

# Keysight Technologies

## Techniques for Precise Cable and Antenna Measurements in the Field

### Using FieldFox handheld analyzers

#### Application Note



This application note introduces the practical aspects of cable and antenna testing, interpreting measurement results and instrument operation including calibration options such as CalReady and QuickCal using a Keysight Technologies, Inc. FieldFox handheld analyzer configured as a cable and antenna analyzer. Measurement examples are provided showing techniques for measuring insertion loss, return loss, and locating faults in a transmission system. *Carry precision with you.*

# Introduction

Cable and antenna measurements are often required to verify and troubleshoot the electrical performance of RF and microwave transmission systems and antennas. In RF and microwave communications industries, measurements are often made along the coaxial cable connecting a transmitter to its antenna and/or between an antenna and its receiver. This process is sometimes referred to as Line Sweeping and results in the measurement of the signal attenuation and return loss as a function of frequency. Line sweeping may also be used to estimate the physical location of a fault or damage along the transmission line using the Distance-to-Fault (DTF) measurement available on many RF and microwave signal analyzers such as FieldFox. Testing the performance of transmission lines is not limited to only coaxial cable types but systems using waveguide and twisted pair cables may also be characterized once the appropriate adapter is installed between the transmission line and the coaxial interface on the analyzer. In addition, antenna measurements, in the form of signal reflection, or namely return loss and VSWR, may be used to verify the performance of an antenna at the installation site. When multiple antennas are required at an installation site, whether the antennas are associated with the same system or different systems, the antenna-to-antenna isolation may also be verified using FieldFox.

Figure 1 shows a typical return loss measurement (upper trace) and DTF measurement (lower trace) for an X-band antenna connected to a 3-meter length of coaxial cable. The antenna was mounted on a vertical mast at a roof-top installation and measured using FieldFox configured with a preset calibration called CalReady. The return loss measurement includes two frequency markers placed across the specified operating band at 8 GHz and 12.4 GHz. The DTF measurement includes a distance marker placed at the location of the antenna at 3.23 meters.

This application note will introduce the practical aspects of cable and antenna testing, interpreting measurement results and instrument operation including calibration options such as CalReady and QuickCal using FieldFox.

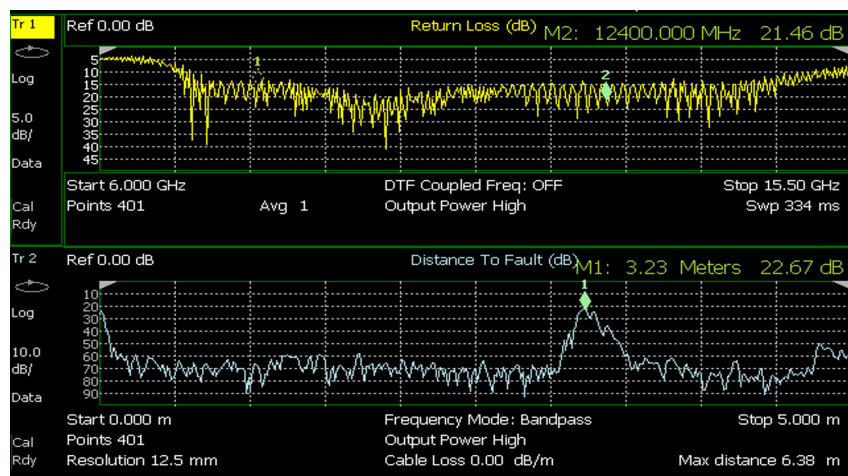


Figure 1. Measured return loss (upper trace) and distance-to-fault (lower trace) for an X-band antenna and coaxial feed cable

## Why Is Cable and Antenna Testing Important?

During the installation, operation and maintenance of a telecommunication system, the connecting cables, adapters and antennas may become damaged or show reduced performance over time. It is known that fifty to sixty percent of cellular base station problems are caused by faulty cables, connectors and antennas. Failure in these components causes poor coverage and unnecessary handovers in the cellular system. In any communication system, it becomes important to have a process and the appropriate instrumentation to verify the performance of the cables and antennas when issues are discovered at the system level.

Cabling and antennas may be installed in a variety of environments including outdoor and indoor installations. Outdoor installations may include roof-top, tower mounted and underground cabling. Indoor installations may include equipment shelters, office buildings, shipboard, aircraft and certain automotive applications. At an outdoor installation of a wireless cellular system, the antenna and portions of the coaxial cabling are often exposed to extreme weather conditions including rain, snow, ice, wind and lightning. Severe environmental conditions can potentially create physical damage to the system components including failed waterproof sealing at interfaces between cables and connectors, failed sealing at cable splices, and weather-induced cracks in the insulation resulting in an ingress of moisture into the cables and interfaces. Sheltered installations can expose components to mishandling, stress, heat, vibration, and oils and other containments that could leak into the system. Cable fault can also occur at any interface between the cables and connectors where solder joints and cable crimps become fatigued and break. It is also possible that cables can be dented,

crushed or improperly routed during or after installation. Conditions may also be created where the minimum bend radius is exceeded beyond the value specified by the cable manufacturer. For example, low-loss coaxial cable may have a specified minimum bend radius of 1 inch to over 10 inches and bending the cable below the specification will cause damage to the cable and substantially degrade its electrical performance.

Verifying and maintaining the operation of the RF and microwave transmission system, including coaxial cable, waveguide and twisted pair line, and antennas, requires fast and accurate measurements of the insertion loss and the return loss as a function of frequency. Also important to field operations is the capability to quickly troubleshoot and locate faults and damage in cables and connectors. A modern handheld analyzer, such as FieldFox, configured for cable and antenna testing (CAT), is an extremely useful tool for characterizing the entire transmission system as well as the performance of individual components in the system. In the next few sections of this application note, measurement examples will be provided showing techniques for measuring insertion loss, return loss and locating faults in a transmission system. The measurements will be made using a FieldFox N991XA analyzer with frequency range up to 26.5 GHz.

## Cable Insertion Loss Measurements

The insertion loss of transmission line or coaxial cable is often measured as a function of the intended operating frequency band. The insertion loss, also referred to as the cable attenuation, is the amount of energy dissipated in the cable. The insertion loss also includes energy lost due to mismatch reflection between the source and load. It is expected that the source (transmitter), the transmission line (coaxial cable), and the load (antenna) are all designed for the same characteristic impedance,  $Z_0$ , usually 50 ohms or 75 ohms when using coaxial cable. It has been shown [1] that coaxial cable having an air dielectric has the lowest insertion loss at 75 ohms and the highest power handling capability at 30 ohms. The Cable TV (CATV) industry has standardized on 75-ohm cable in order to maximize signal transmission over very long cable distances required by the system. On the other hand, the majority of the RF and microwave industry has standardized on 50-ohm impedance as a compromise between the lowest loss and the highest power handling. Most RF and microwave analyzers, such as FieldFox, are configured with 50-ohm test port impedances. When measuring 75-ohm cables and components, 50-ohm to 75-ohm adapters, such as the Keysight Technologies, Inc. N9910X-846, should be connected to the analyzer.

Once the transmission line cables are installed into a system, it is often difficult and costly to remove them in order to verify their operation and troubleshoot cable failures. Also with very long cable runs, access to both ends of the cable at the same time is typically impossible, especially when attempting to connect the cable to the test instrumentation. Under these conditions, techniques that allow cable insertion loss measurements to be made from only one end of the cable are preferred. Figure 2 shows two configurations for measuring the insertion loss of a cable using Field-

Fox with CAT mode. Figure 2a shows the traditional method for measuring the insertion loss of a cable using a two-port technique. Figure 2b shows a novel technique, available on the FieldFox, for measuring the insertion loss of a cable using measurements obtained from only one end of the cable. Both of these techniques will be discussed.

