Anritsu

Reflectometer Measurements – Revisited

Application Note

Linking the World

Twenty four years ago Wiltron (now Anritsu) published a Technical Review "Why Tolerate Unnecessary Measurement Errors", long since out of print. Thousands were printed and it was widely used by test engineers. At that time the principal network analyzer used by industry was the scalar analyzer. Today while scalars are still used, the Vector Network Analyzer (VNA) has also become common in both engineering and manufacturing environments. Many measurements are made and recorded with little attention given to the actual accuracy of the measurement.

This Review will include some of the material originally presented in 1975 as it still very important and addresses problems that regularly appear in current applications. It will also treat the VNA which is regarded properly as the most accurate measurement tool; but, when "taken for granted" can provide data that is "out of bounds"!

Uncertainty (Inaccuracy) in Reflection Measurements

Excluding noise, which will be addressed later, the dominant sources of error in a microwave reflectometer measurement system are directivity, source match, and load match. This is true for both scalar and vector systems. The systems differ in that a scalar system's performance is related to the quality of the hardware used, and in general users are well aware of hardware limitations. They will pay more money to obtain a bridge or coupler with higher directivity or a termination with superior return loss. In the case of the VNA these error terms are appropriately termed "effective" directivity, "effective" source match and "effective" load match. The magnitude of these terms is established by the calibration process and the user is not usually aware of the actual values of these important parameters when measurements are being recorded.

Errors Associated with Directivity and Port Match

There are two characteristics of the reflectometer that influence its contribution to measurement accuracy. This is true of any reflectometer, be it a directional coupler, a reflection bridge or a hybrid network. The first of these to be considered is termed directivity. Figure 1 shows a directional device terminated in an ideal Z_O. All the energy from the test port is absorbed in Z_O and there is none reflected back to the measuring system. However, there is an output, and we define this output as the directivity, shown as E_d, and measure it in dB below a full reflection. This directivity signal arises from deviations from the ideal within the directional device, and can come from many sources, such as deviations from prescribed geometry, connector mismatches or imperfect internal terminations. The summation of all of these effects is called the directivity of the device. (In the case of a VNA the effective directivity can be attributed to a less than perfect calibration.). In Figure 1, an example is shown in which the directivity is 35 dB, or .0178 of a full reflected signal.

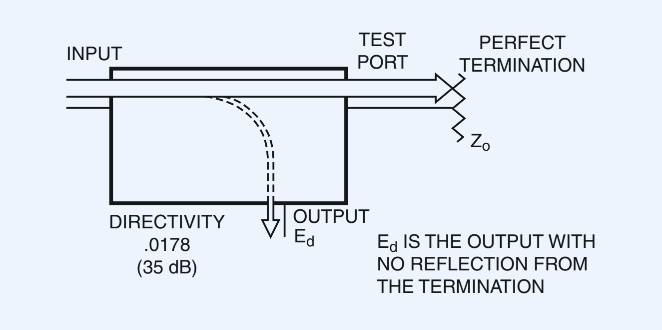


Figure 1. *Directivity of a directional device.*

Figure 2 shows the way the directivity signal influences an actual measurement. In this example the device being measured has a Return Loss of 20dB (SWR = 1.22) which is typical of many common microwave devices. The reflected signal, 20 dB down from a full reflection is only 15dB larger than the directivity signal. The phasor diagram shows how the two signals can combine at the output port. The resulting measurement Em depends upon the phase relationship of the two signals. The limits of the possible error in the measurement are then shown alongside. A 20 dB return loss being measured will be indicated somewhere between 18.58 and 21.7 dB using this directional device, because of the consequences of directivity. In the worst case this would be a 17.8% error!

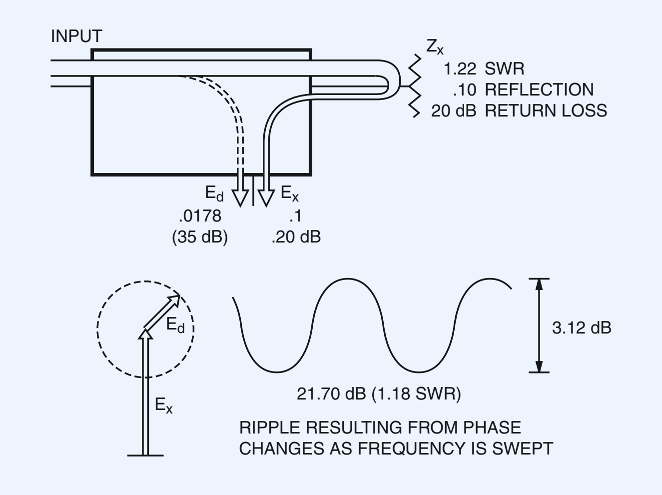


Figure 2. *Possible error of a 1.22 SWR caused by directivity.*

Figure 3 also presents a graphic display of the possible measurement error due to a 35 dB directivity specification for different measured values. From the above, it is easy to see why this error is small for large reflections, and increases dramatically as smaller reflections (representing larger return losses) are measured. Notice that an attempt to measure a return loss equal to the directivity specification can result in a –6 dB to +xx dB error in the measurement. A decent rule of thumb: To obtain decent return loss measurements the directivity of the reflectometer should be at least 15 dB greater than the return loss being measured.

The means to easily determine the dB interaction of one signal upon another is provided by the RF Measurement Chart, Table 1. The first three columns give easy conversion from any input of SWR, Reflection Coefficient, or Return Loss to the other two relations. The next four columns show the limit extremes of a smaller signal interacting with a larger signal taken as a reference.

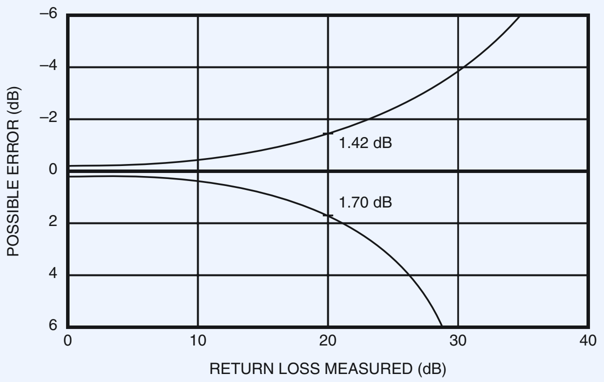
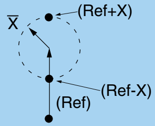


Figure 3. *Error limit caused by directivity of 35 dB as a function of return loss measured.*

Conversion tables for return loss, reflection coefficient, and SWR are shown. The “Ref + x” and “Ref - x” columns contain resultant error values for interaction of a small phasor X with a large phasor (unity reference) according to the relative magnitude of the smaller phasor, which is expressed as X dB below the reference.



