A COMPARISON OF VARIOUS HYDROGEN-MASER FREQUENCY STANDARDS

A.E.E. Rogers and A.R. Whitney, (NEROC, Haystack Observatory),
L.B. Hanson, (Lincoln Laboratory, Millstone Hill Field Station),
Wesford, Massachusetts
01886

ABSTRACT

Comparisons have been made between several hydrogen-maser frequency standards of different design to test their sensitivities to changes in environmental factors. These comparisons are carried out with one maser placed in the standards' room of the Haystack Observatory and the other in a special room at the Westford antenna, about 1.2 km distant. A phase stable link connects the two facilities. The room at Westford allows the pressure, temperature, and magnetic field to be changed and controlled within certain limits. The room at Haystack is controlled in temperature, but is unshielded from variations in magnetic field and atmospheric pressure. Results will be presented from pairwise comparisons between four hydrogen masers, one each of the NP2 and NX2 design, built at Goddard Space Flight Center, and one each of the VLG10-P2 and VLG10-P8 design, built at the Smithsonian Astrophysical Observatory.

INTRODUCTION

Earlier tests[1] of hydrogen maser frequency standards at the Haystack Observatory had shown maser standards to be quite sensitive to temperature, pressure and magnetic field. Over the past few years several improvements have been made in hydrogen maser standards. SAO has eliminated the pressure sensitivity evident in the original VLG masers and NASA has decreased the temperature and magnetic field sensitivity evident in the NP masers with a new generation of masers to be based on the NX-2 design.

Recently three hydrogen masers have been operated simultaneously at the Haystack Observatory. Long term stability still appears limited by environmental sensitivity of the masers but drifts of less than a part in 10^{13} have been observed for periods extending over several days.

ENVIRONMENTAL SENSITIVITY MEASUREMENTS

The sensitivity of various frequency standards to temperature, pressure and magnetic field have been measured by placing the standard in an enclosure at the Westford facility 1.2 km away from the reference standard at Haystack Observatory. The pressure within the enclosure at Westford can be changed by ~0.15" Hg by changing the Westford antenna "balloon" radome pressure from low to high limits. Figure 1 illustrates the small but noticeable effect of cycling the pressure (with a 3-hr period) at Westford upon the frequency of the SAO built VLG-10-P2 maser using the NASA NP-2 as reference. A pressure sensitivity coefficient can be determined by synchronously averaging many pressure cycles.

Table 1 summarizes the enviornmental sensitivities measured from early 1975 to the present; the data was obtained by cycling one environmental parameter at a time.

[1] A.R. Whitney, et al., "Applications of very-long-baseline interferometry and geodesy: Effects on accuracy of frequency-standards instability", Proc. of 6th Annual DOD/NASA PTTI Planning Meeting, Wash., D.C., 1974.

The SAO VLG masers were originally quite sensitive to barometric pressure. Modifications* have been made to the base plate of the vacuum chamber which have reduced the pressure sensitivity to the point where it is now not possible to see correlation between frequency and barometric pressure variations.

Figure 2 shows the long term frequency variations between NP-2 and NX-2. For these measurements NP-2 was located at Haystack and NX-2 at Westford. Frequency comparisions were made using a 5 MHz phase comparator and electronically compensated cables. Each point is the average frequency for a time interval of 900 seconds. The variations present are highly correlated with temperature variations in the room in which NP-2 was operating, although the correlation is somewhat complicated by the action of the NP-2 maser autotuner† which attempts to correct the cavity tuning with a time constant of several days. A temperature coefficient of $-3 \times 10^{-14} (^\circ C)^{-1}$ was measured using a 3 hour temperature cycle period. However the temperature coefficient derived from the data in Figure 2 is almost $-1 \times 10^{-13} (^\circ C)^{-1}$ because the maser's thermal time constant is sufficient to smooth out the variations in a 3 hour cycle, but not over the much longer time span presented in Figure 2. NX-2 appears to have a thermal time constant as long as 3 days and the coefficient given in Table 1 was derived using a 24 hour temperature cycle. The temperature coefficient of NX-2 derived from observing the effect of a temperature step after 2 days is approximately $5 \times 10^{-14} (^\circ C)^{-1}$. Note that there is no correlation with the large barometric pressure changes associated with hurricane "Belle" as neither maser is measurably sensitive to barometric pressure.

