An Improved Storage Bulb Mount for DSN Hydrogen Masers

P. R. Dachel, D. P. Russell, T. K. Tucker, and L. B. Stratman
Communications Systems Research Section

This article compares the presently used JPL hydrogen maser suspended atomic storage bulb to a new, rigid, single-plane mounted bulb. The new bulb incorporates three major design changes:

(1) Mounting design.

(2) Alterations to the collimator.

(3) Decrease in mass.

These design changes are expected to increase the long-term stability of the frequency standard by reducing its sensitivity to vibration and thermal effects.

I. Introduction

In June of 1976, an experiment to test the gravitational redshift using a hydrogen maser in a suborbital rocket probe was successfully performed jointly by the Smithsonian Astrophysical Observatory (SAO) and NASA's Marshall Space Flight center (Ref. 1). The design of the space maser was the result of a program begun under NASA sponsorship in 1962 (Ref. 2), and one of the results of this design effort was the single-plane mounted atomic hydrogen storage bulb. This mount consisted of a solid quartz collar with one rim fused to the quartz storage bulb and the other fixed to the RF cavity base plate. By lightening and refining this basic collar design, SAO designed the tetrahedral spoke support system that is used in the SAO VLG-11 today (Ref. 3).

The success of the solid-mounted SAO storage bulb design prompted JPL to test this concept in one of two prototype masers that was disassembled for repair. The rebuilt prototype masers (designated P_2 and P_3) will be used as reference standards in the Frequency Timing System (FTS) test facility at JPL. The rigid mount bulb to be tested is shown in Fig. 1.

II. Two-Point Suspension Storage Bulb

In the present JPL Hydrogen Maser design, the storage bulbs are suspended in the microwave cavity by a two-point mounting system (Fig. 2). The upper support is a quartz rod fixed to the center line of the storage bulb. This rod extends through the cavity frequency adjustment plate into a spring-loaded mounting fixture. The spring pressure on the rod holds the storage bulb securely against the cavity base plate. The lower support is a Teflon[1] plug that is fixed to the cavity base plate and inserted into the neck of the storage bulb. The press fit of the Teflon plug into the neck of the storage bulb pro-

[1] Teflon is a Dupont name for tetrafluorethylene fluorinated ethylene propolene copolymer.

vides support on a radial and transverse plane. This plug is center bored so that it also serves as a collimator for the storage bulb. One difficulty with this mounting scheme is that the bulb moves if the maser physics package receives a slight jolt. The magnitude of the displacement is determined by the clearance required in the slip joint of the spring mount, and it is this clearance that allows the storage bulb to rock slightly on the Teflon plug. Although the displacement of the storage bulb is small (0.0025 cm, 0.001 inches), it is sufficient to change the output frequency by approximately a part in 10^{-12}. Since it is practically impossible to avoid some form of physical shock at different times during maser operation, this shift poses a real problem.

The collimator consists of a center-bored Teflon plug with a 0.953-cm (0.375-inch) diameter orifice. The dimensions of the collimator are primary factors in determining the atomic storage time in the microwave cavity. The equation for storage time for the special case of a spherical storage bulb with a cylindrical collimator is:

$$T_b = \frac{2a^3 \ell}{\bar{\nu} b^3} \tag{1}$$

where:

T_b is the storage time

ℓ is the length of the collimator

b is the radius of the collimator

a is the radius of the storage bulb

$\bar{\nu}$ is the mean velocity of the hydrogen atoms entering the storage bulb

Since the collimator is part of the storage area, it has an effect on the wall shift. In fact, since the collimator is a solid plug of Teflon, it has a different wall shift than the storage bulb, which is coated with Teflon. The equation for wall shift in a storage area coated with a single material (Ref. 4) is

$$\Delta\omega = \frac{\phi}{t_0} \tag{2}$$

where:

$\Delta\omega$ is the shift in line frequency

ϕ is the phase shift in atomic wave function per collision

t_0 is the mean time between collisions

III. Rigid Single Plane Mount Bulb

Comparing Figs. 2 and 3, it can be seen that with the removal of the support rod, there is no direct connection between the frequency adjustment plate and the rigid single-plane mount bulb. All support is through the base plate. Also, it can be seen in Fig. 3 that the collimator is no longer used for support. Freed from this duty, the collimator can be made a permanent part of the storage bulb. This improves the characteristics of the wall shift since the entire storage bulb substrate is quartz, coated with a continuous film of Teflon. Due to the rigid mounting design, resettability of the maser is improved since there is no chance of changing 1) the alignment of the collimator with respect to the storage bulb, and 2) the quartz (dielectric) position within the cavity electromagnetic field.