Phasor Interaction

			Relative to Unity Reference							Relative to Unity Reference			
SWR	**Reflection Coefficient**	**Return Loss (dB)**	**X dB Below Reference**	**Ref + X (dB)**	**Ref – X (dB)**	**Ref ± X Pk to Pk Ripple**	**SWR**	**Reflection Coefficient**	**Return Loss (dB)**	**X dB Below Reference**	**Ref + X (dB)**	**Ref – X (dB)**	**Ref ± X Pk to Pk Ripple**
17.3910	0.8913	1	1	5.5350	19.2715	24.8065	1.0580	0.0282	31	31	0.2414	0.2483	0.4897
8.7242	0.7943	2	2	5.0780	13.7365	18.8145	1.0515	0.0251	32	32	0.2155	0.2210	0.4365
5.8480	0.7079	3	3	4.6495	10.6907	15.3402	1.0458	0.0224	33	33	0.1923	0.1967	0.3890
4.4194	0.6310	4	4	4.2489	8.6585	12.9073	1.0407	0.0200	34	34	0.1716	0.1751	0.3467
3 5698	0.5623	5	5	3.8755	7.1773	11.0528	1.0362	0.0178	35	35	0.1531	0.1558	0.3090
3.0095	0.5012	6	6	3.5287	6.0412	9.5699	1.0322	0.0158	36	36	0.1366	0.1388	0.2753
2.6146	0.4467	7	7	3.2075	5.1405	8.3480	1.0287	0.0141	37	37	0.1218	0.1236	0.2454
2.3229	0.3981	8	8	2.9108	4.4096	7.3204	1.0255	0.0126	38	38	0.1087	0.1100	0.2187
2.0999	0.3548	9	9	2.6376	3.8063	6.4439	1.0227	0.0112	39	39	0.0969	0.0980	0.1949
1.9250	0.3162	10	10	2.3866	3.3018	5.6884	1.0202	0.0100	40	40	0.0864	0.0873	0.1737
1.7849	0.2818	11	11	2.1567	2.8756	5.0322	1.0180	0.0089	41	41	0.0771	0.0778	0.1548
1.6709	0.2512	12	12	1.9465	2.5126	4.4590	1.0160	0.0079	42	42	0.0687	0.0693	0.1380
1.5769	0.2239	13	13	1.7547	2.2013	3.9561	1.0143	0.0071	43	43	0.0613	0.0617	0.1230
1.4985	0.1995	14	14	1.5802	1.9331	3.5133	1.0127	0.0063	44	44	0.0546	0.0550	0.1096
1.4326	0.1778	15	15	1.4216	1.7007	3.1224	1.0113	0.0056	45	45	0.0487	0.0490	0.0977
1.3767	0.1585	16	16	1.2778	1.4988	2.7766	1.0101	0.0050	46	46	0.0434	0.0436	0.0871
1.3290	0.1413	17	17	1.1476	1.3227	2.4703	1.0090	0.0045	47	47	0.0387	0.0389	0.0776
1.2880	0.1259	18	18	1.0299	1.1687	2.1986	1.0080	0.0040	48	48	0.0345	0.0346	0.0692
1.2528	0.1122	19	19	0.9237	1.0337	1.9574	1.0071	0.0035	49	49	0.0308	0.0309	0.0616
1.2222	0.1000	20	20	0.8279	0.9151	1.7430	1.0063	0.0032	50	50	0.0274	0.0275	0.0549
1.1957	0.0891	21	21	0.7416	0.8108	1.5524	1.0057	0.0028	51	51	0.0244	0.0245	0.0490
1.1726	0.0794	22	22	0.6639	0.7189	1.3828	1.0050	0.0025	52	52	0.0218	0.0218	0.0436
1.1524	0.0708	23	23	0.5941	0.6378	1.2319	1.0045	0.0022	53	53	0.0194	0.0195	0.0389
1.1347	0.0631	24	24	0.5314	0.5661	1.0975	1.0040	0.0020	54	54	0.0173	0.0173	0.0347
1.1192	0.0562	25	25	0.4752	0.5027	0.9779	1.0036	0.0018	55	55	0.0154	0.0155	0.0309
1.1055	0.0501	26	26	0.4248	0.4466	0.8714	1.0032	0.0016	56	56	0.0138	0.0138	0.0275
1.0935	0.0447	27	27	0.3798	0.3969	0 7765	1.0028	0.0014	57	57	0.0123	0.0123	0.0245
1.0829	0.0398	28	28	0.3391	0.3529	0.6919	1.0025	0.0013	58	58	0.0109	0.0109	0.0219
1.0736	0.0355	29	29	0.3028	0.3138	0.6166	1.0022	0.0011	59	59	0.0097	0.0098	0.0195
1.0653	0.0316	30	30	0.2704	0.2791	0.5495	1.0020	0.0010	60	60	0.0087	0.0087	0.0174

Table 1. *RF Measurement chart*

The directivity error in Figure 2 conveniently demonstrates the use of the chart. Given that the directivity of the coupler in use is 35 dB, and the observed measurement is near 20 dB, one can note that the directivity error is 15dB below the measurement level. Relating this to the chart, x is 15dB below the reference phasor (the measurement in this case), and entering at 15dB, one can read the resultant effect of 1+x = 1.42 dB and 1 –x = –1.7 dB or 3.12 peak to peak ripple. Since Loss is being measured (Return Loss), our reference is negative and the Loss deviation is –1.42 and +1.70. The resulting return loss will range from 18.58 to 21.7 dB.The first three columns may be used to convert the dB limits into Reflection coefficient or SWR by simple interpolation.

Note that the chart can be used entering in different ways. If one observed a 3.12 dB peak to peak ripple superimposed on a 20 dB reading, it would be apparent using the chart that an error signal 15 dB smaller than the measurement existed. If the measurement was Return Loss, as in the previous example, one could estimate the directivity contribution as 15 dB below –20, or –35 dB. The decibel value can be converted to a decimal voltage ratio using the second and third columns. The 35 dB directivity is .0178 of a full reflection.

