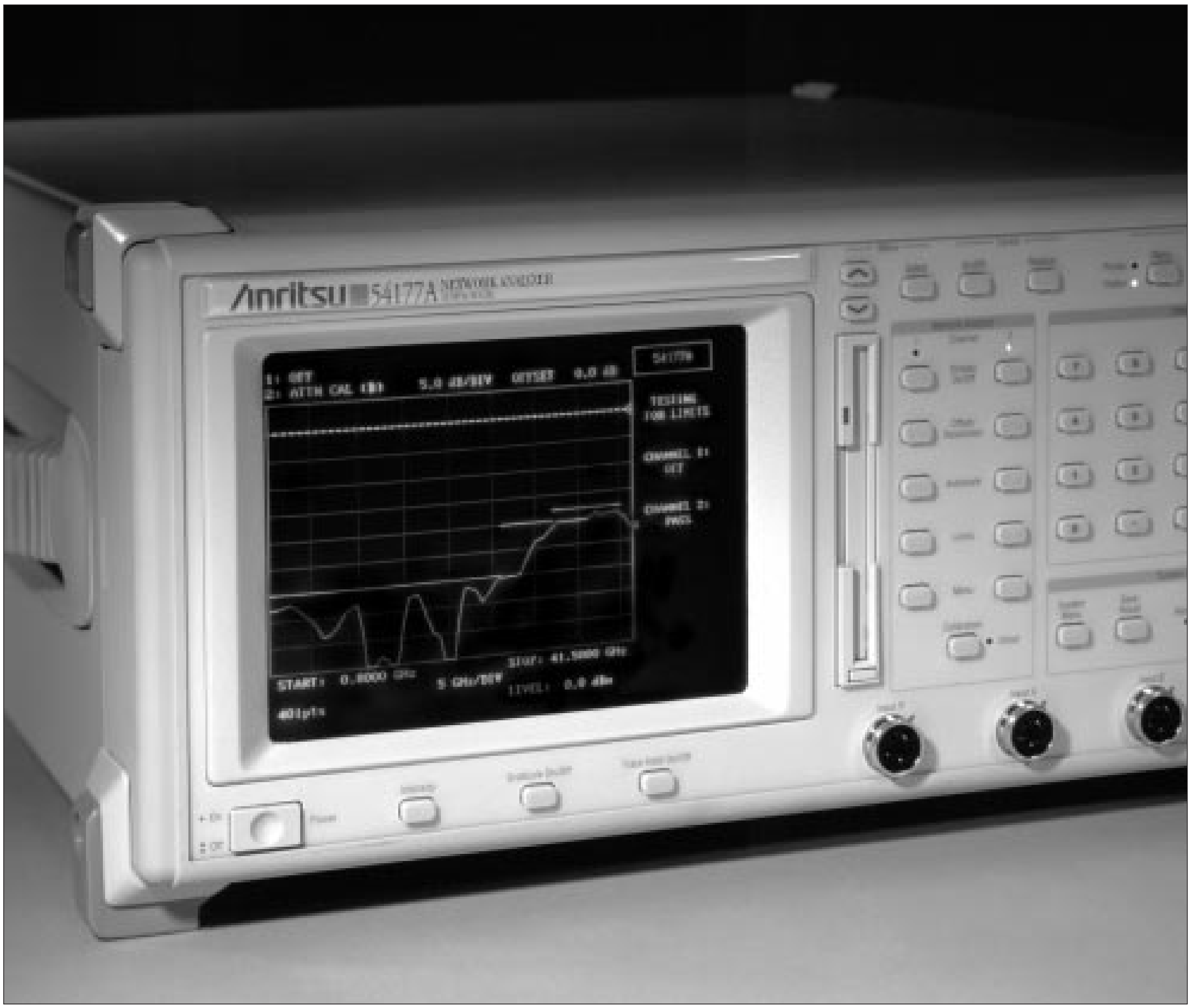
Anritsu

54100A Series

Network Analyzers

Application Note



Precision Return Loss Measurements

Linking the World

Introduction

With implementation of ISO-9002 some manufacturers are completing test accuracy analysis for the first time. Understanding measurement uncertainty is the first step toward ensuring quality. But, how often do calibration stickers appear on benchtop terminations, attenuators, adapters, and other components? Even if proper calibrations are performed annually, What guarantees that an accidental fall to the floor or repeated excessive torque will not degrade the electrical performance of these RF devices?

Precision Return Loss (PRL) is a technique which uses vector signal addition principles to extend the directivity of network analyzer measurements. The 15 to 20 dB directivity improvement allows accurate verification and calibration of very high return loss devices such as terminations, attenuators, and adapters – components which are common to almost every RF test bench.

PRL measurements are NIST traceable and are performed with a microwave network analyzer – the same unit used for daily production work. A typical set of benchtop test gear can be verified in five to ten minutes.

Directivity

Standard SWR Autotesters and RF Bridges have a directivity of approximately 40 dB. This allows accurate testing of DUTs with up to 25 dB of Return Loss. DUTs with higher return loss characteristics will have errors greater than ±1.5 dB when tested with a 40 dB directivity device.

