Application Note

Anritsu Advancing beyond

Testing RF Cables in Cellular Networks Combining LTE and 5G Technologies

Introduction

5G technology is now becoming commonplace in cellular networks globally. Network operators are increasing capacity and opening up new business opportunities such as massive Internet of Things (IoT) to connect billions of devices to the internet and low latency private networks to enhance manufacturing and logistics processes. As 5G networks are rolled out, it is interesting to note that the use and need for legacy cellular standards remains strong. Operators continue to expand LTE networks to improve coverage and capacity and even General Packet Radio Service (GPRS) networks maintain a position in many markets where long term contracts have been sold using GPRS modems.

Each country and operator has unique requirements that mean there is no single implementation of a 5G network. Some of the challenges of 5G networks centers around the physical positioning of the new antennas. The 5G standard allows for standalone networks which use 5G technology for call setup signaling and data communications and non-standalone networks which offload the call setup and signaling to the legacy LTE network. Early expectations for 5G base stations (gNB) was to use active antennas with massive MIMO implemented by an array of typically 64 antenna elements in a single housing. This technology offers advantages including very high data throughput and simple installation that only requires two physical connections, a fiber for the data plus a power line.

In many instances, the active antenna is the best solution, but other considerations and driving approaches include tower load or space and the need to support multiple LTE bands and 5G at the same location. It is often necessary to minimize the weight of the cellular infrastructure mounted on a transmitter tower knowing that active antenna arrays can be too heavy to add alongside legacy antennas. It is increasingly common for operators to select multi-band integrated antennas that support two or three cellular bands such as 800 MHz and 1900 MHz LTE plus 3.5 GHz 5G. The radio hardware can then be located in an equipment room at ground level, which reduces the load on the tower. Even for rooftop installations, it is common to see jumper cables from a 5G radio to an antenna array.

Another consideration is that many operators are achieving an early 5G roll out by supporting 5G technology in existing sub 2.5 GHz bands using dynamic spectrum sharing (DSS). DSS technology dynamically allocates spectrum resources between LTE and 5G technologies in an LTE frame structure. DSS technology can often be implemented with a software update to existing LTE radios and antennas. These network deployments usually implement traditional base station and antenna architectures with RF cable feeds between the two components.

The result is that many operators continue to deploy multi-band, multibeam massive MIMO hybrid antennas. These antennas are fed by RF cables from the radio and depending on the network, a single hybrid antenna may have 16 or more RF connector and cables feeding it. The overall performance of the network requires these cables to be low loss and all connectors, bends and clamping brackets to be formed and installed correctly.

Core Base Station Installation Measurements

When installing new LTE or 5G base stations that include RF cable feeds to the antenna installation teams need to be certain that the overall system is performing to specification. These measurements typically fall into four categories:

1. Base station power and modulation quality
2. RF cable and antenna measurements
3. Cell site coverage
4. EMF

Modulation Quality

Modulation quality of LTE base stations is most commonly performed from an RF test port on the radio. An instrument, such as the Anritsu Field Master Pro MS2090A, has built-in routines for measurement of occupied bandwidth (OBW), channel power, error vector magnitude (EVM), RSRP, and other modulation quality metrics. These measurements can be made before the base station is connected to the antenna system. Many 5G base stations do not have an RF test port causing measurements to be made over-the-air (OTA). Again, the Field Master Pro MS2090A offers a comprehensive suite of modulation quality measurements. It is important to remember that it is necessary to connect the base station to the antenna via a long RF cable up to the tower or via short jumper cables from a rooftop mounted base station to the antenna when testing OTA.

Cable and Antenna Measurements

Each base station installation has its own characteristics that are driven by regulation, location, and operators network requirements. Many 5G base stations will be located at existing LTE sites that may be rooftop or tower based. Each tower has a loading factor that defines the weight of the radios and antennas that can be mounted. Due to legacy hardware on the tower, the radio may be required to be installed at ground level and only the antenna to be tower mounted. The antenna may combine elements for LTE and 5G frequencies, for example, 800 MHz, 1900 MHz, and 3.5 GHz.

The RF cables running up the tower can have a length of a few meters to tens of meters depending on the tower construction. As the RF signal travels through the cable some of the energy will be dissipated in the cable and connectors. A cable insertion loss measurement must be made during installation to confirm that the loss is within specification. Low loss cables must be used to minimize the base station power and maximize efficiency. Cables with larger diameters have less insertion loss and better power handling capabilities than smaller diameter cables, but are more expensive and much heavier. RF cable losses at 1000 MHz are in the order of 0.08 dB per meter, so the loss over 20 meters will be 1.5 dB. This means that longer runs could easily see 3 dB power loss or half the transmitter power lost before it reaches the antenna.

