Application Note

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# PTC Testing using Anritsu LMR Master™ S412E

## Background

Radio manufacturers have already started to ship their new ITC-R Positive Train Control (PTC) radios, and the first PTC digital radio communications systems are now being deployed and tested in the field. Information is beginning to be gathered on how these new PTC signals propagate, and an understanding of PTC system performance is beginning to emerge. Advanced propagation prediction software has been used to estimate coverage, and verification work is under way using the first deployed base stations to measure and confirm effective RF propagation.

PTC radio systems project commissioning teams from several different railroads are using their own individual approaches, with no final testing procedures defined yet. The focus on PTC RF testing has been mostly on verifying through RSSI (Received Signal Strength Indication) values that the coverage for each base station is similar to what the propagation software predicted. Typically, previously installed base station radios are used to transmit and receive PTC signals, and sometimes locomotive and/or wayside radios are also used in the field to verify coverage to and from the base stations.

This document describes and proposes an improved PTC field testing methodology which will be more precise, time saving, and cost effective. The improved methodology uses features already available in instruments such as the Anritsu S412E LMR Master™, and different configurations of instruments and PTC radios. Anritsu's LMR Master includes optional support for ITC-R PTC testing with a PTC Signal Generator, PTC Signal Analyzer, Spectrum Analyzer, and the ability to coverage map RSSI, BER, and Error Vector Magnitude (EVM) for PTC systems.

This document consists of four sections: Testing Parameters, Field Testing, Comments and Suggestions, and Test Bench pictures.

## Testing Parameters – Section 1.0

This section is focused on the parameters being measured during PTC wireless path testing in the field, what is normally being measured and how it can be improved. This section also describes the PTC testing features available on the Anritsu LMR Master. Several recommendations and testing tips are offered to improve the quality and accuracy of the testing and to fully utilize the features of the PTC Analyzer/Generator of the LMR Master.

Current field testing methodologies may address one or more of the following:

- Coverage, currently measured in RSSI
- Variable noise floor and de-sensing in some areas
- On-channel interference from other radios
- Near-channel interference from other radios
- Intermodulation products from other radios on several frequencies
- Random noise with different patterns from multiple sources
- Multipath fading caused by reflections on structures, terrain and large vehicles
- Other interference including radars, power lines and broadcasting systems

The main parameter currently measured is RSSI. One or more of the other parameters listed above may also be measured and recorded, but as of today there is no process in place to correlate how one or more interfering parameters might affect RSSI.

## Field Testing – Section 2.0

This section examines methodologies currently employed for PTC wireless path field testing, and provides several recommendations to change and improve the entire testing process, making it much faster and significantly reducing the cost of field testing work. Some semi-automated testing methods are proposed and described.

### 2.1 RSSI Testing (Current Testing Method)

RSSI provides a signal level resulting from the sum of multiple components that include the original signal received directly from the transmitter, other multipath signals produced by one or more reflections/bounces of the original signal on structures, terrain or other physical objects, plus any other signals from other radios, or products from different types of interference such as intermodulation or equipment noise, plus the ambient RF noise floor, which in densely populated areas may exceed –95 dBm.

An RSSI value can be estimated/extrapolated taking into consideration all the external factors, but it would not be very accurate or useful to determine how the PTC wireless path will be operating in the real world. There could be a section of 60 miles of track with a noise floor below –120 dBm, and almost perfect coverage of every foot of track with RSSI levels between –75 and –90 dBm, and there could still be large holes in coverage caused by multipath and other factors that degrade the PTC wireless path performance.

RSSI measurements only provide a small, one-dimensional view of the overall system performance. RSSI cannot discriminate between desired signals and undesired RF intereference, thus testing which relies solely on RSSI can lead to false consclusions, poor system performance, and added expense to diagnose and resolve failures. RSSI can be used as a secondary source for reference, but the primary testing has to be done using a more robust, precise testing method measuring the actual packet success performance of the PTC wireless path under test. This performance varies and so even with an adequate RSSI level there could be communications problems in the PTC wireless path.

## 2.2 BER Testing (Improved Methodology)

While it is indispensable to examine the ambient RF noise environment and establish how path characteristics affect performance of PTC radios; RSSI is not a measure of performance. The primary measurement used should be BER (Bit Error Rate), providing data packet success information. Instruments such as the LMR Master can simultaneously observe, geo-tag, and record BER, EVM (Error Vector Modulation) and RSSI measurements. The Anritsu LMR Master measures BER in percentage values, and the geo-tagged data is available as both an industry-standard KML and a CSV text file – both of which are easily manipulated by post-processing tools written in PERL and Python.

First step in the process is to determine a maximum acceptable BER figure for the PTC wireless path. This can be determined by setting up a PTC transmitter and a PTC receiver, and then observing packet success rates between the TX and RX radios while the RF path is deliberately degraded and the BER figure increases. The pair of radios will have to be carrying live PTC data traffic; the maximum acceptable BER for the PTC wireless path will be set at the point that this PTC data traffic quality of service becomes marginal. This maximum BER figure will be used as a benchmark for PTC wireless path measurements to be carried out in the field, and it will replace RSSI as the main parameter used to measure PTC wireless paths.

Any path measurement figures in excess of the maximum acceptable BER for PTC radios should be flagged for more detailed testing and analysis of that path. This testing will include verification of the actual path loss against the propagation prediction software for that path, and checking for the existence of interference, intermodulation, or other RF issues that might be causing unacceptably high BER values. It is possible that the path loss will be within the RSSI range expected from the values determined through propagation prediction software, but the BER values could still be beyond the maximum acceptable values to achieve packet success between the TX and RX radios; in this case the problem will be identified faster. The solution might involve mitigation by filtering or similar means, or the problem may ultimately require relocation of the base station to a better radio site, and/or deployment of additional base stations.

Some current PTC path measurements sometimes are done using PTC radios to measure BER, but the measurement range of these radios cannot provide the requisite depth of information. A typical PTC radio can only measure up to $1 \times 10^{-4}$ or $1 \times 10^{-5}$ BER, perhaps good enough for a quick snapshot, but not sufficient for formal PTC field testing. Radios are not designed to work as instruments; they are not calibrated to provide traceable measurements and they cannot emulate the multiple features and functions found on instruments specifically designed to carry out testing in the field.

When detailed analysis of a “flagged” PTC wireless path is required, the problem can be resolved by replacing the PTC transmitter in question with a transmitter consisting of an Anritsu S412E LMR Master transmitting PTC test signals into a 50 dB gain 100 watt power amplifier, and using another LMR Master to receive and analyze the PTC test signals. This will permit testing with variable TX power across a broad range of power levels, and it would be possible to observe BER values and how they change when TX power is gradually increased in small 1 dB steps from minimum measurable power to maximum power output, i.e., 75 watts. (See Figure 4)

If the transmitted power is slowly increased and the BER starts to deteriorate, this will point to the existence of path degradation due to the existence of power dependent RF issues such as intermodulation. This would be very difficult to discover when testing with RSSI alone or using PTC radios to measure BER.

Figure below shows typical testing of RSSI and BER in the field, and some of the differences between the two methods. Even with a good RX signal level between –75 and –90 dBm, and a noise floor below –115 dBm, a PTC wireless link can be interrupted in several points, and BER is the only way to find out where those interruptions occur.

