Interoffice

VLBA Electronics Memo No. 114

National Radio Astronomy Observatory

New Mexico
May 11, 1989

To: VLBA Electronics Group

From: Larry Beno

Subject: VLBA Electronics Memorandum

This VLBA technical memorandum contains a report prepared by personnel at the Jet Propulsion Laboratory, Pasadena, California. The report contains stability results of VLBA Maser #2 and #3 measured at JPL.

A few clarifications are in order:

1) Stability data in Figure 3 is the net result between the two masers under test. Assuming identical masers, the Allan variance for a single maser is reduced by 0.707.

2) The magnetic sensitivity results are indeed out of the NRAO specification. This problem was also determined at the factory with Masers #1, 2, and 3. It was discovered that the magnetic shields in these masers were improperly annealed and caused the degraded performance. All subsequent masers contain the proper shields and the sensitivity measured at the factory meets the NRAO specification of $2x10^{-14}$ per gauss.

   Typical maximum magnetic field perturbations at the maser location caused by position changes of the VLBA antenna were less than 50 milligauss.

3) The phase noise plot in Figure 6 shows a significant noise increase at frequencies above 30 Hz compared to the 10 Mhz noise in Figure 7. This effect, although not affecting the NRAO spec, will be investigated for future maser improvements.

4) Sidebands @ 33 Hz in Figure 8 are caused by the Auto-tuner cavity switching frequency. These sidebands are typically -75 dBc in all masers. After the JPL tests all VLBA masers have been modified for a switching frequency of 57.1 Hz. Any loss of correllation can be improved by turning off the Auto-tuner. The Auto-tuners time constant is set to improve stability beyond 10^4 seconds.

5) VLBA maser specification: A53308N001.

TEST REPORT

OPERATING AND ENVIRONMENTAL CHARACTERISTICS OF SIGMA TAU MODEL VLBA–112 HYDROGEN MASERS

Prepared
by:
Thomas K. Tucker
Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, CA 91109

In cooperation
with:
The National Radio Astronomy Observatory
2015 Ivy Road
Charlottesville, VA 22903–1797

Abstract

This report presents the results obtained from performance evaluation of a pair of Sigma Tau Standards Corporation, Model VLBA–112, active hydrogen maser frequency standards. These masers were manufactured for the National Radio Astronomy Observatory (NRAO) for use on the Very Long Baseline Array (VLBA) project and were furnished to the Jet Propulsion Laboratory (JPL) for the purpose of these tests.

Tests on the two masers were performed in the JPL Frequency Standards Laboratory (FSL) as a cooperative effort with NRAO, and included the characterization of output frequency stability versus environmental factors such as temperature, humidity, magnetic field, and barometric pressure. The performance tests also included the determination of phase noise and Allan Variance using both FSL and Sigma Tau masers as references. All tests were conducted under controlled laboratory conditions, with only the desired environmental and operational parameters varied to determine sensitivity to external environment.

Contents

1 Introduction

1.1 Purpose:

The tests described herein were performed by the Jet Propulsion Laboratory (JPL) as a cooperative effort with the National Radio Astronomy Observatory (NRAO). JPL was chosen for this evaluation because of its unique testing capability and facilities, and in order to provide an independent evaluation of Sigma Tau hydrogen maser performance. Support for these tests was provided by the JPL Deep Space Network Advanced Systems Program, Frequency and Timing Research RTOP62.

All tests were conducted at JPL in the Frequency Standards Research Laboratory Test Facility in Pasadena, California, between March and September 1988.

1.2 Sigma Tau Hydrogen Masers:

The Model VLBA–112 is a compact and ruggedized active hydrogen maser manufactured by the Sigma Tau Corporation for NRAO for use on the Very Large Baseline Array (VLBA) Project. The essential physical and electrical characteristics, as given by the manufacturer, are outlined in Table 1 below:

Table 1.
Physical and Electrical Characteristics:

Size:	Height	107cm (42 inches)
	Width	46cm (18 inches)
	Depth	76cm (30 inches)
Weight:	238kg (525 lbs)	
Input Power:	AC 115V ±10% rms, 50–60 Hz, 140 Watts	
	DC 24 to 28 V, 4 Amp. (typ.)	
	Built–in Standby Battery Supply	
Outputs:	100 MHz (2 ea.), 1 ±0.3V rms	
	10 MHz (1 ea.), ≈0.5V rms	
	5 MHz (2 ea.), 1 ±0.3V rms	

1.3 Test Facilities:

The JPL Frequency Standards Laboratory is responsible for the research, development and implementation of a wide variety of state–of–the–art frequency generation and distribution equipment used within the Deep Space Network (DSN). In order to achieve the demanding performance and reliability requirements, a substantial amount of assembly and subassembly testing is required. Toward this end, an extensive testing capability has been developed which includes special equipment, facilties, procedures and personnel skilled in the testing and characterization of precision oscillators and other signal sources.

The stability and environmental tests which are routinely performed, in this facility, are as follows:

1. Allan Variance	4. Humidity Sensitivity
2. Spectral Density of Phase	5. Barometric Pressure Sensitivity
3. Temperature Sensitivity	6. Magnetic Field Sensitivity

The instrumentation and test area has approximately 2,700 square feet of floor space, and houses the necessary instrumentation and test equipment. Additionally, two active hydrogen maser frequency references are conveniently located in this area. All critical equipment as well as the units under test are powered by an uninterruptable power source. The entire test area, as well as the environmental control system is backed up by an automatically switched motor generator. Temperature control is maintained to within ±0.05 degrees Centigrade through the use of a doubly redundant air conditioning system. Ambient magnetic field variations are minimized by the use of non–magnetic construction materials throughout the facility. As an additional precaution, one of the reference hydrogen masers is housed in a magnetically shielded enclosure.

Environmental testing capability is provided by three Tenny Corporation environmental test chambers. Each chamber includes 64 square feet of floor space and is approximately 10 feet high, providing adequate space for equipment under test as well as required cables and peripherals.

The environmental testing capabilities are as shown in Table 2 below:

Table 2.
Environmental Test Capability

Parameter	Range
Temperature	15 to 35 deg. C ±0.05 deg.
Pressure	±24 inches of water ±0.5 inches.
Relative Humidity	11 to 90% RH ±5%
Magnetic Field	±0.5 Gauss

1.4 Test Plan

All tests were performed by FSTL personnel, in accordance with a test plan. This plan was prepared to establish the procedures and environmental conditions to be followed during the course of testing. A copy of that plan follows on pages 9 thru 12.

