D-band Vector Network Analyzer*

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Abstract

This paper will describe the design, calibration, and performance of a 2 port vector network analyzer designed to operate between 140–160 GHz. Single frequency measurements can be made over this entire band. Signal level problems require broadband measurements is two ranges between 140 and 150 GHz and between 150 and 160 GHz. An external computer is used for the purpose of calculating the calibration coefficients of the network analyzer. The system can be calibrated to a systematic error of 1.5 dB with the limitations in the accuracy of the calibration due to loss in the system, limitations on the calibration standards, and reflections in the system. Problems in the calibration and software computer control will be described and several representative one port measurements results between 140 and 150 GHz will be presented.

1. Introduction

Vector measurement of devices and circuits is an important design and analysis tool at microwave frequencies. Direct probing of active devices on wafer and measurements on circuits using automatic vector network analyzers has reduced the time and greatly improved the accuracy of these measurements. Commercial systems are available from Hewlett Packard [1] and Wiltron [2] to 50 GHz for coaxial systems and to 110 GHz in waveguide. There are a variety of uses of these measurement systems at higher frequencies. Modern transistors have predicted unity current gain and

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power gain frequencies of several hundred GHz. However, these frequencies are based on extrapolated predictions based on measured data at lower frequencies. Recently Matloubian [3] published data that questioned the usual 6 dB per octave rolloff used in transistor frequency measurement. With higher frequency measurement systems available, S parameters could be obtained directly at higher frequencies. Transistor models could be confirmed, or more accurate models could be developed to improve device understanding and millimeter-wave circuit accuracy.

A second application of higher frequency vector measurement systems is the direct measurement of embedding circuits. Present millimeter wave mixer or harmonic multiplier circuits are usually designed as scale models, and measurements are obtained at lower frequencies and scaled. With the aid of precise millimeter-wave standards, a variety of embedding circuit may be characterized. Each of the standards would be measured by the network analyzer, and the program used for calibration would calculate the de-embedding parameters. These parameters can also be used to characterize the embedding structure whether it is some waveguide to microstrip transition or an antenna array.

A third area of interest is in the physics of semiconductor materials. The frequency range above 100 GHz corresponds to typical scattering, momentum and energy relaxation time in semiconductor materials. These time constants can have a large effect on the terminal characteristics of devices above 100 GHz [4]. Direct measurement of the vector impedance of semiconductor samples over a range of frequencies would provide useful information about the basic properties and time constant of materials.

There are other network analyzer systems currently on the market which offer measurement to 110 GHz. Hewlett Packard offers test sets for its HP8510 network analyzer which allow measurements up to 110 GHz. A W band two port system would cost approximately $80K - $100K in additional to the cost of the basic network analyzer. The purpose of this paper is to describe a low cost two port frequency extender for an network analyzer for operation between 140 and 160 GHz. The design and operation of the extender is described in the next section. Calibration techniques and limitations and some one port measurement results are discussed in section 3. A brief summary and proposed additional measurements are given in the last section.

2. Design

The D-band frequency extender uses frequency translation to allow measurements in the 140 - 160 GHz frequency range with an HP 8510 network analyzer and a HP 8515 test set. Most of the display functions of the 8510 system are used in the translated frequency range. The internal error correction can be used with error vectors obtained under external computer control. The extender is small enough to fit in front of an 8510 test set. The unit was fabricated by Millitech Corp. A block diagram of the measurement system is shown in figure 1. The extender is connected to the two measurement ports of the 8515 test set. This test set acts as an IF receiver, measuring ratios of reflected, transmitted and incident signals at frequencies between 6 and 26 GHz. The extender uses a mixer in each signal path for both up and down conversion. The mixers have a local oscillator frequency of 134 GHz. This is provided by a voltage tunable Gunn diode operating at 67 GHz and a doubler. A portion of the 67 GHz signal is sampled with a direction coupler and harmonic mixer and used to source lock the Gunn. The counter has an upper frequency limit of 100 GHz, preventing direct use of a 134 GHz source. The 134 GHz signal is split with a 3 Db hybrid and drives the two mixers through 10dB coupler couplers. The 134 GHz pump frequency mixes with the signal from the test set producing the 140 to 160 test signal. The 134 GHz local oscillator and the lower sideband image frequency are also present. Those frequencies are trapped inside the measurement system by high pass filters at the two test ports. The return signal from the measurement passes through system in the opposite direction, is mixed down to the 6–26 GHz frequency and returns to the 8510 test set. The image frequency will reflect off the high pass filter, and also appear as the same frequency as the test signal at the 8510 measurement port. The effect of the image frequency can be partially removed with careful calibration. The calibration procedure is described in the next section.

