Option 100 Fault Location and Structural Return Loss Measurements

Agilent Technologies 8712ET/ES and 8714ET/ES RF Network Analyzers

User's Guide Supplement

Agilent Technologies

Part No. 08714-90020
Printed in USA
Print Date: June 2000

Supersedes: October 1999

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Safety Information

Refer to your analyzer's *User's Guide* for safety, warranty, and assistance information.

Key Conventions

This manual uses the following conventions:

FRONT PANEL KEY: This represents a key physically located on the analyzer (a "hardkey").

Softkey : This indicates a "softkey"—a key whose label is determined by the instrument's firmware, and is displayed on the right side of the instrument's screen next to the eight unlabeled keys.

Agilent Technologies Sales & Service Offices

UNITED STATES

Instrument Support Center
Agilent Technologies
(800) 403-0801

EUROPEAN FIELD OPERATIONS

Headquarters
Agilent Technologies S.A.
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Switzerland
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France
Agilent Technologies France
1 Avenue Du Canada
Zone D'Activite De Courtaboeuf
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France
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Germany
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Great Britain
Agilent Technologies
Eskdale Road, Winnersh
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INTERCON FIELD OPERATIONS

Headquarters
Agilent Technologies
3495 Deer Creek Rd.
Palo Alto, CA 94304-1316
USA
(650) 857-5027

Australia
Agilent Technologies Australia Ltd.
31-41 Joseph Street
Blackburn, Victoria 3130
(61 3) 895-2895

Canada
Agilent Technologies (Canada) Ltd.
17500 South Service Road
Trans-Canada Highway
Kirkland, Quebec H9J 2X8
Canada
(514) 697-4232

Japan
Agilent Technologies Japan, Ltd.
Measurement Assistance Center
9-1, Takakura-Cho, Hachioji-Shi
Tokyo 192-8510, Japan
TEL (81) -426-60-2111
FAX (81) -426-56-7840

Singapore
Agilent Technologies Singapore (Pte.) Ltd.
150 Beach Road
#29-00 Gateway West
Singapore 0718
(65) 291-9088

Taiwan
Agilent Technologies Taiwan
8th Floor, H-P Building
337 Fu Hsing North Road
Taipei, Taiwan
(886 2) 712-0404

China
China Agilent Technologies
38 Bei San Huan X1 Road
Shuang Yu Shu
Hai Dian District
Beijing, China
(86 1) 256-6888

Book Overview

This book documents the use of Option 100 (fault location and structural return loss (SRL) measurement capability) with the following network analyzers:

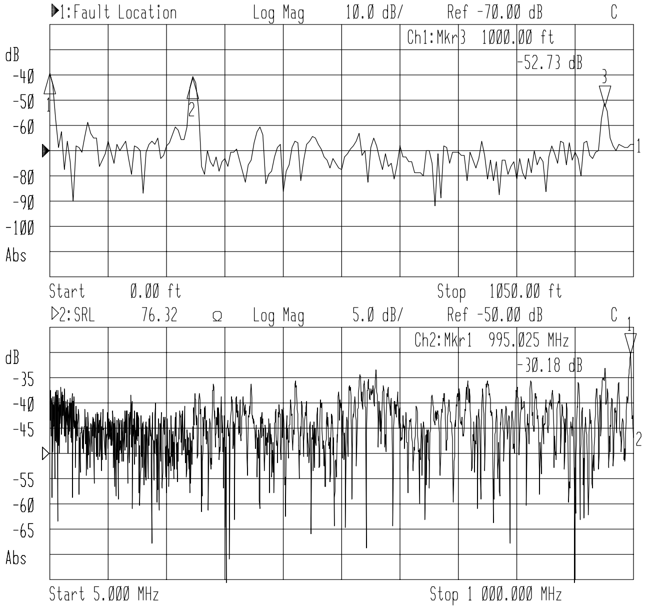
- Agilent Technologies 8712ET/ES
- Agilent Technologies 8714ET/ES

Fault location and SRL measurements can help you test and troubleshoot 50 ohm or 75 ohm transmission lines. Both fault location and SRL measurements are used to identify damaged cables.

Fault location is best used to identify single faults greater than –40 dB.

SRL measurements are typically made before a cable has been installed and are best used to identify many small evenly-spaced imperfections that may be too small for a fault location measurement to detect.

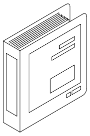
The following illustration depicts a cable being measured simultaneously in fault location and SRL modes. The upper display shows a fault location measurement in the distance domain. The bottom display shows a structural return loss measurement.



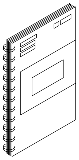
Agilent 8712ET/ES and 8714ET/ES Network Analyzer Documentation Map

The **CDROM** provides the contents of all of the documents listed below.

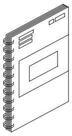
The **User's Guide** shows how to make measurements, explains commonly-used features, and tells you how to get the most performance from the analyzer.



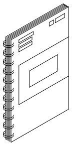
The **LAN Interface User's Guide Supplement** shows how to use a local area network (LAN) for programming and remote operation of the analyzer.



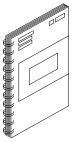
The **Automating Measurements User's Guide Supplement** provides information on how to configure and control test systems for automation of test processes.

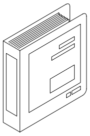


The **Programmer's Guide** provides programming information including GPIB and SCPI command references, as well as short programming examples.

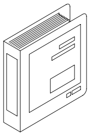


The **Example Programs Guide** provides a tutorial introduction using BASIC programming examples to demonstrate the remote operation of the analyzer.

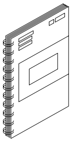




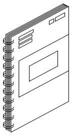
The **Service Guide** provides the information needed to adjust, troubleshoot, repair, and verify analyzer conformance to published specifications.



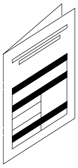
The **HP Instrument BASIC User's Handbook** describes programming and interfacing techniques using HP Instrument BASIC, and includes a language reference.



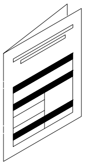
The **HP Instrument BASIC User's Handbook Supplement** shows how to use HP Instrument BASIC to program the analyzer.



The **Option 100 Fault Location and Structural Return Loss Measurements User's Guide Supplement** provides theory and measurement examples for making fault location and SRL measurements. (Shipped only with Option 100 analyzers.)



The **CATV Quick Start Guide** provides abbreviated instructions for testing the quality of coaxial cables. (Shipped only with Option 100 analyzers.)



The **Cellular Antenna Quick Start Guide** provides abbreviated instructions for verifying the performance of cellular antenna systems. (Shipped only with Option 100 analyzers.)

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1

Introduction and Measurement Theory

Fault Location Measurement Theory

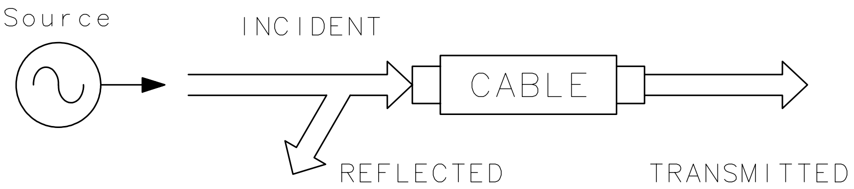
This section describes basic fault location measurement theory, how the analyzer converts frequency-domain data to distance-domain data, and the relationship between start distance, stop distance and frequency span.

Fault location measurements are designed to quickly and easily locate faults, or discontinuities, in either 50 ohm or 75 ohm transmission lines. Refer to Figure 1-1 for the following discussion.

The network analyzer has an RF signal source that produces an incident signal that is used as a stimulus to locate and measure discontinuities in your transmission line or cable. Each fault or discontinuity responds by reflecting a portion of the incident signal and transmitting the remaining signal.

The analyzer measures the frequency response of the cable and then transforms the frequency data to distance data.

Figure 1-1 **Fault Response to an RF Signal**



Typically, fault location measurement results are expressed in one of four ways:

Format	Select FORMAT	Description
Return Loss (RL)	**Log Mag**	The number of dB that the reflected signal is below the incident signal. Its relationship to the reflection coefficient (ρ) is described by the following formula: $RL = -20 \log \rho$.
Reflection Coefficient (ρ)	**Lin Mag**	The ratio of the reflected voltage wave to the incident voltage wave.
Standing Wave Ratio (SWR)	**SWR**	Any two waves traveling in opposite directions (the incident and reflected for example) cause a “standing wave” to be formed on the transmission line. SWR is defined as the maximum voltage over the minimum voltage of the standing wave. SWR can also be mathematically derived from the reflection coefficient (ρ) with the following formula: $SWR = \frac{1+\rho}{1-\rho}$
Impedance Magnitude	**Impedance Magnitude**	The magnitude of the complex impedance at each measurement point. See “How to Make Impedance Measurements” on page 6-4 for information on making impedance measurements. $ImpedanceMagnitude = \lvert Z \rvert = \sqrt{Z^2_{real} + Z^2_{imaginary}}$

How the Analyzer Converts Frequency Data to Distance Data

Fault-location measurements are single-ended measurements, meaning that only one end of a cable under test need be connected to the analyzer's RF OUT (or PORT 1) test port.

This type of measurement is generally called a reflection measurement and typically displays a response commonly known as return loss.

The analyzer performs swept-frequency measurements of return loss versus frequency, then uses the Fourier transform to convert the response-versus-frequency to a response-versus-distance. The analyzer's internal computer makes the calculation by using either the inverse discrete Fourier transform (inverse FFT) technique or the chirp-Z Fourier transform technique.

The Fourier transform technique is essentially a process of adding the signals measured by the analyzer in the frequency domain and combining them to create the fault-location response in the time domain.

The resulting measurement is an error-corrected fault-location response of the cable under test.

Start/Stop Distance and Frequency Span Explanation

When the analyzer is set up for a fault location measurement, you can determine the center frequency (when in band pass mode — see "2. Enter the Measurement Parameters" on page 3-5 for more information on band pass mode), and start and stop distances for the measurement. The distance range (start distance – stop distance) determines the frequency span, which in turn determines the start and stop frequencies.

NOTE In band pass mode (as opposed to low pass mode), you can select center frequency. Changes to distance range do not affect the user-chosen center frequency. Refer to "2. Enter the Measurement Parameters" on page 3-5 for more information about band pass and low pass mode.

The analyzer will attempt to set the frequency span to the setting required for the distance range. The maximum setting for the frequency span cannot exceed the analyzer's frequency capability. For instance, the start frequency cannot be lower than the analyzer's low frequency limit, and the stop frequency cannot be higher than the analyzer's high frequency limit.

When the distance range requires a span that exceeds the analyzer's capability, the frequency span is set to the maximum available setting and a chirp-Z transform is done on the frequency domain data to provide the response in the distance domain.

The chirp-Z transform creates a distance domain response with arbitrary start and stop distances for a given frequency span. Because the chirp-Z transform requires more processing, sweep update rates will slow down in this mode. The analyzer will generally attempt to set frequency span to an allowable setting for the requested distance range before using the chirp-Z transform.

Cable Impedance and Structural Return Loss Measurement Theory

The SRL feature is designed to measure cable impedance and structural return loss. Cable impedance is the ratio of voltage to current of a signal traveling in one direction down the cable. Structural return loss is the ratio of incident signal to reflected signal in a cable, referenced to the cable's impedance.

The network analyzer uses a synthesized RF signal source to produce an incident signal as a stimulus. A reflection measurement is made and then used to compute the cable impedance. The structural return loss measurement is displayed referenced to the measured cable impedance.

For CATV cable, the cable is measured from 5 MHz to 1000 MHz at narrow frequency resolutions down to 125 kHz. The analyzer will automatically scan the cable, then report the worst-case responses.

Cable Impedance

The analyzer automatically computes the cable impedance (Z). However, if you wish to turn off this “auto Z” function and input your own value of impedance, you can. See “Connector Model for Short Cables” on page 4-13.

In coaxial cable, the value of the impedance will depend upon the ratio of the inner and outer conductor diameters, and the dielectric constant of the material between the inner and outer conductors. The cable impedance will also be affected by changes in conductivity. These changes are a natural consequence of RF currents that flow near the surface of a conductor. This effect is known as the “skin effect.” Also, the construction of the cable can change along the length of the cable, with differences in conductor thickness, dielectric material and outer conductor diameter changing due to limitations in manufacturing. Thus the cable impedance may vary along the length of the cable.

The extent to which manufacturing imperfections degrade cable performance is characterized by a specification called structural return loss (SRL). SRL is the ratio of incident signal to reflected signal in a cable. This definition implies a known incident and reflected signal. In practice, the SRL is loosely defined as the reflection coefficient of a cable referenced to the cable's impedance. The reflection seen at the input of a cable, which contributes to SRL, is the sum of all the tiny reflections along the length of the cable. In terms of cable impedance, the SRL can be defined mathematically as:

Equation 1

$$Z_{SRL}(\omega) = \frac{Z_{in}(\omega) - Z_{cable}}{Z_{in}(\omega) + Z_{cable}}$$

Z_{in} is the impedance seen at the input of the cable, and Z_{cable} is the nominal cable impedance.

Cable impedance is a specification that is defined only at a discrete point along the cable, and at a discrete frequency. However, when commonly referred to, the impedance of the cable is some average of the impedance over the frequency of interest. Structural return loss, on the other hand, is the cumulative result of reflections along a cable as seen from the input of the cable. The above definitions need to be expressed in a more rigorous form in order to apply a measurement methodology.

Defining Cable Impedance

Following are three common methods of defining cable impedance. Although all three methods may be commonly used in your industry, your network analyzer uses the third method (Z-average normalization) to define cable impedance.

Method 1. One definition of cable impedance is that impedance which results in minimum measured values for SRL reflections over the frequency of interest. This is equivalent to measuring a cable with a return loss bridge that can vary its reference impedance. The value of reference impedance that results in minimum reflection, where minimum must now be defined in some sense, is the cable impedance. Mathematically, this is equivalent to finding a cable impedance such that:

Equation 2

$$\frac{\partial[\bar{\rho}(\omega, Z_{cable})]}{\partial(Z_{cable})} = 0$$

where ρ is some mean reflection coefficient. Thus, cable impedance and SRL are somewhat inter-related: the value of SRL depends upon the cable impedance, and the cable impedance is chosen to give a minimum SRL value.

Method 2. An alternate definition of cable impedance is the average impedance presented at the input of the cable over a desired span. This can be represented as:

Equation 3

$$Z_{avg} = \frac{\int_{F_{min}}^{F_{max}} Z_{in}(F)\,dF}{(F_{max} - F_{min})}$$

The value found for Z_{avg} would be substituted for Z_{cable} in Equation 1 to obtain the structural return loss from the cable impedance measurement.

Method 3 (Z-average normalization). The mathematics for the Z-average normalization as performed by the analyzer are shown below.

Equation 4

$$Z_{in}(\omega) = Z_0 \times \frac{(1+\rho(\omega))}{(1-\rho(\omega))}$$

Z_0 = system impedance, 50 or 75 Ω

Equation 5

$$Z_{cable} = \frac{\sum_{n=1}^{N} |Z_{in}(\omega_n)|}{N}$$

Equation 6

$$\rho_{SRL}(\omega) = \frac{Z_{in}(\omega) - Z_{cable}}{Z_{in}(\omega) + Z_{cable}}$$

In Equation 4, ρ(ω) is the reflection coefficient from the analyzer measured at each frequency and $Z_{in}(\omega)$ is the impedance of the cable for that measured reflection coefficient.

The calculation of Z_{cable}, described in Equation 5, is the Z-average impedance of the cable over the number of frequency points (N). The default frequency range is approximately 5 MHz to 200 MHz. This frequency range is chosen because mismatch effects of the input connector are small. High quality connectors must be used if the average impedance is calculated over a wider span. The frequency range for this calculation can be modified by using the **Z cutoff Frequency** softkey in the connector model menu to change the cable impedance cutoff frequency.

Equation 6 is the structural return loss for the cable. This calculation can be done by the analyzer or an external computer.

SRL and Periodic Cable Faults

SRL is the measure of the reflection of incident energy that is caused by imperfections or disturbances (bumps) in the cable which are distributed throughout the cable length. These bumps may take the form of a small dent, or a change in diameter of the cable. These bumps are caused by periodic effects on the cable while in the manufacturing process. For example, consider a turn-around wheel with a rough spot on a bearing. The rough spot can cause a slight tug for each rotation of the wheel. As the cable is passed around the wheel, a small imperfection can be created periodically corresponding to the tug from the bad bearing.

Each of these small variations within the cable causes a small amount of energy to reflect back to the source due to the non-uniformity of the cable diameter. Each bump reflects so little energy that it is too small to observe with fault location techniques. However, reflections from the individual bumps can sum up and reflect enough energy to be detected as SRL. As the bumps get larger and larger, or as more of them are present, the SRL values will also increase. The energy reflected by these bumps can appear in the return loss measurement as a reflection spike at the frequency that corresponds to the spacing of the bumps. The spacing between the bumps is one half the wavelength of the reflection spike and is described by equations 7 and 8.

Equation 7

$$wavelength \approx \frac{c}{f}$$

$c = speed\ of\ light$ $\quad$ $f = frequency$

Equation 8

$$\frac{wavelength}{2} = spacing\ between\ the\ bumps$$

The wavelength/2 spacing corresponds to the frequency at which down and back reflections will add coherently (in-phase). The reflections produce a very narrow response on the analyzer display that is directly related to the spacing of the bumps. The amount of reflected energy is observed as return loss. When this return loss measurement is normalized to the cable impedance, the return loss becomes structural return loss.

Figure 1-2 diagrams reflections from bumps in a cable. We can combine the energy reflected by each bump in a cable and make a few basic assumptions, to mathematically describe SRL by the series shown in Equation 9.

Equation 9

$$V_{ref} = [V_{in}L\Gamma L] + [V_{in}L(1-\Gamma)L\Gamma LL] + [V_{in}L(1-\Gamma)L(1-\Gamma)L\Gamma LLL] + \ldots$$

V_{ref} = reflected Voltage

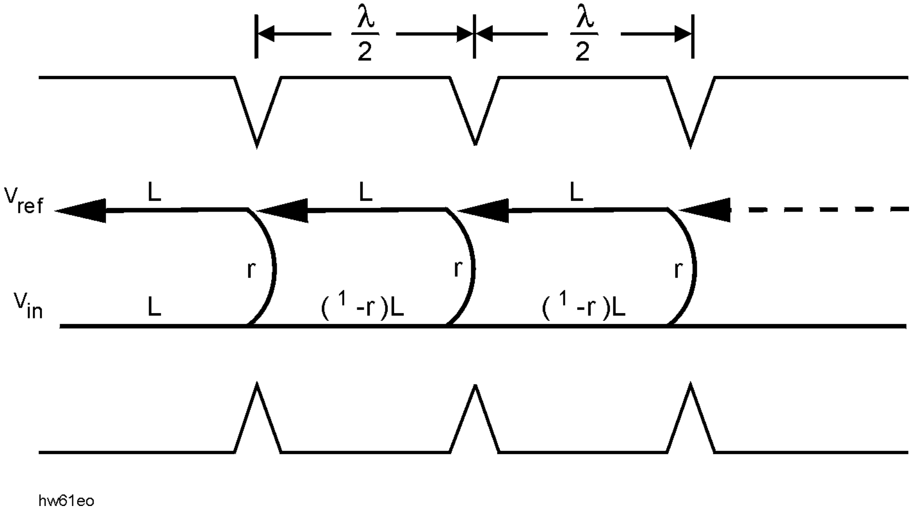
V_{in} = incident Voltage

L = cable loss

Γ = reflection coefficient of the bumps

The bumps are assumed to be uniform in reflection and spaced by a wavelength/2 separation.

Figure 1-2 **Periodic Bumps in a Cable**



The series may be reduced to a simple form to leave us with the relationship shown in Equation 10. The term L is a function of the loss of the cable at a specific frequency and the wavelength at that frequency.

Equation 10

$$SRL = \frac{Vref}{Vin} = \Gamma\left(\frac{L^2}{1-L^2}\right)$$

The term $(L^2)/(1–L^2)$ can be thought of as the number of bumps that are contributing to SRL. It represents a balance between the contribution of loss in a single bump and further bumps in the cable for the specified frequency and cable loss. Calculate the distance into the cable by multiplying the term $(L^2)/(1–L^2)$ by the distance between bumps.

Table 1-1 illustrates some calculated values for a typical trunk cable. From the table, bumps spaced 1.5 meters apart out to 307 meters will contribute to SRL.

Table 1-1 **SRL Equation Constant**

Frequency	Spacing (λ/2)m	Loss (dB)/m	dB/bump	bumps $L^2/(1–L^2)$	Distance(m)
100 MHz	1.5	0.014	–0.02	205	307
500 MHz	0.6	0.033	–0.01	433	129
1 GHz	0.3	0.15	–0.0075	554	83

How to Use Table 1-1

Refer to Figure 1-2 and Equation 10 for the following discussion.

Γ = the reflection coefficient of each bump $(V_{reflected}/V_{incident})$

L = the cable loss between bumps $(V_{transmitted}/V_{incident})$

The distance between bumps equals λ/2 (1/2 wavelength).

Typical values:

$\Gamma << 1$

$L \leq 1$ for low loss cable

Derivation of L. In Equation 10, L is the cable loss for a 1/2 wavelength length of cable, expressed in linear.

1. Find the cable loss from a spec sheet. Cable loss is typically expressed in loss per foot.
2. Convert loss per foot to loss per meter.
3. Find the 1/2 wavelength in meters. This will be the spacing between bumps.
4. Multiply loss per meter × 1/2 wavelength to get dB loss per bump.
5. Convert dB loss per bump to linear.

Example.

1. A spec sheet states that the cable loss spec at 300 MHz is 1 dB per 100 feet.
2. Convert loss per foot to loss per meter:
   1 dB/100 ft ≈ 1 dB/30 m ≈ 0.033 dB/m
   This is the **Loss (dB)/m** *column in* Table 1-1.
3. Find the 1/2 wavelength in meters:
   1/2 wavelength at 300 MHz ≈ 0.5 meters
   This is the **Spacing (λ/2)m** *column in* Table 1-1.
4. Multiply loss/meter × 1/2 wavelength:
   0.033dB/meter × 0.5 meters = 0.0165 dB = L_{dB}
   This is the **dB/bump** *column in* Table 1-1.
5. Convert L_{dB} (loss) in dB to linear:
   $20 \log (L_{dB}) = -0.0165$ $L = 10^{(-0.016/20)} = 0.998$
6. $L^2/(1 - L^2) \approx 262$
7. There are approximately 262 bumps contributing to SRL at 300 MHz.
8. 262 × 0.5 = 131. The distance into the cable for 262 bumps is 131 meters.

In actual cables, the reflections from the bumps and the spacing of the bumps may vary widely. The best case for a minimum SRL, is that the bumps are totally random and very small. Real world examples are somewhere in between the uniform bumps and the scattered case. As the sizes of the bumps, their spacing, and the number of bumps vary within the manufacturing process, varying amounts of SRL are observed.

SRL and Discrete Cable Faults

In addition to a set of periodic bumps, a cable can also contain one or more discrete faults. For this discussion, discrete imperfections will be referred to as “faults,” and periodic imperfections will be referred to as “bumps.”

Reflections from discrete faults within the cable will also increase the level of SRL measured. The energy reflected from a fault will sum with the energy reflected from the individual bumps and provide a higher reflection level at the measurement interface. Examining the cable for faults before the SRL measurement is a worthwhile procedure. The time required to perform the fault location measurement is small compared to the time spent in performing an SRL measurement scan.

A fault within the cable will provide the same type of effect as a bad connector. If the fault is present within the end of the cable nearest to the analyzer, the effect will be noticed throughout the entire frequency range. As the fault is located further into the cable, the cable attenuation will reduce the effect at higher frequencies. The reflected energy travels further through the cable at lower frequencies where the cable attenuation per unit distance is lower.

Techniques for Removing Connector Effects

Connector Effects on SRL

To remove the unwanted effects of worn connectors, the SRL measurement uses a built-in connector model. The connector model consists of compensation for connector length and compensation for connector capacitance (connector C).

The “connector C” compensation emulates the C trim value of a variable impedance bridge.

The connector length is used to compensate for the effects of an electrically long connector and extends the calibration reference plane.

