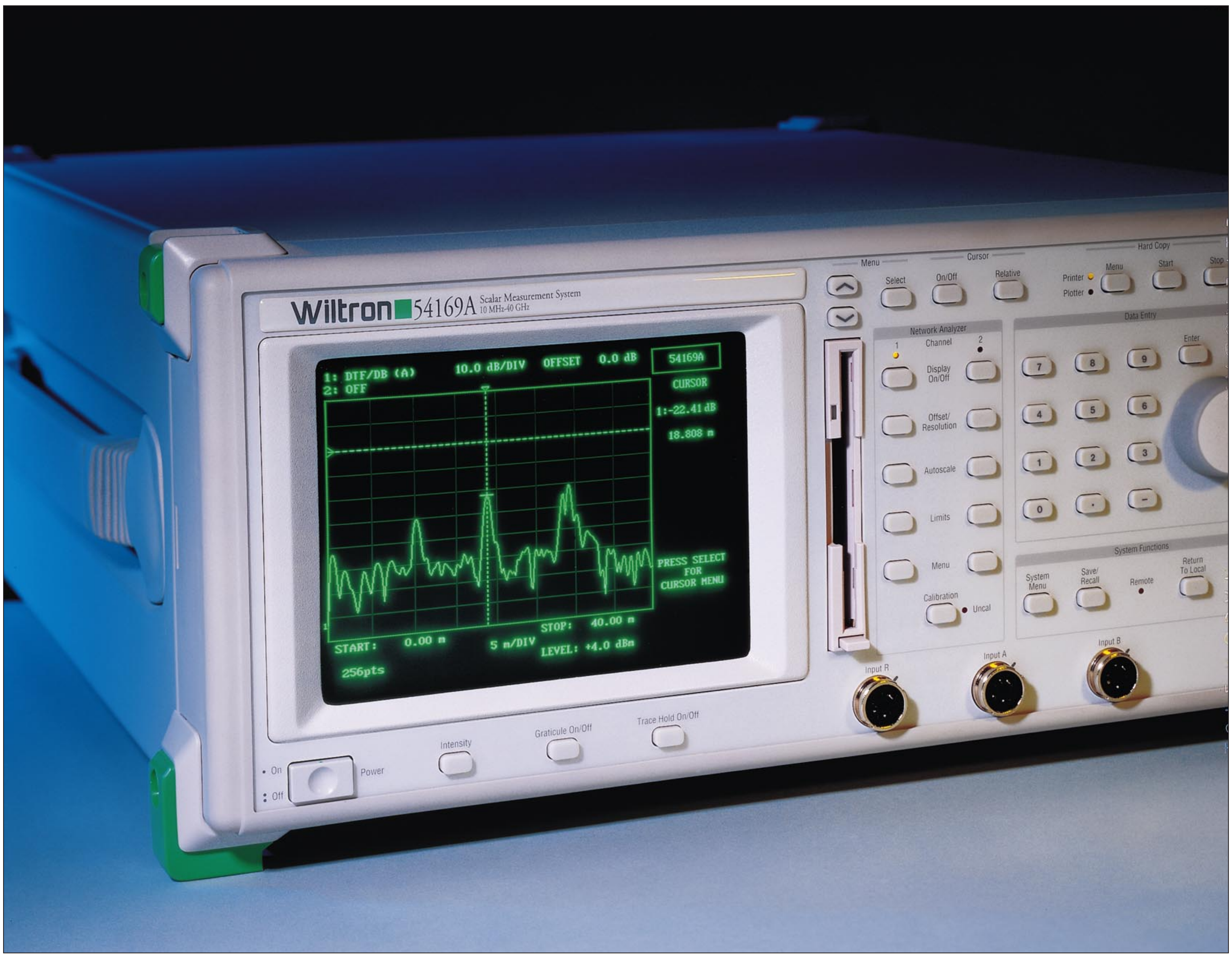
Anritsu
Wiltron

54100A Series

Distance-To-Fault

Application Note



Antenna/Transmission Line Installation and Maintenance.
How To Control Costs and Maximize Reliability Using Frequency Domain Reflectometry

Introduction

Frequency Domain Reflectometry (FDR) is a transmission line fault isolation technique which precisely identifies signal path degradation for coaxial and waveguide transmission lines. FDR principles are used for Distance-To-Fault (DTF) software, a performance verification and failure analysis tool for antenna and transmission line service. This dual role of predicting future failure conditions and isolating existing problems makes DTF an important part of service/maintenance planning.

DTF displays RF return loss or SWR data versus distance. The effects of poor connections, damaged cables, or faulty antennas are quickly identified. Since DTF automatically accounts for attenuation versus distance, the display accurately indicates the return loss of the antenna – allowing technicians to perform fault isolation from ground level.

For the majority of tower mounted transmission lines and antennas, the absence of DTF capability renders preventative maintenance procedures impractical. RF failure conditions at the top of the tower frequently aren't measurable with traditional tools such as time domain reflectometers (TDR) and spectrum analyzer/tracking generators. Thus, there is little hope of monitoring performance degradation between maintenance intervals without the FDR techniques.

Maintenance Planning

Good service and maintenance organizations don't happen by accident. They're planned. First, goals are set based upon providing high quality, continuous service to the customer.

Second, technical performance indicators such as return loss, insertion loss, and DTF are identified to tie measured system performance to the customer based goals.

Third, the required measurement accuracy and operating conditions are identified. The instruments should be accurate enough to detect small dimensional changes within the transmission line and antennas. Further, managers must consider operating environment conditions such as exposure to RF interference or requirements to test the antenna system without climbing the tower.

Finally, a performance tracking system – usually PC based – must be organized to maintain a history of antenna performance. Table 1 identifies a typical task list for plan implementation and ongoing maintenance cycles.

Maintenance Goal Setting

- System Reliability, Up Time Ratio
- Failure Rate
- Annual Cost Per Site
- Preventive Maintenance Objectives

Design the Maintenance Process

- Identify Report Information
  - Antenna Return Loss (SWR)
  - Transmission Line Return Loss (SWR)
  - Frequency of Maintenance Check (Monthly, Quarterly)
  - Required Measurement Accuracy
  - Database for History File (Computer or Paper Files)
- Budget and Plan for Data Collection
- Train Maintenance Technicians/Supervisors

Site Commissioning and Signoff

- Perform Baseline Tests
- Review Specifications and Equipment Accuracy
- Save Measurement Data in Computer or Paper File

Monthly/Quarterly Maintenance Procedure

- Perform Maintenance Checks
- Compare to Specs and Baseline History
- If Problem Found, Identify and Repair
- Save Performance-To-History File
- Print Monthly/Quarterly Report

Table 1
Maintenance planning is based upon quality of service goals to improve up time and reduces long term costs.

