FAQs Regarding Circulator & Isolator Intermodulation

What is Passive Intermodulation (PIM)?

Circulator and isolator are passive devices operating within RF or MW frequency range. Passive IM, similar to Active IM, is present whenever RF signals at two or more frequencies are simultaneously present in a conductor of RF energy. Every passive RF device generates passive IM products when more than one frequency is present in the device. The signals are mixed by the non-linear properties of junctions between dissimilar materials. Typically, it is the odd-ordered products (e.g. IM3=2*F1-F2) that can be very problematic should they fall within an uplink, or receive band of the base station because they appear to the receiver as interference. The result can be a receiver desensitization which is independent of the receiver's random noise floor.

How is PIM Specified?

Passive IM is typically specified in absolute power (units of dBm) or power relative to only one of the test tones (units of dBc). For example, a -110dBm IM signal caused by two +43dBm tones is also specified as a -153dBc IM level.
It is important to note that a carrier power level must always be specified with the given PIM performance level. This applies equally to PIM performance specified in units of dBm and dBc.

Why would I care about PIM?

Ultimately, it is the performance of the integrated base station that is important. Although most wireless transmit and receive frequency bands are carefully selected to avoid landing the largest IM products within the receive band, self-generated higher order products (IM5, 7, 9) do land within some communication bands. More frequently, IM products from a nearby (or co-located) competitor's site can become troublesome sources of interference.

To the receiver, PIM products appear as interference. Once the PIM power level rises above the random (kTBF) noise floor of the receiver, the system C/I become adversely impacted. Because PIM products typically increase significantly as the average transmit power level increases, the impact of PIM on a base station may only become significant when the base station becomes fully loaded. Just when the most capacity is needed, passive IM level can rise up and interfere with normal base station operation.

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What are "IM3" and "IM5"?

This annotation is commonly used to specify the order of the IM product being discussed. The IM stands for "intermodulation." The numeric value that follows is the sum of the integer multipliers used for each of the two parent tones to realize the given IM product. This is best understood by reviewing the following table:

IM Calculation	IM Order
2*F1 ± 1*F2 = FIM3	Third Order (2+1=IM3)
3*F1 ± 2*F2 = FIM5	Fifth Order (3+2=IM5)
4*F1 ± 3*F2 = FIM7	Seventh Order (4+3=IM7)
5*F1 ± 4*F2 = FIM9	Ninth Order (5+4=IM9)

Most commonly, the lower order tones are of the largest magnitude. However, in frequency-selective systems, it is possible that an IM5 product might actually appear larger to the receiver than an IM3 product.

What are the Typical Causes of IM?

In RF components (antennas, cables, filters, etc.), there are typically three causes:

1. Poor mechanical junctions in the RF path;
2. RF components fabricated with materials which exhibit some level of hysteresis (e.g., stainless steel);
3. Contaminated surfaces or contacts within the RF path. Examples might include flux (which can attract other contaminants) and metallic particles from the machining process.

In integrated base stations, significant levels of passive IM can be generated within any of the passive components between the high power amplifiers and the receiver filter. Passive IM can also be generated on the tower ("rusty bolt noise") or by nearby metallic objects in the direct beam of the transmit antenna.

What is a "Good" PIM Level?

The required PIM performance for a given RF device is a strong function of where that device is located in the final system. For example, an antenna must have excellent PIM performance as the PIM generated in the antenna is both received and radiated by the base station. Further, the transmit antenna is subjected to nearly the full carrier power of the base station. On the other hand, the PIM performance of a receive "clean-up" filter need not be so stringent. This filter might be located on the other side of a diplexer thus preventing the full carrier power level from reaching its input connector.

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Ultimately, it is up to the buyer to specify the maximum acceptable PIM level and carrier power levels. Commonly seen specifications for antennas are -100 to -110dBm IM3 levels with two, +43dBm (20 Watt) per carrier tones.

Does PIM Vary with Power Level?