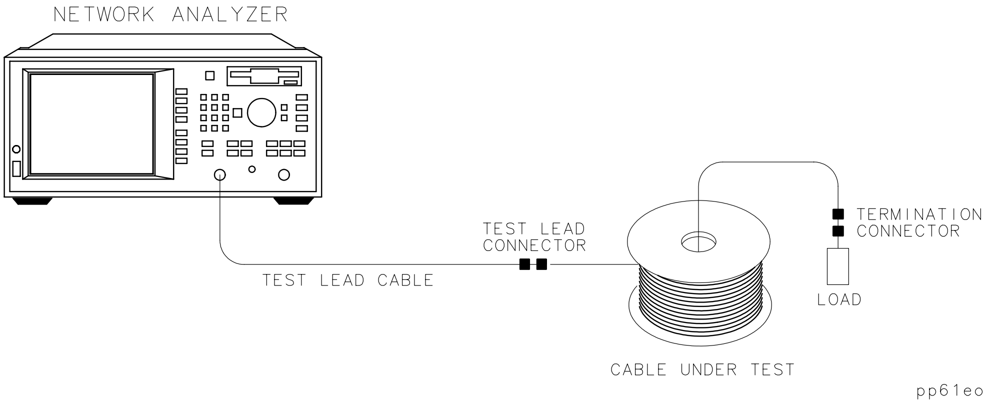
NOTE A calibration reference plane is established at the point where the short, open, and load standards have been measured.

The analyzer can automatically measure the optimum values for your connector model, or you may enter them manually.

The default values for the connector model are 0.00 mm length, and 0.00 pF capacitance (no compensation).

When measuring spools of cable, typically two connectors are used: the test-lead connector and the termination connector. (See Figure 1-3.) These connectors provide the cable interface and are measured as part of the cable data.

Figure 1-3 **Basic SRL Measurement Setup and Connections**



Often, slight changes in the test-lead connector can cause significant changes in the values of structural return loss measured at high frequencies. This is because the reflection from a connector increases for high frequencies. In fact, the return loss of a test-lead connector can dominate the SRL response at frequencies above 500 MHz. This is where training, good measurement practices, and precision cable connectors are needed, especially for measurements up to 1 GHz. Precision connectors are required to provide repeatability over multiple connections. Slip-on connectors are used to provide rapid connections to the cables, but require careful attention in obtaining good measurement data. Repeatability of measurement data is directly affected by the connector's ability to provide a consistently good connection. This is the major cause of repeatability problems in SRL measurements.

Effects of the test-lead connector at the measurement interface are observed as a slope in the noise floor at higher frequencies. (See Figure 4-6 on page 4-11.) By observing the SRL measurement display and slightly moving the connector, the effects of the connection can be observed at the higher frequencies. The test-lead connector should be positioned to obtain the lowest possible signal level and the flattest display versus frequency. The mechanical interface typically provides an increasing slope with frequency and flattens out as the connection is made better.

The termination connector may also affect the SRL measurement if the cable termination connector and load provide a significant amount of reflection and the cable is short enough. As longer lengths of cable are measured, the cable attenuation provides isolation from the termination on the far end. Use a fault location measurement technique to observe the reflection from the termination at the far end of the cable. If the termination is shown as a fault, the reflection from the terminating connector is contributing to the reflection from the cable. A more suitable termination is required or a longer section of cable must be measured. The cable must provide sufficient attenuation to remove the effects of the connector and load for a good SRL measurement. Performing a good measurement on a short length of cable is quite difficult and requires connectors with very low reflections to be effective.

Fixed Bridge with Connector Compensation

The analyzer employs the fixed-bridge method and instrument software to emulate the traditional variable-bridge method. Vector error correction is used to provide the most accurate measurements up to the calibration plane defined by the calibration standards. Additional corrections can also be used to minimize the effects of the test-lead connector on the measured SRL response.

The error corrections done for a fixed bridge can also include connector compensation. The fixed bridge method with connector compensation technique mathematically removes the effects of the test-lead connector by compensating the predicted connector response given by a connector model.

Shunt C Connector Model

One model that can be used for the cable connector is the shunt C connector model. With this model, the adjustment of the C value given in a variable impedance bridge can be emulated. The shunt C connector model assumes the discontinuity at the interface is abrupt and much smaller than a half wavelength of the highest frequency of measurement. With this assumption, the discontinuity can be modeled as a single-shunt twisted pair, where $C = C_0$ + second and third order terms.

Intuitively this is the right model to choose because the effect of a typical poor connector on structural return loss measurement is an upward sloping response, typically worst at the high frequencies.

Using a shunt C to model the connector, a value of the susceptance, –C, may be chosen by the network analyzer to cancel the equivalent C of the connector and mathematically minimize the effect of the connector on the response measurement.

The equations for computing structural return loss and the average cable impedance with capacitive compensation are described next.

Equation 11

$$Z'_{in}(\omega) = \frac{Z_{in}(\omega) \cdot \frac{1}{jwC}}{Z_{in}(\omega) + \frac{1}{jwC}}$$

Equation 12

$$Z'_{cable} = \frac{\sum |Z'_{in}(\omega)|}{N}$$

Equation 13

$$\rho'_{SRL}(\omega) = \frac{Z'_{in}(\omega) - Z'_{cable}}{Z'_{in}(\omega) + Z'_{cable}}$$

In Equation 11, $Z_{in}(\omega)$ is calculated from the measured return loss as described in Equation 4, previously. The primed values are the new calculation values using the capacitive compensation. With these equations, the network analyzer can compute values for the cable impedance and mathematically compensate for the connector mismatch with a given value of C connector compensation.

Connector Length

The shunt C connector model can be improved with the addition of connector length. Connector length is used to compensate for the phase shift caused by the electrical length within the connector. The calibration plane can be moved from one side of the cable connector to the other side, so that the shunt C is placed exactly at the discontinuity of the connector and the cable under test.

Measurement Uncertainties

In any comparison of cable impedance or structural return loss data, it is important to understand the measurement uncertainty involved in each type of measurement. This is critical for manufacturers, who often use the most sophisticated techniques to reduce manufacturing guard bands. It is also important in field measurements that users choose the proper equipment for their needs, and understand the differences that can occur between manufacturers’ data and field data. Also, note that measurement uncertainty is usually quoted as the worst-case result if the sources of error are at some maximum value. This is not the same as error in the measurement, but rather a way to determine measurement guard band, and to understand how closely to expect measurements to compare on objects measured on different systems.

The errors that can occur in a reflection measurement are reflection tracking (or frequency response), T, source match, Γ_M, and directivity, D. The total error in a measurement can be shown to be

Equation 14

$$\Gamma_{MEAS} = T \cdot \left[D + \frac{(\Gamma_{DUT})}{(1 - \Gamma_M \Gamma_{DUT})}\right]$$

where Γ_{DUT} is the reflection response of the DUT.

Error correction techniques can effectively remove the effects of tracking. Also, source match effects are small if Γ_{DUT} is small. This leaves directivity as the largest error term in the reflection measurement. The causes and effects of these error terms will be described for each of the measurement methodologies.

For variable bridge measurements, the directivity of the bridge is the major error term. One-port vector error correction reduces the effects of tracking and source match, and improves directivity. The directivity after error correction is set by the return loss of the precision load, specified to be better than 49 dB at 1 GHz. However, the directivity is only well known at the nominal impedance of the system, and the directivity at other impedances should be assumed to be that specified by the manufacturer. For best performance, the bridge should be connected directly to the cable connector, with no intervening cable in between.

The directivity of the bridge could be determined at impedances other than 75 ohms, by changing the impedance and measuring the resulting values. This can be done by changing the reference impedance to the new value, say 76 ohms, changing the bridge to that value, and measuring the impedance on a Smith chart display. The difference from exactly 75 ohms represents the directivity at that impedance.

For fixed bridge methods, the reflection port is often connected to the cable connector through a length of test lead. A one-port calibration is performed at the end of the test lead. The directivity will again be set by the load, but any change in return loss of the test lead due to flexing will degrade the directivity of the measurement system. In both fixed and variable bridge measurements, the repeatability and noise floor of the analyzer may limit the system measurement. A convenient way to determine the limitation of the measurement system is to perform a calibration, make the desired measurement, then re-connect the load to check the effective directivity. A very good result will be better than –80 dB return loss of the load. Typically, flexure in the test leads, connector repeatability, or noise floor in the network analyzer will limit the result to between –60 to –40 dB. If the result is better than –49 dB, then the system repeats better than the load specification for the best available 75 ohm loads. Thus, the effective directivity should be taken to be the load spec of –49 dB. It is possible to reduce this limitation by having loads certified for better return loss.

Measurement Uncertainty for Impedance Measurements

The fixed bridge method calculates the cable impedance by averaging the impedance of the cable over frequency. The variable bridge uses a reading of the impedance from the dial on the bridge. The directivity at any impedance can be determined, as stated earlier, but only to the limit of the return loss of the load, and the system repeatability. Table 9-1 on page 9-5 shows the effect of directivity on cable impedance measurement uncertainty.

Any connectors and adapters used to connect the test-lead cable to the cable under test can have a significant effect on the impedance measurement. With the variable bridge method, the operator determines the appropriate setting, taking into account the capacitive tuning adjustment. With the fixed bridge method, it is also possible to compensate somewhat for the connector. However, it is often the case that the cable impedance is determined by the low frequency response, up to perhaps 200 MHz to 500 MHz, where the connector mismatch effects are still small. The choice of frequency span to measure cable impedance can itself affect the value obtained for cable impedance. In general, as the connector return loss becomes worse, it will have a greater effect on the resulting impedance measurement. The uncertainty caused by the connector is difficult to predict, but large errors could occur if the low frequency return loss is compromised to achieve better high frequency structural return loss.

Finally, note that since both methods average, in some way, the measurement over the entire frequency range, it is probable that the worst case error will never occur at all frequencies, and with the same phase. In fact, it is more likely that the errors will cancel to some extent in cable impedance measurements. Also, the loads that are used will invariably be somewhat better than specified, especially over the low frequency range. From this, it is reasonable to assume that the errors in impedance measurements are at least 50% less than listed in Table 9-1 on page 9-5.

Measurement Uncertainty for Structural Return Loss

The same factors that affect cable impedance — directivity, system and test lead stability, and cable connector mismatch — also affect structural return loss. However, since structural return loss is measured at all frequencies, it is much more likely that a worst case condition can occur at any one frequency. For that reason, the measurement uncertainty must include the full effect of the above listed errors.

Refer to Chapter 9 for further discussion on this subject.

2

Cable Preparation

Cable preparation (for slip-on connectors) can be critical for some SRL measurements, especially when measuring mainline cables with an SRL of –30 dB or lower. An improperly prepared cable can degrade the cable/connector response which may affect the measurement enough to make a “good” cable fail.

This chapter describes the most common cable preparation problems that should be avoided in order to obtain good measurements.

The measurement results shown are similar to the actual results that may be obtained with each cable preparation problem. Their purpose is to provide you with an idea of what type of measurement results to expect.

NOTE The procedures and illustrations in this manual assume the use of an Agilent Technologies 8712ET or 8714ET. If you are using an Agilent Technologies 8712ES or 8714ES, some key presses and displays will be slightly different.

Cable Preparation Problems

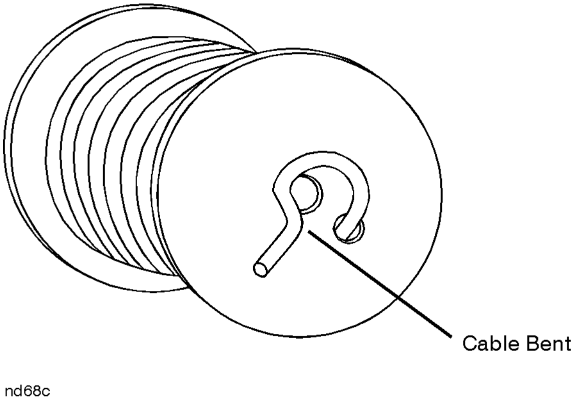
Follow the preparation instructions provided by the connector manufacturer and take great care to avoid the following cable preparation problems:

- bent cable
- deformed cable
- contaminated dielectric
- damaged outer conductor
- non-flush cut

Bent Cable

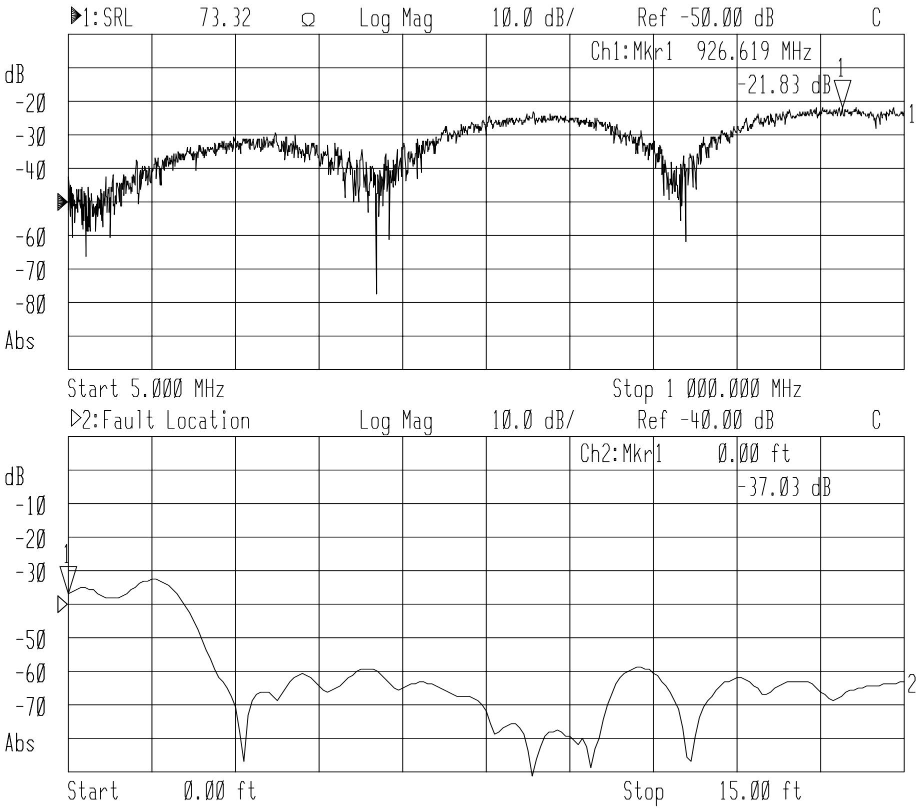
Poor measurement results can occur if the cable is bent or kinked near the end of the spool. See Figure 2-1 and Figure 2-2.

Figure 2-1 **Bent/Kinked Cable**



The upper trace in Figure 2-2 is an SRL measurement. The lower trace is a fault location measurement showing the connector at 0.0 ft and the first 15 ft of the cable. The multiple bumps in the SRL response indicate the likelihood of multiple cable faults. The fault location response shows two significant bumps at 0.0 ft and at 1.5 ft. The bump at 1.5 ft is a response from the bend in the cable. The bend should be removed before proceeding with the SRL measurement.

Figure 2-2 **Measurement Trace with a Bent/Kinked Cable**



NOTE The built-in connector modeling will attempt to remove the effects of the connector at 0.0 ft. However, the modeling cannot remove the effects of the cable bend at 1.5 ft.

Deformed Cable

Compressing the dielectric (the gap) will produce egg-shaped or oval deformations which can cause impedance mismatches and affect the quality of the connector model compensation. See Figure 2-3 and Figure 2-4. This can easily happen when using diagonal cutters to cut the cable.

Figure 2-3 **Deformed Cable (cut with diagonal cutters)**

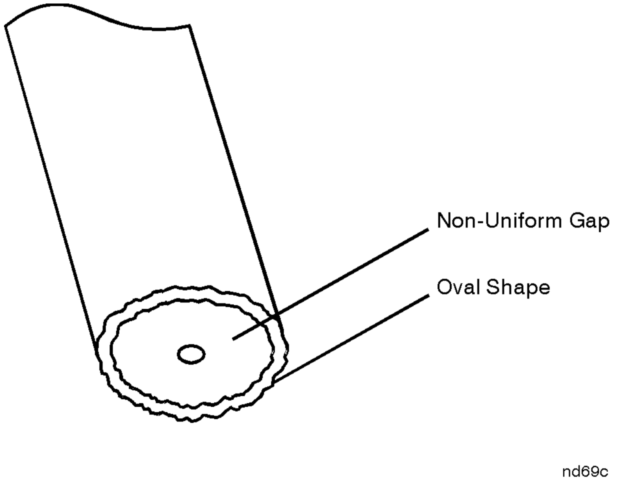
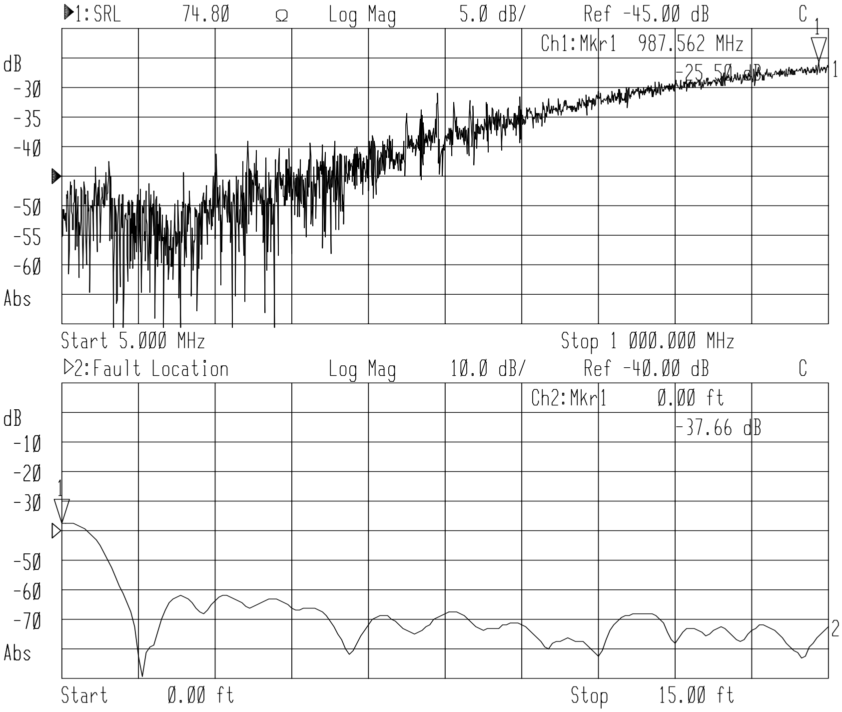


Figure 2-4 **Measurement Trace with a Deformed Cable**



NOTE

The built-in connector modeling will attempt to remove the effects of the connector. The connector response is shown at 0.0 ft. on the bottom trace. The extent to which the effects of the connector can be removed may depend on the quality of the cable preparation as well as the connector.

Contaminated Dielectric

When a cable is cut, contamination of the dielectric can occur from cuttings or shrapnel from the outer or inner conductor. This type of contamination can cause problems and change the connector model compensation needed. See Figure 2-5 and Figure 2-6.

Figure 2-5 **Contaminated Cable Dielectric**

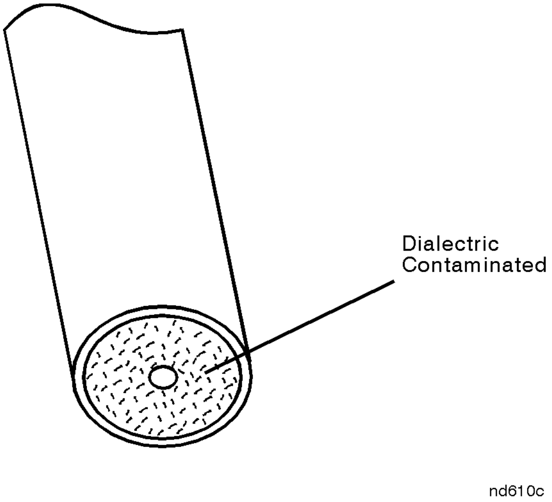
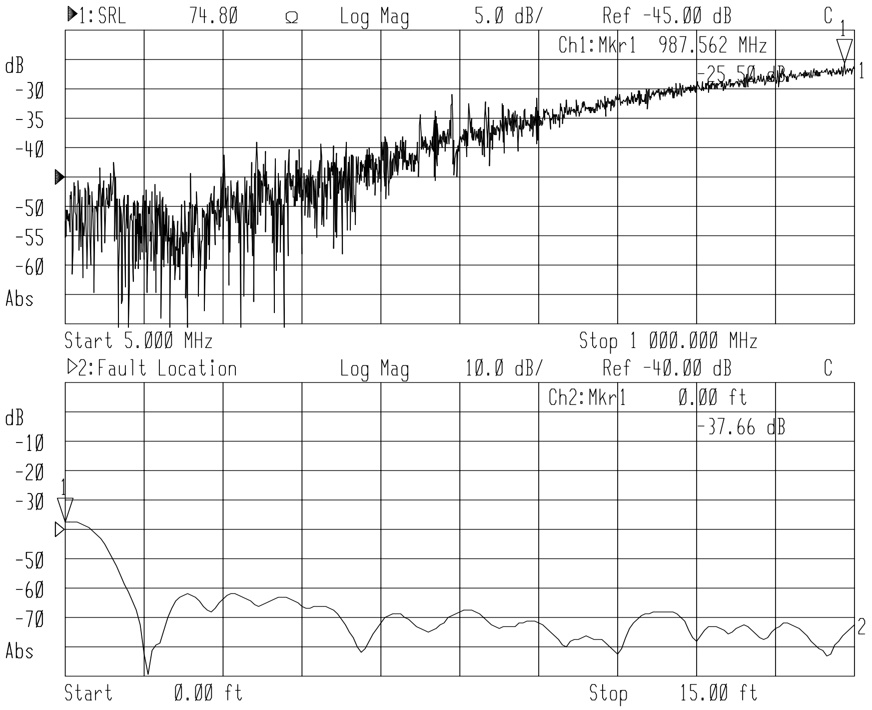


Figure 2-6 **Measurement Trace with Contaminated Cable Dielectric**



NOTE The built-in connector modeling will attempt to remove the effects of the connector. The connector response is shown at 0.0 ft. on the bottom trace. The extent to which the effects of the connector can be removed may depend on the quality of the cable preparation as well as the connector.

Damaged Outer Conductor

The outer conductor may be cut or dented when the outer insulation is removed. This can cause a close-in fault which cannot be compensated by the connector model. See Figure 2-7 and Figure 2-8.

Figure 2-7 **Scarred Outer Conductor of Cable**

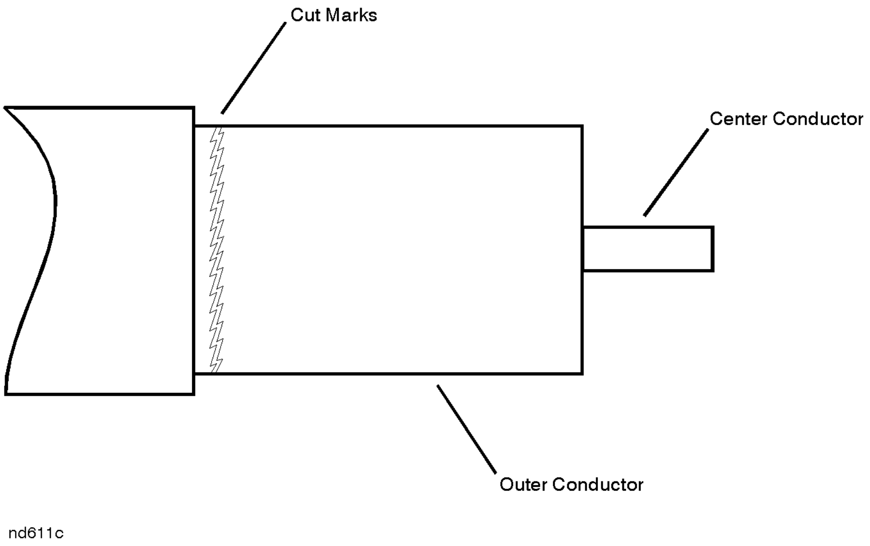
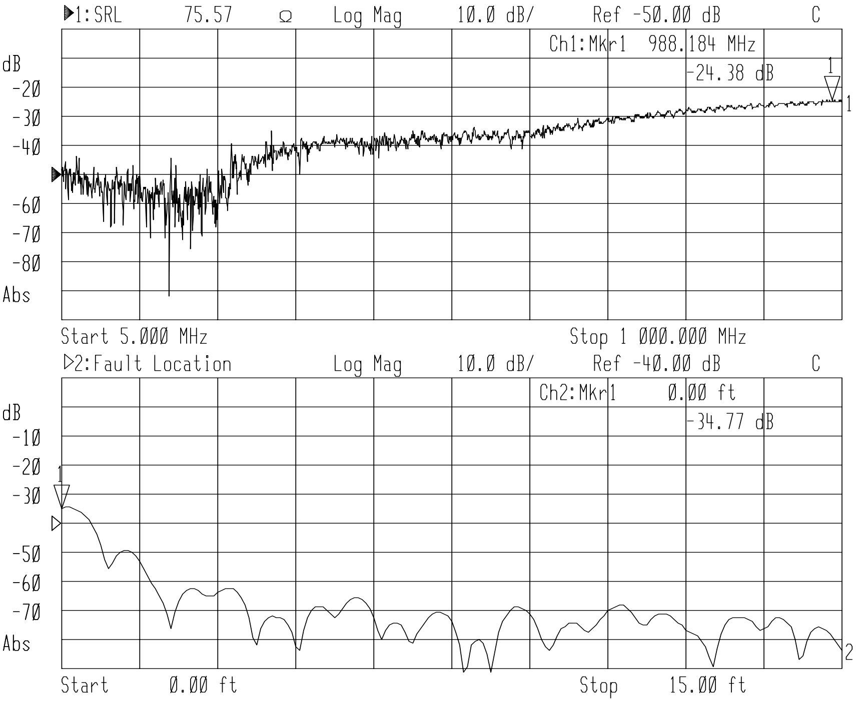


Figure 2-8 **Measurement Trace with a Cut Outer Conductor**



NOTE The built-in connector modeling will attempt to remove the effects of the connector at 0.0 ft. However, the modeling may not remove the effects of the outer conductor damage (which is a few inches into the cable).