3. Calibration Procedure and Results

The 8510 network analyzer has internal software for error correction of measured data. Error correction involves measurements on known standards and calculation of error coefficients. The process is under internal software control in normal 8510 operation. Once these error coefficients are determined, error corrected data can be displayed. Typical waveguide standards are combinations of loads, shorts and offset shorts. A problem occurs with the D band system. The internal software uses a frequency dependent waveguide dispersion equation. Since the measurement frequency is shifted by 134 GHz, the resulting internal phase information is incorrect. To overcome this problem three D-band standards are measured and their uncorrected scattering parameters are uploaded to an IBM-XT computer using an IEEE-488 interface bus. A Pascal program was written which measures three standards: a matched load, a short, and an offset short. The error coefficients are calculated by the XT and downloaded back to the 8510 as a calibration set. Calibration problems, results and measured data are described in the next section.

The first attempt at one port calibration used a waveguide load, a flush short and an offset short. Since no calibration standards are commercially available above W band, the standards were machined internally. A resulting corrected measurement is shown in figure 2. There are two sources of error in this measurement. The first is the ripple in the data across frequency. Part of this ripple is due to a design problem with the system. In theory, the effect of the image frequency in the measurement system can be corrected by calibration. This is true over a narrow frequency range. However, there is a resonance in the system as the signal and image frequency sweep corresponding to multiple half wavelength distances between the mixer and the high pass filter at the image frequency. This effect was confirmed by changing the Gunn diode frequency by a small amount and noting a corresponding change in the resonance. A future design will have image trapped mixers. A second problem is the quality of the standards. The D band tunable load has a nominal return loss of approximately 25 Db. The waveguide offset short was machined out of a piece of brass and the guide had quarter rounded corners limited by the end mill diameter. A second set of standards used a standard gain horn as a load. Although the nominal VSWR of the horn was higher than the load, the actual reflection coefficient was better. A tunable short was used for the short and offset short standards. A resulting corrected measurement is shown in figure 3. The ripple in the data is approximately 1.5 Db. Similar ripple information for HP waveguide systems is shown in figure 4 [the HP datapoints are from page 21 of reference 5]. The system was next used to measure some simple D band components. The return loss of a variable attenuator terminated with a short is shown in figure 5. For attenuation settings to approximately 10 - 15 Db, the return loss is the two way insertion loss of the attenuator. At higher attenuation levels, the return loss is limited by the input VSWR of the attenuator. Figure 6 shows the return loss of a standard gain horn radiating onto a metal plate at a distance of several inches.

4. Conclusions

The paper has discussed the design, calibration and performance of a vector network analyzer operating in D band. The system has a calibrated one port system ripple of 1.5 Db and a phase ripple of about 5 degrees. Preliminary results show that the system should be useful for device characterization, circuit measurements and a range of studies on semiconductor materials.

Acknowledgments: The initial design for this system was based on unpublished work and conversations with Dr. Dean Peterson. The unit was fabricated at Millitech Corp. with the help of Rich Chedester.

