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White Paper

PIM Testing

Advanced wireless services emphasize the need for better PIM control

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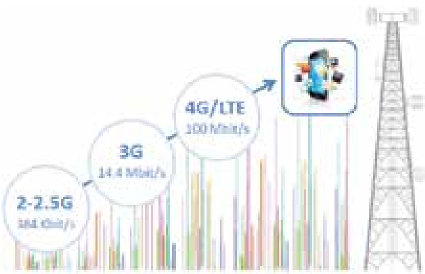

"Because 4G/LTE networks feature an increased mobile data rate of 100 Mb/s, this higher transmission rate will expose PIM vulnerabilities in today's networks on a much bigger scale."

—Understanding PIM testing, *RCR Wireless*

In just a few short years, passive intermodulation has gone from a vaguely understood but accepted nuisance to a major concern that wireless service providers seek to manage and minimize. PIM's rise in importance coincides with the increasing complexity of today's wireless networks, including the use of higher orders of modulation and more frequency bands. As wireless service providers add the most recent 4G/long-term evolution (LTE) capabilities to their networks, the incidence and effects of PIM on performance and profitability are on the rise.

In the testing lab and among RF engineers, PIM is a key concern. Wireless service providers have been vigilant about establishing more stringent PIM standards. Many system vendors have created proactive processes and testing procedures to ensure these standards are being met, if not exceeded.

When it comes to field-testing by installers and services technicians, however, the awareness of PIM and how to properly detect may not be strong as it needs to be. Field testing for PIM introduces a number of additional variables that, if not properly accounted for, may result in wide-ranging discrepancies and inaccurate readings.

CommScope has developed this white paper to offer wireless service providers and installers a better understanding of how PIM is created in today's multilayered, highly sensitive networks. It also addresses how to accurately field test for PIM and neutralize the variables that may affect test results.

PIM basics

PIM is defined as the nonlinear mixing of two or more frequencies in a passive circuit. The mixing, which typically occurs in the transmit path, generates unwanted signals — or distortion. Distortion becomes problematic when it occurs at a frequency within the receive band and at a level high enough to interfere with the desired signal.

Nonlinearity in a passive RF circuit is typically the result of current rectification at conductor joints, poor mechanical junctions or both. These can be caused by a number of factors, including:

- Surface oxidation in the RF path
- Loose metal-to-metal contacts
- Contaminants such as solder splatters
- Ferromagnetic materials in or near the current path
- Contact between dissimilar metals
- Insufficiently thick plated metal
- Improperly torqued connectors
- Structures or objects in close proximity to the site
- Scratches on the connector faces
- Contamination in dielectric material

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As signal amplitudes increase, the effect of nonlinearities becomes more pronounced, causing more prominent distortion.

As shown in **Figure 1** and **Figure 2**, PIM generation occurs on various orders that are classified based on their proximity to the fundamental or intended signal. Third-order PIM — distortion closest to the intended signal — produces the highest level of interference, followed by fifth- and seventh-order. An accurate understanding of where the distortion is occurring is as important as the levels of distortion being created. The PIM levels of two systems may appear similar, but if one is measuring third-order interference and the other is measuring fifth-order interference, the two systems will perform very differently. Third-order PIM will cause more severe system consequences than fifth or seventh.

It is also important to realize that the intermodulation products (IMPs) can occupy significant bandwidth. If the fundamental signal occupies 1MHz, the third-order IMPs may spread out across 3MHz on either side, while the fifth order may take up even more bandwidth.