Non-Flush Cut

Cables which require a flush cut, such as for GTC-XXX-TX-N ("Pogo") connectors, might not actually be cut in such a way. This can cause an inconsistent connection or poor repeatability of the SRL measurement. See Figure 2-9 and Figure 2-10.

Figure 2-9 **Cable Cut Flush (good) and Non-Flush (bad)**

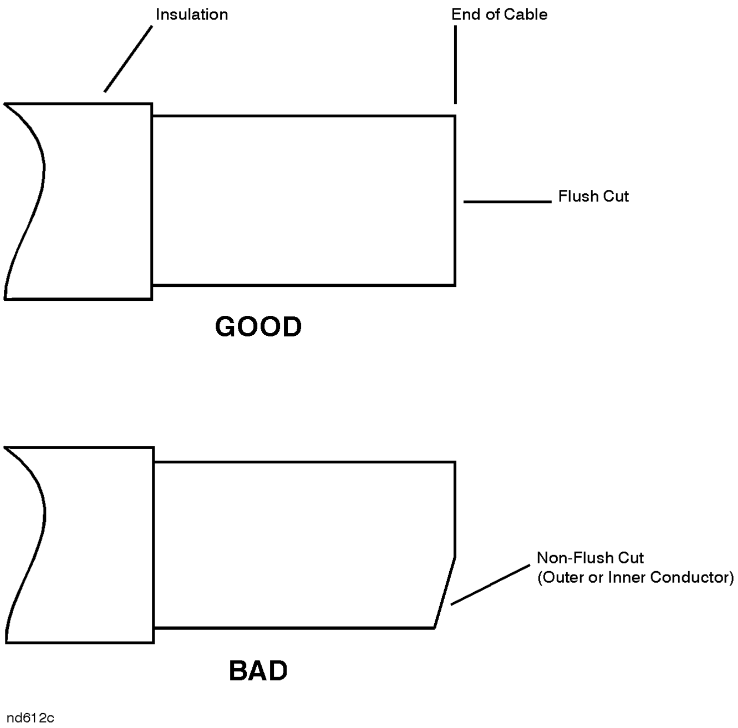
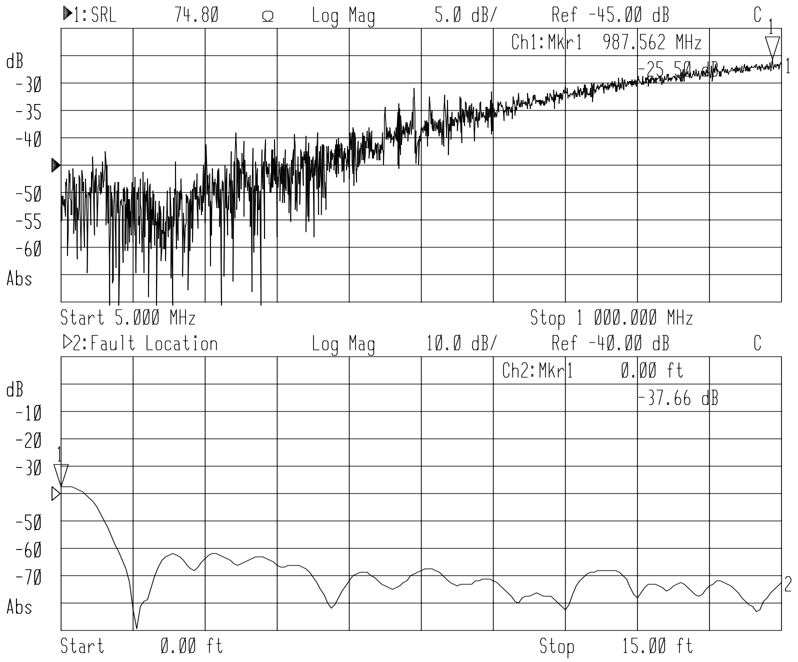


Figure 2-10 Measurement Trace with a Non-Flush Cut Cable



NOTE

The built-in connector modeling will attempt to remove the effects of the connector. The connector response is shown at 0.0 ft. on the bottom trace. The extent to which the effects of the connector can be removed may depend on the quality of the cable preparation as well as the connector.

Recommended Tools and Cables

Recommended Tools

For connectors such as the GTC-XXX-TX-GHZ-N (“GHZ”) connector, cable prep tools similar to CableMatic Model SST-A (Ripley Company) are recommended.

Recommended Cables

The following table lists the recommended test lead cables for use in cable testing applications.

Table 2-1 **Recommended Test Lead Cables**

Cable Description	Part Number
75 Ohm Type-N 10 ft. (m-m)	8120-6737
75 Ohm Type-N 10 ft. (m-f)	8120-6740
75 Ohm Type-N 15 ft. (m-m)	8120-6738
75 Ohm Type-N 15 ft. (m-f)	8120-6741
75 Ohm Type-N 30 ft. (m-m)	8120-6739
75 Ohm Type-N 30 ft. (m-f)	8120-6742

3

Making Fault Location Measurements

This chapter contains the following information:

- how to make and interpret fault location measurements
- example fault location measurements

NOTE

Refer to "Fault Location Measurement Theory" on page 1-2 for detailed information on how the analyzer measures fault location.

NOTE

The procedures and illustrations in this manual assume the use of an Agilent Technologies 8712ET or 8714ET. If you are using an Agilent Technologies 8712ES or 8714ES, some key presses and displays will be slightly different.

How to Make and Interpret Fault Location Measurements

A typical fault location measurement consists of the following steps:

1. Select fault location as the type of measurement
2. Enter the measurement parameters
3. Calibrate the analyzer
4. Connect the equipment
5. Interpret the measurement

The next few pages explain how to perform each of these steps.

1. Select Fault Location as the Type of Measurement

To select fault location, press

(PRESET)

(BEGIN)

Toggle **User BEGIN** to OFF (if necessary)

Cable

Fault Location .

2. Enter the Measurement Parameters

Use the front panel keys to enter the following parameters:

Parameter	**Comments**
Start Distance	
Stop Distance	
Distance Units	Choose feet or meters.
Low Pass Mode	This mode is useful for measuring non band-limited devices, such as cables. No restrictions are placed on stimulus frequencies to be used. The analyzer will set the stimulus frequency automatically to the required frequency span. Unlike band pass mode, lowpass mode does not maintain the same center frequency for all distance settings. Center frequency will change with distance (and frequency span) so that: Center Frequency ≈ Frequency Span/2 To see the frenquency range used for a given measurement press: SYSTEM OPTIONS then **Operating Parameters**. See Table 9-10 on page 9-13 and Table 9-11 on page 9-16 for the relationship between frequency span and distance.

Parameter	Comments
Band Pass Mode	This mode is called bandpass because it works with band-limited devices. Stimulus frequencies are limited to the range specified by the **Center Frequency** setting and the **Band Pass Max Span** (in the fault loc frequency menu) setting. For example, bandpass mode should be selected for measurements on systems which can operate only over narrow specified frequency ranges. In this mode, the frequency span for the fault measurement cannot exceed the **Band Pass Max Span** setting.
Center Frequency	This parameter is only used with band pass mode.
Sweep Time	When making fault location measurements, the sweep time is set automatically based on the stop distance setting you have chosen. Sweep time may be entered manually, however, using the SWEEP **Sweep Time** key.

3. Calibrate the Analyzer

When practical, a calibration should be done at the measurement reference plane using open, short, and load calibration standards to correct the instrument and optimize accuracy. If calibration standards are not available, the default instrument calibration can be used.

NOTE

Most fault location measurements are made by connecting the cable under test directly to the analyzer's RF OUT (or PORT 1) test port. In this case the measurement reference plane would be the analyzer's port and you would connect calibration standards to the RF OUT (or PORT 1) test port as shown in Figure 3-1. Fault location measurements may also be made using a test lead cable. If this is the case, the measurement reference plane would be the end of the test lead cable as shown in Figure 4-1 on page 4-5, and calibration standards would be connected to the end of the test lead cable.

Entering Calibration Parameters

If fault location is already selected as the type of measurement, press CAL and then enter the velocity factor and cable loss parameters. The value for cable loss should correspond to the center frenquency of the range used for the fault measurement.

NOTE Inspect or measure your cable for velocity factor and cable loss per 100 feet specifications. If your cable is not marked with these parameters, you may refer to Appendix A for some typical values. The values in Appendix A are typical only.

Automatically Determining Velocity Factor and Cable Loss

An alternative to entering the velocity factor and cable loss of your cable is to use the algorithm built in to the analyzer to determine these values automatically. To use this function, you need a known length of cable of the same type being measured that is at least 30 feet long.

Press the **Calibrate Cable** key and follow the prompts. See "**Calibrate Cable**" in Chapter 8 for more information.

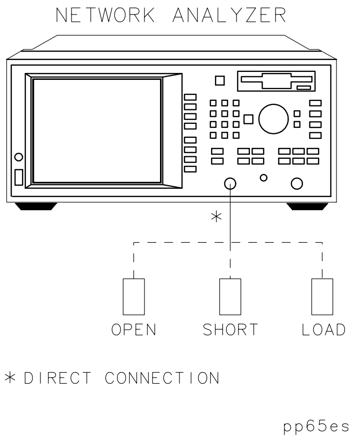
Using Calibration Standards to Calibrate the Instrument

To calibrate the instrument using calibration standards, perform the following steps:

1. Press CAL **Full Band Cal** . (Fault location must already be selected as the type of measurement.)
2. Follow the prompts on the analyzer's screen to connect the open, short, and load to the analyzer's RF OUT (or PORT 1) test port. (See Figure 3-1.) Or, if your measurement reference plane is the end of a test lead cable, connect the standards to the end of the test lead cable.
3. After the calibration is complete, a “C” is displayed in the channel annotation area in the upper right-hand corner of the analyzer's display. The “C” indicator is a visual verification that a full band (not instrument default) calibration is in use and has been completed properly.

NOTE A full band calibration is valid over the entire frequency range of the analyzer and is valid for any frequency setting.

Figure 3-1 **Calibrate the Instrument**



Using the Default Calibration

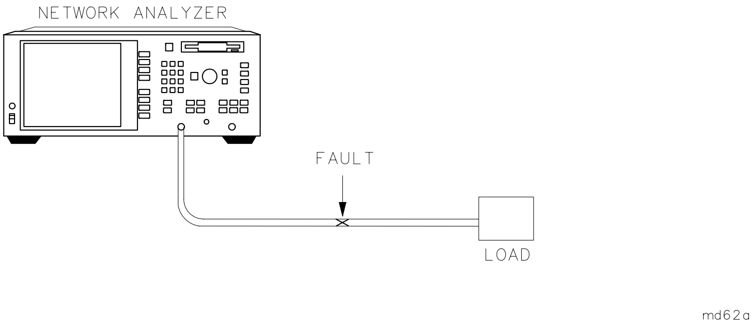
To use the instrument default calibration, press CAL **Default Cal** and then enter the velocity factor and cable loss parameters. (Fault location must already be selected as the type of measurement.)

NOTE When the default cal is used, the "C" indicator does not appear on the display.

4. Connect the Equipment

The basic equipment setup for fault location measurements is illustrated in Figure 3-2.

Figure 3-2 **Basic Fault Location Measurement Setup**

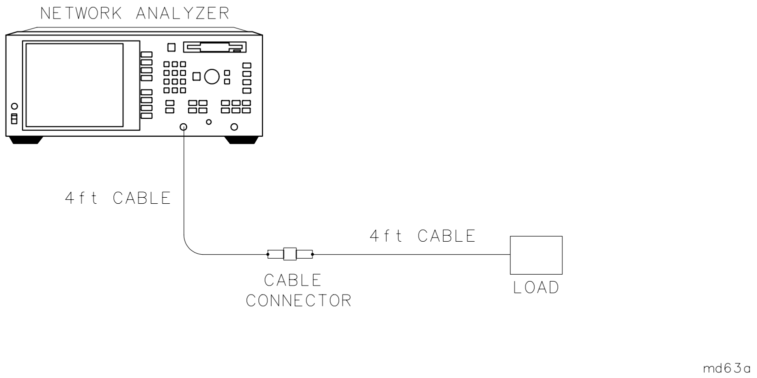


5. Interpret the Measurement

Once the measurement parameters have been set up, you can use markers to find the peak responses (which indicate faults or discontinuities), or you can place a test limit line on the screen that will indicate whether or not your cable meets a particular specification.

In the following example, two four-foot cables are connected in series to the RF OUT (or PORT 1) test port of the analyzer and are terminated with a 50 ohm load. See Figure 3-3.

Figure 3-3 **Equipment Setup**

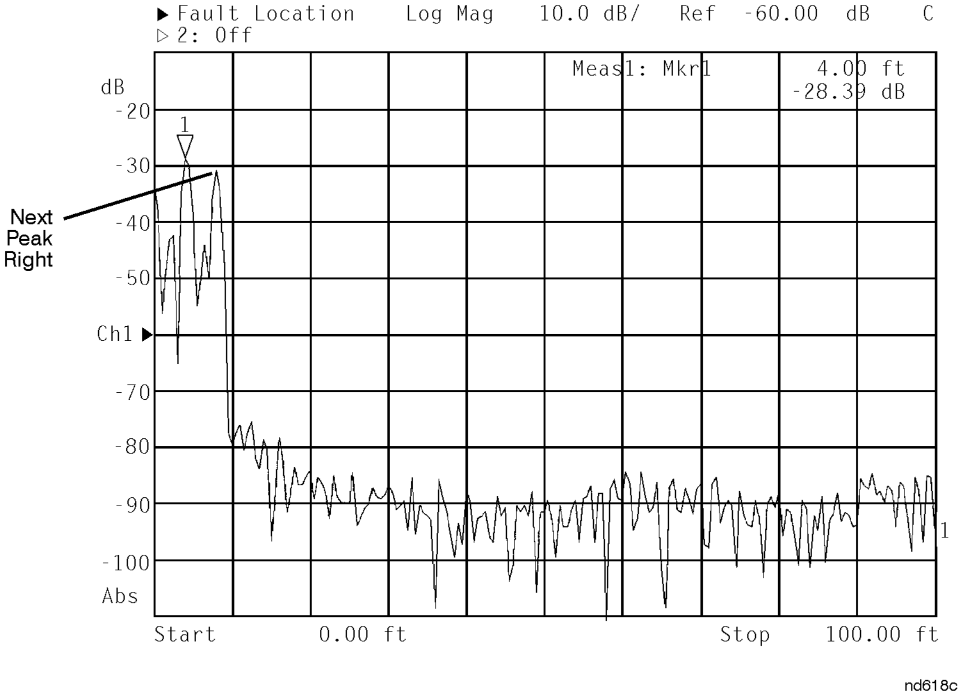


Using Markers to Find Peak Responses

Press (MARKER) **Marker Search** **Max Search** .

Marker number 1 will automatically be placed on the peak with the highest response. Refer to Figure 3-4. Notice that the display indicates that the response marked by marker number 1 is 4.000 feet from the RF OUT (or PORT 1) test port, and has a return loss of –28.39 dB. Knowing that we connected two four-foot cables together for this example, it can be determined that this discontinuity is created by the connection between the two cables.

Figure 3-4 **Interpreting Fault Location Measurements**



Press **Next Peak Right** . When this function is used, the active marker moves to the next highest peak to the right. If you were performing this example, you would notice that marker number 1 has now moved over to the peak indicated as "Next Peak Right" in Figure 3-4. You would also notice that the display would now indicate that the response marked by marker number 1 is 8.000 feet from the RF OUT (or PORT 1) test port. Knowing that we connected two four-foot cables for this example, it can be determined that this response is created by the termination at the end of the two cables.

See "Using Markers" in Chapter 4 of your analyzer's *User's Guide* for more information on using markers.

Using a Limit Line for Testing a Cable

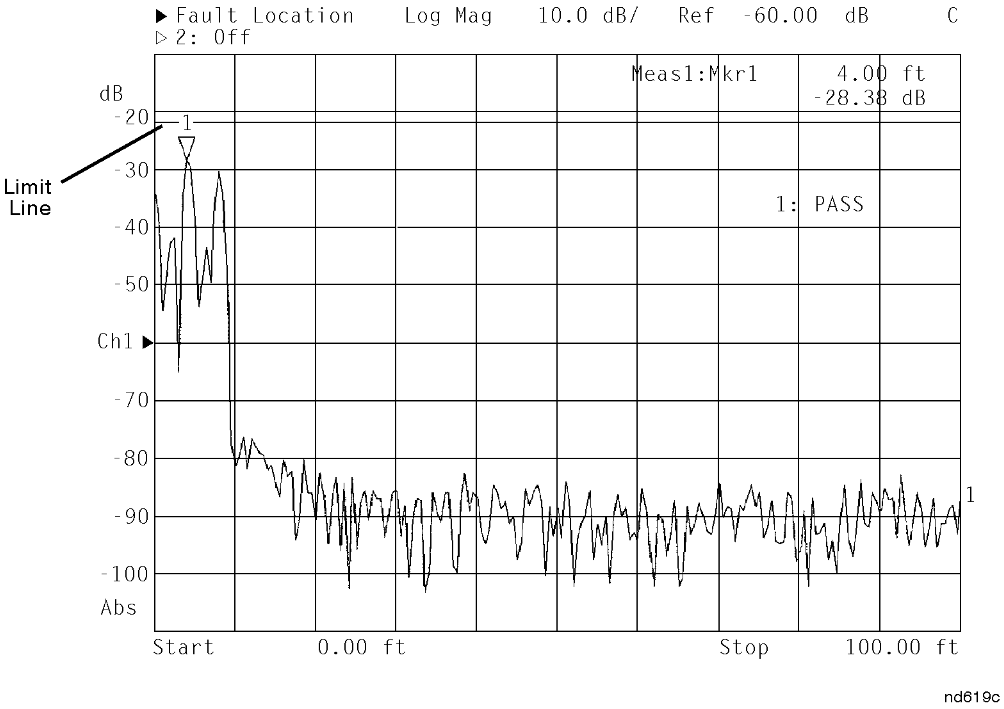
NOTE For more detailed information on using limit lines see “Using Limit Lines” in Chapter 4 of your analyzer's *User's Guide*.

In this example, we have a transmission line return loss specification of <–22 dB. To set the limit line to –22 dB, press DISPLAY **Limit Menu** **Add Limit** **Add Max Line** **Begin Limit** –22 ENTER **End Limit** –22 ENTER.

Press **Prior Menu** **Prior Menu** and turn limit testing on by pressing the **Limit Test on OFF** softkey until the word ON is in capital letters, indicating that limit testing is on.

Refer to Figure 3-5. Since all responses in this example fall below the test limit line, the display indicates PASS.

Figure 3-5 **Limit Line**



Press **Edit Limit** **Begin Limit** (–30) (ENTER) **End Limit** (–30) (ENTER).

In this example, setting the limit line to –30 dB return loss would cause the display to indicate `FAIL.` This is due to the response at 4 feet exceeding the –30 dB limit. In a real test situation, you could quickly and easily determine whether or not your cable meets your specification by correctly setting the limit line to your return loss specification and just looking for the PASS or `FAIL` indicator. With a failure you might want to activate a marker (or markers) to determine the magnitude and location of any out-of-specification responses.

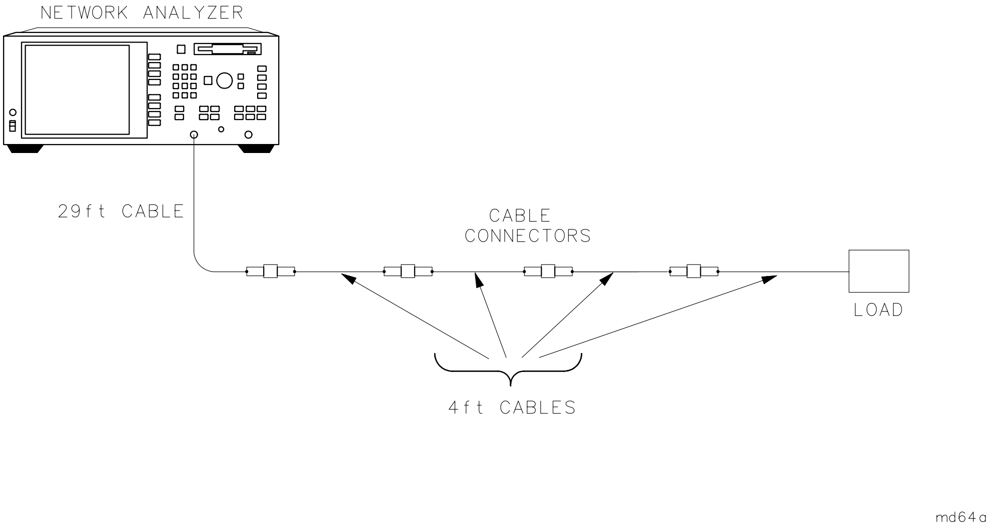
Example Fault Location Measurements

This section contains three measurement example displays with an explanation of the measurement results. These examples may be reproduced by using the test setup diagrams, procedures and explanations with each example.

Example 1: Identify Mismatches Expressed as Return Loss

1. Set up the equipment as shown in Figure 3-6.

Figure 3-6 **Example 1: Equipment Setup**

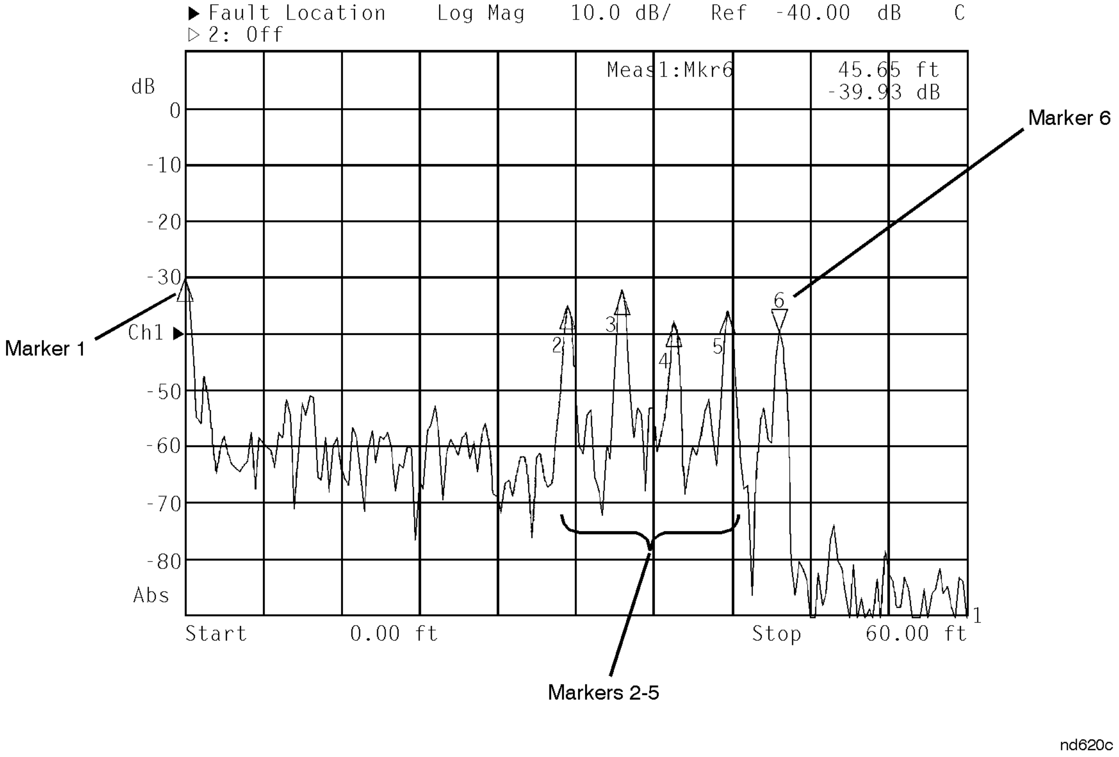


2. Press (PRESET) (BEGIN) **Cable** **Fault Location**.
3. Press **Stop Distance** (60) (ENTER).
4. Press (MARKER) and then use the front panel knob and/or up and down arrow keys to place marker 1 all the way to the left side of the display as in Figure 3-7.

