dbSpectra

TECHBOOK

Series

UNDERSTANDING PIM

- RF Filters
- RF Distribution Design
- Antennas
- Understanding PIM
- Intermodulation
- Sensitivity

Interference is the most common cause of coverage reduction and performance degradation and can be classified as internal or external. Internal interference is created within the RF network and can be seen without an antenna attached. This document will focus on one very specific form of internal interference called Passive Intermodulation (PIM). PIM like other internal forms of interference such as Sideband Noise and Receiver Desense can be prevented during the design phase and reduced as a risk. This document will focus on what PIM is and how it can be prevented.

The techniques and recommendations presented in this document are reflected in the standards published by the international Standards body International Electrotechnical Commission (IEC) and documented in their **IEC 62037-1 International Standard**.

What is PIM

Intermodulation (also called IM and Intermod) occurs when two or more carriers mix in a non-linear junction and produce additional carriers called intermod products. Passive Intermodulation (PIM) is a special type of intermodulation that is mainly evident in the transmit network ***Figure 1***. It is created and can be destructive because the very high transmitter power levels mix and produce PIM signals that can fall within the receive band and cause degradation. PIM occurs in components normally considered linear and not expected to cause problems such as combiners, connectors, cables, and antennas. All components within the transmit network that are exposed to multiple carriers can produce PIM. It takes only one weak PIM product to cause degradation. When it is created, it is radiated from the transmit antenna to other receivers on site. This radiation increases the noise floor and can degrade receiver operation.

