VERIFYING VNA SOURCE MATCH USING COAXIAL OFFSET SHORTS

First published: March 1990; Revised and republished: February 2006.
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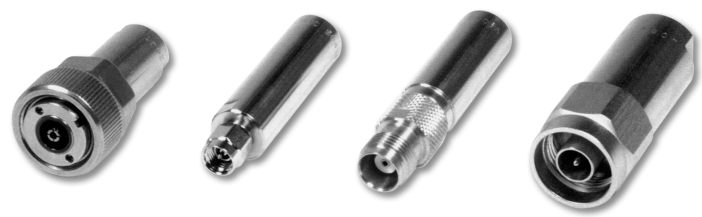
Introduction

In the measurement of complex reflection coefficient using a VNA (Vector Network Analyzer) there are three significant errors that can affect measurement accuracy. These are:

- Directivity
- Reflection frequency response tracking
- Source match



A sampling of the 2.498 cm Offset Shorts Available from Maury.

The one-port calibration of the VNA measures these errors and stores them for subsequent vector correction of the measured DUT (Device Under Test) reflection coefficient.

Effective source match, i.e.: the residual source match error after the VNA is calibrated, is an accuracy consideration in the measurement of medium to high reflection coefficients. This covers a large percentage of practical day-to-day DUT measurements.

The purpose of this application note is to describe a method, using just a long offset short, of evaluating effective source match in coaxial measurement systems.

Calibration

Prior to attempting a measurement of effective source match, the VNA should be carefully calibrated in the most accurate fashion available.

Most VNAs offer several calibration methods. For example: on the Agilent 8510 depressing the CAL key on the menu block brings up the main calibration menu. Selecting either the CAL 1 or CAL 2 softkey from this menu displays the calibration method choices.

"Response" calibrations do not measure and cannot correct for source match error and should not be used to prepare for this measurement.

A two-port calibration (One-Path, Full, or TRL) can be used, but if the purpose of the calibration is a one-port measurement (such as effective source match), a two-port calibration is an unnecessary complication.

Depending upon whether the measurement is to be made on Port 1 or Port 2 of the VNA, the selection should be either "S11 One-Port" or "S22 One-Port".

The traditional one-port calibration technique is referred to as OSL (Open-Short-Load). The equipment required consists of a metrology grade sliding load, an open circuit, and a short circuit. The latter two must be characterized for offset length (the electrical length between the outer conductor reference plane and the short or open plane). In addition, the capacitance coefficients of the open must be known.

These components and those required for a complete, two-port calibration are provided in all Maury high precision VNA calibration kits. The kits also provide the characterization data, such as the open capacitance coefficients, in media (floppy diskette or tape cartridge) appropriate for a specific network analyzer.

Maury manufactures VNA calibration kits for all popular coaxial connector series and VNAs, and in several price ranges. **Table 1** is a listing of the model series for the most popular connectors. A model letter suffix designates the applicable VNA (Anritsu 360, Agilent 8510, 8720, etc.) and the caliber of the

CONNECTOR TYPE	MODEL SERIES	KIT TYPE
1.85mm	7850A	Standard (Fixed Offset Short)
1.85mm	7850F/M	Fixed Termination (Single Sex)
1.85mm	7860A	TRL/LRL
2.4mm	7950A	Standard (Fixed Offset Short)
2.4mm	7950F/M	Fixed Termination (Single Sex)
2.4mm	7960A	TRL/LRL
2.92mm (K)	8770C	Standard (Fixed Offset Short)
2.92mm (K)	8770D	Fixed Termination
2.92mm (K)	8760A	TRL/LRL
3.5mm	8050A	Standard (Fixed Offset Short)
3.5mm	8050Y	Expanded (Fixed Offset Short)
3.5mm	8050B	Fixed Termination
3.5mm	8060A	TRL/LRL
3.5mm	8050Q	Economy
7mm	2650	Expanded & Fixed Termination
7mm	2660B	TRL
7mm	2660Q	Economy TRL
Type N	8850A	Standard (Fixed Offset Short)
Type N	8850P	Fixed Termination
Type N	8860A	TRL/LRL
Type N	8880A/B	75 Ohm Fixed Termination
Type N	8850Q	Economy
TNC	8650E	Standard (Fixed Offset Short)
TNC	8650P	Fixed Termination
TNC	8650Q	Economy
AFTNC	8680A	Standard (Fixed Offset Short)
AFTNC	8680B	Fixed Termination
TNCA	8670A	Standard (Fixed Offset Short)
TNCA	8670B	Fixed Termination
BNC	8550E/F/G	Fixed Termination
BNC	8580A	75 Ohm Fixed Termination
BNC	8550Q	Economy
OSP™	8780A	Standard (Fixed Offset Short)
OSP™	8780F/M	Fixed Termination (Single Sex)
14mm	2450	Expanded (Fixed Offset Short)
7-16	2750B	Fixed Termination
7-16	2750F/M	Fixed Termination (Single Sex)
7-16	2760B	TRL/LRL

