Troubleshooting Passive Intermodulation Problems in the Field

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1.0 Introduction

The introduction of high-speed data within mobile communications devices has increased the network traffic within a cellular system to the degree that it is greatly affecting network performance.

It is broadly understood that Passive Intermodulation (PIM) is a formidable issue within the cellular industry. This type of test has been in use for 15 years or more within the OEM industry throughout the world. As extra cellular transmitters and modulation formats are commissioned into service in new or existing sites, the statistical performance can appear to change dramatically. Ultimately, this can result in poor site/sector performance and reduced coverage, and this is why testing for PIM is now required in the field.

The purpose of this paper is to introduce the troubleshooting methods currently used in the cellular construction industry as well as to offer some background knowledge of Passive Inter-Modulation (PIM).

2.0 What is PIM?

PIM is a form of intermodulation distortion that occurs in components normally thought of as linear, such as cables, connectors, and antennas. However, when subject to the high RF powers found in cellular systems, these devices can generate spurious signals.

An on site PIM test is a comprehensive measure of linearity and construction quality.

PIM shows up as a set of unwanted signals created by the mixing of two or more strong RF signals in a non-linear device, such as in a loose or corroded connector, or in nearby rust. Other names for PIM include the diode effect and the rusty bolt effect.

This pair of formulas can predict PIM frequencies for two carriers:

nF1 – mF2

nF2 – mF1

F1 and F2 are carrier frequencies and the constants n and m are positive integers. When referring to PIM products, the sum of n + m is called the product order, so if m is 2 and n is 1, the result (2+1=3) is referred to as a third order product. Typically, the third order product is the strongest, causing the most harm, followed by the fifth and seventh order products, which also cause significant harm. Because PIM amplitude becomes lower as the order increases, higher order products typically are not strong enough to cause direct frequency problems, but they usually assist in raising the adjacent noise floor.

Once this raised noise floor crosses into the Rx band, it then has an open door (and sometimes gain via an LNA) into the BTS.

A standard PIM test will almost always test for the 3rd order because it is almost always the most predictable. The actual problem that exists within a site, however, may actually be 5th or 7th order PIM products that are causing the degradation in site performance.

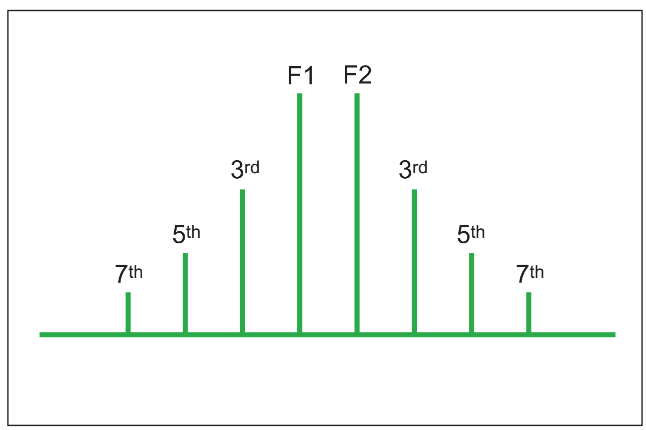

Figure 1. Carriers F1 and F2 with 3rd through 7th order products.

IM from Modulated Signals

Intermodulation products from Continuous Wave (CW) signals, such as might be created by a PIM tester, appear as single frequency CW products. When spotting PIM that is created from modulated carriers (the sort of fault that might be seen with live signals), it is important to recognize that intermodulation created from modulated signals takes more bandwidth than the fundamentals. For instance, if both fundamentals are 1 MHz wide, the third order product may have a 3 MHz bandwidth, the fifth order product may have a 5 MHz bandwidth, and so forth. PIM products can be very wide-band, covering wide swaths of frequencies.

With the overlay of Spread Spectrum signals into current site infrastructure, the mixing (due to a transmission system linearity problem) of a 3 channel UMTS transmission with a 10 Mhz LTE (assuming 10 Mhz) would be disastrous. In theory, this could create a 3rd order product with a bandwidth over 30 Mhz, and this example does not include any effect that 5th and 7th order would introduce. This would be an interesting experiment to document because 100 Mhz+ noise issues are certain to be present.