As well as measuring the cable loss, it is important to measure the magnitude of any RF reflections in the cable and antenna system. Both the RF cable and antenna have nominal 50 ohm impedance. Loss of efficiency can be caused by distortion from cable and antenna feed reflections due to the power being reflected back towards the base station. The most common causes of reflections are:

- Poorly installed connectors that are loose or not correctly torqued.
- Connectors that have degraded over time due to weather damage. Water ingress into the connector and then into the dielectric is also a common failure mechanism.
- RF cable damage, such as over-tightening cable clamps and bend radius resulting in kinks.
- Damaged and/or incorrect antennas.

A Typical Cellular Tower with Insert Highlighting RF Cable Feeds to Antennas

Return loss and voltage standing wave ratio (VSWR) are the most common measurements of reflection.

Return loss is defined as: return loss = 10 log10 ($P_{incident}/P_{reflected}$)

Some useful return loss values are:

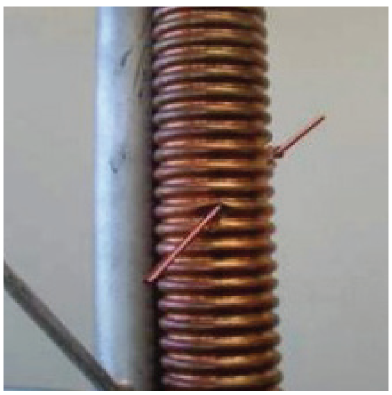
- 0 dB return loss represents 100% reflection and would be expected from an open or short circuit
- 10 dB return loss represents 10% reflected power
- 20 dB return loss represents 1% reflected power
- 40 dB return loss represents a typical match from a precision 50 ohm load

A typical return loss specification for a RF cable feed and antenna at a cellular base station is around 15 to 20 dB. High cable loss can result in higher return loss values which may make a bad antenna match look better than it actually is.

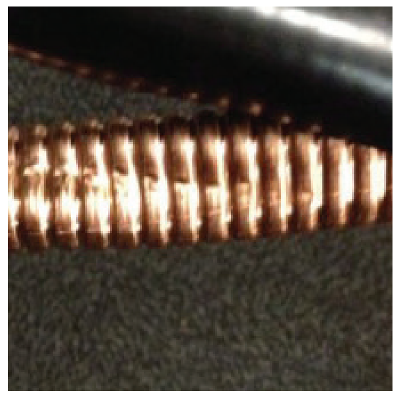
Voltage standing wave ratio (VSWR) is defined as: The ratio between transmitted and reflected voltage in a transmission line. Useful values are:

- 1.0:1 - A perfect 50 ohm impedance
- 1.02:1 - A typical precision 50 ohm load
- 1.4:1 - A typical antenna VSWR
- 2.0:1 - A badly matched antenna
- ∞ Complete reflection (Short or Open circuit)

Cable loss and return loss are measured as swept frequency traces across the full operating band of the antenna. Connectors that have not been torqued up to the correct value can result in narrow band “suck outs” with very high insertion loss. It is important to sweep the full operating band to find such failures and to understand that cable loss has an effect on measured return loss.