References

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3. "Wide-Band Millimeter Wave Characterization of Sub-0.2 Micrometer Gate-Length AlInAs/GaInAs HEMT'S," by M. Matloubian, S.E. Rosenbaum, H.R. Fetterman and P.T. Greiling, *IEEE Microwave and Guided Wave Letters*, vol. 1, no. 2, i pp. 32–34, Feb., 1991.
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5. System manual for HP8510 A network analyzer system for R,Q,U,V and W bands

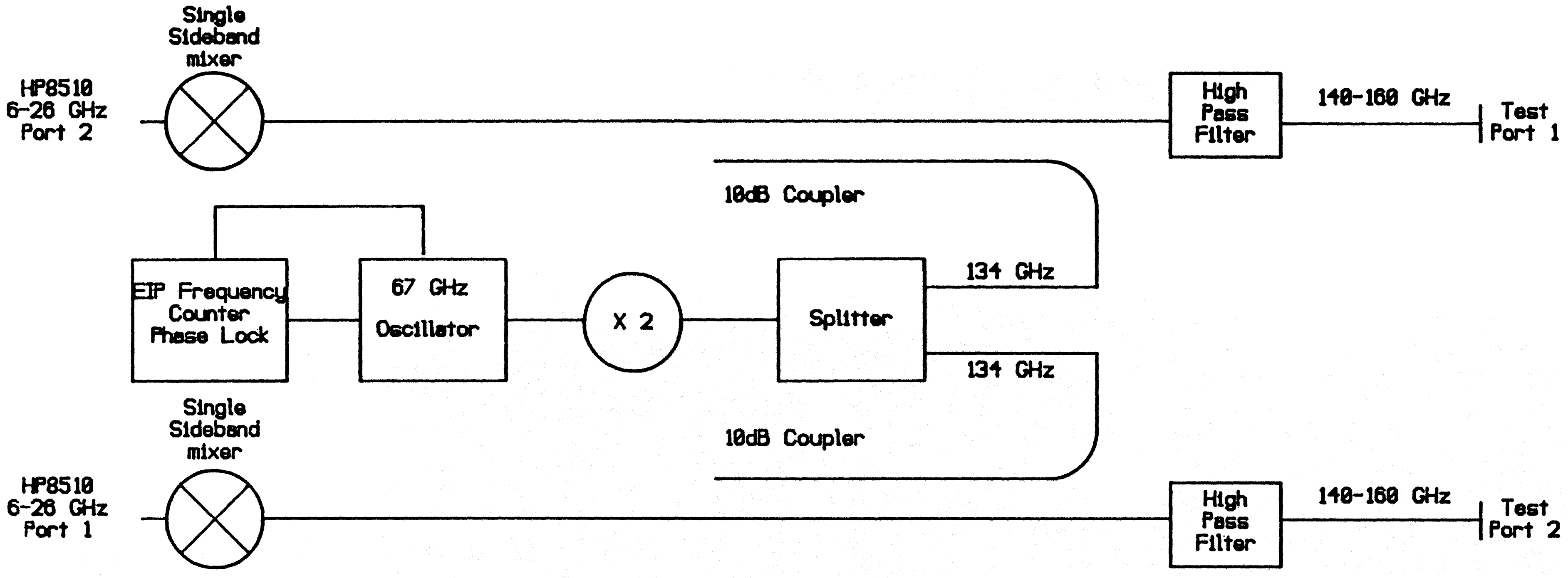

Figure 1. D-Band system Block Diagram

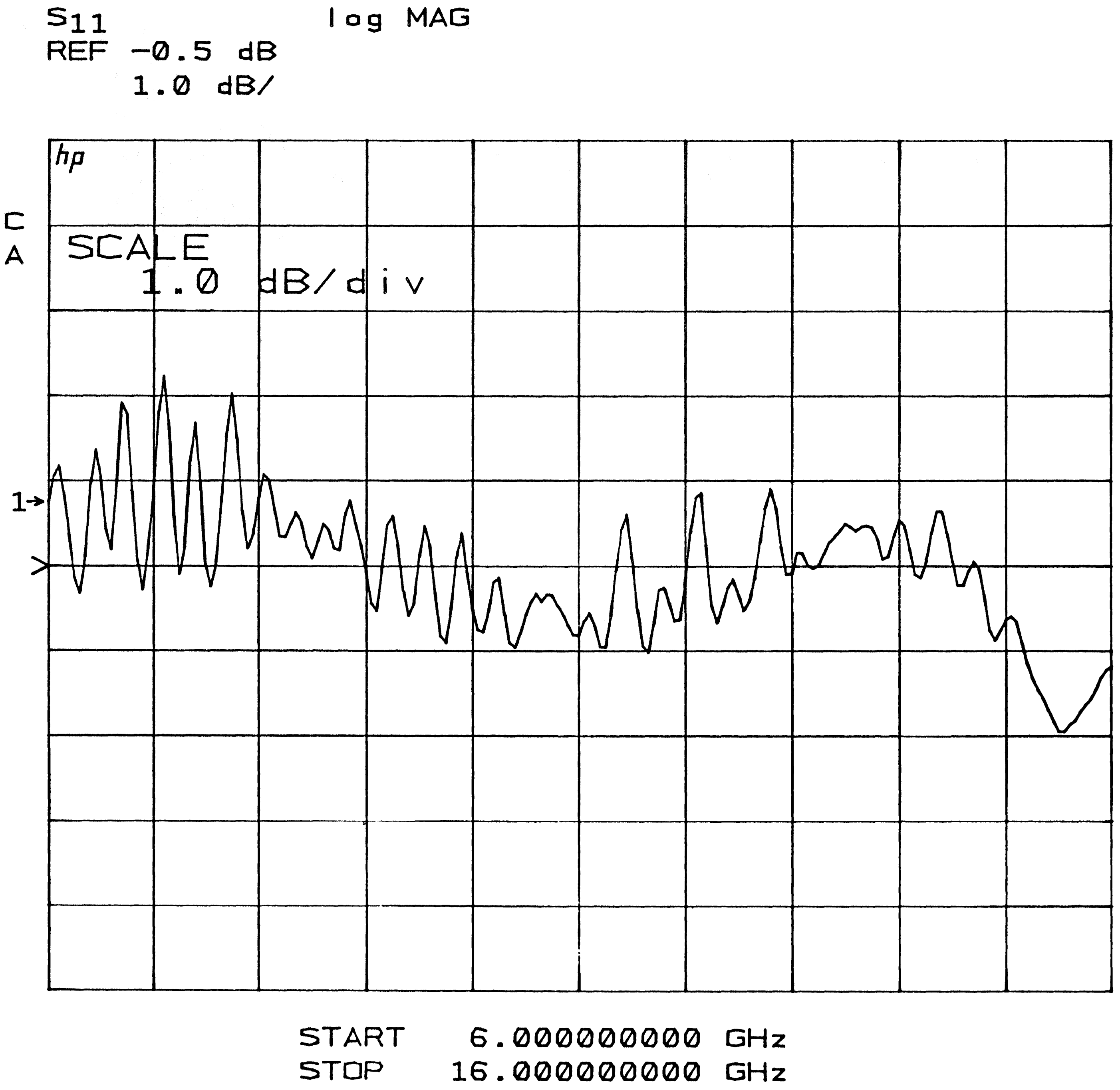

Figure 2. Phase and return loss of tunable waveguide short (140-150 GHz), cal set 1.