Table 1. Maury Coaxial Vna Calibration Kits

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kit (basic, expanded, high precision, etc.). Maury also manufactures a full line of waveguide calibration kits.

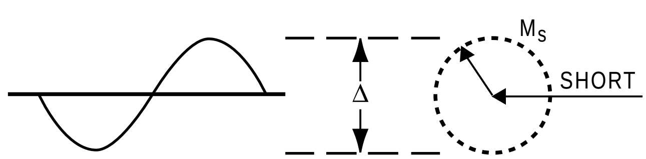
Figure 1. The Maury 8650E Precision TNC Calibration Kit for the Agilent 8510

Once the VNA is calibrated for a one-port measurement, the error terms are stored in memory, and subsequent measurements are corrected in accordance with he error model. The general question is, how good is the calibration? The remainder of this application note will be devoted to evaluation of one of the one-port measurement errors: the effective source match.

Verification of Source Match

Verification refers to the process of measuring the effective source match error. There are several means of doing this; however, the simplest and most effective method is to measure the S11 of a long offset short after the VNA has been calibrated.

If the effective directivity is considered perfect, then the effect, as seen from the reference point of the short, is to cause the source match vector to rotate around the tip of the short vector as the frequency changes. This is illustrated in **Figure 2**.



$$M_S = 20\ \mathrm{LOG10}\ (1 - 10^{-\Delta/40})$$

Figure 2. Trace Ripple in a S11 Plot Due to Rotation of the Source Match Vector

Note that if the effective source match were perfect, the output display would be a straight line. The rotation of the source match vector and its finite size give rise to a ripple in the plot of S11 versus frequency. The peak-to-peak magnitude of the ripple, therefore, is a measure of the effective source match as shown by the equation in **Figure 2**. For convenience, this equation is plotted in **Figure 3**.

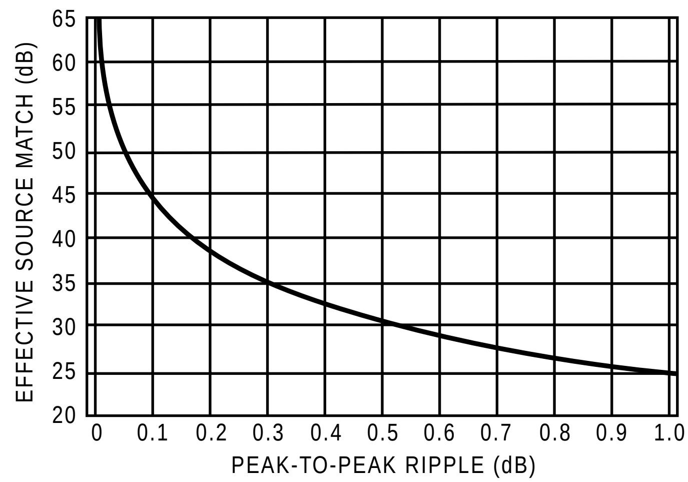


Figure 3. Plot of Effective Source Match Versus Peak-to-Peak Trace Ripple

The measurement is quite simple, and the procedure is as follows:

Step 1.
Calibrate the analyzer for a one-port measurement over the frequency range of interest.

