

SRS Tech Note

Theoretical Overview of Rubidium Frequency Standards

Stanford Research Systems

April 9, 2020

Rubidium is an alkali metal (like lithium, sodium, potassium and cesium). There are two naturally occurring isotopes of rubidium, Rb85 and Rb87, which have relative abundances of 72% and 28% respectively. The metal has a melting point of 39 °C.

The alkali metals behave similarly: they have one electron outside an inert core. Most of the chemical, electronic and spectroscopic properties of these elements are determined by this outer electron. The deep red glow of a low power rubidium discharge lamp is due to the resonance line transitions of the outer electron as it emits a red photon and drops back to the ground state.

The ground state of Rb87 is split by a very small energy due to the relative orientation of the magnetic spins of the electron and the nucleus. The split corresponds to the energy of a photon with a (microwave) frequency of 6.834,682,612,8 GHz. It is this hyperfine transition frequency which will be used to stabilize the 10 MHz output of the PRS10.

To see how this is might be done, Figure 1 shows a typical physics package which uses a discharge lamp, an isotopic filter, and a resonance cell. We will see that the amount of light which passes through the resonance cell to the photodetector can be reduced when the resonance cell is exposed to microwaves at the hyperfine transition frequency.

To simplify the discussion, we will assume that the light from the Rb87 discharge lamp consists of just two lines corresponding to transitions from a single excited state to the split ground state. The filter cell contains Rb85 vapor which also has a split ground state and an isotopic shift (relative to Rb87) as well. An important coincidence exists: one of the lines from the Rb87 discharge corresponds one of the transitions in Rb85. This will allow us to reduce the intensity of this line by passing the Rb87 discharge light through the Rb85 vapor.

Normally, atoms in the ground state will be equally distributed between the split states, as the splitting is much less than the thermal energy of the atoms in the vapor. This distribution is modified by the filtered light from the discharge, by a process called "optical pumping".

Suppose that the filter can completely remove one of the two discharge lines. The remaining light can be absorbed by Rb87 atoms in the resonance cell which are in the lower ground state, moving them to the upper state. When they decay from the upper state, they fall with equal probability into either ground state. As this continues, population will be moved from the lower ground state to the upper ground state, circulating through the upper state. As the population in the lower ground state is decreased, the amount of light which reaches the photodetector will increase, as the number of atoms which can absorb the radiation is reduced.

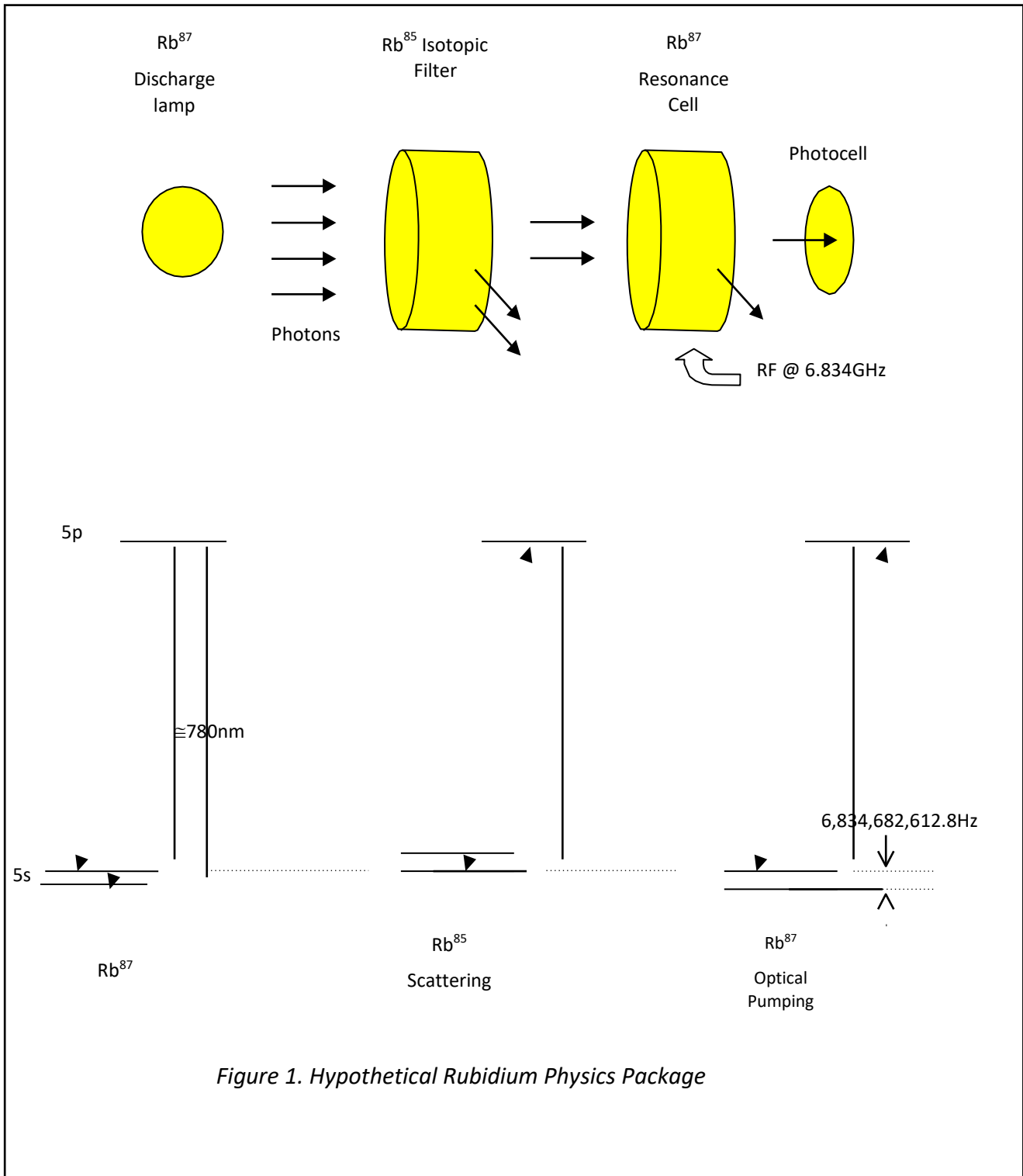


Figure 1. Hypothetical Rubidium Physics Package

Now, if we apply a microwave field at the frequency corresponding to the hyperfine transition frequency (6.834,682,612,8 GHz), the populations in the ground state will mix, and the amount of light reaching the photodetector will decrease.

The PRS10 uses the “integrated filter” topology: rather than a separate filter cell, the resonance cell contains a mixture of the two rubidium isotopes, along with a buffer gas. The lamp also contains a mixture of isotopes. The isotopic mixtures, buffer gases, and operating conditions are chosen so as to minimize temperature coefficients and intensity shifts of the apparent hyperfine transition frequency.

The apparent transition frequency will be shifted by about 3 kHz from the natural transition frequency by the buffer gas and discharge lamp spectral profile. The transition frequency differs slightly for each unit, depending on the fill pressure, etc. The transition frequency is also tuned over a few Hertz by a magnetic field which may be varied.

In the PRS10, the rubidium physics package acts as a very stable frequency detector for a frequency around 6.834 GHz. By using a microwave frequency synthesizer which is referenced to the 10 MHz OCXO, the 10 MHz may be stabilized to the rubidium hyperfine transition frequency.