PERFORMANCE OF A DUAL SIX-PORT AUTOMATIC NETWORK ANALYZER

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ABSTRACT

The precision, accuracy, and stability of an experimental dual 6-port automatic network analyzer operating in the 2-18 GHz range are given. Accuracy of 0.001 in reflection coefficient and 0.003 dB in attenuation have been maintained at 3 GHz over a 10 week period without recalibration.

Introduction

An experimental automatic network analyzer (ANA) incorporating two 6-port reflectometers has been constructed at NBS for measuring the network parameters of 1-port and 2-port devices from 2-18 GHz. The precision, accuracy, and stability of the ANA are now being determined. Results obtained so far are summarized in this paper.

System Description

A block diagram of the dual 6-port ANA is shown in figure 1. Measurements of the reflection coefficient of 1-port devices are made by connecting the termination to either 6-port reference plane. The network parameters of a 2-port device are measured by inserting the 2-port between the two 6-port reflectometers. The theory of operation and a description of the basic system have already been published.[1]

Accuracy of a 6-port measurement is primarily a function of the quality of the standard transmission line used in the calibration, and of the resolution and linearity of the 4 sidearm power detectors. Greatest accuracy has been obtained using thermistor type power detectors driven by NBS Type IV power meters.[2] The thermistor detectors are housed in an aluminum block whose temperature is held constant to 0.01°C. The present system has a phase-locked source whose output power is externally leveled. Connectors at the measurement planes are APC-7. The system is controlled by a programmable calculator.

Accuracy in Measuring Attenuation

The accuracy of the dual six-port ANA in measuring attenuation of reciprocal two-ports at 3 GHz is shown in figure 2. The solid line is the estimated uncertainty expressed as the standard deviation of a single measurement. It varies from 0.0003 dB at low values of attenuation to 0.15 dB at 60 dB. The observed uncertainty follows closely that predicted by theory which is indicated by the shaded band. The accuracy from 2 to 12 GHz is essentially the same as that at 3 GHz. From 12 to 18 GHz the uncertainty increases to about twice that shown at 3 GHz.

How Accuracy Was Determined

The accuracy in measuring attenuation was determined as follows: First the precision of the dual six-port ANA in measuring attenuation was determined by repeated calibrations of the system and measurements of seven pads having values of 0, 3, 5, 10, 20, 40, and 60 dB. The precision is indicated by the σ's in figure 2 which is the standard deviation of five calibration and measurement cycles.

The accuracy of the dual six-port ANA was then determined by measuring different combinations of two of these pads in cascade. The measured value of attenuation of the cascaded pair was then compared to that calculated from the individually measured S-parameters of each pad. For example, the 10 dB and 20 dB pads were cascaded to make approximately 30 dB. This combination was measured and its value compared to the value calculated from the individually measured S-parameters of the 10 dB pad and of the 20 dB pad. The difference between the two values at 30 dB is plotted as a triangle (Δ) in figure 2. The different combinations that were measured are 3+5, 3+10, 10+20, 10+40, and 20+40 dB.

In all cases, the differences between the measured cascade value of attenuation and that calculated from the individual measurements fell along a curve determined by the precision of the measurements. This is an indication that the systematic error in the measurements is less than the random error in the measurements. The solid curve in figure 2 was obtained by drawing a line through the upper values of the σ's and Δ's. This curve is our best estimate of the uncertainty (one standard deviation) in measuring attenuation at 3 GHz.

Accuracy in Measuring Γ

The accuracy in measuring reflection coefficients was determined by first measuring Γ of three terminations having nominal values of Γ equal to 0.01, 0.1, and 1.0. The S-parameters of four attenuators having nominal values of attenuation equal to 0, 3, 6, and 10 dB were also measured. Then the reflection coefficient at port 1 of each attenuator was measured when port 2 was terminated by each of the terminations. The measured value of Γ of each of these 12 attenuator-termination combinations was then compared to that calculated from the individually measured S-parameters of each attenuator and the measured Γ of each individual termination. The difference between the measured Γ of the combinations and Γ calculated from individual measurements is shown in figure 3.

The imprecision in measuring Γ or any individual S-parameter is about 0.00004, excluding connector repeatability. The calculated value of Γ of an attenuator-termination combination would be expected to have an imprecision of up to four times this value or 0.00016. Since some of the differences shown in figure 3 are significantly larger than 0.00016, they indicate a systematic error of up to 0.0004 in measuring Γ. The uncertainty in measuring Γ is therefore taken to be this value of 0.0004.

