Passive Inter Modulation (PIM) Testing

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DECLARATION

I hereby declare that I carried out the work reported in this Internship in the Department of **Electronics and Communication Engineering**, **East West University**, under the supervision of **Dr. M. Ruhul Amin**. I also declare that no part of this work has been submitted elsewhere partially or fully for the award of any other degree or diploma. All material reproduced in this internship has been properly acknowledged. All sources of knowledge used have been duly acknowledged.

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Approval

The Internship titled as '**Passive Inter Modulation (PIM) Testing**' has been submitted to the following respected members of the Board of Examiners of the Faculty of Engineering for partial fulfillment of the requirements for the degree of Bachelor of Science in Electronics & Telecommunications Engineering.

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CHAPTER - 1

INTRODUCTION

1. INTRODUCTION

The objective of this document is to define best practices for measurement and prevention of Passive Inter modulation (PIM) in wireless networks. While International Electro technical Commission (IEC) specification does a good job of defining test procedures for PIM testing individual RF components in a factory environment, additional guidelines are needed for field environments.

Due to the added complexity in-building environments, has been included to provide best practices for Distributed Antenna System (DAS) applications. Similarly, has been included to provide best practices for Small Cell deployments.

PIM testing fiber-fed antenna installations which run optical fiber and DC power directly to the antenna structure, also referred to as Active Antenna Solutions (AAS), are outside of the scope of this document.

1.1 PIM DEFINATION

Passive Inter Modulation (PIM) is a form of Inter Modulation distortion that occurs in components normally thought of as linear, such as cables, connectors and antennas. However, when these non-linear, passive components are subjected to the RF power levels found in cellular systems, they behave like a mixer, generating new frequencies that are mathematical combinations of the downlink frequencies present at the site. PIM signals that fall in an operator’s uplink band can elevate the noise floor, resulting in higher dropped call rates, higher access failures and lower data transmission rates.

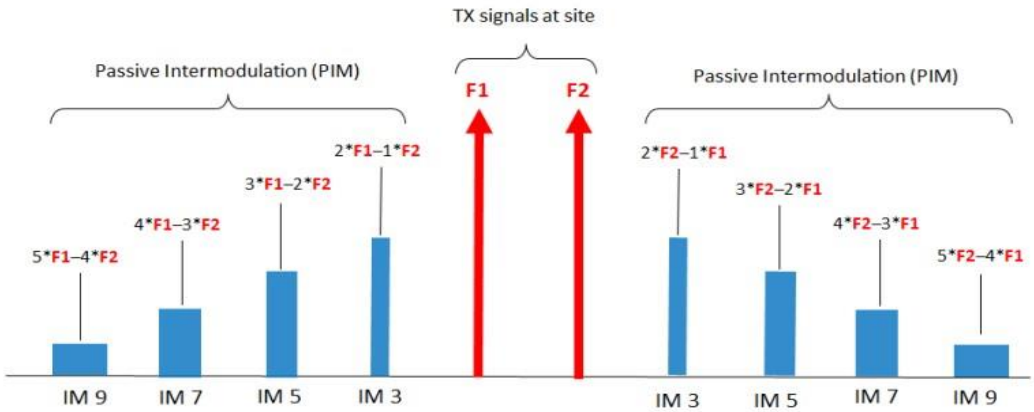

Figure 1.1 Passive Inter modulation (PIM) products produced by two signals

When referring to PIM products, the sum of the multipliers (n + m) is called the product order, so if m is 2 and n is 1, the result is referred to as a third-order product. Generally, lower order Inter Modulation Products (IM3, IM5) have higher magnitude than higher order Inter Modulation Products (IM7, IM9, IM11, etc.) If the downlink frequencies in use at a site are able to combine in such a way that low order IM products fall in an operator's uplink band, PIM interference will be likely. This is not to say that higher order Inter Modulation Products can be ignored. Depending on the degree of non-linearity and the power levels in use at a site, even high order IM products may be strong enough to impact site performance.

1.2 PIM REVITION

PIM can be generated anywhere in the RF path. The RF path includes not only the antenna feed system but also includes the antenna itself, as well as objects illuminated by the antenna. Since RF currents are strongest inside the coaxial cables and physically close to the antenna radiating aperture, non-linear junctions or materials in these locations are more likely to generate harmful PIM than non-linearity away from these regions.

