SYMMETRIC TEST FIXTURE CALIBRATION

Eric R. Ehlers

Hewlett-Packard Co., Microwave Technology Division
Santa Rosa, California 95401

Abstract

A symmetric test fixture can be calibrated for error-corrected measurements with two standards. Equations are presented for calibrating with either of two special sets of standards: 1) a thru of zero length and a matched load and 2) a thru of zero length and a matched 2-Port with unknown transmission characteristics. A measurement example is described for a fin-line test fixture.

Introduction

Calibration of a microwave or millimeter-wave test fixture requires the measurement of a number of standards with known, or partially known, characteristics. If the test fixture is symmetric only two standards are required.

Calibration techniques that take advantage of fixture symmetry have been described previously [1,2,3] but require approximations or iterative calculations. Closed-form equations are presented for calibrating with either of two special sets of standards: 1) a thru of zero length and a matched load and 2) a thru of zero length and a matched 2-Port with unknown transmission characteristics.

Calibration Equations

A symmetric fixture can be described by its voltage scattering parameters. The flowgraph representation of the fixture alone and with two symmetric 2-Port standards is shown in Figure 1. Fixture parameters have the subscript "y" and subscripts "a" and "b" refer to the parameters of the two standards. Measured scattering parameters of the fixture with standard "a" have the subscript "ma" and the measured parameters of the fixture with standard "b" have the subscript "mb".

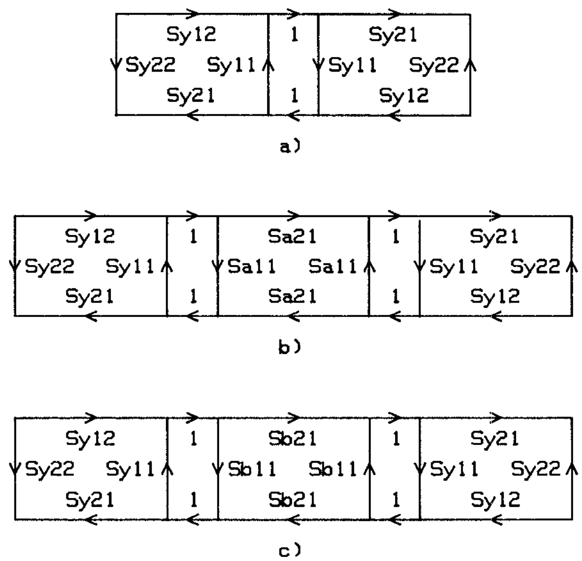

Fig. 1 Flowgraph representation of a) a symmetric fixture, b) a symmetric fixture with standard "a" and c) a symmetric fixture with standard "b".

The first set of standards is a thru of zero length (a "direct connection") at the center of the fixture and a matched load. Referenced to the dominant mode of propagation at the center of the fixture, the scattering parameters of these standards are simple. If the thru is standard "a" and the matched load is standard "b" then Sa11=0, Sa21=1, Sb11=0 and Sb21=0. For these standards the equations for the fixture voltage scattering parameters are given by equations (1) - (3).

$$S_y11 = \frac{S_{ma}11 - S_{mb}11}{S_{ma}21} \quad (1)$$

$$S_y12S_y21 = S_{ma}21\ [\,1-(S_y11)^2\,] \quad (2)$$

$$S_y22 = S_{mb}11 \quad (3)$$

The second set of special standards is a thru of zero length and a matched 2-Port. Referenced to the dominant mode of propagation at the center of the fixture the scattering parameters of the thru (standard "a") and the matched 2-Port (standard "b") are Sa11 = 0, Sa21 = 1, Sb11 = 0 and the unknown transmission parameter Sb21. For these standards the fixture parameters and Sb21 are given by equations (4) - (7).

$$S_b21 = \frac{-B \pm (B^2 - 4)^{1/2}}{2} \quad (4)$$

$$B = \frac{(S_{ma}11 - S_{mb}11)^2 - (S_{ma}21)^2 - (S_{mb}21)^2}{S_{ma}21S_{mb}21}$$

$$S_y11 = \frac{2 - K(1 - S_b21)}{2S_b21 + K(1 - S_b21)} \quad (5)$$

$$K = \frac{2S_{ma}21}{S_{ma}11 + S_{ma}21 - S_{mb}11 - S_{mb}21}$$

$$S_y12S_y21 = S_{ma}21\ [\,1-(S_y11)^2\,] \quad (6)$$

$$S_y22 = S_{ma}11 - S_y11S_{ma}21 \quad (7)$$

Both sets of standards include a zero-length thru, which is a simple standard to fabricate. The matched load is more difficult but in waveguide fixtures a reasonable load can be made by gradually attenuating the traveling wave over many wavelengths with an absorbing material. Two advantages of using the thru and load standards are that only one fixture is required and the calibration can be broadband if a broadband load is available.

