THE APPLICATION OF "THRU-SHORT-DELAY" TO THE CALIBRATION OF THE DUAL SIX-PORT

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Abstract

In a companion paper, in this digest, a scheme for reducing the (single) six-port calibration problem to that of an equivalent four-port reflectometer has been described. This now makes it possible to apply existing four-port calibration schemes. One such method is the "thru-short-delay" (TSD) procedure. This paper briefly outlines this calibration approach.

Theory

In a companion paper[1] the existence of a method for effecting a reduction from the six-port to an equivalent four-port reflectometer was noted. This procedure is briefly as follows:

If for the four power meters that are associated with the six-port one takes the ratio of three of these readings to the fourth (i.e., P_3/P_4, P_5/P_4, P_6/P_4), then one can consider these observations as determining a point in a three-dimensional "P-space." It has been shown[2], moreover, that three of the four power meter readings determine the fourth to the extent of a choice between two possible values. An equivalent statement is that the set of possible values for P_3/P_4, P_5/P_4, P_6/P_4 lie on a quadric surface. This surface is an elliptic paraboloid which is tangent to the planes $P_3/P_4 = 0$, $P_5/P_4 = 0$, $P_6/P_4 = 0$.

A general quadric surface involves nine arbitrary constants. The foregoing stipulations, however, reduce the number of arbitrary constants from nine to five. It is possible to describe the six-port to four-port reduction in terms of the parameters that characterize this paraboloid.

If for a variety of arbitrary terminations at the measurement port one obtains a corresponding collection of nine or more sets of values for P_3/P_4, P_5/P_4, P_6/P_4, then the solution of a linear system of equations will yield the nine constants associated with the general quadric surface passing through these points. Ideally, this surface would be a paraboloid and would satisfy the tangency conditions outlined above; but, because of measurement errors, this will only be approximately true. Next, the constraints among these nine constants which enforce the tangency and paraboloid conditions, are imposed upon the solution already obtained. This leads to a system of five nonlinear equations, and an iterative procedure is required. Ordinarily, however, the solution to the linear system provides a good approximation of the desired results, and the convergence is rapid. This provides the necessary information to reduce the six-port to an equivalent four-port.

At this point it may be convenient to visualize the problem as shown in Figure 1. In particular, the five paraboloid parameters, together with the observed values of $P_3 \ldots P_6$, permit one to determine the wave amplitudes at two fictitious reference planes, which are the inputs to two fictitious two-ports (or error boxes) labeled A, B. These wave amplitudes, in turn, are related to those that actually exist at the measurement planes 1, 2, by the well-known bilinear transformation. The remaining problem is to determine the three complex constants that characterize this transformation for each of the two-ports, A, B.

This is the basic problem to which a calibration technique known as "TSD" (thru, short, delay) addresses itself[3,4]. As input data, the "TSD" solution calls for the scattering parameters of three distinct two-ports. The first of these is comprised of A and B in cascade and is formed by connecting the measurement planes 1 and 2 together. (This comprises the "thru" connection.) The second two-port is a degenerate one, in that $S_{12} = S_{21} = 0$. The S_{11} and S_{22} are the reflection coefficients that exist at the fictitious input planes of A, B respectively, when planes 1, 2 are terminated by shorts. (This represents the "short" connection.)

Finally, the third two-port is comprised of a cascade combination of A, an unknown length of transmission line connected between planes 1, 2, and B. (This represents the "delay.")

In order to obtain the scattering parameters of the first and third of these combinations, it is necessary to excite each of the resulting two-ports under a minimum of three different conditions. As already explained, the paraboloid parameters, together with the observed values of $P_3 \ldots P_6$, permit a determination of the wave amplitudes at both fictitious input planes. Given this information, the scattering parameters of the cascaded fictitious two-ports, with and without the delay inserted, may be obtained as explained in an earlier paper[5]. This now represents the required data for the "TSD" solution which, in turn, yields the parameters of A and B.

It may be noted in this context that a minimum of three measurements, (using different test signals) are required in each of the "thru" and "delay" modes. This, together with the "short" measurements, comprises seven of the nine observations required to effect the six-port to four-port reduction. To complete the required number, it is convenient to add a fourth measurement in each of the "thru" and "delay" modes.