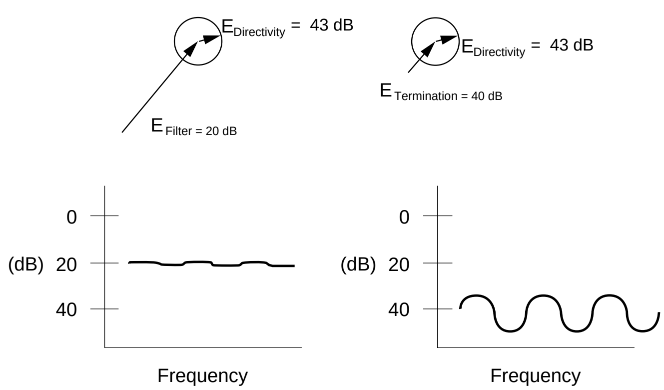


Figure 1: Vector Signal Addition
The vector signal addition or two RF signals creates a ripple pattern on the network analyzer's display. Vectors of similar magnitude have larger peak-to-peak ripples.

This principle is illustrated in Figure 1 where an SWR Autotester with 43 dB directivity is used to test two devices: a filter with 20 dB return loss and a precision termination with 40 dB return loss.

The desired measurement is the DUT's reflection vector "E_{Filter}" or "$E_{Termination}$". The undesired signal is the directivity vector, "$E_{Directivity}$", of the measurement device.

The relative phase angle of the two vectors changes as frequency is changed; thus, the vectors add and subtract with each other during the network analyzer's frequency sweep. The result is a ripple pattern. If the two vector magnitudes are known, the magnitude of the ripple pattern can be calculated according to:

$$\text{Error Range}_{PK\text{-}PK} = ER = 20\,[\,\log(1+10^{-E_\Delta/20}) - \log(1-10^{-E_\Delta/20})\,] \qquad (1)$$

where,
$$E_\Delta = E_{Directivity} - E_{DUT} \qquad (2)$$

As E_Δ becomes small, Error Range $_{PK\text{-}PK}$ increases rapidly. Equation (1) calculates the uncertainty of measurements performed with standard SWR Autotesters or RF Bridges. Since the magnitudes of the two interfering vectors are known, the Error Range $_{PK\text{-}PK}$ can be calculated.

PRL Measurement Theory

The PRL technique uses this same principle, but the equation is reversed. If the peak-to-peak ripple resultant and one of the vectors are known, then the other vector can be calculated. PRL directly measures the magnitude of the peak-to-peak ripple, "ER", and then solves for E_Δ.

$$E_\Delta = -20\,[\,\log(10^{ER/20} - 1) - \log(10^{ER/20} + 1)\,] \qquad (3)$$

Since the $E_{Directivity}$ is measured during calibration, E_{DUT} is easily calculated by (2). The PRL measurement configuration, Figure 2, requires two measurement accessories, an Offset SWR Autotester and a Precision Airline. The Offset SWR Autotester is deliberately tuned for a poor directivity: 15 dB or 20 dB is typically used. This range of $E_{Directivity}$ value is easily measured by the analyzer to very high accuracy.

Measurement Procedures

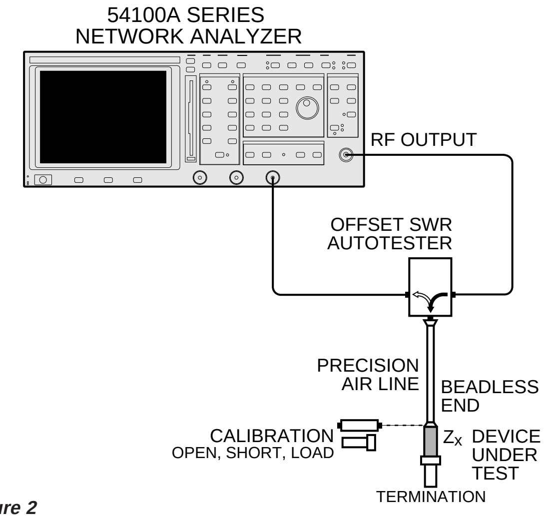


Figure 2
Precision Return Loss measurement requires two specialized components: an Offset SWR Autotester and a Precision Airline.

The Precision Airline physically separates the Offset SWR autotester's measurement detector from the DUT's input. The physical separation causes the relative phase of the E_{DUT} reflection vector to rotate rapidly with respect to the $E_{Directivity}$ vector. An example of the resultant "raw data" for this measurement is shown in Figure 3.

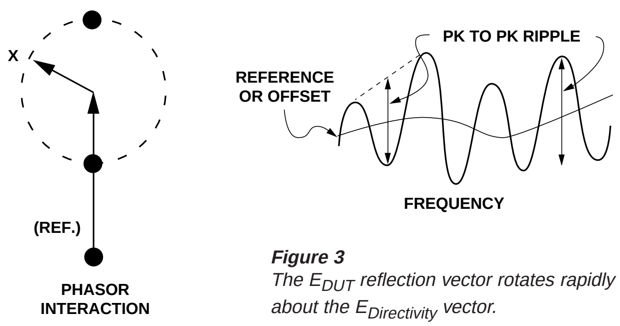


Figure 3
The E_{DUT} reflection vector rotates rapidly about the $E_{Directivity}$ vector.

In practical PRL measurements, neither the Offset Reference nor the DUT's return loss are constant versus frequency. As the frequency sweeps, variations in the offset reference cause the ripple mid-point to vary. As the DUT return loss changes, the peak-to-peak ripple varies. Equations (2) and (3) convert the raw ripple data into the displayed return loss values.