Error Due to Test Port Match

The second measurement error of the reflectometer arises from the test port match at the measuring port. For a directional coupler this match is equivalent to the main line SWR specification. The error consequence of the test port mismatch is demonstrated in Figure 4. A full reflection returns all the incident signal and gives a reference output. Some of this returning signal will be re-reflected due to the test port mismatch. In the example shown for a 1.25 SWR at the test port, there will be 11.2% of the test signal re-reflected, or a signal 19 dB below the complete reflection.* This reflected signal, arriving again at the short, is fully reflected, so that it arrives at the output differing by only 19 dB from the reference signal. The phasor diagram shows the effect for different phasing, such that a variation from –.92 dB or +1.03 dB will be effected on a full reflection. In a sweeping application, the phasing will vary between the fully-reflected and the re-reflected signal causing a ripple pattern to be displayed. The ripple is dependent upon the width of the frequency sweep and the electrical distance from the short to the test port mismatch.

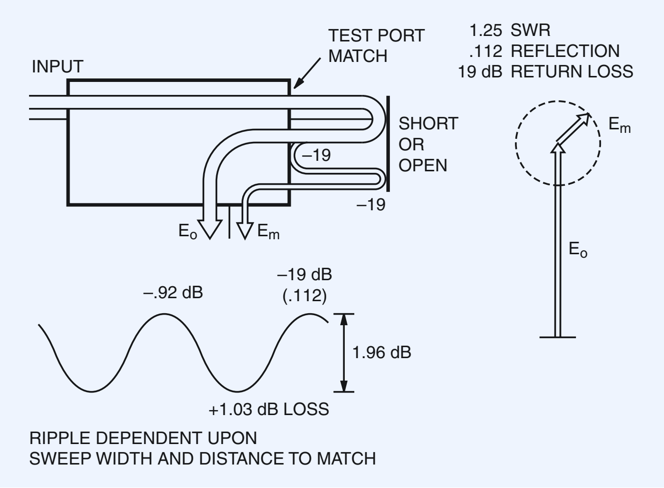


Figure 4. *Possible error due to full reflection.*

The error due to test port match becomes much smaller as the unknown becomes a better match. This is demonstrated in Figure 5, using the same test port match as in the prior example. In this case, measuring a 1.22 SWR unknown, the error contribution of the test port match is + or – .098 dB. Note that this signal is significantly smaller than the error due to directivity shown in Figure 2. This test port match error is graphically shown in Figure 6 for different values of the return loss being measured. Note that the contribution is maximum when the unknown is a full reflection and diminishes rapidly for higher return losses.

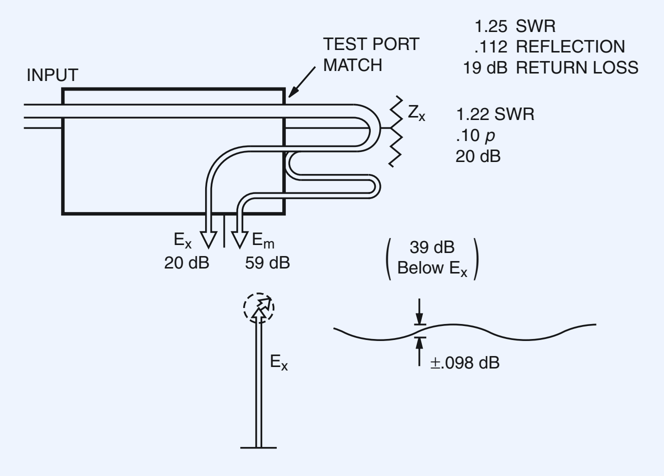


Figure 5. *Possible error of a 1.22 SWR caused by test port match.*

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* This excludes second order terms which can be significant if the test port match is poor; but these second order terms can usually be neglected.

Total Measurement Error Limits From the Reflectometer

The combined error plot is also displayed in Figure 6, where the total measurement error limit for the reflectometer is plotted for different values of return loss being measured. This curve is the sum of the two measurement errors just discussed, and the line drawn is that for a 35 dB directivity and 1.25 SWR port match.

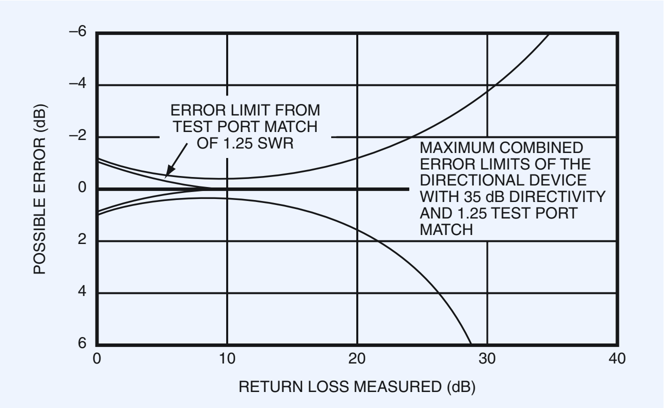


Figure 6. *Error limits of a directional device when measuring a reflection.*

General Error Limit Curves for Reflection Measurements

A curve which shows both the error limits from directivity and port match is presented in Figure 7. This curve is constructed in a general manner so the limits for any directivity from 20 to 50 dB and any test port match up to 2.0 SWR can be determined.

A very good approximation to the total possible error for the reflectometer can be constructed by summing the two limits on the curve. The two errors more properly should be summed as amplitude factors and that sum converted to dB; however, for typical small errors, the difference is trivial when the summing is done in dB.

This set of curves enables one to draw in the error related to a specific set of reflectometer parameters for convenient reference. It also makes it easy to compare two different systems measurement performance.

It is important to realize that the above principles apply to scalar or VNA reflection measurements.