One possible source of this error is in the precision transmission line used in calibrating the two 6-port reflectometers. This line is assumed to be non-reflecting. Any reflections in the line will cause a systematic error in measuring Γ.

Stability of Calibration Constants With Time

Repeated calibrations of the dual six-port ANA over a 10 week period indicate that the calibration constants are quite stable with time. Beginning November 9, 1978, the dual 6-port ANA was calibrated each week at 3 GHz to determine how the calibration constants change with time. After each calibration, five pads having nominal values of attenuation of 3, 10, 20, 40 and 60 dB were measured. Their S-parameters were calculated using calibration constants from the fresh calibration and then calculated again with constants from the original calibration of November 9. The difference in the calculated values of $|S_{11}|$ and $|S_{22}|$ as well as of attenuation and phase shift are shown in figure 4. These curves show the effect of changes in the calibration constants, which is more meaningful than plotting the actual calibration constants themselves. The curves indicate that if the constants from the original calibration had been used throughout the 10 week period, the calculated values of attenuation would have been off no more than 0.003 dB and 0.16 degree from that obtained from a fresh calibration every day. The calculated values of $|S_{11}|$ and $|S_{22}|$ would have been off no more than 0.001 from that obtained from a fresh calibration every day.

Most of the imprecision in each calibration seems to be due to the connectors. One can draw this conclusion from figures 4c and 4d. Note that the differences in S_{12} calculated from the fresh or old calibration constants are essentially independent of the value of S_{12} for pads up to 40 dB. This type of constant offset can be caused by a slight change in the loss and phase shift through the connectors at the 6-port reference planes. This change in the connectors can be measured by connecting the two reference planes together and measuring the S-parameters using the old calibration constants. Ideally the attenuation of this "thru" measurement would be zero with zero phase shift. In actual measurements, these values of attenuation and phase are not zero, and can take on positive or negative values. Beginning on day 15 of the long term run, data for the "thru" measurement was saved along with that for the pads so corrections could be made for wear on the connectors. The correction was made by subtracting the value of S_{12} for the "thru" measurement from S_{12} for each pad, both calculated using the original day zero calibration constants. The differences between the corrected S_{12} for each pad and that obtained from fresh calibration constants are less than 0.001 dB and 0.02 degree as shown in figure 5. The improvement is quite significant.

The results shown in figure 5 imply that a simple correction can be made for day to day changes in the connectors by measuring S_{12} of a "thru" connection and subtracting this S_{12} from the S_{12} of other 2-ports being measured. This correction is essentially as good as a complete recalibration in the measurement of attenuation.

The data taken so far suggests that the dual 6-port ANA need not be calibrated more often than once every couple of months, but that the "thru" measurement should be made daily or more often depending on connector wear.

Acknowledgement

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References

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2. Neil T. Larsen, "A New Self-Balancing DC-Substitution RF Power Meter," IEEE Trans. on Instrumentation and Measurement, Vol. IM-25, pp. 343-347, Dec. 1976.

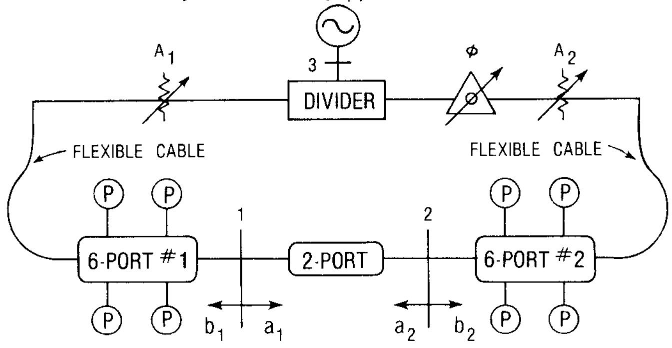

Figure 1. Block diagram of the dual 6-port automatic network analyzer, where P indicates a power detector.