Step 2.
Connect the equipment as shown in **Figure 4**. Note the use of a Test Port Adapter to reduce wear and tear on the test set connector and avoid costly repair bills (see **Table 2**).

Step 3.

Set the measured parameter to S11.

Agilent 8510

Depress the S11 key in the Parameter control block.

Anritsu 360

Depress the S-parameters key in the Display control block. Use the on-screen Menu cursor/Enter keys to select S11.

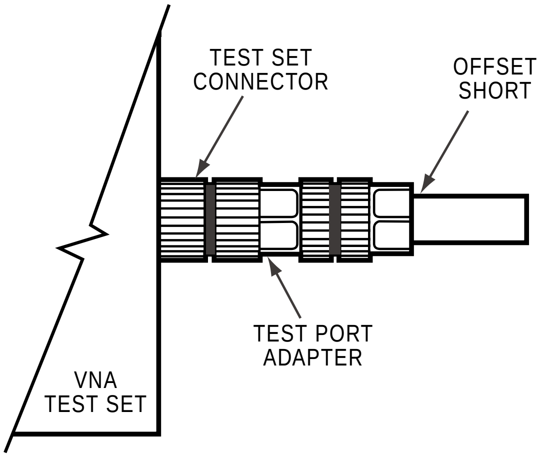


Figure 4. Set-up for Measuring Effective Source Match

Step 4.

Set the display format to Log Magnitude.

Agilent 8510	Anritsu 360
Depress the LOG MAG key in the Format control block.	Depress the Graph Type key in the Display control block, and use the Menu cursor/Enter keys to select LOG MAGNITUDE.

Step 5.

Set the Reference position to the center of the scale.

Agilent 8510	Anritsu 360
Depress the REF POSN key in the Response control block.	Depress the SET SCALE key in the Display control block, and use the Menu cursor/Enter keys to select REFERENCE LOCATION.
Depress 5, X1 in the Entry control block.	Use the control knob to set the reference line indicator to the centerline of the vertical scale.

Step 6.

Set the value of the reference line to 0 dB.

Agilent 8510	Anritsu 360
Depress the REF VALUE key in the Display control block.	Use the onscreen Menu cursor/Enter key to select REF VALUE.
Depress 0, X1 in the Entry control block.	Depress 0, X1 in the Entry control block.

Step 7.

Adjust the scale resolution such that the ripple is measurable.

Agilent 8510	Anritsu 360
Depress the SCALE key in the Display control block.	Use the onscreen Menu cursor/Enter key to select RESOLUTION.
Depress 0.05, X1 in the Entry control block.	Depress 0.05, X1 in the Entry control block.

NOTE: This sets the on-screen resolution to 0.05 dB/division and is suggested as typical. Higher resolution may be used; however, trace noise may interfere with accurate location of the peaks and troughs of the display.

Step 8.

Measure the maximum peak-to-peak ripple in dB on the analyzer display. The delta Marker mode is quite useful for this purpose.

Step 9.

Use **Figure 3** or the equation in **Figure 2** to determine effective source match.

A typical VNA display of a S11 measurement of a 2.498cm offset short is shown in **Figure 5**. This result was obtained after a standard OSL calibration using a sliding load. The test port connector was type N female. The worst case peak-to-peak ripple of about 0.06 dB can be read directly from the display. Using **Figure 3**, the effective source match can then be determined to be about 49 dB.