DTF and return loss are key indicators of the health of a transmission line. When these two characteristics are stable over time, other key characteristics, such as insertion loss and third order intermodulation, also tend to remain stable. Thus, maintenance tests can be limited to the DTF and return loss tests, a subset of the complete Site Commissioning RF path tests. Both tests can be conducted from ground level and with a minimum of test equipment.

It is imperative that the DTF and return loss measurement equipment be repeatable and accurate, even in the presence of RF interference. Otherwise, the measured data will not be sufficient to monitor degradation over time – greatly increasing the probability that undetected problems will eventually degenerate into intermittent or complete failure.

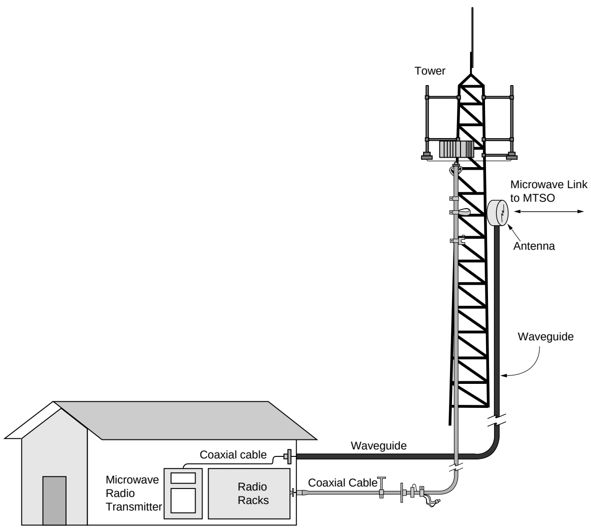


Figure 1
Cellular and PCS/PCN base station antenna towers may include microwave waveguide in addition to coaxial RF transmission lines.

In digital cellular and PCS systems, DTF is particularly applicable. "Fix only after failure" service philosophies were adequate for analog cellular. However, the improved SWR performance required for the new TDMA and CDMA standards force a more proactive maintenance approach. Component specifications are changing. For example, N-type connectors are being phased out in favor of the 7/16 standard – a performance requirement for GSM and DCS-1800 – due to significantly better intermodulation performance and superior power handling. Naturally, test requirements are also more stringent. Transmission line components are routinely specified to 30 dB return loss, rather than the 17 to 20 dB range more common to analog cellular designs.

The quality of test equipment required and the frequency ranges are also a concern. Many cell sites include microwave waveguide as in Figure 1. In most cases, each service technician will have a battery powered analyzer for testing the RF frequency coaxial cables. Microwave DTF analyzers to 20 GHz or 40 GHz are typically shared among a service group.

Data Storage/Recall

On site measurements are compared to previously taken "Baseline" or "Site Commissioning" data. The baseline data and instrument configuration are recalled from a 3.5″ DOS disk. The disk also stores data from regular maintenance intervals – allowing transmission line performance changes to be monitored over time.

IMPROVED DATA ACCESS

Software tools within the 54100A Series allow fast access to the PC environment. First, the ASCII data format also contains an early "1-2-3 type" database header. Most spread sheets recognize the header and automatically convert the ASCII data into the spread sheet without intervention of the PC operator.

Second, file extension's such as "XLS" or "WP4" can be automatically appended by the analyzer. Thus, when using Windows-type PC word processing software, quality conformance reports can be generated automatically. For example, the operator simply inserts the disk into a PC and then prints the report. The report might contain a graphical comparison to historical performance. As long as the correct filename is used on the disk, most Windows based software has the ability to automatically read the disk and then update graphics within the printed report.

Encapsulating measured data into PC data files is further aided when multiple transmission lines are to be tested. The 54100A's automated file naming system can increment the DOS filename by one character every time new data is saved. Filename entry does not need to be repeated manually for each transmission line. Thus, data acquisition, presentation, and statistical analysis are implemented in a simple, streamlined process.

Reduce Maintenance Expense

Without DTF, the singular task of finding failures is difficult. As transmission lines age, the number of service calls increases rapidly. With DTF available, service can be handled promptly. Connector corrosion can be detected early and the weather seals can be replaced before the moisture destroys expensive cables or waveguide. DTF finds these problems because the FDR technique can accurately detect very small impedance changes within the transmission line.

Tower mounted transmission lines and cables are replaced frequently, perhaps every five to ten years, in some cases. Usually, all the site's cables are replaced – based upon the assumption that maintenance calls are imminent on other feeds in addition to the problem cable. This practice may be precipitated by the cable installer; who would likely make the same mistakes on each cable connection. Replacing all the cables frequently is an expensive proposition. It is much less expensive to monitor individual transmission lines for slight degradation and fix the problem early, before serious damage occurs.

Fortunately, when quality components are properly installed and sealed against vapor intrusion, high quality operation can continue well beyond the 5 to 10 years.

Common Failure Conditions

Transmission lines are typically the most common failure point in a communication system. Tower mounted transmission lines are exposed to weather, and will degrade over time. Lightning can sever a portion of the antenna or damage the in-line lightning arrestor. Sunlight exposure can change the dielectric properties of the antenna's housing, causing the antenna bandwidth to drift. Common problems are listed in Table 2. Each causes unwanted signal reflections.

Cable Problems

- Cable Discontinuities
- Braid Wire Ground Shield Fault (Appears as a Notch Filter)
- Damaged/Cut Ground Shields
- Dielectric Fault or Narrowed Dielectric Diameter
- Fasteners Pinch Cables

Connector Problems

- Low Quality Connectors
- Connector Pin Offset (Poor Mating Contact)

Antenna Problems

- Antenna Out of Specification
- Antenna Storm/Shipping Damage
- UV Damage to Dielectric

Table 2
Common Transmission Line Problems

Effective maintenance planning stems from knowledge of these common failure causes as well as local site conditions. For example, tower painting contractors have occasionally dented RF cables. Poorly tightened connectors and poor environmental seals are exacerbated by acid rain corrosion. Eventually, these problems cause intermittent outage and failures at exactly the times they are least welcome – such as during thunder storms or during periods of extreme cold.

How To Compare "Signatures"

The presence of these problems is easily detected by comparing a DTF measurement to a previously stored baseline "DTF Signature" measurement of the cable. Both DTF (Frequency Domain Reflectometry) and return loss measurements are based upon the same basic, signal reflection principles shown in Figure 2. No transmission line component is a perfect impedance match: each will reflect some of the signal energy. The DTF analyzer detects the reflections.

Reflections from the transmission line's various components are vector signals which will add and subtract vectorially depending upon their relative phases. The relative phases are dependent upon 1) the individual characteristics of each device and 2) their relative physical position in the transmission line. When measuring at the end of a transmission line, addition and subtraction of the various reflections create a nearly random pattern of ripples at the DTF analyzer's measurement detector. The result is that each individual cable or waveguide run will tend to have it's own signature in both return loss and DTF. Variations in either between maintenance intervals offers a good indication of damage or damage causing conditions.