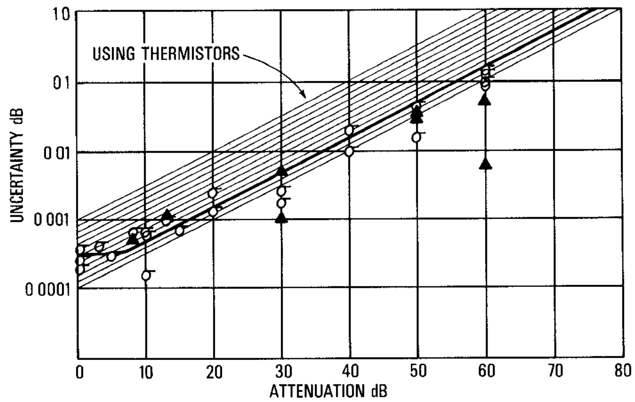

Figure 2. The solid line represents the estimated uncertainty (one standard deviation) in measuring attenuation with the dual 6-port ANA using thermistor type detectors. The shaded band represents the range in which the uncertainty was expected to fall based on computer simulation. Each σ represents the standard deviation of 5 measurements of attenuation. Each triangle represents the difference in the measured attenuation of two cascaded pads from the attenuation calculated from their individually measured S-parameters.

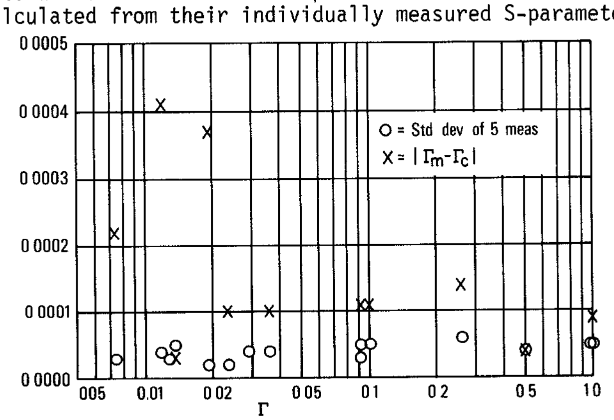

Figure 3. Precision and accuracy in measuring reflection coefficient, Γ. Each circle represents the standard deviation of 5 measurements of Γ. Each X represents $|\Gamma_m - \Gamma_c|$ where Γ_m is the measured Γ of an attenuator-termination combination, and Γ_c is Γ calculated from the measured S-parameters of the attenuator and the measured Γ of the termination.

