A MICROWAVE NETWORK ANALYZER USING TWO 6-PORT REFLECTOMETERS*

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Abstract

Theory is presented for designing a microwave network analyzer which measures the circuit parameters of a 2-port device by connecting small portable 6-port reflectometers on each side of the 2-port. Several calibration techniques are described, including self-calibration.

Basic Idea

The basic setup for using two 6-port reflectometers to measure all of the scattering parameters of a 2-port device is shown in figure 1. The rf signal is applied to both 6-port reflectometers at the same time. The left 6-port reflectometer measures the ratio $\rho_1 = b_1/a_1$, and the right one measures the ratio $\rho_2 = b_2/a_2$. These two complex ratios are related by the S-parameters of the 2-port device inserted between the two 6-port reflectometers. From the scattering equations for the 2-port under test,

$$\rho_1 \equiv \frac{b_1}{a_1} = S_{11} + S_{12}\frac{a_2}{a_1} \tag{1}$$

$$\rho_2 \equiv \frac{b_2}{a_2} = S_{22} + S_{21}\frac{a_1}{a_2}\,. \tag{2}$$

Eliminating a_2/a_1 from (1) and (2) gives

$$\rho_2 S_{11} + \rho_1 S_{22} + S_{12}S_{21} - S_{11}S_{22} = \rho_1\rho_2. \tag{3}$$

Three equations like (3) are needed to solve for the S-parameters. These equations are generated by measuring ρ_2 and ρ_2 for three different values of a_2/a_1 which are determined by the setting of the attenuators α_1,α_2 and of the phase shifter ϕ. The values of α_1,α_2 and ϕ do not need to be known. These three equations can be solved for S_{11}, S_{22}, and $\Delta \equiv S_{12}S_{21} - S_{11}S_{22}$. If the 2-port device is reciprocal so that $S_{12} = S_{21}$, then S_{12} is obtained from Δ.

If the 2-port device is not reciprocal, $|S_{12}|$ and $|S_{21}|$ can still be obtained using (1) and (2) which give

$$|S_{12}| = |\rho_1 - S_{11}| \left|\frac{a_1}{a_2}\right| \tag{4}$$

$$|S_{21}| = |\rho_2 - S_{22}| \left|\frac{a_2}{a_1}\right|\,. \tag{5}$$

The 6-port reflectometer measures $|a_2/a_1|$ as well as ρ_1 and ρ_2 to use in these equations. The phase angles of S_{12} and S_{21} cannot be separated when the 2-port is not reciprocal.

Six-Port Reflectometer

The two "6-port" reflectometers are identical in design to the 7-port reflectometer shown in figure 2 where only four of the five detectors are normally used. The upper part, everything above the bottom quadrature hybrid, is the same circuit as has been used in the 6-port microwave vector voltmeter.[1] Each 6-port reflectometer and its detectors are small enough to be used as a portable "probe" which is connected directly to the device under test, thus eliminating flexible cables or arms between the test set and the device under test. If the components are ideal, the reflection coefficient Γ of a one-port load or ρ of a 2-port device is given by

$$\rho = \Gamma = \frac{(P_5 - P_7) + j(P_6 - P_8)}{P_3}\,. \tag{6}$$

The detectors $P_5 \ldots P_8$ can be used to display Γ (or ρ) on a scope. Since the components are not ideal, one uses the more general equation[2]

$$\rho = \Gamma = \frac{\Sigma\, c_i P_i + j\,\Sigma\, s_i P_i}{\Sigma\, \alpha_i P_i} \tag{7}$$

which, with few exceptions, applies to any 6-port junction. Usually only four of the five detectors are used, choosing P_3 plus three of the four remaining detectors. Then each summation in (7) is the sum of those four power readings with each reading multiplied by a different real constant c_i, s_i, or α_i.

Calibration Techniques

There are a number of ways that the calibration constants c_i, s_i, and α_i can be determined. One way is to first calibrate one 6-port reflectometer with a sliding short and a sliding load,[3] or with four known loads as shown in figure 3. Then if the reference planes of the two reflectometers are connected together, the first 6-port reflectometer will calibrate the second one.

Self-calibration techniques can also be used. By "self-calibration" is meant that both 6-port reflectometers can be calibrated for making complex impedance ratio measurements without using any standards. In place of standards, a "calibration circuit" is used as shown in figure 4. Three possible calibration circuits are shown in figure 5.

The calibration at a given frequency consists of the following operations which are illustrated in figure 4b.

1. The two reference planes are connected together and four measurements taken at different settings of α_1,α_2 and ϕ.

2. Six-port #1 is connected to the calibration circuit and two or three measurements taken depending on what is used in the calibration circuit.