In the traditional two-port setup, the cable under test is connected to two separate ports on FieldFox. FieldFox injects a test signal into the cable from the RF OUT port conveniently positioned along the top of the analyzer. As the test signal passes through the cable, a small portion of the energy is absorbed by resistive and dielectric losses in the cable. Discontinuities from cable connectors, cable splices, damage and other factors will reflect a portion of the energy back to the source resulting in an additional increase in the measured insertion loss. The remaining signal exiting the cable is then measured by FieldFox at the RF IN port.

The ratio between the input and output signals represents the total insertion loss of the cable usually expressed in decibels (dB). An ideal lossless cable would have 0 dB insertion loss. The cable manufacturer usually provides a table of the insertion loss as a function of frequency. For example, an LMR900 coaxial cable would have 2.2 dB insertion loss for a 100 meter length of cable measured at 150 MHz. The same cable would have 7.4 dB loss at 1.5 GHz. Those familiar with vector network analyzers (VNA) will recognize this insertion loss measurement as the absolute value of the  $S_{21}$  transmission scattering parameter (S-parameter). Additional information regarding VNA options on FieldFox and the basics of network analysis can be found at the following references [1] and [2]. It should be noted that accurate insertion loss measurements require an initial calibration of FieldFox.

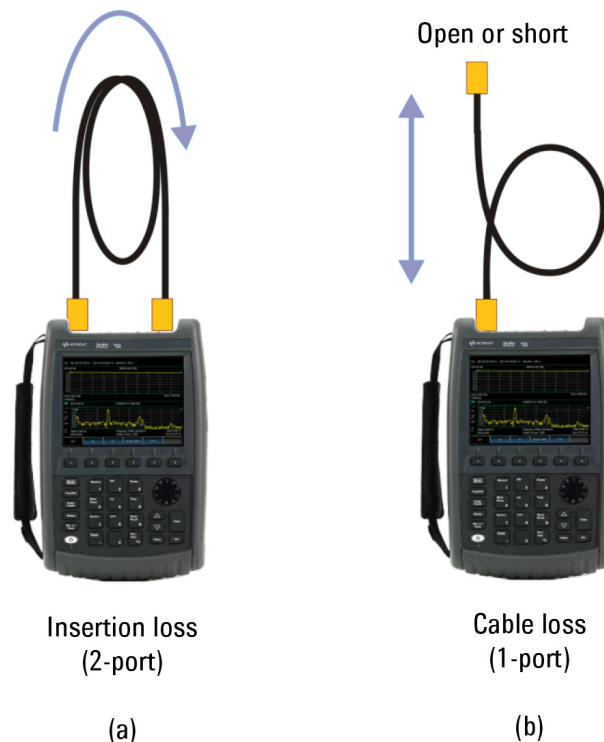


Figure 2. Configurations for measuring the insertion loss of a cable using FieldFox with CAT mode

## Cable Insertion Loss Measurements (continued)

The calibration removes the insertion loss effects of the equipment, adapters and jumper cables as a function of frequency. The calibration of FieldFox for making one and two-port measurements will be discussed later in this application note. Figure 3 shows the insertion loss measurement of a coaxial cable using the 2-port technique over the frequency range of 30 kHz to 18 GHz. This figure also shows a measurement of the insertion loss using a 1-port cable loss technique to be discussed next.

As previously mentioned, when a cable is installed into a system, it is often difficult to physically connect FieldFox to both ends of a very long cable without introducing an equally long jumper cable into the test setup. Fortunately, FieldFox has a convenient technique to measure cable insertion loss from only one end of the cable under test. This eliminates the need to carry an extra-long, high-quality test cable as part of the equipment requirements. Figure 2b shows the simple 1-port configuration for measuring cable insertion loss by attaching one end of the cable to FieldFox and leaving the other end open or terminated in a short. It is preferred at microwave frequencies to use the short circuit to eliminate fringing fields found in an open-ended cable which could alter the measured results. In this configuration, FieldFox injects a test signal into the cable from the RF OUT port, same as before. The test signal passes through the cable, is completely reflected from the open end (or shorted end), passes through the cable a second time and lastly measured by FieldFox using the same port. FieldFox is configured with an internal factory-calibrated “reflectometer” 1 for measuring reflected signals at the RF OUT port. This internal calibration, called CalReady, is available at instrument turn-on and instrument preset and will be discussed later in this application note.

Once the reflected measurement is complete, FieldFox, using a built-in model for coaxial cable dispersion and knowing that the measured signal contains twice the cable insertion loss (due to the round trip path), can now report the cable insertion loss as a function of frequency. Figure 3 shows a comparison of the measured insertion loss using the 2-port and 1-port techniques. In this figure, the blue line represents the 2-port insertion loss measurement and the yellow line represents the 1-port cable loss measurement. As observed in figure 3, the 1-port technique contains additional amplitude ripple across the measured frequency range due to mismatch effects between the open (short) and the input connector. Using FieldFox, the amplitude ripple may be reduced with an additional measurement of a 50-ohm load placed at the end of the cable under test. In this case, the measurement of the 50-ohm load is saved to memory using the Trace, Data-> Mem.

The load is removed and the cable is terminated in an open (or short), same as before. The measurement of the open (short) is then subtracted from the memory using the Data Math, Data-Mem. This additional measurement step may improve the observed ripple in the 1-port cable measurement. In general, the traditional 2-port insertion loss measurement will be more accurate than a 1-port cable measurement but having a measurement process that does not require an instrument connection to both ends of the cable is a great benefit when characterizing installed cabled systems.

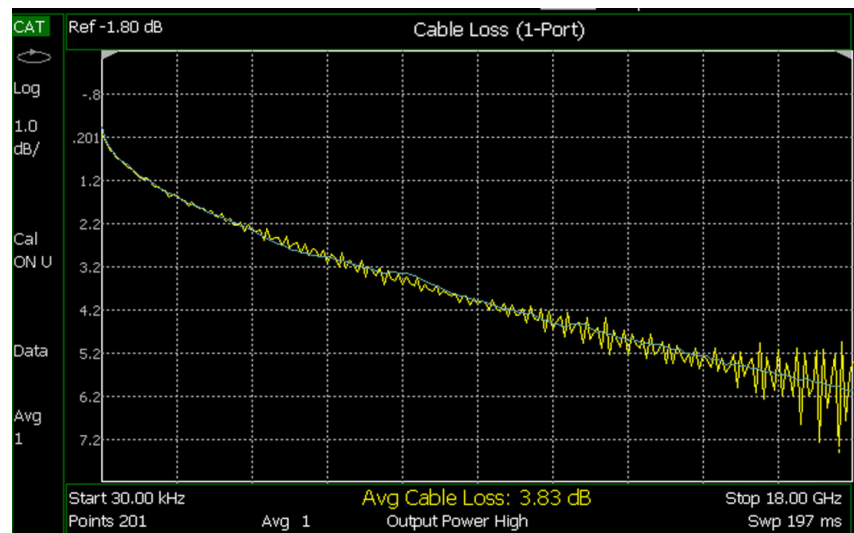


Figure 3. Measurement of coaxial cable insertion loss using a novel one-port technique (yellow) and a traditional two-port technique (blue), both available on FieldFox

## Cable Insertion Loss Measurements (continued)

There is another configuration for measuring cable insertion loss that does not require a long coaxial cable in the return path back to FieldFox. In this configuration, FieldFox is configured as a power meter connected to a Keysight U2000 Series USB power sensor. As shown in figure 4, one end of the cable under test is directly connected to the RF OUT port of FieldFox. The other end of the installed cable is connected to the USB power sensor. FieldFox is configured to generate a CW signal at the RF OUT port. This CW signal is the test signal that will be transmitted along the cable and measured by the USB power sensor. If the cable ends are physically separated by a large distance, the USB sensor can be connected back to FieldFox through a USB cable extender. USB cable extenders are commercially available with ranges of 500 meters or more. This configuration overcomes the limitation of running an expensive coaxial cable between one end of the installed cable back to the instrument. The main constraint using the power meter solution is that swept frequency measurements are not available and therefore changing test frequencies will require manual tuning of FieldFox's settings.