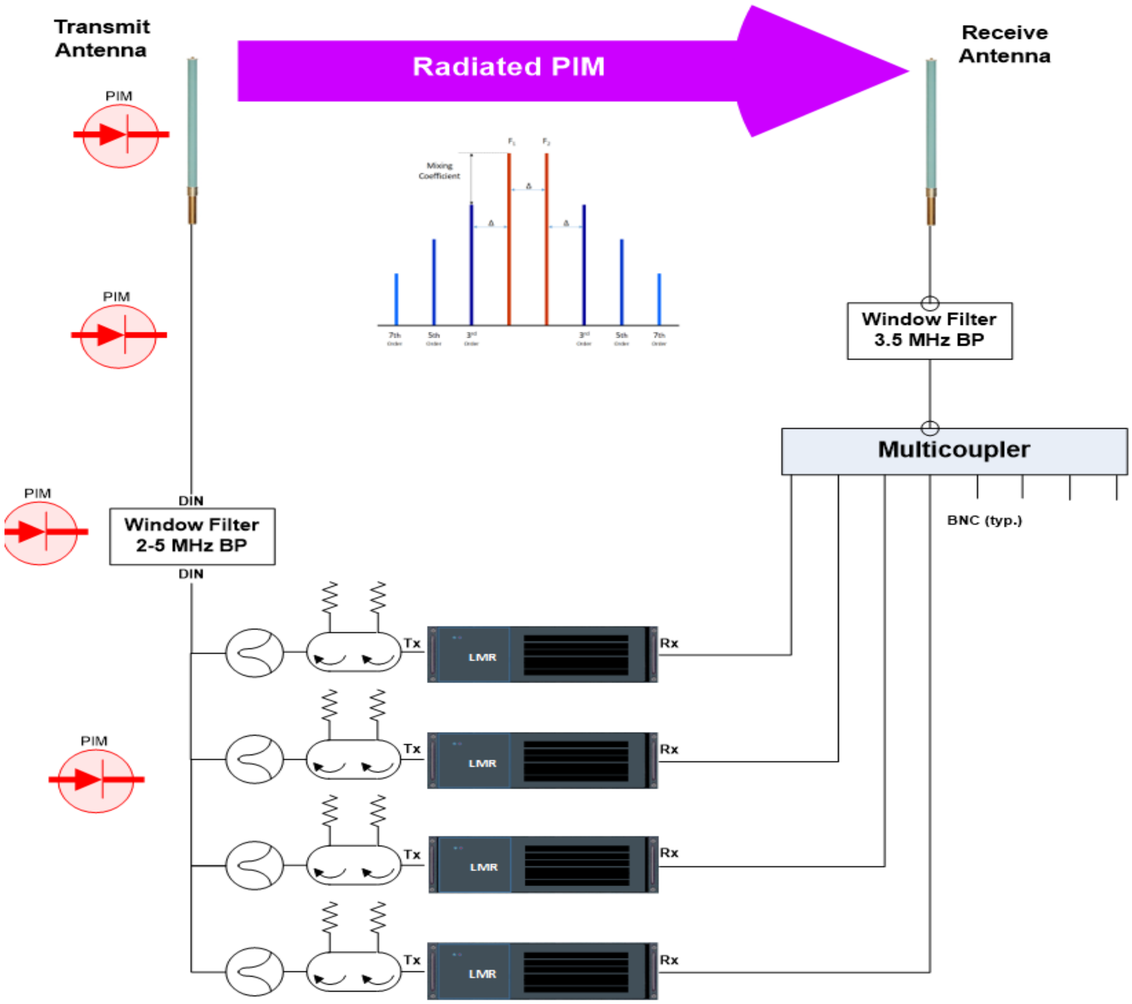

Figure 1: PIM Generation points

When a non-desired frequency is created on the desired frequency the conflict between these frequencies is called degradation. When degradation occurs, the desired frequency must be greater for the same coverage. PIM mathematically falls on a specific frequency and is created because of the non-linear characteristics of faulty components. As the number of carriers is increased the number of PIM products is also increased. When new and properly installed components are used, the PIM characteristics of most connectors and cables are minimal because these components are linear. If installed improperly or poor quality components are used the resulting PIM can cause degradation and loss of coverage.

Below is a list of components and their risk to create PIM.

Components that create PIM risk and their risk factor

- Transmit Combiner - Low if designed for low PIM and output has DIN connector
- Transmit Filter - Low if designed for low PIM and output and input use DIN Connectors
- Coax Cable - Low if solid design and connectors installed properly
- Superflex Cable - High PIM risk because of outer conductor seating. Not for multicarrier operation
- DIN Connectors - Low if installed properly
- N-Type Connectors - High PIM risk because of construction not designed for PIM
- Antennas - Low if PIM rated in specifications over -150 dBc
- Receive network - Low because the levels generated will not create PIM above noise floor

PIM is measured at the 3rd order product. Because PIM is related to carrier activity the resulting degradation and coverage loss will be dependent on multiple transmitters being active.

The non-linear component is called the mixing point because two or more carriers mix and produce the unwanted intermodulation products. The mixing point is the cook pot for the creation of PIM. These intermodulation products are carriers themselves and will have significant RF power on the intermod frequency. The highest level product is the 3rd order product. The 3rd order product occurs above the highest frequency and below the lowest frequency. The 3rd order product can be calculated using the formula $2F1 - F2$ = Lower 3rd order product or $2F2 - F1$ = Higher 3rd order product.

The level of the 3rd order product is determined by the mixing coefficient of the mixing point and the level of the two fundamental carriers. The mixing coefficient can be thought of as the efficiency of the mixing point. The higher the efficiency (more non-linear) the higher the 3rd order product.

The mixing coefficient identifies the relationship between the fundamental carrier and the amplitude of the 3rd order products. This is measured by applying equal level carriers to the mixing point and measuring the resultant 3rd order product. The level of the PIM is indicated by how far below the fundamental carrier levels the 3rd order product is. If the 3rd order product is 80 dB below the fundamental carriers, the mixing coefficient would be -80 dBc or 80 dB below carrier. PIM may be created in combinations of multiple transmitters and become complex and a higher risk as more carriers are active.

Figure 2 shows the relationship between the fundamental carriers and the intermod product. While there are higher level products than 3rd order (5th, 7th, and 9th …), PIM is related to only the 3rd order product because the 3rd order product is the highest level product and the most destructive. If the 3rd order product falls on a receive frequency, there will be severe degradation and reduced coverage. To prevent reduced coverage from occurring the IM product must be maintained as low as possible. RF best practices dictate that transmitter and receiver frequency combination producing third order IM should not be allowed to exist at the same radio site. However, with proper PIM design, 5th and higher IM products can co-exist at a site.)