3. Six-port #2 is connected to the calibration circuit, and two or three measurements taken as before.

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These measurements which use no standards give enough information to calibrate each 6-port reflectometer for making complex impedance ratio measurements. To complete the calibration requires only one standard.

Standards Needed

The standard can be a uniform length of line which is inserted between the two reflectometers or one known load which is connected to either reflectometer. If it is desired to measure power as well as impedance, a power standard must be added also. That completes the calibration. Either 6-port reflectometer can now be used to measure power or impedance or reflection coefficient of loads connected to either reflectometer, or the two 6-port reflectometers can be used to measure the S-parameters of a 2-port device between them.

Calibration Circuit

Once the calibration is complete, the value of the components used in the calibration circuit can also be calculated. If the circuit in figure 5a is used, the three loads are now known. If the circuit in figure 5b is used, the two loads and the ratio of the two different power levels are known. Or if a third uncalibrated 6-port reflectometer is used as in figure 5c, that reflectometer is now calibrated also.

Assuming that the calibration circuit is stable and repeatable, it can now be used as a check standard or reference standard in doing future calibrations of the two 6-port reflectometers. When the calibration circuit is known, the three steps outlined in figure 4b are sufficient to completely calibrate both 6-port reflectometers. It should therefore not be necessary to use the standard length of line or the standard load except when the calibration circuit is being recalibrated, or when using the system at a frequency where the calibration circuit has not previously been calibrated.

Results

Experimental results will be given in the paper using the calibration circuit in figure 5b.

References

1. C. A. Hoer and K. C. Roes, "Using an Arbitrary Six-port Junction to Measure Complex Voltage Ratios," IEEE Trans. Microwave Theory and Techniques, vol. MTT-23, no. 12, pp. 978-984, Dec. 1975.

2. C. A. Hoer, "Using Six-Port and Eight-Port Junctions to Measure Active and Passive Circuit Parameters," NBS Tech. Note 673, 23 pp. Sept. 1975.

3. G. F. Engen, "Calibration of an Arbitrary Six-port Junction for Measurement of Active and Passive Circuit Parameters," IEEE Trans. Instrumentation and Measurement, vol. IM-22, pp. 295-299, Dec. 1973.

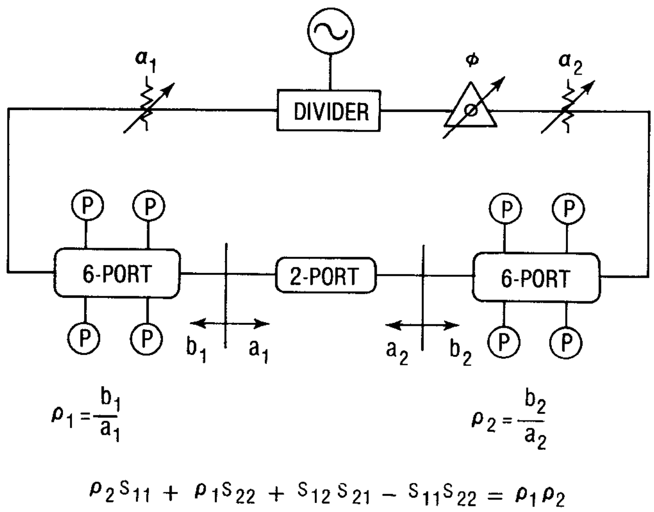

Fig. 1-Using two 6-port reflectometers to measure all of the scattering parameters of a 2-port device

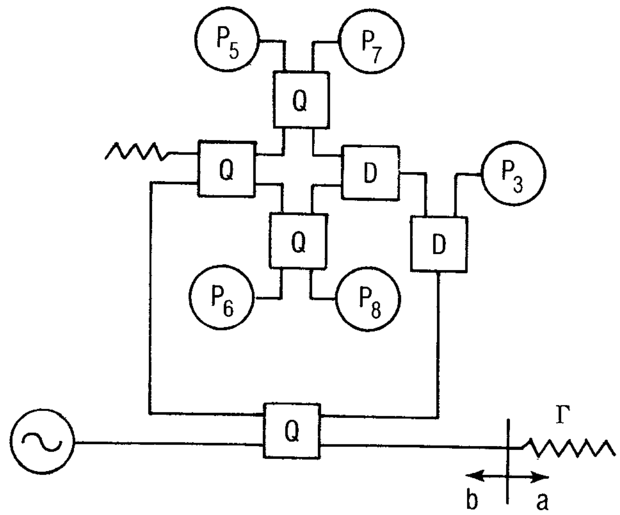

Fig. 2-A 7-port reflectometer constructed with quadrature hybrids, Q, and in-phase power dividers, D. A 6-port reflectometer is obtained by replacing one of the power detectors $P_5 \ldots P_8$ with a load.