When measuring cables with high insertion loss, the displayed measurement trace may exhibit a relatively high level of noise as the measured signal amplitude approaches the noise floor of the analyzer. One way to improve the relative signal to noise and improving the associated measurement accuracy is to set the output power on FieldFox to High Power mode. High Power mode is the default setting for FieldFox and is typically used for most passive device measurements. The Low Power mode is typically used when measuring high-gain or low-noise amplifiers to prevent saturation and potential damage to the amplifier.

The High Power setting results in a port power of approximately +5 dBm, the Low Power setting is approximately -25 dBm.

Other techniques to reduce the displayed noise level include increasing the number of trace averages or decreasing the IF bandwidth setting. Trace averaging will reduce the effects of random noise on the measurement by averaging the results from multiple sweeps. FieldFox trace averaging can be set over a range from 1 (no averaging) to 1000.

Knowing that trace averaging requires the measurement of multiple traces, it should be expected that there will be an increase in the total measurement time as multiple sweeps are required. Reducing the IF bandwidth setting on FieldFox will also reduce displayed noise. The IF bandwidth can be adjusted over the range of 100 Hz to 300 kHz. It should be noted a lower IF bandwidth will also increase the overall measurement time as lower bandwidths increase the instrument sweep time.

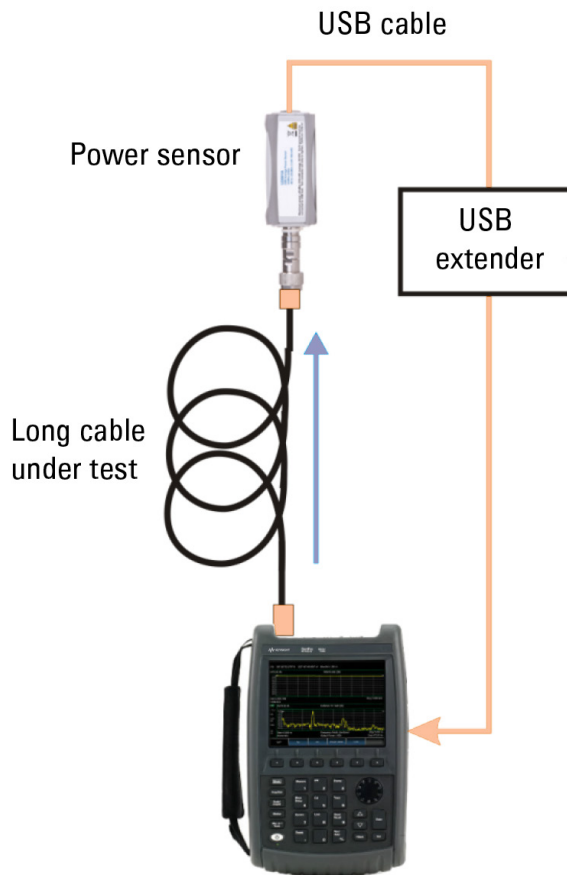


Figure 4. Configuration for measuring cable loss using FieldFox and a USB power sensor

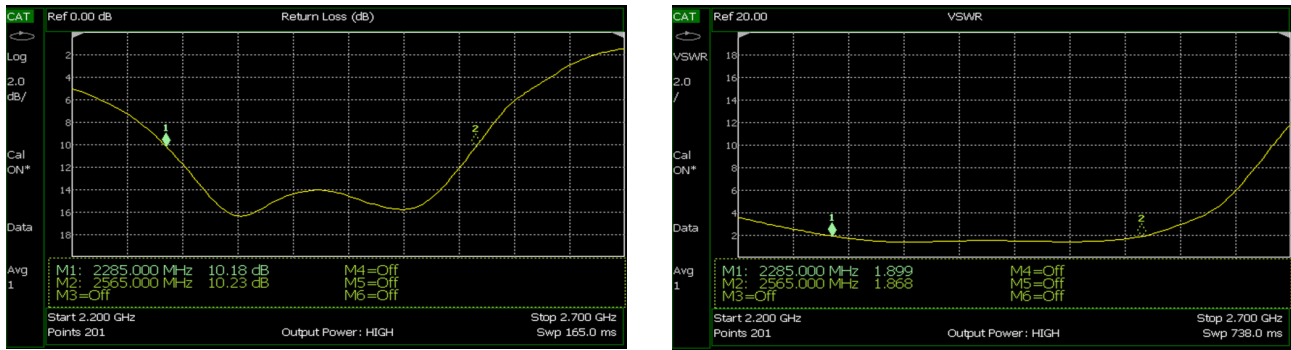


Figure 5a and 5b. Frequency response measurement of a panel antenna showing (a) return loss (dB) and (b) VSWR

## Antenna Return Loss and VSWR Measurements

Antennas are specified by their gain factor and return loss or voltage standing wave ratio (VSWR). The return loss and VSWR are standard measurements reported for most RF and microwave components and systems and can easily be measured with FieldFox in the field or in the lab. Antenna gain measurements are typically performed in a special test facility, such as an anechoic chamber. During antenna gain testing, a transmission measurement is made from the antenna under test to a second calibrated antenna, and any free-space loss, are removed from the transmission measurement resulting in the desired antenna gain. The measurement of antenna gain in the field is rather difficult as environmental reflections and inaccessibility around the antenna prevent this type of testing. When an antenna is installed in a system, it will therefore be required to only measure the reflection properties of the antenna in order to determine if an antenna is faulty or damaged. Return loss and the associated VSWR will be used to characterize the performance of an antenna. These 1-port measurements are typically performed over the intended frequency band of interest.

A typical antenna with a return loss of 10 dB or higher would represent a reasonably well-matched antenna. A 10-dB return loss is equivalent to having 90% of the incident energy radiated by the antenna with 10% of the energy being reflected back to the transmitter. For some applications where high efficiency is required, such

as base station antennas, the return loss may be specified at 15 dB or higher. A 10-dB return loss is approximately equal to a VSWR of 2:1 which is also quoted in the specifications. Appendix A includes a conversion table relating values of return loss to VSWR. Fortunately, FieldFox handles this conversion and can be configured to display the measured response as return loss (dB) or VSWR.

Figure 5 shows the measured reflection characteristics of a 2.4 GHz patch panel antenna. This antenna included a short 6-inch length of 50-ohm coaxial cable ending with a Type-N female connector at the end. A standard Type-N male-to-male adapter was required to interface the antenna to the Type-N female connector of FieldFox. When interfacing any component to an instrument, it is very important to use high quality adapters to improve the accuracy and repeatability of the measurement. For this measurement example, the adapter and cable was included as part of the measured results. The adapter characteristics can be removed from the measured results by using the QuickCal or O,S,L calibration available on FieldFox. Calibration options will be discussed later in this application note. Figure 5a shows the measured return loss over the range of 2.2 to 2.7 GHz. Two markers are placed at the points of 10-dB return loss signifying an appropriate bandwidth for this antenna. A marker table lists the amplitude and associated frequency for each active marker up to a total of six. Figure 5b shows the equivalent VSWR measurement for

the same antenna. When measuring the reflection characteristics of an antenna, it is important to attach the analyzer as close to the antenna as possible. If a long length of cable is inserted between the antenna and the analyzer or if the cable has become excessively lossy due to damage, then the high insertion loss of the cable will mask the true return loss of the antenna. For example, if the return loss of a damaged antenna is actually 6 dB but a jumper cable with 3 dB insertion loss is connected between the antenna and the analyzer, then the measured return loss of the combination of the antenna and cable would be 12 dB ( $3 \text{ dB}_{\text{cable loss}} + 6 \text{ dB}_{\text{antenna RL}} + 3 \text{ dB}_{\text{cable loss}}$ ). In this case it would be necessary to attach the analyzer directly to the antenna in order to properly measure the true performance of the antenna or perform a user calibration at the end of the jumper cable.

