NEW HYDROGEN MASERS AT THE NATIONAL RESEARCH COUNCIL OF CANADA

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Abstract

Two active hydrogen masers for laboratory use have been constructed recently at the National Research Council of Canada (NRC). These have been designed to be operated as clocks and as contributors to the NRC time scale. Details of their design are presented. Although the masers have not yet been operated under full temperature control and with the complete electronics package, some preliminary measurements of line-Q and frequency stability have been made, and will be discussed.

INTRODUCTION

The National Research Council of Canada has been involved in research in the PTTI field for over 40 years. A number of designs of primary cesium beam frequency standards and clocks have been built and, currently, three are in operation. These are designated CsV, CsVIA, and CsVIC. In addition, two hydrogen masers, H1 and H2, have been operated as frequency standards for over 20 years. At present, one of these (H1) is still in use. Recently, two new active hydrogen masers, designated H3 and H4, have been designed and constructed. They form the subject of this paper. Details of their design will be presented, together with some preliminary operating characteristics.

GENERAL DESIGN DETAILS

The design of these masers has been based partly on experience gained at NRC[1] and at Laval University in Quebec City where hydrogen masers have also been built. Details of the Laval masers were presented at an earlier PTTI meeting[2].

Eventually, it is planned to operate the masers H3 and H4 as clocks and as contributors to the NRC time scale. This requires that they exhibit good reliability and good long-term frequency stability. To this end, considerable care has been taken to isolate the resonant cavity mechanically and thermally. Also, a number of improvements have been made over the earlier masers constructed at NRC. For example, only metal seals are used on the vacuum system. Improved magnetic shielding and improved temperature control systems are also employed.

The masers are housed in cabinets 71 cm wide, 120 cm long and 155 cm high. They can be moved to different locations in the building, if desired, but are not designed for complete portability. The electronic circuits are contained in the maser cabinets. DC power for the masers is obtained from float-charged storage batteries, and AC power from the line with back-up diesel generator protection.

The design of the masers is shown in Fig. 1. Many of the features are quite conventional and only certain points of interest will be referred to. To reduce the effect of ambient magnetic field fluctuations five layers of magnetic shielding are used. The dimensions and spacing of these shields are similar to those used on the Laval University masers[2] for which a longitudinal shielding factor of 100,000 was measured[3]. A similar value is expected in this case. This means that a 10% fluctuation in the earth's field should cause a frequency change of less than 1 part in 10^{15}.

Three concentric ovens are used outside the vacuum system for temperature control and, inside the vacuum system, two thermal shields consisting of aluminum cylinders and end plates enclose the resonant cavity. They are thermally insulated from each other and from the vacuum enclosure by means of ceramic spacers. This arrangement should result in high isolation of the cavity from external temperature changes.

CAVITY SUPPORT STRUCTURE

The structure used for supporting the cavity inside the thermal shields and the vacuum enclosure has been designed to give good mechanical decoupling from outside vibration and barometric pressure changes. The bases of the thermal shields are supported on kinematic mounts employing the ceramic spacers already mentioned and pyrex balls. The quartz baseplate of the cavity is supported on three titanium pins with rounded tips which fit into conical holes in the quartz. Flexing of the pins will take up the difference in dimensions due to relative thermal expansion of the quartz and aluminum. The top plates of the cavity and the thermal shields are lightly loaded mechanically by beryllium copper leaf springs which are thermally isolated by pyrex balls. Details of the cavity region are shown in Fig. 2.

The resonant cavity is made of fused quartz. It is thermally compensated by means of a re–entrant aluminum disk attached by three aluminum posts to the quartz ring at the top. The quartz is silvered internally using fired-on silver paint. The loaded Q of the cavity is 38 000. There are two coupling loops, one with a coupling coefficient of about 0.15 and the other with a much lower value. A spherical storage bulb 18 cm in diameter is symmetrically located in the cavity. It is coated internally with FEP–120 Teflon and the neck of it is fitted with a collimator consisting of a bundle of seven thin–walled quartz tubes inside a quartz sleeve. The tubes are also coated with Teflon. The theoretical storage time is 3 seconds.

