White Paper

Anritsu Advancing beyond

Evaluation of RF Network Testing

An Industry Review of Techniques and Procedures

Transmission line and antenna testing has become a common test of RF network integrity. This testing methodology is the result of test equipment evolutions and the need to fully understand the integrity of RF networks after installation. While common today, in the past this component was ignored because the equipment necessary to perform the tests was either laboratory-grade or non-existent in the field. While the capabilities of testing the integrity of transmission line, connectors, and antennas is readily available in the field, the results and conclusions of this testing are not consistent. Cable and antenna manufacturers are often blamed for failed tests, even though the hardware is proven to be fully compliant and functional as designed. In an effort to improve these valuable tests and establish consistency in our results and conclusions from the test, experts from the industry decided to work together to establish some basic guidelines for the tests and Methods of Procedure (MOP). This consensus work was performed in a controlled environment with the major leaders of the industry present. The recommendations and techniques presented were developed to improve the integrity of the results and represent effective conclusions that can be reached, regardless of the cable, connector, test equipment, or antenna evaluated. The purpose of this paper is to develop and achieve consistent results.

I. Introduction

A workshop was held that brought together industry leaders and manufacturers to discuss and develop a unified understanding of line sweeping methodologies. This group of attendees was made up of antenna manufacturers, cable manufacturers, filter and RF manufacturers, field engineers, system technologists, test equipment manufacturers, and business managers. A complete list of the collaborating manufacturers involved is included in the Appendix.

Standardized testing has been a part of RF communications since the first conversation was transmitted. To ensure reliable communication, the health of the components involved was required to be tested and verified. Until recently this applied to the communication hardware but not the RF network. The RF network refers to the hardware between the transmitter/receiver and the antenna. The RF network transports the modulated RF energy to the antenna or from the antenna to the receiver. This network allows the antenna to effectively radiate or receive energy. The RF network has, for the most part, been taken for granted and is expected to be a drop-in component. Very little testing and evaluation was performed in the past, however, the expectation of a stable, predictable, and dependable component was not warranted. Components, while reliably designed and manufactured, were damaged when installed, shipped, or improperly installed. The simple testing performed on-site was inadequate to properly evaluate the effectiveness of the hardware. Recently, with the evolution of new test equipment, the ability to test the RF network components and antennas to a degree that resembles the manufacturer's testing has led to new procedures and expectations. Field personnel now expect to be able to reproduce the same data that the manufacturers declare on the components. While this expectation is achievable, discipline is required.

Return Loss vs. Frequency is the primary means of testing RF networks because the effectiveness of an RF network depends so greatly on impedance matching. Physics dictates that maximum power is transferred from the point of origin to the destination when the origin, transmission network, and the destination impedances are perfectly matched. Return Loss (RL) and/or Voltage Standing Wave Ratio (VSWR) are the measure of the deviation from a theoretically ideal impedance match. The higher the absolute value of the RL, the better the match, resulting in better power transfer. Impedance irregularities anywhere in the RF network will result in power being reflected back to the source. This reflected power reduces the amount of power transferred from a source to a load. In order to maximize the radiated power from a system, the RL of all of the components must be established and verified. The impedance could vary at certain points due to manufacturing variances or because of faults at certain points in the network. Regardless of how or why these occur, the overall result is a reduction in transferred power. Transmission line testing is critical in determining if there are irregularities and to locate where these occur. Testing is also important in establishing a benchmark for future measurements to find changes or deterioration of components. More important than performing these tests is to ensure testing is done consistently and competently. Without standardized testing procedures, the opportunity for inconsistencies exists.

II. Test Equipment

The goal as RF system engineers is to provide site designs that will perform as the customer requires. Test equipment allows the components of the system to be optimized and verified to specific standards used in the design. When the performance of a system equals the designed performance, energy transfer from the source to the load will meet or exceed design criteria and maximum coverage will result. Without the ability to test the installed equipment, the system coverage is a leap of faith. This is how systems were designed and installed in the 20th century but not in the 21st century. Best practices say we should validate the operation against the design goals empirically.

A. Test Equipment Available

RF network test equipment migrated from the laboratory into the field beginning in the late 80s and early 90s as integrated circuits capable of performing the required analysis and computation became available. Test equipment that could only be maintained and used by laboratory engineers was now available to technicians and RF installation field personnel. While this precision test equipment became available because the test equipment manufacturers made it less complicated to use, significantly smaller, and more rugged, without the accuracy and detailed testing possible. Tests now can be performed in the field that were not even available in large, high-priced, laboratory-grade equipment ten years ago.

1) Wattmeter

The wattmeter has been used for years to evaluate the quality of the RF network using transmit power. While providing a very crude VSWR measurement, the wattmeter did not allow testing of the receive network or assist in understanding where problems occurred in the network.

The wattmeter simply measures the power in the forward and reverse directions. Comparing these two measurements allows the calculation of VSWR, which can be converted mathematically to Return Loss. While the VSWR measured may be accurate for the position of the wattmeter in the system, it does not allow for an understanding of where a mismatch is located or how bad it may be. If the mismatch occurs far down the transmission line, the full effect of the mismatch may be masked by the loss of the transmission line in between. A mismatch occurring in the antenna cannot be distinguished from cable/connector problems. The use of a wattmeter to determine RF network quality is about as effective as trying to read a book in the dark.

2) Time Domain Reflectometer (TDR)

The original piece of equipment in this family was the Time Domain Reflectometer (TDR), a device that inserted a DC pulse into a system. The pulse traveled from the insertion point to the antenna and was reflected back by any irregularities, shorts, or opens within the system. The speed of the pulse is known as the speed of electromagnetic radiation — the speed of light. Because of the “velocity factor” of the cable, the pulse is slowed by a known amount, which is included in the calculations. Using the return time and the level of the returning signal, the device calculates the distance to any faults in the system.

All of the RF specifications for a system are based on the frequency of operation. A TDR sends a DC pulse through the system that does not take the frequency-specific characteristics into account. A TDR’s pulsed DC stimulus reflects little energy at RF faults or impedance mismatches. Furthermore, almost 100% of the TDR’s source energy is reflected by the antenna or any other in-line, frequency-selective device (e.g., frequency combiners, filters, or quarter-wave lightning arrestors). Due to the square wave nature of the DC pulse, the TDR’s spectral content is splattered across a wide frequency range, but the amplitude is not consistent with frequency and the spectral magnitude and the output pulses tend to roll off rapidly at high frequencies. Typically, less than 2% of a TDR’s pulsed energy is distributed in the RF frequency ranges. For these reasons - and others - the use of the TDR is deemed marginal for evaluating RF networks.