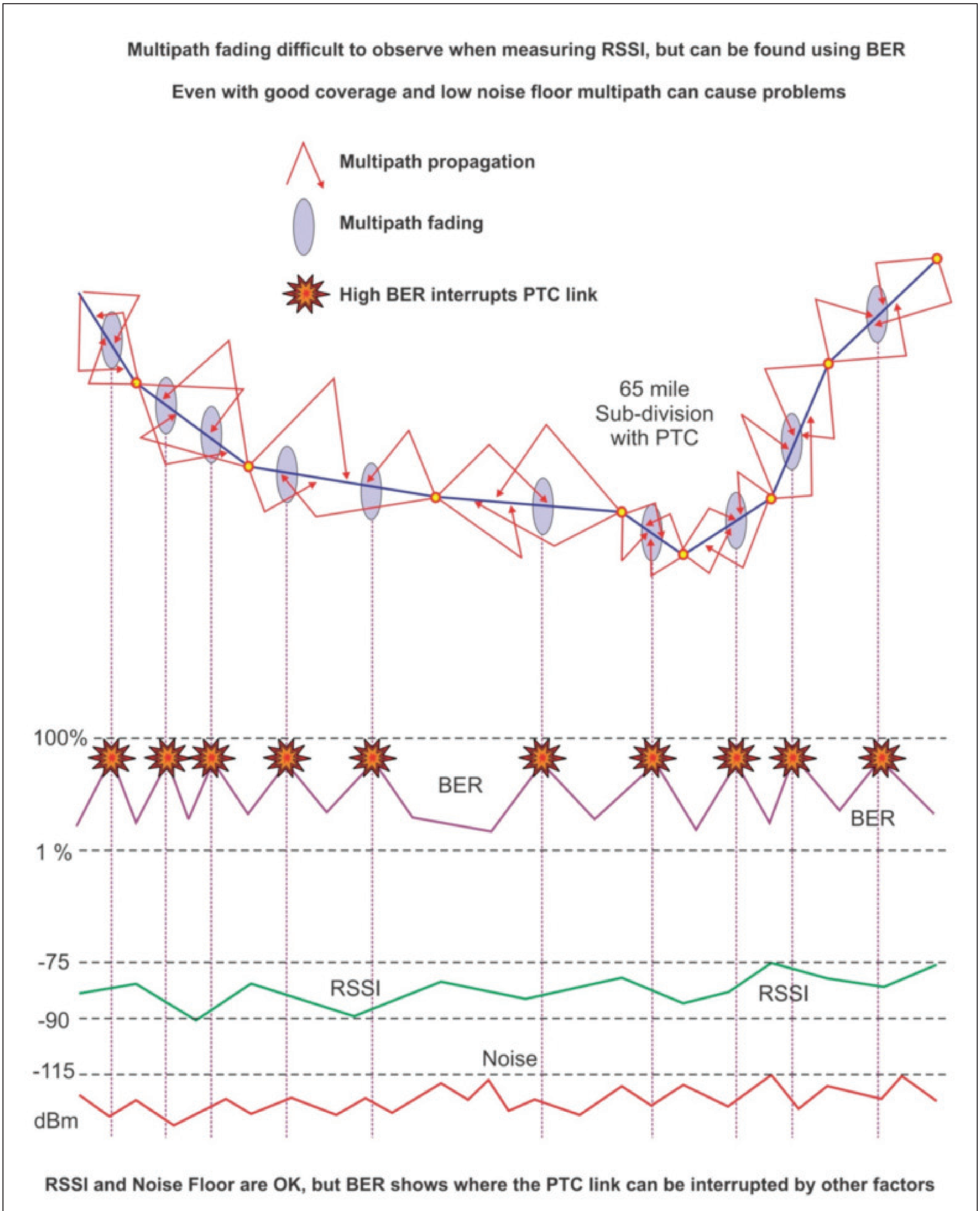



*Figure 1. RSSI and BER testing*

## 2.3 Interference and Noise Testing (Current Testing Method)

Current testing methods often identify RF issues caused by one or more factors that result in interference to PTC signals. With instruments such as the LMR Master it is possible to observe, measure and record with high accuracy a complete set of test data for each of the RF issues found and identified.

A list of these RF issues could include one or more of the following:

- Variable noise floor and de-sensing in some areas
- On-channel interference from other radios
- Near-channel interference from other radios
- Intermodulation products from other radios on several frequencies
- Random noise with different patterns from multiple sources
- Multipath fading caused by reflections on structures, terrain, vehicles
- Other interference including radars, power lines and broadcasting

In the current testing methodology, multiple measurements are taken in the field to identify, measure and record RF issues that may interfere with or degrade PTC signals. All these measurements are saved and can be used to render the RF issues in graphic format for further evaluation and analysis. However, even with precise measurements results and graphics, it will not be possible to determine to what the degree of impairment or degradation that each of these RF issues, or a combination of them, can cause to a wireless link carrying PTC signals.

In the real world it will not be possible, or practical, to address and resolve each and every RF issue identified and measured in the field. It will be necessary to rate each of these RF issues in terms of the amount of impairment that they introduce to wireless PTC data packet communications, and then decide which of the RF issues will be practical and/or cost effective to resolve, leaving other RF issues as they are.

In some cases it might be necessary to increase the number of base stations so that the PTC radio link signal level will be higher than interfering RF signals that cannot be resolved. In other cases, base stations will have to be re-located to other sites. A different testing methodology will be required, to determine the quality of service of a wireless PTC link, compare it with the performance predicted by coverage prediction software programs, and if that performance is not achieved, look for and resolve RF issues and other factors that might be responsible.

## 2.4 Interference and Noise Testing (Improved Methodology)

Initial testing will have to be based on BER performance/packet success, as described in Section 2.2. above. All testing will have to be done using BER, and those PTC wireless radio paths with performance below what was forecasted by propagation prediction programs will have to be further tested to determine if the lower performance than expected is due to radio link parameters, due to some type of interference, or a combination of both.

Before starting to test BER, a brief, cursory set of measurements could be taken to verify that there are no significant problems with one or more of the seven RF issues listed in the second paragraph of Section 2.3 above. No extensive testing and recording of measurements will be required for analysis of these seven RF issues.

The most important testing effort will be measuring BER of the PTC wireless path. It might be possible to do it using a PTC radio to transmit PTC test signals or, preferably a PTC test signal generator using amplified test signals as described in the paragraph below.

PTC packet success/performance BER testing can be done more accurately using two Anritsu LMR Master instruments, a PTC test transmitter, and a PTC test receiver used to measure a PTC wireless path. Readings are taken in BER and also in EVM and RSSI, with all results automatically recorded to digital storage memory.

### 2.5 Intermodulation measurements in locomotives and base stations

Locomotives and radio sites with multiple base stations present some unique intermodulation challenges requiring innovative approaches to measuring and addressing intermodulation issues. Most railroads operate multiple voice and data radios in unique, challenging environments. Locomotives typically have more than a dozen radios in multiple bands with all the antennas placed next to each other on the roof within a space of about 6 ft X 6 ft with no vertical separation. Locomotives are more like multi-radio, multi-frequency band “rolling base stations” than they are mobile radio platforms, which typically only have less than a handful of radios. (Most mobile systems only have one or two radios.)

The larger STB Class One railroads also have complex radio sites along the tracks with several different types of base stations for voice and data operating on different frequency bands. For example, a Class One railroad has an average of six base station radios per site. Antennas are more physically separated on radio towers than on the aforementioned locomotives, but the towers are typically crowded and antenna isolation can be a problem due to cross-coupling.

Intermodulation generated by the RX front end of several radios with their antennas located in close proximity to each other can be challenging to observe and track down to the origin, since there are several radio front ends generating intermodulation products. Many radios are simultaneously impacted by the transmissions of other radios, and intermodulation products are transmitted through the antenna of all radios, which in turn generates a “second wave” of intermodulation. The result is a large portion of spectrum across several bands which is affected by a high number of difficult to track intermodulation products.

An effective way to monitor and measure how much intermodulation is generated and transmitted by each of the multiple radio front ends is to use a bi-directional coupler to measure the RF energy entering and leaving each radio by connecting an Anritsu LMR Master alternatively to the TX and RX sensing ports of the coupler (Figure 2).