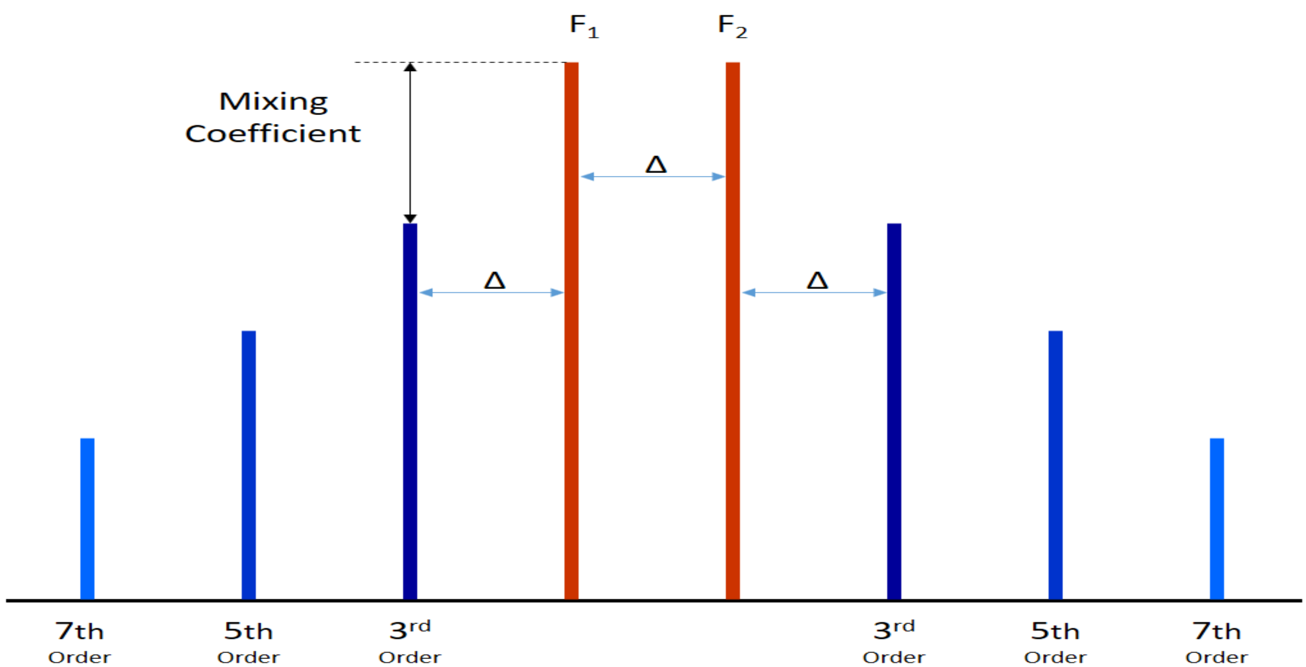

***Figure 2**: Intermodulation relationship to Fundamental carriers*

While any multiple transmitter distribution system can and will produce IM, the UHF (380 MHz – 512 MHz) and VHF (150 MHz – 175 MHz) are the highest risk due to existing frequency allocations. Depending on frequency assignments, it is possible for IM products to fall on receive frequencies. ***Figure 3*** shows the frequency relationship that can cause destructive interference. Note that due to large guard bands (the frequency distance between transmit and receive frequency groups), 700/800 MHz and 900 MHz frequency plans cannot create 3rd order intermodulation carriers that will interfere with their own carriers. While the intermodulation will not fall in band to the receive frequencies they will still be radiated and can be destructive to other user bands such as cellular and LTE.

