WHITEPAPER
V250523

EXTERNAL PIM MITIGATION

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INTRODUCTION

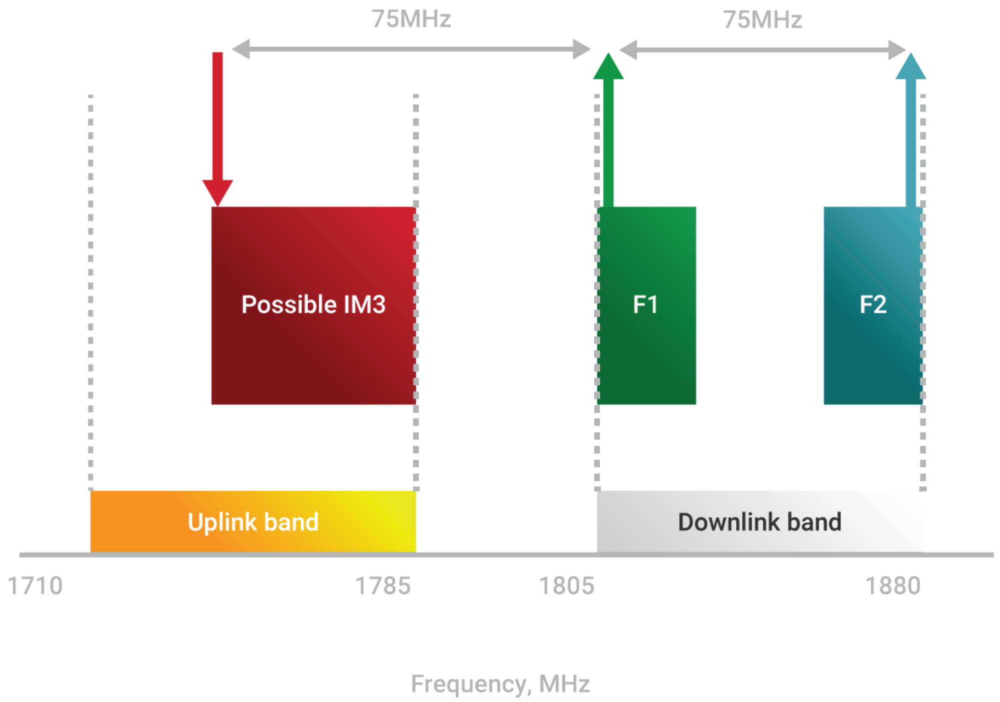
Passive intermodulation (PIM) is a huge issue for cellular network operators that is ever growing in complexity.

The original understanding of PIM saw the problem caused by aging equipment, co-location of new carriers, or poorly installed equipment. It is now compounded by vast bandwidths of spectrum cleared of old licenses such as television and satellite services, then re-auctioned or allocated for cellular communications. Much of this spectrum is higher in frequency than the original 4G services (except the 600MHz band) and much more wideband than our current bands. As a result, we must reconsider how to treat the overall PIM testing and mitigation strategy as new services gain users and growth.

Now the industry is experiencing in-band interference and an increase in the noise floor because of external PIM faults on the tower and the site. Rooftop sites are particularly susceptible to externally generated PIM. This paper will offer insight into the problems and solutions for the wireless industry.

