Frequency Generation and Control: Atomic Hydrogen Maser Frequency Standard

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System considerations are described for a prototype hydrogen maser cavity tuner for use with the atomic hydrogen maser frequency standard developed at the Jet Propulsion Laboratory.

The long-term frequency stability of a hydrogen maser oscillator is determined by the stability of the microwave cavity resonant frequency. Temperature controller drifts, mechanical shocks, and relaxation cause cavity frequency displacements which must be periodically corrected. To maintain long-term maser frequency stabilities of 10^{-14}, the frequency of the 1420-MHz maser RF cavity must be maintained within 0.5 Hz. If a periodic cavity retuning scheme were not employed, a 10^{-14} maser stability requirement would dictate that cavity dimensions must be maintained within 10^{-10} and cavity temperature must be controlled within 0.003°C. In the long term (days), these tolerances on dimensional and thermal stability are not practical. Therefore, an automatic cavity tuner has been developed which removes long-term drift.

The quantitative effect of cavity pulling of the maser output frequency is given by (Ref. 1)

$$f_n - f_o \approx (f_n - f_c)\frac{Q_c}{Q_l}$$

where

f_n = the atomic hydrogen transition frequency ($\approx 1.420 \times 10^9$ Hz)

f_o = the maser oscillation frequency

f_c = the cavity resonance frequency

Q_c = the cavity frequency divided by its bandwidth ($\approx 45{,}000$)

Q_l = the atomic hydrogen transition frequency divided by its line width ($\approx 1.4 \times 10^9$)

Therefore, the maser output frequency is pulled by the cavity resonance frequency by the ratio of Q_c/Q_l (3×10^{-5}). The most acceptable maser cavity tuning method (Ref. 2), and the one used at JPL, is to increment the transition line width and adjust the cavity frequency f_c such that this increment in line width does not change the output frequency.

Manual cavity tuning is accomplished by plotting the oscillation frequency as a function of transition line width for large cavity frequency offsets and extrapolating to the tuning point which is insensitive to transition line width variations. Manual tuning has these disadvantages:

(1) Is time consuming (several hours).

(2) Requires a fair degree of operator skill.

(3) Requires two hydrogen masers for practical tuning times.

(4) Does not remove the spin-spin interaction frequency shift (Ref. 3).

(5) Requires surveillance of tuning accuracy.

(6) Requires system down time for cavity tuning.

The design of an automatic maser cavity tuner obviously must meet operational constraints of the frequency and timing system. The author has considered the following modes:

(1) *Two* masers at each antenna site, for redundancy and rapid tuner response times. The role of each maser will be separated into a long-term and short-term standard. The long-term standard will be controlled by the automatic tuning servo and will have a degradation in short-term stability to achieve high-gain, short response time cavity tuning. The second maser will be maintained at a constant offset from the first; it will not be tuned and its adjustable physical parameters will be set to optimize short-term stability.

(2) *One* maser at each site. The automatic tuner would use an auxiliary tuning reference such as the site rubidium standard. This allows the maser to be an independent standard with a degradation in tuning accuracy and tuner response time (several days). Automatic tuning would have to be performed at non-critical use times, since tuner modulation would degrade short-term stability substantially more than for the case of two masers at each site.

The hydrogen maser frequency stability is independent of the measurement time for times greater than approximately 100 s and less than the time dictated by the cavity frequency stability. For measurement periods less than 100 s, receiver noise degrades the maser frequency stability.

Signal-to-noise ratio restrictions require tuning integration times of several days, where a reference source other than a second hydrogen maser is used. As previously noted, delay of 100 s is required to make an accurate output frequency determination. These two factors necessitate the "ideal" integrator of a characteristic digital servo design. A block diagram of the tuning servo system presently in use on the research masers at the Goldstone DSCC is shown in Fig. 1. The maser tuner modulates the hydrogen transition line width by limiting the dissociator power and, therefore, the supply of hydrogen atoms to the oscillator. This increases the life time of excited atoms within the storage bulb, and decreases the transition line width. The cavity is tuned by a varactor connected through a directional coupler to the cavity coupling loop. The period of the beat frequency between the hydrogen maser and a frequency reference is measured to determine incremental frequency change produced by a flux change.

Figure 2 shows the timing sequence of the tuner operation. The upper sinusoid is the beat between the reference oscillator and the maser of an approximately 100-s period. The counter up-counts an internal clock for the first beat

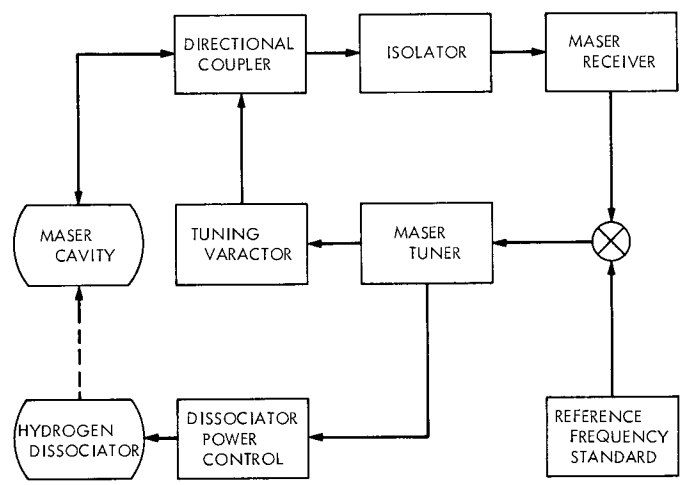

Fig. 1. Maser tuner system block diagram

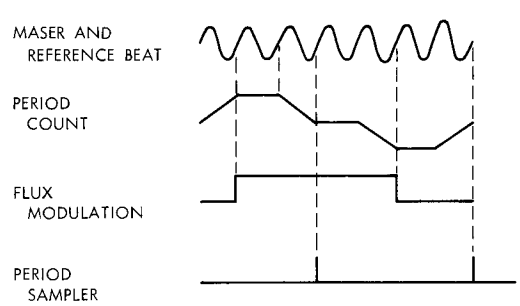

Fig. 2. Tuner operation sequence

period. The flux is increased and the counter down-counts for one period after a one-period delay to allow the physical system of the dissociator to reach equilibrium at the new flux level. At the end of the down count, the residual in the counter is transferred to a buffer supplying a digital-to-analog converter. The tuning varactor voltage is taken from the digital-to-analog converter. The next count cycle is reversed, the high-flux down count is taken first and the low-flux up count is second. The latter averages any linear drift term longer than 800 s in the reference oscillator.

References

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