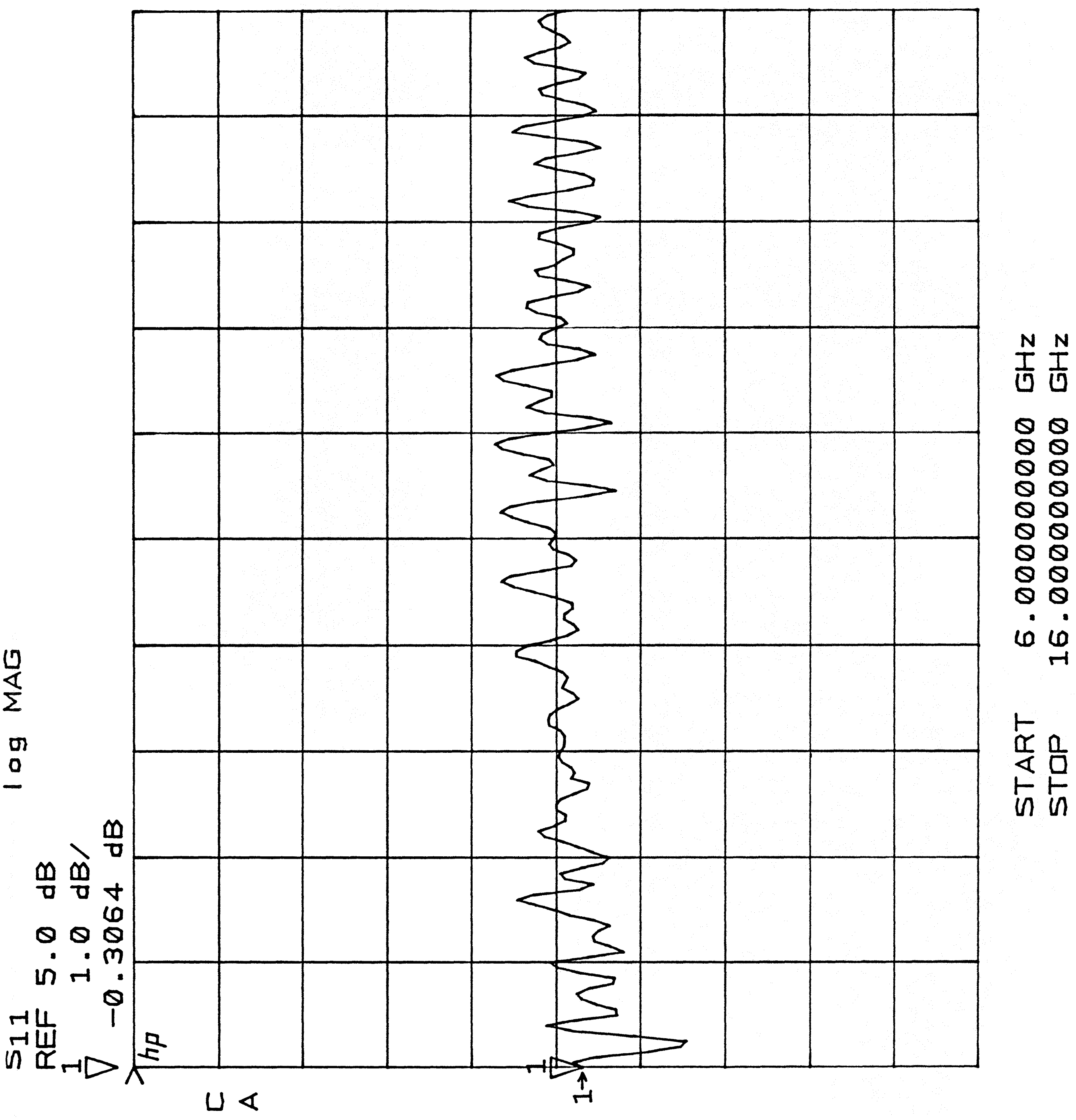

Figure 3. Phase and return loss of tunable waveguide short (140-150 GHz), cal set 1.