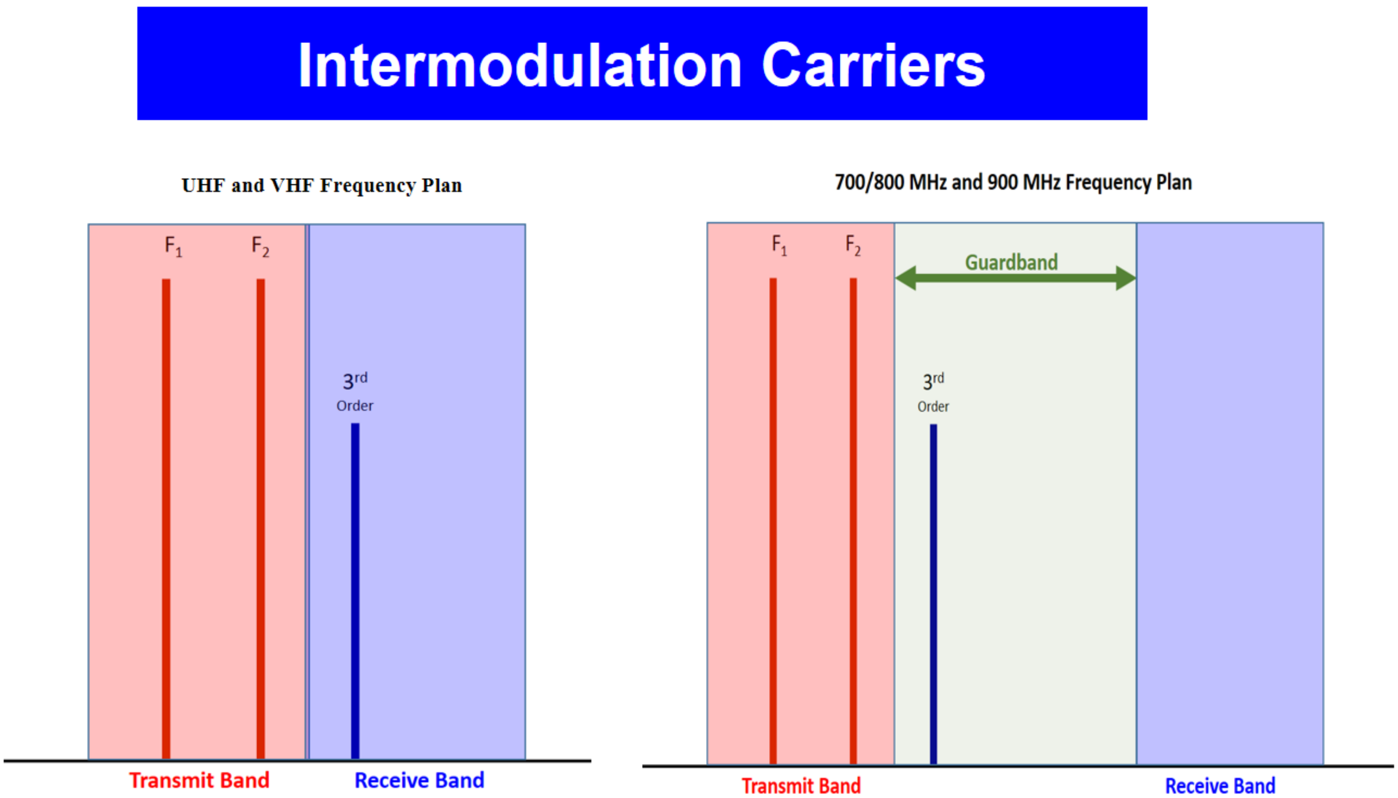

***Figure 3**: Receive interference created by PIM*

Sources of PIM

There are several sources of PIM that must be considered. Some of these are under the control of the installer and system engineer, but most of them are related to the way products are manufactured, designed, installed, and serviced. RF distribution systems can be divided into two categories; High level carrier (transmit network) and low level carriers (receive network). As previously stated, the level of the 3rd order products determine the PIM level and is related to the level of the fundamental carriers. For high level networks, the resulting PIM may be developed high enough to interfere with low level carriers from subscribers and thus cause degradation, interference, and ultimately inbound coverage loss. For low level networks, the mixing can mathematically occur but the resultant will be significantly below the sensitivity of the receiver and thus will not cause interference. For these reasons the focus of PIM prevention should be aimed at the multicarrier section of the high level (transmit) network.

The transmit network ***(Figure 4)*** includes the transmit combiner, all RF connectors after the combiner, surge protectors, and coaxial cable. These components must all be PIM rated and designed for minimum PIM if the network is to be protected and the risk controlled.