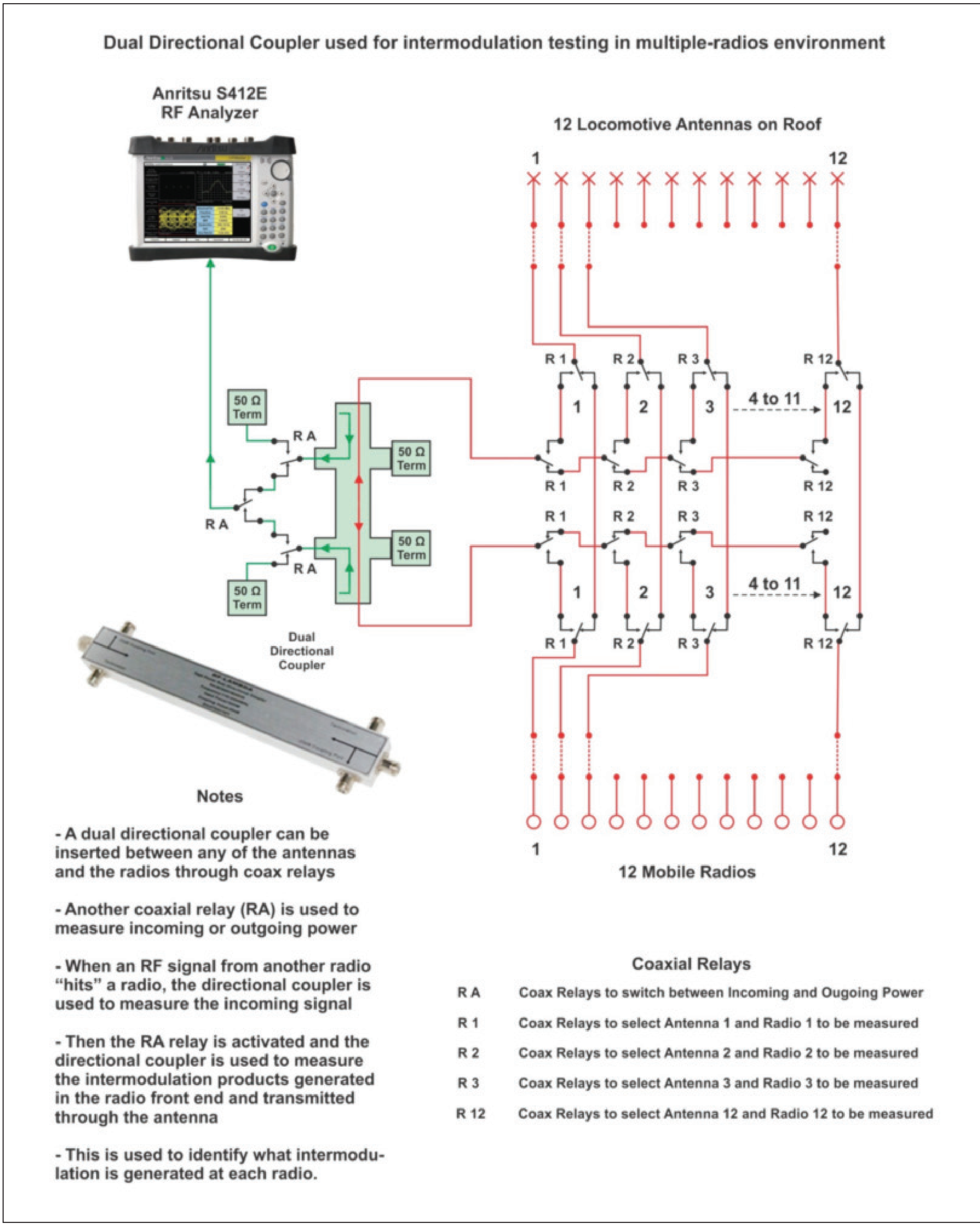



*Figure 2. Intermodulation testing in multiple-radios environment*

Using the LMR Master in PTC coverage analysis mode, with the onboard GPS receiver locked, it will be possible to move around while making measurements. BER, EVM, and RSSI data is gathered continuously, and five color-coded flags can be used to provide the operator real-time feedback on BER measurements being made. A map displays the path of the PTC receiver as it moves around, and the color- coded flags show the BER level along the path, as shown in Figure 3 below.

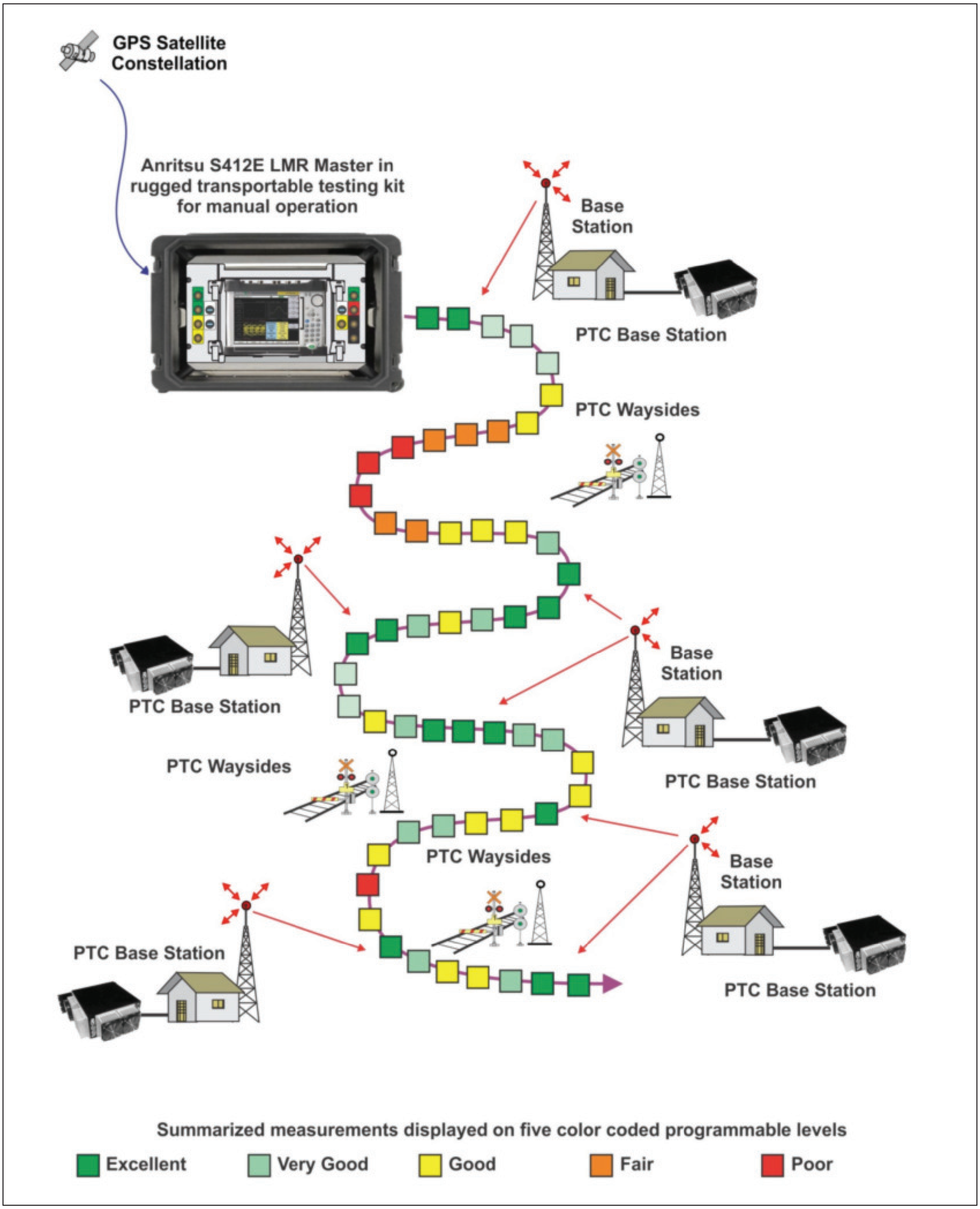



*Figure 3. Initial BER coverage drive testing to flag RF issues for later analysis*

Where the BER performance measured is lower than predicted, a secondary suite of measurements will be carried out. These measurements will include the RSSI figures recorded during the BER performance testing, and several other RF parameters including one or more of the seven RF issues described in the second paragraph of Section 2.3. Extensive measurements focused on these RF issues will only be required if the performance testing indicates that the BER measurements along the PTC wireless path exceed the maximum acceptable BER values.