VACUUM SYSTEM AND HYDROGEN SOURCE

All vacuum seals on the masers use metal wires or rings: either copper or indium. Pumping is performed by a single 270 L/s ion pump. A successful sealing arrangement for the pyrex source bulb is shown in Fig. 3. It uses a double indium wire seal. Two stainless steel rings are clamped to a flange on the source bulb using one indium seal. The assembly, consisting of the bulb plus the rings, is then inserted into the housing and clamped against the second indium seal.

The hydrogen pressure in the source bulb is stabilized by using a servo system controlling the temperature of a thin–walled tube of palladium–silver alloy closed at one end and heated by passing a current directly through it. This system has a response time of a few seconds, making it very useful for rapid beam flux changes required when cavity tuning by spin exchange broadening is used.

MASER ELECTRONICS

The masers have been designed with the option of operating either free–running, with stand–alone cavity frequency servos employing injected square wave FM signals[4], or with an external spin–exchange auto–tuner which uses each maser in succession as a stable frequency reference[5]. A simplified block diagram of the receiver is shown in Fig. 4. A 5 MHz BVA quartz crystal oscillator is locked to each maser. The signal injection cavity control servo shown can be disabled quite simply if free–running operation of the maser is desired.

When the masers are used as time standards, it is necessary to run the 5 MHz crystal oscillators at their nominal values by adjustment of the 5751 Hz synthesizers. These can be adjusted in steps of 0.1 mHz, resulting in minimum relative frequency changes in the maser output of steps of 7 parts in 10^{14}.

If an external spin–exchange auto-tuner is used there must be a frequency offset between the signals from the two masers so that suitable beat periods can be measured. It is preferable to do this without adjusting the settings either of the 5751 Hz synthesizers or of the magnetic fields of the masers. One way of accomplishing this is to use the system shown in Fig. 5. The 5 MHz output from maser H4 is multiplied to 1400 MHz and that from H3 is multiplied to 1440 MHz. These are mixed and filtered to give the 40 MHz component, which is again mixed with a signal derived from H3. This signal is produced by mixing the outputs of a multiplier and a synthesizer, to give a frequency of 40 MHz $+ \delta$, where δ is the desired beat frequency (typically 1 Hz). The beat frequency may be changed by adjustment of the synthesizer frequency. Although it is not obvious from Fig. 5, the circuitry is designed so that it is a simple matter to switch from the signal injection cavity servo mode to the external auto– tuner mode.

PRELIMINARY PERFORMANCE DATA

Masers H3 and H4 are not yet in full operation. However, mechanical construction is complete and preliminary testing has been carried out. Both masers have oscillated at low magnetic fields, and preliminary measurements have been made using a temporary receiver. A line Q value of 4×10^9 at a reasonable operating flux level has been measured. This compares favorably with the value of 1.9×10^9 at normal operating flux for maser H1. Fig. 6 shows a plot of maser power as a function of linewidth for H4. The experimental values of linewidth at the extremes of the oscillation curve correspond to line–Q values of 6.1×10^9 and 1.3×10^9 respectively. The accuracy to which the maser can be tuned when the spin–exchange method[6] is used depends on the relative linewidth broadening between operation at a low beam flux setting and a higher one. With the range of linewidths available at reasonable flux levels in this case the accuracy of tuning can be made high. Crampton and Wang[7] have shown that by fitting a quadratic to the power vs linewidth data it is possible to derive the value of several maser parameters and, in particular, the quality factor q[1,2]. From the data shown in Fig. 6 a value of q of 0.08 was derived.

The receivers and cavity control circuits have now been completed and installed on the masers. However, they have not yet been completely checked out. Earlier this year, preliminary frequency stability measurements were made using a temporary receiver. In this test the magnetic field of one maser was increased in order to obtain a frequency offset of the masers of about 0.1 Hz. The measured frequency stability is shown in Fig. 7. This preliminary measurement shows a minimum value of $\sigma(2,\tau)$ of 5.0×10^{-15} (3.5×10^{-15} on a per maser basis) at 1000 s. In view of the lack of temperature control on the masers and the use of temporary electronic circuits, it is felt that this is a satisfactory result.