3) Frequency Domain Reflectometer (FDR)

An FDR generates an RF sweep that includes only the frequency range selected by the operator, allowing frequency-selective characteristics to be displayed clearly. Measurements include RL or VSWR vs. frequency RL (or VSWR) vs. distance. FDR developed as embedded processors became available to handle the higher data rate and complex mathematics needed to perform this type of test. The FDR injects RF energy of constant amplitude across the frequency band of interest and analyzes the returned signal to look at each part of the RF system across the band. The FDR does work similarly to the TDR in that they both inject energy into a system and compare it to the energy returned, however the FDR uses a constant amplitude sweep of frequencies. The FDR is able to detect the reactance of components instead of DC resistance or the presence of a short or open. By doing this, it is capable of quickly giving the operator a “snapshot” of how the entire system reacts to the RF bands of interest. By applying mathematics to convert frequency domain into the time domain, fault location is possible.

The Anritsu Site Master®, Agilent FieldFox®, and Bird Site Analyzer® are just a few examples of FDR devices available. All of these products display insertion or cable loss relative to frequency, VSWR relative to frequency, RL relative to frequency, and Distance-to-Fault measure in RL or VSWR relative to distance. Each of these measurements is helpful in evaluation and maintaining a system. FDR capabilities are being integrated into multipurpose testing equipment.

All test equipment, including frequency domain reflectometers, have accuracy specifications published by their respective manufacturers that should be understood and considered by the end user of the equipment, and included in determining the condition of feed line and other components in transmit or receive systems.

III. Absolute vs. Relative Testing

Testing of an RF network can be performed in two configurations – absolute and relative testing. The degree and accuracy of the information obtained is the primary difference between them. Absolute testing is performed with a 50 ohm precision load as the termination of the product or system being tested. Relative testing uses a non-precision load, such as the antenna, to terminate the system.

1) Absolute Testing

Absolute testing relates to using laboratory precision terminations and controlled testing techniques. Absolute testing is precision testing within a controlled testing environment that emulates the tests performed by the manufacturer and can be used to validate manufacturer specifications.

The RF network is tested in a closed manner that factors out external uncertainties. Absolute testing is never conducted with the final antenna attached. Depending on which measurement is being made, a known good and calibrated open, short or load termination must be inserted at the end of the network under test. A calibration standard (sometimes called a “CalKit”) has three different terminations: a calibrated OPEN, a calibrated SHORT, and a calibrated 50 ohm LOAD. A calibrated load is different from other 50 ohm loads used for line termination because it is an extremely pure load that has not only been made from a precision resistor, but also designed to have known consistent frequency, amplitude, and phase characteristics. Likewise, the calibrated open and short are designed to respond to RF energy in a specific and repeatable way. The quality of your measurements is only as good as the quality of your calibration standard! Before any absolute testing can be performed, the calibration standard must be verified. A calibration standard that has been stored in a tool box, or never calibrated, could be damaged and should not be used for absolute testing. The calibration standard must be treated with the same respect and care any piece of precision test equipment deserves. Understanding the accuracy and repeatability of the calibration standards RF response is crucial in absolute testing. It is critical that the calibration standard be returned along with the test equipment during the regular calibration cycle. This allows the calibration lab to validate and verify each of the calibration standards. To further ensure an accurate calibration standard is used, it is recommended that a cross-verification be performed regularly. Cross-verification refers to using a second network analyzer or FDR to verify the calibration standard in question. Remember, the calibration standard is a piece of test equipment itself and should be treated as such.

Since absolute testing is based on known matching characteristics, the results can be used to compare with a manufacturer’s specifications. Performing absolute testing on an existing system requires taking the system off the air and inserting the appropriate termination at the top of the tower. Because of this expense and associated difficulty, absolute testing is normally reserved for initial commissioning or critical troubleshooting.

Feed line manufacturers publish product specifications in various formats that must be properly applied. Some present impedance characteristics such as “50 ohms +/-1 ohm”. Others may supply VSWR instead of RL, or impedance may be given in the frequency domain only rather than as a Distance-to-Fault (DTF) specification. Regardless of format, the specification provided by the manufacturer is what should be applied in determining feed line health.

2) Relative Testing

Relative testing relates to performing tests outside of a controlled environment and without controlled test terminations. This type of testing occurs when an installed system is tested without the benefit of calibration standards. In a relative testing environment the matching network or “load” of the RF system is the antenna itself. Antennas have significantly varying impedances and matching characteristics depending on the frequency, design, quality, antenna type and installation. They can also be affected by movement, proximity to other objects including people, and RF signals from other systems. Because of the uncertainty of the antenna as a precision load, the results cannot be referenced back to manufacturer specifications other than performance specifications of the antenna itself. However, this type of testing is beneficial when compared against a benchmark portfolio of tests and sweeps that were performed during the initial installation. As the name implies, relative testing must be compared with something. Absolute testing is compared with the manufacturer's testing and specifications, but relative testing must be compared with the initial installation test results. When initial test results and sweeps are available, a comparison with the current sweeps will show changes that may affect operation. Since the cable matching in the same network is used in the initial benchmark tests, the comparison establishes a benchmark to which later tests can be reliably compared with. As long as the comparison is equal, or close, it can be assumed that the RF network has not changed significantly.

IV. Standardized Tests

Proper evaluation of an RF network involves performing a set of standardized tests consistently. If performed in the same manner, the results will be consistent and reflect real world performance. If not performed properly they will be of no use to anyone trying to evaluate the system.

1) Return Loss (RL)

The RL and VSWR measurements are key measurements for anyone making cable and antenna measurements in the field. These measurements show the user the impedance match of the system and if it conforms to system engineering specifications. If problems show up during this test, there is a very good likelihood that the system has problems that will affect the end user. A poorly matched antenna will reflect costly RF energy that will not be available for use at the load. This extra energy returned to the source will affect the efficiency of the transferred power and the corresponding coverage area.

An absolute RL (or VSWR) test is taken with a known calibrated load at the end of the RF network to ensure a perfect match. This allows the network to be the limiting factor in most reflections. With the calibrated load in place of the antenna, most reflections that occur will be the result of impedance mismatches in the network itself. This test allows the network to be compared to manufacturer specifications that were taken in like manner. The return loss measurement should also be taken with the final antenna connected and installed in the final location, as this shows the delivered return loss of the system and takes installation distortions into consideration. This relative test will uncover irregularities not caused by the hardware, such as mounting too close to other metal objects.

Figure 1 shows a typical RL sweep. This sweep over frequency can be used to validate manufacturer specifications only when a calibrated termination is used.