1.5 Measurement Systems

Figure 1 is a block diagram of the measurement system used to determine frequency stability and the Allan variance (deviation) between the Sigma Tau masers and the laboratory reference masers. Figure 2 is a block diagram of the measurement system used to determine the spectral density of phase of the two Sigma Tau masers at the 5, 10, and 100 MHz outputs.

2 TEST RESULTS

2.1 Sequence of Tests:

The tests and test limits are as follows in Table 3:

Table 3.
Test Sequence and Limits

Parameter	Range
Allan Variance	
Spectral Density of Phase	
Temperature	17 to 27 Deg. C
Humidity	20 to 80% RH
Barometric Pressure	±24 inches of water
Magnetic Field	±0.5 Gauss
Power Supply Variations	24 to 28 VDC

2.2 Preliminary Tests:

Prior to the commencement of performance and environmental testing, both masers were tuned and all settings nominalized in accordance with the manufacturers specifications. The critical operating parameters of each of the two masers, identified as Serial Numbers 2 and 3, were then determined and recorded as follows in Table 4.

Table 4.
Operating Characteristics:

Parameter	S/N 2	S/N 3
Output Power:	–100 dBm	–100 dBm
Line Q:	1.82×10^9	1.64×10^9
Cavity Loaded Q:	33,000	37,800
Coupling Factor:	0.35	0.30
Rx Noise Figure:	< 1 dB	< 1 dB
Zeeman Frequency:	827.7 Hz	808.9 Hz

Note: All tests were performed in the AUTOTUNE mode.

2.3 Allan Variance and Spectral Density of Phase Tests:

Figures 3, 4 and 5 are plots of the Allan Variance between the two Sigma Tau masers, and also between each of the Sigma Tau masers and one of the laboratory reference masers which serve to verify near equal performance of the two Sigma Tau masers. Included in Figure 2 is the measurement system noise floor. Figures 6, 7 and 8 are plots of the spectral density of phase between the two Sigma Tau masers at the 5, 10, and 100 MHz outputs. The spurious signals seen in each of the plots is predominantly the result of the autotuner modulation signal with some additional contribution from power supply noise.

2.4 Environmental Tests:

The purpose of these tests was to characterize each maser in terms of frequency shift for a given change in environmental condition. In each test, the output frequency was carefully monitored while one of the environmental conditions was varied as specified in Table 3. The results of each of these environmental tests is itemized below:

1. Output Frequency vs Temperature Tests — The masers were placed individually in the test chamber and the chamber temperature was cycled between 17 and 27 °C, the resultant variation in output frequency was plotted. The frequency sensitivity, of each maser, as a function of ambient temperature is shown in Figure 9.

2. Output Frequency vs Relative Humidity Tests — With the chamber temperature held constant, the chamber relative humidity was cycled between 20% and 80% , with a 48 hour stabilization period at each limit. The observed variations in output frequency vs the relative humidity were well below 1×10^{-14}.

3. Barometric Pressure Tests — No output frequency variations were observed as the masers were individually subjected to barometric pressures of 24 inches of water above and below ambient pressure with a two hour dwell at each extreme.

4. Magnetic Field Sensitivity Tests — In order to determine the maser magnetic field sensitivity, a large (90 inch) Helmholtz coil was placed around the maser. The coil was positioned to provide a vertical magnetic field and was centered around the maser physics unit. Since the magnetic shielding effectiveness is dependent upon the magnitude of the applied magnetic field, the sensitivity was measured at three different field values. The magnetic field sensitivity of each maser is shown in Table 5 below:

Table 5.
Magnetic Field Sensitivity

Field	S/N 2	S/N 3
Small Field (± 0.1 G)	-1.42×10^{-13}/ Gauss	-4.74×10^{-13}/ Gauss
Medium Field (± 0.25 G)	-1.05×10^{-13}/ Gauss	-3.98×10^{-13}/ Gauss
Large Field (± 0.5 G)	-8.04×10^{-14}/ Gauss	-3.17×10^{-13}/ Gauss

5. Output Frequency vs Power Supply Variations — With the internal battery supply disconnected, the input DC voltage was varied between 24 to 28 VDC. No output frequency shift was observed as a result of these supply variations.

3 SUMMARY

A summary of the environmental sensitivities of the two Sigma Tau masers is presented in Table 6 below:

Table 6.
Environmental Sensitivity Summary

Condition	S/N 2	S/N 3
Temperature (17 to 27 °C)	1.37×10^{-14}/°C	4.2×10^{-14}/°C
Humidity (20% to 80% RH)	$< 1 \times 10^{-14}$	$< 1 \times 10^{-14}$
Barometric Pressure (±24 in. Water)	$< 1 \times 10^{-14}$	$< 1 \times 10^{-14}$
Magnetic Field (± 0.1 Gauss)	-1.42×10^{-13}/Gauss	-4.74×10^{-13}/Gauss
Power Supply Variations (24 to 28 VDC)	$< 1 \times 10^{-14}$	$< 1 \times 10^{-14}$

Throughout the test series the Sigma Tau masers performed reliably,and were well behaved. Of particular interest is the fact that both masers were transported from Socorro, NM to Pasadena, CA, a distance of some 800 miles, in the back of a carryall van. Only a minimum of protection from shock and vibration was provided during transit, and upon arrival both masers were within normal operating parameters.

4 ACKNOWLEDGEMENTS

The author wishes to acknowledge the generous contributions of several individuals to this effort. In particular, that of Albert Kirk and Bill Deiner of JPL for their assistance in the performance of the many tests. Additionally, the generous technical assistance of Harry Peters of the Sigma Tau Corp. during the initial setup and preparation for testing is gratefully acknowledged.

JET PROPULSION LABORATORY
Test Plan
Sigma Tau Hydrogen Masers

Prepared by: T. K. Tucker   Date: March 23, 1988

1.0 General Description: This test plan outlines the tests and test sequences required to characterize a pair of hydrogen masers, and is intended to outline the minimum test requirements, but not necessarily limit the scope of testing.

1.1 Objective: This document establishes the procedures for testing a pair of hydrogen masers manufactured by the Sigma Tau Corporation for the National Radio Astronomy Observatory (NRAO), for use on the Very Large Array (VLA) Project. The maser performance will be tested under laboratory conditions with the environmental and operational parameters varied as specified herein to determine sensitivity to external influences.

1.2 Effectivity: This procedure is effective for the JPL Frequency Standards Laboratory (FSL).

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on the date of release of this document, form a part of this document to the extent specified herein.

SPECIFICATIONS

National Radio Astronomy Observatory

A53308001	Hydrogen Maser Frequency Standard, Electrical Requirements

Sigma Tau Corporation

Model VLBA–112	Atomic Hydrogen Maser Frequency Standard, Operation and Instruction Manual

3. TEST EQUIPMENT AND FACILITIES

3.1 Test Equipment: Required test equipment is available in the Frequency Standards Test Laboratory (FSTL) and shall be selected by FSTL personnel as required to perform the tests delineated herein.