Typically, return loss measurements are used to verify the transmission line performance to the engineering specifications. DTF measurement is the primary "Signature" analysis tool.

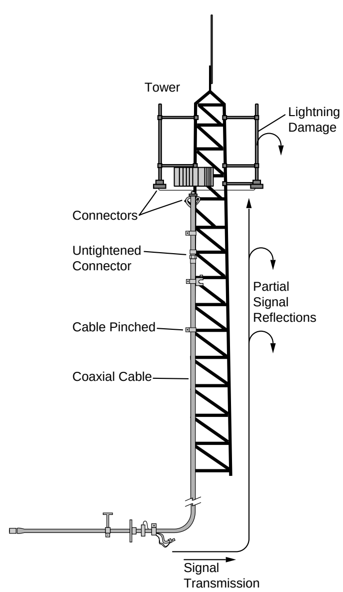


Figure 2
Transmission line faults such as poor connectors, pinched cables, and lightning damage reflect the transmitter's output energy backward toward the source.

DTF Test Process

Distance-To-Fault accurately verifies the transmission line and antenna system performance. Performance monitoring consists of several specific steps.

1. Recall the instrument configuration and "Site Baseline" DTF measurement data from the DOS disk. If data is retained in a notebook PC, recall the measurement data from the PC's database.
2. Calibrate the test setup and perform DTF measurement.
3. Compare the measurement to the stored data.
4. Investigate any transmission line section showing a discrepancy from the stored data.
5. Repair any problems, then repeat the measurement and store the data as the new baseline.
6. Upload the measurement data from the DOS disk or notebook PC to the maintenance report database.

Ideally, the DTF analyzer uses inexpensive, standard test components which are readily available rather than specialized test heads.

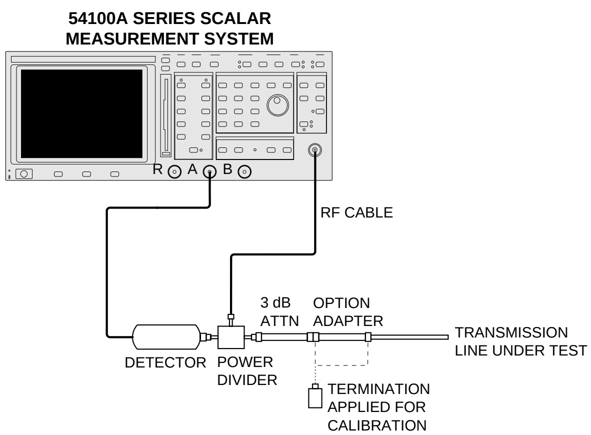


Figure 3
Standard RF components are used for DTF. Special test fixtures are not required.

FDR Measurement Theory

DTF software uses a technique called Frequency Domain Reflectometry (FDR). The measurement principle involves the vector addition of the source's output signal with reflected signals from faults and other reflective characteristics within the tested transmission line. The vector addition of the signals creates a ripple pattern at the network analyzer's RF detector similar to the principles exhibited in Figure 4. The number of ripples is directly proportional to the distance to the reflective point on the transmission line.

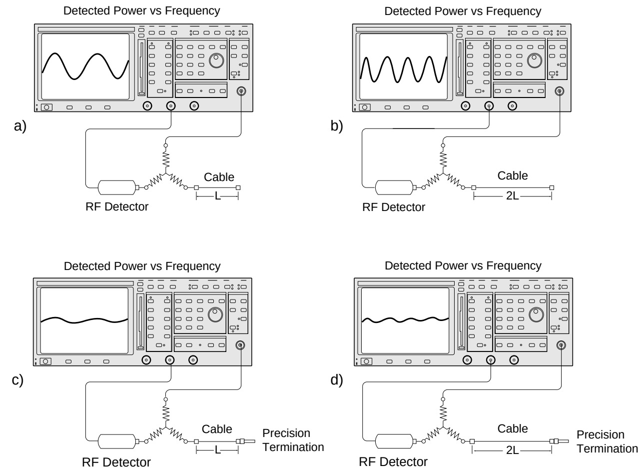


Figure 4
a) b) As the distance to the open circuit condition increases, more ripples appear on the analyzer display. c) d) When the open circuit is replaced with a termination, the amplitude of the ripple is severely attenuated.

For over 3 decades, the following formula has been used to manually calculate distance from the displayed ripple data.

$$n = (2*L*\Delta f)/(c*kp) \quad (1)$$

"n" is the integer number of ripples present in a given sweep range, "Δf" in Hz. "c" is the speed of light in meters per second. "kp" is the relative propagation velocity constant (relative to air) of the cable. For typical polyethylene dielectric RF cables, the propagation velocity averages between 0.64 and 0.68. Assuming that only one ripple is present and assuming the cable's propagation constant is both exact and continuous throughout the cable, we can solve for "L", the distance to the fault. Inserting constants in the formula above, we can use the formula below to identify the distance to a highly reflective fault.

$$\text{Fault Distance "L" in meters} = L = (35)/(\Delta f \text{ in MHz}) \quad (2)$$

Thus, by identifying the frequency difference between two adjacent maximums on the ripple display, we can easily calculate the fault position.

FDR VERSUS TDR

FDR and TDR (Time Domain Reflectometry) are used for similar purposes, but are very different in their technical implementation. TDRs send pulsed DC signals into a copper pair and then digitize the return response of reflected pulses. FDR technique requires that a swept frequency oscillator input a swept signal into the transmission line. A radio frequency receiver monitors the output signal's interference pattern with reflected signals. A Fast Fourier Transform calculates the fault distance. Historically, TDRs have been much less expensive than FDR based devices. While the price discrepancy no longer exists today, the technical differences remain.

In cellular and PCS applications, TDRs are limited because a corroded junction might easily pass a DC signal, but cause large reflections of RF power. Despite commercial claims of high equivalent bandwidth, pulse TDRs do not provide sufficient effective directivity for accurate RF frequency tests such as return loss and insertion loss. Sensitivity is not adequate to identify small changes in return loss characteristics. Further, TDRs frequently fail to measure in the presence of RF interference from nearby transmitters. Thus, TDR measurements support only catastrophic open and short circuit failure conditions.

FDR tests the cable and antennas at RF, their frequency of operation. By measuring RF characteristics directly, FDR provides a clear performance indication. FDR is also inherently immune to RF transmitter interference. The FDR technique – being calculated from a frequency bandwidth sweep – tends to reject RF interference spikes because of the FFT's anti-aliasing software.

When properly calibrated, FDR measurements are highly sensitive. The high sensitivity detects hard to measure conditions such as corroded connection terminals, partially mated (untightened) connectors, dented cables, moisture, and damaged lightning arrestors. FDR also compensates for the insertion loss of the RF cables, thus, the antenna return loss display is not perturbed by the cable's inherent insertion loss. This allows easy identification of problems, such as moisture collection or antennas damaged by lightning, at the top of the tower.