5. Press **2:** to activate marker 2 and use the front panel knob, the up and down arrow keys, the **Next Peak Left**, or the **Next Peak Right** functions to place marker 2 on the next response as shown in Figure 3-7.
6. Repeat the previous step for markers 3 through 6.

In this example, the first marker displays the return loss at the cable connector. Markers 2, 3, 4, and 5 identify barrel connectors separated by 4 feet. Marker 6 identifies the 50 ohm termination.

Figure 3-7 **Example 1: Identify Mismatches Expressed as Return Loss**



Example 2: Identify Mismatches as the Magnitude of Reflection Coefficient

For this example, use the same equipment setup and steps to place markers on responses as instructed in example 1.

Press the following keys:

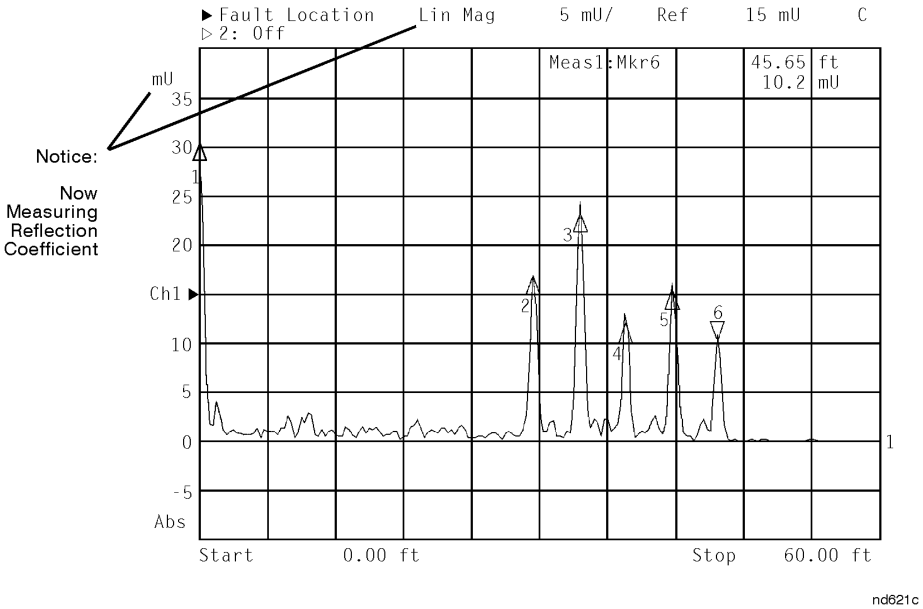
FORMAT **Lin Mag**

SCALE **Autoscale**

This example is very similar to example 1 except that the responses are measured in terms of reflection coefficient rather than return loss. **Autoscale** is used to optimize the viewing of the data trace within the display area.

As in example 1, the response designated by marker 1 identifies the cable connector. Markers 2, 3, 4, and 5 identify barrel connectors separated by 4 feet. Marker 6 identifies the 50 ohm termination.

Figure 3-8 **Example 2: Identify Mismatches as the Magnitude of Reflection Coefficient**



Notice:

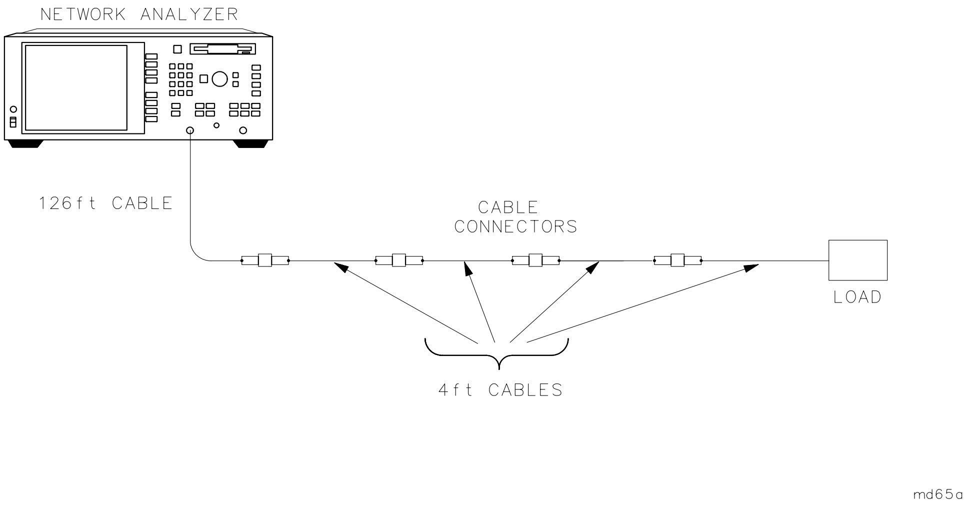
Now Measuring Reflection Coefficient

Example 3: Identify Mismatches at Greater Distances

In the previous two examples, we were dealing with relatively short lengths of cable (≈ 45 feet). In this example, a longer length cable is used.

1. Set up the equipment as shown in Figure 3-9.

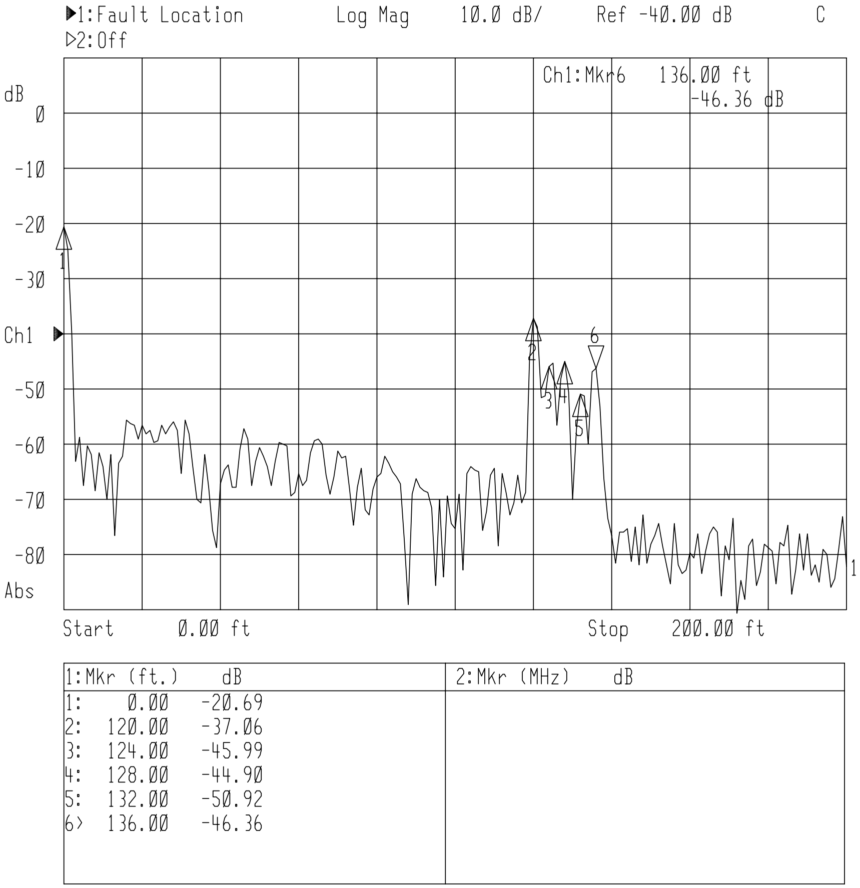
Figure 3-9 Example 3: Equipment Setup



2. Press (PRESET) (BEGIN) **Cable** **Fault Location** .
3. Enter a stop distance of 200 feet.
4. Enter a cable loss factor of 1.8 dB/100 feet by pressing (CAL) **Cable Loss** (1.8) (ENTER).
5. Use markers to identify the responses. See "Example 1: Identify Mismatches Expressed as Return Loss" on page 3-14 for details on how to place markers.

   The display should now look similar to Figure 3-10. (The marker table only appears on plots.)
6. At greater distance the resolution is decreased. In this example, marker 1 identifies the cable connector. Markers 2, 3, 4, and 5 identify barrel connectors. Marker 6 identifies a 50 ohm termination.

Figure 3-10 **Example 3: Identify Mismatches at Greater Distance**



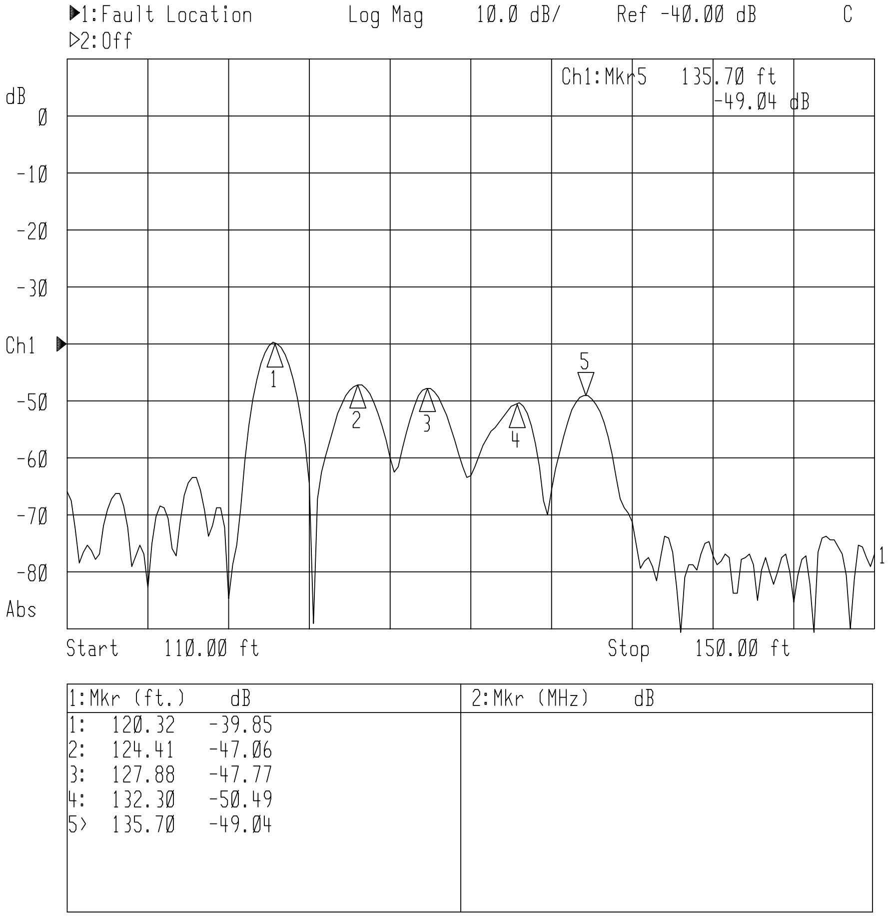
1:Mkr (ft.)	dB
1: 0.00	-20.69
2: 120.00	-37.06
3: 124.00	-45.99
4: 128.00	-44.90
5: 132.00	-50.92
6> 136.00	-46.36

2:Mkr (MHz)	dB

You can now change the **Stop Distance** and **Start Distance** (in the MENU **Distance** menu) to zoom in around the responses marked by markers 2 through 6. See Figure 3-11. (The marker table only appears on plots.)

Use the MARKER menu to place markers 1 through 5 on the peak responses. Marker 1 is the first connector. Marker 5 identifies the 50 ohm termination.

Figure 3-11 **Example 3: Zoom In on Suspected Mismatches**



```
▶1:Fault Location        Log Mag     10.0 dB/     Ref -40.00 dB        C
▷2:Off
                                           Ch1:Mkr5    135.70 ft
                                                       -49.04 dB
Start     110.00 ft                                Stop    150.00 ft
```

1:Mkr (ft.)	dB
1: 120.32	-39.85
2: 124.41	-47.06
3: 127.88	-47.77
4: 132.30	-50.49
5> 135.70	-49.04

2:Mkr (MHz)	dB

4 Making SRL Measurements

This chapter contains information on how to make and interpret SRL measurements.

NOTE Refer to "Cable Impedance and Structural Return Loss Measurement Theory" on page 1-6 for detailed information on how the analyzer measures cable impedance and structural return loss.

NOTE The procedures and illustrations in this manual assume the use of an Agilent Technologies 8712ET or 8714ET. If you are using an Agilent Technologies 8712ES or 8714ES, some key presses and displays will be slightly different.

How to Make and Interpret SRL Measurements

A typical SRL measurement consists of the following steps:

1. Select SRL as the type of measurement.
2. Calibrate the analyzer.
3. Connect the equipment.
4. Determine the connector model.
5. Perform the SRL cable scan.
6. Interpret the SRL measurement.

The next few pages explain how to perform each of these steps.

1. Select SRL as the Type of Measurement

To select SRL mode, press (PRESET) (BEGIN) **Cable** **SRL** .

NOTE The SRL Cable Scan function operates over a frenquency range of 5 MHz to 1000 MHz with 1601 measurement points. These values must be used for all SRL measurements.

2. Calibrate the Analyzer

When practical, a calibration should be done at the measurement reference plane using open, short, and load calibration standards. If calibration standards are not available, the default instrument calibration can be used.

NOTE Most SRL measurements are made using a test lead cable. If this is the case, the measurement reference plane would be the end of the test lead cable as shown in Figure 4-1. If you will be testing cables by connecting them directly to the analyzer's RF OUT (or PORT 1) test port, you should perform the calibration at the analyzer's port as shown in Figure 3-1 on page 3-8.

Using Calibration Standards to Calibrate the Instrument

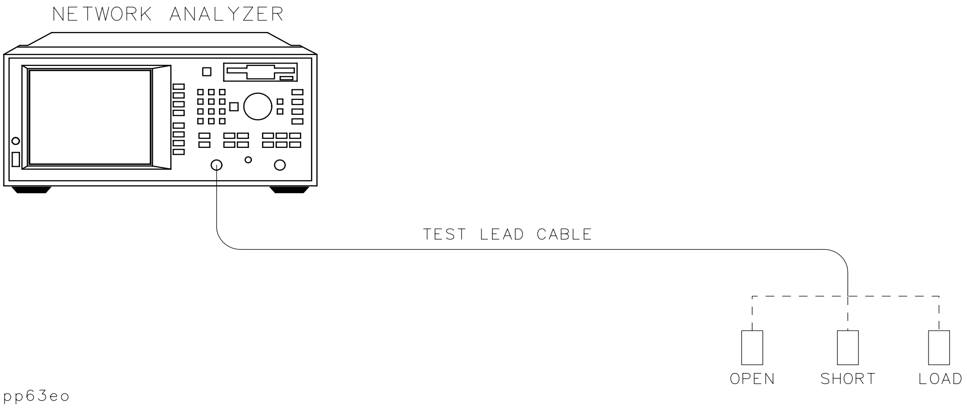
This calibration will correct for directivity, source match, and frequency response errors. Refer to “SRL Measurement Uncertainty vs System Directivity” on page 9-4 for more information.

To calibrate the instrument using calibration standards, perform the following steps:

1. If SRL is already selected as the type of measurement, press CAL **Full Band Cal**.
2. Follow the prompts on the analyzer's screen to connect the open, short and load to the measurement reference plane. (See Figure 4-1.)
3. After the calibration is complete, a C is displayed in the measurement channel annotation area in the upper right-hand corner of the analyzer's display. The C indicator is a visual verification that a full band (not instrument default) calibration is in use and has been completed properly.

NOTE A full band calibration is valid over the entire frequency range of the analyzer and is valid for any frequency setting.

Figure 4-1 **Calibrate the Instrument for an SRL Measurement**



Verifying the Calibration

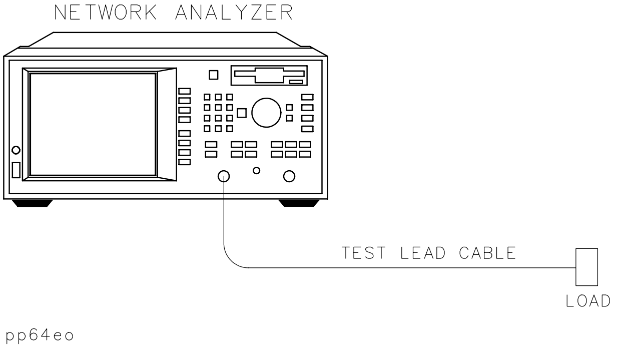
After calibrating, it is important to verify that the calibration is good. Always determine your system directivity and verify the quality of your test lead cable after performing a calibration.

When verifying the calibration and the quality of your test lead cable, you should look for a combination of good system directivity (<–50 dB, but acceptable up to –40 dB) and small variations in peak amplitudes (<10 dB) when the test lead cable is wiggled or moved.

Determine System Directivity.

1. Determine the system directivity by connecting the load standard to the end of the test lead cable as shown in Figure 4-2. (Or, if your reference plane is the analyzer's RF OUT (or PORT 1) test port, connect the load directly to that front panel connector.)

Figure 4-2 **Connect the Load**



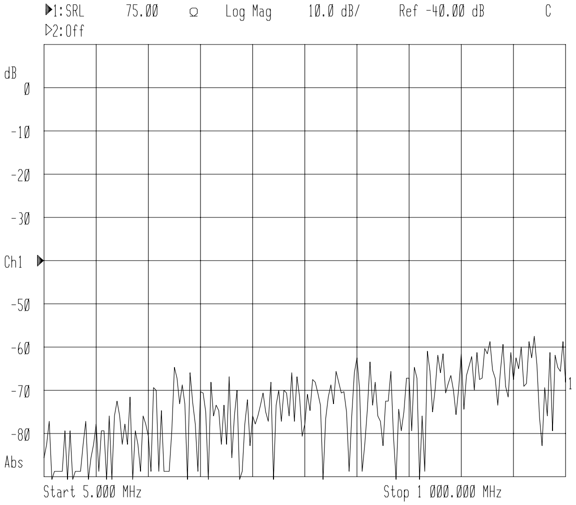
2. Observe the magnitude of the response on measurement channel 1. See Figure 4-3 for an example response. The highest peak response on channel 1 is the system directivity. If the peak response on channel 1 is <–50 dB, the calibration is good. If the peak response is >–40 dB, you should recalibrate the analyzer.

NOTE

Measurement quality is related to system directivity. For the highest quality measurements, system directivity should be <–50 dB, but measurement quality is acceptable up to –40 dB. See “SRL Measurement Uncertainty vs System Directivity” on page 9-4.

Also see “Measurement Uncertainties” on page 1-18.

Figure 4-3 **Determine System Directivity**



Determine the Quality of the Test Lead Cable.

1. Leave the load connected to the end of the test lead cable and note the level of the peak response on measurement channel 1 (the system directivity).
2. Wiggle the test lead cable while observing the response on the analyzer's display.
    a. If the measurement trace is relatively stable, the test lead cable is of good quality.
    b. If you observe significant movement in the peaks of the measurement trace when wiggling the cable (>10 dB), the test lead cable may need to be replaced.

NOTE Variation in the system directivity that occurs as a result of test lead cable movement degrades the quality and repeatability of SRL measurements. Take precautions to protect your test lead cables from mishandling or abuse. Do not step on or drive vehicles over test lead cables.

Using the Default Calibration

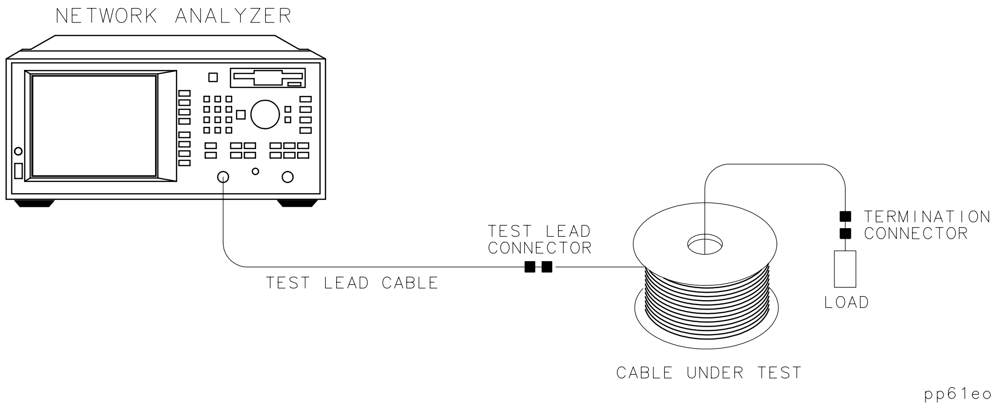
To use the instrument default calibration, press (CAL) **Default Cal**. (SRL must already be selected as the type of measurement.)

NOTE When the default cal is used, the “C” indicator does not appear on the display.

3. Connect the Equipment

The basic equipment setup for SRL measurements is illustrated in Figure 4-4.

Figure 4-4 **Basic SRL Measurement Setup**



You may want to verify that the sweep time is valid for the length of cable being measured. To verify the sweep time is correct, press (SWEEP) **Sweep Time**. Then use the front panel knob, the front panel arrow keys, or the numeric keypad to vary the sweep time. Choose the fastest sweep time that does not cause a change in the response.

4. Determine the Connector Model

After connecting the cable under test as shown in Figure 4-4, you should determine the connector model for the best response. The connector model may need to be determined each time a new cable is tested.

When using connectors that have very consistent interfaces, modeling the connector for each new connection to a cable may not be required. When using connectors that do not have a repeatable interface contact, modeling the connector for each new connection to a cable *is* necessary.

For some SRL measurements, the response of the connector can be critical for obtaining a true measurement of structural return loss. For example, a connector with a return loss of 30 dB will swamp out SRL responses less than about –20 dB. A connector with a 40 dB return loss will provide a more accurate measurement of the –20 dB responses.

Table 4-1 shows the effects of a connector mismatch on the measurement of a –35 dB SRL spike.

Table 4-1 **Measurement Results with Varying Connector Mismatches**

Corrected Connector Return Loss	SRL	Total Measured
–53 dB	–35 dB	–34 dB
–42 dB	–35 dB	–31.8 dB
–35 dB	–35 dB	–29 dB

As indicated by Table 4-1, the best true SRL measurement is made when the contribution of the connector is minimized by

- a good calibration (see “Verifying the Calibration” on page 4-5)
- a high-quality connector and connection (see Chapter 2, "Cable Preparation")
- a connector model which provides the lowest corrected connector response

The effects of the connector response can be minimized with the built-in connector model and the corrected connector response can be measured while the SRL measurement is being made. For some connectors, a response correction of up to 15 dB or more improvement is possible with the built-in connector model.

NOTE

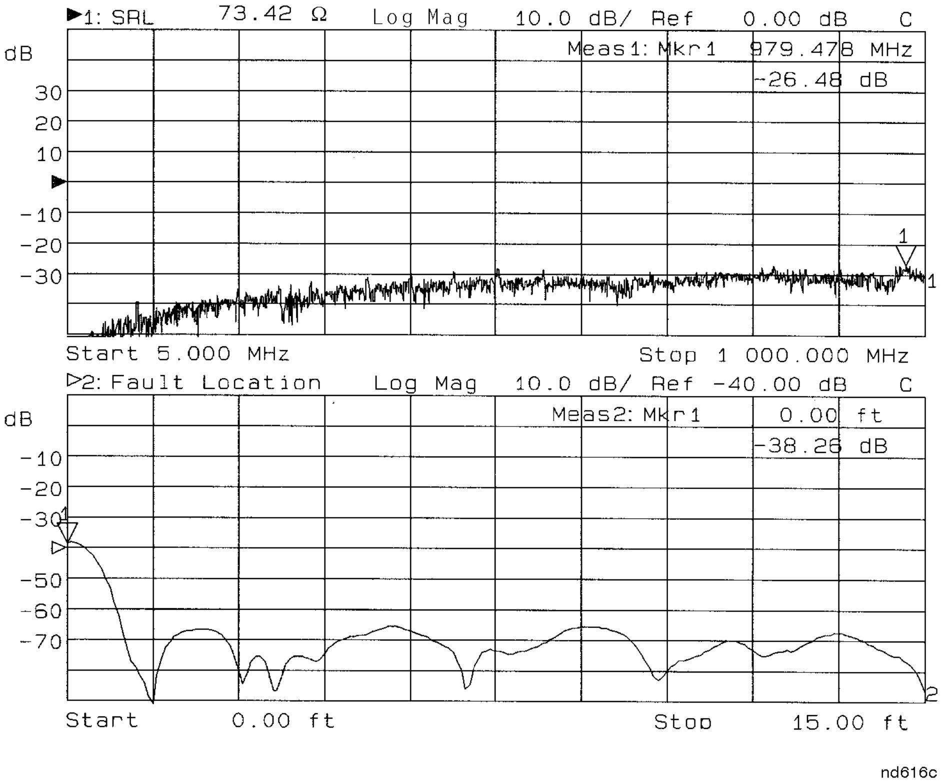
The maximum extent to which the effects of the connector response can be removed is to the accuracy and repeatability of the analyzer system (including the effects of test lead cable stability and quality). The accuracy of the system is given by the system directivity of the analyzer (which can be determined from the trace with a load connected after calibration).