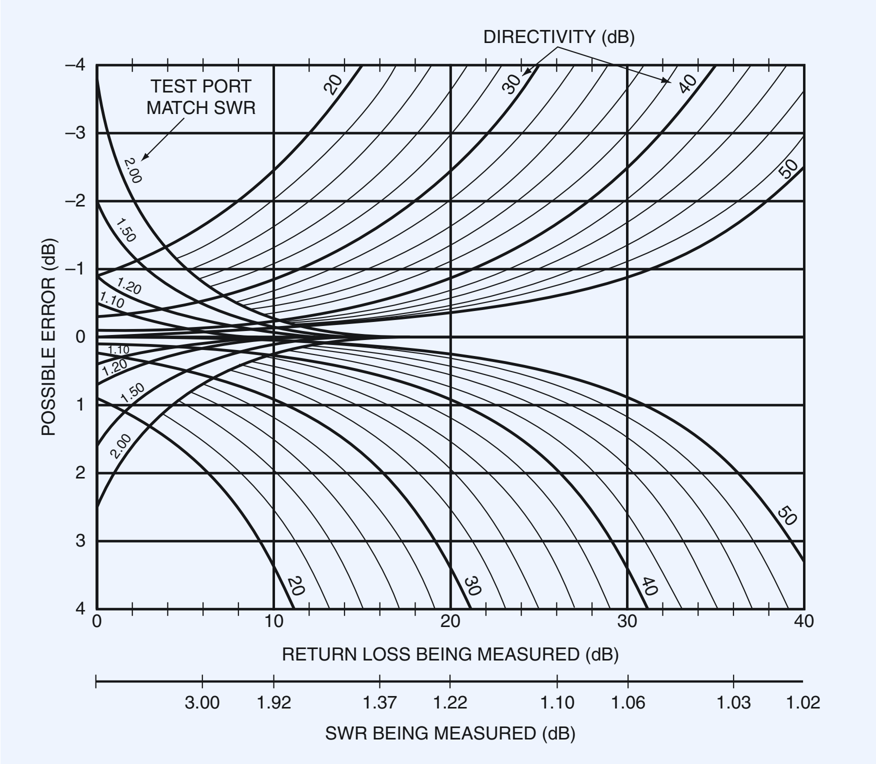


Figure 7. *General error limit curves for a directional device.*

Connector	Frequency (GHz)	Directivity (dB)	Source Match (dB)	Load Match (dB)	Reflection Frequency Tracking (dB)	Transmission Frequency Tracking (dB)	Isolation (dB)
GPC–7	0.0225	>52	>44	>52	±0.003	±0.004	>105
	2	>52	>44	>52	±0.003	±0.004	>115
	18	>52	>42	>52	±0.004	±0.012	>112
GPC–7 LRL Calibration	2	>60	>60	>60	±0.001	±0.001	>115
	18	>60	>60	>60	±0.001	±0.001	>112
N-Type*	0.0225	>46	>36	>46	±0.004	±0.004	>105
	2	>44	>36	>44	±0.004	±0.004	>115
	18	>40	>32	>40	±0.005	±0.012	>112
3.5mm	0.0225	>44	>40	>44	±0.005	±0.030	>105
	2	>44	>40	>44	±0.005	±0.030	>115
	20	>44	>38	>44	±0.006	±0.050	>110
	26.5	>44	>34	>44	±0.006	±0.070	>102
K	0.0225	>42	>40	>42	±0.005	±0.030	>105
	2	>42	>40	>42	±0.005	±0.050	>115
	20	>42	>38	>42	±0.006	±0.070	>110
	40	>38	>38	>38	±0.006	±0.080	>100

Figure 8. *Typical VNA test port specifications.*

Now we should take a closer look at the VNA calibration process. It would appear from the many inquiries we receive relating to VNA applications, that the VNA calibration process is often taken too casually and presumed to be good, which is a questionable presumption. Unfortunately the calibration is not failsafe.

Much has been written about error models[1,2,3,4] and the mathematics associated with the various calibration approaches such as OSLT (Open, Short, Load, Through), TRM (Through, Reflect, Match) and LRL (Line,Reflect,Line) and this material is rigorous and correct; but, what about our common measurement environment. OSLT is the most common approach to calibration for coaxial measurements. To obtain an accurate calibration it is critical that the “standards” used meet criteria established when the OSLT parameters are defined for the VNA. These criteria must be absolutely correct for the calibration to be accurate. For instance L, the Load is usually defined to be a reflectionless 50 ohm termination. This can be approached if a good sliding load is used properly. Opens and Shorts are often offset from the connector interface which establishes the reference plane, the precise length of this offset must be included in the definition of the Open or Short. The Open used must also be characterized for it’s inherent fringing capacitance. Manufacturers have gone to great lengths to properly characterize this fringing capacitance for the opens they supply in their calibration kits. This is usually a polynomial of the form:

$$C = C_0 + C_1 \cdot f + C_2 \cdot f^2 + C_3 \cdot f^3$$

This fringing capacitance differs significantly for various connector types and slightly between different manufacturers calibration kits. It is very important that the correct open is used for the calibration. Given the above, if the calibration components are clean and properly used, at the conclusion of the calibration the VNA should exceed it’s specifications for test port parameter performance, and the user could have some confidence that this was the case: but, how does he know that all the pieces fell properly into place? Figure 8 shows a typical set of test port specifications. These specifications, particularly the most important ones which are highlighted are dependent upon the calibration kit used.

How can we evaluate the quality of a calibration? We would really like to know the effective directivity and port match of the measurement system after calibration; but, that isn’t readily available. A common approach to calibration evaluation is to measure the calibration components and this process is often misunderstood. The essence of the OSLT method is to map the VNA data collected during calibration, to the standard definitions. If the standards are measured after calibration, the measurements will confirm the expected, as shown in Figure 9. They show as they were defined, EVEN IF THIS IS GROSSLY IN ERROR. The most easily observed example of this is the measurement of the fixed load often used for an OSLT calibration (how many of you use a sliding load in

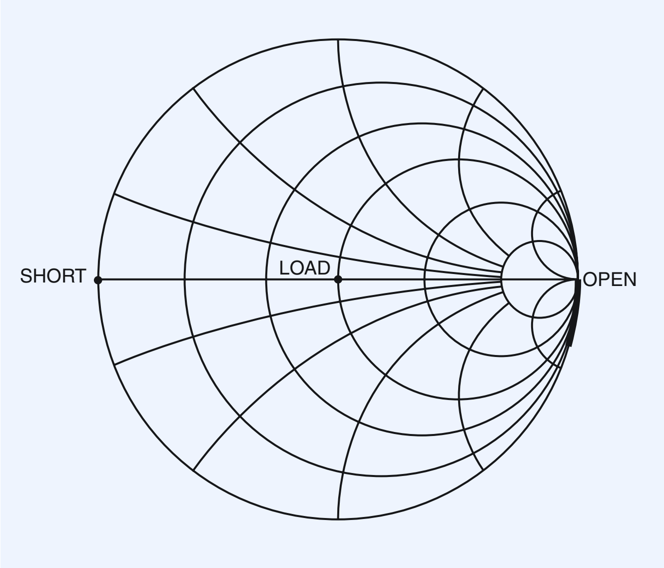


Figure 9.

your everyday calibrations?). Immediately after calibration if the load is measured it will show a return loss of 50 or 60 dB on a log magnitude scale as shown in Figure 10. This is obviously wrong as we are probably well aware the load return loss is in the range 20 – 40 dB. It should be emphasized that calibration using broadband loads should be done with caution . The effective directivity after a broadband load calibration is essentially equal to the return loss of the load used for calibration. Unless the user is certain that the return loss of the load is at least 15 dB greater than return loss of devices to be measured, significant errors can result. Sliding loads are recommended for calibration and VNA test port specifications are based upon sliding load calibrations.