A convenient matched 2-Port for the second set of standards is a length of transmission line or waveguide that is approximately a quarter wavelength long. The disadvantages of using this standard are that an additional lengthened fixture may be needed and the standard cannot be used at frequencies where it is close to a half wavelength (or multiples of a half wavelength). However, this standard is easily fabricated and its use should result in an accurate calibration. Note that there are two possible solutions for Sb21 and the correct one can usually be identified without difficulty if Sb21 is known approximately. For example, if the standard is a length of transmission line that is known to be less than a half wavelength over the frequency range of interest the correct solution has a negative phase angle.

Measurement Example

Both sets of special standards have been used to calibrate a symmetric fin-line test fixture in R-band (26.5 to 40 GHz). The fin-line standards and test circuits are mounted in the center of a reduced height (.28 cm) waveguide and are fabricated with gold conductors on .0254 cm thick fused silica. The thru, load and matched 2-Port standards are shown in Figure 2. The resistive film for the load is tantalum nitride, 50 ohms per square.

A measurement example is shown in Figure 3. The device measured is a beam-leaded GaAs Schottky diode pair that is mounted in shunt across the fin-line gap of .0254 cm in the center of the test circuit (identical to the thru standard circuit). An HP-8510 R-band vector network analyzer system was used to make the measurements [4]. A "one-path two-port" calibration was first made with waveguide standards to calibrate the system and the thru and matched 2-Port fin-line standards were measured. The scattering parameters of the fixture were then calculated and the error coefficients of the network analyzer were modified using these parameters to correct (or "de-embed") the final measurements [5]. A separate calibration was also made using the first set of standards (a thru and a matched load); the results were similar but it was felt that the thru and matched 2-Port calibration was more accurate.

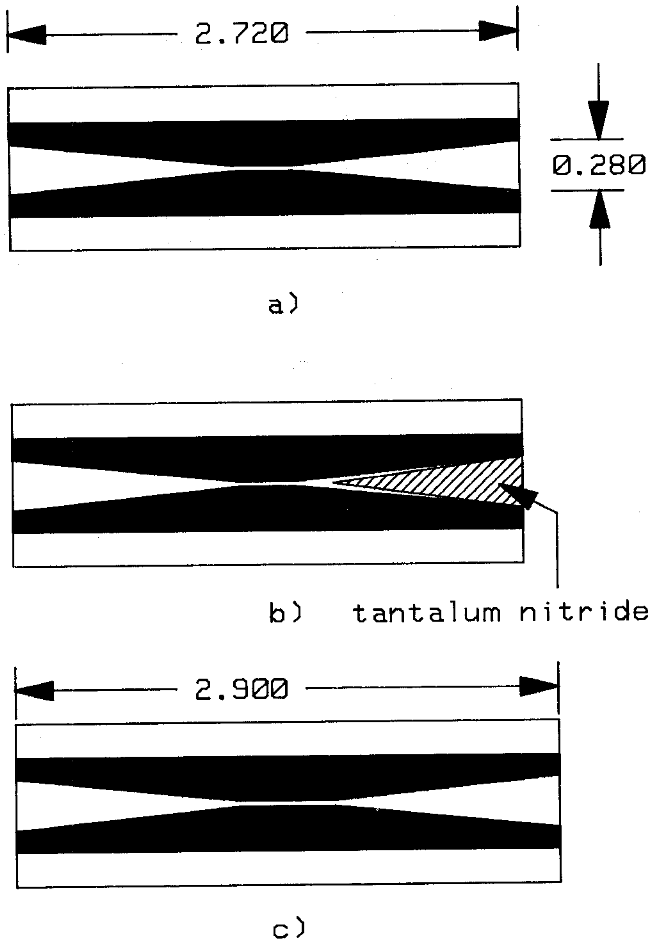

Fig. 2 Fin-line standard circuits: a) a zero-length thru b) a matched load c) a matched 2-Port (extra length thru). Dimensions are in centimeters.

The fixture without calibration is not very good; the minimum Return Loss of the thru is 7 dB. This is due primarily to the abrupt height change from standard waveguide to the reduced height in the fixture. Because of this, however, the improvement due to calibration is readily apparent. Also shown in Figure 3 is S11 of the diode pair without full calibration; a vector normalization was made to correct only for fixture transmission magnitude and phase. The improvement due to full calibration can be seen in the lack of fixture resonances that are present in the normalized data.