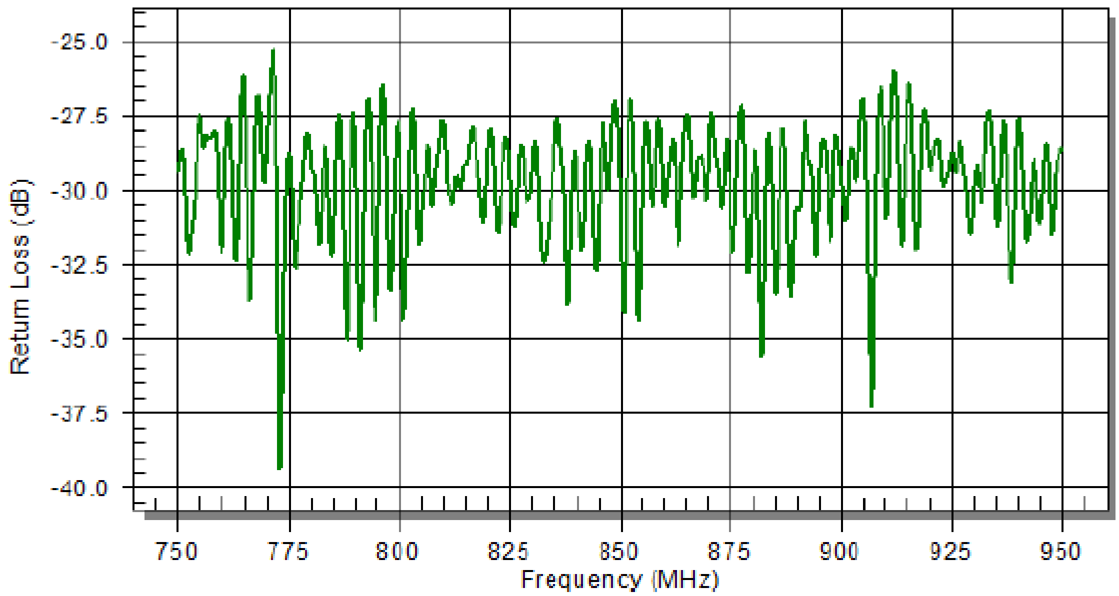

Figure 1. Typical Return Loss Sweep

2) Insertion Loss (IL)

As the RF signal travels through the RF network, some of the energy will be dissipated in the cable and the components. A cable loss measurement is usually made during the installation phase to ensure that the cable loss is within manufacturer's specification. A cable loss measurement is not isolated to the transmission line but all components in the network. When performing cable loss measurements, be aware of components that may have frequency characteristics which could affect the results.

There are two types of cable loss measurement. Two-Port Insertion Loss (2PIL) uses a test instrument in which the test signal is generated on one RF port and received by a second RF port on the same instrument. This method directly measures the loss of a system with high accuracy, however it is not always possible to connect physically to both ends of a cable so a second method is needed. One-Port Cable Loss (1PCL, or just CL) uses a measurement method in which the RF energy is generated and received by a single port. In effect, 1PCL is insertion loss divided by two, and as such it must be understood that it suffers from the same uncertainties as RL. 1PCL is only an absolute test when done with a calibrated open or short connected to the end of the RF network, because only a calibrated open or short provides a consistent and total reflection to the test signal. The test instrument compares the generated signal against the reflected signal and divides the difference by two. The 1PCL data is normally the average of the maximum/minimum value. The 1PCL measurement can only be accurate if the reflection is total; i.e. a calibrated short or open must be used. Relative CL tests cannot be performed as the energy used to measure system loss will be radiated by the antenna and not reflected. Figure 2 shows a typical CL sweep taken with a calibrated open or short at the end of the cable. The results of this sweep can be compared with the insertion loss of the cable, connectors, and any other devices present to the manufactured standard.

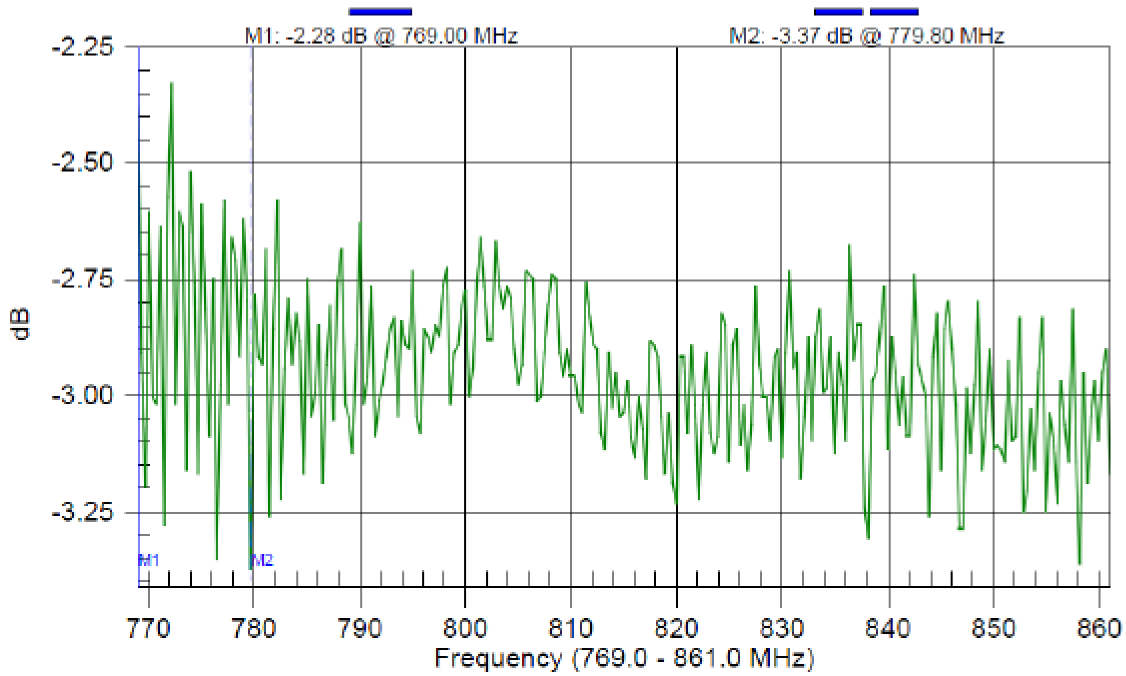

Figure 2. Typical Return Loss Sweep

3) Distance-to-Fault (DTF)

The most controversial test is the DTF. The DTF maps the RL (or VSWR) over the length of the complete network; this is referred to as DTF-RL. While the DTF sweep is a great troubleshooting tool, it is also a great quality analysis tool. There are times when the CL and RL sweeps meet the manufacturer specifications, yet irregularities along the cable cause failure in DTF expectations. Two very specific situations will be shown in the Case Studies that show the DTF can fail and real problems exist, even when the RL and CL sweeps pass. The DTF sweeps can only be performed reliably and effectively in the absolute testing mode. DTF is not reliable in the relative mode for determining failure, unless another previous relative sweep is available for comparison. Figure 3 shows a typical DTF-RL sweep.