3.2 Facilities: All tests described herein are to be performed in the FSTL.

4. TEST PROCEDURES

4.1 Introduction: Tests in this section are to be performed generally as described. Additional tests may be performed as determined by FSTL personnel.

4.2 Test Data: All test data along with other pertinent information shall be recorded in the appropriate FSTL log book and the "Maser Operating Point and Test Conditions" form as a permanent record of the test results and conditions for each test series. If there is any question, record it in the log!

4.3 Initial Tests: Verify proper operation of each maser under room ambient conditions. Measure and record all operating points and test conditions as baseline data for subsequent tests. As a minimum, the initial tests to be performed are as follows:

a. RF Output level at each output.

b. Harmonic distortion at each output.

c. Phase noise at each output.

d. Allan Variance (24 HOUR).

e. Output frequency vs. reference.

f. Verify proper operation of all operator controls.

g. Zeeman frequency.

h. Spin exchange frequency shift.

i. Offset between autotuner and spin exchange tuning.

4.4 Power Supply vs Output Frequency: Measure the output frequency change vs. input supply voltages as follows:

a. With PS2 and the external DC supply disconnected, measure the output frequency change as the input AC voltage on PS1 is varied through the range of 105 to 120 VAC.

b. With PS1 and the external DC supply disconnected, measure the output frequency change as the input AC voltage on PS2 is varied through the range of 105 to 120 VAC.

c. With PS1 and PS2 both disconnected, measure the output frequency change as the external DC supply voltage is varied through the range of 22 to 30 VDC.

d. Verify that both AC supplies are reconnected.

4.5 Temperature Coefficient of Frequency: Measure the output frequency change vs. temperature over the range of +17 to +27 degrees Celcius as follows:

a. With the maser stabilized at +22 degrees, increase the chamber temperature to +27 degrees and allow the maser to stabilize until the output frequency is stable (48 hours minimum).

b. Reduce the chamber temperature to +17 degrees and again permit the maser to stabilize.

c. Return the chamber temperature to +22 degrees and permit the maser to stabilize.

4.6 Barometric Pressure Coefficient: Measure the output frequency vs. barometric pressure over the range of ambient ±24 inches of water as follows:

a. With the chamber temperature stabilized at +22 degrees Celcius, increase the chamber pressure to 24 inches of water above ambient pressure.Permit the maser to stabilize at this pressure (two hours minimum).

b. Reduce the chamber pressure to ambient minus 24 inches of water and again permit the maser to stabilize at this pressure or soak for two hours minimum.

c. Restore the chamber pressure to ambient barometric pressure.

d. Repeat the above cycle.

4.7 Humidity Test: Measure the output frequency vs. ambient humidity over the range of 20% to 80% relative humidity as follows:

a. With the chamber stabilized at +22 degrees Celcius, elevate the chamber humidity to 80% and permit the maser to stabilize at this setting (two days minimum).

b. Reduce the chamber humidity to 20% and again permit the maser to stabilize at this humidity or soak for two days minimum.

c. Open the chamber to ambient humidity conditions, and permit the maser to stabilize for a minimum of two days prior to conducting further tests.

4.8 Magnetic Field Coefficient: With the maser at standard ambient operating conditions of temperature and humidity, install the Helmholtz coil over the maser in a horizontal plane, centered about the cavity. This position yields a vertical magnetic field about the maser cavity shields. Vary the applied magnetic field as follows:

a. Increment the applied magnetic field ±100 mGauss, and measure the Zeeman frequency, IF level, and freq. shift at each step.

b. Repeat step a using ±250 mGauss increments.

c. Repeat step a using ±500 mGauss increments.

4.9 Re–Verification Tests: Repeat all of the tests previously listed in Par 4.3 above to verify that the maser is operating within normal operating parameters prior to performance of the final Allan Variance, drift, and synthesizer calibrations.

4.10 Allan Variance: Perform an Allan Variance test for a minimum of 4 days (longer if possible) to obtain data out to 1×10^5 seconds.

4.11 Synthesizer Calibration: Adjust the maser synthesizer frequency so that the maser output frequency is equal to the FSTL reference masers.

5. CONCLUDING PROCEDURES:

5.1 After completion of the above tests, verify that all test equipment has been disconnected, and that all controls, covers, and connector dust caps are locked in place in preparation for shipment.