During the PRL calibration procedure, the 54100A automatically measures the value of the offset reference. The offset is $E_{Directivity}$ in equation (2). During PRL measurement, the peak-to-peak ripple, ER, is measured. With the $E_{Directivity}$ and ER data known versus frequency, the 54100A automatically calculates the return loss of the DUT, E_{DUT}.

PRL Component Kit	N-type Connectors	SMA Connectors	K-type Connectors
Offset SWR Autotester	560-97A50-20	560-98KF50-15	560-98KF50-15
Precision Airline	18NF50	19SF50	19KF50
Precision Airline	18N50	19S50	19K50
Open/Short	22N50	22S50	22K50
Open/Short	22NF50	22SF50	22KF50
Precision Termination	28NF50-2	28SF50-1	28KF50
Precision Termination	28N50-2	28S50-1	28K50
Offset Termination	29A50-20	29KF50-15	29KF50-15
Adapter for 54169A	34RSN50	34RKRK50	34RKRK50
Adapter for 54147A	34NN50A	34RSN50A	34RSN50

Table 1
Components model numbers for Precision Return Loss testing

Procedure; Return Loss

This procedure for Adapters, Terminations, and Attenuators applies to 541XXA Series models.

NOTATION

[xxxx] used for front panel keypad.
(xxxxx) used for menu selections.

Initial Setup

Connect the 541XXA as shown.

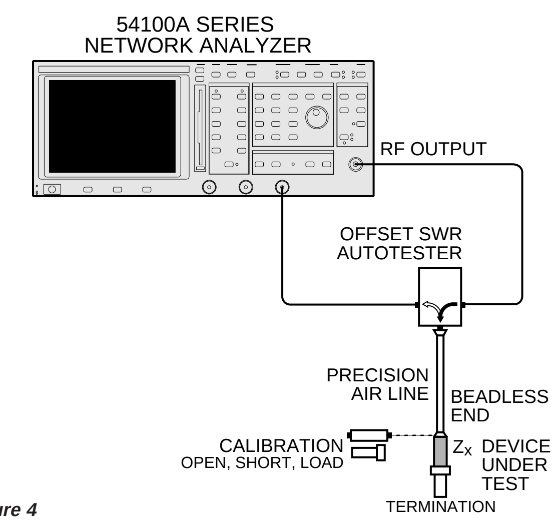


Figure 4
541XXA Precision Return Loss Connections

IMPORTANT: Position the airline pointing vertically upward – not horizontal, and not vertically downward as shown in Figure 4. Downward or horizontal positions make connector center pin alignment difficult. If the test bench is subject to excessive vibration, mount the Offset SWR Autotester in a heavy vise. Position the vise on top of a small neoprene pad.

Reset to default conditions.

541XXA	[System Menu]	(RESET)	[Select]

NOTE: Make sure that no arrows are pointing to CAL DATA, MARKERS, or LIMITS.

in RESET menu	(RESET TO FACTORY DEFAULTS)	[Select]

Channel 2 should now be defined as input B.

Optional: Set the frequency range desired. Generally, you can use the default frequency settings.

541XXA	[Frequency]
	(START) [#] [#] [Enter]
	(STOP) [#] [#] [Enter]

Turn Channel 1 OFF

541XXA	Channel 1 [Display On/Off]

Set Channel 2 to Precision RL

541XXA	Channel 2 [Menu]	(PRECISION RL)	[Select]

Optional: Turn ON the Channel 2 Reference Line and the Graticule.

541XXA	Channel 2 [Menu]	(REF LINE)	[Select]
		(ON)	[Select]
	[Graticule On/Off]		

Calibration

Start Calibration by pressing the Calibration Key.

541XXA	[Calibration]	(START CAL)	[Select]

Follow the prompts on the screen for connection of Open, Short, and 50Ω Load Termination.

The full reflection reference is established by measuring a short and an open. The average of the two responses is the 0.0 dB reference. The termination is used to measure the dB magnitude of the offset inside the Offset SWR Autotester. The termination used must have a least 5 dB better Return Loss than the dB value of the offset.

CAUTION

During both calibration and measurement, be sure to properly align the beadless connector of the airline. When connectors are mis-aligned, a spike will usually be visible on the display.

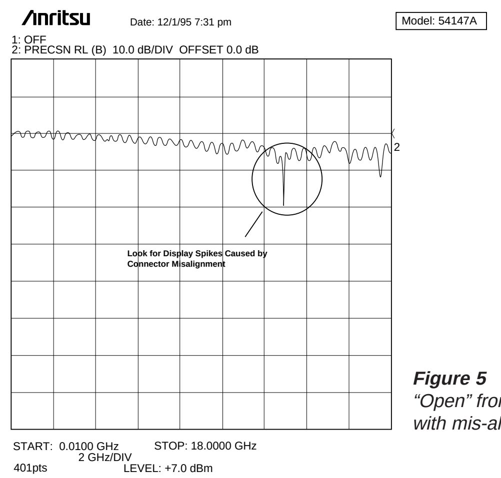


Figure 5
"Open" from calibration with mis-aligned connector

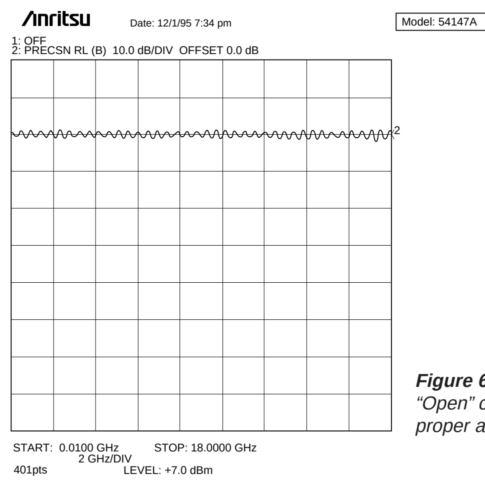


Figure 6
"Open" calibration with proper alignment

During the calibration, use the display to verify proper connection as shown in Figures 5 and 6.

