Range to Fault Technology

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1. Introduction:

Passive intermodulation (PIM) has been recognized as a problem in communications systems for nearly 50 years. The phenomenon occurs when two or more signals encounter a non-linear junction and "child" frequencies are generated that are mathematically related to the "parent" signals. With the advent of cellular communications, PIM began to rise in prominence as a concern due to the quality of service impact these unintended signals can have by interfering or blocking the uplink (receive) channels of the base station.

Production PIM test equipment was introduced by Kaelus (formerly Summitek Instruments) in 1996 to enable RF equipment manufacturers to verify the PIM performance of their products. In 2005 Kaelus introduced portable PIM test equipment giving network operators the ability to perform PIM tests in the field. These field tests have proven effective at identifying components damaged in transport as well as installation workmanship issues on the RF infrastructure. As a result, field PIM testing has been increasingly adopted by wireless operators around the world as an essential test to certify optimum system performance.

PIM testing is different from traditional VSWR testing in that mechanical stimulus (tapping or flexing) needs to be applied while testing to ensure a meaningful test. If the PIM spikes above a threshold value during dynamic testing, the component or loose connection must be repaired or replaced. In most cases determining the location of the PIM fault is relatively straight forward; the fault is located where you are tapping.

Occasionally PIM faults will occur that do not produce large spikes in magnitude when dynamically tested. Determining the location of these "non-responsive" or "static" PIM sources becomes more challenging and can often be time consuming. To address this problem Kaelus has developed **Range to Fault (RTF)** technology similar to that used in VSWR testing to help identify the location of these static PIM sources. This paper discusses the capability and limitations of this new technology as well a recommended test method for deploying RTF analysis in the field.

2. Existing PIM test equipment / test process:

Passive Intermodulation test equipment transmits two 20W (+43dBm) test signals into the line or device under test. If the test signals encounter a non-linear junction, mixing occurs causing the PIM frequencies to be generated. The PIM test equipment measures the magnitude of the PIM generated by the test signals and displays this information to the test operator.

The 3rd order product (IM3) is used to characterize PIM performance both in the factory and in the field. The IM3 signal generated by a non-linear junction is usually higher magnitude than the other PIM products enabling greater measurement accuracy. The higher order products (IM5, IM7, IM9, etc.) typically fall off in magnitude by 5 to 10dB for each successive PIM product. By controlling IM3 of the system to a specified level, the higher order products (which are more likely to fall in the operators own Rx band) will be held well below the specified IM3 level.

The specific test frequencies used to excite PIM defects at a cell site are not critical as long as the following criteria are met:

- All RF components in the path (Cables, Antennas, TMA's, etc.) must be able to pass the two test frequencies and be able to pass the IM3 frequency you are measuring.

- The two test frequencies ***must*** be within the operator's licensed spectrum or be guard band frequencies between licensed spectrum blocks to prevent interference with other operators. This applies to all system level tests where the test frequencies will be broadcast through the antenna.

- The two test frequencies need to be selected so that they will produce IM3 within the receive band for that system. This will typically require test tones with wider frequency spacing than can be achieved within the licensed frequency block for a given market. For this reason, at least one guard band frequency will need to be selected.

During the PIM test all components and RF connections on the line should be subjected to dynamic test conditions. If a component or RF connection generates unacceptable levels of PIM when subjected to light mechanical stress it needs to be repaired. Passing a dynamic PIM test ensures that the RF infrastructure is robust and will operate properly when exposed to normal environmental stresses caused by wind and temperature extremes.

When testing a cell site it is recommended that a preliminary static PIM test be conducted to evaluate the starting condition of the system. If the system passes the static test the operator will proceed directly to dynamic testing. If the system fails the static test the operator should disconnect the feed system from the antenna and install a low PIM load at the end of the line. This method enables the test crew to isolate the feed system to resolve PIM problems independently from the antenna and objects radiated by the antenna. Once the feed line passes dynamic testing it can be re-connected to the antenna to verify system performance.