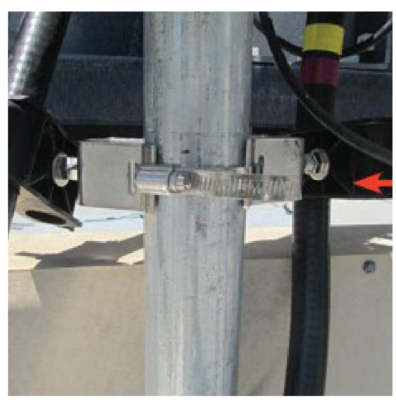


Foreign Object Piercing the RF Cable



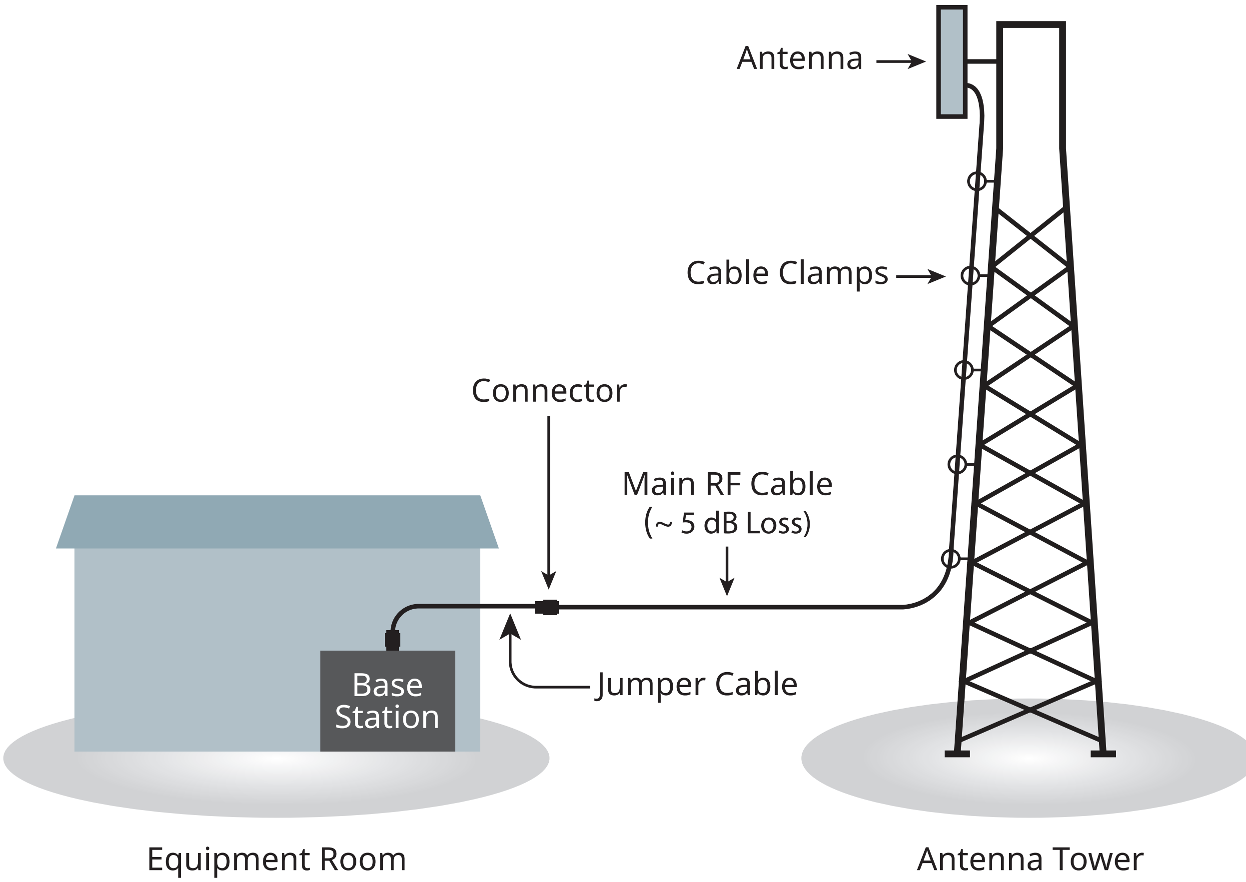
Twisted or Kinked Outer Conductor

Dirt in Connector



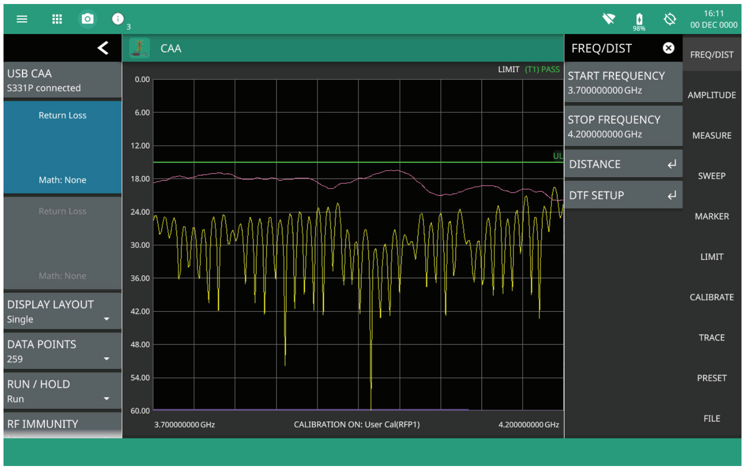
Proof of Overtightened Cable Clamps

Here are Four Examples of Typical Causes of Poor RF Cable Performance



This is an Example of a Typical Base Station/Tower Configuration

The diagram above highlights how cable loss changes the measured antenna performance. The antenna itself has a return loss of 15 dB but the 5 dB insertion loss improves the perceived system return loss by 10 dB (5 dB *2). Even though this is something system designers take into consideration when setting up the specifications of the site, it is important to be aware of the effects the insertion loss and cable return loss can have on the overall system return loss. A very good system return loss may not necessarily be the result of an excellent antenna; it could be a faulty cable with too much insertion loss or an antenna out of specification. This would result in a larger than expected signal drop and once the signal reaches the antenna, a great portion of the signal is now reflected since the match is worse than expected. The end result is that the transmitted signal is lower than expected and the coverage from the base station is reduced. This highlights the need to measure both cable loss and return loss to be confident in the overall performance of the system.