All these measurements can be carried out using Anritsu LMR Master instruments. Typically, several concurrent RF issues will be found which will make individual problems appear to be larger than they really are.

Using Anritsu LMR Master instruments, it will be possible to identify individual RF problems which can then be quantified and their causes identified so that technical teams can resolve each of them individually. In some cases, these issues might be mitigated by simply adding bandpass filters, increasing isolation between antennas, or removing/covering nearby rusty metal which can cause passive intermodulation (PIM).

After implementing mitigation countermeasures, the BER performance of the PTC radio link will be measured again. If it still falls below expected performance, another type of solution will have to be developed. Relocation of the PTC base station radio site or adding more PTC base station radios may be required.

The main difference between the current testing method and the proposed new method is that no extensive testing of RF issues will be carried out up front, only a brief check to verify that no major problems exist will be required. At the core of the testing effort will be the measurement of BER to determine if the path is capable of carrying PTC live data packet traffic. If the BER performance measurements indicate that the performance is below acceptable BER values, then more testing will be done to verify the RSSI level, and then look for any other RF issues that might be degrading the PTC wireless path.

When poor BER performance is detected and a path is flagged for more testing, precision measurements will be required. A team of field engineers with advanced skills will have to be deployed to the site. This team will have to carry all the instruments and equipment, set them up in the field, connect them, and carry out the testing under varying and likely adverse environmental and weather conditions. Extreme heat and cold, humidity, and dust may be present.

This is similar to the current testing methods used by some railroads, which may take several days or even weeks to complete. Several separate instruments have to be carried to the field in the area where testing has to take place, and a team of test engineers will have to travel and spend a considerable amount of time on site, even if they are only required or able to do testing for a small part of the time. Field testing is always challenging in that power supplies/systems have to be deployed and all instruments, attenuators, filters, etc have to be interconnected with a variety of connectors and cables that are used many times in different sites and require calibration for every single measurement session.

Cables laying on the ground or hanging from equipment and other structures often get damaged when their minimum bending radius is exceeded and kinks/dents are produced along the cable by nearby physical objects, changing the cable transmission characteristics and causing testing errors. Many connectors are also damaged during field work. Testing crews are aware that it is difficult to emulate a lab environment in the field, and are used to dealing with variable or less than accurate results due to factors described above.

The entire process can be expedited by pre-assembling all instruments and equipment in sturdy, shock-absorber mounted rack frame inside a clamshell transportable enclosure. All connectors will be gold plated and all cables would be double shielded RG 31DS type. Field deployment and testing will be completed in much less time, and with greater accuracy. Low-noise, 2 kilowatt gas powered portable inverter generators will be shipped to the field with each transportable enclosure. Figure 4 below shows a typical test system.

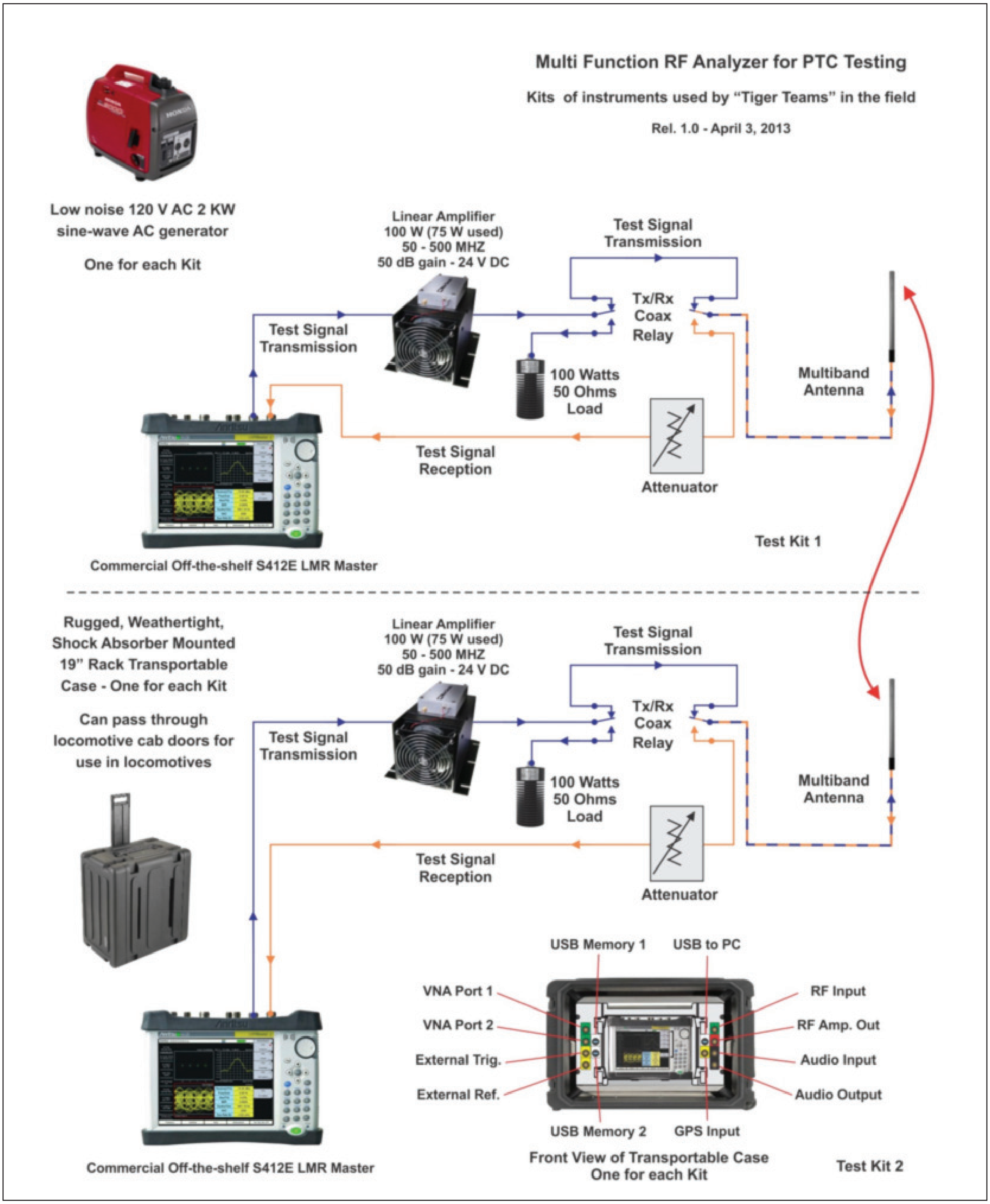



*Figure 4. Typical set of two field testing kits for use by "tiger teams" in the field*

## Current Testing Methods

Current testing methods can be very involved and time consuming, as well as quite expensive. They require the deployment of personnel and equipment to the field, setting up the instruments, laying cables on the ground, calibrating the instruments with the cables used, and trying to use similar testing procedures through several hundred to thousands of measurements that have to be taken. It is difficult to replicate the same testing procedures across several testing sites as each field deployment is different. Many tests involve manual readings and annotations of results by hand. Since the uninterrupted presence of PTC signals along the tracks with appropriate RSSI and low noise floor does not guarantee continuous coverage and operation of PTC systems, it is indispensable to test continuously along the tracks. Drive testing has to provide an uninterrupted set of measurements along the entire track section being measured.