On some sites, particularly rooftop installations, the source of the PIM may be located beyond the antenna. Since it is generally not the installation crew's responsibility to resolve external PIM sources, operators will generally accept the following three pieces of information as evidence that the site was built according to specifications, even when the system PIM test fails:

1) Passing dynamic feed line test (into low PIM load)

2) Passing antenna test (antenna pointed at sky)

3) Failing system test when passing antenna and passing line are put together

3. New RTF analysis / technical limitations:

Range to Fault (RTF) technology from Kaelus is an analysis tool developed to enhance, not replace, standard fixed tone PIM testing. The RTF solution includes the additional hardware and signal processing software needed to transform frequency information into time domain plots using inverse Fast Fourier Transform (FFT) and digital enhancement algorithms. RTF technology is similar to the familiar Distance to Fault (DTF) function widely used at cell sites to identify VSWR fault locations.

RTF works by transmitting two 20W (+43 dBm) test frequencies into the system under test. One test frequency is fixed while the second frequency is swept over a range of frequencies to produce IM products in the receive band of the system under test. Since RTF analysis requires high power signals to be swept outside the operator's licensed spectrum, ***this test should only be conducted on systems that are terminated into a low PIM load*** to prevent interference.

The inverse FFT algorithm is used to reconstruct time domain range pulses by digitally summing the quantized phase and amplitude components of each frequency involved in

the computation. The more bandwidth available for analysis the sharper the mathematical pulse edges will be providing improved resolution of closely spaced PIM sources.

Where resolution is defined as the distance between two equal amplitude pulses separated by a 6dB null, the resolution in meters which can be achieved using this analysis is expressed by the following equation:

$\Delta d = 150\ vf\ /\ BW$ Where: Δd = resolution in metres
vf = velocity factor (fraction of speed of light)
BW = PIM sweep bandwidth in MHz

Using PCS spectrum as an example (Tx =1930–1990MHz and Rx = 1850–1910MHz) the maximum IM3 sweep range that can be achieved in the PCS Rx band using two PCS Tx tones is 40MHz. This is achieved by holding one test frequency fixed at 1930MHz and sweeping the other test frequency between 1950 and 1990MHz. This combination of frequencies will generate IM3 products ranging from 1870 to 1910MHz in the PCS Rx band. Using this 40MHz of swept IM3 bandwidth and a cable velocity factor of 0.88, the maximum resolution achievable using only PCS spectrum is **3.3m**. Kaelus has employed proprietary signal processing techniques to further enhance resolution but the absolute accuracy of the prediction algorithm will suffer when multiple PIM sources are located within the minimum resolution distance on the line.

The most effective way to use RTF analysis is to systematically remove the largest magnitude PIM source identified on the line. Repeat the analysis and continue removing the largest PIM source found until all significant static PIM sources have been removed. Regardless of its location on the line, the distance to the largest PIM source will be predicted most accurately by the algorithm. Each time a PIM source is repaired the accuracy for locating the next largest PIM source will improve.