CONCLUSIONS

While many improvements have been made in the latest generation of hydrogen masers, their long term stability may still be limited by variations in the environment in which the maser is operated. Currently it is possible to maintain long term drift within 1×10^{-13} provided room temperature is held within 1°C. Continued intercomparison of masers in separate environments may be useful in further evaulation of environmental effects and long term aging which have so far been undetected. Improved hydrogen maser performance is

*R.C. Vessot - Private Communication

†For all the measurements reported the NP masers were autotuned against an HP105 crystal oscillator.

important in the development of increasingly accurate geodesy and astronomy using very-long-baseline interferometry (VLBI).

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FIGURE CAPTIONS

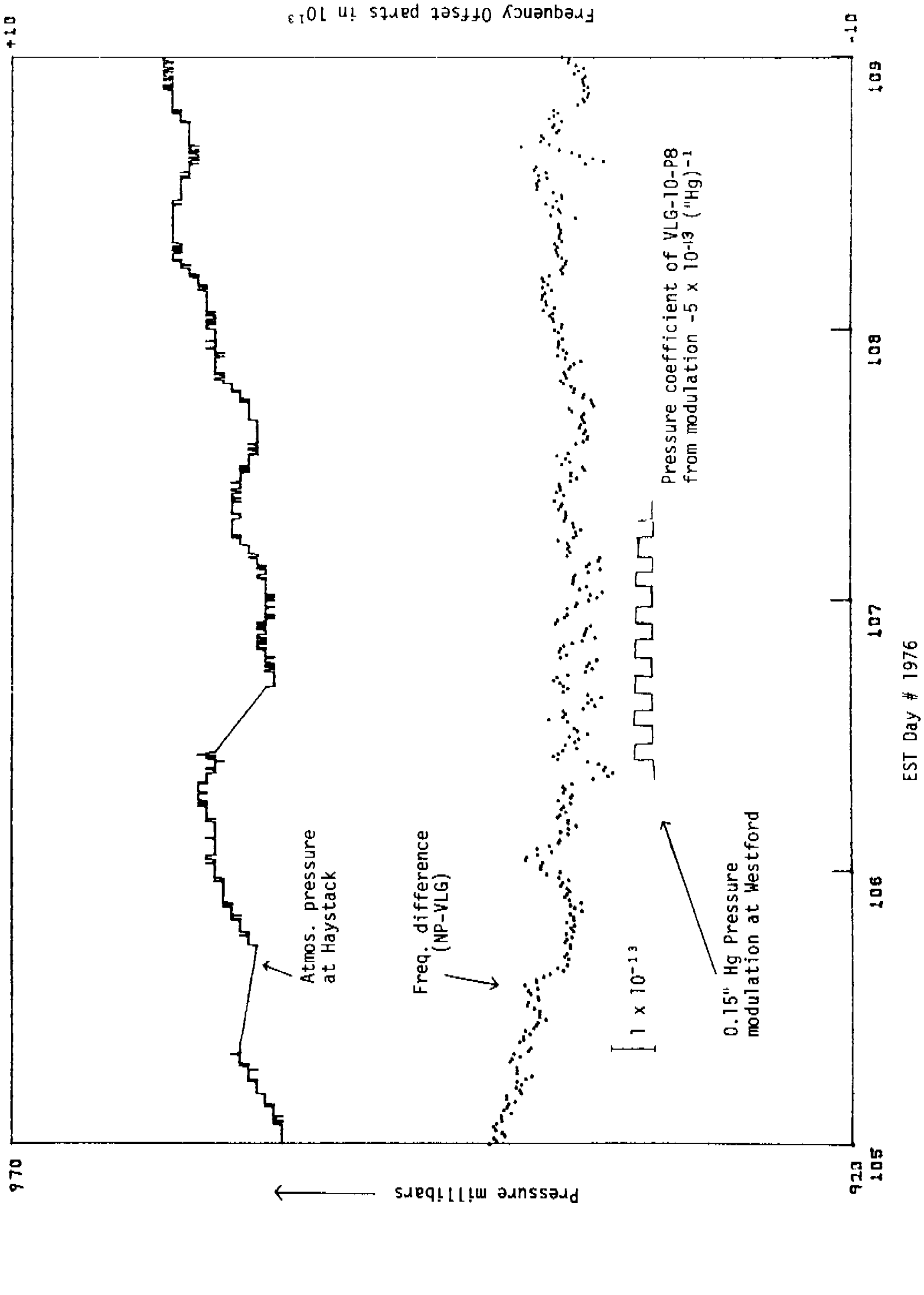
Figure 1. The effect of barometric pressure changes on the frequency of the SAO VLG-10-P2 maser before modification. (After modification the effect of 0.15" Hg pressure modulation on maser frequency were not detectable - see Table 1.)