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MODEL	ADAPTS	
	SIDE A	SIDE B
7809A1	NMD1.85mm female	1.85mm female
7809A2	NMD1.85mm female	1.85mm male
7809K	NMD1.85mm female	NMD1.85mm male
7809G	NMD1.85mm female	NMD2.4mm male
7809H	NMD1.85mm male	NMD2.4mm female
7809F1	NMD1.85mm female	2.92mm (K) female
7809F2	NMD1.85mm female	2.92mm (K) male
7809B1	NMD1.85mm female	3.5mm female
7809B2	NMD1.85mm female	3.5mm male
7809C	NMD1.85mm female	7mm
7809D1	NMD1.85mm female	Type N female
7809D2	NMD1.85mm female	Type N male
7909A1	NMD2.4mm female	2.4mm female
7909A2	NMD2.4mm female	2.4mm male
7909K	NMD2.4mm female	NMD2.4mm male
7909H	NMD2.4mm female	NMD3.5mm male
7909F1	NMD2.4mm female	2.92mm (K) female
7909F2	NMD2.4mm female	2.92mm (K) male
7909B1	NMD2.4mm female	3.5mm female
7909B2	NMD2.4mm female	3.5mm male
7909C	NMD2.4mm female	7mm
7909D1	NMD2.4mm female	Type N female
7909D2	NMD2.4mm female	Type N male
8009A	NMD3.5mm female	3.5mm female
8009B	NMD3.5mm female	3.5mm male
2633C	NMD3.5mm female	7mm
8829A	NMD3.5mm female	Type N female
8829B	NMD3.5mm female	Type N male
2433A1	NMD3.5mm female	14mm (GR900 equiv)
8022A1	3.5mm female	7mm
8022B1	3.5mm male	7mm
2633A	7mm	7mm ‘female’
2606C	7mm	Type N female
2606D	7mm	Type N female
2622A1	7mm	TNC female
2622B	7mm	TNC male
2607A1	7mm	14mm (GR900 equiv)

Table 2. Maury Test Port Adapters

CONNECTOR TYPE	MODEL	SEX	OFFSET LENGTH INCHES	OFFSET LENGTH (cm)	λ/4 FREQUENCY GHz
2.92mm (K)	8771A1	female	1.1803	(2.9980)	3.00
	8771B1	female	0.6885	(1.7488)	6.00
	8771C1	female	0.4862	(1.2349)	10.20
	8771D1	female	0.4040	(1.0262)	14.24
	8771E1	female	0.3295	(0.8369)	22.24
	8771F1 [1]	female	0.1970 [1]	(0.5004) REF	
	8772A1	male	1.1803	(2.9980)	3.00
	8772B1	male	0.6885	(1.7488)	6.00
	8772C1	male	0.4862	(1.2349)	10.20
	8772D1	male	0.4040	(1.0262)	14.24
	8772E1	male	0.3295	(0.8369)	22.24
	8772F1 [1]	male	0.1970 [1]	(0.5004) REF	
3.5mm	8046A	female	1.1803	(2.9980)	3.00
	8046B	female	0.6885	(1.7488)	6.00
	8046C	female	0.4862	(1.2349)	10.20
	8046D	female	0.4040	(1.0262)	14.24
	8046E	female	0.3295	(0.8369)	22.24
	8046F [1]	female	0.1970 [1]	(0.5004) REF	
	8047A	male	1.1803	(2.9980)	3.00
	8047B	male	0.6885	(1.7488)	6.00
	8047C	male	0.4862	(1.2349)	10.20
	8047D	male	0.4040	(1.0262)	14.24
	8047E	male	0.3295	(0.8369)	22.24
	8047F [1]	male	0.1970 [1]	(0.5004) REF	
7mm	2649A	N/A	0.9830	(2.4976)	3.00 [2]
	2649B	N/A	0.4915	(1.2484)	6.00 [2]
	2649C	N/A	0.2892	(0.7346)	10.20 [2]
	2649D	N/A	0.2070	(0.5258)	14.24 [2]
TNC	8615A [1]	female	0.5000 [1]	(1.2700) REF	
	8606A	female	1.1920	(3.0277)	3.00
	8606B	female	0.8460	(2.1488)	6.00
	8606C	female	0.7035	(1.7869)	10.20
	8606D	female	0.6455	(1.6396)	14.25
	8615B [1]	male	0.7000 [1]	(1.7780) REF	
	8607A	male	1.1820	(3.0023)	3.00
	8607B	male	0.8360	(2.1234)	6.00
	8607C	male	0.6935	(1.7615)	10.20
	8607D	male	0.6355	(1.6142)	14.25

[1] Reference shorts and reference offset lengths for each model series. The relative offset length of other models in each series is derived by subtracting their offset lengths (shown in this table) from the offset length of their appropriate reference short.

[2] Relative to 0 (zero).