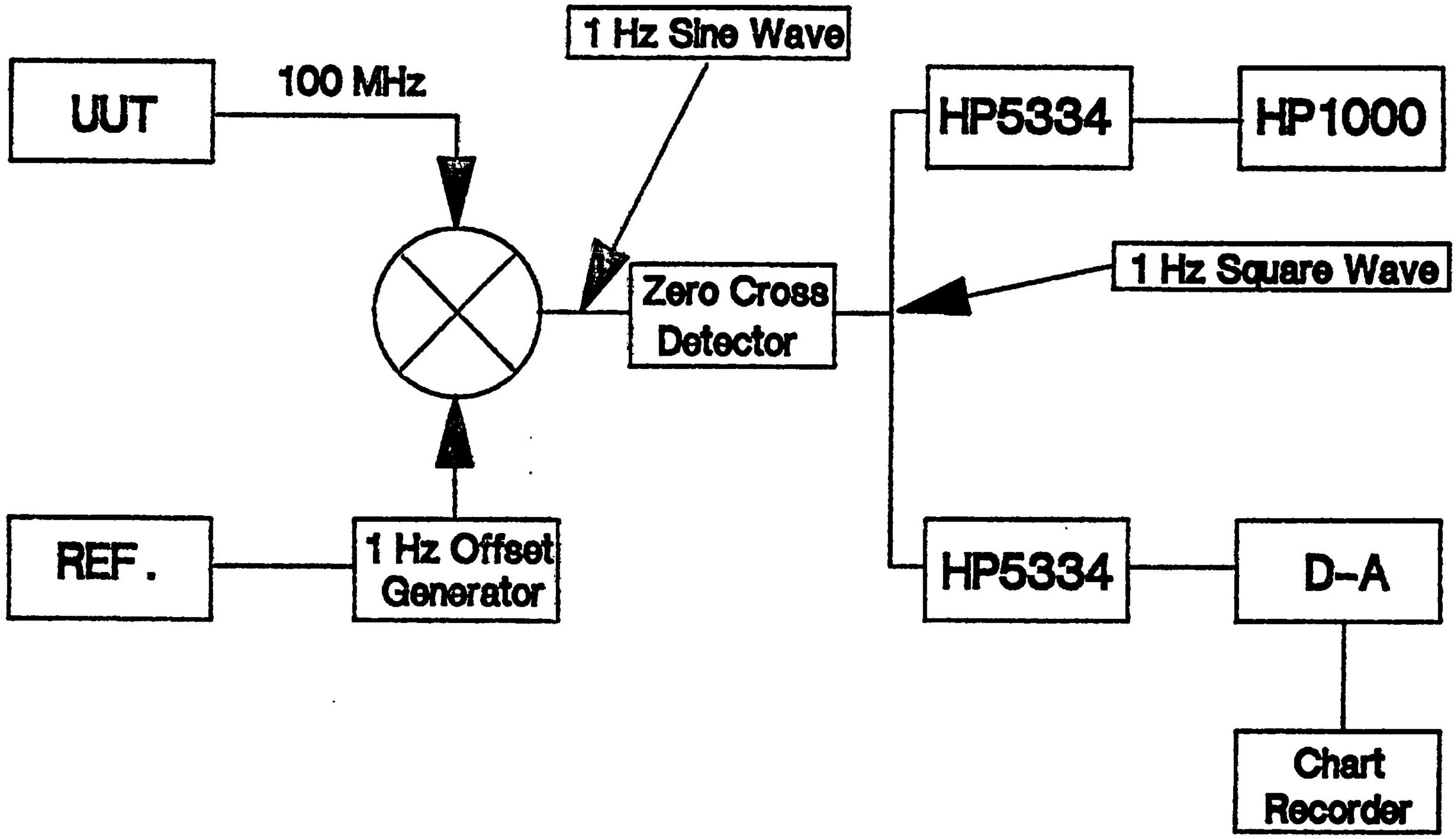

Figure 1. Measurement System for Frequency Shift & Allan Variance

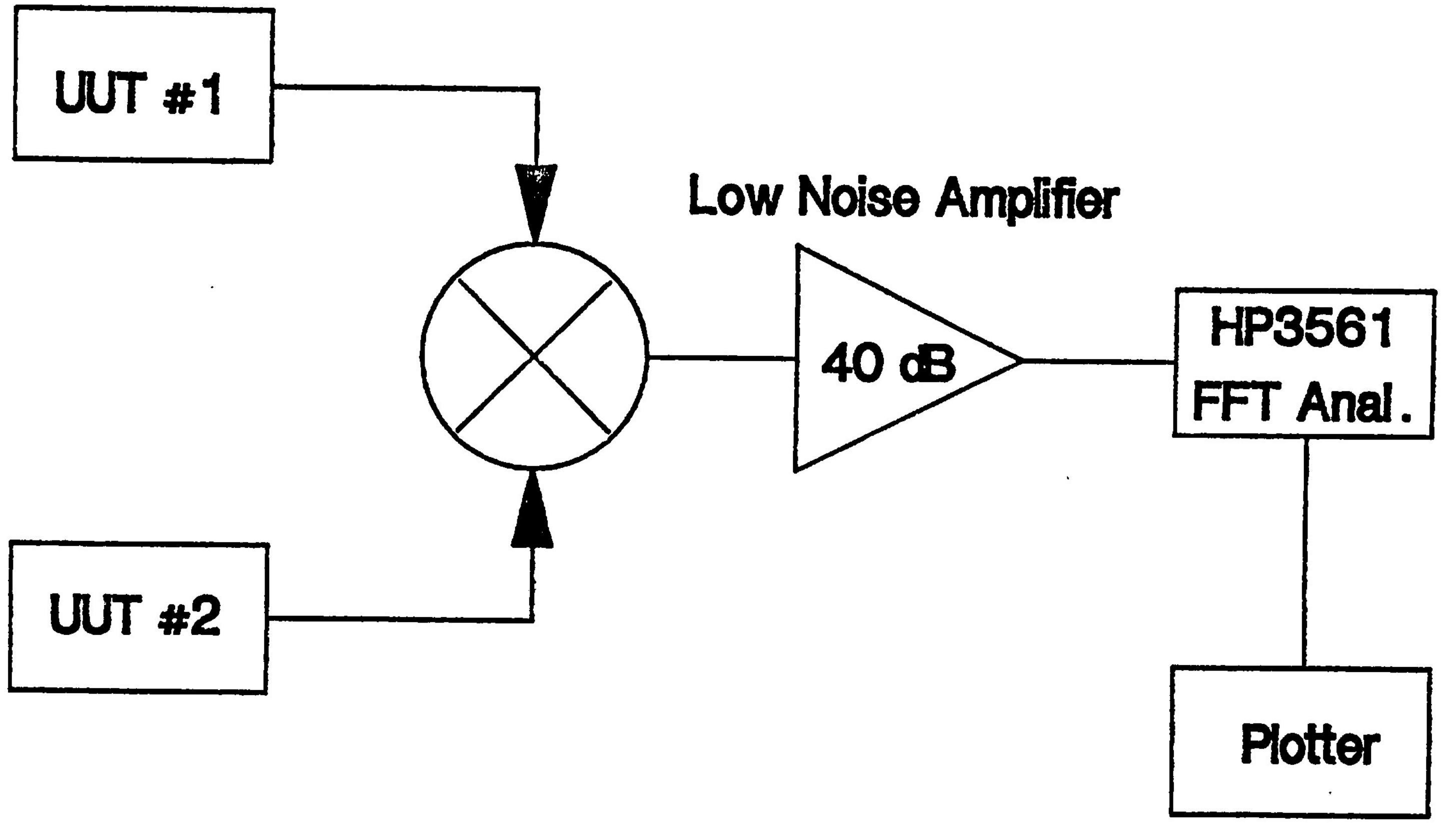

Figure 2. Phase Noise Measurement System