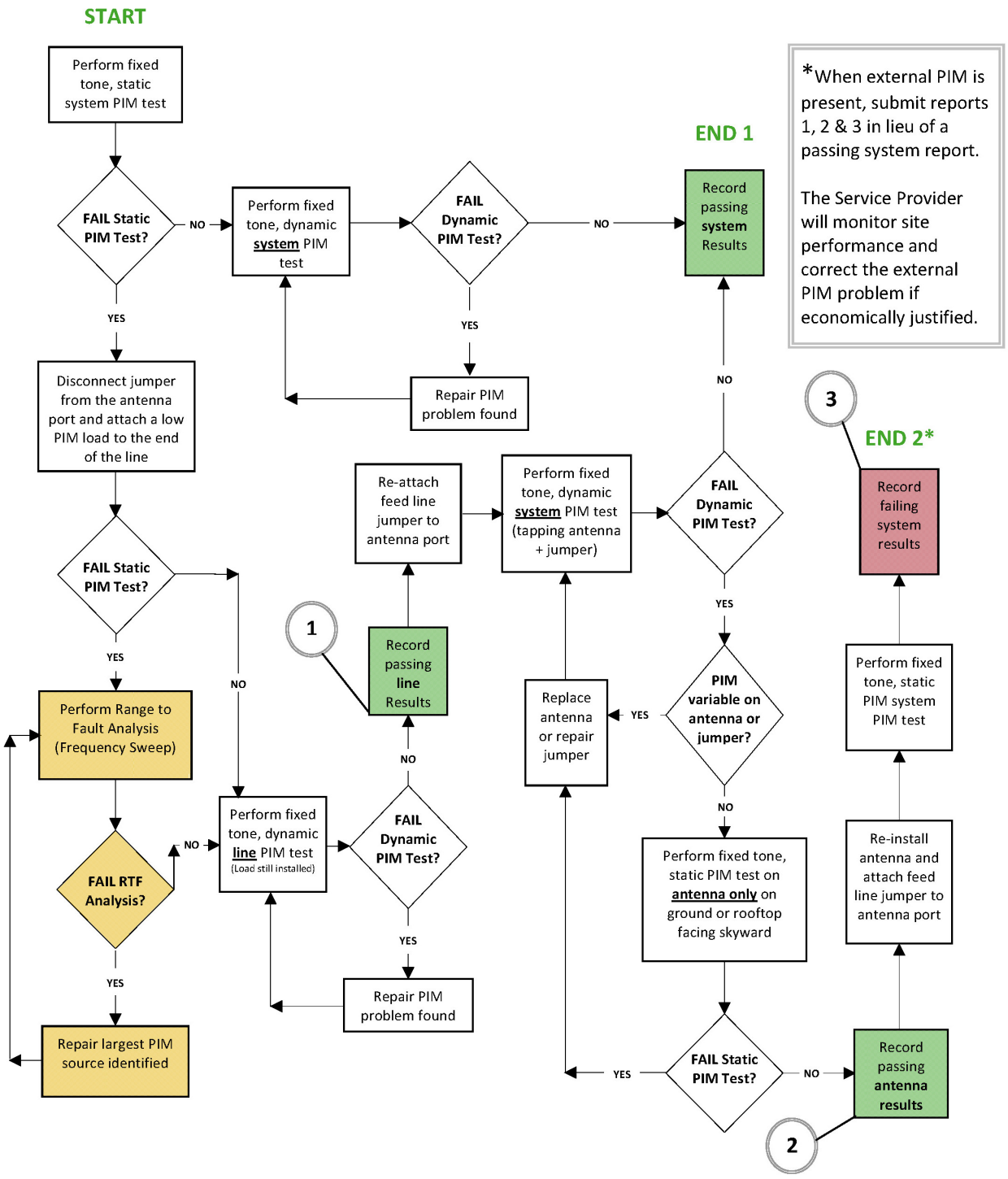
As initially stated, RTF analysis is not a replacement for dynamic PIM testing. RTF analysis will enhance site testing and potentially speed the removal of static PIM sources at the cell site. The analysis alone, however, should not be used to certify construction quality because;

- Knowing the range to a fault provides a helpful starting point but does not ensure there are no other hidden PIM sources within the RF feed system
- The absolute value of the RTF PIM magnitude may not be accurate due to distortion brought about by frequency sensitive group delay in RF devices such as surge arrestors, filters, TMAs etc.
- “Ghost” PIM sources can be created as a product of the mathematics and/or by impedance mismatches in the system that reflect PIM generated at different locations on the line

The process flow chart shown in Section 4 illustrates the correct way to utilize RTF analysis when PIM testing at a cell site. The cells highlighted in yellow represent the RTF test loop for removing static PIM sources.

The data presented in Section 5 shows actual measurements recorded while following the flow chart to repair a system with multiple static and dynamic PIM problems on the line.