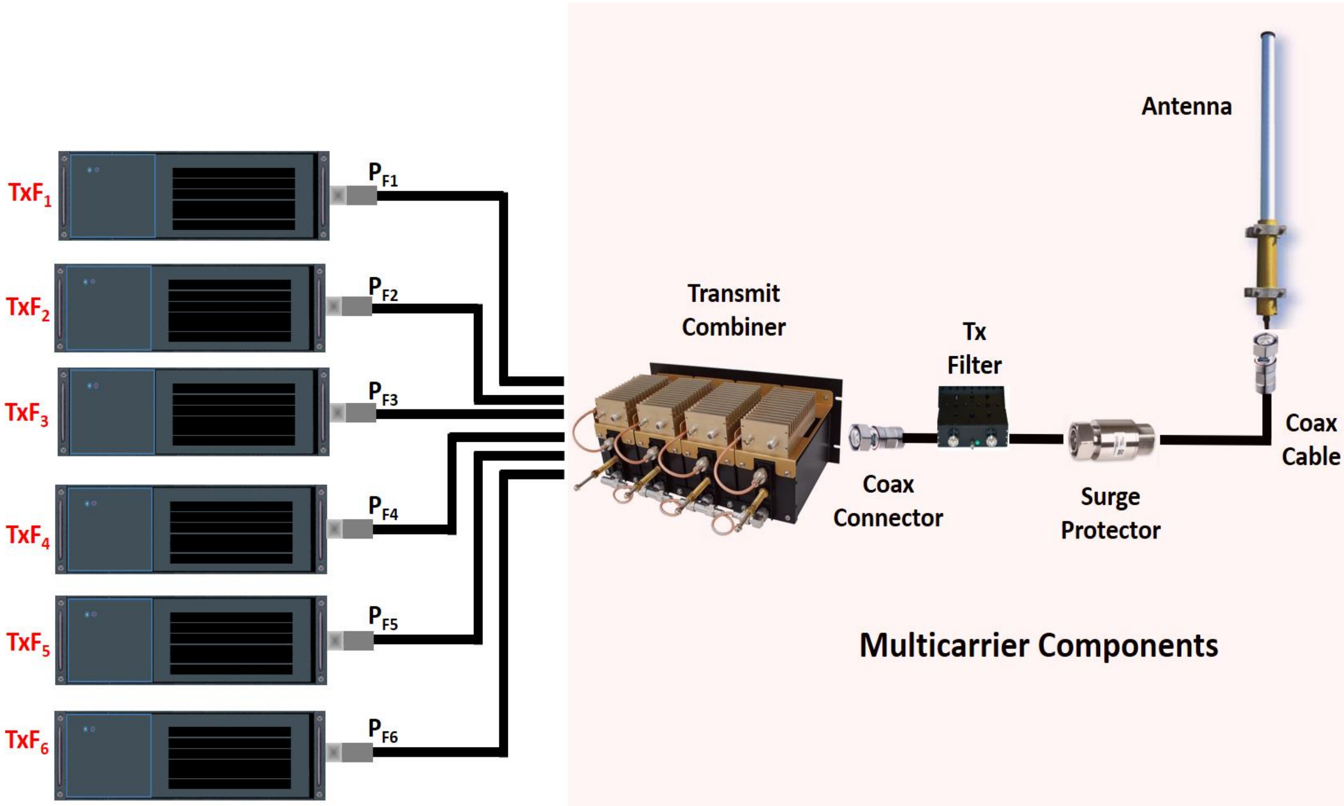

***Figure 4**: Multicarrier components*

Products used in the design of an RF distribution system should have PIM specifications on all components subjected to multicarrier transmit frequencies. Having a PIM or IM specification provides not only good PIM operation but prevents the product PIM performance from deteriorating. The specification provided should be referenced and tested to two +43 dBm (20 W). This standard definition of PIM specifications allows a comparison and equivalence test to be made between products.

Transmit Combiner – The transmitter combiner may produce the highest PIM because it has the highest levels applied and is the first stage in the multicarrier network. Each band requires different considerations in the design because of the frequency plans. When transmitter combiners are tested for PIM the specification must reference forward PIM testing. Forward PIM testing applies two carriers and measures the 3^{rd} order products on the output which simulates normal operation while providing the best assurance of PIM performance. dbSpectra designs, constructs, and tests all combiners to ensure the lowest PIM possible.

Transmitter Isolators – Transmitter isolators are fertile mixing points for PIM. ***(Figure 5)*** While single carriers are applied to the isolator, off frequency signals from other channels on the combiner leak through the channel cavity and will mix in the isolator. The selectivity of the combiner filter is important in preventing signals from mixing in the combiner. This is the source of most PIM generated in the combiner. If the selectivity of the combiner filter is designed correctly the leakage signal will be low and the PIM will be reduced significantly.

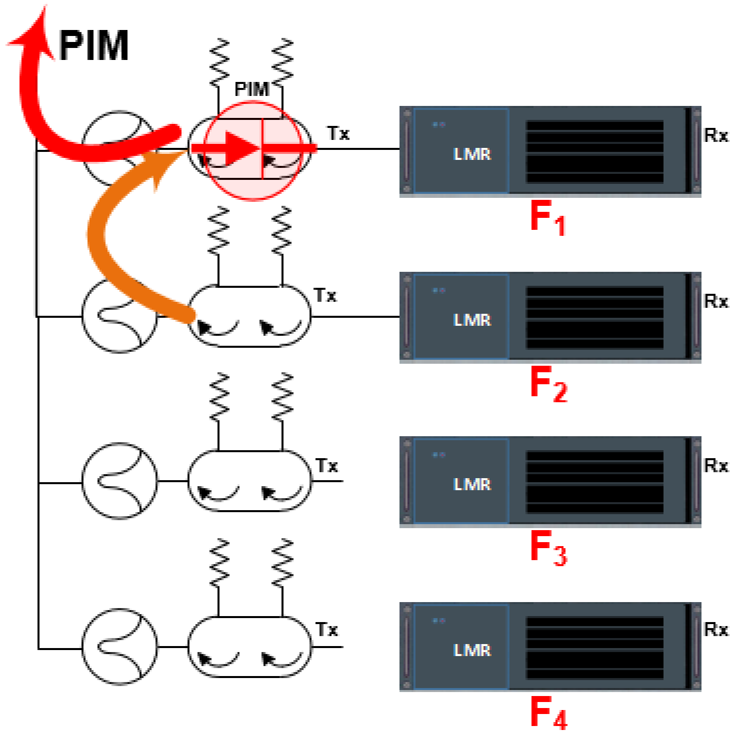

Figure 5: PIM generation in an isolator

Cables – Cables normally have a very high PIM rating to prevent intermodulation. The best cable is solid coax cable with a high PIM specification. Super flexible type corrugated cable and braded cables can and will cause IM because of their inherent characteristics. Braided can cause PIM because of potential discontinuities between the braided material and Superflex can cause PIM because of connector seating. Solid corrugated cables provide optimum continuity and connector bonding and thus better PIM specification and stability over time. Solid corrugated cables provide optimum continuity and connector bonding and thus better PIM specification and stability over time. Industry expectation is to have cable rated at greater than -160 dBc.

