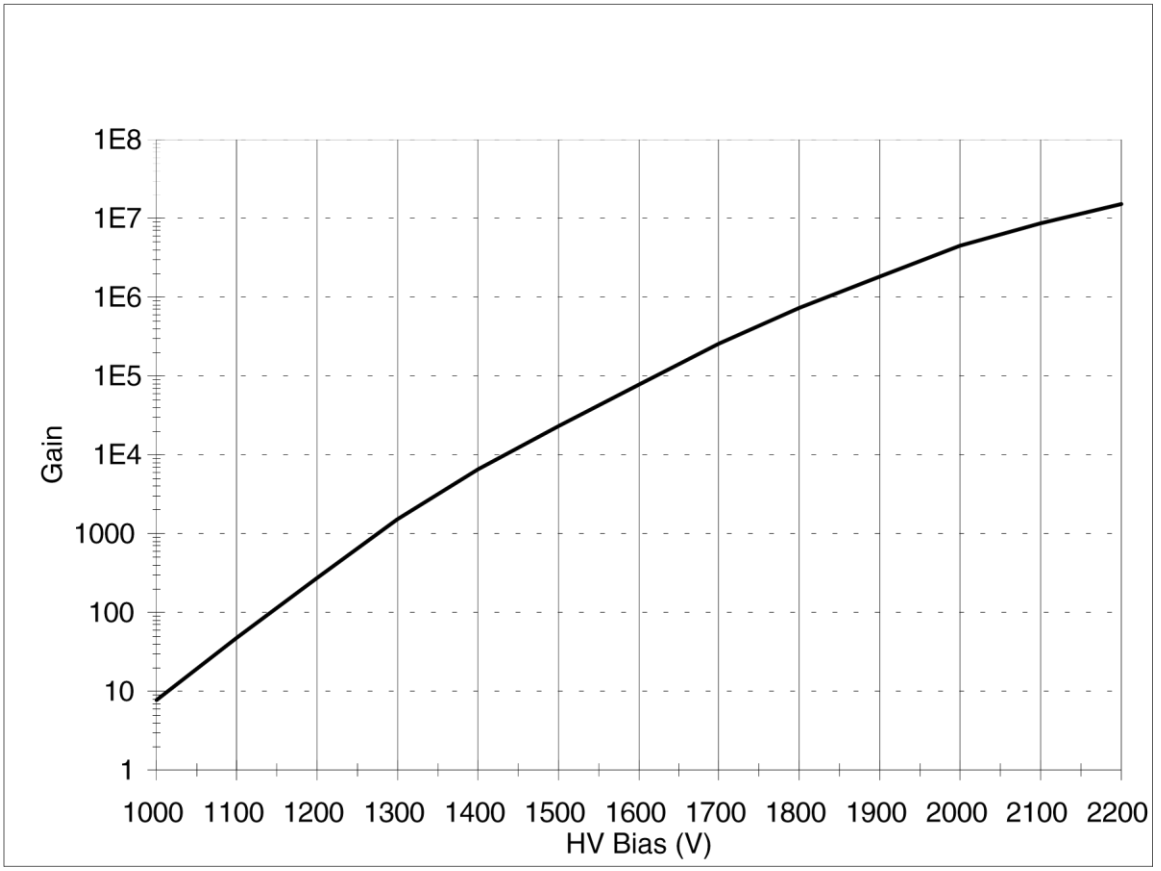

Figure 3-9 Typical CDEM Gain Characteristic Curve

Very high gain values can be obtained and controlled with voltages smaller than -2500 Volts. **The sensitivity of the spectrometer increases with the gain of the electron multiplier**. Higher sensitivities provide lower minimum detectable partial pressures and

faster spectral scans. Minimum detectable partial pressure limits as low as $5 \cdot 10^{-14}$ Torr are commonly achieved.

However, the increase in sensitivity is obtained at the price of limited dynamic range, mass discrimination effects, gain instabilities and finite lifetime of the device. A good understanding of these limitations is very important to assure accurate quantitative measurements.

The **dynamic range** of electron multipliers is determined by their dark current at the low end, and by the bias current value at the high end.

The **bias current** is established by the external voltage drop along the resistive glass tube and flows along the channel walls replenishing their charge as secondary electrons are emitted. **Channel electron multipliers, operate linearly in the analog mode until the output current is approximately 10% of the bias current.**

The **dark current** of a multiplier is the electron current measured at its output in the absence of an input ion current. **The minimum output current that can be accurately measured with the multiplier is equal to the dark current noise.**
Example: For a typical resistance of 200 MΩ, and a bias voltage of -2000V, the bias current is 10 μAmps and the output current must be kept under 1 μAmp. Since the gain at that voltage is roughly 10^6, the maximum input current at which the output current behaves linearly is 10^{-12} Amps (1 μAmp / 10^6). Typical dark currents are lower than 10^{-13} Amp, and the minimum input current that can be detected is 10^{-19} Amps. For a sensitivity of 10^{-4} Amp/Torr, this corresponds to the lower and upper limits of 10^{-15} and 10^{-8} Torr, respectively, and 7 orders of magnitude of dynamic range.

The total gain of electron multipliers varies as a function of the mass of the incident ions. As a rule of thumb, and for small molecules, **the gain decreases as mass increases**. This mass discrimination effect is caused by the dependence of ion-electron conversion efficiencies on the velocities of the ions entering the detector. For example, an inverse relationship with the square root of the mass has been reported for monoatomic ions of the same energy. For accurate quantitative measurements, it is essential to calibrate in advance the gain of the multiplier for the specific ionic species being detected.

An important problem when working with multipliers is that their gain changes with time. **Gain degradation** is unavoidable, and particularly serious just after the detector has been exposed to air, or after high quantities of reactive gases have been introduced into the vacuum system. The increased surface area provided by the extra channels in the multi-channel devices reduces this problem; however, frequent calibration of the multiplier gain against the FC output is recommended for reliable quantitative measurements. This is done automatically with the RGA software.

Gain degradation limits the **lifetime** of all electron multipliers. Eventually the gain drops to unacceptable values and the multiplier needs to be replaced. As a rule of thumb, **the multiplier should be replaced when the required gains can no longer be achieved by increasing the bias voltage.** The lifetime of electron multipliers is ultimately dependent upon the accumulated charge drawn from the multiplier (**Gain degradation typically starts at accumulated output current values of a few thousand μAmp-hr)**. However, the lifetime also depends critically on the residual gas environment and the duration of transient signals. Contamination by organic compounds (i.e., diffusion or mechanical

pump oil) and the interaction with highly reactive gases must be avoided at all times.

It has been found that, in many cases, channel multipliers may be successfully **refreshed** by cleaning them in high purity isopropyl alcohol. The procedure is described in the RGA Maintenance chapter (CDEM Refreshment section) and, even though **it is not guaranteed to always work**, it is worth trying as a last resort before discarding a multiplier.

Channel electron multipliers have a history of high performance and dependability in mass spectrometry applications. However, in order to achieve maximum useful lifetime and optimum performance, it is very important to handle them very carefully. Please read the **CDEM Handling and Care** section in the **RGA Maintenance** chapter to familiarize yourself with some of the basic procedures that must be followed for the correct operation of the multipliers.

Hardware Modifications

Warning
The information in this section is for the use of Qualified Personnel only. To avoid shock and irreparable damage to the unit, do not attempt any of the changes in this section unless you are authorized to do so.
Read and follow all "Safety and Precaution" instructions before handling the product.
Because of the danger of introducing additional hazards, do not install substitute parts or perform any unauthorized modification to the product. Do not use the product if it has unauthorized modifications. Return the product to SRS for service and repair to ensure that safety features are maintained.

The SRS RGA is a quadrupole mass spectrometer specially engineered to perform all the functions of a residual gas analyzer, and its standard electron impact ionizer is designed specifically for that type of operation. However, the simplicity of design of the probe facilitates the modification of the instrument so that measurement applications other than simple partial pressure analysis are possible. The relative insensitivity of quadrupole mass filters to variations in ion entrance conditions makes it possible to apply quadrupole mass spectrometers to the detection of ions from sources other than the standard electron impact ionizers of RGA's. For example, quadrupole mass filters have been used to monitor ion formation in plasma, SIMS, electrospray, ICP, laser ionization and surface desorption experiments.

Many of the changes required to apply the RGA probe to alternative measurement schemes involve the modification of the ionizer from its standard design. The ionizer is of a very simple design and can be completely disassembled by the user loosening a few screws (please see the RGA Maintenance chapter). Ease of disassembly is ideal for periodic cleaning and very convenient when design modifications are needed. Special applications might require modifying, replacing or even removing ionizer parts. The scope of this section is to discuss the effects that design changes will have on the overall performance of the probe. These types of modifications are most common in research applications, and obviously **should only be attempted by qualified personnel who completely understand the operation of the quadrupole mass spectrometer.**

It is a good practice to minimize the changes performed on the probe so that the RGA can still perform its basic functions of residual gas analysis, which are invaluable tools for vacuum system diagnostics.

Repeller and anode grid modifications

The two ionizer grids can easily be removed from the probe for replacement or modification. They are structurally very strong because they are made out of sintered wire mesh (i.e., all crossing wires are welded to each other). Typical modifications, such as punching holes or cutting slots, can be performed by skilled personnel without compromising their shape. The replacements and modifications should obviously be compatible with the operation of the rest of the quadrupole probe. Optimum performance of the quadrupole can only be achieved if the ions are injected in the form of a beam of low energy (2 to 15 eV) and low divergence (i.e., close to and parallel to the axis of the quadrupole). For example, it is well established that the correct alignment of the anode grid is critical to the operation of RGA spectrometers: a misalignment as small as 0.010" can result in decreased sensitivity, decreased resolution and peak shape deterioration (i.e. peak splitting).
The alignment and symmetry of the repeller are not as critical as that of the anode grid.

Repeller removal

It is possible to operate the ionizer without the repeller. The repeller is held in place by a single, easily accessible screw (See RGA Probe Assembly drawing). It is sometimes eliminated when a smaller ionizer insertion volume is needed, when a laser beam needs to be focused into the anode grid or when a collimated beam of molecules needs to be directed through the anode grid without molecular scattering taking place at the repeller's wires.
The repeller serves several purposes in the ionizer that must be carefully considered before removal:

1. It mechanically protects the delicate filament while the probe is being mounted on the vacuum system. The filament might easily be damaged during installation without that protection.

2. It constrains the electrons to the ionizer volume, minimizing cross talk with other gauges in the vacuum system (Free electrons can affect the readings of neighboring ion gauges).

3. It increases the ionization efficiency by folding the electron trajectories back into the anode grid (multiple-pass configuration). A decrease in ionization efficiency will usually be noticed when the repeller is removed.

Operation without a filament

It is possible to use the quadrupole mass filter to detect ions originating from sources other than the standard electron impact ionizer. For example, the filament and the grids can easily be removed to expose the quadrupole to ions from a SIMS or Laser desorption ionization experiment. All the measurement and scanning functions of the mass spectrometer are still operational when the filament is not installed or not emitting electrons As mentioned previously, optimum performance of the quadrupole can only be

achieved if the ions are injected into the filter in the form of a beam of low energy (2 to 15 eV) and low divergence (i.e. close to and parallel to the axis of the quadrupole).

Whenever possible, complete removal of the filament and the grids should be avoided so that the residual gas analysis functions of the RGA are still available. For example, since service is not interrupted if a single filament burns out, it might be possible to keep one of the sides of the filament intact instead of removing it completely.

RGA Cover Nipple Replacement

A stainless-steel tube covers the probe assembly with the exception of the ionizer. This tube, referred to as the RGA Cover Nipple, contributes to the overall capacitance of the quadrupole rod assembly, and should not be removed from the probe unless it is replaced with a similar grounded metal shield tube inside the vacuum system (see below). Failure to replace the Cover Nipple will push the RF driving circuit out of regulation, and will limit the operating mass range of the quadrupole filter. The tube also acts as a barrier, preventing ions from sources other than the RGA's ionizer from reaching the detector and affecting the ion current readings.

The RGA Cover Nipple consists of two non-rotatable, 2.75" CF Flanges, connected by a short section of 1.5" OD tube (0.065" wall thickness). The entire part is made out of stainless-steel type 304, and its overall length is 6.75" (including the two flanges.)

Some experiments require being able to insert the RGA's probe deep into the vacuum chamber. When a large insertion depth is required, the standard RGA Cover Nipple can be replaced with the O100MAX Maximum Insertion nipple illustrated in Figure 10.

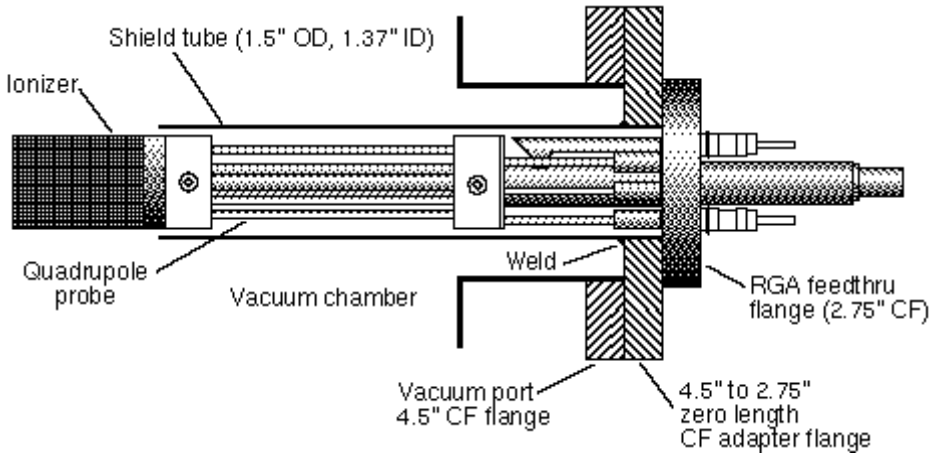

Figure 3-10 RGA Probe with Shield Tube

The O100MAX Shield tube consists of a 1.5" OD tube welded onto the large-flange side of a 4.5"-to-2.75" Zero Length CF Adapter Flange. The tube has a wall thickness of 0.065" and is strictly perpendicular (90° ±0.2°) to the flange's face. The RGA's quadrupole assembly is attached to the small-flange side of the Adapter Flange so that the tube completely covers the mass filter (replacing the standard RGA Cover Nipple). This

modified probe can be mounted on any standard 4.5” CF port of a vacuum chamber, and the ionizer penetrates the vacuum system by roughly 7”.

Chapter 4

RGA Electronic Control Unit

This chapter describes the most important features of the RGA Electronics Control Unit.

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Introduction

The SRS RGA is a mass spectrometer consisting of a quadrupole probe, and an Electronics Control Unit (ECU). The ECU completely controls the operation of the RGA, handles its data and transmits it to the computer for analysis and display.

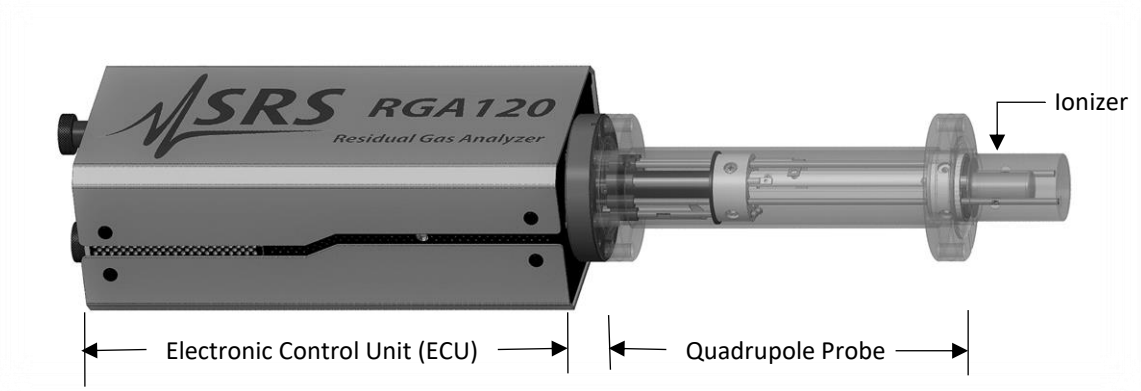

Figure 4-1 Quadrupole Head Components

The ECU is a densely packed box of electronics (3" x 4" x 9") that connects directly to the probe's feedthrough flange and also to a host computer. It includes several regulated power supplies, a built-in microprocessor, control firmware, and an RS232, a USB and a Ethernet communication ports. It is powered by either an external 24VDC (@3 Amps) power supply or an optional, built-in power module which plugs directly into an AC outlet.

Warning
The ECU does not have any serviceable parts and does not require any routine maintenance. All calibration procedures should be done using the RS232 interface and the RGA calibration command set.

During normal operation of the RGA, regulated power supplies built into the ECU set the electron emission current, the voltage levels on the ionizer electrodes, and the high voltage across the electron multiplier. RF/DC levels for each mass are also set and regulated by the ECU, based on internal mass calibration parameters permanently stored in non-volatile memory. A built-in, electrometer detects the ion currents collected by the FC, or electron multiplier, and converts them to voltage signals that are read by a built in A/D converter. The microprocessor automatically computes the magnitude of the ion currents using internal calibration parameters. The ion currents are then averaged as needed, offset corrected and transmitted to the host computer for immediate display.

Several built-in checks constantly monitor the operation of the probe and its operating environment. For example, the filament emission, and the electron multiplier, are immediately turned off in the case of accidental overpressure.

Active LED's on the rear panel of the ECU provide constant feedback on the status of the

filament, electron multiplier, electronics system, probe and communications, and alert the user of any problems.

Front Panel

The ECU mounts directly on the probe's feedthru flange. Its front panel is designed to rest flat against the back surface of the probe's flange, and it is not visible while the ECU is locked in place.

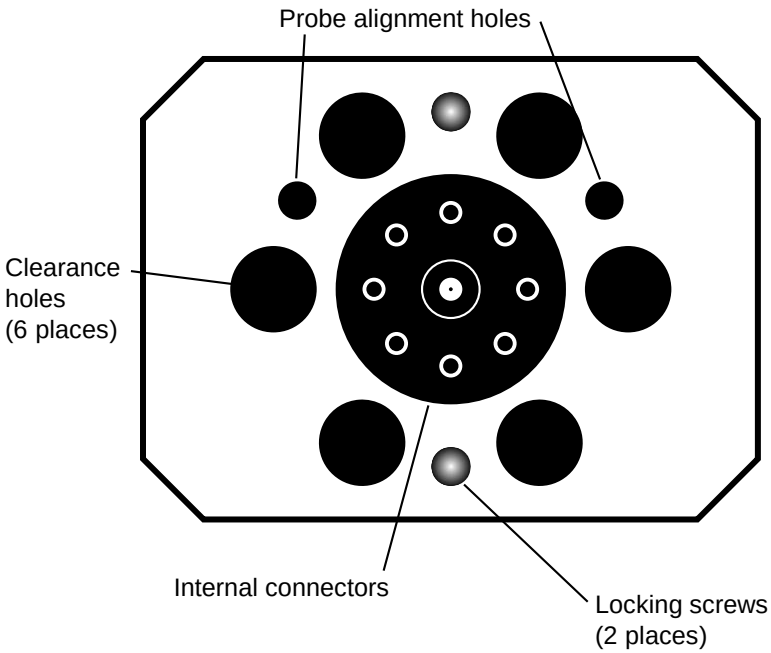

Figure 4-2 ECU Front Panel

The front panel of the ECU box has nine holes of three different sizes, and two locking screws.

The big hole in the center provides access to internal connectors that line up with the feedthru connectors of the probe. The six equally-spaced holes, surrounding the big hole, provide clearance for the six bolt heads on the back of the probe's feedthru flange.
The two remaining holes (1/4" diameter) line up with the alignment rods of the probe and assure the correct alignment between the ECU and the Probe during installation.
The locking screws line up with two threaded holes on the back of the feedthru flange, and are used to lock the ECU box in place.

Rear Panel

The rear panel of the standard ECU Box has two connectors, two locking knobs, a cooling fan, and eight LED's.

Units with the optional, built-in power module (Option 02) also have a fused Power Entry Module with a built-in power switch.

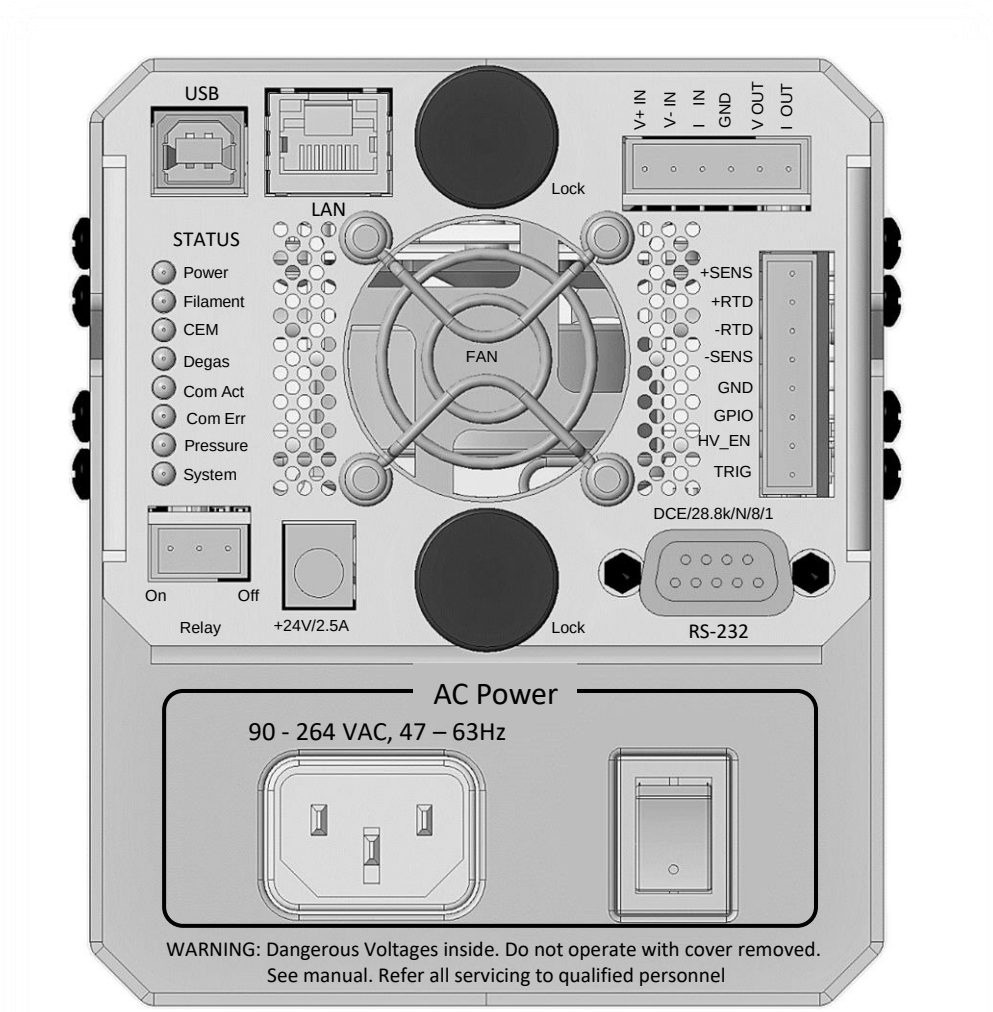

Figure 4-3 ECU Rear Panel with built in power supply module (Option 2)

+24VDC / 2.5A Connector

Use this connector to provide external power to the RGA. The ECU electronics must be powered with a 24 V (+/- 2V) power supply with 2.5 Amps or more current. The power supply must have a cable with a barrel connector on the free end.

USB Connector

Use this connector to interface the RGA to a computer with a type A to type B USB cable. Use 115200 baud rate, 8 data bits, no parity, 1 stop bit for serial communication setting.

LAN Connector

Use this connector to interface the RGA to a computer with an Ethernet (Cat 5) cable for 10/100 BASE-T speed

RS232 DCE/28.8k/N/8/1 Connector

Use this connector to interface the RGA to a computer with a RS232 cable. The RS232 interface connector of the RGA is configured as a DCE (transmit on pin 3, receive on pin 2) with full RTS/CTS handshaking enabled. Use a straight through RS232 cable with 9-pin, type D connectors to connect the computer (usually DTE) to the ECU. The communication parameters are fixed at: 28,800 baud rate, 8 data bits, no parity and 1 stop bits.

Relay

Use this relay to turn on/off a resistive load up to 125VDC (30W) or 125 VAC (50 VA)

Analog I/O

Use V+IN and V-IN to monitor a differential voltage input between 0 and 10 V.
Use I IN and GND to monitor a current input between 4 and 20 mA.
Use V OUT and GND to source a voltage output between 0 and 20 V.
Use I OUT and GND to source a current output between 4 and 20 mA.

RTD, GPIO, TRIG, and HV_EN

Connect +RTD and –RTD to a resistive temperature detector (RTD) for 2 wire measurement.
Connect +RTD, -RTD and +SENSE for 3 wire measurement.
Connect +RTD, -RTD, +SENSE and –SENSE for 4 wire measurement

Use TRIG to trigger an armed scan.
Set HV_EN to GND will turn off the filament and CEM HV

General purpose digital input output (GPIO) can be used for 1 bit digital input and out.

LED's

Eight LED's provide constant feedback on the operation of the RGA. The function of the LED's is described later in this chapter.

Locking Knobs

Use the two knobs to lock the ECU box in place at the end of the ECU installation procedure. Do not overtighten the knobs. (Hand tighten only.)

Power entry module (Option 02)

Use this connector to power the RGA directly from an AC outlet. Use the three-wire power cord provided by SRS to connect the RGA directly to a properly grounded AC outlet. Use the built in switch to turn the unit on-off.

Refer to the first page of this manual for instructions on selecting the correct line voltage and fuse. The built-in power module (Option 02), has universal input (90-264 VAC, 47-63 Hz), and completely eliminates the need for an external 24VDC power supply connection.

LED Functionality

LED's on the rear panel of the ECU provide constant feedback on the status of the filament, electron multiplier, electronics system, probe and communications, and alert the user of any detected errors. This section describes in detail the function of each LED.

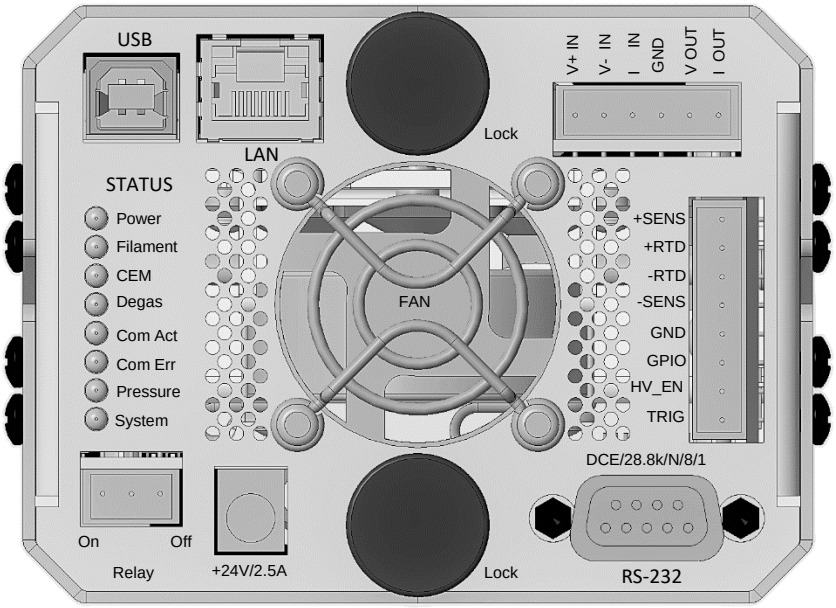

Figure 4-4 ECU LED's

STATUS (Green) LED's

Power: The Power LED is turned on whenever the RGA is successfully powered up. When power is applied to the ECU, a firmware routine automatically checks the external voltage level and turns on the Power LED if the voltage is within the acceptable range of 24 +/-2 V DC. The same test is performed in units with built-in power modules (Option 02) to check the voltage output of the internal switching power supply. If the check fails, the red Error LED is turned on instead to indicate the problem.

Note: A check on the external power supply can be performed at any time during operation using the EP? diagnostic command.

Filament: The Filament LED indicates the presence of electron emission current in the RGA's ionizer. It is turned on when a finite emission current is requested by the user and during Degas processes. It is turned off when the user requests a null emission current or when a filament error condition (i.e. overpressure, worn out or burnt filament) is detected and the filament emission is turned off.

Note: Filament error conditions are easily diagnosed with the help of the Pressure LED and the assortment of diagnostic checks built into the firmware and supported by the RGASoft program.

CEM: The CEM LED is turned on whenever the electron multiplier detector is active (i.e., when a finite biasing voltage is applied across the electron multiplier).
Several different mechanisms can turn off the electron multiplier and its LED: a null bias voltage request by the user, a Degas process, and an overpressure that shuts down the filament emission.

Degas: The Degas LED is activated during Filament Degas processes.
The Filament LED is also activated during a Degas.
The CEM LED is turned off during a Degas.

ComAct: The communication activity LED reflects the activity on the communication interfaces (USB, LAN and RS232).

ERROR (Red) LED's

ComErr: The communication error LED indicates the presence of errors in the communication interface.

Pressure: The Pressure LED is automatically turned on whenever the filament heater is unable to establish a requested emission current. The most common reason for this problem is a serious leak in the vacuum system. In the event of an overpressure detection, the filament emission and the electron multiplier are immediately turned off, and the Error and Leak LED's are turned on to indicate the problem.

Important: The Pressure LED will also be turned on if the thoria coating of the filament is excessively worn down or damaged. However, this is a rare event due to the long life of the thoriated iridium filaments.

System: The System LED indicates the presence of errors in the operation of the RGA. Errors can originate from many different sources including hardware, communications, probe (i.e., bad filament) and operating environment (i.e. overpressure). Troubleshooting is simplified by an assortment of diagnostic commands built into the firmware, and fully supported by the RGA Windows program.

Tuning chapter.

Maintenance and Service

- The ECU box does not have any serviceable parts and does not require any routine maintenance.
- Do not perform any unauthorized service, adjustment or modification of the instrument.
- Do not install any substitute parts.
- Contact the factory for instructions on how to return the instrument for authorized service and adjustment.

Chapter 5

RGA Software

For detailed information of the RGASoft program please refer to the RGASoft Online Help files provided with the program disks. The Online Help includes current and detailed descriptions of all the features, procedures, and commands available in the program.

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Overview

Software Program Structure

The RGA software program, namely RGASoft, is an interactive Windows program supporting SRS's RGA instruments. One RGASoft instance connects and controls one RGA unit. Likewise, multiple instances of the software program can independently connect to different RGA units. The number of instances is virtually unlimited and only constrained by the system resources.

An RGASoft instance, visible as a separate window, is used not only to control and acquire data from an RGA but also to review saved data and perform offline analysis. You can have one instance connecting to an RGA to perform a scan, and another one opening a saved data file.

Once an RGA is connected to RGASoft (via an Ethernet or a Serial connection), you can calibrate and tune the RGA's parameters, or perform scans with different modes and configurations. A scan run is organized as a sequence of scan steps where each step can be specified by a different scan mode or settings. The acquired data is saved to files. The saved data includes scan configuration, scan data, and the *view*. The first two items are the core of the data and are not meant to be changed later. On the other hand, the *view* which contains the visual and analysis settings can be modified when viewing the data.

The RGASoft's main user interface (UI) consists of a side bar which houses frequently used controls (RGA connect, scan run, pause, stop, etc.), a collapsible control panel to set up scan configurations and to view status, and a set of docking windows where each one contains plots and tables to present the data associated with a scan step. The UI also includes the menu to give access to many other components.

RGASoft Files

RGASoft is capable of saving files in a variety of formats. This section describes all the file formats and their different uses.

RGA data files (.rgadata)

RGA data files are the main files used in RGASoft. They are binary files that contain scan data with all the information on the scan parameters, scan trigger settings, RGA status, etc. You can open this file in RGASoft to view the scan data and perform offline analysis or to load its scan parameters to use in a new scan. The RGA data file is accompanied with a *view* file (.rgaview) to store the visual settings.

RGA view files (.rgaview)

An RGA view file supplements an RGA data file (.rgadata) in providing visual settings. Its file name is the same as the RGA data file name with a different extension. When you load configuration from an RGA data file, if the view file is available in the same location as the data file, the visual settings you have saved will also be loaded. Without a view file, RGASoft will use default visual settings. Visual settings cover a wide set of settings including the custom display of plots and tables, the alarm settings, or the composition analysis settings. While the data file stays unchanged after a scan run

finishes, you can modify the visual settings and save them to the view file. This allows you to perform offline analysis and save the analysis settings.

Export Text files (.txt)

RGASoft provides options to export plot data or table data to a text file in CSV (comma-separated values) format. This format can be easily read by a spreadsheet program for data analysis. The RGASoft program does not read these text files, it only writes to them.

Export Image files (.bmp, .jpg, .gif, .png, .tif)

In addition to text files, RGASoft can also export a plot image to a file with one of the common graphic formats. These files are easily read by many word processing, page layout, and graphic programs.

INI file (rgacfg.ini)

This configuration file contains some advanced settings and should only be modified in special cases such as when you're experiencing a slow network, or you want to capture a verbose software log for troubleshooting purposes. The RGASoft program reads the *rgacfg.ini* file upon launching. Changing the file requires relaunch of the software for the settings to take effect.

Log files (.log)

Log files are located under the *%temp%\RGASoft* folder of the Windows system. Each instance of RGASoft has a separate log file. It captures various information output by the software program, ranging from critical errors to status information. In a normal operation, users may not be concerned with the log file. However, when a problem is encountered, the log file may provide some clues to the problem.

System Requirements

The RGASoft program system requirements vary depending on the performance required of the RGA system, on how many software instances are open, and how many RGA are connected and run simultaneously. The RGA can scan data at different scan rates that affect noise floor and averaging.

Following, is the **minimum** recommended system to run a single RGA system:

- Computer with Microsoft Windows 10 or later
- Mouse or equivalent pointing device
- 200 Mbytes of free hard disk spaces (for RGA installation and runtime use)
- One of the following communication ports and matching cables
    - USB port and USB A to USB B cable.
    - Serial port (or USB serial port adapter) and DB-9 to DB-9 RS232 cable.
    - Ethernet port and Cat-5 cable.

Getting Started

Note:
For detailed information of the RGASoft program please refer to the RGASoft Online Help files provided with the program disks. The Online Help includes current and detailed description of all the features, procedures and commands available in the program.

The following sections describe how to launch the RGASoft program and start acquiring data from the RGA.

Starting RGA Software

To start the RGA software program simply double-click on the RGASoft icon in the "SRS RGASoft" program group, or the desktop shortcut created by the RGASoft installation program. You may also type the full path name of the RGASoft program in the Run command from the Program manager.

Multiple instances of the RGASoft program can run at the same time. You can start a new instance via one of the ways described above or select menu *File > New Window* from an existing instance.

Connecting to RGA

You can connect to an RGA with either a Serial or an Ethernet connection. The RGA120 family instruments support RS232 and USB ports for a serial connection and an Ethernet port for an Ethernet connection.

Depending on the type of connection, you would need either an RS232, USB or Ethernet port on your computer. An DB9-DB9 RS232 cable, USB cable or Ethernet cable is also required.

To connect to an RGA do the following:

1. Connect either an RS232, USB or LAN cable to the RS232, USB or LAN port on the RGA.

2. Connect the other end of the cable to the corresponding RS232 port (or serial adapter), USB or LAN port on the computer.

3. Turn on the RGA.

4. Start MS Windows and the RGASoft program.

5. Upon launching, RGASoft shows the Connections dialog box. Serial connections such as RS232 and USB are automatically detected and displayed in the table. An Ethernet connection requires the following one-time setup:

   Ethernet Connection Setup: Press the Refresh button to search for the new RGA. Double-click the table row with status *New Device* to bring up the Ethernet Connection Settings dialog box. Enter the RGA credentials to save them on the computer. The default login/password for an RGA120 Series unit is *admin*/*admin*. If

you don't see your RGA, it is possible that the RGA Ethernet settings haven't been configured to work with your network. Press the Set Up RGA Ethernet button to set it up first.

6. Select the COM port or the IP address to which the RGA is connected, and where the status shows *Available*.

7. Press the Connect button.

The connection is made when *Connected* is displayed in the status column of the Connections dialog box, and the control panel is enabled.

Acquiring Data

Once connected to an RGA, you can customize the scan settings and collect data from the RGA. Following steps outline the basic procedure for data acquisition:

1. Use the Scan Settings panel to select the scan mode and configure the scan parameters. Optionally add more steps to the scan sequence.

2. Configure the scan run trigger (Scan Settings panel > Trigger Setup tab) to customize how to trigger the scans and how recurring scans should run.

3. Turn on the filament (menu Probe > Turn On Filament).

4. Select the scan run command (menu Scan > Run, or the Run button (▶ icon)).

Note:
Upon launching, RGASoft provides a single-step Analog scan sequence in a continuous time-triggered mode. Simply performing step 3 & 4 (without step 1 & 2) would give you analog mass spectrum data.

Shutting Down RGA System

The recommended shutdown procedure is as follows:

1. Stop the scan if there is one in progress using menu Scan > Stop Now command or click the shortcut button (the STOP sign button).

2. Turn off the filament by selecting menu Probe > Turn Off Filament command.

3. Save the scan data using menu File > Save As command if it's not automatically saved.

4. Terminate the RGASoft program using menu File > Exit command.

5. Turn off the RGA.

Features and Operation

Note:
For detailed information of the RGASoft program please refer to the RGASoft Online Help provided with the program. The Online Help includes a detailed description of all the features, procedures and commands available in the program.

RGASoft Instance

An RGASoft program instance, visible as a main window, connects to an SRS RGA operating in one or more scan modes. Multiple program instances can run at the same time to connect to different RGA units. An instance does not need to be connected to an RGA at all times. You can open an RGASoft instance to view offline data, export data or perform composition analysis. An RGASoft main window contains a control panel and one or more dock widgets, each represents the data of a scan step. A dock widget can be docked to the main window or stay afloat as a separate window. The control panel is where you set up the scan steps and control the scan run.

Scan Sequence

RGASoft allows different types of data scan to be configured as a scan sequence. The scan sequence is made up of one or more scan steps. The steps are executed sequentially in a scan run. You use the Scan Settings panel to add or remove steps, select a scan mode for each step, and to configure the parameters for that mode.

Each scan step has a corresponding dock widget to display the data. Depending on the scan mode of the step, the dock widget may contain different widgets to present the step scan data. Use the dock widget's menu (≡ icon) to access its widgets.

Scan Modes

There are four scan modes and a hardware control mode available. The hardware control mode can be inserted between scan steps to control the hardware settings. A scan mode has its own display of the scan data, notably a main plot for the mode. For example, the Analog scan data is presented on the analog plot, the Histogram scan data is presented on the bar plot, etc. The main plot along with other complement widgets reside on a dock widget.

Following are the available modes:

Analog

Analog mode is the spectrum analysis mode common to all Residual Gas Analyzers. In Analog mode the RGA scans from the Start to the Stop mass using the Points Per AMU scan parameter. This parameter is used to determine the mass increments between data points. The time to acquire each intensity value depends on the scan rate selected. On the analog plot, the X-Axis represents the mass range chosen in the scan parameters. The Y-Axis represents the ion current amplitudes of every mass increment measured.

In addition to the analog plot to display the data, the dock widget of Analog mode comes with a Derived Pressure vs. Time (PvsT) plot. This time plot lets you display the partial pressure of a certain gas mass over a period of time. Its data is extracted from the Analog spectrum. To show traces on this plot, first, use the dock widget's menu (≡ icon) to show

the Mass table. Then select the gas mass on the Mass table to display its data on the Derived PvsT plot.

Histogram

Histogram mode displays the individual mass amplitudes for the selected scan range on a bar plot. In this mode the RGA performs a peak-lock for each mass and calculates one amplitude per mass. This peak is then plotted as a bar at the appropriate mass. The X-Axis of the bar plot represents the mass range chosen in the scan parameter. The Y-Axis represents the ion current amplitudes of every mass measured.

In Histogram mode the RGA scans from the Start to the Stop mass. The peak value within ±0.3AMU of each nominal mass is then sent to RGASoft. This results in one point per mass being plotted as a bar graph. The time to acquire each intensity value depends on the scan rate selected.

Similar to Analog mode the dock widget of Histogram mode comes with a Derived Pressure vs. Time (PvsT) plot. This plot lets you display the partial pressure of a certain gas mass over a time period. Its data is extracted from the Histogram spectrum. To show traces on this plot, first, use the dock widget's menu (≡ icon) to show the Mass table. Then select the gas mass on the Mass table to display its data on the Derived PvsT plot.

Pressure vs Time

Unlike Analog and Histogram modes where the scan is performed for the whole mass spectrum, the Pressure versus Time (PvsT) mode lets you specify individual gas masses to scan. This results in a faster turnaround of scan data. In this mode, the data is presented in a time plot. The gas masses, names, and parameters can be set on the Scan Settings panel. Each PvsT entry can be configured with its own scan rate.

The Mass table on the dock widget displays the partial pressure of each gas mass at a given time. When the scan is in progress, the latest data is shown. When viewing offline data, you can browse any data point on the time axis. Use the dock widget's menu (≡ icon) to show or hide the Mass table.

The PvsT mode also provides Annunciator panels. The Annunciator panels use the same data as in the PvsT plot and the Mass table. They provide an effective way to visually monitor gas warning levels from a distance. The panels are grouped as boxes where each represents a gas and alarm level. The partial pressure value is clearly visible and so is the gas name. When an alarm level is reached, the panel color changes to a preconfigured color and the appropriate message is shown. Audible alarm is also available. The panels can share the dock widget's space with the PvsT plot and the Mass table, or they can be resized to take up all the space they need. The alarm settings are configured for each gas mass from the panel or from the Mass table. You can change the alarm settings before or after the scan run starts.

Leak Test

Leak Test mode provides the most effective way to study the behavior of a single gas. In this mode the partial pressure for the specified gas is acquired by querying the RGA for that specific mass only. The time to acquire each partial pressure depends on the scan rate selected. This mode supports a time plot that monitors the gas trend over a time period, a Mass table for instantaneous partial pressure readout, and an Alarm message box. The

alarm colors and messages are configurable. An audible beep with a pitch proportional to the partial pressure is also available.

The gas mass, name, and scan parameters are configured on the Scan Settings panel. The leak unit can be selected to show as pressure or leak rate (Leak Rate Tuning is required for the leak rate option).

Hardware Control

Hardware Control is not a scan mode but rather a supporting mode that can be inserted between scan steps in a scan sequence to make changes to the RGA hardware or to delay a scan step. For instance, if you want to switch the detector type from one scan step to the next, you can insert the Hardware Control between the two steps and set the detector type the same as that of the next scan step. The Hardware Control gives you the option to wait for the detector to be stabilized before proceeding. Without it, the detector change still takes place, but the switching may not give the detector enough time to stabilize before a scan.

Scan Parameters

In a scan sequence, every step has its own set of scan parameters depending on the scan mode. RGASoft uses the parameters to set up display and to acquire data from the RGA. An RGA must be connected to configure a scan sequence and parameters. In a scan run, the parameters are sent to the RGA at the beginning of every scan step if parameter values change.

To change the scan parameters of a step in the sequence, simply select the step – represented as an accordion tab – on the Scan Settings panel and modify the parameters. Press the Apply button on the scan step to update the display. You may skip the Apply button. Pressing the Run button (▶ icon) updates the display and starts the scan run in a single step.

Scan Run Trigger

A run trigger tells RGASoft when to start the next scan cycle. A trigger applies to the whole scan sequence, not individual scan steps. There are two trigger modes: Time Triggered and Hardware Triggered mode. As the name implies, the Time Triggered mode gives you the trigger options based on a time variable, whether continuous or a time interval. The Hardware Triggered mode provides options to initiate the scan when a hardware signal is detected. This hardware signal comes from an external device connected to the RGA's Trigger port.

To modify a run trigger, locate the Trigger Setup tab on the Scan Settings panel. The run trigger default setting is Time Triggered, continuous run (the setting appears as *Triggered every 0 second*). For Time Triggered mode, if the trigger period is non-zero, make sure it is longer than the time it takes to run one cycle. Otherwise, the next cycle will start immediately. For Hardware Triggered mode, select how the hardware signal would cause a trigger: Low, High, Falling Edge or Rising Edge. Specify the trigger timeout. The scan run will stop if no trigger is detected when the timeout expires. After a trigger is fired, you have the option to repeat a specified number of scan cycles before re-arming the trigger. If you wish to continue scanning after a trigger, specify a large number of scan cycles to avoid re-arming the trigger.

Data Acquisition

The terms Data Acquisition and Scanning are used interchangeably in the SRS RGA documentation. A scan implies that the SRS RGA is performing ion current readings and sending the data over the RS232, USB or LAN cable to the computer running the RGASoft. This data is presented on the dock widget that is associated with the current step of the scan sequence. The data update speed depends on the computer's resources, the network condition, the scan settings, etc.

The main procedure for establishing a live scan is outlined below:

1. Turn on the SRS RGA.

2. Establish a connection between the RGASoft and the RGA unit (menu File > Connect RGA command or Connection button).

3. Turn on the filament (menu Probe > Turn On Filament command).

4. Select the desired scan mode and parameters on the Scan Settings panel. Optionally add more scan steps. The default scan sequence is a single-step, Analog mode.

5. Select the scan trigger options (Scan Settings panel > Trigger Setup tab).

6. Select the scan run command (menu Scan > Run or Run button (► icon)).

Scan Data Saving

The scan data is continuously saved to a file while the scan run is in progress. If the data auto save is enabled (the default setting), the scan data is saved to a file whose name is created by a preferred format. The available formats are Scan Mode, RGA Serial Number, or User Defined. If auto save is not enabled, the scan data is saved to a temporary file. You can perform a *save-as* on demand later. The data location is specified under File > Preferences menu.

It is possible to do a *save-as* while the scan run is in progress. This allows you to save the on-going scan data to a separate file without stopping the scan. You can then open the file in another RGASoft instance without interfering with the scan process.

Once the data is displayed on a plot or table, it can be copied to the system clipboard or exported to a text file. The CSV formatted text can be easily imported into a spreadsheet program. The plot display can also be exported as an image in a similar way.

Data Display

RGASoft presents data using plots, tables and other widgets. Except for the Hardware Control mode which does not have any data, each scan step in the scan sequence has a corresponding *dock widget*. This section discusses in detail the dock widget and other graphical user interface (GUI) components that it contains.

Dock Widgets

RGASoft makes use of docking windows, also known as *dock widgets*, to organize GUI components. A dock widget can be docked to the main window or can stay afloat as a modeless dialog box. Each scan step in the scan sequence is associated with a dock

widget. Gas Library and Composition Analysis also utilize dock widgets to present the data. A dock widget contains other widgets such as plots, tables, panels, etc. to display the data. It provides a menu (≡ icon) to access its components. Use the horizontal handle (**.....** icon) or vertical handle (⋮ icon) to resize the components. Press and hold down the mouse over the top area of a dock widget and drag it to dock/undock or to move it.

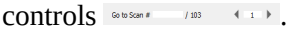
Context Menu

To get to options and actions of a widget such as a plot or a table, context menus are often used. You invoke a context menu by right-clicking your mouse on the GUI component. A widget may have different context menus depending on where the mouse pointer is at the time of selection.

Plots

Plots are widely used in RGASoft to present data. Most of plot options and actions are available from the plot's context menu which can be invoked from the plot canvas. The *Customize Plot* option from this menu gives you more visual settings to control the plot's look and behavior. A new plot would take the default settings from the Preferences (File menu).

To customize the display of a trace in a time plot use the context menu invoked from the trace's legend. The custom settings are saved to the RGA view file (.rgaview). This view file is paired with the RGA data file (.rgadata) when saved. When you load the configuration from a file (menu File > Load Configuration), the custom visual settings will be loaded from the RGA view file.

Each scan mode has a main plot which resides on the top of the dock widget associated with the scan step. For example, Analog scan comes with an analog plot, PvsT scan comes with an PvsT plot, etc. The main plot is supplied with a toolbar that holds most frequently used options and scan browsing controls 

. The plot toolbar can be shown or hidden from the dock widget's menu (≡ icon). When you view offline data, the scan browsing controls let you navigate to a scan of interest.

Tables

RGASoft uses tables to provide a snapshot of a data series. A Mass table, an Auxiliary Signal table or a Composition table (in Composition Analysis) are a few examples.

A Mass table, which is available on a dock widget of a scan step, provides the scan data of that step in a cycle. In a live scan, a Mass table shows the latest scan data. In an offline view, you can jump to any scan from the plot and the Mass table is updated with the scan data. In Analog and Histogram scan mode, the Mass table also gives you the options to extract the data for the Derived PvsT plot. Simply selecting a gas mass on the Mass table, you can plot the partial pressure of the gas on the time plot.

An Auxiliary Signal table accompanies a Mass table, displaying data for total pressure, temperature measurements or I/O signals. The Auxiliary Signal table resides below the Mass table and can be accessed via the dock widget's menu.

Like other GUI components, a table context menu provides options and actions you can perform on the table data. For example, the Mass table lists the options to export the data on its context menu while the Auxiliary Signal table provides shortcuts to set up I/O signals.

Annunciators

In PvsT mode, annunciator panels are included on the dock widget along with the PvsT plot. They can be shown by selecting a show option from the dock widget's menu or by simply holding and dragging the horizontal handle (**.....** icon) separating the plot and the annunciator container. Annunciator panels give you a large display of gas information. They are automatically resized and rearranged to make the best use of the space they occupy. Double-clicking on an annunciator panel would bring up the alarm setup dialog box. You can set up the alarm before or after starting a scan run. If you don't see the annunciator panel for newly added gas, press the Apply button on the scan step configuration panel to update the display.

Background Data

When setting up a scan step, you have the option to apply background data subtraction to yield a clean baseline. When the option is enabled, the background data is subtracted from the newly acquired scans. The background data comes from a data file you collect when you set up your environment with just the background noise. The background data and the new scans must have the same spectrum range or same individual gas masses. The background subtraction option is available in Histogram and PvsT mode.

Setup Procedure

1. Prepare your vacuum system with just the background noise.

2. Set up a scan in the target mode. For example, if you intend to do a Histogram scan later, then configure a Histogram scan now with the same mass range as you would use later. If doing a PvsT scan, then specify the same set of gas masses.

3. Start the scan run and save data to a file. This is your background data. You can run as many scans as you would like. The last scan would be used as the background data.

4. Now, in another scan where you would like to use the background data, go to the scan step on Scan Settings panel and press the More Options button to show the options. Check the *Enable Background Subtraction* checkbox. Make sure the scan mode is the same as the one you did in step 2.

5. Provide the data file you collect in step 3. Specify how the newly acquired data would be calculated from the reference, whether the scan data is subtracted from the reference, or the reference is subtracted from the scan data.

Data Averaging

One of the methods to improve noisy signals is signal averaging. RGASoft supports data averaging in Analog and Histogram modes. The averaging can be applied directly to the acquiring data or applied after you collect your data. The latter option lets you try different averaging functions and settings.

To apply averaging to the acquiring data, on the scan step of the Scan Settings panel, press the More Options button and check the *Enable Data Averaging* checkbox. Make sure the scan step is in either Analog or Histogram mode. Specify the averaging function and parameters. The collected data will be averaged, and you wouldn't be able to change the averaging parameters later.

When you are not sure what averaging function and parameters are best for your data, you can collect a small set of scans without applying averaging. Then follow the steps below to try out different averaging settings.

1. Open the offline data.

2. On the dock widget of an Analog or Histogram scan step, press the menu (≡ icon) and select *Apply Data Averaging* from the dropdown menu.

3. On the Average Setup dialog box, select the averaging function and parameters and press the OK button. The data will be updated based on your settings. If you want to reset the data, select None for the averaging function.

I/O Signals

With the RGA120 Series supporting various I/O ports from RTD to Analog I/O, you can interface the RGA with external devices to utilize the I/O signals for a wide range of applications. Use menu *ECU* > *Set Up I/O* to set up I/O signals. For input signals, RGASoft supports RTD, Analog Input Voltage and Current, and GPIO input. These signals are grouped under the Auxiliary Signal table of the dock widget of each scan step. Use the dock widget's menu (≡ icon) to access the table. Selecting a signal would plot it on the right Y-Axis of the PvsT time plot. The I/O signal intensities can be displayed alongside the partial pressure of individual gas masses on the same plot. Their timestamps are synchronized to give an easy view of the signals.

The Analog Input Voltage/Current values can be mapped to a measurement range in linear or logarithmic scale so that the actual measurement unit of the connected device is shown instead of the voltage or the current values. The opposite is also available for Analog Output signals where an RGA measurement is mapped to a provided range of output voltage or current.

An addition to input ports on the RGA120 Series is the dedicated Trigger port. This port gives you the option to trigger a scan based on the connected signal. With the Trigger port connected, you can configure the scan run trigger with the Hardware Triggered mode under the Trigger Setup tab of the Scan Settings panel.

Composition Analysis

Mass spectrum analysis takes you one step beyond visual analysis and Gas Library lookup. Based on your provided gas species, RGASoft applies the Least Squares Fitting algorithm to approximate the composition of the residual gas. The composition can be expressed in either pressure units or percentages. The scan spectrum should cover the highest AMU value of anticipated gases. The analysis can be done with both live scan data and offline data.

Analysis Procedure

This procedure can be done before, in the middle, or after a scan run. If you work with live scan data, do it before starting a scan run so that you wouldn't lose any analysis data.

1. On a dock widget that associated with an Analog or a Histogram scan step, click on the menu (≡ icon) and select *Show Scan Analysis* from the dropdown menu. An Analysis dock widget is opened. It's linked to the dock widget of the scan spectrum.

2. On the Analysis dock widget, click the menu (≡ icon) to select the *Select Gases for Analysis* option from the dropdown menu. You can also use the composition table's context menu to choose the same command (the composition table is located on the top right corner of the dock widget).

3. On the pop-up dialog box, check the checkbox for the gases or gas mixtures you would expect from your vacuum system. This gas list is populated from the gas library file. For better fitting calculation, select only the gases that have the mass spectrum covered by your scan spectrum. Press the OK button to add the gas list to the composition table.

4. Optional – If you want to capture the gas composition data in a text file, press the *Log Save* button to show the save settings. Provide the information for data auto-save.

5. On the Scan Data group box, check the *Auto Update with Live Scans* checkbox if you work with live scan data. The live scan data will be imported at the end of the scan step. If you perform the analysis with offline data, press the *Select Scans* button to bring up the scan selection dialog box. On this dialog box, select a single or multiple scans to import.

Once the scan spectrum is imported, either with a live scan update or with manual scan selection, the Analysis plot will display the best fit of the scan spectrum and the provided gases. Use the plot's context menu to access different options. To change the bar color of a gas, use the context menu of the composition table.

The composition table shows the partial pressure of each gas and its composition as a percentage. Note that the partial pressure value of a gas is the same as the intensity of the principal mass. Double-clicking on a gas name would bring up a panel showing the gas' fragmentation pattern in a table. The *Edit Gas* command on the composition table's context menu gives you the option to edit the attributes of a gas. The Gas Editor dialog box invoked from this command saves the gas attributes directly to the Gas Library file. Use the reload button (⟳ icon) below the composition table to reload the gas list from the library file.

In addition to the Analysis plot which presents the composition per mass spectrum, the *Composition vs Time* plot displays the composition over a time period. Use the Analysis dock widget's menu (≡ icon) item *Show Composition vs Time Plot* to show this plot. You navigate this plot the same way you do with other time plots. Use the plot's context menu to change the display of the Y-Axis as a pressure unit or as a percentage.

Preferences

The menu *File* > *Preferences* gives access to the Preferences dialog box where you can set default options for various settings. The display options serve as the default settings for a new GUI component. You often can customize local settings for each component independently. The Alarms and Data options are global settings. For example, if you change the pressure unit, data of all scan steps will be shown in the new unit. The Preferences menu item is enabled only when the system is idle.

Utilities

Note:
For detailed information of the RGASoft program please refer to the RGASoft Online Help provided with the program. The Online Help includes a detailed description of all the features, procedures and commands available in the program.

Gas Library

A Gas Library lets you find a chemical species and view its fragmentation pattern in the tabular or graphical representation. Select menu *Utilities* > *Gas Library* to open the Gas Library dock widget. Deselect the option to close it. The content of the Gas Library is read from the library file specified under the Preferences (menu File > Preferences > Data > Gas Library).

Mass Spectrum View

On the Gas Library dock widget, simply selecting a gas to display its mass spectrum on a bar chart. The fragmentation factors as percentages are shown in the fragment table. Note that the intensities are normalized to the principal mass (a mass with highest intensity). In the Normalized display mode, the principal mass carries a value of 1.0 on the bar chart and 100.0% in the fragment table. If you have a reference partial pressure of a gas, you can display the intensities of the gas masses in the pressure unit. Use the Reference Partial Pressure display mode in this case.

Gas Search

The Gas Library supports searching of a chemical species by its name or chemical formula. Simply provide a name or a chemical formula in the search box and press the Search button to perform a search. Note that formula is an optional attribute of a gas item therefore it may be empty as in the case of a gas mixture.

In addition to searching by name, you can also search for gas candidates based on a list of masses. The advanced mass search provides a further option by searching only the major peaks for gas candidates. This option helps to narrow down candidates when you are more interested in the gas' major peaks.

Gas Library Editor

RGASoft comes with a default gas library. The library data file is listed under the Preferences (menu File > Preferences > Data > Gas Library). The Gas Library Editor is provided as a tool to edit the content of this file. You can build your own version of the library by modifying an existing gas, or import a mass spectrum either from an RGA data file (*.rgadata) or from a NIST Chemistry WebBook JCAMP-DX file (*.jdx). To open the library editor, select menu *Utilities* > *Edit Gas Library*. The editor is a modeless dialog box. Upon opening, it reads the library data file and loads its content.

Modifying a Gas

A gas is identified by its name. You should keep the name unique.

1. Double-click a gas or gas mixture listed in the table to bring up the individual Gas Editor dialog box where you can modify the mass spectrum and gas attributes.

2. When done editing on the Gas Editor dialog box, press the OK button to accept the changes.

3. On the library editor, press the Save button to save the library content back to the data file. If you want to save the library as a different file, press the Save As button and provide a file name. You must later specify the new file under Preferences to use it.

Importing from JCAMP-DX File

Suppose you have downloaded a .jdx file containing a chemical species with the mass spectrum from NIST Chemistry WebBook, follow steps below to import the gas:

1. On the library editor, press the *Import* button.

2. On the file dialog box, select the *JCAMP-DX (*.jdx)* file filter.

3. Locate your directory and select one or more *.jdx* files. Press the Open button to import.

4. Press the Save button to save the library content back to the data file or press the Save As button to save it to a different file.

Importing from RGA Data File

Suppose you have collected either an Analog scan or a Histogram scan and saved it to an RGA data file (.rgadata). Follow steps below to import the mass spectrum:

1. On the library editor, press the *Import* button.

2. On the file dialog box, select the *RGA Data File (*.rgadata)* file filter.

3. Locate your data directory and select the *.rgadata* file. Press the Open button to start the import process.

4. An import dialog box is shown detailing the content of the data file. On this dialog box, you can select a particular scan to extract the data. Other options include the mass range and the peak threshold value. A data point with an intensity equal to or above the threshold is considered a peak.

5. Press the Extract button (▸ icon) to extract the mass spectrum. Adjust the gas masses and intensities if necessary.

6. Provide the name and other attributes for the gas. Press the Import button to import the gas to the gas library.

7. On the library editor, press the Save button to save the library content back to the data file or press the Save As button to save it to a different file.

Common Gases Editor

Common gases refer to a set of gas molecules frequently present in your vacuum system or ones that you are most interested in. You can label the common gases on an analog or

histogram plot to have a quick view of the gases present in your system. The Common Gases Editor allows you to edit the list of the gases that more relevant to your environment.

To open the editor dialog box, select menu *Utilities* > *Edit Common Gases*. The editor allows you to modify a gas item, add a new one or remove an irrelevant one. A gas item consists of a gas name and an associated mass.

Once done editing, press the OK button to save the list. The list is stored in the system registry and recalled when you launch the software.

Audible Alarm

The audible alarm option allows you to enable the audio for the alarm when it's triggered in PvsT or Leak Test mode. In the PvsT mode, the audio file specified in the Preferences (menu File > Preferences > Alarms > Wave File) is played. In the Leak Test mode, the alarm uses the system beep with a varied pitch and rate depending on the signal strength. Select menu *Utilities* > *Enable Audible Alarm* to turn on the sound. Deselect the option to turn it off.

Ethernet Setup Tools

A new RGA120 Series unit must have its Ethernet settings correctly configured to be used in a network environment. The Ethernet Setup Tools facilitate the configuration tasks.

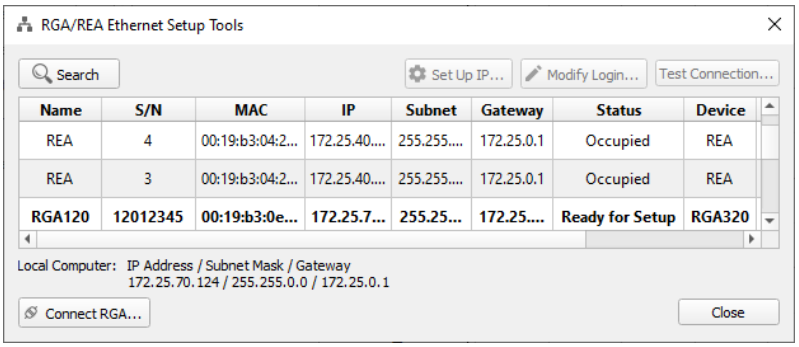


Figure 5-1 Ethernet Setup Tools Dialog Box

IP Address Setup

To set up a new IP address for the RGA, follow the steps below:

1. Keep the RGA powered off.

2. Connect the RGA to the local area network (LAN) with an Ethernet cable.

3. Get the RGA in the *Setup* state by detaching the probe from the Electronic Control Unit (ECU) then power up the ECU. **It is important to power up the ECU without the probe plugged in.**

4. Open the Ethernet Setup Tools dialog box from menu *Utilities* > *Set Up RGA Ethernet*. Upon opening the dialog box, the software program broadcasts a status

request to all RGA units on the LAN. Reachable units are displayed in the table as illustrated in Figure 5-1. The units which are in the *Setup* state are shown with the status *Ready for Setup*. If the Ethernet Setup Tools dialog box is opened before step 3, press the Search button to find your device.

5. Select your RGA unit in the table and press the Set Up IP button. Make sure its status is labeled *Ready for Setup*. Use the serial number to identify the unit if necessary.

6. On the *IP Setup* dialog box (Figure 5-2), select either to use a static IP address or to obtain a dynamic IP address (DHCP). If you choose to use a static IP address, provide the IP address, subnet mask and the gateway information. Check the *Reset Username/Password* checkbox if you wish to reset the username and password to the defaults. If you choose to obtain an IP address automatically, make sure a DHCP server is running in your network.

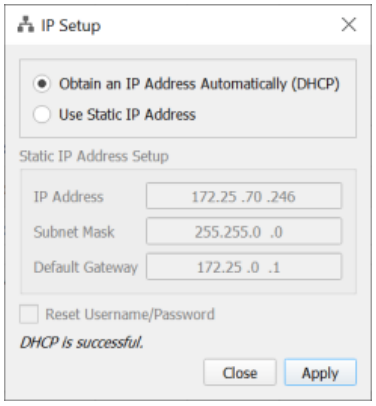


Figure 5-2 IP Setup Dialog Box

7. Press the **Apply** button on the *IP Setup* dialog box to send the request to the RGA. Progress messages are displayed near the bottom of the dialog box to tell you when the configuration is complete.

8. Press the **Close** button to close the *IP Setup* dialog box. The table in the *Ethernet Setup Tools* dialog box will refresh to show the updated status for the RGA. An RGA is ready when its status is either *Available* or *Available (DHCP).*

Modify Login

An RGA's login credentials, or its name can be modified once its IP address is successfully set up. To change a unit's login information, follow steps below:

1. Select an RGA on the *Ethernet Setup Tools* dialog box (Figure 5-21) with the status *Available* or *Available (DHCP)*, then press the **Modify Login** button.

2. On the popup *Modify Login* dialog box (Figure 5-3), provide the RGA's current login credentials and press the **Login** button to log in. The default username and password are *admin*/*admin*.

3. After successfully logged in, provide a new name or a new username/password under the *Device Settings* group. The device name is limited to 15-character long for the RGA120 Series.

4. Press the **Apply** button to send the request to the RGA. The device settings will be refreshed with the updated values.

5. Press the **Close** button when done.

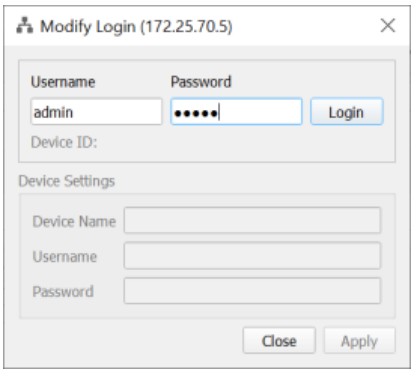


Figure 5-3 Modify Login Dialog Box

RGA Calibration

Note:
For detailed information of the RGASoft program please refer to the RGASoft Online Help provided with the program. The Online Help includes current and detailed description of all the features, procedures and commands available in the program.

WARNING!
The sensitivity tuning procedure should be performed by qualified personnel only. A mistuned RGA could give erroneous readings until it is retuned properly.

Please refer to the RGA Tuning Chapter for more information about tuning and calibration.

Sensitivity Tuning

To set the sensitivity factors of the RGA you must have a reference pressure gauge installed on your vacuum system. There are two sensitivity factors, one for total pressure and one for partial pressure. Both factors are stored in non-volatile memory of the RGA's ECU. Follow the procedure below for sensitivity factor tuning.

Note:
While performing the tuning procedure the total pressure in the vacuum chamber should be around 10^{-6} Torr.

Tuning Procedure

1. Select menu Probe > Sensitivity Tuning.

2. Select which sensitivity factor you would like to adjust from the Measurement Mode section (Partial Pressure or Total Pressure).

3. If you select Partial Pressure, then enter the mass whose pressure you will be measuring in the Mass edit box.

4. Enter the pressure indicated by your pressure gauge in the Reference Pressure edit box.

5. Press the Measure button. The Sensitivity Factor section will update the ion current reading from the RGA, and the calculated sensitivity factor.

6. Press the Save button to save the new factor to the RGA.

CEM Tuning

When Channel Electron Multiplier (CEM) is specified as the detector in a scan run, the RGASoft program takes into account the CEM gain to calculate the signal intensity. To find the required high voltage for a desired gain (or vice versa), *CEM Tuning* is needed.

To adjust the CEM gain, there must be a partial pressure reading detectable by the Faraday cup at the Reference mass. The signal at the Reference mass must be large

enough to detect with the Faraday cup, but not so large that the CEM signal is saturated. The readings from the two detectors are compared to establish the desired gain.

Tuning Procedure

1. Select menu Probe > CEM Tuning.

2. Select the setting option:
   - Set Gain: set your desired gain and the program will search the required high voltage for the gain. This procedure usually takes longer than the Set Voltage option.
   - Set Voltage: set your desired high voltage and the program will calculate the corresponding gain.

3. Specify the desired value on either the *Gain* or the *Voltage* edit box based on the option in the previous step.

4. Specify the gas mass on the *Reference Mass* edit box.

5. Press the **Start Tuning** button. The program will perform a series of ion current readings with Faraday cup and CEM as the detector and find the gain and high voltage values.

6. Press the ***Save & Close*** button after the tuning complete to save the values to the RGA. Press the **Cancel** button to close the dialog box without saving.

Peak Tuning

Peak Tuning allows the user to calibrate the mass scale and the resolution, $\Delta m_{10\%}$, of the mass spectrometer. The procedure requires a mixture of gases whose mass spectra is well known. There are two tuning modes: manual tuning and auto tuning. In the manual tuning mode, a two-gas mixture, one with *low mass* peaks and one with *high mass* peaks, is sufficient. The auto tuning mode supports up to 10 mass peaks.

Auto Tuning Procedure

The auto peak tuning works by gradually fitting the mass peak to the center of a target mass with the specified peak width. A peak should not drift too far from its target mass before the tuning. The auto tune is more successful if the peak is within +/- 1.5 AMU of the target mass. It supports up to 10 mass peaks. You can run the scan continuously or one at a time until you are satisfied with the tuning results. The procedure is as follows:

1. Select menu Probe > Peak Tuning.

2. Select Auto option under the Tuning Mode.

3. On Target Mass Peaks table, provide 2 to 10 gas masses that you know have noticeable signals.
   Requirements: A mass must be in the range of 12-200 AMU. Mass values must be at least 2-AMU apart.

4. Specify the peak width at FWHM (the width of the spectrum curve at half of its maximum amplitude). A value of 0.6 AMU is equivalent to a width of 1 AMU at 10% of maximum amplitude ($\Delta m_{10\%}$).

5. Optionally specify the scan rate.

6. Start the scan run and observe the peak at the specified masses. At the end of each scan cycle, the peak positions and widths are displayed on the Analog plot. You can pause the scan run to have more time to review the tuning results.

7. When you are satisfied with the tuning results, stop the scan run and close the Peak Tuning to save the tuning parameters to the RGA. To revert the tuning parameters to the original values (the values before entering the Peak Tuning), press the **Reset** button.

Manual Tuning Procedure

The manual peak tuning requires a *low* and *high* mass gas mixture. You basically observe how each mass peak looks and manually adjust the position and the width of the peak. The procedure for RGA120 Series is as follows:

1. Select menu Probe > Peak Tuning.

2. Select Manual option under the Tuning Mode.

3. Provide the *low* and *high* mass of the gas mixture that was introduced in the vacuum. Optionally specify the scan rate.

4. Start a scan run to see where the peaks are positioned and how wide they are. Mass spectra will be shown on the *Low* and *High Mass Analog Scan* plots.

5. Adjust the position of the *Low Mass* and *High Mass* peak if the peak does not fall exactly at its required mass. Also, adjust the width of the mass peaks so that the full width at 10% of its maximum amplitude is less than or equal to 1 AMU ($\Delta m_{10\%}$= 1 AMU). Start a scan run.

6. Repeat step 5 as needed. If you're satisfied with the results, close the Peak Tuning. To revert tuning parameters to the initial settings (the values before entering the Peak Tuning), press the **Reset** button.

Leak Rate Tuning

Leak rate tuning is required for the RGASoft program to properly display leak rates in the Leak Test mode. The leak rate factor is computed by measuring the partial pressure of a gas from a calibrated leak and calculating the effective pumping speed of the system based on the known leak rate.

Follow steps below for the tuning procedure:

1. Select menu Probe > Leak Rate Tuning.

2. Enter the known leak rate in the Reference Leak Rate edit box. The value is in units of *Torr*Liter/Second*.

3. Enter the gas mass whose pressure you will be measuring.

4. Press the **Measure** button to perform pressure reading from the RGA. The partial pressure reading along with the calculated leak rate factor are shown in the *Leak Rate Factor* field.

5. Press the **OK** button to accept the value. The value is stored in the system registry and the data file. Since it is not stored in the non-volatile memory of the RGA, you need to tune the leak rate for different RGA units.

Electronics Calibration

There are various procedures to calibrate different components of RGA electronics. Follow the steps below to perform electronics calibration:

1. Select menu ECU > Calibrate Electronics.

2. Make sure the checkbox for the procedure you want to run is checked.

3. Press the Calibrate button to start. The status for each selected procedure will cycle through *Pending → In Progress → Complete. Some procedures may take longer than others.*

4. *Close the dialog box when all the procedures are finished.* If a procedure failed, the RGA would report a *Procedure_Fail* error, and a *Failed* status will be displayed for that procedure.

RGASoft Online Help

The RGASoft Online Help contains detailed information on operations of the program that may not be covered in this manual. Use the Online Help to get up to date detailed information on the RGASoft program. The following sections describe the different ways to use RGASoft Online Help.

Context Sensitive Help

Context Sensitive Help provides a quick and direct way to display information on a specific topic. Make sure the GUI component has the mouse focus. Press F1 key to launch the Help Browser. The help topic of the component in focus will be shown. If the Help Browser is already open, changing the mouse focus on the RGASoft program will switch the help topic to the component that has the focus if the help topic is available.

Help Search

You may search the RGASoft Online Help for any topic or keyword. Once you have the Help Browser open, select menu View > Search or click on the Search tab to show the Help Search. Enter any keyword to display that topic.

Help Index

The Help Browser's Index displays a comprehensive index to information contained in the RGASoft Online Help. Once you have the Help Browser open, select menu View > Index or click on the Index tab to show the Help Index. Double-click on a topic to view it. You can also search for a topic on the index list.

Chapter 6

Remote Commands

This chapter describes how to control and configure the RGA head from a host computer using the remote commands over remote communication interfaces.

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Introduction

The functionality of the RGA is accessed by sending and receiving data over a remote communications interface. The RGA comes standard with an RS232 communications port, a USB communications port, and an Ethernet port. A host computer interfaced to the RGA can configure, calibrate, diagnose and operate the quadrupole mass spectrometer and other components using ASCII commands. The RGA executes the commands in the order received and, when information is requested, data is returned to the computer for analysis and display.

The command set detailed in this chapter describes how to interface with all the features available from the RGA.

External Interface

RS-232 Interface

The RS232 interface connector of the RGA is a standard 9 pin, type D, female connector configured as a DCE (transmit on pin 3, receive on pin 2) with full RTS/CTS handshaking enabled. The CTS signal (pin 8) is an output indicating that the RGA is ready, while the RTS signal (pin 7) is an input that is used by the host computer to control the RGA's data transmission.

The default communications parameters are set to:

- 28800 baud
- 8 data bits
- 1 stop bit
- no parity

This is provided for legacy device support where user software may expect to communicate with the RGA over 28.8k baud.

Cable Connection

Use a straight through RS232 cable with 9-pin, type D connectors to connect the host computer to the RGA. A DB9 to DB25 adapter will be needed if the host computer has a 25 pin type D connector.

USB Interface

The USB interface on the RGA is a type B USB connector. The connection is compatible with USB2.0 Full Speed protocol. Connecting a host computer to the RGA with a USB cable will show the RGA as a USB Serial Device.

The default communications parameters are set to:

- 115200 baud
- 8 data bits
- 1 stop bit
- no parity

Important

To use the USB Serial Interface, the host computer should have all required drivers installed before communication is attempted. See Appendix x for more information on how to install USB Serial drivers.

Ethernet Interface

The RGA comes standard with an RJ-45 network communications port located on the rear panel. The port may be used to communicate with the RGA over a 10/100 Base-T Ethernet connected network or LAN. Before connecting the RGA to your LAN, check with your network administrator for the proper method of configuration of networked instruments on your network.

By default, when the RGA is powered up and an Ethernet cable is connected, the RGA will use DHCP to search for a DHCP server to request for an IP address. If there is no DHCP server available, you will need to set up the RGA Ethernet IP address manually through a serial interface, or through the RGASoft Application.

Network Security

Network security is an important consideration for all TCP/IP networks. Please bear in mind that the RGA does NOT provide security controls, such as encryption, for controlling access to the RGA. If such controls are needed, you must provide it at a higher level on your network. This might be achieved, for example, by setting up a firewall and operating the RGA behind it.

LED Indicators

To assist in programming, the RGA has two status LEDs on the rear panel.

- **COM Act**: The activity indicator will flash whenever a character is received or transmitted over any of the interfaces.
- **COM Err**: The error indicator will flash momentarily when a command or execution error has been detected.

SCPI Command Language

The RGA uses the SCPI (Standard Commands for Programmable Instruments) language for controlling the instrument over a remote interface. The SCPI language is an ASCII based command language that organizes functions into a hierarchical tree of commands with branches of the tree separated by colons.

SubSystems

The base or root of the tree represents a subsystem of the instrument. Each succeeding branch of the tree subdivides the subsystem into related categories of functionality. The final branch of the tree identifies a command related to the subsystem that can be executed by the RGA120. This structure facilitates understanding of the functions carried out by commands. As an example, consider the subset of the STATus subsystem shown below.

```
STATus:
    GLOBal?
    GLOBal:
        SERVicemask(?)
        TEXT?
    CONDition?
    CONDition:
        ASSERT
        TEXT?
    EVent?
    EVent:
        ENable(?)
        TEXT?
    DEFaultmask
```

`STATus` is a subsystem of the RGA and it is at the root of the tree. At the next level down, the `STATus` subsystem is divided into multiple branches. Each of these categories can then be further subdivided into more branches. However, because of the hierarchical structure of the language, we can infer that the commands listed under the Global branch refer to global status register, while those listed under `CONDition` refer to condition status registers. Thus, the hierarchical structure of the commands aids the user in interpreting the scope of execution carried out by the individual commands.

Understanding Command Syntax

SCPI commands often take one or more parameters which modify or identify the numerical value a variable should take. Some parameters are required. Others may be optional. Furthermore, the data types for each parameter may differ. Thus, for brevity, we need a set of conventions for defining commands which clearly identifies all the valid

variations of the command without having the list each possibility separately. These conventions are set forth here.

Three example commands are illustrated below:

```
FILament:EMISsion <milliAmps>
ANALog:OUTput:VOUT:SELection:MIN <selection>, <value>
ION:VOLT {<voltage>|DEFault|MINimum|MAXimum}
```

Keyword Case

Keywords are defined with a mixture of upper-case and lower-case letters. The upper-case letters indicate the short or abbreviated version of the keyword. The user may send either the short version or the entire long version of the keyword in their programs. The case of the letters sent to the RGA does not matter. It is only used here to succinctly identify the two versions of the keyword. Thus, `FILament`, `filament`, and `Fil` are all acceptable forms of the keyword. Other forms, such as FILA, or FILAM, are not. Given the definition above, the following commands are all identical:

- `FIL:EMIS 1`
- `FILAMENT:EMISSION 1`
- `ANA:OUT:VOUT:SEL:MIN 1, 1.0`

Punctuation Used in Definitions

The following punctuation is used to identify variations and options for the command:

- Braces ({ }) enclose different parameter choices. The braces, themselves, are not sent with the command
- A vertical bar (|) separates alternative parameter choices for the command. In the third example above, the choices are a <voltage> or one of the keywords:DEFault, MINimum, or MAXimum. The vertical bar is not sent with the command. Thus, one could set the ion energy to the default by sending the following command:

  ```
  ION:VOLT DEF
  ```

- Triangle brackets (< >) indicate that you must specify a numerical value. In the example above, <voltage> would be specified as a number. The triangle brackets are not sent with the command. Thus, one could set the ion energy using the following command:

  ```
  ION:VOLT 12
  ```

Examples

Putting it all together, all of the following commands are valid given the example definitions presented above.

```
ANALOG:OUT:VOUT:SELECTION:MINIMUM 1, 1e-4
FIL:EMIS 0.1
ANALOG:OUT:VOUT:SEL:MINIMUM 2, 0.4
Analog:Out:Vout:Sel:Min 0, -2.0
```

Queries

Command queries are usually formed by appending a question mark (?) to the command. To query the measured filament emission current we use the following command:

```
FILament:EMISsion?
```

Separators

As mentioned above, a colon (:) separates the different keywords that make up a command. If a command takes a parameter, a space MUST separate the last keyword of a command and the first parameter of that command. If a command takes multiple parameters, they are separated from each other with a comma (,). Finally, a semicolon (;) is used to separate multiple commands on the same line. If the following command is in the same subsystem as the preceding command then the subsystem is not repeated for the second command. Otherwise the command must be fully specified and preceded by a colon. Given the example command tree presented in section SubSystems above, the following commands are valid:

```
STAT:EV:EN 1, 256; TEXT? 1
STAT:COND? 2, 1; :FIL:EMIS?
```

In the first line, both ENable and TEXT are in the same subsystem, STATus:EVent, so that portion of the command is omitted for the TEXT? query. However, in the second set, the two command queries are in different subsystems, so the filament emission current query is preceded by a colon and fully specified on the command line.

When multiple queries, separated by semicolons, are made in a single command line, the responses from the individual queries are separated by a semicolon as well.

Parameter Types

The SCPI language supports several different data types for use with command parameters.

Numeric Values

Parameters that take numeric values accept all common decimal representations of numbers, including optional signs, decimal points, or scientific notation. Hexadecimal values specified with a prefix of 0x prefix as used in the C language are also accepted. If only certain values are allowed, numeric entries will be rounded to the nearest allowed value. The following examples are all valid numeric entries:

```
100
-123.456
+1.23456e2
-.456
0x64
```

The last example, 0x64, is the hexadecimal representation for the decimal number 100.

Many commands that take numeric parameters will also accept the keywords `MINimum`, `MAXimum`, or `DEFault` to set the parameter to the requested value for that parameter.

Discrete Parameters

Some parameters take one of a small list of allowed keywords. In addition to numeric value parameters, some commands define a set of keywords that can be used in place of numeric values. These keywords may help readability or reduce confusion when entering the command interactively or when reviewing commands used in an execution script.

Consider the following command definitions:

```
IOUTput:ENable <OFF | ON | 0 | 1>
IOUTput:ENable?
```

When using the set command, `IOUT:EN`, any one of the following arguments may be used for the command: `OFF`, `ON`, `0`, `1`. The case of the keyword is ignored. Uppercase and lowercase are allowed.

For query commands, numeric values are always returned.

String Parameters

Quoted string parameters allow one to send almost any sequence of characters, including characters that are normally reserved as separator characters, such as a comma, semicolon, or colon. The string must begin and end with the same quote character: either a single quote, or a double quote. The quote delimiter may itself be included in the string if it is typed twice without any characters in between.

Command Termination

Commands should be terminated with a carriage return <CR>. An optional line feed <LF> can precede or follow the carriage return <CR>, however, the line feed <LF> will be ignored. As previously noted, multiple commands may be sent in a single line if they are separated by a semicolon (;). Commands are executed in the order received and execution commences once the command separator or terminator is received.

Remote Command Set

Calibration Commands

INITialize < 0 | 1 | 2 >

Initialize the RGA to a known state.

Three different levels of initialization are provided.

Command execution times vary depending on the pre-existing ionizer conditions.

INIT 0: Initialize communications and check ECU hardware.

The input and output data buffers are emptied (all communications are disabled while this happens)

INIT 1: Reset the RGA to default settings

In addition to INIT 0, the RGA ionizer and scan settings are reprogrammed to its default (preferred) values:

Total Pressure measurement is enabled

Default parameter settings are selected for:

```
SCAN:MASS:INITIAL 1
SCAN:MASS:FINAL MAX
SCAN:RESolution 20
SCAN:RATE 8.0
IONIZER:ION:VOLT 12
IONIZER:ELECTRON:VOLT 70
IONIZER:FOCUS:VOLT 90
```

The filament electron emission setting is left unmodified and the ionizer is biased to default voltages if necessary.

INIT 2: Activate Standby Mode

In addition to the changes in INIT 1, the filament and CEM are turned off.

```
IONIZER:EMISSION 0
```

```
CEM:VOLT 0
```

CALIBRATE
CALIBRATE < integer >

This command will perform a calibration of one or more subsystems of the RGA instrument.

If an integer argument is provided, one of the following internal calibrations will be performed:

1	Repeller Offset
2	Grid Offset
3	Analog Scan High Mass Offset
4	RF Phase Tracker
5	Low Mass RF Frequency
6	Ion Detector Offset
7	RF Detector Offset

Table 6-1 Arguments of the CALIBRATE command

If no argument is provided, each of the calibration steps will be performed in turn. If any calibration fails, a status bit will indicate that an error occurred and further calibration steps will not be performed.

Command execution times vary depending on the pre-existing ionizer conditions.

The full calibration is performed when the instrument is first powered on.

ELECtrometer:CALibrate

This command will perform an immediate calibration of the RGA electrometer using an internal precious current source. The result of the calibration will be saved for use in future scans.

The user can use this command to perform a single calibration and then a series of fast scans with low time pre-scan overhead with the automatic electrometer calibration disabled.

ELECtrometer:CALibrate:AUTO < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables electrometer calibration per scan
1, ON – Enables electrometer calibration per scan

Before any analog or histogram scan, the RGA instrument can be set to calibrate the electrometer using an internal precision current source. This calibration is part of the overhead at the start of each scan.

The user can reduce the overhead time prior to each scan by disabling the automatic calibration using this command. However, the electrometer response may drift after time due to temperature or other changes.

ELECtrometer:CALibrate:AUTO?

Returns whether the instrument will perform an automatic electrometer calibration before each scan.

0 – Per scan electrometer calibration disabled
1 – Per scan electrometer calibration enabled

Ionizer Setting Commands

IONIZER:ELECTRON:VOLT <integer | DEFault>

Allowed values: 25 – 110 eV, DEFault = 70 eV

Set the Electron Impact Ionization Energy of the Ionizer. The parameter represents the desired electron ionization energy in units of eV.

If the filament is emitting electrons at the time the command is invoked, the repeller voltage is immediately reconfigured to provide the desired electron energy, while the ion energy and electron emission currents remain unaffected.

If the filament is off, the new electron energy is stored in memory for the next time the filament's emission is activated.

Note: The instrument can be configured to set the repeller voltage when the filament is off by changing the Ionizer Potentials Auto mode to OFF. See `IONIZER:POTENTIALs:AUTOmode` for more information.

Note: The Electron Impact Ionization Energy is set to the default value when the unit is turned on.

IONIZER:ELECTRON:VOLT?

The electron energy parameter setting is returned in units of eV.

IONIZER:EMISsion <floating point value in mA | DEFault | OFF>

Allowed values: 0, 0.01 – 4.0 mA, DEFault = 1 mA, OFF = 0 mA

Set the electron emission current level in the ionizer. The parameter represents the desired electron emission current in units of mA.

When a value other than 0 is entered, the instrument biases the ionizer's repeller, grid, and focus plate, and activates the filament's heater until the requested electron current is established.

For a value of 0, the instrument turns off the filament and grounds the ionizer's repeller, grid, and focus plate.

Command execution times vary depending on the pre-existing ionizer conditions. The instrument will buffer any subsequent commands until the filament emission target is reached or an error has occurred. In the event of an error, the filament will be shut off, and an instrument status bit will be set to indicate the nature of the error.

The Filament LED reflects the ionizer's energized status at all times. When off, the filament is de-energized. When lit, the filament is energized. The filament may not be emitting electrons even when the LED is lit.

Note: The instrument can be configured to maintain voltage potentials on the repeller, grid, and focus plate when the filament is off by changing the Ionizer Potentials Auto mode to OFF. See `IONIZER:POTENTIALs:AUTOmode` for more information.

Note on filament emission errors

The RGA internally monitors the state of the filament to protect the instrument from over-pressure conditions. When the filament starts from a de-energized state, the filament may fail to start heating because the RGA has detected an over-pressure event. If the total pressure is within acceptable limits when this occurs, try to energize the filament once again.

IONIZER:EMISsion?

Returns the setpoint of electron emission current requested in mA.

To return a reading of the measured electron emission current, use the command `FILament:EMISsion?`

IONIZER:EMISsion:STORED <value in milliamps>

Allowed values: 0.01 to 4.0

Store a value of ionizer electron emission current in non-volatile memory in the RGA. The parameter is expressed in milliamps. The stored voltage value is helpful to reference a filament emission current for a later time.

Note: The emission current stored by this command is not used directly by the RGA. This value is used for storage for later retrieval by a controlling host computer.

IONIZER:EMISsion:STORED?

Returns the ionizer electron emission current value stored in non-volatile memory in the RGA. This can be used by a controlling host computer to retrieve previous settings at a later time.

IONIZER:FOCUS:VOLT <volts | DEFault>

Valid values: 0 - 110 V. DEFault = 90 Volts

Set the focus plate bias voltage in the ionizer. The value represents the magnitude of the bias voltage (negative) in Volts. Although the valid values of this command are positive values, they represent negative bias voltages applied to the focus plate.

The ions formed inside the anode grid are extracted into the quadrupole mass filter by the negative attractive potential of the "Focus" or Extraction Plate. The plate serves the dual purpose of drawing the ions away from the anode grid, and containing the ionizing electrons inside the source. Electron leakage into the filter is only detectable at low mass settings (1 to 10 amu) and can be easily eliminated by biasing the focus plate at least 30V more negative than the repeller.

Careful adjustment of the voltage results in optimum coupling of the ion bean into the QMF and maximum sensitivity.

This potential is applied only when the filament is energized. If the filament is on, the new setting will be applied immediately. If the filament is off, the focus plate potential, along with repeller and grid anode, will remain near 0 V. The new potential value will be applied when the filament is once again energized.

Note: The instrument can be configured to set the focus plate voltage when the filament is off by changing the Ionizer Potentials Auto mode to OFF. See `IONIZER:POTENTIALs:AUTOmode` for more information.

Note: The Focus Plate bias voltage is set to the default value when the RGA is powered on.

IONIZER:FOCUS:VOLT?

This will return the requested focus plate bias setting in units of Volts.

IONIZER:ION:VOLT <value in volts | DEFault | LOw | HIgh>

Valid values: 4 - 16 V. DEFault = 12 V, LOw = 8 V, HIgh = 12 V.

Set the Ion Energy in electron-volts. This is equal to the anode grid voltage.

This potential is applied only when the filament is energized. If the filament is on, the new setting will be applied immediately. If the filament is off, the anode grid potential, along with repeller and focus plate, will remain near 0 V. The new potential value will be applied when the filament is once again energized.

Note: The instrument can be configured to set the focus plate voltage when the filament is off by changing the Ionizer Potentials Auto mode to OFF. See `IONIZER:POTENTIALs:AUTOmode` for more information.

Note: The Ion Energy is set to the default value when the RGA is powered on.

IONIZER:ION:VOLT?

This will return the requested ion energy setting in eV.

IONIZER:POTENTIALs:AUTOmode < 0 | 1 | OFF | ON | DEFault >

During normal operation, when the filament is off, the ionizer potentials are automatically grounded. The repeller, grid, and focus plate voltages are brought down to near ground potential. When the filament is turned on, the potentials for the ionizer elements are brought to their setpoints.

However, this command and be used to keep the ionizer potentials in place even when the filament is off. This may be useful for specialized uses of the RGA where filament is not required, but the electric field created by the ionizer elements are still necessary.

