Rubidium Oscillator Design

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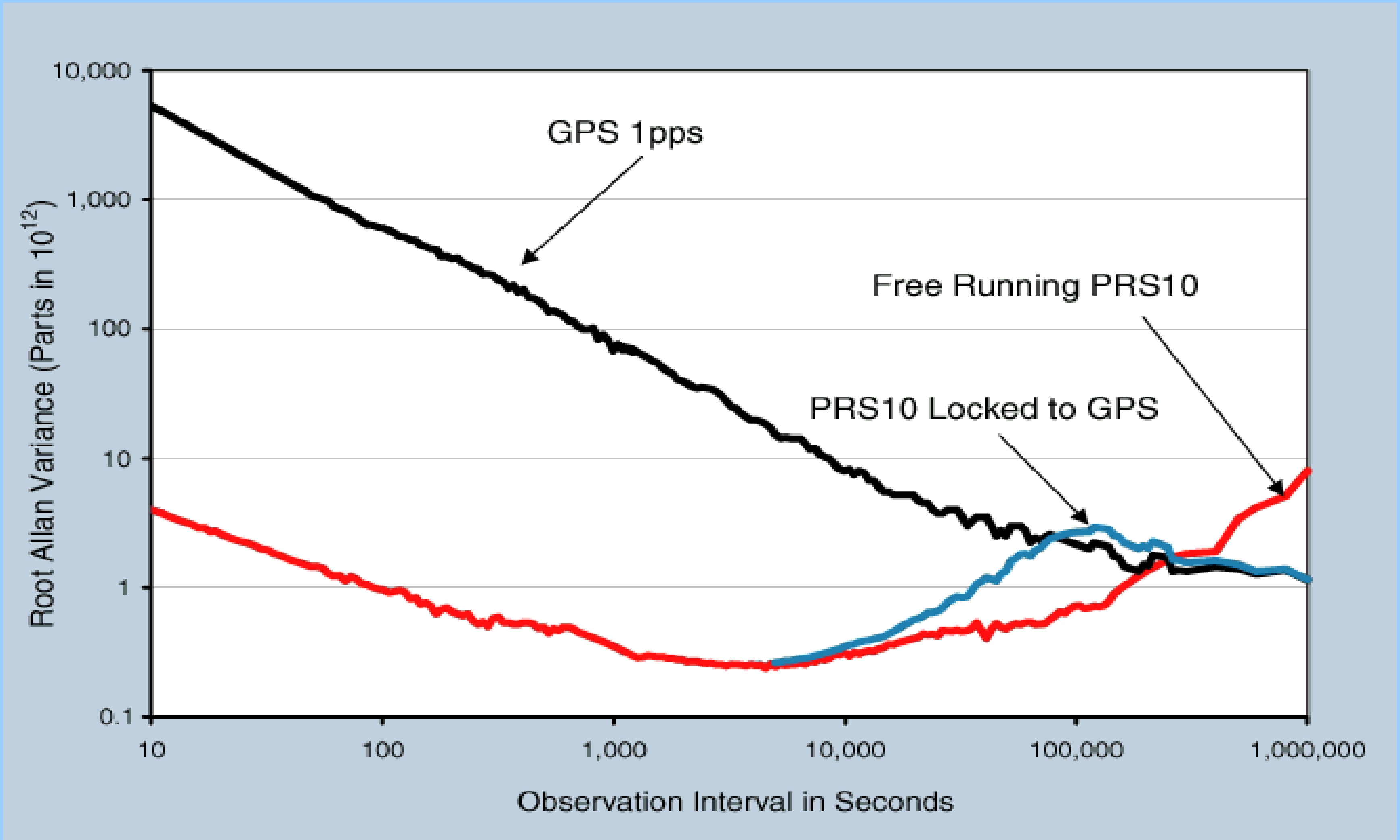
Why Rubidium?

- Reliable, mature technology
- Low aging and low environmental coefficients
- Excellent short term stability
- Stratum-1 when mated with GPS
- Low cost

Phase Locking to GPS



The PRS10 Rubidium Frequency Standard

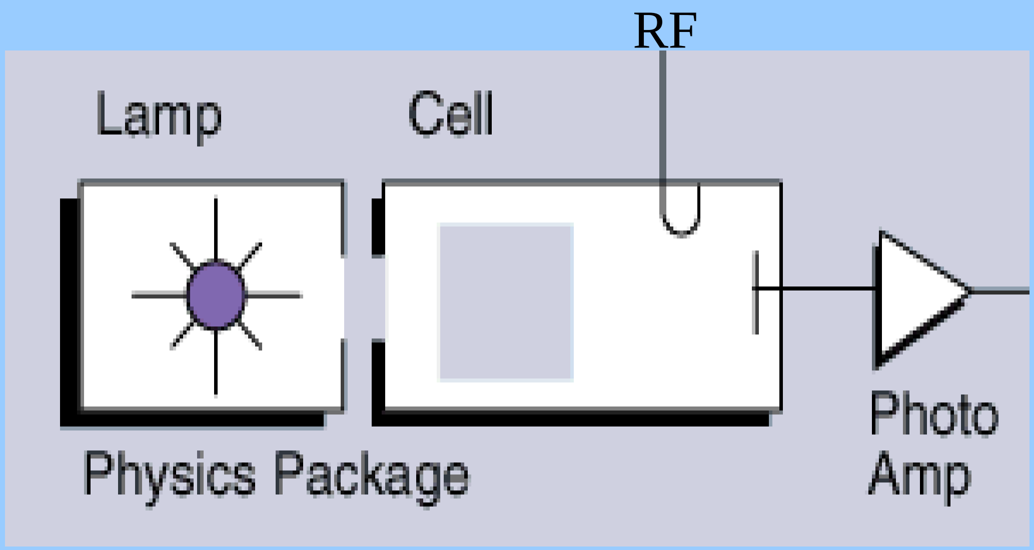
- Standard mechanical and electrical form-factor
- Updated technology
- Feature rich, high-end performance
- Established reliability