FUTURE PLANS

This paper is essentially a progress report on the development of the two new hydrogen masers. More comprehensive results will be reported at a later date, when all the final electronic circuits are in use. It is planned to obtain frequency stability data under free–running conditions and with the two different tuning systems before deciding which system gives rise to the best long term frequency stability. After this decision is made the masers will be incorporated into the NRC time scale as clocks.

ACKNOWLEDGEMENTS

We would like to thank Mr. R. Cote and Mr. G.J. Trudeau for the mechanical construction of the masers, Mr. M. Kotler for assistance with the mechanical design, and Mr. W. Cazemier and Mr. J. Belanger for technical assistance with electronic circuits and mechanical assembly, respectively.

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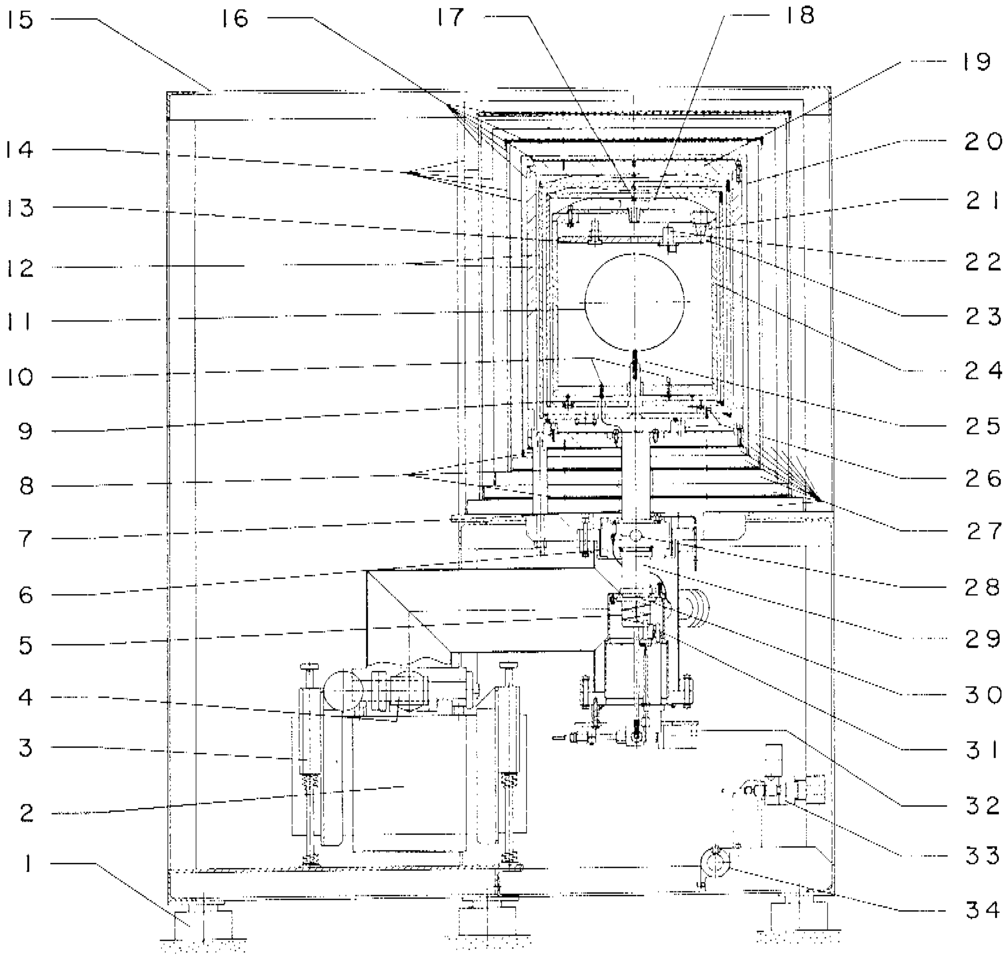