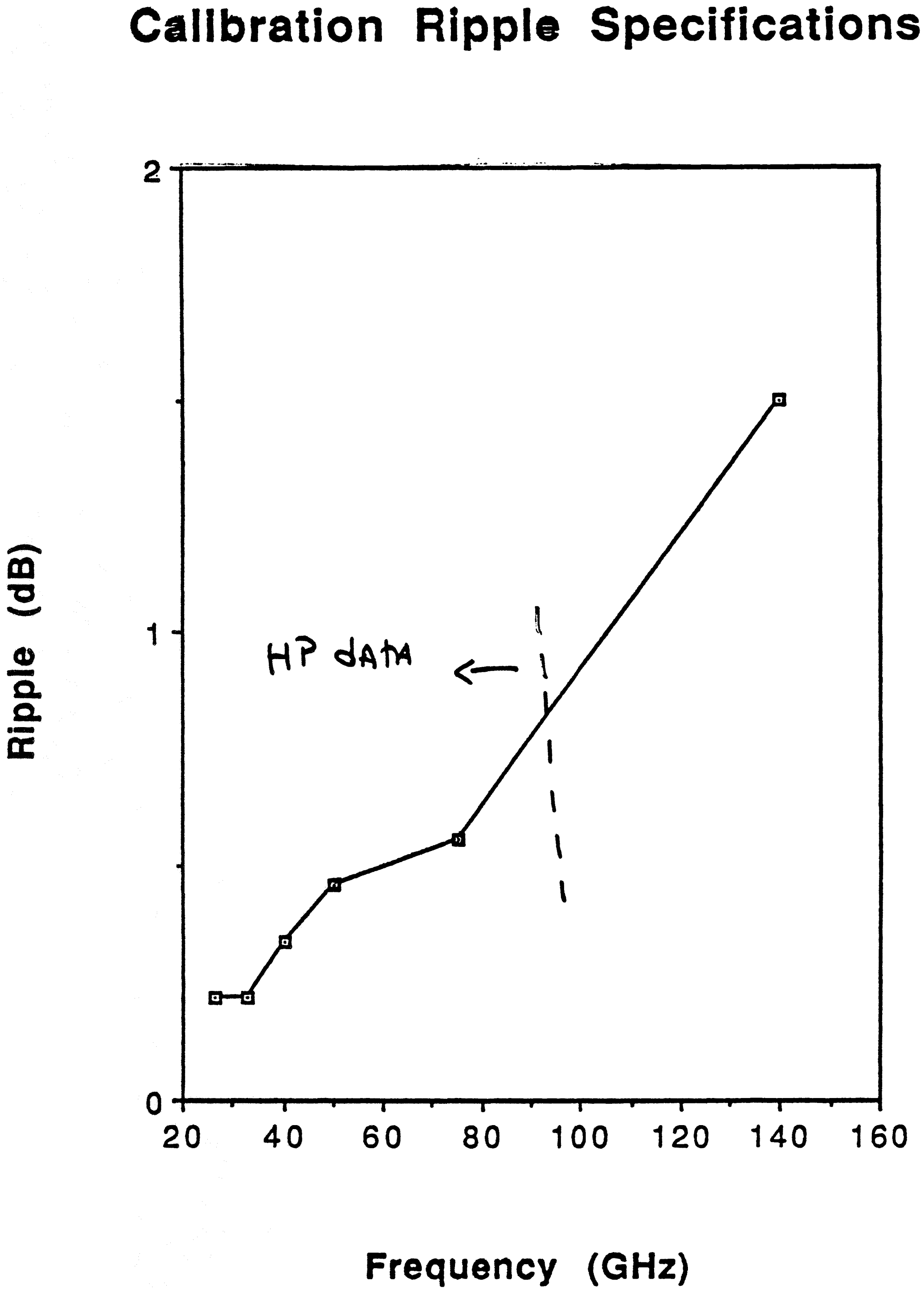

Figure 4. Overall system ripple comparison

