RADIO FREQUENCY SYSTEMS
The Clear Choice®

A primer on passive intermodulation (PIM)

Written by Frank Hall, Manager, Applications Engineering, RFS

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Executive Summary

PIM or **P**assive **I**nter**M**odulation should be a major concern to every engineer, technician and site installer out there. Why, because it can cause a major adverse effect on the quality and performance of a typical communications site. Good site design, good installation practices and good site maintenance can keep PIM from becoming a major problem affecting everyone. In this document we will cover several topics related to PIM, including a basic definition of PIM, the effect on a system, measurement techniques, real world causes, and methods of mitigation.

A primer on passive intermodulation (PIM)

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The basics

The first thing to understand is what is PIM? PIM is the unwanted mixing of two or more signals in a non-linear junction within a system creating additional undesirable harmonic signals. These signal could be in your own receive band, or in the receive band of another carrier at the same site.

Fortunately the frequencies of these harmonic signals can be determined mathematically if you know the frequencies of the two primary signals F1 and F2.

The signals mix in predetermined sequences as follows:

- 1f1 ± 2f2 or 2f1 ± 1f2 = 3rd order product
- 2f1 ± 3f2 or 3f1 ± 2f2 = 5th order product
- 3f1 ± 4f2 or 4f1 ± 3f2 = 7th order product

As can be seen from the formulas above the order number is equal to the multiple of f1 + the multiple of f2, so as shown **2**f1 ± **3**f2 = 5th order **[figure 1]**.

The spacing between the different intermodulation products will always be the same as the spacing between the two primary signals, (Δf1 to f2 = Δf1 to 2f1-f2) and as the order of the signal increases the amplitude decreases. The amplitude of the product signal is dependant on the amplitude of the input signals; the higher the input signals the higher the product (PIM) signals.

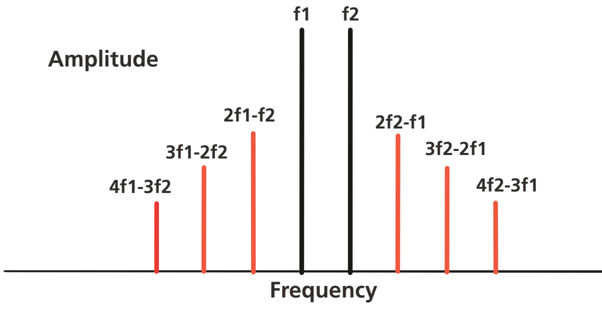

Figure 1 Primary vs secondary tones

Affects on a system

Now that we know what PIM is, we need to go the next step and understand how it affects a system. In a world of single channel radio systems, PIM would not be an issue as it takes more than one signal to create it, however in most of today's radio systems you commonly have two or more separate carriers sharing not just the same site but the same cable runs and antenna systems simultaneously, in both the uplink and downlink bands. The problems arise when downlink signals create PIM in uplink bands. These signals, while of a relatively low level by themselves, are frequently at a level that is on the same order as the signals that the site would be receiving from a mobile unit.

At the site, the radio receiver may not be able to differentiate between the unwanted PIM generated signals and the wanted uplink signals from the mobile, in addition PIM can raise the site's noise floor by several dB, and cause a decrease in receiver sensitivity. These issues are the heart of the problem. These effects can drastically degrade the