When making measurements with FieldFox attached to an antenna, it may be possible that undesired interference from outside the system may be captured by the antenna and measured by FieldFox. The interference may appear as a spike or lack of stability in the measured trace. FieldFox includes an Interference Rejection setting that may minimize the effects of any interfering signal. The Interference Rejection setting is found under the Measurement Setup menu. Once enabled, up to six measurement sweeps may be required to reduce or eliminate the interference.

## Antenna-to-Antenna Isolation

In many wireless applications, different systems will be co-located to share tower and shelter structures. For example, figure 6a shows a typical repeater where antennas from multiple systems are mounted onto the common structure. It is important that antennas, either operating within the same system or between different systems, are physically spaced far enough apart to maintain an adequate level of isolation in order to prevent the creation of intermodulation distortion in the transmit amplifiers and/or noise desensitization in the receivers. Intermodulation distortion and receiver desensitization may be created when energy from a high power transmitter radiated from one antenna couples into a nearby antenna and enters the amplifiers of the coupled system. Systems are often designed with duplexing and other filters to reject signals from nearby transmitters and other interference but system performance may require an antenna-to-antenna isolation of 60 dB or more. It is therefore necessary to sweep the antenna-to-antenna isolation across all frequency bands of interest. Figure 6b shows a configuration for measuring the antenna-to-antenna isolation using FieldFox. FieldFox is set to measure 2-port insertion loss and calibrated using short jumper cables with a “normalize” calibration type. The measurement of isolation is reciprocal so it does not matter which antenna is attached to the RF OUT port of FieldFox.

Figure 7 shows an example of the measured isolation between two panel antennas mounted to a common structure. One antenna was designed to operate in the 900-MHz band and the other at 2.4 GHz. As shown in this figure, the antenna-to-antenna isolation is above 44 dB across the 902 to 928 MHz band but is only 35 dB in the 2.4 to 2.485 GHz band. This level of isolation implies that energy transmitted from the 2.4-GHz system will enter the 900-MHz receiver front-end at a



Figure 6a. Microwave repeater showing multiple co-located antennas.<sup>3</sup>

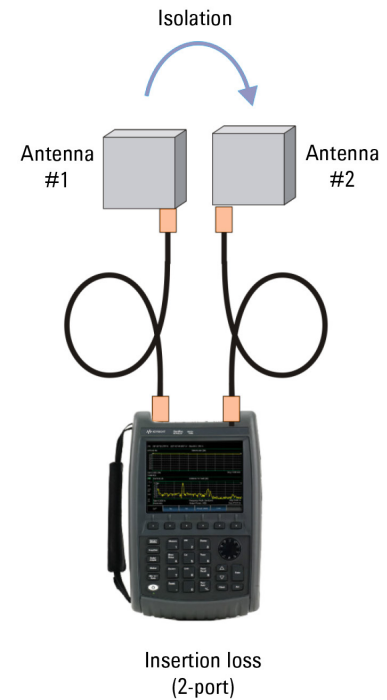


Figure 6b. Configuration for measuring antenna-to-antenna isolation

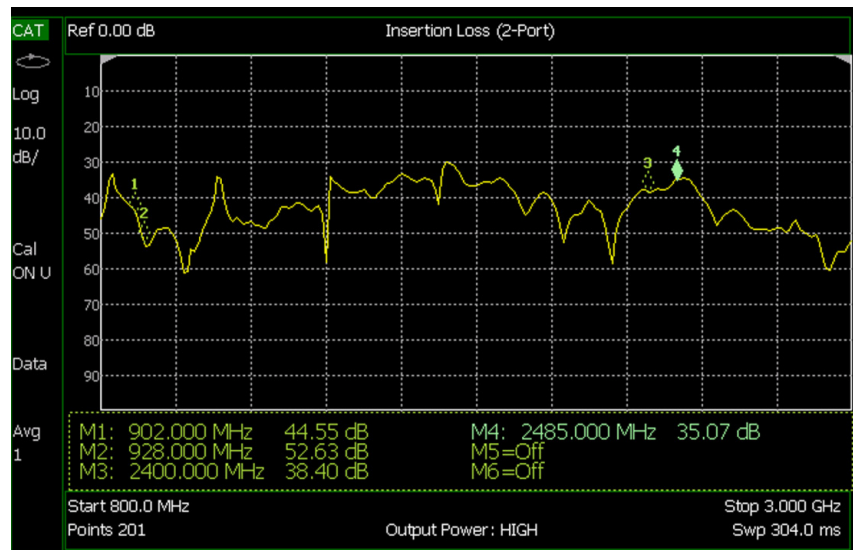


Figure 7. Measured antenna-to-antenna isolation between a 900-MHz panel antenna to a 2.4-GHz panel antenna mounted on the same structure

system will need to have adequate filtering to provide additional rejection of the 2.4-GHz signal otherwise the 900-MHz receiver will be desensitized by this high level signal.



## Locating Faults Along Transmission Lines

Once it has been determined that the cable insertion loss is higher than expected or the return loss and associated VSWR is out of spec, it becomes necessary to find the possible locations for the fault(s) along the transmission system. The location of discrete and periodic cable faults can be determined using the distance-to-fault (DTF) measurement available on FieldFox. DTF uses reflection measurements taken from the transmission line and calculates the individual amplitude response of any discontinuities as a function of distance. DTF measurements using FieldFox are similar to time domain measurements found on a vector network analyzer 4 but DTF reports distance to the discontinuity instead of time delay. Figure 1 shows a dual display of the return loss as a function of frequency (upper trace) and the associated DTF measurement (lower trace) from a section of coaxial cable connected to an antenna. When examining the DTF display, high amplitude level signals are located at the points where discontinuities exist along the transmission line and at the load. The location of these high amplitude signals will provide an important troubleshooting tool when attempting to determined faults in the cabled transmission system.

Figure 8 shows a typical configuration for measuring the DTF on FieldFox. In this example, it is assumed that some type of the load is connected to FieldFox through two sections of coaxial cables. The load can be the system antenna, a 50-ohm termination or just an open ended cable. In this example, the two cable sections are connected together with an adapter. Figure 8 also shows a table of important cable specifications as supplied by the manufacturer. The specification for velocity factor is very important to enter into FieldFox in order for the instrument to correctly display the distance to each cable discontinuity. Velocity factor is the signal's propagation velocity in the transmission line relative to signal velocity travelling in a vacuum (speed of light). When a signal travels in a coaxial cable, the dielectric between the inner conductor and outer conductor of the cable will reduce the signal's velocity resulting in a velocity factor less than 1.0. For the cable specified in figure 8, the signal's velocity factor in this cable is 0.66 which implies that the signal travels at a rate of 66% of the speed of the light in free space. The velocity factor is entered into FieldFox under the DTF Cable Specifications located in the Measurement Setup menu.