Possible values for AUTOmode are as follows:

1, ON, DEFault –	Auto mode on, Ionizer potentials are set when the filament is on, and grounded when the filament is off.
0, OFF –	Auto mode off. Ionizer potentials remain at their set points even when the filament is off.

Note: On instrument startup, the ionizer potentials automode is always set to ON.

IONIZER:POTENTIALs:AUTOmode?

Returns the state of the ionizer potentials automatic mode. Possible values are:

1 – ionizer element potentials automatically grounded when filament is off
0 – ionizer element potentials remain at their setpoints when filament is off

Scan Commands

SCAN:ANAlog?

Execute an analog scan under the present scan conditions.

Analog scanning is the most basic operation of the RGA as a quadrupole mass spectrometer. During analog scanning, the quadrupole mass spectrometer is stepped at fixed mass increments through a pre-specified mass range. The ion current is measured after each mass increment step and transmitted to the host computer over the external interface used when entering this command. The mass range for the scan is set in advance with the commands `SCAN:MASS:INITIAL` (initial mass), `SCAN:MASS:FINAL` (final mass), and mass increments are fixed with the command `SCAN:RESolution` (scan resolution points per amu)

The type of detector used, whether Faraday Cup or CEM, is determined using the `CEM:VOLT` command. The scan rate, how fast measurements progress, is set using the `SCAN:RATE` command. A current value is transmitted for each mass increment value between initial and final mass for a total of (final mass – initial mass) * scan resolution + 1 measurements. (See `SCAN:ANAlog:POINTS?`)

The ion currents are represented as 32-bit single precision floating point numbers in units of 10^{-16} Amps, and transmitted directly in hex format (four bytes, 2's complement, little endian format).

Important:

Any command received by the RGA in the middle of a scan will immediately stop the scan, halt transmission and clear the RGA's transmit buffer.

The detector's zero offset and the internal scan parameters are checked and corrected at the beginning of each scan resulting in a slight delay before the scan actually starts. See `SCAN:OFFSET:AUTO` to disable this feature to reduce scan overhead.

A Total Pressure measurement is performed at the end of each scan and transmitted out to the host computer. See the `PRESSURE:TOTAL:ENable` command to disable or enable this measurement. If this measurement is disabled, the measurement will not be made, however, the total pressure will still be reported as a 4-byte floating point number representing 0 pressure.

Programming Tips:

Any command received by the RGA while scanning will immediately stop the scan process and clear he RGA's transmit buffer. Remember to also clear the computer's receive buffer to reset the communications. The new command which stopped the scan will be executed.

The RGA has the ability to store a complete scan in its output buffer. The scan remains in memory until all the data is transmitted out to the host computer. As a result of the high acquisition rate of the RGA, there might be a delay between the time at which the data is

collected internally and the time at which a complete spectrum is transmitted to the host computer. The time lag between data acquisition and transmission depends on a large number of factors including the scan rate (SCAN:RATE) of the RGA, the host computer's processing speed, and the amount of handshaking activity over the external interface.

SCAN:ANAlog:POINTS?

Query the total number of ion currents that will be measured and transmitted during an analog scan under the current scan conditions.

Important: The query response does not include the extra current (4 bytes) corresponding to the total pressure measurement performed at the end of the analog scans (Please see SCAN:ANAlog? command for details.)

The number of points (i.e. ion currents) returned is calculated based on the initial mass, final mass, and scan resolution parameters. Number of points = (final mass – initial mass) * scan resolution + 1. The first point corresponds to the initial mass value and the subsequent values are from scanning to the final mass with the scan resolution steps per amu. Each point transmitted represents an ion current and as such corresponds to 4 bytes being received by the host computer.

The query is used to verify that the RGA and the host computer agree on the number of bytes that will be exchanged over the remote interface during an analog scan.

The total number of bytes sent out to the host computer during an analog scan is obtained by multiplying by four the number returned by the query plus the four bytes that corresponds to the total pressure measurement. Note that if the total pressure measurement is disabled, the four bytes are still transmitted that represents zero.

SCAN:FILTER:ENable < 0 | 1 | OFF | ON >

Allowed values:

- 0 or OFF disables this feature
- 1 or ON enables this feature

Enables (or disables) the ion current noise filter when performing an Analog Scan (using SCAN:ANAlog?), a Histogram Scan (using SCAN:HISTogram?), or a single or multiple mass scan (SCAN:SINGLE? or SCAN:MULTIPLE?).

The ion current noise filter smooths out high-frequency noise components from the ion current measurement by selectively averaging measurements from nearby mass increments. This results in more easily recognizable mass peaks for each mass number.

SCAN:FILTER:ENable?

Returns the state of the ion current noise filter. The possible return values are:

0 – noise filter disabled
1 – noise filter enabled

SCAN:HISTogram?

Execute a histogram scan under the present scan conditions.

A histogram scan consists of a succession of individual mass measurements (see `SCAN:SINGLE` command) over a pre-specified mass range.

The mass range for the scan is set in advance with the commands `SCAN:MASS:INITIAL` (initial mass) and `SCAN:MASS:FINAL` (final mass). The type of detector used, whether Faraday Cup or CEM, is determined using the `CEM:VOLT` command. The scan rate, how fast measurements progress, is set using the `SCAN:RATE` command. A current value is transmitted for each integer mass value between initial and final mass for a total of (final mass – initial mass + 1) measurements. (See `SCAN:HISTogram:POINTS?`)

For maximum data throughput, ion currents are represented as 32-bit single precision floating point numbers in units of 10^{-16} Amps, and transmitted directly in hex format (four bytes, 2's complement, little endian format).

Important:

Any command received by the RGA in the middle of a scan will immediately stop the scan, halt transmission and clear the RGA's transmit buffer.

The detector's zero offset and the internal scan parameters are checked and corrected at the beginning of each scan resulting in a slight delay before the scan actually starts. See `SCAN:OFFSET:AUTO` to disable this feature to reduce scan overhead.

A Total Pressure measurement is performed at the end of each scan and transmitted out to the host computer. See the `PRESSURE:TOTAL:ENable` command to disable or enable this measurement. If this measurement is disabled, the measurement will not be made, however, the total pressure will still be reported as a 4-byte floating point number representing 0 pressure.

SCAN:HISTogram:POINTS?

Query the total number of ion currents that will be measured and transmitted during a histogram scan under the current scan conditions.

Important: The query response does not include the extra current (4 bytes) corresponding to the total pressure measurement performed at the end of the histogram scan (Please see `SCAN:HISTogram?` command for details.)

The number of points (i.e. ion currents) returned is calculated based on the initial mass and final mass parameters. Number of points = (final mass – initial mass) + 1. The first point corresponds to the initial mass value and the subsequent values are from scanning to the final mass with scan resolution of one step per amu. Each point transmitted represents an ion current and as such corresponds to 4 bytes being received by the host computer.

The query is used to verify that the RGA and the host computer agree on the number of bytes that will be exchanged over the remote interface during a histogram scan.

The total number of bytes sent out to the host computer during a histogram scan is obtained by multiplying by four the number returned by the query plus the four bytes that corresponds to the total pressure measurement. Note that if the total pressure measurement is disabled, the four bytes are still transmitted that represents zero.

SCAN:MASS:FINAL < integer value in mass units >

Allowed values: 1 to M_MAX where M_MAX is based on the RGA model (120, 220, or 320)

Set the final mass value (in amu) for Analog and Histogram scans.

The last ion current measurement during an analog or histogram scan corresponds to the mass-to-charge ratio specified by the parameter to this command.

Note that the final mass setting is shared by both Histogram and Analog scans, and must be an integer number.

The argument value must be within the allowed range and must be greater than or equal to the final mass value given by `SCAN:MASS:INITIAL`.

SCAN:MASS:FINAL?

Returns the final mass value to be measured during an analog or histogram scan.

SCAN:MASS:INITial < integer value in mass units >

Allowed values: 1 to M_MAX where M_MAX is based on the RGA model (120, 220, or 320)

Set the initial mass value (in amu) for Analog and Histogram scans.

The first ion current measurement during an analog or histogram scan corresponds to the mass-to-charge ratio specified by the parameter to this command.

Note that the initial mass setting is shared by both Histogram and Analog scans, and must be an integer number.

The argument value must be within the allowed range and must be less than or equal to the final mass value given by `SCAN:MASS:FINAL`.

SCAN:MASS:INITial?

Returns the initial mass value to be measured during an analog or histogram scan.

SCAN:MULTIPLE? < (m_1, m_2, … m_n) > list of integer mass numbers

Allowed values: A table of up to 20 integer mass numbers, from 1 to M_MAX where M_MAX is 120, 220, or 320 depending on the RGA model. Each mass should be separated by commands, and the entire list should be surrounded by parentheses.

Example:

```
SCAN:MULTPLE? (14, 18, 28, 32, 40, 44)
```

Execute multiple single ion current measurements at specified mass settings. The parameters are the integer mass numbers (mass-to-charge ratio in amu units) at which the measurements are performed.

The type of detector and scan rate settings to be used by the measurement must be selected in advance with the `CEM:VOLT` and `SCAN:RATE` commands.

The precision and duration of the measurement are totally determined by the `SCAN:RATE` setting. The command execution time includes some initial time spent waiting for the Quadrupole Mass Filter and the electrometer response to settle. As usual, a compromise must be made between signal-to-noise and measurement time.

The ion currents are expressed in the same format as for analog and histogram scans: 4 bytes long, single-precision floating point number in little-endian format representing the ion current in units of 10^{-16} A. One 4 byte value will be transmitted for each mass in the argument list.

This command can be used to perform multiple single mass scan measurements at different masses while avoiding the overhead from remote interface communications and pre-scan offset measurement and RF settling time.

The masses can be listed in any order, and may be repeated within the command. The ion currents will be scanned and transmitted in the order requested in the list.

Important:

During a Multiple Mass Measurement, the RGA performs a “Miniscan” around each mass requested, and the maximum current value measured is sent to the host computer over the external interface. The scanning procedure, referred to as Peak-Locking, is designed to measure peak currents for individual masses in a mass spectrum without being affected by drifts in the mass-axis calibration. The Miniscan covers a 0.6 amu

range centered at the mass requested, and selects the maximum current from 13 individual measurements performed at 0.05 amu mass increments.

The detector settings (type of detector and scan rate settings) to be used during the measurement must be selected in advance with the CEM:VOLT and SCAN:RATE commands. The measurements are performed with the detector settings at the time the scan is triggered.

The ion detector offset is measured at the start of this command. The noise level associated with this offset measurement correlates with the speed of the scan through the SCAN:RATE parameter. This offset measurement requires some amount of time to complete. This offset measurement can be bypassed using the SCAN:OFFSET:AUTO command. Note: If the offset has not been measured yet since power on, the first scan will force one offset measurement regardless of the setting for SCAN:OFFSET:AUTO.

SCAN:OFFSET:AUTO < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables automatic offset measurements
1, ON – Enables automatic offset measurements

Prior to any ion mass scan, whether analog, histogram, single, or multiple, a detector offset reading is usually made to estimate the detector zero level. This measurement can be disabled to reduce time overhead prior to each scan.

Note: Regardless of the setting of this command, if the offset has not yet been measured since power-on, the RGA will force one measurement of the offset at the start of the first scan.

SCAN:OFFSET:AUTO?

Returns whether detector offsets will be measured automatically before any ion current scan.

Return values:

0 – Offset Measurements Disabled
1 – Offset Measurements Enabled

SCAN:OFFSET:AVERAGE < integer value >

Allowed values: integer value from 1 to 100.

Set the averaging constant used to smooth out variations in scan-to-scan detector offset measurements.

Detector offset measurements may be subject to noise. Any one noisy detector offset measurement may cause an entire scan spectrum to change by the noise in the offset

measurement. By averaging the offset measurement over several scans, the effect on each scan's overall offset noise level can be reduced.

The parameter is used as the smoothing factor in an exponential moving average filter, where the smoothing factor is the inverse of the integer argument.

A value of 1 indicates no averaging while larger values indicate a longer filter time. While some filtering is useful to filter out short-term noise, it is usually best to keep the averaging constant small. Large filter constants can cause a long lag if the detector zero does shift due to external factors such as change in temperature, and this change in offset may not be seen for a significant time if too large a filter value is used.

Note:

Regardless of the offset average filter constant, the first offset value measured at the first scan will be used as the starting point for future filtering.

SCAN:OFFSET:AVERAGE?

Returns an integer indicating the exponential average filter constant used for filtering the noise in the electrometer offset value measurement from scan to scan. The value returned is the inverse of the smoothing constant in the exponential average filter used.

SCAN:OFFSET:CEM < floating point value in 10^{-16} A >

Allowed values: Any value representable as a single precision 32-bit floating point value.

Manually set the detector offset value used for scans using the CEM as the electrometer detector. Normally, this command is unnecessary. The electrometer offset value is measured at the start of a scan initiated by the user. However, this command allows the user flexibility to set a manual value if desired.

Note: While the user can set this value, it remains subject to change with future scans. To set this value as a constant, be sure to disable automatic offset measurements with `SCAN:OFFSET:AUTO OFF`.

SCAN:OFFSET:CEM?

Returns the detector offset value that was last set or measured using the CEM as the electrometer detector.

This value is updated after it is set manually using `SCAN:OFFSET:CEM` or after an offset measurement is made before a scan when `SCAN:OFFSET:AUTO` is enabled. Any offset measurement made before a scan is filtered with an exponential moving average filter described by `SCAN:OFFSET:AVERAGE`. The filtered value is the offset value set here and is used as the offset value for the scan that follows.

SCAN:OFFSET:FC < floating point value in 10^{-16} A >

Allowed values: Any value representable as a single precision 32-bit floating point value.

Manually set the detector offset value used for scans using the Faraday Cup as the electrometer detector. Normally, this command is unnecessary. The electrometer offset value is measured at the start of a scan initiated by the user. However, this command allows the user flexibility to set a manual value if desired.

Note: While the user can set this value, it remains subject to change with future scans. To set this value as a constant, be sure to disable automatic offset measurements with `SCAN:OFFSET:AUTO OFF`.

SCAN:OFFSET:FC?

Returns the detector offset value that was last set or measured using the Faraday Cup as the electrometer detector.

This value is updated after it is set manually using `SCAN:OFFSET:FC` or after an offset measurement is made before a scan when `SCAN:OFFSET:AUTO` is enabled. Any offset measurement made before a scan is filtered with an exponential moving average filter described by `SCAN:OFFSET:AVERAGE`. The filtered value is the offset value set here and is used as the offset value for the scan that follows.

SCAN:RATE < floating point value in amu per second >

Allowed values: 0.08 to 260.4 amu per second

Set the rate for ion current measurements.

A decrease in scan rate setting results in cleaner baselines and lower detection limits during scans and single mass measurements, but also means longer measurement and scanning times due to the reduced bandwidth of the electrometer and increased averaging,

The `SCAN:RATE` parameter bust be chosen keeping in mind the strong interplay between detection limits and acquisition speed.

Histogram scans, analog scans, single-mass measurements, multiple mass measurements, and total pressure measurements all share the same value of `SCAN:RATE`.

Important: The `SCAN:RATE` parameter is set to its default value with the RGA is powered on.

The scan rate indicates how quickly a scan will progress. For example, an analog scan from 1 to 100 with a scan rate of 1 Amu/second should take about 99 seconds to complete after the initial pre-scan overhead is completed. This remains true for all scan resolution settings. The scan rate set here is the target scan rate. Internally, the actual scan rate is calculated to be as close as possible to the requested scan rate. The analog scan

rate will depend on the SCAN:RESolution parameter value. The histogram scan rate will be calculated based on the fixed 0.05 amu scan resolution.

See either SCAN:RATE:ANAlog? or SCAN:RATE:HISTogram? to read back the actual scan rate that will be used for a scan.

Note: single-mass and multiple-mass measurements will use the SCAN:RATE:HISTogram? calculated scan rate value.

SCAN:RATE?

Returns the target scan rate in amu/s for an ion current mass scan.

SCAN:RATE:ANAlog?

The user sets the target scan rate using the SCAN:RATE command. The actual scan rate for an analog scan is limited based on the scan resolution. This command returns the closest scan rate that will be used for an analog scan.

Note: To achieve the highest scan rates, it is necessary to reduce the SCAN:RESolution to lower values. The maximum scan rate of 260.4 amu/s can be achieved only for a scan resolution of 10 points per amu.

SCAN:RATE:HISTogram?

The user sets the target scan rate using the SCAN:RATE command. The actual scan rate for a histogram scan is limited based on the fixed resolution steps used for a histogram scan. This command returns the closest scan rate that will be used for a histogram scan, or for a single-mass or multiple-mass measurement.

Note: The fixed resolution of a histogram scan limits the upper-end of the scan rate to about 130.2 amu/second.

SCAN:RESolution < integer divisions per amu >

Allowed values: integer value from 10 to 25.

Set the number of steps executed per amu for an analog scan. The parameter specifies the number of steps per amu.

During an analog scan, the quadrupole mass filter is stepped at fixed mass increments through the mass range specified by the initial mass (MASS:INITIAL) and final mass (MASS:FINAL) values. An ion current is measured after each step and transmitted to the host computer over the remote interface. This command programs the number of steps executed by the RGA per amu of an analog scan. The fixed mass increment is equal to the inverse of the command parameter value. The parameter value can be interpreted as

the approximate number of ion currents to be collected for each mass peak in the spectrum.

SCAN:RESolution?

Returns the number of steps per amu currently in use for analog scans. Ion currents will be returned for an analog scan for each mass increment from initial mass to final mass, and the mass increment will be equal to the inverse of the scan resolution returned by this command.

SCAN:SETTLINGtime < time in milliseconds >

Allowed values: 0 to 2000.0 milliseconds

This sets the amount of time that will be used for the initial Quadrupole Mass Filter RF/DC setting for settling to its initial state before starting a scan or a measurement.

Normally, this command is unnecessary. The factory setting for settling time is sufficient to settle the RF/DC settings prior to the start of measurements. However, this command is made available for situations where the user may benefit from longer or shorter settling times.

SCAN:SETTLINGtime?

Before a scan is started, the Quadrupole Mass Filter RF/DC voltages are set. These take some time to settle to their set value. This command returns the number of milliseconds that the instrument idles while it waits for the RF/DC voltages to settle.

SCAN:SINGLE? < integer value in mass units >

Allowed values: 1 to M_MAX where M_MAX is 120, 220, or 320 depending on the RGA model.

Execute a single ion current measurement at a specified mass setting. The parameter is an integer mass number (mass-to-charge ratio in amu units) at which the measurement is performed.

The type of detector and scan rate settings to be used by the measurement must be selected in advance with the `CEM:VOLT` and `SCAN:RATE` commands.

The precision and duration of the measurement are totally determined by the `SCAN:RATE` setting. The command execution time includes some initial time spent waiting for the Quadrupole Mass Filter and the electrometer response to settle. As usual, a compromise must be made between signal-to-noise and measurement time.

The ion current is expressed in the same format as for analog and histogram scans: 4 bytes long, single-precision floating point number in little-endian format representing the ion current in units of 10^{-16} A.

Important:

During a Single Mass Measurement, the RGA performs a "Miniscan" around the mass requested, and the maximum current value measured is sent to the host computer over the external interface. The scanning procedure, referred to as Peak-Locking, is designed to measure peak currents for individual masses in a mass spectrum without being affected by drifts in the mass-axis calibration. The Miniscan covers a 0.6 amu range centered at the mass requested, and selects the maximum current from 13 individual measurements performed at 0.05 amu mass increments.

The detector settings (type of detector and scan rate settings) to be used during the measurement must be selected in advance with the `CEM:VOLT` and `SCAN:RATE` commands. The measurements are performed with the detector settings at the time the scan is triggered.

The ion detector offset is measured at the start of this command. The noise level associated with this offset measurement correlates with the speed of the scan through the `SCAN:RATE` parameter. This offset measurement requires some amount of time to complete. This offset measurement can be bypassed using the `SCAN:OFFSET:ENable` command. Note: If the offset has not been measured yet since power on, the first scan will force one offset measurement regardless of the setting for `SCAN:OFFSET:ENable`.

Filament Status Commands

FILament:EMISsion?

The filament electron emission current is monitored on a regular basis. Readings are taken every 20 milliseconds. This command returns the last measurement of filament emission current in milliamps. If the filament is not energized, or if the reading is below the minimal possible reading, a value of 0.00 is returned.

FILament:VOLTage?

Returns the last reading of the measured voltage drop over the filament in volts. Readings are taken every 20 milliseconds. If the filament is not energized, a value of 0.00 is returned.

FILament:CURRent?

Returns the last reading of the measured current through the filament in amperes. Readings are taken every 20 milliseconds. If the filament is not energized, a value of 0.00 is returned.

CEM Settings commands

CEM:OPTION?

Query the electron multiplier (CEM) option in the RGA unit being programmed.

The RGA is provided standard with a Faraday Cup detector. For increased sensitivity and faster scan rates, an optional CEM is offered. The MO? command can be used to determine whether the CEM detector is an option for this RGA.

Possible return values:

0 – CEM option is not available
1 – CEM option is available

CEM:STORED:GAIN <valuex1000>

Valid values: 0.0 to 2000.0

Store a value of electron multiplier (CEM) gain in non-volatile memory in the RGA. The gain parameter value is expressed in units of thousands.

The command is typically used with `CEM:STORED:MASS` and `CEM:STORED:VOLTage` to store the set of values associated with calibrating the gain of the CEM module.

Note: The gain stored by this command is not used by the RGA to correct ion currents measured with the CEM. This value is used for storage for later retrieval by a controlling host computer.

CEM:STORED:GAIN?

Returns the CEM gain value stored in non-volatile memory in the RGA. This can be used by a controlling host computer to retrieve previous settings at a later time.

CEM:STORED:MASS <value in AMU>

Valid values: 0 to maximum mass of instrument model (120, 220, 320)

Store a mass in non-volatile memory in the RGA. The mass parameter is expressed in units of AMU. The stored mass value is helpful to reference which mass value was used to calculate the stored gain and voltage settings.

The command is typically used with `CEM:STORED:GAIN` and `CEM:STORED:VOLTage` to store the set of values associated with calibrating the gain of the CEM module.

Note: The mass stored by this command is not used by the RGA to correct ion currents measured with the CEM. This value is used for storage for later retrieval by a controlling host computer.

CEM:STORED:MASS?

Returns the CEM mass value stored in non-volatile memory in the RGA. This can be used by a controlling host computer to retrieve previous settings at a later time.

CEM:STORED:VOLTage <value in Volts>

Allowed values: 0.0 to 2490.0

Store a value of electron multiplier (CEM) voltage in non-volatile memory in the RGA. The voltage parameter is expressed in Volts. The stored voltage value is helpful to reference a CEM voltage potential for CEM operation at a later time.

The command is typically used with `CEM:STORED:MASS` and `CEM:STORED:GAIN` to store the set of values associated with calibrating the gain of the CEM module.

Note: The voltage stored by this command is not used by the RGA to correct ion currents measured with the CEM. This value is used for storage for later retrieval by a controlling host computer.

CEM:STORED:VOLTage?

Returns the CEM voltage value stored in non-volatile memory in the RGA. This can be used by a controlling host computer to retrieve previous settings at a later time.

CEM:VOLT <DEFault | value in volts>

Valid values: 0 – 2490 V. DEFault = 1400 V

Set a negative voltage potential across the electron multiplier. The parameter value represents the magnitude of the bias voltage in Volts. The high voltage on the CEM allows the CEM to magnify ion currents. This increases the sensitivity of the electrometer. The electrometer can then measure these magnified currents that would otherwise be too small to be measured using the Faraday Cup.

NOTE: When the RGA is powered on, the RGA electrometer is set to measure ion currents from the Faraday Cup. To use the CEM, this command must be used to enable the CEM and set the voltage potential.

NOTE: The voltage set by this command is the output of the high voltage power supply. A 2 MOhm resistor is placed between that output and the CEM cone. The internal

resistance of a typical CEM have a range between 50-2500 MOhm. The CEM becomes part of a voltage divider in conjunction with the 2 MOhm resistor. As a result, the voltage measured on the CEM will always have a magnitude smaller than the value set by this command.

`CEM:VOLT 0`

- When set to 0 volts, the instrument will be configured to measure ion currents from the Faraday Cup.
- Ion current will be reported to the host system during subsequent
- The CEM indicator LED will be turned off as an outward sign that the CEM is off.

`CEM:VOLT <value>` value > 0

- This will enable the CEM for ion current detection.
- The requested bias voltage is set on the CEM.
- The electrometer is configured to measure the CEM electron current.
- Electron currents will be reported to the host system controlling the RGA during all subsequent scans.
- The CEM indicator LED will be turned on as an outward sign that the CEM is on.

Degas Commands

DEGAS:RUNNING?

Query the state of the DEGAS procedure. Return values are 0 - not running, 1 - running.

DEGAS:START

Start the degas procedure. The evolution of the procedure is outlined above. After entering this command, control is immediately released back to the user.

Changes to instrument voltages and other internal parameters are locked out until the procedure has completed or is stopped with `DEGAS:STOP`. If such an attempt is made, the status bit PROCEDURE_RUNNING will be set. See **Instrument Status** for more details.

DEGAS:STOP

Stops the degas procedure if it is currently running. Filament emission, CEM bias voltage, and ionizer potentials will be restored to the original values from before the procedure started.

DEGAS:TIME <integer minutes | DEFault>

Allowed values: 0 – 20 minutes, DEFault = 3 minutes

This command sets the total time for the degas procedure. This includes the initial ramp-up time of 1 minute.

The parameter is an integer with a range of 0 to 20 minutes. If the time is set to 0, `DEGAS:START` will immediately end with no degas procedure.

DEGAS:TIME?

Returns the requested total time for the degas procedure in minutes. The value will be an integer from 0 to 20.

Pressure Commands

PRESsure:SENSitivity:PARTIAL < value in mA/Torr >

Allowed values: 0.0 – 10.0 mA/Torr

Store a value of Partial Pressure Sensitivity, expressed in mA/Torr, in non-volatile memory of the SRS RGA head.

Important: The sensitivity factor is not used internally by the RGA to convert ion currents into partial pressures. It is simply stored in memory so it can be read and used by any host computer connected to the instrument.

Partial Pressure Sensitivity factors are gas specific, probe specific, and highly dependent on the ionizer and quadrupole mass filter conditions and on aging of the probe.

Note: The parameter value loaded at the factory is the partial pressure sensitivity factor for N_2 under default ionizer conditions.

Typical value is 0.1 under default ionizer settings.

PRESsure:SENSitivity:PARTIAL?

Returns the partial pressure sensitivity factor stored in non-volatile memory in the RGA. The value is in units of mA/Torr.

PRESsure:SENSitivity:TOTAL < value in mA/Torr >

Allowed values: 0.0 – 100.0 mA/Torr

Store a value of Total Pressure Sensitivity, expressed in mA/Torr, in non-volatile memory of the SRS RGA head.

Important: The sensitivity factor is not used internally by the RGA to convert ion currents into a total pressure. It is simply stored in memory so it can be read and used by any host computer connected to the instrument.

Total Pressure Sensitivity factors are gas specific, probe specific, and highly dependent on the ionizer and quadrupole mass filter conditions and on aging of the probe.

Note: The parameter value loaded at the factory is the total pressure sensitivity factor for N_2 under default ionizer conditions.

Typical value is 0.01 under default ionizer settings.

PRESsure:SENSitivity:TOTAL?

Returns the total pressure sensitivity factor stored in non-volatile memory in the RGA. The value is in units of mA/Torr.

PRESsure:SENSitivity:TOTAL:OFFSET < value in 10^{-16} A >

Allowed values: Any floating point value

Store a value of Total Pressure offset ion current, expressed in 10^{-16} A, in non-volatile memory of the SRS RGA head.

Important: The total pressure offset is not used internally by the RGA to convert ion currents into a total pressure. It is simply stored in memory so it can be read and used by any host computer connected to the instrument.

Note: The parameter value loaded at the factory is the total pressure offset factor for N_2 under default ionizer conditions.

PRESsure:SENSitivity:TOTAL:OFFSET?

Returns the total pressure offset stored in non-volatile memory in the RGA. The value is in units of 10^{-16} A.

PRESsure:TOTAL:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables total pressure measurements
1, ON – Enables total pressure measurements

Total pressure measurements are automatically requested at the end of each analog and histogram scan, and can also be made directly by the user with the `PRESsure:TOTAL?` Command. The response of the RGA to a total pressure measurements request at the end of an analog or histogram scan depends on the status of this parameter at the time the measurement is requested.

If enabled, the measurement is performed and the total ion current is transmitted over the external interface.

If disabled, no measurement is made. A zero ion current is returned at the request for any total pressure measurement. This includes at the end of an analog or histogram scan.

Total pressure measurements are enabled on power-on reset and is disabled when the CEM is activated.

When a total pressure measurement is made at the end of an analog or histogram scan, the total ion current measured by the electrometer is transmitted as a 4-byte long single-precision floating point number in little endian format representing ion current in units of 10^{-16} A.

If a total pressure measurement is made on demand with `PRESsure:TOTAL?`, the total ion current will be returned as a floating point number in ASCII format.

Notes:

While performing a total pressure measurement, the RF in the quadrupole mass filter is set to a low mass value and the DC bias is set near zero. All ionic species have stable trajectories down the filter under those conditions and reach the ion current detector with different efficiencies.

The Total Pressure Measurement is disabled whenever the CEM is energized to any voltage more than 0 V. This is done to protect the multiplier from large ion currents. The Total Pressure Measurement may be enabled after energizing the CEM after making sure the total pressure is in a “safe” range for the CEM.

The sensitivity of the RGA for total pressure measurements will usually be affected after mass axis recalibrations. Check the sensitivity calibration after any peak tuning procedure.

Important: The sensitivity factor for the Total Pressure measurements is highly mass dependent. The additional mass discrimination that takes place in the filter results in the mass dependence of the RGA readings being very different from that of the Bayard Alpert gauge readings. Expect to see deviations between the two gauges as the composition of a residual gas changes.

PRESsure:TOTAL:ENable?

Returns the state of total pressure measurements. If disabled, any request for a total pressure measurement will return a value of 0.0

0 – Total Pressure measurements Disabled
1 – Total Pressure measurements Enabled

PRESsure:TOTAL?

If total pressure measurements are enabled, this command will start a total pressure measurement and return the total ion current as a floating point value in ASCII format in units of 10^{-16} A.

If total pressure measurements are disabled, this command will return 0.0. A total pressure measurement is not started.

Instrument Status Commands

Instrument Status Registers are used to communicate to the user unusual or abnormal status events that have occurred in the instrument. By monitoring the status registers on a regular basis, the user can be informed of errors or problems encountered by the instrument, and can take action appropriately.

The status registers are broken down into a set of related events. Each register consists of up to 16 bits. Each bit corresponds to one type of instrument status.

The general status register description is listed in the table below. For additional information about the individual events in each register, consult the Instrument Status section of the manual.

Register Number	Weight	Description
0	1	Communications
1	2	Filament
2	4	QMF
3	8	CEM
4	16	Auxiliary I/O
5	32	Ion Detector
6	64	Power Supply
7	128	Ionizer
8	256	Electronics
9	512	Pressure

Table 6-2 Instrument Status Registers

STATus:CONDition? < status register number >
STATus:CONDition? < status register number, integer status bit >

Read the status condition register or an individual status condition register bit.

The first form of the command, using the status condition register number as a single parameter, will give a result of all the status condition bits in a status condition register.

The return value is an integer that is the sum of the individual weights for those status conditions that are set within the specified register.

The second form allows the user to query a specific individual status condition within the status condition register.

Possible return values when querying an individual status condition bit

0 – Status condition not set
1 – Status condition set

The Instrument Status section details the status conditions defined for each register.

STATus:CONDition:ASSERT

This command copies any bits that are set in each status condition register onto their respective event register.

When a status condition is detected, the corresponding bit in the event register is also set. When the event register is read, all bits in the event register are cleared. However, if the condition remains active, the bit in the corresponding event register does not get set again immediately.

Normally, an event register bit is set only when a status condition is detected and changes from 0 to 1. If the status condition does not reset to 0, the corresponding bit in the event register will not be set even though the status condition bit is set to 1.

This command can be used to see what status conditions may still persist even though the event register was set. This may be useful if the event register was read, and thus reset to 0, and needs to be read once again at some future time.

STATus:DEFaultmask

This command resets the instrument status event enabled bits to their default settings. It also resets the Service LED register mask to the default setting back to the power-on condition.

See the Instrument Status section for more details on the default settings that are applied by this command.

STATus:EVent? < status register number >
STATus:EVent? < status register number, status bit >

Read the status event register or an individual status event register bit.

The first form of the command, using the status event register number as a single parameter, will give a result of all the status event bits in a status event register.

The return value is an integer that is the sum of the individual weights for those status events that are set within the specified register.

The second form allows the user to query a specific individual status event within the status event register.

Possible return values when querying an individual status event bit

0 – Status event not set
1 – Status event set

The Instrument Status section details the status conditions defined for each register.

Note: When an event register is queried, the entire event register is cleared back to 0. When an individual event bit is queried, only that event bit is cleared back to 0.

After a status event has been cleared, it may remain cleared even when the corresponding status condition remains set. The status event will be set only after the status condition is reset first and set afterwards.

STATus:EVent:ENable < status register number, integer value >
STATus:EVent:ENable < status register number, status bit, 0 | 1 | OFF | ON >

Set all bits for an instrument status event enabled register or an individual status event enabled bit in one register. When an event enabled bit is set to 1 or ON, the event bit will be set when the corresponding status condition changes from unset to set.

In the first form of the command, the user can set or reset all event bits within an entire status event register. The allowed range of register numbers is detailed in the Table 6-2 Instrument Status Registers above.

The event enable parameter value is formed by adding the weights of all event bits that are to be enabled. All other bits in the register will be disabled.

Event register have a maximum of 16 event bits. The second parameter has a range of values of 0 to 65535. This allows access to set and reset all 16 possible event bits in the specified register

In the second form of the command, the user can set or reset an individual event bit within a status event register.

The allowed range of register numbers is detailed in the Table 6-2 Instrument Status Registers above.

The second parameter specifies the event enabled bit within the status register. There are a total of up to 16 event bits per register. The allowed values are integers from 0 to 15.

The event bit state specifies what the event enabled bit should be set to by this command.

Allowed values: 0, OFF – Disables status event
1, ON – Enables status event

STATus:EVent:ENable? < status register number >
STATus:EVent:ENable? < status register number, status bit >

This command returns the setting for the specified instrument status event enabled register, or for an individual event within an instrument status event enabled register.

When enabled, the instrument status registers can be used to notify the user of error or problems inside the instrument.

In the first form of the command, the command returns the combined setting for event enabled bits within an individual register. The value is the sum of all the weights for each event that is enabled. All other events within a register are disabled. The allowed range of register numbers is detailed in the Table 6-2 Instrument Status Registers above.

In the second form of the command, the command returns the event enabled status for an individual event.

The allowed range of register numbers is detailed in the Table 6-2 Instrument Status Registers above.

The second parameter specifies the event enabled bit within the status register. There are a total of up to 16 event bits per register. The allowed values are integers from 0 to 15.

Possible return values are:

0 – Instrument Status Event is disabled
1 – Instrument Status Event is enabled.

STATus:GLOBal?
STATus:GLOBal? < status register number >

This command returns the combined event state for all instrument status event registers or for an individual status event register.

This allows for a quick summary of all enabled instrument status events rather than querying each status event register individually.

In the first form of the command, the command returns the combined state of all enabled events within each status event register. The value is the sum of all the weights for each event register that has at least one event enabled and set. The weights are listed in the Table 6-2 Instrument Status Registers above.

In the second form of the command, the parameter specifies the status event register to be queried. The allowed range of register numbers is detailed in the Table 6-2 Instrument Status Registers above.

The returned value indicates if any status event for the specified register is enabled and set.

Possible return values are:

0 – No events are enabled and set in the status event register
1 – At least one event is enabled and set in the status event register

---

STATus:GLOBal:SERVicemask < integer value >
STATus:GLOBal:SERVicemask < status register number, 0 | 1 | OFF | ON >

This command connects the combined status of a status event register to the Service LED on the back panel. This can be used to notify the user with the indicator light that the instrument has encountered an error or other problem that should be addressed.

In the first form of the command, the user can connect or disconnect all the status event register settings for the Service LED.

The parameter value is formed by adding the weights of all event registers to be connected to the Service LED. All other event registers will be disconnected. For event status register weights, see the Table 6-2 Instrument Status Registers above.

In the second form of the command, the user can connect or disconnect an individual status event register to the Service LED.

The allowed range of register numbers is detailed in the Table 6-2 Instrument Status Registers above.

The second parameter specifies whether the status event register is connected to the Service LED or not.

Allowed values: 0, OFF – Status event register is disconnected from Service LED
1, ON – Status event register is connected to Service LED

STATus:GLOBal:SERVicemask?
STATus:GLOBal:SERVicemask? < status register number >

This command returns the combined value for all status event registers connected to the Service LED or the connected status for an individual status event register.

This shows which status event registers are connected to the Service LED. When connected, any status event that is enabled and set will cause the Service LED to light up. This gives an external and immediate indication of a potential instrument error or problem that should be addressed.

In the first form of the command, the command returns the combined state of all connected status event registers. The value is the sum of all the weights for each event register that is connected. The weights are listed in the Table 6-2 Instrument Status Registers above.

In the second form of the command, the parameter specifies the status event register to be queried. The allowed range of register numbers is detailed in the Table 6-2 Instrument Status Registers above.

The returned value indicates if the status event register is connected to the Service LED.

Possible return values are:

0 – Status event register is not connected to the Service LED
1 – Status event register is connected to the Service LED.

Mass Filter Control Commands

QMF:MASS:LOCK < value in amu >

Allowed values: 0 to M_MAX where M_MAX is based on the RGA model (120, 220, or 320)

Activate the quadrupole mass filter (QMF) and center its pass-band at the mass value specified by the parameter. The QMF is parked at the mass requested but no ion current measurements take place.

The command execution involves two steps:

1. The RF/DC levels corresponding to the mass requested are calculated and set on the QMF rods based on the mass axis calibration parameter values specified by the last Peak Tuning procedure.
2. The firmware stabilizes the voltage output of the RF Driver's controller against temperature fluctuations.
3. The firmware also controls the RF frequency to maintain resonance between the driver circuitry and the RF output on the rods.

Use `QMF:MASS:LOCK 0` to turn off the RF/DC voltages when finished performing measurements and before quitting the program controlling the RGA.

QMF Tuning Commands

The QMF Tuning Commands relate a set of RF/DC tuning parameters to a calculation for RF and DC voltages to be applied to the Quadrupole Mass Field.

The basic relationship is:

$$RF(V) = RF_{slope}\left(\frac{V}{AMU * MHz^2}\right) * M(AMU) * RF_{freq}^2(MHz^2) + RF_{offset}(V) + RF_{corr}(V)$$

$$DC(V) = DC_{slope}\left(\frac{V}{AMU * MHz^2}\right) * M(AMU) * DC_{freq}^2(MHz^2) + DC_{offset}(V) + DC_{corr}(V)$$

RF/DC slope, offset, and correction factors can be adjusted using the commands in this section. The RF Frequency is constantly being tuned by the RGA firmware. In practice, this frequency is nominally between 2.6 and 2.8 MHz, but it is dependent on the RGA and probe combination.

QMF:DC:OFFSET < value in Volts | FACTORY >

This is one parameter of the set of RF/DC tuning parameters. This constant voltage is added to the calculation for determining what DC voltage to apply for a given mass.

To reload the factory stored value for this parameter, use the argument FACTORY.

Important: Caution should be exercised with this command. The command affects the RF/DC to ion mass relationship in a way that can produce unexpected results if the parameter value is chosen incorrectly. To get a feel for how this command works, start with small changes.

Note: The relationship for DC voltage does not correspond directly to either peak width or position. Increasing or decreasing this parameter will affect both peak position and width.

QMF:DC:OFFSET?

This returns the constant DC voltage that is added in the calculation for the RF and DC voltages for a given mass value in AMU. The value is reported in Volts.

QMF:DC:QUADratic < value in Volts per AMU^2 | FACTORY >

This is one parameter of the set of RF/DC tuning parameters. It is used to correct for the slight non-linearity in the normally linear relationship between RF/DC settings as a function of mass in AMU.

This command will add a correction value in DC voltage. The amount of DC voltage applied will be increased (for positive values) or decreased (for negative values) by the following amount:

$$DC_{correction}(V) = DC_{quad}(V/AMU^2) * Mass(AMU)^2$$

value is set at the factory and should be left unchanged. However, it may be adjusted here with this command.

To reload the factory stored value for this parameter, use the argument FACTORY.

Important: Extreme caution should be exercised with this command. The command affects the RF/DC to ion mass relationship in a way that can produce unexpected results if the parameter value is chosen incorrectly. To get a feel for how this command works, start with small changes.

Note: The relationship for DC voltage does not correspond directly to either peak width or position. Increasing or decreasing this parameter will affect both peak position and width. The relationship changes as the square of the mass, so it will mostly impact peaks at the high end of the mass spectrum, leaving low mass peaks relatively unaffected.

QMF:DC:QUADratic?

This returns the correction term applied to the RF voltage as part of the set of RF/DC tuning parameters. The value is returned in units of V per AMU^2.

QMF:DC:SLOPE < value in Volts / AMU / MHz^2 | FACTORY >

This is one parameter of the set of RF/DC tuning parameters. It is a linear scale factor in mass. The DC Voltage is increased by this parameter times the mass number of the ion current to be detected.

The parameter is further scaled by the square of RF Frequency in units of MHz. While the RF Frequency is continuously monitored and changed for optimal power transfer, it is expected to range between 2.4 and 2.8 MHz.

To reload the factory stored value for this parameter, use the argument FACTORY.

Important: Caution should be exercised with this command. The command affects the RF/DC to ion mass relationship in a way that can produce unexpected results if the parameter value is chosen incorrectly. To get a feel for how this command works, start with small changes.

Note: The relationship for DC voltage does not correspond directly to either peak width or position. Increasing or decreasing this parameter will affect both peak position and width.

QMF:DC:SLOPE?

This returns the DC voltage that is added per AMU in the calculation for the RF and DC voltages for a given mass value in AMU. The value is scaled by the square of the RF Frequency, and is reported in Volts / AMU / MHz^2.

QMF:RF:OFFSET < value in Volts | FACTORY >

This is one parameter of the set of RF/DC tuning parameters. This constant voltage is added to the calculation for determining what RF voltage to apply for a given mass.

To reload the factory stored value for this parameter, use the argument FACTORY.

Important: Caution should be exercised with this command. The command affects the RF/DC to ion mass relationship in a way that can produce unexpected results if the parameter value is chosen incorrectly. To get a feel for how this command works, start with small changes.

Note: The relationship for RF voltage does not correspond directly to either peak width or position. Increasing or decreasing this parameter will affect both peak position and width.

QMF:RF:OFFSET?

This returns the constant RF voltage that is added in the calculation for the RF and DC voltages for a given mass value in AMU. The value is reported in Volts.

QMF:RF:QUADratic < value in Volts per AMU^2 | FACTORY >

This is one parameter of the set of RF/DC tuning parameters. It is used to correct for the slight non-linearity in the normally linear relationship between RF/DC settings as a function of mass in AMU.

This command will add a correction value in RF voltage. The amount of RF voltage applied will be increased (for positive values) or decreased (for negative values) by the following amount:

$$RF_{correction}(V) = RF_{quaa}(V/AMU^2) * Mass(AMU)^2$$

This value is set at the factory and should be left unchanged. However, it may be adjusted here with this command.

To reload the factory stored value for this parameter, use the argument FACTORY.

Important: Extreme caution should be exercised with this command. The command affects the RF/DC to ion mass relationship in a way that can produce unexpected results if the parameter value is chosen incorrectly. To get a feel for how this command works, start with small changes.

Note: The relationship for RF voltage does not correspond directly to either peak width or position. Increasing or decreasing this parameter will affect both peak position and width. The relationship changes as the square of the mass, so it will mostly impact peaks at the high end of the mass spectrum, leaving low mass peaks relatively unaffected.

QMF:RF:QUADratic?

This returns the correction term applied to the DC voltage as part of the set of RF/DC tuning parameters. The value is returned in units of V per AMU^2.

QMF:RF:SLOPE < value in Volts / AMU / MHz^2 | FACTORY >

This is one parameter of the set of RF/DC tuning parameters. It is a linear scale factor in mass. The RF Voltage is increased by this parameter times the mass number of the ion current to be detected.

The parameter is further scaled by the square of RF Frequency in units of MHz. While the RF Frequency is continuously monitored and changed for optimal power transfer, it is expected to range between 2.4 and 2.8 MHz.

To reload the factory stored value for this parameter, use the argument FACTORY.

Important: Caution should be exercised with this command. The command affects the RF/DC to ion mass relationship in a way that can produce unexpected results if the parameter value is chosen incorrectly. To get a feel for how this command works, start with small changes.

Note: The relationship for DC voltage does not correspond directly to either peak width or position. Increasing or decreasing this parameter will affect both peak position and width.

QMF:RF:SLOPE?

This returns the RF voltage that is added per AMU in the calculation for the RF and DC voltages for a given mass value in AMU. The value is scaled by the square of the RF Frequency, and is reported in Volts / AMU / MHz^2.

QMF:SHIFT:POSition:OFFSET < value in AMU >

Allowed values: -4.0 to +4.0 AMU

This command can be used to manually adjust the RF/DC tuning parameters along the mass axis. It will adjust the RF/DC tuning parameters to SHIFT the entire mass spectrum lower or higher in mass for any future scans.

A positive number will shift all peaks forward by that number of AMU. A negative number will shift all peaks backward by that number of AMU.

Important: Caution should be exercised with this command. The command affects RF/DC tuning parameters in a way that can produce unexpected results if the parameter is chosen incorrectly. To get a feel for how this command works, start with small changes, less than 1.0 AMU.

Note: The change to RF/DC tuning parameters is approximate. The result will be close to the desired result but may not shift by exactly the amount desired. Peak widths may also be affected to some small degree. After using this command, a new analog scan should be performed to assess the result of using this command.

QMF:SHIFT:POSition:SLOPE < value in AMU per AMU >

Allowed values: -0.05 to +0.05 AMU per AMU

This command can be used to manually adjust the RF/DC tuning parameters along the mass axis. It will adjust the RF/DC tuning parameters to SHIFT the position of each mass peak for any future scans. The amount that the peak position is shifted forward (for positive value) or backward (for negative values) is the magnitude of the argument multiplied by the mass number.

Example:

```
QMF:SHIFT:POSITION:SLOPE 0.001
```

This will shift the position of each mass peak in a linear fashion. For a peak at mass 1, this will shift the mas peak position forward by 0.001 AMU. For a peak at mass 100, this will shift the mass peak forward by 100 times that, 0.1 AMU. For a peak at mass 300, the mass peak shift will be 0.3 AMU!

Important: Extreme caution should be exercised with this command. The command affects RF/DC tuning parameters in a way that can produce unexpected results if the parameter is chosen incorrectly. To get a feel for how this command works, start with small changes, less than 0.001 AMU per AMU.

Note: The change to RF/DC tuning parameters is approximate. The result will be close to the desired result but may not shift by exactly the amount desired. Peak positions may also be affected to some small degree. After using this command, a new analog scan should be performed to assess the result of using this command.

QMF:SHIFT:WIDTH:OFFSET < value in AMU >

Allowed values: -0.5 to +0.5 AMU

This command can be used to manually adjust the RF/DC tuning parameters along the mass axis. It will adjust the RF/DC tuning parameters to SHIFT the width of each mass peak for any future scans.

A positive number will shift all peak widths more broadly by that number of AMU. A negative number will shift all peaks widths more narrowly by that number of AMU.

Important: Caution should be exercised with this command. The command affects RF/DC tuning parameters in a way that can produce unexpected results if the parameter is chosen incorrectly. To get a feel for how this command works, start with small changes, less than 0.1 AMU.

Note: The change to RF/DC tuning parameters is approximate. The result will be close to the desired result but may not shift by exactly the amount desired. Peak positions may also be affected to some small degree. After using this command, a new analog scan should be performed to assess the result of using this command.

QMF:SHIFT:WIDTH:SLOPE < value in AMU per AMU >

Allowed values: -0.05 to +0.05 AMU per AMU

This command can be used to manually adjust the RF/DC tuning parameters along the mass axis. It will adjust the RF/DC tuning parameters to SHIFT the width of each mass peak for any future scans. The amount that the peak width is increased (for positive value) or decreased (for negative values) is the magnitude of the argument multiplied by the mass number.

A positive number will shift all peak widths more broadly by that number of AMU. A negative number will shift all peaks widths more narrowly by that number of AMU.

Example:

```
QMF:SHIFT:WIDTH:SLOPE 0.001
```

This will increase the width of each mass peak in a linear fashion. For a peak at mass 1, this will increase the FWHM width by 0.001 AMU. For a peak at mass 100, this will increase the FWHM width by 100 times that, 0.1 AMU. For a peak at mass 300, the increased width will be 0.3 AMU!

Important: Extreme caution should be exercised with this command. The command affects RF/DC tuning parameters in a way that can produce unexpected results if the parameter is chosen incorrectly. To get a feel for how this command works, start with small changes, less than 0.001 AMU per AMU.

Note: The change to RF/DC tuning parameters is approximate. The result will be close to the desired result but may not shift by exactly the amount desired. Peak positions may also be affected to some small degree. After using this command, a new analog scan should be performed to assess the result of using this command.

QMF:TUNE:AUTO:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables RF/DC Peak Auto-tuning
1, ON – Enables RF/DC Peak Auto-tuning

The RGA has the ability to adjust the RF/DC levels on a scan-by-scan basis for analog scans. The user first selects a list of mass peaks that are known to have strong signals

during an analog scan. See **QMF:TUNE:TABLE** for more information in entering the mass peak table.

With RF/DC peak auto tuning enabled, the RGA will attempt to identify the peaks listed by the user in the resulting scan. After each peak position and width is identified, the RGA will adjust the RF/DC tuning parameters to place the mass peaks closer to the center of the mass numbers in the list, and will also adjust the width of each peak to match the desired peak width.

For each successful auto-tuning scan, the RGA algorithm will adjust the following tuning parameters:

```
QMF:DC:OFFSET
QMF:DC:SLOPE
QMF:RF:OFFSET
QMF:RF:SLOPE
```

The quadratic correction factors are not changed by the algorithm. The values used for `QMF:DC:QUADratic` and `QMF:RF:QUADratic` are too sensitive to be adjusted by this autotuning algorithm.

Important: The scan noise filter **must** be enabled using `SCAN:FILTER:EN 1`. If the scan filter is disabled, the Auto-Tuning step will not be completed.

Note: The RGA Auto-Tuning algorithm operates only for analog scans. Histogram scans will not start an Auto-Tuning step.

Note: This procedure will require multiple scans for the auto-tune procedure to reach the desired level of accuracy. Each change in RF/DC tuning parameters is small to not overshoot the target.

Auto-tuning has better results with strong, clean ion peaks. The chances of success can be improved by increasing signal to noise ratio. The easiest way to do that is to lower the `SCAN:RATE` of the next scan.

Important: For this feature to work, the RGA must already be tuned well enough that peaks are recognizable and located near the expected location near their respective mass. If the RF/DC levels are highly out of tune, this procedure will not be successful.

The start and final masses do not need to but should include the entire table of masses defined in `QMF:TUNE:TABLE`. If fewer than 2 of the listed peaks are detected, the auto-tuning algorithm will exit, unable to perform a proper fit of the peak parameters.

If the RGA Auto-Tuning algorithm cannot identify the peak locations successfully after a scan, the RF/DC tuning parameters are not changed.

If the RGA is completely out of tune such that the peaks are unrecognizable or out of place, it would be best to reload the tuning parameters from the factory settings with `QMF:TUNE:FACTORY:LOAD`. With a properly paired RGA and probe from the

factory, the factory settings should provide tuning parameters that can be used as a starting point for auto tuning to be successful.

QMF:TUNE:AUTO:ENable?

Returns whether the RGA RF/DC Peak Auto-tuning algorithm is enabled.

0 – RF/DC Peak Auto-tuning Disabled
1 – RF/DC Peak Auto-tuning Enabled

QMF:TUNE:FACTORY:LOAD

Reload the factory RF/DC tuning parameters.

For situations where mass peaks cannot be reliably identified during an analog or histogram scan, this command will reload the tuning parameters that were calibrated for this RGA at the factory. This default set of tuning parameters should provide an analog scan that is close to the optimal tuning parameters for an RGA/probe pair.

Note: This provides a default set of tuning parameters that should work only if the RGA is properly paired with the probe that was shipped with the RGA. Each probe and RGA has specific characteristics that are known at manufacturing time. This may not be valid if the RGA is placed on a different probe.

QMF:TUNE:RESULTS?

This command returns the result of the auto-tuning from the last analog or histogram scan where auto-tuning was enabled.

Results are returned in JSON format over the external interface. This allows for host computer software to more easily process the results into a user-readable form.

The generalized JSON standard format for successful auto-tune results are as follows:

```
{"results" : [
      { "mass" : m1, "position" : x1, "width" : y1 },
      { "mass" : m2, "position" : x2, "width" : y2 },
      { "mass" : m3, "position" : x3, "width" : y3 },
      …
      { "mass" : mn, "position" : x1, "width" : yn }
] }
```

The lines are separated by linefeed characters. At the end, the final terminator is the standard linefeed/carriage return pair/

Each line in the results corresponds to a mass peak whose position and width have been identified. The candidate mass peak positions are defined using QMF:TUNE:TABLE.

The fields for each line are as follows:

"mass" – the nominal mass of the peak to be auto-tuned.

"position" – the position of the fit peak relative to the nominal position. Positive values indicate the mass peak was identified to be located above the expected mass position. Negative values indicate the mass peak was identified to be located below the expected mass position. The auto-tuning algorithm will adjust the RF/DC tuning parameters so that future scans will be closer to the nominal mass positions.

"width" – the overall width of the peak. This is defined as the width (in amu) where the amplitude falls down to half of the peak amplitude (Full Width Half Maximum). The auto-tuning algorithm will adjust the RF/DC tuning parameters so that future scans will result in peak widths closer to the target peak width set by QMF:TUNE:WIDTH

Mass peaks that could not be identified are not reported in the results.

As an example for results after a successful scan, consider a scan done with the following defined table of candidate mass peaks:

```
QMF:TUNE:TABLE (14, 28, 32, 40, 44)
```

The following shows what may be results after a single scan with auto-tuning enabled:

```
{"results" : [
      { "mass" : 14, "position" : 0.2013, "width" : 0.5094 },
      { "mass" : 28, "position" : 0.2080, "width" : 0.5129 },
      { "mass" : 32, "position" : 0.1561, "width" : 0.5415 },
      { "mass" : 40, "position" : 0.0424, "width" : 0.6069 },
      { "mass" : 44, "position" : 0.0226, "width" : 0.6483 }
] }
```

For this example, `QMF:TUNE:WIDTH` is set to 0.6. The RF/DC tuning parameters will be adjusted such that, in following scans, the measured and fit peak positions and widths will be closer to the expected values with position 0, and width 0.6.

Other result reports:

If auto-tuning is disabled, calling this command will return the following results in JSON format:

```
{"results" : "Tune disabled"}
```

At power-on and when the auto-tune mass table is modified, the auto-tune results are cleared. If this command is sent before an auto-tuning scan is performed, the following result is returned in JSON format:

```
{"results" : "No Valid Scan"}
```

If there is an error in the auto-tune fitting algorithm and no solution could be found, the following result is returned:

```
{"results" : "Error Fitting"}
```

If the scan filter is disabled during the last analog scan while auto-tuning is enabled, the following result is returned:

```
{"results" : "Filter Disabled"}
```

QMF:TUNE:TABLE < (m_1, m_2, … m_n) > list of integer mass numbers

Allowed values: A table at least 2 up to 10 integer mass numbers, from 1 to M_MAX where M_MAX is 120, 220, or 320 depending on the RGA model. Each mass should be separated by commands, and the entire list should be surrounded by parentheses.

For the RGA scan Auto-tuning procedure, this command defines the peaks which will be used for peak identification and fitting.

At a minimum, at least 2 mass peaks are needed for peak fitting to work. The user can provide a list of up to 10 mass peaks to search for with the following requirements:

- Mass numbers can appear in any order in the list.
- Mass numbers must be separated by at least 2. Repeated mass number arguments are not allowed. Adjacent mass numbers are also not allowed.

For best results, select only mass numbers where residual ion currents are expected to dominate the scan spectrum. Mass numbers should not be added to the list if another mass peak within 2 AMU is higher. Otherwise, the peak fitting algorithm may misidentify the mass peak and the resulting RF/DC tune parameter shifts will be misadjusted.

QMF:TUNE:TABLE?

Returns the list of mass numbers that will be used for the next auto-tuning step after an analog scan. The format of the returned mass values is equivalent to the argument for `QMF:TUNE:TABLE`.

Example:

```
QMF:TUNE:TABLE?
( 14, 28, 32, 40, 44 )
```

QMF:TUNE:WIDTH < value in AMU | DEFault >

Allowed values: floating point value from 0.4 to 1.0 AMU. DEFault = 0.6 AMU

This command defines the desired peak widths for the RGA Auto-Tuning algorithm. This is defined as the width of the peak where the amplitude is one half of the maximum amplitude (Full Width Half Maximum).

The width of the peak can be adjusted as needed to select for either increased resolution (smaller value) or increased sensitivity (higher value). This is done by either closing or opening the overall aperture to the detector by using slightly different RF and DC values during a scan.

Important: Peak ion currents depend highly on the peak width. Changing this parameter will necessitate recalculating the relation between reported ion currents and partial pressure.

Note: Using narrower peak widths may cause ion current peaks to be undetectable and may even cause ion peaks to sink below the noise floor. A slower `SCAN:RATE` should be used to increase signal-to-noise for the increased resolution of using narrower peaks.

QMF:TUNE:WIDTH?

This returns the target value for Full Width Half Maximum for each detected and fit mass peak in an Auto-Tuning procedure after an analog scan with Auto-Tuning and Scan Mass Filter enabled.

The value returned is in units of AMU.

Temperature Status Commands

TEMPerature:CPU?

Returns the last measured temperature of the instrument CPU in degrees C.

TEMPerature:FLANGE?

Returns the last measured temperature of the connection to the instrument flange in C.

TEMPerature:HVboard?

Returns the last measured temperature of the instrument high voltage board in degrees C.

Trigger Commands

TRIGger:SCAN:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables external scan trigger

1, ON – Enables external scan trigger

The external trigger input can be used to trigger the start of a scan. When the Scan Trigger is enabled with this command, and the Scan Trigger Mode is set appropriately, any command to start a scan such as an analog or histogram scan, or a single-mass or multiple mass measurement, will not start until the trigger conditions are met.

The scan trigger can allow the user to hold off the start of a scan until some external conditions are met as defined by the user.

TRIGger:SCAN:ENable?

The command returns whether the Scan Trigger is enabled.

Possible return values are:

0 – Disabled. Scans do not require a trigger to start.
1 – Enabled. Scans require a trigger condition to be met to start

When disabled, any ion current scan or measurement will begin immediately. When enabled, scans will wait for a trigger condition to be detected. Only then will a scan start running.

TRIGger:SCAN:MODE < 0 | 1 | 2 | 3 | LOw | HIgh | RISING | FALLING >

Allowed values: 0, LOw – Level Trigger low
1, HIgh – Level trigger high
2, RISING – Edge trigger, Rising edge
3, FALLING – Edge trigger, Falling edge

When the external scan trigger is used to start a scan, this command indicates the trigger condition necessary to start the scan.

Note: for level triggers, if a scan command is sent, and the trigger level is already at the mode set with this command, the scan starts immediately. For edge triggers, a level transition from LOW to HIGH or from HIGH to LOW is necessary to start the scan.

TRIGger:SCAN:MODE?

This command returns the presently configured external scan trigger mode. When the external Scan Trigger is enabled, any scan will start only when the selected trigger condition has been met.

Possible return values are:

0 – Level trigger LOW
1 – Level trigger HIGH
2 – Edge trigger RISING edge

3 – Edge trigger FALLING edge

TRIGger:SOFTware:ARM

This command arms the software trigger. It will place the software trigger in a state where the instrument will wait for the trigger condition to be met. It can be called any time as long as the Software Trigger is enabled.

This command has no effect if the Software Trigger is disabled.

TRIGger:SOFTware:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables software trigger
1, ON – Enables software trigger

The external trigger input can be used by host computer software to simulate a trigger to start another external process. When the software trigger is enabled, host computer software can arm and then query the trigger state to determine if the trigger condition has been met. When the host computer software is ready to wait for another trigger, it can reset the trigger, arm it once more and poll for the trigger condition to be met once again.

Note: It is not advised to use both the Scan Trigger and the Software Trigger simultaneously. Only one trigger can provide useful functionality over any external interface.

TRIGger:SOFTware:ENable?

The command returns whether the Software Trigger is enabled.

Possible return values are:

0 – Software trigger is disabled.
1 – Software trigger is enabled.

TRIGger:SOFTware:FIRED?

This command returns whether a software trigger is armed and the trigger condition has been met. See `TRIGger:SOFTware:MODE` to set the trigger condition. See `TRIGger:SOFTware:RESET` and `TRIGger:SOFTware:ARM` to reset and arm for the next trigger.

Possible return values are:

0 – Software trigger has not fired.
1 – Software trigger has fired.

TRIGger:SOFTware:MODE < 0 | 1 | 2 | 3 | LOw | HIgh | RISING | FALLING >

Allowed values: 0, LOw – Level Trigger low
1, HIgh – Level trigger high
2, RISING – Edge trigger, Rising edge
3, FALLING – Edge trigger, Falling edge

When the Software trigger is set to the Armed state, this command sets the condition that fires the Software Trigger.

Note: for level triggers, if the Software Trigger is armed, and the trigger level is already at the mode set with this command, the trigger automatically fires. For edge triggers, a level transition from LOW to HIGH or from HIGH to LOW is necessary for the trigger to fire. Use `TRIGger:SOFTware:FIRED?` to poll the fired state.

TRIGger:SOFTware:MODE?

This command returns the presently configured Software Trigger mode. When the Software Trigger is enabled and armed, the trigger will fire when the selected trigger condition is met.

Possible return values are:

0 – Level trigger LOW
1 – Level trigger HIGH
2 – Edge trigger RISING edge
3 – Edge trigger FALLING edge

TRIGger:SOFTware:RESET

This command sets the Software Trigger in a standby state. The instrument will not look for the trigger condition to fire.

Note: This command has no effect if the Software Trigger is disabled.

TRIGger:SOFTware:STATE?

This command returns the present state of the Software Trigger.

Possible return values are:

0 – Disabled. Software trigger is off.
1 – Reset. Software trigger is in standby, and is not ready to fire.
2 – Armed. Software trigger is waiting for the trigger condition.
3 – Fired. Software trigger has detected a trigger condition.

TRIGger:THRESHOLD < value in Volts | DEFault >

Allowed values: 0 to 3.3 V, DEFault = 1.65 V

This sets the voltage threshold for the hardware TRIGger input on the back panel of the instrument.

The RGA instrument monitors the voltage on the TRIGger input at regular intervals. When the instrument detects that the voltage falls below the threshold set by this command, the trigger level is set LOW. If the voltage is above the threshold set by this command, the trigger level is set HIGH.

Note: the threshold is not exact. To reliably use this feature to set the hardware digital trigger level LOW through an external signal, the signal should be driven towards zero volts. For an open connection, the input voltage will be pulled up to 3.3 V, equivalent to a HIGH level.

TRIGger:THRESHOLD?

Returns the comparator value in Volts that separates the trigger input being interpreted as a HIGH or LOW level. If the input voltage is above the threshold, this corresponds to a HIGH level. If the input voltage is below the threshold, this corresponds to a LOW level.

TRIGger:VALue?

This command returns the last detected digital level of the trigger input. The digital level depends on if the voltage detected at the input is above or below the threshold voltage value set with `TRIGger:THRESHOLD`

Possible return values are:

0 – LOW
1 – HIGH

Note that the hardware trigger input is connected to a pull up resistor. For open connections, `TRIG:VALue?` should always be 1, HIGH.

Analog Output Commands

The RGA has terminal connections on the back panel that provide an analog output voltage or current. The voltage/current can be a value manually selected within the allowed range for each output. The analog output may also be configured to represent a real-time value for an instrument measurement by mapping that measurement value to a range in voltage or current.

Table 6-3 represents the real time measurements that can be mapped to the analog output terminals. Any one of the following values can be selected for the analog output voltage or current:

Integer Value	Keyword	Description
-1	CONSTANT	constant current or voltage
0	SCAN	real time value of ion current during an analog or histogram scan
1	MASS	readout of last ion current measurement for a specified ion mass
2	FLANGEtemp	readout of monitored flange temperature in Celsius
3	RTDtemp	readout of monitored RTD temperature in Celsius
4	EMISsion	readout of monitored filament emission current in milliAmps.
5	PRESSURE	total pressure ion current in units of (0.1 femtoAmps)

Table 6-3 Analog Output Selections

For analog output selections that are measured internally, the instrument maps the measured value to an output current or voltage along a continuous range between a minimum and maximum value set by the user. Commands that set the analog output selection minimum and maximum values expect arguments in the units described in Table 6-4.

Integer Value	Keyword	Description
0	SCAN	ion current in units of (0.1 femtoAmps)
1	MASS	ion current in units of (0.1 femtoAmps)
2	FLANGEtemp	degrees Celsius
3	RTDtemp	degrees Celsius
4	EMISsion	milliAmps of emission
5	PRESSURE	total pressure ion current in units of (0.1 femtoAmps)

Table 6-4 Units for analog output selection minimum and maximum values

Analog Current Output

The Analog Current Output provides a stable value between 4 to 20 mA. The current output may be a static value manually set by remote command, or it may be set to map an internally RGA measured quantity to an analog current.

IOUTput:ENable < OFF | ON | 0 | 1 >

This command enables or disables the analog current output from the RGA back panel terminal connections.

- 0 or OFF disables this feature
- 1 or ON enables this feature

Note: For analog current output, if the connection between the analog current output terminal is open, or if the resistance between the terminals is high, (>200 ohms), the current source will be unable to provide the analog current. As a result, an instrument status bit will be set to indicate this condition (AuxIO Status Register (4) - Bit 2 - Analog Output Current Trouble Flag). See Instrument Status for more information about how to detect this condition.

IOUTput:ENable?

Returns the state of the analog current output.

Possible return values are:

0 – Disabled. No analog current output provided.
1 – Enabled.

IOUTput:MANual < value in milliAmps >

Allowed Range: 0 to 20 mA

When the Analog Current Output selection is set to CONSTANT, the analog current output will provide a constant current equal to the value set by this command.

IOUTput:MANual?

Returns the constant value of current in milliAmps provided at the Analog Current Output terminal when the output selection is set to Manual.

IOUTput:MASSreading:AMU < integer in AMU >

Allowed Range: 1 to (120 / 220 / 320), depending on RGA model

When the Analog Current Output selection is set to MASS, the current reflects the last measurement of the ion current for a single ion mass. The output current remains constant until the next time a measurement is made for the ion mass setting.

At startup, and when the mass is changed to a different value, the represented ion current value is reset to 0. It remains 0 until the next valid ion current reading for that mass.

IOUTput:MASSreading:AMU?

Returns the mass whose ion current is monitored by the analog current output in AMU.

IOUTput:MAXout < DEFault | value in milliAmps >

Allowed Range: 0 to 20 mA, DEFault = 20 mA

Sets the maximum scaled analog output current for a measurement for all selections other than CONSTANT.

Note: It is allowed to have MAXout be less than MINout. This may be useful for specific conditions, but it is more typical to define the min/max Analog Output current where MAXout is greater than MINout.

It is also allowed to have MAXout be equal to MINout, but this has limited usefulness. The analog output current is then limited to that singular value, making it equivalent to a CONSTANT value.

IOUTput:MAXout?

Returns the present maximum analog output current that can be seen for an analog output selection other than for CONSTANT.

IOUTput:MINout < DEFault | value in milliAmps >

Allowed Range: 0 to 20 mA, DEFault = 4 mA

Sets the minimum scaled analog output current for a measurement for all selections other than CONSTANT.

Note: It is allowed to have MINout be greater than MAXout. This may be useful for specific conditions, but it is more typical to define the min/max Analog Output current where MINout is less than MAXout.

It is also allowed to have MINout be equal to MAXout, but this has limited usefulness. The analog output current is then limited to that singular value, making it equivalent to a CONSTANT value.

IOUTput:MINout?

Returns the present minimum analog output current that can be seen for an analog output selection other than for CONSTANT.

IOUTput:SELection < integer | keyword >

When enabled, the Analog Current Output can be set to output a constant, manually selected current, or can scale an internally measured quantity to a range of output current. This command selects the quantity that is used as the primary measurement that is scaled to an analog current.

Refer to Table 6-3 to see the list of defined selection integer/keyword values.

The argument can be either the integer value, or the keyword, in short form or long form.

IOUTput:SELection?

Returns the present measurement selection for the analog current output. The value returned is an integer as listed in the Table 6-3 for `IOUTput:SELection`.

IOUTput:SELection:LOG < integer | keyword, LINear | LOG | 0 | 1 >

For measurement values that are between the minimum and maximum limits, the output current will be set to a linear or logarithmic interpolation between the input value to the output current value.

For linear mapping, the interpolated value is determined using the following formula:

$$I_{out} = MINout + \left[(MAXout - MINout) * \frac{x - SELection{:}\,MIN}{SELection{:}\,MAX - SELection{:}\,MIN}\right]$$

For logarithmic mapping, the interpolated value is determined using the following formula:

$$I_{out} = MINout + \left[(MAXout - MINout) * \frac{\log(x) - \log(SELection{:}\,MIN)}{\log(SELection{:}\,MAX) - \log(SELection{:}\,MIN)}\right]$$

Refer to Table 6-3 to see the list of defined selection integer/keyword values.

When providing an integer parameter for the mapping, the keywords LINear and LOG may be used, or the following integers are allowed:

0 or LINear – linear scaling
1 or LOG – logarithmic scaling

IOUTput:SELection:LOG? < integer | keyword >

This returns the mapping used to interpolate measured values between the minimum and maximum values that are set for a selected measurement. Refer to Table 6-3 to see the list of defined selection integer/keyword values.

The following return values are possible:

0 – linear scaling
1 – logarithmic scaling

IOUTput:SELection:MAX <integer | keyword, value >

This command sets the value of the specified measured quantity that scales to the maximum analog output current. The units of the value depend on the measured quantity specified in the command.

The user can set the maximum scaled value for any measured quantity except for CONSTANT. Refer to Table 6-4 for selections and the units expected for the value.

This sets the upper bound for the measurement that is scaled to the analog output current. For any value measured above the maximum value set here, the analog output current is set to the maximum value set by `IOUTput:SELection:MAX`.

The settings for each measured quantity are independent and are saved in memory and flash at an appropriate time (see Autosave). They can be set at any time even while analog output current is not enabled.

IOUTput:SELection:MAX? < integer | keyword >

Returns the value that sets the upper bound for the measured quantity specified. A measurement at or above this value will result in the maximum analog output current at the terminals on the back panel of the instrument.

Refer to Table 6-3 for the list of valid selections.

IOUTput:SELection:MIN < integer | keyword, value >

This command sets the value of the specified measured quantity that scales to the minimum analog output current. The units of the value depend on the measured quantity specified in the command.

The user can set the maximum scaled value for any measured quantity except for CONSTANT. Refer to Table 6-4 for selections and the units expected for the value.

This sets the lower bound for the measurement that is scaled to the analog output current. For any value measured above the maximum value set here, the analog output current is set to the minimum value set by `IOUTput:SELection:MIN`.

The settings for each measured quantity are independent and are saved in memory and flash at an appropriate time (see Autosave). They can be set at any time even while analog output current is not enabled.

IOUTput:SELection:MIN? < integer | keyword >

Returns the value that sets the lower bound for the measured quantity specified. A measurement at or below this value will result in the minimum analog output current at the terminals on the back panel of the instrument.

Refer to Table 6-3 for the list of valid selections.

IOUTput:VALue?

Returns the latest value for analog output current being provided to the terminals at the instrument back panel.

Analog Voltage Output

The Analog Voltage Output provides a stable value between 0 and 10 V. The voltage output may be a static value manually set by remote command, or it may be set to scale an internally RGA measured quantity to an analog voltage.

VOUTput:ENable < OFF | ON | 0 | 1 >

This command enables or disables the analog voltage output from the RGA back panel terminal connections.

- 0 or OFF disables this feature
- 1 or ON enables this feature

VOUTput:ENable?

Returns the state of the analog voltage output.

Possible return values are:

0 – Disabled. No analog voltage output provided.
1 – Enabled.

VOUTput:MANual < value in Volts >

Allowed Range: 0 to 10 V

When the Analog Voltage Output selection is set to CONSTANT, the analog voltage output will provide a constant voltage equal to the value set by this command.

VOUTput:MANual?

Returns the constant value of voltage in Volts provided at the Analog Voltage Output terminal when the output selection is set to Manual.

VOUTput:MASSreading:AMU < integer in AMU >

Allowed Range: 1 to (120 / 220 / 320), depending on RGA model

When the Analog Voltage Output selection is set to MASS, the voltage reflects the last measurement of the ion voltage for a single ion mass. The output voltage remains constant until the next time a measurement is made for the ion mass setting.

At startup, and when the mass is changed to a different value, the represented ion voltage value is reset to 0. It remains 0 until the next valid ion voltage reading for that mass.

VOUTput:MASSreading:AMU?

Returns the mass whose ion voltage is monitored by the analog voltage output in AMU.

VOUTput:MAXout < DEFault | value in Volts >

Allowed Range: 0 to 10 V, DEFault = 10 V

Sets the maximum scaled analog output voltage for a measurement for all selections other than CONSTANT.

Note: It is allowed to have MAXout be less than MINout. This may be useful for specific conditions, but it is more typical to define the min/max Analog Output voltage where MAXout is greater than MINout.

It is also allowed to have MAXout be equal to MINout, but this has limited usefulness. The analog output voltage is then limited to that singular value, making it equivalent to a CONSTANT value.

VOUTput:MAXout?

Returns the present maximum analog output voltage that can be seen for an analog output selection other than for CONSTANT.

VOUTput:MINout < DEFault | value in Volts >

Allowed Range: 0 to 10 V, DEFault = 0 V

Sets the minimum scaled analog output voltage for a measurement for all selections other than CONSTANT.

Note: It is allowed to have MINout be greater than MAXout. This may be useful for specific conditions, but it is more typical to define the min/max Analog Output voltage where MINout is less than MAXout.

It is also allowed to have MINout be equal to MAXout, but this has limited usefulness. The analog output voltage is then limited to that singular value, making it equivalent to a CONSTANT value.

VOUTput:MINout?

Returns the present minimum analog output voltage that can be seen for an analog output selection other than for CONSTANT.

VOUTput:SELection < integer | keyword >

When enabled, the Analog Voltage Output can be set to output a constant, manually selected voltage, or can scale an internally measured quantity to a range of output voltage. This command selects the quantity that is used as the primary measurement that is scaled to an analog voltage.

Refer to Table 6-3 to see the list of defined selection integer/keyword values.

The argument can be either the integer value, or the keyword, in short form or long form.

VOUTput:SELection?

Returns the present measurement selection for the analog voltage output. The value returned is an integer as listed in the Table 6-3 for `VOUTput:SELection`.

VOUTput:SELection:LOG < integer | keyword, LINear | LOG | 0 | 1 >

For measurement values that are between the minimum and maximum limits, the output voltage will be set to a linear or logarithmic interpolation between the input value to the output voltage value.

For linear mapping, the interpolated value is determined using the following formula:

$$V_{out} = MINout + \left[(MAXout - MINout) * \frac{x - SELection{:}\,MIN}{SELection{:}\,MAX - SELection{:}\,MIN}\right]$$

For logarithmic mapping, the interpolated value is determined using the following formula:

$$V_{out} = MINout + \left[(MAXout - MINout) * \frac{\log(x) - \log(SELection{:}\,MIN)}{\log(SELection{:}\,MAX) - \log(SELection{:}\,MIN)}\right]$$

Refer to Table 6-3 to see the list of defined selection integer/keyword values.

When providing an integer parameter for the mapping, the keywords LINear and LOG may be used, or the following integers are allowed:

0 or LINear – linear scaling
1 or LOG – logarithmic scaling

VOUTput:SELection:LOG? < integer | keyword >

This returns the mapping used to interpolate measured values between the minimum and maximum values that are set for a selected measurement. Refer to Table 6-3 to see the list of defined selection integer/keyword values.

The following return values are possible:

0 – linear scaling
1 – logarithmic scaling

VOUTput:SELection:MAX < integer | keyword, value in Volts>

This command sets the value of the specified measured quantity that scales to the maximum analog output voltage. The units of the value depend on the measured quantity specified in the command.

The user can set the maximum scaled value for any measured quantity except for CONSTANT. Refer to Table 6-4 for selections and the units expected for the value.

This sets the upper bound for the measurement that is scaled to the analog output voltage. For any value measured above the maximum value set here, the analog output voltage is set to the maximum value set by `VOUTput:SELection:MAX`.

The settings for each measured quantity are independent and are saved in memory and flash at an appropriate time (see Autosave). They can be set at any time even while analog output voltage is not enabled.

VOUTput:SELection:MAX? < integer | keyword >

Returns the value that sets the upper bound for the measured quantity specified. A measurement at or above this value will result in the maximum analog output voltage at the terminals on the back panel of the instrument.

Refer to Table 6-3 for the list of valid selections.

VOUTput:SELection:MIN < integer | keyword, value in Volts >

This command sets the value of the specified measured quantity that scales to the minimum analog output voltage. The units of the value depend on the measured quantity specified in the command.

The user can set the maximum scaled value for any measured quantity except for CONSTANT. Refer to Table 6-4 for selections and the units expected for the value.

This sets the lower bound for the measurement that is scaled to the analog output voltage. For any value measured above the maximum value set here, the analog output voltage is set to the minimum value set by `VOUTput:SELection:MIN`.

The settings for each measured quantity are independent and are saved in memory and flash at an appropriate time (see Autosave). They can be set at any time even while analog output voltage is not enabled.

VOUTput:SELection:MIN? <integer or keyword>

Returns the value that sets the lower bound for the measured quantity specified. A measurement at or below this value will result in the minimum analog output voltage at the terminals on the back panel of the instrument.

Refer to Table 6-3 for the list of valid selections.

VOUTput:VALue?

Returns the latest value for analog output voltage being provided to the terminals at the instrument back panel.

Analog Input Commands

IINput:LOOP < value in Volts >

Allowed Range: 0 to 20 Volts

Set the Analog Input Loop Power Voltage in volts. This is used for instruments that require an external voltage in order to provide an analog current for their measurement

results. Consult the instruction manual for any external sensor for the correct voltage to use.

IINput:LOOP?

Returns the Analog Input Current Loop Power Voltage setting in volts.

IINput:OVERPRESSURE:ENable < OFF | ON | 0 | 1 >

Enables or disables the overpressure protection feature for the analog current input.

0 or OFF disables this feature
1 or ON enables this feature

IINput:OVERPRESSURE:ENable?

Returns the setting for the overpressure protection feature for the analog current input.

Possible return values are:

0 - Disabled. No overpressure protection from the analog current input.
1 - Enabled.

IINput:OVERPRESSURE:THRESHOLD < value in mA >

Allowed range: 0 to 24 mA

Set the limit to be used for overpressure protection in milliamps. For analog current input, this circuit is designed to operate for standard 4-20 mA devices. The typical operating range for this parameter is between 4 and 20 mA, but all values are allowed between 0 and 24 mA.

IINput:OVERPRESSURE:THRESHOLD?

Returns the overpressure protection limit setting for the analog current input in mA.

IINput:VALue?

Query Analog Input Current. The returned value is in mA.

Note: For analog current input, if the connection between the analog current input terminal and the return is open, or if the current source is out of the standard range of 4 to 20 mA, the analog current input reading may not be accurate. As a result, an instrument status bit will be set to indicate this condition (AuxIO Status Register (4) - Bit 2 - Analog

Input Undercurrent or Bit 3 - Analog Input Overcurrent). See Instrument Status for more information about how to detect this condition.

VINput:OVERPRESSURE:ENable < OFF | ON | 0 | 1 >

Enables or disables the overpressure protection feature for the analog voltage input.

0 or OFF disables this feature
1 or ON enables this feature

VINput:OVERPRESSURE:ENable?

Returns the setting for the overpressure protection feature for the analog voltage input.

Possible return values are:

0 - Disabled. No overpressure protection from the analog current input.
1 - Enabled.

VINput:OVERPRESSURE:THRESHOLD < value in Volts >

Allowed range: 0 to 20 V

Set the limit to be used for overpressure protection in Volts.

VINput:OVERPRESSURE:THRESHOLD?

Returns the overpressure protection limit setting for the analog voltage input in Volts.

VINput:VALue?

Query Analog Input Voltage. The returned value is in Volts.

RTD Commands

RTD:CORRection:OFFSET < value in C | DEFault >

DEFault = 0.0 C

Temperature measurements from the RTD input convert the measured resistance from the connected RTD to a temperature by inverting the Callendar-Van Dusen equation and using standard coefficients for a 100 Ω Pt RTD.

The standard coefficients may be slightly inaccurate due to RTD lead configuration and electronics tolerances. When higher accuracy is needed, the measured temperature can be adjusted through an additional linear correction provided by the user.

This command sets an offset value. This adjusts the measured RTD temperature by a constant value.

The RTD measured temperature is adjusted by the following formula:

$$T_{adj} = T_{RTD} * SLOPE + OFFSET$$

The slope correction may be set with the command `RTD:CORRection:SLOPE`.

This adjustment is applied when using the `RTD:TEMPerature?` command to query the temperature from the RTD.

RTD:CORRection:OFFSET?

This returns the constant value in degrees Celsius used when adjusting the temperature measured by the RTD.

RTD:CORRection:SLOPE < value | DEFault >

DEFault = 1.0

Temperature measurements from the RTD input convert the measured resistance from the connected RTD to a temperature by inverting the Callendar-Van Dusen equation and using standard coefficients for a 100 Ω Pt RTD.

The standard coefficients may be slightly inaccurate due to RTD lead configuration and electronics tolerances. When higher accuracy is needed, the measured temperature can be adjusted through an additional linear correction provided by the user.

The RTD measured temperature is adjusted by the following formula:

$$T_{adj} = T_{RTD} * SLOPE + OFFSET$$

The offset correction may be set with the command `RTD:CORRection:OFFSET`.

This adjustment is applied when using the `RTD:TEMPerature?` command to query the temperature from the RTD.

RTD:CORRection:SLOPE?

This returns the slope used to adjust an internally calculated temperature from a connected RTD.

RTD:RESistance?

This command returns the measured resistance of the RTD as connected in Ω. If the RTD status is not connected properly, the resistance returned is a default value of -1000.000000.

RTD:STATus?

This command returns the status of the connection from the instrument to an external RTD. This status can be used to determine that an RTD has been connected properly, and to help troubleshoot possible problems with the RTD or the connection.

Positive return values indicate that the RTD is connected properly and the RGA can calculate valid temperature results.

Negative return values indicate an improper connection and may offer a hint to fix the problem.

Possible return values:

1	Valid 2-Wire connection
2	Valid 3-Wire connection with SENS+ connected
3	Valid 3-Wire connection with SENS- connected
4	Valid 4-Wire connection with both SENS+ and SENS- connected.
-1	RTD ADC Error
-2	ADC measurement is negative
-3	No RTD connected
-4	SENS+ and SENS- wires are swapped
-5	Negative RTD resistance measured

Typically, when the user has difficulty using the RTD interface, the RGA will respond with status code -3: No RTD connected, or -4: SENS+/SENS- wires are swapped.

For a 3 or 4 wire RTD connection, if either or both SENS wires are connected to the wrong terminal, the RTD status command will return status code -4: SENS+/SENS- wires swapped. Swapping the location of one or both sense wires should fix the problem.

If there is no RTD connected, or if the RTD that is connected has a standard resistance of 1000 ohms or higher, the RTD status command will return status code: -3 No RTD connected. Not that only 100 Ω RTDs are supported by the RTD interface.

Status codes -1, -2, and -5 are anomalous status values that should not be encountered during normal use of an RTD. These codes may be the result of applying external voltages to any of the 4 RTD terminal connections. If any of these status values are seen, all wires connected to the RTD terminal should be removed. If the status continues to return an anomalous value with no wires connected, this may indicate an internal hardware fault. Otherwise, reconnect the RTD to the correct terminal points and try again.

RTD:TEMPerature?

This returns the temperature in Celsius. If the RTD status indicates that there is no valid connection, the temperature returned is a default value of -1000.000000.

Note: The temperature returned by this command is after a linear correction is applied by the slope and reference values specified by `RTD:CORRection:SLOPE` and `RTD:CORRection:REFerence`.

GPIO Direction and Input Commands

GPIO:DIRection < 0 | 1 | INput | OUTput >

Allowed values: 0, INput – Set GPIO pin as Input
1, OUTput – Set GPIO pin as Output

The external GPIO pin connection on the RGA can be configured as either an input pin or an output pin.

As an input, the acceptable input voltage levels are between 0 and +3.3 V.

The output level (either LOW or HIGH), can be programmed either manually or it can be connected to indicate the status of a particular event. See the Digital Output Limit Control Commands for more information on using the GPIO pin as an output.

GPIO:DIRection?

This command returns the direction that the external GPIO pin is configured.

Possible return values are:

0 – Input
1 – Output

Note that the hardware trigger input is connected to a pull up resistor. For open connections, `TRIG:VALue?` should always be 1, HIGH.

GPIO:THRESHOLD < value in Volts | DEFault >

Allowed values: 0 to 3.3 V, DEFault = 1.65 V

This sets the voltage threshold for the hardware TRIGger input on the back panel of the instrument.

The RGA instrument monitors the voltage on the TRIGger input at regular intervals. When the instrument detects that the voltage falls below the threshold set by this

command, the trigger level is set LOW. If the voltage is above the threshold set by this command, the trigger level is set HIGH.

Note: the threshold is not exact. To reliably use this feature to set the hardware digital trigger level LOW through an external signal, the signal should be driven towards zero volts. For an open connection, the input voltage will be pulled up to 3.3 V, equivalent to a HIGH level.

GPIO:THRESHOLD?

Returns the comparator value in Volts that separates the GPIO input being interpreted as a HIGH or LOW level. If the input voltage is above the threshold, this corresponds to a HIGH level. If the input voltage is below the threshold, this corresponds to a LOW level.

GPIO:LEVEL?

When the external GPIO pin is configured as an input pin, using `GPIO:DIRECTION 0`, this command returns the detected status of the input level.

Possible return values are:

0 – Low
1 – High

Low indicates that the input voltage is below the threshold voltage set by `GPIO:THRESHOLD`. High indicates that the input voltage is above the threshold value.

This command describes the value returned only when the GPIO pin is configured as an input. If it is configured as an output pin, see `GPIO:LEVEL?` in the Digital Output Limit Control Commands.

Digital Output (Relay/GPIO) Limit Control Commands

The GPIO Output and External Relay allow the user to be notified of the status of a subset of instrument conditions without the need to query or poll the conditions over a remote interface such as USB or Ethernet. The commands in this section allow the user to configure the GPIO Output and External Relay to flag when such an event condition is detected, and automatically reset when the abnormal condition is no longer in effect.

The first step to making use of this feature is to identify the event of interest. Each output can be configured to flag high or on when any one of a set of conditions are met.

Use `GPIO:EVENT:ENable`, `RELAY:EVENT:ENable` to enable the events that are of interest.

The RGA regularly monitors the state of all the events and sets the GPIO Output and Relay position as necessary to reflect the state of the enabled event conditions.

Below is a table of the defined events. The event number is used as an argument in the `:EVENT:ENable` command. Each event can be enabled on or off individually, or the entire register may be set with an integer argument where each event number is summed using the weight of each event.

For example, to enable event 0, 1, 7, and 8, the command to set the GPIO output to monitor all these events would be either:

```
GPIO:EVENT:EN 0      disables all events
GPIO:EVENT:EN 0, 1   enables Service LED on event
GPIO:EVENT:EN 1, 1   enables Pressure LED on event
GPIO:EVENT:EN 7, 1   enables Communications Idle on event
GPIO:EVENT:EN 8, 1   enables RGA Reset on event
```

Or the equivalent:

```
GPIO:EVENT:EN 387    enables events 0, 1, 7, 8. Disables all other events
```

The second form enables all 4 events at the same time and disables all other events. This is done by making a binary number out of the enabled event numbers. The argument to this command would be $2^8 + 2^7 + 2^1 + 2^0 = 256 + 128 + 2 + 1 = 387$.

Some events require further configuration. The commands in this section allow the user to set limits for analog input current and voltage and to set limits for the measured ion current of a specified mass. These are examples of digital output events that would require further configuration.

See the Digital I/O section for more information about the definition of each event.

Event number	Weight	Event type
0	1	Service LED on
1	2	Pressure LED on
2	4	Filament Emission On
3	8	Filament Emission Off
4	16	Analog Input Voltage Beyond Limit
5	32	Analog Input Current Beyond Limit
6	64	Mass Ion Current Measurement Beyond Limit
7	128	Communications Idle Timeout
8	256	RGA Reset
9	512	Electrometer ADC Overflow
10	1024	Scan Sync Pulse
11 – 15		Reserved

Table 6-5 Events defined for GPIO Output and Relay

GPIO:EVENT:ENable < integer, 0 | 1 | OFF | ON >
GPIO:EVENT:ENable < integer bitfield value >

To enable or disable individual events, the first parameter indicates the event number. The second parameter indicates the enabled or disabled status.

First parameter is the event number:

Allowed values: integer from 0 to 15

The second parameter indicates whether the event should be enabled or disabled.

Allowed values: 0, OFF – Disables digital output event
1, ON – Enables digital output event

To enable/disable each event in a single command, convert the desired event enabled status into a bitfield where 1 is enabled, and 0 is disabled. The binary value, converted to decimal format, should be the parameter provided to the command.

Allowed values: integer from 0 to 65535

The event enabled status is the sum of the individual weights of each event enabled for the GPIO output.

GPIO:EVENT:ENable? < integer >
GPIO:EVENT:ENable?

The first form of the command, with an integer parameter, returns the enabled status of that individual digital output event.

