Station Stability Measurement

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Methods and instrumentation are being developed to determine the frequency stability of Deep Space Stations. The efforts are presently focused on the verification of the stability of the X-band uplink and other RF and microwave subsystems which contribute to the overall stability of the system. The measurement methodology is presented as well as frequency stability data generated with the development measurement system. The system characteristics are highlighted and the potential areas where improvements could be made are discussed.

I. Introduction

The measurement of frequency stability has been of concern in the DSN since the implementation of the hydrogen masers. Highly stable reference signals derived from the hydrogen maser degrade as these are distributed and processed throughout the station. In addition, requirements for greater tracking accuracies and space-charged particle calibrations have given impetus to the development of an X-band uplink with much-improved short- and long-term frequency stabilities that need to be verified in the station. A method, described below, is being developed to determine the overall stability of a Deep Space Station (DSS) by measuring the contributions of key elements of the RF and microwave subsystems. Previously, it was not possible to make these measurements on the station site, and components could be measured only by special laboratory techniques. The new method described below is presently being used for measuring the frequency stability of a Block III receiver in Compatibility Test Area (CTA) 21. After completion of the tests at CTA 21, the stability measurement equipment will be transported to Goldstone for measurements at DSS 13, which will have the X-band uplink capability. The outcome of these measurements at DSS 13 will be the demonstrated frequency stability of the overall system as a function of operating modes and conditions.

The approach for measuring frequency stability at the station utilizes recently developed commercial instrumentation in conjunction with specially built frequency translators to interface the key RF and microwave assemblies in the DSS with the measurement equipment. This approach was selected after an investigation of the state of the art in the measurement of frequency stability. The commercial instrumentation chosen as the initial development tool was the Hewlett-Packard Frequency Stability Analyzer, Model HP5390A. The basis for the selection was performance, availability, and portability. It was necessary, however, to experimentally assess the HP5390A system capabilities with respect to ultrastable sources such as the hydrogen masers. Evaluation test results obtained at JPL's Interim Frequency Standards Test Facility (IFSTF) are presented below after a discussion of the measurement methodology. Finally, the initial frequency stability data obtained at CTA 21 on Block III receiver are presented.

II. Measurement Methodology

Stability (or instability) refers to the degree to which a signal departs from a nominal value over a designated time interval. The generally accepted method of determining frequency stability in the time domain is by the two-sample deviation (or the square root of the Allan Variance). The theory and justification for the two-sample deviation is well-understood (Ref. 1), and it is sufficient here to state only the working equation. The two-sample fractional frequency deviation, $\sigma_{\Delta f/f}(N, \tau)$, is given by

$$\sigma_{\Delta f/f}(N, \tau) = \frac{1}{2N} \sqrt{\sum_{i=1}^{N} \left(\frac{\Delta f_{i+1}}{f_o} - \frac{\Delta f_i}{f_o} \right)^2} \qquad (1)$$

in which τ is the time interval over which the RMS deviation of the signal from the carrier is measured, N is the number of samples to be averaged, f_o is the nominal frequency, Δf_{i+1} and Δf_i denote the two contiguous samples of frequency deviation averaged over the time period, τ. To get meaningful stability data with the above working expression one requires a sufficiently large number of statistical samples, typically 100 samples for values of $\tau < 10$ seconds and 25 samples for values of $\tau \sim 10^3$ seconds. The large number of samples and long averaging times imply that the measured deviation includes the effects of noise, spurious signals, and short-term drifts. These effects become important considerations with respect to the measurement equipment. The components of the measurement system have been selected for their high stability, thereby minimizing noise and spurious signals. However, because there are some temperature-sensitive components that may affect the measurements, especially in a field environment, the use of temperature-stabilized ovens to control these components has been considered to eliminate temperature-related drifts. The measurement equipment components are described in the paragraphs below.

The standard method of measuring the frequency stability of a signal in the time domain is illustrated in Fig. 1. The beat frequency, f_b, is filtered, amplified, and measured with a period counter over an interval of time, τ. The commercially available Hewlett-Packard System (HP5390A) uses a similar method, and comprises five major components: a mixer/amplifier unit, a high-resolution reciprocal counter, a measurement storage plug-on unit, a desk-top calculator, and a printer/plotter output device. Communication and control between the various instruments is provided by a digital interface bus. A block diagram of the HP5390A system is shown in Fig. 2. The measurement process is controlled via software supplied with the system. The key features of the HP5390A system are that it is compact, portable, and that it uses the generally accepted algorithm for calculating fractional-frequency deviation.

