CALIBRATING A DUAL SIX-PORT OR FOUR-PORT FOR MEASURING TWO-PORTS WITH ANY CONNECTORS

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ABSTRACT

A technique is described for calibrating a dual six-port or four-port ANA so that the scattering parameters of two-port devices having any combination of connectors can be measured. The technique is a generalization of the "thru-reflect-line" (TRL) calibration technique in which the "thru" is replaced with a second length of precision transmission line.

INTRODUCTION

The TRL technique [1] for calibrating a dual six-port or four-port reflectometer has been modified so that the scattering parameters of two-port devices having any combination of connectors can be measured.

The "Through," "Reflect," and "Line" measurements made in the TRL calibration are shown in Figure 1a. The complex sidearm ratios w_1 and w_2 are measured for the three measurement conditions shown. The measurement planes are connected together, then one or more highly reflecting terminations are connected to one six-port and then to the other six-port. Finally a length of precision transmission line is connected between the two six-ports. For a dual six-port, w_1 and w_2 are each obtained from four power measurements made on the four sidearms of each six-port [1]. For a dual four-port, w_1 and w_2 are obtained from a detector which measures the complex sidearm ratio directly.

The TRL calibration yields the parameters a,b,c of four-port A, and α,β,δ of four-port B. Also obtained from the TRL solution are the reflection coefficients of all the terminations used in the "reflect" measurements, and $\gamma\ell$ of the precision transmission line used in the "line" measurement, where γ is the propagation constant of the line, and ℓ is its physical length. As shown in figure 1a, the TRL technique can be applied only to reflectometers having identical sexless connectors at the test ports. If the requirement for making a "through" connection is replaced by a measurement with a short length of line as shown in Figure 1b, then the calibration technique can be applied to a pair of reflectometers having identical connectors of any type, not just sexless connectors. This LRL (Line-Reflect-Line) calibration technique is the subject of this paper.

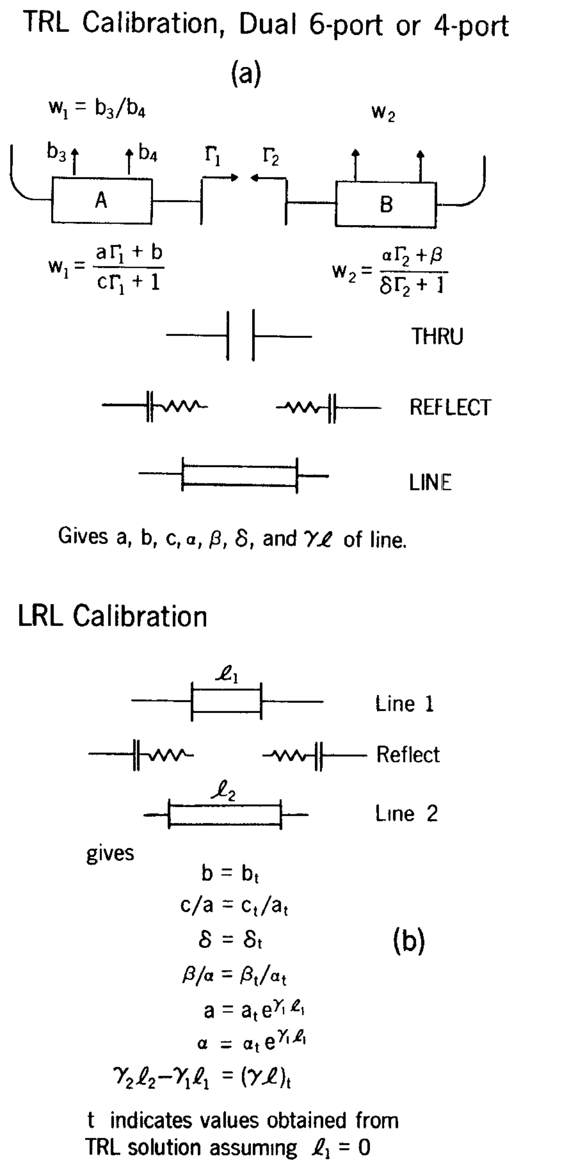

Figure 1. a) TRL technique for calibrating a dual six-port or four-port reflectometer. b) LRL calibration technique where the "thru" is replaced with a short length of line.

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LRL EXAMPLES

a) Two pairs of lines:
An example of the LRL calibration technique is shown in Figure 2a where both test-port connectors are identical male connectors. When the calibration using two lines and one or more terminations with female connectors is complete, the S-parameters of two-port devices that have female connectors on both ends can be measured.

Figure 2b shows an example where adapters have been added to obtain two female port connectors. The LRL calibration can be applied to these new test ports using lines and terminations with male connectors. Then two-port devices that have male connectors on both ends can be measured.

To measure two-port devices that have one male and one female connector, adapter C (or D) is removed to obtain the test port configuration shown in Figure 2c. The parameters for reflectometer A are known from the calibration in Figure 2a, and the parameters for reflectometer configuration F are known from the calibration in Figure 2b. Note that the repeatability of adapter C (or D) is not important when this sequence of measurements is used.