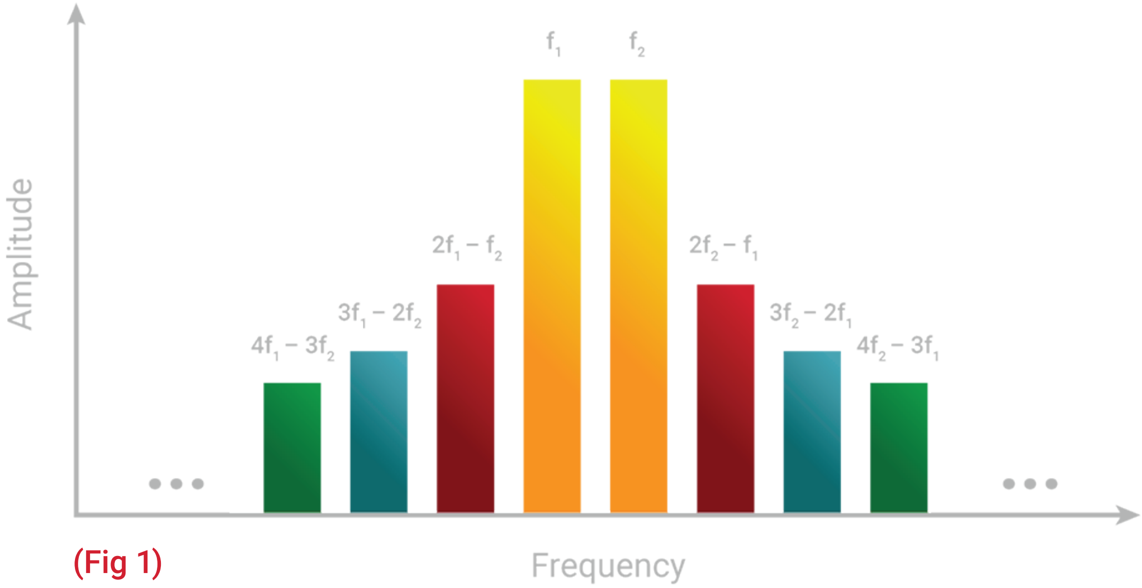
PIM BASICS

Passive intermodulation (PIM) is interference that's created when cellular downlink (transmit) signals mix because of a nonlinear device or material junction within reach of the transmission signal. This is quite normal for RF signals, and design engineers use this phenomenon to their advantage when designing transmitters and receivers with the use of mixers. The problem occurs when the mixed products from the cellular site's downlink falls into the uplink band of wireless service. These wireless services are the ones we use daily for our business, personal, and emergency communications.



PIM is caused by two or more high-power RF signals present in a nonlinear environment. As the two (or more) signals pass through a nonlinear junction, such as a poorly fitted connector or even generic cable hangers and various bolts around the antennas, a series of intermodulation products can arise. This is because of poor electrical contact and dissimilar metals. PIM has been a problem for the communications industry for decades and was initially discovered on navy ships. When PIM testing became common in the wireless industry, larger PIM problems were contained within the transmission system. This includes jumper cables and their connectors, main feed lines, all filtering and duplexing, as well as the antennas. The presence of PIM was a shock to the wireless industry professionals, who felt they understood their technology very well. Eventually, the manufacturers invested in this knowledge and could create stronger and more linear designs that can perform well under multi-carrier transmission systems.

The simplest way of calculating the 3rd/5th/7th order of PIM is to measure the difference in the frequency of the two main frequencies. This value in MHz determines the spacing among all orders of PIM harmonics. F1 and F2 represent two transmitters on the cell sector (see Fig1). The other lower-level signals are all byproducts of F1 and F1.



(Fig 1)

Example: **F1 = 935 MHz** **F2 = 960 MHz**

F1 and F2 are 25 MHz apart, thus PIM harmonics are located 25 MHz both above and below F1 and F2. The 3rd orders will be 910 MHz and 985 MHz, followed by 5th orders at 885 MHz and 1010 MHz, as shown in Fig 1. The issue here is that adjacent carriers can produce PIM that interferes with an uplink band (receive), and, in this case, the low side 3rd and 5th order products are within the uplink band. We also have 2nd order products at 1870 MHz and 1920 MHz.

External PIM is now also generated around the site and is appearing to be worse than the original internal PIM problems. A whole industry that produces shielding materials, special paints, shielding tape, even roofing materials has appeared from the need to hide and mitigate the generation of PIM. Several manufacturers are producing stealthing materials and some materials are so technical in their composition that RF test data is furnished from the production process to the customer.

Now we have the culmination of two distinct problems:

* Many sites have significant external construction problems that cause PIM to hinder the performance of any site and sector that can receive this signal.

* Wireless operators are gaining more spectrum. This compounds the problem as now 2nd order harmonics and PIM affect the sector's performance.

EXTERNAL PIM AND INTERFERENCE

Another significant hurdle is how to identify if a problem is caused by external PIM or interference. This is the single biggest mistake made when a technician is making measurements and repairs on a site. Both types of signals, often depicting a rise in the noise floor, are easy to misunderstand.

The BTS receivers are very sensitive and can typically process a signal as low as –120 dBm or better depending on sub-carrier spacing and noise figure (noise fig = typical insertion loss from antenna radome to 1st gain stage). As a result, an interfering signal's source could be located a great distance off-site and can easily affect several other sites. Likewise, a PIM signal generated externally of the antennas could also propagate into other sectors and other sites some distance away depending on the scenario.

We use four devices to make the measurements, not including RF cables and adapters.

The most important is the SAF Spectrum Compact, as its size and weight makes the task easy followed by an in-line filter to attenuate the downlink signals, so the front end of the spectrum analyzer is not overloaded. If the input to the instrument is overloaded, intermodulation will be produced internally to the measurement system, causing test data to be false. This is a common trait of all spectrum analyzers and receivers.