The technique developed for making the stability measurements at any DSS utilizes the HP5390A in conjunction with a synthesizer and a frequency translator to provide stable offsetable signals. The block diagram illustrating this method is shown in Fig. 3. The salient feature of this technique is that a large number of signals with different frequencies can be measured without requiring different reference oscillators. For example, at the DSS 13 receiver, the anticipated number of points to be measured is twelve. Each of these points has a different frequency over the range 10 kHz to 8400 MHz. The synthesizer depicted in Fig. 3 covers a narrow frequency range (10 kHz-1200 MHz), and frequency translators especially designed for the frequencies of interest are used to provide the frequencies above 1200 MHz. The use of the synthesizer and the frequency translators allows the overall system to be independent and totally portable.

The key set of measurements at DSS 13 will be performed on the exciter which is being developed for the X-band uplink. This exciter will have greater phase stability (Ref. 2) than its predecessors and will require the measurement system to have a fractional-frequency deviation noise floor lower than 1×10^{-15} for sampling times of 1000 seconds. This noise floor level is the most difficult requirement that must be met by the measurement system.

In order to make meaningful measurements and to determine that a noise floor $< 1 \times 10^{-15}$ can be achieved, it is necessary to fully characterize the HP5390A system along with the synthesizer and frequency translators, so that measurement errors will not be introduced inadvertently by any component. To this extent, efforts have been made to characterize synthesizers and translator components with respect to frequency instabilities. In addition, the HP5390A system and synthesizers have been tested at JPL's Interim Frequency Standard Test Facility against the equipment used for measuring the stability of hydrogen masers. The following section describes the tests performed and the results obtained.

III. Experimental Results

To ascertain the capabilities of this initial development system, use was made of JPL's Interim Frequency Standard Test Facility (IFSTF), which is equipped to make two-sample $\Delta f/f$ deviation measurements. Hydrogen masers with well-known stability characteristics were used as the reference oscillators. A series of tests was made, and data measured with the HP5390A system were directly compared with those measured with the IFSTF equipment that provided the standard.

The most stringent test that the HP5390A was subjected to was the measurement of two hydrogen masers. One of these masers (DSN2) was used as the reference oscillator, and the other one (DSN3) was used as the test oscillator. The test setup used is that shown in Fig. 2. The objective of this test was to obtain the measurement capability of the HP5390A when operating with very stable inputs and at its limit with respect to the smallest allowable offset frequency (1 Hz). A 1-Hz frequency offset was the largest frequency difference that could be obtained between two hydrogen masers. In addition, the measurement bandwidth of the IFSTF equipment is fixed at 1 Hz, and measurements with larger frequency offsets cannot be easily made. To make the HP5390A system comparable with the IFSTF equipment, a 1-Hz low-pass filter was externally connected to the mixer/amplifier module of the HP5390A. The measurements were taken simultaneously and the results are shown in Fig. 4 where the two-sample deviation is plotted as a function of τ, the sampling time interval.

It is evident from the plots that a significant discrepancy exists at all values of τ to 1000 seconds. The data shown in Fig. 4 are somewhat typical in that all the $\Delta f/f$ deviations measured with HP5390A system were usually 25 to 50 percent higher than the deviations measured with the IFSTF equipment. For example, a simultaneous test was performed with the two measurement systems on a cesium maser. The DSN3 hydrogen maser was used as the reference oscillator. In this particular application, the measurement was made at least two orders of magnitude above the noise floor of the HP5390A and data discrepancies between the two systems were not expected. The results of this test are shown in Fig. 5. In this case also a discrepancy between the two systems is noted, and it is about 25 percent.

A systematic discrepancy of the type exhibited by the aforementioned tests is acceptable providing all possible uses of the equipment are known, and providing the system is calibrated for each particular use. Another proviso is that the cause for the discrepancy must be known in order to ascertain whether it truly is systematic. An experiment that sheds light on this subject was performed and points to future improvements to the HP5390A system.