Important Specifications

- 10MHz, +7dBm, 50Ω, sine output
- *L(f)* < –125 dBc / Hz at 10 Hz offset
- $\Delta f/f < \pm 5 \times 10^{-11}$ (over -20°C to +65°C)
- $\Delta f/f < \pm 5 \times 10^{-11}$ (aging per month)
- RS232 control and calibration

The Physics Package

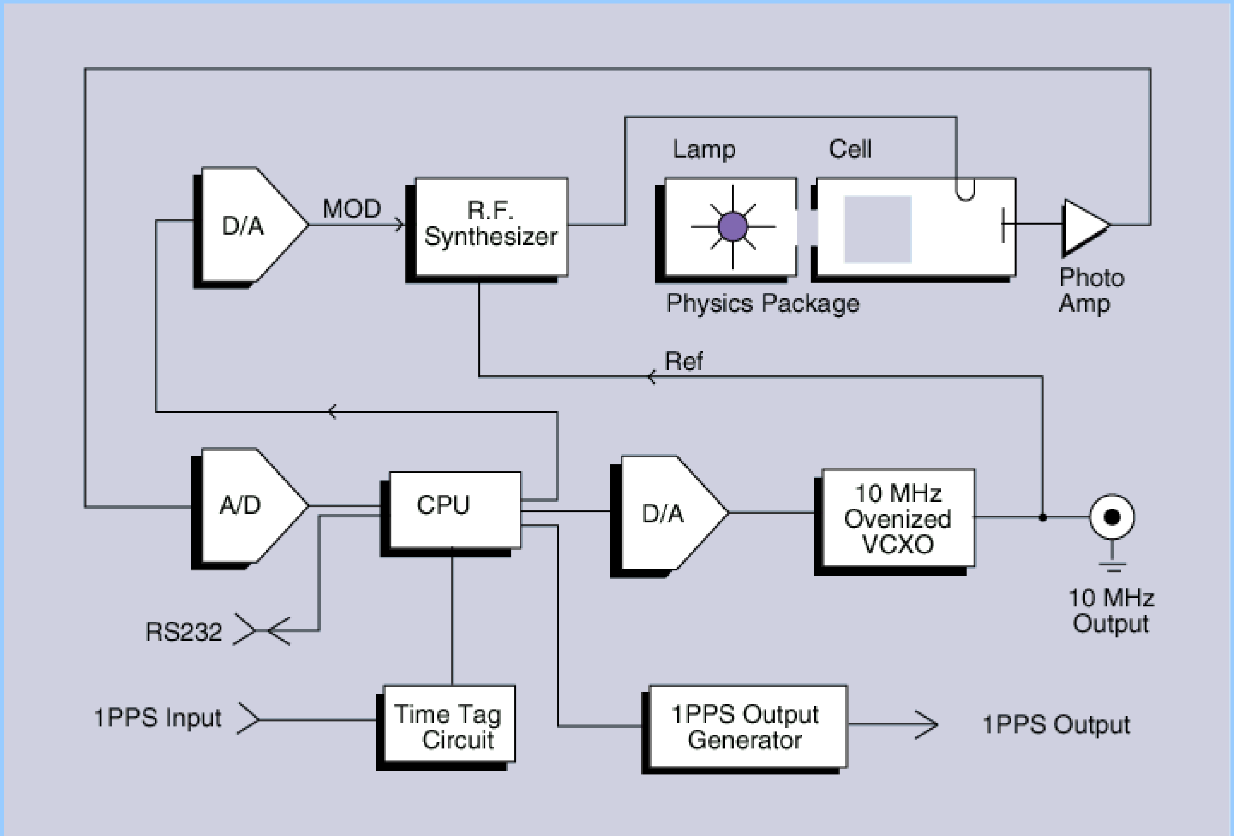
- Lamp
- Resonance cell
- RF source
- Photocell



•The physics package is a frequency detector. The light seen by the photocell is reduced by about 1:1000 when the RF sweeps through 6,834,682,612 Hz. The linewidth of the detector is $\Delta f/f \approx 10^{-7}$.