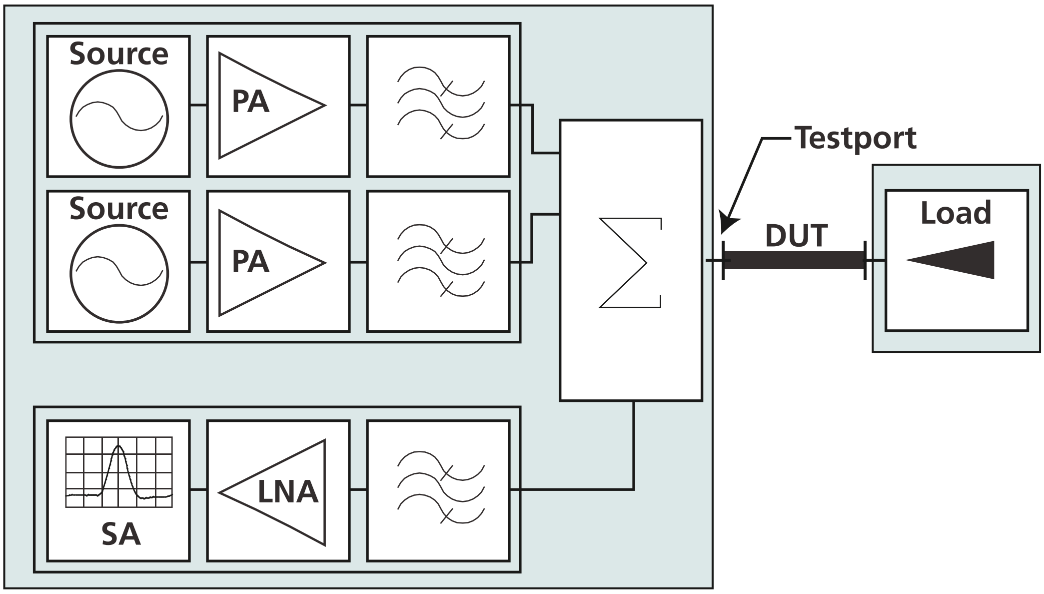

Figure 2 PIM measurement test setup

performance of a site causing a loss of capacity, an increase in the number of dropped calls and increased data errors.

Loss of capacity at a site means that more base stations are required to maintain appropriate coverage levels in a region. Dropped calls and poor quality service can result in subscriber churn.

Measurement

PIM measurements are typically done according to IEC standard 62037-2. This standard defines that 2 test tones of 20W (43dBm) shall be used, however the frequency of the test tones will be dependent of the specifics of the system being tested.

The standard test set as shown in the diagram above consists of two signal sources (including power amplifiers and narrow band filters), a summation and directional coupler module, and a spectrum analyzer. Low PIM loads and test cables are required accessories.

The test process is to set each source to a specific frequency [F1 and F2 as shown in Figure 1] and power level (43dBm), sum the two signals and apply them to the DUT (Device Under Test), and then analyze any reflected signals on the spectrum analyzer.

Any signals appearing to the analyzer except for the incident F1 and F2 signals are generated by PIM **[Figure 2]**.

The level of the PIM signal is measured in dBm and compared back to the reference source (Carrier) signals to define the PIM value in dBc **[Figure 3]**. For example, if the carrier (test) signals are 43 dBm and the measured PIM

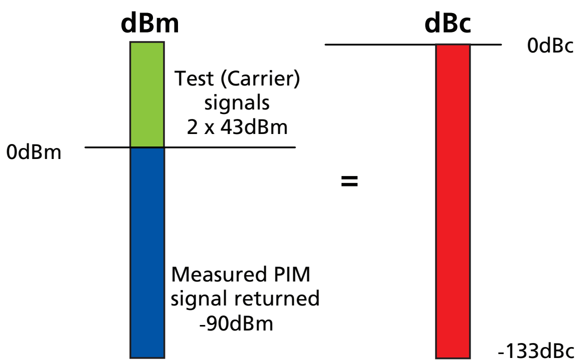

Figure 3 Measuring PIM

signal is at -90 dBm then the PIM value is defined as -133 dBc (133 dB below the carrier).

One of the reasons the IEC standard defines the levels of the test tones is that, since the junction causing the spurious signals is in effect a point of restricted current flow, the lower the test tone power levels, the lower the PIM, as there is less current flow through the junction. This is also true in reverse, higher carrier levels product higher (worse) PIM.This is part of the non-liner nature of PIM. A general rule of thumb is that for every 1dB increase in carrier power you get ≈ 2.5 dB increase in PIM noise.

To demonstrate this using the example in Figure 3 with test tones of only 30 dBm, the PIM would appear to be much better; the measured PIM signals would be as low as -123 dBm indicating a PIM value of -153 dBc. A PIM performance specification therefore must include a reference to the carrier levels to be of any relevance. One other point to note about the testing conducted for PIM is that two types of test are typically conducted, one test while the DUT is stationary called static PIM, and the other while the DUT is being moved called dynamic PIM.

The causes

At this point we have seen what PIM is, its effects, and the method used to quantify the issue. The next thing required is an understanding of the actual causes of PIM in a typical base station. We will look at both field installation and manufacturing issues.

Field prevention

The real culprit in most site related PIM problems are issues associated with installation and cleanliness. Installation of all components must be done properly to ensure proper PIM performance. Proper installation means that correct torque is applied on all connections and ensuring that all connection points are free of contaminants. Site cleanliness is not limited to the transmission line, all tower and fencing components at the site should be free of corrosion and properly maintained.

Proper connector installation is foremost in ensuring good PIM performance, and there are several steps that need to be performed correctly and with appropriate attention to quality detail. RF connectors are precision designed and constructed components and should be treated as such if proper RF performance is expected.

Step 1 Proper cable preparation; using custom cable preparation tools or a proper quality saw, ensure the cable end is properly flush cut perpendicular to the cable axis. Use of a premium grade saw is required. An appropriate saw blade should be un-painted, have a high tooth count (recommend 32 teeth / inch or better), and if possible be of an inline type i.e., no offset on the teeth. A good quality blade can help ensure that the conductors are not damaged, deformed or scratched and that the amount of cutting debris is limited. Whenever possible, orient the cable end downward while cutting to limit the amount of debris entering the cable core.