1 -SHOCK MOUNTS
2 -ION PUMP 270 L/s
3 -PUMP MOUNT
4 -UHV VALVE
5 -SOURCE BULB
6 -NECK COIL
7 -NECK HEATER
8 -OVENS
9 -TITANIUM PINS
10 -COUPLING LOOPS
11 -QUARTZ STORAGE BULB (TEFLON COATING)
12 -THERMAL SHIELDS
13 -TUNING PISTON
14 -MAGNETIC SHIELDS
15 -FRAME
16 -OVENS
17 -GLASS BALLS
18 -LEAF SPRINGS
19 -VACUUM ENCLOSURE
20 -SOLENOID
21 -COMPENSATION POSTS
22 -VARACTOR TUNER ASSEMBLY
23 -TUNING PLATE
24 -SILVERED QUARTZ CAVITY
25 -BULB COLLIMATOR
26 -KINEMATIC MOUNTS
27 -THERMAL INSULATION
28 -STATE MIXING COIL
29 -HEXAPOLE MAGNET
30 -SOURCE COLLIMATOR
31 -SOURCE OSCILLATOR
32 -PALLADIUM VALVE
33 -HYDROGEN PRESSURE REGULATOR
34 -HYDROGEN CYLINDER

Fig. 1. Drawing showing the design features of the masers.

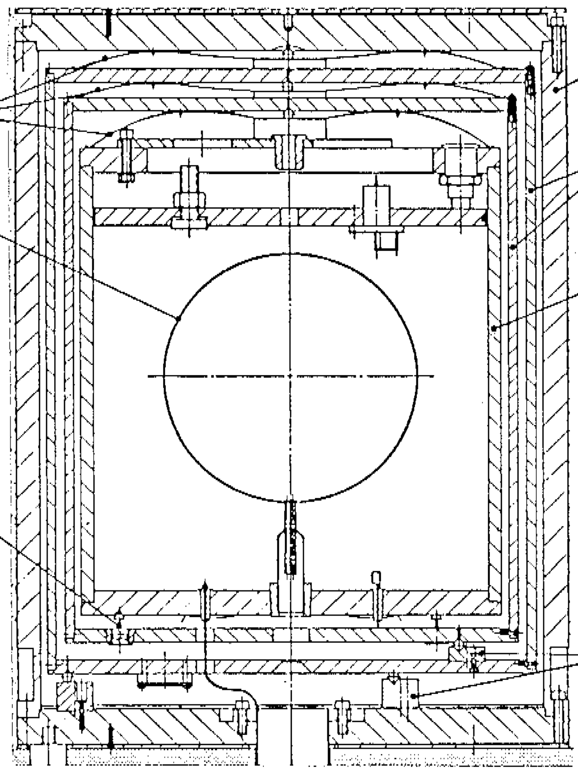

Fig. 2. Detail of cavity region showing thermal shields and kinematic supports.

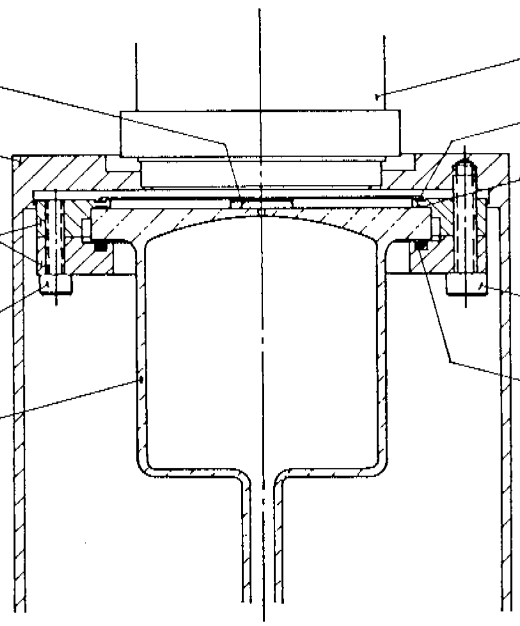

Fig. 3. Detail of vacuum seal to the hydrogen source. The seal is shown in process of assembly.