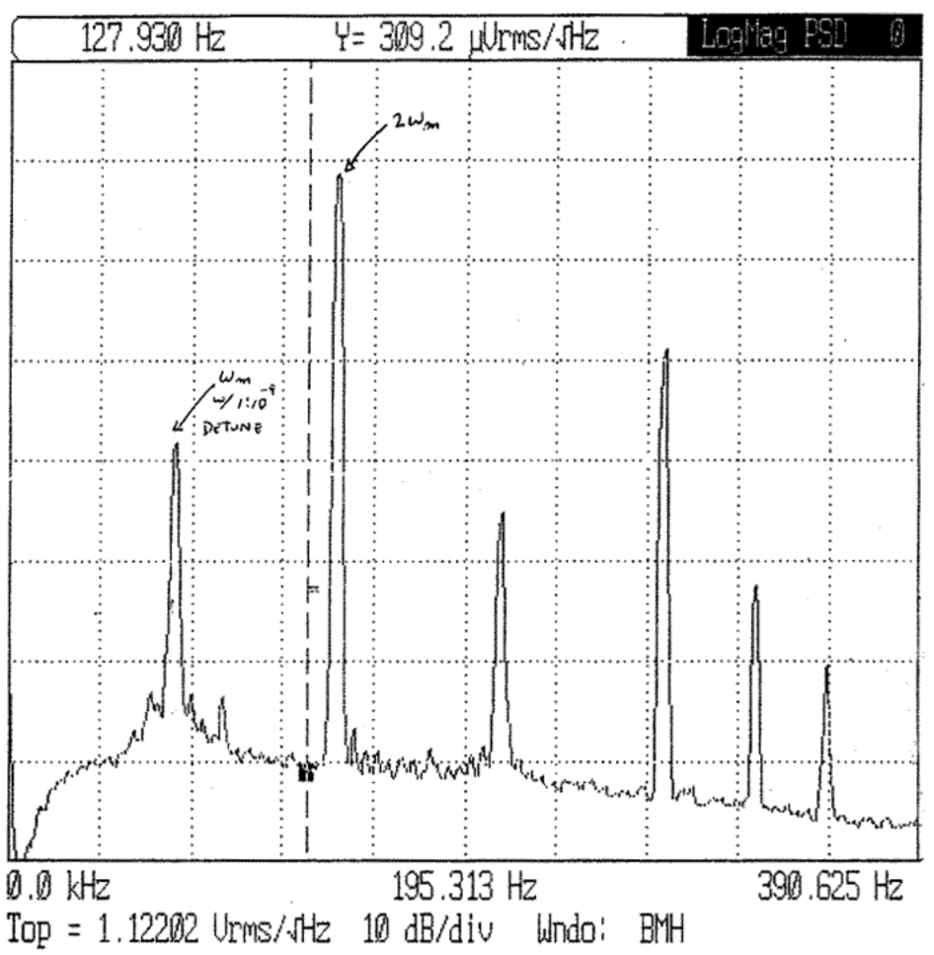
Block Diagram

- 10 MHz SC-cut ovenized oscillator
- RF synthesizer
- Frequency lock-loop
- Microprocessor based design



Frequency Spectrum of Photo-Signal

- Modulate RF around resonance at 70 Hz
- When centered, see only 140 Hz signal (2ω)
- When off frequency, see component at 70 Hz.
- Synchronously detect signal at 70 Hz and adjust VCXO via DAC to null
- Signal-to-noise at a glance

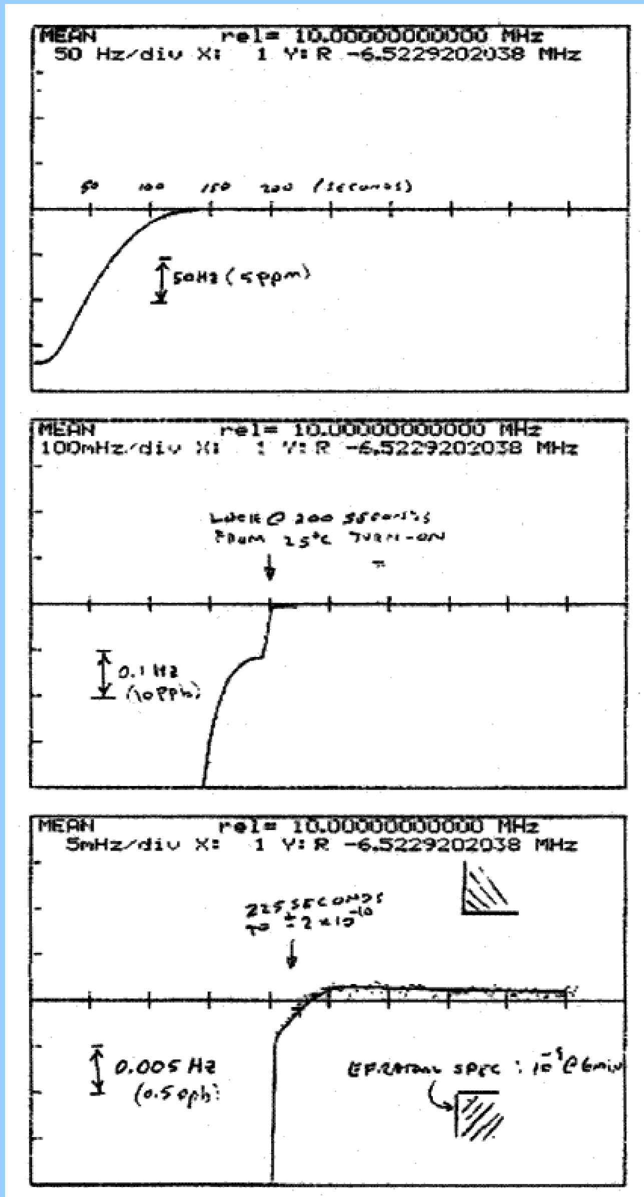


Microprocessor Functions/Advantages

- Housekeeping, DACs, ADCs, and program synthesizer
- 70 Hz modulation of RF and synchronous detection
- Digital filtering of control signal (no modulation spurs)
- Time-tag input with 1ns resolution
- Automatic phase-lock to reference (such as GPS)
- 1 PPS output set with 1ns resolution
- RS232 communications with host system
- Smooth startup and glitch immunity
- Magnetic field commutation (x25 reduction of $\Delta f/B$)