The experiment performed was essentially a repeat of the first test described above. In other words, the setup shown in Fig. 4 was used except that the mixer/amplifier of the HP5390A was disconnected, and instead the mixer/amplifier of the IFSTF equipment was used. The results of this stability test are shown in Fig. 6. In this case, the systematic measurement discrepancy was eliminated and the IFSTF data points are within the repeatability of the HP5390A system. Error bars are shown on the data points taken with the HP5390A system "as is" to show that the new data is beyond the measurement error.

The above test data point to the HP5390A's mixer/amplifier unit as being noisier and/or wider in bandwidth than the IFSTF's mixer/amplifier. This aspect will be investigated as soon as possible because the outcome will quickly transform the measurement system from a developmental stage to a field-ready system capable of standard test-laboratory accuracies.

Other tests performed at the Interim Frequency Standard Test Facility were to characterize the stability of various synthesizers to determine their noise floor. Comparative data are shown in Fig. 7, which depicts the frequency stability of three Dana synthesizers and one from Hewlett-Packard (Model 8662A). These plots exhibit only the contribution of the synthesizers since these are data measured with the IFSTF test equipment. The lower noise floor generally exhibited by the HP8662A makes this synthesizer the indicated one for use in the station stability measurement systems, except for measurements of the X-band uplink. The noise floor of the HP8662A synthesizer is higher (4×10^{-15}) than the requirement for the X-band uplink exciter. For the X-band uplink measurements the synthesizer will be deleted, and only frequency translators (multipliers) will be used. In practice, by proper selection, phase-locked multipliers exhibit greater frequency stability than the hydrogen maser. Thus, the noise floor expected for the X-band uplink measurements is essentially that shown in Fig. 4 for the HP5390A. In addition, significant margin can be obtained by improving the mixer/amplifier unit.

After the selection of the HP8662A synthesizer for use in conjunction with the HP5390A Frequency Stability Analyzer for the less stringent requirements, the two were tested as a system. This test would confirm the method shown in Fig. 3 and also establish its noise floor. This is particularly true because the frequency translators will have a significantly lower noise floor than that of the synthesizer. The signal source selected for this test was that from the hydrogen maser, DSN2. The test setup for this measurement along with the test results are shown in Fig. 8. The discrepancies between the two sets of data are attributed partly to the fact that the tests cannot be absolutely simultaneously conducted and partly due to the repeatability of both systems.

To affirm the notion of portability and on-site measurements, fractional-frequency deviation tests have been performed at CTA 21 using the method shown in Fig. 3. These are only initial measurements but they lend credence to the correctness of the application. As the specially designed frequency translators are built and tested, more test points will be measured until DSS 13 is fully characterized. The key test points of the Block III receiver and X-band uplink exciter are delineated in Table 1. In the table, the expected two-sample, fractional-frequency deviations are also given, as well as the noise floor expected from the frequency translators. The initial experimental data acquired at CTA 21 on a Block III receiver are presented in the table. The estimated value of 1×10^{-13} for $\tau = 1000$ seconds is an extrapolation from the measured data. New table entries of measured stability will be made as the different points in the receiver and exciter are measured. It is important to stress that the preceding efforts and those to take place at CTA 21 are preparatory to the actual measurements to be taken at DSS 13. However, the above experiments and the data generated from them give sufficient confidence that meaningful measurements of frequency stability can be made on the DSS 13.

IV. Conclusion

The investigation to determine the frequency stability of a Deep Space Station has led to a method for making stability measurements at the station site. The method will measure the fractional-frequency deviations of the key components of the RF and microwave subsystems. The goal is to identify the assemblies or subsystems that must be improved to obtain balanced system performance consistent with the X-band uplink stability and that of the hydrogen maser frequency standard.

The method utilizes a synthesizer and specially built frequency translators in conjunction with the HP5390A Frequency Stability Analyzer. Calibration tests have been performed on the HP5390A system and HP8662A synthesizer, and the results indicate that the system is capable of measuring the frequency stabilities expected in the Block III receiver and exciter subsystems. The frequency stability measurement system as delineated above is currently in use, testing a Block III receiver in CTA 21. The stability measurements at DSS 13 will be performed when the special frequency translators are built and tested. With respect to improved performance of the measurement system, it has been determined that by improving the mixer/amplifier unit, the present system can make a leap from its present developmental stage to a field-ready system capable of standard test-laboratory accuracies. The exploitation of this measurement capability will aid in improving DSN capability.

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References

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2. Hartop, R., Johns, C., and Kolbly, R., "X-Band Uplink Ground Systems Development," *DSN Progress Report 42-56*, pp. 48-58, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 1980.