Summary

By following a procedure that permits the six-port to be reduced to an equivalent four-port reflectometer, it is possible to apply an existing calibration scheme to the dual six-port with a minimum of additional operator effort.

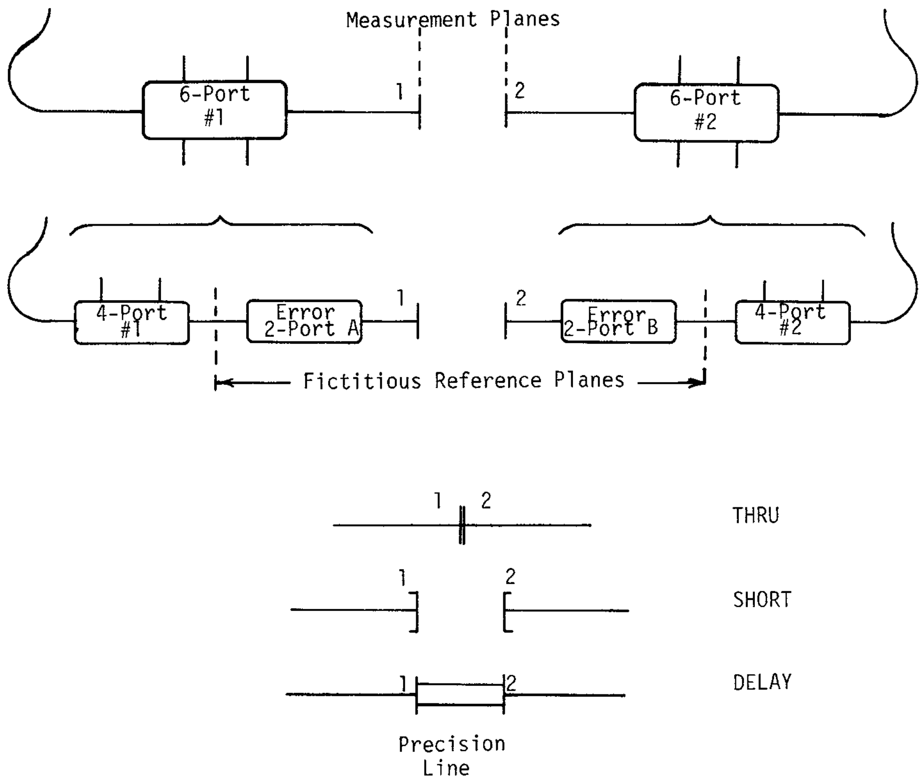

Figure 1: Each Six-Port May Be Reduced To An Equivalent (Ideal) Four-Port Reflectometer And "Error Two-Port" Which May Then Be Evaluated Via The "Thru-Short-Delay" Method.

References

[1] G. F. Engen, "Calibrating the Six-Port Reflectometer," (to be found elsewhere in this program digest).

[2] G. F. Engen, "The Six-Port Reflectometer: An Alternative Network Analyzer," IEEE Trans. Microwave Theory Tech., Vol. MTT-25, pp. 1075-1080, Dec. 1977.

[3] N. R. Franzen and R. A. Speciale, "A New Procedure for System Calibration and Error Removal in Automated S-Parameter Measurements," Proceedings of the 5th European Microwave Conference, Hamburg, Germany, 1-4 September 1975, pp. 69-73, Publ.: Microwave Exhibitions and Publishers, Sevenoaks, Kent, England.

[4] N. R. Franzen and R. A. Speciale, "Accurate Scattering Parameter Measurements on Nonconnectable Microwave Networks," Proceedings of the 6th European Microwave Conference, Rome, Italy, 14-17 September 1976, pp. 210-214, Publ.: Microwave Exhibitions and Publishers, Sevenoaks, Kent, England.

[5] C. A. Hoer, "A Network Analyzer Incorporating Two Six-Port Reflectometers," IEEE Trans Microwave Theory Tech., Vol. MTT-25, pp. 1070-1 1075, Dec. 1977.