The most questionable item is the DTF-RL threshold to be used for pass/fail. Cable manufacturers are just now beginning to perform DTF on their products and have not published specifications for DTF-RL. While there is not a true standard for the acceptable level of DTF-RL, it is a reasonable expectation that it should be between -40 dB and -50 dB when sweeping primary feed lines. A DTF Return Loss of -50 dB will have fewer imperfections and irregularities than a network measuring -40 dB. Risk and system requirements are the two determining components in selecting a tolerance threshold. A mission-critical public safety system may require a DTF-RL better than -45 dB where a commercial cellular system may require only -40 dB. The expectation must be identified before testing begins.

Failure of DTF-RL is associated with impedance changes along the cable or at the transition of a connector. These changes can be caused by cable bends that kink, improperly installed connectors, stretched cable, dents which change the dielectric spacing, or water intrusion. Because one or two irregularities can have minimal effect on the overall RL characteristics of the cable, the absolute RL sweep may not be affected. Nevertheless, if dents, kinks, or other impairments exist the cable could be considered bad. DTF not only helps identify where irregularities occur on the cable but also their severity.

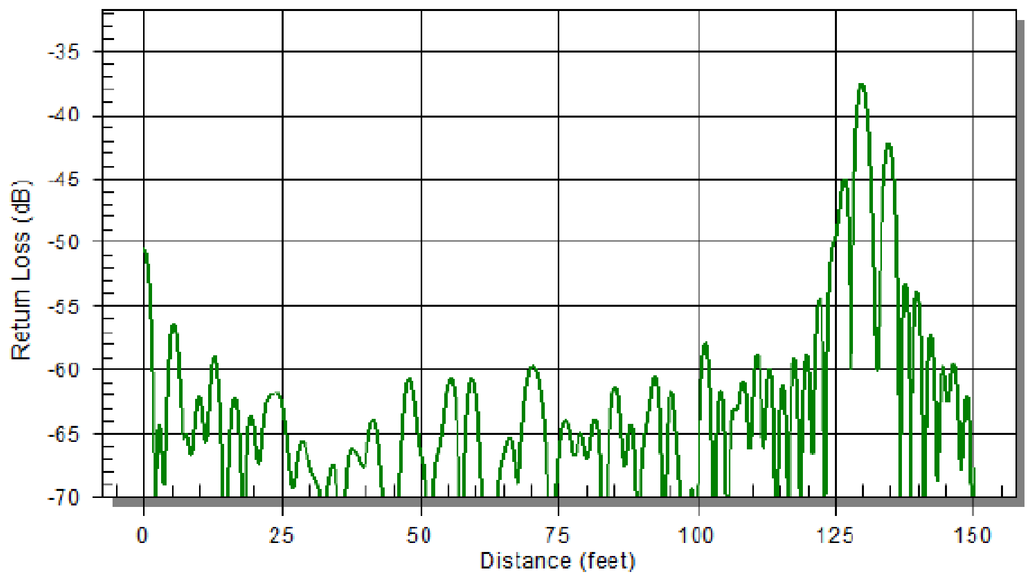

Figure 3. Typical Distance-to-Fault Loss Sweep

V. Method of Procedure

A Method of Procedure (MOP) is needed to ensure a standardized approach to testing. The MOP is a written document of procedures and testing methods that outlines exactly what and how the data is collected. The MOP is similar to the checklist used by airline pilots to ensure everything is done completely in a specific order. When an engineer or technician is performing a deployment verification, hardware validation, or relative testing of an existing system, an understanding of what and how the tests were performed is critical in obtaining acceptance of the results by reviewers that were not on site. The MOP establishes a consistent foundation for the testing methodology and removes uncertainties that could cause invalidation of the data.

Antenna system commissioning is necessary to verify the integrity and performance of an antenna system and involves both physical inspection and electrical testing. Physical inspection of the antenna system should include an installation audit that includes an audit of the cable while still on the reel, transmission line ground kits, transmission line mounting hangers, and lightning suppressors. A physical audit is important to ensure any damage that may have occurred during transit is found before an expensive installation occurs. The electrical testing includes a series of tests using a Frequency Domain Reflectometer (FDR).

The MOP is not intended to replace proper training in the field of antenna system concepts, nor is it intended to replace training in the use and operation of the test equipment. The MOP is designed as a guideline for trained and experienced technologists and engineers.

The MOP must contain several important components to consider as line sweeping is performed. If these components are not included in the process the results may be questionable.

Below are components that should be considered in any MOP. While the expected results may vary depending on the system type and requirements of the system deployment team, the components and the processes should vary little.

1) Data Collection and Documentation

Before antenna and line commissioning or testing is started, it is necessary to have the electrical specifications for all the RF network components.

The system designer should supply this information or make it available before the MOP is begun. This site-specific information establishes the expectation and allows rapid comparison of the collected data. This data is also needed to program the test equipment to ensure it knows the cable type and characteristics. Drawings also allow the person performing the test to fully understand the components included in the network which will assist in understanding and interpreting the results.

The electrical specifications needed are:

- Antenna frequency range and return loss specifications
- Jumper cable type, velocity factor, insertion loss, and return loss
- Transmission line type, velocity factor, insertion loss, and return loss
- Lightening suppressor frequency range, insertion loss, and return loss
- RF connector type, insertion loss, and return loss
- Expected transmission line system insertion loss

2) Analyzer and Test Requirements

The analyzer used in the field is considered laboratory-grade equipment, and must be treated and used accordingly. Proper setup and configuration of the analyzer is critical for meaningful and accurate measurements. Below is a list of the analyzer and test configuration requirements:

- Analyzer should be loaded with the most current firmware
- Analyzer must be in known good working order and serviced at the factory as recommended by the manufacturer
- Precision load must be in known good working order

The precision load is a very delicate piece of equipment and must be treated with care. If the precision load is dropped from any height it should not be used again on projects until its proper operation is verified by the manufactuer.

- Analyzer must be calibrated at the ambient temperature in which it will be operated.
- Analyzer must be re-calibrated whenever its temperature changes significantly, or when the analyzer display indicates that the calibration is no longer valid due to temperature change.
- Analyzer must be re-calibrated whenever the setup frequency changes.
- Analyzer must be re-calibrated whenever the test port extension cable is added, removed, or replaced.
- Analyzer must be re-calibrated if it has been turned off for any significant length of time.
- Analyzer must be re-calibrated anytime “noise” or “picket fencing” appears at the bottom of the display during a distance-to-fault measurement (down around -50dB).
- The calibration results and precision load should be tested by performing a return loss test on the load after calibration. A return loss of -42dB or better should be obtained from the precision load.
- Analyzer resolution should be set to maximum for the highest quality and most accurate printouts.
- When using a load, only a precision load shall be used.
- Adapters should be avoided whenever possible. If adapters are needed, only precision adapters shall be used.
- If an extension cable is needed, only a phase stable cable shall be used.

Never use your primary calibration standard on the tower or at the remote end for absolute testing. Keep your calibration standard in a controlled environment to ensure integrity.