Then we choose either a near-field probe antenna or a Yagi, and this is determined by the specific test.

The probe antenna is used for sniffing around the mounting system on the tower and the immediate area around the antennas in a rooftop site. It is designed not to be sensitive to signals that are far away.

The Yagi antenna is used for signals that may be further away and is unsuitable for PIM measurements close to the sites sector antennas. It is best to use antennas that are specifically designed for PIM measurements, as their internal linearity is key to measurement accuracy, as an antenna not designed specifically for this purpose can generate PIM that will distort the measured data.

The simplest way to find the source of a signal is to make the same measurement from more than one location. When making on-site measurements with a Yagi type antenna and filter, it is possible to measure signals from a distance. This may cause confusion if PIM is generated on the site as well. By making the same measurement from various locations, it is possible to add isolation by space and distance between the source or sources, and, by doing this, it is possible to triangulate the source. It is also possible to receive a signal from directly behind the antenna, as most small Yagi antennas are not designed to have significant front-to-back performance. The technician can easily add front-to-back isolation by standing directly behind the Yagi antenna, isolating any distant signal coming from behind. Another valuable way to check for PIM sources is to disable each transmitter one at a time while monitoring the relevant uplink band to determine an active relationship with the PIM signal being measured.

2ND HARMONIC PROBLEM

In North America, there have been issues where transmit signals from the 850-downlink band (869-894) are subject to a PIM source on site which can excite a 2nd harmonic strong enough to disrupt the performance of the AWS uplink band (1710-1785 MHz). 869 MHz x 2 = 1738 MHz. In this scenario, we would waste our time trying to find a problem in the AWS spectrum using a 1900-2100 MHz PIM test because the issue is caused in the 850 MHz band and the antenna's proximity to hardware (in this case – DC surge and lightning protection components) on the tower or mounting system. The technicians would use a spectrum analyzer, RF band-pass filter, and antenna to monitor the AWS uplink as potential external PIM problems are isolated while either the 850 MHz service is powered up or using a dedicated PIM tester in place of the site's radios. It should be noted that this scenario occurs even though the base station has high-performance filtering that aggressively suppresses the 2nd harmonics produced in the power amplifiers, as this problem is generated externally.

The 2nd harmonic scenario is quite common to all global wireless systems where 800-900 MHz services and 1700-2100 MHz services exist and are served from the same site or closely located competitors. Also, the licensing of the CBRS- and C-bands are very susceptible to 3rd and 5th order PIM problems, all generated from the 600/700/800/1900/2100 MHz bands.

It is important for the technician to understand which downlink frequencies are on site and what the uplink frequencies are. Typically, all measurements are made in the uplink band and its associated guard band. The technician must be able to calculate 3rd/5th/7th order intermodulation products. There are PIM calculators available for free and CommScope has a good one that is downloadable.

PIM MITIGATION ON SITE

There is much confusion relating to the current PIM mitigation procedures used by the different carriers. The process is continuously evolving. If we start with basic PIM hygiene, many of the small PIM issues can be taken care of with no service interruption or a commitment to roll a crew.

LEGACY APPROACH

When a PIM tester is used in place of radio, we must consider how we monitor the PIM level as the technician probes around the vicinity of the antennas. The pulsed PIM testers (newer models) will not always display accurately on all spectrum analyzers due to sweep versus duty cycle mismatches therefore, test data may be compromised. The older Kaelus IQA series of PIM test systems are of the continuous wave (CW) type and any generated PIM signals will be continuous also, meaning a simpler spectrum analyzer can be used. The tradeoff is weight, portability, and power requirements, and these common rooftop problems may prevent the use of a CW PIM tester altogether, although the CW type is the preferred system for exciting non-linear PIM sources. The spectrum analyzer should have a specific setup available to ensure that pulsed PIM testers are measured correctly, such as the SAF Spectrum Compact includes from the factory to easily measure both pulsed and CW signals.

The downsides to using a PIM tester is:

* The traffic is vacated, and the radios are shut down. Then the technician must break into the cabling to insert the PIM tester and perform testing. This risks damage to the performance of the site because known good connections are opened.

* Some carriers hold the crew responsible if the system PIM deteriorates after their tasks are complete, if remote radio heads (RRH) are used on the site, it may be impossible to reach them due to height and access restrictions.

IMPROVED APPROACH

A less intrusive method is to simply monitor the uplink bands while the site is on air and use a spectrum analyzer, filter, and antenna to look for a rising noise floor around the vicinity. The technician may struggle to understand the measured data as the sector load changes dramatically with user traffic, causing the intermodulated noise to fluctuate as well.