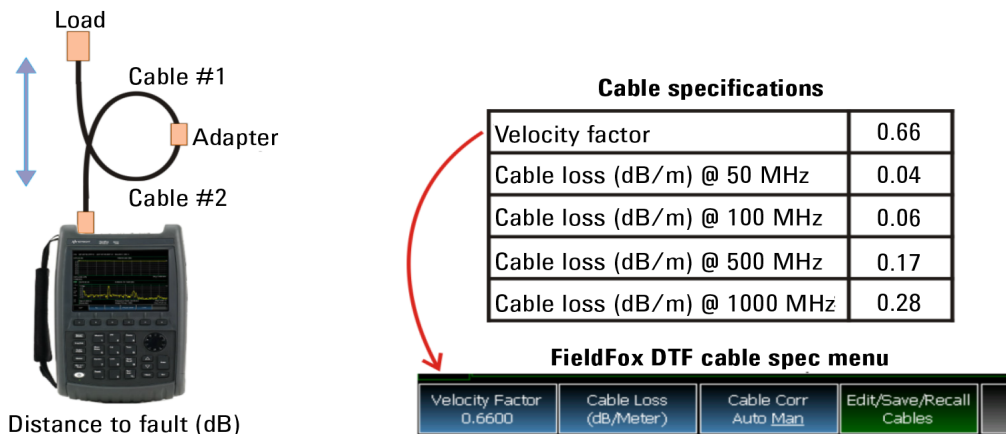


Figure 8. Configuration for measuring the distance-to-fault (dB) in a system having two coaxial cables connected to a load; also shown are the specifications for the cables used in this example

## Locating Faults Along Transmission Lines (continued)

Figure 9 shows the DTF measurement for the simple example shown in figure 8. The cables are initially terminated in a 50-ohm coaxial load. Markers are placed at the three peaks in the DTF response. The first marker, shown on the far left, reports a distance of 0 meters. This marker represents the interface between FieldFox and the first coaxial cable. The second marker reports a distance of 4 meters. This marker is located at the adapter between the two cables. It also implies that the length of the first cable is 4 meters. The third marker is located at the 50-ohm load and is reported at 13.8 meters. This measurement can be used to calculate the length of the second cable which is 9.8 meters (13.8 meters – 4 meters). There is a noticeable drop in the measured amplitude after the 50-ohm load signifying the location of the end of the cable. It should be noted that if the cable's velocity factor was not correctly entered, the distance measurements would not be correct making it difficult to accurately locate the physical distance to a discontinuity in the cable. It should also be noted when two cable types with different velocity factors are included in the measurement, such as a short jumper cable connected to a long Helix cable, the velocity factor of the longer cable should be entered into FieldFox. Ideally, the short jumper cable should be included as part of QuickCal and therefore its effects will be calibrated out from the measurement.

Figure 10 shows the measurement for the same configuration as in figure 8 but the 50-ohm load was removed and the cable was left open ended. As a comparison, the yellow trace is the current measurement having the cable with the open end and the blue trace, stored to memory, is the measurement using the 50-ohm load. As expected, the start, the adapter and the cable end are measured at the same location using the open but there is a notice

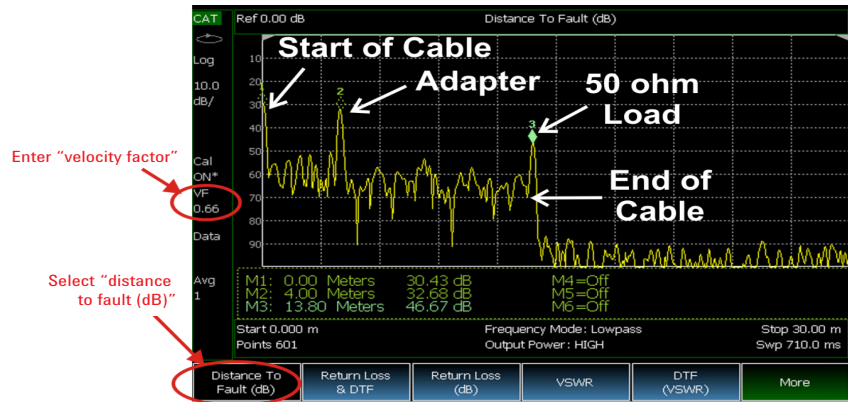


Figure 9. Measurement of the distance-to-fault (dB) for the configuration shown in figure 8

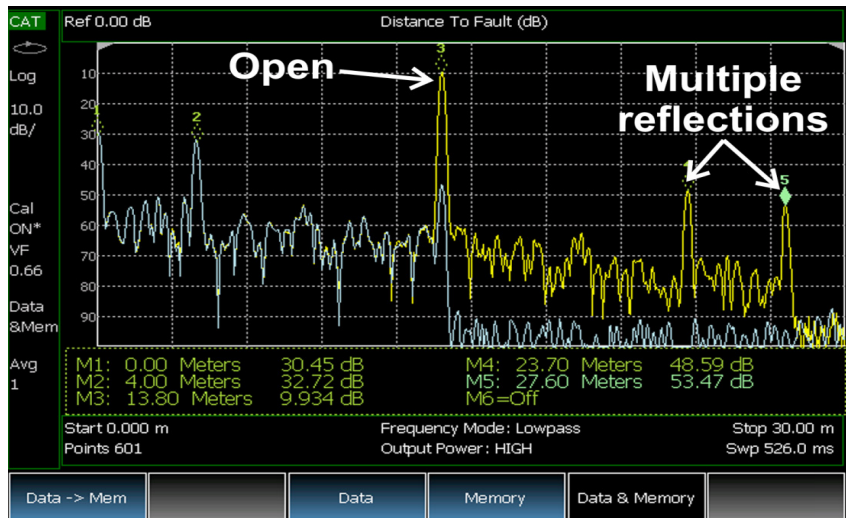


Figure 10. DTF measurement comparison between cable terminated in open circuit (yellow) and 50-ohm load (blue)

able increase in the amplitude of the reflected signal from the open.

As FieldFox is measuring the two-way reflection properties from the cables under test, the displayed DTF measurements are calculated by taking one-half of the actual measured distance. From figure 10, it is also observed that two additional peaks appear to the right of the open. As these measured cables are not that long, these peaks are created by re-reflections from the multiple discontinuities throughout the cable set. For these two peaks, marker 4 is measured to be located at 23.7 meters and marker 5 is located at 27.6 meters.

These measurement peaks are the result of signals that travel through sections of the cables multiple times and interact with open circuit and adapter discontinuities along the way.

## Locating Faults Along Transmission Lines (continued)

Figure 11 shows a simplified diagram on the various propagation paths back to FieldFox for the cable configuration shown in figure 8. Figure 11a shows the main reflected signal from the open-ended cable resulting in the signal at 13.8 meters (marker 3 in figure 10). Figure 11b shows the re-reflections between the adapter and the open resulting in a peak at approximately 23.7 meters (marker 4). The last peak, not shown in figure 11, represents the re-reflections between FieldFox and the open resulting in a peak at approximately 27.6 meters (marker 5 = (4 m + 9.8 m + 9.8 m + 4 m + 4 m + 9.8 m + 9.8 m + 4 m)/2).

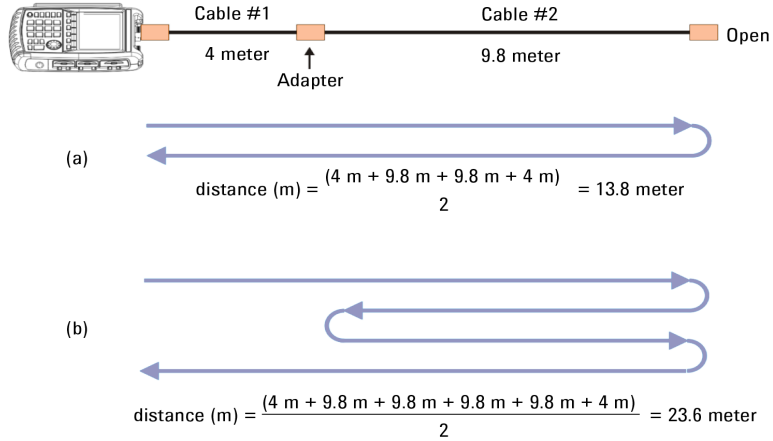


Figure 11. Signal propagation paths between FieldFox and an open-ended cable; (a) signal reflection from the open end, (b) double reflection from the open end and the adapter.