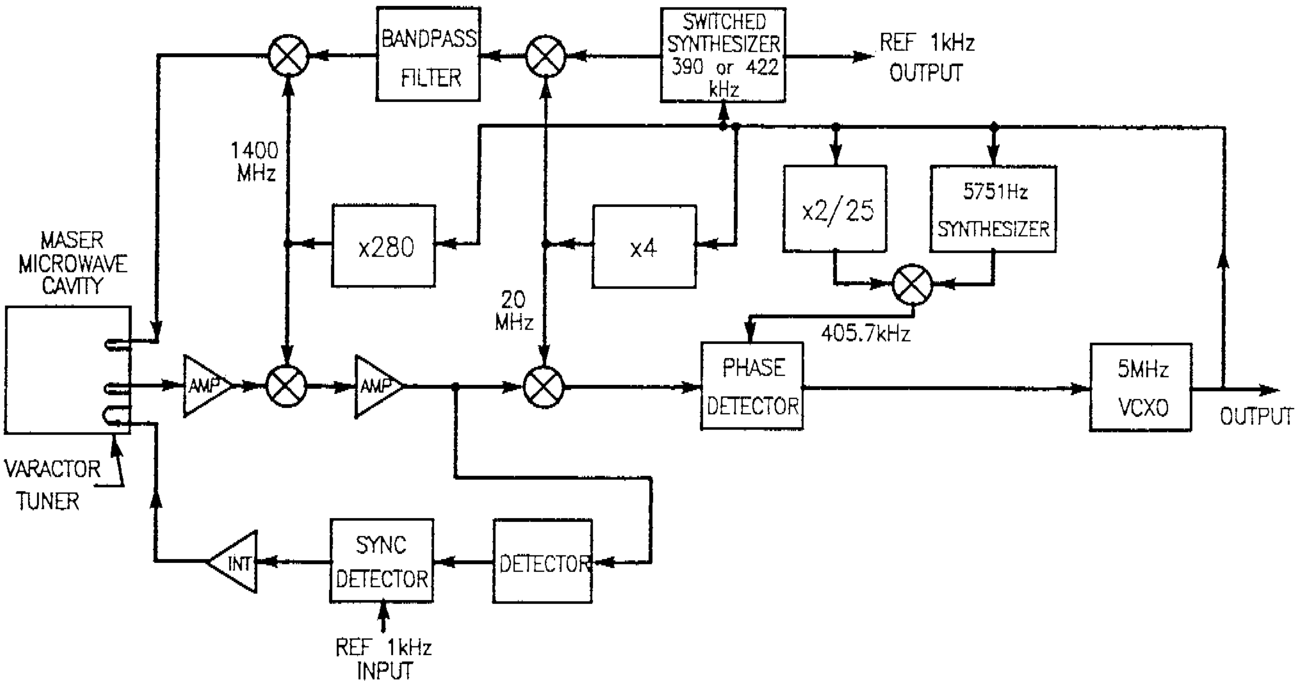

Fig. 4. Simplified block diagram of the maser receiver.