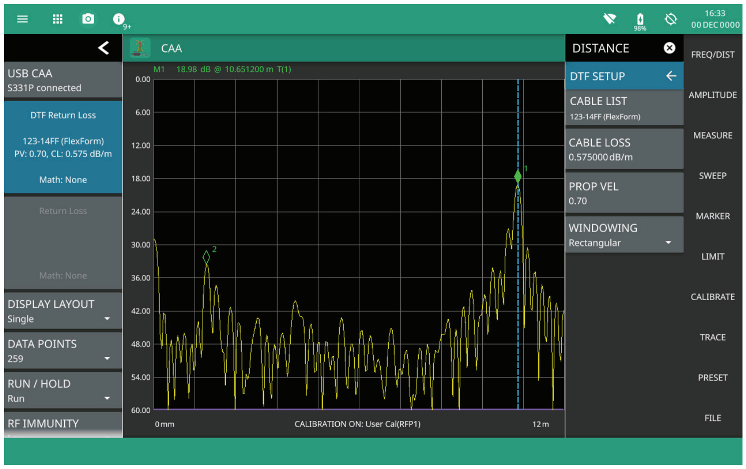


This Screen Shot Shows Return Loss of an Antenna in the Pink Trace and the Return Loss of the Cable Feed and the Antenna Assembly in the Yellow Trace. Note: The Insertion Loss of the Cable has the Effect of Improving Overall Return Loss

Return loss/VSWR measurement characterizes the performance of the overall system. If either of these are failing, a distance-to-fault (DTF) measurement can be used to troubleshoot the system and locate the exact location of a fault. It is important to understand that the DTF measurement is strictly a troubleshooting tool and best used to compare relative data and monitor changes over time with the main purpose of locating faults and measuring the length of the cable. Using the DTF absolute amplitude values derived from the DTF data as a replacement for return loss or as a pass/fail indicator is not recommended.

The DTF measurement sweeps the cable in the frequency domain and then, applies an Inverse Fast Fourier Transform (IFFT), which converts from the frequency domain to the time domain.

The dielectric material in the cable affects the propagation velocity that affects the velocity of the signal traveling through the cable. The user must input the velocity of propagation (VOP) for the cable under test and this value is commonly provided by the cable manufacturer. Accuracy of the VOP value will determine the accuracy of the location of the discontinuity.



This Screen Shot Shows a Typical Antenna Feed DTF Trace with Jumper Cable Connectors at 1.5 Meters and the Antenna at 10.6 Meters

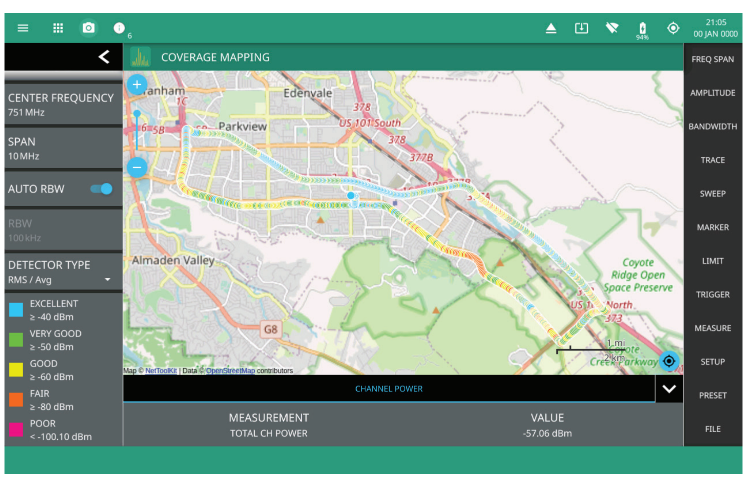
The above DTF measurement shows the location of connectors in the system with the connector at 1.5 meters clearly visible, the large reflection at 10.6 meters is the antenna. This is valuable information when installing cable feeds as the failure of the return loss measurement can now be directly related to a specific connector. By examining the connector for dirt in the joint or the connector being incorrectly tightened up should resolve the issue.

The Field Master Pro MS2090A with the Site Master S331P cable and antenna analyzer accessory are ideal instruments for performing line sweep measurements in the field, including return loss, cable loss, and DTF.

Cell Site Coverage

A coverage map for the surrounding area is required to validate that coverage meets the planners modeling when a base station is brought online.

The Field Master Pro MS2090A supports downloading of digital maps directly from the internet that are displayed on the instrument screen. Plotting a channel power measurement onto the digital map using color to represent relative strength provides a graphical and easy to interpret overview of the cell site coverage. The most common method for creating a coverage map of the surrounding area is to drive a vehicle around the streets of interest with a magnetic mount omni-directional antenna on the roof. Data points are gathered at a defined distance interval and plotted using global navigation satellite system (GNSS) information on the map.

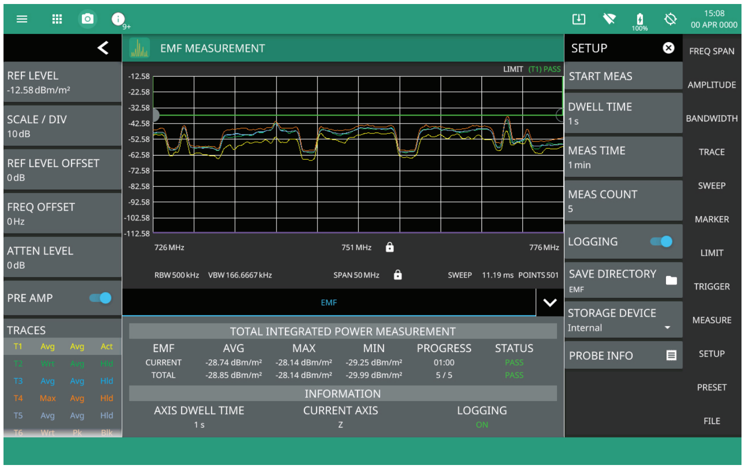


This Screen Shot Shows Coverage Mapping Plots for Channel Power Values on a Digital Map and Highlights Coverage Levels over a Wide Geographic Area

EMF Measurements

Operators of cellular networks often need to reassure the local community that the total radiated power from a new cell site base station installation is not harmful. Regulators and standards bodies such as the FCC and ICNIRP define limits for RF field strength guaranteeing that they are safe for the general public, and for technicians working in the industry.