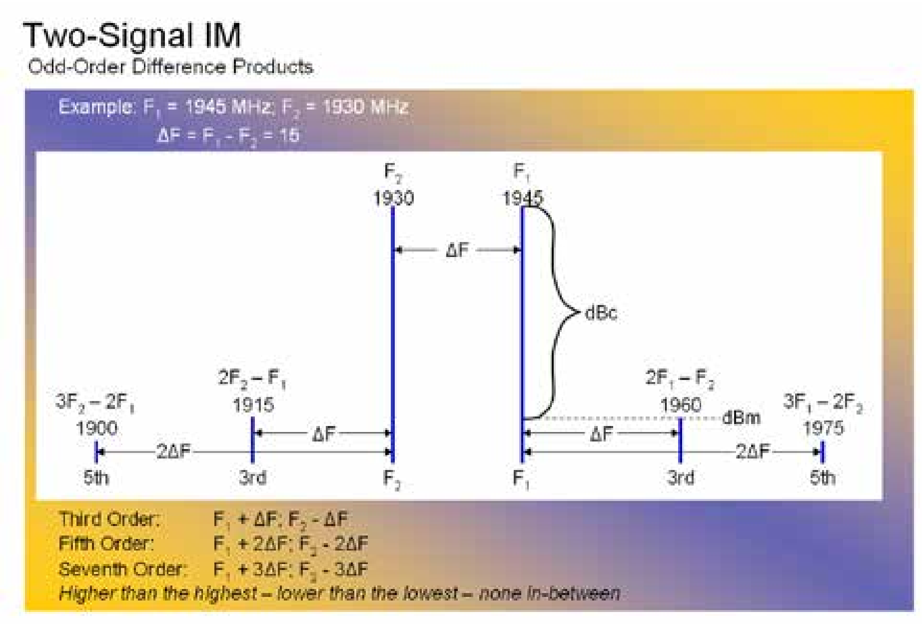

Figure 1: Spectral relationship of third and fifth order PIM products

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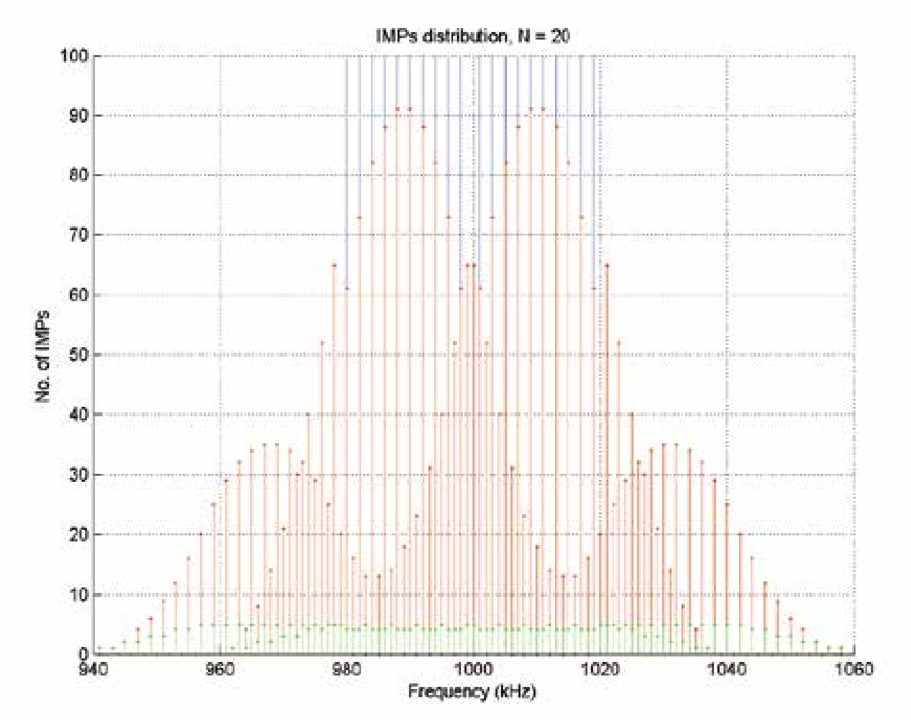

Figure 2: Multi-tone signal third-order intermodulations indicating the fundamental carriers (blue), dominant IMPs (red) and specific IMPs (green).[10]

> "In the past, careful frequency planning could eliminate concerns about PIM, but in LTE and 4G networks, the probability of interference is greater, making PIM a larger concern."[1]

4G services put PIM in the spotlight
RF engineers have long acknowledged PIM as a potential threat to network efficiency. In fact, all RF systems with at least two components generate some level of PIM. Why, then, should wireless service providers be more worried now than in the past?

The industry's transition to LTE systems has heightened the awareness of PIM. According to the Global Mobile Suppliers Association, 260 commercial LTE networks will be operating in 93 countries by end the 2013. *Converge! Network Digest* reports that, as of September 2013, 1,064 LTE user devices have been announced by 111 manufacturers, representing approximately 150% annual growth.[2]

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What has changed?

The wireless landscape is quickly changing. In an effort to accommodate more demand and more bandwidth, wireless service providers are opening the door to higher and higher levels of PIM interferences. Recent developments that increased the likelihood of higher than acceptable PIM levels include:

- Frequency overlays — 700, 800, 900, 2,000MHz
- Equipment co-location
- Higher traffic level and utilization of the network
- Expanded usage of data and higher data rates
- In-building coverage expansion and environment

In most cases, LTE services are being deployed as overlays instead of converged services. The overlay of LTE services onto existing 2G and 3G services makes wireless service providers more vulnerable to the effects of PIM. This is true for several reasons:

1. Antennas and radios designed to handle these higher-performing services use 64-QAM modulation, which is engineered to be more sensitive to noise and interference than typical modulations. This higher order of modulation can only function well with very clean signals and minimal interference. As a result, these LTE signals are more sensitive to PIM.