	FDR (Frequency Domain Reflectometry)	**TDR (Time Domain Reflectometry)**
Stimulus Signal	RF Sweep	DC Pulses
Immunity to Interference	High	Poor
Compensates For Cable Insertion Loss	Yes	No
Measures Antenna SWR/Return Loss	Yes	No
Measures Waveguide	Yes	No
Measures Open or Short Circuit Faults	Yes	Yes
Typical Price	$4,000 to $29,000	$1,500 to $20,000

Table 3

Figure 5
FDR techniques reject external RF interference at "live sites" such as this NAMPS cell site, where two competing service providers have co-located base station antennas.

Example: Cellular Antenna Test

Return loss and DTF measurements are used together to confirm conformance to specification and identify cable/connector problems.

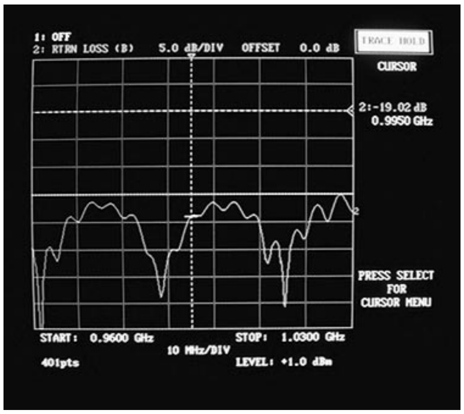


Figure 6
This swept frequency plot of a transmission line cable and antenna marginally meets the -15 dB return loss specification.

The measurements above are from a cellular cable/antenna with a corroded connector. The long cable to the bottom of the tower has 8 to 10 dB of attenuation; thus, a simple 16 dB to 20 dB (2x the cable attenuation) return loss test spec is likely to pass – even though the antenna connection is defective.

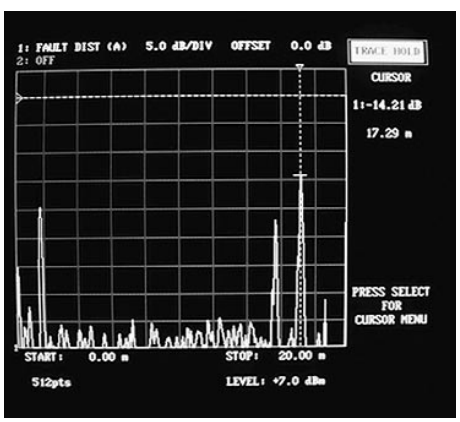


Figure 7
A Distance-To-Fault measurement reveals that the second connector is the source of excessive reflection.

Example : Avionics Test

Consider the case of a large commercial aircraft operated by a major US carrier. Pilots were alarmed by a radio link which tended to fail intermittently during final approach. Maintenance technicians repeatedly removed the aircraft from active service. Radios were swapped. The cables passed TDR tests. Return loss tests performed with a spectrum analyzer, tracking generator, and RF bridge also passed. The antenna was removed and tested in the depot with a network analyzer. Similarly, it passed all tests.

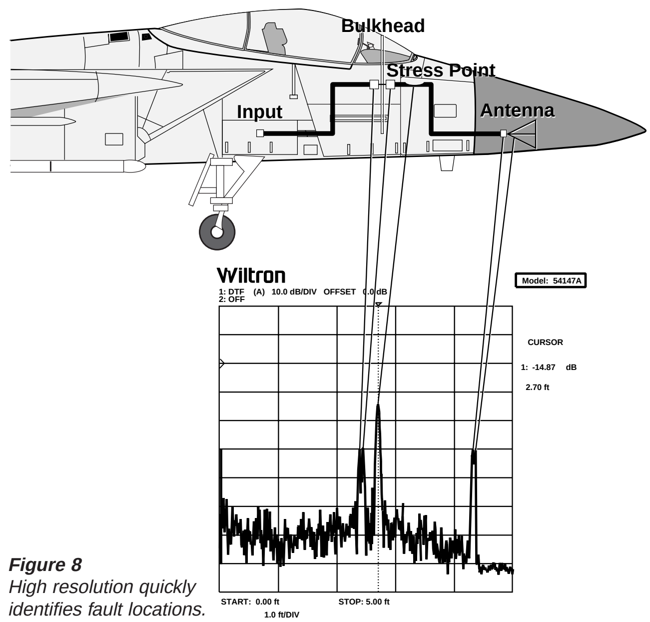


Figure 8
High resolution quickly identifies fault locations.

Months passed; pilot's complaints continued. Eventually, FDR based DTF testing was performed just after the aircraft landed. The DTF display revealed a high return loss spike at the antenna. Upon later analysis, technicians discovered that a defective weather seal had allowed intrusion of water vapor into the antenna's connector housing. The failures occurred as the aircraft descended from altitude. Ice crystals would condense into failure causing water vapor. The TDRs weren't sensitive to the "RF problem." The spectrum analyzer and tracking generator could not account for the insertion loss of the transmission line's long cable. When the antenna was removed and taken to the depot for test, the water vapor had simply evaporated. Only the FDR technique could find this type of problem. With the weather seal and antenna replaced, the intermittent outages ceased.

OPERATING MODES

The 54100A Series has three different selections for transmission line type: Coax only, Waveguide only and Coax & Waveguide. The different modes are required because waveguide is dispersive; different frequencies propagate at different speeds within the waveguide. Coaxial cable is non-dispersive. Thus, the software used to compute the discrete FFT are different dependent upon transmission line type. For example, when measuring a waveguide transmission line, the analyzer's coaxial DTF mode causes errors: the DTF spike smears horizontally across the display and is reduced in amplitude.

The Coax & Waveguide mode implements partial dispersion correction. The 54100A identifies the length of the coaxial cable during calibration, then the analyzer automatically applies the frequency dispersion correction for the waveguide portion only.

Thus, 54100A DTF measurements are accurate and repeatable regardless of the length or type of coaxial cable used as a test signal input lead.

Many cell sites (Figure 9) and telecommunications systems have some waveguide runs that are fed by short runs of coaxial cables. The measurement mode avoids separation of the waveguide connection – thus preventing intrusion of humid air, which might result in condensation and eventual corrosion. Coax & Waveguide mode is useful in shipboard applications where coax-to-waveguide transitions may be located behind a bulkhead. In applications such as aircraft mounted electronic warfare pods, waveguide transmission lines are pressurized with nitrogen to prevent dielectric breakdown.