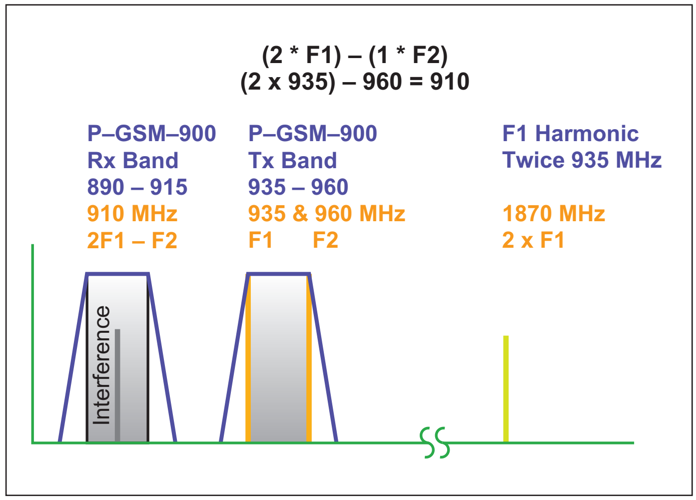

Figure 4. PIM causing receiver de-sense at 910 MHz.

PIM Calculation Examples

Here are two PIM examples: one from the 850 MHz band and one from the 1900 MHz band.

In the first example, 1750 MHz is one of the third order products and falls within the AWS-1 base station receive band. If the 1940 MHz and 2130 MHz carrier sources are physically close to each other, or even sharing the same antenna, any corrosion or other non-linear effect will generate a third order passive intermodulation product at 1710 MHz that can cause receive de-sense, or blocking. It is worth mentioning that PIM products do not need to fall directly on the uplink channel to cause problems. They only need to fall within the receiver's pre-filter, which is typically a full band component.

A PIM example for the widely used 900 MHz band assumes two GSM carriers, one at 935 MHz, and the other at 960 MHz. In this case, the 910 MHz third order product is in the base station receive band.

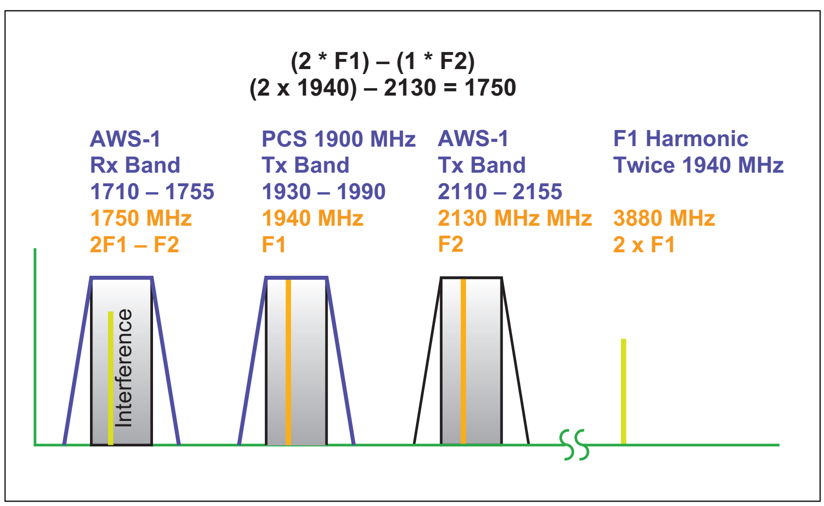

Figure 3. PIM causing receiver de-sense at 1710 MHz.

Three or More Carriers

The calculations so far have assumed that only two carriers are present. That is not always the case in the real world. At the base station, one needs to account for not only carriers within an antenna system, but the stronger signals from nearby transmitters as well. The signals can back-feed into an antenna system, find non-linear devices, mix with other carriers, and create PIM. This issue compounds quickly when highly complex modulation platforms are used. This is already very evident within the cellular field even with relatively narrow bandwidths in use.

When three or more carriers are involved, the calculations quickly become complex. The larger carriers within North America transmit 4-7 CDMA carriers per sector, and this usually has at least one EV-DO transmitter also!

3.0 What Problems Exist?

The problems experienced on site are not always directly related to PIM or to Micro arcing; however, we use a PIM test to find them. The current standard of PIM testing offers a well-known system of two primary carriers and a calculated PIM frequency, which is monitored via spectrum analyzer or receiver.

The main reason we use a PIM test across many different possible faults is that it is the most comprehensive measure of electrical connection quality that is commercially available. This allows the user to cover many fault types with one test format.

The current PIM test systems cannot measure S parameters. This means the test set will not see an open or short condition, unless the fault displays non-linear behavior. A return loss figure that is failing will not be determined with a PIM test set. It is important to remember that PIM testing does not replace current line sweep testing. The two tests are vastly different in their specialized testing areas.

Components deteriorate as they age due to a number of issues, including poor mechanical design, poor installation, and moisture ingress (which is the most significant).

On-site faults can mostly be categorized into two main types: Impedance related and load/ linearity related.

Impedance Related

An impedance related fault is one that can be found with a sweep test. Minor impedance variations will appear as poor return loss. A BTS would usually give a VSWR alarm under a constant poor return loss condition.

If a main line had suffered from damage, a PIM test would not find a fault if linear characteristics are present, nor would it be able to offer a measurement that could actually measure the return loss across the band of interest. The operator would need to perform a line sweep to determine how bad the damage is and its location.