Measurement

Connect a precision termination to the end of the airline. Compare the response to other terminations.

Optional: To check connector alignment during the measurement process, you can access the raw measurement data in the Precision RL "Tuning" mode. "Tuning" mode is slightly faster than "Final" mode.

541XXA	Channel 2 [Menu]	(PRECISION RL)	[Select]
		(TUNING)	[Select]

Required: If you switched to the "Tuning" mode above, return to the "Final" mode.

541XXA	Channel 2 [Menu]	(PRECISION RL)	[Select]
		(FINAL)	[Select]

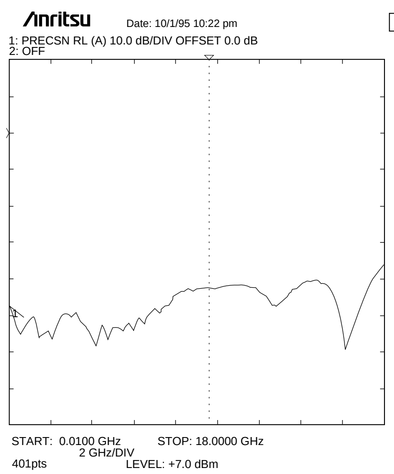


Figure 7
PRL measurement of a Precision Termination

Figure 7 shows the calibration of a precision termination. Precision terminations are used during the manufacture of high quality coaxial switches and adapters. A poor quality return loss from the termination would cause large measurement errors during the switch's return loss testing.

Measurement Comparisons

Save the precision termination measurement to trace mask.

541XXA	Channel 2 [Limits]	
	(TRACE MASK)	[Select]
	(STORE TRACE TO MASK)	[Select]
	under MASK: (ON)	[Select]

Remove the precision termination and attach a typical, benchtop termination.

The following chart uses trace memory to display measurements of two different terminations.

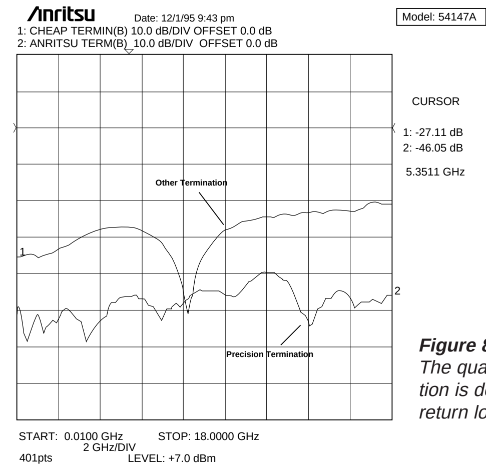


Figure 8
The quality of a termination is determined by its return loss

Now place an adapter between the end of the airline and the precision termination. Note the change in magnitude and ripple pattern.

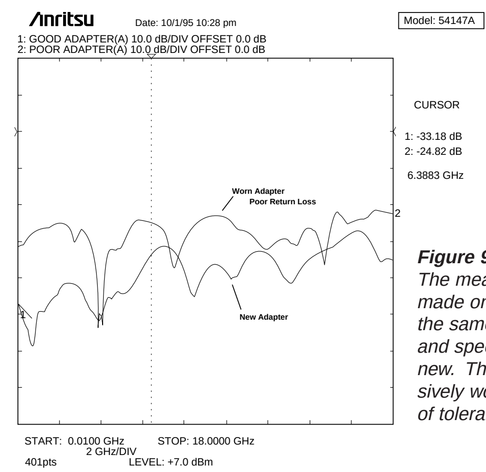


Figure 9
The measurement above is made on two adapters with the same model number and specifications. One is new. The other is excessively worn and is now out of tolerance.

Figure 9 compares the return loss performance of two adapters which are identical except for their age. The older, worn adapter is now out of specification. This adapter problem is surprisingly common. With the exception of a slightly dingy exterior, the physical appearance of the two adapter's mating surfaces appeared substantially identical. A microscope revealed excess wear to the center conductor of the older adapter.

On a typical test bench, adapters are disconnected and reconnected repeatedly. Regardless of the initial quality, any coaxial adapter will eventually wear out.

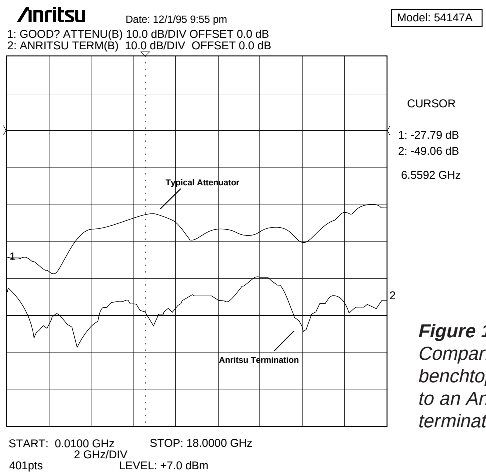


Figure 10
Comparison of a typical benchtop attenuator to an Anritsu precision termination.