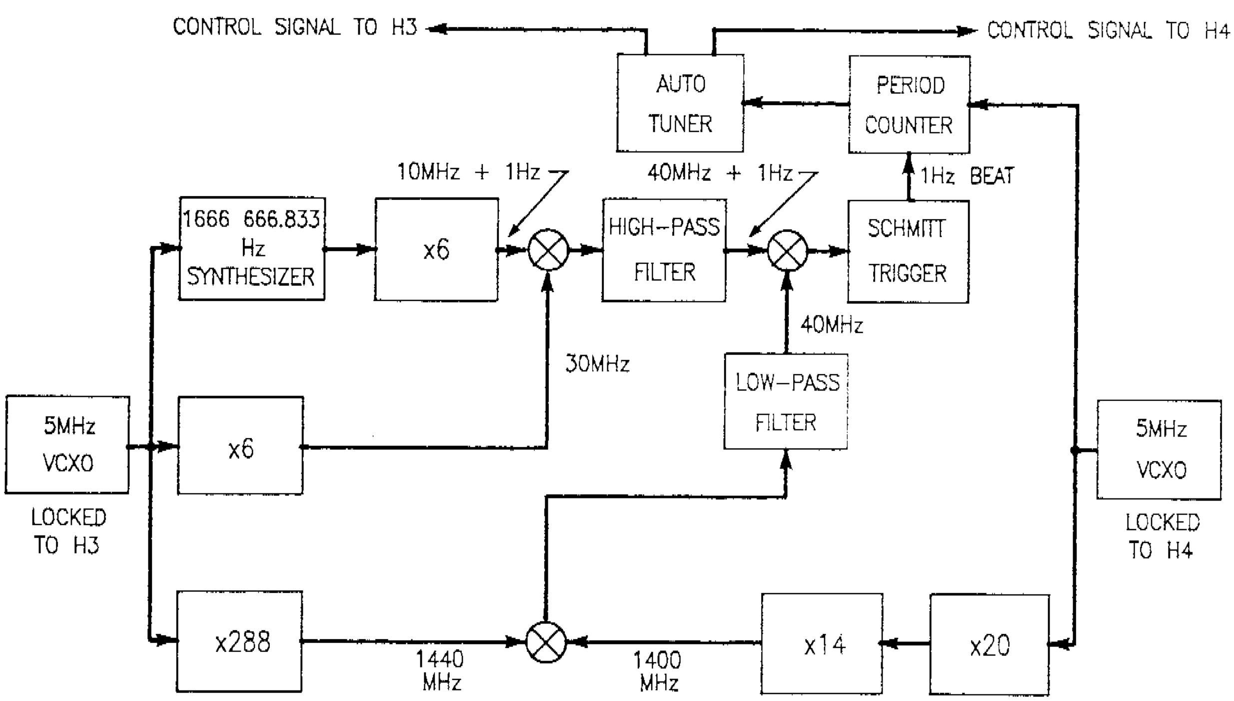

Fig. 5. Block diagram of system designed to produce beats between the masers.

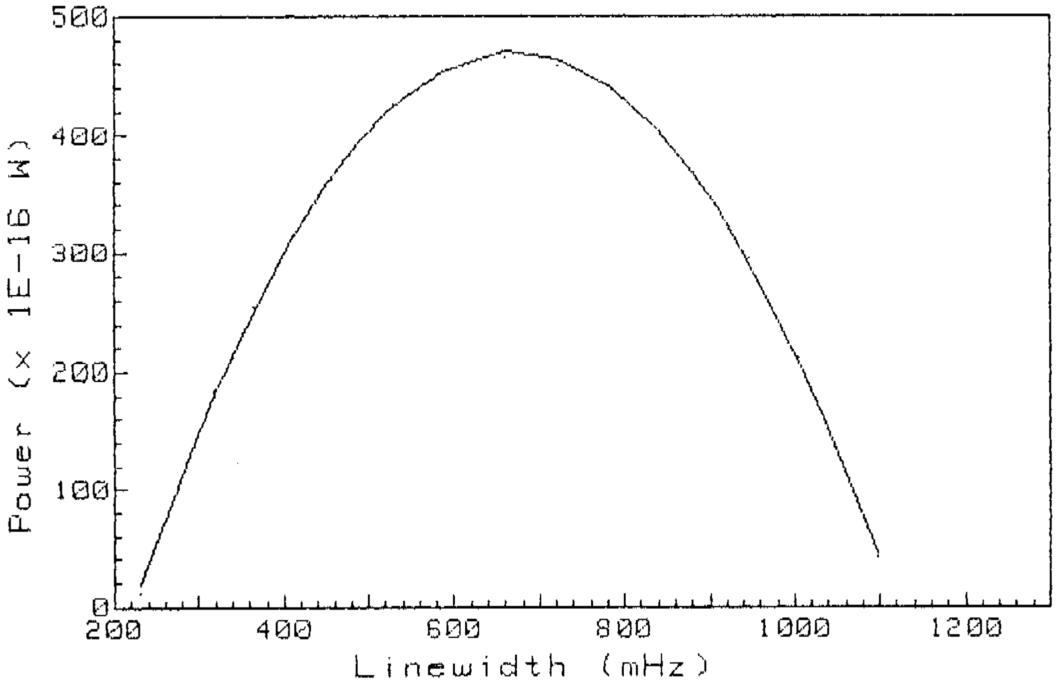

Fig. 6. Output power of maser H4 as a function of linewidth.