   While PIM levels are relatively low, occurring about 100dB down from the intended signal frequency, they are being detected with more regularity by the hypersensitive equipment. In other words, networks are working with increasingly thinner margins for error. For example, a standard pass level for PIM is about –97dBm (140dBc), which is not difficult to achieve onsite. With LTE overlays, however, wireless service providers are advised in many instances to reduce the PIM pass level to ensure the system exceeds the specified receiver sensitivity level, usually around -100 dBm/-143 dBc.[3]

2. LTE invites a higher level of interference by increasing the portion of cell-edge areas where two or more base stations compete for coverage.[4] Although LTE is designed to tolerate high levels of interference, PIM creates a level of inter-cell interference to the extent that it reduces cell and neighbor capacity.

   This can adversely impact eNodeB performance. LTE signals use multiple subcarriers to transmit the modulated information. A 10MHz LTE transmit signal, for example, contains 50 resource blocks, each consisting of 12 subcarriers. Essentially, there are 600 total subcarriers within a 10MHz frequency, each transmitting a discrete signal. Each signal is composed of discrete tones capable of producing PIM. The result is a wide band of third-order PIM, which, if it falls in the receive band, will impair the received signal. The net effect on the eNodeB is an increase in the noise floor, a degradation of receiver sensitivity, a direct impact on dynamic range and a reduction of average data throughput.

3. As wireless service providers add advanced 4G services, the complexity of the RF path is growing dramatically. Having evolved well beyond a simple antenna/cable assembly/radio configuration, many systems contain up to 10 or more individual components in the RF path. A typical network may feature remote electrical tilt (RET) antennas, quad antennas, crossband couplers, tower-mounted amplifiers, scalable IP/Ethernet radios with adaptive modulation, cross-polar interference cancellers and ortho-mode transducers. Each new element introduced to the system increases the chances for PIM.

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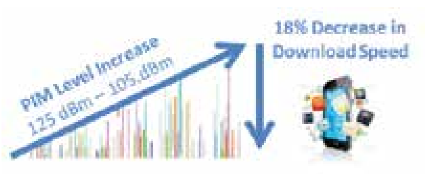


"Drive tests have revealed an approximate 18% drop in download speed when residual PIM level increases from –125dBm to –105dBm."[3]

How small is the margin for error?

Hypersensitive antennas and radios, multiple frequency overlays and more components in the RF path create an environment in which the margin for error regarding PIM continues to shrink.

Assume a network's stated PIM threshold is 150dBc. Visualize the carrier level (0dBc) as a road that is precisely 500 miles long. The margin for error, when it comes to PIM (-150dBc) would equal one inch — out of 32 million total inches! More than that is enough to exceed the stated 150dBc threshold and significantly degrade the quality of service.