Until recently, the VSWR test or line sweep was the industry standard acceptance test for cellular sites. Most service providers insist on the inclusion of linearity testing as part of the standard site acceptance report. Data rates and traffic through a cell site have increased dramatically over the past few years, and this is the reason for such a massive change in the industry. Both tests should be performed, each is important in its own respective field.

Load/Linearity Related Faults

A load related fault is a fault that becomes evident under load. A sweep test (impedance) will not likely find this fault due to the low power signal that is traditionally used.

A good example of a load related fault is a corroded car battery terminal. The battery is charged, and the radio works, but the terminal connection becomes resistive under load (cranking) and cannot rotate the engine.

Cell sites offer similar problems in that a coaxial connection on a tower may behave differently under load, even though this goes against theory.

Traffic through the site plays a big part – a relatively quiet site will not usually see the same performance problems that a busy site will see.

If maintenance crews have spent large amounts of time trying to improve site performance without showing any conclusive results, checking the site for PIM is highly recommended.

It is also worth considering the likelihood of failures. How often do you need to replace a BTS filter module or mainline within a site? Certainly not often. Over the past few years, it has become quite common to replace components within a cell site even though there is no concrete evidence that the component is faulty. It is common to hear reports of upwards of $100K having been spent on a site, and it still shows no real improvement in performance or rectification of the original fault.

Often it is difficult to tell if a repair has been successful, because the BTS may need to re-calibrate over a period and allow statistical data to generate.

Another area to look for is the presence of a raised noise floor in the receive band. This is almost certainly attributed to PIM, whereas an external interferer may be frequency specific.

The BTS can also be fooled by noise floor levels. Some BTS units measure the noise floor over a period of hour or days and assume the level is a particular figure, say -110 dBm. If this figure is not -110 dBm in reality, the BTS will calibrate with the incorrectly assumed reference figure, and all gain and power levels may be incorrect.

PIM testing can appear overwhelming, so it is advisable to pick a small number of sites to start with and analyze the performance data in detail.

An elevated noise floor on both receive paths (when only one has Tx power) is likely caused by something external to the antenna system.

If a cell site performs poorly when dry conditions exist but improves dramatically when a rainstorm passes through the region, then immediately inspect the surrounding area for items that have rusty mounts, such as Air Conditioning ducts. This very common fault is often found in rooftop sites located in densely populated areas.

4.0 Locating PIM Issues within a System

It is essential to have and use the correct termination tools with PIM testing. Calibrated torque wrenches are required and should be used when justified. Cleanliness is key and alcohol wipes should be used to clean every step of the termination process.

Currently, sites are repaired using a method of isolation to find the offending junction or component.

This involves checking the residual PIM of the test set and then performing a PIM test on the antenna system. All connections should be checked for cleanliness and torque, and this needs to become second nature to the operator of the equipment.

Care must be exercised when PIM testing. Every time a connector is mated, you are effectively wearing out the interface. A large number of faults are caused by over testing and by damage from repeated torque. Antennas require special attention. The connectors are generally weak in their mounting mechanics, and repeated testing and torque cycling can loosen the base and render the entire antenna useless.

One recommended approach is to remove the seals from DIN connectors while faults are investigated, because this allows much less torque to be used while testing. A large part of the torque spec is used to crush the seal, and preliminary testing does not require much more than hand tight connections.

Once the system is clean of PIM, replace the seals for the final certification of the complete line. Test cables should not use any seals. Multiple connections of a test cable result in the seal becoming contaminated with metal shavings from the repeated mating cycles. The metallic particles will be evident after the first mating cycle and will contaminate every additional connection made.

N Type connectors are not recommended for PIM applications when possible. The N connector was not designed for multiple carrier high power installations. It is a good connector that has definitely stood the test of time. The mating surface area of the male outer component is quite small and is very easily damaged by over-torque. The N platform of connectors were originally designed by Paul Neill of Bell Labs in the 1940's and are usually specified only for handling a few hundred watts of power. N connectors of good quality can test very well for PIM, but they can be very sensitive to torque and vibration.

Loose connectors (at the cable interface) are probably the most common fault found on site. It is also interesting to note that a consistent theme will exist depending on the skill and experience of the individuals involved. If one connector within a site was installed incorrectly, most of the other connectors will probably need attention as well.

The easiest way to locate PIM problems within a site is to simply step through the installation using a low PIM load. The low PIM load is the most important accessory used with PIM testing. It is the reference used to ensure that PIM results are accurate. Because PIM testing is a dynamic test, it is important to manipulate each connection to try to excite any latent problems. Bending cables slightly or tapping lightly on components will easily identify PIM problems while under test. Never hit anything harder than you would knock on a door, and never over-bend a cable. Specifications are available from each vendor, and these products are designed to withstand reasonable abuse. A good rule to follow regarding cables is to move the cable no more than 1 inch off axis at 12 inches away from the connector.