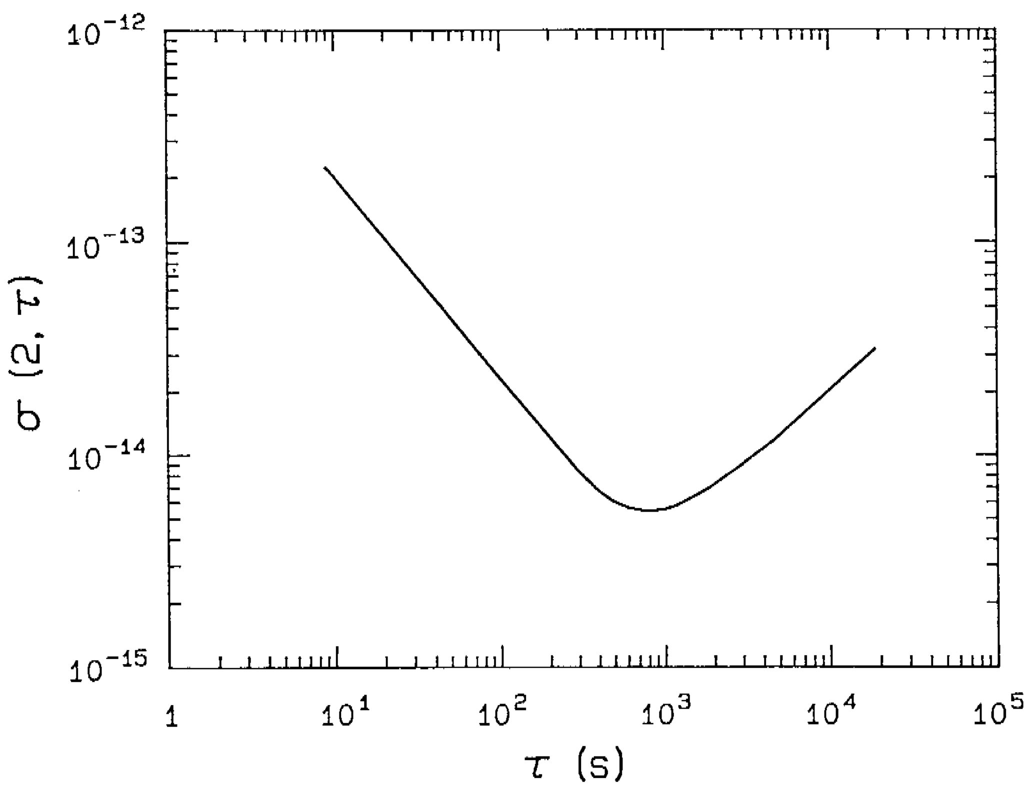

Fig. 7. Preliminary frequency stability data.

QUESTIONS AND ANSWERS

ALBERT KIRK, JPL: How do you introduce the hydrogen into the dissociator bulb and what kind of seal do you use there?

MR. MORRIS: We use a palladium leak which is brazed on and then copper seals are used.

MR. KIRK: Copper seals between the palladium and the glassware?

MR. MORRIS: There is a metal–glass seal and then the stainless steel tubing seal with copper rings seal to the palladium leak.

FRED WALLS, NIST: Do you have any magnetic shielding between the source and the state selector and the entrance to the magnetic shields around the cavity?

MR. MORRIS: No, we don't. We have a coil that can be activated if necessary in the region between the source and the underside of the magnetic shields. We haven't really had a chance to look at any effects yet, but a quick look at, applying reasonable currents, seemed to show no change in oscillation level.

DAVID ALLAN, NIST: The turn up in the σ vs. τ curve, was that cavity pulling or do you know what be the cause?

MR. MORRIS: We had no temperature control on the masers, there were cables all over the place. It was just to get an initial look at how they were working. We don't have the proper receivers in operation yet, either.