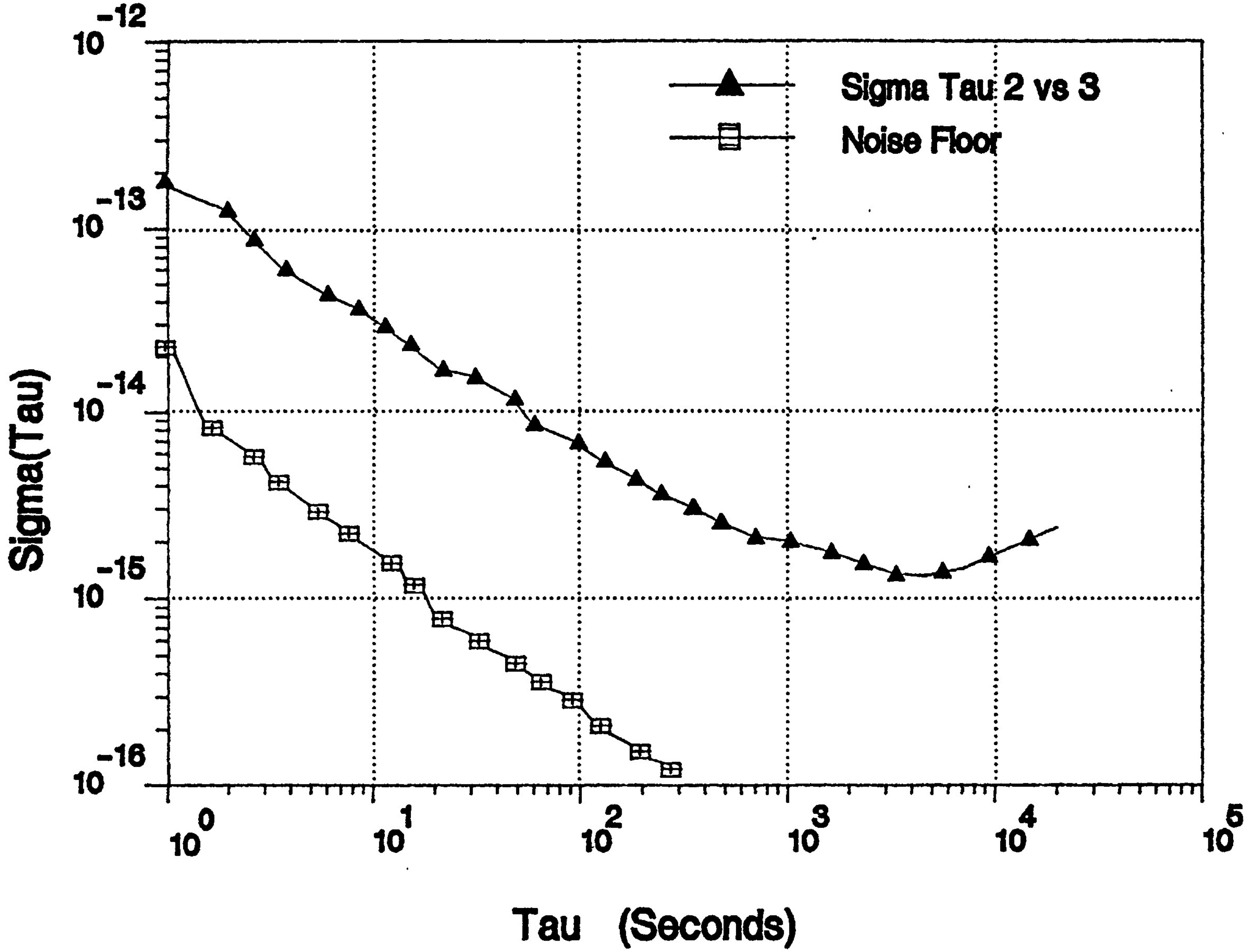

Figure 3. Allan Variance – Sigma Tau 2 vs 3

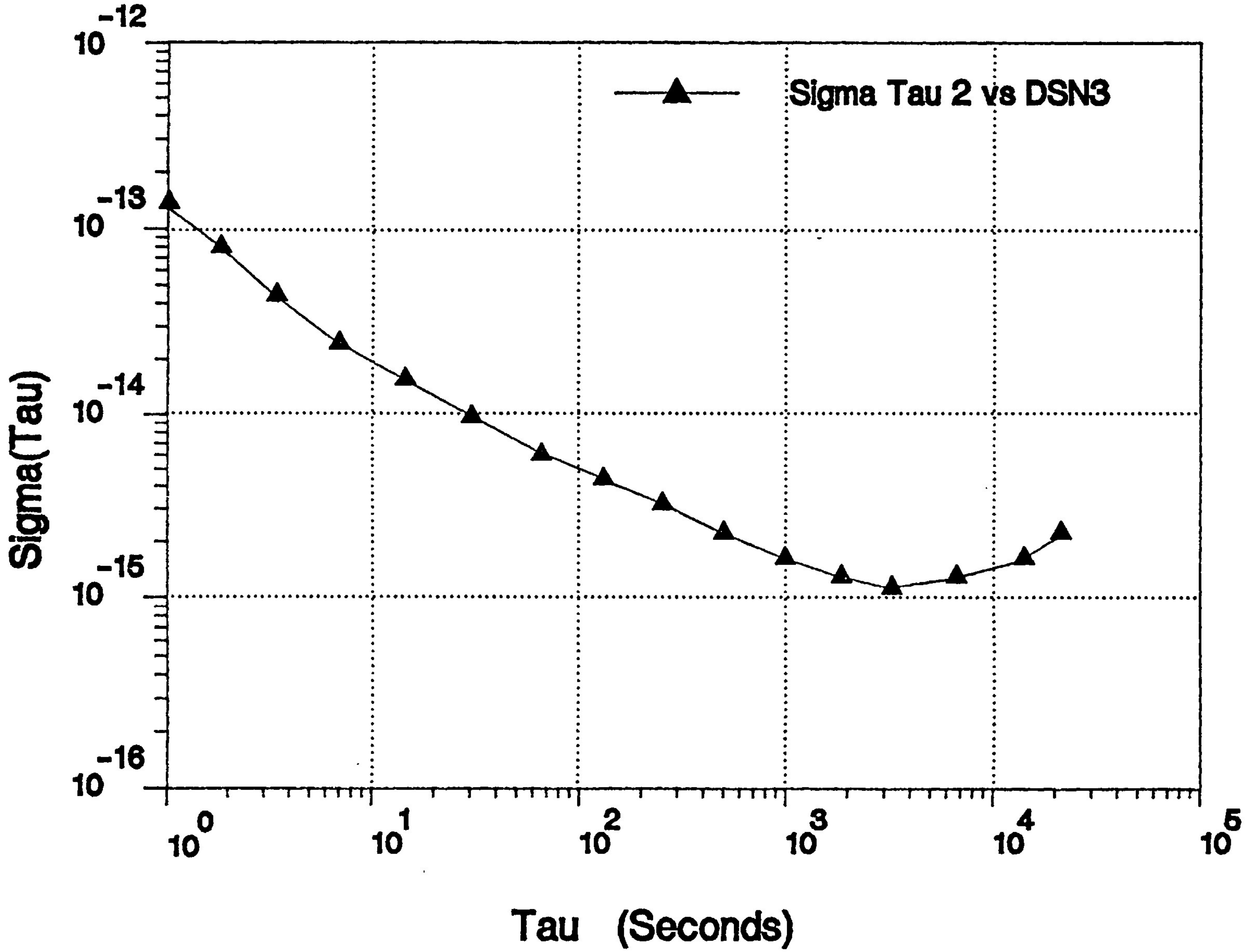

Figure 4. Allan Variance – Sigma Tau 2 vs Ref.