3) Testing Documentation

When antenna system commissioning is performed, it is necessary that all tests are properly documented for use in the system manual and for future antenna system testing and/or troubleshooting. All relative testing accuracy will depend on the quality and the attention to detail used in the commissioning documentation.

The results of the MOP tests should be readily available in the system manual as a viewable file, such as *.pdf or *.wmf formats. To allow side-by-side comparison of relative data, the raw data files should also be available. To coordinate use, all traces should contain common information and be taken in similar formats.

As a minimum, all software traces should identify the following:

- Site name
- Clear identification of Antenna system tested (e.g., TX 1, TX 2, TX North leg, RX, Blue, Red, etc.)
- Test type (e.g., Return Loss, Insertion Loss, or Distance-to-Fault)
- Test details (e.g., with jumper, terminated with precision load, terminated with open/short or terminated with antenna)

4) Standardized Tests to Perform

A list of all tests that should be performed is critical in ensuring complete and thorough testing. These tests will involve both relative testing and absolute testing. While the procedure for performing these tests is very important, it is beyond the scope of this paper to present. Each MOP developed should outline exactly how and any special considerations to be used in performing the tests. Standardized testing must be preceded with visual inspection of the cable and reel to identify any shipping or other damage that may have occurred.

Tests that should be considered a part of the MOP are:

- Jumper Insertion Loss and Return – All jumpers should be tested and verified before installation. (Absolute Test)
- Antenna Testing – Each antenna should be tested on the ground before installing. When testing an antenna, the location should not be near metallic materials and needs to be above the ground as much as possible. If using a directional antenna, the antenna shall be pointed vertically and/or away from possible sources of RF energy. (Relative Test)
- Verify End of the Antenna System – This test involves performing a DTF using precision terminations (open or short) and is the absolute verification of the cable that can be compared with the manufacturer specifications. This test verifies that cable supplied is the length specified and that the end of the cable is actually visible on the sweep. This test may involve installing test connectors on a reel of cable. (Absolute Test)
- Antenna System Insertion Loss (Cable Loss) – This test is used to measure and validate the insertion loss of the entire antenna system (i.e., main transmission line, jumpers, and lightning suppressor) with a calibrated open or short. The results of this test can be compared with the design engineer’s theoretical expectations. (Absolute Test)
- Transmission Line Distance-to-Fault While Terminated with Antenna Jumper and Precision Load – This test is similar to the “Verify End of the Antenna System” test with the exception that this test is performed after installation and will show installation errors. (Absolute Test)
- Transmission Line Return Loss While Terminated with Antenna Jumper and Precision Load – Final RL test after installation. This validates the RF network match. This test will be used as the foundation for operational validation. (Absolute Test)
- Complete Antenna System Return Loss – Similar to the Absolute Test of Return Loss, except this test is performed with the actual antenna connected. This test will be used to validate changes in the antenna system over time without the need for a tower climb. (Relative Test)
- Complete Antenna System Distance-to-Fault - Similar to the Verify End of Antenna System, except the final antenna is used for termination. This test will be used to validate changes in the antenna system over time without the need for a tower climb. (Relative Test)

VI. EXAMPLE CASE STUDIES

To fully understand the mistakes and uncertainties that can exist, three case studies are presented that demonstrate how the lack of discipline in testing and evaluation produced significant miscommunication and mistakes. These case studies will also demonstrate how organized testing can eliminate problems before installation. These case studies point to the logic of a standardized MOP, in order to control data collection and evaluation.

1) Case Study Number 1

The first case study is an actual city-wide public safety project that experienced significant delays and unnecessary complexity. The customer wanted to reuse their existing cables and connectors on a new communication system. While it was strongly recommended that new cable and connectors be used because of the age of the existing cables, the customer was adamant concerning the reuse of the old cable. The customer hired an independent "line sweeping consultant(s)" and used a contractor's staff members to conduct line sweeps. Because of the non-standard tests performed and lack of understanding of the testing conditions, the results were not readily accepted. Debate over what the data showed occurred over the next three month between the project team, the feed line manufacturer, two test equipment manufacturers, multiple line sweeping experts, and others with line sweeping experience and expertise. This debate and review by experts could not produce agreeable results.

Four major points resulted in the data not being acceptable or useable:

- Documentation was poor or non-existent for most sites
- Procedures used were sloppy and were not standardized (a MOP was not followed)
- The test equipment used was older and not in verifiable condition
- Calibration certification of terminations was not available.

The results of the sweeps produced evidence of cables that did not meet manufacturer specifications.

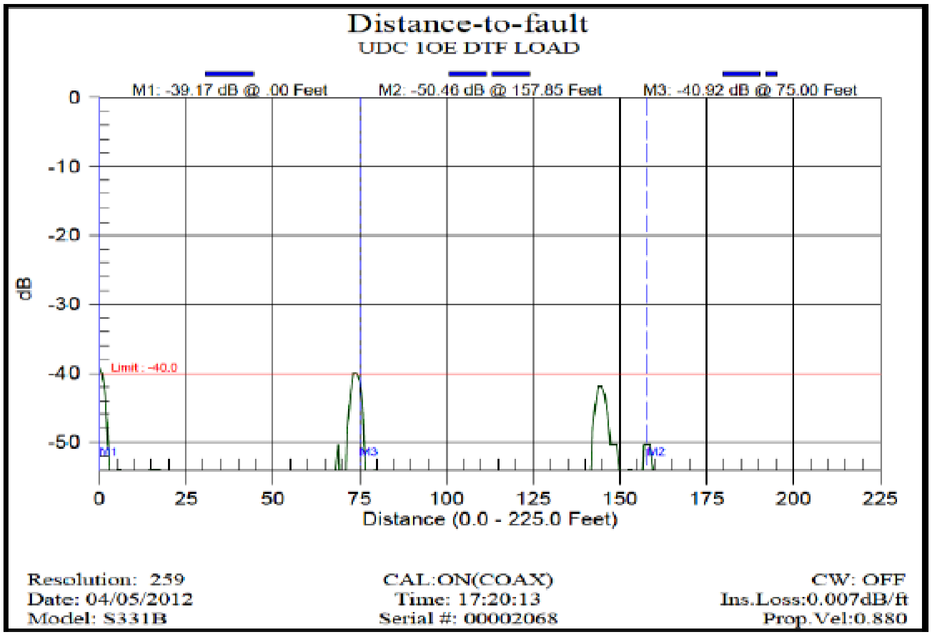

Figure 4. Questionable DTF Sweep

For one specific DTF sweep, the sweep showed several spikes that were questionable (Figure 4). Depending on the threshold used for acceptability, the line could be considered bad. Nevertheless, there are issues indicated on the cable. Following absolute testing procedures would have provided conclusive non-controversial data to evaluate the quality of the cable.