Wireless path testing has to be done under various weather conditions and at different times and with different temperatures, then the results of all these tests need to be compared and final average or median values have to be determined to be documented as the results of the testing. This could tie up testing crews in the field for several days or even weeks to complete a single stretch of track. While this process is not cost effective, a bigger concern is the time it takes to complete the tests, due to the limited number of available staff with the requisite training. Class One railroads have approximately 60,000 miles of track equipped with ITC-R PTC, approximately 14,000 PTC base stations, and about 30,000 PTC waysides. Using current methods and with the available human resources to carry out the testing in the field, it might take several years to complete the testing, past the deadline set forth by the US Government to deploy and commission PTC systems. A new approach to testing has to be developed and implemented, including semi-automated testing that can be done much faster and using less testing staff.

## Field Testing Recommendations – Remote Testing

A new testing approach has to be developed. First, start field testing with quick, cost effective “pass/fail” tests with semi-automated, remotely controlled test equipment verifying compliance or non-compliance of a PTC wireless path with a pre-established template. Flag the PTC Paths that fail, and only doing “in-depth” testing when required by deploying a team to the field with integrated equipment and instruments to work faster and more efficiently.

The testing methodology could use simple PTC base station radio transmitters to send PTC test signals, which would be measured by the LMR Master inside test equipment enclosures that would be traveling on regular freight trains. This would allow carrying out multiple measurements of a PTC wireless path at different times of the day, with different temperatures, and under various weather conditions.

When a PTC wireless path fails the first test, it will be flagged and a more comprehensive test will be done, this time using LMR Master PTC test signal generators with linear power amplifiers to simulate PTC radio transmitters, and LMR Master PTC signal analyzers.

Testing will be done from a Central Testing Facility (CTF) that will operate 24/7 and control the railroad’s PTC base stations along the tracks by remote control, turning PTC test signals TX on and off, changing channels, and also changing TX power in large steps of about 10 watts at a time. The CTF will also remotely access and control all test equipment and instrument enclosures in the field.

This testing will be done without testing staff in the field, and will be much more efficient, faster and precise than current field testing. This process is called “Remote Testing”, and will use LTE wireless broadband modems similar to what is used today in locomotives (More information on remote testing in Figures 5–6).

This first level of testing can be done simultaneously over several different sub-divisions across the entire railroad using remotely controlled equipment and instruments placed on the second unit of a freight train. Since all the testing will be controlled from a single CTF at each railroad, one single team of expert and similarly trained test engineers will be able to simultaneously operate several remote testing systems increasing testing efficiency several fold.

The equipment and instruments enclosures will be installed and removed from the locomotives by trained radio techs or locomotive electricians, without having to deploy to the field expert test engineers. The equipment will be anchored with a chain and padlock to the Conductor's seat post, and the power will be obtained from the locomotive 72 VDC power system.

The transportable equipment and instruments enclosures will have solid state servers recording to solid state hard drives all the measurements. Even if communications are briefly interrupted the measurements will continue.

The process will be very similar to what was described in section 2.4, and in figure 3, except that instead of a team of field engineers moving along the tracks with the test equipment, the instruments will move inside a locomotive or other vehicle, with all the testing being controlled and done remotely from a CTF.

This effort will be facilitated by the use of color-coded flags produced by the LMR Master BER coverage testing process, with full BER, EVM and RSSI measurement details stored in solid state memory.

The "tiger team" will be equipped with kits of pre-configured, pre-calibrated instruments and equipment to carry out and complete testing and verification of a PTC wireless path in much less time than it currently takes to do it, transmitting the testing process and information in real time to the expert testing team in the central testing facility.

Anritsu LMR Master instruments can be controlled from a PC. These instruments are fully customizable and can be programmed in several different ways to provide the requisite functionality for PTC testing in the field, either by local or by remote access and control. The LMR Master has a built in remote web server that can be used to remotely operate the instrument via any modern web browser. All that is required is to connect the LMR Master to a network via an Ethernet connection.

Current RSSI testing is done mostly using a constant power transmitter such as a PTC radio base station, which makes it more difficult to observe the effect of RF issues whose presence and magnitude depend of the level of the transmitted power, such as intermodulation. PTC TX power should be fully adjustable in small increments such as in one dB step at the time. When a "tiger team" is deployed with instrument and equipment kits including a 100 W power amplifier, they will be able to excite the power amplifier from the LMR Master PTC signal generator, adjusting the TX power in increments of 1 dB.

Since the LMR Master instrument can be equipped to operate with FM and on NXDN™ radio systems, it will be possible to use a combination of an LMR Master transmitting FM or NXDN test signals and a 100 watt linear power amplifier to include in the testing process measurements on FM and NXDN radio systems; for example, to emulate and verify an NXDN system that might be causing interference to PTC systems when transmitting.

LMR Master instruments can also be equipped to operate with ETSI DMR and TETRA and with APCO Project 25 (aka P25) Phase 1 and Phase 2 systems, FirstNet LTE systems, and WiMAX™ (both Fixed and Mobile varieties).