Table 1. Block III Receiver/Exciter Measurement Points

DSS 13 CTA 21	Blk III/rcvr/exciter assemblies	Estimated $\Delta f/f$ deviation for τ = 1000 sec	Measured $\Delta f/f$ deviation	
10 MHz	Rcvr output	$\sim 2.0 \times 10^{-13}$	1.02×10^{-10} for τ = 1 sec	for 10 MHz
10 MHz	Rcvr output (after mix)		2.43×10^{-11} for τ = 4 sec	
			9.50×10^{-12} for τ = 10 sec	
			2.44×10^{-12} for τ = 40 sec	
			9.11×10^{-13} for τ = 100 sec	
			2.89×10^{-13} for τ = 400 sec	
			(Estimate 1.0×10^{-13} for τ = 1000 sec)	
50 MHz	Rcvr front-end output		1.43×10^{-14} for τ = 1000 sec	for 50 MHz
69 MHz	Rcvr RF loop			
66 MHz	S-band xltr in	$\geqslant 8.0 \times 10^{-14}$		
2105 MHz	S-band xltr S-band xmtr	$\geqslant 8.0 \times 10^{-14}$		
2295 MHz 2295 MHz	S-band xltr test sig S-band maser output	$\sim 1.2 \times 10^{-13}$		
2245 MHz	S-band lo	$\sim 1.0 \times 10^{-13}$		
7200 MHz	X-band uplink exciter output	2.0×10^{-15}		
8400 MHz 2300 MHz	X-X exc test sig X-X doppler ref X-S exc test sig X-S doppler ref	4.0×10^{-15}		

Note: Expected $\Delta f/f$ deviation for receiver translators is 5×10^{-15} and 6.5×10^{-16} for the X-band uplink translators.