After considerable debate over the quality and condition of the line, an inspection was conducted. One of the spikes of questionable quality occurred at 74 feet (-40 dB). The tower crew was asked to return to the site to verify what was at the physical location. The physical inspection revealed incorrect cable clamps (Figure 5) that did not provide uniform pressure to the cable.

Figure 5. Improper Cable Clamps

Case Study Number 1 Conclusion: Proper documentation and following an acceptable MOP would have made a significant difference in the outcome of this discussion. As recommended elsewhere in this document, a systematic approach to sweeping the lines and determining the health of the system requires all the tests to be executed properly. In this instance, it was found that the testing was not complete; the system contained nearly 30% of feed lines that should have been condemned and replaced, but were instead left in place potentially compromising coverage and reliability. Many of the feed lines showed signs of water intrusion and corrosion at the connectors, problems not seen or noted by the crew conducting the testing.

2) Case Study Number 2

After the receipt of a new reel of cable, a project team performed absolute line sweeping tests on the cable following the certified MOP tests. Performing these tests while still on the ground and not installed is a very good procedure. This testing identifies "As Received" before installation and can prevent installing bad cable. The test identified an issue with the cable. In this case, the team jumped to the conclusion that the cable had manufactured defects. Testing of the reel showed a good RL sweep (Figure 6) but a questionable DTF sweep (Figure 7).

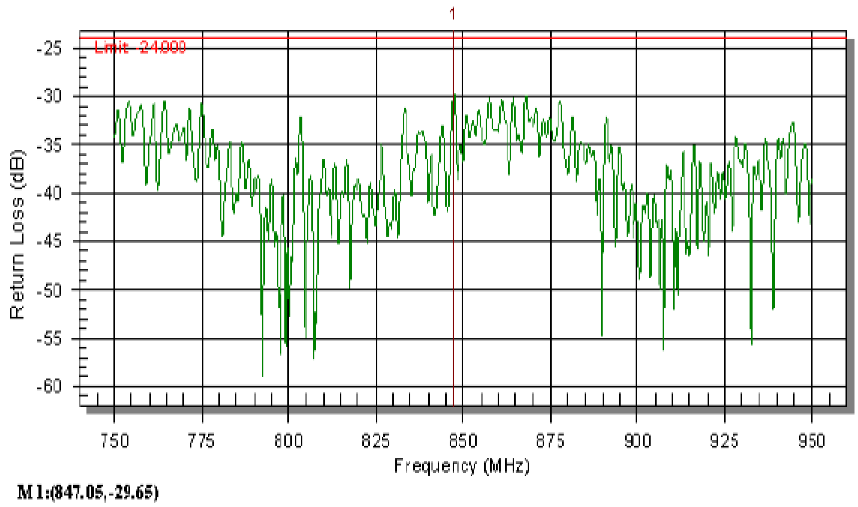

Figure 6. Good RL Sweep

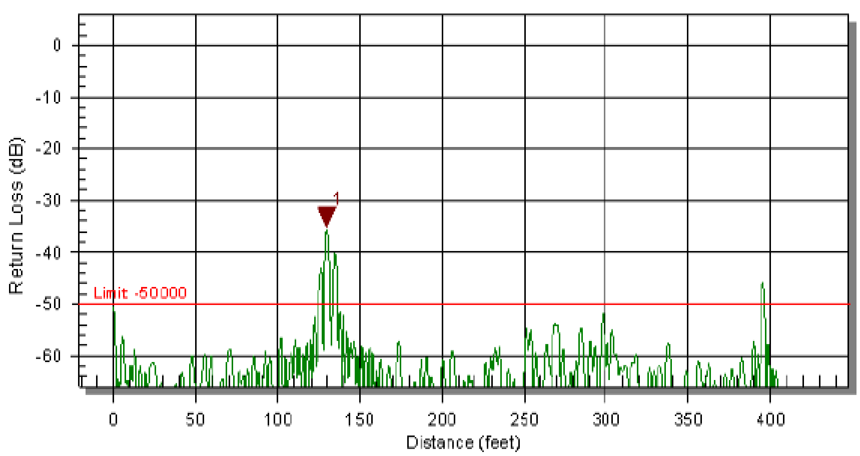

Figure 7. Questionable DTF Sweep

The cable was returned to the manufacturer for testing and analysis. The manufacturer compared the quality data on the bulk reel before it left the manufacturing facility with the returned cable. The bulk reel is a large 10,000 foot reel that is used to supply cable of different lengths from a cutting process. This cutting process may be done by distributors or by the manufacturer. The cable did exhibit a DTF spike greater than -40 db as found by the field team. Visual examination of the cable shows a large dent in the cable (Figure 8).

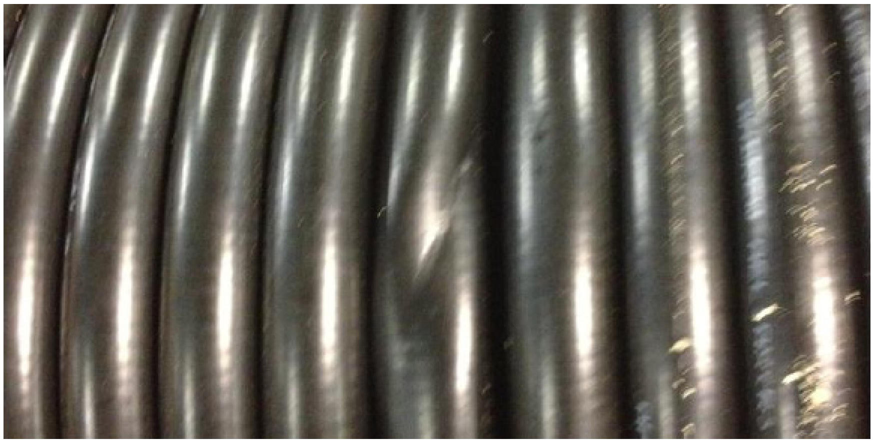

Figure 8. Dented Cable

The dented area was removed and the cable retested. The DTF sweep was performed again and the cable tested to better than -50 dBm. The jacket was removed from damaged area to expose a dent in the cable (Figure 9).