For determining measurement uncertainty, use the value of the system directivity and the connector response. See “SRL Measurement Uncertainty vs Connector Fault” on page 9-8.

Connector Fault Display

After the calibration is completed, the test lead cable (if used) has been verified and the equipment is connected, display the connector response by selecting (BEGIN) **Cable** **SRL** **Connector Fault** . Fault location from 0.0 to 15.0 ft. will be displayed on the second measurement channel and a marker will be placed at 0.0 ft. The response of the connector is equal to the return loss read by the marker at a distance of 0.0 ft. See Figure 4-5.

Figure 4-5 **Connector Fault Display**



To enter the connector model menu, press **Connector Model** . As the following connector modeling procedures are performed, the **Connector Fault** display will allow you to monitor the connector response improvements.

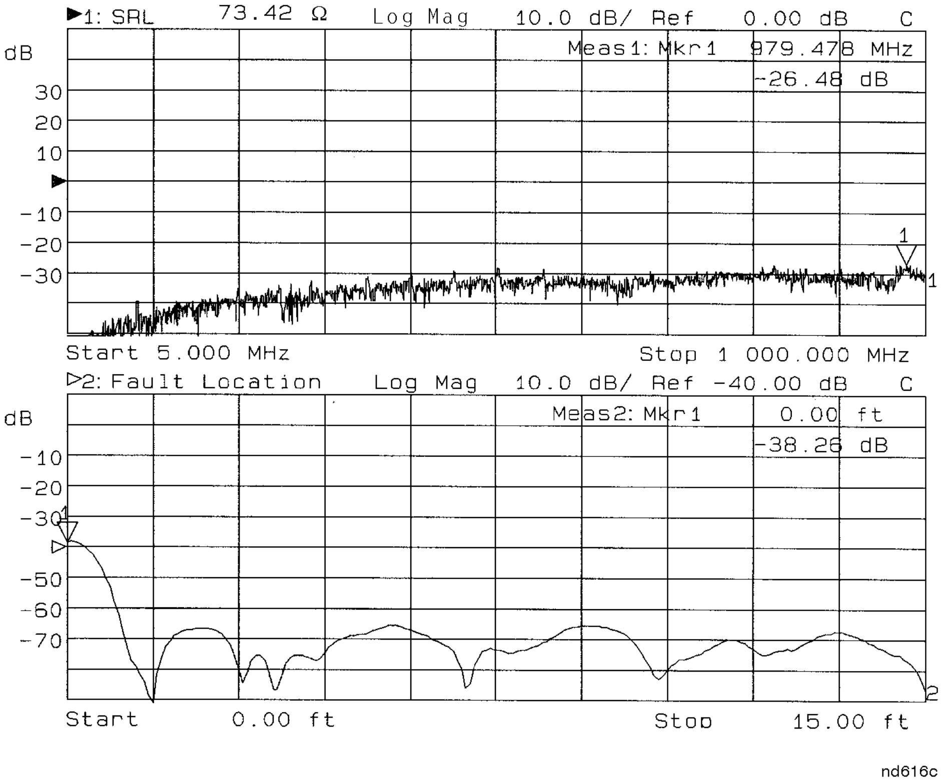
When the optimum connector response has been obtained, refer to "SRL Measurement Uncertainty vs Connector Fault" on page 9-8.

Connector Model for Long Cables

If a long cable is being measured, you can use the “Measure Connector” feature to automatically determine the L and C values. (A long cable is defined as approximately ≥300 m (1000 ft)).

1. Figure 4-6 shows an SRL and fault location response measurement with no connector model applied. The upward slope indicates the possibility that a poor quality or worn out connector is being used.

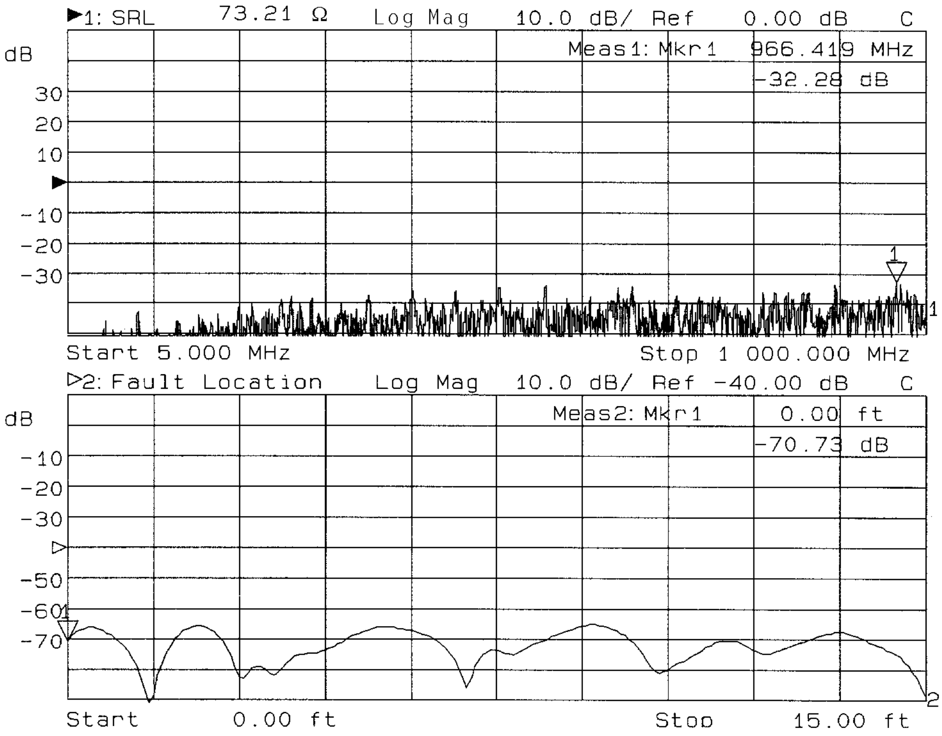
Figure 4-6 **SRL Response with a Poor Connector and No Connector Model Applied**



2. Press the **Measure Connector** softkey and follow the instructions on the analyzer's display.

3. The analyzer will automatically compute the optimum values of connector length and connector C, and then update the SRL and fault location response, as in Figure 4-7.

Figure 4-7 **SRL Response with a Poor Connector and Connector Model Applied**



nd617c

4. Note the improvement in the SRL and fault location response.

NOTE

The corrected connector response shown by marker 1 on the bottom trace of Figure 4-7 is –70.73 dB. This is well below the system directivity and indicates that the effects of the connector have been removed from the SRL response to the accuracy of the analyzer system.

5. The values used in this example to improve the response were:

L = 56.8 mm (2.24 in.)

C = –1.23 pF

Connector Model for Short Cables

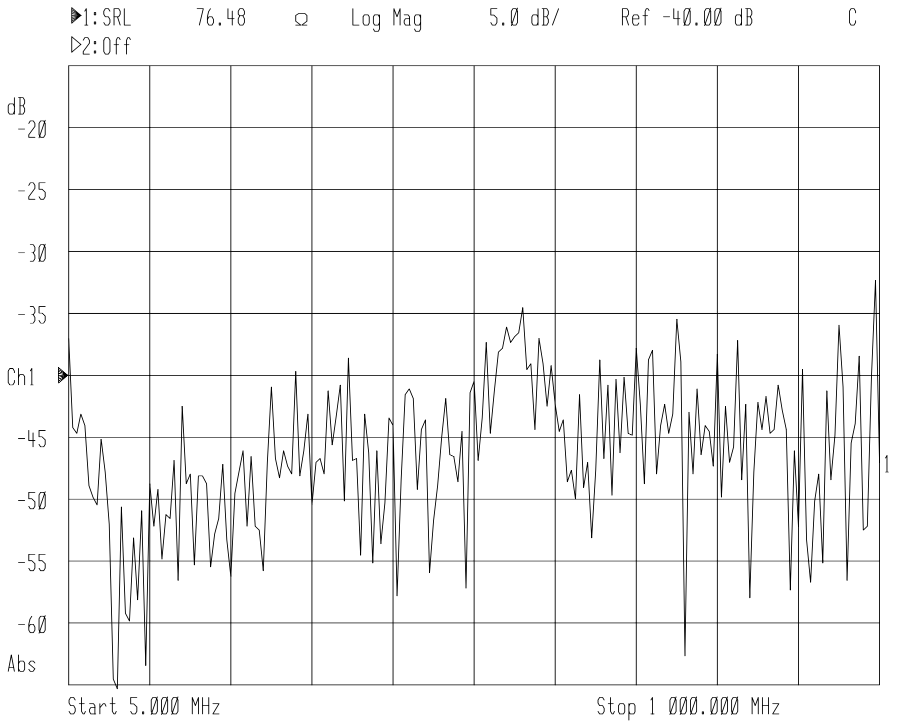
1. Turn off the connector fault display by pressing (DISPLAY) **More Display** **Split Disp FULL split** (MEAS 2) **Meas OFF**.
2. If you are measuring a short cable, or if you have very large mismatches in the cable under test, you may need to manually set the **Connector Length** (L) and **Connector C** (C).
3. Observe the SRL measurement trace while adjusting the connector length and C values for the best (lowest overall) response.
4. Some cables may be best measured by adjusting only the connector length, other cables may require a connector C adjustment, and some others may require a combination of connector length and C values.

NOTE When manually adjusting the connector length or connector C values, be sure to wait for the analyzer to complete a sweep and update the display before trying another value.

5. Use **Manual Z** to compensate for cables with large variations from the average cable impedance.
6. You may need to measure the connector using a Smith chart to get the best connector model:

   Press (FORMAT) **Smith Chart** to observe the SRL response. Observe the display while adjusting the connector C and connector length parameters. The best response is obtained when the Smith chart response has been most compacted by the connector C and connector length adjustments.
7. Figure 4-8 shows a typical SRL measurement response with a properly adjusted connector model. Compare this response to the sloping response of Figure 4-6.

Figure 4-8 **Typical SRL Measurement Response with Good Connector Model**



NOTE

If you cannot obtain a low enough response by adjusting the connector length and/or connector C values, you should perform a fault location measurement on the connector and the cable under test. (See Chapter 3, “Making Fault Location Measurements.”) Be sure to determine the quality of the connector being used; some cable connectors degrade rapidly with use. The response of a bad connector is often large enough to swamp out the response from cable SRL.

Connector L and C Values

Table 4-2 shows some typical values for two types of slip-on connectors for mainline cable:

Table 4-2 **Typical L and C Values**

Connector	L Value	C Value
GTC-700-TX-GHZ-N (“GHz”)	40 to 80 mm	0 to 0.15 pF
GTC-700-TX-N (“Pogo”)	–12 to 12 mm	0 to 0.125 pF

For the connectors in Table 4-2, use of values within these ranges should be optimum for the best corrected connector fault response and lowest SRL spikes. Values far outside this range usually indicate a bad calibration, a poor connector or connection, or a close-in cable fault which cannot be compensated by the connector model.

NOTE The optimum calculated value for the connector lengths of “Gilbert Pogo” connectors may be slightly negative. This is a *normal* value and should not be a cause for concern.

For type-F connectors, which are typically used to measure 75 ohm drop cable, the range of connector L and C values will vary widely and will depend greatly on the quality of the type-F connector.

5. Perform the SRL Cable Scan

Once the connector model has been established for the best response, the cable should be scanned at narrow frequency resolution to look for narrow response spikes that are characteristic of periodic defects in the cable. The SRL cable scan is required to determine the cable's SRL with 125 kHz resolution.

By taking five sweeps of 1601 points each at slightly different frequency ranges (see Table 4-3 on page 4-17), the analyzer can obtain 8005 distinct frequency points to achieve the desired frequency resolution of 125 kHz.

The resolution of the SRL measurement is determined by the following formula:

$$Resolution = \frac{F_{stop} - F_{start}}{N}$$

where N is the number of measurement points. See the table below.

	F_{start}	F_{stop}	**N**	**Resolution**
No Cable Scan	5 MHz	1000 MHz	201	4.95 MHz
	5 MHz	1000 MHz	1601	612 kHz
Using Cable Scan	**5 MHz**	**1000 MHz**	**8005**	**125 kHz**

1. With the cable under test still connected as shown in Figure 4-4, press (BEGIN) **Cable** **SRL** **SRL Cable Scan** .
2. The analyzer first displays a pop up message that says: `Setting up SRL Cable Scan`.... The message `Scanning Cable`... appears while the scan is in process.
3. Pressing any key will abort the scan.

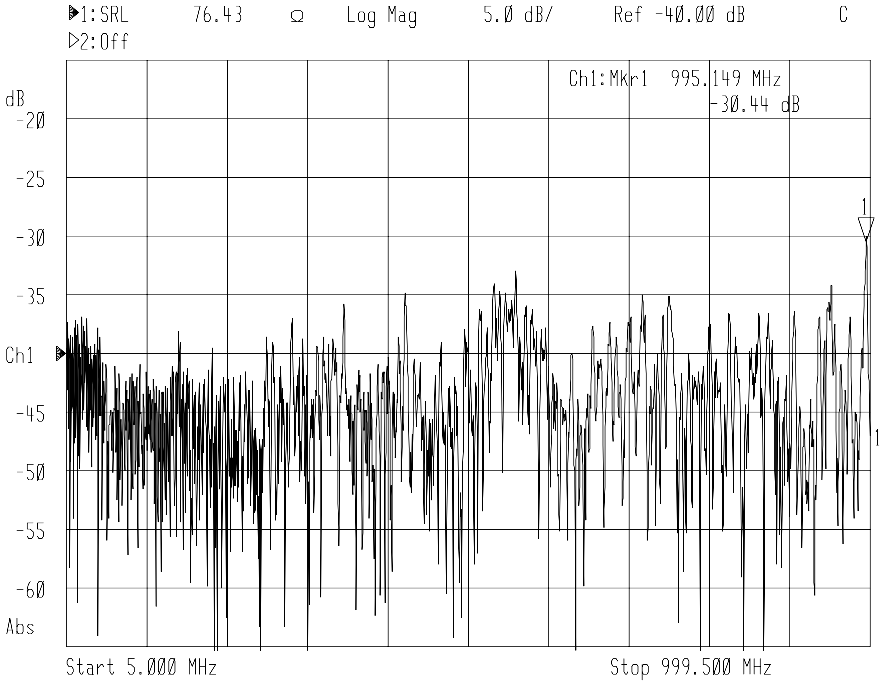
4. During the cable scan, the analyzer takes five sweeps of the cable at the following frequencies:

Table 4-3 **SRL Cable Scan Frequency Sweeps**

Sweep Number	Start Frequency (MHz)	Stop Frequency (MHz)
1	5.000	999.500
2	5.125	999.625
3	5.250	999.750
4	5.375	999.875
5	5.500	1000.000

5. After the last sweep, the analyzer then displays the worst-case response among the five sweeps.
6. Note that the measured impedance is displayed at the top of the analyzer's display area (see Figure 4-9).
7. You can use a limit line to quickly see if your cable has passed or failed your SRL specifications. For an example of how to set a limit line, see “5. Interpret the Measurement” on page 3-10. For more detailed information, see “Using Limit Lines” in Chapter 4 of your analyzer’s *User's Guide*.
8. Press (MARKER) **Marker Search** **Max Search** to pinpoint the worst case SRL response of the cable under test.
9. Figure 4-9 shows a typical SRL cable scan measurement response.

Figure 4-9 **Typical SRL Cable Scan Response**



10. To remeasure the cable, or to measure a new one, press (BEGIN) **Cable** **SRL** **SRL Cable Scan**. It may be desirable to reverify the quality of the calibration before measuring a new cable.

6. Interpret the SRL Measurement

Periodically spaced SRL response bumps will cause frequency spikes at a frequency given by the following formulas:

$$wavelength \approx \frac{c}{f}$$

$c = \text{speed of light}$ $\qquad f = \text{frequency}$

$$\frac{wavelength}{2} = \text{spacing between the bumps}$$

The bumps may be located near one end of the cable or somewhere in the middle. Although the bumps from individual defects may be small, fault location measurements may be useful to determine the location(s) of the cable's defect(s).

See Chapter 5, "Making Simultaneous Fault Location and SRL Measurements" for information on how to perform SRL and fault location measurements simultaneously.

See “SRL and Periodic Cable Faults” on page 1-10 for more information.

5

Making Simultaneous Fault Location and SRL Measurements

Fault location and SRL measurements can be made simultaneously and viewed together by taking advantage of the analyzer's split display feature. By making these two measurements simultaneously, both large single faults (identified by fault location measurements) and small periodic imperfections (identified by SRL measurements) can be viewed at the same time, making the overall results easier to interpret.

Refer to Figure 5-1. The magnitude of the connector response (marker 1 in measurement channel 1) appears to be about –40 dB. A connector response <–40 dB indicates that the connector being used for this measurement is relatively good.

A connector response of >–40 dB indicates that the measurement could be improved either by compensating for the connector with appropriate connector model parameters or by replacing the connector.

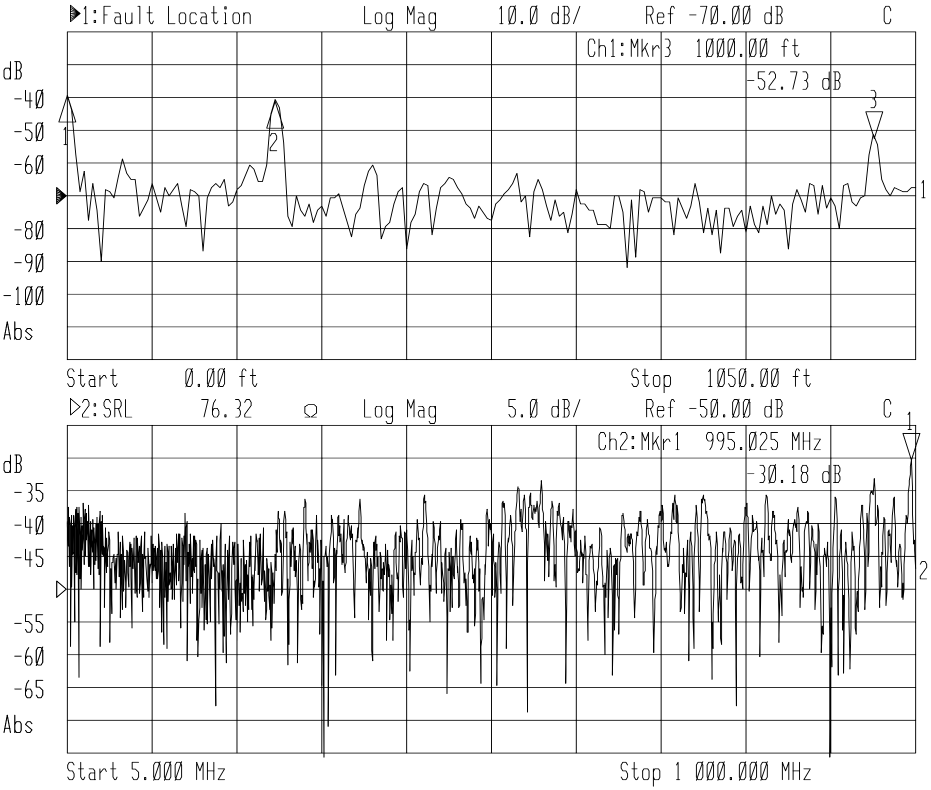
Marker 2 on measurement channel 1 indicates an additional –40 dB response at about 250 feet. Marker 3 indicates the load termination at the end of the cable.

A true SRL spike can be observed at marker 1 on measurement channel 2 at 995.025 MHz.

NOTE To view the close-in connector response, use the “Connector Fault” feature which also uses the analyzer's split display. See “4. Determine the Connector Model” on page 4-8.

NOTE The procedures and illustrations in this manual assume the use of an Agilent Technologies 8712ET or 8714ET. If you are using an Agilent Technologies 8712ES or 8714ES, some key presses and displays will be slightly different.

Figure 5-1 **Simultaneous Measurements**



How to Make Simultaneous Measurements

To measure and view fault location and SRL simultaneously, perform the following steps:

1. Select measurement channel 1 by pressing (PRESET) (MEAS 1), and then do the following:
    a. Select fault location as the type of measurement.
    b. Enter the measurement parameters.
    c. Calibrate for a fault location measurement.
    d. Enter any other features desired, such as limit lines.

    (See "How to Make and Interpret Fault Location Measurements" on page 3-3 for detailed instructions.)

2. Press (MEAS 2), and do the following:
    a. Select SRL as the type of measurement.
    b. Enter the measurement parameters.
    c. Calibrate for an SRL measurement.
    d. Enter any other features desired, such as limit lines.

    (See "How to Make and Interpret SRL Measurements" on page 4-3 for detailed instructions.)

3. Connect the cable to be tested.
4. Press (DISPLAY) **More Display** **Split Disp FULL split** to invoke the split display feature. The top half of the display will now be showing the fault location measurement on measurement channel 1, while the bottom half of the display will be showing the SRL measurement on measurement channel 2.
5. Most all analyzer features and parameters can be independently set for each measurement channel. Be sure to select (MEAS 1) before entering parameters or invoking features for your fault location measurement, and (MEAS 2) before entering parameters or invoking features for your SRL measurement.

6

Making Impedance Measurements

The impedance of a cable under test can be displayed by selecting FORMAT **More Format** **Impedance Magnitude** . The impedance can be displayed versus distance (for fault location measurements), or versus frequency (for reflection measurements).

The measured reflection coefficient is used to compute the impedance. The analyzer uses the formula

$$Z = Z_{sys} \cdot \left| \frac{(1+\Gamma)}{(1-\Gamma)} \right|$$

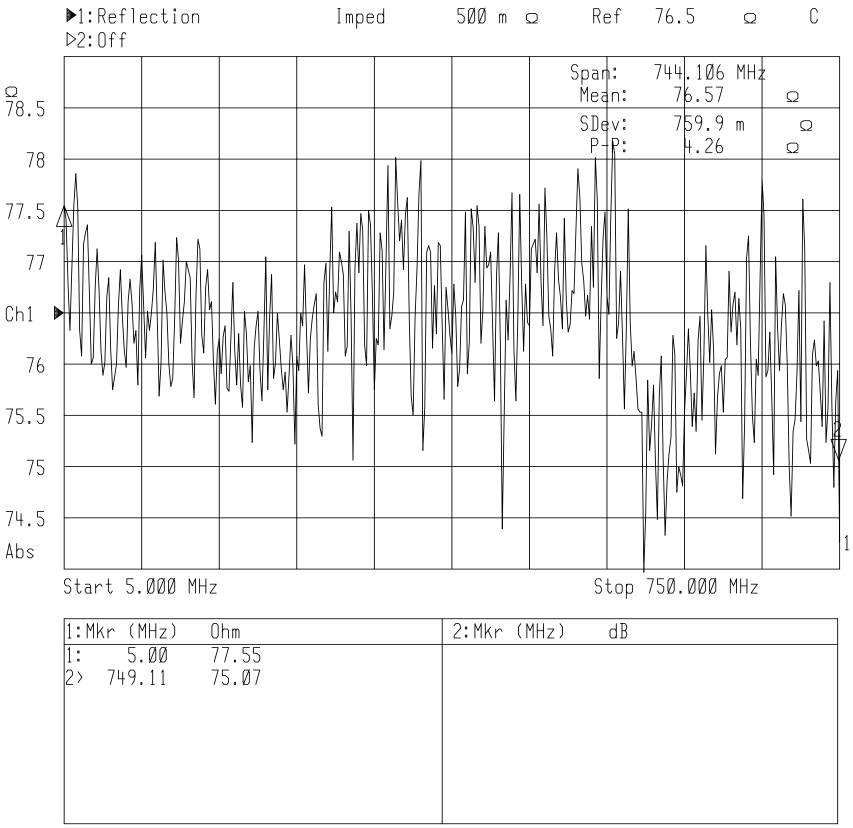
where Γ *= measured complex reflection coefficient and*
where Z_{sys} *= 50 or 75* Ω

When the complex reflection coefficient, Γ, is zero, there are no reflections and the cable under test will be exactly the same impedance as the system impedance, Z_{sys}.

NOTE

The procedures and illustrations in this manual assume the use of an Agilent Technologies 8712ET or 8714ET. If you are using an Agilent Technologies 8712ES or 8714ES, some key presses and displays will be slightly different.

Figure 6-1 Impedance Measurement Example



```
1:Mkr (MHz)   Ohm          2:Mkr (MHz)    dB
1:    5.00    77.55
2>  749.11    75.07
```

How to Make Impedance Measurements

For an example, refer to Figure 6-1. Notice the average impedance of the cable under test is 76.57 Ω. The peak-to-peak deviation in the cable impedance is 4.26 Ω.