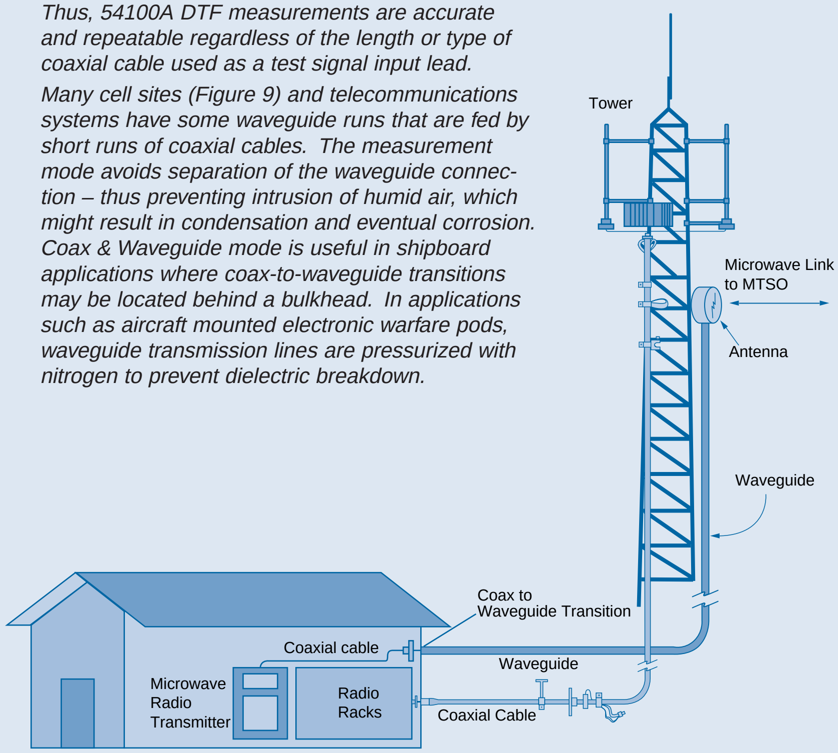


Figure 9
Coax feeders on waveguide transmission lines are common in Telecom and Military applications.

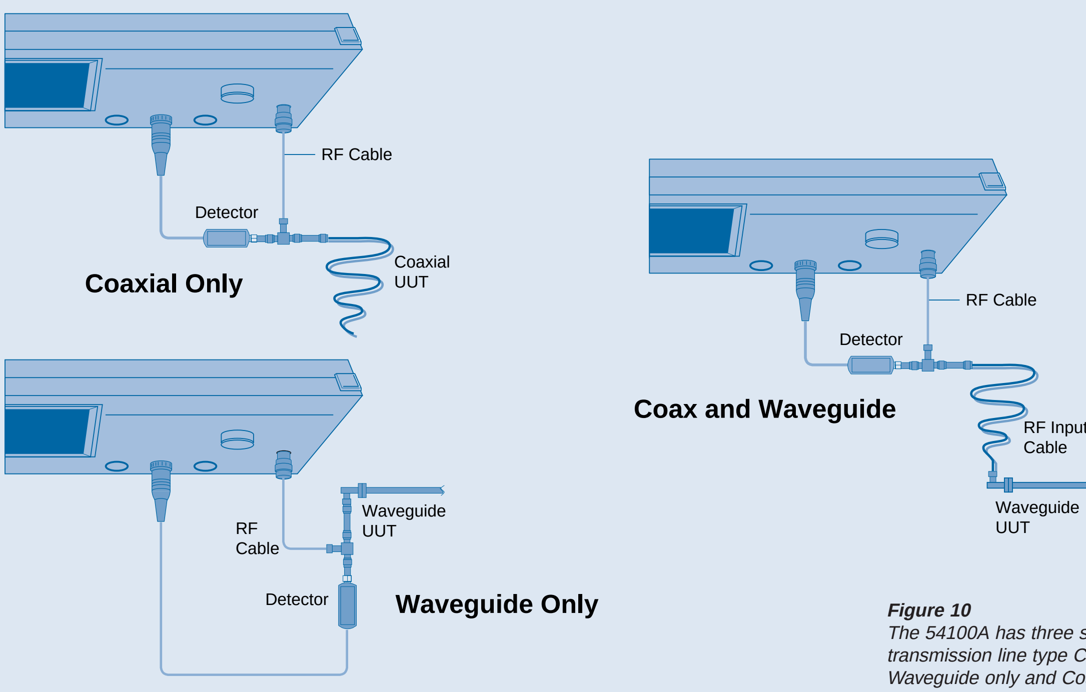


Figure 10
The 54100A has three selections for transmission line type Coax only, Waveguide only and Coax & Waveguide.

Long Procedure (Site Commissioning and Signoff) Antenna System Baseline	Short Procedure (Monthly/Quarterly Maintenance) Antenna System Verification
Step #1a: Configure 541##A Reset the Analyzer Set Channel 1 measurement to "DTF" Enter Start and Stop Frequencies Select Cable or Waveguide Type from Menu Verify Propagation Velocity & Loss Create New Cable/Waveguide Type, if Necessary Enter DTF Range Select Number of Data Points	**Step #1b: Configure 541##A** Recall Complete Instrument State or Setup Only
Step #2a: DTF Calibration Press the Calibration Key Display the Connection Instructions Perform Calibration	**Step #2b: DTF Calibration** Press the Calibration Key Display the Connection Instructions Perform Calibration
Step #3a: Perform Measurement Connect DUT Read Instrument Screen to Identify Faults If Fault is Found, Fix the Problem	**Step #3b: Perform Measurement** Connect DUT Read Instrument Screen to Identify Faults Turn ON Channel 2 and Compare to Saved DTF Data If Fault is Found, Fix the Problem
Step #4a: Store Test Results Store DTF Data (Spread Sheet Format to Disk) Store DTF Data to the Channel 2 Trace Memory **Step #5a: Save Instrument Setup** Save Setup or Complete Instrument State	**Step #4b: Store Test Results** Store DTF Data (Spread Sheet Format to Disk) Recall Setup for Next Cable Go to Step #3b: "Perform Measurement" or #2b: "DTF Calibration"

Table 4
DTF test procedure for site commissioning and periodic maintenance.

DTF MEASUREMENT Equipment

54100A with Option 7: Distance-To-Fault

RF Cable

Three Resistor Power Divider

3 dB attenuator

Precision Termination

RF Detector

Adapters (if necessary)

DTF MEASUREMENT PROCEDURE

Procedure applies to all 541XXA Series instruments with Option 7.

NOTATION

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

Initial Setup

During measurement the 541XXA is connected as shown in Figures 11 and 12. Make sure the connection of the source port, divider, detector, and 3 dB attenuator remain tight during measurements. DTF measurement is very sensitive: if any of the interconnections are rotated or moved, re-calibration is recommended.