IEC provides useful manufacturing process and material selection guidelines that should be followed to prevent PIM in RF components. The following list provides guidelines for preventing PIM at cellular installations:

- Use factory terminated and PIM tested RF jumper cables where possible.
- Visually inspect RF connectors & RF cables before assembly to remove all metal flakes.
- Verify that RF mating surfaces are clean and free of mechanical damage prior to assembly.
- Wipe mating surfaces with a lent-free wipe, moistened with alcohol to remove dirt & oils.
- Face coaxial cables downward while cutting so that any metal flakes produced fall out rather than into the coaxial cable.
- Always use sharp cutting tools when preparing the ends of coaxial cables.
- Use the correct cable preparation tools for the type and size coaxial cable you are working with.
- Remove any metal burs from the cut edges of coaxial cables prior to connector attachment.
- Prevent foam dielectric material from getting trapped between metal contacting surfaces.
- Remove all adhesive residues from the mating region of the coaxial cable center conductor. Properly align RF connectors prior to assembly to prevent damage to mating surfaces. Apply the manufacturer's specified torque to all mated pairs of RF connectors.
- Do not over-torque RF connectors as this may cause damage to contacting surfaces.
- Prevent excessive vibration and shock to RF components when transporting them to the site.
- Prevent RF components from impacting the tower while hoisting.
- Leave protective caps on RF connectors until you are ready to attach the mating cable.
- Avoid loose metal objects within the half power beam widths of base station antennas. Cable trays, vent pipes, air conditioning units, metal flashing, guy wires, etc.
- Avoid loose metal objects anywhere within one wavelength of base station antennas. Loose mounting hardware, safety chains, etc.

CHAPTER - 2

PIM DETECTION AND MEASUREMENT

2. INTRODUCTION

PIM test analyzers are specialized, self-contained instruments designed to test the linearity of an RF path. These analyzers transmit two specific test tones into the system under test and measure the magnitude of the noise generated at a specific Inter Modulation frequency in order to "characterize the linearity" of that system. The 3rd order Inter Modulation products (IM3) are typically used for this test since the (IM3) magnitude is relatively high, enabling accurate measurement. In addition, (IM3) is closest in frequency to the two test frequencies. This usually enables two downlink band test signals to be selected, producing a 3rd order IM product that falls in the uplink bandwidth of the system under test.

In order to accurately measure PIM, the two test tones must be able to pass completely through the system under test and the IM product being measured must be able to return to the PIM test equipment receiver for measurement.

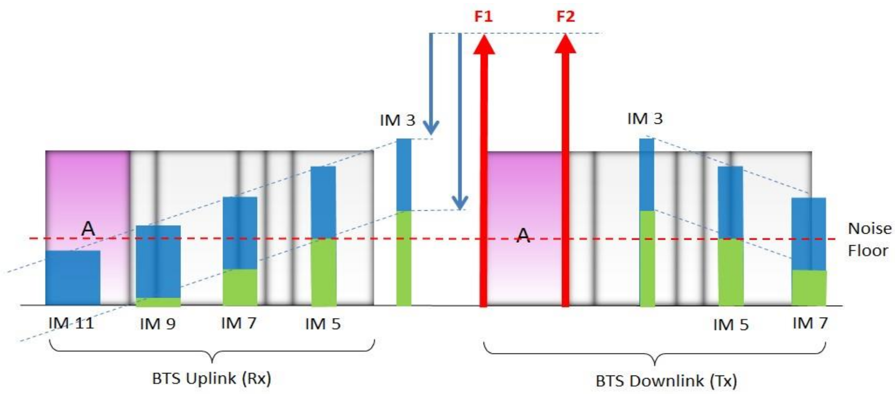

Figure 2.1 Improving linearity reduces the magnitude of IM3 as well as higher order PIM products

Highly linear systems will produce low magnitude IM3 signals when subjected to a PIM test. Systems with poor linearity will generate high IM3 signals when subjected to a PIM test. When these non-linearities are identified and repaired, the magnitude of all IM products will be reduced. So, by measuring and reducing IM3, higher order IM products, which are more likely to fall in an operator's own uplink band, will also be reduced to levels that do not impact system performance.