Procedure; Directivity

The PRL technique is also used to verify and calibrate the directivity of SWR Autotesters, RF Bridges, and couplers. In Figure 11, the DUT replaces the Offset SWR Autotester and a 20 dB or 15 dB Offset Termination replaces the 50 Ω load.

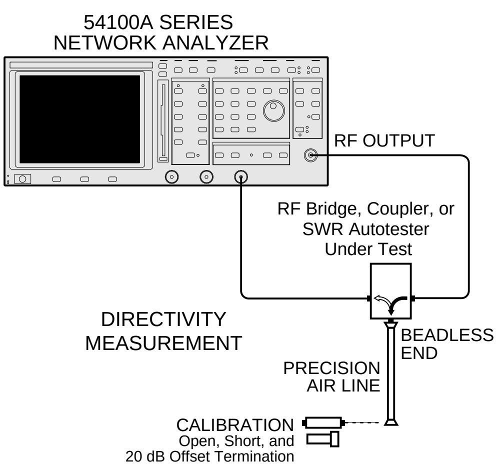


Figure 11
Connections for Directivity Measurement of couplers, RF bridges, and SWR Autotesters.

This procedure for RF bridges, couplers, and SWR Autotesters applies to 541XXA Series models >8.6 GHz maximum frequency.

Connect the 541XXA as shown.

IMPORTANT: Position the airline pointing vertically upward.

NOTE

Testing the directivity of couplers with main line lengths longer than one third the length of the airline is not recommended.

Start the Calibration by pressing the Calibration Key.

541XXA [Calibration] (START CAL) [Select]

First, a connection diagram will be shown. This diagram is slightly different than the setup shown in Figure 11.

Perform the Open and Short calibrations as prompted. DO NOT use a 50 Ω Precision Termination for the "Termination" step: use a 20 dB Offset Termination. A 20 dB Offset Termination has a 20 dB nominal return loss.

The 20 dB Offset should remain connected during measurement. If a 20 dB Offset Termination is not available, an RF detector (most have return loss values close to 20 dB) is usually a good substitute.

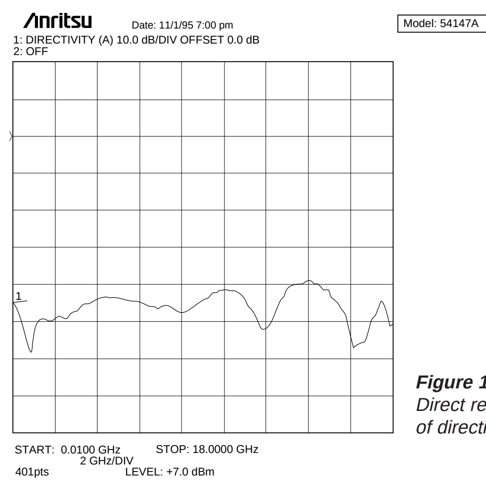


Figure 12
Direct readout of directivity

This directivity measurement of an N-type SWR Autotester was performed with the Precision Return Loss mode. Since the N-Type Precision Airline has a return loss of about 55 dB, the 40 dB directivity measurement above has about 1.5 dB of measurement uncertainty.

WHY CALIBRATE ADAPTERS AND TERMINATIONS?

If you use an adapter on the test port, the error effect can be represented as a reduction to the SWR Autotester's directivity. Effective Directivity is the sum of the internal directivity and the adapter's SWR.

At microwave frequencies, reflections from poor quality or dirty adapters dominate the effective directivity.

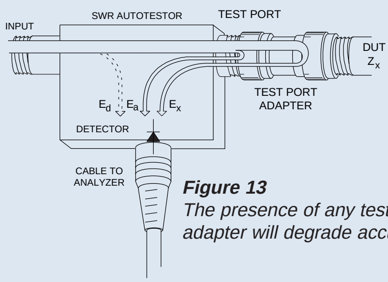


Figure 13
The presence of any test port adapter will degrade accuracy.

Notice that using an adapter on the test port creates an additional reflection signal (E_a in Figure 13) due to the connectors on the adapter. Most adapters available on the manufacturing floor are inexpensive, poor return loss devices. Effectively, the adapter's return loss becomes the directivity of the measurement setup. If adapters must be used, be sure to use a precision adapter which has a return loss comparable to – and preferably about 6 dB better than – the directivity of the autotester or return loss bridge.

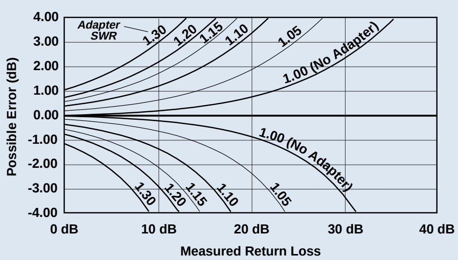


Figure 14: Uncertainty Due to Effective Directivity
Measurement uncertainty increases rapidly as the test port adapter's SWR increases. Chart is based upon adapter attachment to a typical 40 dB directivity SWR Autotester.