Refer to the Table 6-5 of events at the beginning of this command section to see the definition of each event.

Allowed values: integer from 0 to 15

Possible return values are:

0 – Event n for GPIO Output disabled
1 – Event n for GPIO Output enabled

The second form of the command, with no parameter, will return a single value that describes the event enabled status for the GPIO Output.

Possible return values are between 0 and 65535.

The event enabled status is the sum of the individual weights of each event enabled for the GPIO output.

GPIO:EVENT:CONDition? < integer >
GPIO:EVENT:CONDition?

The first form of the command, with an integer parameter, returns the condition status of that individual digital output event. If the event condition is set, that means that the GPIO output event is enabled and the condition for this event is detected. This would cause the GPIO Output to be set HIGH.

Refer to the Table 6-5 at the beginning of this command section to see the definition of each event.

Allowed values: integer from 0 to 15

Possible return values are:

0 – Event n for GPIO Output condition is not set
1 – Event n for GPIO Output condition is set

The second form of the command, with no parameter, will return a single value that describes the event condition status for enabled events for the GPIO Output.

Possible return values are between 0 and 65535.

The event condition status is the sum of the individual weights of each event enabled for the GPIO output.

This can be used to determine which event or events are the cause for the GPIO Output being set HIGH.

Note: If the event is not enabled for GPIO Output, its condition value will always be 0.

GPIO:FORCE < -1 | 0 | 1 | EVENT | LOw | HIgh >

Allowed values: -1, EVENT – GPIO Output value set by event status
0, LOw – GPIO Output pin is set to 0 V.
1, HIgh – GPIO Output pin is set to +3.3 V.

When the External GPIO pin is set to Output direction using `GPIO:DIRECTION 1`, this command can force the digital output level to 0V when set LOW, or to +3.3 V when set HIGH.

Additionally, the pin can be set to -1, or EVENT mode. In event mode, the output pin can be configured to go HIGH when one or more specific events are triggered. See `GPIO:EVENT:ENable` for more information on how to configure the Event settings for the GPIO output pin.

GPIO:FORCE?

Returns the presently set value for the GPIO Output Force value.

Possible return values are:

-1 – GPIO Output value is set by event status
0 – GPIO Output is set to 0 V.
1 – GPIO Output pin is set to +3.3 V

GPIO:LIMits:COMM:IDLE < integer value in seconds >

Allowed values: Any integer value over 0 seconds.

This command is used to set up an event condition that can be used to control the GPIO Output level. When this event type is enabled for the GPIO Output, the condition is met if the communications over any external interface (RS-232, USB, or Ethernet) is idle for more than the time period specified for this command.

This could be used to notify the user that communication to the RGA has been idle or lost. The host computer or other external device can take action based on this event.

GPIO:LIMits:COMM:IDLE?

Returns the integer number of seconds that is used as an idle timer for communications. If this event is enabled for the GPIO Output, and communication between the host computer and the RGA has been idle for longer than this time, the condition will be met and the GPIO output will be set to HIGH.

When the RGA detects communication from the host computer, the condition is reset, and the idle timer is reset to zero. If no other event conditions are set, the GPIO output will be set to LOW.

GPIO:LIMits:IINput:HI:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables analog input current hi limit for GPIO Output
1, ON – Enables analog input current hi limit for GPIO Output

This command allows the user to set an upper limit for the reading in the input current. With this hi limit set and enabled, and the analog input current event enabled with `GPIO:EVENT:ENable`, any time the analog input current reading is above the limit, the event condition is met and the GPIO Output level will be set to HIGH.

This can be used to notify any host computer connected that the analog input current reading goes beyond the set limit without querying the input current readings directly over an external interface such as USB or Ethernet.

See the Analog I/O section for further information on how to use this command as a part of external event monitoring.

GPIO:LIMits:IINput:HI:ENable?

This returns whether the high limit is enabled for analog input current readings for the GPIO Output.

Possible return values are:

0 – Analog input current hi limit for GPIO Output disabled
1 – Analog input current hi limit for GPIO Output enabled

GPIO:LIMits:IINput:HI:VALue < value in mA >

Allowed values: Any non-negative value in milliamps.

This sets the high limit value for the analog input current event for the GPIO Output. If the analog input current and the high limit are enabled for this measurement, the event condition will be met if the analog input current reading is higher than the value set here.

Note: analog input current readings are measured in positive values only, regardless of the direction of the current flowing on the analog input current pin.

GPIO:LIMits:IINput:HI:VALue?

This returns the value for the analog input current high limit in milliamps. When this limit is enabled, and the analog input current event is enabled for GPIO output, any time the analog input current goes above this set limit, the GPIO output will be set HIGH.

GPIO:LIMits:IINput:HYSTEResis < value in mA >

Allowed values: Any non-negative value in milliamps.

Hysteresis is a property of a system where the output does not change immediately when the input changes. Instead, the output remains unchanged until the input crosses a certain threshold.

Once the analog input current readings have exceeded either the high (upper) or low (lower) limit threshold, the GPIO Output condition is set. To reset the condition, the input current reads must fall back within the limits by the amount specified here as hysteresis. This is the amount the measurement must go below the limit setpoint before the condition will reset.

For example, assume the GPIO IINput low limit is set to 4 mA, and the Hysteresis value is set to 1 mA. If an analog input current reading measurement is made at 2 mA, this limit condition is set. This condition will reset only when the analog input current reading is above 4 + 1, or 5 mA.

GPIO:LIMits:IINput:HYSTEResis?

This returns the amount that an analog input current reading must exceed when crossing back under the threshold limit value to reset the GPIO Output analog input current condition. The value returned is in units of mA.

GPIO:LIMits:IINput:LO:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables analog input current lo limit for GPIO Output
1, ON – Enables analog input current lo limit for GPIO Output

This command allows the user to set an lower limit for the reading in the input current. With this lo limit set and enabled, and the analog input current event enabled with GPIO:EVENT:ENable, any time the analog input current reading is below the limit, the event condition is met and the GPIO Output level will be set to HIGH.

This can be used to notify any host computer connected that the analog input current reading goes beyond the set limit without querying the input current readings directly over an external interface such as USB or Ethernet.

See the Analog I/O section for further information on how to use this command as a part of external event monitoring.

GPIO:LIMits:IINput:LO:ENable?

This returns whether the low limit is enabled for analog input current readings for the GPIO Output.

Possible return values are:

0 – Analog input current lo limit for GPIO Output disabled
1 – Analog input current lo limit for GPIO Output enabled

GPIO:LIMits:IINput:LO:VALue < value in mA >

Allowed values: Any non-negative value in milliamps.

This sets the low limit value for the analog input current event for the GPIO Output. If the analog input current and the low limit are enabled for this measurement, the event condition will be met if the analog input current reading is lower than the value set here.

Note: analog input current readings are measured in positive values only, regardless of the direction of the current flowing on the analog input current pin.

GPIO:LIMits:IINput:LO:VALue?

This returns the value for the analog input current lo limit in milliamps. When this limit is enabled, and the analog input current event is enabled for GPIO output, any time the analog input current goes below this set limit, the GPIO output will be set HIGH.

GPIO:LIMits:MASSreading:AMU < value in AMU >

Allowed values: any integer value from 0 to 320

This sets the mass which is used when monitoring ion current measurements. During any analog or histogram scan, or after any single or multiple mass measurement that measures the mass set here, the ion current reading for that mass is checked against any hi or lo limits set and enabled.

Note: For this GPIO Output event to function, the mass set here must be part of a scan that is run afterwards. The measurements used for the GPIO Output event status are updated after that mass has been measured.

The ion current used is the maximum ion current measured within a -0.3 to +0.3 AMU window around the mass set here.

If this parameter is set to 0, no ion current measurements will be made for this mass, and the limits will not be checked.

GPIO:LIMits:MASSreading:AMU?

This returns the mass used for checking ion current measurements against a hi or lo limit that is set and enabled for the GPIO Output. The value returned is in units of AMU.

GPIO:LIMits:MASSreading:HI:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables mass ion current hi limit for GPIO Output
1, ON – Enables mass ion current hi limit for GPIO Output

This command allows the user to set an upper limit for the reading in the monitored mass ion current. With this hi limit set and enabled, and the monitored mass ion current event enabled with GPIO:EVENT:ENable, any time the monitored mass ion current reading is above the limit, the event condition is met and the GPIO Output level will be set to HIGH.

This can be used to notify any host computer connected that the monitored mass ion current reading goes beyond the set limit without analyzing the returned ion currents from a scan.

See the Analog I/O section for further information on how to use this command as a part of external event monitoring.

GPIO:LIMits:MASSreading:HI:ENable?

This returns whether a hi (upper) limit is enabled for monitored mass ion current readings for the GPIO Output.

Possible return values are:

0 – Monitored mass ion current hi limit for GPIO Output disabled
1 – Monitored mass ion current hi limit for GPIO Output enabled

GPIO:LIMits:MASSreading:HI:VALue < value in 10^{-16} A >

Allowed values: Any value in 10^{-16} A.

This sets the hi limit value for the monitored mass ion current event for the GPIO Output. If the monitored mass ion current and the hi limit are enabled for this measurement, the event condition will be met if the monitored mass ion current reading is higher than the value set here.

GPIO:LIMits:MASSreading:HI:VALue?

This returns the value for the monitored mass ion current high limit in units of 10^{-16} A. When this limit is enabled, and the monitored mass ion current event is enabled for GPIO output, any time the monitored mass ion current goes above this set limit, the GPIO output will be set HIGH.

GPIO:LIMits:MASSreading:HYSTEResis < value in 10^{-16} A >

Allowed values: Any value in 10^{-16} A

Hysteresis is a property of a system where the output does not change immediately when the input changes. Instead, the output remains unchanged until the input crosses a certain threshold.

Once the monitored mass ion current readings have exceeded either the high (upper) or low (lower) limit threshold, the GPIO Output condition is set. To reset the condition, the mass ion current reads must fall back within the limits by the amount specified here as hysteresis. This is the amount the measurement must go below the limit setpoint before the condition will reset.

For example, assume the GPIO MASSreading Lower limit is set to 10000 10^{-16} A, and the Hysteresis value is set to 2000 10^{-16} A. If an analog input current reading measurement is made at 6000 10^{-16} A, this limit condition is set. This condition will reset only when the analog input current reading is above 10000 + 2000, or 12000 10^{-16} A.

GPIO:LIMits:MASSreading:HYSTEResis?

This returns the amount that a monitored mass ion current reading must exceed when crossing back under the threshold limit value to reset the GPIO Output monitored mass ion current condition. The value returned is in units of 10^{-16} A.

GPIO:LIMits:MASSreading:LO:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables mass ion current lo limit for GPIO Output
1, ON – Enables mass ion current lo limit for GPIO Output

This command allows the user to set a lower limit for the reading in the monitored mass ion current. With this lo limit set and enabled, and the monitored mass ion current event enabled with `GPIO:EVENT:ENable`, any time the monitored mass ion current reading is below the limit, the event condition is met and the GPIO Output level will be set to HIGH.

This can be used to notify any host computer connected that the monitored mass ion current reading goes beyond the set limit without analyzing the returned ion currents from a scan.

See the Analog I/O section for further information on how to use this command as a part of external event monitoring.

GPIO:LIMits:MASSreading:LO:ENable?

This returns whether a lo (lower) limit is enabled for monitored mass ion current readings for the GPIO Output.

Possible return values are:

0 – Monitored mass ion current lo limit for GPIO Output disabled
1 – Monitored mass ion current lo limit for GPIO Output enabled

GPIO:LIMits:MASSreading:LO:VALue < value in 10^{-16} A >

Allowed values: Any value in 10^{-16} A.

This sets the lo limit value for the monitored mass ion current event for the GPIO Output. If the monitored mass ion current and the lo limit are enabled for this measurement, the event condition will be met if the monitored mass ion current reading is lower than the value set here.

GPIO:LIMits:MASSreading:LO:VALue?

This returns the value for the monitored mass ion current lo limit in 10^{-16} amps. When this limit is enabled, and the monitored mass ion current event is enabled for GPIO

output, any time the monitored mass ion current goes below this set limit, the GPIO output will be set HIGH.

GPIO:LIMits:VINput:HI:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables analog input voltage hi limit for GPIO Output
1, ON – Enables analog input voltage hi limit for GPIO Output

This command allows the user to set an upper limit for the reading in the input voltage. With this hi limit set and enabled, and the analog input voltage event enabled with `GPIO:EVENT:ENable`, any time the analog input voltage reading is above the limit, the event condition is met and the GPIO Output level will be set to HIGH.

This can be used to notify any host computer connected that the analog input voltage reading goes beyond the set limit without querying the input voltage readings directly over an external interface such as USB or Ethernet.

See the Analog I/O section for further information on how to use this command as a part of external event monitoring.

GPIO:LIMits:VINput:HI:ENable?

This returns whether a hi (upper) limit is enabled for analog input voltage readings for the GPIO Output.

Possible return values are:

0 – Analog input voltage hi limit for GPIO Output disabled
1 – Analog input voltage hi limit for GPIO Output enabled

GPIO:LIMits:VINput:HI:VALue < value in Volts >

Allowed values: Any non-negative value in volts.

This sets the hi limit value for the analog input voltage event for the GPIO Output. If the analog input voltage and the hi limit are enabled for this measurement, the event condition will be met if the analog input voltage reading is higher than the value set here.

GPIO:LIMits:VINput:HI:VALue?

This returns the value for the analog input voltage high limit in volts. When this limit is enabled, and the analog input voltage event is enabled for GPIO output, any time the analog input voltage goes above this set limit, the GPIO output will be set HIGH.

GPIO:LIMits:VINput:HYSTEResis < value in Volts >

Allowed values: Any non-negative value in Volts.

Hysteresis is a property of a system where the output does not change immediately when the input changes. Instead, the output remains unchanged until the input crosses a certain threshold.

Once the analog input voltage readings have exceeded either the high (upper) or low (lower) limit threshold, the GPIO Output condition is set. To reset the condition, the input voltage reads must fall back within the limits by the amount specified here as hysteresis. This is the amount the measurement must go below the limit setpoint before the condition will reset.

For example, assume the GPIO VInput Lower limit is set to 5 V, and the Hysteresis value is set to 1 V. If an analog input voltage reading measurement is made at 3 V, this limit condition is set. This condition will reset only when the analog input voltage reading is above 5 + 1, or 6 V.

GPIO:LIMits:VINput:HYSTEResis?

This returns the amount that an analog input voltage reading must exceed when crossing back under the threshold limit value to reset the GPIO Output analog input voltage condition. The value returned is in units of Volts.

GPIO:LIMits:VINput:LO:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables analog input voltage lo limit for GPIO Output
1, ON – Enables analog input voltage lo limit for GPIO Output

This command allows the user to set a lower limit for the reading in the input voltage. With this lo limit set and enabled, and the analog input voltage event enabled with `GPIO:EVENT:ENable`, any time the analog input voltage reading is below the limit, the event condition is met and the GPIO Output level will be set to HIGH.

This can be used to notify any host computer connected that the analog input voltage reading goes beyond the set limit without querying the input voltage readings directly over an external interface such as USB or Ethernet.

See the Analog I/O section for further information on how to use this command as a part of external event monitoring.

GPIO:LIMits:VINput:LO:ENable?

This returns whether a lo (lower) limit is enabled for analog input voltage readings for the GPIO Output.

Possible return values are:

0 – Analog input voltage lo limit for GPIO Output disabled
1 – Analog input voltage lo limit for GPIO Output enabled

GPIO:LIMits:VINput:LO:VALue < value in Volts >

Allowed values: Any non-negative value in volts.

This sets the lo limit value for the analog input voltage event for the GPIO Output. If the analog input voltage and the lo limit are enabled for this measurement, the event condition will be met if the analog input voltage reading is lower than the value set here.

GPIO:LIMits:VINput:LO:VALue?

This returns the value for the analog input voltage lo limit in volts. When this limit is enabled, and the analog input voltage event is enabled for GPIO output, any time the analog input voltage goes below this set limit, the GPIO output will be set HIGH.

GPIO:VALue?

This returns the present status of the output GPIO pin when the pin is configured as an output using `GPIO:DIRECTION 1`

Possible return values are:

0 – Low
1 – High

A value of 0 indicates that the GPIO output level is set to 0V. This is set by either using the `GPIO:FORCE` command to manually set it low, or, when configured to monitor one or more events, none of the event conditions have been met.

A value of 1 indicates that the GPIO output level is set to 3.3V. This is set by either using the `GPIO:FORCE` command to manually set it high, or, when configured to monitor one or more events, at least one of the event conditions have been met.

See `GPIO:EVENT:ENable` for more information about how to configure the Event settings for the GPIO output pin.

RELAY:EVENT:ENable < integer, 0 | 1 | OFF | ON >
RELAY:EVENT:ENable < integer value >

To enable or disable individual events, the first parameter indicates the event number. The second parameter indicates the enabled or disabled status.

First parameter is the event number:

Allowed values: integer from 0 to 15

The second parameter indicates whether the event should be enabled or disabled.

Allowed values: 0, OFF – Disables digital output event
1, ON – Enables digital output event

To enable/disable each event in a single command, convert the desired event enabled status into a bitfield where 1 is enabled, and 0 is disabled. The binary value, converted to decimal format, should be the parameter provided to the command.

Allowed values: integer from 0 to 65535

The event enabled status is the sum of the individual weights of each event enabled for the Relay position.

RELAY:EVENT:ENable? < integer >
RELAY:EVENT:ENable?

The first form of the command, with an integer parameter, returns the enabled status of that individual digital output event.

Refer to the Table 6-5 at the beginning of this command section to see the definition of each event.

Allowed values: integer from 0 to 15

Possible return values are:

0 – Event n for the Relay is disabled
1 – Event n for the Relay is enabled

The second form of the command, with no parameter, will return a single value that describes the event enabled status for the Relay position.

Possible return values are between 0 and 65535.

The event enabled status is the sum of the individual weights of each event enabled for the Relay.

RELAY:EVENT:CONDition? < integer >
RELAT:EVENT:CONDition?

The first form of the command, with an integer parameter, returns the condition status of that individual digital output event. If the event condition is set, that means that the Relay event is enabled and the condition for this event is detected. This would cause the Relay position to be set ON.

Refer to the Table 6-5 at the beginning of this command section to see the definition of each event.

Allowed values: integer from 0 to 15

Possible return values are:

0 – Event n for Relay condition is not set
1 – Event n for Relay condition is set

The second form of the command, with no parameter, will return a single value that describes the event condition status for enabled events for the Relay.

Possible return values are between 0 and 65535.

The event condition status is the sum of the individual weights of each event enabled for the Relay.

This can be used to determine which event or events are the cause for the Relay position to be set ON.

Note: If the event is not enabled for the Relay, its condition value will always be 0.

RELAY:FORCE < -1 | 0 | 1 | EVENT | LOw | HIgh >

Allowed values: -1, EVENT – Relay position set by event status
0, OFF – Relay position is set to the OFF position
1, ON – Relay position is set to the ON position

This command can force the external Relay connection to the OFF or on position directly.

Additionally, when the external Relay is set here with -1 or EVENT mode the relay position can be configured to go to ON when one or more specific events are triggered. See `RELAY:EVENT:ENable` for more information on how to configure the Event settings for the external Relay connection.

RELAY:FORCE?

Returns the presently set value for the GPIO Output Force value.

Possible return values are:

-1 – Relay position is set by event status
0 – Relay position is set to the OFF position
1 – Relay position is set to the ON position

RELAY:LIMits:COMM:IDLE < integer value in seconds >

Allowed values: Any integer value over 0 seconds.

This command is used to set up an event condition that can be used to control the external Relay position. When this event type is enabled for the Relay, the condition is met if the communications over any external interface (RS-232, USB, or Ethernet) is idle for more than the time period specified for this command.

This could be used to notify the user that communication to the RGA has been idle or lost. The host computer or other external device can take action based on this event.

RELAY:LIMits:COMM:IDLE?

Returns the integer number of seconds that is used as an idle timer for communications. If this event is enabled for the relay, and communication between the host computer and the RGA has been idle for longer than this time, the condition will be met and the relay will be set to the ON position.

When the RGA detects communication from the host computer, the condition is reset, and the idle timer is reset to zero. If no other event conditions are set, the relay position is switched to the OFF position.

RELAY:LIMits:IINput:HI:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables analog input current hi limit for the Relay
1, ON – Enables analog input current hi limit for the Relay

This command allows the user to set an upper limit for the reading in the input current. With this hi limit set and enabled, and the analog input current event enabled with `RELAY:EVENT:ENable`, any time the analog input current reading is above the limit, the event condition is met and the Relay position will be set to ON.

This can be used to notify any host computer connected that the analog input current reading goes beyond the set limit without querying the input current readings directly over an external interface such as USB or Ethernet.

See the Analog I/O section for further information on how to use this command as a part of external event monitoring.

RELAY:LIMits:IINput:HI:ENable?

This returns whether a hi (upper) limit is enabled for analog input current readings for the Relay.

Possible return values are:

0 – Analog input current hi limit for the Relay disabled
1 – Analog input current hi limit for the Relay enabled

RELAY:LIMits:IINput:HI:VALue < value in mA >

Allowed values: Any non-negative value in milliamps.

This sets the hi limit value for the analog input current event for the Relay position. If the analog input current and the hi limit are enabled for this measurement, the event condition will be met if the analog input current reading is higher than the value set here.

Note: analog input current readings are measured in positive values only, regardless of the direction of the current flowing on the analog input current pin.

RELAY:LIMits:IINput:HI:VALue?

This returns the value for the analog input current high limit in milliamps. When this limit is enabled, and the analog input current event is enabled for Relay, any time the analog input current goes above this set limit, the Relay will be set ON.

RELAY:LIMits:IINput:HYSTEResis < value in mA >

Allowed values: Any non-negative value in milliamps.

Hysteresis is a property of a system where the output does not change immediately when the input changes. Instead, the output remains unchanged until the input crosses a certain threshold.

Once the analog input current readings have exceeded either the high (upper) or low (lower) limit threshold, the Relay condition is set. To reset the condition, the input current reads must fall back within the limits by the amount specified here as hysteresis. This is the amount the measurement must go below the limit setpoint before the condition will reset.

For example, assume the Relay IInput Lower limit is set to 4 mA, and the Hysteresis value is set to 1 mA. If an analog input current reading measurement is made at 2 mA, this limit condition is set. This condition will reset only when the analog input current reading is above 4 + 1, or 5 mA.

RELAY:LIMits:IINput:HYSTEResis?

This returns the amount that an analog input current reading must exceed when crossing back under the threshold limit value to reset the GPIO Output analog input current condition. The value returned is in units of mA.

RELAY:LIMits:IINput:LO:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables analog input current lo limit for the Relay
1, ON – Enables analog input current lo limit for the Relay

This command allows the user to set an lower limit for the reading in the input current. With this lo limit set and enabled, and the analog input current event enabled with `RELAY:EVENT:ENable`, any time the analog input current reading is below the limit, the event condition is met and the Relay position will be set to ON.

This can be used to notify any host computer connected that the analog input current reading goes beyond the set limit without querying the input current readings directly over an external interface such as USB or Ethernet.

See the Analog I/O section for further information on how to use this command as a part of external event monitoring.

RELAY:LIMits:IINput:LO:ENable?

This returns whether a lo (lower) limit is enabled for analog input current readings for the Relay position.

Possible return values are:

0 – Analog input current lo limit for the Relay disabled
1 – Analog input current lo limit for the Relay enabled

RELAY:LIMits:IINput:LO:VALue < value in mA >

Allowed values: Any non-negative value in milliamps.

This sets the lo limit value for the analog input current event for the Relay. If the analog input current and the lo limit are enabled for this measurement, the event condition will be met if the analog input current reading is lower than the value set here.

Note: analog input current readings are measured in positive values only, regardless of the direction of the current flowing on the analog input current pin.

RELAY:LIMits:IINput:LO:VALue?

This returns the value for the analog input current lo limit in milliamps. When this limit is enabled, and the analog input current event is enabled for Relay, any time the analog input current goes below this set limit, the Relay will be set ON.

RELAY:LIMits:MASSreading:AMU < value in AMU >

Allowed values: any integer value from 0 to 320

This sets the mass which is used when monitoring ion current measurements. During any analog or histogram scan, or after any single or multiple mass measurement that measures the mass set here, the ion current reading for that mass is checked against any hi or lo limits set and enabled.

Note: For this Relay event to function, the mass set here must be part of a scan that is run afterwards. The measurements used for the Relay event status are updated after that mass has been measured.

The ion current used is the maximum ion current measured within a -0.3 to +0.3 AMU window around the mass set here.

If this parameter is set to 0, no ion current measurements will be made for this mass, and the limits will not be checked.

RELAY:LIMits:MASSreading:AMU?

This returns the mass used for checking ion current measurements against a hi or lo limit that is set and enabled for the Relay. The value returned is in units of AMU.

RELAY:LIMits:MASSreading:HI:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables mass ion current hi limit for the Relay
1, ON – Enables mass ion current hi limit for the Relay

This command allows the user to set an upper limit for the reading in the monitored mass ion current. With this hi limit set and enabled, and the monitored mass ion current event enabled with `RELAY:EVENT:ENable`, any time the monitored mass ion current reading is above the limit, the event condition is met and the Relay position will be set to ON.

This can be used to notify any host computer connected that the monitored mass ion current reading goes beyond the set limit without analyzing the returned ion currents from a scan.

See the Analog I/O section for further information on how to use this command as a part of external event monitoring.

RELAY:LIMits:MASSreading:HI:ENable?

This returns whether a hi (upper) limit is enabled for monitored mass ion current readings for the Relay.

Possible return values are:

0 – Monitored mass ion current hi limit for Relay disabled
1 – Monitored mass ion current hi limit for Relay enabled

RELAY:LIMits:MASSreading:HI:VALue < value in 10^{-16} A >

Allowed values: Any value in 10^{-16} A.

This sets the hi limit value for the monitored mass ion current event for the Relay. If the monitored mass ion current and the hi limit are enabled for this measurement, the event condition will be met if the monitored mass ion current reading is higher than the value set here.

RELAY:LIMits:MASSreading:HI:VALue?

This returns the value for the monitored mass ion current high limit in units of 10^{-16} A. When this limit is enabled, and the monitored mass ion current event is enabled for the Relay, any time the monitored mass ion current goes above this set limit, the Relay position will be set ON.

RELAY:LIMits:MASSreading:HYSTEResis < value in 10^{-16} A >

Allowed values: Any value in 10^{-16} A

Hysteresis is a property of a system where the output does not change immediately when the input changes. Instead, the output remains unchanged until the input crosses a certain threshold.

Once the monitored mass ion current readings have exceeded either the high (upper) or low (lower) limit threshold, the Relay condition is set. To reset the condition, the mass ion current reads must fall back within the limits by the amount specified here as hysteresis. This is the amount the measurement must go below the limit setpoint before the condition will reset.

For example, assume the Relay MASSreading Lower limit is set to 10000 10^{-16} A, and the Hysteresis value is set to 2000 10^{-16} A. If an analog input current reading measurement is made at 6000 10^{-16} A, this limit condition is set. This condition will reset only when the analog input current reading is above 10000 + 2000, or 12000 10^{-16} A.

RELAY:LIMits:MASSreading:HYSTEResis?

This returns the amount that a monitored mass ion current reading must exceed when crossing back under the threshold limit value to reset the GPIO Output monitored mass ion current condition. The value returned is in units of 10^{-16} A.

RELAY:LIMits:MASSreading:LO:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables mass ion current lo limit for the Relay
1, ON – Enables mass ion current lo limit for the Relay

This command allows the user to set a lower limit for the reading in the monitored mass ion current. With this lo limit set and enabled, and the monitored mass ion current event enabled with `RELAY:EVENT:ENable`, any time the monitored mass ion current reading is below the limit, the event condition is met and the Relay position will be set to ON.

This can be used to notify any host computer connected that the monitored mass ion current reading goes beyond the set limit without analyzing the returned ion currents from a scan.

See the Analog I/O section for further information on how to use this command as a part of external event monitoring.

RELAY:LIMits:MASSreading:LO:ENable?

This returns whether a lo (lower) limit is enabled for analog input voltage readings for the Relay.

Possible return values are:

0 – Analog input voltage lo limit for the Relay disabled
1 – Analog input voltage lo limit for the Relay enabled

RELAY:LIMits:MASSreading:LO:VALue < value in 10^{-16} A >

Allowed values: Any value in 10^{-16} A.

This sets the lo limit value for the monitored mass ion current event for the Relay. If the monitored mass ion current and the lo limit are enabled for this measurement, the event condition will be met if the monitored mass ion current reading is lower than the value set here.

RELAY:LIMits:MASSreading:LO:VALue?

This returns the value for the monitored mass ion current lo limit in 10^{-16} amps. When this limit is enabled, and the monitored mass ion current event is enabled for the Relay, any time the monitored mass ion current goes below this set limit, the Relay position will be set ON.

RELAY:LIMits:VINput:HI:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables analog input voltage hi limit for the Relay
1, ON – Enables analog input voltage hi limit for the Relay

This command allows the user to set an upper limit for the reading in the input voltage. With this hi limit set and enabled, and the analog input voltage event enabled with `RELAY:EVENT:ENable`, any time the analog input voltage reading is above the limit, the event condition is met and the Relay position will be set to ON.

This can be used to notify any host computer connected that the analog input voltage reading goes beyond the set limit without querying the input voltage readings directly over an external interface such as USB or Ethernet.

See the Analog I/O section for further information on how to use this command as a part of external event monitoring.

RELAY:LIMits:VINput:HI:ENable?

This returns whether a hi (upper) limit is enabled for analog input voltage readings for the Relay.

Possible return values are:

0 – Analog input voltage hi limit for the Relay disabled
1 – Analog input voltage hi limit for the Relay enabled

RELAY:LIMits:VINput:HI:VALue < value in Volts >

Allowed values: Any non-negative value in volts.

This sets the hi limit value for the analog input voltage event for the Relay. If the analog input voltage and the hi limit are enabled for this measurement, the event condition will be met if the analog input voltage reading is higher than the value set here.

RELAY:LIMits:VINput:HI:VALue?

This returns the value for the analog input voltage high limit in volts. When this limit is enabled, and the analog input voltage event is enabled for the Relay, any time the analog input voltage goes above this set limit, the Relay position will be set ON.

RELAY:LIMits:VINput:HYSTEResis < value in Volts >

Allowed values: Any non-negative value in Volts.

Hysteresis is a property of a system where the output does not change immediately when the input changes. Instead, the output remains unchanged until the input crosses a certain threshold.

Once the analog input voltage readings have exceeded either the high (upper) or low (lower) limit threshold, the Relay condition is set. To reset the condition, the input voltage reads must fall back within the limits by the amount specified here as hysteresis. This is the amount the measurement must go below the limit setpoint before the condition will reset.

For example, assume the Relay VInput Lower limit is set to 5 V, and the Hysteresis value is set to 1 V. If an analog input voltage reading measurement is made at 3 V, this limit condition is set. This condition will reset only when the analog input voltage reading is above 5 + 1, or 6 V.

RELAY:LIMits:VINput:HYSTEResis?

This returns the amount that an analog input voltage reading must exceed when crossing back under the threshold limit value to reset the Relay analog input voltage condition. The value returned is in units of Volts.

RELAY:LIMits:VINput:LO:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables analog input voltage lo limit for the Relay
1, ON – Enables analog input voltage lo limit for the Relay

This command allows the user to set a lower limit for the reading in the input voltage. With this lo limit set and enabled, and the analog input voltage event enabled with `RELAY:EVENT:ENable`, any time the analog input voltage reading is below the limit, the event condition is met and the Relay position will be set to ON.

This can be used to notify any host computer connected that the analog input voltage reading goes beyond the set limit without querying the input voltage readings directly over an external interface such as USB or Ethernet.

See the Analog I/O section for further information on how to use this command as a part of external event monitoring.

RELAY:LIMits:VINput:LO:ENable?

This returns whether a lo (lower) limit is enabled for analog input voltage readings for the Relay.

Possible return values are:

0 – Analog input voltage lo limit for the Relay disabled
1 – Analog input voltage lo limit for the Relay enabled

RELAY:LIMits:VINput:LO:VALue < value in Volts >

Allowed values: Any non-negative value in volts.

This sets the lo limit value for the analog input voltage event for the Relay. If the analog input voltage and the lo limit are enabled for this measurement, the event condition will be met if the analog input voltage reading is lower than the value set here.

RELAY:LIMits:VINput:LO:VALue?

This returns the value for the analog input voltage lo limit in volts. When this limit is enabled, and the analog input voltage event is enabled for the Relay, any time the analog input voltage goes below this set limit, the Relay position will be set HIGH.

RELAY:VALue?

Possible return values are:

0 – OFF
1 – ON

A value of 0 indicates that the external Relay position is set to OFF. This is set by either using the `RELAY:FORCE` command to manually set it low, or, when configured to monitor one or more events, none of the event conditions have been met.

A value of 1 indicates that the external Relay position is set to ON. This is set by either using the `RELAY:FORCE` command to manually set it high, or, when configured to monitor one or more events, at least one of the event conditions have been met.

See `RELAY:EVENT:ENable` for more information about how to configure the Event settings for the external Relay.

Ethernet Commands

Ethernet:CONFIG < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables UDP Configuration
1, ON – Enables UDP Configuration

The RGA instrument uses an internal UDP based messaging protocol to configure a number of internal Ethernet parameters including the following:

IP address
Device Name
Subnet
Gateway
Preferred DNS

The messaging protocol can also be used to reset the login/password to the default 'admin/admin' configuration.

The RGA PC software makes use of this messaging protocol to make changes to these settings as requested.

For security, to prevent unauthorized users from changing settings through this protocol, this configuration is normally disabled. This command enables the configuration mode for 30 minutes. After that time, configuration is automatically disabled.

Note: When the RGA instrument is not connected to a probe, configuration mode is enabled for 30 minutes after startup. This allows the user to set Ethernet parameters in a desktop setting before final placement.

Ethernet:CONFIG?

The return value indicates whether the RGA instrument can be configured through the instrument's internal UDP messaging protocol.

0 – Ethernet Configuration Disabled
1 – Ethernet Configuration Enabled

Ethernet:DHCP:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables DHCP
1, ON – Enables DHCP

This command will attempt to set the instrument IP address by seeking a DHCP server on the local network and requesting an IP address from the DHCP server.

If DHCP is successful, the RGA will override any manually set IP address and will use the address provided by DHCP.

If DHCP is disabled, the RGA will revert to any manually set IP address it had stored before DHCP was enabled.

Ethernet:DHCP:ENable?

Returns the present setting for Ethernet Discovery.

0 – Ethernet DHCP Disabled
1 – Ethernet DHCP Enabled

The return value indicates whether the RGA instrument's IP address is set manually or expects to be set through a DHCP server on the network.

Note: If DHCP is enabled, the IP address may not be set automatically. The process requires that a DHCP server is available on the local network and can provide an address to the instrument. Additionally, this process takes some time, perhaps up to a minute or more, before an address is provided.

Ethernet:DISCovery:ENable < 0 | 1 | OFF | ON >

Allowed values: 0, OFF – Disables Ethernet Discovery
1, ON – Enables Ethernet Discovery

The RGA PC software uses Ethernet Discovery to broadcast a request to all RGA instruments to identify themselves. This command can be used to allow a reply when enabled. From the factory, the RGA instrument has Ethernet Discovery enabled.

To hide the RGA instrument from being seen by others using Ethernet Discovery, disable this feature with this command.

Ethernet:DISCovery:ENable?

Returns the present setting for Ethernet Discovery.

0 – Ethernet Discovery Disabled
1 – Ethernet Discovery Enabled

Ethernet:DNS < x.x.x.x > where x is in the range 0 to 255

Manually set the IPv4 preferred DNS server for the RGA instrument.

Note: This is not used for instrument functionality. It is strictly used for internal network identification purposes.

Ethernet:DNS?

Returns the IPv4 address for preferred DNS server as set by the user.

Ethernet:GATEWAY < x.x.x.x > where x is in the range 0 to 255

Manually set the IPv4 gateway address for the RGA instrument.

Note: This is not used for instrument functionality. It is strictly used for internal network identification purposes.

Ethernet:GATEWAY?

Returns the IPv4 gateway address as set by the user.

Ethernet:IP < x.x.x.x > where x is in the range 0 to 255

Manually set the IPv4 address of the instrument. The change takes place immediately. If the IP address was previously obtained by DHCP, the new address disables the instrument's use of DHCP and uses this static IP address.

Note: If you use this command over the Ethernet interface, the TCP/IP session will be closed.

Ethernet:IP?

This command returns the IP address of the instrument in the form: x.x.x.x where x is a number in the range 0 to 255.

A value of 0.0.0.0 indicates that the instrument has no IP address. A TCP/IP session cannot be opened to the instrument until an IP address has been set.

Ethernet:LOGIN <@ followed by string of 0 to 15 bytes>

Valid values: string of characters starting with an '@' character, followed 0 to 15 additional characters. Only alpha-numeric characters are supported, a-z, A-Z, and 0-9.

This command sets the LOGIN name used when opening a TCP/IP session with the instrument. The LOGIN name and PASSWORD are used when connecting to an RGA instrument over the Ethernet interface.

Login arguments greater than 15 bytes in length will be truncated to 15 bytes.

Examples

`ETH:LOGIN @admin`	sets the login name to ‘admin’
`ETH:LOGIN @`	clears the login name

Note: Zero character login names are accepted. This allows the user to bypass the login prompt by simply pressing return.

Ethernet:LOGIN?

Returns the login name that is accepted when starting a TCP/IP session with the instrument over the Ethernet interface.

Ethernet:MAC?

Returns the MAC address of the instrument in 6 hex byte values, in the form: xx:xx:xx:xx:xx:xx This address is set at the factory and cannot be changed.

Ethernet:NAME <@ followed by string of 0 to 15 bytes>

Valid values: string of characters starting with an ‘@’ character, followed by a string of characters from 0 to 15 bytes long. Only alpha-numeric characters are supported, a-z, A-Z, and 0-9.

This command sets the Device Name that is returned when querying the RGA over UDP Discovery. Setting the device name can be used to find a specific RGA in a network where a number of RGA instruments are connected.

Device name arguments greater than 15 bytes in length will be truncated to 15 bytes.

Examples

ETH:NAME @rga1	sets the device name to ‘rga1’
ETH:NAME @	clears the device name

Note: Zero character length device names are accepted.

Ethernet:NAME?

Returns the device name that identifies the RGA instrument over UDP Discovery.

Ethernet:NETMASK< x.x.x.x > where x is in the range 0 to 255

Manually set the IPv4 netmask for the RGA instrument.

Note: This is not used for instrument functionality. It is strictly used for internal network identification purposes.

Ethernet:NETMASK?

Returns the IPv4 netmask as set by the user.

Ethernet:PASSWORD <@ followed by string of 0 to 15 bytes>

Valid values: string of characters starting with an '@' character, followed by 0 to 15 additional characters. Only alpha-numeric characters are supported, a-z, A-Z, and 0-9.

This command sets the PASSWORD used when opening a TCP/IP session with the instrument. The LOGIN name and PASSWORD are used when connecting to an RGA instrument over the Ethernet interface.

Password arguments greater than 15 bytes in length will be truncated to 15 bytes.

Examples

`ETH:PASSWORD @admin`	sets the login name to 'admin'
`ETH:PASSWORD @`	clears the login name

Note: Zero character length passwords are accepted. This allows the user to bypass the password prompt by simply pressing return.

Ethernet:PASSWORD?

Returns the password that is accepted when starting a TCP/IP session with the instrument over the Ethernet interface.

Ethernet:TELNET:CLOSE

This command immediately closes any active TCP/IP telnet session that is currently active over the Ethernet interface.

This can be useful when the user terminal program fails to properly close the telnet connection and the RGA instrument cannot be accessed over the Ethernet interface until the Ethernet timeout has expired. By necessity, as the Ethernet interface would be unavailable in such an instance, the command should be sent via either USB or RS-232 interface.

Note: If this command is sent via the Ethernet interface, the TCP/IP telnet session will immediately close.

Ethernet:TIMEOUT < value in seconds >

Allowed values: 30 to 86400 seconds

This sets the Ethernet timeout value. The RGA instrument allows for only one interactive TCP/IP telnet session. Any further attempts to open a telnet session is refused. The timeout allows the instrument to close any open telnet connection after the timer expires. This allows the user to regain access to the RGA instrument if the host computer loses connection to the RGA instrument.

This requires that the user send a command at an interval less than the expiration time. A null command <CR-LF> is an acceptable command to reset the expiration timer.

For networks that have poor connectivity, a shorter time period is suggested.

Ethernet:TIMEOUT?

Returns the Ethernet timeout period set in the RGA instrument in seconds. If an open TCP/IP telnet session does not send a command to the RGA instrument within the timeout period, the connection is closed.

Miscellaneous Commands

INSTrument:ID?

Returns the instrument ID

HVENable:THRESHOLD < value in Volts | DEFault >

Allowed values: 0 to 3.3 V, DEFault = 1.65 V

This sets the voltage threshold for the HVENable input on the back panel of the instrument.

The RGA instrument monitors the voltage on the HVENable input at regular intervals. When the instrument detects that the voltage falls below the threshold set by this command, all high voltage components are shut down. This includes the focus plate, repeller, RF and DC high voltage. Any filament emission is also stopped.

After the voltage is raised above the threshold once more, the original values for high voltage are restored.

Note: the threshold is not exact. To reliably use this feature to disable the high voltage through an external signal, the signal should be driven towards zero volts. When allowing

for high voltage, the input can be left open connection. Changing this value should be done only when necessary to use non-standard signal sources.

HVENable:THRESHOLD?

This returns the threshold value for the HVENable back panel input in Volts. If the detected voltage is below this value, the RGA instrument shuts down all high voltage components.

HVENable:VALue?

This returns the digital value for the HVENable back panel input. The digital value indicates the detected voltage is above or below the threshold value.

1 – Above the threshold value
0 – Below the threshold value

Interlock Commands

For the following interlock commands, when setting the ENable value for any of them, the allowed arguments are presented here:

0, OFF – interlock is disabled
1, ON – interlock is enabled

Table 6-6 Allowed arguments for interlock commands

When an interlock is enabled, that means that the specific protection mechanism is in effect. When an anomalous condition is detected, the interlock will engage and protect that subsystem in some way. There are circumstances where one or more protection mechanisms described here may interfere with instrument operation. For example, overpressure protection provided by the Pirani interlock may be overly sensitive to actual filament and test chamber pressure conditions. In such situations where this prevents further analysis, the user may disable the protection mechanism.

In such cases, it is strongly recommended that the following interlocks remain enabled. Disabling any interlock may result in instrument damage. Such action should only be taken when the need to do so is fully understood.

INTERLOCK:CEMprotect:ENable < 0 | 1 | OFF | ON >

This command enables or disables the CEM protection interlock. The interlock condition is triggered if the power supply for the CEM indicates it cannot provide the power necessary to maintain the voltage potential requested.

Table 6-6 summarizes the allowed argument values for this command.

INTERLOCK:CEMprotect:ENable?

Returns the enabled state of the CEM protection interlock. The returned value is an integer that is summarized in Table 6-6.

INTERLOCK:CEMprotect?

Returns the triggered state of the interlock. If the CEM protection interlock was triggered, this event is latched and the status is saved. If the interlock is disabled, this will always return 0.

1 – The interlock was triggered at some point since the last time the register was read.
0 – The interlock was not triggered or the interlock is disabled.

Sending this command will reset the register.

INTERLOCK:FILament:ENable < 0 | 1 | OFF | ON >

This command enables or disables the Filament Emission interlock. Filament emission current is closely monitored by the instrument and adjusted to maintain a constant emission current at the setpoint. If a problem occurs that causes an interruption in the control of emission current, the instrument shuts down the filament to protect the filament and overall instrument.

If this interlock is disabled, the instrument will continue to monitor the emission current and will continue to try to maintain stability, but if a stability issue is detected, the filament will not stop emission. The instrument will continue to try to maintain a stable emission current.

This interlock guards against instrument hardware failure, so it should remain enabled. However, unstable chamber pressure may affect stability of emission current beyond acceptable limits. This interlock can be disabled but should be done only under very carefully considered circumstances.

Table 6-6 summarizes the allowed argument values for this command.

INTERLOCK:FILament:ENable?

Returns the enabled state of the Filament emission interlock. The returned value is an integer that is summarized in Table 6-6.

INTERLOCK:FILament?

Returns the triggered state of the interlock. If the Filament Emission interlock was triggered, this event is latched and the status is saved. If the interlock is disabled, this will always return 0.

1 – The interlock was triggered at some point since the last time the register was read.
0 – The interlock was not triggered or the interlock is disabled.

Sending this command will reset the register.

INTERLOCK:FILAMENTSINGLE:ENable < 0 | 1 | OFF | ON >

The resistance of the filament is regularly monitored when filament emission is enabled. When the measured resistance indicated that one half of the double filament is broken, a status bit will indicate the problem condition.

When this interlock is disabled, the resistance test for a single filament is also disabled. This does not affect emission current.

The interlock should remain enabled during normal operation, but may be disabled when intentionally using a single filament. Non-standard filament thicknesses or compositions may also trigger this interlock.

Table 6-6 summarizes the allowed argument values for this command.

INTERLOCK:FILAMENTSINGLE:ENable?

Returns the enabled state of the Single Filament interlock. The returned value is an integer that is summarized in Table 6-6.

INTERLOCK:FILAMENTSINGLE?

Returns the triggered state of the interlock. If the Single Filament interlock was triggered, this event is latched and the status is saved. If the interlock is disabled, this will always return 0.

1 – The interlock was triggered at some point since the last time the register was read.
0 – The interlock was not triggered or the interlock is disabled.

Sending this command will reset the register.

INTERLOCK:PIRANI:ENable < 0 | 1 | OFF | ON >

This command enables or disables the Pirani pressure test that is performed when starting filament emission. The Pirani pressure test is used to indicate that the chamber pressure is safe for the filament to start electron emission. It is important to use this test to be sure

the chamber pressure is low enough for filament emission to proceed. When this interlock is disabled, the Pirani pressure test is bypassed.

This interlock can be disabled if there is difficulty in starting filament emission, but only if it is confirmed through other means that chamber pressure is safe.

Table 6-6 summarizes the allowed argument values for this command.

INTERLOCK:PIRANI:ENable?

Returns the enabled state of the Pirani test interlock. The returned value is an integer that is summarized in Table 6-6.

INTERLOCK:PIRANI?

Returns the triggered state of the interlock. If the CEM protection interlock was triggered, this event is latched and the status is saved. If the interlock is disabled, this will always return 0.

1 – The interlock was triggered at some point since the last time the register was read.
0 – The interlock was not triggered or the interlock is disabled.

Sending this command will reset the register.

INTERLOCK:PROBEpresent:ENable < 0 | 1 | OFF | ON >

From power on, the instrument detects if it is connected to a probe. When not connected to a probe, a number of instrument functions are not allowed. Filament emission cannot be enabled, the CEM cannot be powered, and ion scans cannot be performed.

When this interlock is disabled, all functionality is allowed. This interlock should remain enabled to protect internal instrument hardware and external connections. Disabling this interlock should be done only under very limited circumstances where it is necessary to continue instrument functions even when the instrument is unable to detect that it is connected to a probe.

Table 6-6 summarizes the allowed argument values for this command.

INTERLOCK:PROBEpresent:ENable?

Returns the enabled state of the Probe Present interlock. The returned value is an integer that is summarized in Table 6-6.

INTERLOCK:PROBEpresent?

Returns the triggered state of the interlock. If the Probe Present interlock was triggered, this event is latched and the status is saved. If the interlock is disabled, this will always return 0.

1 – The interlock was triggered at some point since the last time the register was read.
0 – The interlock was not triggered or the interlock is disabled.

Sending this command will reset the register.

INTERLOCK:TEMPerature:ENable < 0 | 1 | OFF | ON >

The instrument continually monitors internal temperature sensors. If the sensor readings indicate excessive temperatures, instrument functions are shut down. Excessive temperatures may indicate a hardware failure or other conditions that affect the instrument's usability.

This interlock should remain enabled to guard against excessive temperatures. If this interlock is disabled, internal temperatures will continue to be monitored, but excessive temperatures will not shut down the instrument.

Table 6-6 summarizes the allowed argument values for this command.

INTERLOCK:TEMPerature:ENable?

Returns the enabled state of the Instrument Temperature interlock. The returned value is an integer that is summarized in Table 6-6.

INTERLOCK:TEMPerature?

Returns the triggered state of the interlock. If the Instrument Temperature interlock was triggered, this event is latched and the status is saved. If the interlock is disabled, this will always return 0.

1 – The interlock was triggered at some point since the last time the register was read.
0 – The interlock was not triggered or the interlock is disabled.

Sending this command will reset the register.

Instrument Setup Commands

SETUP:DEFAULT

This command loads default values for all instrument settings. The default values for instrument settings can be found in Table 6-7 in the Instrument Settings section.

SETUP:LOAD

This command can be used to revert previous user settings that have not yet been saved either through a prior `SETUP:SAVE` command or through the Autosave mechanism. This can be useful if the user made a mistake in changing some user setting but wants to return to the previous configuration.

Note: The Autosave mechanism will overwrite the previously saved user settings after some idle time. If this command is to be used, it should be done soon after the initial user setting has been changed.

SETUP:SAVE

This command will save all user settings immediately to non-volatile flash memory. This can be used to save any changes to user settings while not waiting for the Autosave mechanism to save the settings automatically. Autosave only occurs after a period of time when the RGA instrument is left idle. The Autosave timer also does not count down during any scans. This command can help ensure that any changes made will be saved.

Instrument Settings

When instrument power is applied, the RGA will load instrument settings from non-volatile memory into RAM. To start the instrument with a default list of settings, see Default Settings below.

Autosave

Changes to instrument settings are not written to non-volatile memory right away. Writing to non-volatile memory causes wear on the electronics. Any changes to persistent instrument settings will be queued up for later processing to prevent premature failure of non-volatile memory,

After a 60 second period of inactivity, the RGA will initiate an Autosave procedure. Any changes to instrument settings will then be written to non-volatile memory.

The inactivity timer is reset back to 0 when the user enters any valid command. The timer is also reset to 0 during any ion current scan.

Instrument setting changes may be saved to non-volatile memory immediately by issuing the following command:

```
SETUP:SAVE
```

Default Settings

Below is a list of all instrument settings and the command used to access the settings. Some settings are not saved to non-volatile memory. For those settings, when the instrument is powered on, the default value for that setting is loaded.

For settings stored in non-volatile memory, the setting values stored in non-volatile memory are loaded when the instrument is powered on.

To set the instrument in a known, default state, use the following command:

```
SETUP:DEFAULT
```

This command will load the default value listed in the table for all the settings below.

Setting Command	Saved to NV Memory	Default Value
IONIZER:FOCUS:VOLT	No	90 V
IONIZER:ELECTRON:VOLT	No	70 V
IONIZER:ION:VOLT	No	12 V
IONIZER:EMISsion	No	0.0
IONIZER:EMISsion:STORED	Yes	N/A
SCAN:OFFSET:FC	No	0.0
SCAN:OFFSET:CEM	No	0.0
SCAN:OFFSET:AUTO	Yes	1
SCAN:OFFSET:AVERAGE	Yes	3
QMF:TUNE:WIDTH	Yes	0.6 AMU
QMF:TUNE:AUTO:ENable	No	0
QMF:TUNE:TABLE	No	( )
SCAN:RATE	Yes	8.0 AMU/s
SCAN:MASS:INITial	Yes	1
SCAN:MASS:FINAL	Yes	MAX_MASS
QMF:MASS:LOCK	No	0
SCAN:RESolution	Yes	20
SCAN:FILTER:ENable	Yes	1
SCAN:SETTLINGtime	Yes	20 ms
IOUTput:ENable	Yes	0
IOUTput:MANual	Yes	4 mA
IOUTput:MASSreading:AMU	Yes	0
IOUTput:MAXout	Yes	20 mA
IOUTput:MINout	Yes	4 mA
IOUTput:SELection	Yes	-1 (MANUAL)
IOUTput:SELection:LOG SCAN	Yes	1
IOUTput:SELection:LOG MASS	Yes	1
IOUTput:SELection:LOG FLANGEtemp	Yes	0
IOUTput:SELection:LOG RTDtemp	Yes	0
IOUTput:SELection:LOG EMISsion	Yes	0
IOUTput:SELection:LOG PRESSURE	Yes	1
IOUTput:SELection:MAX SCAN	Yes	10000000
IOUTput:SELection:MAX MASS	Yes	10000000

IOUTput:SELection:MAX FLANGEtemp	Yes	100
IOUTput:SELection:MAX RTDtemp	Yes	100
IOUTput:SELection:MAX EMISsion	Yes	10
IOUTput:SELection:MAX PRESSURE	Yes	10000000
IOUTput:SELection:MIN SCAN	Yes	100
IOUTput:SELection:MIN MASS	Yes	100
IOUTput:SELection:MIN FLANGEtemp	Yes	0
IOUTput:SELection:MIN RTDtemp	Yes	0
IOUTput:SELection:MIN EMISsion	Yes	0
IOUTput:SELection:MIN PRESSURE	Yes	100
VOUTput:ENable	Yes	0
VOUTput:MANual	Yes	0 V
VOUTput:MASSreading:AMU	Yes	0
VOUTput:MAXout	Yes	10 V
VOUTput:MINout	Yes	0 V
VOUTput:SELection	Yes	-1 (MANUAL)
VOUTput:SELection:LOG SCAN	Yes	1
VOUTput:SELection:LOG MASS	Yes	1
VOUTput:SELection:LOG FLANGEtemp	Yes	0
VOUTput:SELection:LOG RTDtemp	Yes	0
VOUTput:SELection:LOG EMISsion	Yes	0
VOUTput:SELection:LOG PRESSURE	Yes	1
VOUTput:SELection:MAX SCAN	Yes	10000000
VOUTput:SELection:MAX MASS	Yes	10000000
VOUTput:SELection:MAX FLANGEtemp	Yes	100
VOUTput:SELection:MAX RTDtemp	Yes	100
VOUTput:SELection:MAX EMISsion	Yes	10
VOUTput:SELection:MAX PRESSURE	Yes	10000000
VOUTput:SELection:MIN SCAN	Yes	100
VOUTput:SELection:MIN MASS	Yes	100
VOUTput:SELection:MIN FLANGEtemp	Yes	0
VOUTput:SELection:MIN RTDtemp	Yes	0
VOUTput:SELection:MIN EMISsion	Yes	0
VOUTput:SELection:MIN PRESSURE	Yes	100
IINput:LOOP	Yes	0
IINput:OVERPRESSURE:ENable	Yes	0
IINput:OVERPRESSURE:THRESHOLD	Yes	12 mA
VINput:OVERPRESSURE:ENable	Yes	0
VINput:OVERPRESSURE:THRESHOLD	Yes	5 V
RTD:CORRection:SLOPE	Yes	1
RTD:CORRection:OFFSET	Yes	0 C
DEGAS:TIME	Yes	3 min
PRESsure:TOTAL:ENable	No	1
PRESsure:SENSitivity:PARTIAL	Yes	N/A
PRESsure:SENSitivity:TOTAL	Yes	N/A
TRIGger:SCAN:ENable	Yes	0
TRIGger:SCAN:MODE	Yes	0 (Level Low)
TRIGger:SOFTware:ENable	Yes	0
TRIGger:SOFTware:MODE	Yes	0 (Level Low)
GPIO:DIRection	Yes	0 (Input)
TRIGger:THRESHOLD	Yes	1.65 V
HVENable:THRESHOLD	Yes	1.65 V
GPIO:THRESHOLD	Yes	1.65 V
GPIO:EVENT:ENable	Yes	0

GPIO:FORCE	Yes	-1 (EVENT)
GPIO:LIMits:IINput:HI:ENable	Yes	0
GPIO:LIMits:IINput:HI:VALue	Yes	FLOAT_MAX
GPIO:LIMits:IINput:HYSTEResis	Yes	0
GPIO:LIMits:IINput:LO:ENable	Yes	0
GPIO:LIMits:IINput:LO:VALue	Yes	-FLOAT_MAX
GPIO:LIMits:MASSreading:HI:ENable	Yes	0
GPIO:LIMits:MASSreading:HI:VALue	Yes	FLOAT_MAX
GPIO:LIMits:MASSreading:HYSTEResis	Yes	0
GPIO:LIMits:MASSreading:LO:ENable	Yes	0
GPIO:LIMits:MASSreading:LO:VALue	Yes	-FLOAT_MAX
GPIO:LIMits:VINput:HI:ENable	Yes	0
GPIO:LIMits:VINput:HI:VALue	Yes	FLOAT_MAX
GPIO:LIMits:VINput:HYSTEResis	Yes	0
GPIO:LIMits:VINput:LO:ENable	Yes	0
GPIO:LIMits:VINput:LO:VALue	Yes	-FLOAT_MAX
GPIO:LIMits:COMM:IDLE	Yes	60 sec
RELAY:EVENT:ENable	Yes	0
RELAY:FORCE	Yes	-1 (EVENT)
RELAY:LIMits:IINput:HI:ENable	Yes	0
RELAY:LIMits:IINput:HI:VALue	Yes	FLOAT_MAX
RELAY:LIMits:IINput:HYSTEResis	Yes	0
RELAY:LIMits:IINput:LO:ENable	Yes	0
RELAY:LIMits:IINput:LO:VALue	Yes	-FLOAT_MAX
RELAY:LIMits:MASSreading:HI:ENable	Yes	0
RELAY:LIMits:MASSreading:HI:VALue	Yes	FLOAT_MAX
RELAY:LIMits:MASSreading:HYSTEResis	Yes	0
RELAY:LIMits:MASSreading:LO:ENable	Yes	0
RELAY:LIMits:MASSreading:LO:VALue	Yes	-FLOAT_MAX
RELAY:LIMits:VINput:HI:ENable	Yes	0
RELAY:LIMits:VINput:HI:VALue	Yes	FLOAT_MAX
RELAY:LIMits:VINput:HYSTEResis	Yes	0
RELAY:LIMits:VINput:LO:ENable	Yes	0
RELAY:LIMits:VINput:LO:VALue	Yes	-FLOAT_MAX
RELAY:LIMits:COMM:IDLE	Yes	60 sec
Ethernet:IP	Yes	N/A
Ethernet:LOGIN	Yes	N/A
Ethernet:PASSWORD	Yes	N/A
Ethernet:TIMEOUT	Yes	N/A
Ethernet:NAME	Yes	N/A
Ethernet:GATEWAY	Yes	N/A
Ethernet:NETMARK	Yes	N/A
Ethernet:DNS	Yes	N/A
Ethernet:CONFIG	Yes	N/A
Ethernet:DHCP:ENable	Yes	N/A
Ethernet:DISCovery:ENable	Yes	N/A
CEM:STORED:GAIN	Yes	N/A
CEM:STORED:VOLTage	Yes	N/A
CEM:STORED:MASS	Yes	N/A
CEM:VOLT	No	0
STATus:GLOBal:SERVicemask	Yes	482
STATus:EVent:ENable 0	Yes	0
STATus:EVent:ENable 1	Yes	49536
STATus:EVent:ENable 2	Yes	0

STATus:EVent:ENable 3	Yes	0
STATus:EVent:ENable 4	Yes	0
STATus:EVent:ENable 5	Yes	1
STATus:EVent:ENable 6	Yes	224
STATus:EVent:ENable 7	Yes	15
STATus:EVent:ENable 8	Yes	239
STATus:EVent:ENable 9	Yes	0
INTERLOCK:PROBEpresent:ENable	No	1
INTERLOCK:TEMPerature:ENable	No	1
INTERLOCK:PIRANI:ENable	No	1
INTERLOCK:FILament:ENable	No	1
INTERLOCK:CEMprotect:ENable	No	1
INTERLOCK:FILAMENTSINGLE:ENable	No	1
IONIZER:POTENTIALs:AUTOmode	Yes	1
ELECtrometer:CALibrate:AUTO	Yes	1
QMF:RF:SLOPE	Yes	N/A
QMF:RF:OFFSET	Yes	N/A
QMF:RF:QUADRATIC	Yes	N/A
QMF:DC:SLOPE	Yes	N/A
QMF:DC:OFFSET	Yes	N/A
QMF:DC:QUADRATIC	Yes	N/A

Table 6-7 Instrument setting default values

Chapter 7

Auxiliary I/O

This chapter describes the auxiliary I/O features of the RGA.

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Introduction

The RGA120 has interfaces for many forms of auxiliary input and output. The connections are made along terminal strips on the back panel of the instrument.

The following connections are available:

- One analog voltage input (0-10 V)
- One analog current input (4-20 mA)
- One analog voltage output (0-20 V)
- One analog current output (4-20 mA)
- One digital input (configurable GPIO pin, 3.3 V max)
- Two digital outputs (Relay output, configurable GPIO output levels 0, 3.3 V)
- One 2 to 4 wire 100 ohm Resistance Temperature Detector (RTD) interface
- One digital HV Enable input (3.3 V max)
- One digital Trigger input (3.3 V max)

Connector Pinouts

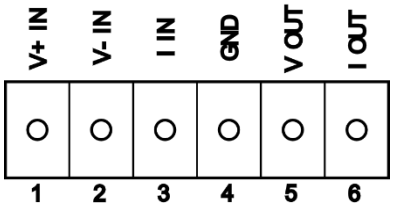

Figure 7-1 Analog Input/Output connections

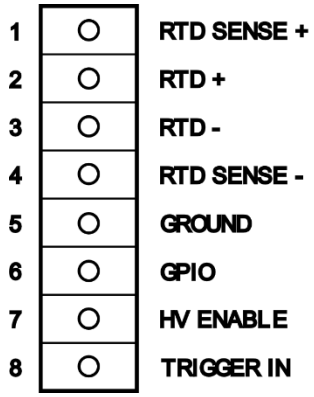

Figure 7-2 RTD/GPIO/HVEnable/Trigger connections

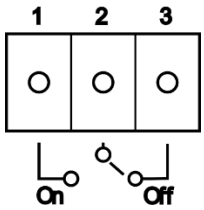

Figure 7-3 Relay connections

Pin	Signal
1	V+ Input
2	V- Input
3	I Input
4	Ground (I Input/V Output/I Out Return)
5	V Output
6	I Output

Table 7-1 Analog I/O Pinout Descriptions

Pin	Signal
1	RTD Sense +
2	RTD +
3	RTD –
4	RTD Sense –
5	Ground
6	GPIO (Input or Output)
7	/HV Enable
8	Trigger Input

Table 7-2 RTD, GPIO, HV Enable, Trigger Pinout Descriptions

Pin	Signal
1	Relay On
2	Relay Common
3	Relay Off

Table 7-3 Relay Pinout Descriptions

Terminal Strip Connectors

The RGA120 uses Phoenix Contact Combicon MC Series connections for its terminal strips. Each terminal strip is made of two pieces: a PCB soldered base strip and a detachable terminal block. Each terminal strip connector in the RGA120 comes with its terminal block inserted into the base strip.

Tip: It's usually easier to remove the terminal strip from the RGA120 before connecting wires. Unplug the terminal strip by pulling straight back from the unit. Loosen the screws before inserting the wires. Make sure to observe the correct pinouts!

The terminal blocks can accept wire sizes from 16 – 28 AWG (1.29 – 0.32 mm dia). Wires are secured by screw connection. Wires may be attached to the terminal block when it is disconnected from the base strip to simplify assembly. Make sure the wire installation is stripped back far enough to ensure good electrical contact.

Analog Input

Introduction

The RGA120 is equipped with terminal connections on the back panel to measure one analog input voltage signal and one analog input current signal. Both inputs are independent and are measured at regular intervals at all times by the instrument.

Voltage Input

The voltage input measures the differential voltage between the V+ and V- connections. The input voltage range of either of the inputs is -20 to +20 V relative to ground. The differential voltage range from (+) to (-) is -10 to +10 V. This allows measurement of signals that are biased above or below ground.

How to Use

Connect a voltage source to the RGA120 in the following configuration:

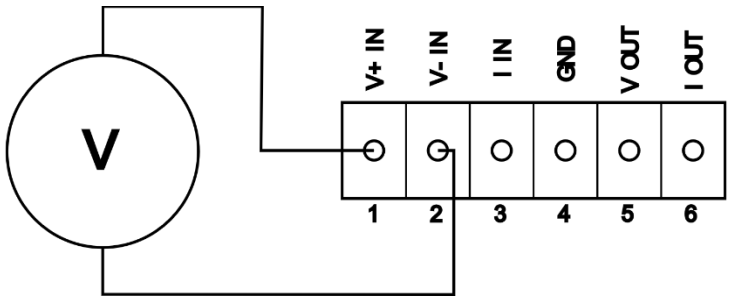

Figure 7-4 Voltage Input Connection

The RGA120 uses an internal ADC to measure the analog input voltage and makes a new measurement each 20 ms on average. Obtain a direct reading of the differential input voltage with the following command:

```
VINput:VALue?
```

The voltage is returned in units of Volts.

Current Input

The current input measures the absolute value of the current from the I Input to Ground connection. The signal can be either polarity, with a maximum of 24 mA. The voltage range at the I Input connection must be between -0.5 and + 20 V; the burden voltage is 2 V for 20 mA. The wide voltage range and low burden voltage allows for multiple sense resistors or an external power supply in series with the current loop.

How to Use

Connect a current source to the RGA120 in the following configuration:

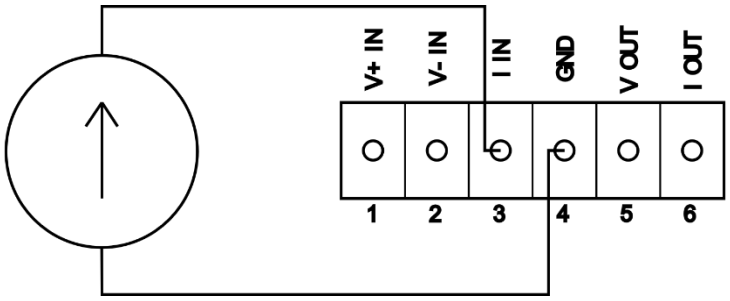

Figure 7-5 Current Input Connection

The RGA120 uses an internal ADC to measure the analog input current and makes a new measurement each 20 ms on average. Obtain a direct reading of the input voltage with the following command:

```
IIN:VALUE?
```

The value returned is in units in milliamps. Note that the value returned is the magnitude of the current regardless of the direction that current is flowing.

Note: The analog current input can operate with any current source as long as the maximum current remains below 24 mA. However, the interface is primarily meant to be used by sensors that operate in the 4-20 mA range.

For this reason, there are instrument status bits that indicate an undercurrent or overcurrent condition. Whenever the detected analog input current goes below or above the acceptable range for a 4-20 mA device, an instrument status bit is set.

Status Register	Status Bit	Description
4	3	Analog Input Undercurrent (< 4 mA)
4	4	Analog Input Overcurrent (> 20 mA)

Table 7-4 Analog Input Current Instrument Status Bits

See Instrument Status for more information regarding these status bits.

Current with Loop Power Voltage Source

Current Input with Loop Power is a special configuration of the current input mode that allow both signal and power to be transmitted over a pair of wires.

The Loop Power voltage source is ground referenced at the RGA120 and requires that the measured current returns to the Ground input. Devices that ground either current loop lead or require a floating loop power supply must use an external supply.

The maximum allowed current amplitude is 24 mA. The Loop Power supply can be set between 0 and 20 V.

How to Use

To set the Loop Power Voltage, use the following command:

```
IIN:LOOP x
```

Where x is the loop power voltage desired in Volts.

You can query the present set value of loop power voltage with the command:

```
IIN:LOOP?
```

This will return the loop power voltage in Volts.

Important: The Analog Input Current circuitry is designed to measure up to 24 mA. If internal circuitry detects an input current over 24 mA in either direction, the instrument will vary the loop power voltage in an attempt to protect the instrument from the overcurrent state.

Do not connect a voltage source or current source that would provide a current over the instrument rating! Doing so will risk damaging the internal measurement circuitry!

Important: If a problem is detected in the loop power voltage circuitry that leads to overheating, this will set a bit in the Instrument Status registers (Register 4, bit 0). See Instrument Status for more information about how to monitor and reset this status bit.

Analog Input Overpressure Protection

The RGA120 can be configured to use the Voltage Input and/or Current Input as an Overpressure detection device. Using an external voltage or current based pressure transducer, the user can program a threshold voltage or current. If the pressure transducer exceeds the threshold value, the RGA120 will consider this as an overpressure event.

When an overpressure event is detected, the RGA120 will shut down the filament and the CEM module if activated. RF and DC voltages to the rods will also be de-energized. The Overpressure LED will be lit, and an instrument status bit will be set (Register 9, bit 3 for Voltage Over Threshold, Register 9, bit 4 for Current Over Threshold). The Overpressure LED will remain lit until the status register is read. See Instrument Status for more information.

Status Register	Status Bit	Description
9	3	Analog Input Voltage Over Threshold
9	4	Analog Input Current Over Threshold

Table 7-5 Analog Input Overpressure Instrument Status Bits

To use this feature, the user must calculate the threshold voltage output that would indicate the pressure is too high. Then program the value into the RGA120:

```
VIN:OVERPRESSURE:THRESHOLD x
```

where x is the calculated threshold voltage.

To enable this feature, use the following command:

```
VIN:OVERPRESSURE:EN 1
```

Similarly, to use a current based pressure sensor, calculate the threshold current output that indicates the pressure is too high. Program this value into the RGA120:

```
IIN:OVERPRESSURE:THRESHOLD x
```

Where x is the calculated threshold current in milliamps.

Then enable this feature with:

```
IIN:OVERPRESSURE:EN 1
```

To protect against noise or other momentary electrical transient causing an overpressure event by mistake, the RGA120 must detect an input voltage or current over the threshold value for at least 400 ms.

Note that usually only one pressure sensor overpressure threshold will be programmed. However, the RGA120 can implement this feature with two independent pressure sensors, one for voltage, the other for current.

Analog Output

Introduction

There are two separate Analog Outputs: one voltage output and one current output. They can be configured to output a manually set voltage or current, or each can be linked to one of several internal instrument measurements. The output full scale ranges can be scaled to match external devices.

Voltage Output

The analog voltage output is unipolar and is ground referenced at the RGA120 and has a range of 0 to 20 V.

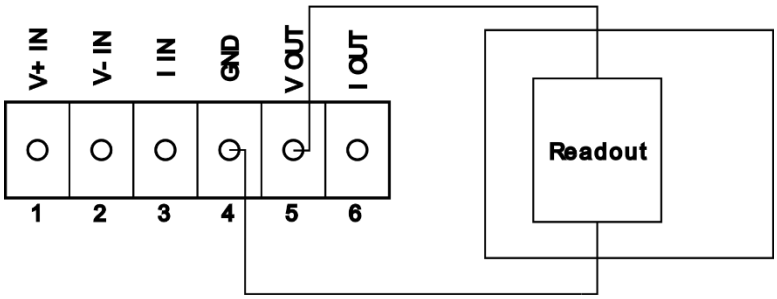

Figure 7-6 Voltage output connection

Important: When voltage output is enabled, if a problem is detected in the voltage output circuitry that leads to overheating, this will set a bit in the Instrument Status registers (Register 4, bit 1). See Instrument Status for more information about how to monitor and reset this status bit.

Current Output

The analog current output is unipolar and returns to the RGA120 ground and has a range of 0 to 24 mA. The maximum load resistance, including cable resistance, is about 800 ohms. Cable resistance can be large depending on the length and wire thickness.

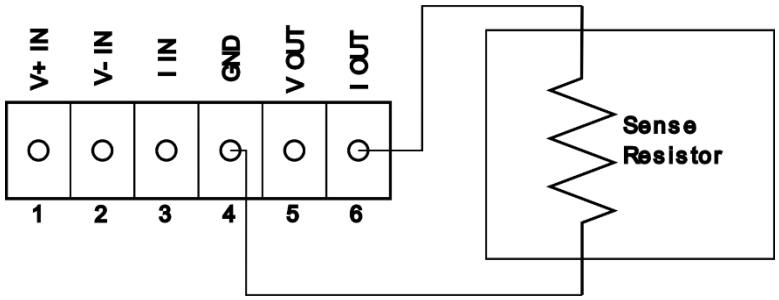

Figure 7-7 Current output connection

Note: When current output is enabled, but the output current cannot be maintained because the load resistance is too high, this sets a bit in the Instrument Status registers (Register 4, bit 2). See Instrument Status for more information about how to monitor and reset this status bit.

Enabling Analog Output

Analog output voltage and current are not always enabled. Either can be enabled or disabled by user command. As an example:

```
VOUT:EN 1
```

will enable analog voltage output. And:

```
IOUT:EN 0
```

Will disable analog current output.

As a convenience, a keyword can be used instead of the values 0 or 1. In this case, OFF will disable an analog output, and ON will enable an analog output.

Example:

```
IOUT:EN ON
```

will enable analog current output.

Analog Output Selection

The analog output, both voltage and current, can each be set to a constant value or be linked to one of several internal instrument measurements. The list of available measurements is detailed in Table 7-6.

Selection	Keyword	Description	Units
-1	CONSTANT	Constant value (manually set)	
0	SCAN	Real time analog scan ion current	10^{-16} A
1	MASS	Mass ion current	10^{-16} A
2	FLANGEtemp	Flange temperature	C
3	RTDtemp	RTD temperature	C
4	EMISsion	Emission current	mA
5	PRESSURE	Total pressure	10^{-16} A

Table 7-6 List of analog output measurement selections

Constant Setting

The analog output voltage or current can be set to a fixed constant value through a user command. First, the fixed voltage or current value should be set. Then the analog output selection should be set to manual according to Table 7-6 above. Finally, the analog output should be enabled.

For example:

```
VOUT:MANUAL 5.0
VOUT:SELECTION -1
VOUT:EN 1
```

will set the analog voltage output to 5.0 V, set the selection to constant, and then enable the voltage output. Correspondingly:

```
IOUT:MANUAL 10.0
IOUT:SELECTION CONSTANT
IOUT:EN ON
```

Will set the analog current output to 10.0 mA, set the selection to constant and then enable the current output.

Linking to Measurements

For the other analog output measurement selections, the internal measurements for each can be smoothly mapped from a user settable range of measurements between two endpoints to a user settable range of output voltage or current.

To do this, a few calculations need to be performed beforehand.

First, the overall output voltage or current range should be set based on the voltage or current sensor that will be connected to the RGA120 analog output voltage or current. For instance, if the external instrument voltage range will be 0 to 10 V, the following user commands will inform the RGA120 that the output voltage range should be fixed to the range of 0 to 10 V:

```
VOUT:MIN 0
VOUT:MAX 10
```

Similarly for current output, most current sensing devices will operate in the 4-20 mA range. The following commands will fix that output range:

```
IOUT:MIN 4
IOUT:MAX 20
```

Even though the absolute voltage and current ranges span beyond these values, any measurement selection will not provide an analog output that will exceed this set of minimum and maximum values.

Note: The measurement selection -1 or CONSTANT is not limited by the minimum and maximum values set here. A constant setting can be any value within the attainable range for output voltage and current.

Next, decide on the measurement that you wish to link to an analog output. It can be any one from the Table 7-6 above.

Example 1

As an example to illustrate how to set up the mapping, let’s choose to link the emission current to the analog voltage output.

After setting the overall voltage limits as above, we need to set the minimum and maximum emission currents that we will monitor. For this example, we will map the range 0 to 4 mA of emission current over the range 0 to 10 V as set by the commands in the previous section.

The minimum emission current to be monitored is 0 mA, and the maximum emission current to be monitored is 4 mA. This is set with the following commands:

```
VOUT:SEL:MIN 4, 0
VOUT:SEL:MAX 4, 4
```

We are setting the minimum and maximum values to 0 and 4 mA for the selection numbered 4. This selection corresponds to the emission current. The selection keyword may be used instead for more command readability

```
VOUT:SEL:MIN EMISSION, 0
VOUT:SEL:MAX EMIS, 4
```

Note that the keyword may be either the short form or the long form keyword as desired. This is denoted by either using the capitalized portion of the keyword or the whole keyword.

For any measurement link setting, the progression from minimum to maximum can go linearly or logarithmically. For this case, where the minimum value is 0, only a linear progression makes sense. Set this with the command:

```
VOUT:SEL:LOG 4, 0
```

Or:

```
VOUT:SEL:LOG EMISSION, LINEAR
```

Finally, choose the output selection with the command:

```
VOUT:SEL 4
```

With the analog output voltage enabled with the above command, the voltage output will provide a voltage that has a linear relationship as described above. With 0 mA of emission linked to 0 V and 4 mA of emission linked to 10 V, for 1 mA of emission current, you should expect a voltage output of about 2.5 V.

Example 2

As another example, we will set the analog output current to monitor the ion current detected for mass 28 (Nitrogen).

We have already set up the current output limits at the start of this section to 4 to 20 mA. So now we focus on ion current measurements. The units of measurements for ion current are in 10-16 A. The user should convert the corresponding minimum and maximum pressures for the chosen mass into the equivalent ion currents.

For instance, if the partial pressure sensitivity is 0.1 mA/Torr, and we are interested in measuring mass 28 ion current values for pressures between 10^{-10} and 10^{-6} Torr, first convert these pressure range limits to equivalent ion currents.

10^{-10} torr * 0.1 mA/Torr = 10^{-11} mA = 10^{-14} A = 100 (10^{-16} A)

10^{-6} torr * 0.1 mA/Torr = 10^{-7} mA = 10^{-10} A = 10^{6} (10^{-16} A)

We set these limits into the RGA120 as follows:

```
IOUT:SEL:MIN 1, 100
IOUT:SEL:MAX 1, 1.0e6
```

For this measurement range, it is reasonable to choose the scale to be logarithmic. To set this, use the command:

```
IOUT:SEL:LOG 1, 1
```

Or

```
IOUT:SEL:LOG MASS, LOG
```

Now any ion current will be mapped to the output current in the following way:

Ion current (10-16 A)	Output Current (mA)
<=100	4
1000	8
10000	12
100000	16
>= 1000000	20

Table 7-7 Ion current to analog output current logarithmic scaling example

One final setting must be made for this measurement link. We need to set the ion mass that we are interested in monitoring. For this measurement, the following command sets the mass:

```
IOUT:MASS:AMU 28
```

The analog current output will now scale to the mass 28 ion current. When the setting is made, the ion current is initialized to 0. The value will update each time the mass ion current is measured during any scan either analog or histogram, or during a single or multiple mass scan.

Notes on Analog Output Measurements

As noted in Example 2, in order to monitor an individual mass ion current, an additional command must be used to set the mass to be monitored. Use:

```
VOUT:MASS:AMU
```

and

```
IOUT:MASS:AMU
```

to set the mass to be monitored.

To monitor the RTD temperature, it is important to have an RTD appropriately connected to the back panel.

The total pressure ion current measurement will only be updated after a total pressure ion current measurement is made. This is done either by directly querying the total pressure with a user command or at the end of analog and histogram scans if the total pressure measurement is enabled.

The command structure allows the user to set up measurement scaling that is counterintuitive or that even makes no sense.

- The minimum and maximum voltage and current values may be opposite from each other. The maximum may be less than the output, if such a measurement scaling is desired.
- The minimum and maximum voltage and current values may be equal to each other. That only guarantees that the voltage/current output will remain constant at all times regardless of the measurement value.
- Similarly, the minimum and maximum measurement values may also be similarly set. By setting the minimum measurement value greater than the maximum value, that creates a negative scaling.
- For minimum and maximum measurement values, in order for LOG scaling to be used, the minimum and maximum measurement values must be greater than 0. If either are below 0, then the scaling is invalid and the measurement output will be stuck to the minimum output value.

The SCAN measurement selection (selection 0) allows the user to monitor all ion current measurements in real time in an analog format. The output will be scaled to the last ion current measurement of any mass. This can be used to view an ion current plot on an oscilloscope if so desired.

Note: for the SCAN measurement, the analog output has a limited slew rate. When using exceptionally fast SCAN:RATE values, this will cause the resulting analog output to be slew rate limited.

Digital Input

Introduction

There is one digital input available on the RGA120. The interface is a shared GPIO pin on the back panel of the RGA120. When configured as a digital input, the RGA120 monitors the voltage on the GPIO pin. The digital level (LOW or HIGH) can be queried by user command.

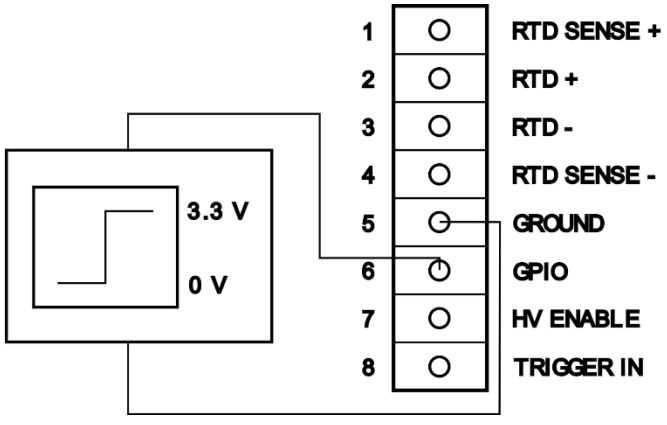

Figure 7-8 GPIO Digital input connection

How to Use

The following command configures the GPIO pin as a digital input:

```
GPIO:DIR 0
```

Similarly, a keyword argument may be used:

```
GPIO:DIRECTION INPUT
```

When configured, the RGA will monitor the voltage level of the digital input through a comparator. The threshold between LOW and HIGH is set at manufacturing time to the midpoint between these two voltages: 1.65 V. This comparator threshold may be changed with the following command:

```
GPIO:THRESHOLD x
```

Where x is the desired threshold level in Volts. The threshold may be set to any value between 0 and 3.3 V.

Note: The threshold level setting is approximate. When using GPIO as a Digital Input, make sure that the HIGH and LOW levels are appropriate for your apparatus.

Important: The voltage range for the GPIO input are limited to 0 to 3.3V. Do not exceed these voltages.

To query the digital input value from the GPIO, use the following command:

```
GPIO:VALUE?
```

The value returned will either be 0 for LOW or 1 for HIGH.

Digital Output

Introduction

The RGA120 has two digital outputs. One is through a shared GPIO pin. When configured as an output, the GPIO pin provides a digital voltage output. LOW is defined as 0 V and HIGH is defined as 3.3 V.

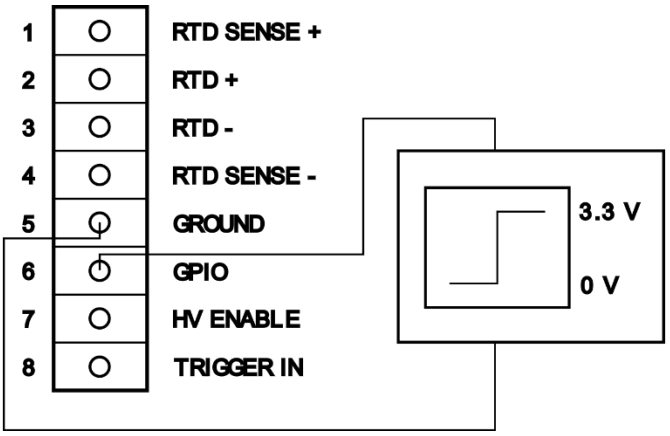

Figure 7-9 GPIO Digital Output connection

How to Use

To set the GPIO pin as an output, use the following command:

```
GPIO:DIR 1
```

Similarly, you can use the keyword parameter:

```
GPIO:DIRECTION OUTPUT
```

The second digital output is a relay connection on the back panel. The user can connect external devices to the relay output for either the off connection, the on connection or both. When the digital output level is LOW or inactive, the relay position closes the connection to pins 2 and 3. When the digital output level is HIGH or active, the relay position closes the connection to pins 1 and 2.

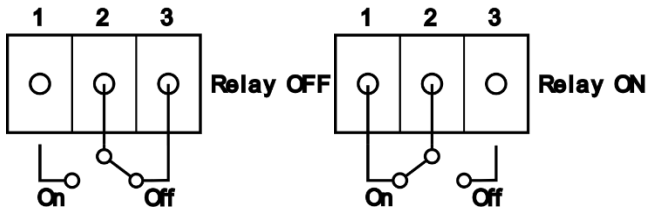

Figure 7-10 Relay Digital Output connections

Setting Digital Output Values

After the GPIO pin has been configured as an output, to set the GPIO Digital Output value to either LOW or HIGH, use any of the following commands:

```
GPIO:FORCE 0
GPIO:FORCE LOW
```

This will force the GPIO output to a LOW level, or 0 V.

```
GPIO:FORCE 1
GPIO:FORCE HIGH
```

This will force the GPIO output to a HIGH level, or 3.3 V.

Similarly, for the Relay Output, any of the following commands will directly set the relay position:

```
RELAY:FORCE 0
RELAY:FORCE OFF
```

This will force the Relay position to OFF, closing the connection between pins 2 and 3.

```
RELAY:FORCE 1
RELAY:FORCE ON
```

This will force the Relay position to ON, closing the connection between pins 1 and 2.

Digital Output Events

The Digital Outputs can also be configured to indicate the status of one or more internal measurements or events.

This mode is enabled with either of the following commands for GPIO Output:

```
GPIO:FORCE -1
GPIO:FORCE EVENT
```

For the Relay position:

```
RELAY:FORCE -1
RELAY:FORCE EVENT
```

The GPIO Output and Relay Output may be configured independently to switch to HIGH or ON respectively when the instrument has detected any combination of the following events:

Digital Output Event	Weight	Description
0	1	Service LED On
1	2	Pressure LED On
2	4	Filament Emission On
3	8	Filament Emission Off
4	16	Analog Input Voltage Beyond Limit
5	32	Analog Input Current Beyond Limit
6	64	Mass Reading Beyond Limit
7	128	Communications Idle Period
8	256	RGA Reset
9	512	Electrometer ADC Overflow
10	1024	Scan Sync Pulse

Table 7-8 Digital Output Events

The RGA120 circuitry is designed so that when more than one event is enabled for a digital output, then any one event that is enabled will cause the digital output to move

from LOW to HIGH in the case of GPIO Output, or from OFF to ON for the Relay position.

The list of enabled events can be set by individually toggling each event bit on or off as needed through a series of commands, or by setting all enabled events simultaneously in one command.

To enable or disable an individual event for a digital output, use the following command:

```
GPIO:EVENT:ENABLE x, y
```

or:

```
RELAY:EVENT:ENABLE x, y
```

x corresponds to one of the digital output events listed in the Table 7-8 above.

y corresponds to either 0 or OFF to disable an event, or 1 or ON to enable an event.

As an example, to enable the Service LED On event for the GPIO Output, the command would be:

```
GPIO:EVENT:ENABLE 0, 1
```

As another example, to disable the Filament Emission Off event for the relay position, the command would be:

```
RELAY:EVENT:ENABLE 3, OFF
```

Note: By enabling any one event, this does not disable all other digital output events. The enabled state is changed only for the event referenced in the command.

If the user would rather enabled and disable all events in one command for a digital output, the same command can be used, but with only one parameter:

```
GPIO:EVENT:ENABLE x
```

or:

```
RELAY:EVENT:ENABLE x
```

where x is the sum of the weights of the individual events that are to be enabled for that digital output. All other digital events are disabled.

As an example, if the user were to set the Relay Position to enable the Service LED On, the Pressure LED On, and the Filament Emission Off events, the following command would be used:

```
RELAY:EVENT:ENABLE 11
```

When multiple digital output events are enabled, it may be difficult to determine which event has caused the digital output to be set to HIGH or ON. For this situation, the commands:

```
GPIO:EVENT:CONDITION?
RELAY:EVENT:CONDITION?
```

will return an integer value. The value is equal to the sum of the weights of those enabled events that are presently set.

To query the condition status of an individual event, a parameter may be used.

```
GPIO:EVENT:CONDITION? x
RELAY:EVENT:CONDITION? x
```

Where x is the digital output event number in the Table 7-8 above.

The return value will be 0 for not set, and 1 for set.

Digital Output Event Configuration

Some digital output events require further configuration to make them usable as an event source.

Service LED On

Pressure LED On

These two events require no further configuration in this section. When enabled, the digital output will change state to HIGH or ON whenever the enabled event LED is lit. The digital output will revert to LOW or OFF when the enabled event LED shuts off, and no other enabled events are set

However, the circumstances for when the Service LED is lit does have further configuration which is described in the Instrument Status section.

Filament Emission On

Filament Emission Off

These two events require no further configuration in this section. When enabled, the digital output will change state to HIGH or ON when the RGA120 detects the filament emission current is greater than 0 for the Filament Emission On Event, or when the detected emission current equals 0 for the Filament Emission Off event.

Note: The two events have opposite meanings. Enabling both events will cause the digital output state to always be set to HIGH or ON. At most one of these events should be enabled for a meaningful output.

Analog Input Voltage Beyond Limit

Analog Input Current Beyond Limit

Limits may be defined for the analog input voltage and current. If the voltage or current exceed the user defined limits, a digital output where this event is enabled will be set to either HIGH for GPIO output, or ON for Relay position.

For either event type, a lower and/or an upper limit may be enabled and defined. There are many combinations of commands to set the upper/lower limits for the GPIO Output/Relay position:

```
GPIO:LIMITS:VIN:LO:VALUE x
RELAY:LIMITS:VIN:LO:VALUE x
```

Similarly for the upper limits:

```
GPIO:LIMITS:VIN:HI:VALUE x
RELAY:LIMITS:VIN:HI:VALUE x
```

In each case, the argument 'x' is the limit value in Volts.

Similar commands exist for the current input limits. For the lower limits:

```
GPIO:LIMITS:IIN:LO:VALUE x
RELAY:LIMITS:IIN:LO:VALUE x
```

And similarly for the upper limits:

```
GPIO:LIMITS:IIN:HI:VALUE x
RELAY:LIMITS:IIN:HI:VALUE x
```

For the analog input current limits, the parameter 'x' is the limit value in milliamps.

Additionally, the RGA120 allows the user to add in hysteresis into the digital output. By setting the hysteresis to a value other than 0, the digital output will remain HIGH or ON until the analog input voltage or current falls back within the limit value by an amount specified by the hysteresis setting.

The commands to set the hysteresis value are for the voltage input:

```
GPIO:LIMITS:VIN:HYSTERESIS x
RELAY:LIMITS:VIN:HYSTERESIS x
```

The parameter 'x' is in units of Volts.