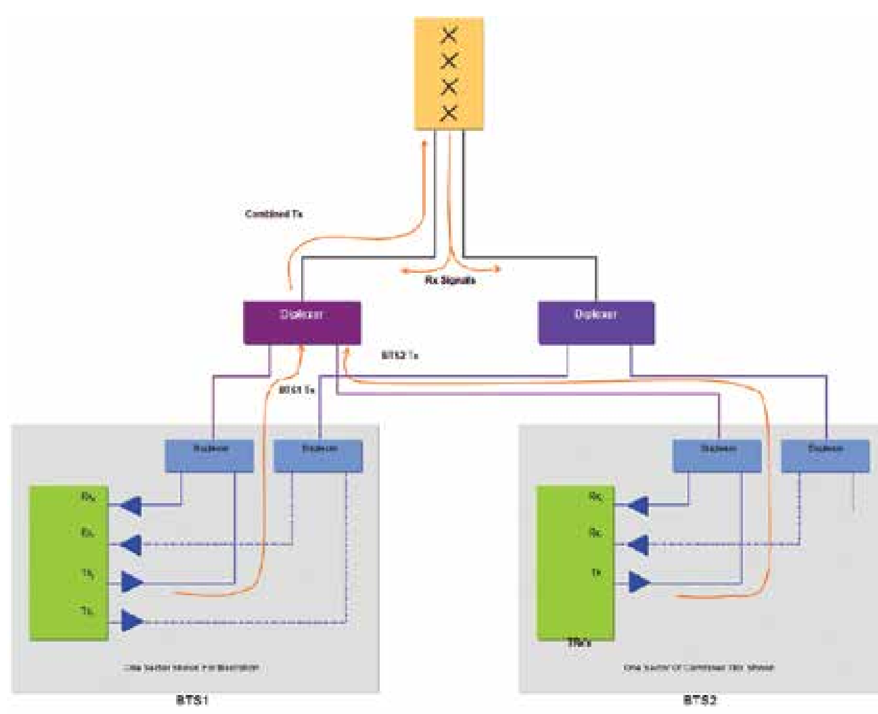
Heightened effects of PIM

Elevated PIM levels pose a significant risk to a network's operational efficiency and profitability. At higher levels, PIM in the transmit signal can overpower receive channels.
When this happens, a base station can easily mistake the signal distortion for an in-use channel and refuse to assign that channel. This causes the system to lose precious channel capacity, airtime and revenue. Given today's highly sensitive equipment, very low levels of PIM are enough to severely degrade system performance. A 1dB drop in uplink sensitivity due to PIM reduces coverage by 11 percent.[5]

By raising the noise floor, PIM also forces the system to operate at maximum power instead of under power control. This produces several undesirable effects, including an increase in power dissipation in the components and greater inter-cell interference.

PIM resulting from multiple overlay signals may render wide swaths of frequency unusable. For example, mixing a 3-channel UMTS transmission with a 10MHz LTE signal could, in theory, create a third-order product with a bandwidth over 30MHz. This does not include any effects from fifth- and seventh-order distortion.[6]

When combined, the above issues can create an operating environment with incomplete and inefficient coverage, higher energy costs and overall OpEx costs that are higher than needed. This does not include the cost of repeated truck rolls to identify and correct PIM-related performance issues.



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"LTE offers faster network speeds and better efficiency through a number of features and its all-IP nature means a "flatter" network architecture. But one common, recurring theme voiced by network experts: LTE is adding complexity to networks in multiple ways, and this is the biggest challenge in testing."[7]

Accurate field-testing is critical

Accurate PIM testing requires a solid understanding of the variables that can affect the test outcomes. Installers and service technicians must know how to neutralize those variables without significantly altering — for the sake of the test — the environment in which the network's transmit and receive equipment must function. Because this environment is extremely difficult to duplicate in the lab, the experience and knowledge of the installers or service technicians is critical; they are the operator's first line of defense when it comes to measuring, identifying and minimizing the damaging effects of PIM.

Figure 3: PIM Measurements – Field Observations
- **On-site antenna measurements with iQA200 portable PIM**
- **Clear sky RF field-of-view required to avoid any secondary PIM sources which could cause false PIM failure**
- **Antennas should be not be placed directly on the ground**

Test conditions, setup and procedures

Conducting accurate PIM testing in the field is especially challenging because PIM levels are extremely sensitive to test equipment and surroundings. The presence of metal objects in proximity to the device under test (DUT) as well as the use of a worn test adapter can increase PIM, resulting in false failures. At one recent field test as shown in Figure 2, the PIM of a BSA was recorded at -123dBm when pointed at a clear sky with no metal objects in the field of the antenna. That figure dropped as low as -84dBm when different objects were moved near the testing equipment.

To ensure test accuracy, there are three key parameters to consider:

1. The test conditions
2. The test set up
3. The test

PIM is also known as "the rusty bolt effect" because PIM levels can be affected by so many different variables. Field testing should be conducted on a clear day and away from other equipment. Forklifts, people with cell phones, metal objects, fences, site equipment — even the weather — can impact the test results. PIM tests have even been shown to fail because of

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buried conduit or the presence of light posts within the beamwidth of the antenna under test. Spurious RF signals from sources like mobile phones transmitting on the same frequency as the third-order PIM, nearby arc welders and other electronic noise generators may also alter the results.

Because virtually any object within the field of the RF path can cause PIM, the test equipment itself may also influence the results. So while external conditions may not be entirely controllable, the test setup can be controlled. Installers and service technicians must account for the variables within the test setup, if the results are to be meaningful.

To help ensure a proper test, make sure to:

- **Validate all test equipment:** First test the entire PIM station setup by itself without the DUT. This residual system test should include all testing adapters and cables. The residual system PIM, typically -160dBc to -165dBc, must be at least -10dB better than the specification level for the DUT. The greater the delta between the two measured PIM levels, the more accurate the measurement. Swept measurements provide more complete results than fixed transmit tones.

- **Use low intermodulation (IM) loads:** A regular high-power load has poor IM because of the absorbing element. Use a low IM load from the supplier of the IM test equipment. Avoid resistive load elements such as braided cables.

- **Ensure the cable ends are properly prepped:** Small burrs or slight irregularities in the face of the cable end are enough to throw off PIM readings. Ensure the cable end is clean, square, properly de-burred and free of debris.