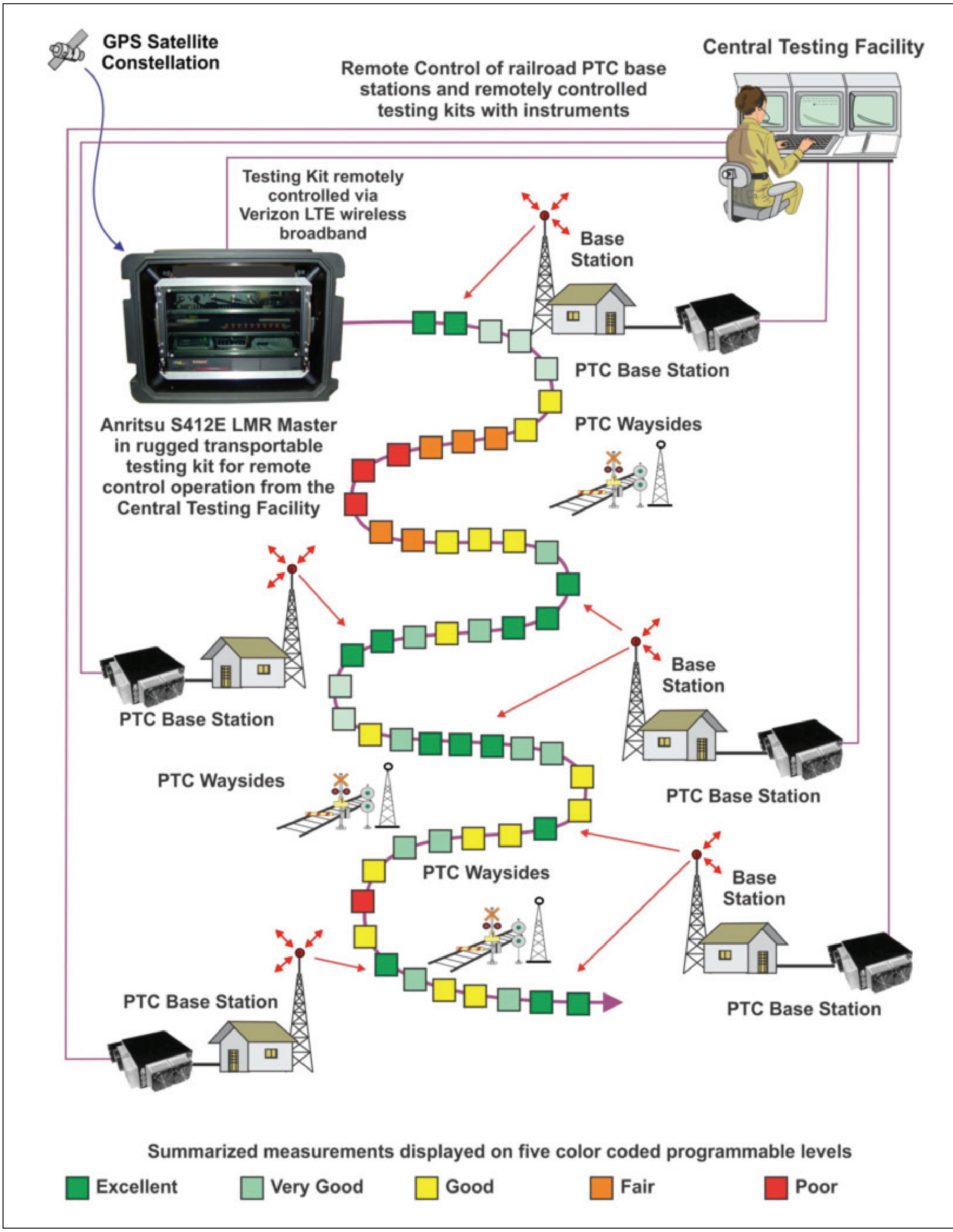



*Figure 5. Remote Testing concept in the field*

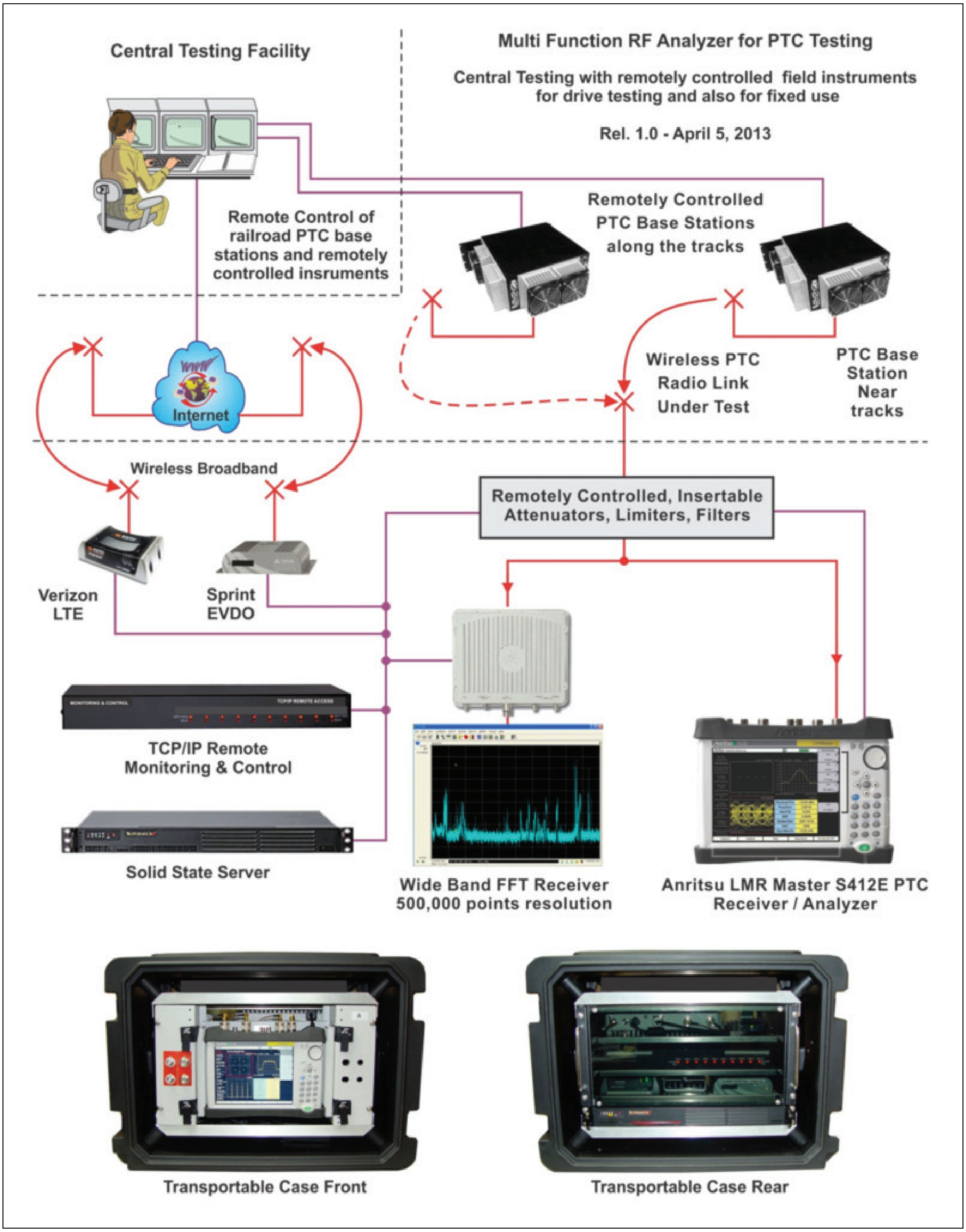



*Figure 6. Remote Testing with Central Testing Facility and field equipment*

## 3. PTC field testing comments and suggestions

Here are a few comments and suggestions for using an Anritsu S412E LMR Master for PTC field testing. Every effort has to be made to protect the instrument from mechanical or electrical damage.

**• Connector adaptors**

Always install semi-permanent N(f)-N(m) adaptors to protect the N female connectors on the instrument.

**• Coaxial cables**

Cables have to be flexible and strong, with strain relief in the attachment point to the connectors. The same cables and connectors should be used for similar tests every time, maximizing the opportunity to make each measurement session identical to any other measurement session.

**• Attenuators**

Always have available suitable attenuators to protect the input of the instrument from excessive input levels. To measure RF power, always use attenuators. RF power probes are not designed to measure high RF power (e.g. 100 watts). Before taking the measurements, verify with the instrument the attenuation in the attenuator.

**• Band pass filters**

Carry a selection of band pass filters to use on each of the RF bands that will be tested, for example 150 MHz, 220 MHz, 450 MHz, 800 MHz, 900 MHz.

**• Linear power amplifiers**

For more precise testing and better PTC Test Signal level control, use a Linear Power Amplifier connected to the output of an LMR Master generating a PTC test signal, which can be adjusted in one dB steps from –120 to 0 dBm.

**• Dual Directional Coupler for Intermodulation Measurements**

In a multiple radio environment, a Dual Directional Coupler can be used to measure the intermodulation products generated by each radio, facilitating the identification, tracking down and mitigation of complex intermodulation signals generated simultaneously by several radios.

**• Power supplies**

It is also important to use the right power supply for the equipment. The Anritsu LMR Master instrument is designed to operate either from 120 V AC or 12 V DC and has certain tolerance for small fluctuations in voltage. However, other instruments and equipment might require a precise voltage supply to operate.

### 3.1 RF Connector Adaptors

Before starting to use the Anritsu LMR Master, obtain and install “connector protectors” or “connector adaptors”, N male to N female adaptors that should be left semi-permanently installed on the N female connectors of the instrument to preserve the threads and mechanical characteristics of the connectors.

A couple of sources could be TE (Tyco Electronics) 1057374-1 N male to N female adapter, or a kit from RF Industries consisting of:

*Unidapt PT-4000-003 N Male*

*Unidapt PT-4000-013 Universal Center Adapter*

*Unidapt PT-4000-009 N Female*

The Unidapt N male connector is attached to one side of the Unidapt universal center adapter, with the Unidapt N female connector attached to the other side of the universal center adapter. All connector contacts are gold plated.

The Unidapt N Male adapter should only be attached (screwed-on) to the instrument N female connector once, and left there semi-permanently attached.