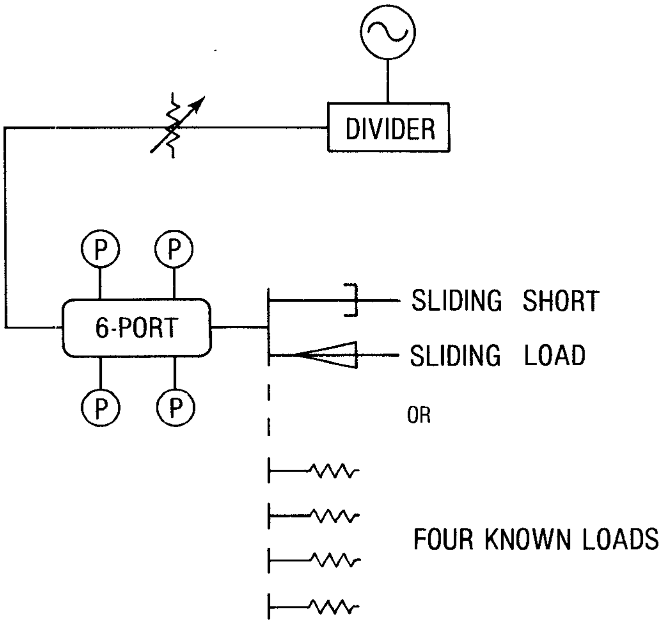

Fig. 3-Calibrating one 6-port reflectometer with either a sliding short and a sliding load or with four known loads.

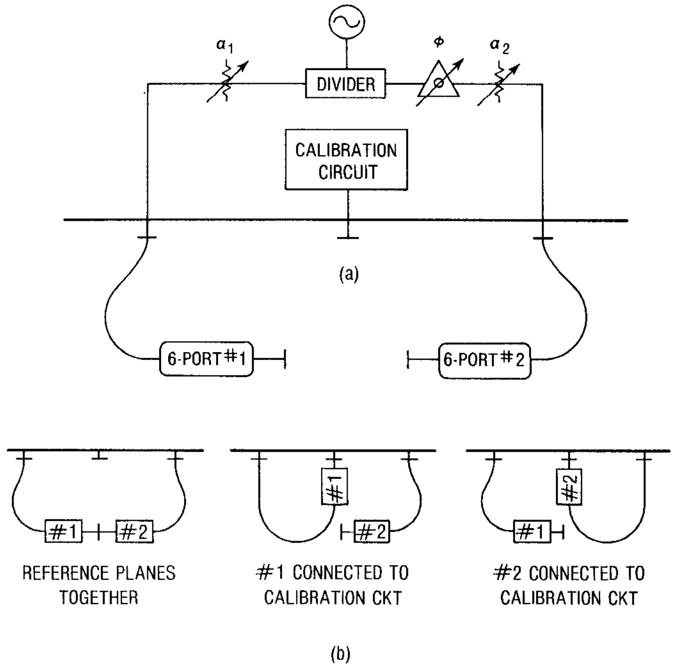

Fig. 4-Illustrating the three different measurement conditions of the self-calibration procedure where the two 6-port reflectometers are each calibrated for making complex impedance ratio measurements without using any standards.

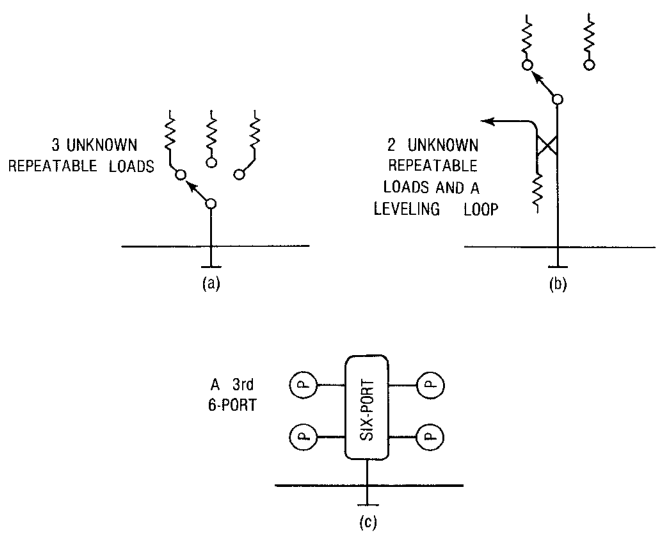

Fig. 5-Three possible calibration circuits that can be used in the self-calibration procedure illustrated in Fig. 4.