For the current input:

```
GPIO:LIMITS:IIN:HYSTERESIS x
RELAY:LIMITS:IIN:HYSTERESIS x
```

The parameter 'x' is in units of milliamps.

Hysteresis is used to reduce the amount of 'clatter' in the digital output level when the analog input readings are close to either the lower or upper limits. In such cases, especially with a noisy input, successive readings may be over or under the set limits. With no hysteresis, the GPIO output level would switch rapidly between LOW and HIGH, or the Relay would switch repeatedly between OFF and ON. If the GPIO output is used to control some external instrumentation, the excessive switching would cause unnecessary mechanical wear.

As an example of how hysteresis works, consider a situation where one wants to set the Relay position to ON when the voltage exceeds 10.0V, but the event is reset when the voltage falls back below 9.5V.

The following commands would perform this task:

```
RELAY:LIMITS:VIN:HI:VALUE 10
RELAY:LIMITS:VIN:HYSTERSIS 0.5
```

In this case, with hysteresis set to 0.5V, the digital output event is set when the analog input voltage exceeds 10 V, and is reset when the digital output voltage falls below 9.5 V.

As another example, consider a situation where one wants to set the GPIO Output to HIGH when the analog input current falls below 5 mA. But the GPIO Output falls to LOW only when the analog input current rises back above 6 mA:

```
GPIO:LIMITS:IIN:LO:VALUE 5
GPIO:LIMITS:IIN:HYSTERESIS 1
```

In this case, with hysteresis set to 1 mA, the digital output is set to HIGH when the analog input current falls below 5 mA, and is reset back to LOW when the input current rises back above 6 mA.

Finally, the following commands enable the upper or lower limit as necessary:

```
GPIO:LIMITS:VIN:HI:ENABLE x
GPIO:LIMITS:VIN:LO:ENABLE x
RELAY:LIMITS:VIN:HI:ENABLE x
RELAY:LIMITS:VIN:LO:ENABLE x

GPIO:LIMITS:IIN:HI:ENABLE x
GPIO:LIMITS:IIN:LO:ENABLE x
RELAY:LIMITS:IIN:HI:ENABLE x
RELAY:LIMITS:IIN:LO:ENABLE x
```

where the parameter ‘x’ is 0 or OFF to disable the limit, and 1 or ON to enable the limit.

Mass Reading Beyond Limit

A digital output event can be defined for upper and lower limits for a specified mass ion current. When this digital output event is enabled, the RGA120 will base the setting of this event on the last measured value of the ion current for the specified mass. This mass ion current measurement may come from an analog or histogram scan, or from a single or multiple mass measurement.

The mass is specified with the following command:

```
GPIO:LIMITS:MASS:AMU x
RELAY:LIMITS:MASS:AMU x
```

where x is the specified mass in AMU.

A lower and/or an upper limit may be enabled and defined. The commands to set the upper/lower limits for the GPIO Output/Relay position:

```
GPIO:LIMITS:MASS:LO:VALUE x
RELAY:LIMITS:MASS:LO:VALUE x
```

Similarly for the upper limits:

```
GPIO:LIMITS:MASS:HI:VALUE x
RELAY:LIMITS:MASS:HI:VALUE x
```

For the mass ion current limits, the parameter 'x' is the limit value in units of 10^{-16} A.

This digital output event also allows a setting for hysteresis. By setting the hysteresis to a value other than 0, the digital output will remain HIGH or ON until the mass ion current falls back within the limit value by an amount specified by the hysteresis setting.

The commands to set the hysteresis value are:

```
GPIO:LIMITS:MASS:HYSTERESIS x
RELAY:LIMITS:MASS:HYSTERESIS x
```

The parameter 'x' is in units of 10^{-16} A.

To enable either lower or upper limit, use the following commands:

```
GPIO:LIMITS:MASS:HI:ENABLE x
GPIO:LIMITS:MASS:LO:ENABLE x
RELAY:LIMITS:MASS:HI:ENABLE x
RELAY:LIMITS:MASS:LO:ENABLE x
```

where the parameter 'x' is 0 or OFF to disable the limit, and 1 or ON to enable the limit.

Communications Idle

This digital output event is set when the RGA120 has detected that all remote interfaces have been idle for a set period of time. This can be used to notify an external instrument that communication has been lost and must be restored.

The communication idle time can be set using the command:

```
GPIO:LIMITS:COMM:IDLE x
RELAY:LIMITS:COMM:IDLE x
```

where x is the parameter in seconds.

Once communication is detected on any remote interface (RS-232. USB, or Ethernet), the digital output event is reset and the time resets to 0.

RGA Reset

If by some chance the RGA is reset, either through an internal watchdog software failure, or by a power cycle or other reset event, this event is set. If this digital output event is

enabled, the GPIO output will be set to HIGH or the Relay position will be set to ON for a period of 30 seconds. After 30 seconds has expired, the digital output event is reset automatically.

Electrometer ADC Overflow

This digital output event requires no further configuration. This event is set in the unlikely event the electrometer ADC encounters a voltage that exceeds the full scale input voltage. The event will reset once the electrometer ADC returns a value below full scale input voltage.

Scan Sync Pulse

This digital output event requires no further configuration. This event is set at the start of an analog or histogram scan when the first mass ion current is reported by the instrument. The event is then reset when the next mass ion current is reported by the instrument.

This event can act as a scan sync pulse to indicate to an external device that a new scan has been started.

RTD Input

Introduction

The RGA has terminal connections on the back panel that can be used to connect a 100 Ω Pt Resistance Temperature Detector (RTD) (100 Ω at 0 °C). When connected appropriately, the RGA will convert the resistance detected into a temperature and the temperature is available as a measurement from the RGA.

Note: The RGA uses the DIN/IEC 60751 (IEC751) standard which requires the Pt RTD to have an electrical resistance of 100 Ω at 0 °C and a temperature coefficient of resistance (TCR) of 0.00385 Ω/°C between 0 and 100 °C. Class A RTDs have a temperature tolerance of ±(0.15 + 0.002*T) °C or 100.00 ± 0.06 Ω at 0 °C. Only 100 Ω RTDs are supported. Connecting any other RTD or device will not give satisfactory results.

The RTD can be connected in one of 4 different configurations:

2-wire

If the RTD probe has only two wires, connect them to the back panel RTD connected to pins 2 and 3:

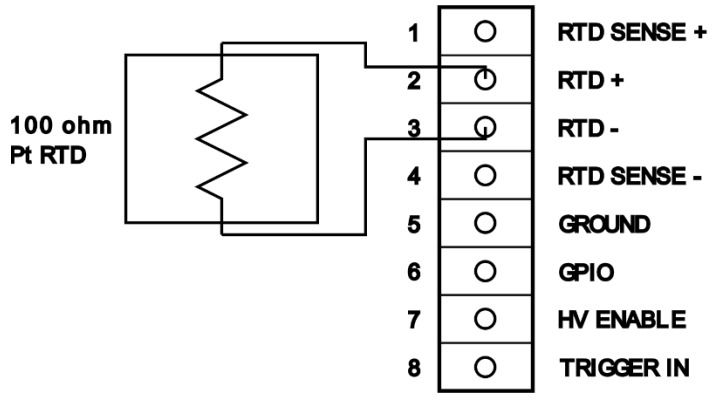

Figure 7-11 2-wire RTD connection

This connection is allowed, but will provide the least accuracy. For the purposes of calculating the probe resistance, and thus its temperature, the lead resistance on both ends is assumed to be 0.25 Ω each. For 2-wire probes where the lead resistance is significantly different, this will result in a slight inaccuracy in reported temperatures.

3-wire, Sense+

3-wire, Sense-

Some RTDs have three wires. In this case, consult the RTD manual to determine the function of each wire. Connect the RTD in the configuration recommended to the RGA back panel as below:

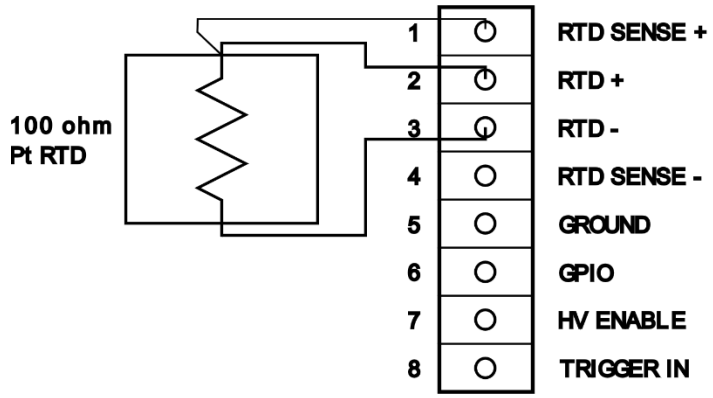

Figure x: 3-wire RTD connection, with connection to Sense+

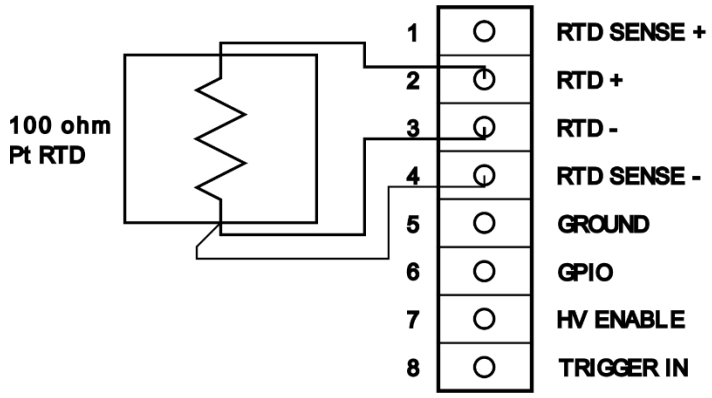

Figure 7-12 3-wire RTD connection, with connection to Sense-

In this case, the accuracy is improved by including one sense wire connection. This allows direct measurement of the resistance of the lead connecting to the RGA. The resistance of the other lead is assumed to be equal to the resistance of the connected sense wire.

4-wire

Some RTDs have 4 wires. This configuration gives the best accuracy for temperature measurements. Connect the RTD to the back panel as below:

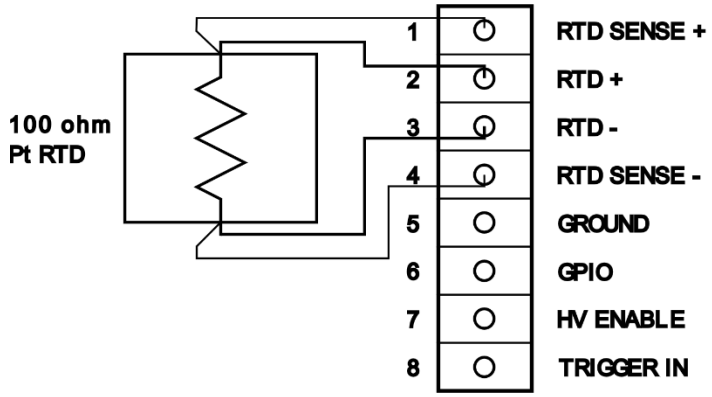

Figure 7-13 4-wire RTD connection

In this configuration, the RGA can measure the resistance of both leads of the RTD.

Connection and RTD Status

After determining the configuration necessary for an RTD probe, connect it to the RGA using the appropriate connection diagram above.

The RGA continuously monitors the voltages at each of the 4 connections. The RGA auto-selects the configuration that is used and can report the measured RTD resistance and temperature.

To query the RGA input status, use the following command:

```
RTD:STATUS?
```

This will return one of the following status results:

Result	Description
1	2-wire connection detected
2	3-wire connection with Sense+ wire detected
3	3-wire connection with Sense- wire detected
4	4-wire connection detected
-1	RTD ADC Error
-2	RTD Negative Voltage Error
-3	RTD Not Connected
-4	RTD Sense Wire Swapped
-5	RTD Negative Resistance Error

Table 7-9 RTD Status Results

Result values with a positive value indicate that a successful measurement can be made for the RTD resistance and will convert the measured resistance into a temperature.

Result values with a negative value indicate some problem with the RTD connection or with internal measurement circuitry.

When there is a problem with the detected RTD connection, an Instrument Status bit will be set (Register 4, bit 5). See Instrument Status for more information.

RTD Error Statuses

RTD ADC Error

The RGA reports that the ADC used to measure the voltages at each of the RTD connections is not operating correctly. This may indicate an internal problem with the RGA. Check your RTD connections and try again. If the error persists, try power-cycling the RGA.

RTD Negative Voltage Error

The RGA uses positive internal voltage sources relative to the RGA ground. The RTD is expected to be a passive device, so no negative voltages are ever expected. This error may indicate that a device other than an RTD is connected. Please check the connections and make sure that only an RTD is connected to the RTD input pins. Do not ground any unused pins or connect them to another device.

RTD Not Connected

The RGA does not detect any appropriate RTD device connected to the RTD+ and RTD- pins. This is the normal status when no RTD is being used. If you do not expect this status, make sure that an appropriate 100 Ω RTD device is connected to the RTD+ and RTD- pins.

RTD Sense Wire Swapped

The RGA has detected that one or both sense wires are connected to the wrong RTD Sense pin. To fix this, disconnect the sense wires from the RGA and connect them to the opposite sense pin.

RTD Negative Resistance

The RGA has detected that the voltage measurements at each of the RTD input pins would yield a negative resistance. Check your RTD connections and try again. Make sure to connect only a 100 Ω RTD to any of the RTD input pins.

RTD Resistance

To obtain the latest measurement of the RTD resistance, use the following command:

```
RTD:RESISTANCE?
```

The value reported will be in Ω.

If there is a problem with the detected RTD connection, the reported value for the resistance will be -1000.0.

RTD Temperature

To obtain the latest measurement of the RTD temperature, use the following command:

```
RTD:TEMPERATURE?
```

The value reported will be in °C.

If there is a problem with the detected RTD connection, the reported value for the temperature will be -1000.0.

RTD Temperature Correction

The RGA expects the connected RTD to follow a temperature to resistance relationship described by the Callender-Van Dusen Equation:

$$R(T) = R0 \cdot [1 + A \cdot T + B \cdot T^2 + C \cdot (T - 100) \cdot T^3]$$

Where:

R0 = Resistance at 0 °C
T = Temperature in °C
A = 3.9083×10^{-3} °C^{-1}
B = -5.775×10^{-7} °C^{-2}
C (T < 0 °C) = -4.183×10^{-12} °C^{-4}
C (T > 0 °C) = 0 °C^{-4}

The RGA inverts this equation to calculate the temperature from the measured RTD resistance. This should provide accurate readings within a range from -200 to +650 °C.

However, an additional correction factor is available for instances where the temperature measured by the RGA deviates from user expectation. In this case, the following commands can be used to tweak the results from the above calculation:

```
RTD:CORRECTION:SLOPE x
RTD:CORRECTION:OFFSET x
```

The slope factor value is °C/°C or effectively unitless. The offset factor units are in °C.

The temperature reported by the RGA for the measured RTD resistance will be adjusted in the following way:

$$T_{corrected} = Slope \cdot T_{calculated} + Offset$$

To eliminate any correction from being done, use a slope factor of 1.0 and an offset factor of 0.0.

HV Enable Input

Introduction

The RGA has an input that can be used as a signal to shut down high voltage components in the RGA. This can be used as a safety measure in case there is a problem with the apparatus in which the RGA is installed.

How to Use

The input has a pull-up resistor so when there is no connection, the HV Enable line remains HIGH and the high voltage remains enabled.

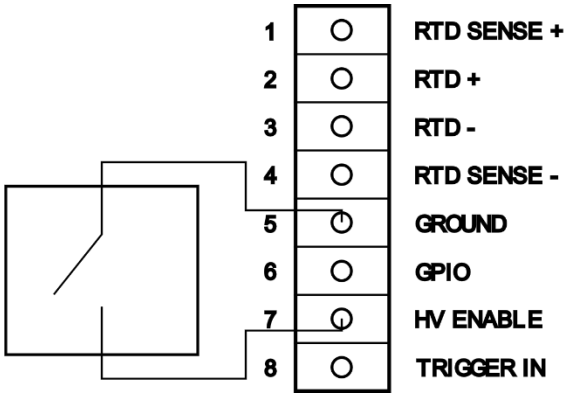

Figure 7-14 Switch connection to HV Enable

By driving the voltage on the HV Enable pin to 0V relative to RGA Ground, the RGA will shut off the following internal components:

- Filament will be shut off
- CEM will be shut off.
- RF and DC voltages to the probe rods will be set to 0
- Repeller, grid, and focus plate voltages will be set to 0

In addition, an Instrument Status bit will be set which will notify the user that this signal has been detected (Register 8, bit 4). See Instrument Status for more information.

When the HV Enable line is brought above the threshold voltage or released to high impedance, the Repeller, grid and focus plate potentials will be restored if appropriate. The probe focusing voltages, the filament, and the CEM will remain off. User commands are necessary to restart the filament and CEM. RF/DC probe focusing voltages will be set as needed during a scan process.

Voltage Threshold

The HV Enable pin acceptable voltage range is 0 to 3.3 V relative to RGA Ground. The threshold voltage between HIGH and LOW can be changed with the following command:

```
HVENABLE:THRESHOLD x
```

Where x is the desired threshold value in Volts.

Note: The comparator threshold value is approximate. To best use this input to disable the high voltage, it is only necessary to connect the HV Enable pin to the ground pin using a switch.

Trigger Input

Introduction

The RGA has an external trigger pin. The allowed voltage range on the trigger pin is 0 to 3.3 V relative to RGA ground. The trigger pin can be used in two contexts:

- Hardware scan trigger
- Software pollable trigger

Below is the basic connection diagram for using the RGA external trigger pin.

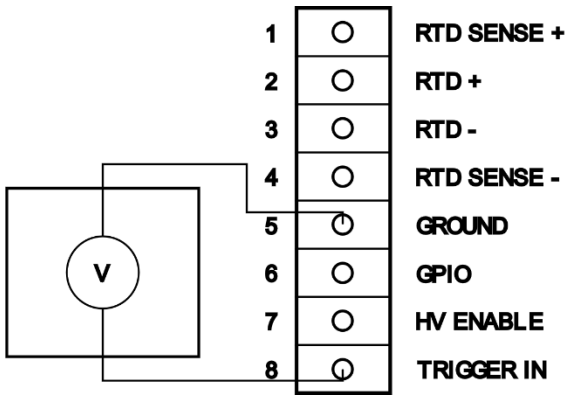

Figure 7-15 External Trigger connection

Voltage Threshold

The Trigger input pin acceptable voltage range is 0 to 3.3 V relative to RGA Ground. The threshold voltage between HIGH and LOW can be changed with the following command:

```
TRIGGER:THRESHOLD x
```

Where x is the desired threshold value in Volts.

Note: The comparator threshold value is approximate. It is best to set the threshold value halfway between the two voltage limits of your voltage source.

Trigger Level

The present trigger input pin level (LOW or HIGH) can be queried with the following command:

```
TRIGGER:VALUE?
```

A value of 0 indicates the trigger input voltage is below the threshold voltage. A value of 1 indicates the trigger input voltage is above the threshold voltage.

Hardware Scan Trigger

When used as a hardware scan trigger, the trigger pin can be configured to start an analog or histogram scan, or a single or multiple mass measurement only when the trigger condition is met.

Once a scan or mass measurement command is sent, the initial preparations for the scan are performed. However, the start of the mass ion current measurements will be held off until a trigger is detected.

To enable the hardware scan trigger, use the following command:

```
TRIGGER:SCAN:ENABLE x
```

To enable the scan trigger, the parameter x should be 1 or ON.

To disable the scan trigger, the parameter x should be 0 or OFF.

The scan trigger condition is set with the following command:

```
TRIGGER:SCAN:MODE x
```

The parameter, x, can be one of the following. Either the numeric value or the keyword may be used.

Trigger Mode	Value	Keyword
Level Low	0	LOW
Level High	1	HIGH
Edge Low to High	2	RISING

Edge High to Low	3	FALLING

Table 7-10 Hardware scan trigger modes

When enabled, and a scan command is sent, the trigger modes listed above will start a scan on the following conditions:

Level Low – The scan begins when the trigger voltage level is below the threshold voltage.

Level High – The scan begins when the trigger voltage level is above the threshold voltage.

Edge Low to High – The scan begins when the trigger voltage transitions from below the threshold voltage to above the threshold voltage.

Edge High to Low – The scan begins when the trigger voltage transitions from above the threshold volage to below the threshold voltage.

Note: The trigger resolution is on the order of 1 ms.

Software Trigger

The trigger input pin can also be used as part of a software pollable trigger. This can be used as part of a trigger state machine for an external device.

The software trigger emulates the trigger state diagram below:

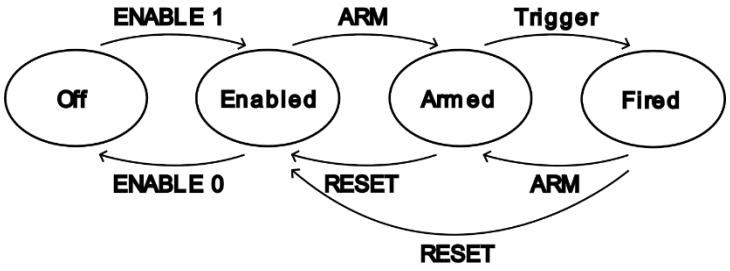

Figure 7-16 Software trigger state diagram

To enable the software trigger, use the following command:

TRIGGER:SOFTWARE:ENABLE x

To enable the software trigger, the parameter x should be 1 or ON.

To disable the software trigger, he parameter x should be 0 or OFF.

The software trigger condition is set with the following command:

TRIGGER:SOFTWARE:MODE x

The parameter, x, can be one of the following. Either the numeric value or the keyword may be used.

Trigger Mode	Value	Keyword
Level Low	0	LOW
Level High	1	HIGH
Edge Low to High	2	RISING
Edge High to Low	3	FALLING

Table 7-11 Software trigger modes

When enabled, the software trigger must then be armed with the following command:

```
TRIGGER:SOFTWARE:ARM
```

Once armed, the RGA will scan for the trigger condition for the mode selected.

When the trigger condition is detected, the software trigger will change to the Fired state.

Trigger conditions:

Level Low – The trigger will be in the fired state when the trigger voltage level is below the threshold voltage.

Level High – The trigger will be in the fired state when the trigger voltage level is above the threshold voltage.

Edge Low to High – The trigger will be in the fired state when the trigger voltage transitions from below the threshold voltage to above the threshold voltage.

Edge High to Low – The trigger will be in the fired state the trigger voltage transitions from above the threshold volage to below the threshold voltage.

The RGA can be queried to determine if the trigger has fired with the following command:

```
TRIGGER:SOFTWARE:FIRED?
```

The command will return 0 if the trigger has not fired and 1 if the trigger has fired.

The software trigger may be reset back to the enabled state with the following command:

```
TRIGGER:SOFTWARE:RESET
```

Lastly, the present state of the software trigger can be queried with the following command:

```
TRIGGER:SOFTWARE:STATE?
```

The command will return one of the following values:

Value	State
0	Off

1	Enabled
2	Armed
3	Fired

Table 7-12 Software trigger states

Note: The software trigger conditions are monitored by the RGA and updated at a rate of about 1 ms.

Chapter 8

RGA Tuning

This chapter describes the tuning procedures needed to calibrate the RGA and assure accurate qualitative and quantitative measurements.

WARNING!

The Tuning procedures described in this chapter should be performed by qualified personnel only. A mistuned RGA could give Erroneous Readings until it is retuned properly.

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Introduction

Accurate qualitative and quantitative partial pressure measurements can only be assured by proper tuning of the RGA.

Correct calibration of the mass scale is essential during qualitative analysis for the correct assignment of mass numbers to the different peaks.

The mass resolution of the quadrupole mass filter, $\Delta m_{10\%}$, must be kept at or under 1 amu to avoid severe overlap between adjacent peaks. Changes in $\Delta m_{10\%}$ during the measurements (caused by aging, severe contamination and large temperature changes) will cause variations in the sensitivity of the instrument and the shapes of the fragmentation patterns of the molecules, seriously affecting all quantitative measurements.

For careful quantitative analysis, it is important that the sensitivity of the RGA be determined for every gas which may be a component of the system and under the same operating parameters used during the actual measurements. Sensitivity factors change as a factor of time due to aging and periodic recalibration is necessary.

The gain of the electron multiplier is mass dependent and needs to be determined prior to performing measurements with the device. The gain characteristics of the multiplier change with time and periodic recalibrations are very important.

The following sections of this chapter describe several tuning procedures designed to assure that all the calibration conditions described above are satisfied prior to a set of partial pressure measurements. All tuning procedures can be executed from RGASoft using a set of Tuning Commands built into the program. The RGA On-line Help files provide all the information necessary to set up and execute the tuning commands. Users writing their own programs can implement the procedures themselves, using the RGA Command Set and the instructions of this chapter.

All the tuning procedures require the ability to introduce pure gases (or a mixture of gases of known composition) into the vacuum system, and a way to measure or calculate pressures. Bayard-Albert gauges are often used to measure the pressure of the calibration gases. Hot cathode gauge displays are usually calibrated for a single gas (N_2 or Ar) and a table of conversion factors will be needed to convert the readings for other gases.

When only a few choices of calibration gases are available choose those that are most likely to be encountered during measurements (i.e. usual major components of the residual gas environment of the chamber) and try to sample as much of the RGA's mass range as possible. Obviously, the correct gases will be needed for sensitivity factor and fragmentation factor determinations.

Important: Tuning should only be attempted after the unit has been warmed up (with the filament on and under typical operating conditions) for at least one complete hour.

Tuning Options

The different tuning procedures, including the corresponding RGASoft commands, are listed in the following table:

Tuning Procedure	RGASoft Command (a)	Options
Peak Tuning	Peak Tuning	Peak Position Peak Width
Sensitivity Tuning	Sensitivity Tuning	Partial Pressure Total Pressure
Electron Multiplier Tuning	CEM Tuning	Gain adjustment

(a) Probe menu command options.

Consult the RGASoft chapter of this manual and the RGA On-line Help files included in the program disks for information on the execution of the Tuning Commands built into the program.

Peak Tuning Procedure

Introduction

When analyzing a sample, you expect the peaks of the different gases to be displayed at their correct mass-to-charge ratio values and the peak widths to be less or equal than 1 amu at 10% of peak height. The correct location of the peaks is essential for accurate qualitative analysis, and unity resolution ($\Delta m_{10\%}$=1 amu) minimizes the overlap between adjacent peaks. Both the calibration of the mass scale and the widths of the peaks can vary with time due to aging of the RGA components. Changes in resolution are particularly serious since they affect the sensitivity of the RGA and introduce errors in the partial pressure measurements.

The Peak Tuning procedures described in this section allow the user to calibrate the mass scale and the resolution, $\Delta m_{10\%}$, of the mass spectrometer. The SRS RGA has a very solid design and this type of tuning procedures should rarely be needed.

WARNINGS

The peak tuning procedures should be performed by qualified personnel only. A mistuned RGA will give Erroneous Readings until it is retuned properly.

Peak Tuning should only be attempted after the unit has been warmed up (with the filament on and under typical operating conditions) for at least a one hour.

Peak Tuning requires a mixture of gases whose mass spectra is well known. In general, a two gas mixture, one with **low mass** peaks and one with **high mass** peaks, is sufficient. The sample is introduced into the vacuum, and the quadrupole mass filter parameters, referred to as Peak Tuning parameters, are adjusted based on the sample analog spectra. The mass scale is adjusted so that all peaks are displayed at their correct mass-to-charge values, and the peak widths, $\Delta m_{10\%}$, are adjusted to unity (or smaller) values. The two tuning procedures are referred to as **Peak Position and Peak Width Tuning**, respectively.

Note: A mixture of He, Ar, Kr and Xe inert gases is used at SRS to Peak Tune the RGA's. The resolution is adjusted to 1 amu and peak tuning parameters are saved into the RGA before shipping. The inert gases cover a broad spectral range, and being inert they do not interact with the RGA probe and do not contribute to its aging.

Peak tuning can be easily performed with **RGASoft** using the Peak Tuning command of the Probe Menu.

An extra copy of the tuning parameters determined at the factory for the mass filter is saved in the RGA before shipping, and those values can be retrieved at any time in case they are necessary. Consult the RGASoft chapter of this manual or the RGA On-line Help Files included with the program for details.

In case it is necessary to reload the factory measured tuning parameters for the RGA, use the following command:

```
QMF:TUNE:FACTORY:LOAD
```

Note: If this command is used, the tuning parameters that are loaded are for the probe module that is paired with this specific RGA electronics module. The tuning parameters should provide analog scans that are close to the expected nominal performance at the time of calibration. However, changes in component performance due to aging or temperature fluctuations may require further tuning using the procedure outlined below to provide optimal scan performance.

Important: If the RGA electronics module has been moved to a different probe module, there is no guarantee that loading the factory measured tuning parameters will provide acceptable scan results. However, it may be possible to refine the tuning parameters using the procedures in this section to optimize the scan performance.

Tip: Virtually every vacuum system will have detectable amounts of hydrogen (2 amu), water (18 amu), carbon monoxide (28 amu) and carbon dioxide (44 amu). Become familiar with these species and their fragmentation patterns, and use their peaks to quickly verify the correct performance of the instrument (i.e. mass scale calibration and mass resolution) while operating the RGA.

Tuning Procedure Notes

Peak tuning requires a mixture of gases with a varying number of mass-to-charge ratios. Ideally, the masses for each gas are spread over the mass range of interest. For example, if measurements are to be made up to mass 100, then a mixture of gasses with a mass number ranging from a low value up to near 100 should be used.

If a higher mass range is to be measured during analysis, it is best to include a gas in the higher mass range for tuning purposes. The tuning procedure will optimize the tuning parameters for the range of masses that are used in the procedure.

Several analog scans are performed on the sample and the peak positions and widths are checked and adjusted as necessary. Changes in resolution affect the sensitivity of the RGA, and a Sensitivity tuning procedure should always be performed at the end of the peak tuning process.

For the tuning procedure to be successful, data from analog scans should already provide recognizable partial pressures from the gas species to be calibrated. An analog scan taken over the range to be calibrated should yield peaks that are within a few amu of the correct mass, and the peak shapes should also be recognizable as measurements coming from the expected mass numbers. If such is not the case, you may be required to load in the factory tune parameters using the command mentioned above to have a good starting point for this procedure.

The entire procedure can be carried out with the help of the Peak Tuning command (Probe Menu) of RGASoft. The program guides you through the calibration procedure and automatically updates the Peak Tuning Parameters in the RGA based on the results of the calibration.

If RGASoft is not available to help perform the tuning procedure, then the following procedure can be used to measure the new RF/DC tuning parameters.

Tuning Procedure

Introduce a sample of the gas that will be used to calibrate the tuning parameters. Include enough gas such that each mass number to be calibrated can be detected in an analog scan. It is important that the gas pressure for each mass is well above the noise floor so that the RGA can measure the presence of the gas.

Make a note of the mass numbers of each gas to be used in the calibration. Two is the minimum number that can be used for a successful calibration. However, up to ten mass numbers can be included in the calibration list.

The mass numbers must follow this list of restrictions:

- Each mass number to be calibrated must be separated by at least 3 amu.
- Each mass number in the calibration list must have a significantly higher partial pressure over a range of +/- 2 amu around that mass number. For example, if mass 28 is included in the list, the partial pressure of mass 28 must be greater than mass 26, 27, 29, and 30. This is so that the tuning algorithm does not get confused between a mass peak you are calibrating and another nearby mass peak.

Note: This may be important for some mass values such as water at 18. Depending on the circumstances of your apparatus, there may be strong partial pressure values from masses 16, 17, 19, or 20. In such cases, where there is no clear peak from a gas species at a known gas value, avoid including mass numbers from this and similar mass ranges.

When the list of mass numbers is known, use the following command to set the mass table in the RGA:

QMF:TUNE:TABLE (m_1, m_2, …, m_n)

Replace the parameter labels m_1, m_2, etc with the integer mass values to be used in the calibration. A minimum of 2 mass numbers are necessary and up to 10 mass numbers can be included in the list. Remember to separate each mass by commas and to enclose the entire argument in a set of parentheses.

Example: to perform an RF/DC auto-tuning procedure over ion current peaks at masses 28, 32, 40, and 44, use the following command:

```
QMF:TUNE:TABLE (28, 32, 40, 44)
```

Make a preliminary analog scan over the entire mass range to be calibrated. The range for the scan should be extended in both directions by at least 3 amu. For example, if the mass table includes mass numbers starting at mass 14 and ending at mass 84, set the scan limits for mass 11 and mass 87.

```
SCAN:MASS:INITIAL 11
SCAN:MASS:FINAL 87
```

Perform an analog scan and analyze the results

```
SCAN:ANALOG?
```

If each mass peak that is included in the table above is visible in a region close to the expected mass value, proceed to the next step. If the mass peak is not visible, there are a few steps that can be taken to help with the calibration.

Increase the amount of gas that is used for calibration so that the mass peak is visible. If taking this approach, make sure that the chamber pressure is not increased above the recommended pressure for normal operation.

Slow the scan rate. This will lower the overall noise floor of the analog scan, but will increase the time to perform each iterative step.

To get the present scan rate, use the command:

```
SCAN:RATE?
```

This will return the rate that analog scans are being measured from the RGA in AMU / s. Set a lower value with the following command:

```
SCAN:RATE x
```

where x is the new scan rate to be used. This will reduce the noise floor. Then repeat the analog scan.

When a preliminary analog scan is acceptable, enable the tuning procedure with the following command:

```
QMF:TUNE:AUTO:ENABLE 1
```

or

```
QMF:TUNE:AUTO:ENABLE ON
```

This command will enable the RGA auto-tuning algorithm. At this stage, after each analog scan is completed, the RGA will analyze the analog scan and adjust the RF/DC tuning parameters to bring the mass values in the mass table to the correct position and resolution for the next analog scan.

Run multiple analog scans. The RF/DC tuning parameters will be adjusted a small amount towards the goal each time. This avoids any overcorrection that may be caused by a misinterpretation of analog scan ion current measurements.

When the analog scan ion current values have approached the desired position and resolution, the auto-tuning feature may be turned off with the following command:

```
QMF:TUNE:AUTO:ENABLE 0
```

or

```
QMF:TUNE:AUTO:ENABLE OFF
```

Variable Mass Peak Width

The RF/DC auto-tune procedure adjusts tuning parameters to center a mass peak on the integer mass value that is listed in the mass table. The width of the mass peak is adjusted, by default, so that $\Delta m_{10\%}$=1 amu. This expected mass peak shape is approximately equal to $\Delta m_{50\%}$=0.6 amu. That is, the ion current at 0.6 amu from the peak center will have an amplitude of 50% of the ion current at the peak.

The peak width can be changed if desired. For additional sensitivity to low concentrations of ion masses, the peak width may be widened. This tuning allows more ions into the detector. However, the peak widths can bleed into neighboring mass numbers. This may

obscure or deform the mass peaks if there are measurable ion currents in neighboring mass values.

The peak width may also be narrowed for more resolution. This pinches off the focus into aperture to allow fewer ions of a given mass into the detector. However, the added resolution when the peaks are narrowed can allow for measurements of peaks that are very close to each other, such as when the mass-to-charge ratios may be a non-integer value.

The goal peak width for the RF/DC auto-tuning procedure can be changed with the following command:

```
QMF:TUNE:WIDTH x
```

where x is the goal peak width. By default, the width is 0.6. The auto-tuning algorithm limits the range of acceptable peak widths from 0.3 to 1.5. A value lower than 0.3 may cause the tuning procedure to accidentally pinch off all ion current, which would cause the tuning procedure to fail. A value larger than 1.5 causes the peaks to be too broad and difficult to center on an integer mass value.

To query the peak width that is used by the auto-tuning procedure, use the following command:

```
QMF:TUNE:WIDTH?
```

This returns the goal peak width for the RF/DC procedure, that is, the distance away in mass from the peak where the ion current is 50% of the ion current at the peak.

Auto-tuning Results

After each tuning step, the RGA can be queried for the results of the tuning procedure with the following command:

```
QMF:TUNE:RESULTS?
```

The command returns details on the measured peak position and width for each mass value in the search table provided by the user with `QMF:TUNE:TABLE`.

The results are returned in JSON format, which can be easily interpreted by a variety of software platforms.

In general, after a successful analog scan with auto-tuning enabled, the results are returned in the following format:

```
{"results" : [
  { "mass" : x1, "position" : y1, "width" : z1 },
  { "mass" : x2, "position" : y2, "width" : z2 },
...
  { "mass" : xn, "position" : yn, "width" : zn }
] }
```

where each xn is the target mass for the peak to be tuned, yn is the position offset in mass units where the peak was measured, and zn is the measured width for that peak. Note that the peak width is the $\Delta m_{50\%}$ value.

Example:

After setting up an auto-tuning procedure to tune peaks to mass 14, 28, 32, and 40 with the following commands:

```
QMF:TUNE:TABLE (14, 28, 32, 40)
QMF:TUNE:WIDTH 0.6
QMF:TUNE:AUTO:EN 1
SCAN:ANALOG?
QMF:TUNE:RESULTS?
```

The following results are returned by the RGA:

```
{"results" : [
  { "mass" : 14, "position" : 0.2262, "width" : 0.5415 },
  { "mass" : 28, "position" : 0.1824, "width" : 0.5607 },
  { "mass" : 32, "position" : 0.1324, "width" : 0.6032 },
  { "mass" : 40, "position" : 0.0149, "width" : 0.6527 }
] }
```

For this case, each peak in the mass search table was found. Each peak position was measured to be positioned slightly beyond the expected mass center. The peak widths for mass 14 and 28 were measured to be narrower than the expected value of 0.6. The peak width for mass 32 was quite close. And the peak width for mass 40 was slightly higher than desired. The RF/DC tuning parameters were then adjusted internally so that the next scan should yield results closer to the expected values.

Auto-Tune Exception Status Results

When the peak for a specified mass value in the tuning table does not meet a minimum criteria for a proper fit, that mass value is excluded from the tuning calculations.

If an analog scan is made, and the RGA cannot detect at least two acceptable measurable peaks for the mass values in the tune table, the command returns:

```
{"results" : "Error Fitting"}
```

If this occurs, verify that the mass search table has been set to the correct set of mass numbers. Also verify that gas of that composition is being measured by the RGA and that the RGA filament has a non-zero emission current. If these remain true, check the Troubleshooting section below for more information.

When the auto-tune procedure is disabled, the command returns:

```
{"results" : "Tune disabled"}
```

When the auto-tune procedure is enabled, but the results query command is sent before any analog scan is made, the command returns:

```
{"results" : "No Valid Scan"}
```

This is also returned when the search table is empty.

Auto-Tune Troubleshooting

If, after an auto-tuning analog scan, the resulting analog scan is unintelligible, (as in, there is only a background noise floor, or the ion current readings do not correspond at all to a recognizable ion current mass peak pattern), there are a few steps that should be taken to make sure that proper measurements are being made.

- The filament should be energized and emitting electrons.
- There is enough residual gas in the analysis apparatus to be detectable by the RGA.
- Ionizer potential voltages should be set to focus ions through the aperture to the detector.

If there is a proper and sufficient gas mixture, and the filament is emitting electrons, then it may be necessary to reload the factory measured RF/DC tuning parameters from non-volatile flash memory. Use the command:

```
QMF:TUNE:FACTORY:LOAD
```

to load in the default values. Then start the RF/DC tuning procedure once more.

RF/DC Tuning Value Discussion

The magnitude of the RF determines the **mass-to-charge ratio** of the ions that can pass through a quadrupole mass filter without striking the rods (i.e. with stable oscillations). A linear relationship between mass and RF amplitude is one of the most attractive features of these type of filters**.** The regulated output of the RF source that powers the RGA's quadruple rods is controlled by, and linearly related to, the voltage output of an RF Driver circuit. The RF Driver uses a digital-to-analog converter and some additional electronics to program its output voltages.

Constant absolute resolution ($\Delta m_{10\%}$) in a quadrupole mass filter requires DC voltages linearly related to the mass, with a slight negative offset at low masses (i.e. negative intercept).

The RGA adjusts the DC levels of the quadrupole filter during measurements so that constant mass resolution is automatically available throughout the entire mass range of the spectrometer.

The RF and DC voltage required follows a linear relationship with the mass-to-charge ratio of the ions to be measured by the detector. The linear relationship for each requires measuring a slope and an offset value for each the RF and DC voltages as a function of mass-to-charge.

The RF/DC Tuning Procedure outlined here adjusts the slope and offset values for the RF and DC voltages.

Note: Due to imperfections in the manufacturing process for the electronics, the RF and DC linear relationship also includes a small quadratic term that is used to correct for the imperfections. The quadratic correction is measured during factory calibration and should not require any adjustment.

The RF and DC linear tuning parameters can be viewed with the following commands:

```
QMF:RF:SLOPE?
QMF:RF:OFFSET?
QMF:DC:SLOPE?
QMF:DC:OFFSET?
```

The RF and DC offset values returned by these commands are in units of Volts. However, the RF and DC slope values are returned in units of Volts/AMU / MHz^2.

The slope values are adjusted by the square of the frequency of the RF signal. Internally, the RF frequency is continuously adjusted to keep the RGA in resonance to maximize power transfer to the probe elements.

When an analog scan is taken with the RF/DC auto-tuning algorithm enabled, the RGA adjusts these four parameters to get a closer match to the correct values necessary to optimally measure ion currents across the entire mass axis in future scans.

Important: These four tuning parameters are highly sensitive to small changes and should not be changed manually except when absolutely necessary. Changing these values manually may cause the RGA to be unable to perform any further useful ion current measurements.

Manual Position and Width Adjustment

The RF and DC slope and offset parameters do not have a direct one-to-one correspondence with a change in peak position or peak width. Changing an RF or DC offset individually will have an overall change on both the peak position and width of all peaks along the mass spectrum.

As an alternative, the RGA has a different set of commands that can be used to adjust the peak position and peak widths

```
QMF:SHIFT:POSITION:OFFSET
QMF:SHIFT:POSITION:SLOPE
QMF:SHIFT:WIDTH:OFFSET
QMF:SHIFT:WIDTH:SLOPE
```

Rather than changing the RF or DC slope or offset parameters discussed earlier, these commands can change the four RF/DC tuning parameters that have the overall effect of shifting either the peak position or the peak width.

The first command:

```
QMF:SHIFT:POSITION:OFFSET x
```

changes the RF/DC tuning parameters to shift the overall peak position of all mass peaks by a constant number of AMU. The parameter, x, is in units of AMU. This is done while minimizing the change in peak width.

As an example, if an analog scan were taken where the ion current peaks were not located at the integer mass values, such as in Figure x, the following command could be used to manually shift the RF/DC tuning parameters for the next analog scan:

```
QMF:SHIFT:POSITION:OFFSET 0.4
```

The next analog scan would then look something like Figure x.

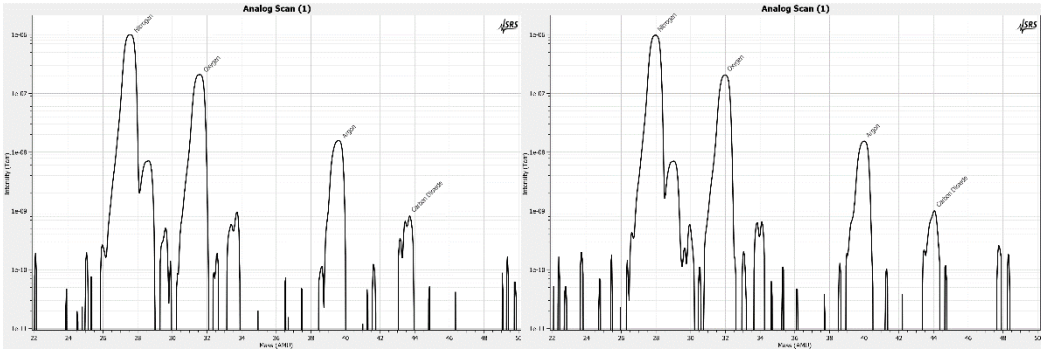

Figure 8-1 Before and after the use of QMF:SHIFT:POSITION:OFFSET 0.4 command

This command could be used to make rough, quick changes to subsequent scan results without requiring the use of the auto-tune procedure or by manipulating the RF/DC slope and offset directly.

Note: The amount of position shift is limited to a range of -4.0 to +4.0 AMU. Using a value beyond this range will result in a command execution error.

The next command requires some more discussion:

```
QMF:SHIFT:POSITION:SLOPE x
```

The parameter x, is in units of AMU / AMU. This command will shift the peak position of each peak at mass number M, by an amount x * M. So a peak located at mass 200 will be shifted by an amount ‘10’ times more than a peak located at mass 20.

This command requires far more thought in its use. The argument values are more restricted in this case as high mass number peaks will be shifted by a greater amount. The range for this parameter is restricted to -0.05 to +0.05 AMU / AMU.

Similarly, the peak width can also be adjusted wider or narrower while the peak position is maintained in place. The command:

```
QMF:SHIFT:WIDTH:OFFSET x
```

will adjust the peak width by the parameter, x, in AMU. A positive value will widen the peak by that amount of AMU. A negative value will narrow the peak by that amount of AMU. This can be useful when studying the effects of the tradeoffs between resolution and sensitivity.

As an example of the effect of using this command to change the peak widths, starting with the following analog scan result as shown in Figure x.

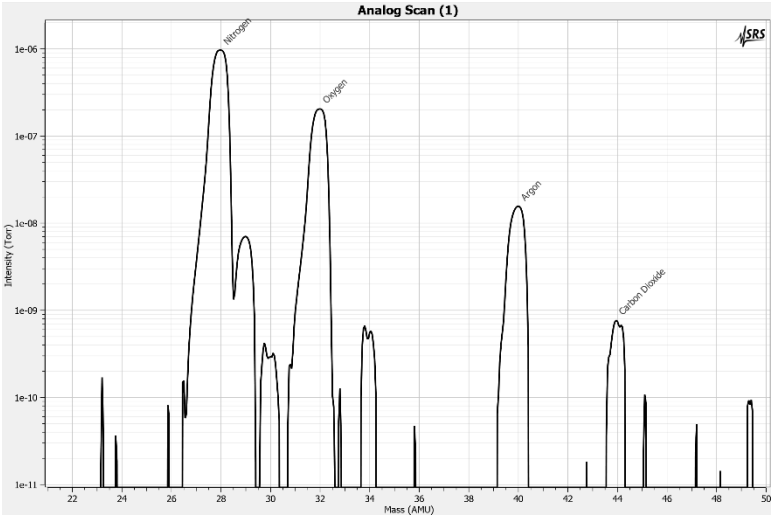

Figure 8-2: Analog scan with peak width for half-maximum set to 0.6 AMU

The following command will decrease the peak width by an overall amount of 0.2 AMU.

```
QMF:SHIFT:WIDTH:OFFSET -0.2
```

Figure x shows the analog scan result after sending this command.

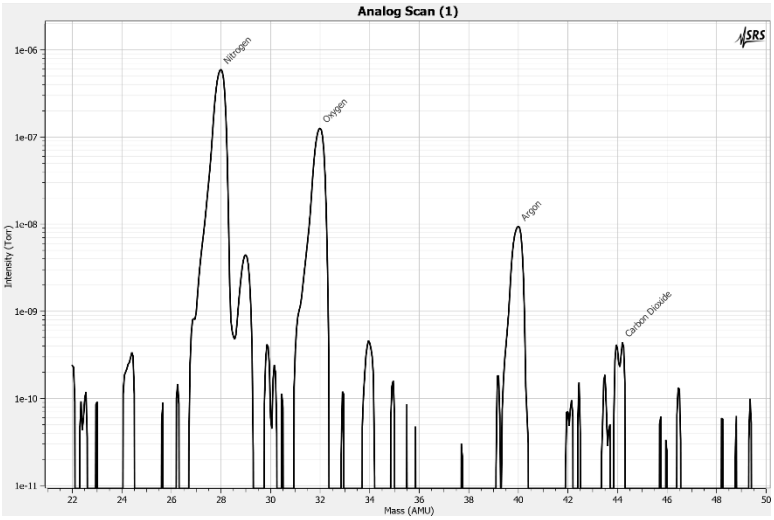

Figure 8-3 Analog scan after QMF:SHIFT:WIDTH:OFFSET -0.2

Using the command once more will decrease the peak width further by 0.2 AMU.

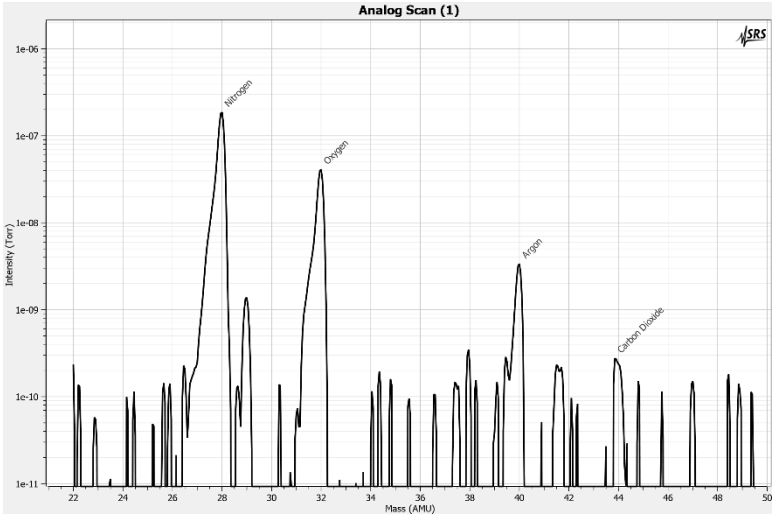

Figure 8-4 Analog scan after a second use of QMF:SHIFT:WIDTH:OFFSET -0.2

Note that the allowed range for the command parameter is -0.5 to +0.5 AMU.

Important: Increasing or decreasing the peak width by a large amount can very easily close off the aperture entirely or open it too wide. This may cause the resulting analog scan results to be unusable.

The last command:

```
QMF:SHIFT:WIDTH:SLOPE x
```

is similar to the shift-position command. The parameter, x, is in units of AMU / AMU. The width for a peak located at mass M will be adjusted by an amount of x * M.

The parameter value used for this command should be chosen carefully as it changes the width of peaks as a function of the mass position of that peak. The peak width for mass 200 will be increased or decreased by 10 times the amount of the peak width adjustment for a peak at mass 20.

As the change can be very drastic for large parameter values, the range is limited to -0.05 to +0.05 AMU / AMU.

Important: Very small values have drastic changes at high mass values. A small parameter value of even 0.001 AMU / AMU will affect the peak width at mass 300 by 0.3 AMU. Given that the nominal default peak width for RF/DC tuning purposes is 0.6 AMU, a shift of 0.3 AMU at this mass is a large shift! Excessively large parameter values for this command may cause unusable scan results.

Note: Each command is designed to change the peak position or the peak width of subsequent analog scans. However, some small shift in the other dimension may result.

Pay close attention to analog scans that are made after the shift commands are used. Consider using the RF/DC auto-tuning procedure to refine the RF/DC tuning parameters further.

Note: Each command can be repeated for additional shifting effect. Also, by repeating a command with the negative parameter value, the previous command's effects can be negated.

For example:

```
QMF:SHIFT:POSITION:OFFSET 0.5
```

followed by:

```
QMF:SHIFT:POSITION:OFFSET -0.5
```

should negate the effects of the first shift command.

Tuning Parameter Retention

When the RF/DC tuning parameters are changed, they are first saved internally to RAM. The parameters will be saved to nonvolatile Flash after a period of inactivity according to the Autosave protocol. See the Autosave section for more information on how instrument settings are saved to Flash.

If the RGA experiences a power failure or is reset in some way before the tuning parameters are saved to Flash, the changes will be lost. To bypass the Autosave procedure and immediately save changed RF/DC parameter values to Flash, use the following command:

```
SETUP:SAVE
```

This will save all persistent instrument settings as well as the RF/DC tuning parameters.

Temperature effects on the mass scale calibration

As the temperature of the RGA changes two different effects affect the calibration of the mass scale:

- **For large temperature changes:** The sensitivity of the RF power supply to its controlling voltages might be affected or, more fundamentally, the relationship between mass and RF levels in the filter might change (for example, if the QMF changes its physical dimensions). In this case a Peak Tuning procedure will be necessary to reestablish the mass axis scale.

Sensitivity Tuning Procedure

All quantitative calculations performed with the SRS RGA rely on the assumption that there is a linear relation between the partial pressure and the corresponding RGA signals of the gases. Each gas ionizes differently, and its ions make it through the mass filter with different efficiencies. As a result, the proportionality constant relating the ion current of a gas to its partial pressure is very dependent on the specific gas.

The **partial pressure sensitivity** of the RGA to a gas g, S_g, is defined as the ratio of the change $(H-H_0)$ in principal mass peak height to the corresponding change $(P-P_0)$ in total pressure due to a change in partial pressure of the particular gas species. H_0 and P_0 are background values.

$S_g = (H-H_0) / (P-P_0)$

The units of S_g are of ion current per unit pressure (amp/Torr, for example).

The sensitivity of the RGA changes with time due to aging, and is a strong function of the operating conditions of the instrument. Careful quantitative analysis requires that the sensitivity factor, S_g, be determined for every gas which may be a component gas in the system being analyzed. The sensitivity factors must be obtained under the same operating conditions that will be used during general partial pressure analysis since they depend on many instrumental parameters, including: ionization energy, emission current, mass filter setting, type of detector, etc.

Important: In order to separate the gain of the electron multiplier from the intrinsic sensitivity of the RGA, the sensitivity factors of the SRS RGA are defined for Faraday Cup detection. A separate Electron Multiplier Gain Factor, is used to correct the ion signals when the electron multiplier is used. See the Electron Multiplier Tuning section for details.

The **partial pressure sensitivity of the RGA** to a particular gas is determined following the steps listed below.

1. Refresh the calibration of the electrometer using the Calibrate Detector command (ECU Menu) of the RGASoft program or the CL command of the RGA command set.

2. Start with the vacuum system at base pressure (preferably under 10^{-7} Torr).

3. Select Faraday cup detection and choose the desired operational parameters for the instrument (See note at the end).

4. Perform a few analog scans on the chamber to assure that the contributions from all other gases to your measurements can be neglected. Check the quality of the analog spectra, and peak tune the instrument if needed.

5. Introduce the pure gas into the vacuum system, at a known or calculable pressure (typically around 10^{-6} Torr).

6. Run a few analog or histogram scans on the sample gas to assure the purity and levels of the calibration gas.

7. Measure the output signal from the RGA for the principal mass peak of the calibration gas (i.e. usually the parent molecule peak) using the Faraday cup detector. Extract the peak value from spectral scans or measure it directly using the single mass measurement mode of the SRS RGA.

8. The ratio of this output signal to the pressure of the gas is the partial pressure sensitivity factor.

9. The sensitivity factor, in units of mA/Torr, can be saved into the non-volatile memory of the RGA using the SP command. The parameter value saved is automatically used by RGASoft as a conversion factor between the ion currents received form the RGA and the partial pressure units selected by the user. See the RGA Command Set listing for details.

Important: The sensitivity factors calculated in this fashion can only be applied to situations where the RGA is used with the same operating parameters. Change the instrument parameter settings to those of your measurements prior to the calibration if necessary.

A **total pressure sensitivity factor** is also needed by the SRS RGA to convert the ion currents obtained during total pressure measurements into total pressures. Total pressure sensitivity factors vary with different gases and share many of the properties of the partial pressure factors. They are determined by a procedure identical to the one described above, but with the partial pressure measurements replaced by total pressure measurements. The total pressure sensitivity factor, in units of mA/Torr, can be saved into the non-volatile memory of the RGA using the command:

```
PRESsure:SENSitivity:TOTAL
```

The parameter value saved is automatically used by RGASoft as a conversion factor between the total ion currents received form the RGA and the pressure units selected by the user. See the RGA Command Set listing for details.

Note: The underlying assumption when using sensitivity factors in quantitative calculations is that there is a linear relation between the pressure and the corresponding RGA signals of the gases. This assumption is only strictly correct as long as the pressures in the RGA are kept below 10^{-5} Torr. Deviations from linearity are to be expected above that pressure value due to space charge effects in the ionizer and ion-neutral scattering interactions in the filter. A more thorough check of the RGA's sensitivity involves measuring the RGA signals over several orders of magnitude of partial pressure to determine the range over which a linear relationship exists. The sensitivity factor for the gas is calculated as the slope of the "signal vs. pressure" response over the linear range.

RGASoft uses the partial pressure and total pressure sensitivity factors stored in the non-volatile memory of the RGA as conversion factors between the ion currents received from the RGA and the pressure units selected by the user. A Sensitivity Tuning command in the Probe menu automates the sensitivity tuning procedure described above and allows the user to recalibrate or change the sensitivity factors very easily. Consult the RGASoft

Chapter of this manual and the On-line Help Files for details on the tuning commands of the program.

The sensitivity factors used by SRS RGA are all for Faraday Cup detection. A separate Electron Multiplier Gain Factor, stored in the non-volatile memory of the RGA, is used by the RGASoft program to correct the ion signals when the electron multiplier is turned on (i.e. all data acquired while the electron multiplier is on gets divided by the gain automatically before it is displayed by the program). See the Electron Multiplier Tuning section of this chapter for details.

Electron Multiplier Tuning Procedure

Accurate quantitative measurements with the electron multiplier detector require the determination of the CDEM gain for all the ion peaks being measured. Frequent recalibrations are recommended to correct against aging of the device.

The gain of the electron multiplier (CDEM) in the SRS RGA is defined relative to the Faraday Cup output (which is assumed to be mass independent). It can be programmed anywhere from 1 to 10^7 adjusting the high voltage applied across the device, is highly mass dependent, and changes with time due to aging.

The electron multiplier gain is easily calibrated in the SRS RGA since it is possible to measure the same ion current with and without the CDEM. The common method of calibrating the electron multiplier gain for a given mass peak is to measure the peak intensity with the Faraday cup, and then repeat the same measurement with the electron multiplier without changing anything else. The gain of the multiplier is the ratio of the multiplier output current to the Faraday cup output current. (Note that there is no need to change the sign of the electron multiplier signal prior to the division since the firmware automatically reverses its sign before transmitting the value.)

The RGA can store a single set of [High Voltage, Gain, Mass] values for the electron multiplier in its non-volatile memory. RGASoft uses the voltage value to bias the CDEM and the gain value to divide the ion currents when the CDEM is turned on. See the commands:

```
CEM:STORED:VOLTAGE
CEM:STORED:GAIN
CEM:STORED:MASS
```

in the RGA Command set for details on the command-level implementation of this procedure.

RGASoft can automatically program the gain of the electron multiplier for any mass using the automatic gain adjustment function of the CEM Tuning command (Probe Menu). Select a gain value between 10 and 1,000,000, choose a mass value for partial pressure measurements, and the RGASoft program automatically calculates the required high voltage setting when the Start Tuning button of the CEM Tuning dialog box is pressed. The HV and gain settings are saved into the RGA and used every time the CDEM is turned on. All data acquired while the CDEM is on gets divided by the gain automatically before it is displayed.

Chapter 9

Instrument Status

This chapter describes the instrument status features of the RGA120/220/320 series.

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Introduction

The RGA is a complex instrument with many components that work together to provide accurate measurements of ion currents over a wide mass range. Most of the time, everything operates normally.

But at times, something prevents the RGA from operating as expected. The sources are varied. External configuration issues can stop the RGA from functioning properly, such as misalignment of the probe module, a very high vacuum chamber pressure, a broken filament wire, or an accidentally disconnected wire. Instrument misconfiguration may cause unexpected behaviors. It's also possible that some hardware or software failure has occurred that stops the RGA from providing expected measurements.

The RGA120 monitors several instrument parameters. When the RGA120 detects an anomalous state of any of these parameters, the RGA sets status registers. The user can query the status registers directly to get information about the instrument state. Also, the user can also configure the status registers to connect with the back panel LEDs. The LEDs then inform the user immediately of any important instrument anomalies when they are detected.

Status Register Model

The RGA120 reports on its status by means of several status registers. These read-only registers record the occurrence of defined status conditions detected by the instrument.

Status registers are broadly grouped according to a subfunction or subsystem of the instrument. The following table lists the available instrument status registers:

Index	Weight	Description
0	1	Remote Communication
1	2	Filament
2	4	Quadrupole Mass Field (QMF)
3	8	CEM
4	16	Auxiliary I/O
5	32	Detector
6	64	Power Supply
7	128	Ionizer
8	256	Electronics
9	512	Pressure

Table 9-1 Instrument Status Registers

Each status register groups together the status conditions of up to 16 individual monitored instrument parameters.

Event Status

Each status register is actually a pair of status registers: a **condition register** and an **event register**. The condition and event registers are both represented as 16-bit integers. Each bit of the condition and event registers corresponds to a specific status condition.

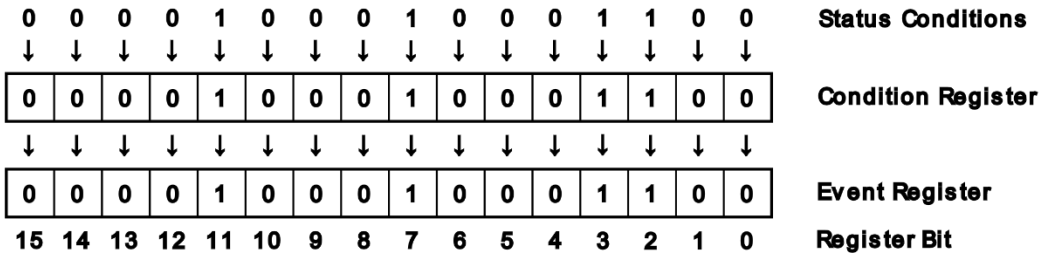

Figure 9-1 Instrument Status Register pair (Condition/Event)

Condition Register

A condition register groups together the last known state of each status condition. When the instrument detects a change in a status condition, the corresponding bit in the condition status register is changed. If the instrument detects that the instrument state exceeds a specific condition, the bit in the condition register is set to 1. If the instrument detects that the instrument state has returned to a normal condition, the bit in the condition register is set to 0.

Note: The bit values for each condition in a condition register changes only when the instrument detects a change. Some status conditions are checked at regular intervals. Other status conditions are checked only when a user command.

Event Register

The event register contains a latched version of the condition register. When a bit in the condition register is set to 1, the corresponding bit in the event register is also set to 1. However, if the same bit in the condition register resets to 0, the bit in the event register remains 1.

The user can query the contents of an event register either by reading the entire 16-bit integer value, or by individual event bit. When an individual event bit is read, the value of that bit in the event register is reset to 0. When an entire 16-bit integer event register is read, the entire 16-bit event register is reset to 0.

Note: Bits in the event register are set to 1 only when the corresponding bit in the condition register changes from 0 to 1.

Examples

Here are a few examples of how status conditions propagate to the condition register and the event register.

Starting with a condition and event register from Figure x above, if a new status condition appears, it changes the bit in the condition register to 1 and also changes the same bit in the event register to 1.

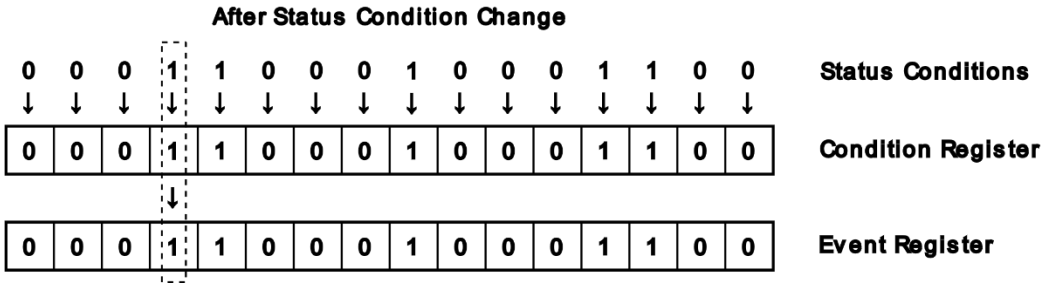

Figure 9-2 Status condition bit set

If a status condition resets to 0, this resets the bit in the condition register to 0. But the corresponding bit in the event register stays 1. This allows the user to be notified that a status condition was detected by the instrument at some time, even if that status condition was transient and is back to normal conditions.

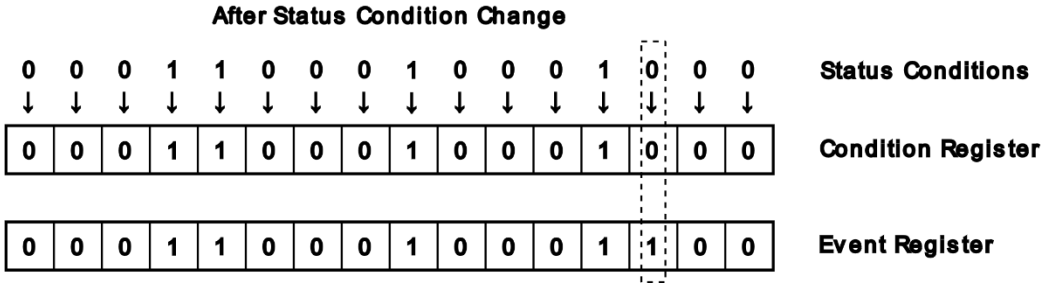

Figure 9-3 Status condition bit reset

If the user then reads the entire event register, all bits in the event register are reset to 0.

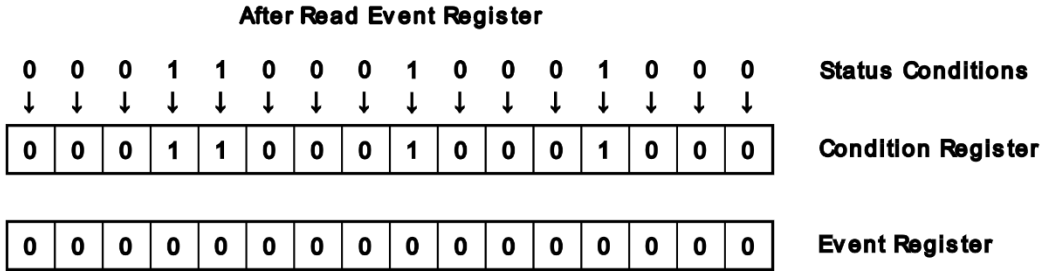

Figure 9-4 Read Event Register

Note that even through the condition register bits are still 1, the event register bits remain 0. The event register bit is set to 1 only when a status condition is set. Then both the condition register bit and the event register bit is set to 1.

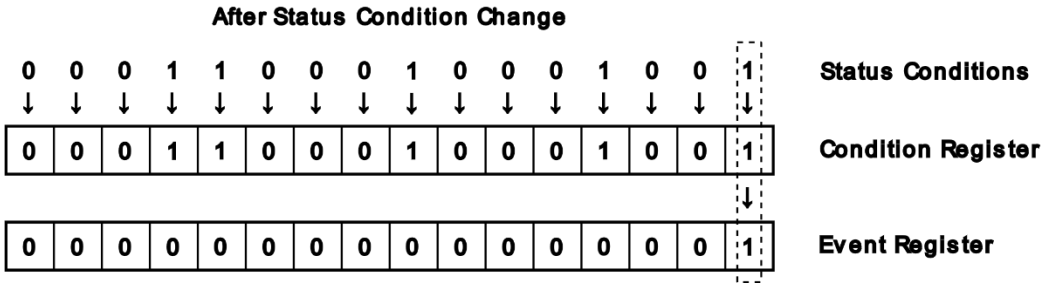

Figure 9-5 Status condition bit set after read event register

Note: Status conditions are normally reset prior to the start of a measurement. Refer to the individual status conditions for more information about each condition.

Status Accumulation

The RGA has additional registers that can be configured by the user to help inform them of specific status conditions that are important and relevant to their application.

The user controls this accumulation through Event Enable Registers. The user sets the bits for the events of each Event Register they wish to accumulate. For those events where the equivalent Event Register bit is set, those events are accumulated and placed into the Global Status Register.

The Global Status Register is itself a 16-bit integer register. Each bit corresponds to the event status of one Event Register. When one or more bits in an Event Register are set to 1 and the corresponding bit is 'enabled' in the corresponding Event Enable Register, the bit for that Event Register is set in the Global Status Register.

The user can then query the Global Status Register as a summary of the instrument status. Any bit set in the Global Status Register indicates that at least one enabled event has been detected in that Event Register.

Event Enable Register

For each event register there is an equivalent Event Enable Register. Each enable register is used to help accumulate events to a Global Status Register.

Each Event Enable Register is a 16-bit integer in the same format as each Event Register. The bit position for each event is equivalent in both the Event Register and Event Enable Register.

The user first decides on a subset of events they wish to be informed of. Not every event may fall within the area of interest. Some status conditions may not apply so they may be disabled by setting the value of that bit to 0.

Events are enabled by setting the bit for each event in the Event Enable Register to 1. When a bit is set in an Event Register that is also 'enabled' in the Event Enable Register, that sets a bit in the Global Status Register.

Global Status Register

The Global Status Register acts as a summary of instrument status. When read, the Global Status Register value will indicate which Event Registers have an enabled event that is set. Each bit corresponds to a different Event Register. The bit positions in the Global Status Register are equivalent to the Index values in Table x above.

A value of 1 for a specific bit in the Global Status Register informs the user that they should query the corresponding Event Register for further information about the events that have been detected.

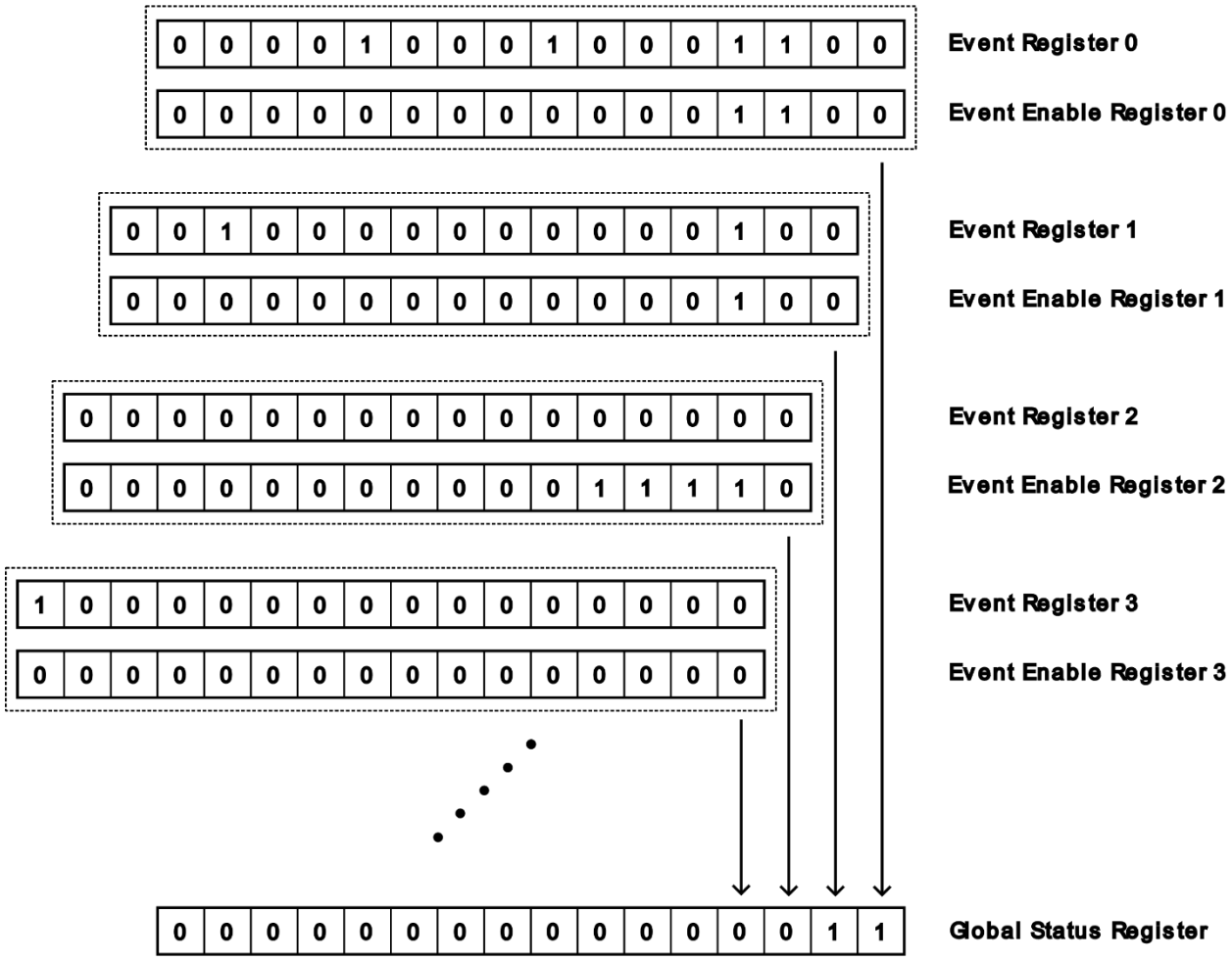

Figure 9-6 Instrument Status accumulation

Examples

Refer to Figure x as an example of how Event Enable Registers work to accumulate instrument status into the Global Status Register.

For Event Register 0, a number of event bits are set. In the Event Enable Register 0, bits 2 and 3 are set. The Event Register also has bits 2 and 3 set. This shows that at least one enabled event has been detected, so this will set bit 0 of the Global Status Register to 1.

For Event Register 1, a number of event bits are set. In Event Enable Register 1, only bit 2 is set. The Event Register also has bit 2 set. With one enabled and detected event, this will set bit 1 of the Global Status Register to 1.

For Event Register 2, none of the event bits are set. Even though the Event Enable Register has a number of events enabled, there are no detected events. This will set bit 2 of the Global Status Register to 0.

For Event Register 3, bit 15 of the Event Register is set, but none of the events are enabled. With no enabled events, this will set bit 3 of the Global Status Register to 0.

This accumulation continues for each Event Register until each bit value is calculated in the Global Status Register.

Reading the Global Status Register will not reset the register, nor will it reset the value of any of the Event Registers.

Service LED

The back panel has a Service LED that can be configured to show instantly when one of a subset of instrument status events has been detected. This is done by configuring the Global Servicemask Register.

Global Servicemask Register

The Global Servicemask Register is a 16-bit integer value. The bit positions are the same as the Global Status Register. The user sets the bits that will be monitored. After the Servicemask Register value has been set, any bits that are set in both the Global Status Register and the Servicemask Register will cause the Service LED to light up.

When the Service LED is lit, the user should read the Global Status Register to determine which Event Registers show an event that is set. Then, after all the Event Registers are read and cleared, the Service LED will turn off.

If the status condition is set once again after that, the condition will propagate through to the Event Register, the Global Status Register and the LED will turn on again.

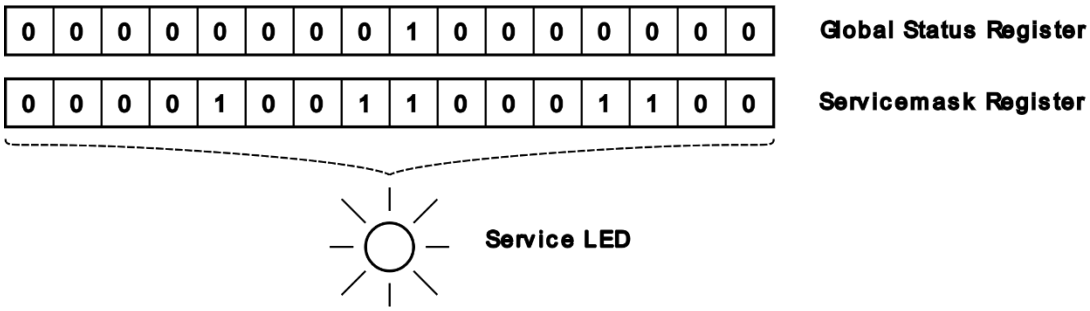

Figure 9-7 Servicemask Register and Service LED

Pressure LED

The back panel has a Pressure LED that is used to indicate when a Pressure related status condition has been detected. The status of the LED depends directly on the Pressure Condition Register and cannot be configured.

When lit, this means that the RGA has made a measurement that may indicate the pressure measured is above an acceptable level. The Pressure Event Status Register will give more information about the pressure event detected.

Refer to the Pressure Status Register (Register 9) for more information regarding pressure related status conditions.

Instrument Status Commands

The user reads instrument status and sets event enable registers thorough a set of commands sent through the remote interface.

Condition Registers

To view the instantaneous state of the most recent value of the condition registers, use the following command:

```
STATUS:CONDITION? x
```

Where x is the register index number to be queried. This will return the sum of the weights of all the instrument conditions for that condition register. Refer to the list of Status Conditions for a table of weights for each register.

Alternately, the user may query for the value of an individual condition in a Condition Register with the following command:

```
STATUS:CONDITION? x, y
```

Where x is the register index number, and y is the bit of the status register. Refer to the list of Status Conditions for a table of bit values for each status condition of each register.

Event Registers

To read an Event Register value, use the following command:

```
STATUS:EVENT? x
```

Where x is the register index number to be queried. This will return the sum of the weights of all the events for that event register. Refer to the list of Status Condition for a table of weights for each register.

To read the value of an individual event in an event register, use the following command:

```
STATUS:EVENT? x, y
```

Where x is the register index number, and y is the bit of the status register. Refer to the list of Status Conditions for a table of bit values for each status condition of each register.

When an entire event register is read as in the first command, the entire contents of that event register is reset to 0. When just one bit is queried as in the second command, then only that bit in the event register is reset to 0.

Event Enable Registers

To set an Event Enable Register, use the following command:

```
STATUS:EVENT:ENABLE x, y
```

Where x is the register index number, and y is the sum of all the weights for those events that are to be enabled. The enabled values for those bits will be set to 1. All other bits will be reset to 0. Refer to the list of Status Condition for a table of weights for each register.

Alternatively, to set or reset an individual bit in an Event Enable Register, use the following command with 3 parameters:

```
STATUS:EVENT:ENABLE x, y, z
```

For this command, x is the register index number, y is the bit of the status register to set or reset, and z is the value for the bit. The value can either be 0 or 1, or can be a keyword token OFF or ON.

The value of the Event Enable Registers can also be queried. The following command will query the contents of an entire event enable register:

```
STATUS:EVENT:ENABLE? x
```

Where x is the register index number. The value returned is the sum of all the weights for those events that are enabled.

Alternatively, an individual bit of an event enable register may be queried with the following command:

```
STATUS:EVENT:ENABLE? x, y
```

Where x is the register index number, and y is the bit for the event enable status to be queried. The value returned will be either 0 for disabled or 1 for enabled.

Examples:

To set bits 3, 4, and bit 0 of the Auxiliary I/O Event Enable Register (register index 4), and set all other bits to 0, combine the weights for each bit and use that as the parameter for the command. The sum of the weights will be 8, 16, and 1, which equals 25.

```
STATUS:EVENT:ENABLE 4, 25
```

To reset bit 3 to 0 of the QMF Event Enable Register (register index 2), use the following command:

```
STATUS:EVENT:ENABLE 2, 3, 0
```

Alternatively, the following command parameter will also work:

```
STATUS:EVENT:ENABLE 2, 3, OFF
```

To set bit 2 of the Electronics Event Enable Register (register index 8), use the following command:

```
STATUS:EVENT:ENABLE 8, 2, 1
```

Alternatively, the following command parameter will also work:

```
STATUS:EVENT:ENABLE 8, 2, ON
```

Global Status Register

The Global Status Register is a query-only register which acts as a summary of instrument status. To query the global status register, use the following command:

```
STATUS:GLOBAL?
```

The value returned is the sum of the weights of each Event Register that has at least one event set in the Event Register that is also enabled in the Event Enable Register. The weights for each Event Register are listed in the table at the start of this chapter.

Alternatively, to query only one bit of the Global Status Register, use the following command:

```
STATUS:GLOBAL? x
```

Where x is the event register index to be queried. The event register indices are listed in the table at the start of the chapter. The value returned will be either 0 or 1. A 0 indicates that no enabled events for that event register have been detected. A 1 indicates that at least one enabled event has been detected for that event register.

Note that by querying the Global Status Register in any way does not reset the Global Status Register. It also does not reset any of the Event Registers.

Global Servicemask Register

This register can be configured to turn on the Service LED on the back panel of the instrument for those Event Registers that have detected any events that are enabled. Once again, this is primarily used to indicate to the user that the instrument has detected an issue that they may need to address.

To set the Global Servicemask Register, use the following command:

```
STATUS:GLOBAL:SERVICEMASK x
```

Where x is the sum of the weights of each Event Register that is to be enabled in the service mask. All other bits in the service mask register will be disabled. Refer to the table of weights for the instrument status registers at the start oft his chapter.

Alternatively, to set or reset only one bit of the Global Servicemask Register, use the following command:

```
STATUS:GLOBAL:SERVICEMASK x, y
```

Where x is the event register index to be set or reset, and y is the value for that register bit. Valid values are 0 to disable that bit, or 1 to enable that bit. Alternatively, the user can use the keywords OFF to disable, or ON to enable.

Power On Register Assignments

When the RGA is first powered up, the RGA enables the Event Registers and the Global Service Mask for a subset of events. These events are considered important enough to have enabled right away.

The following is a list of status registers, bit values, and descriptions of each event that is enabled at startup.

Register	Bit	Description
1	7	No Filament
1	8	Internal Emission Measurement Failure
1	10	Filament Control Voltage Imbalance
1	14	Filament Emission Unstable
1	15	Filament Emission Runaway
5	0	Probe Not Present
6	5	Power Supply Overcurrent
6	6	Power Supply Undervoltage
6	7	Power Supply Overvoltage
7	0	Repeller Thermal Limit
7	1	Repeller Overcurrent
7	2	Focus Plate Thermal Limit
7	3	Focus Plate Overcurrent
8	0	Instrument Shutdown Detected
8	1	Instrument Overtemperature
8	2	Shift Register Error
8	3	Flash Memory Error
8	5	SPI Transfer Error
8	6	Watchdog Reset
8	7	Unexpected Instrument Reset

Table 9-2 Events enabled at RGA Startup

The Global Servicemask is set to connect all the enabled events above to the Service LED on the back panel. The Service Mask register value will have bits 1, 5, 6, 7, and 8 set, for a weighted value of 482.

Instrument Status Conditions

The RGA can inform the user of a wide variety of unexpected events. When the user is notified of a specific event, refer to the list below for a description of each status condition and how to troubleshoot the condition to return the instrument to normal operation.

While each status register is a 16-bit integer value, not all 16 bits are assigned to status conditions. All unassigned bits are reserved for future use.

Remote Communication (Register 0)

This register reports events that occur as a result of user commands sent over a remote interface.

Bit	Weight	Description
0	1	Invalid Command
1	2	Invalid Parameter
2	4	Invalid String
3	8	Parameter Missing
4	16	Extra Parameter
5	32	Command Timeout
6	64	Command Too Long
7	128	Output Buffer Overflow
8	256	Execution Error
9	512	Command Locked
10	1024	Connection Lost
11	2048	Command Interrupted
12	4096	Procedure Running
13	8192	Procedure Failed

Table 9-3 Remote Communication Register Status Conditions

For status conditions in this register, the status condition is set when the user enters a new command. When the instrument parses a command terminator, the status condition is reset to 0 and the command is parsed.

If the command is parsed and completes successfully, all status condition bits for this register remain 0. If an error is encountered when either parsing or executing a command, a status condition bit will be set to 1.

Note: Each time a remote command fails, the Com Err LED will flash momentarily as an outward indicator to the user that the command failed execution in some way.

Invalid Command (Bit 0)

This status condition means that the RGA has encountered an invalid command.

This typically occurs because of a syntax error in the command sent. If this is unexpected, check the spelling of the command. Make sure the format of the command is as specified in the remote command set.

If the command syntax is correct, check that the communications speed is appropriate for the external interface that is used (115.2k baud for USB, and 28.8k baud for RS-232)

Invalid Parameter (Bit 1)

This status condition indicates that the user has provided a valid command name, but the parameter of that command was not in the correct format. In general, most command parameters are either an integer or a floating point number. For some commands, a keyword can be used to indicate a parameter value.

For this status condition check the documentation for the command and make sure that the parameter sent is in the correct format and in the valid range for that command.

Other commands require a list of integers. For those commands, make sure that the format for that parameter matches what is detailed in the command documentation.

Invalid String (Bit 2)

This is specific to commands that accept a character string as a parameter. Check the command documentation and make sure the format for the string parameter matches what is specified.

Parameter Missing (Bit 3)

This status condition is set when a command cannot find a parameter that it was expecting. Check the command documentation and make sure that the correct format is used and that all expected parameter values are provided.

Extra Parameter (Bit 4)

This status condition is set when a command has been sent with one or more extra parameters. Check the command documentation and make sure that the correct format is used and that all expected parameter values are provided.

Command Timeout (Bit 5)

Some commands require some time to execute. During this time, the remote interface will not execute another command until the pending command has completed. If command execution goes beyond an expected time period, command execution will abort and this status condition will be set.

This status condition is not expected during normal operation. It may point to a problem with internal instrumentation, or some external connection that is interfering with the normal command execution.

When this status condition is encountered, check to make sure that this command is appropriate for the instrument for its present configuration. Try executing the command again. If the command is expected to execute yet this error persists, it may point to an error internal to the instrument.

Command Too Long (Bit 6)

The command input buffer has a finite size. If the user tries to send a command that is too long for the command parser, the entire command will be rejected and this status condition will be set.

For this status condition, make sure that the command is being sent in the right format with the expected termination character sequence. Also make sure that the communication speed is set appropriately to the remote interface being used.

Output Buffer Overflow (Bit 7)

The remote interface output buffer has a finite size. If command execution generates an output that is too large, some data will be lost and this status condition will be set.

This does not occur during normal operation but could potentially happen if the user has blocked communication from the RGA using DTS/CTS hardware flow control, or if command output is too fast for the given communication speed of the remote interface being used. For these cases, make sure that hardware flow control is set to allow the RGA to send back command replies.

Execution Error (Bit 8)

This status condition is a catch-all for many unexpected errors with command execution. This does not occur during normal operation, and may indicate an issue with internal instrumentation and electronics or with external factors interfering with the RGA. For this status condition, verify the syntax and parameter values for the command being sent and try again.

This may also be caused by trying to send a command that is not allowed because the HV Enable pin on the back panel is active, or if the probe module is not connected to the RGA. If either of these are true, set the HV Enable pin back to the normal state. Or, if the probe is disconnected, power off the RGA, then reconnect the probe. Then power the instrument back on and try again.

Command Locked (Bit 9)

The RGA allows for command execution to take place over multiple remote interfaces simultaneously. This is not recommended, but is allowed when circumstances require a separate connection over another interface while the primary interface is being used.

While one interface is executing a command, another interface may issue query commands and other commands that do not change the state of the instrument. However, all other commands are locked out. This condition status indicates that a command has been sent that cannot be executed while another interface is busy with a different command.

For this status condition, refrain from sending commands that change the status of the instrument, or make sure that command execution has completed on all other remote interfaces before sending this command.

Connection Lost (Bit 10)

When used, the Ethernet interface expects to have an open TCP/IP connection to a host computer while command execution takes place. If the TCP/IP connection is lost during command execution, this status condition is set and any remaining command output is lost.

This status condition may occur on unstable or unreliable Ethernet networks and connections, or when the host computer loses power or has some other hardware failure that breaks connection with the RGA.

Check that both the host computer is powered up, the host software is running, and that the Ethernet connection between the host computer and RGA is stable. Make sure that the Ethernet cables are securely plugged in to all Ethernet ports and that the cables are reliable.

Command Interrupted (Bit 11)

Some commands require time to execute. The commands may require so much time that they can be interrupted by the user. These are typically the analog and histogram scan commands, and the single and multiple measurement commands.

When the command parser has detected a new command, even a null command, any interruptible command stops executing and this status condition is set to inform the user that the command execution was interrupted.

For cases when this status condition is unexpected, make sure that the host computer does not send any spurious commands during command execution.

Procedure Running (Bit 12)

Some commands are run internally as a multi-step procedure within the instrument. These commands take some time to complete. If another interface tries to execute a command that runs an internal procedure, command execution pauses until the first procedure is complete. However, if the wait time goes beyond a certain preset limit, the command will fail and this status condition will be set.

For this status condition, when executing complex commands that change many internal instrument parameters, it is best to execute these commands sequentially from one designated interface. Other interfaces may be used to monitor internal parameters through query commands.

Procedure Failed (Bit 13)

Some commands are run internally as a multi-step procedure within the instrument. These commands take some time to complete. If the procedure fails in some way, this status condition is set.

This result is unexpected, but may not be an indication of a problem. This may occur when starting the filament. Some data measurements may have encountered an unexpected spurious data point and the procedure is aborted.

The next step when this status condition is seen is to check the conditions of the RGA and then try the command again. If the condition persists or occurs frequently, this may indicate an internal instrument problem.

Filament (Register 1)

This register reports events that are related to filament emission. These may occur when the user tries to start the filament or as a response to a change in the filament conditions.

The filament condition register bits are reset each time the filament emission setting is changed by the user.

Bit	Weight	Description
0	1	Single Filament Detected
1	2	Cannot Set Emission
2	4	Pirani Test Failure – Unknown Error
3	8	Pirani Test Failure – Cool Down Error
4	16	Pirani Test Failure – Timeout
5	32	Unknown Filament Emission Error
6	64	Timeout – Cannot Set Emission
7	128	No Filament
8	256	Internal Emission Measurement Failure
9	512	Degas Failure
10	1024	Control Voltage Imbalance
14	16384	Filament Emission Unstable
15	32768	Filament Emission Runaway

Table 9-4 Filament Register Status Conditions

Single Filament Detected (Bit 0)

When the filament is energized and emitting electron current, the RGA monitors the voltage and electrical current through the filament. Nominally, the filament is composed of two wires in the probe sharing the burden of producing electron emission. If the instrument detects that the voltage and current readings show that one of the filament wires has broken into an open connection, this status condition will notify the user that there is only one filament in operation.

This does not necessarily point to an imminent problem, but the user should consider repairing the filament in the near future.

This status condition relies on using a standard dual Thoriated Iridium filament. If the user has changed the filament wire to a different composition or thickness, that may confuse the RGA into believing there is only a single filament.