PIM test equipment reports the magnitude of the IM signal, generated by the test tones, as a single number, making it easy to use for comparing linearity and for setting pass or fail levels. Using consistent test parameters (test power, IM order, etc.) is crucial for making this test consistent, as will be discussed in the next Section.

It is important to note that PIM testing is a linearity measurement that complements return loss measurements. In both cases, the test parameters are selected to allow objective comparisons and evaluation of these key performance metrics with test instruments that are practical and reasonable in cost. PIM tests do not attempt to simulate the operating conditions of the base station, which would require test sets capable of producing a wide variety of modulation schemes, power levels, and number of frequencies. The following test parameters are recommended as they have been proven to sufficiently characterize the system linearity.

2.1 TEST PERAMETARS

1. IM product to be measured: Third order (IM3)
2. Test Power: 43 dBm (20 watts) per test tone. Lower test power may be required for Small cell and Distributed Antenna System (DAS) testing.
3. Number of test tones: 2
4. Modulation scheme: Continuous Wave (CW) while sampling
5. Test frequencies: Fixed
6. Dynamic stimulus: Lightly tap on RF connectors & components while measuring PIM

The following guidelines should be used for selecting test frequencies:

- F1, F2 and IM3 must be able to propagate through the RF path of the system under test.
- F1 and F2 test frequencies must be spaced far enough apart to place the IM3 frequency within the receive band of the test instrument.
- F1 and F2 should be selected to minimize potential interference with other wireless networks.

2.2 ACCEPTANCE LEVELS

The Pass/Fail criteria for site certification should be defined by the network operators. This criteria typically assumes that PIM interference must not exceed the BTS receiver sensitivity for actual use conditions at the site. Determining an acceptable pass/fail level requires an understanding of the power levels in use and which IM produces fall in the uplink bands based on the frequencies in use at the site. Assumptions must then be made with regard to

PIM power level vs. IM order. Factors should also be included to adjust for PIM magnitude differences between modulated signals and CW test signals. At best, the resulting calculation will yield an approximation for an acceptable test level and will require validation.

After performing this analysis, many operators have concluded that a system level IM3 of -97 dBm with 2 x 43 dBm test signals (-140 dBc) provides a reasonable pass / fail level for field testing at macro sites. For individual components and feed systems terminated into low PIM terminations, a pass / fail level of -107 dBm (-150 dBc) is often specified. For applications, such as in-building DAS, the pass / fail criteria may need to be adjusted due to the lower power levels present. In addition, systems supporting LTE may require more stringent test levels due to the lower resource block sensitivity level compared to other air interfaces.

2.3 TEST METHODS

A recommended procedure for performing PIM tests in the field is shown in Figure (2.2). Following this procedure in the order shown will ensure maximum mechanical reliability as well as maximum performance of the RF infrastructure.

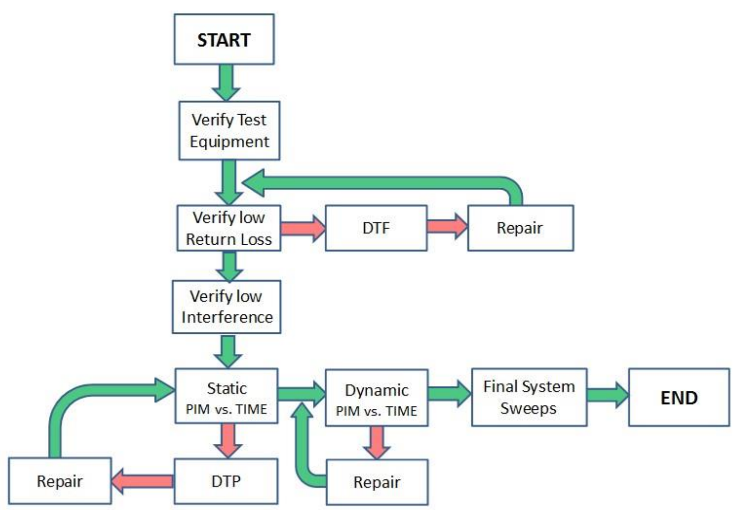

Figure 2.2 Recommended test procedures for verifying site performance

2.3.1 VERIFY TEST EQUIPMENT

PIM test equipment, including any test cables and test adapters used while testing, should be checked before each use to verify that they are operating correctly. The minimum required tests include visual inspection all RF connectors, measurement of residual PIM and measurement of a PIM standard.