As a practical demonstration a precision termination was tested with and without a test port adapter. In Figure 15, the lower trace was performed by an SWR Autotester which mated directly to the WSMA precision termination. The higher trace was made by an N-type SWR Autotester and a typical benchtop N-SMA adapter.

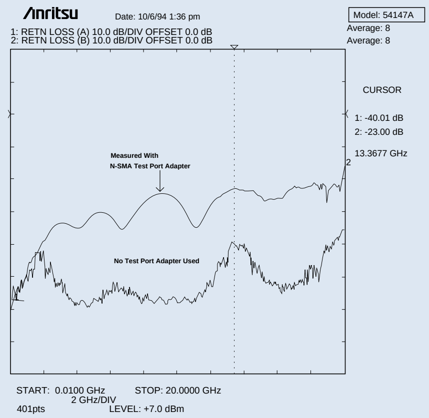


Figure 15
Measurement of a precision termination showing errors caused by test port adapters.

DIRTY OR DAMAGED CONNECTORS

Oils, dirt, and metallic dust will accumulate inside the mating surfaces of test connectors. The deposits should be cleaned per the manual instructions. Typically, a soft cotton swab moistened with isopropyl alcohol is recommended. Avoid exerting pressure on the center conductors: damage will result.

Damaged test connectors and adapters will cause significant error – even when no damage is visible to the eye. Careless bench handling can easily damage a precision connector. Standard test bench components should be checked on a weekly or daily basis. As a minimum, verify critical test components on a monthly basis. To determine the best time interval, consider how much re-testing would be required. If an adapter which is used daily is verified on a monthly basis only, a defective condition would cause a big re-work job.

POOR QUALITY OR DAMAGED TERMINATIONS

Terminations are used when testing low loss DUTs, such as RF switches and cables. The termination reduces – but can not completely eliminate, reflections at the DUT's port two output. Dirty or damaged terminations cause large errors.

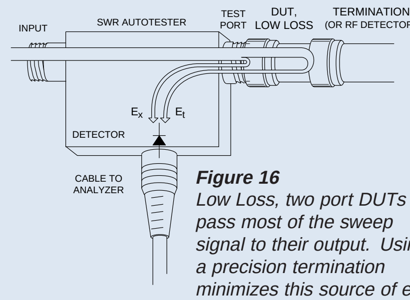


Figure 16
Low Loss, two port DUTs pass most of the sweep signal to their output. Using a precision termination minimizes this source of error.

To keep this error under ±1.5 dB, the return loss of the termination must be at least 15 dB better than the return loss of the DUT.

PASSING YOUR NEXT ISO QUALITY CONFORMANCE AUDIT

With the implementation of ISO-9002, it's no longer acceptable to simply nod approvingly to the technician and say, "That one looks good."

Today, we can not ignore the implications of test accuracy problems such as, poor quality terminations, test port adapters and high harmonic frequency sources. The combined effect of the these error terms can move the measurement uncertainty well outside of typical manufacturing floor measurement tolerances.

Worst Case analysis is the rule, not the exception. In an ISO-9002 system, quality is an "all-of-the-time" experience. Qualifying statements like "usually," "typically," and "sometimes" are not part of the program.

In practical application, adapters tend to perform better than their specifications. The single SWR specification applies to the entire frequency range of the adapter, rather than the smaller range within which testing is conducted. Unfortunately, this may be of little consequence in the eyes of a Quality Control Auditor. The best alternative is to use an SWR Autotester with a correctly mating test port connector. If an adapter must be used, the adapter SWR performance can be verified by the operator or the factory calibration laboratory using PRL.

PRL Accuracy

The measurement technique relies upon the quality of Precision Airlines which, being physical impedance standards, can be used as primary reference standards. By virtue of precise mechanical dimensions, the precision airlines can have 50 to 60 dB return loss performance.

Figure 17
Traceable, precision airlines are used to verify coaxial test components.

The accuracy of the PRL measurement is determined by the Airline's return loss. Figure 18 compares the directivity of standard SWR Autotesters and the directivity improvement provided by PRL.

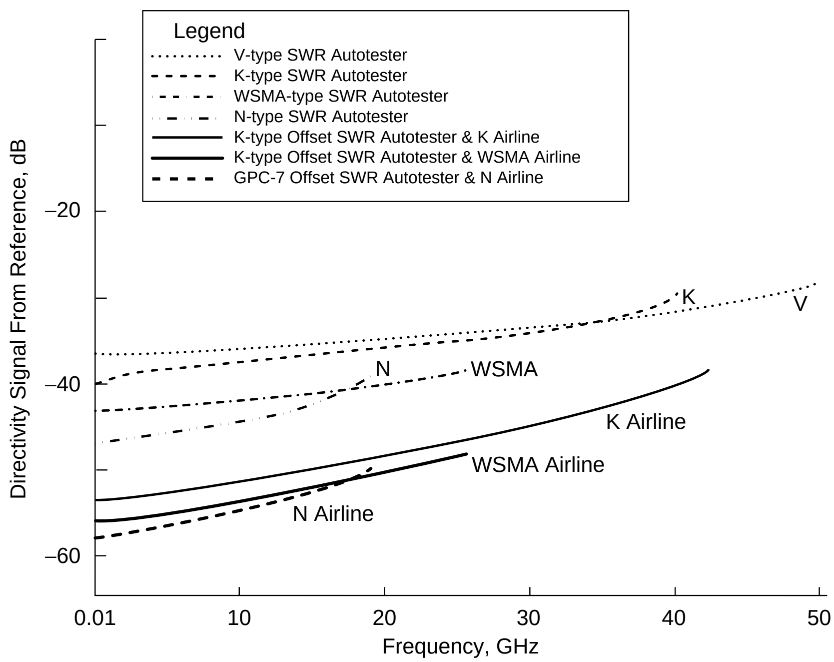


Figure 18
PRL directivity improvement over standard bridge techniques is typically 15 dB.