The Unidapt universal center adapter is attached to the back of the N male connector, and the Unidapt female N connector attached to the universal center adapter.

With field testing, use of the connectors is going to sustain wear and tear, to the point that they might introduce errors in the measurement. When the Unidapt N female connector wears out it can be simply unscrewed from the center adapter and replaced by another brand new Unidapt N female connector.

When many Unidapt N female connectors are replaced over time, the Unidapt universal center adapter thread might also wear out and introduce errors; at that point the Unidapt universal center adapter can also be replaced by a new one.

After a long time with many replacements of the Unidapt universal center adaptor the Unidapt N male connector attached to the instrument will also degrade, and at that point it will have to be removed from the instrument and a new Unidapt N male connector semi-permanently attached to the instrument N female connector.

An additional benefit is that there are Unidapt connectors available for almost all existing RF connectors in the market, and these Unidapt connectors can be attached to the Unidapt universal center adapter to the instrument without having to screw in and remove from the instrument different types of RF adaptors. This may extend the life of the instrument mounted connectors by several years.

## 3.2 RF Coaxial Cables

Good quality coaxial cables have to be used, they must be flexible yet strong. A good choice would be to use LMR-240 ready-made cable assemblies with strain reliefs where the cable enters the connectors, and gold plated contacts with N male connectors.

For example, Amphenol Connex 175101-22-48.00-ND, pre-assembled 48” LMR-240 coaxial cable with N male connectors attached on each end. Pre-assembled cables are fully tested and have similar RF parameters from cable to cable.

*Amphenol Connex 175101-22-48.00-ND*
*Cable Assembly*

## 3.3 Anritsu MA25200A High Power Tx/Rx Input Protection Module

The maximum RF power that can be applied to any of the LMR Master Instrument RF connectors should never exceed +20 dBm (0.1 Watt).

It is highly recommended to alway carry an Anritsu MA25200A High Power Tx/RX Input Protection Module with the S412E instrument. The MA25200A high power protection module safeguards the S412E ports from high power portable, mobile, or base station transmitters. It can accept 125 watt base station transmitters for up to one minute and 25 watt mobile transmitters for indefinite periods. It combines the signal generator port into the test port to support full duplex testing.


*Anritsu MA25200A High Power Tx/Rx Input Protection Module*

## 3.4 RF Filters

A kit of bandpass filters with centers in the 150, 220, 450, 800 and 900 MHz should be carried with the instrument. It will be helpful for these to have a rejection of 60 to 80 dB below and above the passband and it would also help if the filters have notches on the sides of the pass band to get a steeper “skirt”. Good quality, low cost, low rejection (30 to 45 dB) can be sourced from Mini-Circuits.They might not be able to provide the requisite attenuation, but will probably suffice to observe the effect when a filter is introduced in the testing.

Other vendors, such as STI-CO offer filters with much higher rejection figures and notches, but may not be available for all bands.

Filters should have N connectors and Unidapt connectors as described above in 3.1 should also be used to protect the filter original connectors.


*STI-CO band-pass filter for 220 MHz PTC band – With > 60 dB rejection*

### 3.5 RF Linear Amplifier

For more precise PTC testing, an Anritsu LMR Master PTC test signal generator is used. The instrument has a calibrated vector signal generator producing a PTC test signal selected between several different test signal patterns to measure BER with another LMR Master PTC analyzer. The Anritsu LMR Master PTC test signal generator is calibrated to deliver a signal adjustable in steps of 1 dB, between –120 dBm and 0 dBm. (1 mW)

A Mini-circuits ZHL-100W-52+ 100 watts linear power amplifier provides the best match to operate with the Anritsu S412E LMR Master PTC test signal generator.

The maximum TX power will not exceed 75 W, the power of a PTC base station.

This amplifier requires a regulated 24 V DC power supply capable of providing 10.5 amps.
(Not 27.6 V DC as most 24 V nominal power supplies deliver)

The amplifier has the following specifications:

- Gain:  50 dB (To be able to produce a signal of up to +50 dBm when excited from the LMR master PTC test signal generator at 0 dBm
- Frequency range:  50 to 500 MHz
- Maximum RF input power:  + 3 dBm (2 mW)
- 50 dB gain across a wide dynamic range of input levels

The amplifier as specified includes and ships with the heatsink and fan attached to it. The same amplifier is also available without the heat sink, this version without heatsink and fan is not recommended for the intended use.


*Mini-circuits ZHL-100W-52+ High Power Linear Amplifier*

### 3.6 Dual Directional Coupler for Intermodulation Measurements

On figure 2, page 8 a diagram shows a Dual Directional Coupler used to measure the individual contribution to intermodulation products from each radio in a multiple radio environment. There are also coaxial relays used to switch from incoming signals to outgoing intermodulation products, and antenna selection.

This Dual Directional Coupler is a hybrid device that has to be terminated with precise 50 ohms impedance loads, and the coaxial relays have to be rated to carry and switch at least 100 watts of RF power.

The Dual Directional Coupler recommended is an RF Lambda RFDDC1M2G20 dual directional coupler with the following specifications:

- Frequency range: 110 MHz to 2 GHz
- Power: 500 W CW / 5 KW Peak
- Coupling 110 to 400 MHz: 21.0 – 23.5 dB
- Coupling 400 to 2000 MHz: 20 ± 1.5 dB
- Directivity: 22 dB (for 20 dB coupling)
- Insertion loss: 0.5 dB
- VSWR: 1.25:1
- Frequency ripple: ± 0.5 dB


*RF Lambda RFDDC1M2G20 Dual Directional Coupler*

A coaxial load with 50 ohms termination is used to balance the hybrid function of the Dual Directional Coupler. For example, one can use a Telewave TWL-35 load operating from 0 to 1000 MHz and able to dissipate an RF power of 35 watts.

This load has a built-in N male connector that can be attached directly to the N female connectors on the Dual Directional Coupler.

*Telewave TWL-35 50 ohms, 35 watts termination load*

### 3.7 Power Supplies

An example of a good regulated 24 V DC (not 27.6 V) 15 amp power supply is the Acopian A24H1500M power supply. It can deliver the 10 to 11 amps used by the High Power Linear Amplifier without overheating.


Acopian A24H1500M 120 V AC to 24.0 V DC Power Supply

When working in the field there are several models of DC to DC inverters to provide 27.6 V DC from a vehicle's 12 V battery, or from a locomotive 72 V DC power supply. It is difficult to find a power supply with a regulated, precise 24.0 V DC output for the High Power Linear Amplifier. It must also be taken into consideration that the power consumption with the amplifier in transmit mode will be approximately 290 watts on the 24.0 V DC power supply.

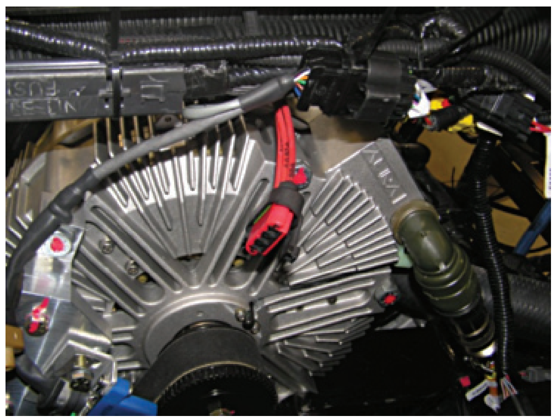
When working on or near locomotives, probably the best approach would be to use a 72 VDC to 120 VAC inverter. Exeltech offers the XP 1100 model which delivers true 1,100 watts (1,375 VA). These inverters use a very quiet 25 kHz sine wave switching frequency and provide "glitch free" 120 V AC to power precision instruments and equipment. This inverter has been very successfully utilized on locomotives to power several lab instruments doing PTC related RF measurements. The 66 Volt model accepts inputs from 58 to 80 V DC, and is not affected by the "dirty DC power" that sometimes is produced by locomotives.