If this status condition is bothersome or does not correctly indicate the filament state because a non-standard filament is used, the user may disable the RGA from monitoring for a single filament status condition with the following command:

```
INTERLOCK:FILAMENTSINGLE:ENABLE 0
```

Or:

```
INTERLOCK:FILAMENTSINGLE:ENABLE OFF
```

This will disable the internal check for single filament operation.

Note: This interlock state is not saved in non-volatile memory. The interlock is always enabled when the instrument is powered on or reset in any way.

Cannot Set Emission (Bit 1)

This status condition indicates that some problem is preventing the filament from being started. If this occurs, reset the event status registers and try starting the filament again before checking other possible reasons for this failure.

There are many reasons for this to occur. Usually, this status condition is set along with another related status condition, so check the following possibilities:

- The filament is broken and there is an open connection in the probe.
- The RGA cannot detect the presence of the probe module. If this is the case, you must power down the RGA, and reseat the instrument onto the probe module firmly.

  Important! Do not reseat the instrument while power is on! Only do so with the instrument powered off!
- The probe module is misaligned and is touching against the inner walls of the vacuum chamber. If this is the case, power down the instrument and re-align the probe module as necessary for your apparatus.
- The repeller voltage is set below a minimum voltage. This should not occur during normal operation. Try setting the repeller voltage to the default value with the following command:

  ```
  IONIZER:REPELLER:VOLT DEFAULT
  ```
- The initial startup Pirani Test procedure failed. This can happen when the filament is first started from a cold state, and potentially when a non-standard filament is used.

  The startup Pirani Test procedure is a fail-safe procedure to protect the RGA instrumentation in cases where the chamber pressure is too high. If the user is confident that the chamber pressure is an acceptable range for RGA operation, the procedure may be disabled with the following command:

```
INTERLOCK:PIRANI:ENABLE 0
```

Or:

```
INTERLOCK:PIRANI:ENABLE OFF
```

Note: This interlock state is not saved in non-volatile memory. The interlock is always enabled when the instrument is powered on or reset in any way.

Pirani Test Failure – Unknown Error (Bit 2)

When the filament is first started from a cold state, the instrument runs a procedure that makes a rough guess at the chamber pressure. If the data from that measurement is corrupted inside, possibly from a measurement transient, the fit parameters will not be realistic. In such a case, this status condition is set.

This status condition may potentially occur when the user has installed a non-standard filament into the probe module.

When this status condition is encountered, it is best to wait a short time and try starting the filament again. If this condition persists, power down the instrument and check the connection with the probe module, then try again. If this condition still persists, it may point to an internal failure in the instrument.

The startup Pirani Test procedure is a fail-safe procedure to protect the RGA instrumentation in cases where the chamber pressure is too high. If the user is confident that the chamber pressure is an acceptable range for RGA operation, the procedure may be disabled with the following command:

```
INTERLOCK:PIRANI:ENABLE 0
```

Or:

```
INTERLOCK:PIRANI:ENABLE OFF
```

Pirani Test Failure – Cool Down Error (Bit 3)

When filament emission is shut off, the filament wire cools down. If filament emission is started again within a set time period (normally 20 seconds), the RGA assumes that the vacuum chamber pressure is acceptable because the test procedure passed the last time filament emission was started.

If the filament has been off for more than that amount of time, then the Pirani Test procedure is run once again. However, if the filament has not cooled down sufficiently in that period, then the test procedure could fail and set this status condition.

If this status condition is seen, wait a longer time and try starting filament emission once again. If the condition persists even after waiting a significant time, it may indicate an internal instrument error.

The startup Pirani Test procedure is a fail-safe procedure to protect the RGA instrumentation in cases where the chamber pressure is too high. If the user is confident

that the chamber pressure is an acceptable range for RGA operation, the procedure may be disabled with the following command:

```
INTERLOCK:PIRANI:ENABLE 0
```

Or:

```
INTERLOCK:PIRANI:ENABLE OFF
```

Pirani Test Failure – Timeout (Bit 4)

Normally, when starting filament emission, the Pirani Test procedure completes in a few seconds. However, if there is a problem completing the procedure, this status condition may be set.

This is an unexpected condition, and should not happen in normal operation. It may point to an internal instrument error. Wait some period of time and try again to see if this status condition persists.

If this status condition is seen, wait a longer time and try starting filament emission once again. If the condition persists even after waiting a significant time, it may indicate an internal instrument error.

The startup Pirani Test procedure is a fail-safe procedure to protect the RGA instrumentation in cases where the chamber pressure is too high. If the user is confident that the chamber pressure is an acceptable range for RGA operation, the procedure may be disabled with the following command:

```
INTERLOCK:PIRANI:ENABLE 0
```

Or:

```
INTERLOCK:PIRANI:ENABLE OFF
```

Unknown Filament Emission Error (Bit 5)

This status condition is a catch-all for any condition that resulted in failure to start filament emission that cannot be explained by any other known reason.

This should not happen in normal operation. If this status condition is encountered, it is best to wait some time and try to start filament emission once again. If the status condition persists, it may point to an internal software or hardware error.

Cannot Set Emission – Timeout (Bit 6)

Each time the filament emission is changed, the RGA tries to control the filament emission to the set point. If, for some reason, emission does not stabilize near the set point within an acceptable time period, this status condition is set and filament emission is shut off.

This should not happen during normal operation, but there are instances where this can happen due to external factors.

This can likely happen if the user has installed a non-standard filament and the RGA does not have sufficient drive power to set the emission current to the setpoint. It may also happen if chamber pressure is high enough to allow a small amount of electron emission, but then cannot provide a larger emission current due to space charge effects.

Ionizer potentials may also affect overall electron emission current. If set far from the default values, this may impact total available electron emission. Check ionizer voltage settings and make sure they are near the default settings.

If the user wishes to bypass this status condition, use the following command:

```
INTERLOCK:FILAMENT:ENABLE 0
```

Or:

```
INTERLOCK:FILAMENT:ENABLE OFF
```

This will disable the internal timer and will not check for filament emission current stability. The filament emission control will continue to operate as best it can but will not signal a problem if the setpoint cannot be achieved in an acceptable time period.

No Filament (Bit 7)

This status condition occurs when the user tries to start filament emission but the RGA detects there is no filament. If this occurs, the only solution is to replace the filament.

To check the filament connectivity, power down the RGA and remove the electronics module from the probe. Use an ohmmeter across the filament terminals to verify that there is a filament. A good filament should read on the order of 1 Ω or less. An open connection indicates the filament is broken.

If the user is trying to perform ion current scans with the filament intentionally off or removed, the ionizer potentials may not be energized. This is done to protect the instrument. Ionizer potentials are normally energized only when filament emission has begun. This can be bypassed with the following command:

```
IONIZER:POTENTIALS:AUTO 0
```

Or:

```
IONIZER:POTENTIALS:AUTO OFF
```

This will allow the instrument ionizer potentials to be energized even with no filament emission.

Internal Emission Measurement Failure (Bit 8)

Measuring filament emission current requires supplemental electronics internal to the RGA. If that internal electronics fails, the RGA is unable to measure filament emission current.

If that occurs, this status condition is set. This indicates a likely failure of internal hardware.

To mitigate this issue, try running at reduced filament emission current. The probability of this failure occurring is reduced at lower emission currents. If no emission current is possible due to this status condition, the RGA may need to be repaired.

Degas Failure (Bit 9)

The Degas procedure places an unusually high level of stress on the filament in order to provide an increasing emission current up to 20 mA. If a problem occurs during the Degas procedure, the degas procedure is aborted and the filament emission current is shut down.

This can occur due to a number of factors. While an internal hardware failure may cause this issue, other external factors may cause the degas procedure to fail.

The filament may require replacement, either due to age or because only a single filament remains in the probe module.

The pressure in the chamber may be too high for the ionizer to produce 20 mA of electron emission current. Reduce the pressure in the vacuum chamber and try again.

Control Voltage Imbalance (Bit 10)

To maintain stable filament emission current, the RGA controls the voltage applied to the filament. When the reading of the control voltage deviates from the set point, this may indicate a hardware problem which can prevent adequate control of the filament emission current.

If the voltage imbalance persists for more than two seconds, filament emission is stopped and this status bit is set. This is likely caused by a failure in internal hardware.

The internal monitoring of filament control voltage is disabled when the Filament Interlock is disabled. See `INTERLOCK:FILament:ENable` in the Remote Command list for more information.

Filament Emission Unstable (Bit 14)

The RGA continuously monitors filament emission current while it is energized. If conditions within the instrument or the vacuum chamber cause the emission control system to be unable to settle the emission current to the set point, this status condition will be set and the emission current will be set to 0.

This status condition is not seen during normal operation. This may be caused by internal hardware failure in the instrument or wildly varying chamber pressure. If the problem is external to the instrument, stabilize the pressure and try restarting filament emission.

Filament Emission Runaway (Bit 15)

The RGA continuously monitors filament emission current while it is energized. If the instrument detects that filament emission is increasing past the set point and cannot be decreased, the instrument shuts down the filament.

This status condition is not seen during normal operation and typically indicates a hardware failure. Other factors could play a part when seeing this status condition. Stray voltages over parts of the internal circuity may confuse the ability for the instrument to control filament emission. If any external modifications have been made to the instrument or if there is unexpected contact between the RGA and other unrelated signals, it may cause this status condition.

Quadrupole Mass Field (Register 2)

This register reports events that are related to the RF/DC voltages generated for ion focusing.

For this register, the status conditions are checked at regular intervals while the RF/DC fields are active during a scan or measurement.

Bit	Weight	Description
0	1	RF Amplitude Mismatch
1	2	RF Drive Current Too High
2	4	RF Drive Voltage Too High
3	8	RF Frequency Range Error

Table 9-5 Quadrupole Mass Field Register Status Conditions

RF Amplitude Mismatch (Bit 0)

The internal RF drive circuitry measures the RF voltage amplitude in the probe module. If the measured RF amplitude deviates from the set voltage by a large amount, this indicates that the instrument cannot provide enough RF energy to measure ion currents.

This status condition is not expected during normal operation. The RF Drive circuitry is responsible for controlling the RF amplitude, but if the internal circuitry becomes saturated, then there is a maximum value for the RF Voltage. When this is detected, the status condition is set.

This may indicate an internal hardware failure, or a software failure in mass tuning. If this status condition is encountered, abort the scan or measurement, and then reload the default RF/DC tuning parameters from factory settings in non-volatile memory with the following command:

```
QMF:TUNE:FACTORY:LOAD
```

This should reload RF/DC tuning parameters that should reasonably match with the matched probe module. Restart the scan.

RF Drive Current Too High (Bit 1)

During ion current scans and measurements, RF voltage is adjusted for the ion mass being measured. During normal operation, the RGA can provide RF energy for all masses within the instrument's range.

This status condition is not expected during normal operation. The RF drive circuitry should be able to provide enough current to support ion currents for any ion mass. This status condition may indicate that the instrument has reached the limit for drive current.

This may indicate a hardware failure. Check for a short in the quadrupole connections.

There may also be a software failure in mass tuning. If this status condition is encountered, abort the scan or measurement, and then reload the default RF/DC tuning parameters from factory settings in non-volatile memory with the following command:

```
QMF:TUNE:FACTORY:LOAD
```

This should reload RF/DC tuning parameters that should reasonably match with the matched probe module. Restart the scan.

RF Drive Voltage Too High (Bit 2)

During ion current scans and measurements, RF voltage is adjusted for the ion mass being measured. During normal operation, the RGA can provide RF energy for all masses within the instrument's range.

This status condition is not expected during normal operation. The RF drive circuitry should be able to provide enough power to support ion currents for any ion mass. This status condition may indicate that the instrument has reached the limit for drive voltage.

This may indicate a hardware failure. Check for a short in the quadrupole connections.

There may also be a software failure in mass tuning. If this status condition is encountered, abort the scan or measurement, and then reload the default RF/DC tuning parameters from factory settings in non-volatile memory with the following command:

```
QMF:TUNE:FACTORY:LOAD
```

This should reload RF/DC tuning parameters that should reasonably match with the matched probe module. Restart the scan.

RF Frequency Range Error (Bit 3)

During ion current scans and measurements, the RF Frequency is adjusted to maintain resonance to provide maximum power transmission. If the resonant frequency shifts too far high or low, this status condition will be set and the RF frequency will not shift beyond the minimum or maximum limit.

This is not expected during normal operation. This status condition may indicate that there is an internal hardware failure inside the RGA or in the probe.

CEM (Register 3)

This register reports events that are related to CEM operation.

The conditions are reset each time the CEM voltage is changed.

Bit	Weight	Description
0	1	Cannot Set CEM Voltage
7	128	No CEM Detected

Table 9-6 CEM Register Status Conditions

Cannot Set CEM Voltage (Bit 0)

When the CEM is enabled by setting a high voltage potential, the RGA monitors the drive voltage necessary to attain the high voltage setting. If the drive voltage is near the maximum full scale value, this status condition will be set, and the CEM will be shut down to protect the CEM module.

This status condition may indicate an installation problem with the CEM on the probe module. It may also indicate aging of the CEM has degraded its performance.

The user may try to operate the CEM at a lower voltage. In addition, the check against maximum drive voltage may be bypassed with the following command:

```
INTERLOCK:CEMPROTECT:ENABLE 0
```

Or:

```
INTERLOCK:CEMPROTECT:ENABLE OFF
```

This will allow the CEM to be enabled without checking the drive voltage. Note that the CEM may not offer the performance expected while the CEM protection is off.

No CEM Detected (Bit 7)

This status condition is set if the RGA does not have on board circuitry to drive a CEM module. It will remain set at all times for any RGA with that configuration.

At this time, all RGA120 family instruments will have on board CEM drive circuitry. So this status condition will not be set, but remains reserved for future use.

Auxiliary I/O (Register 4)

This register reports events that are related to auxiliary I/O on the instrument back panel. Refer to the section on Auxiliary I/O for more information on how to use this feature.

Bit	Weight	Description
0	1	Input Current Loop Voltage Power Error
1	2	Output Voltage Failure
2	4	Output Current Under/Overcurrent
3	8	Input Undercurrent

4	16	Input Overcurrent
5	32	RTD Connection
6	64	HV Disabled

Table 9-7 Auxiliary I/O Register Status Conditions

Input Current Loop Voltage Power Error (Bit 0)

Internal circuitry supplies loop power voltage for analog input current. If the RGA detects a problem that causes this voltage source to overheat, the RGA will shut down the voltage source and set this status condition.

This status condition should not be seen during normal operation. If this status condition is set, verify that any external instrumentation is correctly connected to the auxiliary I/O terminals on the instrument back panel. Disconnect the external instrumentation if necessary.

If this status condition persists after disconnecting any external devices, this may indicate an internal hardware problem.

Output Voltage Failure (Bit 1)

Internal circuitry supplies an output voltage on the back panel terminal connectors. If the RGA detects a problem that causes this voltage source to overheat, the RGA will shut down the voltage source and set this status condition.

This status condition should not be seen during normal operation. If this status condition is set, verify that any external instrumentation is correctly connected to the auxiliary I/O terminals on the instrument back panel. Disconnect the external instrumentation if necessary.

If this status condition persists after disconnecting any external devices, this may indicate an internal hardware problem.

Output Current Under/Overcurrent (Bit 2)

Internal circuitry supplies an output current on the back panel terminal connectors. If the RGA detects that either it cannot source an adequate current or that too much current is being sourced by the instrument, this status condition will be set.

This status condition is normally seen when analog output current is enabled, but the analog output current terminals are not connected to an external device made to sense current. This may also occur if the connected external device has an impedance too high to drive the current that is being source by the RGA.

If this status condition is seen, verify that the external device connections are correct. Verify that the input impedance of the external device does not exceed the maximum impedance that can by driven by the current source.

Additionally, the analog current output can also be disabled to reset this status condition.

Input Undercurrent (Bit 3)

Analog current input is always enabled and is monitored by the RGA at all times. The current input operates with the expectation of a range of 4-20 mA of current. If the RGA detects that the analog current input value is below that range, this status condition is set.

This status condition is normally seen when there is no current source connected to the RGA. If an external device is connected to the analog current input and this status condition is seen but is unexpected, verify that the external device is connected correctly to the RGA back panel terminal. If the external device requires loop power to operate, then enable loop power voltage in the RGA. Refer to the Analog I/O section for more information about setting loop power voltage.

Input Overcurrent (Bit 4)

Analog current input is always enabled and is monitored by the RGA at all times. The current input operates with the expectation of a range of 4-20 mA of current. If the RGA detects that the analog current input value is above that range, this status condition is set.

This status condition indicates that the external analog current source may not be operating correctly, or is not configured to sink or source a 4-20 mA current. Verify that the device is configured and connected to the RGA correctly.

RTD Connection (Bit 5)

The RGA monitors the state of any RTD connected to the instrument back panel. If the RGA detects that the RTD is disconnected, or miswired in any way, this status condition will be set. See the discussion on RTDs in the Analog I/O chapter for more information on how an RTD is connected and used.

Note that this status condition will be set during normal operation if there is no RTD connected. The status condition will remain set. If the event register is read and cleared, the RTD connection event will not be set again.

HV Disabled (Bit 6)

The RGA has detected that the HV Enable pin on the back panel of the instrument is below the threshold voltage and has disabled the high voltage components inside the instrument. This status condition is set to notify the user that this has occurred.

Detector (Register 5)

This register reports events that are related to the ion detector circuitry.

Bit	Weight	Description
0	1	Probe Not Present
1	2	Detector Offset Out of Range
2	4	Electrometer ADC Overflow
3	8	Detector Latchup
7	128	ADC Test Failure

Table 9-8 Detector Register Status Conditions

Probe Not Present (Bit 0)

The RGA cannot sense the presence of the probe module. The instrument capabilities are limited to operations that can be performed without with probe module.

If this status condition is unexpected, power off the RGA and verify that the RGA is firmly seated onto the probe module.

If the status condition persists, this may indicate a problem with the electrical connection between the electronics module and the probe module.

Detector Offset Out of Range (Bit 1)

When the detector offset is measured by the RGA at the start of each scan (unless offset measurement is disabled), if the detector offset is too high, this will distort ion current measurements. When the measured detector offset is too high, this status condition will be set.

If this status condition is seen, repeat the measurement. If the status condition persists, this may indicate an internal measurement problem.

Electrometer ADC Overflow (Bit 2)

During any ion current scan or measurement, the RGA records measurements from the ADC that measures ion current. If the ADC reports an overflow, this status condition will be set.

This status condition should not be seen during normal operation. The RGA is limited in its ability to measure ion current by the full scale amplitude of the ADC. If this is exceeded, then the RGA cannot accurately report ion currents.

If this status condition is seen, it may be caused by an overly high ion current being measured. If this is the case, reduce the pressure inside the vacuum chamber and repeat the measurement. If the CEM is being used, reduce the HV gain or disable it and repeat the measurement.

If the status condition persists, this may indicate a hardware issue with the electrometer ADC.

Detector Latchup (Bit 3)

The RGA performs a detector temperature calibration on a regular basis. A constant current source is used to calibrate the electrometer. This constant current source is switched into the electrometer input during calibration. If the switch fails, this will cause ion current scans to be incorrect.

If this status condition is seen, it means that the switch has experienced a failure. This normally can be corrected by power cycling the RGA instrument.

If the status condition repeats and persists, it may indicate a permanent failure of the switch.

ADC Test Failure (Bit 7)

During ion current scans and measurements, the RGA queries the status or the electrometer ADC. If an error is reported by the ADC, this status condition will be set.

This status condition should not be seen in normal operation. This may be caused by an ADC overflow from measuring excessively high ion currents. It may also be caused by an internal error in the ADC.

Power Supply (Register 6)

This register reports events that are related to values that are monitored from the external power supply.

Bit	Weight	Description
5	32	Power Supply Overcurrent
6	64	Power Supply Undervoltage
7	128	Power Supply Overvoltage

Table 9-9 Power Supply Register Status Conditions

Power Supply Overcurrent (Bit 5)

This status condition indicates that the RGA power supply is supplying too much current. Check all connections to the RGA and verify that none of the probe elements are shorted to the vacuum chamber. Also verify that all other devices are connected correctly to the RGA and are operating correctly.

Power Supply Undervoltage (Bit 6)

This status condition indicates that the RGA power supply is below 22V. Check the power supply or replace it with another that can supply a steady voltage between 22-26 V. For RGAs with a built-in power supply, this may indicate a problem with internal circuitry.

Power Supply Overvoltage (Bit 7)

This status condition indicates that the RGA power supply is above 26V. Check the power supply or replace it with another that can supply a steady voltage between 22-26 V. For RGAs with a built-in power supply, this may indicate a problem with internal circuitry.

Ionizer (Register 7)

This register reports events that are related to ionizer focusing element electronics.

Bit	Weight	Description
0	1	Repeller Thermal Limit
1	2	Repeller Overcurrent
2	4	Focus Plate Thermal Limit
3	8	Focus Plate Overcurrent
4	16	Repeller Undervoltage

Table 9-10 Ionizer Register Status Conditions

Repeller Thermal Limit (Bit 0)

The repeller voltage circuitry has detected a thermal problem which has caused a shutdown. This status condition should not be seen during normal operation. It may indicate an internal hardware problem, or may indicate an interaction with external components contacting the repeller portion of the probe module.

Inspect the probe module and verify that it is not in contact with any other material.

Repeller Overcurrent (Bit 1)

The repeller voltage circuitry has detected that too much current is being used to supply the voltage potential requested. The typical reason for this is that the repeller cage has shorted by contacting the metal of the vacuum chamber.

Inspect the probe module and align the apparatus so that it is not in contact with any outside material.

Focus Plate Thermal Limit (Bit 2)

The focus plate voltage circuitry has detected a thermal problem which has caused a shutdown. This status condition should not be seen during normal operation. It may indicate an internal hardware problem, or may indicate an interaction with external components contacting the focus plate portion of the probe module.

Inspect the probe module and verify that it is not in contact with any outside material.

Focus Plate Overcurrent (Bit 3)

The focus plate voltage circuitry has detected that too much current is being used to supply the voltage potential requested. This status condition should not be seen during normal operation. It may indicate that some part of the probe module is misaligned and the focus plate is being shorted.

Repeller Undervoltage (Bit 4)

The repeller voltage potential is essential to the operation of the RGA. The voltage potential must be high enough to maintain the ability to measure other internal parameters.

This status condition should not be seen during normal operation. Normally, the repeller voltage settings are limited such that the user cannot set the value too low. Set the repeller voltage higher, or to the default voltage.

This status condition may also be set when the repeller cage is shorted to ground. This can occur if the repeller cage is touching the interior metal walls of the vacuum chamber.

Inspect the probe module and align the apparatus so that it is not in contact with any other material.

Electronics (Register 8)

This register reports events that are related to general electronics on the main board.

Bit	Weight	Description
0	1	Instrument Shutdown Detected
1	2	Instrument Overtemperature
2	4	Shift Register Error
3	8	Flash Memory Error
5	32	SPI Transfer Error
6	64	Watchdog Reset
7	128	Unexpected Instrument Reset
8	256	Power On Reset
15	32768	Unknown Instrument Error

Table 9-11 Electronics Register Status Conditions

Instrument Shutdown Detected (Bit 0)

The RGA firmware must remain in contact with the RGA hardware at regular intervals. If a deadline is missed, then the hardware assumes the firmware has failed in some way. Hardware shuts down all high voltage components of the instrument for instrument protection. The CEM and filament are powered down. RF/DC fields are shut down. All Analog Output is also shut down.

If the firmware resumes contact with the RGA hardware, the firmware restores high voltage and sets this status condition. The filament and CEM remain off.

This is not expected in normal operation. It may indicate a problem with firmware operation. The state of the instrument may be unstable. The best solution for this is to power cycle the RGA and resume normal use. If this status condition continues to be set, there may be internal hardware issue affecting the firmware in unexpected ways.

Instrument Overtemperature (Bit 1)

There are multiple temperature sensors within the RGA. If any of them go above a preset threshold, this status condition is set.

This is not expected in normal operation, but may happen if the RGA is heated above normal temperatures.

If the sensors have failed, or if the user is confident that RGA operation can proceed despite the high temperature condition, this status condition may be suppressed with the following command:

```
INTERLOCK:TEMPERATURE:ENABLE 0
```

Or:

```
INTERLOCK:TEMPERATURE:ENABLE OFF
```

Note: Running the RGA at excessive temperatures may affect the reliability of instrument measurements.

Shift Register Error (Bit 2)

This status condition indicates there was a data transfer error internal to the instrument. This may be caused by spurious noise which disrupted communication in some way. While not expected during normal operation, it may be a transitory situation. The best solution is to power cycle the instrument and continue with normal operation.

If the status condition continues to occur, it likely is caused by an internal software or hardware problem.

Flash Memory Error (Bit 3)

This status condition indicates there was an error accessing the internal flash memory. This may be caused by spurious noise which disrupted communication in some way. While not expected during normal operation, it may be a transitory situation. The best solution is to power cycle the instrument and continue with normal operation.

A flash memory error may affect the ability to save parameters.

If the status condition continues to occur, it likely is caused by an internal software or hardware problem.

SPI Transfer Error (Bit 5)

This status condition is set when there is a problem with internal communications between two instrument subsystems. This is not expected during normal operation and typically indicates that there is a problem with the instrument.

The best solution is to power cycle the instrument and continue with normal operation. If the status condition continues to occur, it will likely affect overall instrument performance.

Watchdog Reset (Bit 6)

If the RGA firmware halts for some reason, an internal watchdog will cause the instrument to reset after some time. This status condition will be set as an indicator that it happened.

This is not expected to occur. If this status condition repeats, this likely indicates a hardware or software failure.

Unexpected Instrument Reset (Bit 7)

If the RGA resets unexpectedly for a reason other than either a power failure or a watchdog reset, this status condition will be set. This is not expected to occur and is likely an indication of a software or hardware failure.

Power On Reset (Bit 8)

This status condition is set for a normal power on reset. The condition bit remains set for the duration of the time the instrument remains powered up. The event bit is set when a normal power on reset occurs as a convenience to the user to indicate that the instrument has power cycled for some reason. When the event register is read, the event bit is cleared and will not be set again until another power on reset occurs.

Note: The command `STATus:CONDition:ASSERT` will set this event bit once again.

Unknown Instrument Error (Bit 15)

This status condition is relegated to cover any software error that occurs due to some internal corrupted data which is beyond the capability of the firmware to process. This is not expected to occur and is likely and indication of a software or hardware failure.

Pressure (Register 9)

This register reports events that are related to instrument parameters that are monitored which may indicate an overpressure condition. Status conditions that are set in this register will light the Pressure LED on the back panel of the RGA.

Bit	Weight	Description
0	1	Filament Drive Overvoltage
1	2	Filament Emission Undercurrent
2	4	Pirani Test Failure
3	8	Analog Input Voltage Over Limit
4	16	Analog Input Current Over Limit
5	32	Focus Plate Overpressure

Table 9-12 Pressure Register Status Conditions

Filament Drive Overvoltage (Bit 0)

As the pressure increases in the vacuum chamber, the filament drive voltage necessary to maintain the set value of electron emission increases. If the drive voltage nears its maximum value, this sets this status condition and shuts down the filament.

Note: This may also be caused by a worn down or damaged Thoria coating on the filament. This is a rare event due to the long life of the thoriated iridium filaments.

Note: Use of non-standard filament thicknesses or composition such as Tungsten may also cause this status condition.

If this status condition is seen, verify that there are no leaks in the vacuum chamber and that the pressure is within acceptable RGA limits. If the pressure is acceptable, check for shorts in the ionizer assembly. Use an ohmmeter to check the conductance between the ionizer's connectors and the vacuum system. (The ionizer feedthrus are easily identified using the drawings in the RGA Assembly section.)

If a short is detected, remove the probe from the vacuum system, inspect the ionizer and fix any shorts. Note: Use the information in the RGA Maintenance section to remove the repeller and/or service the ionizer.

If the short is still present, remove the RGA Cover Nipple and inspect the rest of the probe for other sources of shorts (misalignments, loose screws, etc.) If no short is detected, the Thoria coating of the filament might be damaged.

Inspect the filament (best with a magnifying glass) and look for large sections of missing Thoria coating. If a problem is suspected, replace the filament using the procedure in the RGA Maintenance section. If the filament still does not turn on, it may indicate a problem internal to the RGA electronics.

If the user is sure that the chamber pressure is within acceptable limits for RGA operation, this parameter monitor may be bypassed with the following command:

```
INTERLOCK:FILAMENT:ENABLE 0
```

Or:

```
INTERLOCK:FILAMENT:ENABLE OFF
```

When disabled, the RGA will not check the filament drive voltage as an indirect indicator of a high vacuum chamber pressure.

Filament Emission Undercurrent (Bit 1)

For overly high vacuum chamber pressure, the RGA reaches a maximum drive power and cannot maintain the requested electron emission current. In this case, the RGA sets this status condition and shuts down the filament.

Note: This may also be caused by a worn down or damaged Thoria coating on the filament. This is a rare event due to the long life of the thoriated iridium filaments.

Note: Use of non-standard filament thicknesses or composition such as Tungsten may also cause this status condition.

If this status condition is seen, verify that there are no leaks in the vacuum chamber and that the pressure is within acceptable RGA limits. If the pressure is acceptable, check for shorts in the ionizer assembly. Use an ohmmeter to check the conductance between the ionizer's connectors and the vacuum system. (The ionizer feedthrus are easily identified using the drawings in the RGA Assembly section.)

If a short is detected, remove the probe from the vacuum system, inspect the ionizer and fix any shorts. Note: Use the information in the RGA Maintenance section to remove the repeller and/or service the ionizer.

If the short is still present, remove the RGA Cover Nipple and inspect the rest of the probe for other sources of shorts (misalignments, loose screws, etc.) If no short is detected, the Thoria coating of the filament might be damaged.

Inspect the filament (best with a magnifying glass) and look for large sections of missing Thoria coating. If a problem is suspected, replace the filament using the procedure in the RGA Maintenance section. If the filament still does not turn on, it may indicate a problem internal to the RGA electronics.

If the user is sure that the chamber pressure is within acceptable limits for RGA operation, this parameter monitor may be bypassed with the following command:

```
INTERLOCK:FILAMENT:ENABLE 0
```

Or:

```
INTERLOCK:FILAMENT:ENABLE OFF
```

When disabled, the RGA will not check the filament emission current as an indirect indicator of a high vacuum chamber pressure.

Pirani Test Failure (Bit 2)

When the filament is first started, the RGA makes a measurement using the filament to test the gas pressure within the vacuum chamber. If the test passes, the filament is brought up to temperature to provide an electron emission current. If the test fails, this status condition is set and the filament remains off.

There are many reasons why this test may fail. The most common reason will be that the chamber pressure is too high. Verify that there are no leaks and lower the chamber pressure to an acceptable level.

If the chamber pressure is acceptable, then wait at least 15 seconds and try to start the filament once more. If this status condition persists, it may indicate a software or hardware failure in the instrument.

If the user is sure that the chamber pressure within acceptable limits for RGA operation, this test may be bypassed with the following command:

```
INTERLOCK:PIRANI:ENABLE 0
```

Or:

```
INTERLOCK:PIRANI:ENABLE OFF
```

When disabled, the RGA will not test the vacuum chamber pressure with the filament when the filament is first started.

Analog Input Voltage Over Limits (Bit 3)

This status condition is used when the analog voltage input is configured with an external pressure gauge to monitor for an overpressure condition. Refer to the Auxiliary I/O section for more information about how to configure this feature.

When the RGA analog input voltage is greater than the user configured voltage value, this status condition is set. The filament is shut off and the Pressure LED is lit as an indicator that a pressure event occurred.

Analog Input Current Over Limit (Bit 4)

This status condition is used when the analog current input is configured with an external pressure gauge to monitor for an overpressure condition. Refer to the Auxiliary I/O section for more information about how to configure this feature.

When the RGA analog input current is greater than the user configured current value, this status condition is set. The filament is shut off and the Pressure LED is lit as an indicator that a pressure event occurred.

Focus Plate Overvoltage (Bit 5)

When ions are formed in the ionizer, they are focused to the detector. The majority of the ions that do not get focused through the aperture strike the focus plate and cause an ion current. If the vacuum chamber pressure is too high, the ion current produced in the focus plate may saturate the measurement. If the ion current in the focus plate is that high, it is a likely indicator that the vacuum chamber pressure is too high. The status condition is set; the filament is shut off, and the Pressure LED is lit as an indicator that a pressure event occurred.

Verify that the chamber pressure is in the acceptable range for RGA measurements. If this status condition persists, it may be caused by an internal software or hardware problem.

Chapter 10

RGA Maintenance

This chapter describes how to maintain the components of the quadrupole probe. The ECU does not have any serviceable parts and should not require any routine maintenance.

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Warnings!

- **The service information in this chapter is for the use of Qualified Service Personnel. To avoid shock, do not perform any procedures in this chapter unless you are qualified to do so.**
- **Read and follow all "Safety and Precaution" warnings before servicing the product.**
- **Dangerous voltages, capable of causing injury or death, are present in this instrument. Use extreme caution whenever servicing any of its parts.**
- **Carefully follow the instructions in this chapter. Failure to do so might result in serious personal injury and damage to the instrument.**
- **Do not substitute parts or modify the instrument. Because of the danger of introducing additional hazards, do not install substitute parts or perform any unauthorized modification to the product. Do not use the product if it has unauthorized modifications. Return the product to SRS for service and repair to ensure that safety features are maintained.**
- **Use only SRS supplied replacement parts.**
- **Disconnect the ECU box from the probe before servicing any of the probe components.**
- **Turn off the emission and wait for at least 30 minutes before removing a probe from a vacuum chamber. Serious burns can occur if the probe components are handled too soon.**
- **Use proper vacuum procedures when handling the probe.**
- **Avoid contaminating the probe:**
  - **Work in a clean, dust free area. A clean room compatible environment is best.**
  - **Do not talk or breath on any of the parts.**
  - **Wear gloves!**
  - **Use clean tools during service procedures!**
  - **Wear face masks, hair covers and no facial make-up.**
- **Protect the integrity of the vacuum seals:**
  - **Avoid scratching the metal seals.**
  - **Do not use nonmetal seals.**
- **Verify that the vacuum port is electrically grounded before attempting installation of the RGA to the vacuum system.**

- **Stanford Research Systems does not guarantee that the cleaning procedures described in this chapter will completely remove contamination from the probe. In some cases (i.e. depending on the vacuum composition) replacement of the parts might be the only solution to a contamination problem.**

Probe Bakeout

Bakeout of the RGA probe is recommended in the following cases:

1. After installation of the probe in the vacuum chamber.

2. After prolonged exposure of the probe assembly to open air.

2. When background contamination is present in the mass spectra.

3. When the performance of the RGA is degraded due to excessive contamination.

When a new component is introduced into a high vacuum system or after the vacuum chamber has been vented up to air, outgassing of molecules (particularly H_2O) from the walls usually determines the time it takes the pumping station to establish the desired base pressure. A bakeout accelerates the outgassing rates and results in reduced pump-down times.

In many cases a bakeout is needed to efficiently remove low-vapor pressure impurities from the walls. A thorough bakeout helps clean the entire probe and usually results in reduced contribution of the RGA sensor to the background signals.

As the RGA is used, deposits form on the ionizer parts and on the filter components. The performance of the spectrometer is affected by the build-up of electrostatic charge on the contaminated surfaces. The symptoms of the problem are: decreased sensitivity, decreased resolution and, in severe cases, unusual peak shapes. A periodic bakeout helps keep the quadrupole probe clean and minimizes this problem.

A thorough bakeout affects the entire probe. It is a better alternative than a “Filament Degas” process which acts only on the ionizer and compromises the lifetime of the filament.

Warnings

- To avoid fire risk use a good quality heater with a built-in temperature limit switch.
- The O100HJR 200 °C self-regulating heater jacket is recommended for use with the standard RGA nipple.
- To avoid overheating the components use a reliable temperature controller to regulate the bakeout temperature.
- Do not leave the system unattended for long periods of time.
- To avoid damage to the electronic components detach the ECU from the probe during bakeout.
- Do not operate the RGA during bakeouts.
- To avoid burns cover the heater with heavy insulation during bakeout, and do not touch the probe until it cools down after bakeout is over.
- Use only metal gasket seals during bakeout since rubber gaskets might melt!

Procedure

1. The quadrupole probe must be mounted on the vacuum system and at a base pressure under 10^{-6} Torr.

2. Turn off the RGA and disconnect the ECU from the probe.

3. Wrap a heating tape or heating jacket around the entire probe and cover with fiberglass insulation if necessary. Make sure the entire probe, including flanges, is evenly covered.

4. Bake the probe to at least 200°C for several hours (i.e. overnight).

5. After bakeout wait for the probe to cool down to room temperature before mounting the ECU back on its flange.

6. Run the peak tuning procedure.

Ionizer Degas

An Ionizer Degas program is built into the RGA to clean up the filament and the ionizer by Electron Impact Desorption. Degassing provides a fast way to clean up the ion source, however, it compromises the lifetime of the thoria coating of the filaments and it is no substitute for a complete bakeout of the probe. Its use is only recommended when contamination of the probe is suspected and a long bakeout is not a practical option.

During the degas process the anode grid and the filament are bombarded by a 20 mA current of 400 eV electrons. The complete process takes three minutes and can be triggered directly from the RGASoft program (Probe Menu). The emission current is ramped slowly during the first minute to eliminate sudden bursts of gases into the vacuum system.

The electron multiplier is turned off at the beginning of the cycle. The emission current is turned back to its pre-degas setting at the end of the degas cycle, but the electron multiplier is always left off for additional protection. Overpressure protection is built into the degas procedure and the filament will immediately shut down if a leak is detected.

For users developing their own software, the Degas process can be triggered with the DG command described in the **RGA Command Set** List, and Degas times as large as 20 minutes long can be selected.

Ionizer Replacement

As the RGA is used, deposits form on the ionizer parts and the sensitivity of the sensor is degraded. Once the sensitivity of the spectrometer is significantly affected by this buildup it is necessary to completely replace the ionizer. All components of the ionizer should be replaced together at once. The replacement procedure is simple and should only take a few minutes.

It is recommended that the filament be replaced as well during this procedure since some damage to its Thoria coating is inevitable during handling.

Equipment

- Ionizer Replacement kit (O100RI): consisting of repeller cage, anode grid, focus plate, and spare screws and e-clips.
- One standard OFHC copper gasket for 2 3/4" CF Flange. New and Clean!
- Precision flat-head screw driver: 2.5 mm head.
- Needle nose pliers.
- Latex gloves/powder free.
- Clean, dust-free work area.

Procedure

1. **Read all warnings** at the beginning of this chapter before attempting to service the probe.
2. Set up in advance a clean dust-free working area where to carry out this procedure.
3. Turn off the RGA and disconnect the ECU from the probe.
4. Wait for the probe to cool down for at least 30 minutes after the emission is turned off. **Severe burns can result if the probe is handled too soon**.
5. Without disconnecting the RGA Cover Nipple from the vacuum port, remove the six bolts from the feedthru flange at the end of the probe and slide the entire probe assembly out of the vacuum system (Note the rotational orientation of the Feedthru Flange before removing the probe assembly from the vacuum system so that the probe can be reassembled in the exact same way at the end of the procedure. Mark the side of the flanges with a permanent marker if necessary.) The ionizer, the filter, and the detector are now fully exposed and easily accessible.

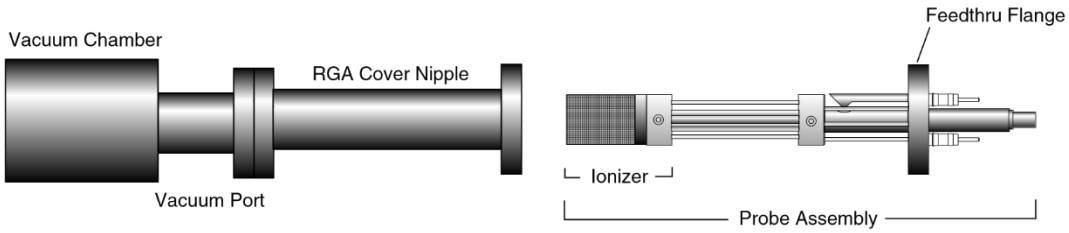


Figure 10-1 Probe Removal for Ionizer Replacement

6. Carry the probe to a clean, dust free area immediately. **Avoid contamination** using handling procedures compatible with high vacuum requirements.

7. Hold the probe in a upright position and do a thorough visual inspection of the unit. Check for loose, damaged, misaligned and contaminated components.

8. Using the clean, flat-head screwdriver remove the screw that connects the repeller to the longest filament rod and pull out the cage exposing the filament and the anode grid. Be careful not to damage the delicate filament if you plan to use it again!

9. Remove the filament following the steps and precautions described in the "Filament Replacement" section of this chapter.

10. Next, pull out the anode grid after removing the two screws that fasten its bottom plate to the alignment rods. The two rods do not need to be replaced and should not be moved during this procedure!

11. Finally, remove the two screws that hold the focus plate against the top alumina spacer and pull out the plate. The short alignment rod will also need to be removed during this step, but it does not need to be replaced (Save it!).

12. Use the new parts from the "Ionizer Replacement Kit" to replace the ionizer components. The new components are clean and vacuum compatible. **Avoid contamination! Replace all components at once! Discard the old ones!**

13. Use two fresh screws from the ionizer replacement kit to mount the new focus plate on the alumina spacer. Make sure the short alignment rod is put back in place and the screws are tight.

14. Install the new anode grid. Use the new screws to fasten its bottom plate to the alignment rods. **Caution:** The anode cage is fairly strong but it should still be handled very carefully since its correct alignment is essential for optimum performance of the RGA.

15. Once the anode grid is secured in place, replace the filament following the steps described in the "Filament Replacement" section of this chapter. **It is highly recommended that a new filament be used for this step since damage to the delicate thoria coating is unavoidable during removal.**

16. Attach the new repeller to the longer filament rod using a fresh screw. Align the cage and tighten the screw (Correct alignment is best assured when the two small holes on the side of the repeller cage line up with the filament screws.)

17. Inspect visually the entire ionizer assembly to assure the correct alignment of its parts, and, if satisfied, mount the probe back on the vacuum system. Check the correct rotational orientation of the feedtrhu flange (i.e. same as it was before disassembly) before tightening the flange bolts.

18. A bakeout of the probe is highly recommended before operating the RGA again.

19. Retune the sensitivity of the RGA, following the instructions in the RGA Tuning chapter, before using the unit for quantitative measurements.

Filament Replacement

The filament eventually wears out and needs to be replaced. There is no need to send the RGA unit back to the factory for this service. The replacement procedure is simple and can be completed in a few minutes by qualified personnel.

The filament is very delicate and should be handled with extreme care. The thoria coating is very delicate and can easily be damaged if the filament is mishandled. Please read the following handling recommendations before opening the filament's box:

Handling and care of the filament

- Do not bend, or twist the filament .
- Do not scratch the filament's thoria coating.
- Do not handle the filament directly with your fingers, use fine tweezers, and hold it by the platinum tabs only.
- Do not attempt to clean the filament.
- Use only SRS provided filaments as replacement.

Equipment

- Filament Replacement kit: consisting of new filament, and spare screws and nuts.
- One standard OFHC copper gasket for 2 3/4" CF Flange. New and Clean!
- Precision flat-head screw driver: 2.5 mm head.
- Needle nose pliers.
- Latex gloves/powder free.
- Clean, dust-free work area.

Procedure

1. **Read all warnings** at the beginning of this chapter before attempting to service the probe.
2. Set up in advance a clean, dust-free working area where to carry out this procedure.
3. Turn off the RGA and disconnect the ECU from the probe.
4. Wait for the probe to cool down for at least 30 minutes after the emission is turned off. **Severe burns can result if the probe is handled too soon**.
5. Unscrew the six bolts from the RGA's mounting flange and remove the entire probe from the vacuum system (Note the rotational orientation of the RGA Mounting Flange before removing the probe from the vacuum system so that it can be placed in the exact same orientation at the end of the procedure. Mark the side of the flanges with a permanent marker if necessary.). The ionizer is now fully exposed and easily accessible.

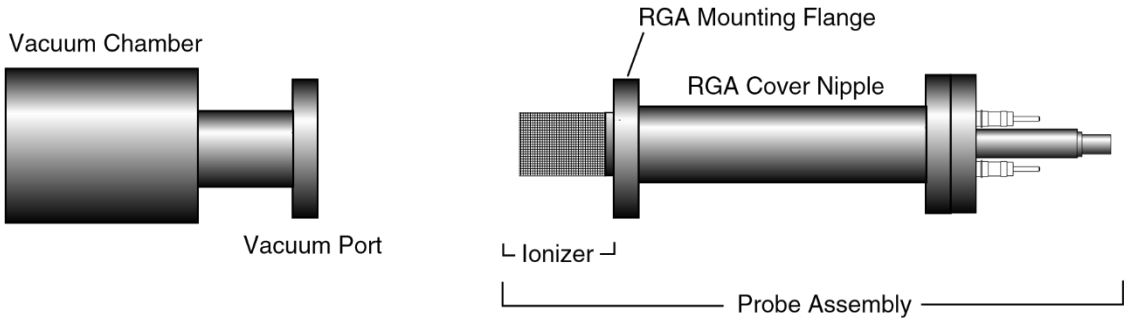


Figure 10-2 Probe Removal for Filament Replacement

6. Immediately carry the probe to a clean, dust-free area and secure it in an upright position. **Avoid contamination** using handling procedures compatible with high vacuum requirements.

7. Using the clean, flat-head screwdriver remove the single screw that connects the repeller to the longer filament rod and pull out the cage exposing the filament and the anode grid.

8. Before replacing the filament, visually inspect the entire ionizer. Check for loose, damaged, misaligned and contaminated components. Some discoloration of the ionizer parts is common, but heavy buildup on the grids and plates is a sign of severe contamination. If problems are detected, a complete "Ionizer Replacement" procedure should be carried out at this time. Otherwise, continue with the filament replacement procedure.

9. Inspect the filament, and become acquainted with the way in which it is mounted on the filament rods: The SRS RGA filament is of a circular shape and made out of very thin, thoria-coated iridium wire. Two platinum tabs, spot-welded at opposite ends of its circumference, provide electrical connection to the rods that deliver the power during emission. Precision machined slots define the exact placement of the filament tabs along the two rods and a small "screw and nut" set secure each tab in place.

10. Without removing the nuts, loosen the two screws that hold the filament in place enough to pull the filament out the ionizer assembly. Discard the old filament.

11. Leave enough clearance between each nut and the top of its corresponding alignment slot to slide the platinum tabs of the new filament during installation.

12. Open the filament box and pick up the filament by one of its platinum tabs with the clean tweezers.

13. Very carefully slide the filament into position, until the platinum tabs fall into the slots. **Do not bend or twist the filament. Do not scratch the thoria coating!**

14. Tighten the screws while pressing the nuts against the rods with the tweezers, making sure the tabs are centered in the slots.

15. Visually inspect the filament alignment and do any adjustments that might be necessary. The filament should form a circle around the anode grid. Slight bends in

the filament are common, and do not compromise its performance. Severe bends might result in electrical-shorts to the repeller and anode grid and need to be corrected. Use gentle pressure on the filament wire to bend it back into its correct shape if needed (Note: use a clean cotton swab for this procedure).

16. Attach the repeller to the longer filament rod using a fresh screw. Align the cage and tighten the screw (Correct alignment is best assured when the two small holes on the side of the repeller cage line up with the filament screws.)

17. Inspect visually the entire ionizer assembly to assure its correct alignment, and, if satisfied, mount the probe back on the vacuum system. Check the correct rotational orientation of the probe (i.e. same as it was before disassembly) before tightening the flange bolts.

18. A bakeout of the probe is recommended before operating the RGA again.

CDEM Handling and Care

Continuous Dynode Electron Multipliers (CDEM) have a history of high performance and dependability in mass spectrometry applications. By following the simple recommendations described below the user should achieve a long useful lifetime from these detectors.

Handling and mounting

Handling and mounting of the CDEM should only be performed in a clean vacuum fashion:

- Work on a clean dust-free area. Avoid dust, lint and any kind of particulate matter.
- Wear talc-free rubber gloves or finger cots.
- Use properly degreased tools.

Avoid excessive shock, such as from dropping onto a hard surface (Remember that CDEM's are made out of glass).

Operating pressure

The recommended operating pressure is $5 \cdot 10^{-6}$ or less. The lower the pressure during any operation, the longer the lifetime of the CDEM.
Never apply voltage to a CDEM at pressures above 10^{-4} Torr.

Operating temperature

The safe operating temperature of a CDEM is less than 100°C.

Bakeout temperature

The bakeout temperature must be less than 300°C with no voltage applied across the unit.

Operating voltage

The maximum voltage applied to any CDEM should never exceed 3500V. The SRS RGA High Voltage power supply is limited to a 2500V output.
Typical operating range is 1100-2500V. In general, *the lower the average signal current drawn from the detector and the lower the operating voltage, the longer the lifetime that will be realized.*

Initial pump-down

To best maintain the high gain and low dark current properties of electron multipliers it is very important to follow the steps described in the **CDEM Pre-conditioning** section of this chapter during the initial pump-down of the electron multiplier. The procedure serves to degas the detector and stabilize the gain. Failure to follow the recommended steps before powering up the multiplier might result in gain degradation by as much as a factor of ten.

Contamination

The active surface of the CDEM can be repeatedly exposed to air without degradation; however, it should not be contaminated with dust, lint or other particles. Organic substances present in the vacuum system tend to accumulate on the active surface of the multiplier and lead to slow performance degradation (due to reduced secondary emission efficiency).
Oil contamination is a serious problem, and can result in catastrophic destruction of the multiplier: use liquid nitrogen traps with diffusion pumps (particularly for slicone oil based pumps) , and molecular sieves traps with mechanical roughing pumps whenever possible.

If the multiplier becomes contaminated it must be cleaned immediately! (See **CDEM Refreshment** procedure in this chapter)

Storage

CDEM's can be stored indefinitely in a clean dry container such as an air or dry nitrogen-filled "dry box". Double bagging with clean, dust-free zip locked bags also works well as a temporary alternative

CDEM Pre-conditioning

The following preconditioning procedure is recommended for the first pump-down and initial operation of a new CDEM:

1. Pump overnight prior to initial application of voltage.

2. Begin operation at the lowest voltage possible, working up to the voltage required to produce observable peaks.

3. Limit the initial operation to trace peaks with gradual increase in abundance levels over the first two hours of operation of a new CDEM.

All CDEM's undergo an initial cleanup phase during which absorbed gases are removed from the active surface. If during this time the detector is exposed to high input currents permanent gain degradation by as much as a factor of ten may result. The steps described above help to control initial outgassing and are performed in order to precondition the CDEM. Optimum sensitivity and longer lifetime will result if the recommendations are followed.

CDEM Refreshment

A CDEM contaminated with organic impurities (i.e. pump oil) can sometimes be refreshed following the cleaning procedure described in this section.
The CDEM should show a gain improvement after the cleaning.

Warning
Stanford Research Systems does not guarantee that this procedure will remove contamination from a detector. Use this method as a last resort only.

Materials

- Ultrasonic cleaner
- Isopropyl alcohol, Electronic grade or better.
- 1000 mL beaker
- Oil-free, dry nitrogen
- Petri dish.
- Clean oven (higher than 100°C setting).

Warning:
The fumes from isopropyl alcohol can be dangerous to health if inhaled and are highly flammable. Work in well ventilated areas and away from flames.

Warning:
Read and follow all directions and warnings of the ultrasonic cleaner regarding the use of organic solvents for cleaning.

Procedure

1. Fill the 1000 mL beaker with isopropyl alcohol.
2. Gently place the CDEM into the alcohol.
3. Insert the beaker containing the CDEM into the ultrasonic cleaner for 10 minutes
4. Remove the CDEM from the isopropyl alcohol and allow it to drain for a few minutes
5. Depending on the contamination level, repeat steps 1-4 as needed.
6. Blow dry the CDEM with oil-free dry nitrogen.
7. Place the CDEM in a clean Petri dish and dry at 100°C for about one hour.

CDEM Replacement

There is no need to send the RGA unit back to the factory for this service. The replacement procedure is very simple and can be completed in a few minutes by qualified personnel.

Gain degradation limits the **lifetime** of all electron multipliers. Eventually the gain drops to unacceptable values and the multiplier needs to be replaced. As a rule of thumb, **the CDEM should be replaced when the required gains can no longer be achieved by increasing the bias voltage.**

Warnings:
The CDEM is very delicate and should be handled with extreme care.
Handling and mounting of the CDEM should only be performed in a clean vacuum fashion:

* Work on a clean dust-free area. Avoid dust, lint and any kind of particulate matter.
* Wear talc-free rubber gloves or finger cots.
* Use properly degreased tools.
* Avoid excessive shock, such as from dropping onto a hard surface (Remember that the CDEM is made out of glass).
* Use only SRS supplied electron multipliers for replacement.

Equipment

- Multiplier Replacement kit: consisting of new CDEM with mounting clamp in place and spare screws and nuts.
- One standard OFHC copper gasket for 2 3/4" CF Flange. New and Clean!
- Precision flat-head screw driver: 2.5 mm head.
- Needle nose pliers.
- Latex gloves/powder free.
- Clean, dust-free work area.

Procedure

1. **Read all warnings** at the beginning of this chapter before attempting to service the probe.
2. Set up in advance a clean dust-free working area where to carry out this procedure.
3. Turn off the RGA and disconnect the ECU from the probe.
4. Wait for the probe to cool down for at least 30 minutes after the emission is turned off. **Severe burns can result if the probe is handled too soon**.

5. Without disconnecting the cover nipple from the vacuum port, remove the six bolts from the feedthru flange at the end of the probe and slide the entire probe assembly out of the vacuum system (Note the rotational orientation of the Feedthru Flange before removing the probe assembly from the vacuum system so that the probe can be reassembled in the exact same way at the end of the replacement procedure. Mark the side of the flanges with a permanent marker if necessary.) The ionizer, the filter, and the detector are now fully exposed and easily accessible.

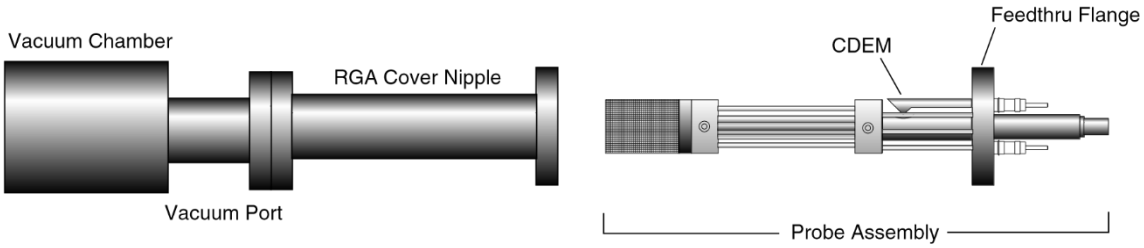


Figure 10-3 Probe Removal for CDEM Replacement

6. Carry the probe to a clean, dust free area immediately. **Avoid contamination** using handling procedures compatible with high vacuum/clean room requirements.

7. Hold the probe in a secure upright position and do a thorough visual inspection of the unit. Check for loose, damaged, misaligned and severely contaminated components. Carefully inspect the ionizer and, if any problems are detected, perform a filament and/or ionizer replacement following the procedures described earlier in this chapter. Inspect the CDEM for signs of arcing and contamination. A blue tinge is an indication of an electrical arc while brown indicates contamination. A "burned" black color may indicate both arcing and contamination have occurred. If excessive contamination is evident take the necessary steps to identify and reduce contamination sources in the vacuum system.

8. **CDEM Removal:**
   Note the position of all parts and their orientation before disassembly!
   The CDEM consists of a straight, four-channel tube made out of glass, with a cone of the same material attached to the front end. It is held upright, next to the FC, and away from the axis of the analyzer, by a **clamp** and a **clip**. The **clamp** wraps around the multiplier tube, and is connected to a neighboring rod. It assures proper alignment of the cone and provides the electrical connection to the High Voltage power supply. A hole on the side of the FC Shield allows space for mounting the cone very close to the FC top. The **clip** is spot welded to the side of the FC shield and holds the lower end of the multiplier's tube at ground. Chrome electrical coatings, deposited at both ends of the multiplier provide the necessary electrical contacts. A plate (**CDEM Anode**) mounted at the exit of the CDEM collects the secondary electrons. The whole assembly is self-aligning.

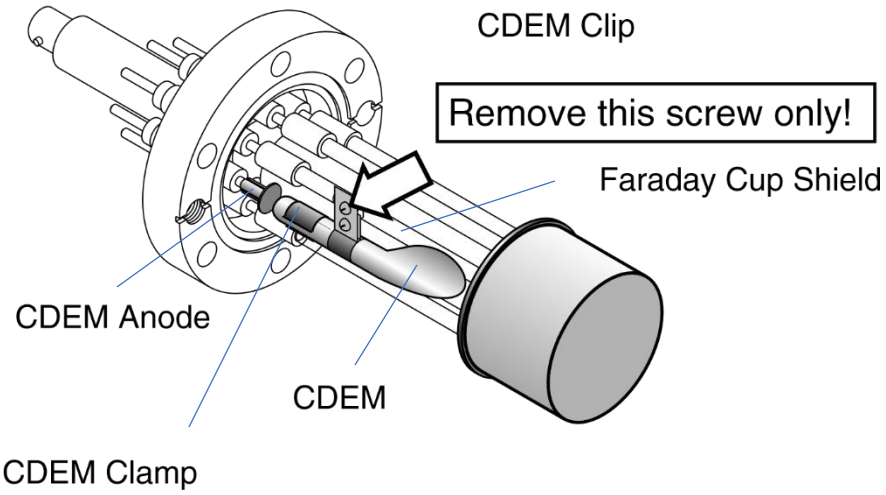


Figure 10-4 CDEM Replacement

9. Using the clean flat head screwdriver, remove the small screw that fastens the clamp to the HV rod and rotate the entire multiplier about its axis until the clamp's end points away from the FC Shield.

10. Holding on to the clamp's end, pull the multiplier out of the clip.

11. Unpack the new multiplier. Notice that the multiplier has a mounting clamp already in place so there is no need to keep the old one. Avoid contamination.

12. Install the new multiplier in place reversing the removal steps. Clip it in place, rotate it about its axis so the clamp fits into the slot in the HV rod, and fasten the clamp with a small screw.

13. Visually inspect the assembly and do any adjustments that might be necessary. The CDEM should be standing straight up, centered between its two neighboring rods, and with its cone facing straight into the hole on the FC shield. The CDEM anode should be ≈1 mm away from the multiplier's exit, and it can easily be pushed up or down with pliers for correct placement. There should be no electrical contact between the cone (HV) and any part of the probe. If necessary loosen the clamp's screws to do adjustments.

14. Once satisfied with the alignment, mount the probe back on the vacuum system and pump it down. Check the correct rotational orientation of the feedtrhu flange (i.e. same as it was before disassembly) before tightening the flange bolts.

15. Perform the **CDEM Preconditioning** steps described in this chapter before using the multiplier for actual measurements.

16. Calibrate the gain of the new electron multiplier before using the device for quantitative measurements. See instructions in RGA Tuning chapter.

Quadrupole filter cleaning

The quadrupole mass filter is the heart of the RGA. The sensitivity and resolution of the instrument are ultimately limited by the quality of the quadrupole field between its rods. Deposits on the rods accumulate electrostatic charge and distort the field, resulting in degraded performance. The deposits typically form at the entrance to the mass filter, when the RGA is operated at high pressures or over long periods of time. They are often seen as a discoloration of the metal but in some cases (i.e. depending on the vacuum composition) they are invisible.

If contamination of the rods is suspected, the first step to take is a one- or two-day long "**Probe Bakeout**". If bakeout is not successful, the quadrupole filter will need to be cleaned. Note that in order to clean the rods, the entire quadrupole head assembly must be taken apart, and unless the exact nature of the deposits is known, the only sure way to remove them will be with a very fine abrasive.

Warnings

- **The exact alignment of the rods in the quadrupole is essential to the optimum performance of the RGA.**
- **Do not scratch the surface of the rods.**
- **Do not remove excessive amounts of surface material with the abrasives.**
- **Use clean tools and procedures.**

Equipment

- Clean, dust-free work area.
- Latex gloves/powder free.
- One standard OFHC copper gasket for 2 3/4" CF Flange. New and Clean!
- Replacement bowed e-clips (SRS Part# 0-00579-000, 12 count)
- Phillips head screw driver: P1 head (clean.)
- Precision flat-head screw driver: 2.5 mm head (clean.)
- Needle nose pliers.
- Micro-Mesh abrasive sheets: 3200 to 12000 grit.
- Ultrasonic cleaner.
- Ultrasonic cleaning solution (high quality, no-rinsing residue).
- 1000 mL beaker.
- Oil-free, dry nitrogen.
- Distilled or de-ionized water.
- Petri dish.
- Clean oven (higher than 100°C setting).

Procedure

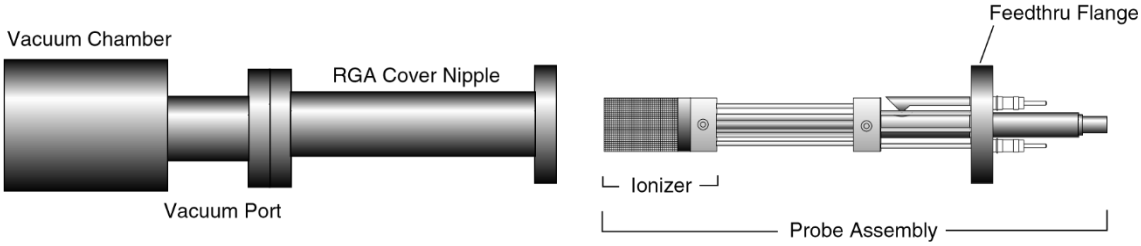
1. **Read all warnings** at the beginning of this chapter before attempting to service the probe.

2. Set up in advance a clean dust-free working area where to carry out this procedure.

3. Turn off the RGA and disconnect the ECU from the probe.

4. Wait for the probe to cool down for at least 30 minutes after the emission is turned off. **Severe burns can result if the probe is handled too soon**.

5. Without disconnecting the cover nipple from the vacuum port, remove the six bolts from the feedthru flange at the end of the probe and carefully slide the entire probe assembly out of the vacuum system. The ionizer, the filter, and the detector are now fully exposed and easily accessible.



6.

Figure 10-5 Probe Removal for Quadrupole Filter Cleaning

7. Carry the probe to a clean, dust free area immediately. **Avoid contamination** using handling procedures compatible with high vacuum requirements.

8. Hold the probe in a secure upright position and do a thorough visual inspection of the unit. Check for loose, damaged, misaligned and severely contaminated components. If excessive contamination is evident take the necessary steps to identify and eliminate the contamination sources in the vacuum system. Carefully inspect the ionizer and, if any problems are detected, replace the filament and/or the ionizer as part of this maintenance procedure. Inspect the CDEM for signs of arcing and contamination. If necessary replace the CDEM as part of this maintenance procedure.

9. **Head disassembly:** Only a rough outline of the complete disassembly of the probe is presented here. Use the **RGA Assembly Drawing** of Chapter 9 as a visual aid during the process.

   Note the placement of all parts and their orientation before disassembly!

   Begin by removing the filament following the necessary steps from the "Filament Replacement" procedure described in this chapter. Be very careful not to damage the thoria coating if you intend to use the same filament during reassembly.
   Next, remove the CDEM following steps from the "CDEM Replacement" procedure.

Store the multiplier in a dry box or desiccator. Loosen the seven screws that fasten the 1/8" diameter rods to the feedthru connectors, and remove the bowed e-clip from the exit plate align rod that is located right above the CDEM. You can now separate the entire quadrupole assembly from the detector/feedthru assembly. There are no serviceable parts in the flange. Set it apart in a safe, clean area. Next, separate the ionizer from the quadrupole filter by removing the e-clips that hold the 1/8" diameter rods in place. Store the ionizer electrodes in a safe clean area. Disassemble the quadrupole and set apart the precision ground rods for cleaning.
This is a good time to carefully inspect all the components of the probe for damage and contamination. Replace or clean any parts that are suspect.

Note: We do not recommend cleaning the alumina spacers, but if signs of severe contamination are evident, ultrasound clean the two rings for 15 minutes with diluted cleaning solution, and bake them out for 2 hours at 180° C after a thorough rinsing.

10. **Rods cleaning:** Use the Micro-Mesh abrasives to clean the rods. Begin by using the finest abrasive which will remove the residue, normally 3200 grit. Then consecutively use the next finer grit down to 12000 until the metal surface has a fine polished appearance. **Warning:** Do not remove excessive material from the surface of the precision-ground rods.

    After all metal surfaces have been polished, they must be cleaned to remove all the abrasive compound from their surface. Begin by placing the rods in a beaker with the ultrasonic cleaner solution (Note: Any good quality cleaning compound that leaves no residue after rinsing is good for this job.) Place the beaker in the ultrasound cleaner and agitate for 30 minutes. Decant off the cleaning solution, and repeat the above agitation with 4 to 5 consecutive washes with distilled water to remove the cleaning solvent. Following the rinses, blow dry the rods with filtered dry nitrogen and then bake them out in an oven at 180°C for fifteen minutes. **Warning:** After the parts have been cleaned and baked out, they should only be handled wearing powder-free latex gloves.

11. **Head Reassembly:** Only a rough outline of the complete reassembly of the probe is presented here. Use the **RGA Assembly Drawing** of Chapter 9 and your own notes as a visual aid during this process.

    Begin by assembling the quadrupole mass filter. Loosely attach the cleaned rods to the alumina spacers with the spring-loaded, perforated screws. Tighten the screws following the **systematic procedure** described next. Work on one spacer at a time, using a single, small turn of the screwdriver on each screw. After a single round of eight screws, hold a spacer in each hand, and slightly torque the assembly back and forth about its axis to make sure the rods are comfortably seated on their alignment grooves. Repeat this tightening procedure, one spacer at a time, constantly checking the alignment, until the spring washers are completely compressed. Once the quadrupole assembly is completed, mount the focus plate and the anode grid on it. Use new e-clips to hold the two ionizer plates against the top alumina spacer, but do not install any e-clips on the bottom grooves of the connection rods at this time. Next, mount the quadrupole assembly on the exit plate of the feedthru flange and secure it in place tightening the two connector screws and inserting an e-clip in the exit plate align rod groove. Insert the rest of the rods in their correct locations and, while checking for the correct alignment of their grooves and slots, tighten the rest of the

feedthru connector screws. Once the rods are in place, attach the two RF ribbon connectors to complete the quadrupole filter assembly.
If the RGA probe has a CDEM, mount the multiplier at this time. Adjust the HV connect rod as needed, and tighten all the necessary screws (The threaded hole on the side slot of the rod lines up with the CDEM Clamp hole, and the top groove should be correctly lined up with the edge of the alumina spacer's alignment hole.)
Install new bowed e-clips in all the grooves located above the alignment holes of the bottom alumina spacer. The clips hold the filter tightly against the exit plate. Finally, install the filament and the repeller cage.

12. Visually inspect the probe to make sure all the parts are in place and correctly aligned. Use an ohmmeter to make sure the electrodes are electrically isolated from each other and from the body of the flange (ground).

13. Once satisfied, install the probe back in the vacuum system and perform a complete "Probe Bakeout" before using the RGA for measurements.

14. Perform a peak tuning procedure on the unit.

SRS Probe Refurbishing Service

The procedures described in this chapter are designed to guide the user through the various steps needed to maintain and/or repair the different components of the RGA probe. These procedures should only be carried out by qualified personnel who fully understand the critical alignment aspects of the instrument. Users who do not feel comfortable or simply do not have the time to go through the different maintenance steps can choose to send the RGA unit back to the factory for a complete Probe Refurbishing Service. Please contact SRS to obtain information on this very fast and convenient service. All refurbished probes are fully tested and calibrated before being returned.

Important: All users returning an RGA Probe back to the factory for repair and/or service must submit a correctly completed "Declaration of Contamination of Vacuum Equipment" form along with the instrument. The SRS personnel carrying out the repair and service of vacuum equipment must be informed of the condition of the components before any work is done on the parts. A copy of the form is attached at the end of this manual.

Chapter 11

RGA Circuit Description

This chapter describes the electronics circuits located inside the Electronics Control Unit of the RGA.
There are no electronics components inside the RGA Probe.
The information in this chapter is provided for the use by qualified technical personnel during service and repairs.

Warnings

- **The ECU is to be serviced by qualified technical personnel only. There are no user serviceable parts inside.**
- **Dangerous voltages, capable of causing injury or death, are present in this instrument. Use extreme caution whenever the ECU covers are removed. Do not remove the covers while the unit is plugged in.**
- **Always disconnect the power before removing the covers of the ECU.**

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Overview of the RGA

The SRS RGA is a mass spectrometer consisting of a quadrupole probe, and an Electronics Control Unit (ECU) which mounts directly on the probe's flange.

The quadrupole probe is a mass spectrometer sensor consisting of an ion source, a quadrupole mass filter, a Faraday cup and an optional electron multiplier (Option 01). Ions are created from the residual gas in a vacuum system by electron impact ionization. Ions of a particular mass-to-charge ratio have stable trajectories through the mass filter, depending on the DC and RF voltages applied to the quadrupole rods. The selected ions are collected in a Faraday cup or multiplied in an electron multiplier.

The ECU box (3" x 4" x 9") contains all the electronics necessary to operate the RGA. It connects directly to the probe's feedthru flange, and also to a host computer. Its regulated power supplies set the ionizer voltages, the filament's electron emission current, the high voltage across the electron multiplier, and the RF/DC levels on the quadrupole filter. A transimpedance amplifier converts ion currents into voltages that are read by an A/D converter. A microprocessor and control firmware direct the operations of the spectrometer, the data acquisition, and the communications with a host computer.

The electronics operate from a single 24 +/- 2 V DC power supply. The peak current requirement is about 2A. A universal input (90-264VAC, 47-63Hz) switching power supply is provided as an option (Option 02) so that the system may be operated directly from a line cord.

The RGA120 Series features include:

- Pirani and ion gauges to monitor vacuum
- Direct digital synthesizer (DDS) frequency tracking of resonate drive circuits.
- Low drift analog transimpedance amplifiers (TIAs) for faster, lower noise spectra
- Digital filters to reduce the noise bandwidth of scan data and increase dynamic range
- RS-232, USB, and Ethernet communications interfaces.
- User interfaces supporting Pt RTD, 0-10 V, loop powered 4-20 mA, and a SPDT relay
- Nearly all electronic components are surface mounted.

Mechanical details

An internal structural bracket extends nearly the entire length of the unit to provide flux shielding, mechanical strength and to reduce thermal gradients. All the PCBs are attached to this bracket before being covered by the outside chassis. There are no TO-220s

mounted to the outside chassis. TO-220 packages on the HV PCB are attached to the internal bracket for heat transfer.

There are several PCBs. The microcontroller, DAC control circuits, and signal-level processing are on the Top PCB. Power supply inverters and filament drive circuits are located on the Bottom PCB. The interface to the vacuum probe is located on the Flange PCB, which is located between the Top and Bottom PCBs. Low noise TIAs are located on the Electrometer PCB, which is also between the Top and Bottom PCBs, and passes signals to the Top PCB. RF drive circuits and the high voltage inverter for the CEM are on the HV PCB, located at the rear of the ECU, between the top and bottom PCBs, and connecting to the Top PCB. Two small jumper PCBs (the RTD and LED PCBs), connect the Top and Bottom PCBs and hold rear panel connectors and LED indicators.

Detachable terminal strip connectors are used for the user analog I/O, RTD, digital control, and SPDT relay. The unit can be powered either from an enclosed, line connected power supply, or from an external +24 Vdc power supply.

List of Schematics

There are 13 pages of schematics at the end of the chapter:

Page 1: Block diagram

Page 2: TIAs for Faraday and CEM current to voltage conversion

Top PCB (on four sheets)

Page 3: 24-bit sigma-delta (ΣΔ) ADC

Page 4: Microcontroller with USB, LAN, RS-232, JTAG and SPI ports

Page 5: Analog inputs and outputs and Pt RTD measurement

Page 6: DDS frequency source, RF detect and control, system DACs, RF phase measurement

Page 7: High voltage PCB (0-2250 Vdc for CEM and Class-D, pull-pull, RF power amplifier)

Page 8: Flange PCB connects to Bottom PCB (Vacuum probe plugs into this PCB)

Page 9: Top/Bottom interconnect PCBs (with RTD connector and rear panel LEDs).

Bottom PCB (on four sheets)

Page 10: Interface between top and bottom PCBs and SPDT relay

Page 11: Filament and grid control, emission current and Pirani gauge measurement

Page 12: ±HV DC for quadrupole rods, focus plate bias and ion gauge measurement

Page 13: System power supplies (starting with +24 Vdc)

Block Diagram

The vacuum probe is shown in the center of the block diagram, with support electronics surrounding it. The electronics provides ±RF and ±DC potentials for the quadrupole rods, current to heat the filament, and monitoring for the emission current, grid current and focus plate (ion) current.

The quadrupole RF amplitude and DC potentials are controlled by a low noise, dual 16-bit DAC.

High voltage DC (0 to -2250 Vdc with 0.5 V resolution) for the CEM is controlled by a 12-bit DAC.

The Faraday cup ion current, and channel electron multiplier (CEM) electron currents, are converted to voltages by a TIAs and digitized by a 24-bit ΣΔ ADC. Digital filtering in the ADC is used to reduce the noise bandwidth of the signal current. (The noise is dominated by the TIA.)

Electrometer PCB

There can be two current signal sources from the RGA vacuum probe. The Faraday cup current output is connected via the center BNC connector. In units equipped with a CEM, the CEM's anode signal is connected to one of the 8 probe pins. Both of these signal sources connect directly to the Electrometer PCB.

TIAs on the Electrometer PCB convert the small current signals to voltages. The TIAs consist of very low input bias current CMOS op amps (±3fA, typical, at room temperature) with feedback via four series 250 MΩ resistors, each shunted by an ultralow leakage diode. The diodes are actually the gate-source junction of JFETs (MMBF4117s). The diodes will be off for signal currents below about 1 nA, so the feedback resistance is 1 GΩ for small signal levels. Above 1 nA, the diodes turn on in a predictable (albeit temperature compensated) manner, allowing the TIA to accurately measure signal currents up to about 1μA.

With the TIA's noise being dominated by the Johnson noise of the 1 GΩ feedback resistance (about 4 fA/√Hz), and a full-scale of 1μA, the dynamic range will be several million during a slow scan. This dynamic range is supported by the 24-bit ADC together with the ADC's bandwidth limiting digital filters.

Top Board

There are four schematic sheets for the top PCB. Relatively quiet circuits are located on the top PCB (such as the 24-bit ΣΔ ADC and analog control DACs). Noisy circuits (such as power supply inverters) are located on the HV PCB and the bottom PCB.

The Electrometer PCB connects exclusively to the top PCB, as does the HV PCB. The top and bottom PCB are connected together via to vertical PCBs, one which holds the rear panel LEDs and the other which holds the Pt RTD connector. The vertical flange

PCB (which the vacuum probe plugs into) is also connected to both the top and bottom PCB.

24-bit sigma-delta (ΣΔ) ADC (Sheet 1 of 4)

The Electrometer PCB connects the FC and CEM TIAs to the top PCB via J101. The differentially routed signals are filtered by a two stage RC filter with a -3 dB bandwidth of 9.6 kHz, and 72 dB of attenuation at 1 MHz. The output noise from the TIAs is dominated by the Johnson noise of the 1 GΩ resistor, which is about 4.1 μV/√Hz.

The ADC, U103, has a +2.50 Vdc internal reference which is also used as a system wide voltage reference. The reference has low frequency noise of about 4.5 μV rms (0.1 Hz to 10 Hz), a broadband noise of about 215 nV/√Hz, and a stability which is better than 10 ppm/C. The full-scale signal input range is ±2.50 V. The +2.50 Vdc reference is multiplied by 1.2x to create a +3.00 Vdc reference (used for the MPU's ADCs), and by 1.806x to create a +4.52 Vdc reference (used by the octal 12-bit DAC).

The outputs from the TIAs are digitized by the 24-bit ΣΔ ADC. The sample rate can be set from 1.25 SPS to 31.25 kSPS. The ADC uses a digital filter with a sinc^3 response and a -3 dB bandwidth which is about 26% of the sample rate. For an input voltage step, the digitized output settles in 3 samples. The ADC is clocked at 2 MHz, derived from the system clock. The digital filter can be configured to notch out 50 Hz and 60 Hz by setting the sample rate to 27.27 Hz.

The SNR is determined by the bandwidth of the ADC. For the lowest sampling rate (1.25 SPS), the noise bandwidth is about 0.325 Hz, for which the TIA noise is about 2.3 μV rms. The corresponding ion current is about 2.3 μV rms/1 GΩ, or about 2.3 fA rms. With a probe sensitivity of 10^{-4} A/Torr, the noise floor is expected to be about 2.3×10^{-11} Torr rms, or about 12×10^{-11} Torr peak-to-peak (without using the CEM). Additional bandwidth limiting can be done with digital filters implemented by the MPU.

While the LSB of the ADC is $2.5 \text{ V}/2^{23} = 0.30$ μV, the effective resolution is limited by the TIA noise. The 2.3 μV rms of noise (for the lowest sampling rate) corresponds to about 8 LSBs of peak-to-peak noise, so the effective resolution is expected to be only $23 - 3 \approx 20$ bits. This implies a dynamic range of about 1:1,000,000.

Microcontroller (Sheet 2 of 4)

A Kinetis K66 microcontroller (U203) is shown on Sheet 2. The MPU has ARM Cortex-M4 core with DSP and floating capabilities operating with a core clock of 175 MHz. There are 2 MB of flash, 256 KB of SRAM, and a 100 Mbits/s Ethernet MAC. There are 12-bit and 16-bit ADCs, 12-bit DACs, timers, three SPI ports and lots of GPIO.

The system's master clock is a 60 MHz oscillator, U221, which clocks a DDS that generates the RF frequency used to drive the quadrupole rods. The 60 MHz clock is divided by two by U219 to provide a 30 MHz clock to the MPU, from which the 175 MHz core clock and 25 MHz Ethernet clocks are synthesized. The master clock is further divided by 15 by U215 to generate the 2 MHz clock used by the 24-bit ADC. A final 4-bit divider, U216, provides 250 kHz and 125 kHz sync references for system power inverters.

The clock tree is important. The concern is that unsynchronized devices will interfere with each other. For example, the 24-bit ΣΔ ADC uses a 1 MHz input modulator, which responds to a 1 MHz interfering signal as if it were DC. If a clock spur wandering near 1 MHz is present at the input to the ADC it would be indistinguishable from a low frequency ion current. There are two strategies to reduce these artifacts: Attenuate the interferers or fix their phase and frequency with respect to the ADC's modulator clock. (A frequency/phase fixed spur would appear as an offset, which could be removed computationally.) All of the clocks in the RGA, with the singular exception of the RF frequency generated by the DDS for the quadrupole rods, are derived from the master clock and have fixed frequency and phase relationships.

An FTDI part (U202, an FT230XQ) is used for the USB interface. A bi-directional limiter, U204, is used to protect the device from static at the USB port. The FTDI part is used (instead of the USB implemented on the MPU) because it is recognized by many computers' operating systems, which will quickly install the appropriate hardware driver to enable communications via the USB.

The RS-232 interface uses one of the MPU's UARTs, with data and control lines buffered, level shifted and inverted by U206, an AMD3202. Since the RS-232 connector is on the bottom PCB, the four signal lines must be routed via one of the vertical jumper boards from the Top PCB to the Bottom PCB.

The Ethernet local area network (LAN) uses a media access controller (MAC) on the MPU and a KSZ8081RNA physical transceiver, U211. Communications can take place up to 100 Mb/s over the reduced media-independent interface (RMII) which operates two full duplex channels at 50 Mb/s each. A 25 MHz clock provided by the MPU on its CLKOUT pin (A11) for the LAN timing reference.

The MPU has three independent SPI ports. Port 0 is used for the three 24-bit ADCs. The ADC used to digitize the TIAs is treated with great care by isolating its SPI clock and data from the noisy SPI traffic unless –CS_ADC_TIA is asserted. This leaves the part entirely undisturbed while it is digitizing and filtering analog signals from the TIAs. Other SPI devices include: Rear panel LEDs, a DDS for RF frequency control, an octal 12-bit DAC, and two dual 16-bit DACs for rod RF and DC control and analog current and voltage outputs.

The MPU has numerous ADC inputs (12-bit and 16-bit), comparator inputs, and digital inputs and outputs. The ADCs monitor numerous system test points including RF drive current phase, filament voltage and current (for the Pirani gauge), filament emission current, grid current, and focus plate ion current (for the ion gauge). The ADCs also monitor the health of the system by measuring test points within control loops (such as inverter center tap voltages and drive currents).

A "Dead Man" safety circuit shuts down the system in the case that the MPU stops functioning properly. A 100 ms retriggerable one-shot, U207, will assert a system -SHUTDOWN level if not strobed by the KEEP_ALIVE_STB. The keep alive strobe is asserted as part of the real time interrupt structure on the MPU.

On turn on, or if ever the program stops execution, -SHUTDOWN is asserted which disables the high voltage RF and CEM, the filament, the degas mode, and the rod DC polarity relay. All 12-bit and 16-bit system DACs are also reset, turning off the filament,

rod RF & DC, grid bias, and analog current and voltage outputs. In the event of a shutdown, all DACs will need to be re-initialized.

A trace capable JTAG interface is provided for development, test and program downloading via J206. A more compact JTAG interface is provided via J207.

Analog inputs and outputs and Pt RTD (Sheet 3 of 4)

The RGA has several analog interfaces: Voltage inputs and outputs, current inputs and outputs (4-20 mA with loop bias power supply), and a Pt RTD. This sheet describes those interfaces. The connector for the analog I/O, J300, is located at the top right corner on the rear panel of the instrument.

The differential voltage input is on pins 1&2 of J300. Both pins have an input resistance of 10 kΩ to ground. A voltage divider reduces each input by about 10x, which are then applied to 24-bit ADC with a full scale of ±1.50 Vdc for a full scale range of $-15 \le V^+-V^- \le +15$ Vdc. The input range of both inputs, V^+ and V^-, is limited to -3 Vdc to +30 Vdc. In most circumstances, the V^- input will be close to ground and the V^+ input will vary from 0 Vdc to +10 Vdc. The instrument will report the difference between the differential inputs.

A voltage output is available on pin 5 of J300. The output is controlled by a 16-bit DAC, U303, and provided by a power op amp configured with a gain of Av = 4.69 and an output offset of -0.205 Vdc. The output is calibrated to provide outputs from 0 to +20 Vdc with about 320 μV steps.

The 4-20 mA current input is located on pin 3 of J300. The 100 Ω shunt resistor, R308, is used to measure the current. U300 is used to provide a loop bias of 0 to +20 Vdc to power remote 4-20 mA devices such as user pressure gauges. A resistor network is used to reduce the common mode voltage at the input of the ADC (U301) to below +3.4 Vdc. Calibration is used to improve the CMRR of the divider. The circuit can report the value of current inputs or outputs with a noise of about 0.25 μA, or about 16 noise free bits on a 4-20 mA span.

A 4-20 mA current output is available on pin 6 of J300. The output is controlled by a 16-bit DAC, U303, and output via a programmable current source (U306 and Q300). In the case that there is no load at any programmed level (4-20 mA), the output of the op amp will go below ground, pulling the trouble flag low (at the output of the comparator, U305), with firmware setting an error status bit.

The RGA can use a Pt RTD (a PTC resistive temperature sensor) to measure the temperature of a remote object. The RTD connects to the Top PCB via the small vertical RTD PCB which holds the rear panel connector. The four RTD signals, ±RTD and ±SENS connect to the Top PCB via J301.

The RGA uses common Pt RTDs that have an electrical resistance of 100 Ω at 0°C and a temperature coefficient of resistance (TCR) of 0.00385 Ω/Ω/°C between 0 and 100°C. The circuit passes about 1 mA of current through the RTD, and determines the voltage across the RTD to compute its resistance. A 24-bit ADC, U307, is used to digitize the voltage (which is about 100 mV at 0°C). The measurements have about 3 μVpp noise, and so the expected resistance noise will be about 0.003 Ω, which corresponds to about

±0.004 C temperature noise. The firmware allows the use (with firmware lead resistance compensation) of 2-wire, 3-wire and 4-wire Pt RTDs.

There are two digital inputs (for triggering a scan and to disable the unit's high voltage) and one general purpose digital I/O bit accessible from the rear panel. Those input are routed to the Top PCB via the small vertical RTD PCB and come onto the Top PCB via J301. The inputs have adjustable input thresholds (the default is 1.0 Vdc), and the GPIO output can be set or reset via a command to the RGA.

RF control and system DACs (Sheet 4 of 4)

Several signals are needed to control the RGA probe during a mass scan. A dual 16-bit DAC (U401) controls the amplitude of the RF and the DC bias for the quadrupole rods. An octal 12-bit DAC, U402, controls the common mode voltage on the rods, the filament heater power, the repeller voltage, the grid voltage, the focus plate voltage, the CEM high voltage, and the 4-20 mA loop power.

A DDS, U409, clocked at 60 MHz and filtered by a differential 3rd order Cauer filter, provides a clock (at about 5.5 MHz) to a flip-flop, U410. The output of the flip-flop provides a differential drive at about 2.75 MHz to the RF power amplifier.

RF Amplitude detector

The amplitude of the RF on the quadrupole rods is detected by a charge pump circuit. A pair of 0.5 pF porcelain capacitors, suspended in air on the flange PCB (so that the PCB's FR-4 does not degrade the capacitors' characteristics), pump charge into the D400-403 Schottky diode bridge. (The 1N5711's bridge diodes are designed for RF mixing and amplitude detection. Commodity rectifier diodes will not do.)

The junction capacitances of the RF bridge diodes (about 2.2 pF each) would act to attenuate small signal RF applied via the 0.5 pF input capacitors by about 10x before is appears across the diode junction. A quiescent bias is used to overcome this threshold effect.

The quiescent diode bias is about 17 μA (15 μA was arranged intentionally with U406A and R417, the other 2 μA is from the op amps' input bias current). Doing so provides a known sensitivity at zero RF amplitude (via the diode bridge's power-law characteristics) and a positive offset of about 8 mV on U406B's output. The offset will assure that the PID controller which follows will be able to shut off the RF drive completely. It is very important that all of the 1N5711's are collocated for best temperature performance.

U406B converts the charge pump current into a voltage with a gain of 499 Ω, with C404 assuring that the output does not exceed the LT1819's specification (±3.7 Vdc, 0-70C). The RF voltage is about 8.6 Vpp/amu and so the full wave (2x) rectified current is given by:

$$I_{rectified} = 2 \cdot 8.6\ (V/amu) \cdot M(amu) \cdot f(Hz) \cdot C(F)$$

At 320 amu and 2.75 MHz the current will be about 7.5 mA, which converts to about 3.75 Vdc by the 499 Ω TIA. The low pass filter, with a notch at 2 x 2.75 MHz, removes the high frequency ripple from the detected signal and attenuates it by 2x, to 1.875 Vdc (at 320 amu).

The detected RF amplitude is compared to the requested amplitude (from the 16-bit DAC) by the proportional-integral controller, U403, whose output controls the RF drive level on the HV PCB via RF_CT_CTL.

RF Phase detector

A doubly balanced mixer (Q400 A&B and Q401 A&B) measures the phase between the voltage and current in the RF driver on the HV PCB. The frequency of the DDS is adjusted to keep this phase near zero where the RF load is resistive.

The phase adjustment is most important at high drive levels (because we lose amplitude off resonance and so could not reach 320 amu) but it will also reduce switching noise, and so allow more reliable amplitude detection, when it is properly adjusted.

The sensitivity of the phase detector is proportional to the center tap voltage on the RF transformer, RF_CT/10. This voltage is used to control the amplitude of the RF drive. The phase is defined using:

$$\varphi \equiv \frac{[(+RF_PHASE) - (-RF_PHASE)]}{RF_CT/10}$$

The DDS frequency is continuously adjusted to maintain the measured phase near zero, insuring that the RF transformer is driven at resonance. The DDS frequency is controlled with the contents of a phase increment register, PIR. We will empirically determine the magnitude and sign of the constant, k , so that the phase converges to zero using:

$$PIR_{i+1} = PIR_i + k \cdot \varphi$$

Changing the RF frequency will also require changing the RF amplitude and DC bias to the quadrupole rods. In addition, the sensitivity of the RF amplitude detector, which is a charge pump detector, is proportional to the RF frequency.

High Voltage PCB

The schematics for the RF driver and CEM HV power supply are on a single sheet and are built on a single PCB which mounts to the interior chassis between the top and bottom PCBs. The HV PCB is connected to the Top PCB via a single connector. High voltage RF and the CEM HV connect from this PCB to the probe flange board via flying leads.

RF Driver

The RF drivers can use up to 2.4 A from the +24 Vdc power supply. Most of this power is dissipated in the resonant RF drive transformer, which is directly cooled by the rear-panel fan.

The RF circuit's principal component is a high turns ratio toroidal transformer. This transformer has a 4-turn center-tapped primary (connected at J100-103) and bifilar wound, two-phase, 40-turn secondaries on a large iron powder core. The self-inductance of the secondaries form a resonate circuit with the capacitive load (the quadrupole rods present about 50 pF). The parasitic inter-winding capacitance of the secondaries is

reduced by using Teflon insulated windings. The low dielectric absorption and high dielectric strength of Teflon is also important, as the circuit is designed to provide $V_p \approx 1700\ V_p = 3400\ V_{pp}$ at about 2.75 MHz.

Since the transformer has a capacitive load, the input of transformer also shows a capacitive reactance, which is a difficult load for the MOSFETs to drive. By adding an inductor at the input to the transformer, and driving the circuit at resonance, the input impedance becomes resistive.

The added inductors would create large voltage spikes if the MOSFETs are not turned off exactly when the current in the inductor is zero. This issue is traditionally handled with a totem-pole MOSFET driver (which requires a high-side driver as was done in the RGA100 series instruments), or energy wasting snubbers. There is another way. By providing a mutual inductance between the inductors, residual stored energy at switching is coupled to the MOSFET which has just switched on avoiding inductive voltage spikes.

