A DUAL SIX-PORT AUTOMATIC NETWORK ANALYZER

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ABSTRACT

A 2 to 18 GHz dual six-port automatic network analyzer is described. The measurements showed accuracies of better than 0.1 dB up to 40 dB insertion loss from 2 to 7 GHz. The cause of deviations at higher frequencies is discussed.

Introduction

Almost ten years ago Hoer and Engen at the National Bureau of Standards (NBS) began to investigate the six-port junction as the heart of a simpler and less expensive automatic network analyzer[1,2]. Since then there has been considerable interest in the six-port technique and several experimental systems have been built. A recent dual six-port system with thermistor power detectors showed very good performance at 3 GHz[3]. In this paper, we describe a diode based six-port system built for the Army Metrology and Calibration Center (AMCC). Our experience has shown that there is still considerable art required and that some subtle questions need to be answered to put six-port technology on firmer ground.

System Description

The Sperry Dual Six-Port Automatic Network Analyzer (DSPANA) was designed to operate over the 2 to 18 GHz frequency range. Figure 1 is a photo of the complete system. From the top of the cabinet, the

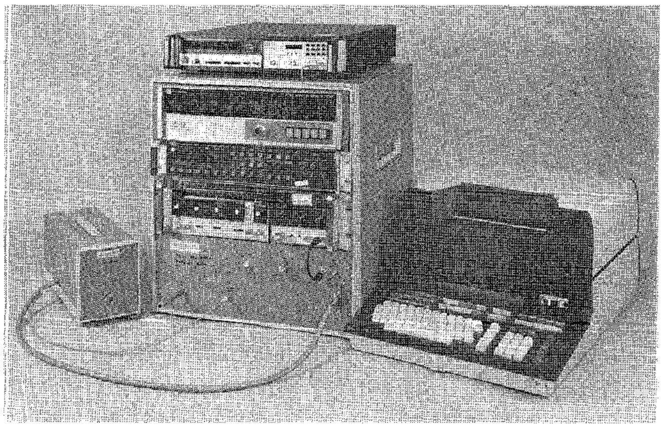

Figure 1. The Sperry Dual Six-Port Automatic Network Analyzer

instruments are a frequency counter with phase lock capability, a scanner, digital voltmeter (DVM), RF sweeper, and a microwave drawer including one six-port junction. The other six-port is exterior to the cabinet, so that the device under test (DUT) can be connected between the two six-ports. All instruments are controlled by the desk-top computer. Upon program command the RF sweeper is set to a specified frequency. The counter measures the actual frequency and phase locks the generator. The scanner controls the 7 mechanical switches and multiplexes the 8 diode outputs into the DVM. The microwave configuration is shown in Figure 2. Note the three position phase shifter and two position attenuator used in the calibration and measurement procedure.