Connectors – The best connector to use for all multicarrier applications is the 7-16 DIN (can also be indicated as 7/16 DIN) connector. The 7-16 DIN connector was developed to minimize PIM and because of the wide use the cost of this connector is comparable with other connectors of inferior PIM quality. Newer connectors, while not widely accepted, also may provide good PIM performance.

The N type connector was originally designed in the 40's when multicarrier transmit networks and highly sensitive receivers were not common. Today the use of N type connectors is highly discouraged in high power multicarrier networks. A new, unused N type connector may have a PIM rating of greater than 150 dBc but there will also be a note indicating this specification is a one connection specification. As the N type connector is connected and disconnected several times the small center pin and small diameter outer conductor surface area will not provide stable PIM operation. Removing an N type connector several times can result in deterioration of the PIM specification by over 40 to 60 dB. For consistent PIM performance never use an N type connector in the transmit network unless connection control can be maintained. Connection control relates to sealing the N type connector with heat shrink tubing after the first connection. This discourages removal and PIM deterioration.

Figure 6 shows the contamination that can be created by improper installation, incorrect connector, and improper cable cutting.

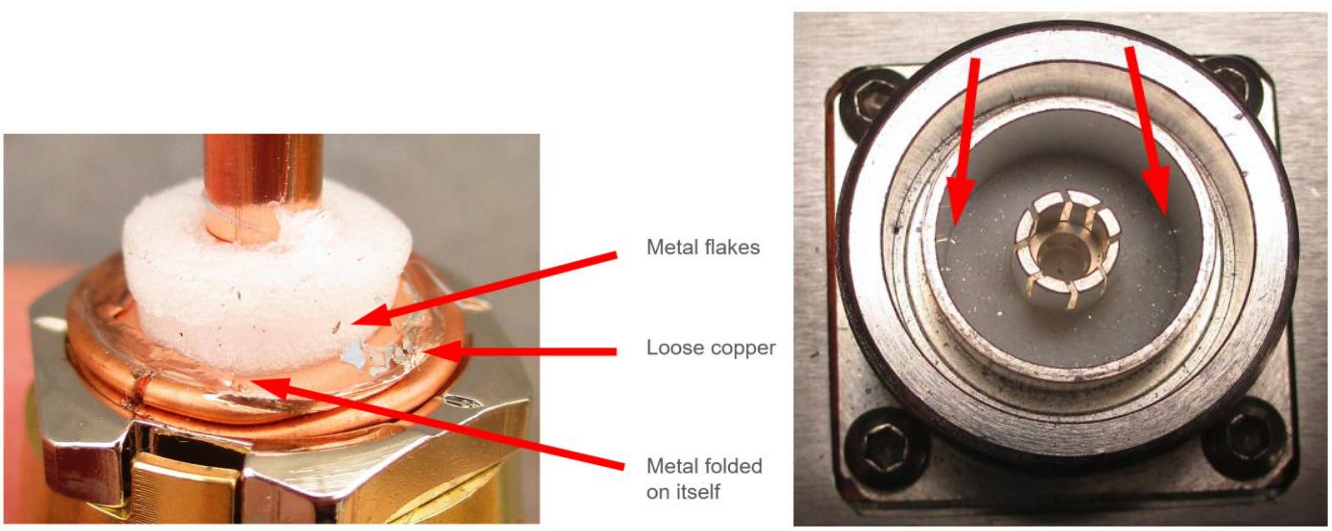

***Figure 6*: Contamination of connectors that can cause PIM**

In addition to using the best connectors to maintain PIM, the assembly and connection of the connectors are also critical. Most manufacturers have assembly tools and cable cutting tools available. These reliably prepare the cable for connector assembly. Using a knife or hack saw places small metal flakes inside the connector which will result in PIM. All connectors should be torqued using a proper torque wrench to ensure PIM specifications are met. ***Figure 7*** shows typical preparation and torqueing tools. Factory torque wrenches are calibrated to prevent over torque of the connectors. Most DIN connectors require 240 inch-pounds of torque. New N-type connectors have hex nuts that allow for proper torque adjustment on single carrier and low level networks. Proper torque on all connectors provides confidence in the assembly and assurance that the connectors are professionally assembled.