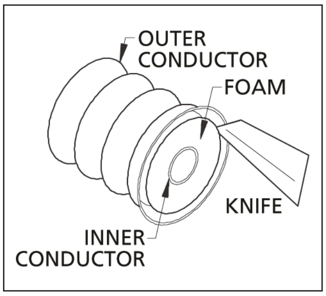

Figure 4 Preparing the flare

Step 2 All metallic and foam cuttings **MUST** be removed. Using a soft bristle brass or nylon brush, remove all loose cutting debris. Additional use of adhesive tape can sometimes remove the finest cuttings that a brush may leave.

Step 3 Properly prepare the flare for connector installation. Using a knife (or similar tool) separate the foam fully from the outer conductor **[Figure 4]** and verify that the foam is symmetrical around the center conductor **[Figure 5]**.

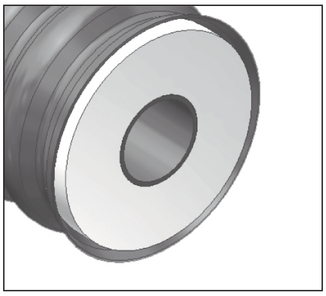
Figure 5 Symmetrical Foam

Step 4 Install the connector onto the prepared cable, and tighten the connector to manufacturers torque specifications. A connector, improperly tightened to the wrong torque value, will not exhibit proper PIM performance.

Step 5 Installation of a shrink boot can help stabilize a connector on a cable and can improve PIM performance in some cases **[Figure 6]**.

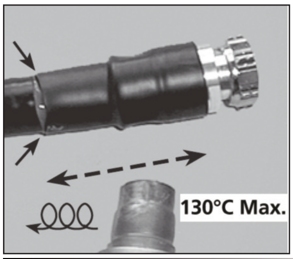

Figure 6 Shrink boot installation

All interconnections between different parts of the system must also be tightened to correct specifications, over or under tightening interconnections will impair performance.

Manufacturing process

There are three basic types of components that exhibit non-linear performance; amplifiers, diodes and devices containing ferromagnetic materials.

Almost all of the things that can create PIM at a site fall under the category of diodes (or more specifically, things that from an electrical perspective, act like diodes). The most common components in a transmission system that fall into this category are antennas, transmission line and connectors. Lets briefly look at the manufacturing phase of each of these items.

In antennas, PIM can be caused by a large assortment of things. Some of the contributors to PIM are poor solder joints, loose connections, dissimilar metal junctions, too many contact points and oxidization between metal surfaces that are in contact with each other. The best ways to prevent PIM in an antenna are proper design that can deal with the number of contacts, materials and plating, and manufacturing controls that deals with soldering issues, loose connections, and general assembly.

In a transmission line reasons for PIM can frequently be related to three specific issues. Metallic fragments remaining in, or on, one of the conductors or the foam, poor quality seam welding, and differences in thermal expansion between the inner and outer conductors. Proper cleaning of the inner and outer conductors at all stages of manufacturing therefore is critical, as this will remove any loose particles of metal. Precision welding conducted in the correct gas environment can ensure a proper weld. Proper control of adhesives and the dimensioning of conductor corrugations can limit the issues with the conductors shifting with respect to each other.

In a connector the primary concerns are the possible use of incorrect materials (ferromagnetics), proper plating of surfaces, and avoidance or loose metallic filings in the connector after it's manufacture. As with transmission line and antennas, the best method to prevent PIM in a connector prior to installation is the proper design of it (including materials), and proper manufacturing quality control.

In the case of amplifiers, the intermodulation products are controlled primarily through proper design and manufacturing processes, and the proper selection of power levels.

Avoiding ferromagnetic effects is mostly a case of the proper selection of materials (non-ferrous (iron containing) metals) in either, the design of specific components (connectors, antennas, surge arrestors, etc.) or the overall site component selection.

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Conclusion

In this paper we have looked at the issues associated with PIM, the causes and the solutions. PIM can produce major headaches to the proper operation of a modern communications system, however it need not be so. By the proper selection of materials and by following proper procedures throughout the complete design and construction of a site, PIM can be controlled and therefore can be eliminated as a contributor to poor performance.

Company profile

RFS serves OEM, distributors, system integrators, operators and installers in the broadcast, wireless communications, land-mobile and microwave market sectors.

As an ISO 9001 & 14001 compliant organization with manufacturing and customer service facilities that span the globe, RFS offers cutting-edge engineering capabilities, superior field support and innovative product design.

RFS is committed to globally fulfilling the most demanding worldwide environmental protection directives and integrating green-initiatives in all aspects of its business.