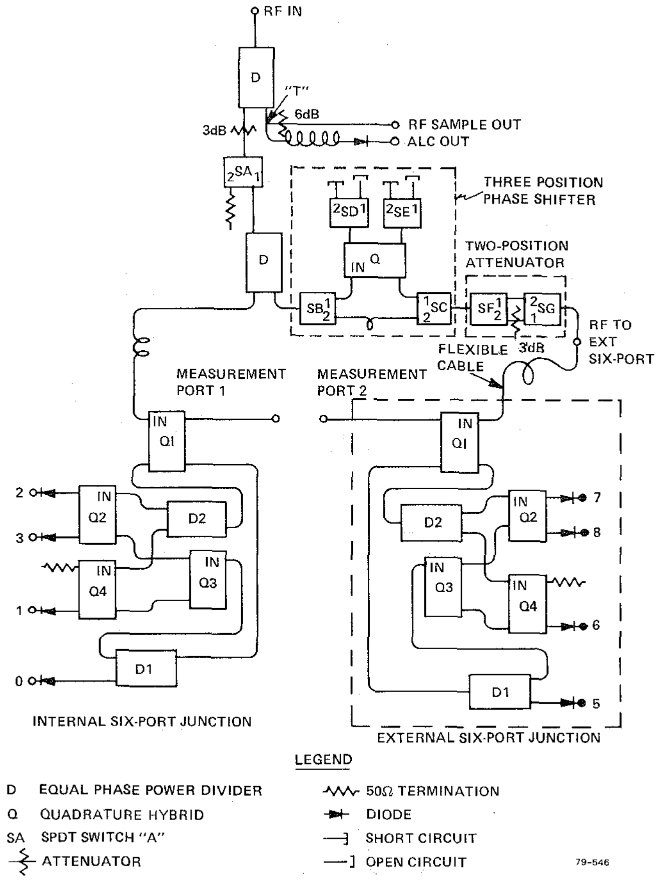

Figure 2. Dual Six-Port Microwave Configuration

Calibration and Measurement

Procedure

The calibration constants of the dual six-port are obtained using a through-delay-short procedure described by Susman[4]. The calibration procedure consists of three steps. In the first step the two six-port junctions are connected together and 8 diode readings are acquired for each of 6 external states at each frequency of interest. Next, a lossy section of beadless airline is connected between the two six-ports and the 48 diode readings are again taken at each frequency. Finally short circuits are attached

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to the measurement ports and the 8 diode readings are taken for one external state at each frequency. These 104 power readings at each frequency determine the calibration constants of both six-port junctions.

In the measurement procedure the DUT is placed between the two six-ports. Under program control 8 diode readings are acquired for each of 3 external states. These 24 readings are then used to compute the magnitude and angle of S_{11}, S_{22}, S_{21} as described by Hoer[5].

Numerical Analysis Considerations

One of the central tasks in determining the calibration constants is to compute the eigenvalues of the matrix of power meter readings given in Ref. 4 equation (5) as

$$\left[P_1' \left(P_2'\right)^{-1} P_2 P_1^{-1}\right] \equiv A_1$$

This is a relatively straightforward task, as long as the four eigenvalues, $e^{+2\alpha\ell}$, $e^{-2\alpha\ell}$, $e^{+2j\beta\ell}$, $e^{-2j\beta\ell}$, are distinct. Here ℓ is the length of the delay line and $-\alpha + j\beta$ is the propagation constant. Distinct eigenvalues result if ℓ is not a multiple of a quarter wavelength and $\alpha \neq 0$. When these conditions are met there are numerous techniques for finding the corresponding eigenvectors. The Sperry DSPANA software uses an algorithm due to Faddeeva[6] for determining the eigenvalues and eigenvectors. Here, from the matrix A_1, the eigenvalues are determined from the coefficients of the characteristic polynomial. The corresponding eigenvectors are derived from the adjoint matrix. In principle, a multiple eigenvalue results in a null adjoint matrix and one can compute the corresponding eigenvectors from the derived adjoint. In practice, the eigenvalues are never multiple, since they are calculated from actual power readings of finite resolution. However, the adjoint matrix approaches the null matrix resulting in unstable estimates of the eigenvectors. Alternate numerical methods have been tried, but to date no reliable algorithm has been found which can operate on actual power readings when a lossless line is used. To circumvent these numerical difficulties a lossy airline is used to calibrate the dual six-port. This delay line introduces approximately 1 dB of loss which is sufficient to stabilize the numerical process. The VSWR of the line is less than 1.05 over the 2-18 GHz band. The assumption that the delay line be nonreflecting is thus reasonably well approximated. However, the lossy line has a complex characteristic impedance. The normalization level of the resulting S parameter measurement is thus complex. A full discussion of these considerations is beyond the scope of this summary and is found in Ref. 7.

System Performance

The system performance of the Sperry SPANA was evaluated by calibrating the system and measuring various two-port passive components. The measurements indicated that accuracies of better than 0.1 dB could be obtained up to 40 dB insertion loss from 2 to 7 GHz. Above this frequency, results were more erratic. The dynamic range was about 50 dB. Some examples of the observed measurement accuracy are given below.