Following the SAO design, the collimator has been lengthened and its inside diameter decreased to 0.559 cm (0.220 inch). From Eq. (1), it is seen that this will increase the storage time by a factor of five, approximately. This increase in storage time will manifest itself as an increase in atomic line Q. From the equation for cavity pulling (Ref. 4):

$$\Delta\omega = \Delta\omega_c \frac{Q_c}{Q_\ell} \tag{3}$$

where:

$\Delta\omega$ is the shift in the output frequency

$\Delta\omega_c$ is the shift in the cavity resonant frequency

Q_ℓ is the atomic line Q

Q_c is the cavity Q

it is seen that the higher the line Q, the smaller the resulting shift in the master output frequency (i.e., the output frequency is more resistant to physical changes in the cavity).

Preliminary test results have shown a factor of 2 increase in line Q using this new bulb configuration.

One additional modification has been incorporated into the rigid mount bulb. The two-point suspension storage bulbs weigh between 280 and 300 grams. Small thermal fluctuations (0.001°C) present in the maser can change the dielectric constant of this mass. Since the storage bulb resides in a region of high electromagnetic fields in the resonant cavity, these changes can affect the output frequency of the maser. By reducing the amount of quartz to 230 grams, it is hoped to reduce this frequency shift.

IV. Conclusion

The P_3 prototype maser is now under construction with the rigid storage bulb mount. The following modifications are necessary to fit the new bulb to the JPL maser:

(1) The material of the cavity bottom plate has been changed from aluminum to quartz (this modification also improves the thermal properties of the microwave cavity by decreasing the coefficient of thermal expansion of the base plate).

(2) The thickness of the base plate has been increased.

(3) A base support groove has been added to the quartz plate (Section A-1, Fig. 3).

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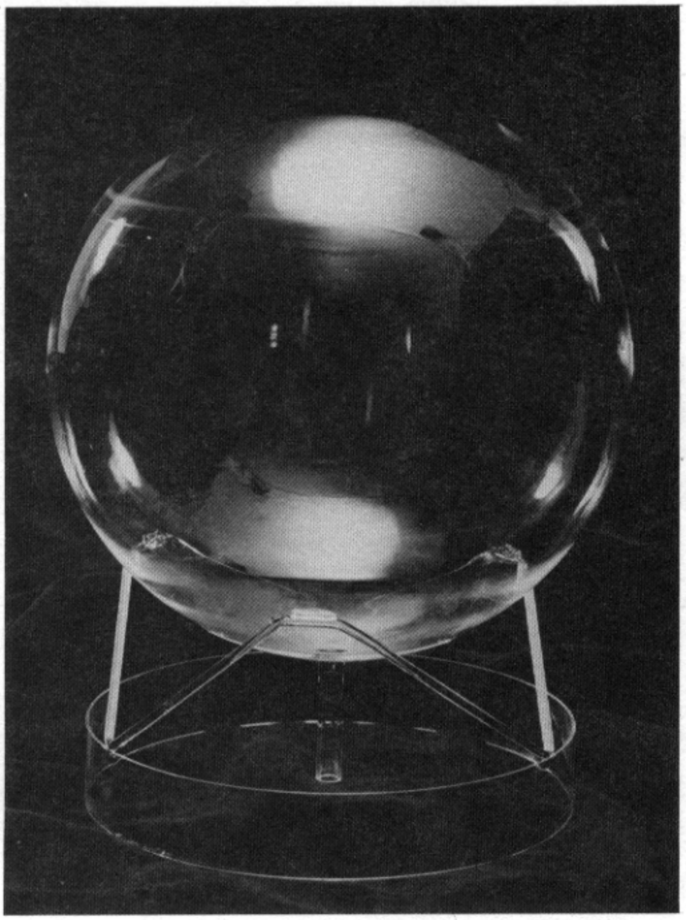