The only thing that the user can correctly conclude by measuring the calibration components is that, if the predicted displays are observed, they may have a good calibration. That is – the test provides necessary; but, not sufficient information to insure an accurate calibration.

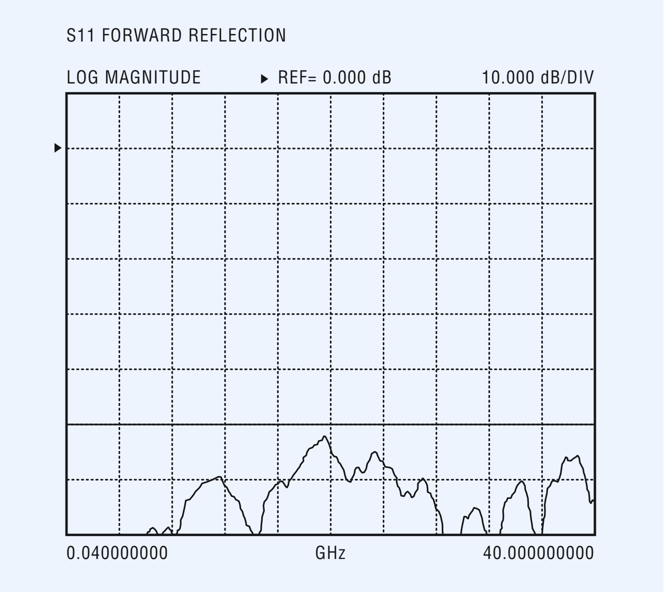


Figure 10. *Measurement of the termination used as load in OSLT calibration*

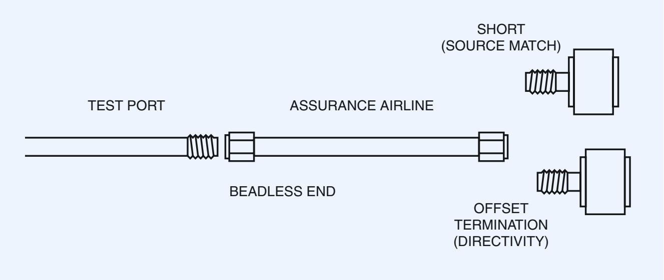


Figure 11. *Assurance airline setup.*

So what can the conscientious user do? If a precision transmission line with a good test port connector interface is available, this “assurance” airline can be used to measure the port match and directivity using ripple measurements or time domain techniques.[5] Figures 11 through 13 show the results using commercially available assurance airlines. With this information it is possible to compute actual measurement uncertainties. In the absence of suitable airlines it would be appropriate to measure a 20 dB attenuator and observe that the S parameters looked close to what they have measured in the past. If this is the case, the probability is high that the calibration was good.

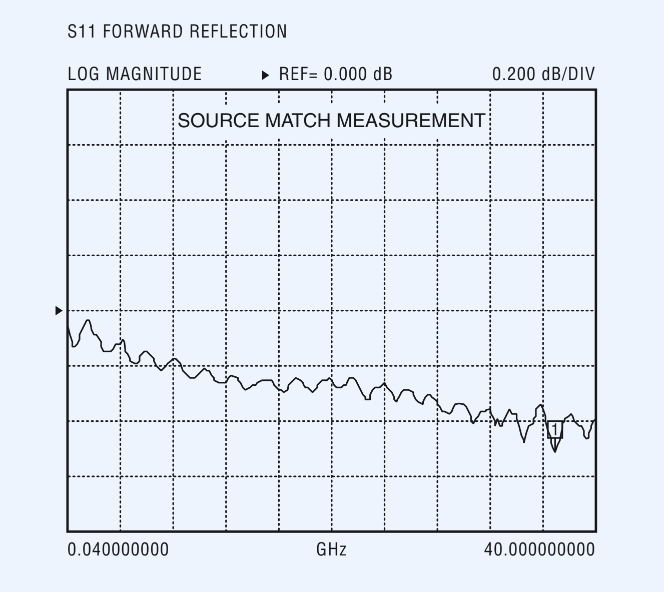


Figure 12. *Ripple measurement indicates that worst case source match after a full 12-term calibration is greater than 40 dB.*

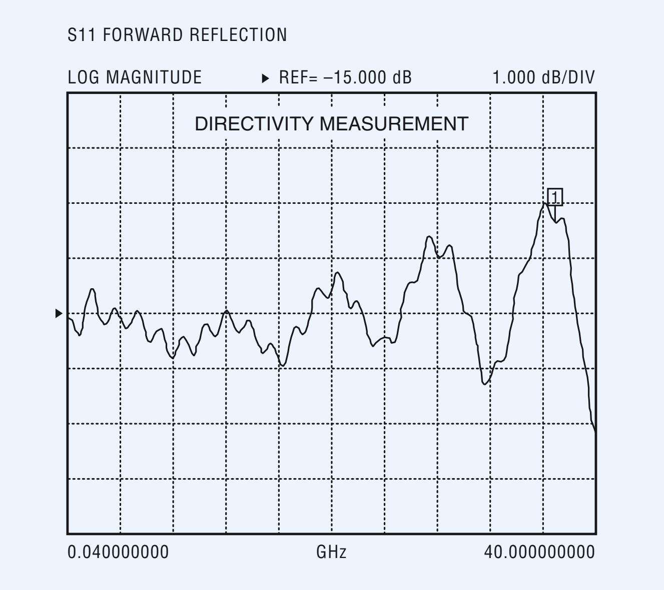


Figure 13. *Ripple measurement indicates that worst case directivity after a full 12-term calibration is greater than 50 dB.*

A note about waveguide or microstrip:

The requirement for a precision transmission line (not a commonly available device for calibration assurance for coaxial measurements), is much simpler if the user is working with waveguide or microstrip calibrations. Precision straight waveguide sections are readily available and the ripple patterns are easily analyzed. In microstrip all the user needs is good section of line, open at the far end, to observe the ripple associated with source match.