The Field Master Pro MS2090A supports accessory omni directional antennas that enable calibrated field strength measurements to be made and tested against the international limits.



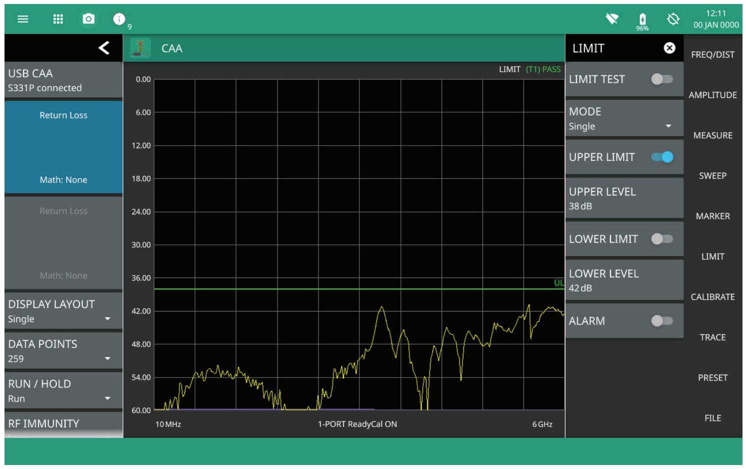
This Screen Shot Shows an EMF Measurement on LTE Transmitters Tested to ICNIRP Standard Limits

Making Cable and Antenna Measurements with the Field Master Pro MS2090A and Site Master S331P Accessory

This procedure highlights the configuration and considerations required for measuring a cable and antenna system when installing a new base station and the recorded result needed for a closeout report.

Return Loss Measurements

Connect the Site Master S331P to any of the USB 3.0 ports on the Field Master Pro MS2090A and put the Field Master Pro MS2090A into CAA-USB mode. The preset screen in CAA mode sweeps the full bandwidth of the connected Site Master S331P, 150 kHz to 4 or 6 GHz. The default condition is the factory calibration data, called ReadyCal. ReadyCal provides a quick and easy way to start making measurements and can reduce overall test time. Connecting a quality 50 ohm load to the test port will show >38 dB dynamic range up to about 6 GHz. For system antennas and antenna/cable feeds that have a specification of 15 dB, the factory calibration will give a very small uncertainty. For the best measurement accuracy or when the ambient temperature is very different from room temperature, it is advised to perform a Standard or Flex calibration.



This ReadyCal Screen Shot Shows >38 dB Dynamic Range with a 50 ohm Load Connected Directly to the Test Port

From the FREQ/DIST menu set the start and stop frequency for the system under test. In this case 3.7 GHz to 4.2 GHz.

This can be done by going to the CALIBRATE menu and the TYPE key menu and selecting Standard or FlexCal™ calibration.

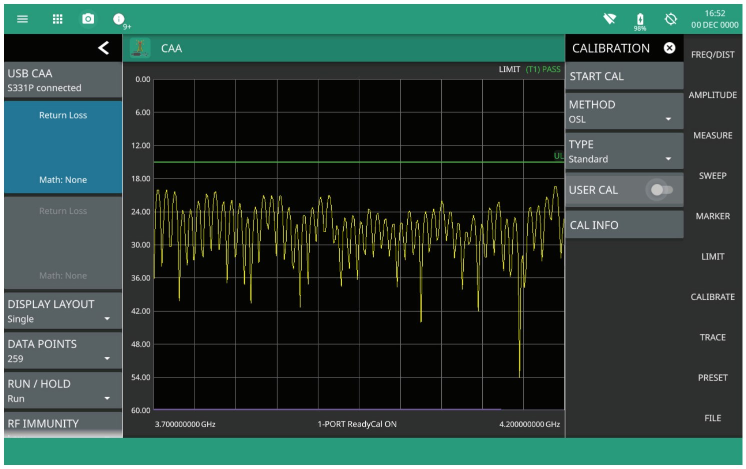
- Standard calibration is only valid for a selected frequency range and is no longer valid if the frequency is changed. It provides the best accuracy and is recommended when results will be submitted in test reports.
- FlexCal calibrates the instrument over the full frequency range of the Site Master S331P connected and interpolates data points if the frequency range is changed. This method saves time and does not require the user to re-calibrate the system for frequency changes. FlexCal is ideal for initial testing and fault finding.