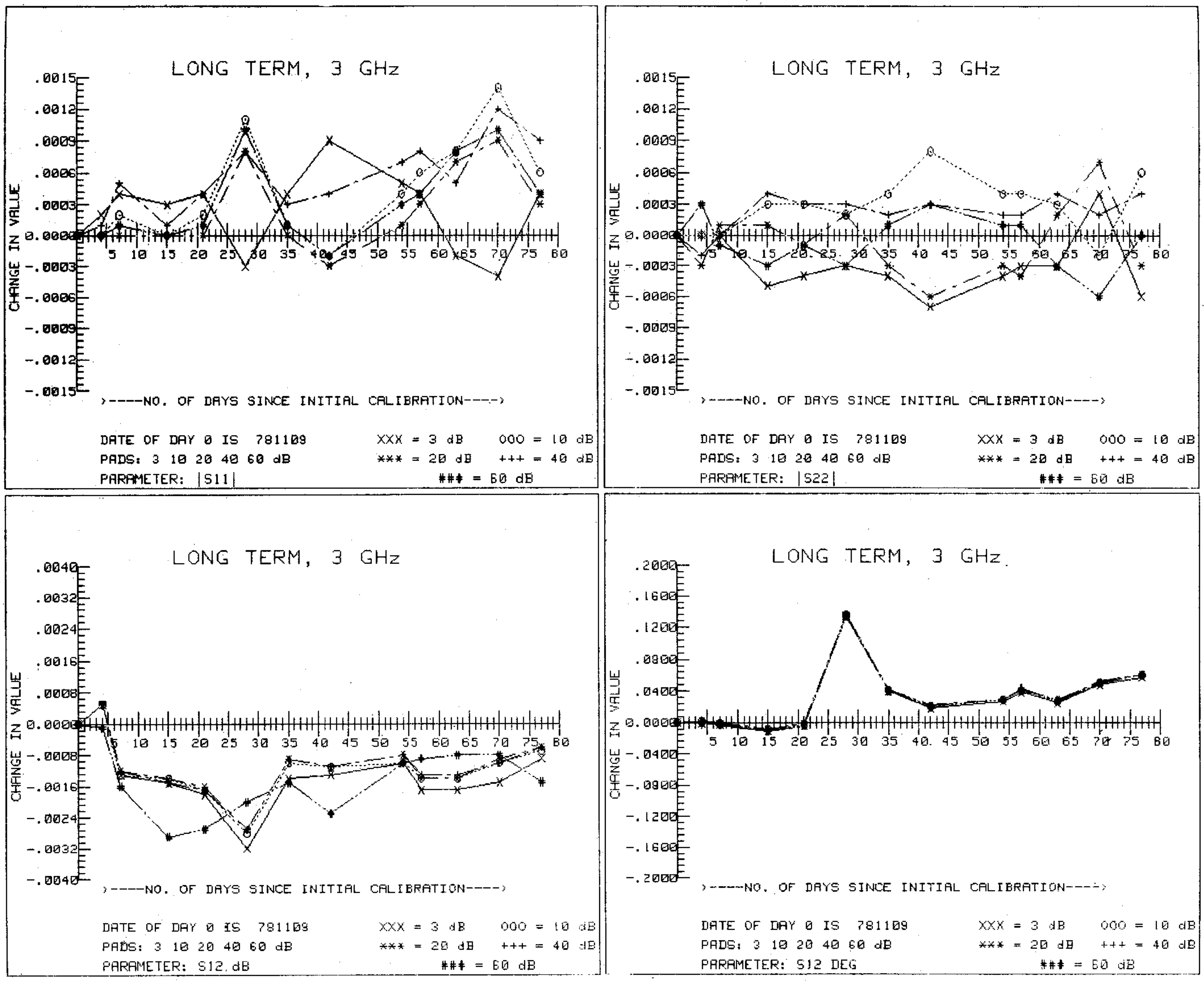

Figure 4. Difference in calculated value of $|S_{11}|$, $|S_{22}|$ and S_{12} (dB and degrees) using fresh calibration constants obtained on the day indicated, and old calibration constants obtained on day zero.

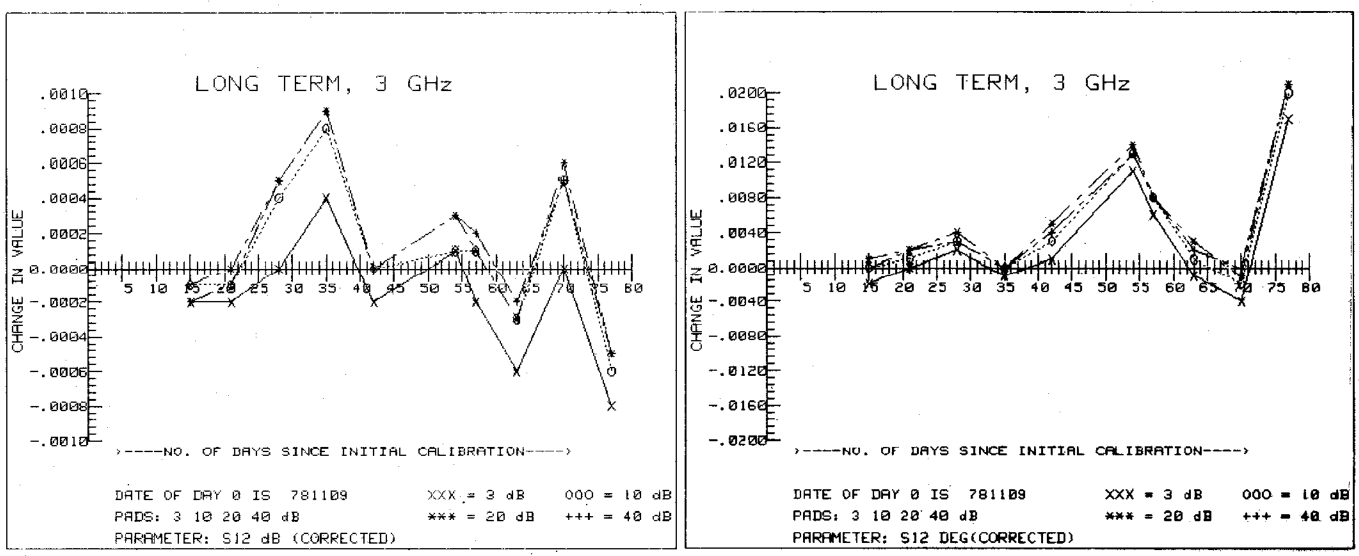

Figure 5. Difference between the corrected value of S_{12} (S_{12} of the pad $-S_{12}$ of the Thru), calculated using old calibration constants obtained on day zero, and S_{12} of the pad calculated using fresh calibration constants obtained on the day indicated.