In the RF drive circuit, the MOSFETs are driven by a MOSFET gate driver (U4) powered from a +8V regulator (U2), and enabled by EN_RF. The gate driver buffers and amplifies the complementary ±RF_DRIVE, which are square waves at about 2.75 MHz. The drive frequency is provided by a DDS which drives the toroidal transformer in resonance with its capacitive load as determined by the phase detector on the Top PCB.

The amplitude of the RF is controlled by the transformer's center-tap voltage which is provided by a high current linear regulator (U1). That regulator, in a TO-220 package attached to the interior chassis, is controlled by the proportional-integral controller on the Top PCB. The regulator provides short-circuit and thermal overload protection as well. The MPU can monitor the operation of the RF driver by measuring the center tap voltage of the transformer (RF_CT/10) and the total drive current (RF_DRIVE_I).

The MPU can also monitor the MOSFET load reactance via the doubly balanced phase detector which measures the phase of ±RF_PRIMARY relative to ±BALUN. When driven at a frequency for which the MOSFET load looks resistive, the phase will be 90˚, and the output of the phase detector will be zero.

Channel electron multipler HV

The CEM requires a large negative bias, typically -1500 Vdc, to operate. The HV is provided by a high voltage charge multiplier, controlled by EN_CEM and CEM_HV_CTL. When enabled, the switch mode controller (U13) drives a high turns ratio transformer (T2) at 62.5 kHz (CEM_SYNC/2).

The primary of T2 presents a large capacitive load to U13 which could lead to power inefficiencies or current tripping. This problem is solved by placing a balun (T3) between U13 and T2. When driven by just one of U13's outputs (SWA or SWB) balun behaves like an inductor, decoupling the capacitive load at T2's primary. Inductive spikes at the switching time are avoided as either SWA or SWB is always on. U13's current limit is set to about 116 mA by R4.

The transformer's secondary drives a voltage multiplying ladder (D1-D10, etc.). A proportional-integral controller (U12) compares the HV output to the CEM_HV_CTL and slews the center tap voltage to T2 via the emitter follower, U11. The non-inverting

input to U12 is biased to 10 mV to assure that the CEM HV inverter can be turned off. The MPU monitors the operation of the circuit by measuring the center tap voltage, CEM_CT/10.

The HV output is filtered and protected by two series 1 MΩ resistors (R35 and R5). The 2 MΩ source resistance must be accounted for when measuring the CEM HV output.

Flange PCB

The eight pins on the vacuum probe plug into the Flange PCB to connect the vacuum probe to the ECU. The Flange PCB has connections to the Top and Bottom PCBs, and is connected to the RF transformer and CEM HV supply via flying leads. The connectors to the bottom PCB are rated to handle the high filament heater current. The Flange PCB is mounted to the internal chassis with four mounting screws. The BNC vacuum feed through for the Faraday cup, and the anode signal from the CEM, pass through the Flange PCB to connect directly to the Electrometer PCB.

A 10 mV/C temperature sensor is the only active component on the PCB. The 0.5 pF porcelain capacitors, which are part of the charge-pump RF amplitude detector, are mounted on leads above the PCB so that their characteristics are not degraded by the poor dielectric characteristics of FR-4. Grounded shield traces encircle sensitive nodes (the CEM anode) and nasty nodes (CEM HV and RF HV).

Interconnect PCBs

There are two vertically oriented PCBs which pass signals between the Top and Bottom PCBs. These small PCBs also hold the rear panel LEDs and modular connector for the external RTD sensor.

The Interconnect PCB, which holds the LEDs, primarily passes signals from the Top PCB to the Bottom PCB. These signals include 12-bit DAC controls, RS-232, and an SPI port. The SPI port loads the 8-bit shift register to control the rear panel LEDs. The SPI port continues to the Bottom PCB to set control bits and read status bits from the Bottom PCB.

A second interconnect PCB, which holds the rear panel modular connector for the RTD, primarily sources power and analog signals from the Bottom PCB to the Top PCB. There are multiple, ballasted copies of +24 V, as well as ±5.0 V, +3.3 V, and analog signals to monitor the filament and the focus plate, which allow the operation of a Pirani gauge and ion gauge in the vacuum probe.

Bottom PCB

The bottom PCB provides system power from a +24 Vdc internal or external power supply. It also controls the filament heater, filament bias, focus plate bias, grid bias, and DC biases for the quadrupole rods. The PCB also precisely monitors the filament

resistance (to implement a Pirani gauge) and the focus plate ion current (to implement an ion gauge).

Interface between top and bottom PCBs and SPDT relay (Sheet 1 of 4)

Connectors to (J100) and from (J101) the Top PCB are shown on this page. There are five TIAs (U100, U104 and U111) which convert signal current (from filament and focus plate monitoring circuits) into voltages (which will be digitized by the MPU's ADCs). Three of these TIAs (for filament voltage, filament current, and focus plate ion current) have switchable gain (between 10 V/mA and 100 V/mA). The TIAs' gains are controlled by bits loaded into the SPI controlled shift register (U107).

Four of U107's control bits are used to enable the filament heater, control the IGC current measurement gain, set the vacuum probe degas mode, and control the rear panel SPST relay. The filament power, degas mode, and rear panel relays are disabled when -SHUTDOWN is asserted by the Top PCB dead man watchdog.

Four status signals, which detect over-current or over-temperature conditions for the repeller and focus plate high voltage op amps, can be read via the SPI port (U110). These bits are never asserted in normal operation. If they are asserted, the mostly likely cause is a short circuit between the repeller cage and the user's vacuum system.

Filament and grid control, emission current and Pirani gauge measurement (Sheet 2 of 4)

Filament heater current and repeller and grid biases are provided by circuits on this sheet.

The filament heater current is provided by a floating full-wave power supply. The amplitude of the heater current is controlled by the center tap voltage on the primary of the filament transformer (T200). That voltage is provided by a linear regulator (U200, for over-current and over-temperature protection) which is controlled by one of the 12-bit DAC ports on the Top PCB (FIL_CT_CTL). That DAC value is adjusted by a firmware control loop which maintains the filament emission current at the set point (typically 1 mA).

The MOSFETs (U204 and U207) on the primary side of the filament transformer are driven by a switch mode controller (U206) operating at 125 kHz and very near 100% duty cycle. (The 250 kHz, 100 ns long PS_SYNC is divided by 2 by the switch mode controller.) The total primary side current can be monitored by the MPU via FIL_I_DRIVE, which can also shut down the MOSFET driver on a cycle-by-cycle basis.

Bias for the filament and repeller cage, which is typically -90 Vdc, is provided by a high voltage op amp (U211). The op amp has a gain of -30.1 for the 12-bit DAC signal, REPELL_V_CTL. The floating filament and repeller are connected to this bias source via a 1 kΩ shunt resistor (R228). The MPU can measure the filament emission current by measuring the voltage across this resistor. If the Repeller cage is accidently grounded in the user's vacuum system, Q203 (which turns on if the op amp sink current exceeds about 13 mA) will disable U211 and alert the MPU via -REPELL_DISABLED.

The filament emission current, its heater current, and the voltage across the filament can be accurately measured by the MPU. The task is somewhat difficult since the filament is biased around -90 Vdc. This problem is overcome by converting the voltage of interest

into a current, which is cascoded back to ground potential and converted back into a voltage by a TIA on Sheet 1 of the Bottom PCB.

The first of three operational transconductance amplifiers (OTAs), U210B, creates a current which is proportional to the voltage across the emission current shunt resistance (FIL_E_OTA). The second (U208B) creates a current which is proportional to the voltage across the filament (FIL_V_OTA). And the third (U203) creates a current which is proportional to the voltage across the heater current shunt resistance.

The op amp circuits whose negative supplies are connected to the repeller and filament potentials are powered by a charge pump circuit (U201 and U205). ±CP_DRIVE (10 volt square waves which are sourced from Sheet 4), are full wave rectified to provide power for these op amps.

When the user requests that the filament or Pirani gauge be turned “on”, the FIL_CT_CTL control is set so that there will be about 200 mV across the filament. By carefully measuring the time response of the heating of the filament, and by following the filament resistance thereafter, the unit can determine the gas pressure in the vacuum probe. If the gas pressure is found to be sufficiently low, the unit will turn up the heater power and bias sources, to generate the filament emission current to create ions from the residual gas.

The filament is continuously monitored during operation. Several conditions can be flagged:

A drop in the filament resistance may indicate that gas is cooling the filament and it should be turned “off”.

A sudden increase (of about 2x) in the filament resistance can indicate that one of the two filaments has burned out. This will cause the firmware to light the rear panel Service LED.

A very slow increase in filament resistance can indicate that the filament is slowly evaporating metal. If the filament resistance increases by 2x the Service LED will be turned “on”.

The grid bias is provided by an op amp (U213A). The grid current, which consists of a significant fraction of the emission current, can be monitored by the MPU. (It may turn out that the grid current is a more reliable indicator of filament emission current than the voltage across the filament emission shunt resistor.)

A Degas Mode allows the heating of the grid structure and the close by ionizer elements to facilitate rapid degassing of the vacuum probe. The degas mode is enabled by the DEGAS bit which activates a relay (U212). The relay disconnects the repeller, filament and grid from their regulated supplies, connecting them instead to the unregulated -125 V and +240 V supplies. (The filament emission current is still regulated by measuring the voltage across the emission current shunt resistance.) The higher voltages and emission current increase the power dissipated in the ionizer, speeding up degassing.

DC for quadrupole rods, focus plate bias (Sheet 3 of 4)

Circuits for focus plate bias and the generation of DC potentials for the quadrupole rods are located on this sheet.

Focus plate

The focus plate is used to extract ions from the region where they are created, causing them to be injected into the quadrupole mass filter. Normally, the focus plate is biased negatively with respect to the repeller and filament, assuring that no emission electrons will be collected by the focus plate (at about -95 Vdc). About half of the ions are collected by the focus plate (instead of being injected into the quadrupole. This ion current is proportional to the gas pressure in the vacuum probe.

The focus plate bias is provided by a high voltage op amp (U305). The op amp is internally protected from over temperature conditions, and will be shut down by an external transistor (Q304) if the total negative supply current exceeds 13 mA. These conditions should only occur during a fault and can be monitored by the MPU.

DC Rod potentials

Circuits to provide the ±DC potentials for the quadrupole rods are also located on this sheet. The rods require up to ±230 Vdc at 320 amu. The op amps (U306) for this circuit operate from ±5 V, but the (inverting) totem pole output drivers that they control operate from either +5 V and -240 V, or +240 V and -5 V. The CMOS op amps have a very low input bias current, avoiding errors due to high source resistances of their feedback networks.

The negative rod potential is controlled by a 16-bit DAC voltage, ROD_DC_CTL. The gain (from ROD_DC_CTL to the negative totem pole output) is -66.66x. With a DAC full-scale of +4.52 V, the LSB resolution is 4.6 mV. The high-side totem pole driver (Q306) is driven by U306A via a voltage divider (R321/R323). The low side driver (Q311) is translated to the -240 V level via a PNP cascode transistor (Q309). Negative feedback is via R325.

The positive supply mirrors the negative supply via a 0.1% 1.000 MΩ voltage divider. Here, U306B's output is level shifted up to +240 V via an NPN cascode transistor (Q307).

Both ±ROD supplies can be offset (in the same direction) with the ±4.5 Vdc "ROD_VCM" signal source by a 12-bit DAC. The ±DC rod supplies are current limited to a few 100 μA but can slew their output filter caps from zero to full scale in about 3 ms. The output filters also attenuate the RF rod voltages which could otherwise interfere with operation. The ±DC rod supplies connect to the Flange PCB via J300.

System power supplies (Sheet 4 of 4)

The final schematic sheet details the system's unregulated power supplies. The unit is powered from +24 Vdc, which is supplied either from a built-in offline OEM switching power supply, or via a rear panel, center-positive, barrel connector. The two power sources are wire-or'd via a dual Schottky diode to prevent conflicts.

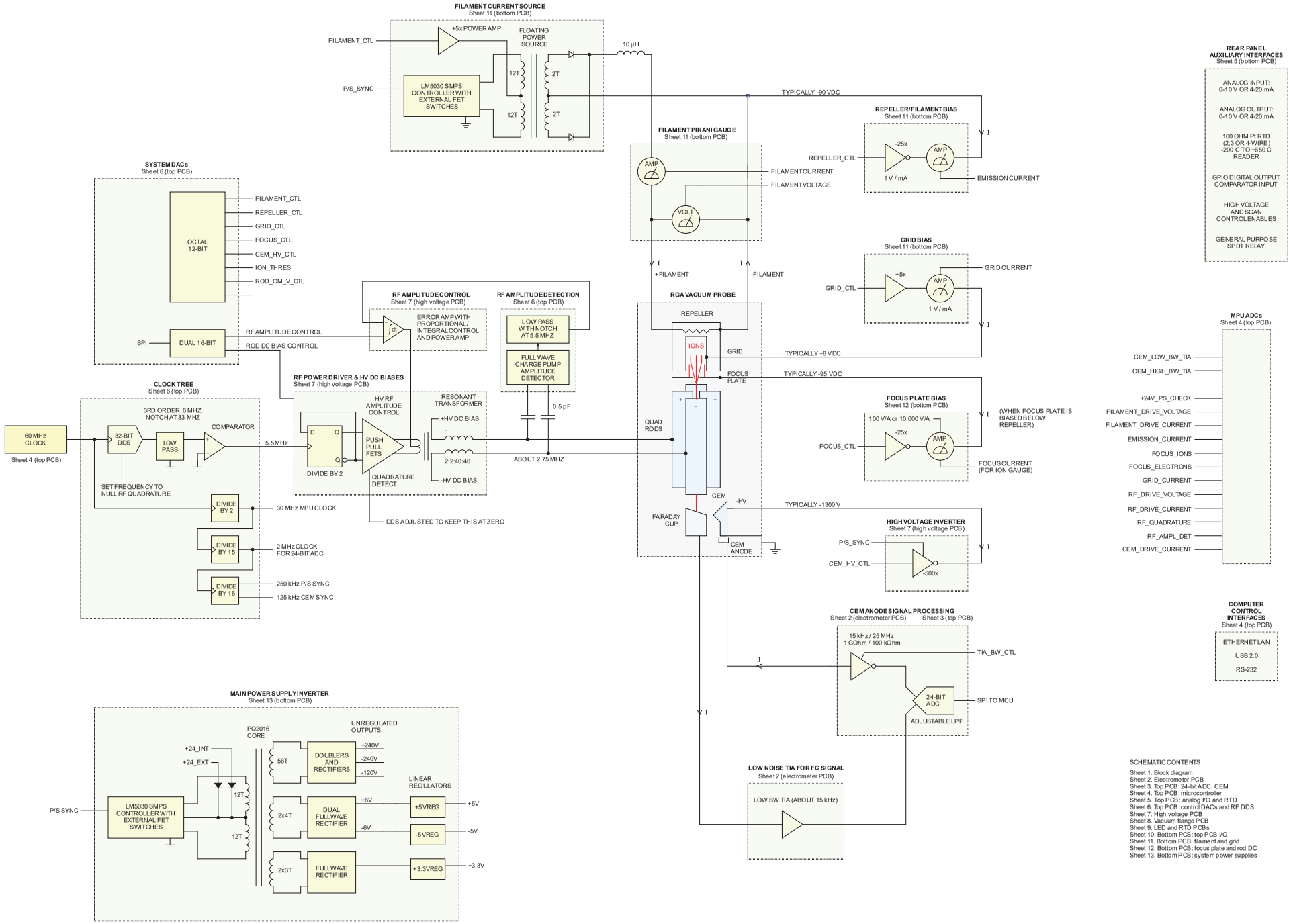
A hot-swap controller (U410) does inrush limiting, overvoltage and undervoltage lockout, soft start, and short circuit protection. U410 provides system power via a MOSFET (U414) with a 12 mΩ channel resistance and with a current trip set to about 4 A.

A +12 V linear regulator (U402) provides power to a switch mode controller (U409), which operates at 125 kHz and near to 100% duty cycle. U409 drives a pair of MOSFETs (U407 and U408) which drive the primary of a center tap transformer (U406). The transformer has secondaries which drive rectifiers to create ±6.5 Vdc, +4.5 Vdc, -120 Vdc, and ±240 Vdc (via a doubler). The primary side drive current can be monitored by the MPU via PS_DRIVE_I, which has a scale factor of 0.9 V/A.

A differential charge pump driver (U413), operating at half the frequency of PS_SYNC, provides drive voltages for the floating power supplies used in the filament and focus plate monitoring circuits.

Low drop-out linear regulators (U400, U403 and U405) are used to provide ±5.0 Vdc and +3.3 Vdc system wide. Protection diodes on these power supplies prevent load currents from pulling their outputs to the opposite polarity during power on and off cycles.

There are connectors for two +24 Vdc fans (one that blows directly on the RF HV transformer) and the other for the +24 Vdc off-line power supply)



SRS

RGA120 block diagram

Assemblies 671-677 Revision A

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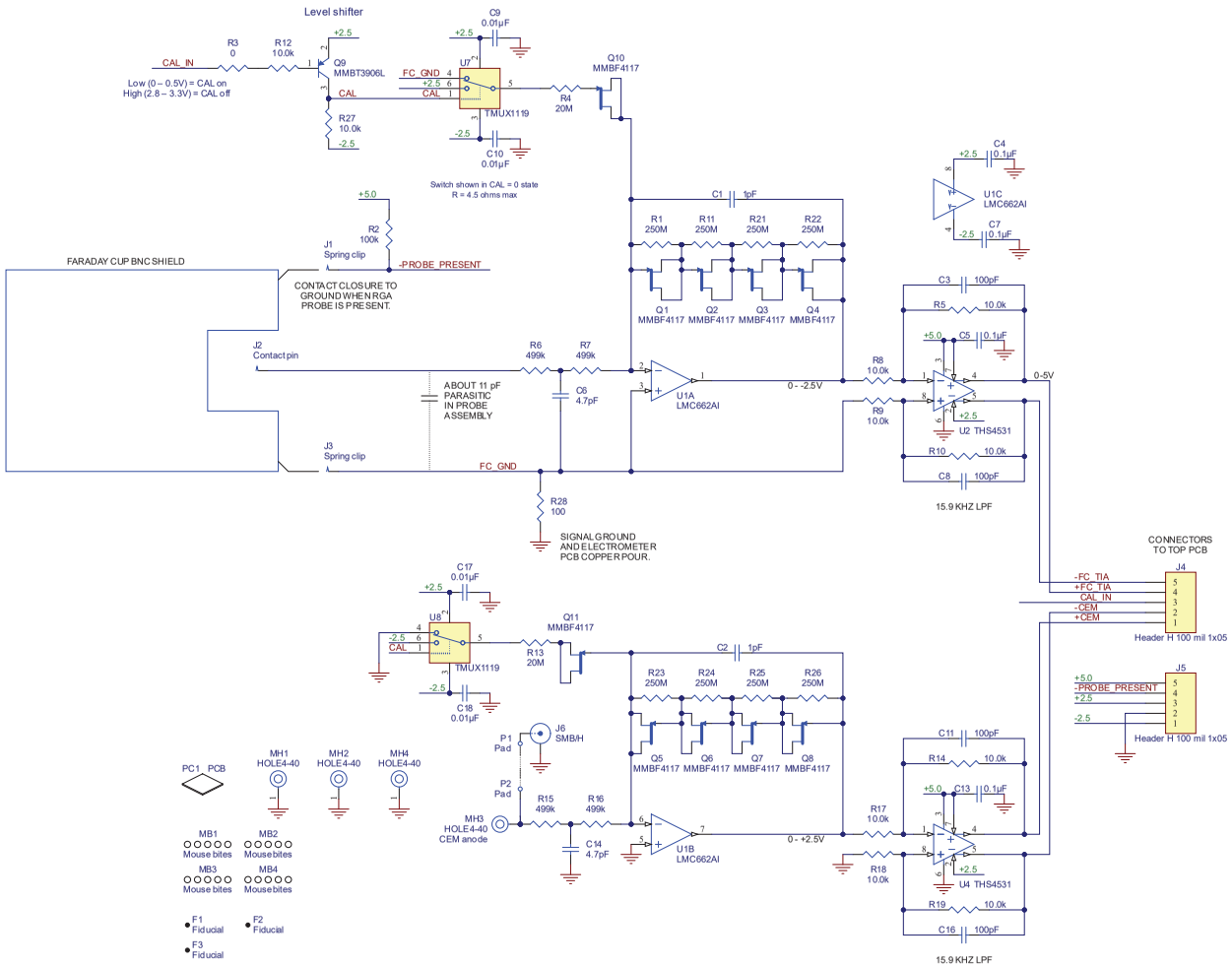

RGA120 electrometer PCB
Assembly 673 Part number 7-02704 Revision E
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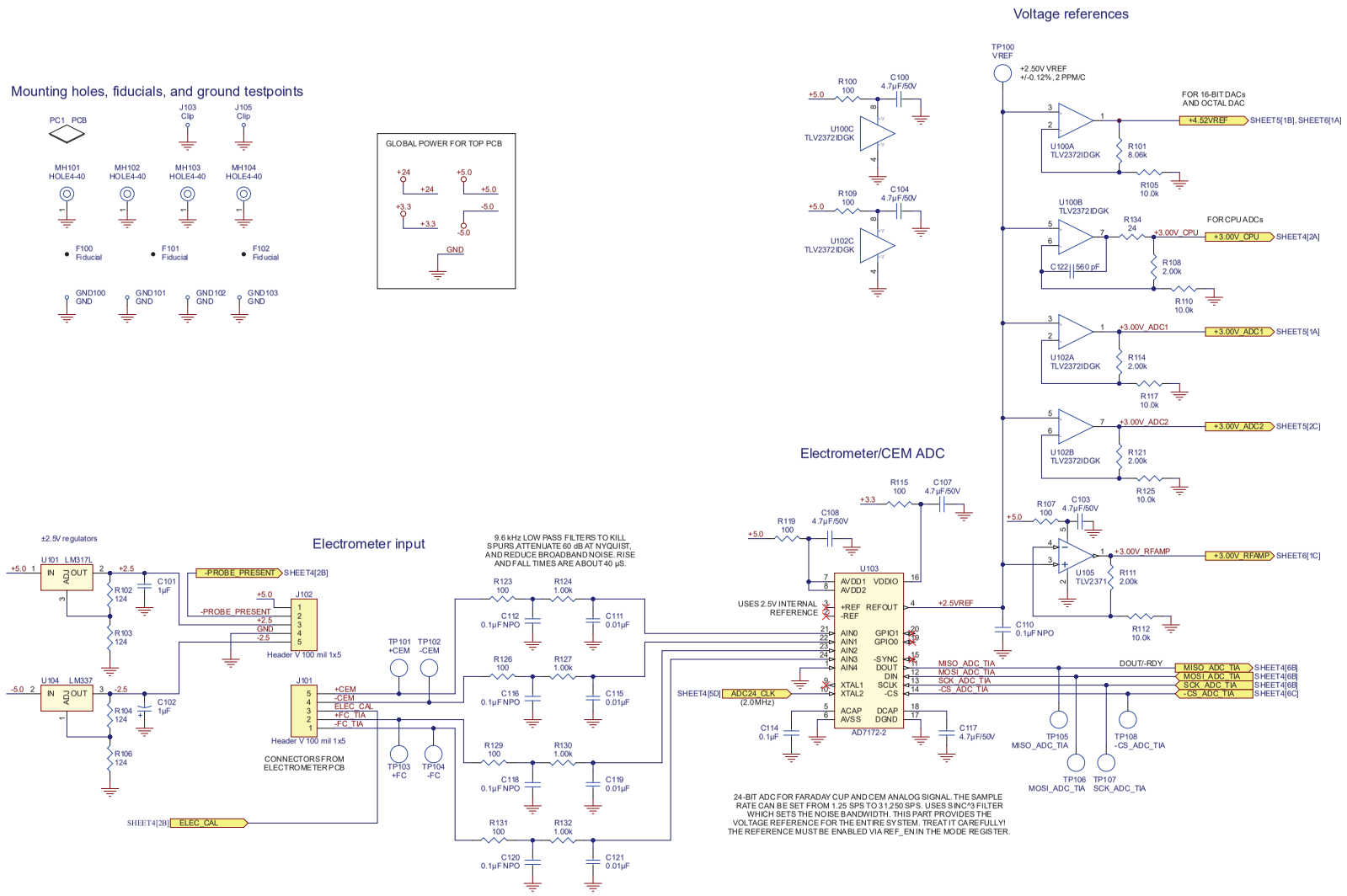

RGA120 top PCB: 24-bit ADC, CEM

Assembly 671 Part number 7-02671 Revision E

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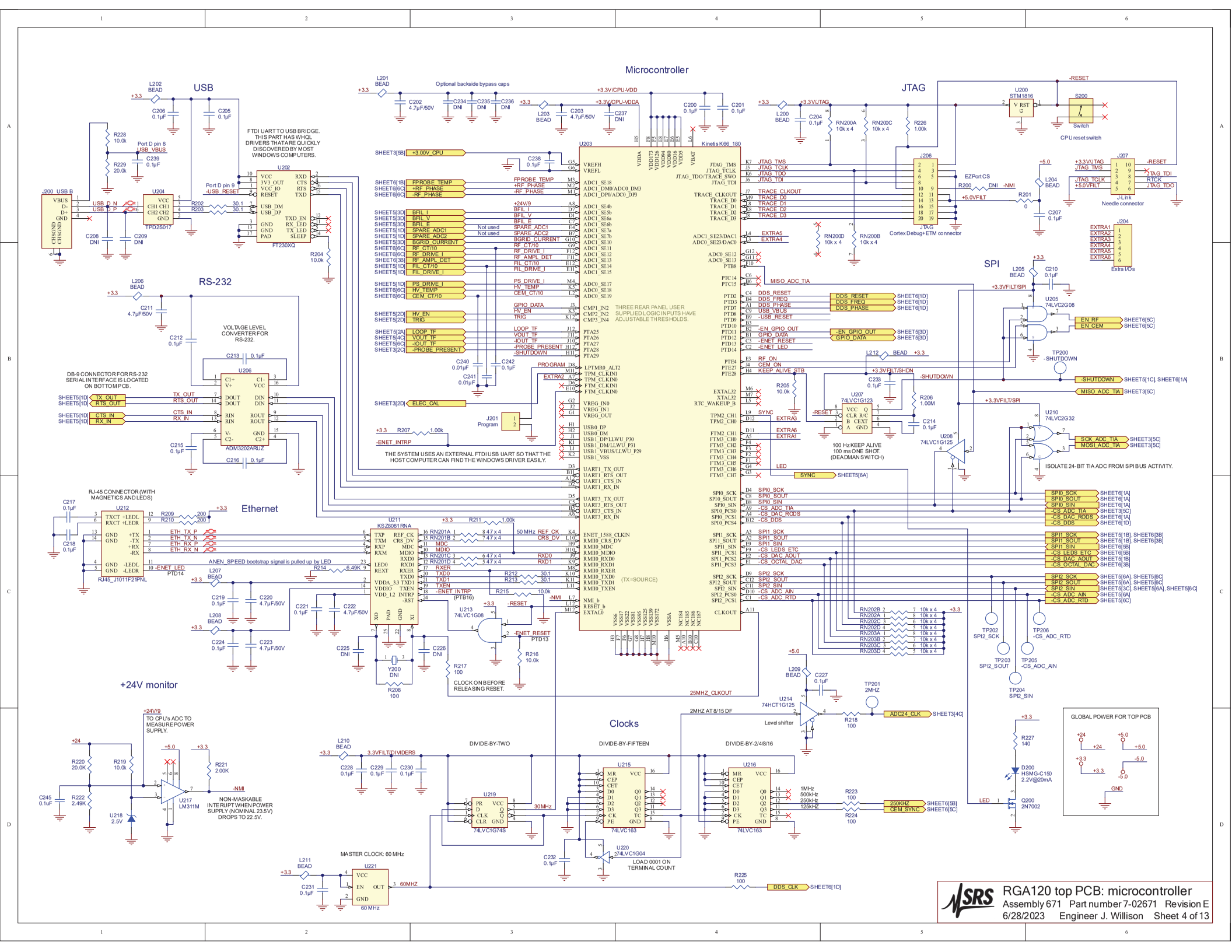

Microcontroller
USB
JTAG
SPI
RS-232
Ethernet
+24V monitor
Clocks
U203
Kinetis K66_180
U202
FT232XQ
U204
TPD2S017
U206
ADM3202ARUZ
U212
RJ45_J1011F21PNL
U211
KSZ8081RNA
U213
74LVC1G08
U214
74HCT1G125
U215
74LVC163
U216
74LVC163
U217
LM311M
U218
2.5V
U219
74LVC1G74S
U220
74LVC1G04
U221
60 MHZ
U200
STM1816
U205
74LVC2G08
U207
74LVC1G123
U208
74LVC1G125
U210
74LVC2G32
J200 USB B
J201
Program
J204
Extra I/Os
J206
JTAG
Cortex Debug+ETM connector
J207
J-Link
Needle connector
S200
Switch
CPU reset switch
TP200 -SHUTDOWN
TP201 2MHZ
TP202 SPI2_SCK
TP203 SPI2_SOUT
TP204 SPI2_SIN
TP205 -CS_ADC_AIN
TP206 -CS_ADC_RTD
Y200 DNI
D200 HSMG-C150 2.2V@20mA
Q200 2N7002
FTDI UART TO USB BRIDGE. THIS PART HAS WHQL DRIVERS THAT ARE QUICKLY DISCOVERED BY MOST WINDOWS COMPUTERS.
Optional backside bypass caps
THREE REAR PANEL USER SUPPLIED LOGIC INPUTS HAVE ADJUSTABLE THRESHOLDS.
THE SYSTEM USES AN EXTERNAL FTDI USB UART SO THAT THE HOST COMPUTER CAN FIND THE WINDOWS DRIVER EASILY.
VOLTAGE LEVEL CONVERTER FOR RS-232.
DB-9 CONNECTOR FOR RS-232 SERIAL INTERFACE IS LOCATED ON BOTTOM PCB.
RJ-45 CONNECTOR (WITH MAGNETICS AND LEDS)
ANEN_SPEED bootstrap signal is pulled up by LED
TO CPU's ADC TO MEASURE POWER SUPPLY.
NON-MASKABLE INTERUPT WHEN POWER SUPPLY (NOMINAL 23.5V) DROPS TO 22.5V.
CLOCK ON BEFORE RELEASING RESET.
DIVIDE-BY-TWO
DIVIDE-BY-FIFTEEN
DIVIDE-BY-2/4/8/16
MASTER CLOCK: 60 MHz
LOAD 0001 ON TERMINAL COUNT
100 Hz KEEP ALIVE 100 ms ONE SHOT. (DEADMAN SWITCH)
ISOLATE 24-BIT TIA ADC FROM SPI BUS ACTIVITY.
GLOBAL POWER FOR TOP PCB
RGA120 top PCB: microcontroller
Assembly 671 Part number 7-02671 Revision E
6/28/2023 Engineer J. Willison Sheet 4 of 13

Auxiliary I/O

4-20 mA aux input

THE LOOP POWER BIAS IS SET BY A 12-BIT DAC AND BUFFERED BY THIS HIGH POWER OP AMP. THE LOOP BIAS CAN BE SET FROM 0.00 VDC TO OVER +20 VDC. FIRMWARE REMOVES THE ERROR ASSOCIATED WITH THE FINITE CMMR OF THE RESISTIVE DIVIDER. (1% CMMR ERROR AT 20V LOOKS LIKE 2mA.)

THE ADC's FULL SCALE IS +/-REF/2 OR +/-1.50 V

SHEET3[5B] +3.00V_ADC1

FROM OCTAL 12-BIT DAC: SHEET6[4B] LOOP_BIAS_CTL

U300 OPA551(D2PAK)

R300 2.00k, R301 8.06k, L304 BEAD, C326 0.1µF, L305 BEAD, C327 0.1µF, R311 30.1k

R303 100, R304 10.0k/0.1%, R305 2.00k, R308 100/0.1%, R309 10.0k/0.1%, R310 2.00k

Thermal shutdown indicator: LOOP_TF → LOOP_TF SHEET4[2B]

D300 SMBJ24A

0–10V aux input

J300 REAR PANEL 0.156" TERMINAL BLOCK FOR ANALOG INPUTS AND OUTPUTS (0-10V AND 4-20mA). +V, -V, I_IN, VOUT, I_OUT, AIO

D301 SMBJ24A, D302 SMBJ24A, D303 SMBJ24A

R312 9.09k, R313 1.00k, R314 9.09k, R315 1.00k

10k OHM INPUTS DIVIDE BY 5.03. ERROR DUE TO CMMR IS ASSUMED SMALL AND IS NOT CORRECTED.

1 kHz LOW PASS FILTER ON REFERENCE AND ANALOG INPUT SIGNALS.

C301 0.1µF, C302 0.1µF, C303 0.1µF, C304 0.1µF, C305 0.1µF, C306 0.1µF

THESE ARE NPO CAPACITORS (FOR LOW MICROPHONICS)

R306 100, R307 100

Aux I/O ADC

24-BIT SIGMA DELTA ADC TO DIGITIZE EXTERNAL VOLTAGES OR CURRENTS.

U301 LTC2492: +REF, VCC, A3, A2, A1, A0, COM, -REF, GND, PAD, SDO, SCK, SDI, -CS, SYNC

+/-5, +/-V/10, -V/10

R302 100, C300 0.1µF

SPI2_SIN SHEET4[6C], SHEET5[3C], SHEET5[6C]
SPI2_SCK SHEET4[6C], SHEET5[6C]
SPI2_SOUT SHEET4[6C], SHEET5[6C]
-CS_ADC_AIN SHEET4[6C]
SYNC SHEET4[4C]

GLOBAL POWER FOR TOP PCB: +24, +5.0, +3.3, -5.0, GND

0–20V aux output

200 mA max

R316 200K, -0.25V offset AO_-IN, R317 9.09k, R320 100.0 SM1206/.25W/0.1% Current limiter, R321 2.49K, C310 0.1µF

Av= 4.32. WITH -0.25VDC OFFSET, VOLTAGE OUTPUT FROM ~.25 TO 21.3V WITH 16-BIT RESOLUTION (ABOUT 0.33mV). CAL FOR 0-20VDC.

U304 OPA551, L308 BEAD, C329 0.1µF, R330 30.1k

Thermal shutdown indicator: VOUT_TF SHEET4[2B]

Aux I/O DAC

L301 BEAD, C311 0.1µF, L300 BEAD, C309 0.1µF

U303 AD5689: VLOGIC, VREF, VDD, NC, SCLK, SDIN, SYNC, RESET, GAIN, RSTSEL, LDAC, A_OUT, B_OUT, SDO, GND, PAD

SHEET3[5B], SHEET6[1A] +4.52VREF

SIGNALS SOURCED BY BOTTOM PCB AND BY REAR PANEL TERMINAL STRIP.

SHEET4[6C], SHEET6[3B] SPI1_SCK
SHEET4[6C], SHEET6[3B] SPI1_SOUT
SHEET4[6C] -CS_DAC_AOUT
SHEET4[6B], SHEET6[1A] -SHUTDOWN

TP302 CS_DAC_AOUT

TP300 VOUT_CTL, TP301 IOUT_CTL

VOUT_CTL, IOUT_CTL

GAIN=1

SPI2_SIN SHEET4[6C], SHEET5[6A], SHEET5[6C]

DUAL 16-BIT DAC PROVIDES REAR PANEL ANALOG VOLTAGE AND 4-20 mA CURRENT OUTPUTS.

4-20 mA aux output

4-20 mA OUTPUT CURRENT SOURCE. (CONTROLLABLE FROM 0 TO 25 mA WITH 16-BIT RESOLUTION.)

L306 BEAD, C307 0.1µF, U302 LM317DCY: IN, OUT, ADJ, +20V, C308 0.1µF, R318 3.74k, R319 249

R322 100.0 SM1206/.25W/0.1%, R323 100, R324 10.0k, R325 10.0k, R326 10.0k, R327 10.0k, R328 20.0k, R329 20.0k

C312 0.1µF, D304 BAV70LT1, U306 AD8510ARZ, Q300 BCV28

L309 BEAD, C330 0.1µF, U305 LM393

-IOUT_TF SHEET4[2B]

External RTD input

THE ADC's FULL SCALE IS +/-REF/2 OR ABOUT +/-1.5V

SHEET3[5C] +3.00V_ADC2 → +3.00V_ADC2

R341 100, C331 0.1µF, R332 20.0k, R333 2.00k, R335 10.0k, R336 1.00M, R337 1.00k, R338 1.00k

ABOUT 2/3 OF FULL SCALE

THERE IS ABOUT 1mA BIAS CURRENT THROUGH 100 OHM PtRDT. CIRCUIT AND CODE ACCOMMODATE 2, 3 OR 4 WIRE RTDs. (IF THE +/-SENS INPUTS ARE ABOVE +RTD, THEY ARE UNCONNECTED AND WILL NOT BE USED.)

FIRMWARE SHOULD ALSO ALLOW THE +/-SENS INPUTS TO BE USED AS HIGH RESOLUTION DIFFERENTIAL (OR SINGLE-ENDED) VOLTAGE INPUTS WITH +/-1.5 VFS.

24-BIT DELTA SIGMA ADC TO DETERMINE RTD CONFIGURATION (2,3 OR 4-WIRE) AND MEASURE RTD RESISTANCE.

U307 LTC2492: +REF, VCC, A3, A2, A1, A0, COM, -REF, GND, PAD, SDO, SCK, SDI, -CS, SYNC

R331 100, C313 0.1µF

SPI2_SIN SHEET4[6C], SHEET5[3C], SHEET5[6A]
SPI2_SCK SHEET4[6C], SHEET5[6A]
SPI2_SOUT SHEET4[6C], SHEET5[6A]
-CS_ADC_RTD SHEET4[6C]
SYNC (INPUT TO ADC)

INPUT PROTECTION: RN301D, RN301C, RN301B, RN301A 5.10k x 4

C314 0.1µF, C315 0.1µF, C316 0.1µF, C317 0.1µF, R342 1.00k, C332 0.1µF

THESE ARE NPO CAPACITORS (FOR LOW MICROPHONICS)

J301 RTD board: +SENS, +RTD, -RTD(GND), -SENS, GND, GPIO_DATA_DIO, HV_EN_IN, TRIG_IN, TX_OUT, CTS_IN, RX_IN, RTS_OUT, SPARE, GND, FIL_E, GND, FIL_V, +5.0, FIL_I, -5.0, FIL_CT/10, GRID_CURRENT, PS_DRIVE_I, SPARE_ADC2, FIL_DRIVE_I, SPARE_ADC1

TP303 SPARE

RN300A 10k x 4, RN300B 10k x 4, RN300C 10k x 4, RN300D 10k x 4

HV_EN SHEET4[2B], TRIG SHEET4[2B]

TX_OUT SHEET4[1B], CTS_IN SHEET4[1B], RX_IN SHEET4[1B], RTS_OUT SHEET4[1B]

FIL_CT/10 SHEET4[2B]

PS_DRIVE_I SHEET4[2B], SPARE_ADC2 SHEET4[2A], FIL_DRIVE_I SHEET4[2B], SPARE_ADC1 SHEET4[2A]

RN304A 4.7k x 4, RN304B 4.7k x 4, RN304C 4.7k x 4, RN304D 4.7k x 4

U309A AD8604, U309B AD8604, U309C AD8604, U309D AD8604, U309E AD8604

C325A 0.1µF x 4, C325B 0.1µF x 4, C325C 0.1µF x 4, C325D 0.1µF x 4

C319A 0.01µF x 4, C319B 0.01µF x 4, C319C 0.01µF x 4, C319D 0.01µF x 4

RN303A 4.7k x 4, RN303B 4.7k x 4, RN303C 4.7k x 4, RN303D 4.7k x 4

RN302A 10 x 4, RN302B 10 x 4, RN302C 10 x 4, RN302D 10 x 4

BFIL_E SHEET4[2A], BFIL_V SHEET4[2A], BFIL_I SHEET4[2A], BGRID_CURRENT SHEET4[2B]

C320 1µF, C321 1µF, C322 1µF, C323 1µF

L303 Bead, C324 0.1µF

Auxiliary digital I/O

GPIO_DATA_DIO

SHEET4[5B] GPIO_DATA

SHEET4[5B] -EN_GPIO_OUT

L302 BEAD, C318 0.1µF, R340 10.0k, R339 1.00k, R334 10.0k

U308 74HCT1G125

1-BIT GENERAL PURPOSE REAR PANEL INPUT/OUTPUT. OUTPUT +5V/0V. INPUT TO COMPARATOR ON MPU.

SRS

RGA120 top PCB: analog I/O, RTD
Assembly 671 Part number 7-02671 Revision E
6/28/2023 Engineer J. Willison Sheet 5 of 13

Quadrupole rod control

Bias/amplitude DAC

DUAL 16-BIT DAC PROVIDES PRECISION CONTROL OF DC BIAS AND RF AMPLITUDE ON QUADRUPOLE RODS.

Control DAC

OCTAL 12-BIT DAC FOR ANALOG CONTROL.

SIGNALS SOURCED BY THE TOP PCB. (+3.3V, ONE SPI AND TWO UART SIGNALS ARE SOURCED BY THE BOTTOM PCB)

RF amplitude detector

CONNECTOR TO FLANGE PCB

LOW PASS FILTER AND 5.5MHZ TRAP.

Center tap voltage

PROPORTIONAL/INTEGRAL AMPLITUDE CONTROLLER RAMPS THE CT VOLTAGE TO THE RF TRANSFORMER UNTIL THE DETECTED AMPLITUDE MATCHES THE SET AMPLITUDE. (PROP/INTEGRAL FOR DIVIDE-BY-10, 20µs PLANT.)

CHARGE PUMP RF AMPLITUDE DETECTOR. RF IS AT ABOUT 2.75 MHz. CONNECTOR IS TO FLANGE PCB.

COMPENSATE CHARGE PUMP FOR CURRENT LOST TO DIODE FORWARD VOLTAGE AND JUNCTION CAPACITANCE.

2 KOHM SOURCE RESISTANCE

THIS DOUBLY BALANCED MIXER MEASURES PHASE BETWEEN THE CURRENT AND VOLTAGE OF THE RF DRIVER. THE DRIVE FREQUENCY WILL BE ADJUSTED TO MAKE THE DETECTED PHASE ZERO (THE FREQUENCY SO THAT THE LOAD IS RESISTIVE).

HEADER TO HIGH VOLTAGE BOARD (0.100" PITCH)

RF waveform generator

DDS FREQUENCY SOURCE FOR 2XRF DRIVE. NOMINAL 5.5MHz OUTPUT AND ABOUT 0.023Hz LSB RESOLUTION.

DDS LOW PASS FILTER: PASSBAND TO 7MHz, STOP BAND ABOVE 48MHz, AND NOTCH AT 55MHz. FULL DIFFERENTIAL REJECTS AMPLITUDE NOISE, GROUND NOISE AND MAGNETIC COUPLING TO FILTER INDUCTORS.

COMPLIMENTARY 5V SQUARE WARES AT ABOUT 2.75 MHz.

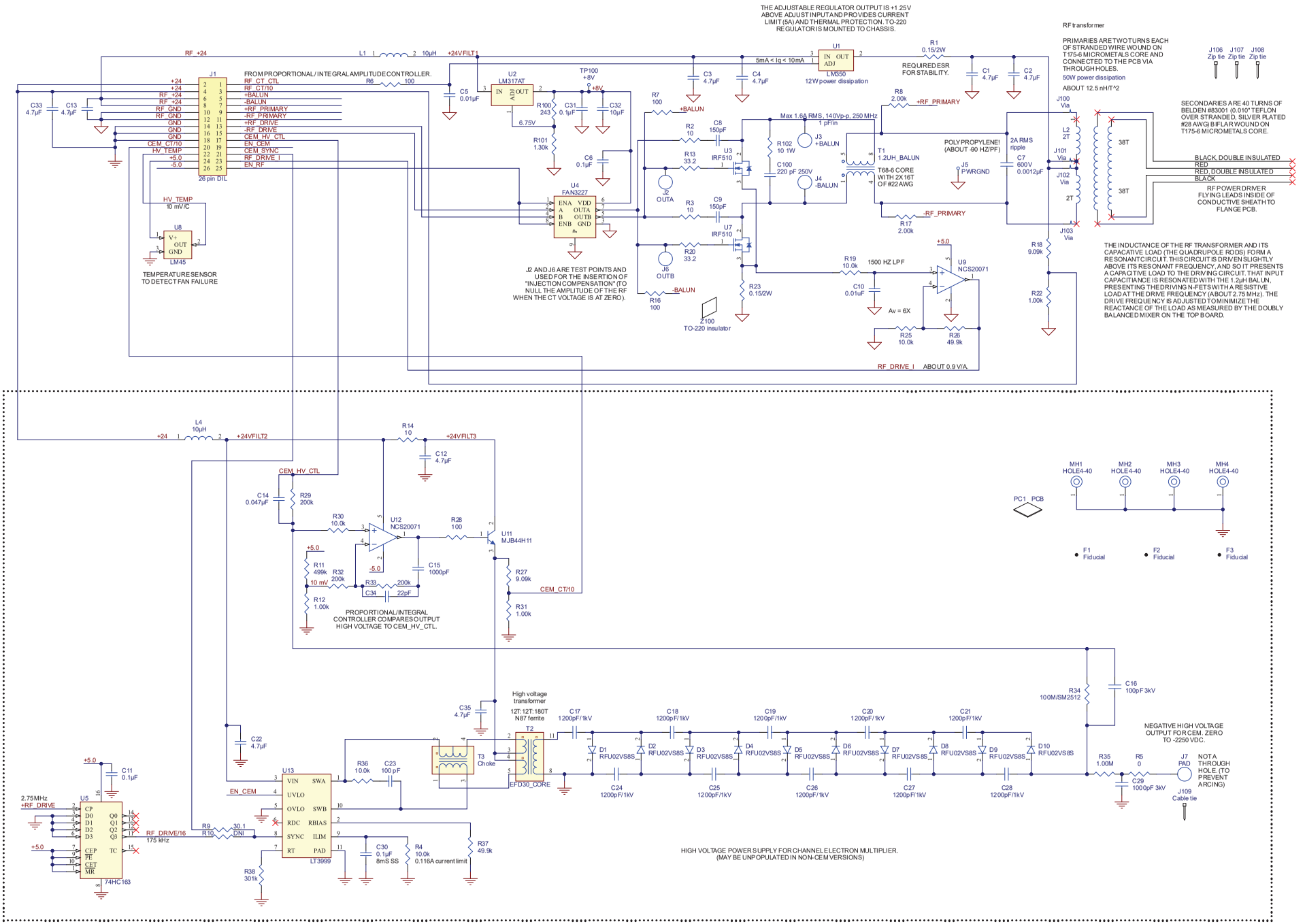
DIVIDE BY 2

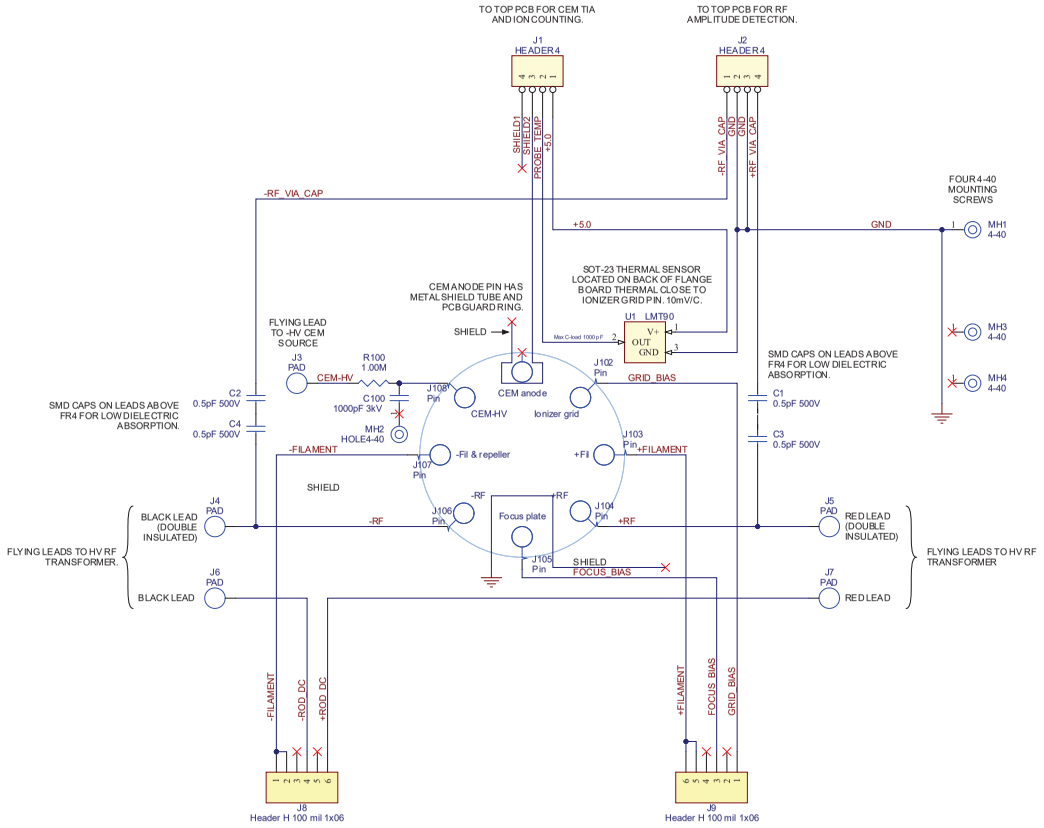
FAST DIFFERENTIAL COMPARATOR.

COMMON GROUND: AC CURRENTS SUM TO ZERO.

GLOBAL POWER FOR TOP PCB

Title	RGA120 top PCB: ctl DACs, RF DDS
Assembly	671
Part number	7-02671
Revision	B
Date	6/28/2023
Engineer	J. Willison
Sheet	6 of 13


THE ADJUSTABLE REGULATOR OUTPUT IS +1.25V ABOVE ADJUST INPUT AND PROVIDES CURRENT LIMIT (5A) AND THERMAL PROTECTION. TO-220 REGULATOR IS MOUNTED TO CHASSIS.
RF transformer
PRIMARIES ARE TWO TURNS EACH OF STRANDED WIRE WOUND ON T175-6 MICROMETALS CORE AND CONNECTED TO THE PCB VIA THROUGH HOLES.
50W power dissipation
ABOUT 12.5 nH/T^2
SECONDARIES ARE 40 TURNS OF BELDEN #83001 (0.010" TEFLON OVER STRANDED, SILVER PLATED #28 AWG) BIFILAR WOUND ON T175-6 MICROMETALS CORE.
BLACK, DOUBLE INSULATED
RED
RED; DOUBLE INSULATED
BLACK
RF POWER DRIVER FLYING LEADS INSIDE OF CONDUCTIVE SHEATH TO FLANGE PCB.
THE INDUCTANCE OF THE RF TRANSFORMER AND ITS CAPACATIVE LOAD (THE QUADRUPOLE RODS) FORM A RESONANT CIRCUIT. THIS CIRCUIT IS DRIVEN SLIGHTLY ABOVE ITS RESONANT FREQUENCY, AND SO IT PRESENTS A CAPACITIVE LOAD TO THE DRIVING CIRCUIT. THAT INPUT CAPACITANCE IS RESONATED WITH THE 1.2μH BALUN, PRESENTING THE DRIVING N-FETS WITH A RESISTIVE LOAD AT THE DRIVE FREQUENCY (ABOUT 2.75 MHz). THE DRIVE FREQUENCY IS ADJUSTED TO MINIMIZE THE REACTANCE OF THE LOAD AS MEASURED BY THE DOUBLY BALANCED MIXER ON THE TOP BOARD.
FROM PROPORTIONAL / INTEGRAL AMPLITUDE CONTROLLER.
RF_CT_CTL
RF_CT/10
+BALUN
-BALUN
+RF_PRIMARY
-RF_PRIMARY
+RF_DRIVE
-RF_DRIVE
CEM_HV_CTL
EN_CEM
CEM_SYNC
RF_DRIVE_I
EN_RF
26 pin DIL
TEMPERATURE SENSOR TO DETECT FAN FAILURE
J2 AND J6 ARE TEST POINTS AND USED FOR THE INSERTION OF "INJECTION COMPENSATION" (TO NULL THE AMPLITUDE OF THE RF WHEN THE CT VOLTAGE IS AT ZERO).
Z100 TO-220 insulator
REQUIRED ESR FOR STABILITY.
LM350 12W power dissipation
5mA < Iq < 10mA
Max 1.6A RMS, 140Vp-p, 250 MHz
1 pF/in
POLYPROPYLENE! (ABOUT -90 HZ/PF)
T68-6 CORE WITH 2X 16T OF #22 AWG
1.2UH_BALUN
2A RMS ripple
1500 HZ LPF
Av = 6X
RF_DRIVE_I ABOUT 0.9 V/A.
PROPORTIONAL/INTEGRAL CONTROLLER COMPARES OUTPUT HIGH VOLTAGE TO CEM_HV_CTL.
High voltage transformer
12T: 12T: 180T
N87 ferrite
EPD30_CORE
T3 Choke
NEGATIVE HIGH VOLTAGE OUTPUT FOR CEM, ZERO TO -2250 VDC.
NOT A THROUGH HOLE. (TO PREVENT ARCING)
HIGH VOLTAGE POWER SUPPLY FOR CHANNEL ELECTRON MULTIPLIER. (MAY BE UNPOPULATED IN NON-CEM VERSIONS)
F1 Fiducial
F2 Fiducial
F3 Fiducial
RGA120 high voltage PCB
Assembly 675 Part number 7-02706 Revision E
6/28/2023 Engineer J. Willison Sheet 7 of 13



PC100
PCB

MB1 Mouse bites
MB2 Mouse bites
MB3 Mouse bites
MB4 Mouse bites

SRS

RGA120 vacuum flange PCB

Assembly 674 Part number 7-02705 Revision C

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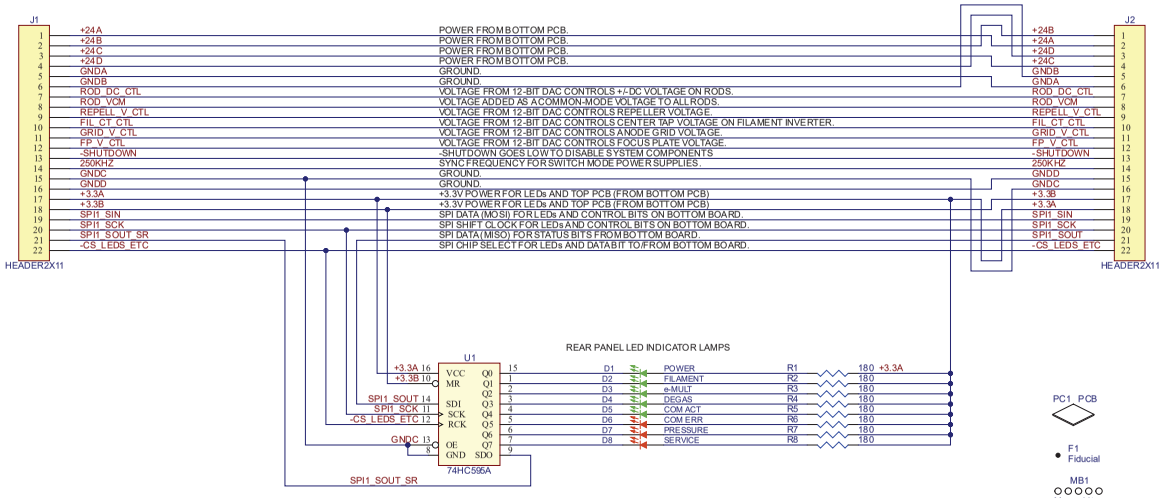
LED board

CONNECTOR TO BOTTOM PCB: SIGNALS SOURCED BY THE TOP PCB. (+3.3, UART RX_IN, CTS_IN AND SDI MOSI ARE SOURCED FROM THE BOTTOM BOARD)

CONNECTOR TO TOP PCB: SIGNALS SOURCED BY THE TOP PCB. (+3.3, UART RX_IN, CTS_IN AND SDI MOSI ARE SOURCED FROM THE BOTTOM BOARD)



REAR PANEL LED INDICATOR LAMPS

DATA IS SHIFTED IN VIA SPI FROM TOP BOARD. DATA PATH CONTINUES TO BOTTOM BOARD TO POPULATE SHIFT REGISTER FOR BOTTOM BOARD CONTROL BITS.

PC1_PCB

F1 Fiducial

MB1 Mousebites

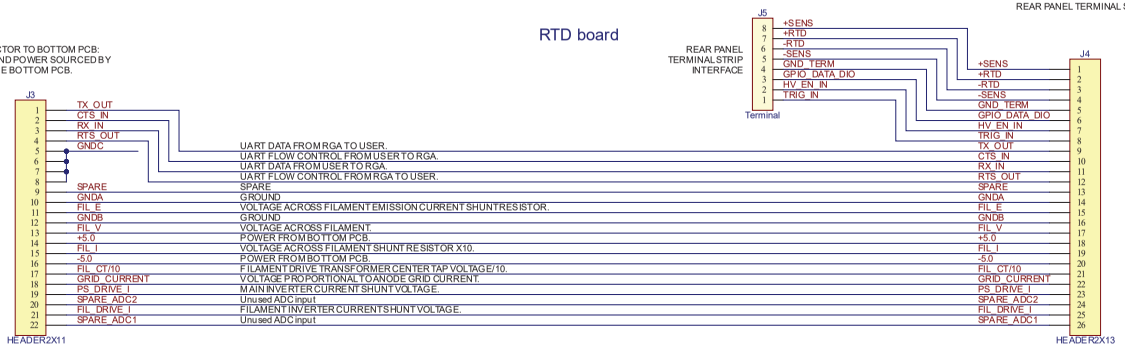
MB2 Mousebites

RTD board

CONNECTOR TO BOTTOM PCB: SIGNALS AND POWER SOURCED BY THE BOTTOM PCB.

CONNECTOR TO TOP PCB: SIGNALS AND POWER SOURCED BY BOTTOM PCB AND FROM REAR PANEL TERMINAL STRIP:

REAR PANEL TERMINAL STRIP INTERFACE



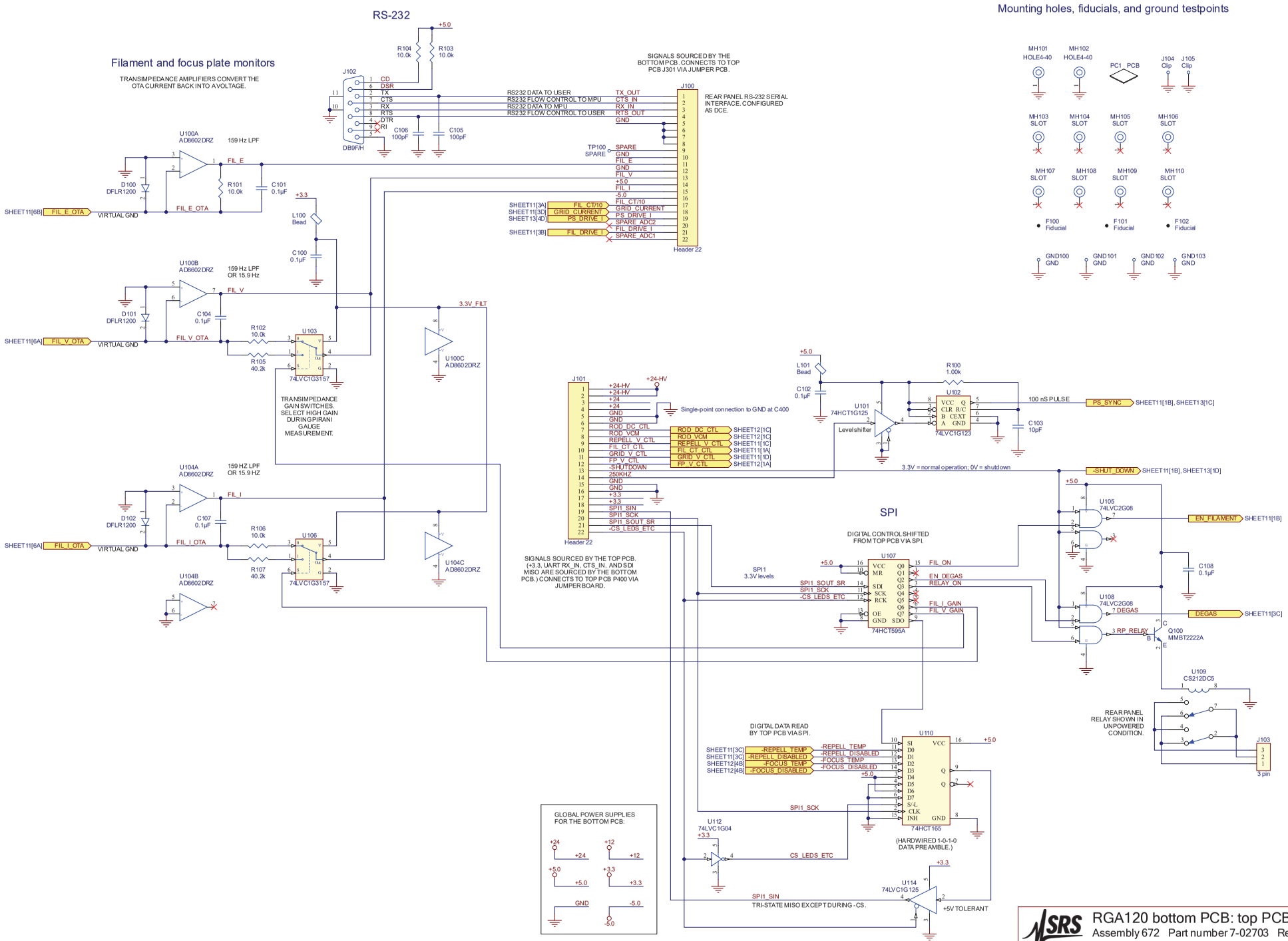
F1 Fiducial

F2 Fiducial

MB1 Mousebites

MB2 Mousebites

RGA120 LED and RTD PCBs
Assembly 676 Part number 7-02709 Revision D
6/28/2023 Engineer J. Willison Sheet 9 of 13


RS-232
Filament and focus plate monitors
TRANSIMPEDANCE AMPLIFIERS CONVERT THE OTA CURRENT BACK INTO A VOLTAGE.
SIGNALS SOURCED BY THE BOTTOM PCB. CONNECTS TO TOP PCB J301 VIA JUMPER PCB.
REAR PANEL RS-232 SERIAL INTERFACE. CONFIGURED AS DCE.
Mounting holes, fiducials, and ground testpoints
TRANSIMPEDANCE GAIN SWITCHES. SELECT HIGH GAIN DURING PIRANI GAUGE MEASUREMENT.
SIGNALS SOURCED BY THE TOP PCB. (+3.3, UART RX_IN, CTS_IN, AND SDI MISO ARE SOURCED BY THE BOTTOM PCB.) CONNECTS TO TOP PCB P400 VIA JUMPER BOARD.
SPI
DIGITAL CONTROL SHIFTED FROM TOP PCB VIA SPI.
DIGITAL DATA READ BY TOP PCB VIA SPI.
(HARDWIRED 1-0-1-0 DATA PREAMBLE.)
REAR PANEL RELAY SHOWN IN UNPOWERED CONDITION.
GLOBAL POWER SUPPLIES FOR THE BOTTOM PCB:
TRI-STATE MISO EXCEPT DURING -CS.
+5V TOLERANT
RGA120 bottom PCB: top PCB I/O
Assembly 672 Part number 7-02703 Revision E
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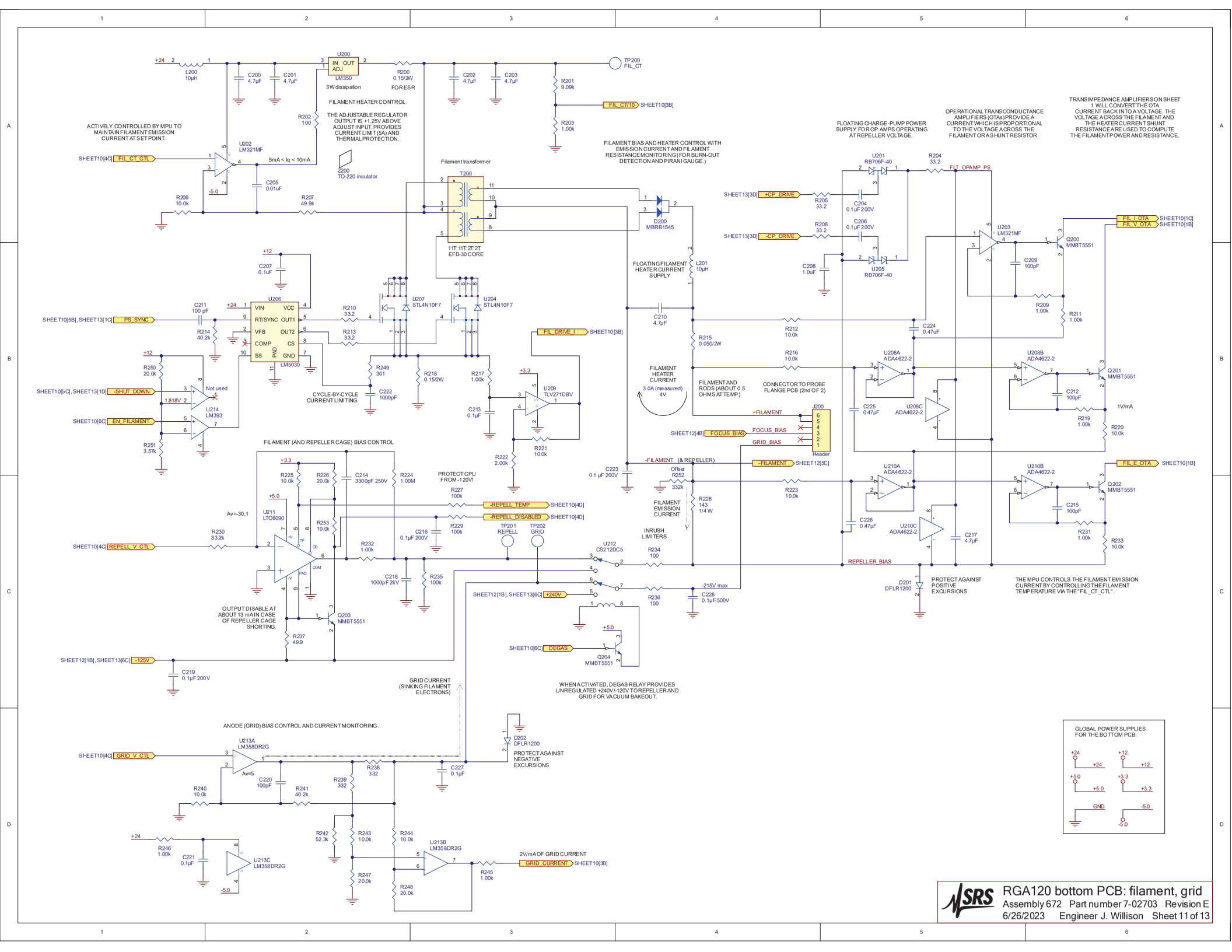
ACTIVELY CONTROLLED BY MPU TO MAINTAIN FILAMENT EMISSION CURRENT AT SET POINT.
FILAMENT HEATER CONTROL
THE ADJUSTABLE REGULATOR OUTPUT IS +1.25V ABOVE ADJUST INPUT. PROVIDES CURRENT LIMIT (5A) AND THERMAL PROTECTION.
3W dissipation
FOR ESR
5mA < Iq < 10mA
Filament transformer
11T:11T:2T:2T
EFD-30 CORE
FILAMENT BIAS AND HEATER CONTROL WITH EMISSION CURRENT AND FILAMENT RESISTANCE MONITORING (FOR BURN-OUT DETECTION AND PIRANI GAUGE.)
FLOATING CHARGE-PUMP POWER SUPPLY FOR OP AMPS OPERATING AT REPELLER VOLTAGE.
OPERATIONAL TRANSCONDUCTANCE AMPLIFIERS (OTAs) PROVIDE A CURRENT WHICH IS PROPORTIONAL TO THE VOLTAGE ACROSS THE FILAMENT OR A SHUNT RESISTOR.
TRANSIMPEDANCE AMPLIFIERS ON SHEET 1 WILL CONVERT THE OTA CURRENT BACK INTO A VOLTAGE. THE VOLTAGE ACROSS THE FILAMENT AND THE HEATER CURRENT SHUNT RESISTANCE ARE USED TO COMPUTE THE FILAMENT POWER AND RESISTANCE.
FILAMENT (AND REPELLER CAGE) BIAS CONTROL
CYCLE-BY-CYCLE CURRENT LIMITING.
FILAMENT HEATER CURRENT 3.0A (measured) 4V
FILAMENT AND RODS (ABOUT 0.5 OHMS AT TEMP)
CONNECTOR TO PROBE FLANGE PCB (2nd OF 2)
PROTECT CPU FROM -120V!
FILAMENT EMISSION CURRENT
INRUSH LIMITERS
OUTPUT DISABLE AT ABOUT 13 mA IN CASE OF REPELLER CAGE SHORTING.
PROTECT AGAINST POSITIVE EXCURSIONS
THE MPU CONTROLS THE FILAMENT EMISSION CURRENT BY CONTROLLING THE FILAMENT TEMPERATURE VIA THE "FIL_CT_CTL".
WHEN ACTIVATED, DEGAS RELAY PROVIDES UNREGULATED +240V/-120V TO REPELLER AND GRID FOR VACUUM BAKEOUT.
GRID CURRENT (SINKING FILAMENT ELECTRONS)
ANODE (GRID) BIAS CONTROL AND CURRENT MONITORING.
PROTECT AGAINST NEGATIVE EXCURSIONS
2V/mA OF GRID CURRENT
GLOBAL POWER SUPPLIES FOR THE BOTTOM PCB:
RGA120 bottom PCB: filament, grid
Assembly 672 Part number 7-02703 Revision E
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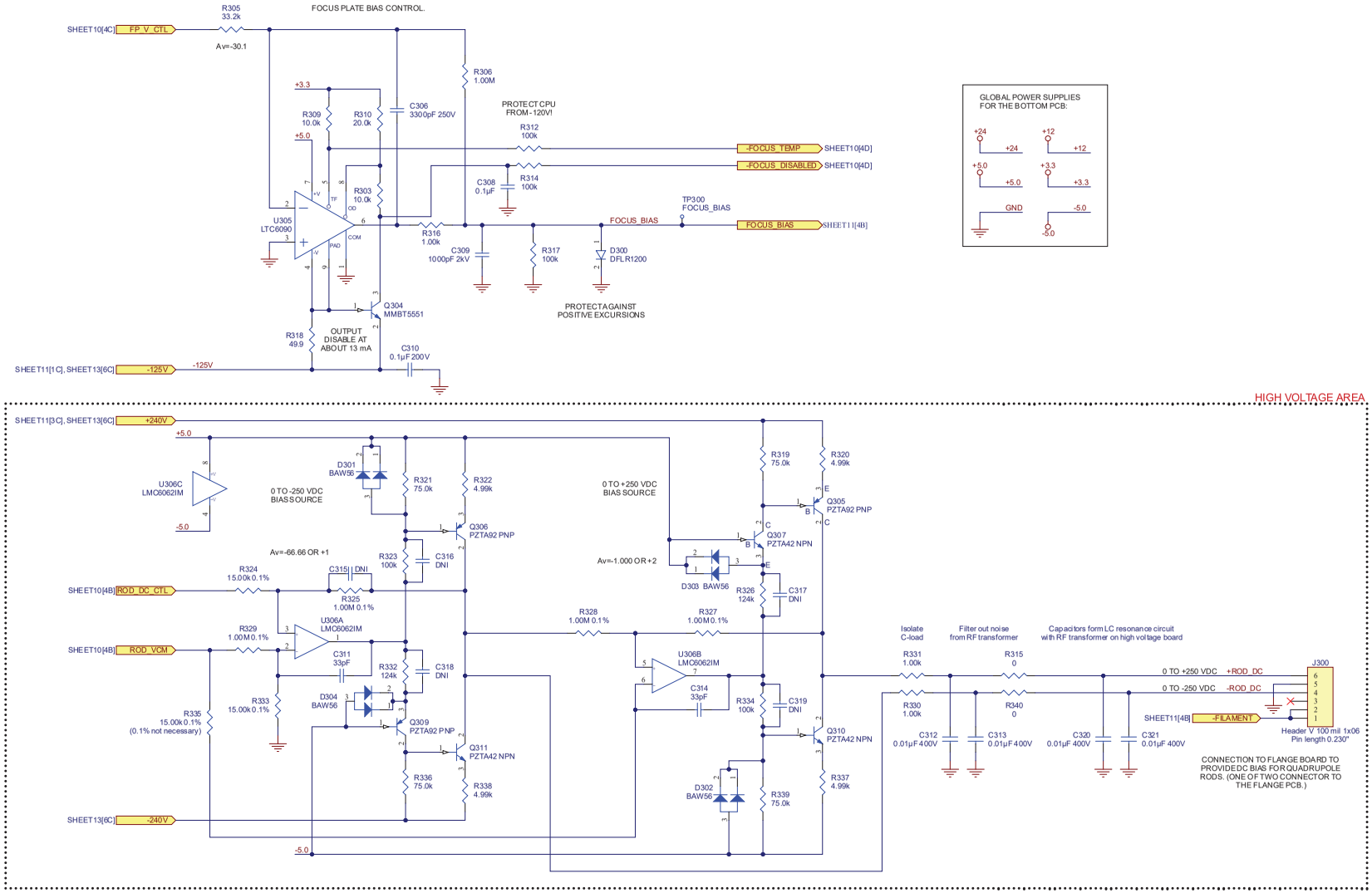

SRS

RGA120 bottom PCB: focus, rod DC

Assembly 672 Part number 7-02703 Revision E

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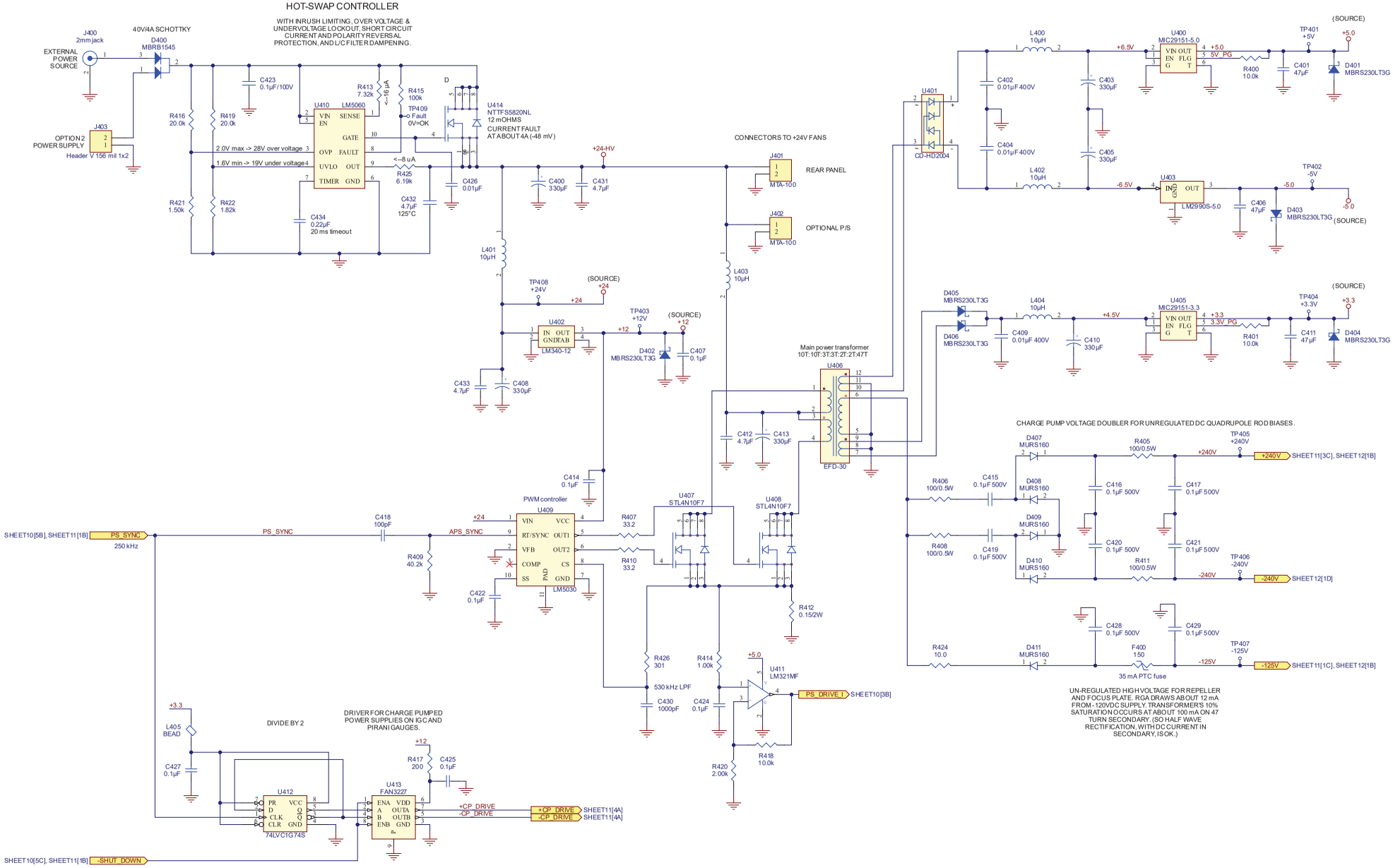

SRS

RGA120 bottom PCB: system power

Assembly 672 Part number 7-02703 Revision E

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Chapter 12

RGA Probe Assembly

This chapter contains two RGA probe assembly drawings.

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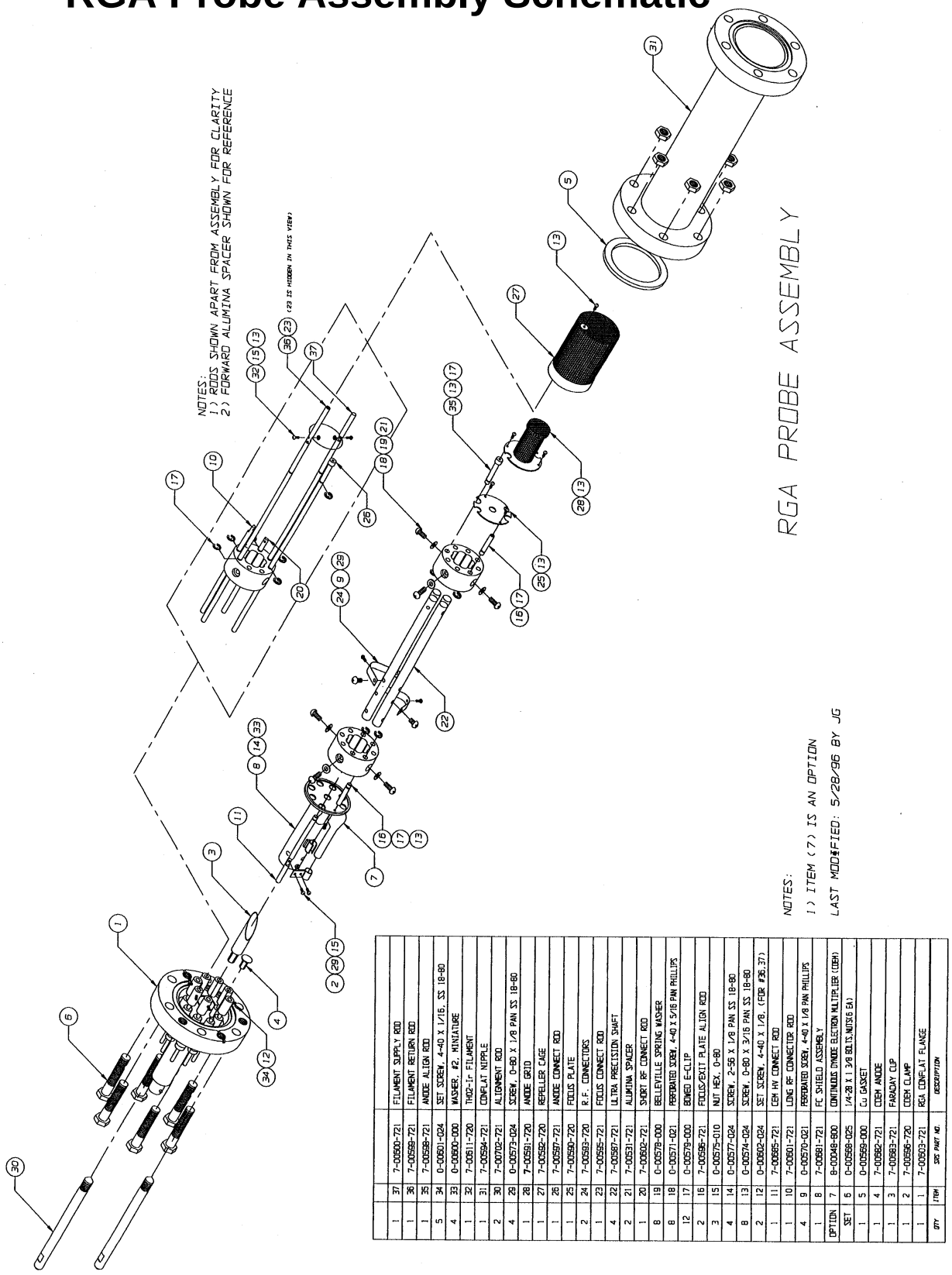
O100MAX Maximum Insertion Nipple Drawing 12-4

RGA Probe Assembly Schematic



QTY	ITEM	SRS PART NO	DESCRIPTION
1	37	7-00500-721	FILAMENT SUPPLY ROD
1	36	7-00599-721	FILAMENT RETURN ROD
1	35	7-00598-721	ANODE ALIGN ROD
5	34	0-00601-024	SET SCREW, 4-40 X 1/16, SS 18-80
4	33	0-00600-000	WASHER, #2, MINIATURE
1	32	7-00511-720	THO2-Ir FILAMENT
1	31	7-00594-721	CONFLAT NIPPLE
2	30	7-00702-721	ALIGNMENT ROD
4	29	0-00573-024	SCREW, 0-80 X 1/8 PAN SS 18-80
1	28	7-00591-720	ANODE GRID
1	27	7-00592-720	REPELLER CAGE
1	26	7-00597-721	ANODE CONNECT ROD
1	25	7-00590-720	FOCUS PLATE
2	24	7-00593-720	R.F. CONNECTORS
1	23	7-00595-721	FOCUS CONNECT ROD
4	22	7-00587-721	ULTRA PRECISION SHAFT
2	21	7-00531-721	ALUMINA SPACER
1	20	7-00602-721	SHORT RF CONNECT ROD
8	19	0-00578-000	BELLEVILLE SPRING WASHER
8	18	0-00571-021	PERFORATED SCREW, 4-40 X 5/16 PAN PHILLIPS
12	17	0-00579-000	BOWED E-CLIP
2	16	7-00596-721	FOCUS/EXIT PLATE ALIGN ROD
3	15	0-00575-010	NUT HEX, 0-80
4	14	0-00577-024	SCREW, 2-56 X 1/8 PAN SS 18-80
8	13	0-00574-024	SCREW, 0-80 X 3/16 PAN SS 18-80
2	12	0-00602-024	SET SCREW, 4-40 X 1/8, (FOR #36,37)
1	11	7-00605-721	CEM HV CONNECT ROD
1	10	7-00601-721	LONG RF CONNECTOR ROD
4	9	0-00570-021	PERFORATED SCREW, 4-40 X 1/4 PAN PHILLIPS
1	8	7-00581-721	PC SHIELD ASSEMBLY
OPTION	7	8-00048-800	CONTINUOUS DYNODE ELECTRON MULTIPLIER (CDEM)
SET	6	0-00569-025	1/4-28 X 1 3/4 BOLTS,NUTS(6 EA)
1	5	0-00599-000	Cu GASKET
1	4	7-00582-721	CDEM ANODE
1	3	7-00583-721	FARADAY CUP
1	2	7-00585-720	CDEM CLAMP
1	1	7-00603-721	RGA CONFLAT FLANGE

Figure 12-1 RGA probe assembly drawing

Feedthru Flange Connector Schematic

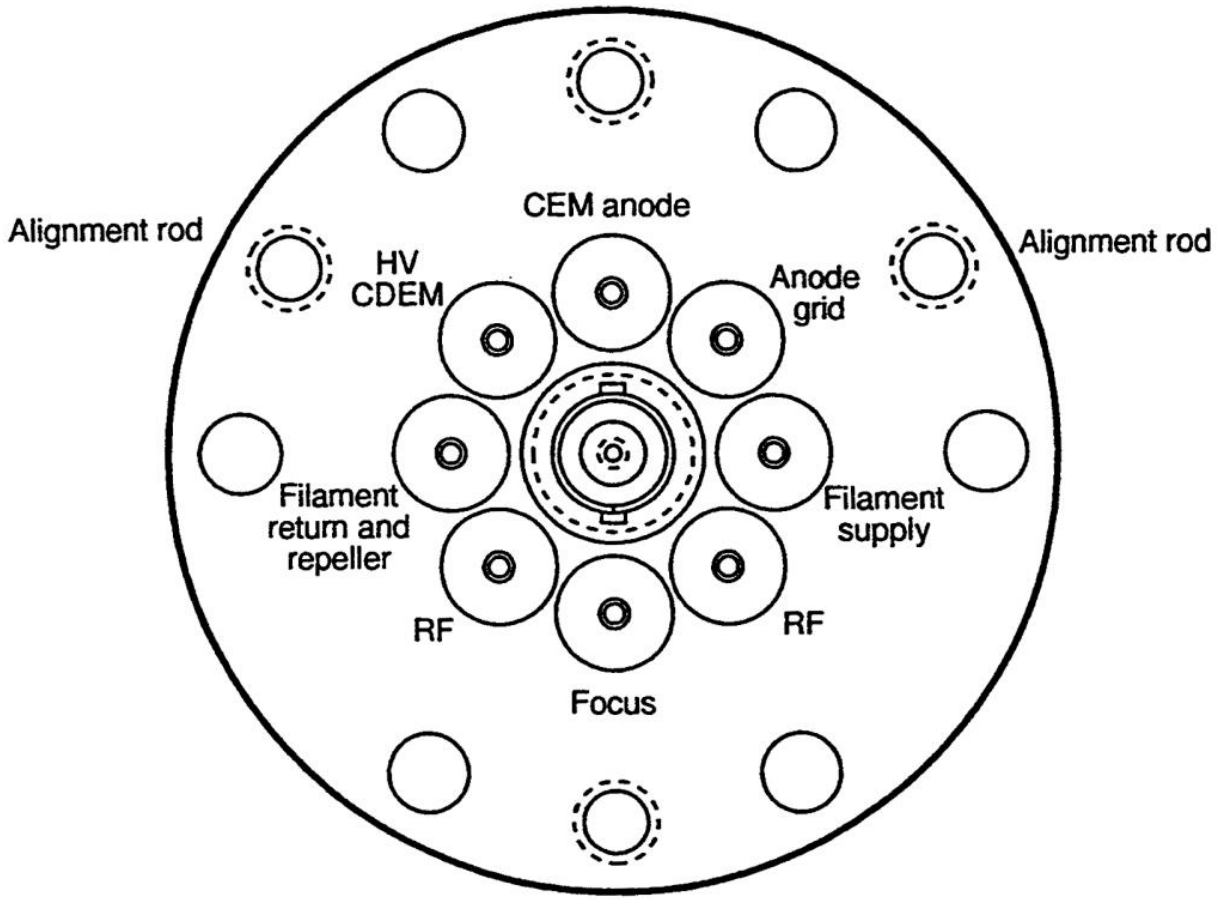


Figure 12-2 Feedthru Flange Connectors

O100MAX Maximum Insertion Nipple

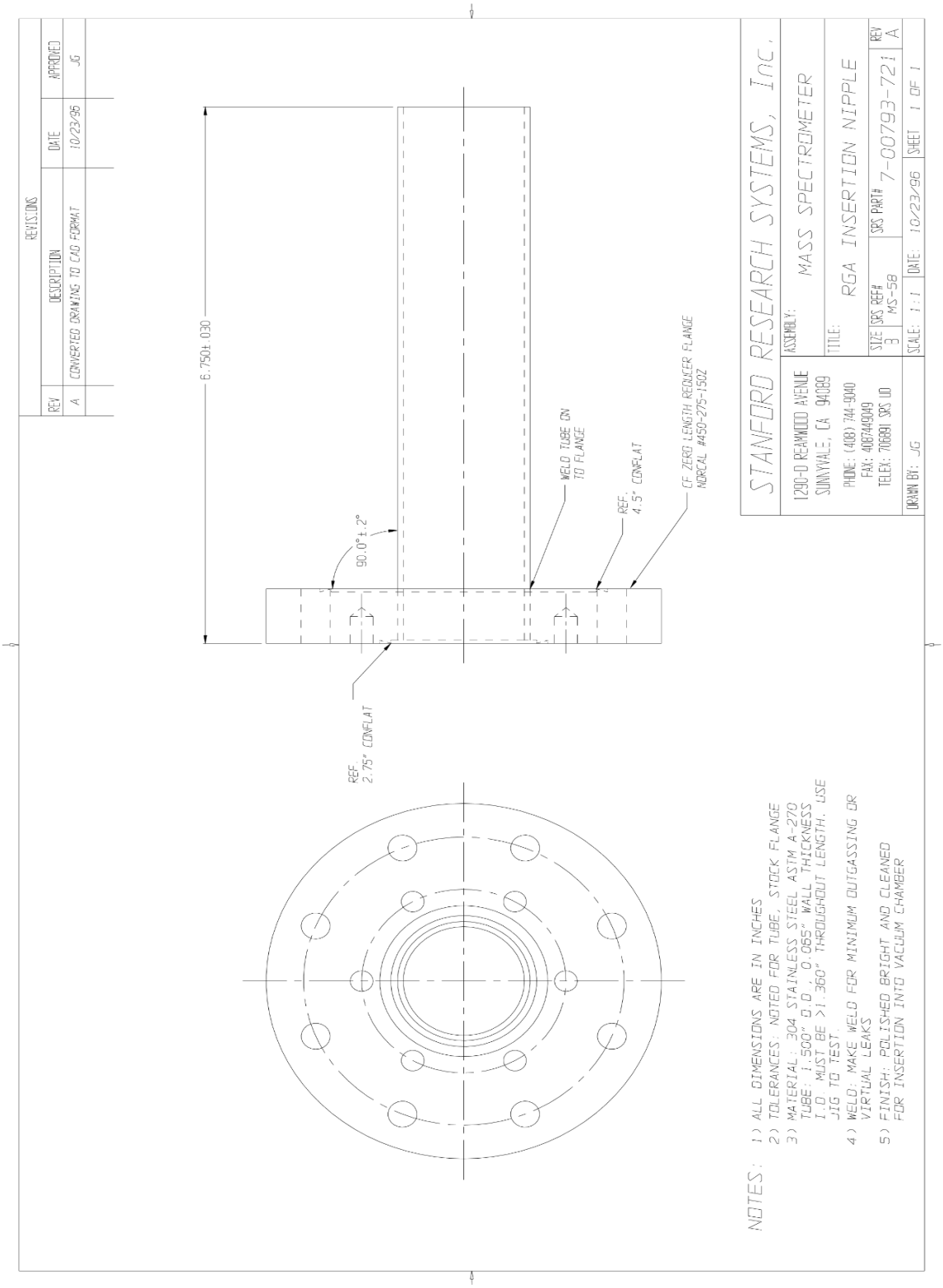


Figure 12-3 Maximum insetion nipple

Chapter 13

Legacy remote commands

This chapter describes remote commands used in legacy RGA100 series.