Figure 3 illustrates three sets of data for $|S_{21}|$ of a 30 dB type N attenuator. The filled circles are calibration points taken by AMCC. These are

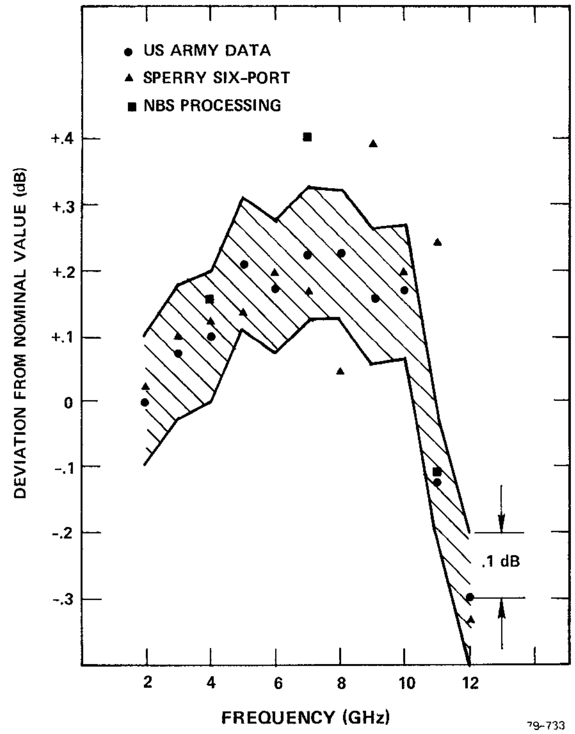

Figure 3. $|S_{21}|$ Measurement Accuracy of 30 dB Type N Attenuator

assumed to be the correct values and a ±0.1 dB cross hatched error band has been placed around them. The filled triangles are the data taken on the Sperry system. At 4, 7, and 11 GHz, we show filled squares for NBS processed data which came from calibration and measurement power readings taken on the Sperry system and processed at NBS using their algorithms. Note that although most of the points fall within the ±0.1 dB band, there are larger deviations in the Sperry data at 8, 9, & 11 GHz. This behavior was fairly typical of all $|S_{21}|$ results.

An example of S_{11} data is shown in Figure 4 for a 3 dB, APC-7 attenuator. The data symbols for the magnitude are the same as described above except that no NBS processed data was taken. Here the difference in $|S_{11}|$ is less than 0.01, except at 10 GHz. The phase differences are less than ±10° through 14 GHz and less than -20° at 16 GHz.

One of the novel features of the dual six-port system is that components with various connectors can be measured without introducing errors due to adapters because the system can be calibrated with adapters in place for almost any connector combination. For example, we measured a 6 dB attenuator with a male N connector on each port. Since the measurement ports of the basic SPANA are equipped with a male N and female N connector, a double female N adapter was connected to the male N measurement port and left in place for the remainder of the calibration and measurement procedure. The through measurement was made with a short section of lossless airline with a male N connector on each port. For calibrating with the lossy airline, the female N connector of the lossy line was replaced by a male N connector. After completing the calibration with shorts, we inserted the 6 dB attenuator with male N connectors on each port. Figure 5 shows the results of insertion loss measurements with a ±0.06 dB (±1%) error band. Over the 2 to 13 GHz band, there is good agreement between the Sperry and AMCC values. Since the attenuator is only specified for use up to 12 GHz, the data suggests that the poor match above 12 GHz greatly influences the agreement.