Warm-up Profiles

SRS Design



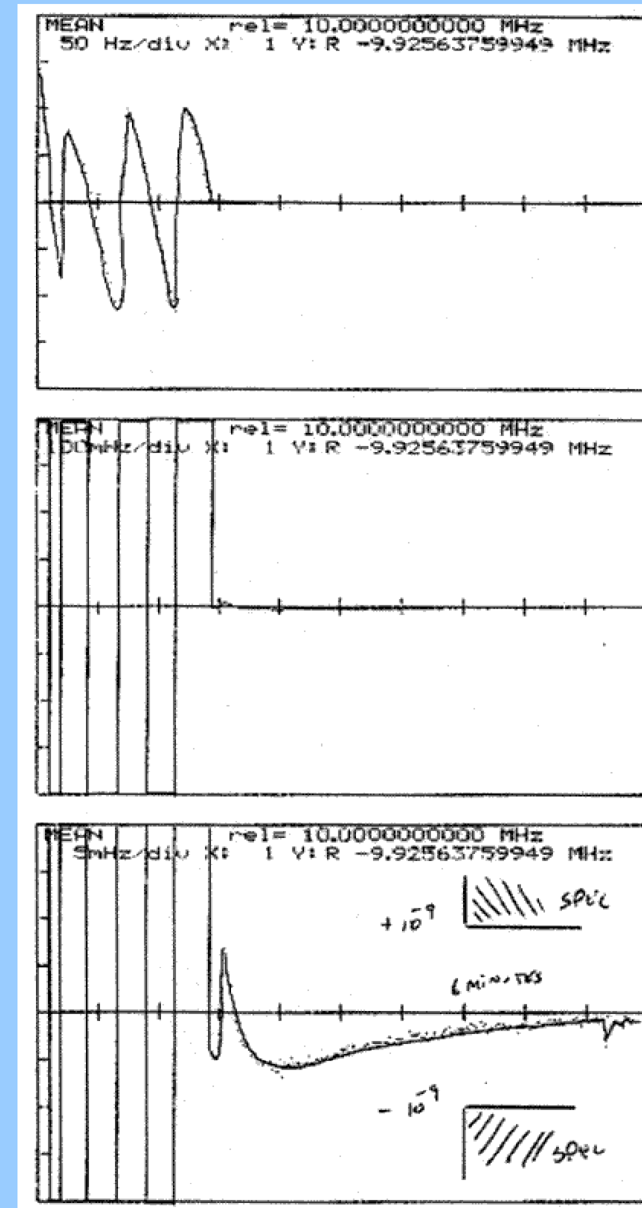
50 Hz/div

0.1 Hz/div

0.005 Hz/div

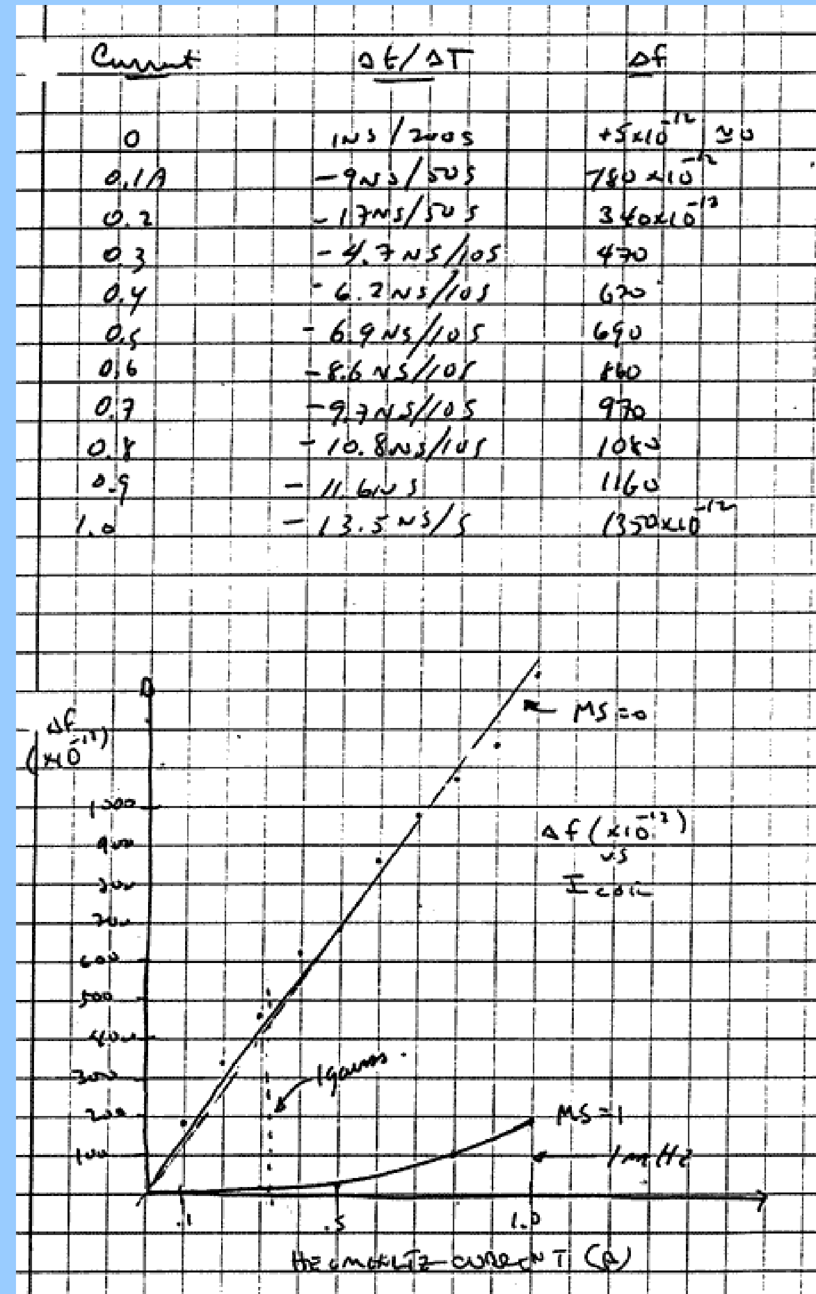
(first 8 minutes)

Analog Design



Magnetic Field Switching

- Small frequency adjustments are done via C-field
- External fields add to C-field and cause a frequency offset
- C-field is toggled at 5 Hz
- Positive frequency offset for half cycle, negative for other
- Digitally sum to null effect
- Result: 25x reduction in sensitivity to external fields