Under some instrument settings, it is possible that a measured peak could be an artifact or “alias” of the calculated DTF response. An alias is not a true cable response and may appear when FieldFox reports an “Alias-free Range = Off” as shown under the DTF Settings page. Aliases will not appear when FieldFox reports an “Alias-free Range = On”. These undesired peaks are more likely to occur with FieldFox settings at short stop distances, less than 10 meters, and/or high resolution, 1001 points. When an alias is suspected, a simple measurement procedure will help determine which peaks are true responses and which are aliases. Place a marker on the response in question and note the measured distance. Change the start or stop distance setting on FieldFox. The displayed distance of a true response will not change. On the other hand, the displayed distance of an alias will appear to move and therefore this peak should not be recorded as an actual DTF response.

It should be noted that for the measurement example shown in figure 10, the expected return loss from an open circuit should be 0 dB but is measured at 9.9 dB (marker 3). Unless the specified cable loss (dB/m) is properly entered into FieldFox,

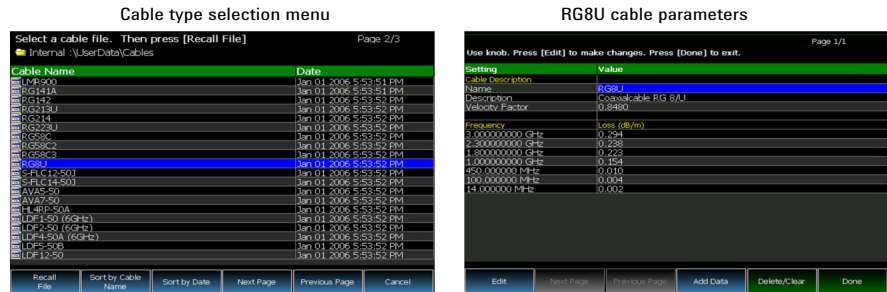


Figure 12. Cable type selection and cable parameter menus on FieldFox

the measured amplitude will not be correct. For this measurement, the cable loss was entered as 0 dB/m (default setting) so the insertion loss of this transmission system is masking the true return loss from the open circuit. If the application requires an accurate amplitude measurement of the return loss from a particular reflection on the DTF display, the cable loss should be entered either manually into FieldFox or selected from a list of stored cable types. Figure 12 shows the cable selection menu (left menu) on FieldFox. In this case, the RG8U cable type is highlighted and selected. The cable parameters can be viewed and edited as shown in the table on the right of figure 12. For this RG8U type, the velocity factor is 0.848 and the cable loss (dB/m) is stored as a function of

frequency. Cable loss values are interpolated between the entered frequency points. In general, DTF measurements of transmission systems are primarily concerned with locating the physical position of faults along the line and therefore, precise amplitude measurements of the return loss and associated VSWR may not be required. Accordingly most applications only require that the cable’s velocity factor be entered into the FieldFox cable specification table.

## Locating Faults Along Transmission Lines (continued)

If the velocity factor (VF) of a cable is unknown but the physical distance of the cable is known, then the DTF measurement may be used to estimate the velocity factor. In this case, the cable is attached to FieldFox and the VF is adjusted until the measured distance matches the known physical length. For example, figure 13 shows the measurement of a 3-meter length of Category 6 twisted pair cable terminated in an open end. The cable was attached to a 100-ohm balanced-to-unbalanced transformer to match the 100-ohm impedance of the twisted pair cable to the 50-ohm impedance of FieldFox's test port connector. The VF setting was adjusted until the measured length was 3 meters and for this example, the velocity factor was 0.70 (70%). This velocity factor may now be used for DTF measurements of other Category 6 cables from this manufacturer.

There are three additional instrument settings that control how FieldFox calculates and displays DTF measurements. The first setting is related to the Frequency Mode of operation found under the Measurement Setup menu on FieldFox. There are two frequency modes available when making DTF measurements - Lowpass and Bandpass. The Lowpass frequency mode will provide the optimum resolution in measured distance but requires test components that have a very wide frequency bandwidth such as transmission lines, including coaxial cables and adapters. The Bandpass frequency mode is required for components that have a narrow operating band such as filters, antennas and waveguide components. As resolution in distance is inversely proportional to measurement bandwidth, the Bandpass mode will not provide the same high resolution in a DTF measurement as the Lowpass mode. In Lowpass mode, the measured frequency range is automatically determined after the start and stop distances are entered for the DTF display.

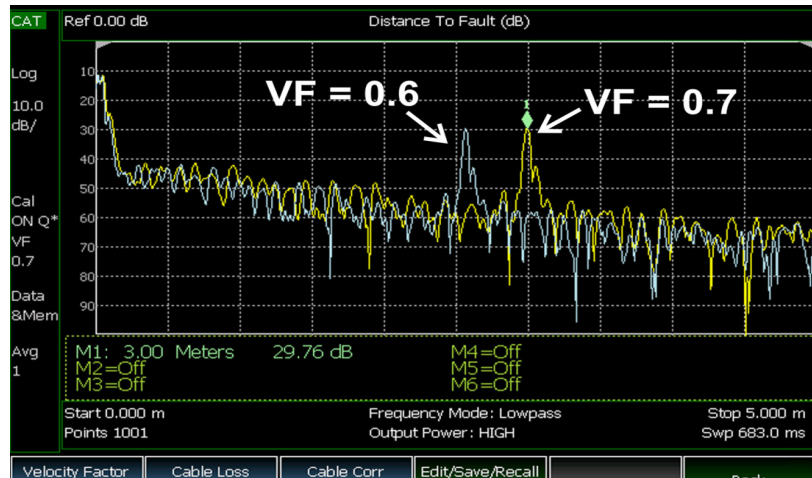


Figure 13. Measurement of a Category-6 patch cable with adjustment to FieldFox's velocity factor correction in order to match the measured distance to the known physical distance

In Bandpass mode, the measured start and stop frequencies are manually entered based on the approximate frequency range for the components under test.

The second DTF instrument setting is related to the Resolution or number of measurement points. The Resolution can be selected from 101, 201, 401, 601, 801, and 1001 points. A larger number of points increases the measurement sweep time but also increases the maximum distance that can be measured on the DTF display. The range resolution is calculated from the measured frequency span. The maximum distance that can be displayed is calculated from the range resolution multiplied by the number of points minus one.

The third DTF instrument setting is the DTF Window. In general, when troubleshooting faults in transmission systems, the default setting with a Maximum Window provides the highest dynamic range for the DTF measurements. Under conditions when attempting to resolve two closely-spaced discontinuities, a Minimum Window would be preferred. Additional information regarding Frequency Mode, Resolution and Windowing can be found in the FieldFox User's Manual.