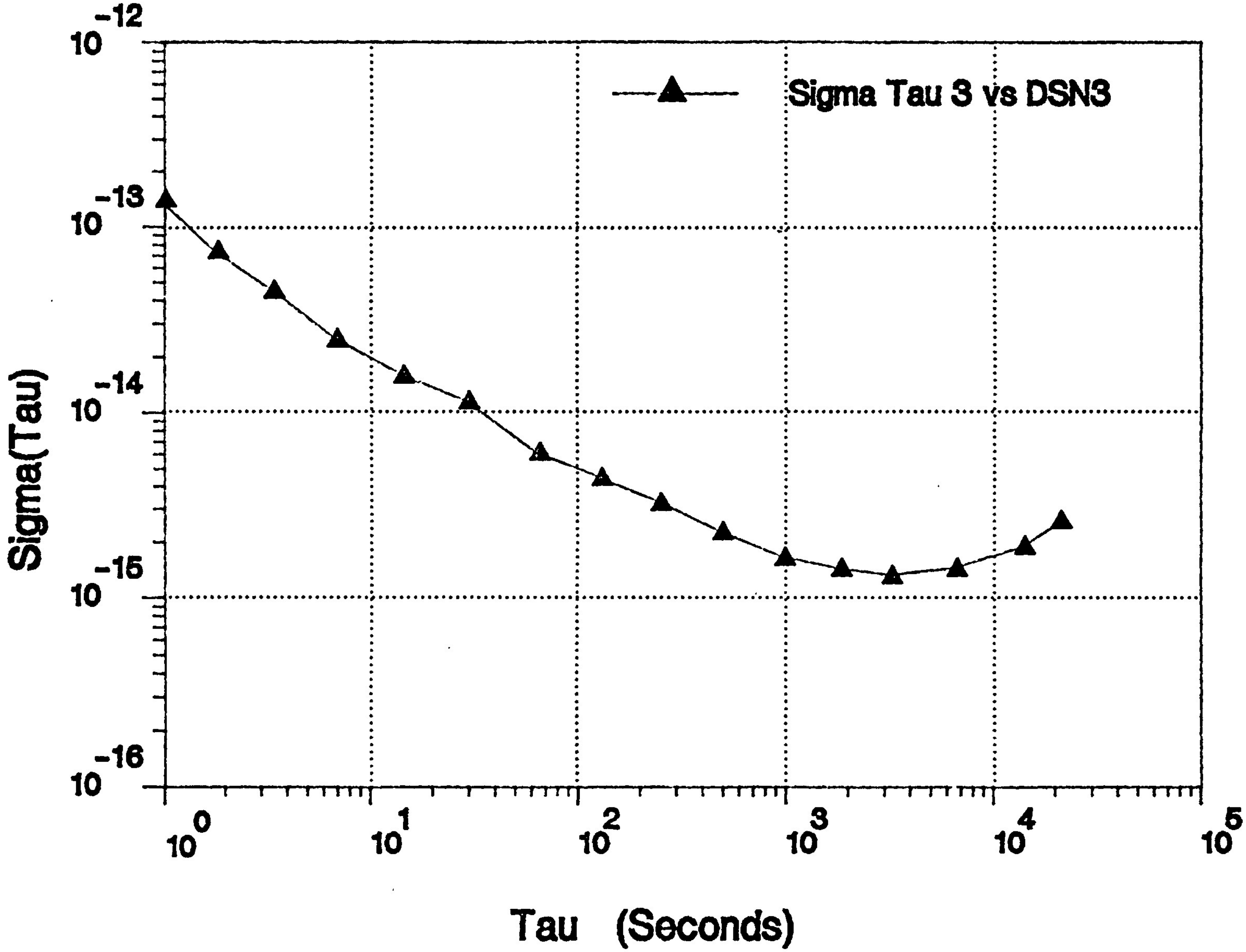

Figure 5. Allan Variance – Sigma Tau 3 vs Ref.