Antennas are the most difficult item to test. Most antennas manufactured before 2006 were not constructed with PIM performance in mind and may never pass a PIM test. All newer antennas should comply, and it is as simple as checking the specs to see if a certain PIM figure is published. Because modern antennas are quite light and fragile, it is advisable to keep all packaging available for transport to and from the site, as warranties are likely to be void if the original packaging is not used.

It is highly recommended to test antennas on the ground prior to mounting on a tower to check both PIM and VSWR performance. Care must be exercised because external interference devices can limit the quality of the testing.

Antennas should be pointed facing clear sky with no metallic objects nearby. Place the antenna on plastic chairs or sawhorses to minimize the effect of any external influences. All metallic mounts and hardware will need to be fixed tightly because loose bolts and brackets will present PIM opportunity.

The PIM test sets transmit 2 x 20 watts, and this power is being transmitted through the antenna. Exposure risks may be present, so it is not advisable to stand in front. In most cases, an antenna under test can be pointed at a metallic device, which should change the PIM performance dramatically. It is advisable to keep a known good antenna aside so the operator can retest if the failure rate appears high. This is also a good way to test a new location for quality of outdoor antenna testing.

When testing antennas on the tower, the quality of mounting hardware is important. Any bolts and fasteners that have been corroded should be replaced, and while testing, tower personnel may need to climb away because tools and safety belts easily generate PIM.

5.0 PIM Limits

Acceptable PIM levels are generally set by the owner of the site or the equipment, and these figures will be based on their specific band and equipment scenario.

Antennas that were installed 10 years ago were probably not manufactured with PIM performance in mind, so it would be unrealistic to set a PIM level greater than -80 dBm/123 dBc because very few would measure favorably. It is also unlikely that PIM specs were even considered when the network was designed.

New antennas and associated components should all have factory test results shipped with the device, and any testing done in the field should correlate closely with these figures.

It is very important to remember that a customer must specify PIM requirements, including specific test parameters and test power within the procurement process. It is hard to claim warranty for a specification that was never requested.

Typical PIM guidelines for antenna systems are between -150 dBc and -170 dBc using a 2 x 20 watt PIM tester. This essentially equates to a maximum PIM level of -107 dBm. New antenna systems typically should be in the lower end of the range, while older antenna systems should at least make the higher end of this range.

A standard figure used around the world is a pass level of -97 dBm/140 dBc. This is not hard to achieve on site, and once you get past the -95 dBm/138 dBc area, the PIM figure will generally improve dramatically, and measurements of -125 dBm/168 dBc are common. With the overlay of LTE services now beginning, a pass value of -97 dBm/140 dBc may not be enough, and it would be wise to achieve the specified receiver sensitivity level (usually around -107 dBm/150 dBc) with PIM testing.

If a particular sector utilizes an external power amplifier, PIM specs may need to be considered differently. If a site was actually transmitting at 50 watts (+47 dBm) and the pass criteria was -97 dBm/140 dBc at 2 x 20 watts (+43 dBm), and if we assume a linearity figure of 2.2 dB of PIM gain for every 1 dB increase in test power, then we should be looking for a pass value 8.8 dB better than originally thought (2.2 x 4 dB). This brings our pass criteria up to -105.8 dB as a minimum.

6.0 Summary

Lack of linearity can limit the receive sensitivity of a cellular system. This limits the reliability, data rate, capacity, coverage, and return on investment of the system. The PIM test is an excellent indicator of linearity and construction quality.

PIM comes from two or more strong RF signals mixing in a non-linear device. These non-linear devices, or junctions, occur in improperly tightened, damaged, or corroded connectors or in damaged antennas. Rusty components, such as mounts and bolts, are also suspect when hunting for sources of PIM.

Many common frequency combinations can produce PIM in a cell's receive band. Signals in the cell's receive band will raise the receive noise floor, increase the bit error rate, and shrink the reception area for cellular communications.

Avoiding PIM starts with quality construction methods. However, increasing capacity, new services, and aging infrastructure are all working against this strategy, and PIM testing is becoming more important every day. It is apparent that most on-site PIM issues that affect service are derived from the sidebands of internally generated interference, not the calculated frequencies themselves.

Proper care and maintenance of connectors is essential to keeping PIM low. Inspection and cleaning is a central part of good performance. Proper torque is important, because the seals and interface areas are designed for this pressure.

PIM testing is becoming more important as cellular systems age and as the carrier count is increased. A test that was not as important when cellular systems were lightly loaded is becoming a critical part of modern cellular maintenance.

A cell site constructed with PIM in mind will cost less to maintain over time. This same site will show cleaner performance than similar sites that were not PIM tested.

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