Accuracy Calculations

When testing single port RF devices such as terminations, the principle uncertainty terms are measurement directivity and channel accuracy The directivity of a PRL measurement is limited by the return loss of the precision airline. Channel accuracy includes noise effects, logarithmic deviation, open/short cal uncertainty, linearity, and instrumentation stability. Second order uncertainty terms such as test port match and source match are typically negligible.

Measurement Uncertainty (dB) = Channel Accuracy + Directivity Uncertainty

$$\text{Measurement Uncertainty (dB)} = -0.5 - 20\log(1 + 10^{-Ed/20}) \quad (4)$$

$$\text{where, } E_d = \text{Airline Return Loss (dB)} - \text{Measured Return Loss (dB)} \quad (5)$$

When measuring two port devices such as adapters and attenuators, an additional term (load match) is required to account for the return loss of the precision termination which is attached to port two of the device under test (DUT).

$$\text{Measurement Uncertainty (dB)} = -0.5 - 20\log(1 + 10^{-Ed/20}) - 20\log(1 + 10^{-Et/20}) \quad (6)$$

$$\text{where, } E_t = \text{Termination's Return Loss (dB)} + 2\,\text{(DUT's Insertion Loss)} - \text{Measured Return Loss (dB)} \quad (7)$$

The accuracy depends upon the DUT. When calibrating terminations, PRL has slightly less uncertainty than a vector network analyzer after a good sliding load or TRL* calibration. A vector network analyzer with a good LRL/LRM calibration (4 samplers required in the VNA) has slightly less uncertainty than PRL.

When calibrating two port devices such as adapters or low loss attenuators, the accuracy is slightly better than a VNA with and OSLT (Open, Short, Load, Thru) calibration. PRL accuracy for two port devices is reduced because a precision termination is required at the DUT output.

Direct display of directivity calibration is possible with PRL, but is not commercially available on a VNA. If it were, however, the PRL uncertainty would be similar to an LRL calibration.

Practical PRL Applications

Calibration and routine verification of test setup components are needed not only in the calibration lab, but also on the manufacturing floor. Test bench components are susceptible to a variety of problems including 1) repeated excess torque, 2) a sharp drop to the floor, and 3) accumulation of dirt. Additionally, since adapters and attenuators are not always labeled for frequency range, they are occasionally used at frequency ranges beyond their specification.

PRL finds these problems quickly. The technique utilizes the same network analyzer which is used for the production process: test operators need only share an Airline and an Offset SWR Autotester. Calibration laboratories use the same technique, except the Precision Airlines utilized may be calibrated by a local standards lab and thereafter kept under lock and key.

Certificate of Calibration

Pages 10 and 11 show an example Certificate of Calibration issued for PRL calibration of a precision adapter. The first page summarizes the adapter's performance and identifies the precision airline calibration standard.

The second page identifies the PRL calibration data for the adapter. The adapter is measured four times. The connection position is rotated in 90 degree increments. The worst case performance for each band of interest is listed under "Maximums".

After the device is measured, the remainder of the table is calculated as follows. "Airline Return Loss" is the calibrated performance of the Precision Airline Standard. If the airline has not been calibrated by NIST or another standards organization, the manufacturer's specification should be used in this column. "Termination Return Loss" is the verified performance of a precision termination plus two times the insertion loss of the device under test: in this case, the adapter's loss is 0.0 dB. The "Sum of Uncert." is a worst case calculation of PRL measurement uncertainty from equation (6).

The required specifications for the adapter are listed under "Spec." "Verification Performance" is the "Measured Value" plus the "Sum of Uncert." "Pass/Fail/Borderline" status is determined by the following.

Verified Performance > Spec	Pass
Measured Value > Spec. > Verified Performance	Borderline
Spec > Measured Value	Fail

Under strict, worst case interpretation, the "Borderline" performance must be classified as a non-conformance to specification.

SUMMARY

For ISO-9000 based manufacturing, the accuracy of production tests should be known. The PRL measurement technique helps to ensure test process compliance by verifying the proper performance of test setup components. The use of traceable Precision Airlines allows calibration of these components to nationally recognized standards.