*Exeltech XP 1100 66 Volts 1,100 watts 58-80 V DC to 120 V AC inverter*

When working on locomotives, it is often necessary to provide power to instruments, notebook computers and other equipment. With this 1,100 watt inverter, it will be possible to simultaneously power not only the Linear Power Amplifier, but several other instruments, computers and other equipment with clean, stable 120 V AC power.

For field work outside a locomotive, the first choice would be to tap the 120 V AC power available from communications and signals shelters and equipment.

Some service vehicles are equipped with DC to 120 VAC inverters; there are too many brands and models to list them in this document. There is a top of the line AC generator produced by Aura Systems, the Auragen VIPER. It is installed under the hood and connected to the engine via a belt. There are several models from 8 to 16 kW of power. A typical use is to power cooling systems on refrigerated trucks that have to drive long distances without interruption in their AC power system. The company's website is www.aurasystems.com.



*Auragen generator installed in engine compartment*

When working in the field using different vehicles, the best option would be a 2 kW gas power generator with a sinewave inverter to provide clean 120 V AC power. There is a new generation of AC inverter based gas powered generators, and these generators can be connected in parallel to double their power. They produce very low noise and are very efficient in gas consumption. They can run about six hours with a full tank.

Honda has several models of portable AC inverter based gas powered generators, similar to the one shown below. This model has a 30 amp socket to connect it in parallel with another similar generator to double the power to 4 KW.

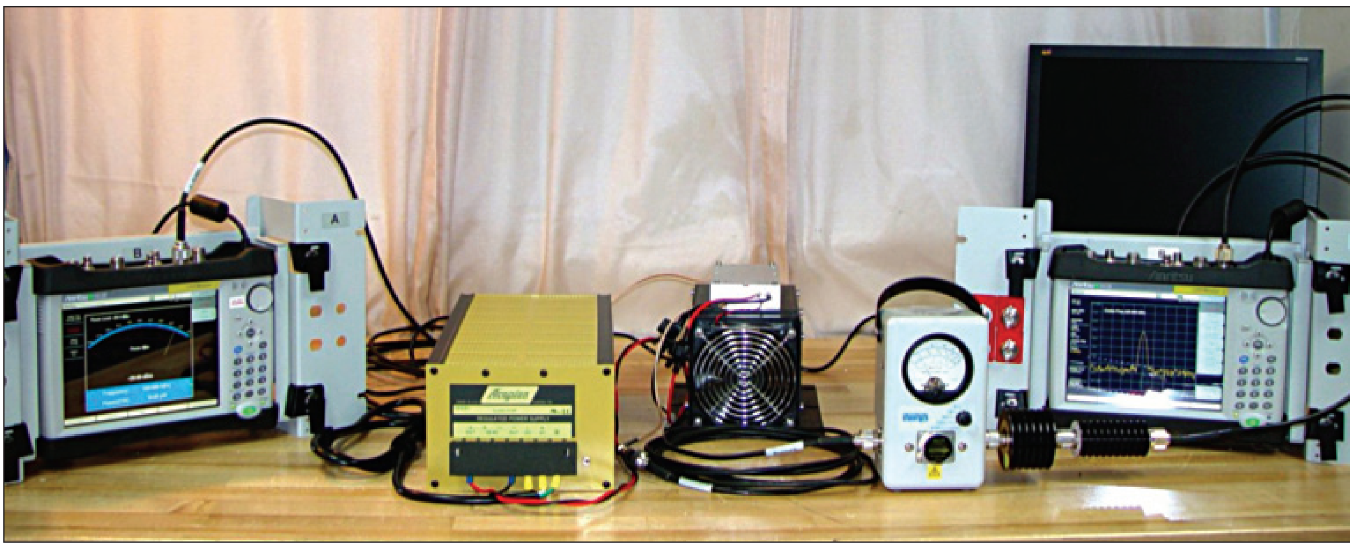

*Honda 2 kW AC Inverter gas powered portable generator*
*EU2000i Companion*

When using any type of AC or DC power supply, a thorough verification for noise and/or spikes should be carried out before connecting the power to any instrument. A good oscilloscope should be used.

There have been cases with other instrument brands where the built-in power supplies from several models of lab instruments had the same spikes generated by the same power supply design, and these instruments had to be replaced in the field. It is extremely important to verify that every instrument has clean power. (For example, terminate the RF in connector with a 50 ohm load and increase the sensitivity of the instrument to observe any spikes on screen)

## 4. Lab Pictures with PTC Test Signal Generator and High Power Amplifier

The picture below shows an example of a lab bench setup with an Anritsu S412E LMR Master generating a PTC Test signal with a high power linear amplifier and another LMR Master measuring it. The amplifier was tested over a wide range of input levels from the LMR Master generating the PTC test signal and maintained a constant gain of 50 dB.



*LMR Master PTC Test Signal Generator, Acopian Power Supply, Mini-circuits Power Amplifier, BIRD Power Meter, LMR Master receiving signal*

*LMR Master PTC Test Signal Generator*

*LMR Master receiving PTC Test Signal*

Anritsu envision : ensure


**• United States**
**Anritsu Company**
1155 East Collins Boulevard, Suite 100,
Richardson, TX, 75081 U.S.A.
Toll Free: 1-800-267-4878
Phone: +1-972-644-1777
Fax: +1-972-671-1877

**• 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 Electrônica 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.**
Av. Ejército Nacional No. 579 Piso 9, Col. Granada
11520 México, D.F., México
Phone: +52-55-1101-2370
Fax: +52-55-5254-3147

**• United Kingdom**
**Anritsu EMEA Ltd.**
200 Capability Green, Luton, Bedfordshire LU1 3LU, U.K.
Phone: +44-1582-433280
Fax: +44-1582-731303

**• France**
**Anritsu S.A.**
12 avenue du Québec, Batiment Iris 1-Silic 612,
91140 Villebon-sur-Yvette, France
Phone: +33-1-60-92-15-50
Fax: +33-1-64-46-10-65

**• 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.**
Via Elio Vittorini 129, 00144 Roma Italy
Phone: +39-06-509-9711
Fax: +39-06-502-2425

**• Sweden**
**Anritsu AB**
Kistagången 20B, 164 40 KISTA, Sweden
Phone: +46-8-534-707-00
Fax: +46-8-534-707-30

**• Finland**
**Anritsu AB**
Teknobulevardi 3-5, FI-01530 VANTAA, Finland
Phone: +358-20-741-8100
Fax: +358-20-741-8111

**• Denmark**
**Anritsu A/S**
Kay Fiskers Plads 9, 2300 Copenhagen S, Denmark
Phone: +45-7211-2200
Fax: +45-7211-2210

**• 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**
Edificio Cuzco IV, Po. de la Castellana, 141, Pta. 8
28046, Madrid, Spain
Phone: +34-915-726-761
Fax: +34-915-726-621

**• United Arab Emirates**
**Anritsu EMEA Ltd.**
**Dubai Liaison Office**
P O Box 500413 - Dubai Internet City
Al Thuraya Building, Tower 1, Suite 701, 7th floor
Dubai, United Arab Emirates
Phone: +971-4-3670352
Fax: +971-4-3688460

**• India**
**Anritsu India Pvt Ltd.**
2nd & 3rd Floor, #837/1, Binnamangla 1st Stage,
Indiranagar, 100ft Road, Bangalore - 560038, India
Phone: +91-80-4058-1300
Fax: +91-80-4058-1301

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

**• P. R. China (Shanghai)**
**Anritsu (China) Co., Ltd.**
27th Floor, Tower A,
New Caohejing International Business Center
No. 391 Gui Ping Road Shanghai, Xu Hui Di District,
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: +81-46-225-8359

**• 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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