Two most common problems:

1) Using a broadband load rather than a sliding load during the calibration process. When this is done the effective directivity will essentially equal the return loss of the load used. (Minor degradation of port match will also occur; but, this is usually a second order issue.) This will be frequency dependent, excellent loads are available to about 20 GHz; but above that, loads greater than 30 dB are hard to come by. In any event you should measure the broadband load after a sliding load calibration, so that you have more confidence in your broadband load calibrations. Remember if the effective directivity is 30 dB, a measurement of a device with 20 dB Return Loss can result in a 30% error!

If the user knows the directivity or effective directivity and the match parameters, an uncertainty analysis can be developed. The analysis is appropriate for either the scalar or the vector system.

2) Users use a calibration kit without insuring that the proper component definitions are prescribed in the analyzer. This can lead to large errors in the measured result.

Before leaving reflection measurements it should be noted that the above analysis is based upon S11 measurements of a one-port device. If a two port is being measured as in Figure 14, the effect of the termination (load match in the case of a VNA) on port 2 must be considered. The magnitude of this effect is dependent upon the value of the termination and the loss of the DUT. It is easy to determine if this factor is significant and must be considered. In many applications it is second order and can be ignored.

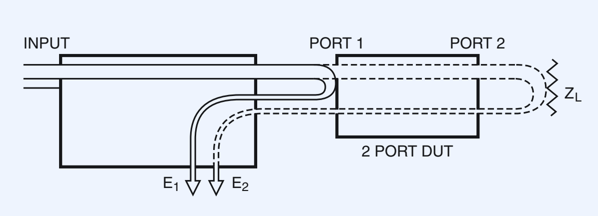


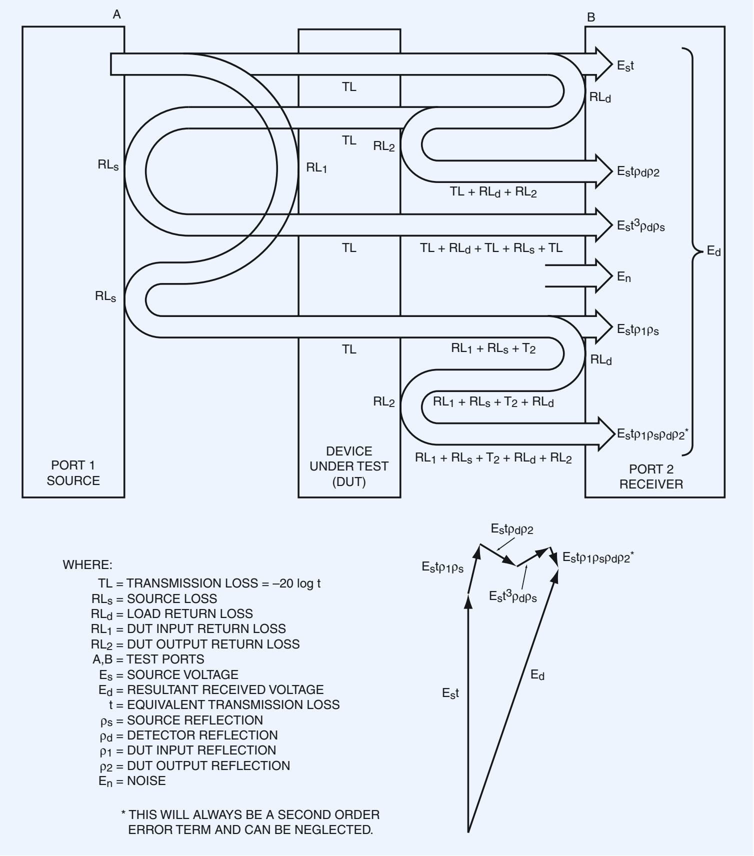
Figure 14. *Typical VNA transmission measurement uncertainty curves.*

Uncertainty in Transmission (Insertion Loss) Measurements

The analysis of transmission measurements is more complex for two main reasons: first, a two port is involved so there are many possibilities for mismatch error signals, some dependent upon the properties of the DUT. Secondly the range of measurement requirements is great, almost without limit; but, from a practical point of view is from 0 to –100 dB for passive devices, which means measurement signal to noise ratio can be a significant factor. The measurement of active devices adds the requirement of measuring devices with gain and brings power level into importance. This will not be specifically treated in this note although many of the factors included in the uncertainty discussion for passive devices are appropriate for active devices.

As usual, the greatest errors occur when measuring the very small or very large insertion losses. Mid range values (6 to 30 dB) effectively “pad” a system to reduce mismatch errors. When measuring low values (less than a few tenths of a dB) mismatch error can lead to the phenomenon of a passive circuit showing “gain”. The measurement of large losses is limited by the dynamic range of the measuring system.

Figure 15 illustrates the complexity of the analysis and shows that the characteristics of the DUT are significant in the result. This diagram is appropriate for both scalar and vector



WHERE:
TL = TRANSMISSION LOSS = –20 log t
RL_s = SOURCE LOSS
RL_d = LOAD RETURN LOSS
RL_1 = DUT INPUT RETURN LOSS
RL_2 = DUT OUTPUT RETURN LOSS
A,B = TEST PORTS
E_s = SOURCE VOLTAGE
E_d = RESULTANT RECEIVED VOLTAGE
t = EQUIVALENT TRANSMISSION LOSS
ρ_s = SOURCE REFLECTION
ρ_d = DETECTOR REFLECTION
ρ_1 = DUT INPUT REFLECTION
ρ_2 = DUT OUTPUT REFLECTION
E_n = NOISE

* THIS WILL ALWAYS BE A SECOND ORDER ERROR TERM AND CAN BE NEGLECTED.

Figure 15. *The accuracy with which transmission loss is measured is affected by reflections and re-reflections from the source match, DUT input, DUT output load match and noise*

systems. In this case hardware limitations in the scalar system can be more serious as they use broadband detectors which can result in errors associated with harmonics. Secondly the detection system is less sensitive, that is – it has a higher noise floor. Broadband Detector match presents problems in both the calibration and measurement steps. The VNA which is a tuned receiver minimizes some of these problems, and the calibration process results in effective source and load match that typically is greater than 30 dB which results in fairly low mismatch errors. It should be mentioned that two 30 dB matches looking at each other produces a 60 dB down error signal (plus or minus about .01 dB) so if the user looks at the through with high resolution (eg: .05 dB/division) they may well see a little "gain". If large values of attenuation are being measured signal to noise ratio (S/N) becomes critical. Actually its effect is similar to that of an interfering signal, and the uncertainty associated with the S/N can be read from the RF Measurement Chart. That is: a S/N of 20 dB will result in uncertainty limits of +.8279 to –.9151 dB.