Fig. 1. JPL hydrogen maser

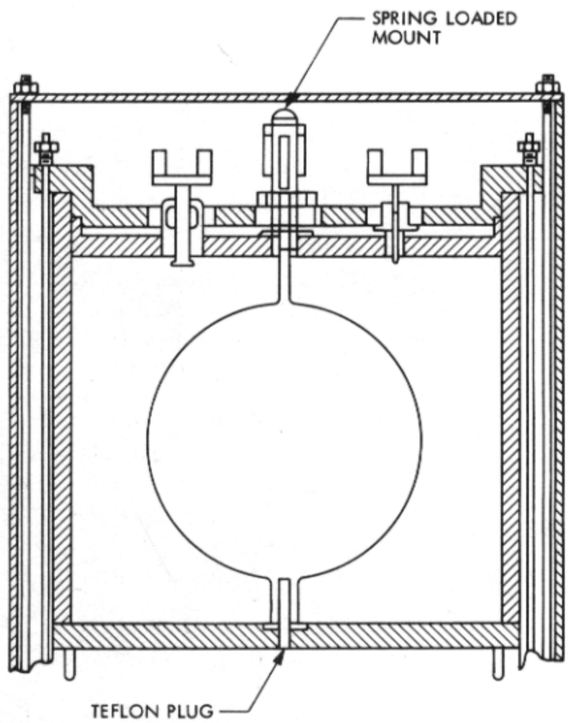

Fig. 2. Two-point suspension

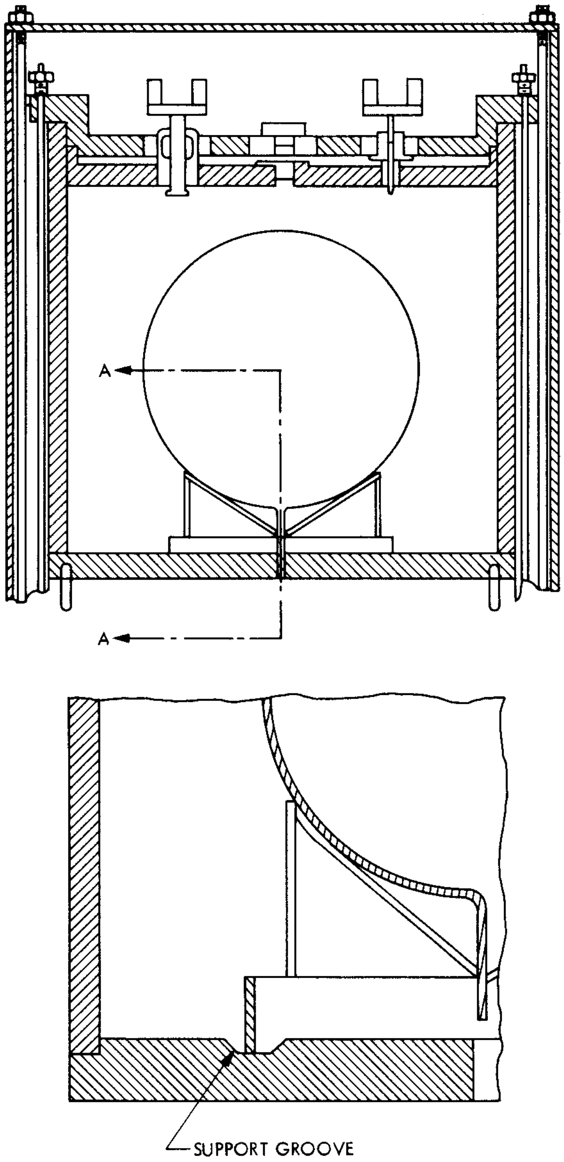

Fig. 3. Rigid mount