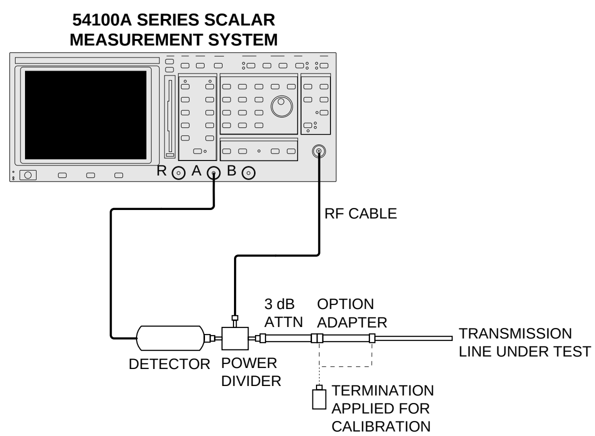


Figure 11
Coaxial Distance-To-Fault Connections

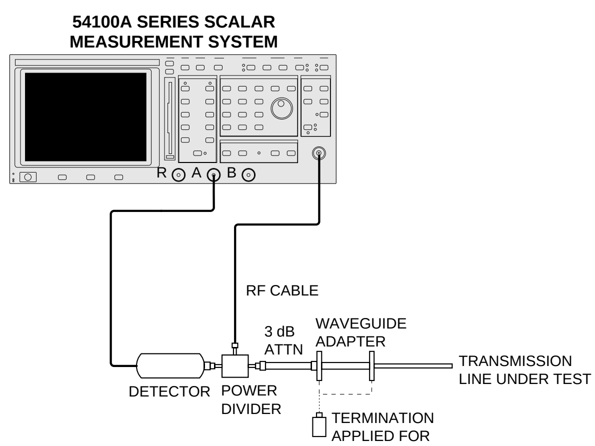


Figure 12
Waveguide Distance-To-Fault Connections

Was the antenna system baseline saved to 3.5″ DOS disk during the site/antenna commissioning? Is it available?

Yes	**Go to Step 1b, page 11**
No	**Continue at Step 1a**

Step 1a: Configure 54100A

Reset to default conditions.

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

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

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

Turn Channel 2 OFF

541XXA Channel 2 [Display On/Off]

Optional: Turn ON the Channel 1 Reference Line and the Graticule

541XXA	Channel 1 [Menu]	(REF LINE)	[Select]
		(ON)	[Select]
	[Graticule On/Off]		

Set Channel 1 to DTF

541XXA	Channel 1 [Menu]	(DTF)	[Select]

Set the frequency range corresponding to the device under test. Generally, the sweep should be wider than the antenna bandwidth. The discrete FFT's data windowing software uses FFT sidelobe controls which significantly attenuate the two ends of the frequency sweep. Two sidelobe settings are available, 42 dB "normal" and 60 dB "low". Thus, the start and stop frequency settings are normally set wider than the antenna's bandwidth. For coaxial cable tests, the frequency range is typically set wider both to improve resolution and to identify the presence of moisture or other penetrating liquids. NOTE: Cable insertion loss and reflection characteristics vary with frequency.

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

TEST TIP

Out-of-band frequency settings can also be a valuable tool. For example: if a cell site receive antenna system has multiple antennas, sweeping the frequency out of band will show large DTF display spikes at the antennas and smaller spikes at power dividers – allowing easy location of transmission line components.

Select the appropriate transmission line parameters from the built-in list or enter your own custom parameters.

Operating Mode	Characteristic Parameter
Coaxial Only	Propagation Velocity and Loss
Waveguide Only	Start, Stop and Cutoff Frequencies; Loss
Coax & Waveguide	1. Coax Propagation Velocity and Loss 2. Waveguide Start, Stop and Cutoff Frequencies; Loss

Table 5
Each of the 541XXA Series DTF operating modes requires entry of transmission line propagation characteristics.

541XXA	(SET MEDIUM)	[Select]
	under "SET MODE:" (COAX) or (WAVEGUIDE) or (COAX + GUIDE)	[Select]
	(COAX LIST) or (GUIDE LIST)	[Select]

ONLY: For "COAX & GUIDE" mode, perform the above for both the coax and the waveguide selection.

TEST TIP

If you do not use "standard" cable values, the propagation velocity and loss of coaxial cable can be determined using a known fixed length of the cable.

ONLY: To change a parameter or to add a new cable name
to the list selection. Make a selection of new coax or new waveguide, then edit the parameters.

541XXA	Channel 1 [Menu] (SET MEDIUM)		[Select]
	(ENTER NEW COAX) or (ENTER NEW WAVEGUIDE)		[Select]
	position cursor under "NAME"		[Select]
	Enter the new name		
	DONE		[Select]

Enter the new coax propagation velocity or the waveguide characteristic frequencies.

[#] [#] [Enter]

Enter the new loss per meter or foot.

[#] [#] [Enter]

NOTE: Loss per meter is dependent upon the DTF frequency sweep range. Press the "Calibration" key to see the DTF frequency sweep range.

ONLY: For "COAX & GUIDE" mode. Above can be performed for both

Optional: Feet or Meters can be selected under the System Menu Key located below the number keypad.

541XXA	[System Menu]	(SYSTEM SETUP)	[Select]
		(MORE)	[Select]
		(FEET)	[Select]

Set the DTF range to approximately 1.5 times (but not more than 2 times) the expected length of the transmission line. This enables the 54100A's high-performance, anti-aliasing software.

541XXA	Channel 1	[Menu]
	(RANGE) [#] [#]	[ENTER]

The analyzer may automatically increase the DTF distance range setting. To reduce the DTF distance range, increase the DTF frequency sweep range and/or reduce the number of data points.

Go to step 2a, DTF Calibration, page 12.

Step 1b: Recall antenna system baseline setup data from 3.5″ disk.

A disk with the site number written on the label should be available to you. Install the disk into the 54100A and recall the previously stored instrument setup.

NOTE

A separate instrument setup is stored for each antenna feed because baseline test data, the cable/antenna's "signature", is stored in the channel 2 comparison mode memory.

Press the save/recall key and recall the previously saved setup.

541XXA	[Save/Recall]	(DATA TYPE)	[Select]
	(SETUP ONLY) or (COMPLETE INST STATE)		[Select]
	(RECALL)	[#] [#] [Enter]	[Select]

The previous antenna cable measurement will be stored on channel 2 of the recalled setup. After calibration and measurement, the channel 1 DTF test data will be compared to the stored, channel 2 cable "signature."

TEST TIP

Consider using at least two saved setups per antenna feed. The first setup uses a narrow frequency sweep that is within the band of the antenna. Since DTF software automatically compensates for cable (or waveguide) insertion loss, the antenna's return loss will be clearly displayed. A second setup uses a wider sweep for testing the cable (or waveguide) and identifying in-line devices such as, adapters, connectors, power dividers, and lightning arrestors. The wider frequency sweep provides better display resolution.

Step 2a & 2b: DTF Calibration

Start the Calibration by pressing the Calibration Key.

541XXA	[Calibration]

Optional: Display the connection instructions.

541XXA (INSTRUCTIONS) [Select]

Note: Wiltron can customize this display for special part numbers and local language. Contact your sales representative.