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Introduction

The RGA120 series firmware supports an extensive SCPI command set for configuration, calibration, diagnosis and operation of the instrument. It also maintains the legacy command set that is found in the RGA100 series. This chapter covers the details of those legacy commands. A table at the end of the chapter lists out the equivalent SCPI commands to the legacy commands. It would help an existing custom program to migrate to the new command set to take advantage of its flexibility and functionality.

Command Syntax

The RGA commands are ASCII character strings consisting of a two letter (case insensitive) **command name**, a **parameter**, and a **carriage return** terminator**.**

Note: The carriage return character, decimal ASCII value=13, is represented throughout this manual with the symbol **<CR>**. All command strings must be terminated with this character to be acknowledged by the RGA.

Valid **parameters** are:
Numbers: Numbers are the most common type of parameter used to program the RGA. Number parameters must be within a command-specific range and must not conflict with any pre-existing parameter values of the RGA. Only Decimal format is accepted. The fractional parts are truncated to four decimal places before being stored in memory. The '+' sign is optional for positive numbers. A zero in front of the period is optional in fractional numbers with magnitude less than one.

Asterisk "✱" (default): A single asterisk indicates that the default parameter value (stored in the RGA's permanent memory) is to be used for command execution. The asterisk must be strictly followed by a <CR>.

Question mark "?" (**Query**): Query commands are used to read error bytes, to measure total pressure and to confirm internal parameter values. The question mark must be strictly followed by a <CR> terminator. With a few exceptions, the data returned by most query commands is a string of ASCII characters terminated by a linefeed (<LF>, decimal ASCII value=10) and a <CR> terminator: string<LF><CR>. Ion currents are represented as integers in units of 10^{-16} Amps, and transmitted directly in Hex format: four byte integers, 2's complement format, Least Significant Byte first.

No parameter: Some commands do not require a parameter.

RGA Legacy Command Set

This section lists and describes the commands of the RGA's Legacy Command Set. The commands are separated into several lists, based on their functions. They are each identified by a **header** that describes the **command's syntax** (with the acceptable parameter values), the **command's function,** and the information returned (**Echo**) to the computer during execution.

Initialization Commands

ID?

Description: Identification query.

Echo: ID string.

Use to identify the RGA connected to the host computer.
The RGA returns the ID string (ASCII format):

SRSRGA###VER#.##SN#####<LF><CR>

The three string parameters, in the exact format shown above, correspond to:

Model number (=M_MAX): 120 for RGA120, 220 for RGA220 and 320 for RGA320.

Firmware version (for example: 0.23).

Serial Number of the unit (5 digit format).

The ID command is used for a variety of purposes:

- Make sure the RGA is powered up and ready to go.
- Check the quality of the connection to the host computer.
- Check the user's communication software to make sure it is communicating properly with the RGA.
- Check the serial numbers of the RGA units connected to the computer's serial ports.

Parameters: Only one possible format:

ID?

Error checking:
Only a query format is accepted. Anything else results in a Bad-parameter error.

IN0, IN1, IN2

Description: Initialization command

Echo: STATUS Byte

Initialize the RGA to a known state.

Three different levels of initialization are available.

Command execution times vary depending on the pre-existing ionizer conditions. The end of the command execution is prompted to the host computer returning the STATUS byte.

Parameters:

IN0: Initialize communications and check the ECU hardware.

- The input and output data buffers are emptied (all communications are disabled while this happens).
- Bit 0 of STATUS and RS232_ERR are cleared.
- A fresh check of the ECU hardware, including the 24V P/S, the Electrometer and the QMF RF P/S, is performed and the necessary error bytes are updated.

IN1: Reset the RGA to its factory default settings.

In addition to the above, the RGA is reprogrammed to its default (i.e. Factory preferred) values:

- Total Pressure measurement is enabled: TP_Flag = 1
- Default parameter settings are selected for: MI (1), MF (M_MAX), SA (10), NF (4), IE (1), EE (70), and VF (90).
- The filament's electron emission setting is left unmodified, and the ionizer is biased to default voltages if necessary.

IN2: Activate Standby mode.

In addition to the above:

- The filament and the CDEM are turned off.

Error Checking:
The command accepts no default or query parameter values.
The absence of a parameter is treated as a bad-parameter error.

Ionizer Control Commands

DGparam, param: 0 - 20,*

Description: Ionizer Degas command

Echo: STATUS error byte (unless command is stopped before completion, or param=0).

DEGAS the ionizer by heating and electron stimulated desorption. The parameter represents the desired DEGAS time in minutes and includes a one-minute initial ramping time. The degas procedure is discussed in Degas Commands of the Remote Command Set chapter.

Any command received before degassing is over will stop the process immediately without the STATUS byte being echoed to the computer. During degassing a check for new commands is done once a second, so a time margin must be allowed once the stop command is issued for the Degas command to react to it. Some more time (a few seconds) must be provided to let the pre-degas electron emission current be reestablished at the end.

Warning: Repeated degassing will considerably limit the lifetime of the filament. Whenever possible replace a Degas procedure with a thorough probe and vacuum system bakeout (See Probe Bakeout in RGA Maintenance Chapter).

Parameters:

DG0: Do nothing command. Commonly used to stop degassing. Nothing is echoed.

DGparam, param: 0-20: The parameter represents the degas time in minutes. The first minute is used to ramp the current up to 20 mA.

DG*: The default time is used to degas.

Default=3 (minutes)

Error Checking:
Number parameters must be within the accepted range, and must be integers.
No parameter (i.e. DG) is treated as a parameter error.
No queries are allowed.

EEparam, param: 25 - 105, *, ?

Description: Electron Energy (eV).

Echo: STATUS error byte or query response.

Set the Electron Impact Ionization Energy of the ionizer. The parameter represents the desired electron ionization energy in units of eV.

Command execution times vary depending on the pre-existing ionizer conditions. The end of the command execution is prompted to the host computer by sending out the STATUS byte.

Note: The Electron Impact Ionization Energy is set to the default value when the unit is turned on.

Important: The repeller grid and the focus plate are only biased while the filament is emitting electrons.

Parameters:

EEparam, param: 25-105: The parameter represents the electron impact ionization energy in eV.

EE*: The default Electron Energy value is used to run the command.

Default: 70 (eV)

EE?: Query. The electron energy parameter setting is returned in ASCII format.

Error checking:
Number parameters must be within the accepted range and must be integers.
The absence of a parameter (i. e. EE) is treated as a parameter-error.

FLparam, param: 0.00 - 3.50, *, ?

Description: Electron emission current (mA).

Echo: STATUS error byte or query response.

Set the electron emission current level in the ionizer. The parameter represents the desired electron emission current in units of mA.

When a finite emission current is requested, the RGA biases the ionizer's repeller grid and focus plate, and activates the filament's heater until the requested electron current is established.

A null parameter value turns off the filament and grounds the ionizer's repeller grid and focus plate.

Command execution times vary depending on the pre-existing ionizer conditions. The end of the command execution is prompted to the host computer sending out the STATUS byte.

The Filament LED reflects the ionizer's emission status at all times.

A firmware-driven "**Filament Protection Mode"** monitors the performance of the filament while it is emitting electrons and if a problem is detected at any time, the heater is immediately shut down and the problem is reported through the error bytes and the error LED's.

WARNING: The pressure in the chamber must be under 10^{-4} Torr before turning the filament on!

Important:

The repeller grid and the focus plate are only biased while the filament is emitting electrons.

In order to protect the filament, the emission current is defaulted to zero when the RGA is turned on.

The CDEM is turned off by any overpressure that also shuts down the filament.

Parameters:

FL0.00: The filament is turned off and the repeller grid and the focus plate are grounded.

FLparam, param: 0.02-3.50: The parameter is the requested Electron Emission Current in units of mA. The repeller grid and the focus plate are biased, and the filament's heater is activated until the requested electron current is achieved.

FL*: The command is executed using the default parameter value.

Default: 1.00 mA

FL?: Returns the value of Electron Emission Current (in mA) actually flowing through the ionizer.

Important: The number returned by the query command will always be very close, but rarely identical, to the current value set with the FLparam command. The difference observed will never exceed +/-0.02 mA. The value returned is the actual electron current circulating through the ionizer as internally calculated by the RGA. The discrepancy is due to the finite resolution of the digital-to-analog converters used to program the ionizer's emission current.

Error Checking:
The absence of a parameter (i. e. FL) is treated as a bad-parameter error.
The STATUS byte is echoed to the host computer at the end of the command execution, and it should be checked to determine whether the requested electron emission current was successfully established. If Bit 1 of STATUS is found set, FIL_ERR should be immediately checked to identify the specific problem (See EF? command in the Error Reporting Commands list). It is good practice to attempt the command a second time before declaring a hardware problem. Once it has been set, FIL_ERR can only be cleared after successfully turning on the filament.

IEparam, param: 0,1, *, ?

Description: Ion Energy (eV).

Echo: STATUS error byte or query response.

Set the Ion Energy to one of two possible levels: Low (8eV) or High (12eV). The parameter represents the ion energy level: 0 for Low and 1 for High.

Since the axis of the quadrupole mass filter is at ground, the ion energy (in eV) is equal to the anode grid voltage (in Volts).

Important: The anode grid is always biased regardless of the ionizer's emission status.

Upon reset the grid level is set to the default value.

Parameters:

IE0 Low ion energy: 8 eV.

IE1 High ion energy: 12 eV.

IE*: The default Ion Energy parameter value is used to run the command.

Default: 1 => high ion energy: 12 eV

IE?: Query. The value of the anode grid parameter is returned in ASCII format. *Note that it is the parameter value and not the actual voltage level that is returned.*

Error checking:
Number parameters can be 0 or 1 only and must be integers.
The absence of a parameter (i. e. IE) is treated as a bad-parameter error.

VFparam, param: 0 - 150, *, ?

Description: Focus plate voltage (Volts)

Echo: STATUS Error Byte and query response.

Set the focus plate voltage in the ionizer. The parameter represents the magnitude of the biasing voltage (negative) in units of volts.

Command execution times vary depending on the pre-existing ionizer conditions. The end of the command execution is prompted to the host computer sending out the STATUS byte.

Parameters:

VFparam, param: 0-150: The parameter represents the magnitude of the focus plate bias potential in Volts (*The actual bias voltage is negative*). The STATUS byte is transmitted at the end of command execution.

VF*: The default Focus plate biasing Voltage value is used to execute the command. Default: 90 (V).

VF?: Query the focus plate biasing voltage setting.

Error checking:
Number parameters must be integers within the accepted range.
The absence of a parameter (i.e. VF) is treated as a bad-parameter error.

Detection Control Commands

CA

Description: Calibrate All.

Echo: STATUS Error Byte.

Readjust the zero of the ion detector under the present detector settings, and correct the internal scan parameters against small temperature fluctuations to assure that the correct RF voltages (i.e. as specified by the last Peak Tuning procedure) are programmed on the QMF rods as a function of mass.

Important:

Offset correction factors for **all** the possible combinations of detector settings can be accumulated in the RGA's memory.

All offset correction factors are automatically cleared after a complete recalibration (CL) of the electrometer is performed, and also when the unit is turned off.

Use the CA command every time the detector settings are changed to values that have not been used in a long time or that were never used since the unit was turned on or recalibrated with the CL command.

The zero of the ion detector is also automatically readjusted at the beginning of each analog and histogram scan so that the baseline is always centered around zero.

In order to correct the mass axis against peak position shifts caused by small-temperature fluctuations, the RGA characterizes the voltage output of the RF driver's control circuit, and **recalculates its internal scan parameters** to assure that the correct RF levels (i.e. as specified by the last Peak Tuning procedure) are programmed on the QMF rods as a funtion of mass.

Important: Use a complete Peak Tuning Procedure to correct the mass axis calibration when large temperature fluctuations are suspected. The calibration procedure triggered by the CA command cannot correct the mass axis against large temperature drifts that affect the response of the RF Driver to its controlling voltage, or the relationship between mass and RF levels in the QMF itself (i.e. due to changes in the QMF's physical dimensions).

Notes:

This mass axis correction procedure can also be triggered at any time, by itself, using the RS and RI commands with no parameters (See Tuning commands).

The correction procedure is also automatically performed at the beginning of all analog and histogram scans. However, no correction is performed at the beginning of single mass measurements since the extra checking would significantly extend the time it would take the measurement to be completed.

Please see the Peak Tuning section of the RGA Tuning chapter for more details on mass axis calibration requirements under small and large temperature fluctuations in the RGA.

Remember that the CA command turns off the RF/DC voltages at the end of execution.

Parameters: Only one possible command format is allowed

CA

Error Checking:
An attempt to pass any parameter with CA results in a bad-parameter error being reported.

CL

Description: Calibrate Electrometer's I-V response.

Echo: STATUS error byte.

Perform a complete calibration of the electrometer's I-V response.

The procedure takes several seconds (longer when CDEM option is installed) and its completion is signaled to the host computer by returning the STATUS byte value.

Important:

The electrometer is designed for maximum long-term stability; however, it is good practice to recalibrate it periodically, particularly in the presence of a large change in the operating temperature of the RGA.

All offset correction factors previously stored in memory are cleared after a complete calibration of the electrometer is performed (see CA command for more information).

Parameters: Only one possible command format is allowed
CL

Error Checking:
An attempt to pass any parameter with CL results in a bad-parameter error being reported.

HVparam, param: 0 - 2490, *, ?

Description: Electron Multiplier High Voltage Bias setting.

Echo: STATUS error byte or Query Response.

Set a negative high voltage across the electron multiplier (CDEM), connect the CDEM signal output to the electrometer and reconfigure the electrometer and current measurement algorithms to handle negative electron currents. The parameter value represents the magnitude of the bias voltage in units of Volts.

Warning: This command only works in RGA units with the CDEM option.

The CEM LED reflects the status of the CDEM bias at all times.

Since it takes time for the CDEM and for the electrometer to settle, completion of the command is prompted to the host computer transmitting the STATUS byte value.

Important:

Faraday Cup detection is the default setting upon a power-on reset of the RGA.

It is good practice to readjust the Zero of the ion detector every time the type of detector (FC or CDEM) is changed. This is particularly important if the new detector settings have not been used in a long time or since the unit was turned on or recalibrated with the CL command. See the CA command for details and more recommendations.

Parameters:

HV0: Use this parameter value to "turn off" the Electron Multiplier and enable Faraday Cup (FC) Detection. The following steps are taken:

- The biasing voltage of the CDEM is set to Zero (i.e. no ion collection and no gain).
- The electrometer is connected to the FC signal output and reconfigured to measure positive currents.
- The firmware algorithms are reconfigured to transmit the **magnitude** of the positive currents measured.
- The CEM LED is turned off.
- The STATUS Byte is sent out to prompt the end of the command.

HVparam, param: 10-2490: The parameter is the magnitude of the CDEM bias voltage requested (the actual biasing voltage is negative). The following steps are taken:

- The requested biasing voltage is set on the CDEM.
- The electrometer is connected to the CDEM anode and reconfigured to measure negative currents.
- The firmware algorithms are reconfigured to transmit the **magnitude** of the negative currents measured.
- The CEM LED is turned on.
- The STATUS Byte is sent out to prompt the end of the command.

HV*: The command is executed with the default parameter value.

Default: 1400 (Volts)

HV?: Returns the magnitude of the biasing voltage on the CEM.

The number returned by the query command is the actual voltage available at the output of the HV driver and will always be very close but rarely identical to the one requested with the HVparam command.

Error Checking:
The CDEM option must be available in the RGA receiving the command or a bad-command error is reported (see MO command for details).

Number parameters must be within the accepted range, and must be integers.

No parameter (i. e. HV) is treated as a bad-parameter error.

Bit3 of STATUS (transmitted at the end of the command) reports errors in the execution of the command. CEM_ERR byte must be consulted to find out the specific problem encountered (See EM? in Error Reporting command list).

MO?

Description: Electron Multiplier Option Query.

Echo: 1.

The RGA120 series currently does not support this legacy command. The query always returns 1 in ASCII format with a <LF><CR> terminator.

Error checking:
Command must have a query format, or a bad parameter error is reported.

NFparam, param: 0 - 7, *, ?

Description: Electrometer's Noise-floor setting.

Echo: Query Response

Set the rate and detection limit for ion current measurements.

A decrease in the Noise-Floor setting results in cleaner baselines and lower detection limits during scans and measurements, but also means longer measurement and scanning times due to the reduced bandwidth of the electrometer and increased averaging.

The NF parameter must be chosen keeping in mind the strong interplay between detection limit and acquisition speed.

Histogram scans, analog scans, single-mass measurements and total pressure measurements all share the same value of NF setting during measurements.

Important: The NF parameter is set to its default value when the RGA is turned on.

It is good practice to readjust the Zero of the ion detector every time the electrometer's noise floor setting is changed. This is particularly important if the new detector settings have not been used in a long time or since the unit was turned on or recalibrated with the CL command. See the CA command for details and more recommendations.

Parameters:

NFparam, param: 0-7: The parameter represents the noise-floor level desired.

Lower parameter values correspond to lower baseline noise, better detection limits and increased measurement times.

Please refer to the Electrometer section of the RGA Electronics Control Unit chapter to obtain detailed information about detection limits and bandwidth values as a function of NF settings.

NF*: The noise-floor is set to its default value.

Default value: 4.

NF?: Returns the noise-floor setting currently used by the electrometer .

Error checking:
Number parameters must be within the specified range and be integers.
The absence of a parameter (i. e. NF) is treated as an error.

Scan and Measurement Commands

AP?

Description: Analog Scan Points Query.

Echo: Query Response.

Query the total number of ion currents that will be measured and transmitted during an analog scan under the current scan conditions.

Important: The query response does not include the extra current (4 bytes) corresponding to the total pressure measurement performed at the end of all analog scans (Please see SC command for details).

The number of points (i.e. ion currents) returned is calculated based on the MI, MF and SA parameter values. Number of points = (MF - MI) * SA + 1. The first point corresponds to the mass MI and the other (MF-MI)*SA are from scanning to MF with SA measurements (steps) per amu. Each point transmitted represents an ion current and as such corresponds to 4 bytes being received by the host computer.

The AP query is used to verify that the RGA and the host computer agree on the number of bytes that will be exchanged during the analog scan.

The total number of bytes sent out to the host computer during an analog scan is obtained multiplying by four the number returned by the AP query.

Parameters: This command is a query, and can only have one parameter format:

AP?

Error checking:
The only acceptable parameter is a question mark.
The absence of a parameter (i. e. AP) is treated as an error.

HP?

Description: Histogram Scan Points Query.

Echo: Query Response

Query the number of ion currents that will be measured and transmitted during a histogram scan under the current scan conditions.

Important: The query response does not include the extra current (4 bytes) corresponding to the total pressure measurement performed at the end of all histogram scans. (Please see HS command for details).

The number of points (ion currents) returned is calculated based on the MI and MF parameter values. Number of points = MF - MI + 1. Each point transmitted represents an ion current and as such corresponds to 4 bytes being received by the host computer.

The HP query is used to verify that the RGA and the host computer agree on the number of bytes that will be exchanged during the histogram scan.

The total number of bytes sent out to the host computer during a histogram scan is obtained multiplying by four the number returned by the HP query.

Parameters: This command is a query, and can only have one parameter format:

HP?

Error checking:
The only acceptable parameter is a question mark.
The absence of a parameter (i.e. HP) is treated as a Bad-Parameter error.

HSparam, param:0 - 255,*

Description: Histogram Scan Trigger.

Echo: Ion Currents.

Execute one or multiple Histogram Scans under the present scan conditions.
The scan parameter can be set for single, multiple and continuous scanning operation.

A Histogram Scan consists of as a succession of individual mass measurements (see MR command) over a pre-specified mass range.

The mass range for the scan is set in advance with the commands MI (Initial Mass) and MF (Final Mass). The type of detector and noise-floor settings to be used during the scan must be selected in advance with the NF and HV commands. A current value is transmitted for each integer mass value between MI and MF for a total of (MF-MI +1) measurements (See HP command).

For maximum data throughput, ion currents are represented as integers in units of 10^{-16} Amps, and transmitted directly in hex format (four byte integers, 2's complement format, Least Significant Byte first).

Important:

Any command received by the RGA in the middle of a scan will immediately stop the scan, halt transmission and clear the RGA's transmit buffer.

The detector's zero and the internal scan parameters are checked and corrected at the beginning of each scan resulting in a slight delay before the scan actually starts.

A Total Pressure measurement is performed at the end of each scan and transmitted out to the host computer (Please see HP and TP Commands).

The measurements are performed with the detector that is active at the time the scan is triggered.

Parameters:

HS: Continuous scanning mode. The RGA produces a continuous string of histogram scans.

A new command must be sent to the RGA in order to stop the scanning activity. Once the command is received, the scan is immediately stopped, all transmission is halted and the transmit buffer is flushed (*all remaining data is lost*). The new command which stopped the scan is executed after the buffer is flushed.

HS0: Do nothing command. Commonly used to interrupt continuous scanning mode.

HSparam, param:1-255: Multiple scans. The number of scans specified by the parameter is executed. Scanning is immediately stopped when a new command is received as in the case of continuous scanning.

HS*: The default parameter value is used for multiple scan excecution.

Default parameter value: 1 (single scan)

Error checking:
Number parameters must be within the specified range and be integers.
No query format is allowed.

MFparam, param: 1 - M_MAX, *, ?

Description: Final Mass (amu) of mass spectra (Analog and Histogram).

Echo: Query Response

Set the Final Mass value (in amu) for Analog and Histogram scans.

The last ion current transmitted during an Analog or Histogram scan corresponds to the mass-to-charge ratio specified by the MF parameter.

Important: Note that the final mass setting is shared by both histogram and analog scans and must be an integer number.

Parameters: Three possibilities :

MFparam, param: 1 - M_MAX: The parameter represents the final scan mass in amu units. The upper mass limit depends on the RGA model number:

The upper mass limit depends on the SRS RGA model number: M_MAX=120 for RGA120, 220 for RGA220 and 320 for the RGA320 units.

MF*: The final mass value is set to its default value.

Default value: M_MAX=120 for RGA120, 220 for RGA220 and 320 for the RGA320.

MF?: Query the value of final mass to be measured during scans.

Error checking:
Number parameters must be within the specified range and be integers.
The mass value set by MF must always be greater than or equal to the initial mass setting of MI or else a parameter-conflict communications error is generated.

The absence of a parameter (i.e. MF) is treated as a bad-parameter error.

MIparam, param: 1 - M_MAX, *, ?

Description: Initial Mass (amu) of mass spectra (Analog and Histogram).

Echo: Query Response.

Set the Initial Mass value (in amu) for Analog and Histogram scans.

The first ion current transmitted during an analog or histogram scan corresponds to the mass-to-charge ratio specified by the MI parameter.

Note that the initial mass setting is shared by both Histogram and Analog scans and must be an integer number.

Parameters:

MIparam, param: 1-M_MAX: The parameter represents the initial scan mass in amu units.

The upper mass limit depends on the SRS RGA model number: M_MAX=120 for RGA120, 220 for RGA220 and 320 for the RGA320.

MI*: The initial mass value is set to its default value.

Default value: 1.

MI?: Returns the value of initial mass to be measured during scans.

Error checking:
Number parameters must be within the specified range and be integers.
The mass value set by MI must always be less than or equal to the final mass setting MF or else a parameter-conflict communications error is generated.
The absence of a param (i.e. MI) generates a bad parameter error.

MRparam, param:0 - M_MAX

Description: Single Mass Measurement

Echo: Ion Current

Execute a single ion current measurement at a specified mass setting. The parameter is the **integer** mass number (mass-to-charge ratio in amu units) at which the measurement is performed.

The type of detector and noise-floor settings to be used by the measurement must be selected in advance with the NF and HV commands.

The precision and duration of the measurement are totally determined by the NF parameter value. The scan rates and signal-to-noise ratios for the different NF settings of the electrometer are listed in a table in the Electrometer section of the "RGA Electronic Control Unit" chapter. The command execution time includes some initial time spent waiting for the Quadrupole Mass Filter and the electrometer response to settle. As usual, a compromise must be made between signal-to-noise and measurement time.

The ion current is expressed in the usual format: 4 byte long, 2's complement integer in units of 10^{-16} A, with Least Significant Byte transmitted first.

Important:

During a Single Mass Measurement the RGA performs a "**Miniscan"** around the mass requested, and the **maximum current value** measured is sent out. The scanning procedure, referred to as **Peak-Locking**, is designed to measure peak currents for individual masses in a mass spectrum without being affected by drifts in the mass-axis calibration. The Miniscan covers a 0.6 amu range centered at the mass requested, and selects the maximum current from 7 individual measurements performed at 0.1 amu mass increments.

The detector settings (i.e. type of detector and noise-floor setting) to be used during the measurement must be selected in advance with the NF and HV commands, otherwise, the measurements are performed with the detector settings at the time the scan is triggered.

Parameters:

MR0: The RF/DC voltages are completely shut down and no measurement is performed (no ion current is transmitted back to the host computer).

Use this command format at the end of a set of single mass measurements to make sure the RF/DC are completely turned off.

MRparam, param:1 - M_MAX : A Miniscan is performed around the mass number selected by the parameter and the maximum ion current is sent out.

The upper mass limit depends on the SRS RGA model number: M_MAX=120 for RGA120, 220 for RGA220 and 320 for the RGA320.

Error Checking:
The command does not accept query or default parameters.

SAparam, param: 10 - 25, *, ?

Description: Steps per amu of analog scan.

Echo: Query Response.

Set the number of steps executed per amu of analog scan. The parameter specifies the number of steps-per-amu.

During an analog scan the quadrupole mass filter is stepped at fixed mass increments through the mass range specified by the MI and MF commands. An ion current is

measured after each step and transmitted to the host computer. SA programs the number of steps executed by the RGA per amu of analog scan. The fixed mass-increment corresponding to each analog scan step is equal to the inverse of the SA parameter value. Since the RGA is usually operated at unit mass resolution throughout its available mass range, the parameter value can also be interpreted as the approximate number of ion currents to be collected for each mass peak in the spectrum.

Parameters:

SAparam, param: 10-25: The parameter specifies the number of steps-per-amu desired during analog scans.

SA*: The number of points per amu value is set to its default value.

Default: 10

SA?: Query. Returns the SA parameter value currently in use by the analog scans.

Error checking:
Number parameters must be integers and within the specified range.
The absence of a parameter (i.e. SA) is treated as an error.

SC[param], param: 0 - 255, *

Description: Analog Scan Trigger.

Echo: Ion Currents

Execute one or multiple analog scans under the present scan conditions.

The scan parameter can be set for single, multiple and continuous scanning operation.

Analog scanning is the most basic operation of the RGA as a quadrupole mass spectrometer. During analog scanning the quadrupole mass spectrometer is stepped at fixed mass increments through a pre-specified mass-range. The ion current is measured after each mass-increment step and transmitted to the host computer. The mass range for the scan is set in advance with the commands MI (Initial Mass) and MF (Final Mass) and the mass-increments are fixed with the command SA. Scan rate and detection limits are pre-programmed by the NF (Noise Floor) setting. A current value is transmitted for MI and after each mass increment through MF for a total of (MF-MI)*SA+1 measurements (See AP query command).

The ion currents are represented as integers in units of 0.1 fA, and transmitted directly in Hex format (four byte integers with 2's complement format and Least significant byte first).

The type of detector and noise-floor settings to be used during the scans must be selected in advance with the NF and HV commands.

Important:

Any command received by the RGA in the middle of a scan will immediately stop the scan, halt transmission and clear the RGA's transmit buffer.

The detector's zero and the internal scan parameters are checked and corrected at the beginning of each scan resulting in a slight delay before the scan actually starts.

A Total Pressure measurement is performed at the end of each scan and transmitted out to the host computer (Please see AP and TP Commands).

Unless otherwise specified, the measurements are performed with the detector settings that are present at the time the scan is triggered.

Parameters:

SC: Continuous scanning mode. The RGA produces a continuous string of analog scans.

A new command must be sent to the RGA in order to stop the scanning activity. Once the command is received, the scan is immediately stopped, all transmission is halted and the transmit buffer is flushed (*all remaining data is lost*). The stopping command is executed after the scan is stopped.

SC0: Commonly used to interrupt continuous scanning mode.

SCparam, param: 1 - 255: Multiple scans. The number of scans specified by the parameter is executed. Scanning is immediately stopped when a new command is received as in the case of continuous scanning.

SC*: The default parameter value is used for multiple scan execution.

Default parameter value: 1 (single scan)

Error checking:
Number parameters must be integers and within the specified range.
No query format is allowed for the parameter.

TP?, TP0, TP1

Description: Total Pressure Measurement.

Echo: Measured Ion Current.

Perform a Total Pressure measurement or toggle the TP_Flag on/off.

Total pressure measurements are automatically requested at the end of each analog and histogram scan, and can also be triggered directly by the user with the TP? command. The response of the RGA to a Total Pressure measurement request depends on the status of **TP_Flag** at the time the measurement is requested:

TP_Flag : 1 The measurement is performed and the total ion current is transmitted.
TP_Flag : 0 No actual measurement is performed but a null current is still sent out.

TP_Flag is set upon a power-on reset and cleared when the CDEM is activated. It can also be toggled on/off by the user with the TP command.

The total ion current measured by the electrometer is transmitted in the standard format: Integer in units of 10^{-16} A, 4 Bytes long, 2's complement format, with the Least significant byte transmitted first.

Notes:

While performing a total pressure measurement the RF in the quadrupole mass filter is set to 1 amu and the DC bias is zeroed. All ionic species have stable trajectories down the filter under those conditions and reach the ion current detector with different efficiencies.

TP_Flag is cleared whenever the CDEM is turned on to protect the multiplier from large ion currents. TP1 can be used to reset **TP_Flag** to one after making sure the total pressure is in a "safe" range for the CDEM.

The sensitivity of the RGA for total pressure measurements will usually be affected after mass axis recalibrations. Check the sensitivity calibration after any peak tuning procedure.

Important: The sensitivity factor for the TP measurements is highly mass dependent. The additional mass discrimination that takes place in the filter results in the mass dependence of the RGA readings being very different from that of the Bayard Alpert gauge readings. **Expect to see deviations between the two gauges as the composition of a residual gas changes.**

Parameters:

TP0: TP_Flag is cleared. Total Pressure measurement is disallowed and a null current value is returned as a response to a total Pressure Measurement request (note that this includes the total pressure measurement requests at the end of scans!).

TP1: TP_Flag is set. Total pressure measurement is fully enabled.

TP?: Total Pressure query. A total pressure measurement is triggered, and a total ion current value is returned. The actual response to the command depends on the status of TP_Flag as described above.

Error Checking:
The absence of a parameter is considered an error.

Parameter Storage Commands

MGparam, param: 0.0000 - 2000.0000,?

Description: Electron Multiplier Gain Storage.

Echo: Query Response.

Store a value of electron multiplier (CDEM) Gain, expressed in units of thousands, in the non-volatile memory of the RGA.

The command is typically used together with the MV instruction to store calibrated sets of [High Voltage and gain] for the Electron Multiplier.

Important: The gain is not used internally by the RGA to correct the ion currents measured with the Electron Multiplier, it is simply stored so it can be read and used by any host computer connected to the instrument.

Parameters:

MGparam, param: 0.0000-2000.0000: The parameter, interpreted as a CDEM gain in units of thousands, is stored in the non-volatile memory of the RGA.

MG?: Electron Multiplier Gain parameter query.

Error checking:
The absence of a parameter (i.e. MG) is treated as an error.
No default value is available.
A bad-command communications error is reported when this command is invoked in a unit with no CDEM option installed (See MO command).

MVparam, param: 0 - 2490,?

Description: Electron Multiplier Bias Voltage Storage.

Echo: Query Response

Store a value of Electron Multiplier (CDEM) Bias Voltage, in units of Volts, in the non-volatile memory of the RGA.

The command is typically used together with the MG instruction to store calibrated sets of [Bias Voltage and gain] for the Electron Multiplier.

Important: The voltage value is not used internally by the SRS RGA to set the bias voltage of the Electron Multiplier; it is simply stored so it can be read and used by a host computer.

Parameters:

MVparam, param: 0-2490: The parameter, interpreted as a CDEM bias voltage in units of Volts, is stored in the non-volatile memory of the RGA.

MV?: CDEM Bias voltage query.

Error checking:
The absence of a parameter (i. e. MV) is treated as an error.
No default value is available.
A bad-command communications error is reported when this command is invoked in a unit with no CDEM option installed.

SPparam, param:0.0000 - 10.0000, ?

Description: Partial Pressure Sensitivity Factor storage and query.

Echo: Query Response

Store a value of Partial Pressure Sensitivity, expressed in units of mA/Torr, in the non-volatile memory of the SRS RGA.

Important: The sensitivity factor is not used internally by the RGA to turn ion currents into partial pressures, it is simply stored in memory so it can be read and used by any host computer connected to the instrument (See HV command.)

Partial Pressure Sensitivity factors are gas specific, probe specific, and highly dependent on the ionizer and quadrupole mass filter conditions and on aging of the probe.

Note: The parameter value loaded at the factory is the partial pressure sensitivity factor for N_2 under default ionizer conditions.

Parameters:

SPparam, param:0.0000 - 10.0000: The parameter, interpreted as a partial pressure sensitivity factor in units of mA/Torr, is stored in non-volatile memory of the RGA. Typical value is 0.1 under default ionizer settings.

SP?: Partial Pressure Sensitivity factor query.

Error checking:
Parameter must be within specified range.
No default value is available.

STparam, param:0.0000 - 100.0000, ?

Description: Total Pressure Sensitivity Factor storage.

Echo: Query Response

Store a value of Total Pressure Sensitivity, expressed in units of mA/Torr, in the non-volatile memory of the RGA.

Important: The sensitivity factor is not used internally by the RGA to turn ion currents into total pressures, it is simply stored so it can be read and used by any host computer connected to the instrument.

Total Pressure Sensitivity factors are gas specific, probe specific, and highly dependent on the ionizer conditions and on aging of the probe.

Note: The parameter loaded at the factory is the total pressure sensitivity factor for N_2 under default ionizer conditions.

Parameters:

STparam, param:0.0000 - 100.0000: The parameter, interpreted as a total pressure sensitivity factor in units of mA/Torr, is stored in non-volatile memory of the RGA. Typical value is 0.01 under default ionizer settings.

ST?: Total Pressure Sensitivity factor query.

Error Checking:
Parameter must be within specified range.
No default value is available.

Mass Filter Control Commands

MLparam, param: 0.0000 - M_MAX

Description: Mass Lock

Echo: none

Activate the quadrupole mass filter (QMF) and center its pass-band at the mass value specified by the parameter. The QMF is parked at the mass requested but no ion current measurements take place.

The parameter is a real number, and the mass increments are limited to a minimum value of 1/256 amu.

The command execution involves two steps:

- The RF/DC levels corresponding to the mass requested are calculated and set on the QMF rods based on the mass axis calibration parameter values specified by the last Peak Tuning procedure.
- The firmware stabilizes the voltage output of the RF Driver's controller against temperature fluctuations. The result is very stable RF/DC levels that are highly insensitive to the operating conditions of the RGA.

Important: The RF/DC stabilization algorithm (Step 2 above) remains active as long as no new commands are detected by the RGA. Once a new command is received, stabilization stops, and the new command is executed.

Use the ML0 command to turn off the RF/DC bias when finished performing measurements and before quitting the program controlling the RGA.

Parameters:

ML0.0000: The RF/DC voltages are completely turned off.

MLparam, param: 0.0040 - M_MAX: The parameter represents the mass setting for the QMF in amu units. The minimum mass increment value is 1/256 amu.

The upper mass limit depends on the RGA model number: M_MAX=120 for RGA120, 220 for RGA220 and 320 for RGA320.

Error checking:
Parameters must be numbers within the specified range.
The absence of a parameter (i.e. ML) generates a bad parameter error.

Error Reporting Commands

EC?

Description: RS232_ERR Byte Query

Echo: RS232_ERR Byte.

Query the value of the RS232_ERR byte. The value of the RS232_ERR byte is sent to the computer in ASCII format and with a <LF><CR> terminator. RS232_ERR and bit 0 of STATUS are then cleared to provide a clean error reporting slate.

Important: See "Troubleshooting the RGA Communications" in the RGA Programming chapter for more details on the use of this query.

Parameters: This command is a query, and can only have one parameter format:

EC?

Error checking:
The only acceptable parameter is a question mark.
The absence of a parameter (i. e. EC) is treated as a bad-parameter error.

ED?

Description: DET_ERR Byte Query

Echo: DET_ERR Byte.

Query the value of DET_ERR and update its value after running a fresh check on the Electrometer (Bit5 of STATUS and the DET_ERR byte are updated based on the tests results). The DET_ERR byte value is returned to the computer in ASCII format and with a <LF><CR> terminator. No errors are present if the byte value is zero.

Consult the Error Byte Definitions section in this chapter for details on the different error bytes of the RGA.

Consult the RGA Troubleshooting chapter of this manual for possible causes and solutions to any problems reported.

Always try the query a second time before declaring a hardware problem.

Important: The electrometer is not affected by this test, and the detector is restored to its pre-test configuration once the command execution is over.

Parameters: This command is a query, and can only have one parameter format:

ED?

Error checking:
The only acceptable parameter is a question mark.
The absence of a parameter (i.e. ED) is treated as a bad-parameter error.

EF?

Description: FIL_ERR Byte Query

Echo: FIL_ERR Byte.

Query the value of FIL_ERR.

The FIL_ERR byte value is returned to the computer in ASCII format and with a <LF> terminator.

FIL_ERR can only be modified by the "Filament Protection Mode" which constantly monitors the filament while it is emitting electrons. No errors are present as long as the byte value is zero. A non-zero FIL_ERR byte is only cleared after the filament's heater successfully (i.e. no detected errors) establishes a finite electron emission current.

Consult the Error Byte Definitions section of this chapter for details on the different error bytes of the RGA.

Consult the RGA Troubleshooting chapter of this manual for possible causes and solutions to any problems reported.

Parameters: This command is a query, and can only have one parameter format:

EF?

Error checking:
The only acceptable parameter is a question mark.
The absence of a parameter (i.e. EF) is treated as a bad-parameter error.

EM?

Description: CEM_ERR byte Query

Echo: CEM_ERR Byte.

Query the value of CEM_ERR.

Bit 7 of CEM_ERR is set if the RGA does not have on board circuitry to drive a CEM module. At this time, all RGA120 family instruments will have on board CEM drive circuitry. So bit 7 will not be set.

In all cases, the CEM_ERR byte value is sent to the computer in ASCII format with a <LF><CR> terminator. CEM_ERR and Bit 3 of STATUS are then cleared.

Parameters: This command is a query, and can only have one parameter format:

EM?

Error checking:
The only acceptable parameter is a question mark.
The absence of a parameter (i.e. EM) is treated as a bad-parameter error.

EP?

Description: PS_ERR Byte Query.

Echo: PS_ERR Byte.

Query the value of PS_ERR and update its value after running a fresh check on the 24V External Power Supply (Bit6 of STATUS and the PS_ERR byte are updated based on the tests results). The PS_ERR byte value is returned to the computer in ASCII format and with a <LF><CR> terminator. No errors are present if the byte value is zero.

Consult the Error Byte Definitions section of this chapter for details on the different error bytes of the RGA.

Consult the RGA Troubleshooting chapter of this manual for possible causes and solutions to any problems reported.

Always try the query a second time before declaring a hardware problem.

Parameters: This command is a query, and can only have one parameter format:

EP?

Error checking:
The only acceptable parameter is a question mark.
The absence of a parameter (i. e. EP) is treated as a bad-parameter error.

EQ?

Description: QMF_ERR Byte Query.

Echo: QMF_ERROR Byte.

Query the value of QMF_ERR and update its value after running a fresh check on the Quadrupole Mass Filter's RF Power Supply (Bit4 of STATUS and the QMF_ERR byte are updated based on the tests results). The QMF_ERR byte value is returned to the computer in ASCII format and with a <LF><CR> terminator. No errors are present if the byte value is zero.

Consult the Error Byte Definitions section of this chapter for details on the different error bytes of the RGA.

Consult the RGA Troubleshooting chapter of this manual for possible causes and solutions to any problems reported.

Always try the query a second time before declaring a hardware problem.

Parameters: This command is a query, and can only have one parameter format:

EQ?

Error checking:
The only acceptable parameter is a question mark.
The absence of a parameter (i. e. EQ) is treated as a bad-parameter error.

ER?

Description: STATUS Byte Query.

Echo: STATUS Byte.

Query the value of the STATUS Error byte.

The STATUS byte value is returned to the computer in ASCII format and with a <LF> terminator. No errors are present if the byte value is zero.

If one or more bits of the STATUS byte are found set, the specific error bytes (PS_ERR, DET_ERR, QMF_ERR, CEM_ERR, FIL_ERR, and RS232_ERR) must be queried individually to diagnose the problem.

Consult the Error Byte Definitions section of this chapter for details on the different error bytes of the RGA.

Consult the RGA Troubleshooting chapter of this manual for possible causes and solutions to any problems reported.

Important: Since internal checks are constantly being performed within the RGA, the STATUS Byte should be queried regularly by the programming software to detect any possible problems.

Parameters: This command is a query, and can only have one parameter format:

ER?

Error checking:
The only acceptable parameter is a question mark.
The absence of a parameter (i. e. ER) is treated as a bad-parameter error.

Tuning Commands

CE?

Description: Calibration Enable Query.

Echo: 1.

Unlike the RGA100 series, the RGA120 series doesn't have a Calibration Enable/Disable jumper. The query always returns 1 in ASCII format with a <LF><CR> terminator.

Error Checking:
The only acceptable parameter is a question mark. The absence of a parameter (i.e. CE) is treated as a bad-parameter error.

DIparam, param: 0 - 255, *, ?

Description: DI Parameter adjust (Peak Width Tuning command).

Echo: Query Response.

Program the value of DI during the Peak Width Tuning Procedure. The parameter (one of four peak tuning parameters) represents the DI value, in bit units.

Warning: Please read the Peak Tuning Section of the RGA Tuning Chapter before using this command.

The RGA adjusts the DC levels of the quadrupole filter during measurements so that constant mass resolution is automatically available throughout the entire mass range of the spectrometer. The bulk of the DC voltage is supplied by a DC power supply whose output is linearly related to the RF amplitude. The rest of the DC voltage (DC_Tweek) is provided by the output of an 8 bit digital-to-analog converter (DAC). The firmware uses two Peak Tuning Parameters : DI (Intercept) and DS (Slope), stored in the non-volatile memory of the RGA, to calculate the 8 bit settings of the DAC according to the linear equation:

$DAC8(m) = DS \cdot m + DI$

where m is the mass in amu, and DAC8(m) is the 8 bit setting at that mass.

The purpose of the Peak Width Tuning Procedure is to determine the values of DI and DS so that all the peaks in an analog spectrum have the desired peak width (typically 1 amu).

The DI command is used to program the value of the DI peak tuning parameter during the Peak Width Tuning Procedure. The value is saved in the non-volatile memory of the RGA and used by the firmware to generate DAC8(m) during measurements.

Parameters:
DIparam, param: 0 - 255: If Calibration is enabled by the jumper JP100 (See CE Command) the value of DI in non-volatile memory is updated and the internal scan parameters used to program the DC during scans and single mass measurements are updated accordingly.

DI*: Use this format to replace the peak tuning parameter with the original factory setting for DI. The factory value is retrieved from memory and used as the new parameter value to execute the command as above.

DI?: Query. Returns the value of DI currently stored in memory.

Error checking:

The absence of a parameter (i. e. DI) is treated as an error in the parameter.
This parameter is protected by an internal jumper (JP100) and a Protection-Violation error will result if the jumper is in the Calibration Disable mode (See CE command).

DSparam, param: -0.8500 - +0.8500, *, ?

Description: DS Parameter adjust (Peak Width Tuning command).
JP100 Jumper protected.

Echo: Query Response.

Important:

RGA200 DS range: -1.2750 - +1.2750

RGA100 DS range: -2.5500 - +2.5500

Program the value of DS during the Peak Width Tuning Procedure. The parameter (one of four peak tuning parameters) represents the DS value, in units of bits/amu.

Warning: Please read the Peak Tuning Section of the RGA Tuning Chapter before using this command.

The RGA adjusts the DC levels of the quadrupole filter during measurements so that constant mass resolution is automatically available throughout the entire mass range of the spectrometer. The bulk of the DC voltage is supplied by a DC power supply whose output is linearly related to the RF amplitude. The rest of the DC voltage (DC_Tweek) is provided by the output of an 8 bit digital-to-analog converter (DAC). The firmware uses two Peak Tuning Parameters : DI (Intercept) and DS (Slope), stored in the non-volatile memory of the RGA, to calculate the 8 bit settings of the DAC according to the linear equation:

$DAC8(m) = DS \cdot m + DI$

where m is the mass in amu, and DAC8(m) is the 8-bit setting at that mass.

The purpose of the Peak Width Tuning Procedure is to determine the values of DI and DS so that all the peaks in an analog spectrum have the desired peak width (typically 1 amu).

The DS command is used to program the value of the DS peak tuning parameter during the Peak Width Tuning Procedure. The value is saved in the non-volatile memory of the RGA and used by the firmware to generate DAC8(m) during measurements.

Note to Supervisors: A calibration disable jumper (JP100) available on the circuit board can be used by a supervisor to block any attempt to modify the value of the DI parameter.

Supervisors may use this feature to prevent accidental changes in the calibration parameters by inexperienced operators. Setting JP100 will disable peak tuning of the RGA.

Parameters:

DSparam, param: -0.8500 - +0.8500: If Calibration is enabled by the jumper JP100 (See CE Command) the value of DS in non-volatile memory is updated and the internal scan parameters used to program the DC during scans and single mass measurements are updated accordingly. RGA100 DS range: -2.5500 - +2.5500

DS*: Use this format to replace the peak tuning parameter with the original factory setting for DS. The factory value is retrieved from memory and used as the new parameter value to execute the command as above.

DS?: Query. Returns the parameter value currently saved in memory.

Error checking:
The absence of a parameter (i. e. DS) is treated as an error in the parameter.

This parameter is protected by an internal jumper (JP100) and a Protection-Violation error will result if the jumper is in the Calibration Disabled mode (See CE command).

RIparam, param: -86.0000 - +86.0000, *, ?, none

Description: RF_Driver output @ 0 amu (Peak Position Tuning command). JP100 Jumper protected.

Echo: Query Response.

Warning: Please read the Peak Tuning Section of the RGA Tuning Chapter before using this command.

Program the output of the RF_Driver @ 0 amu during a Peak Position Tuning Procedure. The parameter (one of four peak tuning parameters) represents the voltage output selected for the RF_Driver @ 0 amu, in mV.

The magnitude of the RF determines the mass-to-charge ratio of the ions that can pass through a quadrupole mass filter without striking the rods (i.e. with stable oscillations). A linear relationship between mass and RF amplitude is one of the most attractive features of these types of filters.

The regulated output of the RF source that powers the RGA's quadrupole rods is controlled by, and linearly related to, the voltage output of an RF_Driver circuit. A linear relation exists between the output of the RF_Driver, the RF amplitude on the rods, and the mass setting of the filter. The purpose of a Peak Position Tuning Procedure is to determine the voltages that the RF Driver must output at 0 and 128 amu so that all the peaks in an analog spectrum appear in the right position. The RI command is used to program the voltage output of the RF_Driver @ 0 amu during the Peak Position Tuning Procedure. The value is saved in the non-volatile memory of the RGA and used by the firmware to generate the internal scan parameters used to step the RF during scans and single mass measurements.

Note to Supervisors: A calibration disable jumper (JP100) available on the circuit board can be used by a supervisor to block any attempt to modify the value of the DI parameter. Supervisors may use this feature to prevent accidental changes in the calibration parameters by inexperienced operators. Setting JP100 will disable peak tuning of the RGA.

Parameters:

RIparam, param: -86.0000 - +86.0000: If Calibration is enabled by the JP100 jumper (See CE Command), the parameter is saved into the non-volatile memory of the RGA and the internal scan parameters used to step the RF during scans and single mass measurements are updated accordingly.

RI*: Use this format to replace the peak tuning parameter with the original factory setting for the RF_Driver output @ 0 amu. The factory value is retrieved from memory and used as the new parameter value to execute the command as above.

RI?: Query. Returns the parameter value currently saved in memory.

RI: Uses the current parameter value to recalculate the internal scan parameters used to step the RF during scans and single mass measurements. This is often used to compensate against small temperature drifts in the mass scale, caused by drifts in the output of the RF_Driver.

Error checking:
The absence of a parameter (i.e. RI) is treated as an error in the parameter.

This parameter is protected by an internal calibration jumper (JP100) and a Protection-violation error will result if the jumper is in the Calibration Disabled mode (see CE command).

RSparam, param: 600.0000 - 1600.0000, *, ?, none

Description: RF_Driver output @ 128 amu (Peak Position Tuning command). JP100 Jumper protected.

Echo: Query Response.

Warning: Please read the Peak Tuning Section of the RGA Tuning Chapter before using this command.

Program the output of the RF_Driver @ 128 amu during a Peak Posion Tuning Procedure. The parameter (one of four peak tuning parameters) represents the voltage output selected for the RF_Driver @ 128 amu, in mV.

The magnitude of the RF determines the mass-to-charge ratio of the ions that can pass through a quadrupole mass filter without striking the rods (i.e. with stable oscillations). A linear relationship between mass and RF amplitude is one of the most attractive features of these types of filters.

The regulated output of the RF source that powers the RGA's quadrupole rods is

controlled by, and linearly related to, the voltage output of an RF_Driver circuit. Clearly, a linear relation exists between the output of the RF_Driver, the RF amplitude on the rods, and the mass setting of the filter. The purpose of a Peak Position Tuning Procedure is to determine the voltages that the RF Driver must output at 0 and 128 amu so that all the peaks in an analog spectrum appear in the right position. The RS command is used to program the voltage output of the RF_Driver @ 128 amu during the Peak Position Tuning Procedure. The value is saved in the non-volatile memory of the RGA and used by the firmware to generate the internal scan parameters used to step the RF during scans and single mass measurements.

Note to Supervisors: A calibration disable jumper (JP100) available on the circuit board can be used by a supervisor to block any attempt to modify the value of the DI parameter. Supervisors may use this feature to prevent accidental changes in the calibration parameters by inexperienced operators. Setting JP100 will disable peak tuning of the RGA.

Parameters:

RSparam, param: 600.0000 - 1600.0000: If Calibration is enabled by the JP100 jumper (See CE Command), the parameter is saved into the non-volatile memory of the RGA and the internal scan parameters used to step the RF during scans and single mass measurements are updated accordingly.

RS*: Use this format to replace the peak tuning parameter with the original factory setting for the RF_Driver output @ 128 amu. The factory value is retrieved from memory and used as the new parameter value to execute the command as above.

RS?: Query. Returns the parameter value currently saved in memory.

RS: Uses the current parameter value to recalculate the internal scan parameters used to step the RF during scans and single mass measurements. This is often used to compensate against small temperature drifts in the mass scale, caused by drifts in the output of the RF_Driver.

Error checking:
The absence of a parameter (i. e. RS) is treated as an error in the parameter.

This parameter is protected by an internal calibration jumper (JP100) and a Protection-violation error will result if the jumper is in the Calibration Disabled mode (see CE command).

Error Byte Definitions

The **Error Bytes** described in this section store the results of the firmware-driven checks built into the RGA. Use the Error Reporting Commands to query the value of the bytes.

Important: No errors are present if all bits in the Error Bytes are cleared.

Bit	Internal Check[a]	ERROR Byte[c]	Query [d]
7	not used	N.A.	N.A.
6	24V External P/S[b]	PS_ERR	EP?
5	Electrometer[b]	DET_ERR	ED?
4	Quadrupole Mass Filter[b]	QMF_ERR	EQ?
3	Electron Multiplier	CEM_ERR	EM?
2	not used	N.A.	N.A.
1	Filament	FIL_ERR	EF?
0	Communications	RS232_ERR	EC?

STATUS Error Byte: General Status byte

Each bit corresponds to a different type of internal check.

(a) RGA component checked. Each check involves several tests on the component.

(b) Checks automatically performed upon a power-on-reset

(c) Error bytes that store the results of the tests for each type of internal check.

(d) Error Reporting command that queries the error byte.

Bit	Description	Error Code
7	External 24V P/S error: Voltage >26V.	PS7
6	External 24V P/S error: Voltage <22V.	PS6
5	Not used	
4	Not Used	
3	Not Used	
2	Not Used	
1	Not Used	
0	Not Used	

PS_ERR Error Byte: 24V P/S Error Byte

Bit	Description	Error Code
7	ADC16 Test failure.	DET7
6	DETECT fails to read +5nA input current	DET6
5	DETECT fails to read -5 nA input current	DET5
4	COMPENSATE fails to read +5nA input current	DET4
3	COMPENSATE fails to read -5nA input current	DET3
2	Not Used	
1	OP-AMP Input Offset Voltage out of range	DET1
0	Not Used	

DET_ERR Error Byte: Electrometer Error Byte

Bit	Description	Error Code
7	RF_CT exceeds (V_EXT- 2V) at M_MAX	RF7
6	Primary current exceeds 2.0A	RF6
5	Not used	
4	Power supply in current limited mode.	RF4
3	Not Used	
2	Not Used	
1	Not Used	
0	Not Used	

QMF_ERR Error Byte: Quadrupole Mass Filter RF P/S Error Byte

Bit	Description	Error Code
7	No Electron Multiplier Option installed	EM7
6	Not Used	
5	Not Used	
4	Not Used	
3	Not Used	
2	Not Used	
1	Not Used	
0	Not Used	

CEM_ERR Error Byte: Electron Multiplier Error Byte

Bit	Description	Error Code
7	No filament detected	FL7
6	Unable to set the requested emission current	FL6
5	Vacuum Chamber pressure too high	FL5
4	Not Used	
3	Not Used	
2	Not Used	
1	Not Used	
0	Single filament operation	FL0

FIL_ERR Error Byte: Filament Error Byte

Bit	Description
7	Not used
6	Parameter conflict
5	Jumper protection violation
4	Transmit buffer overwrite
3	OVERWRITE in receiving
2	Command-too-long
1	Bad Parameter received
0	Bad Command received

RS232_ERR Error Byte: Communication Error Byte

Equivalents of SCPI and Legacy Commands

For an existing custom program that wishes to migrate to the new SCPI commands, the table below would help to find the equivalent of the legacy commands. The operation of SCPI commands is not always the same as the legacy commands and there may not be a one-to-one mapping of a command. Therefore, refer to the description of the SCPI commands for details. The following list is a start point for the lookup of the 2 command sets.

Command Group	Legacy Commands	SCPI Commands	Notes
Initialization	ID?	ID?	
	IN0, IN1, IN2	INITialize <0 | 1 | 2>	
Ionizer Control	DG	DEGAS:TIME DEGAS:START DEGAS:STOP	
	EE	IONIZER:ELECTRON:VOLT	
	FL	IONIZER:EMISsion	
	IE	IONIZER:ION:VOLT	
	VF	IONIZER:FOCUS:VOLT	
Detection Control	CA	CALIBRATE	
	CL	ELECtrometer:CALibrate	
	HV	CEM:VOLT	
	MO	No equivalent command.	
	NF	SCAN:RATE	NF to Scan Rate: NF0: 0.5 amu/s NF1: 1.0 amu/s NF2: 2.5 amu/s NF3: 5.0 amu/s NF4: 7.94 amu/s NF5: 22.22 amu/s NF6: 33.33 amu/s NF7: 66.67 amu/s
	AP?	SCAN:ANALOG:POINTS?	

Scan and Measurement	HP?	SCAN:HISTogram:POINTS?	
	HS	SCAN:HISTogram?	
	MF	SCAN:MASS:FINAL	
	MI	SCAN:MASS:INITial	
	MR	SCAN:SINGLE?	
	SA	SCAN:RESolution	
	SC	SCAN:ANAlog?	
	TP? TP0/TP1	PRESsure:TOTAL? PRESsure:TOTAL:ENable	
Parameter Storage	MG	CEM:STORED:GAIN	
	MV	CEM:STORED:VOLTage	
	SP	PRESsure:SENSitivity:PARTIAL	
	ST	PRESsure:SENSitivity:TOTAL	
Mass Filter Control	ML	QMF:MASS:LOCK	
Error Reporting	EC? ED? EF? EM? EP? EQ?	STATus:EVent?	There are no exact equivalent commands for error reporting but similar errors can be traced using these 2 SCPI commands.
	ER?	STATus:GLOBal?	
Tuning	CE?	No equivalent command.	No calibration enable/disable jumper in RGA120 series.
	DI	QMF:DC:OFFSET	
	DS	QMF:DC:SLOPE	
	RI	QMF:RF:OFFSET	
	RS	QMF:RF:SLOPE	

Table 13-1 Equivalents of SCPI and legacy commands

Appendix A
Vacuum Diagnosis with SRS RGA's

Introduction

Residual Gas Analyzer (RGA) is the term for a class of mass spectrometers. They are all quadrupole mass spectrometers and typically cover mass ranges from 1 to 100 or 200 amu (atomic mass units). The RGA's resolution is sufficient to clearly distinguish peaks that are 1 amu apart. They are designed for the analysis of the gases present in high and ultra high vacuum systems. The specifications of the RGA are a perfect match for vacuum diagnosis. Not many materials with a mass greater than 200 amu will be volatile, and so a small mass range is suitable. The high resolution of a research grade mass spectrometer is not necessary for the analysis of low molecular weight species. Overall, RGA's are affordable instruments that can be permanently attached to a vacuum system.

Experiments and processes are performed under vacuum for two main purposes: to lower the total pressure to a suitable level and to provide an extremely clean environment. An ion gauge addresses the first purpose, but only an RGA can address the second. The high sensitivity of some processes to specific impurities makes the goal of cleanness more difficult to achieve than the required total pressure. A typical method of making a system cleaner is to lower the total pressure. The assumption being that the partial pressure of the impurities is directly related to the total pressure. This assumption fails in two ways. First, it is simply not true; a total pressure measurement cannot tell the user tell the user the level of impurities. As an example, a system operating at a total pressure of 1.1×10^{-8} mbar might consist of 1.0×10^{-8} mbar of water due to outgassing and 0.1×10^{-8} mbar of air due to a leak. An overnight bake out of the vacuum system reduces the total pressure to 0.2×10^{-8} mbar; 0.1×10^{-8} mbar is water and 0.1×10^{-8} mbar is air. Is the vacuum system cleaner than before the bakeout? If the process or experiment is sensitive to oxygen, the system is no cleaner than before the bakeout. Second, the assumption fails because total pressure measurement is not very precise; measurements more precise than 10% are difficult and expensive. If a system is operating at a standard pressure of 1.0×10^{-7} mbar and the next day the pressure is 1.1×10^{-7} mbar would there be cause for concern? The vacuum system could be filled with 10% oil vapor or the pressure gauge sensitivity could have changed 10%. The RGA is designed to address exactly these types of questions, by immediately showing the user **what** is in their vacuum system.

The primary application of the RGA is to analyze the composition of a vacuum system. The composition can be used to detect impurities, monitor gas fills, or analyze ongoing chemistry. Another application of the RGA is as a leak detector. It serves this use very well and in many ways is superior to a portable helium leak tester. In the remainder of this application note we will illustrate the usefulness of an RGA. The data shown are real results from experiments designed to illustrate certain points.

Composition Analysis

The SRS RGA software allows the composition of the vacuum system to be analyzed by two methods. The most common is to measure the mass spectrum of the vacuum. This provides a "fingerprint" of the residual gases in the vacuum system. A second method is to track specific species or peaks of the mass spectrum. The first method, analog scan mode, is most useful when the user does not know what is present in the chamber. Once the identities of the species have been determined, individual peaks can be tracked using either pressure vs. time, table or annunciator mode.

The Mass Spectrum

The fundamental operation of the RGA is as a mass spectrometer. Figure 1 shows a graph of partial pressure versus mass, which was measured with an RGA with an electron multiplier detector.

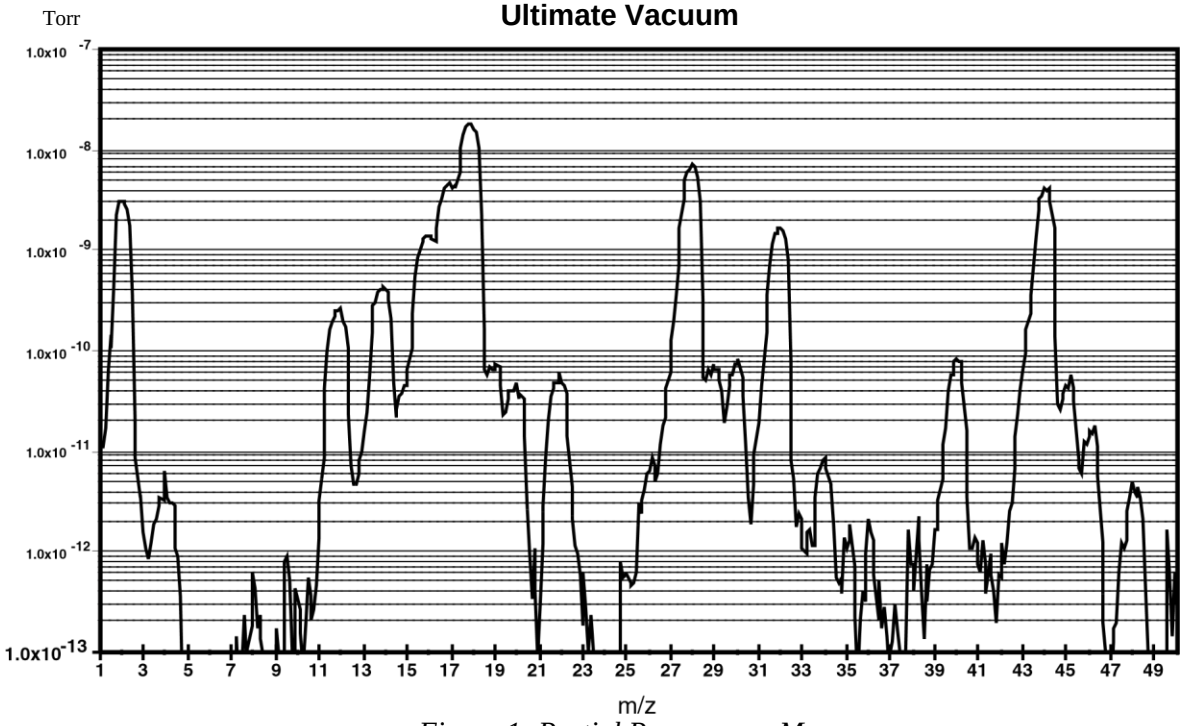

Figure 1: Partial Pressure vs. Mass

The scan was taken of a vacuum system near its ultimate vacuum. The pressure axis is plotted on a logarithmic scale so that a large range can be seen. The log scale makes the peaks appear wider than when plotted on a linear scale. This scan from 1 to 75 amu shows some gases commonly present in vacuum chambers. There are many peaks, but they are caused mainly by 7 species: Hydrogen is at 2 and helium at 4. Water gives primary peaks at 16, 17, and 18 due to the species O^+, HO^+, and H_2O^+ . The smaller peaks at 19 and 20 are due to ^{18}O which is naturally present at 0.2%. Nitrogen is at 28 and also causes the peaks at 14 by atomic N^+ and the doubly ionized N_2^+. Molecular oxygen shows a peak at 32 and an isotope peak at 34. Argon shows a peak at 40. Carbon dioxide shows a peak at 44 and a peaks for CO_2^{++} and C^+ at 22 and 12. The other peaks are caused by fragments of these species and contaminants.

The presence of air components in the spectra might lead us to believe that the system is leaking, but this is untrue. The hybrid turbomolecular pump has simply reached its compression limit. The foreline of the pump was operating at a total pressure of 0.5 Torr; thereby the compression ratio is in the 10^8 range (as the pump specifications indicate). Nitrogen, oxygen and argon are all present in the same ratios as standard atmosphere. The presence of helium is interesting, because it is present in the atmosphere at about 7 ppm. Its peak might be expected 6 decades smaller than the nitrogen peak. The low compression ratio of the turbo pump for helium (10^5) explains why the peak is only three decades smaller.

The ability to detect these common species and many others is the essence of the RGA. The fragmentation of molecules in the ionizer of the RGA gives each molecule a distinct fingerprint. The fragmentation patterns for many molecules is available from the library in the SRS RGA program. Keeping a historical record of the typical spectrum of a vacuum system allows the appearance of peaks to be instantly detected. For instance, the peak at 48 in Figure 1 is SO from SO_2 (a matching peak at 64, not shown on the figure confirmed this). On occasion this peak is seen in our chambers. If SO_2 appeared in your vacuum system would you want to know? In addition to these simple gases, we are interested in molecules with higher weights. The next two examples show how oil and solvents can be detected.

Oil Contamination

Figure 2 contains a mass spectrum of a common contaminant of vacuum systems, oil. The top pane is the measured spectrum and the bottom pane is the library data.

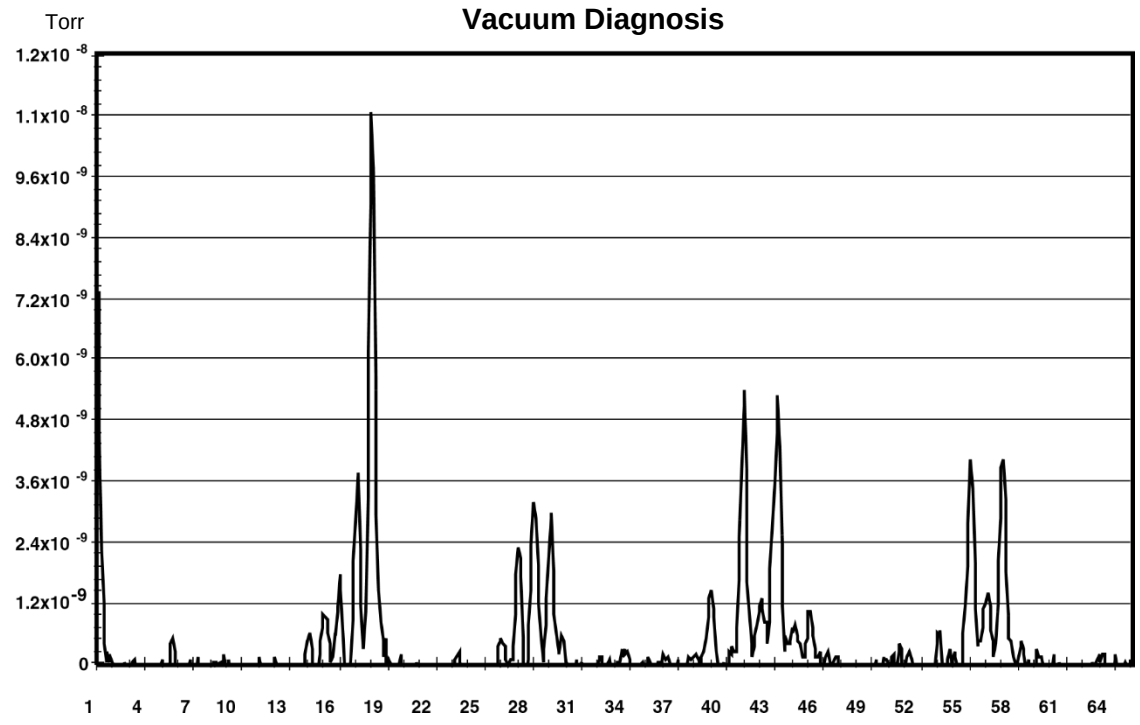

Figure 2a: Pump Oil Contamination

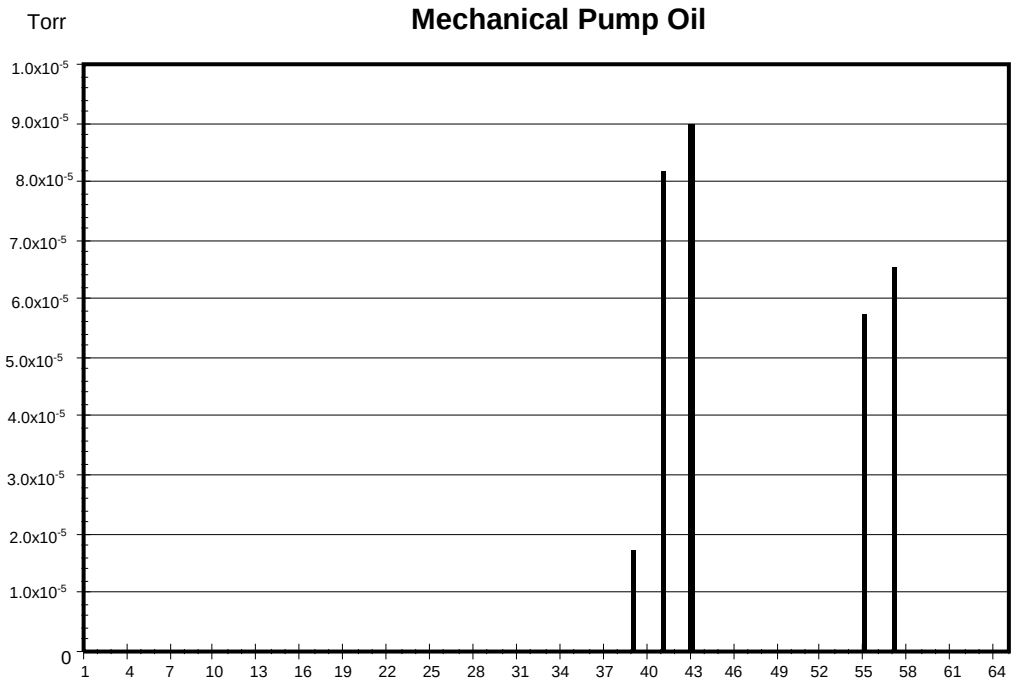

Figure 2b: Library Pump Oil Data

The presence of mechanical pump oil is immediately obvious. The peaks at masses 39, 41, 43, 55, and 57 are caused by mechanical pump oil backstreaming into the vacuum chamber during a load lock sequence. The total pressure in the chamber was dominated by water and was less than 2×10^{-8} Torr. In this case, the total pressure might satisfy operating conditions but the spectra reveals that the system is heavily contaminated with oil. This could have been caused by improper valve sequencing or a saturated oil trap. Without an RGA, only operating procedures for valves and a maintenance schedule for traps can ensure that the cleanliness of a vacuum system is maintained. With the RGA, the cleanliness can be **guaranteed** before a process or experiment begins.

Solvent Contamination

Oil contamination is common in vacuum systems. Cleaning parts with solvents is a common approach to removing this contamination. We have observed that organic solvents such as acetone and 1,1,1-trichloroethane (TCE) are more tenacious contaminants than the oil they are designed to remove. Figure 3 shows the spectrum of a vacuum system contaminated with TCE as evidenced by the major peaks at 97 and 99, and the minor peaks at 61, 63, 117 and 119. The paired peaks are caused by the natural isotopic occurrence of ^{35}Cl and ^{37}Cl (75% and 25%). This spectrum was measured one week after the initial contact with the solvent. The TCE permeated into the o-rings in the system during a cleaning step. The TCE continued to outgas from the o-rings for two weeks and showed no signs of stopping. At that time they were removed and baked in an oven, which eventually removed the TCE.

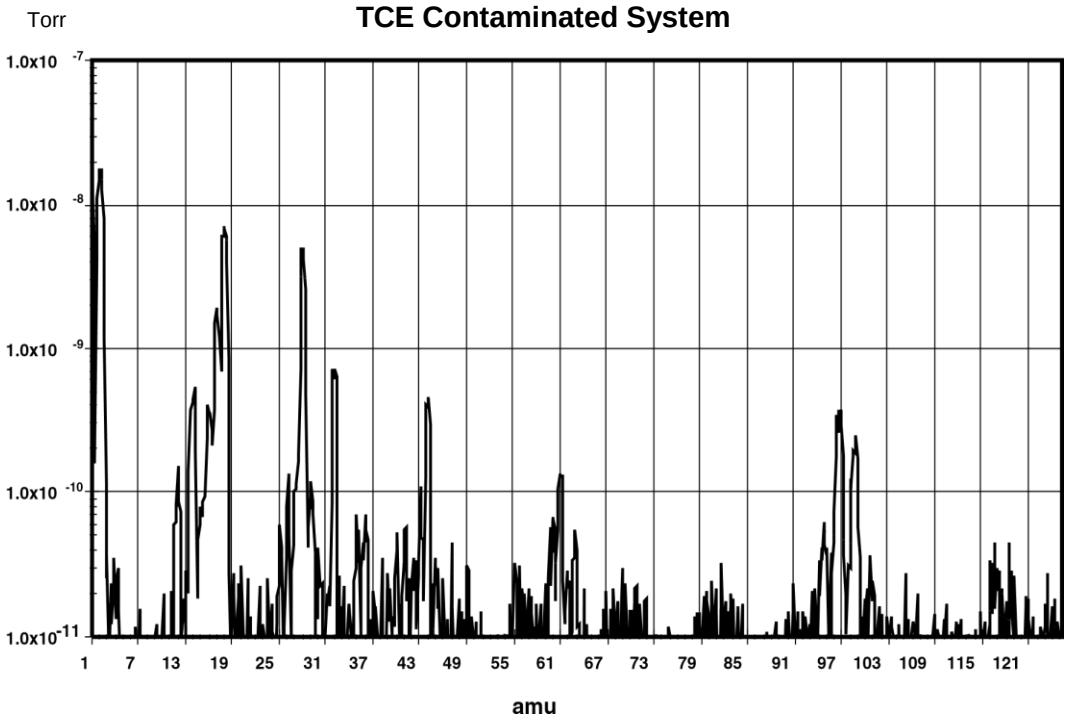

Figure 3: TCE Contaminated System

Data like this is invaluable to the development of cleaning procedures. While the TCE successfully removed the oil, the vacuum chamber was left more contaminated than it would have been without the cleaning. The mass spectrum provides a more accurate evaluation of cleaning procedures than pump down time and base pressure. Just because a system pumps down quickly does not guarantee that undesirable contaminants have been eliminated.

The large dynamic range of the RGA also allows evaluations to be made more quickly. After a vacuum system has been brought up to atmospheric pressure, it will require an extended period to pump back down to its ultimate vacuum. If the vacuum system does not quickly reach its ultimate vacuum, the next step is commonly a high temperature bakeout. If the vacuum system has still not reached its ultimate vacuum, problems are suspected and typically a leak tester would be attached to the system. With the RGA, the user does not have to wait several hours for the water to pump down or perform a bakeout before determining if a system is contaminated. The RGA can make measurements as soon as the total pressure reaches 10^{-5} mbar. The large dynamic range will allow impurities to be seen at 10^{-10} mbar or leak testing to be performed in a this high total pressure. Thereby, the RGA allows a great reduction in turn-around time after a vacuum system has been brought up to atmosphere

Single Mass Measurement

For vacuum systems that only need to be clean, the mass spectrum is the most useful measurement. During experiments and processes the partial pressure of certain species is of more interest. The RGA software provides three modes that are used to measure selected peaks. The selection of which mass is associated with which species is usually straightforward, *i.e*. the mass of the molecule is chosen. When two species have

overlapping peak patterns, the user chooses the strongest peak that does not interfere. For example N_2 and CO both have a mass of 28. In a system with a large CO interference, N_2 could be measured at mass 14. Because the peak at 14 is smaller than the major peak, a scaling factor is required. The set of peaks of interest are entered into the RGA software by the user. During measurements, the RGA measures only each peak. Because the whole spectrum is not measured, data is acquired much faster. The two examples that follow show an interesting pressure vs. time experiment and a method of increasing the dynamic range of measurements.

Pressure vs. time

Figure 4 shows the use of the P vs. t Mode to monitor an air lock sequence. The process is to open an air lock, place the sample in it, and move the sample into the main vacuum chamber. The air lock is pumped from atmospheric to rough vacuum using the same mechanical pump as the main vacuum chamber. This requires isolating the foreline of the turbo pump during the time the sample is in the air lock. To keep oxygen out of the main vacuum chamber, the air lock is flushed with dry nitrogen then pumped to rough vacuum. The flush is repeated two additional times before the sample is finally transferred. If this procedure is successful, the main vacuum chamber should not be disturbed.

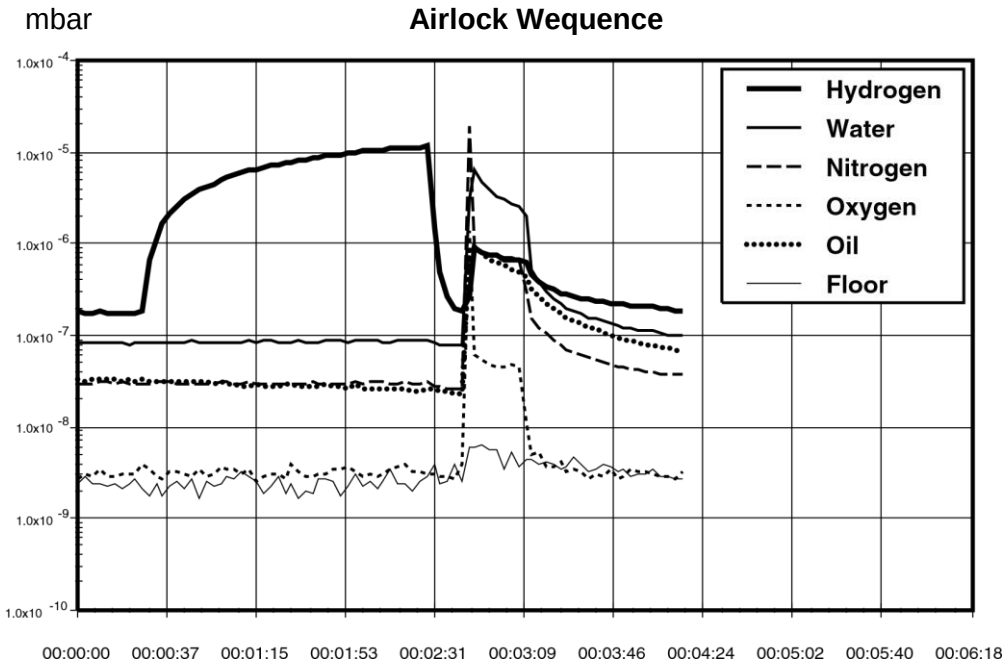

Figure 4: Airlock Sequence

To make these measurements, the electron multiplier detector has been used with a gain of 100, which allows all six channels to be recorded every three seconds. The standard Faraday cup detector is able to detect these partial pressures, but not at this rate. The "floor" channel is set to mass 21. There is rarely anything present at this mass, which allows it to be used as an indicator of the minimum detectable partial pressure.

The sequence starts with the main vacuum chamber at its base pressure of 2×10^{-8} mbar. The chamber is pumped by a turbomolecular pump that is backed by a rotary vane pump. A small load lock is attached to the chamber, which can be rough pumped by the same mechanical pump and purged with nitrogen.

At 0:30, the isolation valve between the turbo pump exit and mechanical pump is shut so that the mechanical pump can be used to rough pump the load lock. During this time, the load lock is repeatedly filled with nitrogen and pumped down. Of interest in the data is the rise in the hydrogen partial pressure during this step of the sequence. The partial pressure of hydrogen increases by a factor of 100 while the partial pressure of the other gasses barely increase. This difference is caused by the low compression ratio that turbo pumps have for light gasses. The heavier gasses are being compressed into the dead volume between the turbo pump exit and isolation valve. But, the turbo pump has insufficient compression ratio to store hydrogen in this manner, causing the partial pressure of hydrogen to rise.

At 2:30, the load lock has been roughed and the turbo pump foreline isolation valve is opened. The pressures of H_2 immediately drops back to the base pressure values.

At 2:40, the load lock is opened to the main chamber causing a jump in pressure. The rise in oxygen and oil pressure indicates that the procedure is operating poorly. Even though the load lock was purged three times with 99.999% nitrogen, oxygen was still introduced into the chamber. This was either caused by a small air leak into the load lock, or permeation of oxygen out of the elastomer seals on the load lock. The rise in oil partial pressure indicates that the trap on the mechanical pump is exhausted and has allowed oil to backstream into the load lock.

At 3:09, the valve between the load lock and main chamber is closed, and the pressures begins to return towards their base values. Oxygen is pumped out of the chamber. Hydrogen, water, and nitrogen recover their original values, but slowly. The oil is alarming because it persists at a higher concentration. If this sequence occurred several more times, the oil would continue to increase. The RGA allows it to be detected before reaching undesirable levels.

Leak Testing

In addition to the diagnosis of vacuum systems, the RGA is invaluable as an intrinsic leak detector. It is always available and does not require perturbing the system. The user does not have to roll up a large leak detector and attach it to the vacuum system. The system does not have to be brought up to atmospheric pressure. The RGA can operate in leak detection mode using any gas, so it does not require helium. For moderate leaks, argon or tetrafluoroethane (a typical gas in cans of "dust off") can be used. Helium is necessary for only the smallest leaks. Having a built-in leak detector makes working with vacuum systems much easier and faster, and the SRS RGA is far less expensive than a standard helium leak detector.

The process of leak detection with an RGA is the same as with a traditional helium leak detector. Place the software in leak detection mode, indicate the mass of the test gas and watch the partial pressure as various joints in the vacuum system are sprayed with the test gas. When the leak is sprayed with the test gas, the partial pressure will rise. The response is immediate if the leak is in a direct path from the outside to the inside of the

system. Figure 6 contains the result of a leak test with helium on a vacuum chamber. The tester moves the helium probe towards and then past the leak, causing the first peak. Once the location of the leak is bounded, the tester tries to precisely locate the leak. For most situations leak testing is straightforward and no different than traditional methods. In the following sections, we discuss a few situations where traditional methods fail and how the RGA provides a better method.

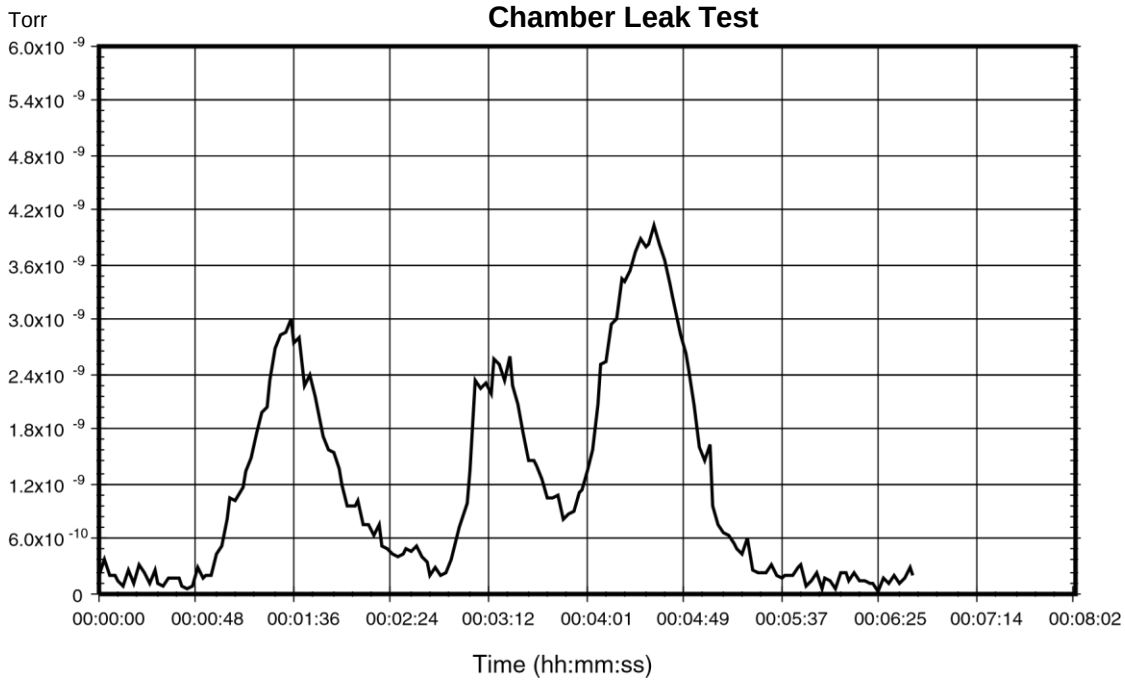

Figure 6: Helium Leak Test Data

The partial pressure of the test gas is directly related to the leak rate into the chamber. Assuming that the vacuum pump is not operating near its compression limit, the throughput of the test gas is equal to the product of the partial pressure and the effective speed of the pump at the RGA ionizer (Q = S P). In Figure 5, the partial pressure was measured in Torr. The effective speed of the turbo pump for helium was approximately 50 liter s^{-1}. The largest peak in this data at 4×10^{-9} Torr represents a leak of 1.5×10^{-7} scc sec^{-1}. (0.76 scc sec^{-1} = 1 Torr liter s^{-1}). From this figure we can estimate a minimum detectable leak of 1×10^{-8} scc sec^{-1}, which is measured with a FC detector. To measure smaller leaks, a CEM detector can be used, or the turbo pump can be throttled to decrease the pumping speed.

Supply Gas Valve Seats

Leaks across valves that supply gasses to a vacuum system cannot be detected with conventional helium leak testers (unless the valve supplies helium). To test a suspect valve would require removing it and attaching it to the leak tester. Because the RGA can monitor any gas, this is unnecessary; the valves on gas supply lines can be tested *in situ*. The procedure is simple: monitor the composition of the vacuum system with a high pressure and then a low pressure behind the valve seat in question. If the partial pressure of the gas in question changes, the valve seat is leaking.

Supply Gas Manifolds

Leak testing supply gas lines can be a very trying experience. The difficulty is mostly because compression type fittings do not have a leak test port. Another difficulty is that supply manifolds commonly have a large number of connections in close proximity. Because the leak in a compression fitting is inside the fitting, transporting the test gas to the leak requires a large flowrate and waiting for an extended time for the gas to diffuse into the fitting. Because of the flowrate and time, it is possible that the test gas can travel to adjacent tube fittings and cause a misleading indication of a leak. Often times "fugitive" leaks appear and disappear at a specific fitting. What is happening is that the test gas is inadvertently flowing to another fitting, which has a real leak. Whether this inadvertent gas flow occurs depends on exactly how the test gas is applied to the fitting with the "fugitive" leak. Small air currents caused by equipment fans or ventilation systems can move the test gas in unpredictable ways. Confining the test gas to the fitting under question can help, but the RGA provides a easier solution: use a gas other than helium. Helium will spread in air quickly and diffuse into many fittings. A heavy gas like argon or tetraflouroethane is far easier to confine to a specific fitting. Once the moderate leaks have been located and eliminated, a follow up with helium to check for tiny leaks is warranted.

Bellow Valves

Bellow valves can be difficult to leak test due to the large volume of gas contained between the bellow and the valve body. To perform a quick leak test it is required to change the composition of the gas in this trapped volume quickly. Unfortunately, for some valves, this volume of gas is not highly accessible. This greatly reduces the response time of a leak test. For a leak causing a base pressure of 10^{-7} mbar in a vacuum system with a 70 l s^{-1} pump, the volumetric flowrate of gas entering from the atmospheric side of the leak is 7 nanoliters per second. For a bellow with a trapped volume of 1 ml trapped, the response time constant would be over 40 hours. This emphasizes the importance of leak test ports on vacuum hardware.

In such situation it is common to place a bag over the body of the valve and fill the bag with helium. The RGA allows us to consider using gases other than helium. The permeability of helium through elastomeric seals can give a false leak reading. And as in manifolds, unless the helium can be strictly confined to the valve body, it may spread to adjacent connections. Given the amount of work and lost time required to remove and repair large valves, false leak readings are expensive. A second test with another gas, such as argon, can confirm that a suspect valve is leaking before starting out on the repair.

Conclusion

An RGA is a real eye opener for users of vacuum systems. With an RGA the process of working with vacuum systems is elevated from an empirical trial and error approach to a systematic approach. The status of the vacuum system can be constantly assessed. When an experiment or process is having problems, the possibility of contamination or leaks in the vacuum system can be immediately ascertained. The RGA provides not only troubleshooting but also historical data. Slow trends in a vacuum system can be noticed and acted on before they become serious problems. Hard to correlate cause-effect relations are much easier to establish with the wealth of statistical data that can be

obtained with a daily spectrum analysis. Good procedure and strict adherence to them allows a user to infer the integrity of a vacuum system. An RGA allows users to prove the integrity of a vacuum system with hard data.

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Appendix B
Using SRS RGA's to Sample High Pressure Gasses

Introduction

The types of analysis performed by an RGA are useful in many applications other than vacuum systems. But, the RGA is intrinsically a vacuum instrument that operates best under 10^{-5} mbar. The instruments response becomes non-linear above 10^{-5} mbar. To sample gases at higher pressures, a pressure reduction system is needed. These systems are basically a restriction and a vacuum pump package. Common restrictions are pinholes and capillaries, which can provide pressure reductions of more than 6 decades of pressure. The vacuum pump package consists of a turbomolecular pump and a backing pump. In addition to achieving the desired pressure reduction, the design of a system should provide for a fast response and high signal to background ratio.