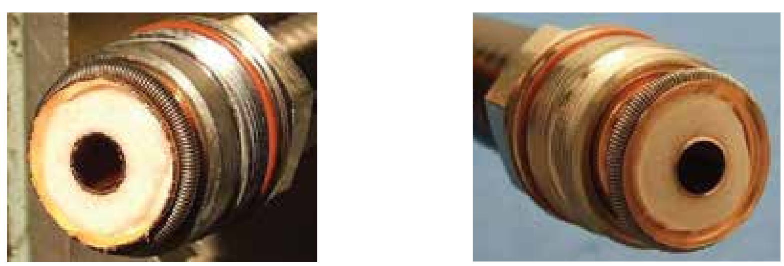

Figure 4: Cable ends should be clean, square, properly de-burred and free of debris.

- **Minimize the number of adapters:** Cable connections are one of the most common sources of PIM. Minimize the number of adapters by using a cable whose connector style matches that of the test equipment. If adapters must be used, ensure they are new. Worn adapters are more prone to loose connections — a known cause of PIM, especially at the inner conductor.

- **Ensure all connections are properly torqued:** Unlike VSWR sweeps, connectors used during PIM testing must be properly torqued — not just hand-tightened — to ensure accurate testing. Set the torque wrench to the connector manufacturer's recommended torque value to avoid mechanical strain. For 7/16 DIN connectors, 20 foot-pounds is generally an accepted value. For Type N connectors, 12 inch-pounds is common.[3]

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The test process

During actual PIM testing, two 20 W (+43dBm) test signals are injected into the line or DUT. If the test signals encounter a nonlinear junction, mixing occurs, which generates PIM frequencies. The PIM test equipment measures the magnitude of the PIM generated by the test signals and displays this information to the test operator.[8]

Although the typical reference (carrier) power level is 20 W (+43dBm), testing may also be done using a 2 W reference power level. In either case, knowing the carrier power level is absolutely critical to interpreting the results. A -150dBc test result using 2 x 2 W (33dBm) carrier power translates to a -117dBm PIM level. However, the same test results using 2 x 20 W (43dBm) carrier power would yield a PIM level of -107dBm.[9]

Should the initial PIM test fall within the wireless service provider's specifications, many PIM testing companies recommend proceeding with dynamic testing. Dynamic testing involves lightly tapping all connector interfaces, tower-mounted amplifiers, diplexers and antennas just enough to identify loose connections or mechanical discontinuities. Jumper cable assemblies should be gently flexed to ensure cable integrity.

Use frequency sweep testing rather than testing individual frequencies. Fixed frequency testing may often yield results that, while encouraging, can frequently be misleading, masking PIM distortion that exists at non-tested frequencies. If the test involves non-swept frequency equipment, repeat the test using two or three different frequencies.

Controlling PIM requires a proactive, comprehensive approach

Wireless technology continues to evolve at an accelerating rate. Developments such as the growth of small cell deployment, use of millimeter wave transmission and increasingly sophisticated modulation schemes add complexity to the design and maintenance of high-capacity, high-availability networks. At the same time, cell towers are quickly becoming overcrowded as wireless service providers turn to co-location strategies in order to rein in costs.

The issue and effects of PIM will only grow in importance. Although component vendors and wireless service providers appear to agree regarding PIM control during manufacturing, that same urgency and effort are not yet evident in the field. This can be seen by the number of known "good" RF components being assessed and returned as faulty. As an industry, we must do a better job of emphasizing the importance of proper connection practices and accurate PIM testing among installers and service technicians.

Nevertheless, positive strides are being made. Comprehensive solutions such as PIM Site Audit and Avoidence by CommScope are successfully driving PIM awareness through all parts of the network, from purchasing and systems design to field installation and testing. By taking advantage of proactive and comprehensive programs such as this, wireless service providers can successfully mitigate the effects of PIM while continuing to evolve their networks.

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2 GSA: 213 LTE Networks in Commercial Operation; Converge! Network Digest; September 2013
3 Understanding PIM; Anritsu newsletter; January 2012
4 Interference Management in LTE Networks and Devices; Senza Fili Consulting white paper; May 2012
5 The Importance of Addressing Passive Intermodulation (PIM) in the Field; Talley Sheet; 4Q 2011
6 Troubleshooting Passive Intermodulation Problems in the Field; Anritsu white paper; December 2010
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8 Range to Fault Technology; Kaelus Inc. white paper; October 2011
9 PIM Power Levels—A Brief Tutorial Introduction; Summitek Instruments; September 2011
10 Wikipedia http://en.wikipedia.org/wiki/Intermodulation

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