The transmission parameter of the matched 2-Port, Sb21, is found during the calibration along with the fixture parameters. The phase of Sb21 is plotted in Figure 4 along with the phase predicted by a spectral-domain fin-line analysis program [6]. The agreement is better than 3 degrees.

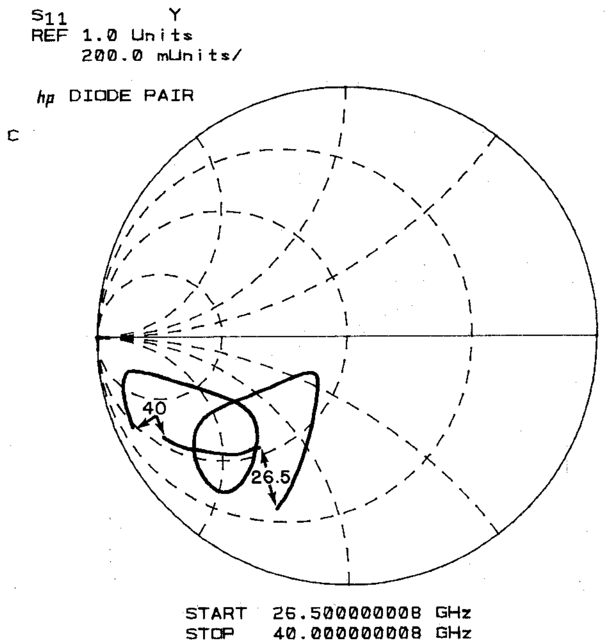

Fig. 3 Measured S11 of a beam-leaded diode pair with full fixture calibration (solid line, short arc) and with partial correction for fixture transmission magnitude and phase (looping, solid line).

Conclusion

Accurate vector measurements can be made by calibrating with two standards in a symmetric test fixture. The two sets of standards described in this paper are simple to fabricate and ideally suited for calibrating waveguide test fixtures. The technique is quite general, however, and should prove useful for calibrating any symmetric fixture for which more conventional standards (such as shorts and opens) are not available.

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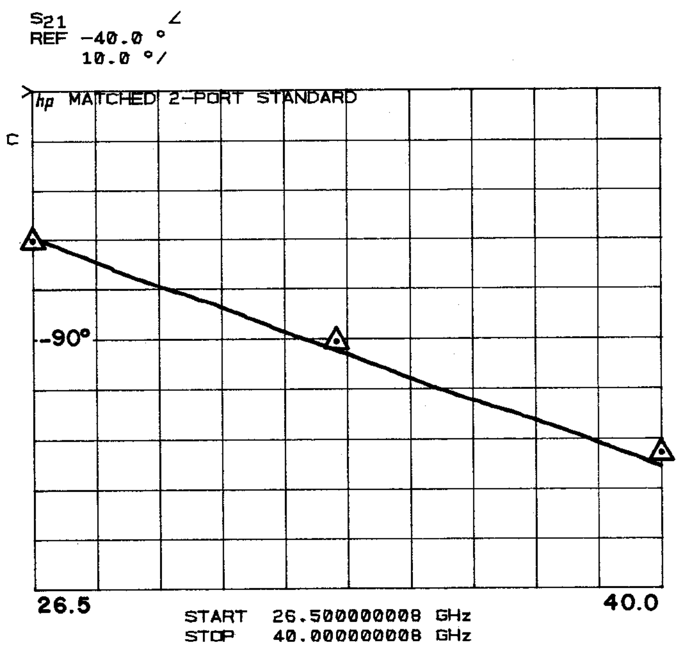

Fig. 4 Measured phase of matched 2-Port standard (solid line) and calculated phase (triangles). Scale is 10 deg per division.

References

(1) K. C. Gupta, R. Garg and R. Chadha, Computer-aided Design of Microwave Circuits, Artech House, pp. 319-321, 1981.

(2) J.R. Souza and E.C. Talboys, "S-parameter Characterization of Coaxial to Microstrip Transition," IEE Proc., Vol. 129, Pt. H., No. 1, pp. 37-40, Feb. 1982.

(3) M. Burton and W.J.R. Hoefer, "An Improved Model for Short- and Open-Circuited Series Stubs in Fin Lines," pp. 330-332, 1984 IEEE MTT-S Digest.

(4) Hewlett-Packard Co., "Procedures Explained for mm-wave Vector Measurements with the HP8510A Analyzer," MSN, pp. 65-90, Dec. 1984.

(5) G. Elmore, "De-embedded Measurements Using the HP8510 Microwave Network Analyzer," 25th Automatic RF Techniques Group (ARFTG) Digest, pp. 124-143, June 1985.

(6) T. Bagwell, Hewlett-Packard Co., private communication.