Figure 7: Cable preparation tool and Torque wrench

Antennas – The most important design consideration in the RF distribution network to prevent PIM is the selection of the antenna. Not all antennas are manufactured alike. A common misunderstanding is that if an antenna has been used for years then it must be a quality antenna. In the past many RF systems were single carrier applications. This application allowed an antenna to have poor or undefined PIM performance and operate satisfactorily. With the increase in the number of multicarrier systems, such as trunking, the requirements have changed. Antennas must be designed and constructed with PIM focus or they will not deliver the required performance. Antennas must deliver reliably over time greater than -150 dBc of PIM suppression. To do this the construction must have welded frames, no screws, or bolts within the design, use of high performance cables and connectors, use material that will not corrode over time and pass rigid tests to validate operation. One very important identification of an antenna that is PIM rated is the use of a 7-16 DIN connector. Any antenna that utilizes an N type connector cannot maintain -150 dBc (150 dB below carrier) IM suppression. While the price of PIM rated antennas may appear to be more expensive than older non PIM rated and designed antennas, PIM design has improved the delivered wind and icing ratings as well as durability and quality of antennas. As more manufacturers design to PIM specifications the price is coming down and application of PIM rated antennas is becoming a common practice.

Selecting and using a PIM rated antenna provides additional benefits in the risk of higher order IM. PIM rated antennas reduce the 3rd order products to the lowest level possible. Higher order products (5th, 7th, 9th, …) will be reduced further and eliminated from causing operational risk. If the antenna used is PIM rated the higher order products do not need to be evaluated in an intermodulation analysis. This allows increased utilization of frequencies available without risk of IM.

Multichannel Combiners – Standard testing and most discussions of PIM focus on two carriers. Most networks will have more than two transmitters active at any time. The maximum recommended number of channels for VHF and UHF is 6. When multiple channels are combined and active the number of PIM components increase exponentially. There are multiple combinations that can occur. Keeping the PIM characteristics of the

Transmit network low will prevent multiple channel mixing and protect the network.

PIM Testing and verification

PIM is not a specification that can be designed into a product and forgotten. PIM must be verified and tested to ensure compliance during manufacturing. RF distribution components used in the Transmit network can have manufacturing issues that can reduce the PIM performance. One-hundred percent PIM testing is necessary to ensure all components are not only designed to this rigid requirement, but also manufactured and delivered to this standard. PIM specifications must always be referenced to the power level of the fundamental carriers. The standard PIM tests as outlined in the International Standard **IEC 62037-1**, references the PIM level of the 3rd order product when the fundamental carriers are calibrated to 20W (+43 dBm) each. The measurement test facility ***(Figure 8)*** must be constantly calibrated to ensure capability well below the standard being tested to. For -150 dBc standard the test equipment must be calibrated to below -155 dBc. Not only must the test equipment be calibrated to this standard, but the equipment must match the frequency band being tested. Some manufacturers have tried to cut corners by testing VHF and UHF equipment with 800 MHz test equipment. PIM results obtained with out of band testing is not reliable and should not be accepted. It is important to note that there are test equipment manufacturers providing PIM test equipment at 800 MHz but none at VHF and UHF. Manufacturers that provide reliable test results have calibrated PIM test equipment for all bands. dbSpectra not only has test equipment calibrated for all bands but constantly calibrates and verifies performance to ensure reliable testing. dbSpectra also offers many PIM rated antennas including multi-element models.