The connector types used in Figure 2a and 2b can be completely different. For example, those in Figure 2a could be type N, while the connectors in Figure 2b could be SMA. Two-ports that have a female type N on one end and a male SMA on the other end can then be measured as in Figure 2c. The LRL calibration technique can also be applied if one set of connectors is waveguide, and the other set is coax.

b) One Pair of Lines:
Only one pair of lines is needed to calibrate the two reflectometers if the connectors on the two-port under test are of the same type. For example, to measure two-port devices that have any combination of type N connectors, the reflectometers are first calibrated with type N male connectors as shown in Figure 3a. Then a female-female type N adapter is measured as shown in Figure 3b, and left connected to one of the reflectometers, say to B. Two-port devices that have male-female type N connectors can now be measured between A and D. To measure two-port devices with two male type N connectors, one may remove adapter D and measure the parameters of another similar adapter C. As shown in Figure 3c, leaving adapter C on reflectometer A, and reconnecting adapter D to reflectometer B provides a pair of female test ports between which two-port devices that have male connectors can be measured.

LRL CALIBRATION

The computations and software used in the TRL solution can also be used in the LRL solution with only slight modifications. If a line of length ℓ_1 is used in the TRL calibration instead of a "through" ($\ell_1 = o$) connection, the following modifications to the error box parameters are obtained:

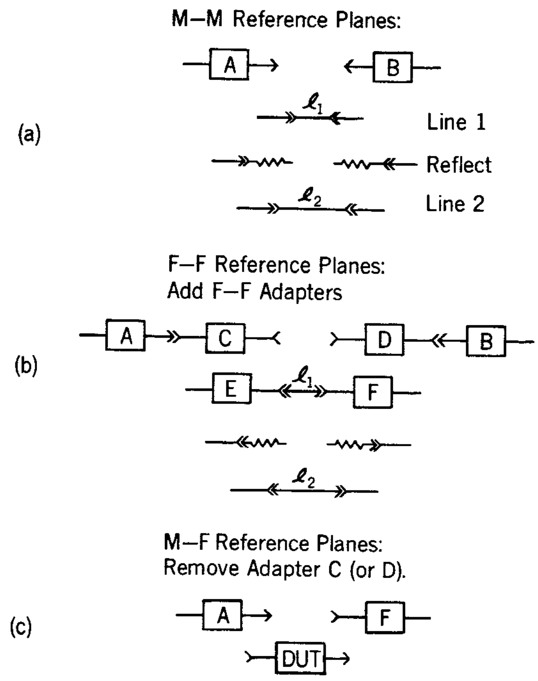

Figure 2. Using a set of female standards and a set of male standards to do a complete LRL calibration so that a two-port device with any combination of connectors can be measured.

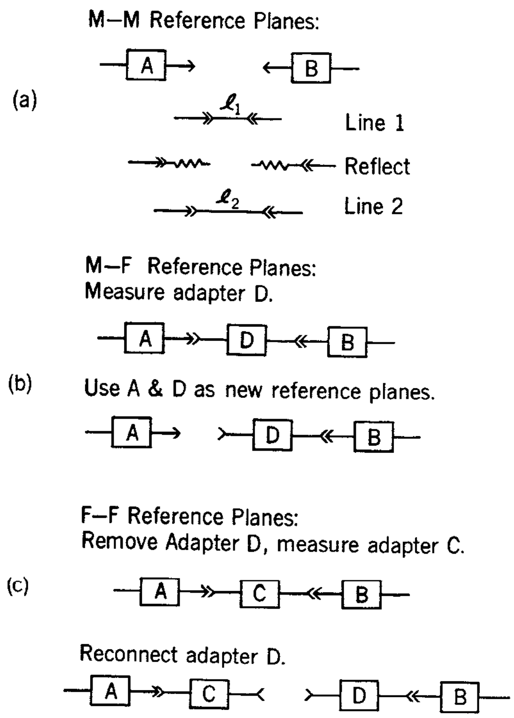

Figure 3. Using one set of standards to do a complete LRL calibration when the connectors on the device under test are the same type (but any combination of sex).

$$b = b_t \quad (1)$$

$$c/a = c_t/a_t \quad (2)$$

$$\delta = \delta_t \quad (3)$$

$$\beta/\alpha = \beta_t/\alpha_t \quad (4)$$

$$a = a_t e^{\gamma_1 \ell_1} \quad (5)$$

$$\alpha = \alpha_t e^{\gamma_1 \ell_1} \quad (6)$$

$$\gamma_2 \ell_2 - \gamma_1 \ell_1 = (\gamma \ell)_t \quad (7)$$

The terms on the left of each equation are the desired parameters. The corresponding parameters on the right of each equation with a subscript t are those obtained from the TRL solution. The first four equations show that the four-port parameters b, c/a, δ, and β/α are exactly equal to those obtained from the TRL solution. Equations (5) and (6) show that the four-port parameters a and α are scaled by $e^{\gamma_1 \ell_1}$.