At pressures common to vacuum processes, a simple aperture based pressure reduction system is suitable. At atmospheric and higher pressures, a two stage reduction based on a capillary and aperture is used. These two systems will be used to illustrate the design of pressure reduction systems for RGA's.

Vacuum Process Sampling (10 to 10-5 mbar)

Figure 1 shows a schematic of a basic pressure reduction system. The system has two paths to the RGA: a high conductance path and an aperture path. The high conductance path (through Valve Hi-C) is provided so that the RGA can monitor the ultimate vacuum of systems before a process begins. The Hi-C path is also used when leak testing the vacuum system with the RGA Software's leak test mode. The aperture path provides the pressure reduction for when the vacuum process is operating at pressures up to 10 mbar.

The design of the aperture path is straightforward. First, the RGA operating pressure is chosen, for example 10^{-6} mbar. The pressure, P, and the pumping speed, S, determine the throughput of the aperture, Q, by the equation $Q = P\,S$. To keep the system cost low, a small turbo pump is chosen. For a 70 liter s^{-1} pump, the required throughput is 7×10^{-5} mbar liter s^{-1}. The throughput of the aperture is related to its conductivity, C, and the pressure drop, ΔP, by the equation $Q = C\,\Delta P$. The process pressure determines the pressure drop thereby determining the required conductivity. Formulas for conductivity of various geometries, *e.g.* capillaries, and pinholes, are available in many references (some are listed at the end of this note).

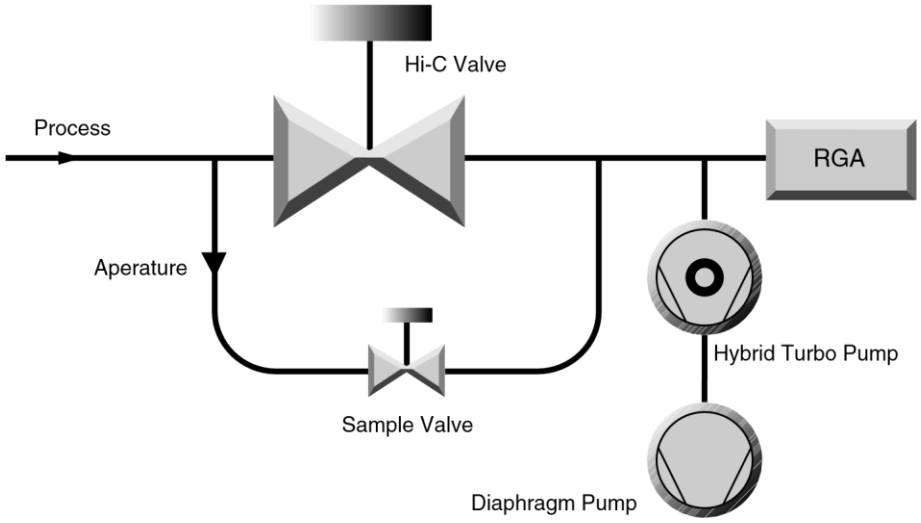

Figure 1: Schematic of a mid-vacuum pressure reduction system

Apertures can be readily designed for process pressures in the range from 10^{-3} mbar to 10 mbar. If the process always operates within a small range, the aperture can be optimized to deliver gas to the RGA at about 10^{-6} to 10^{-5} mbar. By operating the RGA at its optimum pressure the data acquisition time is kept to a minimum and the full dynamic range in partial pressure is available. For many applications, the process is operated at one pressure and the aperture can be optimized. If the process pressure varies over a range of 2 decades or more, the aperture size must be compromised to tolerate the pressure range. For example, consider a process pressure that varies from 10^{-1} to 10 mbar. The aperture would be designed to drop the pressure from 10 mbar to 10^{-5} mbar.

When the process pressure was at 10^{-1} mbar, the pressure at the RGA would be 10^{-7} mbar. The minimum detectable partial pressure (MDPP) of the RGA does not depend on the operating pressure; for a Faraday cup detector it is about 10^{-10} mbar. Therefore the dynamic range of the measurement varies from 5 decades at high process pressure to only 3 decades at the low pressures. For applications where the full dynamic range is not needed, operating the RGA at low pressure may be acceptable. If the full dynamic range is required over a variety of process pressures, a variable reduction is required. Suitable variable leak valves are available, but are significantly more expensive than a fixed aperture. Another method of increasing the dynamic range and data acquisition rate is to use an RGA with an electron multiplier. The electron multiplier provides gains up to 10^{6} and lowers the MDPP to under 10^{-13} mbar. This lower MDPP allows the RGA to provide large dynamic range even at low operating pressures.

A high operating pressure (or throughput of the aperture) at the RGA also improves the signal to background ratio. In this context, signal is the gas that is drawn through the aperture and background is outgassing from the system plus backstreaming through the turbo pump. The ultimate vacuum of many turbo pump packages is about 10^{-9} mbar. The outgassing background will be mostly hydrogen, water, and nitrogen. The backstreaming background will be air. If measurements are being made near these background peaks, the operating pressure should be kept as high as possible. The background can be minimized by designing the tubing such that the effective pumping speed at the RGA ionizer is as high as possible. Figure 2 shows two layouts that both have the same "signal" level. The layout with the RGA at the end of a small tube has a small effective pumping speed and will show a larger background level.

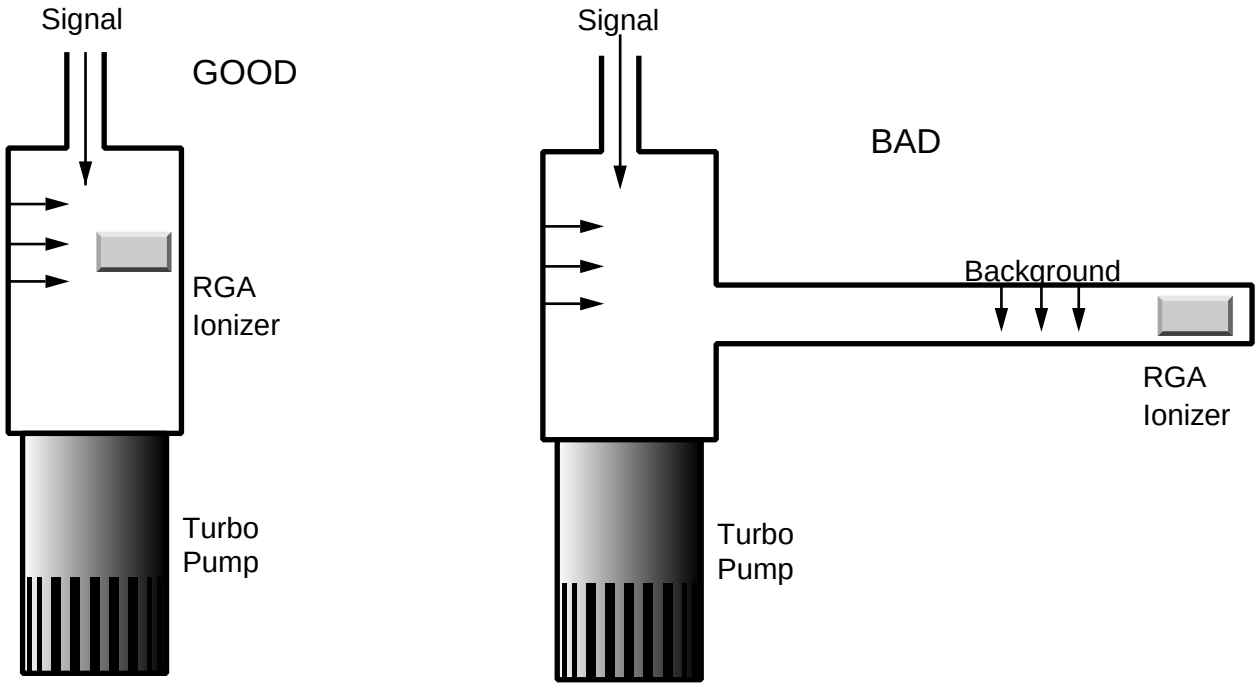

Figure 2: Two Layouts of Post-Aperture Vacuum System.

The system shown in Figure 1 can be assembled as a simple package. Using a small (70 liter s^{-1} or less) hybrid turbo pump and a diaphragm backing pump will eliminate any concern of oil. The use of this pump pair also eliminates foreline traps and isolation valves. The operation of the system should be simple: open the Hi-C valve at low pressures, or open the sample valve at high pressures.

High Pressure Sampling (>100mbar)

At high pressure the aperture assembly is insufficient to reduce the pressure, while maintaining response time. Consider an aperture that reduces the pressure from 10 mbar to 10^{-6} mbar when used with a 70 liter s^{-1} turbo pump. The volumetric flowrate on the high pressure side of the aperture would be 7 microliter s^{-1}. Any dead volume on the high pressure side of the aperture (Figure 3) would cause a large response time constant (t_c = volume / flowrate). If the aperture had a small dead volume of 1/2 inch of 0.250 OD tube (0.028 wall), the time constant would be 35 seconds. This is not an acceptable response time.

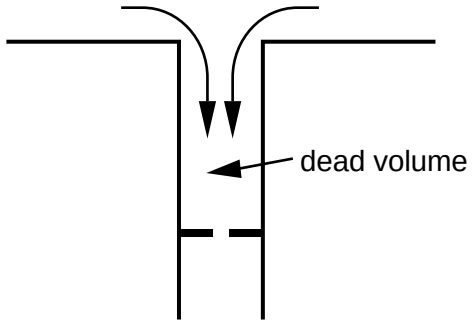

Figure 3: Small Dead Volume Slows Process Response time.

To achieve a fast response time, a capillary inlet is used with bypass pumping as shown in Figure 4. The system reduces the pressure in two stages. Most of the sampled gas is drawn through the capillary and directly to the diaphragm pump, *i.e*. bypasses the RGA. The pressure at the exit of the capillary is about 1 mbar. A small amount of the sampled gas is diverted to the RGA through an aperture. This configuration improves the response time by two methods. First, the pressure on the high side of the aperture is held to about 1 mbar. But even this pressure would give a time constant of 3.5 seconds in the 1/2 inch dead volume example mentioned above. The second method to decrease the time constant is to ensure that any dead volume is well mixed. After the capillary, the gas is traveling at significant velocity (several meters per second). Proper layout of the inlet tubing will use the kinetic energy of the sampled gas to mix the dead volume (in a sense keeping the volume alive). Figure 5 shows the response to bursts of gas at the inlet of an atmospheric sampler designed with the above considerations. The sub-second response and cleanup are almost as fast as the RGA can acquire data.

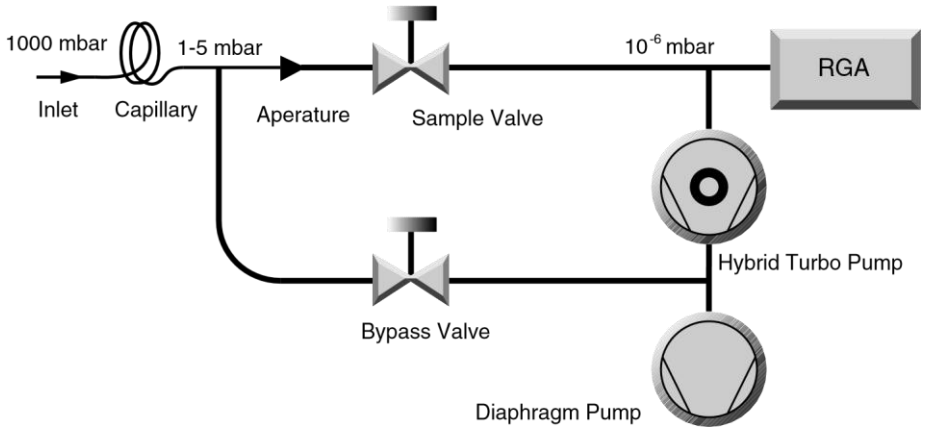

Figure 4: High Pressure Sampling Using Bypass Pumping

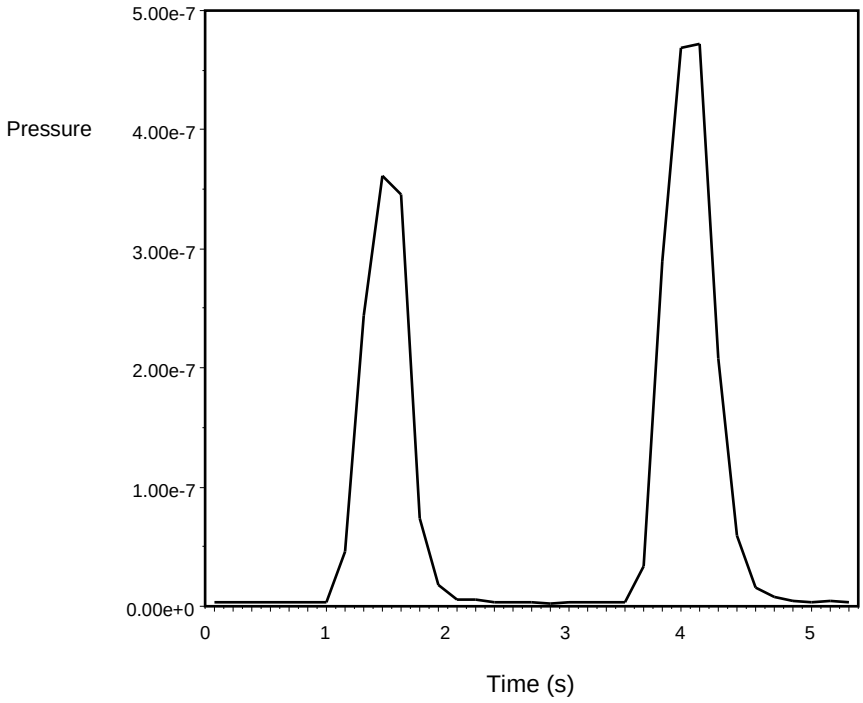

Figure 5: Response of Bypass Pumped System to Gas Bursts.

Glass capillaries are available with small enough bores to reduce pressure from 1000 mbar to 10^{-6} mbar without bypass pumping. While it is possible to build a atmospheric sampling system based on a 1/4 meter 50 μm glass capillary, there are considerable reasons to use a bypass pump configuration. Bypass pumping improves the operation of a system by increasing the flowrate of gas through the capillary about 3-4 orders of magnitude. The higher flowrates and smaller pressure drop allow a wider selection of capillaries to be practical. Stainless steel and PEEK capillaries are more

affordable and flexible than glass capillaries. A large flowrate means that the volumetric flowrate at the inlet of the capillary is more reasonable. For a system with 70 liter s^{-1} pumping speed, operating at 10^{-6} mbar, the volumetric flowrate at the inlet would be 70 nanoliter s^{-1}. Any dead volume at the inlet of the capillary would result in an unreasonable response time. With such small flowrates, inlet devices such as filters, valves, or connecting hardware cannot be used. Overall, the bypass pumped capillary system is more flexible and only requires a minor addition of hardware (one valve and some tube).

The configuration seen in Figure 4 is made possible by the recent advances in hybrid turbomolecular/drag pumps and diaphragm pumps. Traditional designs would have relied on a **two** rotary vane pumps and standard turbomolecular pump. The high compression ratios of the hybrid turbo pumps allow the two streams (bypass and sample) to be combined. The low ultimate vacuum of contemporary diaphragm pumps makes them suitable as a foreline pump. The combination of these modern technologies means that an atmospheric sampling system can be constructed into a very small packages (less than 8 inch high in a 19 inch rack mount chassis), which is portable and easy to operate.

Conclusion

Although the RGA is intrinsically a vacuum instrument, inlet systems are easily designed that allow it to sample gasses at any pressure. A more descriptive name for such systems would be "online quadrupole mass spectrometer". Mass spectrometry is a well proven analytical technique, but traditionally used an expensive large machine. Reduction in cost of quadrupoles and vacuum pumps, along with the development of easy to use software interfaces makes process analysis with mass spectrometry an attractive technique.

Further Reading

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Moore, J.H., Davis, C.C., and Coplan, M.A., *Building Scientific Apparatus, 2nd ed.*, Addison-Wesley, New York, 1989

Appendix C Glossary of Terms

The following is a listing of some of the most important terms used throughout the SRS RGA Operations Manual. For a more complete listing of terms relevant to partial pressure analyzers in general, refer to:

"A Dictionary of Vacuum Terms used in Vacuum Science and Technology, Surface Science, Thin Film Technology and Vacuum Metalurgy", edited by M. S. Kaminsky and J. M. Lafferty, published by the American Vacuum Society, 1979.

A. Basford et. al., J. Vac. Sci. Technol. A 11(3) (1993) A22-40: "Recommended Practice for the Calibration of Mass Spectrometers for Partial Pressure Analysis. Update to AVS Standard 2.3".

Anode Grid (Ionizer Component): Positively biased grid cage of the ionizer within which the ionization of the gas molecules takes place. **Note**: In the SRS RGA, the voltage bias of the anode grid, in Volts, sets the ion energy (in eV) for the spectrometer.

Atomic mass unit (abbreviation: amu). A unit of mass equal to one twelfth the mass of a neutral carbon atom having six protons and six neutrons (^{12}C); equivalent to $1.660566 \cdot 10^{-27}$ kg.

Background signal, H_0. Output signal, measured with respect to baseline, which is obtained before the introduction of any gas in the chamber.

Base pressure (also Background pressure). Total pressure before introduction of any gases into a vacuum system. Usually, the base pressure is the lowest pressure that is typically achieved in the vacuum chamber.

Baseline. The output signal from the RGA when no ions are arriving at the detector.

CDEM. Abbreviation for the type of electron multipliers known as: Continuous Dynode Electron Multiplier.

CF. Abbreviation for Conflat type flange.

CF Nipple. A short section of vacuum pipe terminated with a standard Conflat flange connector at each end.

Charge, Q. The electron charge of an ion. Ion charge occurs in multiples of the electron charge, e^-.

Drift. A change in time in the avearge output signal at constant partial pressure.

ECU. Abbreviation for electronics control unit.

Electron emission. The release of electrons from the heated filament in the ionizer. The electrons are accelerated into the **anode grid** where the ionization of the gas molecules occurs.

Electron emission current. The electron current from the filament to the grid in mAmps.

Ion current signals scale linearly with the electron emission current. **Note**: The available emission current range in the SRS RGA is 0 to 3.5 mA.

Electron Energy. The kinetic energy of the electrons (in eV) used for electron bombardment in the ionizer. **Note:** In the SRS RGA the Electron Energy is equal to the voltage difference (in Volts) beween the filament and the anode grid.

Electronics Control Unit (abbreviation: ECU). Electronics box that attaches directly to the probes feedtrhu flange and contains all the necessary components to operate the quadrupole mass spectrometer and communicate with a host computer.

Faraday Cup. A charged particle detector, consisting of a metal electrode, for the direct collection and detection of charged particles. **Note:** Typical designs are cup shaped to minimize secondary electron losses.

Filament (Ionizer Component). The source of the ionizing electrons. Thin, thoria coated, Iridium wire that operates at a negative potential relative to ground and is resistively heated to incandescence with an electrical current from the emission regulator. The thermionically emitted electrons are accelerated towards the anode grid which is positively charged with reference to the filament and ground.

Focus Plate (Ionizer component). Ionizer's electrode plate that serves the double purpose of drawing the ions away from the anode grid, and containing the ionizing electrons inside the source.

Fragment ion. An ion of mass smaller than that of the original parent molecule.

Fragmentation factor. The fragmentation factor of gas g at mass M is defined as the ratio of ion signal at mass M to the ion signal at the principal mass peak of gas g.

Fragmentation of molecules: The breaking of multi-atomic molecules into units of fewer atoms, some of which are usually electrically charged.

Fragmentation (or cracking) pattern. The fragment distribution of ionic species which results from dissociation and ionization of multi-atomic molecules of given species in the ionizer.

Head (also RGA Head). The combination of the Probe and the Electronics Control Unit.

Inert Gas. A gas that does not normally react chemically with other substances. Example: He, Ar, Kr and Xe. Typically used for calibration purposes in RGA's.

Ion. An atom or molecule which has gained or lost one or more electrons and therefore has a negative or positive charge. Note: Most RGA's use electron bombardment to ionize molecules and detect only positive ions.

Ion current. The rate of ion flow into the detector. Usually expressed in units of amps.

Ion Energy. The kinetic energy of the ions as they move down the quadrupole mass filter**,** and expressed in eV. **Note**: In the SRS RGA the Ion Energy is equal to the voltage biasing of the anode grid in Volts and has two possible settings (i.e. Low and High).

Ionization. The process that results in the formation of ions from neutral atoms or molecules. During ionization, electrons are added or removed from the molecules to form negative or positive ions respectively. **Note**: In the SRS RGA the ionization is caused by electron bombardment; outer electrons are removed by the impact of energetic electrons on the molecules.

Ionization efficiency. The ionization probability normalized to the probability of ionization of a reference gas.

Ionization Potential. The minimum energy per unit charge (often in eV) required to remove an electron from an atom (or molecule) to infinite distance. **Note**: In the SRS RGA the Electron energy must be set above the ionization potential of the molecules for ionization to occur.

Ionization probability. The number s of ion pairs (equal amounts of positive and negative charges appear as ions) produced by an electron traveling a unit ditance (typically 1 cm) through a gas at unit pressure (typically 1 mTorr). It depends on the ionization potential of the electrons used for bombardment.

Ionizer (Probe Component). The portion of the mass psectrometer probe that generates the ions and accelerates them as a beam. **Note:** The components of the SRS RGA ionizer are: anode grid, repeller, focus plate, and filament.

Linearity. The extent to which the change in output signal of the RGA is proportional to the corresponding change in partial pressure.

Linear response range. The partial pressure range over which linearity in the signal response is observed. See linearity.

Mass-to-charge ratio: The mass-to-charge ratio, **M/Q**, is defined as the ratio of the mass number M of the ion to its charge Q, measured in units of the electron charge e^-. For example: doubly charged ions of argon isotope 36 ($^{36}Ar^{2+}$) and singly charged ions of water, $^{1}H_2{}^{16}O^{1+}$, have M/Q = 18, and cannot be differentiated from each other with most mass spectrometers. **Note:** Mass spectrometers do not actually measure the molecular mass directly, but rather the mass-to-charge ratio of the ions. For singly charged ions, the mass to charge ratio is numerically equal to the mass of the ion in atomic mass units (amu).

Mass analyzer (Probe component). The portion of the mass spectrometer probe that separates the ion beam into its various mass-to-charge ratio components. Also referred to as Quadrupole mass filter.

Mass Number, M. The mass number, M, is the sum of the number of protons and neutrons in an atom or molecule.

Mass peak. The ion current pattern in the vicinity of maximum amplitude by scanning through a small portion of the mass range containing ions of a single mass-to-charge ratio. Very often, the term "mass peak" refers to the signal developed from singly charged ions. For example, nitrogen is said to have a "mass 28 peak".

Mass Range. The range of mass numbers defined by the mass number of the lightest and the heaviest singly charged ions which can be detected by the RGA.

Mass spectrometer. An instrument which produces a beam of molecular ions from a sample, separates the resulting mixture of ions according to their mass-to-charge ratios, and provides output signals which are measures of the realtive abundances of the ionic species present.

Mass spectrum. A graph of ion abundance vs mass-to-charge ratio.

Minimum Detectable Partial Pressure change (MDPP). The partial pressure change corresponding to the smallest signal change which can be distinguished from noise. A common prescription is, $\Delta p_{min} = \sigma / S_g$, where σ is the noise and S_g is the partial pressure sensitivity for the gas being measured.

Noise. Random fluctuation in the output signal unrelated to a change in the partial pressure of the gas from which the signal is derived. The appropriate measure of noise is the standard deviation σ_N of N independent determinations of the average output signal obtained at constant partial pressure.

Open Ion Source (Also Nude Ion Source). An ionizer with electrodes of high transparency to gases.

Outgassing. The evolution of gas molecules from the internal wall surfaces of the vacuum system.

Parent ion. An ion of the same mass as that of the original parent molecule.

Partial Pressure. The pressure of a designated component of a gaseous mixture within a system as it is exerted on the chamber walls. The sum of the partial pressures of all the kinds of gases gives the total pressure.

Partial Pressure Analyzer (abbreviation: PPA). A compact mass spectrometer used to analyze the residual gas composition in a vacuum system.

Peak height (also peak intensity). The maximum ion signal developed in the RGA for a given mass-to-charge ratio peak.

Peak width ($\Delta M_{v\%}$). The difference between the mass-to-charge ratio values on either side of a mass peak at which the signal has dropped to v% of the peak height, H. See also Resolution.

Principal mass peak. The most intense peak in the fragmentation pattern of any molecule.

Probe (also RGA Probe). Quadrupole mass spectrometer sensor consisting of an ionizer, a mass analyzer and a detector (Farday cup or optional electron multiplier).

Repeller (Ionizer Component). The repeller grid cage completely encloses the ionizer, is biased negative relative to the filament, and prevents the loss of electrons from the ion source.

Residual Gas Analyzer (abbreviation: RGA). A compact mass spectrometer used to analyze the residual gas composition in a vacuum system (same as Partial Pressure Analyzer).

Resolution, or Absolute Resolution, $\Delta M_{10\%}$. The width **ΔM** of the pass band of the filter, defined as the full width at which the ion current falls down to 10% of the maximum value. In mass-to-charge ratio units. See also Peak width.

Resolving Power: R= M/$\Delta M_{10\%}$: Ratio between a particular mass-to-charge ratio **M** and the resolution, $\Delta M_{10\%}$, at that mass. Dimensionless ratio.

RGA. Abbreviation for Residual Gas Analyzer.

RGA Cover Nipple. CF Nipple that covers the RGA Probe.

Scan Speed (mass spectrometer). The speed at which the RGA scans through a range of succesive mass numbers.

Scanning. The procedure of continuously changing the mass tuning of the quadrupole mass spectrometer to bring successive mass numbers into tune.

Sensitivity.

Partial Pressure:

The partial pressure sensitivity of the RGA to a gas g, S_g, is defined as the ratio of the change $(H-H_0)$ in principal mass peak height to the corresponding change $(P-P_0)$ in total pressure due to a change in partial pressure of the particular gas species. H_0 and P_0 are background values.

$$S_g = (H-H_0) / (P-P_0)$$

The units of S_g are of ion current per unit pressure (amp/Torr, for example).

Total Pressure:

The total pressure sensitivity of the RGA to a gas g, is defined similarly as the ratio of the change $(H-H_0)$ in total ion current to the corresponding change $(P-P_0)$ in total pressure due to a change in partial pressure of the particular gas species. H_0 and P_0 are background values.

Sensitivity calibration. The act of establishing a a correspondence between the change in ion current and the corresponding change in partial pressure of the gas from which the ion is produced. The correspondence might be represented graphically or as a table of values. See also Sensitivity.

Space charge. The electrical charge carried by a cloud of free elctrons or ions. Space charge can causes serious changes in the potential distributions of the ionizer, and ultimately limits the pressure operating range of all RGA's.

Total Pressure. The average normal force per unit area exerted by all the gas molecules impacting on the internal surfaces of the vacuum chamber. Units are typically Torr, mbar or Pascal. Note: The SRS RGA is capable of collecting total ion currents that can be turned into total pressure measurements with the help of gas dependent total pressure sensitivity factors.

UHV. Abbreviation for Ultra High Vacuum. Pressure < 10^{-9} Torr.

Appendix D Vacuum References

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Vacuum Technology Books

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2. J. H. Leck, "Total and Partial Pressure Measurement in Vacuum Systems", Blackie, Glasgow&London, 1989. **Note**: Another classic. Great chapters on gauging.

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6. John H. Moore et. al. , "Building Scientific Apparatus: A Practical Guide to Design and Construction, 2nd edition", Addison Wesley, Redwood City, CA, 1989. Note: Every science research laboratory must have a copy of this book on its shelfs. The Vacuum Technology chapter (Chapter 3, p. 75) provides one of the best introductions to vacuum technology and vacuum system design we have ever seen!

7. Walter H. Kohl, "Handbook of Materials and Techniques for Vacuum Devices", American Vacuum Society Classics, AIP Press, New York, 1995.

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2. **The Journal of Vacuum Science & Technology B**. Microelectronics and Nanometer Structures. Published six times annually by the American Vacuum Society (www.vacuum.org). A consistently good journal with lots of refereed papers on semiconductor processing issues. Available on-line: http://ojps.aip.org/jvstb/

3. **Vacuum**. The international journal Vacuum publishes high quality papers on latest advances in the many areas which now require the production and control of a

working environment at pressure below one atmosphere. Published by Pergamon Press, a division of Elsevier Books and Journals: www.elsevier.nl.

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Appendix E Parts List

Top board (assembly 671)

PCB reference	Name	Description	SRS part number
C100	4.7U/50V	4.7 µF 1206 capacitor, 50V X5R 10%	5-00807-578
C101	1 µF	1 µF 0603 capacitor, 25V X5R 10%	5-00790-578
C102	1 µF	1 µF tantalum, 16V 78 mA 20%	5-00513-569
C103	4.7U/50V	4.7 µF 1206 capacitor, 50V X5R 10%	5-00807-578
C104	4.7U/50V	4.7 µF 1206 capacitor, 50V X5R 10%	5-00807-578
C107	4.7U/50V	4.7 µF 1206 capacitor, 50V X5R 10%	5-00807-578
C108	4.7U/50V	4.7 µF 1206 capacitor, 50V X5R 10%	5-00807-578
C110	0.1 µF NPO	0.1 µF 1206 capacitor, 50V NP0 5%	5-00886-500
C111	0.01 µF	0.01 µF 0603 capacitor, 25V C0G 5%	5-00869-580
C112	0.1 µF NPO	0.1 µF 1206 capacitor, 50V NP0 5%	5-00886-500
C114	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C115	0.01 µF	0.01 µF 0603 capacitor, 25V C0G 5%	5-00869-580
C116	0.1 µF NPO	0.1 µF 1206 capacitor, 50V NP0 5%	5-00886-500
C117	4.7U/50V	4.7 µF 1206 capacitor, 50V NP0 5%	5-00807-578
C118	0.1 µF NPO	0.1 µF 1206 capacitor, 50V NP0 5%	5-00886-500
C119	0.01 µF	0.01 µF 0603 capacitor, 25V C0G 5%	5-00869-580
C120	0.1 µF NPO	0.1 µF 1206 capacitor, 50V NP0 5%	5-00886-500
C121	0.01 µF	0.01 µF 0603 capacitor, 25V C0G 5%	5-00869-580
C122	560 pF	560 pF 0603 capacitor, 50V C0G 5%	5-00734-580
C200	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C201	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C202	4.7U/50V	4.7 µF 1206 capacitor, 50V NP0 5%	5-00807-578
C203	4.7U/50V	4.7 µF 1206 capacitor, 50V NP0 5%	5-00807-578
C204	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C205	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C206	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C207	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C210	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C211	4.7U/50V	4.7 µF 1206 capacitor, 50V NP0 5%	5-00807-578
C212	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C213	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C214	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C215	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C216	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C217	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C218	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C219	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C220	4.7U/50V	4.7 µF 1206 capacitor, 50V NP0 5%	5-00807-578
C221	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C222	4.7U/50V	4.7 µF 1206 capacitor, 50V NP0 5%	5-00807-578
C223	4.7U/50V	4.7 µF 1206 capacitor, 50V NP0 5%	5-00807-578
C224	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C227	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C228	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C229	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C230	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C231	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100

C232	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C233	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C238	0.1 µF	0.1 µF 1206 capacitor, 25V NP0 5%	5-00882-578
C239	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C240	0.01 µF	0.01 µF 0603 capacitor, 25V C0G 5%	5-00869-580
C241	0.01 µF	0.01 µF 0603 capacitor, 25V C0G 5%	5-00869-580
C242	0.1 µF	0.1 µF 1206 capacitor, 25V NP0 5%	5-00882-578
C245	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C300	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C301	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C302	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C303	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C304	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C305	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C306	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C307	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C308	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C309	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C310	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C311	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C312	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C313	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C314	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C315	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C316	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C317	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C318	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C319	0.01 µF x 4	0.01 µF x 4 1206 capacitor array, 100V X7R 20%	5-00654-500
C320	1 µF	1 µF 0603 capacitor, 25V X5R 10%	5-00790-578
C321	1 µF	1 µF 0603 capacitor, 25V X5R 10%	5-00790-578
C322	1 µF	1 µF 0603 capacitor, 25V X5R 10%	5-00790-578
C323	1 µF	1 µF 0603 capacitor, 25V X5R 10%	5-00790-578
C324	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C325	0.1 µF x 4	0.1 µF x 4 1206 capacitor array, 16V X7R 20%	5-00627-578
C326	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C327	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C328	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C329	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C330	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C331	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C332	100N	0.01 µF 1206 capacitor, 50V C0G 5%	5-00886-100
C400	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C401	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C402	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C403	3900 pF	3900 pF 0603 capacitor, 50V X7R 10%	5-00747-581
C404	1000 pF	1000 pF 0603 capacitor, 50V X7R 10%	5-00740-100
C405	22 pF	22 pF 0603 capacitor, 50V C0G 5%	5-00700-580
C406	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C407	680P	680 pF 0603 capacitor, 50V C0G 5%	5-00736-100
C408	680P	680 pF 0603 capacitor, 50V C0G 5%	5-00736-100
C409	1800 pF	1800 pF 0603 capacitor, 50V X7R 10%	5-00743-581
C410	4.7U/50V	4.7 µF 1206 capacitor, 50V X5R 10%	5-00807-578
C411	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C412	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C413	12pF	12 pF 0603 capacitor, 50V C0G 5%	5-00694-100
C414	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C415	0.1 µF	0.1 µF 1206 capacitor, 25V NP0 5%	5-00882-578
C416	0.022 µF	0.022 uF 0603 capacitor, 50V X7R 10%	5-00756-581

C417	0.022 µF	0.022 uF 0603 capacitor, 50V X7R 10%	5-00756-581
C418	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C419	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C420	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C421	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C422	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C423	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C424	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C425	0.1UF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-100
C426	100P	100 pF 0603 capacitor, 50V X7R 10%	5-00716-100
C427	100P	100 pF 0603 capacitor, 50V X7R 10%	5-00716-100
C428	100P	100 pF 0603 capacitor, 50V X7R 10%	5-00716-100
C429	100P	100 pF 0603 capacitor, 50V X7R 10%	5-00716-100
C430	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C432	1000 pF	1000 pF 0603 capacitor, 50V C0G 5%	5-00740-100
C433	1000 pF	1000 pF 0603 capacitor, 50V C0G 5%	5-00740-100
C?	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
D200	HSMG-C150	1206 Surface Mount Chip LED, Red	3-02250-363
D300	SMBJ24A	Transient voltage suppression diode	3-02369-142
D301	SMBJ24A	Transient voltage suppression diode	3-02369-142
D302	SMBJ24A	Transient voltage suppression diode	3-02369-142
D303	SMBJ24A	Transient voltage suppression diode	3-02369-142
D304	BAV70LT1	Dual Diode, 0.855V@10 mA	3-00544-145
D400	1N5711	Thru-hole Schottky diode, 15mA, 0.6V@10 mA	3-00203-301
D401	1N5711	Thru-hole Schottky diode, 15mA, 0.6V@10 mA	3-00203-301
D402	1N5711	Thru-hole Schottky diode, 15mA, 0.6V@10 mA	3-00203-301
D403	1N5711	Thru-hole Schottky diode, 15mA, 0.6V@10 mA	3-00203-301
D404	1N5711	Thru-hole Schottky diode, 15mA, 0.6V@10 mA	3-00203-301
D405	1N5711	Thru-hole Schottky diode, 15mA, 0.6V@10 mA	3-00203-301
J101	Header 1x5	0.1 in bottom entry SIP header, 5-pin vertical	1-01546-131
J102	Header 1x5	0.1 in bottom entry SIP header, 5-pin vertical	1-01546-131
J103	Clip	Spring clip	0-00546-000
J200	USB B	USB B socket	1-01370-143
J201	Program	2-pin 100 mil jumper	1-00006-130
J206	JTAG	Kinetis JTAG header	1-01493-176
J300	CON6	0.15 in. terminal block, horizontal, 6 position	1-01030-100
J301	26 pin DIL	0.1 in backside entry DIP header, 16-pin vertical	1-01502-100
J400	Backside header	Bottom entry header	1-00265-131
J401	26 pin DIL	0.1 in backside entry DIP header, 26-pin vertical	1-01502-100
J402	Header 22	Header, 22-Pin	1-01503-131
J403	Backside header	Bottom entry header	1-00265-131
L200	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L201	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L202	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L203	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L204	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L205	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L206	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L207	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L208	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L209	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L210	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L211	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L212	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L300	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L301	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L302	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L303	Bead	Ferrite bead, 0603, 400 mA, 150 ohms@100 MHz, 0.15 ohm@DC	6-00759-631

L304	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L305	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L306	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L307	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L308	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L309	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L400	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L401	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L402	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L403	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L404	39 µH	39 uH 1210 inductor	6-01247-609
L405	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L406	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L407	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L408	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L409	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L410	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
L411	8.2 µH	8.2 uH 1210 inductor, 130 mA, 3 ohms, 10%, SRF 90 MHz	6-01246-609
L412	8.2 µH	8.2 uH 1210 inductor, 130 mA, 3 ohms, 10%, SRF 90 MHz	6-01246-609
PC1	PCB	Printed circuit board	7-02671-701
Q200	2N7002	N-Channel MOSFET	3-02247-360
Q300	BCV28	PNP Darlington transistor	3-02580-360
Q400	MBT3906DW1	Dual PNP Transistor	3-01419-360
Q401	MBT3906DW1	Dual PNP Transistor	3-01419-360
R100	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R101	8.06K	8.06k 0603 resistor, 1/16W 1%	4-02244-110
R102	124	124 ohm 0603 resistor, 1/16W 1%	4-02070-466
R103	124	124 ohm 0603 resistor, 1/16W 1%	4-02070-466
R104	124	124 ohm 0603 resistor, 1/16W 1%	4-02070-466
R105	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R106	124	124 ohm 0603 resistor, 1/16W 1%	4-02070-466
R107	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R108	2.00K	2.00k 0603 resistor, 1/16W 1%	4-02186-110
R109	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R110	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R111	2.00K	2.00k 0603 resistor, 1/16W 1%	4-02186-110
R112	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R114	2.00K	2.00k 0603 resistor, 1/16W 1%	4-02186-110
R115	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R117	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R119	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R121	2.00K	2.00k 0603 resistor, 1/16W 1%	4-02186-110
R123	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R124	1.00K	1.00k 0603 resistor, 1/16W 50 ppm/C 1%	4-02157-110
R125	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R126	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R127	1.00K	1.00k 0603 resistor, 1/16W 50 ppm/C 1%	4-02157-110
R129	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R130	1.00K	1.00k 0603 resistor, 1/16W 50 ppm/C 1%	4-02157-110
R131	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R132	1.00K	1.00k 0603 resistor, 1/16W 50 ppm/C 1%	4-02157-110
R134	24	24 ohm 0603 resistor, 1/16W 200 ppm 5%	4-01830-465
R201	0	0 ohm 0603 resistor	4-01796-100
R202	30.1	30.1 ohm 0603 resistor, 1/16W 1%	4-02011-466
R203	30.1	30.1 ohm 0603 resistor, 1/16W 1%	4-02011-466
R204	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R205	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R206	1.00M	1.00M 0603 resistor, 1/16W 50 ppm/C 1%	4-02445-110

R207	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R208	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R209	200	200 ohm 0603 resistor, 1/16W 200 ppm/C 5%	4-01852-465
R210	200	200 ohm 0603 resistor, 1/16W 200 ppm/C 5%	4-01852-465
R211	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R212	30.1	30.1 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02011-466
R213	30.1	30.1 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02011-466
R214	6.49K	6.49k 0603 resistor, 1/16W 1%	4-02235-110
R215	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R216	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R217	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R218	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R219	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R220	20.0k	20.0k 0603 resistor, 1/16W 50 ppm/C 1%	4-02282-466
R221	2.00k	2.00k 0603 resistor, 1/16W 1%	4-02186-466
R222	2.49k	2.49k 0603 resistor, 1/16W 1%	4-02195-466
R223	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R224	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R225	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R226	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R227	140	140 ohm 0603 resistor, 1/16W 1%	4-02075-110
R228	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R229	R/20.0k 0603	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R300	2.00K	2.00k 0603 resistor, 1/16W 1%	4-02186-110
R301	8.06K	8.06k 0603 resistor, 1/16W 1%	4-02244-110
R302	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R303	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R304	10.0k/0.1%	10.0k 0603 resistor, 1/16W 25 ppm/C 0.1%	4-02659-110
R305	2.00k/0.1%	2.00k 0603 resistor, 1/16W 10 ppm/C 0.1%	4-02631-110
R306	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R307	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R308	100/0.1%	100 ohm 0603 resistor, 1/16W 5 ppm 0.1%	4-02607-110
R309	10.0k/0.1%	10.0k 0603 resistor, 1/16W 25 ppm/C 0.1%	4-02659-110
R310	2.00k/0.1%	2.00k 0603 resistor, 1/16W 10 ppm/C 0.1%	4-02631-110
R311	30.1K	30.1k 0603 resistor, 1/16W 25 ppm/C 1%	4-02299-110
R312	9.09K	9.09k 0603 resistor, 1/16W 1%	4-02249-110
R313	1.00K	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R314	9.09K	9.09k 0603 resistor, 1/16W 1%	4-02249-110
R315	1.00K	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R316	200K	200k 0603 resistor, 1/16W 25 ppm 1%	4-02378-110
R317	9.09k	9.09k 0603 resistor, 1/16W 1%	4-02249-466
R318	3.74K	3.74k 0603 resistor, 1/16W 1%	4-02212-110
R319	249	249 ohm 0603 resistor, 1/16W 1%	4-02099-110
R320	100	100 ohm 1206 resistor, 1/4W 25 ppm 0.1%	4-02610-110
R321	2.49K	2.49k 0603 resistor, 1/16W 1%	4-02195-110
R322	100	100 ohm 1206 resistor, 1/4W 25 ppm 0.1%	4-02610-110
R323	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R324	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R325	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R326	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R327	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R328	20.0K	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R329	20.0K	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R330	30.1K	30.1k 0603 resistor, 1/16W 25 ppm/C 1%	4-02299-110
R331	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R332	20.0K	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R333	2.00k	2.00k 0603 resistor, 1/16W 1%	4-02186-110
R334	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110

R335	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R336	1.00M	1.00M 0603 resistor, 1/16W 50 ppm/C 1%	4-02445-110
R337	1.00M	1.00M 0603 resistor, 1/16W 50 ppm/C 1%	4-02445-110
R338	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R339	1.00K	1.00k 1206 MELF resistor, 1/4W 50 ppm/C 1%	4-01117-110
R340	10.0K	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R341	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R342	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R400	20.0K	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R401	20.0K	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R402	2.00K	2.00k 0603 resistor, 1/16W 1%	4-02186-110
R403	4.53k	4.53k 0603 resistor, 1/16W 1%	4-02220-110
R404	2.00K	2.00k 0603 resistor, 1/16W 1%	4-02186-110
R405	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R406	200	200 ohm 0603 resistor, 1/16W 25 ppm/C 1%	4-02090-110
R407	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R408	4.53k	4.53k 0603 resistor, 1/16W 1%	4-02220-110
R409	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R410	200	200 ohm 0603 resistor, 1/16W 25 ppm/C 1%	4-02090-110
R411	499	499 ohm 0603 resistor, 1/16W 1%	4-02128-466
R412	499	499 ohm 0603 resistor, 1/16W 1%	4-02128-466
R413	499	499 ohm 0603 resistor, 1/16W 1%	4-02128-466
R414	49.9k	49.9k 0603 resistor, 1/16W 1%	4-02320-110
R415	49.9k	49.9k 0603 resistor, 1/16W 1%	4-02320-110
R416	499	499 ohm 0603 resistor, 1/16W 1%	4-02128-466
R417	100k	200k 0603 resistor, 1/16W 25 ppm 1%	4-02378-466
R418	4.99k	4.99k 0603 resistor, 1/16W 1%	4-02224-466
R419	4.99k	4.99k 0603 resistor, 1/16W 1%	4-02224-466
R420	2.00K	2.00k 0603 resistor, 1/16W 10 ppm/C 0.1%	4-02631-110
R421	2.00K	2.00k 0603 resistor, 1/16W 10 ppm/C 0.1%	4-02631-110
R422	200	200 ohm 0603 resistor, 1/16W 25 ppm/C 1%	4-02090-110
R423	200	200 ohm 0603 resistor, 1/16W 25 ppm/C 1%	4-02090-110
R424	499	499 ohm 0603 resistor, 1/16W 1%	4-02128-466
R425	499	499 ohm 0603 resistor, 1/16W 1%	4-02128-466
R426	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R427	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R428	332	332 ohm 0603 resistor, 1/16W 1%	4-02111-110
R429	332	332 ohm 0603 resistor, 1/16W 1%	4-02111-110
R430	332	332 ohm 0603 resistor, 1/16W 1%	4-02111-110
R431	332	332 ohm 0603 resistor, 1/16W 1%	4-02111-110
R432	6.81k	6.81k 0603 resistor, 1/16W 1%	4-02237-466
R433	0	0 ohm 0603 resistor	4-01796-100
R434	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R435	499	499 ohm 0603 resistor, 1/16W 1%	4-02128-466
R436	499	499 ohm 0603 resistor, 1/16W 1%	4-02128-466
R437	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
RN200	10k x 4	10k 0603 resistor array, 1/16W 5%, x4	4-00912-463
RN201	47 x 4	47 ohm 1206 resistor array, 1/16W 5%, x4	4-00916-463
RN202	10k x 4	10k 0603 resistor array, 1/16W 5%, x4	4-00912-463
RN203	10k x 4	10k 0603 resistor array, 1/16W 5%, x4	4-00912-463
RN300	10k x 4	10k 0603 resistor array, 1/16W 5%, x4	4-00912-463
RN301	1.0KX4D	1.0k x 4 0603 resistor array, 1/16W 5%	4-00910-120
RN302	10X4D	10k 0603 resistor array, 1/16W 5%, x4	4-01764-463
RN303	4.7KX4D	4.7k x 4 0603 resistor array, 1/16W 5%	4-00911-120
RN304	4.7KX4D	4.7k x 4 0603 resistor array, 1/16W 5%	4-00911-120
S200	Switch	6 mm momentary pushbutton switch, NO	2-00053-000
U100	TLV2372IDGK	Dual 3 MHz op amp	3-01434-360
U101	LM317L	Adjustable 100mA voltage regulator	3-02299-360

U102	TLV2372IDGK	Dual 3 MHz op amp	3-01434-360
U103	AD7172-2	24-bit ADC	3-02576-360
U104	LM337	Adjustable 1.5A negative voltage regulator	3-01734-360
U105	TLV2371	3 MHz rail-to-rail op amp	3-02016-360
U200	STM1816	Reset circuit	3-02084-360
U202	FT230XQ	USB to UART converter	3-02314-360
U203	Kinetis K66_180	180 MHz ARM microcontroller	3-02577-360
U204	TPD2S017	2-channel ESD protection	3-02291-360
U205	74LVC2G08	Dual 2-input AND gate	3-01656-360
U206	ADM3202ARUZ	RS-232 line driver/receiver	3-01757-360
U207	74LVC1G123	Single retriggerable monostable multivibrator	3-02344-360
U208	74LVC1G125	Bus buffer/line driver	3-01886-360
U210	74LVC2G32	Dual 2-input OR gate	3-02621-360
U211	KSZ8081RNA	Ethernet PHY	3-02591-360
U212	RJ45	RJ-45 connector with magnetics and LEDs	1-01292-100
U213	74LVC1G08	AND gate	3-01203-360
U214	74HCT1G125	Bus buffer/line driver	3-02578-360
U215	74LVC163	4-bit binary counter	3-01863-360
U216	74LVC163	4-bit binary counter	3-01863-360
U217	LF111	LM311 gen purpose jellybean JFET comparator	3-00813-360
U218	2.5V	Zener diode, 2.5V 0.225W	3-02013-313
U219	74LVC1G74S	Flip-flop	3-01973-360
U220	74LVC1G04	Single inverter gate	3-02619-360
U221	60 MHz	60 MHz oscillator, 3.3V, 25ppm, no PLL	6-01244-621
U300	OPA551(D2PAK)	30V 200mA op amp	3-02579-360
U301	LTC2492	4-channel, 24-bit, 15 Hz ADC	3-02297-360
U302	LM317DCY	Adjustable voltage regulator	3-02620-360
U303	AD5689	Dual 16-bit DAC	3-02581-360
U304	OPA551	30V 200mA op amp	3-02579-360
U305	LM393	Dual comparator	3-00728-360
U306	AD8510ARZ	JFET op amp	3-01318-360
U307	LTC2492	4-channel, 24-bit, 15 Hz ADC	3-02297-360
U308	74HCT1G125	Bus buffer/line driver	3-02578-360
U309	AD8604	CMOS quad op amp	3-02625-360
U400	TLV271DBV	3 MHz op amp	3-02048-360
U401	AD5689	Dual 16-bit DAC	3-02581-360
U402	LTC2620CGN	Octal 12-bit DAC	3-01185-360
U403	AD8510ARZ	JFET op amp	3-01318-360
U406	LT1819	400 MHz dual op amp	3-02582-360
U409	AD9834	75 MHz Direct Digital Synthesis chip	3-02518-360
U410	74LVC1G74	Flip-flop	3-01973-360
U411	TLV3501	Comparator	3-01782-360

Bottom board (assembly 672)

PCB reference	Name	Description	SRS part number
C100	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C101	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C102	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C103	10pF	10 pF 0603 capacitor, 50V C0G 5%	5-00692-100
C104	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C105	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C106	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C107	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C108	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581

C109	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C110	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C200	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C201	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C202	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C203	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C204	0.1 µF 200V	0.1 µF 1210 capacitor, 200V X7R 20%	5-00571-500
C205	0.01 µF	0.01 µF 0603 capacitor, 25V C0G 5%	5-00869-580
C206	0.1 µF 200V	0.1 µF 1210 capacitor, 200V X7R 20%	5-00571-500
C207	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C208	0.1 µF 200V	0.1 µF 1812 capacitor, 200V X7R 20%	5-01047-578
C209	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C210	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C211	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C212	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C213	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C214	3300 pF 250 V	3300 pF 1206 capacitor, 250V C0G 5%	5-01009-578
C215	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C216	0.1 µF 200V	0.1 µF 1210 capacitor, 200V X7R 20%	5-00571-500
C217	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C218	1000 pF 2 kV	1000 pF 1206 capacitor, 2000V X7R 10%	5-00876-578
C219	0.1 µF 200V	0.1 µF 1200 capacitor, 200V X7R 20%	5-00571-500
C220	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C221	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C222	1000 pF	1000 pF 0603 capacitor, 50V X7R 10%	5-00740-100
C224	0.47 µF	0.47 µF 0603 capacitor, 25V X7R 10%	5-00874-578
C225	0.47 µF	0.47 µF 0603 capacitor, 25V X7R 10%	5-00874-578
C226	0.47 µF	0.47 µF 0603 capacitor, 25V X7R 10%	5-00874-578
C227	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C300	0.1 µF 200V	0.1 µF 1200 capacitor, 200V X7R 20%	5-00571-500
C301	0.1 µF 200V	0.1 µF 1200 capacitor, 200V X7R 20%	5-00571-500
C302	0.1 µF 200V	0.1 µF 1200 capacitor, 200V X7R 20%	5-00571-500
C303	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C304	0.01 µF	0.01 µF 0603 capacitor, 25V C0G 5%	5-00869-580
C305	0.01 µF	0.01 µF 0603 capacitor, 25V C0G 5%	5-00869-580
C306	3300 pF 250 V	3300 pF 1206 capacitor, 250V C0G 5%	5-01009-578
C307	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C308	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C309	1000 pF 2 kV	1000 pF 1206 capacitor, 2000V X7R 10%	5-00876-578
C310	0.1 µF 200V	0.1 µF 1200 capacitor, 200V X7R 20%	5-00571-500
C311	33 pF	33 pF 0603 capacitor, 50V NP0 5%	5-00704-581
C312	0.01µF 400V	0.01 µF 1913 film capacitor, 400V 5%	5-00947-120
C313	0.01µF 400V	0.01 µF 1913 film capacitor, 400V 5%	5-00947-120
C314	33 pF	33 pF 0603 capacitor, 50V NP0 5%	5-00704-581
C320	0.01µF 400V	0.01 µF 1913 film capacitor, 400V 5%	5-00947-120
C321	0.01µF 400V	0.01 µF 1913 film capacitor, 400V 5%	5-00947-120
C400	330µF	330 µF through-hole aluminum electrolytic capacitor, 35V 20%	5-00516-001
C401	47 µF	47 µF 1210 capacitor, 16V X5R 20%	5-00968-578
C402	0.01µF 400V	0.01 µF 1913 film capacitor, 400V 5%	5-00947-120
C403	330µF	330 µF through-hole aluminum electrolytic capacitor, 35V 20%	5-00516-001
C404	0.01µF 400V	0.01 µF 1913 film capacitor, 400V 5%	5-00947-120
C405	330µF	330 µF through-hole aluminum electrolytic capacitor, 35V 20%	5-00516-001
C406	47 µF	47 µF 1210 capacitor, 16V X5R 20%	5-00968-578
C407	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C408	330µF	330 µF through-hole aluminum electrolytic capacitor, 35V 20%	5-00516-001
C409	0.01µF 400V	0.01 µF 1913 film capacitor, 400V 5%	5-00947-120
C410	330µF	330 µF through-hole aluminum electrolytic capacitor, 35V 20%	5-00516-001
C411	47 µF	47 µF 1210 capacitor, 16V X5R 20%	5-00968-578

C412	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C413	330µF	330 µF through-hole aluminum electrolytic capacitor, 35V 20%	5-00516-001
C414	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C415	0.1µF 500V	0.1 µF 1210 capacitor, 500V X7R 10%	5-00999-578
C416	0.1µF 500V	0.1 µF 1210 capacitor, 500V X7R 10%	5-00999-578
C417	0.1µF 500V	0.1 µF 1210 capacitor, 500V X7R 10%	5-00999-578
C418	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C419	0.1µF 500V	0.1 µF 1210 capacitor, 500V X7R 10%	5-00999-578
C420	0.1µF 500V	0.1 µF 1210 capacitor, 500V X7R 10%	5-00999-578
C421	0.1µF 500V	0.1 µF 1210 capacitor, 500V X7R 10%	5-00999-578
C422	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C423	0.1µF/100V	0.1 µF 1206 capacitor, 100V X7R 10%	5-00856-100
C424	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C425	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C426	0.01 µF	0.01 µF 0603 capacitor, 50V X7R 10%	5-00752-100
C427	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C428	0.1µF 500V	0.1 µF 1210 capacitor, 500V X7R 10%	5-00999-578
C429	0.1µF 500V	0.1 µF 1210 capacitor, 500V X7R 10%	5-00999-578
C430	1000 pF	1000 pF 0603 capacitor, 50V X7R 10%	5-00740-100
C431	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C432	4.7µF	4.7 µF 1206 capacitor, 50V X7R 10%	5-00964-100
C433	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C434	0.22 µF	0.22 µF 0603 capacitor, 50V X7R 10%	5-00989-581
D100	DFLR1200	1.0A surface mount rectifier, 200V reverse voltage	3-02302-140
D101	DFLR1200	1.0A surface mount rectifier, 200V reverse voltage	3-02302-140
D102	DFLR1200	1.0A surface mount rectifier, 200V reverse voltage	3-02302-140
D103	DFLR1200	1.0A surface mount rectifier, 200V reverse voltage	3-02302-140
D104	DFLR1200	1.0A surface mount rectifier, 200V reverse voltage	3-02302-140
D200	MBRB1545	Power rectifier	3-02472-143
D201	DFLR1200	1.0A surface mount rectifier, 200V reverse voltage	3-02302-140
D202	DFLR1200	1.0A surface mount rectifier, 200V reverse voltage	3-02302-140
D300	DFLR1200	1.0A surface mount rectifier, 200V reverse voltage	3-02302-140
D301	BAW56	Dual surface mount switching diode	3-00649-145
D302	BAW56	Dual surface mount switching diode	3-00649-145
D303	BAW56	Dual surface mount switching diode	3-00649-145
D304	BAW56	Dual surface mount switching diode	3-00649-145
D400	MBRB1545	Power rectifier	3-02472-143
D401	MBRS230LT3G	2.0A 30V Schottky power rectifier	3-02091-143
D402	MBRS230LT3G	2.0A 30V Schottky power rectifier	3-02091-143
D403	MBRS230LT3G	2.0A 30V Schottky power rectifier	3-02091-143
D404	MBRS230LT3G	2.0A 30V Schottky power rectifier	3-02091-143
D405	MBRS230LT3G	2.0A 30V Schottky power rectifier	3-02091-143
D406	MBRS230LT3G	2.0A 30V Schottky power rectifier	3-02091-143
D407	MURS160	SMB diode, 1.0A 600V, 75 ns reverse recovery	3-02598-360
D408	MURS160	SMB diode, 1.0A 600V, 75 ns reverse recovery	3-02598-360
D409	MURS160	SMB diode, 1.0A 600V, 75 ns reverse recovery	3-02598-360
D410	MURS160	SMB diode, 1.0A 600V, 75 ns reverse recovery	3-02598-360
D411	MURS160	SMB diode, 1.0A 600V, 75 ns reverse recovery	3-02598-360
F400	35 mA	35 mA PTC resettable fuse, radial through-hole	6-01274-611
J100	Header 22	Header, 22-Pin	1-01503-131
J101	Header 22	Header, 22-Pin	1-01503-131
J102	DB9F/H	RS-232 connector, horizontal	1-01556-160
J103	3 pin	3-position horizontal terminal block header	1-01422-100
J104	Clip	Spring clip	0-00546-000
J200	Header	0.1 in SIP header, 6-pin vertical	1-00660-130
J300	Header V 100 mil 1x06	0.1 in SIP header, 6-pin vertical	1-00660-130
J400	2mm jack	PCB mount 2 mm DC power jack	1-01374-100
J401	MTA-100	0.1 in MTA-100 header	1-00473-114

J402	MTA-100	0.1 in MTA-100 header	1-00473-114
J403	Header V 156 mil 1x2	0.1 in SIP header, 2-pin vertical	1-00250-116
K300	DPDT relay	Relay, DPDT, non-latching, max 10V DC 10 mA	3-02515-335
K301	DPDT relay	Relay, DPDT, non-latching, max 10V DC 10 mA	3-02515-335
L100	Bead	Ferrite bead, 0603, 400 mA, 150 ohms@100 MHz, 0.15 ohm@DC	6-00759-631
L101	Bead	Ferrite bead, 0603, 400 mA, 150 ohms@100 MHz, 0.15 ohm@DC	6-00759-631
L200	10µH	10 µH inductor, 3.8A, 18.5 mOhm	6-01085-609
L201	10µH	10 µH 10x10 mm inductor, 3.8A ±20%	6-01085-100
L400	10µH	4A shielded inductor	6-01085-100
L401	10µH	4A shielded inductor	6-01085-100
L402	10µH	4A shielded inductor	6-01085-100
L403	10µH	4A shielded inductor	6-01085-100
L404	10µH	4A shielded inductor	6-01085-100
L405	BEAD	0603 ferrite bead, 400 mA, 0.15 ohms@DC, 150 ohms@100 MHz	6-00759-631
PC1	PCB	RGA120 bottom board	7-02703-701
Q100	MMBT2222A	General purpose NPN transistor	3-01421-150
Q200	MMBT5551	High voltage NPN transistor	3-02435-360
Q201	MMBT5551	High voltage NPN transistor	3-02435-360
Q202	MMBT5551	High voltage NPN transistor	3-02435-360
Q203	MMBT5551	High voltage NPN transistor	3-02435-360
Q204	MMBT5551	High voltage NPN transistor	3-02435-360
Q300	MMBT5551	High voltage NPN transistor	3-02435-360
Q301	MMBT5551	High voltage NPN transistor	3-02435-360
Q302	MMBT5551	High voltage NPN transistor	3-02435-360
Q303	MMBT5551	High voltage NPN transistor	3-02435-360
Q304	MMBT5551	High voltage NPN transistor	3-02435-360
Q305	PZTA92 PNP	High voltage PNP silicon transistor	3-02465-360
Q306	PZTA92 PNP	High voltage PNP silicon transistor	3-02465-360
Q307	PZTA42 NPN	High voltage NPN silicon transistor	3-02466-360
Q309	PZTA92 PNP	High voltage PNP silicon transistor	3-02465-360
Q310	PZTA42 NPN	High voltage NPN silicon transistor	3-02466-360
Q311	PZTA42 NPN	High voltage NPN silicon transistor	3-02466-360
R100	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R101	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R102	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R103	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R104	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R105	40.2k	40.2k 0603 resistor, 1/16W 25 ppm/C 1%	4-02311-110
R106	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R107	40.2k	40.2k 0603 resistor, 1/16W 25 ppm/C 1%	4-02311-110
R108	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R109	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R110	100k	100k 0603 resistor, 1/16W 25 ppm 1%	4-02349-110
R200	0.15/2W	0.15 ohm 2512 resistor, 1%, 2W	4-02549-400
R201	9.09k	9.09k 0603 resistor, 1/16W 1%	4-02249-466
R202	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R203	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R204	33.2	33.2 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02015-100
R205	33.2	33.2 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02015-100
R206	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R207	49.9k	49.9k 0603 resistor, 1/16W 1%	4-02320-110
R208	33.2	33.2 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02015-100
R209	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R210	33.2	33.2 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02015-100
R211	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R212	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R213	33.2	33.2 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02015-100
R214	40.2k	40.2k 0603 resistor, 1/16W 25 ppm/C 1%	4-02311-110

R215	0.050/2W	0.050 ohm 2512 resistor, 2W 100 ppm/C 1%	4-02759-454
R216	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R217	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R218	0.15/2W	0.15 ohm 2512 resistor, 1%, 2W	4-02549-400
R219	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R220	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R221	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R222	2.00k	2.00k 0603 resistor, 1/16W 1%	4-02186-110
R223	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R224	1.00M	1.00M 0603 resistor, 1/16W 50 ppm/C 1%	4-02445-466
R225	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R226	R/20.0k 0603	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R227	100k	100k 0603 resistor, 1/16W 25 ppm 1%	4-02349-110
R228	143	143 ohm 1206 resistor, 1/4W 25 ppm/C 0.1%	4-02732-468
R229	100k	100k 0603 resistor, 1/16W 25 ppm 1%	4-02349-110
R230	33.2k	33.2k 0603 resistor, 1/16W 50 ppm/C 1%	4-02303-100
R231	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R232	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R233	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R234	100/0.5W	100 ohm 1206 resistor, 0.5W	4-02555-110
R235	100k	100 k 1206 resistor, 1% 50 ppm	4-01309-462
R236	100/0.5W	100 ohm 1206 resistor, 0.5W	4-02555-110
R237	49.9	49.9 ohm 0603 resistor, 1/16W 25 ppm/C 1%	4-02032-466
R238	332	332 ohm 0603 resistor, 1/16W 1%	4-02111-110
R239	332	332 ohm 0603 resistor, 1/16W 1%	4-02111-110
R240	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R241	40.2k	40.2k 0603 resistor, 1/16W 25 ppm/C 1%	4-02311-110
R242	52.3k	52.3k 0603 resistor, 1/16W 1%	4-02322-110
R243	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R244	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R245	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R246	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R247	R/20.0k 0603	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R248	R/20.0k 0603	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R249	301	301 ohm 0603 resistor, 1/16W 1%	4-02107-466
R250	R/20.0k 0603	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R251	3.57k	3.57k 0603 resistor, 1/16W 1%	4-02210-466
R252	332k	332k 0603 resistor, 1/16W 25 ppm 1%	4-02399-110
R253	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R300	33.2	33.2 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02015-100
R301	33.2	33.2 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02015-100
R302	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R303	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R304	33.2	33.2 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02015-100
R305	33.2k	33.2k 0603 resistor, 1/16W 50 ppm/C 1%	4-02303-100
R306	1.00M	1.00M 0603 resistor, 1/16W 50 ppm/C 1%	4-02445-466
R307	1.00M	1.00M 0603 resistor, 1/16W 50 ppm/C 1%	4-02445-466
R308	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R309	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R310	R/20.0k 0603	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R311	100M	100Mohm 1206 resistor, 0.3W 100ppm/C 1%	4-02715-454
R312	100k	100k 0603 resistor, 1/16W 25 ppm 1%	4-02349-110
R313	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R314	100k	100k 0603 resistor, 1/16W 25 ppm 1%	4-02349-110
R315	0	0 ohm 0603 resistor	4-01796-100
R316	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R317	100k	100k 1206 resistor, 1% 50ppm	4-01309-110
R318	49.9	49.9 ohm 0603 resistor, 1/16W 25 ppm/C 1%	4-02032-466

R319	75.0k	75.0k 0603 resistor, 1/16W 50 ppm/C 1%	4-02337-466
R320	4.99k	4.99k 0603 resistor, 1/16W 1%	4-02224-466
R321	75.0k	75.0k 0603 resistor, 1/16W 50 ppm/C 1%	4-02337-466
R322	4.99k	4.99k 0603 resistor, 1/16W 1%	4-02224-466
R323	100k	100k 0603 resistor, 1/16W 25 ppm 1%	4-02349-110
R324	R/15.0k 0603 0.1%	15.0k 0603 resistor, 1/16W 25 ppm/C 0.1%	4-02653-468
R325	1.00M 0.1%	1M 1206 resistor, 1/8W 25 ppm/C 0.1%	4-02637-408
R326	124k	124k 0603 resistor, 1/16W 50 ppm 1%	4-02358-466
R327	1.00M 0.1%	1M 1206 resistor, 1/8W 25 ppm/C 0.1%	4-02637-408
R328	1.00M 0.1%	1M 1206 resistor, 1/8W 25 ppm/C 0.1%	4-02637-408
R329	1.00M 0.1%	1M 1206 resistor, 1/8W 25 ppm/C 0.1%	4-02637-408
R330	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R331	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R332	124k	124k 0603 resistor, 1/16W 50 ppm 1%	4-02358-466
R333	R/15.0k 0603 0.1%	15.0k 0603 resistor, 1/16W 25 ppm/C 0.1%	4-02653-468
R334	100k	100k 0603 resistor, 1/16W 25 ppm 1%	4-02349-110
R335	R/15.0k 0603 0.1%	15.0k 0603 resistor, 1/16W 25 ppm/C 0.1%	4-02653-468
R336	75.0k	75.0k 0603 resistor, 1/16W 50 ppm/C 1%	4-02337-466
R337	4.99k	4.99k 0603 resistor, 1/16W 1%	4-02224-466
R338	4.99k	4.99k 0603 resistor, 1/16W 1%	4-02224-466
R339	75.0k	75.0k 0603 resistor, 1/16W 50 ppm/C 1%	4-02337-466
R340	0	0 ohm 0603 resistor	4-01796-100
R405	100/0.5W	100 ohm 1206 resistor, 0.5W	4-02555-110
R406	100/0.5W	100 ohm 1206 resistor, 0.5W	4-02555-110
R407	33.2	33.2 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02015-100
R408	100/0.5W	100 ohm 1206 resistor, 0.5W	4-02555-110
R409	40.2k	40.2k 0603 resistor, 1/16W 25 ppm/C 1%	4-02311-110
R410	33.2	33.2 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02015-100
R411	100/0.5W	100 ohm 1206 resistor, 0.5W	4-02555-110
R412	0.15/2W	0.15 ohm 2512 resistor, 1%, 2W	4-02549-400
R413	7.32k	7.32k 0603 resistor, 1/16W 1%	4-02240-466
R414	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R415	100k	100k 0603 resistor, 1/16W 25 ppm 1%	4-02349-110
R416	20.0K	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R417	200	200 ohm 1206 resistor, 0.4W 1% 50 ppm/C	4-01050-462
R418	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R419	20.0K	20.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02282-110
R420	2.00k	2.00k 0603 resistor, 1/16W 1%	4-02186-110
R421	1.50K	1.50k 0603 resistor, 1/16W 25 ppm/C 1%	4-02174-110
R422	1.82K	1.82k 0603 resistor, 1/16W 25 ppm/C 1%	4-02182-110
R424	10	10.0 ohm 1206 resistor, 50 ppm/C 1%	4-00925-110
R425	6.19k	6.19k 0603 resistor, 1/16W 1%	4-02233-110
R426	301	301 ohm 0603 resistor, 1/16W 1%	4-02107-466
T200	Custom transformer	Filament transformer	6-01269-610
U100	AD8602DRZ	8 MHz op amp	3-02296-360
U101	74HCT1G125	Bus buffer/line driver	3-02578-360
U102	74LVC1G123	Single retriggerable monostable multivibrator wth Schmitt-trigger inputs	3-02344-360
U103	74LVC1G3157	Single-pole double-throw analog switch, 6 ohm, 1.65-5.5V	3-02015-360
U104	AD8602DRZ	8 MHz op amp	3-02296-360
U105	74LVC2G08	Dual 2-input AND gate	3-01656-360
U106	74LVC1G3157	Single-pole double-throw analog switch, 6 ohm, 1.65-5.5V	3-02015-360
U107	74HCT595A	8-bit SPI-to-parallel converter	3-02169-360
U108	74LVC2G08	Dual 2-input AND gate	3-01656-360
U109	CS212DC5	DPDT relay	3-00196-335
U110	74HCT165	Parallel-to-SPI converter	3-02592-360
U111	TLV271IDBV	3 MHz rail-to-rail op amp	3-02048-360
U112	74LVC1G04	Single inverter gate	3-02070-360

U113	74LVC1G3157	Single-pole double-throw analog switch, 6 ohm, 1.65-5.5V	3-02015-360
U114	74LVC1G125	Single bus buffer gate with 3-state output	3-01886-360
U200	LM350	3A low dropout adjustable voltage regulator	3-00384-329
U201	RB706F-40	Schottky barrier diode	3-02583-360
U202	LM321MF	Low power 1 MHz op amp	3-02010-360
U203	LM321MF	Low power 1 MHz op amp	3-02010-360
U204	STL4N10F7	Power MOSFET, N-channel, 100V, 62 mOhms	3-02550-300
U205	RB706F-40	Schottky barrier diode	3-02583-360
U206	LM5030	PWM switching power supply controller	3-02549-360
U207	STL4N10F7	Power MOSFET, N-channel, 100V, 62 mOhms	3-02550-300
U208	ADA4622-2	Dual single-supply, rail-to-rail FET-input op amp	3-02638-360
U209	TLV271DBV	3 MHz rail-to-rail op amp	3-02048-360
U210	ADA4622-2	Dual single-supply, rail-to-rail FET-input op amp	3-02638-360
U211	LTC6090	1 MHz 140V precision op amp	3-02355-360
U212	CS212DC5	DPDT relay	3-00196-335
U213	LM358DR2G	Low power dual 1 MHz op amp, unity gain stable	3-00773-360
U214	LM393	Dual comparator	3-00728-360
U300	RB706F-40	Schottky barrier diode	3-02583-360
U301	MMBF4117	N-channel JFET	3-01410-360
U302	RB706F-40	Schottky barrier diode	3-02583-360
U303	MMBF4117	N-channel JFET	3-01410-360
U304	TLV271DBV	3 MHz rail-to-rail op amp	3-02048-360
U305	LTC6090	1 MHz 140V precision op amp	3-02355-360
U306	LMC6062IM	Precision dual low-power op amp	3-00677-360
U400	NCP59151DS50R4G	5.0V 1.5A linear regulator with 300 mV dropout	3-02595-360
U401	CD-HD2004	2.0A full wave bridge rectifier, 40V peak reverse voltage	3-02597-360
U402	LM340-12	12V 1A linear regulator	3-01762-360
U403	LM2990S-5.0	-5V 1.8A voltage regulator	3-02482-360
U405	NCP59151DS33R4G	3.3V 1.5A linear regulator with 300 mA dropout	3-02551-360
U406	EFD-30	Main power transformer	6-01268-610
U407	STL4N10F7	Power MOSFET, N-channel, 100V, 62 mOhms	3-02550-300
U408	STL4N10F7	Power MOSFET, N-channel, 100V, 62 mOhms	3-02550-300
U409	LM5030	PWM switching power supply controller	3-02549-360
U410	LM5060	Power supply protection controller	3-02643-360
U411	LM321MF	Low power 1 MHz op amp	3-02010-360
U412	74LVC1G74S	Flip-flop	3-01973-360
U413	FAN3227	Dual 2A gate drivers, TTL version	3-02622-360
U414	NTTFS5820NL	60V 37A N-channel power MOSFET	3-02644-360
Z200	TO-220 insulator	Thermally conductive insulator w/adhesive, 10.5 x 12 in. sheet, 0.94°C/W when used with TO-220 packages	0-01095-003

Electrometer board (assembly 673)

PCB reference	Name	Description	SRS part number
C1	1 pF	1 pF thru capacitor, 100V NP0 ±0.25pF	5-01000-502
C3	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C4	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C5	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C6	4.7 pF	4.7 pF 0603 capacitor, 50V C0G 5%	5-00682-100
C7	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C8	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C9	1 pF	1 pF thru capacitor, 100V NP0 ±0.25pF	5-01000-502
C11	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C12	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C13	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581

C14	4.7 pF	4.7 pF 0603 capacitor, 50V C0G 5%	5-00682-100
C15	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C16	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
J1	Spring clip	Spring contact	1-01523-100
J2	Contact pin	Battery contact	1-01516-100
J3	Spring clip	Surface mount contact for AAA batteries	1-01523-100
J4	Header H 100 mil 1x05	0.1 in SIP header, 5-pin horizontal	1-01543-133
J5	Header H 100 mil 1x05	0.1 in SIP header, 5-pin horizontal	1-01543-133
PC1	PCB	Printed circuit board	7-02704-701
Q1	MMBF4117	N-channel junction FET, 40 V 30 uA	3-01410-360
Q2	MMBF4117	N-channel junction FET, 40 V 30 uA	3-01410-360
Q3	MMBF4117	N-channel junction FET, 40 V 30 uA	3-01410-360
Q4	MMBF4117	N-channel junction FET, 40 V 30 uA	3-01410-360
Q5	MMBF4117	N-channel junction FET, 40 V 30 uA	3-01410-360
Q6	MMBF4117	N-channel junction FET, 40 V 30 uA	3-01410-360
Q7	MMBF4117	N-channel junction FET, 40 V 30 uA	3-01410-360
Q8	MMBF4117	N-channel junction FET, 40 V 30 uA	3-01410-360
R1	250M	250M 1206 resistor, 1/4W 500 ppm 5%	4-02760-461
R2	100k	100k 0603 resistor, 1/16W 25 ppm 1%	4-02349-110
R5	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R6	499k	499k 0603 resistor, 1/16W 50 ppm 1%	4-02416-466
R7	499k	499k 0603 resistor, 1/16W 50 ppm 1%	4-02416-466
R8	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R9	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R10	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R11	250M	250M 1206 resistor, 1/4W 500 ppm 5%	4-02760-461
R14	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R15	499k	499k 0603 resistor, 1/16W 50 ppm 1%	4-02416-466
R16	499k	499k 0603 resistor, 1/16W 50 ppm 1%	4-02416-466
R17	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R18	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R19	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R21	250M	250M 1206 resistor, 1/4W 500 ppm 5%	4-02760-461
R22	250M	250M 1206 resistor, 1/4W 500 ppm 5%	4-02760-461
R23	250M	250M 1206 resistor, 1/4W 500 ppm 5%	4-02760-461
R24	250M	250M 1206 resistor, 1/4W 500 ppm 5%	4-02760-461
R25	250M	250M 1206 resistor, 1/4W 500 ppm 5%	4-02760-461
R26	250M	250M 1206 resistor, 1/4W 500 ppm 5%	4-02760-461
U1	LTC6268	500 MHz ultra-low bias current FET input op amp	3-02630-360
U2	THS4531	36 MHz differential op amp with shutdown	3-02632-360
U3	LTC6268	500 MHz ultra-low bias current FET input op amp	3-02630-360
U4	THS4531	36 MHz differential op amp with shutdown	3-02632-360
U5	LM45	SOT-23 precision centigrade temperature sensors	3-00775-360

Vacuum flange board (assembly 674)

PCB reference	Name	Description	SRS part number
C1	0.5PF 500V	0.5 pF 1210 porcelain capacitor, 500V	5-00339-574
C100	1000PF 3kV	1000 pF 1812 capacitor, 3kV X7R 10%	5-01003-578
C2	0.5PF 500V	0.5 pF 1210 porcelain capacitor, 500V	5-00339-574
C3	0.5PF 500V	0.5 pF 1210 porcelain capacitor, 500V	5-00339-574
C4	0.5PF 500V	0.5 pF 1210 porcelain capacitor, 500V	5-00339-574
J1	HEADER 4	Header, SIM, Right Angle, Hi Temp	1-00267-130
J102	Pin	Single receptacle for 0.084-0.102 inch pins	1-01517-131
J103	Pin	Single receptacle for 0.084-0.102 inch pins	1-01517-131

J104	Pin	Single receptacle for 0.084-0.102 inch pins	1-01517-131
J105	Pin	Single receptacle for 0.084-0.102 inch pins	1-01517-131
J106	Pin	Single receptacle for 0.084-0.102 inch pins	1-01517-131
J107	Pin	Single receptacle for 0.084-0.102 inch pins	1-01517-131
J108	Pin	Single receptacle for 0.084-0.102 inch pins	1-01517-131
J2	HEADER 4	Header, SIM, Right Angle, Hi Temp	1-00267-130
J8	Header H 100 mil 1x06	0.1 in SIP header, 6-pin horizontal	1-01542-131
J9	Header H 100 mil 1x06	0.1 in SIP header, 6-pin horizontal	1-01542-131
PC100	PCB	Printed circuit board	7-02705-701
R100	1.00M	1.00 Mohm MELF resistor, 50 ppm/C 1%	4-01405-110
U1	LMT90	-40-125°C SOT-23 analog temperature sensor, unlimited C-load	3-02727-360

High voltage board (assembly 675)

PCB reference	Name	Description	SRS part number
C1	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C2	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C3	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C4	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C5	0.01 µF	0.01 µF 0603 capacitor, 50V X7R 10%	5-00752-100
C6	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C7	0.0012µF	Capacitor, Polypropylene, 630V, 5%, Rad	5-00348-557
C8	150 pF	150pF 0603 capacitor, 50V C0G 5%	5-00719-580
C9	150 pF	150pF 0603 capacitor, 50V C0G 5%	5-00719-580
C10	0.01 µF	0.01 µF 0603 capacitor, 50V X7R 10%	5-00752-100
C11	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C12	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C13	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C14	0.047 µF	0.047 µF 0603 capacitor, 50V X7R 10%	5-00760-100
C15	1000 pF	1000 pF 0603 capacitor, 50V C0G 5%	5-00740-100
C16	100PF 3kV	100 pF 1808 capacitor, 3kV U2J 5%	5-01002-578
C17	1200PF/1KV	1200 pF 1210 capacitor, 1kV U2J 5%	5-01001-536
C18	1200PF/1KV	1200 pF 1210 capacitor, 1kV U2J 5%	5-01001-536
C19	1200PF/1KV	1200 pF 1210 capacitor, 1kV U2J 5%	5-01001-536
C20	1200PF/1KV	1200 pF 1210 capacitor, 1kV U2J 5%	5-01001-536
C21	1200PF/1KV	1200 pF 1210 capacitor, 1kV U2J 5%	5-01001-536
C22	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C23	100 pF	100pF 0603 capacitor, 50V C0G 5%	5-00716-580
C24	1200PF/1KV	1200 pF 1210 capacitor, 1kV U2J 5%	5-01001-536
C25	1200PF/1KV	1200 pF 1210 capacitor, 1kV U2J 5%	5-01001-536
C26	1200PF/1KV	1200 pF 1210 capacitor, 1kV U2J 5%	5-01001-536
C27	1200PF/1KV	1200 pF 1210 capacitor, 1kV U2J 5%	5-01001-536
C28	1200PF/1KV	1200 pF 1210 capacitor, 1kV U2J 5%	5-01001-536
C29	1000PF 3kV	1000 pF 1812 capacitor, 3kV X7R 10%	5-01003-578
C30	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C31	0.1 µF	0.1 µF 0603 capacitor, 50V X7R 10%	5-00764-581
C32	10 µF	10 µF 1206 capacitor, 16V X5R 10%, 9.112µF@5V	5-00597-578
C33	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C34	22 pF	22 pF 0603 capacitor, 50V C0G 5%	5-00700-580
C35	4.7 µF	4.7 µF 1206 capacitor, 50V X7R 10%, 4.6 µF@5V	5-00964-568
C100	220 pF 250V	220 pF 0603 capacitor, 250V NP0 5%	5-01008-578
D1	RFU02VS8S	800V 0.2A diode, 20 ns recovery	3-02605-313
D2	RFU02VS8S	800V 0.2A diode, 20 ns recovery	3-02605-313
D3	RFU02VS8S	800V 0.2A diode, 20 ns recovery	3-02605-313
D4	RFU02VS8S	800V 0.2A diode, 20 ns recovery	3-02605-313

D5	RFU02VS8S	800V 0.2A diode, 20 ns recovery	3-02605-313
D6	RFU02VS8S	800V 0.2A diode, 20 ns recovery	3-02605-313
D7	RFU02VS8S	800V 0.2A diode, 20 ns recovery	3-02605-313
D8	RFU02VS8S	800V 0.2A diode, 20 ns recovery	3-02605-313
D9	RFU02VS8S	800V 0.2A diode, 20 ns recovery	3-02605-313
D10	RFU02VS8S	800V 0.2A diode, 20 ns recovery	3-02605-313
J1	26 pin DIL	0.1 in DIP header, 26-pin vertical	1-01518-130
J106	Zip tie	PCB-mounted zip tie	0-01535-000
J107	Zip tie	PCB-mounted zip tie	0-01535-000
J108	Zip tie	PCB-mounted zip tie	0-01535-000
J109	Cable tie	4 inch cable tie	0-00089-033
L1	10µH	10 µH inductor, 3.8A, 18.5 mOhm	6-01085-609
L2	2T	RF transformer	6-01271-610
L4	10µH	10 µH inductor, 3.8A, 18.5 mOhm	6-01085-609
PC1	PCB	Printed circuit board	7-02706-701
R1	0.15/2W	0.15 ohm 2512 resistor, 1%, 2W	4-02549-400
R2	10	10 ohm 0603 resistor, 1/16W 50 ppm 1%	4-01965-110
R3	10	10 ohm 0603 resistor, 1/16W 50 ppm 1%	4-01965-110
R4	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R5	1.00M	1.00 Mohm MELF resistor, 50 ppm/C 1%	4-01405-110
R6	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R7	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R8	2.00k	2.00k 0603 resistor, 1/16W 1%	4-02186-110
R9	30.1	30.1 ohm 0603 resistor, 1/16W 50 ppm/C 1%	4-02011-466
R11	499k	499k 0603 resistor, 1/16W 50 ppm 1%	4-02416-466
R12	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R13	33.2	33.2 ohm 1206 resistor, 1/4W 50 ppm/C 1%	4-00975-462
R14	10	10 ohm 1206 MELF resistor, 1/4W 50 ppm 1%	4-00925-462
R16	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R17	2.00k	2.00k 0603 resistor, 1/16W 1%	4-02186-110
R18	9.09k	9.09k 0603 resistor, 1/16W 1%	4-02249-466
R19	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R20	33.2	33.2 ohm 1206 resistor, 1/4W 50 ppm/C 1%	4-00975-462
R22	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R23	0.15/2W	0.15 ohm 2512 resistor, 1%, 2W	4-02549-400
R25	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R26	49.9k	49.9k 0603 resistor, 1/16W 1%	4-02320-110
R27	9.09k	9.09k 0603 resistor, 1/16W 1%	4-02249-466
R28	100	100 ohm 0603 resistor, 1/16W 1%	4-02061-110
R29	100k	200k 0603 resistor, 1/16W 25 ppm 1%	4-02378-466
R30	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R31	1.00k	1.00k 0603 resistor, 1/16W 1%	4-02157-110
R32	100k	200k 0603 resistor, 1/16W 25 ppm 1%	4-02378-466
R33	100k	200k 0603 resistor, 1/16W 25 ppm 1%	4-02378-466
R34	100M/SM2512	100 Mohm 2512 resistor, 5% 1W 200 ppm/C	4-02717-460
R35	1.00M	1.00 Mohm MELF resistor, 50 ppm/C 1%	4-01405-110
R36	10.0k	10.0k 0603 resistor, 1/16W 25 ppm/C 1%	4-02253-110
R37	49.9k	49.9k 0603 resistor, 1/16W 1%	4-02320-110
R38	301k	301k 0603 resistor, 1/16W 50 ppm 1%	4-02395-466
R100	243	243 ohm 0603 resistor, 1/16W 1%	4-02098-466
R101	1.30k	1.30k 0603 resistor, 1/16W 1%	4-02168-110
R102	10 1W	10 ohm 2512 resistor, 1W 100 ppm 1%	4-02722-454
T1	1.2UH_BALUN	1.2 µH balun, T68-6 core	6-01272-610
T2	EFD30_CORE	High voltage transformer	6-01270-610
T3	Choke	1.2A, 0.25 mH common mode choke	6-01300-610
U1	LM350	3A low dropout adjustable voltage regulator	3-00384-329
U2	LM317AT	Adjustable 1.5A voltage regulator, TO-220	3-00765-329
U3	IRF510	N-channel power MOSFET, R(on)=0.54 ohm	3-00629-329

U4	FAN3227	Dual 2A gate drivers, TTL version	3-02622-360
U5	74HC163	4-bit counter	3-01503-360
U7	IRF510	N-channel power MOSFET, R(on)=0.54 ohm	3-00629-329
U8	LM45	SOT-23 precision centigrade temperature sensors	3-00775-360
U9	NCS20071	3 MHz 36V rail-to-rail op amp, 5 pA bias, TSOP-5 package	3-02713-360
U11	MJB44H11	NPN power transistor, 10 A	3-02714-360
U12	NCS20071	3 MHz 36V rail-to-rail op amp, 5 pA bias, TSOP-5 package	3-02713-360
U13	LT3999	Low noise 1A DC/DC transformer driver	3-02603-360
Z100	TO-220 insulator	Thermally conductive insulator w/adhesive, 10.5 x 12 in. sheet, 0.94°C/W when used with TO-220 packages	0-01095-003

LED board (assembly 676)

PCB reference	Name	Description	SRS part number
D1	GREEN_LED	3mm green through-hole LED	3-00010-303
D2	GREEN_LED	3mm green through-hole LED	3-00010-303
D3	GREEN_LED	3mm green through-hole LED	3-00010-303
D4	GREEN_LED	3mm green through-hole LED	3-00010-303
D5	GREEN_LED	3mm green through-hole LED	3-00010-303
D6	RED_LED	3mm red through-hole LED	3-00011-303
D7	RED_LED	3mm red through-hole LED	3-00011-303
D8	RED_LED	3mm red through-hole LED	3-00011-303
J1	HEADER2X11	2 x 11-pin right angle header	1-01520-130
J2	HEADER2X11	2 x 11-pin right angle header	1-01520-130
PC1	PCB	Printed circuit board	7-02709-701
R1	180	180 ohm 1206 resistor, 1/8W 5%	4-01461-461
R2	180	180 ohm 1206 resistor, 1/8W 5%	4-01461-461
R3	180	180 ohm 1206 resistor, 1/8W 5%	4-01461-461
R4	180	180 ohm 1206 resistor, 1/8W 5%	4-01461-461
R5	180	180 ohm 1206 resistor, 1/8W 5%	4-01461-461
R6	180	180 ohm 1206 resistor, 1/8W 5%	4-01461-461
R7	180	180 ohm 1206 resistor, 1/8W 5%	4-01461-461
R8	180	180 ohm 1206 resistor, 1/8W 5%	4-01461-461
U1	74HC595A	8-bin serial-to-parallel converter	3-00672-360

RTD board (assembly 676)

PCB reference	Name	Description	SRS part number
J3	HEADER2X11	2 x 11-pin right angle header	1-01520-130
J4	HEADER2X13	Header, 26-pin right angle	1-01521-130
J5	CON8	8-pin 3.81mm terminal block header	1-01376-136

Appendix F Installing USB Drivers

Introduction

In most cases, the USB drivers for the RGA should automatically install when the unit is first connected to a Windows computer. However, in some cases this may not work due to a lack of internet connection, Windows version or other incompatibility. In these cases the drivers can be manually installed using the following procedure.

The RGA uses a FTDI FT230X USB interface chip. FTDI provides USB drivers for several different operating systems. Drivers and their documentation are available on the FTDI website: www.ftdichip.com/FTDrivers.htm

Driver Types

There are two different drivers that can be used to communicate with the RGA over USB: VCP and D2XX.

VCP or Virtual COM Port makes the RGA look like an additional COM port available to the computer. Application software can access the RGA in the same way as it accesses any standard COM port. This is the commonly used for communications between a user created program and the RGA.

The D2XX driver gives access the RGA through a DLL. Application software can access the RGA through a series of function calls.

For most applications, the VCP driver is the preferred driver to use for communications between the host computer and the RGA over USB. However, the FTDI installer may include both drivers when using the installer made for Windows 7 to 11. If both drivers are installed, the Windows PC will automatically use the appropriate driver.

Driver Version

Be sure to install the appropriate driver for your operating system. The FTDI website contains drivers for Windows versions from the present back to Windows 98. Drivers for Linux, MAC and Android are also available.

Driver Installation

Go to www.ftdichip.com/FTDrivers.htm and download the driver(s) to the computer. If the computer is not connected to the internet download the drivers on a different computer and copy them to a USB thumb drive. Move the thumb drive to the computer that needs the drivers installed.

Go to www.ftdichip.com/Support/Documents/InstallGuides.htm and download the appropriate installation guide. Follow the Install Guide instructions to install the drivers.

Note: In some cases Windows may complain that the driver is not certified or verified. If you are certain of the source of the driver, the warning can be ignored and you can continue the installation.

Connect the RGA to the computer. The “Found New Hardware” message may appear. Say “No” to Windows Update and instead select “Install Software Automatically”.

Contact FTDI if you are unable to successfully install the FTDI USB drivers. Contact information is available at www.ftdichip.com/FTContact.htm.