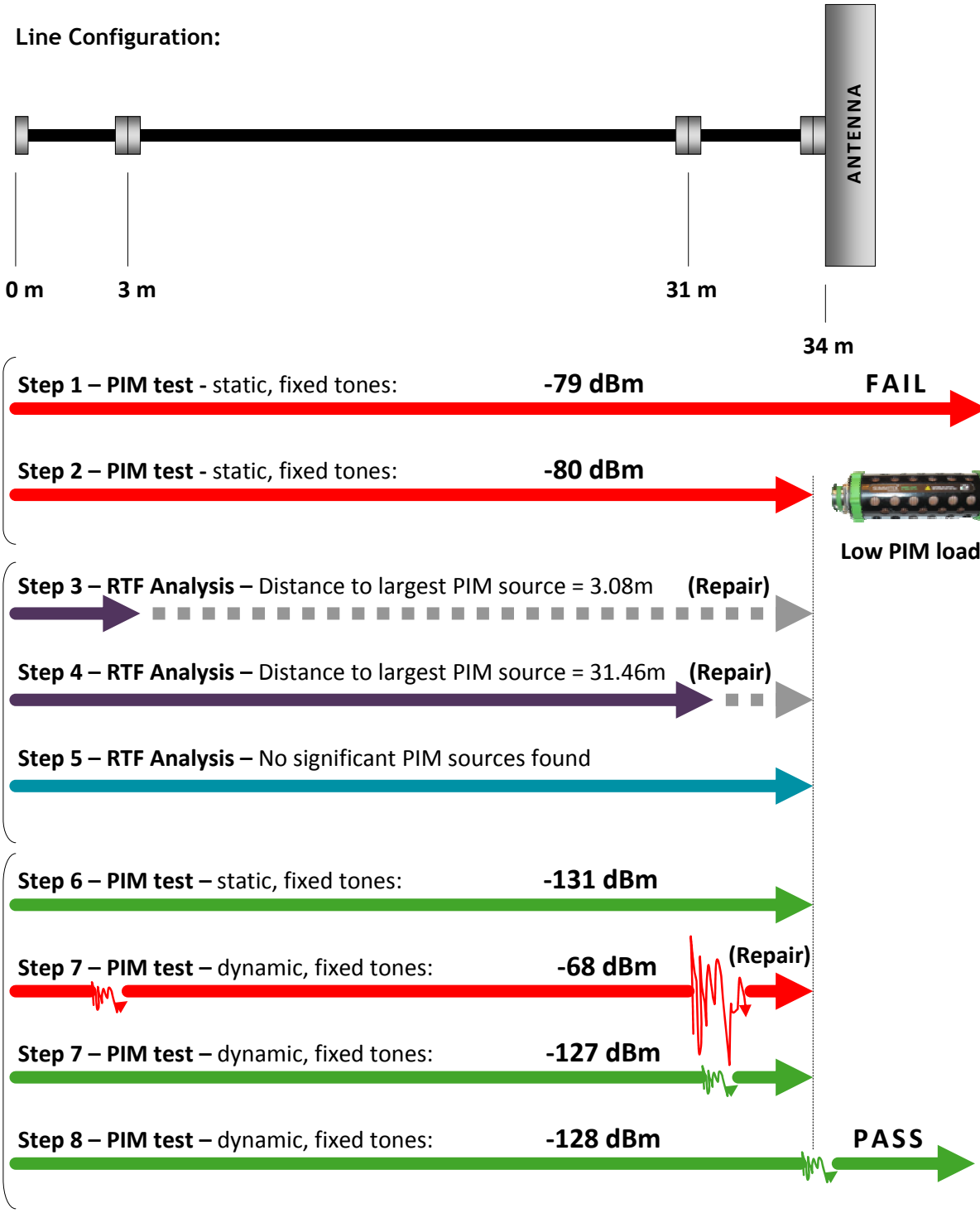
4. PIM test flow chart including RTF analysis:



5. Example site data:

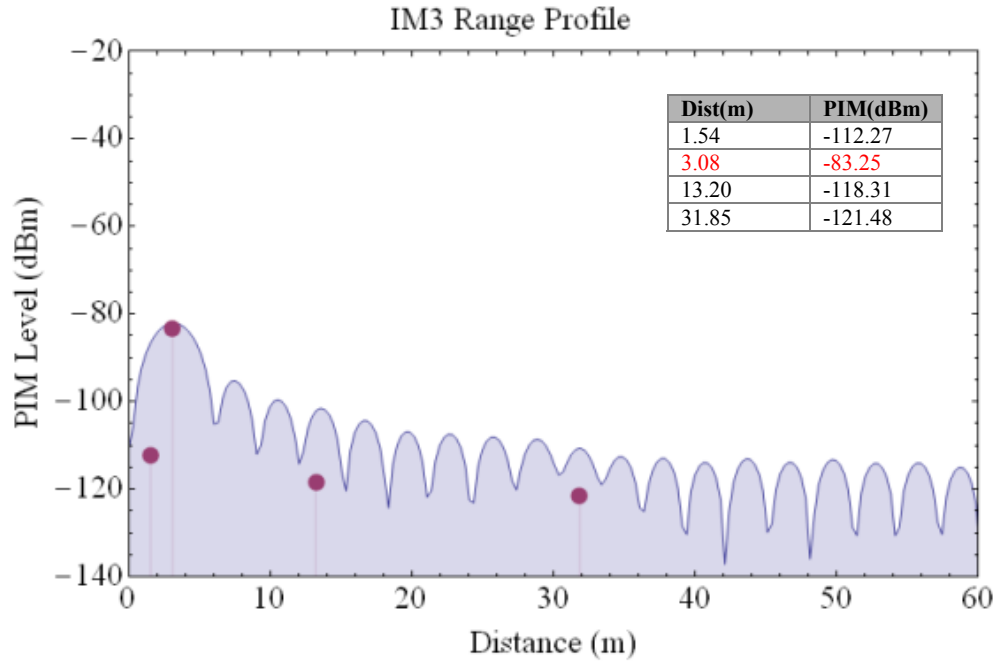
The following example shows actual test results from a feed line with multiple static and dynamic PIM problems. The results not only show the benefit of RTF technology but also confirm the importance of dynamic PIM testing at a cell site.