Exit the instructions

541XXA [Clear]

Start the Calibration process.

(PERFORM CALIBRATION) [Select]

Follow the prompts on the 54100A display screen

ONLY: For Coax & Waveguide Mode.

DURING CALIBRATION: Use the spin knob to place the cursor at the spike caused by the coax-to-waveguide transition. Or, use the keypad to enter the length of the coaxial transmission line input to the waveguide run.

If you will compare the measurement to a previously saved system "baseline" go to step 3b: Perform Measurement.

Step 3a: Perform Measurement.

Connect the DUT and verify the display setup parameters. If the opposite end of the transmission line is an open or short circuit, the spike should peak at approximately the 0.0 dB reference line. This principle can be used to set the correct value of insertion loss per meter. This value is likely to change every time the DTF frequency sweep range is changed. You can check the current frequency sweep range by pressing the "Calibration" key.

Alternately, if an antenna is attached, and the frequency is set to the antenna's bandwidth, the spike should now display the correct return loss of the antenna. If the frequency sweep excludes the antenna bandwidth, the result will almost reach the 0.0 dBm open/short circuit value.

NOTE

RF cables are not perfect. The propagation velocity will vary slightly through the length of a cable. The dielectric thickness – which determines the impedance characteristics – tends to vary by about 10% in typical cables. The loss per meter will also have some variation.

If a fault is found, perform the repair.

Go to step 4a: Store Test Results

Step 3b: Perform Measurement

Connect the DUT and verify the display setup parameters.

Turn on the channel 2 compare mode to see if any transmission line characteristics have changed.

541XXA Channel 2 [Display On/Off]

Inspect the transmission line if there is any significant difference between the two displays. Small differences may occur seasonally, but large differences are indicative of an impending problem.

If any changes or repairs are performed or if the measurement is new "baseline" data, procede to step 4a, otherwise go to step 4b: Store Test Results on page 13.

Step 4a: Store Test Results

Store the measured DTF trace to the Channel 2 compare mode trace memory. Future measurements will be compared to this stored data.

541XXA Channel 2 [Display On/Off]

Channel 2 [Menu]

(STORE DTF DATA TO TRACE MEMORY) [Select]

(VIEW TRACE MEMORY) [Select]

Automation Tip: The Spreadsheet Format must be used so that maintenance reports can be automatically generated in the Windows PC operating system. The Spreadsheet Format eliminates the need for manual ASCII-to-database format data conversion steps.

Automation Tip: Press the Save/Recall Key. Under "CONFIGURE" you may set a file name extension that matches a particular PC spread sheet.

When testing multiple antenna feeds during the installation process, the AUTOSAVE automatic file naming system provides additional convenience.

Save the trace data to disk in the Spreadsheet Format. Memory locations 21 to 99 are on the disk drive.

541XXA [Save/Recall] (DATA TYPE) [Select]

(DISPLAYED TRACES (SPREADSHEET FORMAT)) [Select]

(SAVE) [Select]

under SAVE TO [2] [1] [Enter] [Select]

NOTE

This step over-writes any previous baseline data. If you re-store this "COMPLETE INST STATE", be sure to use a different name than any previously saved System Baseline configuration data.

Go to step 5a: Save Instrument Setup

Step 4b: Store Test Results

Save the trace data to disk in the Spreadsheet Format. Memory locations 21 to 99 are on the disk drive.

541XXA	[Save/Recall]	(DATA TYPE)	[Select]
	(DISPLAYED TRACES (SPREADSHEET FORMAT))		[Select]
	(SAVE)		[Select]
	under SAVE TO [2] [2] [Enter]		[Select]

Recall the Setup for the Next Cable.

541XXA	[Save/Recall]	(DATA TYPE)	[Select]
	(SETUP) or (COMPLETE INST STATE)		[Select]
	(RECALL) [#] [#] [Enter]		[Select]

Go to Step 3b, page 11

Step 5a: Save Instrument Setup

Save this Complete Instrument State or Setup Only to disk for future comparisons. Memory locations 21 to 99 are on the disk drive. This step should always be completed during site commissioning or whenever a new antenna feed is tested for "baseline performance signoff".

541XXA	[Save/Recall]	(DATA TYPE)	[Select]
	(SETUP ONLY)		[Select]
	(SAVE)		[Select]
	[4] [1] [Enter]		[Select]

Proceed to the next cable or waveguide transmission line. If the transmission line and antenna are the same type as previous, go to Step 3a – re-calibration is not necessary. If the transmission line type and frequency ranges are different, go to Step 1a, page 10.

DTF Performance

Resolution and distance range are dependent upon the frequency sweep width. With adequate frequency sweep range, 3 millimeters can be resolved. Distance range can exceed 5 kilometers.

DTF software optimizes sensitivity and return loss measurement accuracy. For example, a precision termination is used during calibration. If the termination is not of high quality, it will reflect some of the source energy rather than absorb it – causing errors in the measurement process.

Low source harmonics ensure that fault indications are from the transmission line – not re-reflections of source harmonic energy.

The use of a specialized Discrete Fourier Transform rather than a more common Fast Fourier Transform also improves performance.

High performance anti-aliasing software prevents the display of false or "ghost" transmission line faults. This is a common problem when the end of the UUT is unterminated or damaged.

High DTF dynamic range is achieved only when 1) source harmonics are as low as possible, 2) precision terminations are used for calibration, 3) anti-aliasing software reduces "ghost faults" from re-reflections.

DTF Accuracy

The accuracy of a Distance-To-Fault measurement is based upon the sensitivity of L to non-linearities of the Δf frequency sweep. Absolute frequency accuracy is not a factor of the formula. Rearranging equation (1) and separating constants ("2", "n", and "c"), note that L is a function of both Δf and k_p.

$$\text{Fault Distance "L" in meters} = L = (nc/2)\,(k_p/\Delta f) \qquad (3)$$

If we assume that the frequency is swept in a linear, but erroneous fashion (such as the sweep is set to cover 1.0 to 3.0 GHz, but the source sweeps only 1.0 to 2.0 GHz), it is possible to cause the DTF display "spike" to move from the correct position. In actual practice however, YIG based frequency sources do not sweep in such an erroneous fashion, they instead have small – essentially random – variations in the sweep step characteristics. This property tends to spread or expand the width of the displayed fault location rather than move it's peak, accurate location.

This type of error is further reduced by the fact that very many ripples are swept during DTF measurements. Thus, any random sweep non-linearity is averaged over multiple ripple cycles. The 54100A's crystal-stabilized, marker-locking source forces the sweep to an aggregate linear trend during the sweep. Thus, with fixed reference points during the sweep, the average sweep linearity is stabilized to the crystal's 1 ppm (10^{-6}) reference accuracy – a full three order's of magnitude away from the specified 0.1% (10^{-3}) of distance performance. While the average sweep linearity is not equivalent to the 10^{-6} stability of the 54100A's crystal reference, it is significantly better than 10^{-4}. Thus, the instrumentation accuracy for a DTF measurement is typically better than 0.01%. A 0.1% specification on "instrumentation accuracy" is extremely conservative.