Yes. However, the relationship between the generated PIM power level and the parent carrier power levels is not always straightforward.
In simple, broadband devices terminated into a broadband termination, the IM3 response typically increases approximately 3 dB for every one dB in carrier power level (assuming equal carrier powers). However, there are many factors which tend to work against this nice, simple relationship. These include:

- High return loss values at n*F1 and/or m*F2;
- Extreme slope variations on the hysteresis curves associated with ferrite devices;
- Non-Linear behavior of electromechanical junctions as they approach a breakdown potential;
- The interaction of multiple IM sources as the impedance of each IM source changes with incident power level.

In general, as the transmitter power increases, the importance of PIM on the overall system performance becomes of increasing concern. As a TDMA system fills available frequency and time channel slots, or as a CDMA system increases forward power levels to increase capacity, PIM levels typically increase.

Does PIM vary with frequency?

It depends. One postulate is that a single IM source which is located at a single point (not spatially distributed) and is matched in impedance to the incident transmission line (or source of stimulus RF energy) generates frequency-independent IM isotropically. This is the analog of the classical "Point Source" of RF in antenna theory.
Given that this point source of PIM exists (at least theoretically), real-world RF devices can be modeled as being comprised of multiple PIM sources. These sources generate IM which has a phase relationship with the parent RF carriers. Once the PIM is generated at each point source within the device, the PIM signals themselves can vectorially combine (either constructively or destructively) to produce a composite PIM response. The phase relationship between the PIM sources will depend upon their physical separation, the dielectric through which the RF must travel between the sources, and the frequency of the parent carriers.

Given that all real world devices have more than one source of PIM, it is quite probable that the device will have a frequency-dependent PIM response. However, if the device is

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electrically small, or if the bandwidth of interest is relatively small compared to the DUT, or if the device is dominated by a single large IM source, the measured frequency response may appear frequency independent.

Does PIM Change with Time?

Possible
Two types of PIM generation are typically found. The first type is of a "burst" nature and is commonly associated with the periodic breakdown of poor mechanical junctions exposed to high RF power levels. With this type of PIM, the IM will appear as a short (less than 1 second) burst of broadband, noise-like energy. On some devices and systems, these bursts have been measured at random intervals from 2 or 3 seconds to several hours.

The second type of PIM generation is more steady state, and coherent in nature. RF heating within RF conductors and around RF interfaces can causes minute changes in the contact integrity. The result is a PIM level which changes with time. A classic example of this can be found by measuring the PIM from a cable assembly which is poorly constructed or has been subjected to mechanical stress. The PIM performance of the cable assembly may appear quite good at first, only to degrade as the assembly heats up. Interesting enough, the opposite has been found to happen. The cable assembly is poor at first, but as the RF heating causes the mechanical interfaces to expand (and compress), the PIM performance improves with time.

Consider an operational and fielded base station. Wind, Rain, and Sun-induced thermal cycling are all at work to continuously stress the mechanical interfaces within the antenna, the cable assemblies, and the connections to the shelter. As the sun rises and heats the RF connections, the PIM levels can rise (or fall) if the cables, connectors, and antennas are not functioning properly. The result can be increased levels of IM only at certain times of the day.

Should RF Sources be “Phase Locked” to “Align” the Carriers?

Not if you are testing with two tones. When two carrier tones are used, the relative rate of phase rotation between the carriers is determined by the frequency separation. The carriers will periodically combine in and then out of phase at a fixed rate for the given frequency separation. Phase locking the carriers together will force the carriers to cross at a known instant in time, relative to the phase of one of the carriers. However, this won't impact the magnitude of the generated PIM levels.

If three or more carriers are utilized for testing, the phase of the third carrier now becomes important. By phase locking the three carriers together, and adjusting their

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relative phases, a specific phase point on the third carrier can be made to align with a known phase crossing point of the first two carriers. This could be used, for example, to establish a worst-case current density at a set of fixed frequencies at a specific point within the DUT.

Whether you are using 2, 3, or 100 carriers to perform PIM testing, it is good practice to connect the clocks together to minimize the impact of RF frequency drift on the measurement. This is especially important if you are using a very narrow receiver to perform the PIM testing.

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