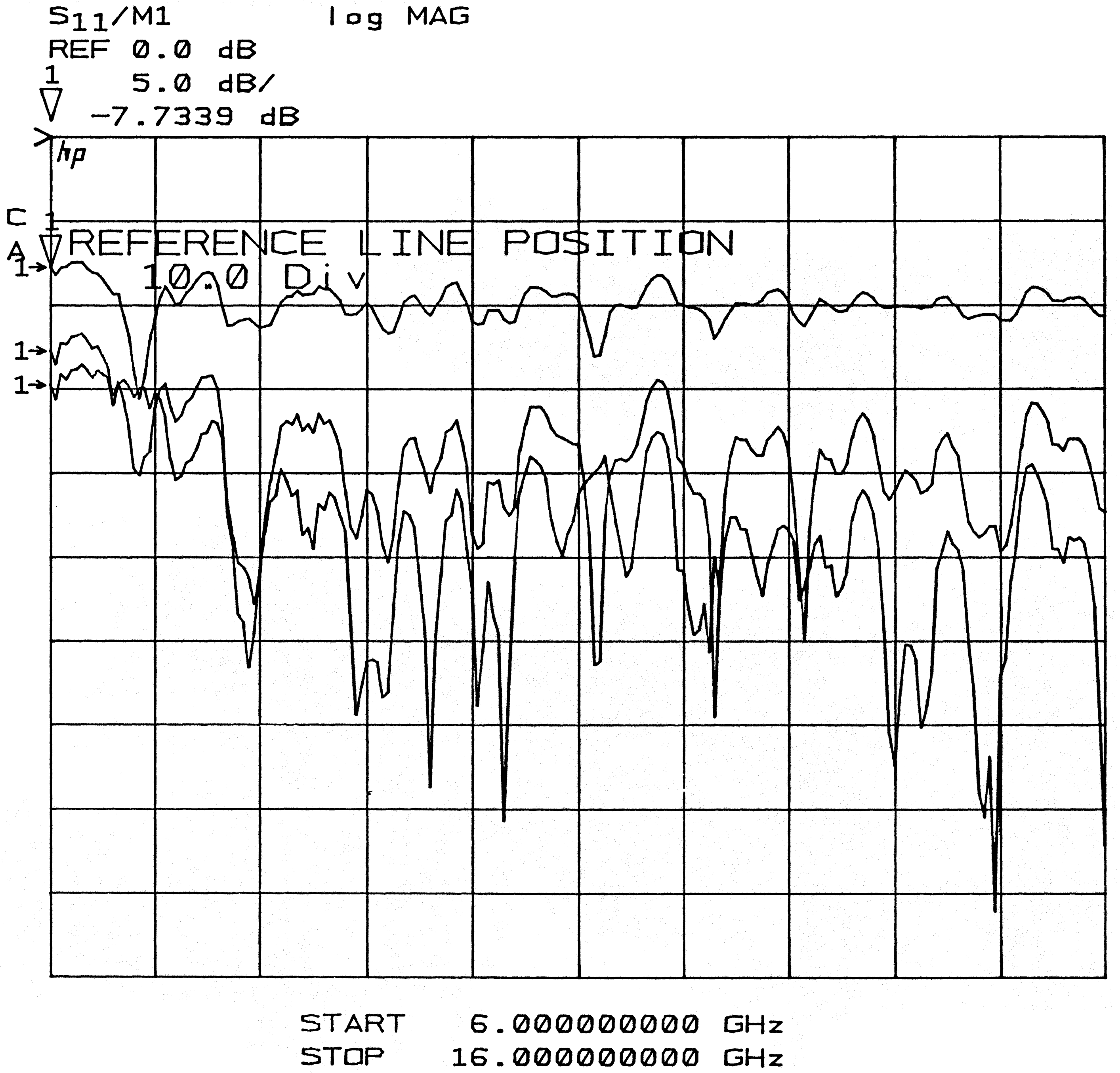

Figure 5. Return loss of a variable attenuator

