LONG-TERM FREQUENCY STABILITY OF A NASA PROTOTYPE HYDROGEN MASER

A. S. Risley, D. W. Allen, J. E. Gray, J. H. Shoaf, H. E. Machlan, D. J. Glaze
National Bureau of Standards, Boulder, Colorado
H. E. Peters, E. H. Johnson
NASA-Goddard Space Flight Center, Greenbelt, Maryland
R. F. C. Vessot, M. Levine
Smithsonian Astrophysical Laboratory, Cambridge, Massachusetts

Introduction

Many applications of frequency standards require excellent stability over averaging times from a few seconds to an hour. Timekeepers, on the other hand, desire that their sources of periodicity--the frequency standards--be stable over indefinitely long times. Hence, an experiment to determine the quality of a frequency standard for use in a time scale takes a very long time to perform. This paper reports the effect of including a state-of-the-art hydrogen maser--the NASA (GSFC) prototype hydrogen maser which has been named NP3--in the NBS (Boulder) time scale system (AT(NBS)) for a period of about three months. In addition to its effects on the time scale we discuss the stability of NP3 versus AT(NBS) and NP3 versus a second hydrogen maser. The second is an experimental maser developed at the Smithsonian Astrophysical Observatory (SAO). For averaging times of 4×10^4 seconds and longer, we substantiate and extend the stability characteristics for the NASA maser given by Peters, et al.[1]

The Measurement Methods

The time-difference method

The NBS atomic time scale consists of a continually calibrated clock ensemble. Each clock is composed of a very stable frequency generator and a divider to generate 1 pulse per second (pps). For this experiment the frequency generators were commercial cesium beam frequency standards. Details of this time scale will be discussed elsewhere.[2] The essential point here is that a weighted combination of the predicted times given by each clock was used to achieve near optimum prediction of true time. AT(NBS) is this weighted clock ensemble. The time difference between any two clocks involved was measured each working day during the experiment (24 Nov 69 to 20 Feb 70) to a precision of 1 nanosecond.

A 1-pps signal was available from NP3, and this signal was used to study the relative stability of NP3 versus AT(NBS) and to also ascertain what effect the inclusion of NP3 into the clock ensemble had upon the precision of the time scale.

The chronograph

The relative stability between the two H-masers was measured by a new system which we call the chronograph.[3] The function of this system is to automatically measure and record the zero crossings of the beat frequency between a pair of oscillators. The chronograph has a dynamic range of about seven decades with typical beat frequency values of about 10^{-1} Hz. The precision of the chronograph was tested and shown not to degrade the stability measurements of the frequency standards in question.

Results

The inclusion of NP3 into the AT(NBS) scale gave a definite improvement in the precision of the scale for prediction times of a few days. The best improvement, more than 40%, was for a single day.

Figure 1 shows the stability $\sigma_y(N=2, T=\tau, \tau)$ for NP3 versus AT(NBS) where $y = \delta\nu/\nu$ and this stability measure is as defined in reference 4. The first four points (τ = 1 through 4 days) are representative of the stability of AT(NBS). Figure 2 shows the frequency fluctuations of NP3 versus AT(NBS) when averaged for four days.

The NP3 maser versus the SAO maser gave a $\sigma_y(N=2, T=\tau, \tau=40{,}000\text{s})$ of 2×10^{-14}. Combining this result with $\tau > 4$ days from Fig. 1 gives excellent agreement with the most optimistic estimates of Peters, et al [1] for the NASA maser stability, and extends a knowledge of the stability behavior for sample times as long as 44 days with a $\sigma_y(N=2, T=\tau, 4 \text{ days} < \tau < 44 \text{ days}) \simeq 1 \times 10^{-13}$.

References

1. Peters, H. E., Johnson, E. H., and McGunigal, T. E., Private communication (1969). This information will be published in the form of a graph in the body of our paper.

2. Allan, D. W., Gray, J. E., and Machlan, H. E., The NBS Time Scale System: AT(NBS), SAT(NBS), and UTC(NBS), to be published.

3. Gray, J. E., and Heim, L. E., to be published.

4. Allan, D. W., Statistics of Atomic Frequency Standards, Proc. IEEE, vol. 54, no. 2, p. 221 (February 1966).

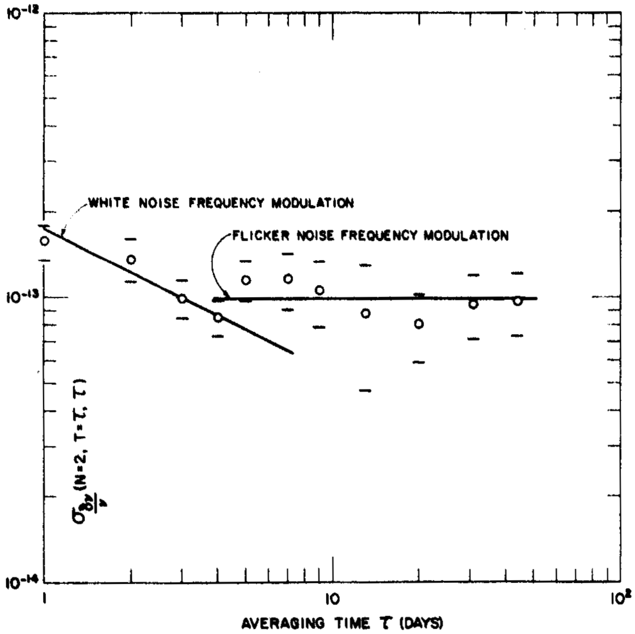

Figure 1. The stability $\sigma_y(N = 2, T = \tau, \tau)$ for NP3 versus AT(NBS) as a function of averaging time τ (where $y \equiv \delta\nu/\nu$ and this stability measure is as defined in [4]).

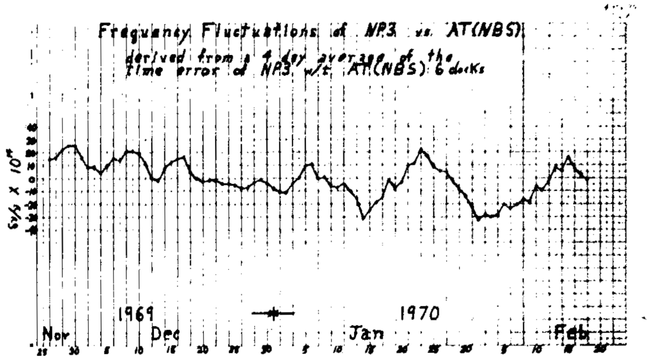

Figure 2. The frequency fluctuation of NP3 versus AT(NBS) as calculated from the time error of NP3 with respect to AT(NBS): 6 clocks. (An averaging time of 4 days was used here to minimize the effect of the fluctuations of AT(NBS).)

A. S. Risley et al., "Long-term Frequency Stability of a NASA Prototype Hydrogen Maser," (Summary) CPEM Digest 1970 Conference on Precision Electromagnetic Measurements (Institute of Electrical and Electronic Engineers, New York, 1970), pp. 74-75.

* * *