FlexCal calibration offers maximum convenience as it is not necessary to recalibrate after each frequency change. The compromise is that there will be fewer calibration correction data points when using FlexCal if the frequency span is reduced. If all measurements are to be made over a fixed frequency sweep the use of Standard calibration is advised.

Press START CAL and follow the on screen instructions to connect the calibration accessory open, short, and load in sequence. After completing a calibration, if the load is left on the test port, the noise floor should be below 50 dB.

A pre-installation test should be performed on the RF feeder cable to the antenna before it is installed on the tower. It is important that the testing be repeated after installation to verify that no damage to the cable has occurred during installation, for example from over tight clamps or at the bend radius.

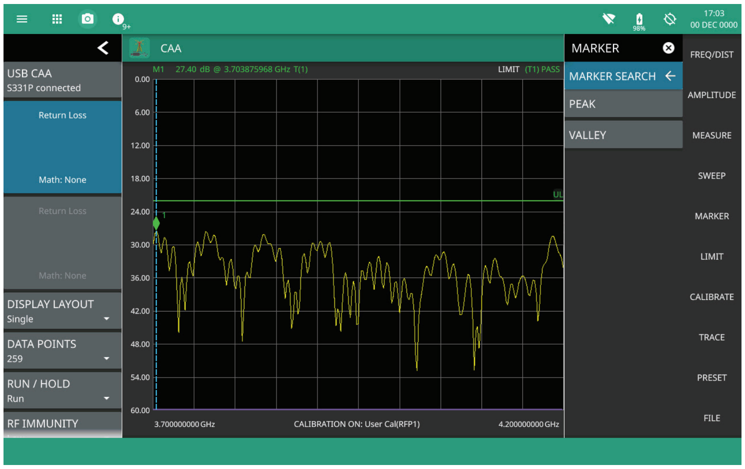
In most installations, it is required to measure the RF cable with a quality load on the far end and then with the antenna connected. First, connect a load to the far end of the RF cable under test. Then connect the other end of the cable to the Site Master S331P test port. A significant advantage of the Site Master S331P is that its small size and USB 3.0 cable connection to the Field Master Pro MS2090A means that the Site Master S331P RF test port can be attached directly to the end of the cable under test, eliminating the need for a test port cable. The Field Master Pro MS2090A screen is now displaying the return loss of the cable and load.



This Screen Shot Shows a Return Loss of Cable Terminated with a 50 ohm Load

Enter the LIMIT menu to set a Pass/Fail limit condition. In the example above a limit of 16 dB is applied. Enabling the LIMIT TEST feature provides a Pass/Fail indication on the instrument display. Complex limit lines with frequency dependent segments are set by changing the LIMIT MODE from Single to Segmented. Note that segmented limits are not common for cable testing.

To place markers on the points of interest (POI) on the trace such as the peak or valley, select MARKER/ENABLED and then MARKER SEARCH/PEAK to place a marker on the highest point on the return loss trace (worst value). To add additional markers, return to the top level marker menu and press SELECT 2, followed by MARKER SEARCH/VALLEY. The marker table will display the current value of all enabled markers.

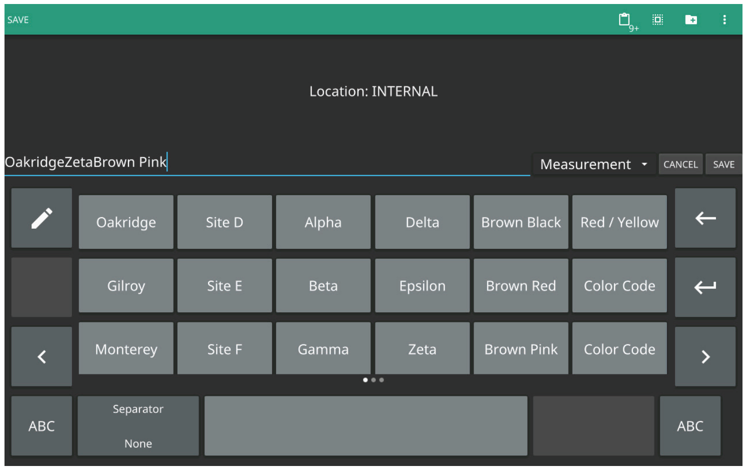


This Screen Shot Show the Markers Search Highlights Frequency Closest to Test Limit

Once the measurement with limit lines and markers has been configured and the wanted result obtained, the trace can be saved for importing into a closeout report. Under the FILE menu SAVE AS, traces can be saved in a number of different formats.