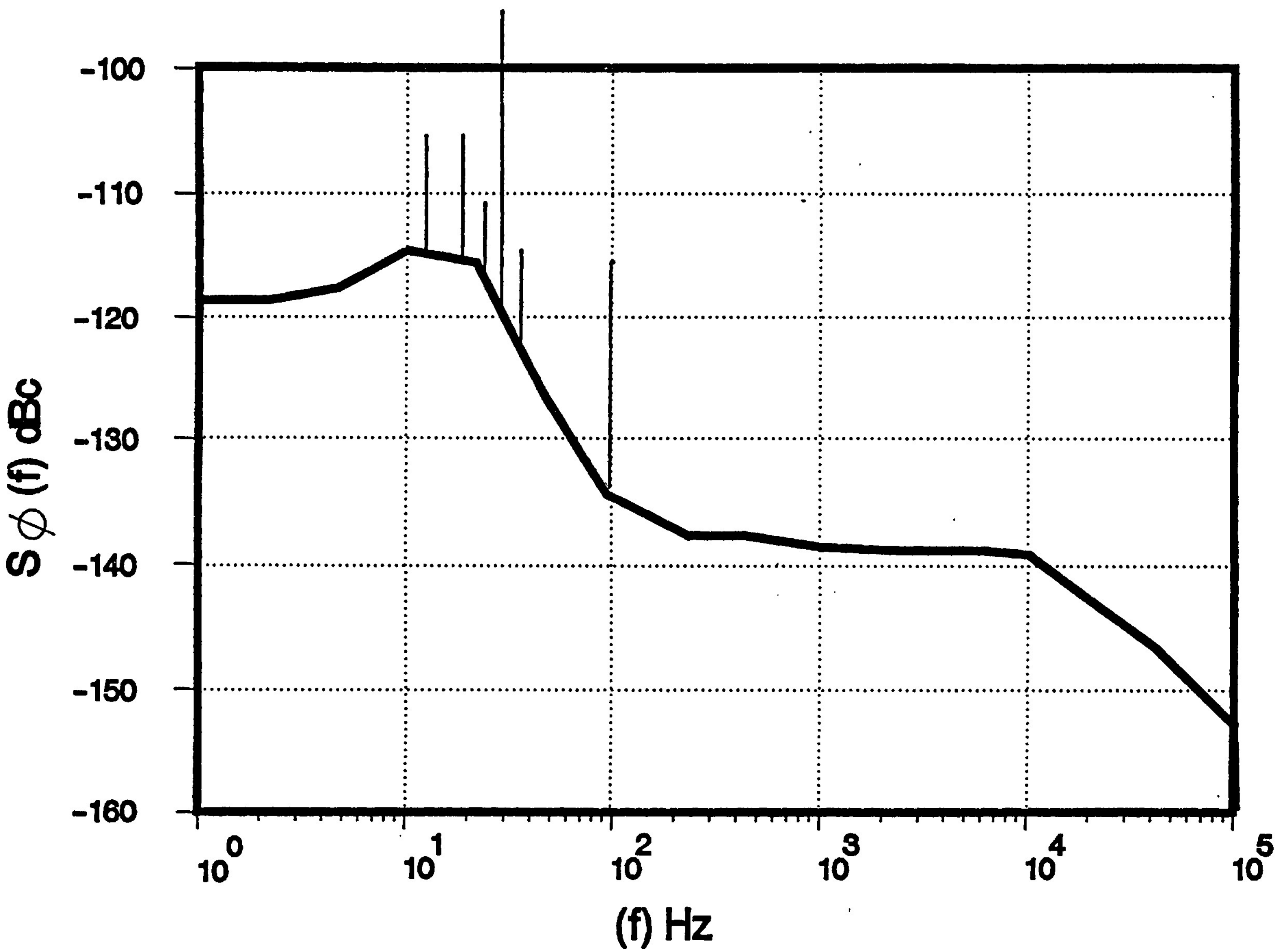

Figure 6. Phase Noise at 5 MHz Outputs

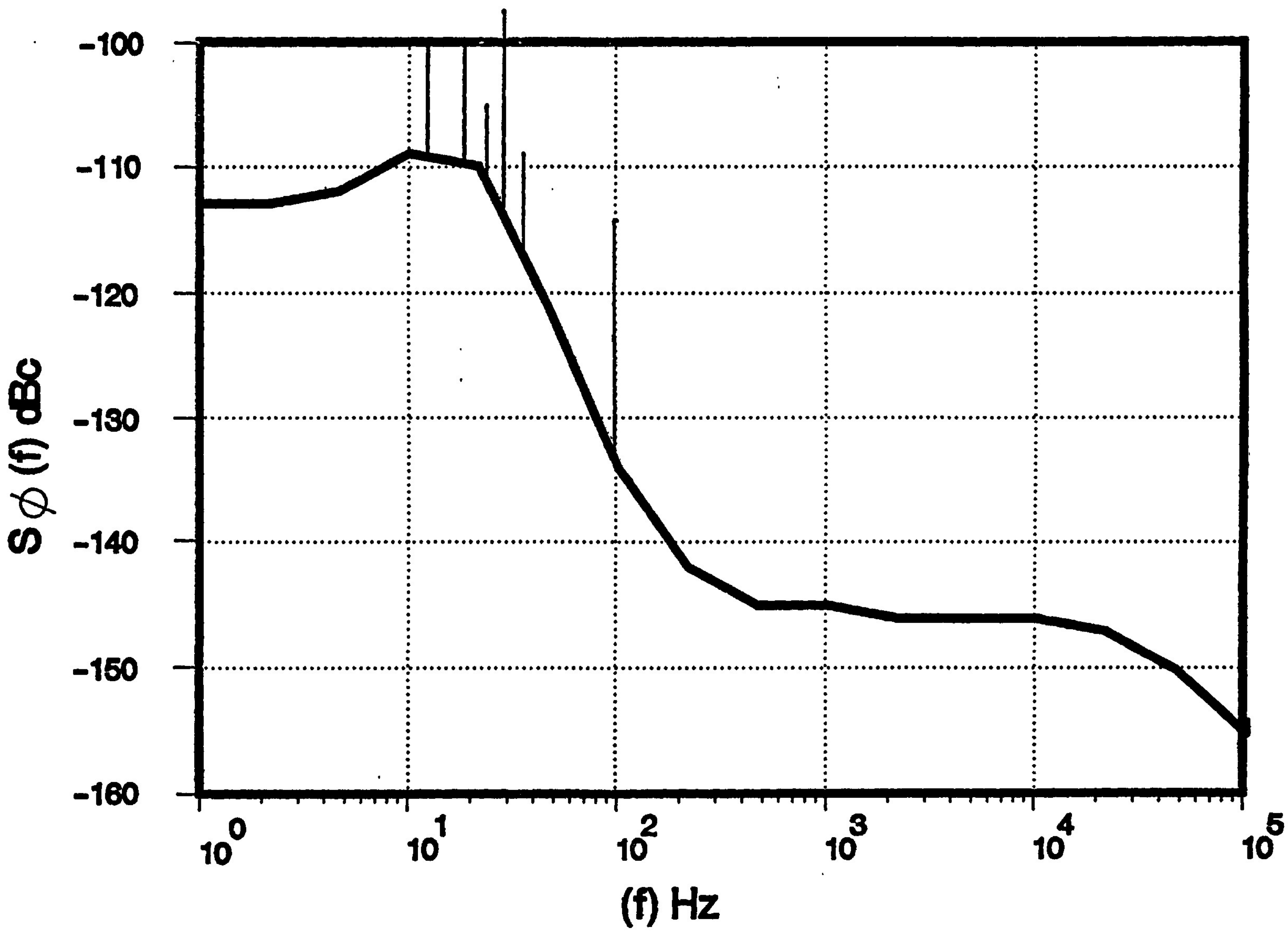

Figure 7. Phase Noise at 10 MHz Outputs