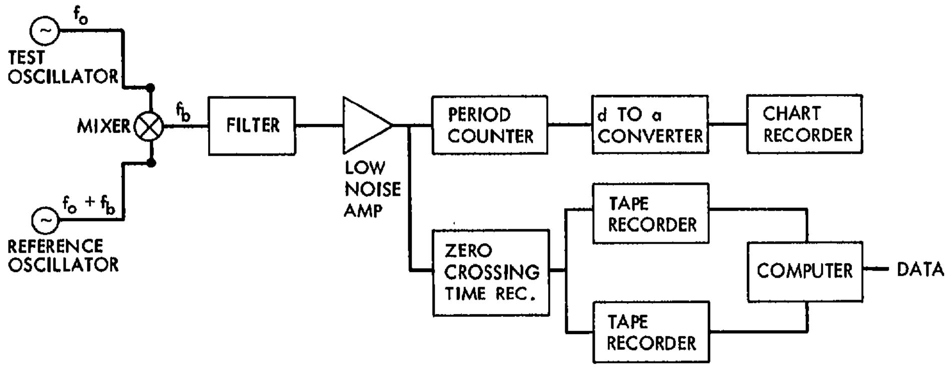

Fig. 1. Standard method of measuring frequency stability

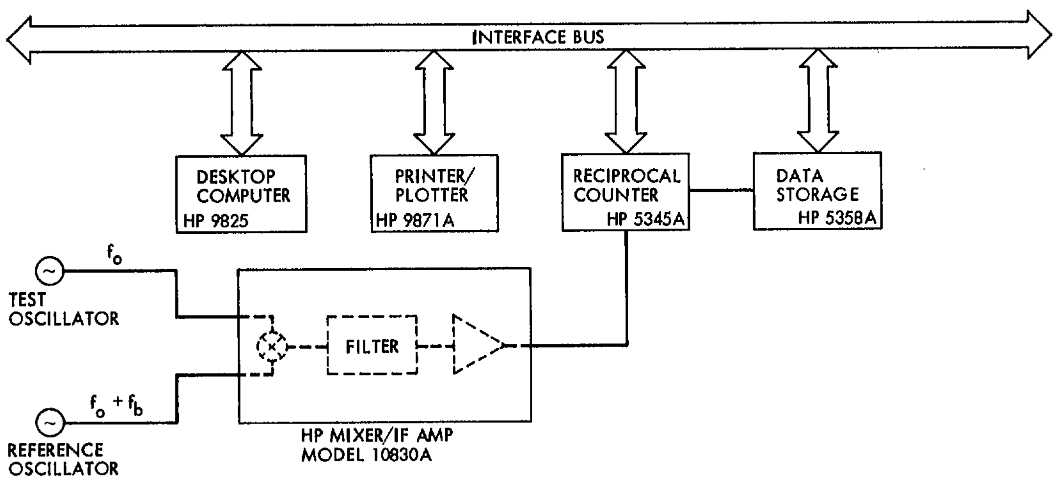

Fig. 2. Block diagram of the HP5390A frequency stability analyzer

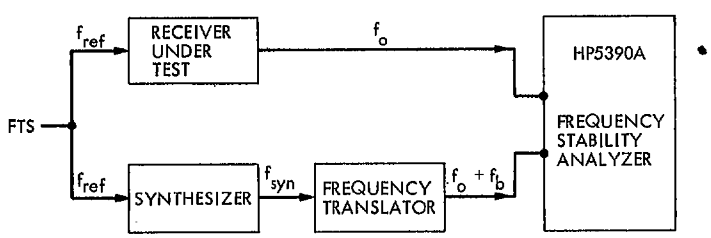

Fig. 3. Measurement method for DSS 13 and DSS 14

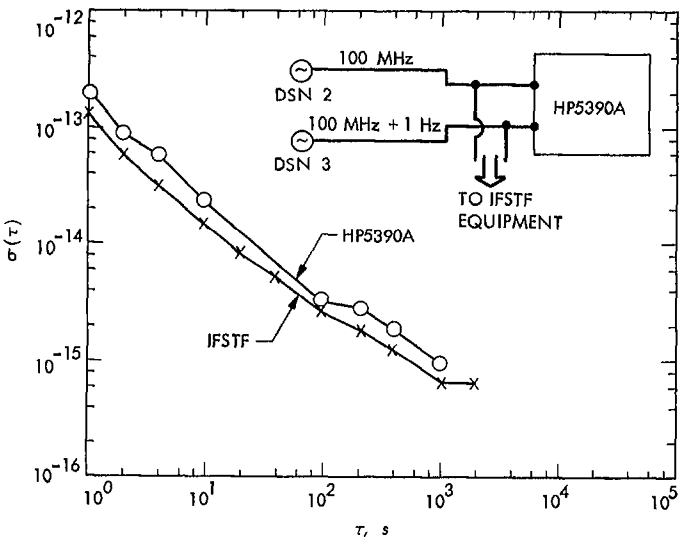

Fig. 4. Fractional frequency deviation noise floor of HP5390A