Figure 2. The effect of temperature variations on the frequency of the NASA NP-2 maser.

Frequency Standard	Temperature* Sensitivity	Thermal time constant	Pressure Sensitivity	Magnetic Field Sensitivity	Date of Measurement	Ref. Standard
SAO-VLG-10-P2 before mod.	$-1\times10^{-13}(°C)^{-1}$		$-3.5 \rightarrow -6.0\times10^{-13}$ $(''Hg)^{-1}$	1×10^{-12} $(Gauss)^{-1}$	Jan. 75	NP-3
NASA NP-3 before mod.	$-2\times10^{-14}(°C)^{-1}$		$<4\times10^{-14}(''Hg)^{-1}$	5×10^{-12} $(Gauss)^{-1}$	Jan. 75	VLG-10-P2
SAO-VLG-10-P8			$-5 \pm 1\times10^{-13}(''Hg)^{-1}$		Apr. 76	NP-2
NASA NP-2 before mod.	$-3\times10^{-14}(°C)^{-1}$	Several days			Apr. 76	VLG-10-P8
SAO-VLG-10-P2			$<4\times10^{-14}(''Hg)^{-1}$		Jul. 76	NP-2
NASA-NX-2	$2\times10^{-14}(°C)^{-1}$	≃3 days			Sept 76	NP-2
SAO-VLG-10-P4	$-5\times10^{-14}(°C)^{-1}$	1 day	$<1.7\times10^{-14}(''Hg)^{-1}$		Nov. 76	VLG-10-P2