In the TRL calibration, the optimum electrical length of the line is 90° (or an odd multiple of 90°). Electrical lengths near 0° or 180° (or even multiples of 90°) must be avoided or the solution becomes ill-conditioned. Equation (7) tells us that when two lines are used, it is the difference in the electrical lengths of the two lines which is optimally 90°, and which must not be near 0° or 180°.

LRL FOR SEXLESS CONNECTORS

At higher frequencies the optimum length of line for the TRL calibration can become physically too short to be practical. However, if two lines are used, ℓ_1 can be some convenient length and ℓ_2 slightly longer so that the difference in length is electrically 90° in the center of the frequency band. For this reason, one may want to use the LRL calibration even for sexless connectors at higher frequencies.

EQUIVALENT REFERENCE PLANE

Equations (1) to (6) lead to

$$\Gamma = e^{-\gamma_1 \ell_1} \Gamma_t, \quad (8)$$

which says that the reflection coefficient Γ of each termination used in the "reflect" measurements, or any other Γ measurement, will differ from Γ_t by the factor $e^{-\gamma_1 \ell_1}$ where Γ_t is the reflection coefficient obtained from a_t, b_t, c_t or α_t, β_t, δ_t. If (8) is compared to the following equation for transforming Γ_L through a nonreflecting line of length ℓ,

$$\Gamma = e^{-2\gamma \ell} \Gamma_L, \quad (9)$$

we see that the effective reference plane of Γ_t is at $\ell_1/2$ which is at the center of the line of length ℓ_1. This location agrees with our intuition as to where the reference plane should be since TRL assumes $\ell_1 = 0$.

DETERMINING $\gamma_1 \ell_1$

To complete the LRL calibration, $\gamma_1 \ell_1$ must be determined. Three methods for determining $\gamma_1 \ell_1$ are outlined below.

a) <u>From ℓ_1 and ℓ_2</u>.
If the lines ℓ_2 and ℓ_1 are made from the same stock and their cross sectional dimensions are sufficiently the same, we can assume that

$$\gamma_2 = \gamma_1. \quad (10)$$

Then (7) becomes

$$\gamma_1 (\ell_2 - \ell_1) = (\gamma \ell)_t, \quad (11)$$

which gives

$$\gamma_1 \ell_1 = K (\gamma \ell)_t, \quad (12)$$

where

$$K \equiv \frac{\ell_1}{\ell_2 - \ell_1}. \quad (13)$$

The physical lengths ℓ_1 and ℓ_2 of the two lines can be measured to obtain a value for K.

b) <u>From a known Γ</u>.
Another way of obtaining $\gamma_1 \ell_1$ is from (8). If Γ is the known reflection coefficient of a highly reflecting termination, then (8) gives

$$\gamma_1 \ell_1 = \text{Log}_e \frac{\Gamma_t}{\Gamma}. \quad (14)$$

Note that a matched termination cannot be used because if Γ and Γ_t are both zero $\gamma_1 \ell_1$ cannot be determined.

c) <u>From ψ of a short</u>.
If the highly reflecting termination is a short or an offset short with reflection coefficients Γ_s, only the phase angle ψ_s of Γ_s needs to be known. To show this one may define the real and imaginary parts of $(\gamma \ell)_t$ as

$$(\gamma \ell)_t = (\alpha \ell)_t + j(\beta \ell)_t. \quad (15)$$

Then substituting (12) and (15) in (8) gives

$$|\Gamma_s| e^{j\psi_s} = e^{-K(\alpha \ell)_t} e^{-jK(\beta \ell)_t} |\Gamma_t| e^{j\psi_t}. \quad (16)$$

If K is real, (which is the case if $\gamma_1 = \gamma_2$) then (16) expands into the following two equations

$$|\Gamma_s| = e^{-K(\alpha \ell)_t} |\Gamma_t| \quad (17)$$

$$\psi_s = -K(\beta \ell)_t + \psi_t. \quad (18)$$

Since $(\gamma \ell)_t$ is mostly imaginary, $(\beta \ell)_t$ is known much more accurately than $(\alpha \ell)_t$. For this reason we choose (18) to calculate K;

$$K = \frac{\psi_t - \psi_s}{(\beta \ell)_t}. \quad (19)$$

Then $|\Gamma_S|$ can be calculated from (17). Thus only the phase angle ψ_S of the short needs to be known.

For a flat short,

$$\psi_S = 180 - 12f\delta, \text{ degrees} \quad (20)$$

where f is the frequency in GHz and δ is the skin depth in centimeters into the face of the short [2].

REFERENCE

[1] G. F. Engen and C. A. Hoer, 'Thru-Reflect-Line': An Improved Technique for Calibrating the Dual Six-Port ANA," IEEE-MTT Vol. 27, No. 12, pp. 987-993, Dec. 1979

[2] P.I. Somlo, "Recession depth in metalic conductors at low frequencies," Electronics Letters, pp. 776-777, July 1971.