A typical cable impedance measurement consists of the following steps:

1. Select reflection as the type of measurement
   a. Press (MEAS 1) **Reflection** (or **S11 Refl Port 1**).
2. Enter the measurement parameters:
   a. Enter frequency and any other appropriate parameters.
3. Calibrate for a reflection measurement:
   a. Press (CAL) **1-Port** (or **User 1-Port**) and follow the prompts to calibrate at the measurement reference plane.
4. Select the marker statistics function:
   a. Press (MARKER) **Marker Functions** **Marker Math** **Statistics**.
   b. Set markers 1 and 2 to define the frequency range of interest. (See Chapter 4 of your analyzer's *User's Guide* for more information on the marker statistics function.)
5. Connect the cable under test and view the results.

7

Characterizing and Verifying Antenna Systems

Fault location measurements are needed to verify and characterize antenna systems.

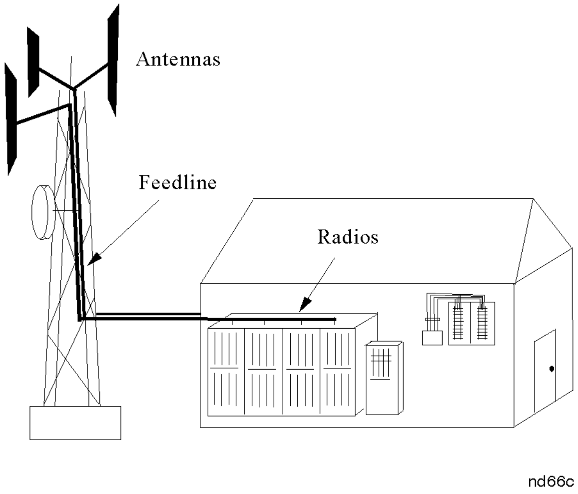
This chapter provides an introduction to the antenna feedline system, including the potential problems that may occur. Typical measurements used to characterize these antenna systems are also described. In conclusion, an installation and maintenance plan that can be used to verify the performance of the antenna system is presented.

This chapter contains the following information:

- antenna feedline system
- potential problems
- typical measurements
- installation and maintenance planning

Antenna Feedline System

Figure 7-1 **Typical Cell Site**



A typical cell site contains many pieces of hardware. These may include, but are not limited to:

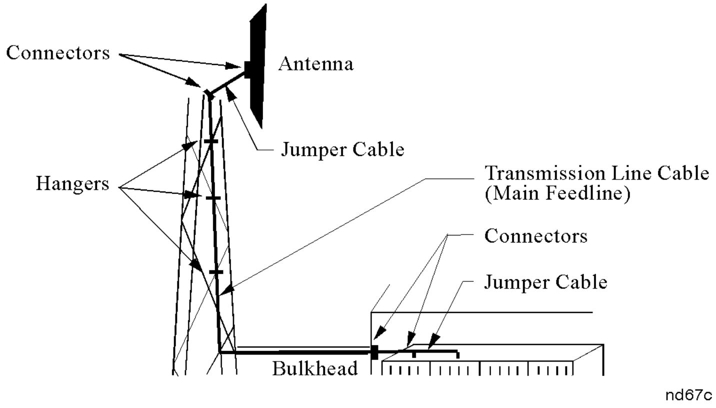
- racks of radios
- combiners
- coaxial feedline
- tower-mounted amplifiers
- lightning protection devices
- filters
- antennas

These may operate at multiple cellular, personal communication system (PCS), and microwave frequencies.

The components of the cell site that lie between the transmitting/receiving ports (radios) up to and including the antenna are commonly referred to as the “antenna system.” Those components between the antenna and the radio ports are referred to as the “antenna feedline system.”

Evaluating the quality of the components within the antenna feedline system is of utmost importance in today's communication systems. For example, the attenuation of the transmission lines, along with the insertion loss of the combiner, determines the majority of loss that occurs in the transmitting portion of the antenna system. Any imperfections or damage to this feedline can severely impact the transmission quality of the entire system.

Figure 7-2 **Antenna Feedline System**



The antenna system assembly consists of:

- main feedline and jumper cables (coaxial or waveguide)
- connectors or flanges
- hangers
- antenna

It is important to understand the effect the feedline assembly has on the entire system to help avoid intermittent problems and failures.

Knowing performance parameters such as feedline loss is especially critical when operating in the 800 to 900 MHz and 1.8 to 2.0 GHz frequency ranges. At these frequencies, the wavelength is very short and suffers greater propagation attenuation than the longer wavelength signals of lower frequencies. Thus, the system performance, in terms of the power transferred from the transmitter to the antenna, and from the antenna to the receiver, is characterized by the antenna feedline.

Potential Problems

Antenna feedline systems are typically the most common sources of failure in a communication system. The problems associated with these systems can be hard to identify and, once found, are usually located high on a tower. With the right test equipment, identifying and isolating problems becomes very easy, and can be done at ground level.

Transmission Lines/Antennas

The following problems may occur with transmission lines or antennas:

- weather damage
    - –lightning
    - –moisture
    - –corrosion
- vandalism
- cable discontinuities
- pinched cables

The transmission lines are exposed to all sorts of weather conditions which cause damage by mechanical stress, lightning, moisture, and corrosive atmospheres. Towers make good targets for vandals, as a very common cause of failure is created by bullet holes in the cables or antennas. Other common problems in the feedlines or antennas include discontinuities such as damaged junctions or support bends, and pinched cables caused by over-tightened hangers, or accidental denting by tower climbers.

Connectors

The following conditions may cause problems with connectors:

- low quality connectors
- poor connector contact
- moisture
- corrosion

Connectors present a great potential for problems, since moisture will invariably find its way inside. Normal atmospheric pressure changes will always equalize unless the system is deliberately pressurized. Low quality connectors, poor connector contact, corroded connectors, and improperly tightened or loose connectors are examples of critical fault conditions. Over time, these conditions can cause degradation or complete system failure.

Typical Measurements

The following typical measurements are used to characterize the antenna feedline system and help identify problems:

- Before installation—*incoming inspection*
  - –cable return loss
  - –characteristic impedance
  - –velocity factor
- Installation—*baseline tests*
  - –insertion loss
  - –antenna return loss (SWR)
  - –feedline system return loss (SWR)
  - –fault location
  - –length
- Maintenance—*compare to baseline*
  - –antenna return loss (SWR)
  - –feedline system return loss (SWR)
  - –fault location

NOTE

To reduce interference when performing return loss and fault location measurements, reduce the system IF bandwidth by pressing AVG **System Bandwidth** **Narrow 250 Hz**. To further reduce interference when performing fault location measurements, use the bandpass mode.

1. To turn on the bandpass mode, press BEGIN **Cable** **Fault Location** **Band Pass**.
2. To enter the center frequency, press **Center Frequency** 900 **MHz** ENTER.
3. To set the frequency span, press FREQ **Fault Loc Frequency** **Band Pass Max Span** 300 **MHz** ENTER.

Before Installation

Before installation, ensuring specified performance with incoming inspection can save hours of needless disassembly and reassembly of the cell site's antenna system. Important characteristics at this stage include cable return loss, characteristic impedance, and velocity factor.

Installation

At installation, it is necessary to do a complete set of tests on the antenna feedline system in order to fully characterize its initial performance. During assembly, return loss is usually measured after the addition of each component. Once assembly is complete, tests such as insertion loss, feedline system return loss, fault location and length are done. For characterization of the antenna, independent of the contributions made by the feed system, an important parameter is antenna return loss.

A significant property of an antenna is the propagation characteristics that result in antenna patterns. Many of the measured properties of the overall antenna system (which are determined at installation) are good indicators of whether or not the antenna pattern has been altered. Typically, this condition is confirmed from data collected by drive tests that define the cell site “foot print.”

The ability to save the measurement data taken at installation for a baseline is very important. This allows you to compare the original data with future measurement results, making problem detection and troubleshooting much easier.

Maintenance

Routine maintenance allows early detection of problems or trends, thus avoiding costly system shutdowns. However, when service must be interrupted, the outage can be minimized with rapid diagnostic procedures. The frequency with which routine maintenance is performed varies widely. But on average, it is done every six months. This is often done by the service provider, or may be contracted out to an independent group. Maintenance tests are typically limited to return loss and fault location, the two key indicators of the antenna feedline's integrity.

Installation and Maintenance Planning

Installation and maintenance planning is used to verify the performance of the antenna system. The following tables can be used to enter test results along with the specified limits and pass/fail margins. This allows for quick monitoring and recording of the antenna system's performance.

Table 7-1 **Incoming Inspection**

Characteristic	Limit/Spec	Test Result	Date/Time
Cable attenuation at 900 MHz (dB/100 ft.)			
Characteristic impedance			
Velocity factor			

Table 7-2 **Installation**

Characteristic	Limit/Spec	Test Result	Date/Time
Insertion loss			
Cable attenuation (dB/100 ft.)			
System return loss (dB)			
Cable length (ft.)			
Connector loss (fault loc., dB)			

Table 7-3 **Maintenance**

Characteristic	Pass/Fail Margin	Test Result	Date/Time
System return loss (dB)			
Connector loss (fault loc., dB)			

As described, the tests are typically divided into three categories:

1. *Incoming inspection*, which includes those tests done on the cable components before assembly to verify specified performance.
2. *Installation measurements*, which allow you to verify system integrity as well as record baseline data.
3. *Maintenance.*

The limits and pass/fail margins are useful for monitoring potential problems. A “fail” condition during maintenance may require immediate repair. By monitoring the “margin” of a pass condition, replacement before failure can be planned.

8 Key Reference

This chapter contains an alphabetical reference of the keys that are specific to fault location and SRL measurements. It also contains entries for some of the standard operation keys that are likely to be used while making fault location and SRL measurements. For a complete reference of standard operation keys, see your analyzer's *User's Guide*.

Alphabetical Key Reference

1:-8:	Markers number one through eight in the MARKER menu. Pressing any one of these softkeys makes the marker the active marker and (if previously off) turns it on. **>** in front of the marker number means the marker is the active marker. **:** means the marker is not the active marker; it may be on or off. See “Using Markers” in Chapter 4 of your analyzer's *User's Guide* for more information on using markers, including an explanation of “active marker.”
Add Limit	Softkey in limit menu. Displays menu to add limit lines or points to the limit table. See “Using Limit Lines” in Chapter 4 of your analyzer's *User's Guide* for detailed information on using limit lines. Access Keys: DISPLAY **Limit Menu**
Add Max Line	Softkey in add limit menu. Displays menu to add a maximum limit line. See “Using Limit Lines” in Chapter 4 of your analyzer's *User's Guide* for detailed information on using limit lines. Access Keys: DISPLAY **Limit Menu** **Add Limit**
Add Max Point	Softkey in add limit menu. Displays menu to add a maximum limit point. See “Using Limit Lines” in Chapter 4 of your analyzer's *User's Guide* for detailed information on using limit lines. Access Keys: DISPLAY **Limit Menu** **Add Limit**

Add Min Line	Softkey in add limit menu. Displays menu to add a minimum limit line. See “Using Limit Lines” in Chapter 4 of your analyzer's *User's Guide* for detailed information on using limit lines. Access Keys: DISPLAY **Limit Menu** **Add Limit**
Add Min Point	Softkey in add limit menu. Displays menu to add a minimum limit point. See “Using Limit Lines” in Chapter 4 of your analyzer's *User's Guide* for detailed information on using limit lines. Access Keys: DISPLAY **Limit Menu** **Add Limit**
All Off	Softkey in the MARKER menu that turns off all of the markers, the delta marker, and marker tracking on the active measurement channel. See “Using Markers” in Chapter 4 of your analyzer's *User's Guide* for detailed information on using markers.
Auto Z ON off	Softkey in the connector model menu. This softkey is used to toggle the SRL measurement automatic impedance function on or off. The analyzer can either automatically compute the impedance on each sweep (auto Z = ON), or use a value that you have entered (auto Z = OFF). The value of Z is displayed at the top of the measurement display. (See Figure 4-9 on page 4-18.) Access Keys: BEGIN **Cable** **SRL** **Connector Model** *or* CAL **Connector Model** (You must already be in SRL measurement mode to access the connector model menu via the CAL key.)
Autoscale	Softkey in SCALE menu. Scales the data trace vertically to fit within the graticule area of the display.

Average Factor	Softkey in AVG menu. Enters the averaging factor (number) in powers of 2. Acceptable values are: 1, 2, 4, 8, 16, 32, and 64. The default averaging factor is 16, the maximum is 64. See AVG, later in this section, for more information on how averaging works.
Average on OFF	Softkey in AVG menu. Toggles the averaging function on and off. Averaging reduces random noise by averaging the measurement data from sweep to sweep. See AVG, later in this section, for more information on how averaging works.
AVG	Hardkey in the CONFIGURE area. Displays the menu that allows selection of averaging parameters as well as fault window selections. Averaging reduces random noise by averaging the measurement data from sweep to sweep. In averaging mode, the analyzer measures each frequency point once per sweep and averages the current and previous trace up to the averaging factor (or number) specified by the user. The analyzer computes each data point based on an exponential average of consecutive sweeps weighted by a user-specified averaging factor. **NOTE** Averaging is performed on the frequency domain only. The distance domain is not averaged.
Band Pass	Softkey in the fault location and fault loc frequency menus. When band pass is selected, you will designate the center frequency, and start and stop distance parameters for your fault location measurement. The analyzer will determine the correct frequency span for your measurement. See "Start/Stop Distance and Frequency Span Explanation" on page 1-5 for more information. Access Keys: BEGIN **Cable** **Fault Location** *or* FREQ **Fault Loc Frequency**

Band Pass Max Span	Softkey in the fault loc frequency menu. Used in fault location measurements to limit the frequency bandwidth where out-of-band responses may interfere. Access Keys: FREQ **Fault Loc Frequency**
BEGIN	Hardkey to left of disk drive. The BEGIN key is the best place to start making cable measurements.
Begin Distance	Softkey used to define a limit line when in fault location measurement mode. See "5. Interpret the Measurement" on page 3-10 of this book; or see "Using Limit Lines" in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: DISPLAY **Limit Menu** **Add Limit** **Add Max Line** / **Add Min Line**
Begin Frequency	Softkey used to define a limit line. See "Using Limit Lines" in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: DISPLAY **Limit Menu** **Add Limit** **Add Max Line** / **Add Min Line**
Begin Limit	Softkey used to define a limit line. See "Using Limit Lines" in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: DISPLAY **Limit Menu** **Add Limit** **Add Max Line** / **Add Min Line**
Cable	Softkey in the BEGIN menu. Displays a menu of measurements suitable for cable measurements: reflection, fault location, SRL, and transmission.

Cable Loss	Softkey in the fault cal menu. This function allows you to enter a new cable loss factor. Cable loss is one of the two required parameters for cable calibration. The cable loss of your cable may be imprinted on the cable. If not, you may refer to Appendix A for some typical values. **CAUTION** The values in Appendix A are typical only. Different manufacturers' cables may vary significantly from the table values. Access Keys: BEGIN **Cable** **Fault Location** CAL *or* CAL (You must already be in fault location measurement mode to access the **Cable Loss** softkey via the CAL key.)
CAL	Hardkey in the CONFIGURE area. Displays the calibration menu. The selections available in the calibration menu change depending on the measurement mode selected.

Calibrate Cable	Softkey in fault cal menu. This function lets you measure a known length of cable and automatically figures cable loss and velocity factors. An alternative to entering the velocity factor and cable loss of your cable is to use the algorithm built into the analyzer to determine these values automatically. To use this function, you need a known length of cable of the same type being measured. The cable should be at least 30 feet (or 10 meters) long. When this softkey is pressed, you will be prompted to enter the length of your cable (with the **Specify Length** softkey) and then to connect it, leaving the free end an open circuit. When the **Measure Cable** softkey is pressed, the analyzer will determine values for velocity factor and cable loss based on the known distance down the line where the open circuit appears. **NOTE** Cable loss is nonlinear with frequency. Therefore, the apparent loss per 100 feet will change as the frequency range is changed. Velocity factor is also somewhat frequency dependent. You may wish to re-examine these values as the frequency limits are changed. Access Keys: BEGIN **Cable** **Fault Location** CAL *or* CAL (You must already be in fault location measurement mode to access the **Calibrate Cable** softkey via the CAL key.)

Center Frequency	Softkey in the fault location menu. Available only when **Band Pass** is selected. When this softkey is pressed, you will be prompted to enter a new center frequency. You can retain the current center frequency if you wish by just pressing (ENTER). The analyzer will select the proper frequency span for your measurement. The center frequency should be set within the operating frequency bandwidth of the transmission line being tested. The center frequency can only be set to a value which will not result in the source going beyond its frequency limits. See "Start/Stop Distance and Frequency Span Explanation" on page 1-5 for an explanation of how the analyzer determines the frequency span. Access Keys: (BEGIN) **Cable** **Fault Location**
Connector C	Softkey in the connector model menu. This softkey is available only while in SRL measurement mode. The connectors used to interface to the cable under test are not ideal and can have some mismatch. This effect can usually be canceled out by entering a small value of capacitance using the **Connector C** softkey. The typical value of compensating capacitance (if needed) is –0.1 pF. Access Keys: (BEGIN) **Cable** **SRL** **Connector Model** *or* (CAL) **Connector Model** (You must already be in SRL measurement mode to access the connector model menu via the (CAL) key.)

Connector Fault	Softkey in the SRL and SRL cal menus. Use this key to display the connector response on both measurement channels 1 and 2 with a full display. This key causes an SRL measurement on measurement channel 1 and a fault location measurement from 0.0 to 15.0 ft. on measurement channel 2. Access Keys: BEGIN **Cable** **SRL** *or* CAL (You must already be in SRL measurement mode to access the **Connector Fault** softkey via the CAL key.)
Connector Length	Softkey in the connector model menu. Use this key to enter the physical length of the connector that is used to interface to the cable under test. Access Keys: BEGIN **Cable** **SRL** **Connector Model** *or* CAL **Connector Model** (You must already be in SRL measurement mode to access the connector model menu via the CAL key.)
Connector Model	Softkey in the SRL, and SRL cal menus. Displays the menu that allows you to characterize your interface connector, as well as selections for cable impedance measurements. Access Keys: BEGIN **Cable** **SRL** *or* CAL (You must already be in SRL measurement mode to access the **Connector Model** softkey via the CAL key.)

Default Cal	Softkey in the fault cal and SRL cal menus. If this key is selected, the default instrument calibration is used. Access Keys: BEGIN **Cable** **Fault Location** / **SRL** *or* CAL (You must already be in fault location/SRL measurement mode to access the **Default Cal** softkey via the CAL key.)
Delete All Limits	Softkey in delete limit menu. Deletes all of the limit lines in the limit line table. Asks for confirmation before deletion occurs. See “Using Limit Lines” in Chapter 4 of your analyzer's *User's Guide* for more information on using limit lines. Access Keys: DISPLAY **Limit Menu** **Delete Limit**
Delete Limit	Softkey in limit menu. Displays menu to delete one segment (or point) of a limit line or all limits. See “Using Limit Lines” in Chapter 4 of your analyzer's *User's Guide* for more information on limit lines. Access Keys: DISPLAY **Limit Menu**
Delta Mkr on OFF	Softkey in marker functions menu. Makes the active marker the delta marker or reference point. See “To Use Delta (Δ) Marker Mode” in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: MARKER **Marker Functions**
DISPLAY	Hardkey in CONFIGURE area of front panel. Displays menu with selections concerning type of data to be displayed, split or full screen, and limit lines.

Distance	1. Softkey under the MENU key. Displays a menu of fault location measurement selections for start and stop distance, the units for distance (feet or meters), and low pass or band pass selection. 2. Softkey in add max point and add min point menus. Sets the distance of a limit point. See "To Create a Single Point Limit" in Chapter 4 of your analyzer's *User's Guide* for an example of how to set a limit point. Access Keys: DISPLAY **Limit Menu** **Add Limit** **Add Max Point** / **Add Min Point**
Edit Limit	Softkey in limit menu. Displays menu to change the frequency (or distance if in fault location mode) or amplitude of previously entered limits, or add a data trace marker. Access Keys: DISPLAY **Limit Menu**
End Distance	Softkey in add max line and add min line menus. Sets the end (or stop) distance of a limit line. See "Using Limit Lines" in Chapter 4 of your analyzer's *User's Guide* for more information on limit lines. Access Keys: DISPLAY **Limit Menu** **Add Limit** **Add Max Line** / **Add Min Line**
End Frequency	Softkey in add max line and add min line menus. Sets the end (or stop) frequency of a limit line. See "Using Limit Lines" in Chapter 4 of your analyzer's *User's Guide* for more information on limit lines. Access Keys: DISPLAY **Limit Menu** **Add Limit** **Add Max Line** / **Add Min Line**
End Limit	Softkey in add max line and add min line menus. Sets the end (or stop) amplitude (height) of a limit line. See "Using Limit Lines" in Chapter 4 of your analyzer's *User's Guide* for more information on limit lines. Access Keys: DISPLAY **Limit Menu** **Add Limit** **Add Max Line** / **Add Min Line**

Fault Location	1. Softkey in cable menu. Sets up the analyzer for making fault location measurements and displays the fault location menu. Access Keys: BEGIN **Cable** 2. Softkey in MEAS menu. Sets up the analyzer for making fault location measurements.

Fault Window

Softkey in the AVG menu.

The fault location measurement mode provides a windowing feature that makes fault measurements more useful for isolating and identifying individual responses. Windowing is needed because of the abrupt transitions in a frequency domain response at the start and stop frequencies. The band limiting of a frequency domain response causes overshoot and ringing in the distance domain response. This gives a non-windowed impulse stimulus a $\sin(\omega t)/\omega t$ shape where $\omega=\pi/(\text{frequency span})$. This has two effects that limit the usefulness of the fault location measurement:

1. **Finite impulse width (or rise time):** This limits the ability to resolve between two closely spaced responses. The effects of the finite impulse are improved as the frequency span is increased.
2. **Sidelobes:** The impulse sidelobes limit the dynamic range of the time domain measurement by hiding low-level responses within the sidelobes of higher level responses. The effects of sidelobes can be improved by windowing.

Windowing improves the dynamic range of a distance domain measurement by filtering the frequency domain data prior to converting to the distance domain, producing an impulse response that has lower sidelobes. This makes it much easier to see distance domain responses that are different in magnitude. This sidelobe reduction is achieved, however, at the expense of increased impulse width.

The following options are available under the window menu:

- **Minimum**

  This is essentially no window. It gives the highest sidelobes and the narrowest impulse response.

- **Medium**

  This is the default selection. Selecting medium provides reduced sidelobes.

- **Maximum**

  This selection provides minimum sidelobes but the widest impulse response.

Feet	Softkey in the fault location and distance menus. Displays the distance in units of feet (rather than meters). Access Keys: BEGIN **Cable** **Fault Location** *or* MENU **Distance**
Flatness	Softkey in marker math menu. Calculates span, gain, slope, and flatness of a trace segment. The trace segment is defined by markers 1 and 2 (on measurement channel 1) and markers 2 and 3 (on measurement channel 2). See “To Use Marker Math Functions” in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: MARKER **Marker Functions** **Marker Math**
Frequency	Softkey in add max point and add min point menus. Sets the frequency of a limit point. (This key is not available when in fault location measurement mode. Limit points are set using the Distance key when in fault location mode.) See “To Create a Single Point Limit” in Chapter 4 of your analyzer's *User's Guide* for an example of how to set a limit point. Access Keys: DISPLAY **Limit Menu** **Add Limit** **Add Max Point** / **Add Min Point**

Full Band Cal	Softkey in fault cal and SRL cal menus. When selecting this key, you will be prompted to connect open, short, and load standards to the measurement reference plane. See "3. Calibrate the Analyzer" on page 3-6 or "2. Calibrate the Analyzer" on page 4-4 for instructions on how to calibrate for fault location or SRL, respectively. See Chapter 6, "Calibrating for Increased Measurement Accuracy", in your analyzer's *User's Guide* for detailed information on analyzer calibration. Access Keys: BEGIN **Cable** **Fault Location** / **SRL** *or* CAL (You must already be in fault location/SRL measurement mode to access the **Full Band Cal** softkey via the CAL key.)
Graticule ON off	Softkey available in two different menus: the more display menu and the define graph menu. This softkey toggles the display graticule (grid) on and off. When pressed in the more display menu, the graticule is suppressed from showing on the CRT. When pressed in the define graph menu, the graticule is suppressed from printing or plotting on a hardcopy. Access Keys: DISPLAY **More Display** *or* HARDCOPY **Define Hardcopy** **Define Graph**
Impedance Magnitude	Softkey in FORMAT menu. Displays impedance magnitude versus frequency on a Cartesian format. See Chapter 6, "Making Impedance Measurements," for more information. Access Keys: FORMAT **More Format**

Limit	Softkey in add max point or add min point menus. Sets the amplitude of a limit point. "To Create a Single Point Limit" in Chapter 4 of your analyzer's *User's Guide* for an example of how to set a limit point. Access Keys: DISPLAY **Limit Menu** **Add Limit** **Add Max Point** / **Add Min Point**
Limit Line on OFF	Softkey in limit line menu. When on, limit lines or points in limit table are visible on the CRT. See "Using Limit Lines" in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: DISPLAY **Limit Menu**
Limit Menu	Softkey in DISPLAY menu. Displays limit menu to display, add, delete, and edit limit lines and points, and select limit test. See "Using Limit Lines" in Chapter 4 of your analyzer's *User's Guide* for more information.
Limit Test on OFF	Softkey in limit menu. Sets limit test status. When limit test is on, FAIL or PASS notation is displayed on the CRT. The limits need not be visible (set to ON) for the limit test to be valid. See "Using Limit Lines" in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: DISPLAY **Limit Menu**
Lin Mag	Softkey in FORMAT menu. Displays a transmission trace in terms of transmission coefficient, displays a reflection trace in terms of reflection coefficient.
Log Mag	Softkey in FORMAT menu. Displays the logarithmic magnitude of the data in dB. This is the default format. Select log mag format when you want to see your reflection measurement results expressed as return loss.