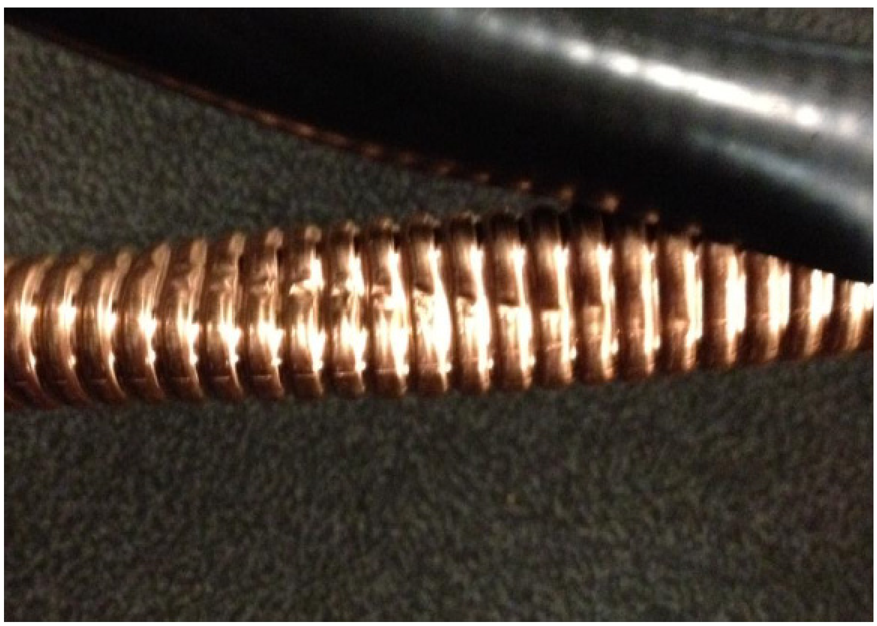

Figure 9. Cable Damage

Case Study Number 2 Conclusions: The dent in the cable was the cause of the DTF spike greater then -40dB. The dent was not caused during manufacturing as the cable would not fit through the jacket extrusion die with the deformity. In addition, the bulk cable passed DTF testing. While the exact cause of the dent and defect was unknown, it was anticipated to be transportation damage. The dent was on the outside layer of the cable reel and thus could have been found with visual inspection. This case study demonstrates the importance of inspecting cable and performing line sweeping tests prior to installation.

3) Case Study Number 3

After the receipt of a new reel of cable, a project team performed absolute line sweeping tests following the certified MOP test procedure. While the tested roll of cable exhibited a good RL sweep (Figure 10) it had a bad DTF spike of -28 dB (Figure 11) at the 148 foot point on the cable.

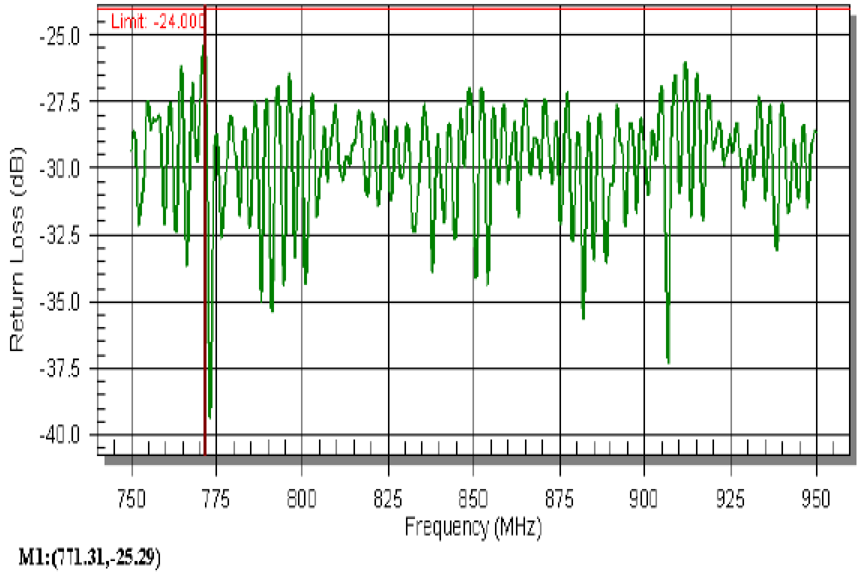

Figure 10. Good RL Sweep

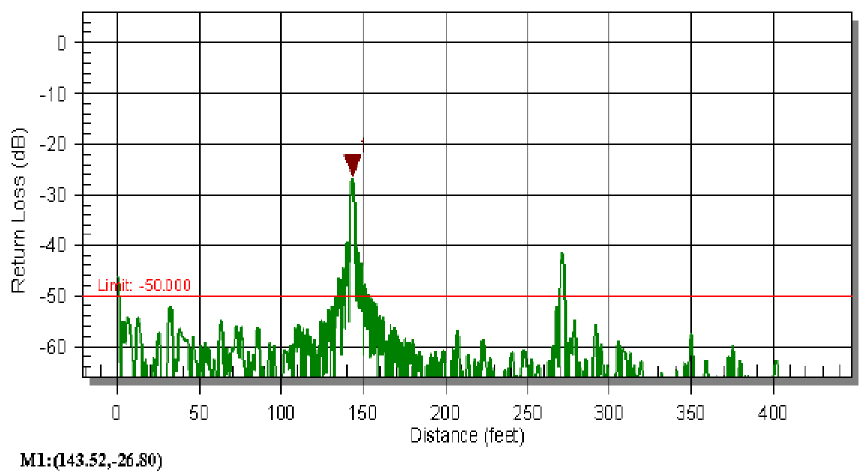

Figure 11. Bad DTF Sweep

The reel of cable was returned to the manufacturer for evaluation. Manufacturer evaluation validated the DTF spike seen in the field but showed the bulk reel had no deformities when it was shipped. The cable was unwound from the cable reel and the point of failure identified. The area was cut out and the reel was re-tested. After the area was extracted, the cable performance was better than -50 dB which compared with the bulk reel performance. When the damaged area was examined it was found to be stretched (Figure 12). Since the damage was found before it was installed, the damage was believed to be caused between the manufacturer facility and delivery to the field. Stretching of the cable is a possible defect in cutting cable. Cable is distributed in very large quantities and cut to length. Cutting involves unrolling the cable from the bulk reel and re-spooling it for shipment. This re-spooling process can cause stretching if the tension is incorrect. This is the probable cause of this cable distortion.

Figure 12. Bad DTF Sweep

Case Study Number 3 Conclusion: The stretched cable (corrugation deformation) caused a DTF spike greater than -50dB. The stretch point in the cable was at 148 ft. While this can occur during cable manufacturing (start up), the bulk length spool did not show this DTF spike and the defect was determined not to be manufacturing related. The cut-off length was supplied by a distributor who purchases bulk cable and then cuts it down to custom lengths to fulfill orders from customers. Although the distributor's facility was not inspected, they did have cable processing capability and it was possible that the cable was stretched during cable processing (cutting for customer order).

VII. Conclusion

All of the preceding case studies support the premise as set out in this position paper — line sweeping executed using current FDRs is a valid test of feed line and component viability. When properly executed and the results are properly and thoroughly documented, line sweeping using a combination of all three tests (RL, IL, and DTF) are important in determining the reliability of feed line systems. These tests will determine if coverage predictions can and will be met. Distance To Fault (DTF), Frequency Match Return Loss sweeps, and Insertion or Cable Loss sweeps all form a valuable set of field tests usable at site commissioning to show that the system, as installed, will meet design specification, and further are reliable techniques for determining system health and finding faults later in the life time of the system under test.