Line Configuration:



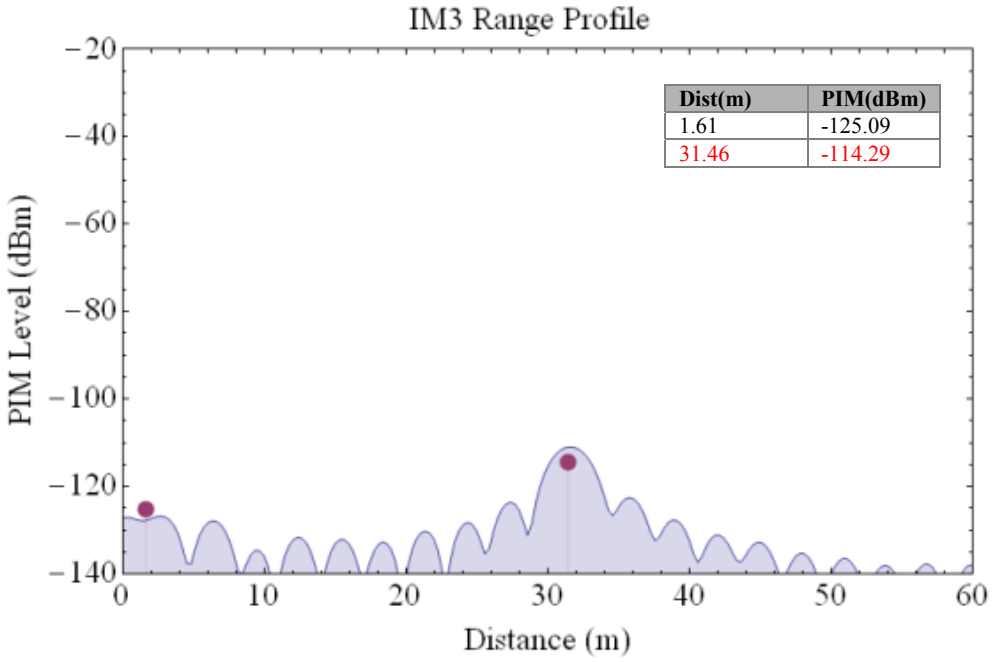
Selected reports / screen shots:

Step 3 - 1st RTF analysis:



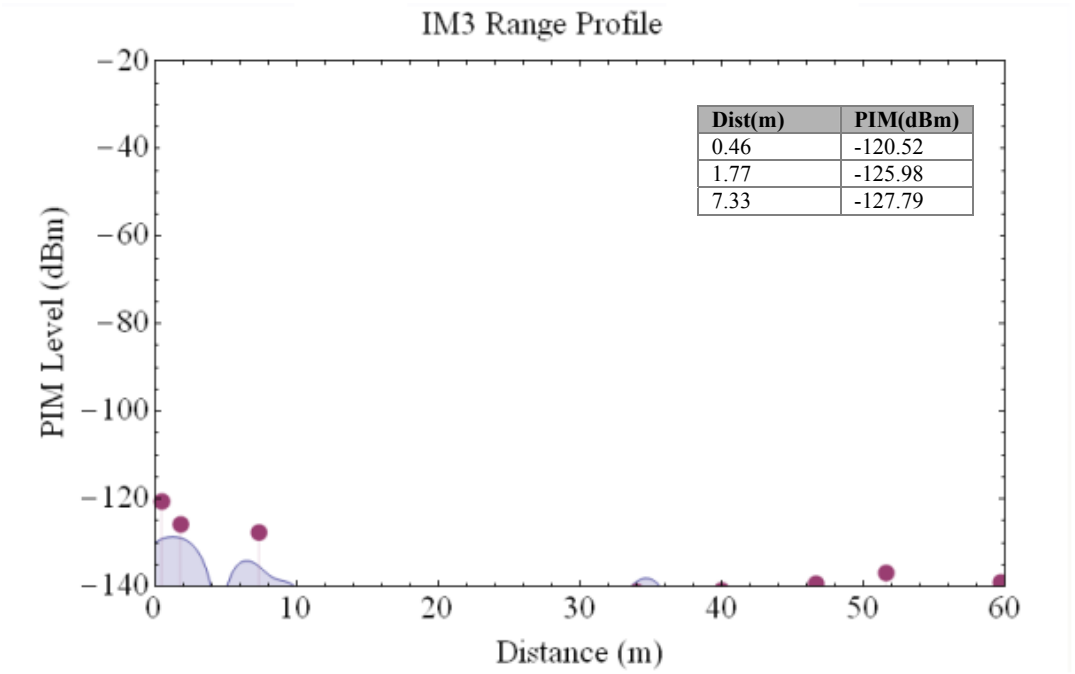
Dist(m)	PIM(dBm)
1.54	-112.27
3.08	-83.25
13.20	-118.31
31.85	-121.48

Step 4 - 2nd RTF analysis (after PIM source at 3m repaired)



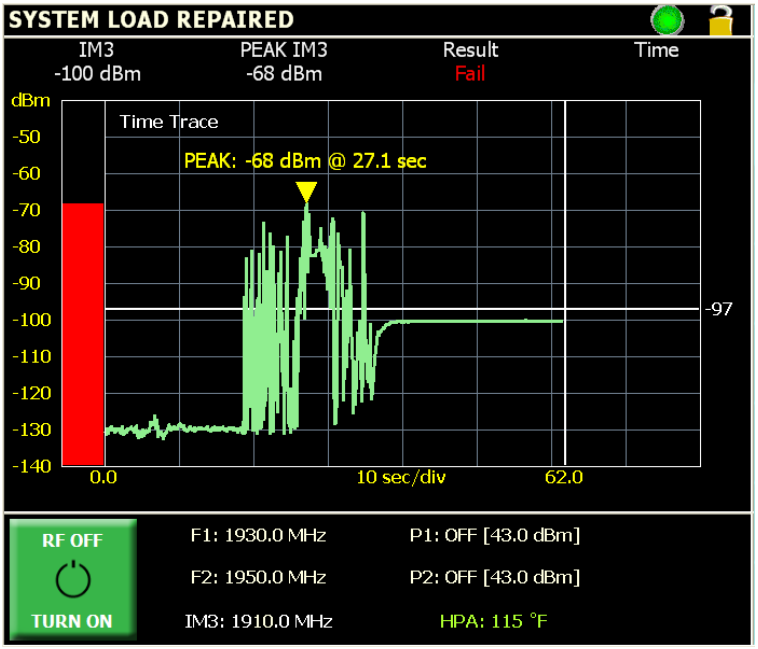
Dist(m)	PIM(dBm)
1.61	-125.09
31.46	-114.29

Step 5 – Final RTF analysis (after 3m and 31m PIM sources repaired)



Dist(m)	PIM(dBm)
0.46	-120.52
1.77	-125.98
7.33	-127.79

Step 7 – Dynamic PIM test results (showing PIM problem not found by static PIM test or RTF analysis)



6. Conclusion:

As demonstrated in the example above, RTF analysis can accurately predict the location of multiple static PIM sources within the RF infrastructure. Armed with this information and following the prescribed test procedure, PIM test crews should be able to repair sites more quickly and reduce site to site repair time variability.

As also demonstrated in the example above, RTF analysis does not replace the need for dynamic PIM testing of the RF feed system. RTF analysis will accurately predict the location of static PIM sources that it can see but will not identify PIM sources that are only excited by mechanical stress.

And finally, RTF analysis is a swept frequency test and should only be conducted on systems that are terminated into a low PIM load. Testing into a load will prevent the broadcast of high power test frequencies outside the operator's licensed spectrum and eliminate the possibility of interference.

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