Low Pass	Softkey in the fault location and fault loc frequency menus. Access Keys: BEGIN **Cable** **Fault Location** *or* FREQ **Fault Loc Frequency**
Manual Z	Softkey in the connector model menu. Allows you to enter a fixed value for Z when making SRL measurements. Auto Z must be turned OFF before you can enter a value using **Manual Z**. Access Keys: BEGIN **Cable** **SRL** **Connector Model** *or* CAL **Connector Model** (You must already be in SRL measurement mode to access the connector model menu via the CAL key.)
Marker	Softkey in add max line, add min line, add max point, and add min point menus. Adds a marker to the data trace and allows it to be moved to identify trace frequencies and amplitudes. Access Keys: DISPLAY **Limit Menu** **Add Limit** **Add Max Line** / **Add Min Line** / **Add Max Point** / **Add Min Point**
MARKER	Hardkey in the CONFIGURE area. Displays menu to set markers, use marker search and delta markers. See “Using Markers” in Chapter 4 of your analyzer's *User's Guide* for more information.
Marker Functions	Softkey in MARKER menu. Invokes menu to select delta marker mode, marker to center, marker to reference, and marker to electrical delay.

Marker Math	Softkey in marker functions menu. Displays menu of marker math functions: statistics, flatness, and RF filter statistics. These marker math functions calculate various statistical and mathematical parameters on a user-defined trace segment. See Flatness, RF Filter Stats, and Statistics in this chapter. Also, see “To Use Marker Math Functions” in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: MARKER **Marker Functions**
Marker Search	Softkey in MARKER menu. Displays marker search menu to set active marker to maximum or minimum point or user defined target value. Also presents bandwidth, notch, multi peak and multi notch, search functions. See “Using Markers” in Chapter 4 of your analyzer's *User's Guide* for more information.
Max Search	Softkey in marker search menu. Places the active marker at the frequency point of maximum amplitude. If tracking is off, marker remains at that frequency. If tracking is on, marker moves to the maximum point with each sweep. See “Using Markers” in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: MARKER **Marker Search**
Maximum	Softkey in the fault window menu. This selection provides minimum sidelobes but the widest impulse response. See **Fault Window** earlier in this section for detailed information about fault window selections. Access Keys: AVG **Fault Window**

Measure Cable	Softkey in the calibrate cable menu. Press this key to measure a known length of cable and have the analyzer automatically calculate the cable loss and velocity factor. See **Calibrate Cable** earlier in this chapter for more information. Access Keys: (BEGIN) **Cable** **Fault Location** (CAL) **Calibrate Cable** *or* (CAL) Calibrate Cable (You must already be in SRL measurement mode to access the calibrate cable menu via the (CAL) key.)
Measure Connector	Softkey in the connector model menu. This function computes the optimum connector length and capacitance compensating values for SRL measurements. See "4. Determine the Connector Model" on page 4-8 for more information. Access Keys: (BEGIN) **Cable** **SRL** **Connector Model** *or* (CAL) **Connector Model** (You must already be in SRL measurement mode to access the connector model menu via the (CAL) key.)
Medium	Softkey in the fault window menu. This is the default window selection. This selection provides reduced sidelobes. See **Fault Window** earlier in this chapter for detailed information about fault window selections. Access Keys: (AVG) **Fault Window**
Meters	Softkey in the fault location and distance menus. Displays the distance in units of meters (rather than feet). Access Keys: (BEGIN) **Cable** **Fault Location** *or* (MENU) **Distance**

Min Search	Softkey in marker search menu. Places the active marker at the frequency point of minimum amplitude. If tracking is off, marker remains at that frequency. If tracking is on, marker moves to the minimum point with each sweep. See "Using Markers" in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: MARKER **Marker Search**
Minimum	Softkey in the fault window menu. This is essentially no window. It gives the highest sidelobes and the narrowest impulse response. See **Fault Window** earlier in this chapter for detailed information about fault window selections. Access Keys: AVG **Fault Window**
Mkr Limits	Softkey in limit menu. Displays marker limits menu where limit testing can be placed on statistics or flatness marker searches. See "To Use Marker Limit Functions" in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: DISPLAY **Limit Menu**
Multi Peak **Corr on/OFF**	Softkey in fault cal menu. Turns multi-peak correction mode on or off. See **Multi Peak Threshold**, next in this section for more information. Access Keys: BEGIN **Cable** **Fault Location** CAL **Multi Peak** *or* CAL **Multi Peak** (You must already be in fault location measurement mode to access the multi peak menu via the CAL key.)

Multi Peak Threshold

Softkey in fault cal menu. Allows entry of new multi-peak threshold. The analyzer can automatically compensate for multiple responses along the cable. For example, consider a cable with three successive faults along its length with reflection coefficients of 0.8. Without multi-peak correction, the measured response would be:

Peak	Measured Response	Calculation
Peak #1	0.8	
Peak #2	0.16	(0.8 * (1 – 0.8))
Peak #3	0.032	(0.8 * ((1 – 0.8) – 0.16))

With multi-peak correction, the measured response becomes:

Peak	Measured Response
Peak #1	0.8
Peak #2	0.8
Peak #3	0.8

Each subsequent peak is corrected based on the magnitude of the previous *n* peaks. Peak values are searched for above a user-defined threshold.

Access Keys: BEGIN **Cable** **Fault Location** CAL **Multi Peak**

or

CAL **Multi Peak** (You must already be in fault location measurement mode to access the multi peak menu via the CAL key.)

CAUTION

There is some uncertainty built into the measurement when multi-peak mode is enabled since the analyzer cannot always distinguish between real responses and response sidelobes which look like responses. To distinguish between side lobes and responses, various window selections should be tried (see **Fault Window**), while looking for changes in the responses.

Next Min Left	Softkey in the min search menu. Moves the active marker to the next nearest minimum point to the left. A peak (minimum) point is detected whenever an amplitude excursion greater than half a division occurs. See "To Use Marker Search Functions" in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: MARKER **Marker Search** **Min Search**
Next Min Right	Softkey in the min search menu. Moves the active marker to the next nearest minimum point to the right. A peak (minimum) point is detected whenever an amplitude excursion greater than half a division occurs. See "To Use Marker Search Functions" in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: MARKER **Marker Search** **Min Search**
Next Peak Left	Softkey in the max search menu. Moves the active marker to the next nearest peak to the left. A peak point is detected whenever an amplitude excursion greater than half a division occurs. See "To Use Marker Search Functions" in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: MARKER **Marker Search** **Max Search**
Next Peak Right	Softkey in the max search menu. Moves the active marker to the next nearest peak to the right. A peak point is detected whenever an amplitude excursion greater than half a division occurs. See "To Use Marker Search Functions" in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: MARKER **Marker Search** **Max Search**
Number of Points	Softkey in the source MENU. Allows selection of the number of measurement points in a sweep: 3, 5, 11, 21, 51, 101, **201** (default), 401, 801, or 1601. As the number of points increases, frequency resolution increases and sweep speed decreases. See "To Reduce the Number of Measurement Points" in Chapter 5 of your analyzer's *User's Guide* for information on how the number of measurement points selected can affect your measurements.
Reference Level	Softkey in SCALE menu. Sets the value of the reference line. The reference value is noted at the top of the screen as `Ref`.

Reference Position	Softkey in SCALE menu. Sets the position of the reference line from the top of the graticule (10) to the bottom (0) or in between. Default position is middle (5). See Chapter 2 of your analyzer's *User's Guide* for more information.
Reflection	Softkey in cable menu. Selects forward reflection type of measurement. Power is output from the RF OUT (or PORT 1) test port and also measured there. See “Measuring Reflection Response” in Chapter 3 of your analyzer's *User's Guide* and “To Perform a Reflection Calibration” in Chapter 6 of your analyzer's *User's Guide* for more information. Access Keys: BEGIN **Cable**
Restart Average	Softkey in AVG menu. Clears the running average and restarts it with the next sweep. See AVG, earlier in this chapter for information on averaging.
RF Filter Stats	Softkey in marker math menu. Measures both the passband and stopband of a filter in one sweep. See “To Use Marker Math Functions” in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: MARKER **Marker Functions** **Marker Math**
SCALE	Hardkey in CONFIGURE area of front panel. Allows changing of scale per division, and reference level and position for optimum viewing of measurements. See “Entering Measurement Parameters” in Chapter 2 of your analyzer's *User's Guide* for more information on using the SCALE functions.
Scale/Div	Softkey in SCALE menu. Sets the value of vertical divisions of graticule. For example, if the scale/div is 10 dB, each graticule line is 10 dB higher than the one below.

Specify Length	Softkey in the calibrate cable menu. Press this key to input the known length of a cable and have the analyzer automatically calculate the cable loss and velocity factor. See **Calibrate Cable** earlier in this chapter for more information. Access Keys: BEGIN **Cable** **Fault Location** CAL **Calibrate Cable** *or* CAL **Calibrate Cable** (You must already be in fault location measurement mode to access the calibrate cable menu via the CAL key.)
Split Disp **FULL split**	Softkey in more display menu. Toggles the display mode between split (measurement channel 1 on top, measurement channel 2 on the bottom) and full (both measurement channels on full screen). See “Entering Measurement Parameters” in Chapter 2 of your analyzer's *User's Guide* for more information. Access Keys: DISPLAY **More Display**
SRL	1. Softkey in cable menu. Sets up the analyzer for making SRL measurements and displays the SRL menu. Access Keys: BEGIN **Cable** 2. Softkey in measurement menu. Sets up the analyzer for making SRL measurements. Access Keys: MEAS 1/MEAS 2
SRL Cable Scan	Softkey in SRL menu. Performs a narrowband cable scan to determine worst-case SRL. See “5. Perform the SRL Cable Scan” on page 4-16 for more information. Access Keys: BEGIN **Cable** **SRL**

Start Distance	Softkey in the fault location menu. Allows entry of a new start distance for making fault location measurements. Access Keys: BEGIN **Cable** **Fault Location** **NOTE** Changing start and/or stop distance will change the frequency span. See "Start/Stop Distance and Frequency Span Explanation" on page 1-5 for detailed information on the relationship between distance range and frequency span.
Start Freq	Softkey in the SRL menu. This is the start frequency for the cable scan. Access Keys: BEGIN **Cable** **SRL**
Statistics	Softkey in marker math menu. Measures a user-defined segment of a measurement trace and calculates the frequency span, mean, and standard deviation of the amplitude response, and the peak-to-peak ripple. See "To Use Marker Math Functions" in Chapter 4 of your analyzer's *User's Guide* for more information. Access Keys: MARKER **Marker Functions** **Marker Math**
Stop Distance	Softkey in the fault location menu. Allows the entry of a new stop distance. The maximum allowable entry for stop distance is 10,000.00 meters (32,808.4 feet). Access Keys: BEGIN **Cable** **Fault Location** **NOTE** Changing start and/or stop distance will change the frequency span. See "Start/Stop Distance and Frequency Span Explanation" on page 1-5 for detailed information on the relationship between distance range and frequency span.
Stop Freq	Softkey in the SRL menu. This is the stop frequency for the cable scan. Access Keys: BEGIN **Cable** **SRL**

SWR	Softkey in FORMAT menu. Displays the data formatted as SWR (standing wave ratio).

Transmissn	Softkey in cable menu. Selects ratioed forward transmission type of measurement, or transmission calibration selections. See “Measuring Transmission Response” in Chapter 3 of your analyzer's *User's Guide* and “To Perform a Transmission Calibration” in Chapter 6 of your analyzer's *User's Guide* for more information. Access Keys: BEGIN **Cable**
Velocity Factor	Softkey in the fault cal menu. This function allows you to enter a new velocity factor. Velocity factor is one of the two required parameters for cable calibration. Velocity factor is the speed of propagation of electrical signals in the cable relative to their speed in a vacuum. The velocity factor of your cable may be imprinted on the cable. If the velocity factor of your cable is not available, you may refer to Appendix A for some typical values. Access Keys: BEGIN **Cable** **Fault Location** CAL *or* CAL (You must already be in fault location measurement mode to access the **Velocity Factor** softkey via the CAL key.)
Z cutoff Frequency	Softkey in the connector model menu. The value of Z cutoff frequency affects the analyzer's calculation of cable impedance. The default Z cutoff value of 210 MHz is chosen to minimize mismatch effects of the input connector. See “Defining Cable Impedance” on page 1-7 for more detailed information on how Z cutoff frequency affects cable impedance measurements. Access Keys: BEGIN **Cable** **SRL** **Connector Model** *or* CAL **Connector Model** (You must already be in SRL measurement mode to access the connector model menu via the CAL key.)

9 Characteristics

Overview of Characteristics

This chapter contains analyzer performance data for SRL and fault location measurements. For complete specification and characteristic information for your analyzer, see your analyzer's *User's Guide*.

Frequency Range Considerations

The higher frequency span available on the Agilent Technologies 8714ET/ES can provide greater resolution when making fault location measurements. See the discussion in "Fault Location Distance Range and Resolution" on page 9-12.

However, when the analyzer has chosen a large frequency span (based on the user-defined start and stop distances), the performance of the system at high frequencies may become important.

Many coaxial cables perform poorly (or not at all) above 1500 MHz. If the cable or system you are measuring does not perform well at high frequencies, change the fault location frequency mode to band pass. Band pass mode may be used to limit the frequency range the analyzer will use when making fault location measurements.

Phase Considerations

In addition to using the connector capacitance and connector length functions to improve the connector model, you can use the electrical length and port extension features. Electrical length and port extension provide the same function as connector length, but these settings are entered in units of seconds, rather than length.

SRL data can also be observed in Smith chart format. The Smith chart can be used to verify the connector model for your SRL measurements.

See "4. Determine the Connector Model" on page 4-8 for more information.

General Performance Characteristics

SRL Measurement Mode	Structural Return Loss
Fault Location Measurement Mode	Return loss (dB) versus distance Reflection coefficient magnitude versus distance SWR versus distance
Dynamic Range	40 dB (based on system directivity after calibration)
Windowing	Minimum, medium and maximum windows are available for optimizing distance response data
Amplitude Accuracy[1]	±2.5 dB typical (minimum windowing) ±1.2 dB typical (medium windowing) ±0.4 dB typical (maximum windowing)
Data Correction	Data is normalized to the open/short/load response at the output port. Data correction for line losses and preceding mismatches is also available.
Measurement and Data Storage[2]	Use the internal disks to store and recall setups and data. Typically, you may store as many as 40 setups on a disk. You may also store data in a format compatible with popular PC-based spreadsheet software. Data may also be stored in HPGL graphics format.
Markers	Eight independently controlled markers can be used to display return loss, reflection coefficient, SWR, or impedance versus distance.
Limit Lines	Limit lines may be entered for comparison to specification limits and pass/fail testing.
Remote Programming	The analyzer can be controlled from an external computer through the IEEE 488.2 GPIB port or the LAN interface. Use standard SCPI program subsystem commands to control the analyzer.
Hard Copy[2]	The analyzer can be configured to output print or plot data to the serial port, the parallel port, the GPIB port, the LAN port, or to a file. The data can be either a graph or a tabular listing of data points. Tabular listings include limit-line information and pass/fail margins, point by point.
Fault Range	Up to 10000.00 meters. (See Table 9-10 and Table 9-11.)
Resolution	Down to 0.195% of range. (See Table 9-10 and Table 9-11.)

1. Inaccurate cable loss factor and/or multiple fault correction may introduce additional error uncertainties.
2. See your analyzer's *User's Guide* for information.

SRL Measurement Uncertainty vs System Directivity

System directivity, system and test lead stability, and cable connector mismatch all affect measurement uncertainty. Figure 9-1 shows a graph of measurement uncertainty curves for a –49 dB directivity system applied to various return loss values. The upper trace is return loss plus error, the bottom trace is return loss minus error, and the middle trace is the return loss with no error.

Figure 9-2 shows the same for a –40 dB directivity system.

Notice as the return loss gets larger (closer to 0 dB), the effect of the error is smaller. One use for this graph is to determine the measurement guard band needed to specify cable performance. For example, if a cable must meet a –30 dB return loss specification, and the system directivity is –49 dB, then the value of –32 dB must be measured to guarantee –30 dB.

To determine what the measured value must be, draw a line perpendicular to the x-axis at the specification value. Draw another line from the point at which it intersects the lower uncertainty trace to the y-axis. The y-axis value is the value that must be measured to guarantee the specification.

Conversely, if a cable is shipped with a measured value of –35 dB for structural return loss, the value that might be measured by a system other than the one it was originally tested on can be determined by drawing a vertical line through the x-axis at –35 dB. (Refer, still, to Figure 9-1). The upper and lower traces show, on the y-axis, the limits with which the cable SRL can be determined. For this example, the –35 dB cable could measure as bad as –33.5 dB, or as good as –37 dB. But there is more to consider. If the first measurement of the cable was performed on a similar system, it will have a similar uncertainty. For this example, a cable measured as –35 dB on the first system could be as bad as –31.5 dB. This could be measured on a second system as good as –35 dB (if the directivity error is exactly the same magnitude and phase as the first system), or as bad as –30.5 dB (if the directivity magnitude is the same, but the phase is opposite). Fortunately, as with impedance measurements, the directivities are unlikely to be worst case in magnitude at the same frequency and with opposite phase on two different systems.

Table 9-1 shows the effect of system directivity on cable impedance. A measured impedance of 74 ohms will have an uncertainty of ±1.5 Ω in a –40 dB system, and an uncertainty of ±0.6 Ω in a –48 dB directivity system.

Table 9-1 **Effect of Directivity on Cable Impedance for Z_{DUT} = 74 Ohms**

Directivity (Logarithmic)	Refl. Coef. (Linear)	Measurement Uncertainty	ρ_m	Z_m
40 dB	±0.01	±1.5 ohm	–0.0167	72.5
			+0.0032	75.5
45 dB	±0.00562	±0.8 ohm	–0.0123	73.2
			+0.0011	74.8
48 dB	±0.004	±0.6 ohm	–0.0107	73.4
			+0.0027	74.6

$$Z_m = 75\left(\frac{1 + p_m}{1 - p_m}\right)$$

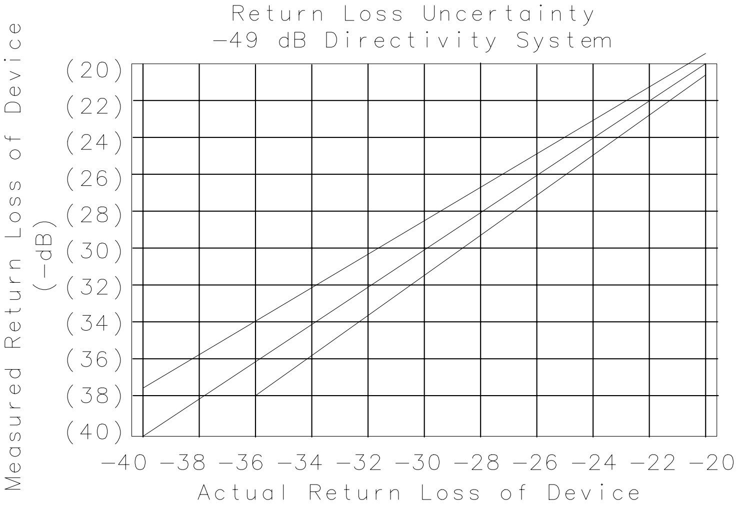
$$\rho_m = \rho_{DUT} \pm 0.01$$

$$\rho_{DUT} = \frac{Z_{DUT} - Z_0}{Z_{DUT} + Z_0}$$

$$\rho_m = \begin{cases} -0.0067 - 0.01 & \text{Min} \\ -0.0067 + 0.01 & \text{Max} \end{cases}$$

$$\rho_{DUT} = \frac{74 - 75}{74 + 75} = -0.0067$$

Figure 9-1 **Return Loss of Device Under Test: –49 dB Directivity**

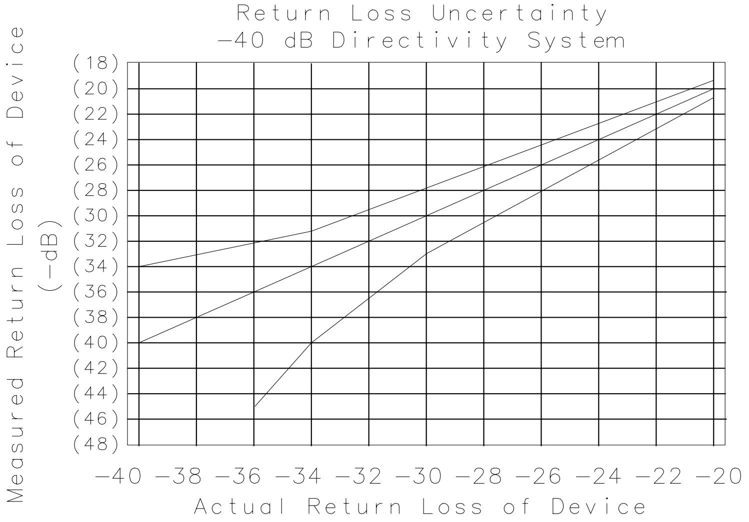


pd66h21

Table 9-2 **Measurement Uncertainty Window for –49 dB Directivity System**

Return Loss of Cable Under Test		
Measured (Nominal)	**Minimum**	**Maximum**
–40.0	–43.7	–37.4
–32.0	–33.4	–30.9
–28.0	–28.8	–27.2
–25.2	–25.8	–24.7
–23.1	–23.5	–22.7
–21.4	–21.8	–21.1
–20.0	–20.3	–19.7

Figure 9-2 **Return Loss of Device Under Test: –40 dB Directivity**



pd67h21

Table 9-3 **Measurement Uncertainty Window for –40 dB Directivity System**

Return Loss of Cable Under Test		
Measured (Nominal)	**Minimum**	**Maximum**
–40.0	—	–34.0
–33.5	–39.0	–30.1
–29.8	–33.0	–27.4
–27.2	–29.4	–25.4
–25.2	–26.9	–23.7
–23.6	–25.0	–22.4
–22.2	–23.4	–21.2
–21.0	–22.1	–20.1
–20.0	–20.9	–19.2

SRL Measurement Uncertainty vs Connector Fault

As discussed earlier, three factors affect the measurement uncertainty:

- system directivity
- system and test lead stability
- cable connector mismatch

System directivity can be measured by connecting the 75 or 50 ohm load standard to the test lead connector and observing the magnitude of the highest response. The highest response is the system directivity. See “2. Calibrate the Analyzer” on page 4-4.

Test lead stability can be measured by connecting the 75 or 50 ohm load standard to the test lead connector, wiggling the cable and observing the response. See “2. Calibrate the Analyzer” on page 4-4.

The cable connector mismatch can be measured by selecting the SRL measurement and “Connector Fault.” The fault response at the connector is displayed by the marker.

The connector mismatch can be improved by the proper connector model. See “4. Determine the Connector Model” on page 4-8.

Minimizing Measurement Uncertainty

The best system performance can be attained by performing a good cal, taking proper care of a high quality test lead cable, and using the best connector model. When these three steps are taken, the optimized connector response can be measured using the “Connector Fault” feature.

You can now calculate the measurement uncertainty using the following procedure and worksheets. Note that the system directivity must also be included when computing measurement uncertainty.

1. Convert the system directivity, fault location, and SRL log (dB) responses to linear reflection coefficients using the following equation:

   $\text{Reflection Coefficient} = 10^{(\text{SRL(dB)}/20)}$

2. Compute the sum and difference responses (assume the responses may have a plus or minus phase).
3. Convert from linear to log (dB) using the following equation:

   $\mathrm{dB} = (20)(\mathrm{Log}_{10})(\text{Reflection Coefficient})$

Example:

Table 9-4 **Uncertainty Worksheet 1**

Measurement	Log (dB)	Refl. Coef. (Linear)
SRL Response	–32 dB	0.0251
Connector Response	–50 dB	0.00316
System Directivity	–49 dB	0.00354

Table 9-5 **Uncertainty Worksheet 2**

Operation	SRL Response	Connector Response	System Directivity	Result (Linear)	Result (dB)
Max (add)	0.0251	0.00316	0.00354	0.0318	–29.97
Min (subtract)	0.0251	0.00316	0.00354	0.0184	–34.70

Measurement uncertainty = –32 dB +2.03/–2.7 dB

Measurement Uncertainty Tables

The following tables show the relationship between the corrected connector fault response, industry standard SRL cable specifications, and the maximum and minimum measured SRL responses. The tables also take into account the affects of system directivity (which can be determined from the trace with a load connected after calibration).