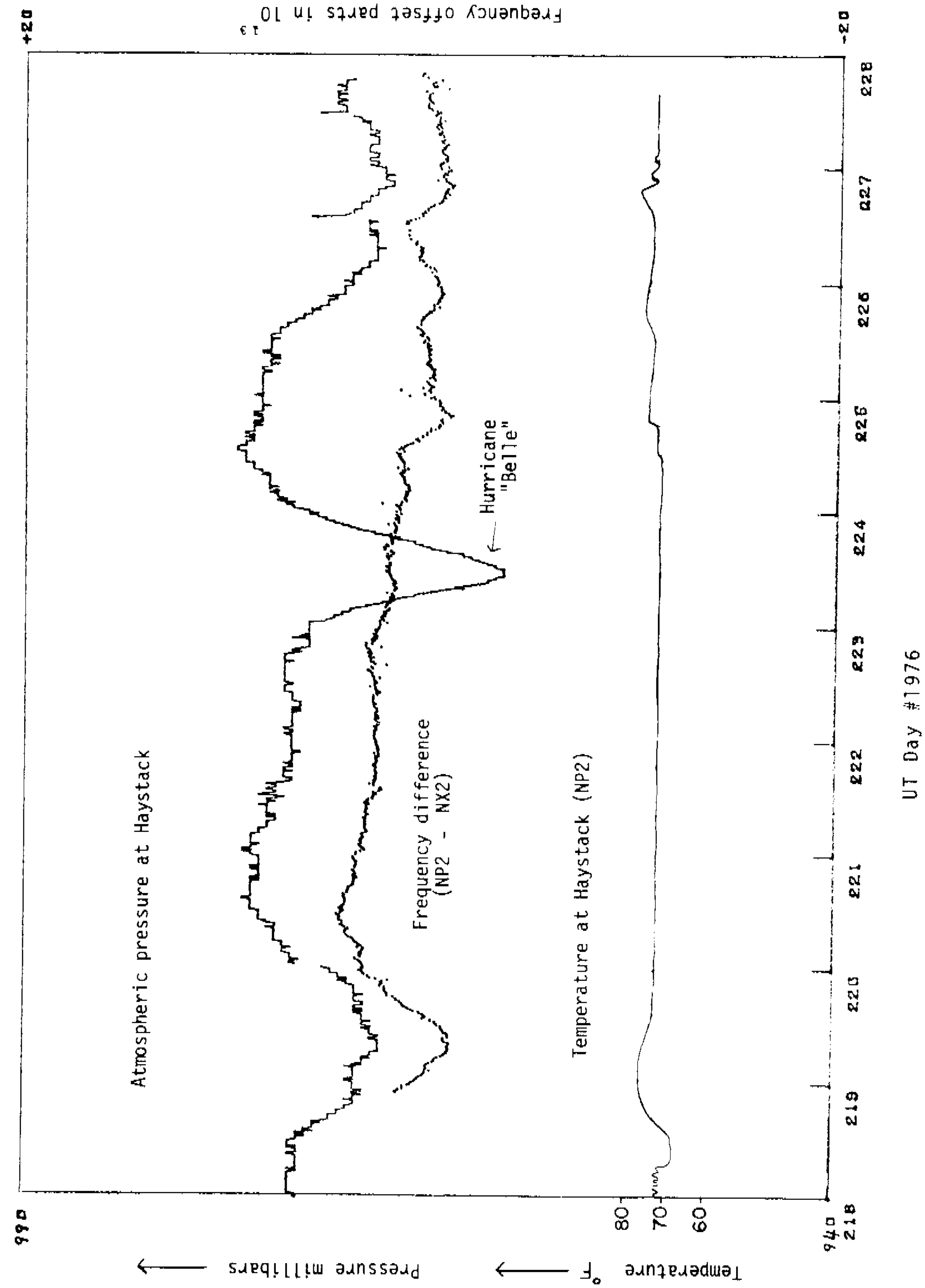
*NP and NX masers have larger temperature sensitivity when the effect of their long thermal time constant is removed - see text

TABLE 1
Environmental Sensitivity of Several Hydrogen Maser Frequency Standards



970
923
Pressure millibars
+10
-10
Frequency Offset parts in 10^{13}
Atmos. pressure at Haystack
Freq. difference (NP-VLG)
1×10^{-13}
0.15" Hg Pressure modulation at Westford
Pressure coefficient of VLG-10-P8 from modulation -5×10^{-13} ("Hg)$^{-1}$
105
106
107
108
109
EST Day # 1976

Figure 1



Frequency offset parts in 10^13
+20
-20
990
940
Pressure millibars
Temperature °F
80
70
60
218
219
220
221
222
223
224
225
226
227
228
Atmospheric pressure at Haystack
Frequency difference
(NP2 - NX2)
Temperature at Haystack (NP2)
Hurricane
"Belle"
UT Day #1976

Figure 2