## Calibrating FieldFox's Test Ports

FieldFox offers a set of user calibrations that can remove the effects of cables and adapters that may be placed between the instrument and the device under test. These types of user calibrations are performed by the operator on a regular basis and are independent of the general instrument calibration that may be required on a yearly cycle. The yearly instrument calibration is a traceable process that is performed by a certified test lab, such as Keysight, and confirms that the instrument is performing to its stated specifications. The yearly instrument calibration should be traceable to International System (SI) units through a national metrology institute such as NIST, NPL or BIPM. With a fully-traceable instrument calibration, FieldFox is capable of making highly accurate measurements at the instrument test ports. In practice, different test requirements may result in a variety of jumper cables and adapters being connected to FieldFox. Often it is preferred that the effects of these cables and adapters are not included in the measurement. In this case, FieldFox allows a user calibration to be performed, with or without a calibration kit, in order to extend the calibration plane beyond the jumper cables and adapters.

Operators familiar with the operation of vector network analyzers (VNAs) will be familiar with these types of user calibrations. The remaining sections of this application note will introduce the different types of user calibrations available for accurately measuring the reflection characteristics and insertion loss of components and systems.

### Calibrating for reflection measurements

There are three types of user calibrations available for accurately measuring the reflection characteristics of transmission systems and antennas. User calibration will improve the results for all previously discussed measurements of return loss, VSWR, 1-port cable loss and DTF. The calibration types (cal types) for reflection measurements are CalReady, QuickCal and 1-port OSL. Figure 14 shows the configuration diagrams for these three cal types including any jumper cables, adapters and calibration standards that may be required. In general, for all cal types, jumper cables and adapters should be high quality items and maintained in very good condition to improve the accuracy and repeatability in the measured data.

#### CalReady

The first and easiest calibration to implement is CalReady, also known as Preset Cal. CalReady is immediately available upon instrument power-on or instrument preset and requires no additional steps to calibrate. This built-in calibration is performed at the factory over the full frequency range of FieldFox and applies directly to the RF OUT test port of FieldFox. CalReady assumes that the device under test (DUT) will be connected directly to FieldFox's Type-N female test port connector or the 3.5-mm male connector on 26.5 GHz models. As shown in figure 14a, CalReady has a calibration plane at the connector of FieldFox and is available for all reflection measurements including return loss, VSWR, 1-port cable loss and DTF. When using CalReady, any jumper cables and/or adapters connected between FieldFox and the DUT will be included in the measured response.

#### QuickCal

The second cal type available for reflection measurements is QuickCal. QuickCal is useful when jumper cables and adapters are placed between FieldFox and the DUT and the user does not want to include their effects in the measured data. QuickCal corrects for phase shift and loss of cables and adapters and electrically moves the calibration plane to the end of these components (see figure 14b). QuickCal requires a single measurement sweep of an open at the end of the jumper cables and adapters, no additional calibration standards are required. Once the calibration sweep is complete, the DUT may be measured without including the effects of these jumper cables and adapters. Jumper cables should be high-quality phase-stable test cables. It should be noted that if the DUT has a good return loss, greater than 20 dB to 25 dB, an optional LOAD standard may be measured during QuickCal to improve the accuracy of the DUT measurements. Ideally the LOAD standard should have the same connector type as the DUT. The Keysight N9910X-800 (801) tee calibration kit contains a Type-N male (female) 50-ohm termination.

## Calibrating FieldFox's Test Ports (continued)

### 1-port OSL

The third cal type available for reflection measurements is 1-port OSL. This calibration requires a calibration kit where the O is the OPEN standard, the S is the SHORT and the L is the LOAD standard. Calibration kits are available in Type-N (50 ohm and 75 ohm), 7/16, 3.5 mm, Type F, 7 mm, TNC and several waveguide kits including X-band, P-band and K-band. When the 1-port OSL cal type is selected on FieldFox, the connector type must be chosen including the connector gender (male or female). The gender is defined as that of the cal kit connector. As each calibration kit is different, proper selection of the connector type and gender will ensure that FieldFox is using the correct cal kit definitions. For the highest measurement accuracy, the cal kit connector type should be the same as the DUT connector. In this way the calibration plane is located directly at the DUT input (see figure 14c). The 1-port OSL cal type is the most accurate of the three available cal types but the calibration process requires three separate measurement sweeps, one for each of the three cal standards. For the highest accuracy when using 1-port OSL, it is important that the OPEN standard from the calibration kit is used instead of just leaving the cable open ended.

### Calibrating for insertion loss measurements

There are several types of user calibrations available for accurately measuring the insertion loss of cables and systems. The cal types are CalReady, QuickCal, Normalization, Enhanced Response and Full 2-port.

### CalReady

CalReady allows users to make cable and antenna measurements at the test port without calibration, if a good quality phase-stable cable is used (25 to 30 dB return loss and much better than system return loss that is under test) to connect FieldFox to the DUT. This is the easiest method to make a cable and antenna sweep in the field.

CalReady for insertion loss measurements is immediately available upon instrument power-on or instrument preset. CalReady is factory-calibrated at FieldFox test ports and is very useful to characterize the insertion loss of jumper cables. In this case, the jumper cable will be connected directly to RF OUT (port 1) and RF IN (port 2) of FieldFox. When measuring the insertion loss of a DUT, jumper cables and/or adapters connected between FieldFox and the DUT will be included as part of the DUT's measured response.

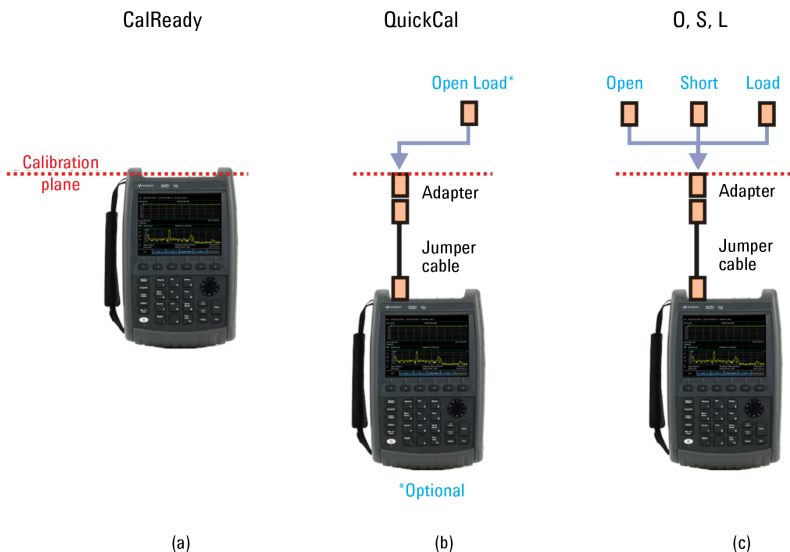


Figure 14. Calibration types and calibration standards required for accurately measuring reflection properties using FieldFox

## Calibrating FieldFox's Test Ports (continued)

### Normalization

A very simple user calibration for removing the effects of the jumper cable and the frequency response of the instrument is the Normalization cal type. During this calibration process, a short jumper cable is connected between the RF OUT port and the RF IN port on FieldFox (see figure 15a). Once the jumper cable is connected, a single measurement sweep is performed during the calibration. All DUT measurements are then normalized, or referenced, to this cable. As the calibration now includes the loss and phase response of the jumper cable, this cable should also be included when making measurements of the DUT as shown in figure 15a. If the jumper cable is removed after the calibration, the measurements of the DUT will be offset by the value of the insertion loss of the jumper cable resulting in a slightly lower measured value of insertion loss for the DUT. It is also possible to use two jumper cables and/or adapters during the instrument calibration, with one connected to each port of FieldFox, as shown in figure 15b. Figure 15b also shows the DUT measurement configuration with connection between the two jumper cables. While the Normalization calibration is one of the easiest to implement, is the least accurate of all the cal types available on FieldFox. It is often advisable to use the one of the other cal types, such as CalReady or QuickCal, for improved measurement accuracy. It should also be noted that the Normalization cal type is also available for reflection measurements where an open or short is used to terminate the test port during the calibration.