It is often important to minimize noise, which can be accomplished by reducing the detection bandwidth or averaging or a combination of the two. Either of these approaches slows down the measurement speed of the VNA. The specifications included on VNA data sheets will usually indicate the bandwidth and averaging used. Averaging of 1024 is typical. Figure 16 shows a typical transmission measurement uncertainty curve.

It should be mentioned that VNA's are sometimes used with simple calibrations, such as Frequency Response or One Path – Two Port. In these cases mismatch errors can be quite large, particularly for coupler based test sets, typical of broadband microwave VNA's, which have "raw" source and load match in the range of 12 dB. The bridge based test sets found in RF VNA's are much better in this respect.

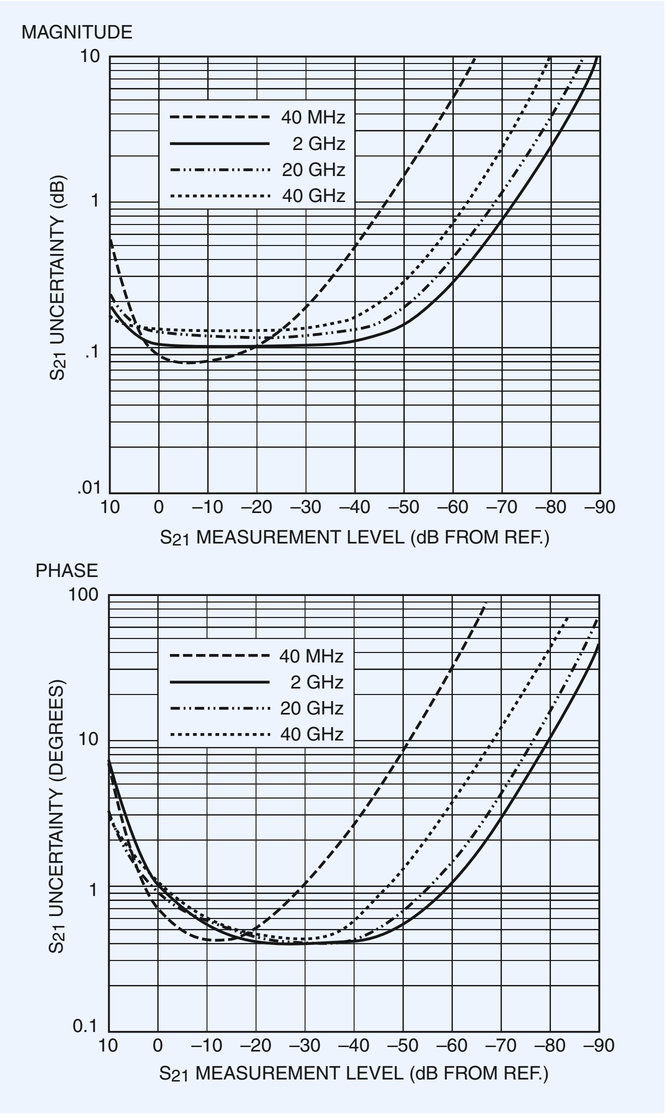


Figure 16. *Typical VNA transmission measurement uncertainty curves.*

Some Practical Situations

The Curse of Adapters

With the variety of connectors in use we have all had the situation where our measurement port will not mate with the device we want to measure. In these situations it is always nice to reach for an adapter. In fact many of us keep a cache of adapters available. But what does this do for our measurement? If an adapter is added to a scalar system or a VNA after calibration, it is going to hurt. When an adapter is used on the test port to adapt to a different sex or connector type, the measurement accuracy is reduced in two ways. The directivity of the reflectometer is reduced because of the reflection from the adapter, and the test port match is degraded as well.

The example in Figure 17 considers an adapter with an SWR = 1.05 (32 dB return loss) attached to a test port of a reflectometer with a directivity of 36 dB, and a test port SWR of 1.15. The directivity of the reflectometer is equivalent to a reflection coefficient of .016 and the reflection from the adapter is .025 (see the RF Measurement Chart – Table 1). These two reflections, when in phase can add to .041, which is the resulting system directivity, and can be expressed in return loss as 27.74 dB. Using a similar approach the resulting test port SWR is 1.32. It is informative to examine the measurement limits when measuring a device that has a nominal 20 dB return loss with and without the adapter. Figure 17 includes this situation. Note that a 2.8 dB error limit has grown to 8 dB as a result of adding a 1.05 SWR (actually pretty good) adapter! When the adapter is added to the device under test, the uncertainty that the adapter alone contributes to the DUT is shown in Figure 18.

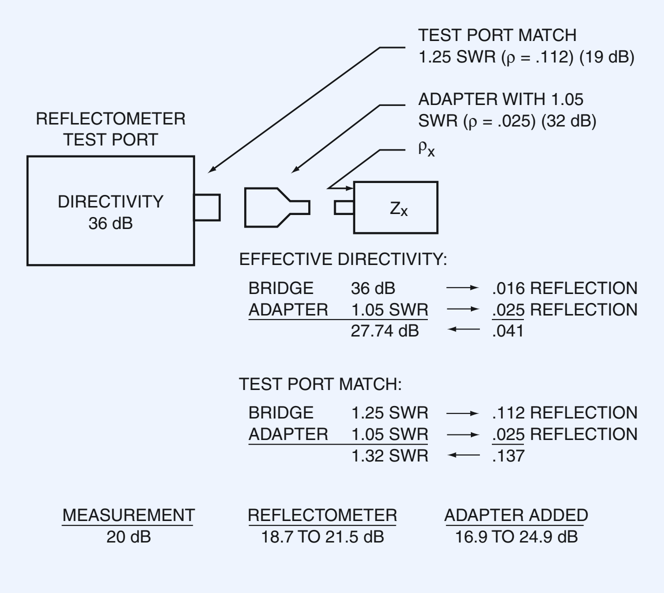


Figure 17. *Adapter error effects on reflection measurement.*

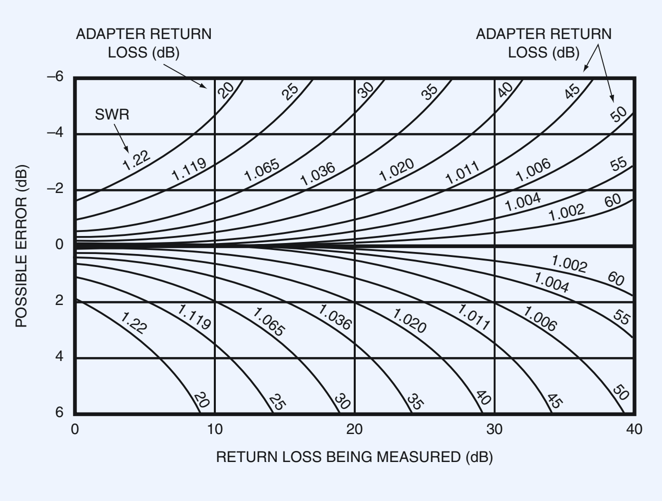


Figure 18. *Uncertainty due to adapter error.*

If a VNA is being used and the adapter can be attached to the test port prior to calibration (This means the user has a calibration kit for the DUT connector system.) then the calibration process deembeds the adapters as well as the rest of the system errors. In this case the adapter has not degraded the measurement system.