- Setup file = saves the current instrument configuration
- Trace file = saves the measurement point (trace) data and the current instrument setup
- Trace .csv file = trace data only in .csv format
- Trace .txt file = trace data only in text format
- Screenshot = .png file of the MS2090A screen
- Measurement (LST Compatible) = .dat file that is suitable for importing into the Anritsu Line Sweep Tools post processing and report generation PC application

Files can be saved to the Field Master Pro MS2090A internal memory or if they need to be transferred on to a PC for use with Line Sweep Tools, they can be saved directly to a USB memory stick. In many field environments, the user will be required to save multiple traces of similar cables. It is vital that file names reflect the specific cable that has been tested. The EZ keyboard helps manage file names with informative titles. After selecting the file type, press the EZ button in the bottom right of the keyboard to open up the EZ naming keypad. Press and hold any tile to change the tile name from the default setting.



The EZ Keyboard Offers Quick File Naming Conventions Using Customizable Tabs

For quick saving of a file, the QUICK SAVE key saves the current result in .dat format to the top-level internal memory location. Files are numbered in numeric order and are time and date stamped.

Once the RF cable has been tested in isolation, it is then attached to the antenna and a return loss measurement repeated. The limit criteria for the cable and antenna assembly will be more lenient than for the cable alone, and so the limit level should be changed to match the required test specification. In most field tests of the cable and antenna assembly, the antenna will be exposed to other environmental RF sources from nearby transmitters in addition to the RF source from the Site Master S331P cable and antenna analyzer. External RF signals incident on the antenna under test can make the measurement look worse than it is. To ensure the external RF sources do not degrade the measurement, it is necessary to put the RF immunity to high. This is enabled in the SWEEP menu, RF IMMUNITY. The RF immunity mode will result in slightly slower sweep speed to enable additional signal processing to remove the effect of the external signals. The RF immunity default setting is low, which makes the instrument more susceptible to interfering signals during a return loss or VSWR measurement, but optimizes sweep speed. The low RF IMMUNITY setting is appropriate for the majority of applications and should not be changed unless you have encountered unexpected and failing results most likely due to external RF signals.

DTF Measurements

Once all the return loss measurements have been completed and saved, the next step is to perform DTF measurements. DTF measurements have value even if the cable and antenna assembly have passed required system limits. If the return loss measurement has failed, the DTF test will pinpoint the location of the most significant causes of RF reflection which will allow for quicker correction. Even if the return loss test was passed, a DTF test will identify any potential future issues early. A saved result can be compared with future measurements to identify locations in the cable run where performance has degraded.

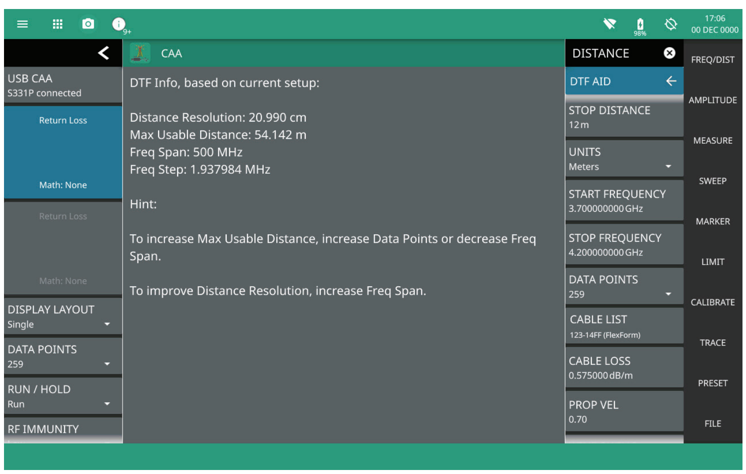
It is important to understand that DTF measurements should not be used as a substitute for return loss or VSWR measurements. The peak values of a DTF measurement are derived from a number of variables including cable propagation velocity factor, cable insertion loss in dB/meter, and temperature coefficients. These variables are processed in an inverse FFT process to identify the position of the largest reflections along a transmission line. The measurement is an excellent troubleshooting aide for cable and antenna issues, but is not a substitute for a return loss measurement. It is commonly used to identify the position of connectors and kinks in RF cable feeds and also to validate that no unexpected reflections exist.

The first measurement is typically to test the cable without the antenna connected. Connect a 50 ohm load to the end of the cable in place of the antenna. A DTF measurement is achieved by performing a sweep in the frequency domain and the data is transformed to the time domain using an inverse FFT. Distance information is obtained by analyzing how much the phase is changing when the system is swept in the frequency domain. The frequency sweep band may be wider than the tuned frequency range of the antenna which is why it is better to perform the initial cable test with a load. The DTF distance range and resolution are dependent on the sweep range and number of data points. Since most users know the approximate length of the cable under test, it is most convenient to use the DTF AID tool to configure the sweep range and number of points automatically.

To perform a DTF measurement on the Field Master Pro MS2090A using the Site Master S331P, in the CAA mode, select MEASURE\MEASUREMENT\DTF return loss. DTF VSWR is an alternative view of the same measurement using VSWR as opposed to dB return loss as the Y axis units. Once in DTF mode, it is necessary to enter the characteristics of the specific cable under test. Press FREQ/DIST\DISTANCE\DTF AID.