However, we can also use the installed radios on site to our advantage. The radio can be placed into a test mode using a CPRI Analyzer (Common Public Radio Interface) where the subscriber traffic retains priority and is not disrupted but the radio can artificially load the unused resource blocks with white noise to achieve an artificial 100% loading of the sector's service. Nokia and Samsung refer to this mode as Orthogonal Carrier Noise Simulation (OCNS) and Ericsson calls this mode Air Interface Load Generation (AILG). Other manufacturers may use different terms for their equivalent artificial loading mode.

When in these modes, the sector can still carry normal traffic, but if PIM problems exist, which is likely, the noise floor will rise in the relevant uplink blocks, and this will affect the key performance indicators (KPIs) of the sector and others. When this mode is employed, the technician will have consistent measurements and the use of a filter and antenna (small Yagi or PIM probe) is necessary. A key indicator of PIM in the uplink band is a raised and sloping noise floor that seems wideband.

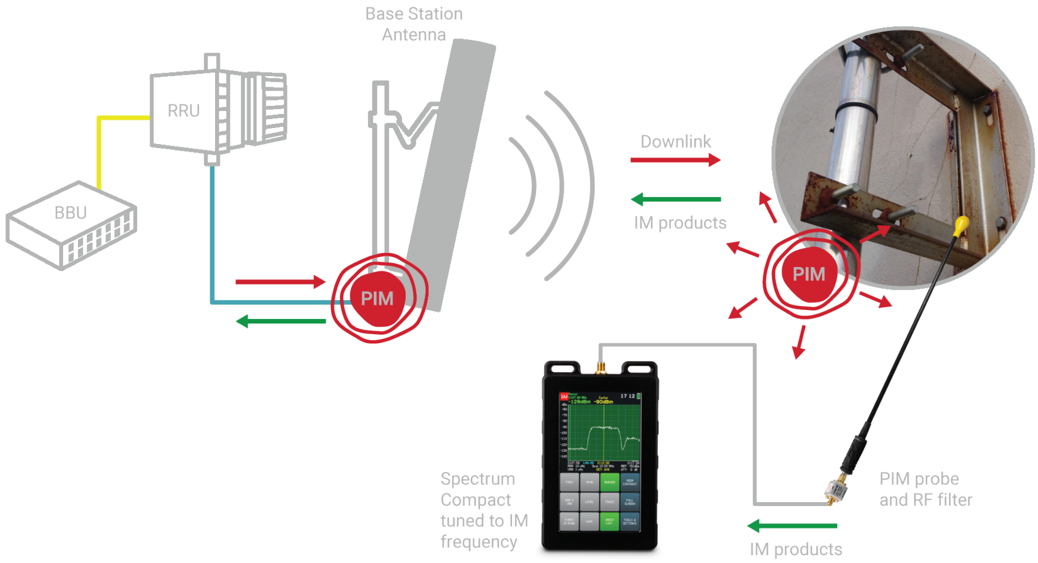
There are significant benefits to using this method:

* By using the radios on site to excite the PIM problems, the technician can see real-world examples of how the site performs under heavy traffic loads.

* The site is using all antenna polarities and ports just like it would under normal service conditions.

* Any mitigation testing performed will be reflected in the sector's KPI data, and this will give a good representation of the actual performance improvements the site may see under normal circumstances when permanent repairs are made.

In this test mode, the crew then eliminates PIM sources in the near field using the industry-standard Yagi and/or probe antenna with filter to identify PIM hotspots, followed by reflective blankets, and other preferred isolation methods to eliminate or hide PIM sources. This method gives a test scenario that is closer to the day-to-day function of the site, including the inherent problems from PIM and interference.



CONCLUSION

Identifying and addressing external PIM sources at cell sites can be a complex task, with some PIM sources being easier to detect than others. The success of the site PIM testing and repair relies on the proficiency and training of the team conducting the tests. While CPRI and RF PIM test methods both offer distinct advantages, it is advisable for operators to initially perform basic PIM measurements using a spectrum analyzer, filter, and antenna to figure out how in-depth the complete mitigation task will be before committing a full crew deployment and interruption of services. It is also a good opportunity to perform some basic PIM housekeeping around the antennas. By using a combination of CPRI and RF PIM methods, operators can first find and address obvious sources of PIM noise and then fine-tune the search with the RF PIM analyzer for the best results if necessary. This approach saves time and enhances confidence in the mitigation recommendations provided.

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