Table 3. Maury Offset Shorts

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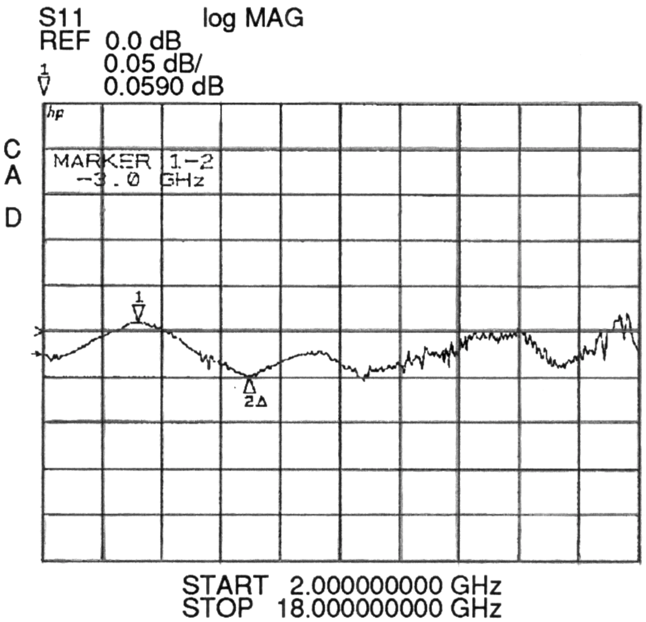

Figure 5. S11 (Log Magnitude) plot of a 2.498 cm Offset Short (7mm Connector)

In principle, the effective directivity vector also rotates around the tip of the effective source match vector. Note that this procedure assumes perfect directivity. Obviously, this is an invalid assumption; however, with most analyzers using a high quality calibration kit, the residual directivity error is at least an order of magnitude less than the effective source match and is generally ignored in most measurements.

Maury application note 5C-026 describes a method of eliminating even this small error from the effective source match measurement.

Offset Length

Development of the ripple pattern requires that the magnitude of the resultant vector sum of the short and effective source match reach both extremes, maximum and minimum, over the frequency band of interest. One immediate thought then would be to use a very long length of line, say 10 centimeters, connected to a fixed (nominally, zero offset) short.

There are two problems with this approach. It requires two coaxial connections which could deteriorate the quality of the short and introduce additional discontinuities. More importantly, as the length of line increases, so does the dissipative loss. The loss would introduce a slope to the ripple pattern making it difficult to accurately determine the ripple envelope.

Coaxial measurements are usually made over broad frequency ranges - 2 to 18 GHz for example, would be typical. For such a measurement, it is only necessary for the offset length to be 1/4 wavelength at or near the lowest measurement frequency.

The plot in **Figure 5** was obtained with a 2.498cm (1/4 wavelength at 3 GHz) offset short. Note that the ripple pattern can be easily extrapolated at least down to 2 GHz even though at this frequency the offset length represents about 0.17 wavelength.

For higher frequency measurements over large bandwidths, smaller offset lengths can be used to further reduce the effect of line loss. For example, if the measurement frequency range is 6 to 18 GHz, an offset length of 1.249cm (1/4 wavelength at 6 GHz) will work quite well.

As can be seen, selection of offset length for broadband applications reduces to determining which standard offset is 1/4 wavelength (or slightly less as noted above) at the lowest measurement frequency. Larger offsets will make the ripple envelope easier to detect; however, the pattern distortion caused by line loss could introduce reading errors and may reduce measurement resolution.

In general, the "A" models noted in **Table 3** - offset length of 2.498cm - have been found to work quite well over the 2 to 18 GHz range, as do the "B" models - offset length 1.249cm - from about 4 to 26.5 GHz.

Maury Microwave manufactures a line of offset shorts that provide a range of offsets in several coaxial connector series ideally suited for this purpose. These are listed in **Table 3**.

Summary and Conclusions

Effective source match (the residual source match error of a VNA after it has been calibrated) can be a significant source of error in VNA measurements - particularly, reflection coefficient. Effective source match can be measured quite easily over broad frequency ranges using an appropriate offset short available from Maury Microwave.