Enter a STOP DISTANCE that is slightly longer than the estimated length of the cable, for example if testing a 20 meter cable, enter a stop distance of 25 meters. The usable distance is a function of the frequency span and number of data points. Increasing the number of data points and decreasing the sweep span both have the effect of enabling a longer cable to be tested.

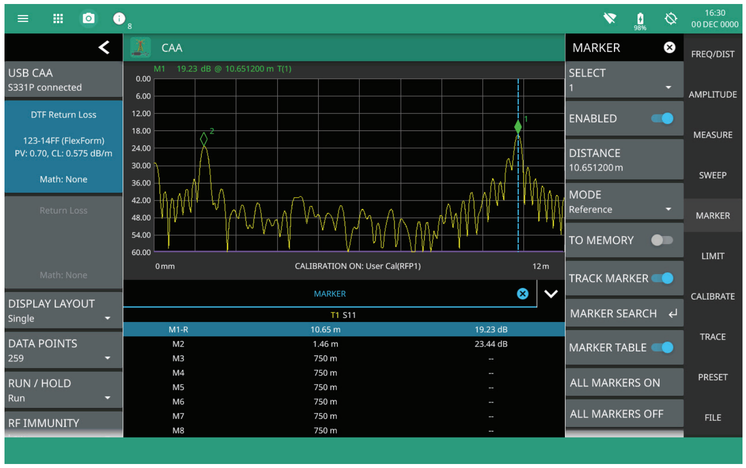
In the example below, the start and stop frequencies are set to 3.4 GHz and 3.7 GHz and the number of points to 517, which enables cables to 257 meters to be tested. The stop distance of 25 meters ensures the display trace only shows the distance of interest.



This Screen Shot Shows the DTF AID Screen Helps Optimize the Trace Resolution and Range Setup

Distance and amplitude accuracy requires knowledge of the specific cables propagation velocity and insertion loss. Propagation velocity is a term used to define the speed of RF signals in the specific cable relative to the speed of light in a vacuum. Propagation velocity values for coaxial cable(s) are always less than 1, for example the 123-14FF cable used in these measurements has a propagation velocity factor of 0.70. The Field Master Pro MS2090A has a library of settings for common cable under CABLE LIST, but if the cable under test is not included in the library the values must be entered manually using the CABLE LOSS and PROP VEL keys.

Having configured the DTF measurement, exit the DTF AID and connect the Site Master S331P test port to the start of the cable run to view the return loss against distance trace. Markers and limit lines are configured in the same way as for return loss measurements described earlier. Positioning a marker on the highest signal identifies the distance along the cable to the largest reflection. Once the highest magnitude reflection has been identified investigative action can be taken to understand the cause. Typically, this may be a loose or damaged connector or a kink in the cable outer conductor due to a bend radius being too tight.

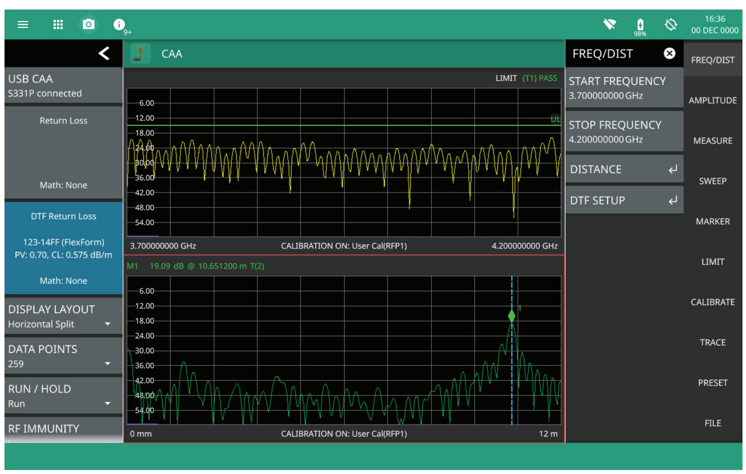


In This Screen Shot the DTF Trace is Highlighting the Jumper Cable Connector to the Antenna

Additional measurements such as cable length and DTF with the antenna attached are simple extensions of the standard DTF measurement.

The measurement resolution can be enhanced by increasing the span of the frequency sweep. This is typically acceptable when testing just a cable, but wider spans may extend beyond the frequency range of any antenna in the system. For this reason, caution should be taken when viewing the reflection from the antenna if the span has been set wider than its frequency range.

Use the MEASURE\DISPLAY LAYOUT\HORIZONTAL SPLIT key to configure the simultaneous viewing of return loss and DTF. This provides the most comprehensive overall summary of the cable and antenna performance.



This Screen Shot Shows the Simultaneous Display of Return Loss and DTF

Summary

The Field Master Pro MS2090A includes a broad range of features to support all aspects of new LTE and 5G base station installation. In addition to modulation quality and coverage mapping measurements, the addition of a Site Master S331P cable and antenna accessory provides a comprehensive instrument for all the key measurements a field technician requires.

Advancing beyond

Specifications are subject to change without notice.

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