Table 9-6 **Measurement Uncertainty with a –20 dB SRL Response**

Corrected Connector	System Directivity	SRL (Actual)	SRL (Measured)	
			Max	Min
–20 dB	–49 dB	–20 dB	–13.83 dB	–49 dB
–25 dB	–49 dB	–20 dB	–15.93 dB	–27.91 dB
–30 dB	–49 dB	–20 dB	–17.38 dB	–23.76 dB
–35 dB	–49 dB	–20 dB	–18.32 dB	–22.08 dB
–40 dB	–49 dB	–20 dB	–18.9 dB	–21.26 dB
–45 dB	–49 dB	–20 dB	–19.24 dB	–20.84 dB
–50 dB	–49 dB	–20 dB	–19.44 dB	–20.6 dB
–55 dB	–49 dB	–20 dB	–19.55 dB	–20.48 dB
–60 dB	–49 dB	–20 dB	–19.61 dB	–20.4 dB
–65 dB	–49 dB	–20 dB	–19.65 dB	–20.36 dB

Table 9-7 **Measurement Uncertainty with a –26 dB SRL Response**

Corrected Connector	System Directivity	SRL (Actual)	SRL (Measured)	
			Max	Min
–30 dB	–49 dB	–26 dB	–21.38 dB	–36.51 dB
–35 dB	–49 dB	–26 dB	–22.92 dB	–30.82 dB
–40 dB	–49 dB	–26 dB	–23.92 dB	–28.74 dB
–45 dB	–49 dB	–26 dB	–24.54 dB	–27.76 dB
–50 dB	–49 dB	–26 dB	–24.91 dB	–27.25 dB
–55 dB	–49 dB	–26 dB	–25.12 dB	–26.98 dB
–60 dB	–49 dB	–26 dB	–25.25 dB	–26.83 dB
–65 dB	–49 dB	–26 dB	–25.32 dB	–26.74 dB

Table 9-8 Measurement Uncertainty with a –30 dB SRL Response

Corrected Connector	System Directivity	SRL (Actual)	SRL (Measured)	
			Max	Min
–30 dB	–49 dB	–30 dB	–23.51 dB	–49 dB
–35 dB	–49 dB	–30 dB	–25.52 dB	–39.75 dB
–40 dB	–49 dB	–30 dB	–26.9 dB	–34.86 dB
–45 dB	–49 dB	–30 dB	–27.79 dB	–32.98 dB
–50 dB	–49 dB	–30 dB	–28.33 dB	–32.07 dB
–55 dB	–49 dB	–30 dB	–28.65 dB	–31.6 dB
–60 dB	–49 dB	–30 dB	–28.83 dB	–31.35 dB
–65 dB	–49 dB	–30 dB	–28.94 dB	–31.21 dB

Table 9-9 Measurement Uncertainty with a –32 dB SRL Response

Corrected Connector	System Directivity	SRL (Actual)	SRL (Measured)	
			Max	Min
–35 dB	–49 dB	–32 dB	–26.66 dB	–48.43 dB
–40 dB	–49 dB	–32 dB	–28.25 dB	–38.73 dB
–45 dB	–49 dB	–32 dB	–29.3 dB	–35.95 dB
–50 dB	–49 dB	–32 dB	–29.94 dB	–34.7 dB
–55 dB	–49 dB	–32 dB	–30.33 dB	–34.07 dB
–60 dB	–49 dB	–32 dB	–30.55 dB	–33.74 dB
–65 dB	–49 dB	–32 dB	–30.68 dB	–33.55 dB

Fault Location Distance Range and Resolution

Resolution improves as the range is shortened and as the number of measurement points are increased. (See the following tables and graphs.) Distance is displayed in feet or meters. Typical range is limited by transmission line losses.

Range

Maximum range is a function of the velocity factor (V_f), frequency span (F_s), the velocity of light in a vacuum (c = 2.99796 X 10^8 m/sec), and the number of measurement points (NP), and is determined (*in meters*) using the following formula:

$$Range = \frac{V_f(c)(NP-1)}{2(F_s)} = StopDistance$$

Resolution

Maximum resolution is a function of the velocity factor (V_f), frequency span (F_s), sampling factor (N_s: 128 for 101 points, 256 for 201 points, and 512 for 401 points), the velocity of light in a vacuum
(c = 2.99796 X 10^8 m/sec), and the number of measurement points (NP), and is determined (*in meters*) using the following formula:

$$Resolution = \frac{V_f(c)(NP-1)}{2(F_s)(N_s)} = \frac{Range}{N_s} = \frac{StopDistance}{N_s}$$

Typical Distance Data in Feet

Table 9-10 **Fault Location Distance Range or Maximum Distance (in feet) Versus Resolution at 201 Points**[1]

Frequency Span (MHz)	Distance Range (feet)	Resolution (feet)	Frequency Span (MHz)	Distance Range (feet)	Resolution (feet)
Velocity Factor = 0.5			**Velocity Factor = 0.8**		
1300	37.18	0.15	1300	59.49	0.23
650	74.36	0.29	650	118.97	0.46
200	241.67	0.94	200	386.67	1.51
60	805.55	3.15	60	1288.88	5.03
20	2416.66	9.44	20	3866.65	15.10
Velocity Factor = 0.6			**Velocity Factor = 0.9**		
1300	44.62	0.17	1300	66.92	0.26
650	89.23	0.35	650	133.85	0.52
200	290.00	1.13	200	435.00	1.70
60	966.66	3.78	60	1450.00	5.66
20	2899.99	11.33	20	4349.99	16.99
Velocity Factor = 0.7			**Velocity Factor = 1.0**		
1300	52.05	0.20	1300	74.36	0.29
650	104.10	0.41	650	148.72	0.58
200	338.33	1.32	200	483.33	1.89
60	1127.77	4.41	60	1611.11	6.29
20	3383.32	13.22	20	4833.32	18.88

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[1] See Appendix A for typical coaxial cable characteristics including velocity factor.

The following two graphs are plots of maximum distance versus frequency span and resolution versus frequency span using data from Table 9-10. Please note that data is plotted only for velocity factors of 0.5 and 1.0.

Figure 9-3

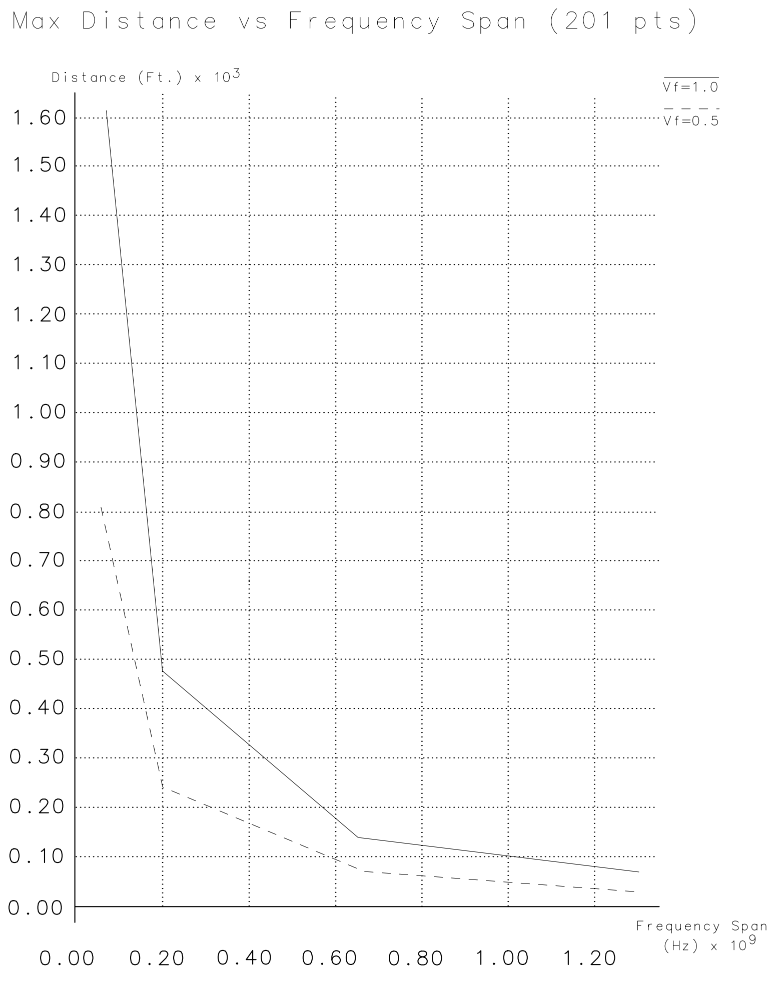
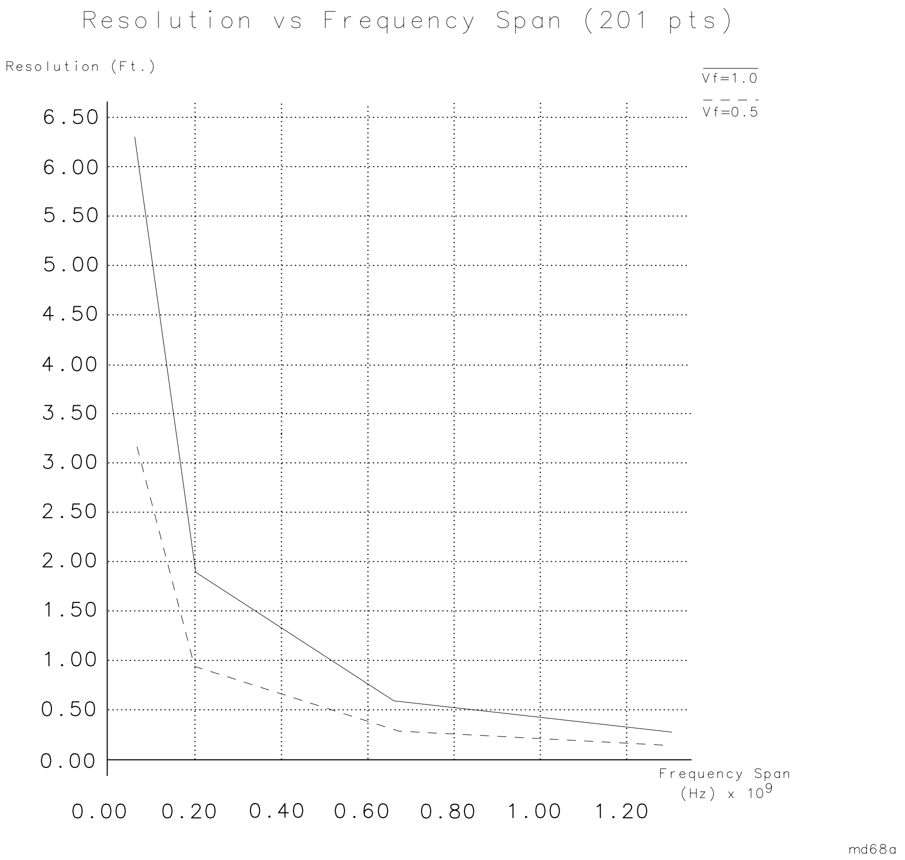


Figure 9-4


Resolution vs Frequency Span (201 pts)
Resolution (Ft.)
Vf=1.0
Vf=0.5
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Frequency Span
(Hz) x 10^9
0.00
0.20
0.40
0.60
0.80
1.00
1.20
md68a

Distance Data in Meters

Table 9-11 **Fault Location Distance Range or Maximum Distance (in meters) Versus Resolution at 201 Points**[1]

Frequency Span (MHz)	Distance Range (meters)	Resolution (meters)	Frequency Span (MHz)	Distance Range (meters)	Resolution (meters)
Velocity Factor = 0.5			**Velocity Factor = 0.8**		
1300	11.59	0.05	1300	18.54	0.07
650	23.18	0.09	650	37.08	0.14
200	75.32	0.29	200	120.52	0.47
60	251.08	0.98	60	401.72	1.57
20	753.23	2.94	20	1205.17	4.71
Velocity Factor = 0.6			**Velocity Factor = 0.9**		
1300	13.91	0.05	1300	20.86	0.08
650	27.81	0.11	650	41.72	0.16
200	90.39	0.35	200	135.58	0.53
60	301.29	1.18	60	451.94	1.77
20	903.87	3.53	20	1355.81	5.30
Velocity Factor = 0.7			**Velocity Factor = 1.0**		
1300	16.22	0.06	1300	23.18	0.09
650	32.45	0.13	650	46.35	0.18
200	105.45	0.41	200	150.65	0.59
60	351.51	1.37	60	502.15	1.96
20	1054.52	4.12	20	1506.46	5.88

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[1] See Appendix A for typical coaxial cable characteristics including velocity factor.

The following two graphs are plots of maximum distance versus frequency span and resolution versus frequency span using data from Table 9-11. Please note that data is plotted only for velocity factors of 0.5 and 1.0.

Figure 9-5

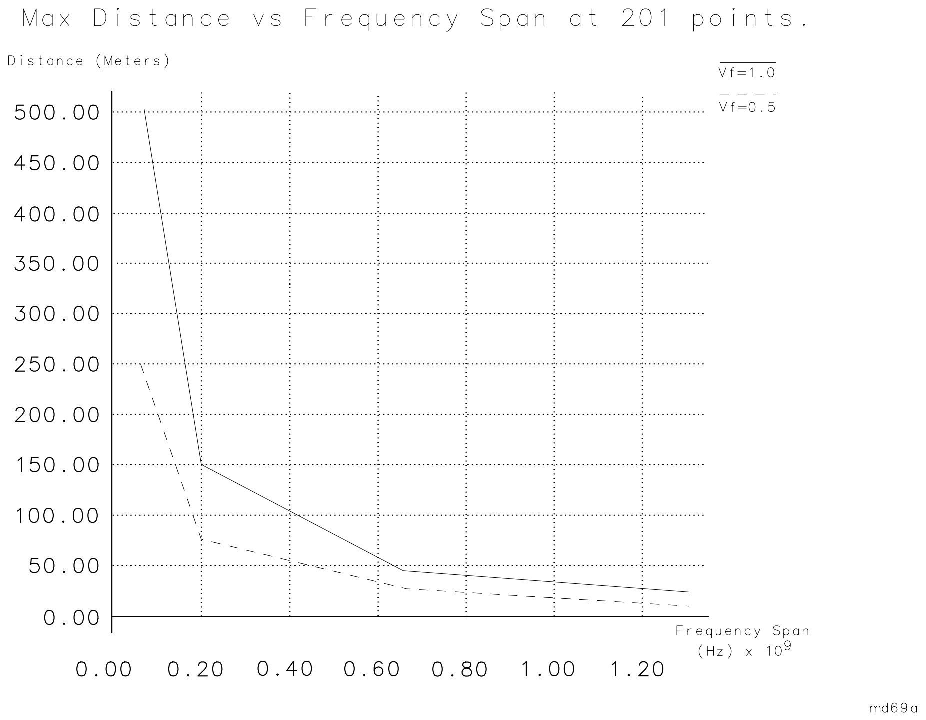
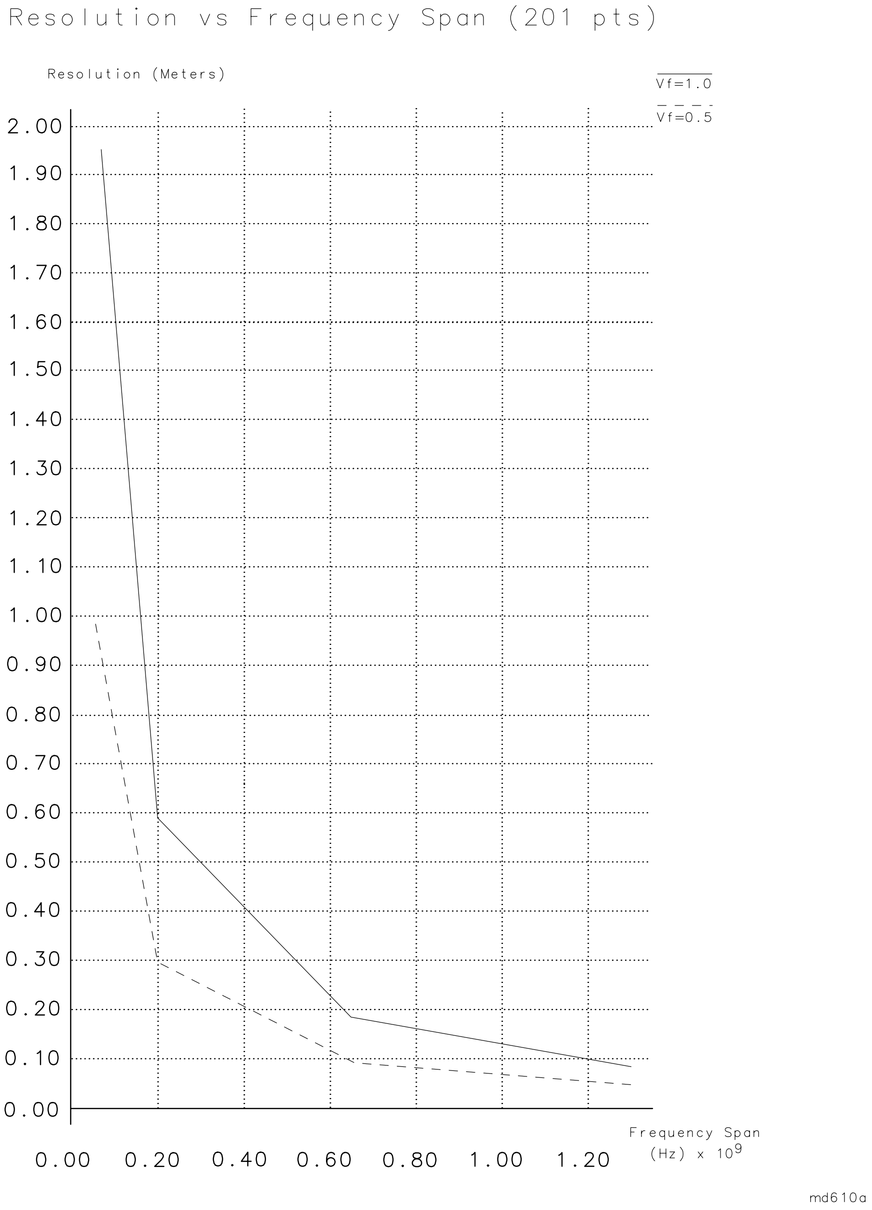


Figure 9-6


Resolution vs Frequency Span (201 pts)
Resolution (Meters)
Vf=1.0
Vf=0.5
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Frequency Span
(Hz) x 10^9
md610a

A

Cable Loss and Velocity Factors

Cable Loss and Velocity Factors

The following table was reprinted from Times Wire and Cable, *RF Transmission Line Catalog and Handbook*. Catalog TL-6, 1972.

Table A-1 **Cable Loss and Velocity Factor Table**

Coaxial Cable Nominal Loss Characteristics dB per Hundred Feet, Frequency in GHz[1]										
RG/U	**Relative Velocity**	**.01**	**.05**	**.10**	**.20**	**.40**	**1**	**3**	**5**	**10**
5, 5A, 5B, 6A, 6B, 212	.659	.80	1.40	2.90	4.30	6.40	11.00	22.00	30.00	52.00
7	.659	.66	1.50	2.20	3.20	4.60	9.00	19.00	28.00	47.00
8, 8A, 10A, 70, 213, 215	.659	.66	1.50	2.20	3.20	4.60	9.00	19.00	28.00	47.00
9, 9A, 9B, 214	.659	.66	1.50	2.20	3.20	4.60	9.00	19.00	28.00	47.00
11, 11A, 12, 12A, 13, 13A, 216	.659	.66	1.50	2.20	3.20	4.60	9.00	19.00	28.00	–
14, 14A, 74, 74A, 217, 224, 293, 293A, 388	.659	.41	1.00	1.40	2.10	3.10	5.80	13.00	19.00	31.00
17, 17A, 18, 18A, 84A, 85A, 177, 218, 219, 295	.659	.23	.56	.81	1.20	1.90	3.80	9.00	13.50	–
19, 19A, 20, 20A, 147, 220, 221	.659	.17	.43	.63	.94	1.50	3.00	7.00	–	–
21, 21A, 222	.659	4.40	9.40	12.90	18.20	26.50	44.00	87.00	–	–
22, 22B, 111, 111A	.659	1.20	2.80	4.20	6.30	9.60	–	–	–	–
29	.659	1.35	3.00	4.30	6.00	8.80	16.50	36.00	51.00	85.00
34, 34A, 34B	.659	.32	.90	1.40	2.10	3.30	5.80	16.00	28.00	
35, 35A, 35B, 164	.659	.24	.60	.90	1.30	2.00	3.70	8.90	15.00	–
54, 54A	.659	.90	2.20	3.30	4.60	6.90	13.10	26.20	35.00	–
55, 55A, 55B, 223	.659	1.35	3.00	4.30	6.00	8.80	16.50	36.00	51.00	85.00
57, 57A, 130, 131, 294, 294A	.659	.65	1.60	2.40	3.60	5.20	10.00	21.20	–	–
58, 58B	.659	1.20	3.10	4.60	7.00	10.00	17.50	38.00	–	–
58A, 58C	.659	1.40	3.30	4.90	7.30	11.00	20.00	41.00	–	–
59, 59A, 59B	.659	1.10	2.30	3.30	4.70	6.70	11.50	25.50	41.00	–
62, 62A, 71, 71A, 71B	.84	.90	1.90	2.80	3.70	5.20	8.50	18.40	29.50	–

Coaxial Cable Nominal Loss Characteristics dB per Hundred Feet, Frequency in GHz[1]										
RG/U	**Relative Velocity**	**.01**	**.05**	**.10**	**.20**	**.40**	**1**	**3**	**5**	**10**
63, 63B, 79, 79B	.84	.50	1.10	1.50	2.30	3.40	5.70	12.20	20.90	–
87A, 115, 115A, 116, 165, 166, 225, 227, 393, 397	.695	.60	1.40	2.10	3.10	4.50	7.50	14.00	21.00	35.00
94	.695	.60	1.30	2.00	2.90	4.20	7.10	13.00	19.00	33.00
94A, 226	.695	.40	1.00	1.50	2.10	3.00	5.00	10.00	15.00	27.00
108, 108A	.659	2.30	5.20	7.50	11.00	16.00	26.20	54.00	–	–
117, 117A, 118, 211, 211A, 228, 228A	.695	.25	.61	.90	1.40	2.00	3.40	7.50	11.50	–
119, 120	.695	.50	1.05	1.60	2.20	3.10	5.10	10.20	15.20	27.30
122	.659	1.60	4.40	6.90	11.00	16.60	29.20	57.20	89.00	–
140, 141, 141A, 142, 142B, 159, 302, 303, 400, 402	.695	1.20	2.70	3.90	5.50	8.00	13.00	26.00	36.00	62.00
143, 143A, 304, 401	.695	.85	1.80	2.50	3.80	5.70	9.70	18.10	26.10	40.70
144	.695	.38	1.00	1.60	2.30	3.80	7.00	15.10	–	–
161, 179, 179A, 179B, 187, 187A	.695	5.00	7.20	9.80	12.70	15.80	25.00	43.00	62.50	135.00
174, 174A	.659	3.80	6.50	8.90	12.00	17.50	31.00	64.30	97.00	185.00
178, 178A, 178B, 196, 196A, 403, 404	.695	5.30	10.00	13.30	20.00	27.50	45.00	78.00	115.00	172.00
180, 180A, 180B, 195, 195A	.695	3.10	4.20	5.10	7.30	10.40	16.50	36.00	49.00	89.00
183	.91	.18	.38	.53	.78	1.20	1.90	3.70	5.00	–
188, 188A, 316	.695	3.80	7.90	11.50	15.00	20.00	30.00	58.00	79.00	133.00
235	.695	.60	1.40	2.10	3.10	4.50	7.50	14.00	21.00	35.00
306, 306A, 336	.80	.15	.33	.52	.80	1.30	2.30	5.20	7.80	–
307, 307A	.80	1.20	2.70	3.80	5.40	7.50	12.00	–	–	–
323, 324, 332, 333, 376	.80	.15	.32	.50	.75	1.20	2.10	4.70	6.50	–
334, 335	.80	.25	.60	.85	1.20	1.90	3.50	7.00	10.00	18.00
360	.80	.18	.40	.60	.90	1.50	2.50	5.30	7.50	

1. Conditions: Ambient 20 °C

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