VIII. CONSENSUS RECOMMENDATIONS

Consistency relies on data collected by different parties being usable with confidence by others. To collect consistent data, discipline must be used and standardized procedures must be followed. Below are several important considerations the industry must consider and followed to ensure useable and correlatable data.

- Before beginning any tests have a good MOP and follow it carefully. The MOP ensures the tests are performed correctly and completely. Don't cut corners.
- Formal training in the proper use of test equipment is critical to ensure measurements are performed reliably and consistently.
- Maintain all test equipment and calibration standards with the respect they deserve.
- Calibration of the test equipment and all calibration standards is critical for reliable and consistent results.
- Perform physical inspections and absolute testing on new cables as they arrive. Don't assume the cable is intact.
- Always keep in mind that measurement data from any test is only as good as the precision and diligence used to perform the test.

Measurement results can only be objectively evaluated when the results are documented in a professional manner. Evaluation relies on having confidence in the data presented. Accurate and consistent record keeping provides a foundation upon which your team can have confidence in the data.

Appendix

List of manufacturers participating in the Line Sweeping workshop.

Below is a list of manufacturers that participated in the two day workshop to discuss all aspects of sweeping RF networks and what is required for reliable and consistent results. These manufacturers worked diligently to produce this consensus document of understanding.

Bryan Corley - Principal Staff Engineer – Motorola Solutions Inc.

Don Huston - Strategic Account Mgr – Bird Technologies

Mike Schaefer - Product Line Manager – CommScope HELIAX® Products

David Witkowski - Senior Product Manager – Anritsu Company

Advancing beyond

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• **United States**
Anritsu Americas Sales Company
450 Century Parkway, Suite 190, Allen, TX 75013 U.S.A.
Phone: +1-800-Anritsu (1-800-267-4878)

• **Canada**
Anritsu Electronics Ltd.
700 Silver Seven Road, Suite 120, Kanata,
Ontario K2V 1C3, Canada
Phone: +1-613-591-2003
Fax: +1-613-591-1006

• **Brazil**
Anritsu Eletronica Ltda.
Praça Amadeu Amaral, 27 - 1 Andar
01327-010 - Bela Vista - Sao Paulo - SP, Brazil
Phone: +55-11-3283-2511
Fax: +55-11-3288-6940

• **Mexico**
Anritsu Company, S.A. de C.V.
Blvd Miguel de Cervantes Saavedra #169 Piso 1, Col. Granada
Mexico, Ciudad de Mexico, 11520, MEXICO
Phone: +52-55-4169-7104

• **United Kingdom**
Anritsu EMEA Ltd.
200 Capability Green, Luton, Bedfordshire, LU1 3LU, U.K.
Phone: +44-1582-433200
Fax: +44-1582-731303

• **France**
Anritsu S.A.
12 avenue du Québec, Immeuble Goyave,
91140 VILLEBON SUR YVETTE, France
Phone: +33-1-60-92-15-50

• **Germany**
Anritsu GmbH
Nemetschek Haus, Konrad-Zuse-Platz 1,
81829 München, Germany
Phone: +49-89-442308-0
Fax: +49-89-442308-55

• **Italy**
Anritsu S.r.l.
Spaces Eur Arte, Viale dell'Arte 25, 00144 Roma, Italy
Phone: +39-6-509-9711

• **Sweden**
Anritsu AB
Kistagången 20 B, 2 tr, 164 40 Kista, Sweden
Phone: +46-8-534-707-00

• **Finland**
Anritsu AB
Technopolis Aviapolis, Teknobulevardi 3-5 (D208.5.),
FI-01530 Vantaa, Finland
Phone: +358-20-741-8100

• **Denmark**
Anritsu A/S
c/o Regus Winghouse, Ørestads Boulevard 73, 4th floor,
2300 Copenhagen S, Denmark
Phone: +45-7211-2200

• **Russia**
Anritsu EMEA Ltd.
Representation Office in Russia
Tverskaya str. 16/2, bld. 1, 7th floor., Moscow, 125009, Russia
Phone: +7-495-363-1694
Fax: +7-495-935-8962

• **Spain**
Anritsu EMEA Ltd.
Representation Office in Spain
Paseo de la Castellana, 141. Planta 5, Edificio Cuzco IV
28046, Madrid, Spain
Phone: +34-91-572-6761

• **Austria**
Anritsu EMEA GmbH
Am Belvedere 10, A-1100 Vienna, Austria
Phone: +43-(0)1-717-28-710

• **United Arab Emirates**
Anritsu EMEA Ltd.
Anritsu A/S
Office No. 164, Building 17, Dubai Internet City
P. O. Box – 501901, Dubai, United Arab Emirates
Phone: +971-4-3758479

• **India**
Anritsu India Private Limited
6th Floor, Indiqube ETA, No.38/4, Adjacent to EMC2,
Doddanekundi, Outer Ring Road, Bengaluru – 560048, India
Phone: +91-80-6728-1300
Fax: +91-80-6728-1301

• **Singapore**
Anritsu Pte. Ltd.
11 Chang Charn Road, #04-01, Shriro House, Singapore 159640
Phone: +65-6282-2400
Fax: +65-6282-2533

• **Vietnam**
Anritsu Company Limited
16th Floor, Peakview Tower, 36 Hoang Cau Street, O Cho Dua Ward,
Dong Da District, Hanoi, Vietnam
Phone: +84-24-3201-2730

• **P.R. China (Shanghai)**
Anritsu (China) Co., Ltd.
Room 2701-2705, Tower A, New Caohejing International
Business Center No. 391 Gui Ping Road Shanghai, 200233, P.R. China
Phone: +86-21-6237-0898
Fax: +86-21-6237-0899

• **P.R. China (Hong Kong)**
Anritsu Company Ltd.
Unit 1006-7, 10/F., Greenfield Tower, Concordia Plaza,
No. 1 Science Museum Road, Tsim Sha Tsui East,
Kowloon, Hong Kong, P.R. China
Phone: +852-2301-4980
Fax: +852-2301-3545

• **Japan**
Anritsu Corporation
8-5, Tamura-cho, Atsugi-shi, Kanagawa, 243-0016 Japan
Phone: +81-46-296-6509
Fax: +81-46-225-8352

• **Korea**
Anritsu Corporation, Ltd.
5FL, 235 Pangyoyeok-ro, Bundang-gu, Seongnam-si,
Gyeonggi-do, 13494 Korea
Phone: +82-31-696-7750
Fax: +82-31-696-7751

• **Australia**
Anritsu Pty. Ltd.
Unit 20, 21-35 Ricketts Road, Mount Waverley, Victoria 3149, Australia
Phone: +61-3-9558-8177
Fax: +61-3-9558-8255

• **Taiwan**
Anritsu Company Inc.
7F, No. 316, Sec. 1, NeiHu Rd., Taipei 114, Taiwan
Phone: +886-2-8751-1816
Fax: +886-2-8751-1817

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