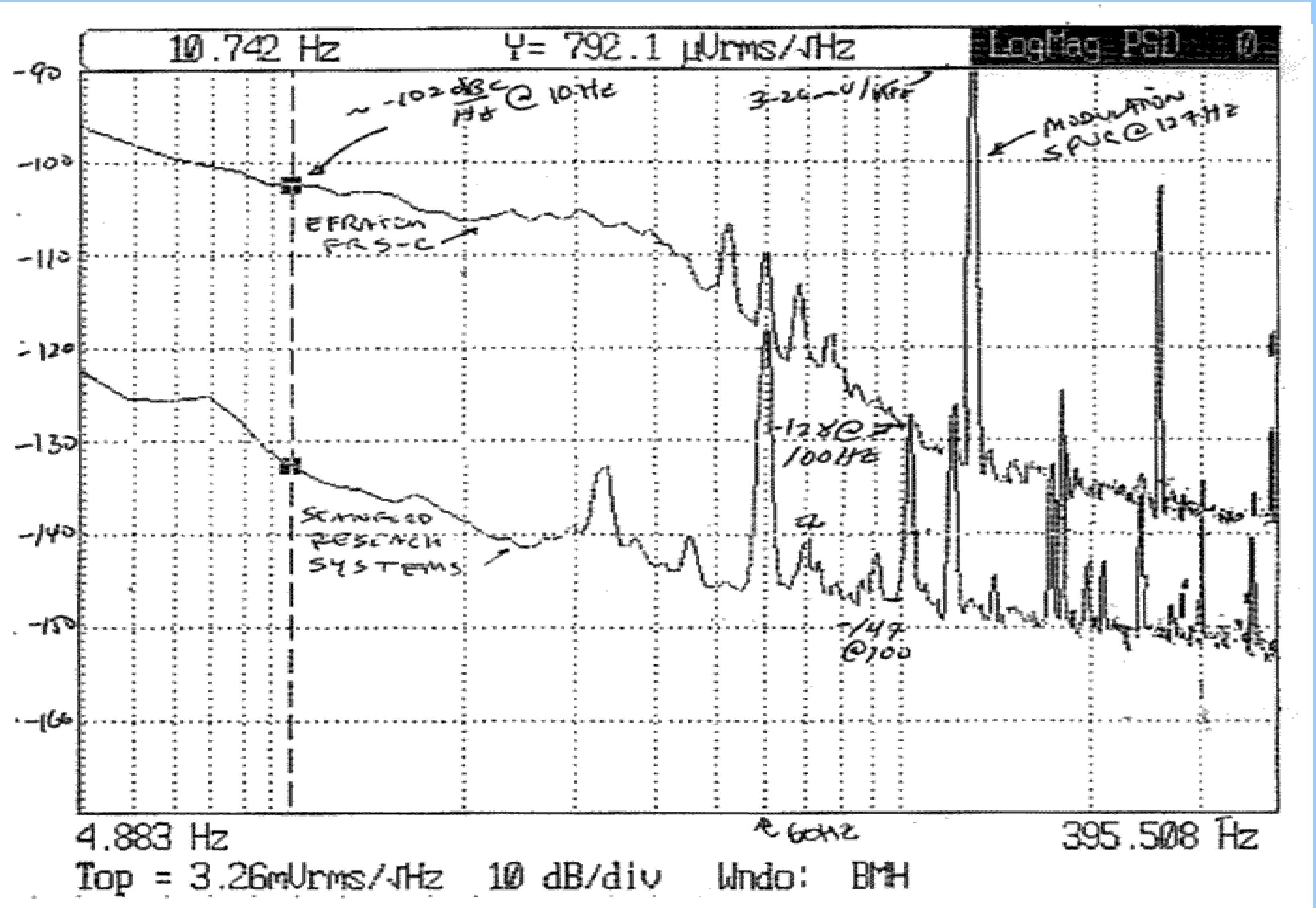


Current	Δt/ΔT	Δf
0	1NS/200S	+5×10⁻¹² ≃ 0
0.1A	−9NS/50S	180×10⁻¹²
0.2	−17NS/50S	340×10⁻¹²
0.3	−4.7NS/10S	470
0.4	−6.2NS/10S	620
0.5	−6.9NS/10S	690
0.6	−8.6NS/10S	860
0.7	−9.7NS/10S	970
0.8	−10.8NS/10S	1080
0.9	−11.6NS	1160
1.0	−13.5NS/S	1350×10⁻¹²

SC-Cut Ovenized Oscillator Advantages

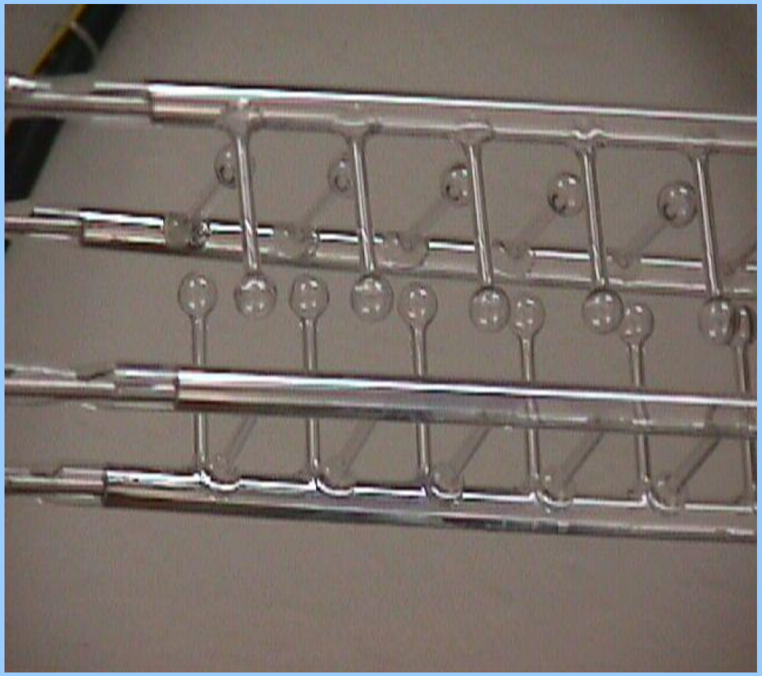
- Smooth start-up, re-start and holdover
- Allows long rubidium lock time-constants
  – Lower lamp drive level
  – Immunity from microphonics
  – Immunity to glitches
- No activity dips
- Very low phase noise