### QuickCal

QuickCal allows users to extend the reference plane to the end of the jumper or adapter without using a cal kit and supports many commonly-used connector types.

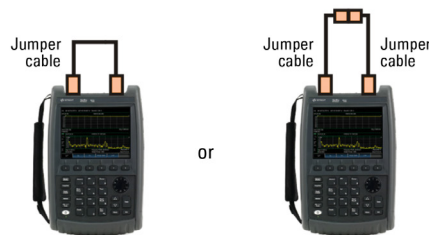
QuickCal for insertion loss measurements begins with the same calibration procedure as that for reflection testing but the measurement sweep of the open-ended jumper cable(s), and the optional LOADs, occurs at both RF OUT (port 1) and RF IN (port 2) of FieldFox. QuickCal for insertion loss testing also requires an additional measurement sweep of a jumper cable(s) connecting RF OUT (port 1) to RF IN (port 2). This additional measurement of the jumper cable is similar to the calibration step shown in figure 15. After calibration, FieldFox will display insertion loss measurements without including the effects of any jumper cables and adapters used as part of the calibration.

### Enhanced response and full 2-Port calibrations

The Enhanced Response and Full 2-Port cal types provide the highest level of measurement accuracy of all the cal types available on FieldFox.

A Full 2-Port calibration requires measurement sweeps of the OSL standards placed at both test ports of FieldFox. This cal type also requires measurement sweeps of the jumper cable(s) connecting RF OUT (port 1) to RF IN (port 2). The Enhanced Response follows the same calibration procedure as the Full 2-Port but does not require measurement sweeps of the OSL standards placed at port 2 of FieldFox. Without measuring the OSL standards at port 2, the Enhanced Response calibration is slightly less accurate than the Full 2-Port calibration. The Enhanced Response and Full 2-Port cal types can be used for both insertion loss testing and reflection testing. While these cal types result in the highest level of measurement accuracy, the user will be required to carry a high-quality calibration kit into the field.

#### Calibration



#### Testing DUT

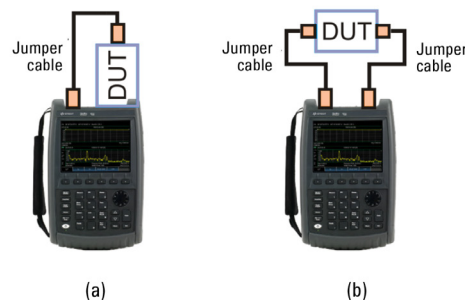


Figure 15. Configuration for the Normalization Cal Type using a jumper cable(s) required for 2-port insertion loss testing of a DUT

## Conclusion

This application note has introduced measurement and calibration techniques for cable and antenna testing (CAT) using FieldFox. Measurement examples were provided for cable insertion loss, return loss, VSWR and Distance-to-Fault (DTF) testing. Antenna measurements were also reviewed and several examples of return loss and antenna-to-antenna isolation were provided. Additional information regarding CAT and line sweeping can be found at the Keysight website. Keysight also provides local and on-site training of CAT and FieldFox applications including the Line Sweep and Antenna Test Training Course H7215x-121.

## References

- [1] Keysight Application Note, "Network Analyzer Basics," Literature Number 5965-7917E, August 2004.
- [2] [www.keysight.com/find/FieldFox](http://www.keysight.com/find/FieldFox)
- [3] Copyright J M Briscoe and licensed for reuse under the Creative Commons Licence.
- [4] Keysight Application Note 1287-12, "Time Domain Analysis Using a Network Analyzer," Literature Number 5989-5723EN, May 2012.

CalReady allows users to make cable and antenna measurements at test ports without calibration, when a good quality, phase-stable cable is used to connect FieldFox to the DUT. QuickCal allows users to extend the reference plane to the end of the jumper or adapter without the need of a cal kit; it supports many commonly-used connector types.

## Appendix A: Return Loss and VSWR Conversion Table

Return loss can be expressed as a voltage standing wave ratio (VSWR) value using the following table:

Return Loss (dB)	VSWR	Return Loss (dB)	VSWR	Return Loss (dB)	VSWR	Return Loss (dB)	VSWR	Return Loss (dB)	VSWR
4.0	4.42	14.0	1.50	18.0	1.29	28.0	1.08	38.0	1.03
6.0	3.01	14.2	1.48	18.5	1.27	28.5	1.08	38.5	1.02
8.0	2.32	14.4	1.47	19.0	1.25	29.0	1.07	39.0	1.02
10.0	1.92	14.6	1.46	19.5	1.24	29.5	1.07	39.5	1.02
10.5	1.85	14.8	1.44	20.0	1.22	30.0	1.07	40.0	1.02
11.0	1.78	15.0	1.43	20.5	1.21	30.5	1.06	40.5	1.02
11.2	1.76	15.2	1.42	21.0	1.20	31.0	1.06	41.0	1.02
11.4	1.74	15.4	1.41	21.5	1.18	31.5	1.05	41.5	1.02
11.6	1.71	15.6	1.40	22.0	1.17	32.0	1.05	42.0	1.02
11.8	1.69	15.8	1.39	22.5	1.16	32.5	1.05	42.5	1.02
12.0	1.67	16.0	1.38	23.0	1.15	33.0	1.05	43.0	1.01
12.2	1.65	16.2	1.37	23.5	1.14	33.5	1.04	43.5	1.01
12.4	1.63	16.4	1.36	24.0	1.13	34.0	1.04	44.0	1.01
12.6	1.61	16.6	1.35	24.5	1.13	34.5	1.04	44.5	1.01
12.8	1.59	16.8	1.34	25.0	1.12	35.0	1.04	45.0	1.01
13.0	1.58	17.0	1.33	25.5	1.11	35.5	1.03	45.5	1.01
13.2	1.56	17.2	1.32	26.0	1.11	36.0	1.03	46.0	1.01
13.4	1.54	17.4	1.31	26.5	1.10	36.5	1.03	46.5	1.01
13.6	1.53	17.6	1.30	27.0	1.09	37.0	1.03	47.0	1.01
13.8	1.51	17.8	1.30	27.5	1.09	37.5	1.03	47.5	1.01

VSWR is sometimes stated as a ratio. For example: 1.2:1 "one point two to one" VSWR. The first number is the VSWR value taken from the table or calculated using the formula. The second number is always 1.



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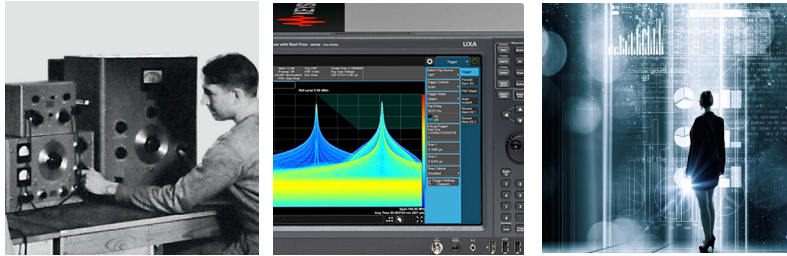
Related literature	Number
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FieldFox Spectrum Analyzers, Technical Overview	5990-9782EN
FieldFox Vector Network Analyzers, Technical Overview	5990-9781EN
FieldFox Handheld Analyzers, Data Sheet	5990-9783EN
FieldFox Handheld Analyzer, Configuration Guide	5990-9836EN
FieldFox N9912A RF Analyzer, Technical Overview	5989-8618EN
FieldFox N9912A RF Analyzer, Data Sheet	N9912-90006
FieldFox N9923A RF Vector Network Analyzer, Technical Overview	5990-5087EN
FieldFox N9923A RF Vector Network Analyzer, Data Sheet	5990-5363EN

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