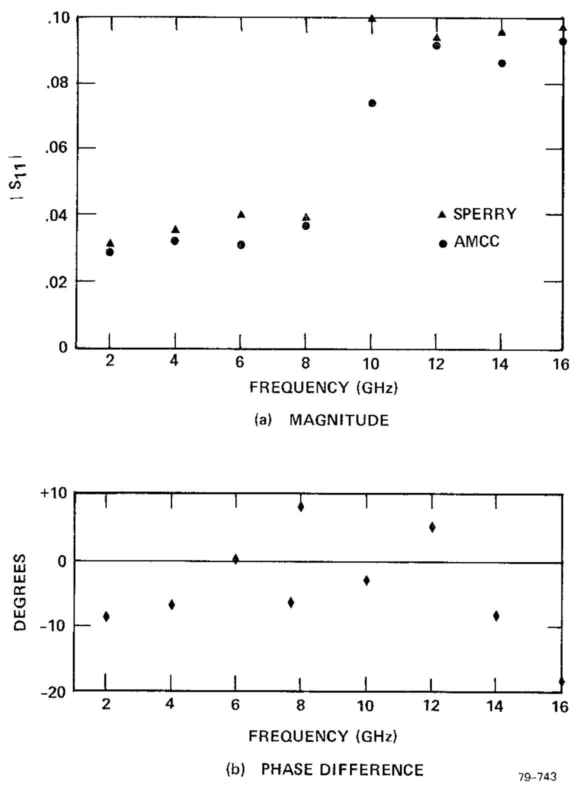

Figure 4. $|S_{11}|$ Measurement Accuracy of 3 dB, APC-7 Attenuator

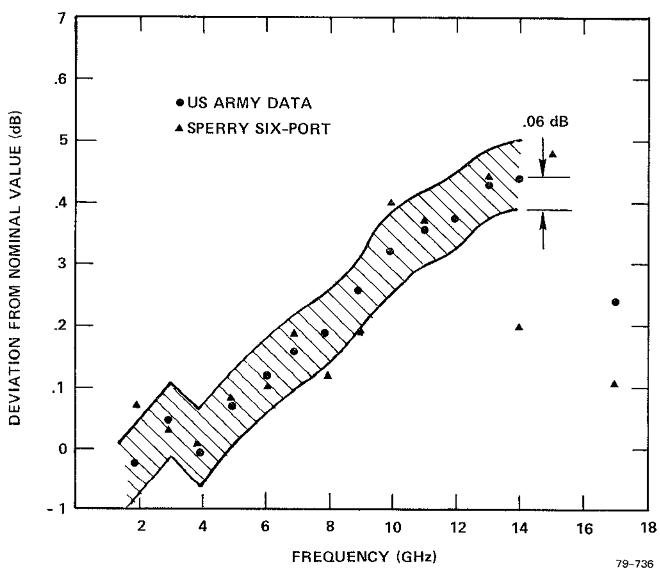

Figure 5. $|S_{21}|$ Measurement Accuracy of 6 dB Attenuator with a Male N Connector

To examine the long term behavior of the calibration constants, 10 measurements were made over a 14 day period. The 20 dB attenuator was measured almost daily using calibration constants stored on tape. Table 1 shows the repeatability with row 1 giving the

FREQUENCY (GHz)	2	3	4	5	6	7	8
AVERAGE (dB)	20.005	20.031	20.021	20.083	20.068	20.106	19.97
STANDARD DEVIATION (dB)	.033	.015	.0145	.0314	.0337	.631	.047
DEVIATION FROM CALIBRATED VALUE (dB)	-.035	-.006	-.011	+.042	+.032	.006	-.18

Table 1. 20 dB Attenuator Repeatability

average value over the 2 to 8 GHz band, row 2 listing the standard deviation, and row 3 showing the deviation from the calibrated values established by the U.S. Army for this component. Note that from 2 to 6 GHz both the standard deviation and deviation from calibrated values are quite small. At 7 GHz the standard deviation is large indicating perhaps a connect-disconnect problem. At 8 GHz the large deviation from the calibrated value may be due to errors in the stored calibration constants.

Conclusions

The main conclusion is that the diode based system is capable of accurate measurements, but that some bugs remain in the system. One area that requires further investigation is a more thorough investigation of the NBS and Sperry calibration procedures and algorithms. Other areas of suspicion are presence of harmonics and possible rogue points slipping into the data.

Acknowledgment

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