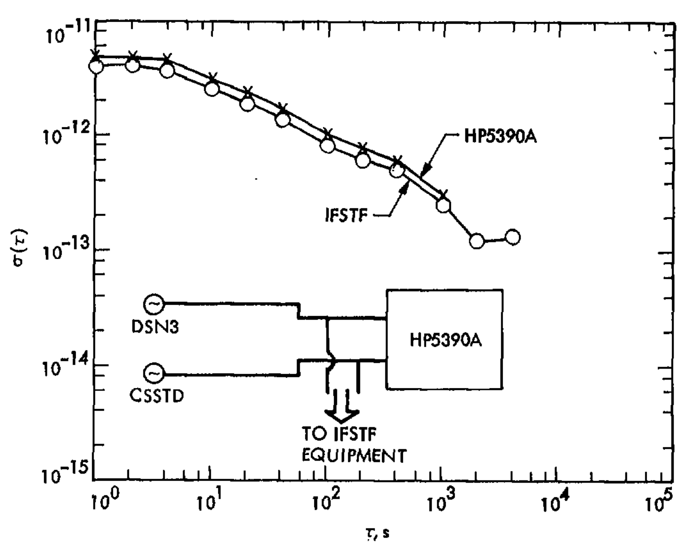

Fig. 5. A cesium standard measured with HP5390A and IFSTF equipment

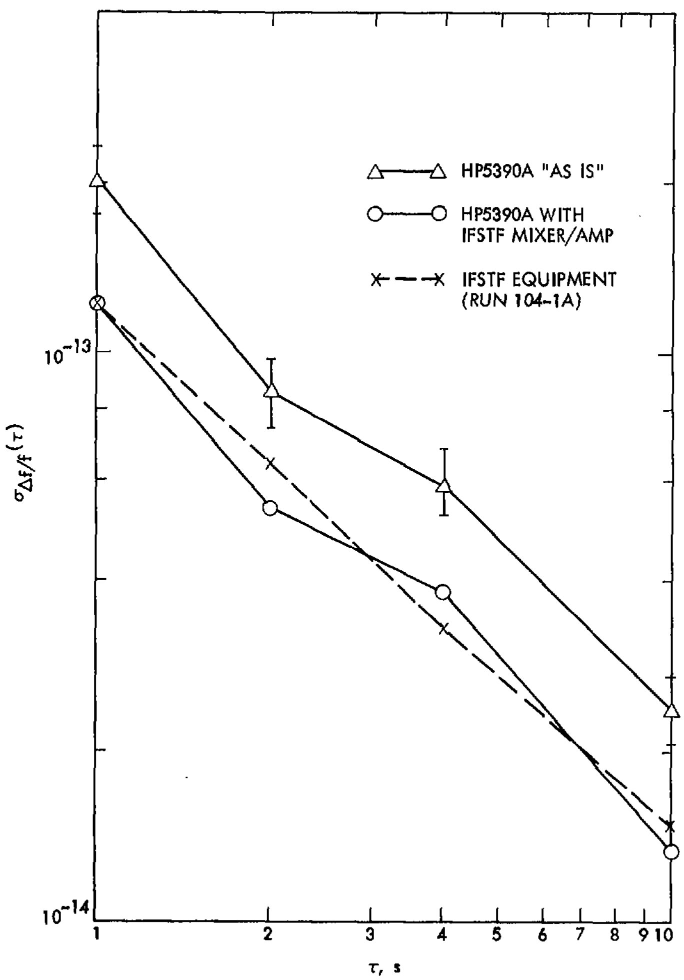

Fig. 6. The IFSTF mixer/amplifier unit eliminates systematic measurement error

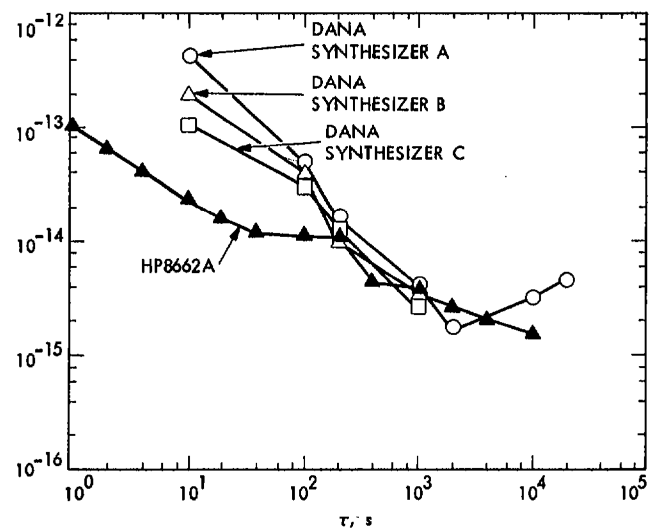

Fig. 7. The HP8662A exhibits a lower noise floor

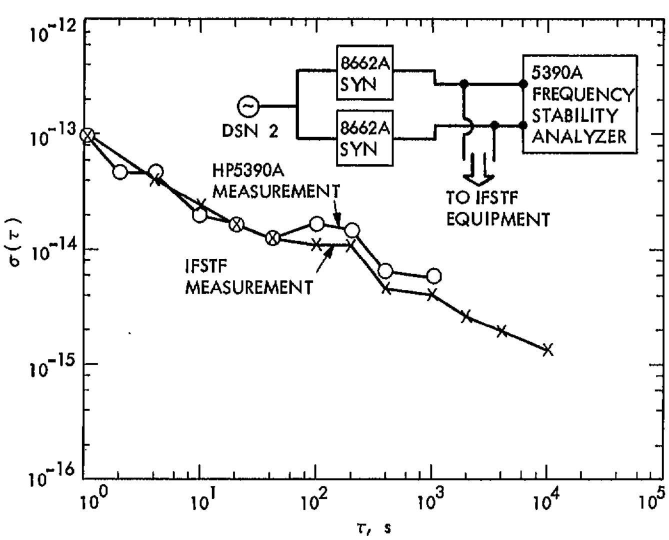

Fig. 8. Noise floor measurement of the HP8662A with the HP5390A