When there are small ripple-to-ripple non-linearities, the width of the displayed fault spike will be wider and shorter rather than inaccurately placed on the distance display. Thus, the practical effect of any frequency linearity jitter during sweep is upon the displayed average return loss accuracy rather than upon fault location accuracy. If this proved problematic, the analyzer's frequency sweep is simply set to cover a slightly wider frequency range, a practice which provides additional linearity averaging.

An accuracy specification of 0.01% or 0.1% of distance can be mis-leading. While the FDR analyzers meet this performance, it is almost impossible to achieve it in the field. Why? It's because of the cables being tested. It's the difference between "DTF Instrumentation Accuracy" and the more practical concern, "Measurement Accuracy".

DTF software, as well as vector analyzer based Time Domain software, are based on the assumption of a specific relative propagation velocity value for the cable or transmission line. Note equation (3) again. If the propagation velocity is deliberately set incorrectly, the analyzer's display will identify the fault's location at the wrong distance.

Relative propagation velocity is calculated as 1/[SQRT(relative dielectric constant)]. The dielectric constant is determined by several factors including the dielectric type of the transmission line and the diameter thickness of that dielectric. Manufacturers of flexible cable – even the highest quality cables – routinely have dielectric constant variations of ±10% along the cable's length. Low quality (inexpensive) cables have even greater variation in dielectric constant. Given today's emphasis on low cost products, the latter represents the most common situation confronting RF service technicians. Further practical impediments to absolute distance accuracy include the various filters, diplexers, adapters, and differing cable types that are typical of most all RF transmission lines. Despite the fact that the analyzer itself is extremely accurate, the characteristics of the DUT confound attempts to specify absolute distance accuracy requirements for practical, in-service measurements.

The net effect is that each transmission line will have it's own "signature" or "finger print" on a DTF display. This is the reason that a DOS disk drive and an automated Comparison Mode is built into the 54100A. When historical data is compared to recent data, large changes in the "signature" indicates a problem. Small changes may indicate aging or dimensional changes due to seasonal temperature conditions.

Is "DTF Measurement Accuracy" critical to the maintenance process? Probably not. The accuracy is adequate when it provides repeatable DTF analysis. Using either analog or synthesized sweep sources, typical absolute measurement accuracy for tower mounted transmission lines is within 1 foot, slightly better than a technician's ability to measure physical length on a tower mounted cable or waveguide transmission line. Further, most service problems are either physical damage or connector problems. Physical characteristics such as connectors, adapters, and bends show up clearly on the DTF display, so identifying a problematic transmission line section is straightforward. For higher frequency cables, accuracy and resolution to 2.0 mm is typical.

From an engineering perspective, DTF is a troubleshooting tool rather than a system performance specification. Components within an RF system are specified in terms of Insertion Loss and Return Loss (or SWR). It is significantly more important that a measurement system maximize the absolute accuracy of these frequency domain measurements.

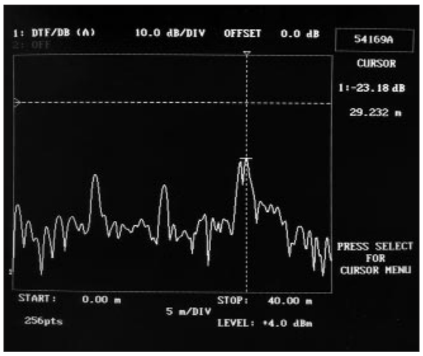
For more information concerning measurement accuracy, see Wiltron Application Note AN54100A-1: "Return Loss Measurement Accuracy."

SUMMARY

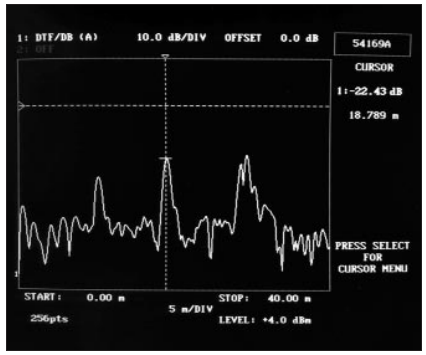
Frequency Domain Reflectometry identifies the health of installed transmission lines – even in the presence of external RF interference. As a troubleshooting tool, FDR techniques pinpoint damage and impending failure conditions. By contrast, previous TDR based fault location and Spectrum analyzer based return loss measurements are error prone and susceptible to RF interference. FDR finds potential problems quickly and reliably – allowing cellular service professionals to implement preventative maintenance plans and reduce cost-per-cell expenses.

Free technical seminars, applications notes, and analysis software covering measurement accuracy are available from Anritsu Wiltron. Contact your local representative for more information.

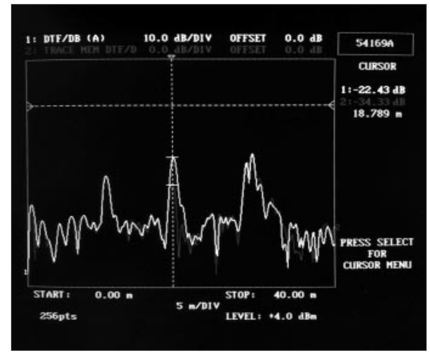
Distance-To-Fault “Signatures” Isolate Cable Problems



a)



b)



c)

Figure 16:
Baseline performance data a) is recorded during site commissioning tests.
Later measurements at regular maintenance intervals b) are compared c) to the baseline data.

Microwave transmission lines tend to have unique Distance-To-Fault (DTF) “Signatures”. The DTF Signature is an excellent indicator of the transmission line’s health because small changes in physical conditions – such as might be caused by dents, moisture accumulation or corrosion – cause large changes in the DTF measurement. Thus, quality problems can be isolated early, before more serious damage and service interruption results.

Figure 16a is a measurement of LDF coaxial cable and an NAMPS cellular antenna. The display cursor is positioned at the antenna’s phasing coil. A poor quality N-type connector interface to the LDF cable makes the antenna appear to have a double peak. The return loss performance of 23 dB meets specification for NAMPS antennas, but might cause adjacent channel interference problems in TDMA or CDMA based digital transmissions. The two single peaks of approximately 10 meters and 18 meters are N connectors joining separate lengths of cable.

Figure 16b is a subsequent maintenance test. When baseline data is recalled, figure 16c, the second N connector appears to be damaged. Subsequent investigation revealed that the connector had loosened – most likely during application of the weather seal. After the connector was re-torqued, the DTF signature matched the original baseline data. Thus, it was not necessary to climb the tower to re-perform other transmission line tests for insertion loss or third order intermodulation.

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