Single-Sideband Phase Noise



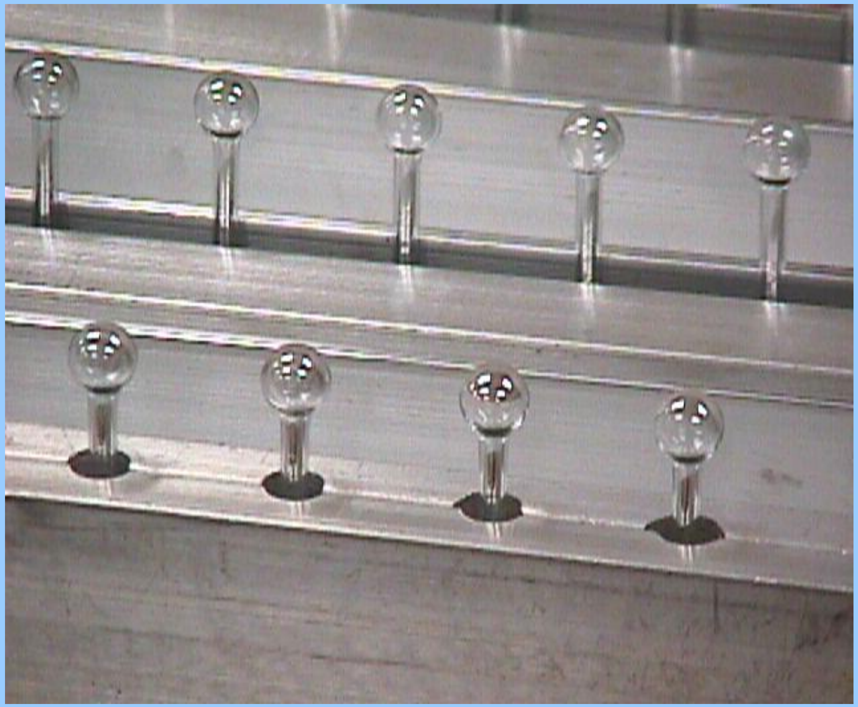
About Discharge Lamps

- Extended high-temp bake-out
- 5x Isotopic Rb overfill prevents log(t) Rb depletion
- Side-arm cell prevents flicker
- Demonstrated reliability
  - Study of 4000 units
  - 1.6 x 10^7 unit-hrs
  - zero lamp failures



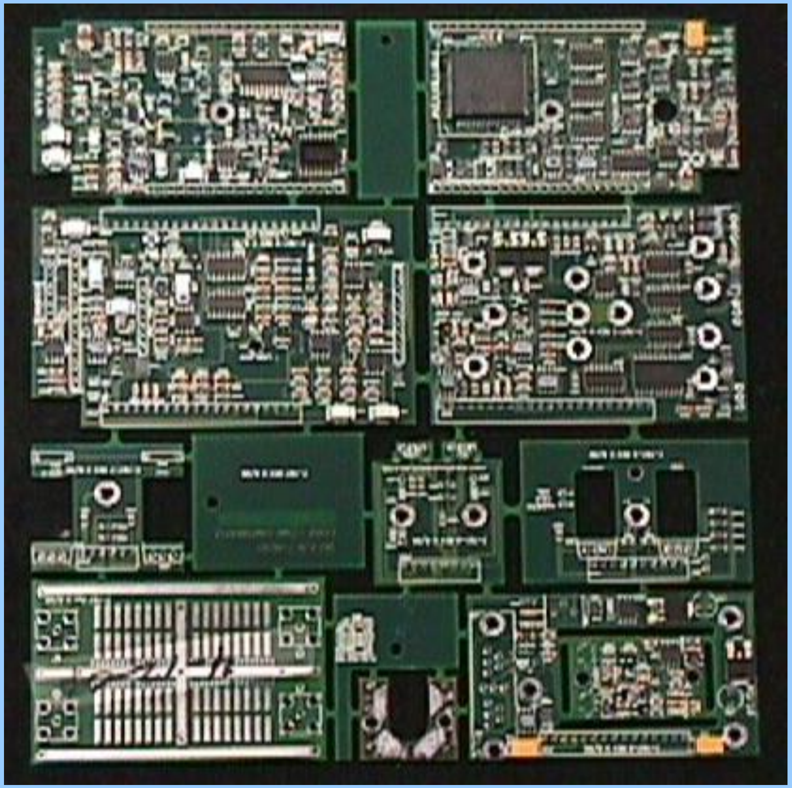
Cells and Lamps

Distillation of rubidium metal from manifolds into cells and lamps.