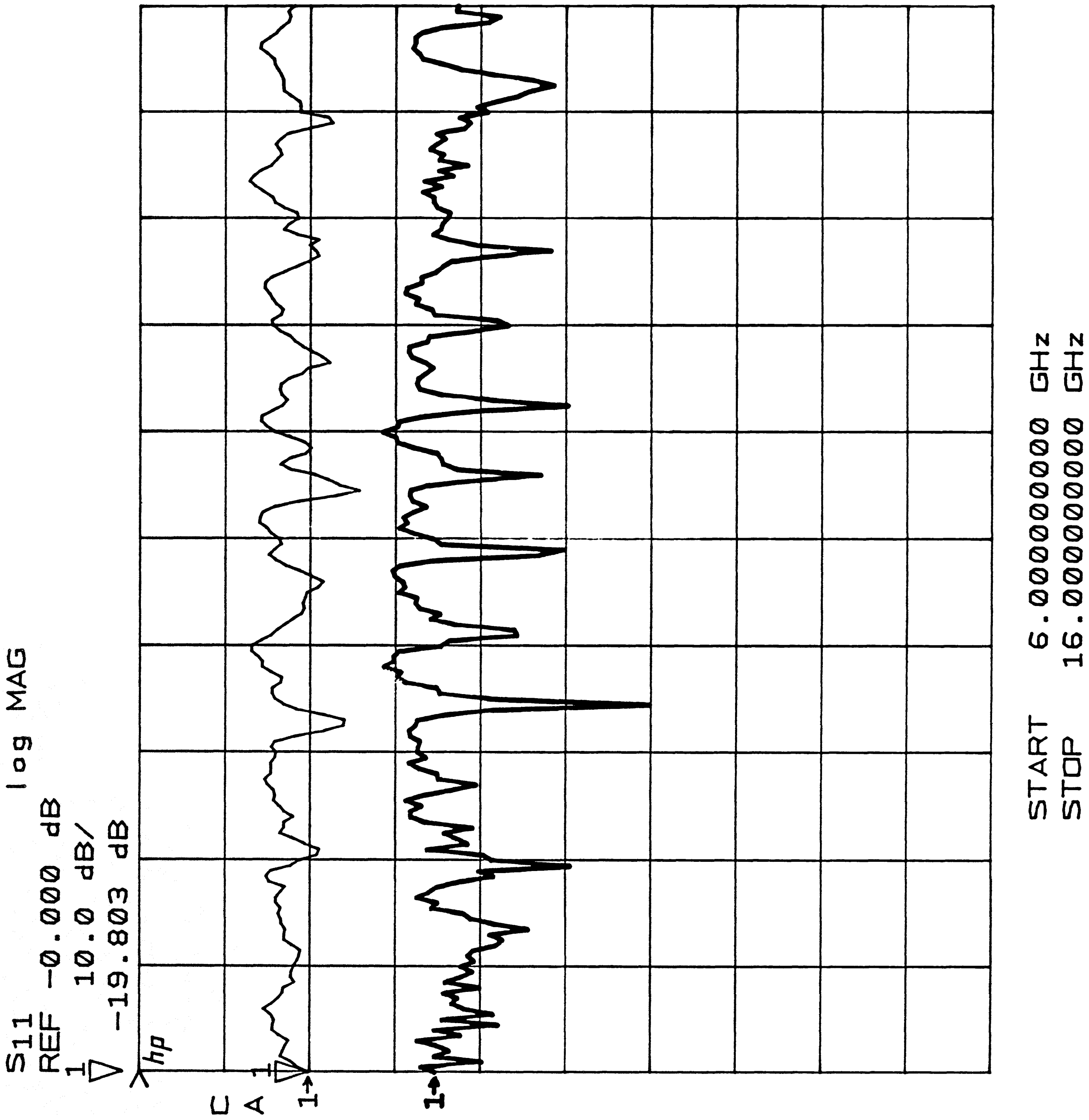

Figure 6. Return loss of a standard gain horn