The Non Insertable Device

Many devices are built with the same sex connector at each end. Cables are usually built with a male connector on each end. Filters and isolators usually have a female connector at each end. An essential step in most calibrations, either scalar or vector, is to connect the two measurement ports together which for most connector types, dictates male and female test port connectors. Therefore; after calibration the non-insertable device cannot be connected. Several solutions are common:

– High quality adapters can be “swapped”. If phase equal adapters are available errors associated with this adapter exchange are very small. Figure 19 shows the recommended sequence. It does use extra adapters; but, this is not a bad idea as the use of adapter at VNA or cable test ports does eliminate wear and tear of expensive connectors.

– For VNA's, a second calibration can be performed and adapter removal software will provide excellent result.

– For VNA's, a calibration using LRL or LRM will also provide an excellent result. This does require components not usually included in commercial calibration kits.

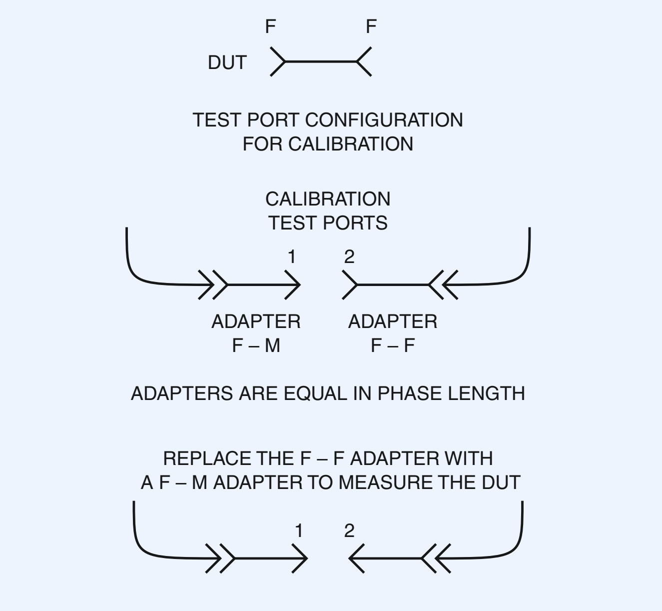


Figure 19.

Small Connectors – K, 3.5mm & SMA[6]

This small group of widely used small connectors have similar mechanical interfaces – they can be connected to each other – but, do have discontinuities that can impact electrical performance at microwave frequencies. This can lead to confusion when calibrating a VNA. What if you have K test ports and a 3.5mm calibration requirement?

It may seem intuitive to replace the K test ports with 3.5mm test ports with suitable adapters – actually that is not necessary. The calibration kit establishes the measurement performance of the system as long as the connection interface is repeatable which is the case with good quality , clean connectors. Any discontinuity is included in the computations that develop error coefficients for the VNA. Figures 20 and 21 shows the effective directivity and port match for a 3.5mm calibration using K and 3.5mm test ports. The performance is essentially identical and the resulting measurement capability would of course be the same.

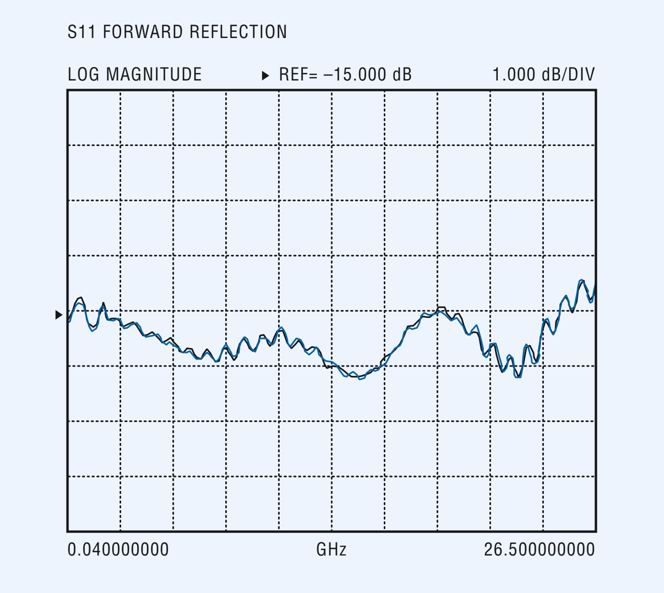


Figure 20.

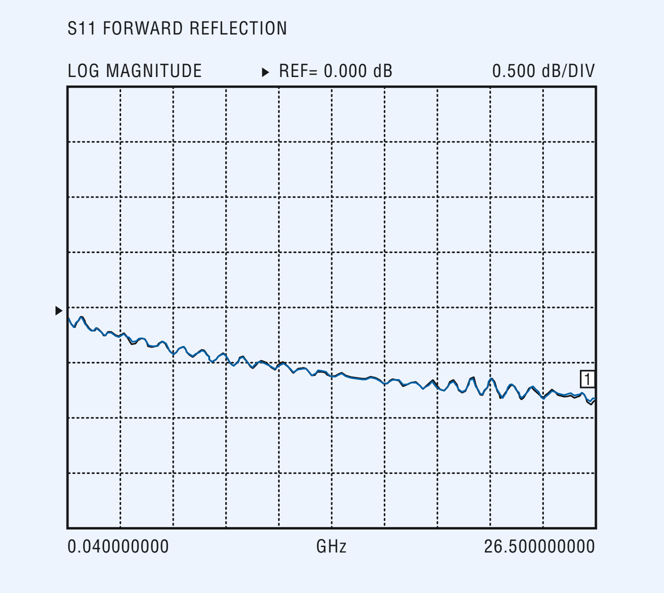


Figure 21.

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