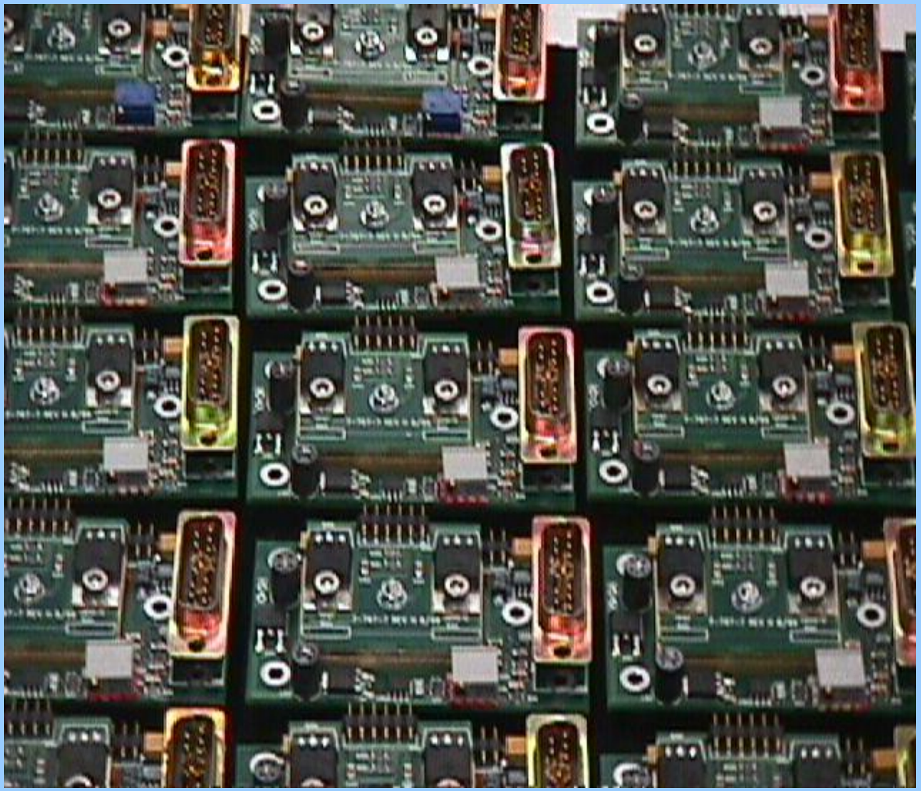


Electronics

- Automatic SMD pick-and-place onto single sheet

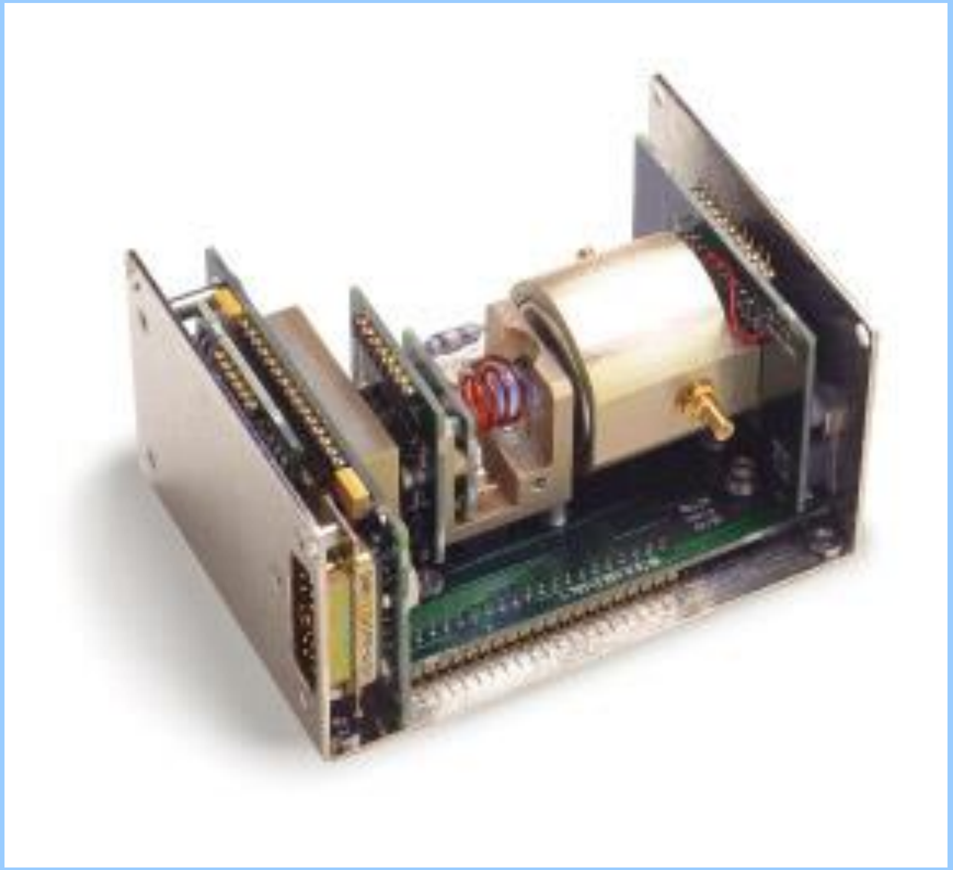


- Oven oscillator sub-assemblies

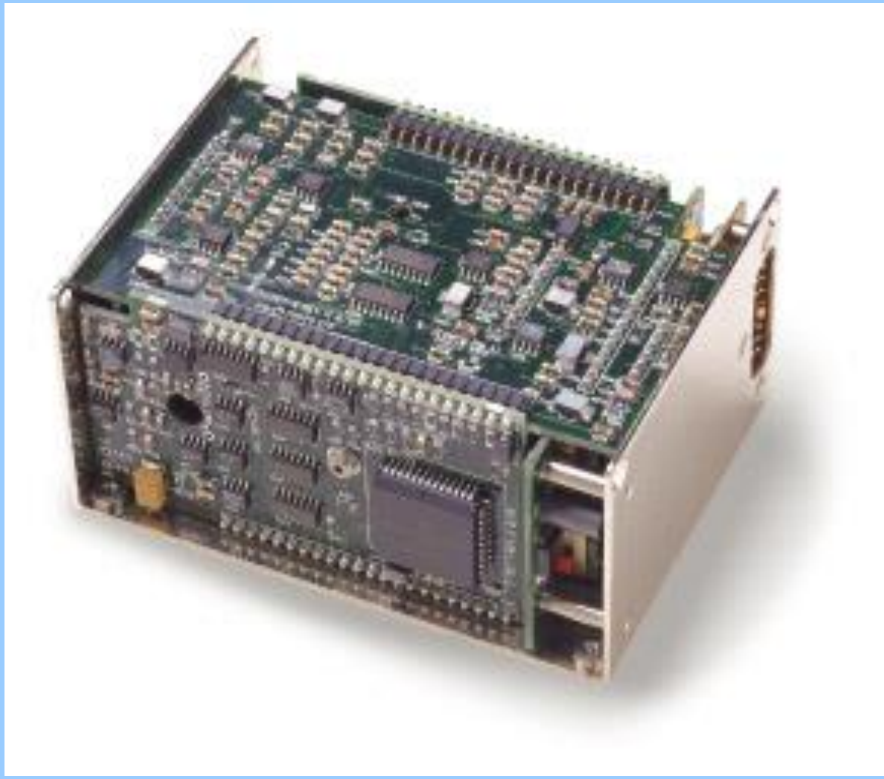


Oscillator and Physics Package

- Resonance cell
- Discharge lamp
- Oven oscillator



Completed Units



Five Week Burn-in

- In-situ calibration
- Complete logging
  - output frequency
  - lamp intensity
  - VCXO aging
  - lock-loop
  - 20 additional analog test points
  - tempco's
  - 8 x 10^6 unit-hr/yr

Burn-in Data Logged Every 20 Minutes

Rubidium Calibration - COM1

File Options

RS232 Communications | Rb Stats | 1 pps Calibration | RF Graph | Lamp Start | Shipping

PRS10_3.15_SN_3124   Update   Do Stats...   COM1   Monitor   SF

Factory Settings

sd0	135	Step Rec. Diode
sd1	128	Delay Value
sd2	55	Fet Voltage Set
sd3	150	Lamp Temp. Set
sd4	198	Crystal Temp. Set
sd5	190	Cell Temp. Set
sd6	124	Output Voltage
sd7	200	RF Modulation
R	5077	SP Param. (PLL)
N	2853	
A	38	
SF	8	Calibration Pot
SS	1289	Set Slope
MO	2439	Mag. Offset
MR	2441	Mag. Read
MS	1	Mag. Switching
LO	1	Lock
GA	7	Gain
PH	24	Phase
EP	1	Enable Power
FC	1660.24	10MHz DAC
DS	-56,849	Signal Values