CERTIFICATE OF CALIBRATION

Issued By Laboratory ________________ Certificate Number: ________________

Calibrated by:	Operator Name	
Calibration Date:	DD/MM/YY	
Device Type:	Manufacturer	ABC Inc.
	Description	N-type, male-male Adapter
	Model	72-Nm
Device Serial Number:	12345	
Environment Details:	Temperature	20˚C – 1˚C
	Humidity	40% – 10%
Calibration Standard:	Standard Type	Precision N(f) Airline
	Serial/Asset	# 98765
	Calibration Date	01/11/95
	Manufacturer	Anritsu
	Return Loss	> 60 dB, 0.5 - 12 GHz
		> 55 dB, 12 - 18 GHz
Measurement Type:	Monthly Return Loss Verification, Two Port Adapters, 30 dB Pass/Fail	
Calibration Procedure:	PRL	
Summary Information:	Connections 4 @ 90˚ rotation	

Maximums Within	**Bands,**	**Verified**	**P/F/Borderline**
0.5 - 4.0 GHz	3.61 GHz	35.3 dB	Pass
4.0 - 8.0 GHz	6.82 GHz	32.7 dB	Pass
8.0 - 12 GHz	9.29 GHz	32.0 dB	Pass
12 - 16 GHz	13.59 GHz	28.5 dB	Borderline
16 - 18 GHz	16.70 GHz	28.2 dB	Borderline

Calibrated by: name ______________________ signature ______________________ date ___________

Checked by: name ______________________ signature ______________________ date ___________

This certificate issued in accordance with.....

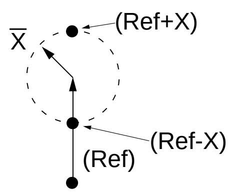
Frequency Range	Band Max	Minimum Measured Value	Airline Return Loss	Termination Return Loss	Sum of Uncert.	Spec.	Verified Performance	Pass / Fail / Borderline
Connection # : 1								
0.5 - 4.0 GHz	3.57 GHz	38.8 dB	60 dB	48 dB	-3.811 dB	30 dB	35.0 dB	Pass
4.0 - 8.0 GHz	6.36 GHz	35.8 dB	60 dB	46 dB	-3.359 dB	30 dB	32.4 dB	Pass
8.0 - 12 GHz	9.27 GHz	36.1 dB	60 dB	43 dB	-4.276 dB	30 dB	31.8 dB	Pass
12 - 16 GHz	13.67 GHz	31.1 dB	55 dB	44 dB	-2.811 dB	30 dB	28.3 dB	Borderline
16 - 18 GHz	16.88 GHz	31.4 dB	55 dB	41 dB	-3.540 dB	30 dB	27.9 dB	Borderline
Connection # : 2								
0.5 - 4.0 GHz	3.75 GHz	38.8 dB	60 dB	48 dB	-3.811 dB	30 dB	35.0 dB	Pass
4.0 - 8.0 GHz	6.37 GHz	35.6 dB	60 dB	46 dB	-3.300 dB	30 dB	32.3 dB	Pass
8.0 - 12 GHz	9.27 GHz	35.8 dB	60 dB	43 dB	-4.166 dB	30 dB	31.6 dB	Pass
12 - 16 GHz	13.59 GHz	30.7 dB	55 dB	44 dB	-2.715 dB	30 dB	28.0 dB	Borderline
16 - 18 GHz	16.70 GHz	31.2 dB	55 dB	41 dB	-3.479 dB	30 dB	27.7 dB	Borderline
Connection # : 3								
0.5 - 4.0 GHz	3.61 GHz	38.5 dB	60 dB	48 dB	-3.711 dB	30 dB	34.8 dB	Pass
4.0 - 8.0 GHz	6.37 GHz	35.7 dB	60 dB	46 dB	-3.329 dB	30 dB	32.4 dB	Pass
8.0 - 12 GHz	9.27 GHz	36.2 dB	60 dB	43 dB	-4.313 dB	30 dB	31.9 dB	Pass
12 - 16 GHz	13.74 GHz	30.8 dB	55 dB	44 dB	-2.738 dB	30 dB	28.1 dB	Borderline
16 - 18 GHz	16.70 GHz	31.3 dB	55 dB	41 dB	-3.509 dB	30 dB	27.8 dB	Borderline
Connection # : 4								
0.5 - 4.0 GHz	3.59 GHz	38.9 dB	60 dB	48 dB	-3.845 dB	30 dB	35.1 dB	Pass
4.0 - 8.0 GHz	6.82 GHz	35.5 dB	60 dB	46 dB	-3.272 dB	30 dB	32.2 dB	Pass
8.0 - 12 GHz	9.29 GHz	35.6 dB	60 dB	43 dB	-4.094 dB	30 dB	31.5 dB	Pass
12 - 16 GHz	13.72 GHz	30.8 dB	55 dB	44 dB	-2.738 dB	30 dB	28.1 dB	Borderline
16 - 18 GHz	16.70 GHz	31.2 dB	55 dB	41 dB	-3.479 dB	30 dB	27.7 dB	Borderline
Minimums								
0.5 - 4.0 GHz	3.61 GHz	38.5 dB	60 dB	48 dB	-3.711 dB	30 dB	34.8 dB	Pass
4.0 - 8.0 GHz	6.82 GHz	35.5 dB	60 dB	46 dB	-3.272 dB	30 dB	32.2 dB	Pass
8.0 - 12 GHz	9.29 GHz	35.6 dB	60 dB	43 dB	-4.094 dB	30 dB	31.5 dB	Pass
12 - 16 GHz	13.59 GHz	30.7 dB	55 dB	44 dB	-2.715 dB	30 dB	28.0 dB	Borderline
16 - 18 GHz	16.70 GHz	31.2 dB	55 dB	41 dB	-3.479 dB	30 dB	27.7 dB	Borderline

Calibrated by: name ______________________ signature ________________________ date ___________

Checked by: name ________________________ signature ________________________ date ___________

RF Measurement Chart

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

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