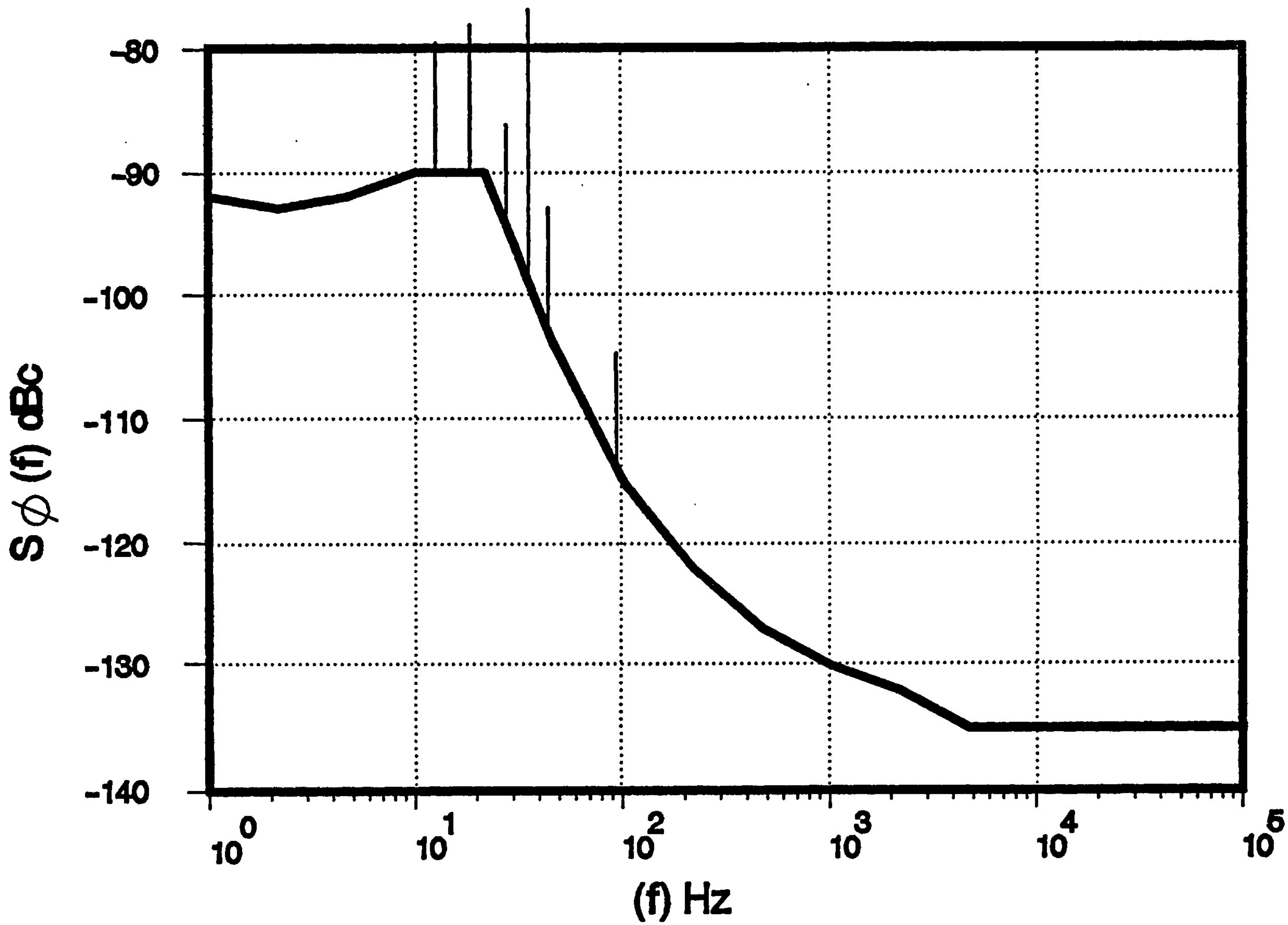

Figure 8. Phase Noise at 100 MHz Outputs

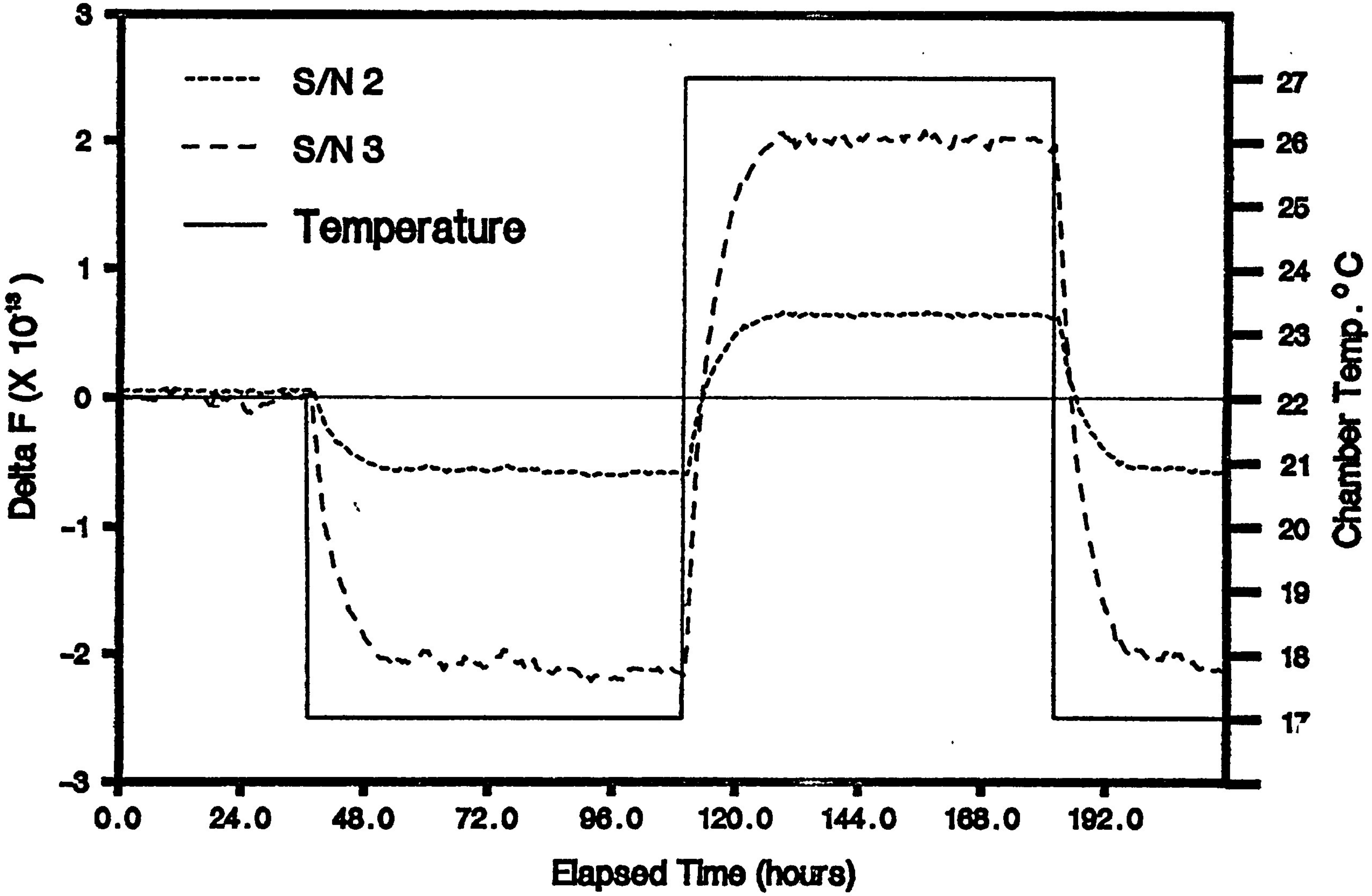

Figure 9. Output Frequency vs Temperature