Analog Output Values

ad0	0.003	Spare
ad1	2.326	+24 Volt Heat.
ad2	2.331	+24 Volt Elec.
ad3	0.495	Lamp Drain
ad4	0.303	Lamp Gate
ad5	2.326	Crystal Heat Ctrl
ad6	2.375	Cell Heat Ctrl
ad7	1.621	Lamp Heat Ctrl
ad8	1.942	AC Photosignal
ad9	3.187	Photocell I/V
ad10	0.645	Case Temp.
ad11	0.945	Xtal Thermistors
ad12	0.950	Cell Thermistors
ad13	0.975	Lamp Thermistors
ad14	2.510	Frequency Pot
ad15	0.003	Analog Ground
ad16	2.540	22MHz Varactor
ad17	3.250	360MHz Varactor
ad18	3.430	Auto Gain Ctrl
ad19	4.760	RF Lock

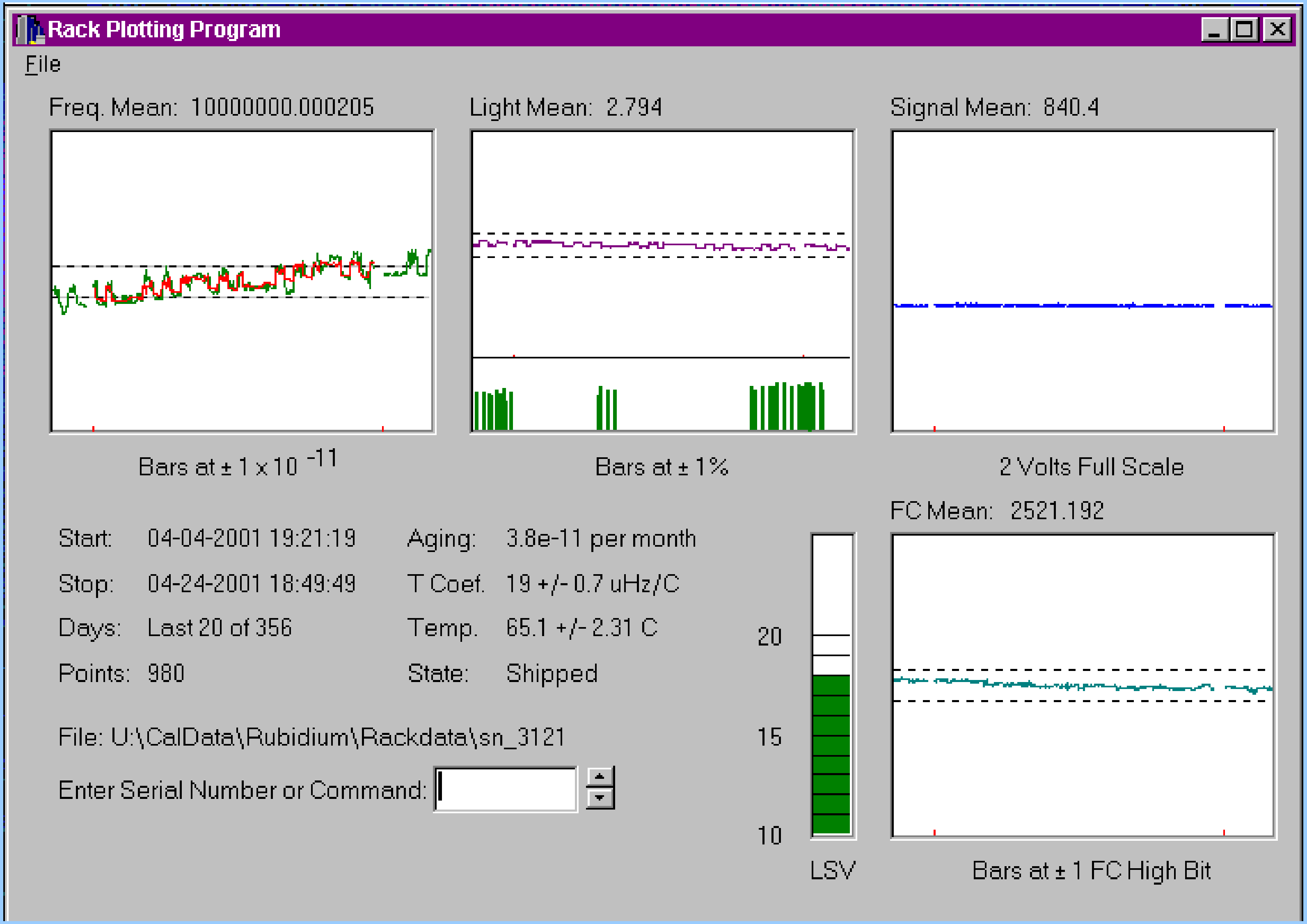
1pps Control

TO	-1804	Time Offset
TS	13980	Time Slope
PS	196	Pulse Slope
PL	1	Phase Lock
PT	14	Time Constant
PF	2	Stability Factor
PI	-1	Integral Term
LM	1	Lock Mode

Statistics

FC Mean	1660.42
FC Bits/Hz	75.44
FC Std. Dev.	0.08
FC Dev. E-12	110.35
W1 Bits/Hz	198161
W1 Mean	11.06
W1 Std. Dev.	74.07
W1 SNR	5982.29
W2 Mean	851.41
W2 Std. Dev.	3.04
SF Bit Size	0.86
Synth. Offset	-0.4841

Burn-in Data Plots (20 Days Shown)



Quality and Reliability

From a study of 4000 units shipped over two-years:

- Incoming inspection:
  - 18 of 4000 units rejected by customer
  - Implies an AQL = 0.45%
- Field failures:
  - 9 failures in 16.4 million hours of operation
  - Implies an MTBF = 1.8×10^6 hours

Advantages of SRS Rubidium Design

- Spur-free output with ultra-low phase noise
- Excellent holdover during rare failures
- Lamp wear-out mechanisms eliminated
- Time-tags and phase locks to external source
- Closed case calibration and control
- Established reliability