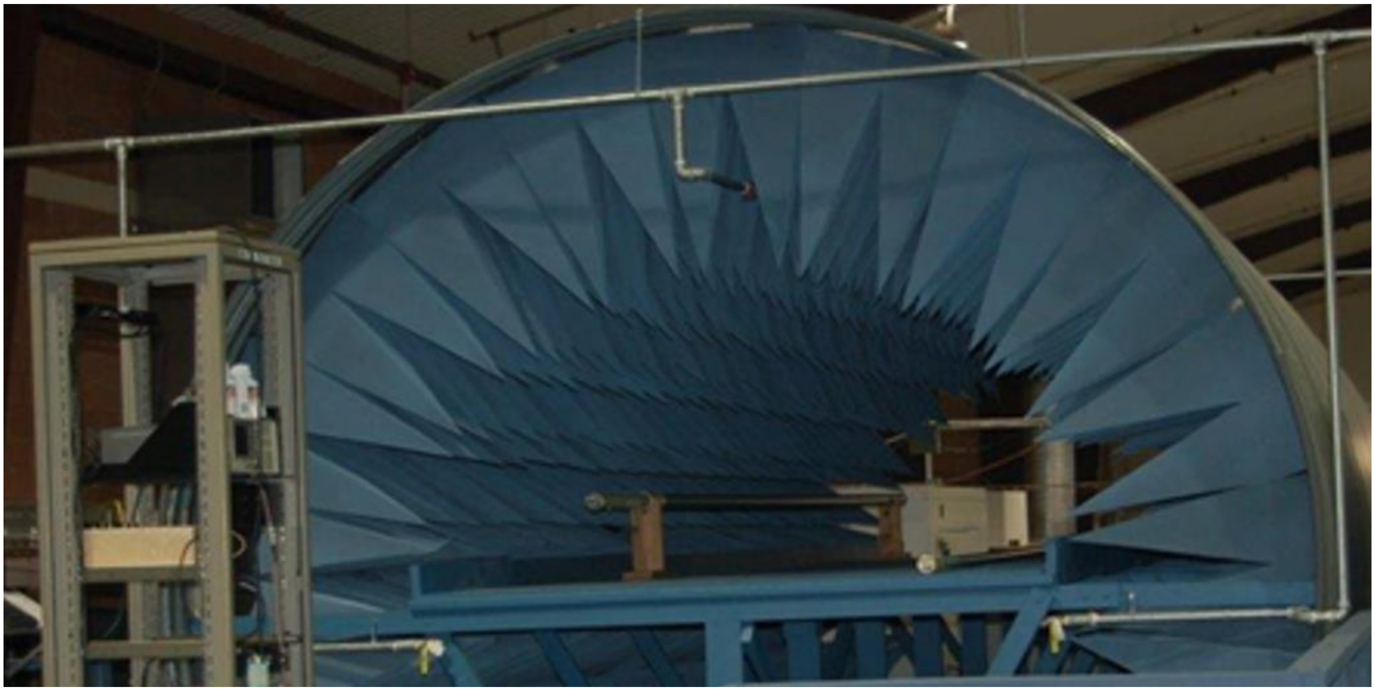

Figure 8: dbSpectra Antenna PIM test chamber

Impedance vs. Linearity

PIM testing should not be confused with return loss (VSWR) testing. Test equipment exists that tests the Distance-to- Fault (DTF), Return Loss (RL), as well as Cable Loss (CL) of the RF network. This equipment relies on impedance measurement. Impedance measurement focuses on the impedance matching capability of the RF network or how reliable it matches 50 ohms. Impedance matching is important in verifying the RF network is designed and installed to maximize the ability to transmit and receive a signal. PIM relies on the linearity of the RF network, not impedance matching. An RF network can pass a PIM test and fail a RL or DTF test or fail the PIM test when the RL/DTF tests pass. RL/DTF tests and PIM testing are not related and should not be confused. The antenna feedline can have metal flakes or other impurities in the connectors which will allow it to pass the RL/DTF test but will fail the PIM tests. These impurities present nonlinear mixing points which will produce high levels of PIM.

How to prevent PIM

In most cases PIM can be designed out of a system. Careful selection of the cable, connectors, surge protectors, and especially the antenna will allow a system to operate at a PIM level to prevent interference. All components used must exceed the anticipated PIM tolerance of the complete network. If the expected performance of the network is -150 dBc or greater then all the components must exceed this requirement. It takes only one component that is not compliant to significantly reduce the network performance. Having all components meet or exceed the system performance expectation is called PIM hardening. PIM hardening is only required on high level RF networks such as the transmit network or a DAS system. These systems transmit carriers more than +20 dBm and can create 3^{rd} order products that will affect operation. PIM hardening is normally not required on receive networks because the levels are usually below -35 dBm and any 3^{rd} order products produced will be below the noise floor and not affect operation.

In addition to selecting the best manufactured and tested products they must be installed properly. Careful installation includes cleaning the connectors prior to assembly, correctly torqueing all connectors during assembly and connection, and utilization of professional tools. As with any component on any product, if assembled incorrectly the designed performance will be jeopardized.

Reducing the PIM received by the receive system is one of the best PIM interference protection methods. Antenna positioning to maximize isolation is the least expensive method to reduce the impact of PIM. Every dB of isolation obtained is equivalent to reducing the PIM generation by an equal amount.

What is dbSpectra TECHBOOK series

To ensure a high-quality RF distribution system there are subjects that must be understood. dbSpectra "**TECHBOOK**" series provide simple discussions of important topics and show ways to ensure the highest quality is designed into the delivered system. Understanding these topics and working with our professional RF system engineers, will allow the design requirements to be met in the first design. Each booklet will discuss topics in as low a technical manner as possible. The **TECHBOOK** series is the first step in understanding complex and complicated RF Topics. Detailed training is available from dbSpectra that will provide more in-depth discussions and understanding. Contact dbSpectra for more information and to schedule training.

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