2.3.1.1 CLEAN AND INSPECT RF CONNECTORS

All RF connections will eventually wear to the point that they produce PIM, and are no longer useable for PIM testing. Protecting these connectors from mechanical damage and keeping them clean will extend their useful life. Each day before use, visually inspect and clean all RF connectors on test equipment, test leads, test adapters, PIM standards and low PIM terminations to maintain low PIM performance.

Mating surfaces inside the RF connectors should be clean and free of oils, dirt or objects that will increase contact resistance. In addition, all metal flakes must be removed from inside the RF connector. One, barely visible metal flakes touching the center conductor or the outer conductor can generate high levels of PIM. Push a lent free wipe the a small amount of alcohol over the mating surfaces and across the dielectric using a
Wooden or other non-metallic stick. The push stick should be small enough to get into the corners, yet sturdy enough to apply sufficient pressure to the wipe. Also be sure to clean the inside of the RF connector protective cap to remove any collected metal flakes.

While cleaning, visually inspect the threads and mating surfaces of all RF connectors. Repair or replace damaged items before use. Minor dents and dings on the mating surfaces may be okay. However, severely deformed RF connectors may scratch or damage other RF connectors when mated. These defective parts should be discarded before they damage other component.

Damaged mating surface

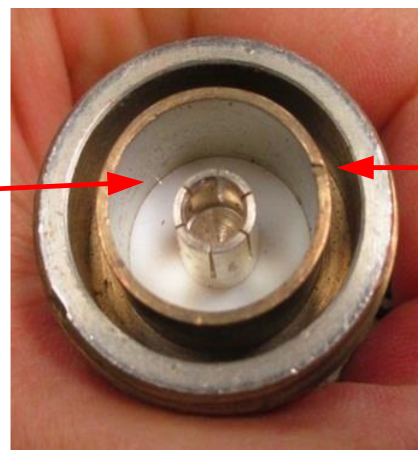

Figure 2.3 Potential sources of PIM inside a 7/16 DIN female RF connector

2.3.1.2 VERIFY TEST EQUIPMENT RESIDUAL PIM

PIM test equipment transmits two high power signals into the line or device under test. Any PIM generated after the two test tones are combined inside the test instrument will be seen by the test instrument receiver. It is important that all self-generated, or residual PIM of the test instrument and components be kept to a minimum to ensure accurate site measurement. IEC 62037-1 requires that the residual PIM of the test instrument, including the test lead and any RF adapters used between the instrument and the system under test, be at least 10 dB lower than site certification level. If, for example, the site pass/fail limit for IM3 is -97 dBm when tested using 2x 43 dBm test tones, the IM3 of the test equipment, test lead and test adapters must be below -107 dBm when tested using 2x 43 dBm test tones.

The residual PIM of the test instrument and test components must be verified each day before use. This test is performed by installing a low PIM termination at the end of the test lead and performing a PIM test at the specified test power level. Flex the test lead while performing this test. The peak PIM level measured during the residual PIM verification test must be at least 10 dB lower than the customer's required pass/fail limit.

If the PIM of the test instrument and components is too high, verify that all RF connector are correctly torqued. It may be necessary to disassemble and re-clean the connectors to remove metal flakes. If the test lead is the source of the high PIM, replace it. Since low PIM terminations will also eventually wear-out and generate PIM, it is good practice to keep a separate low PIM termination that is only used for residual PIM.

2.3.1.3 MEASURE A PIM STANDARD

A PIM standard is a device that produces a known 3rd order inter modulation level when subjected to a specific test power. Measuring this PIM standard before testing each day will determine in one simple step whether or not the test equipment output power is correct and whether or not the receiver is working properly. This works based on the knowledge that the PIM produced by a typical non-linearity will change approximately 2.5 dB for every 1 dB change in test power. If the test equipment transmit power were off by 3 dB, either due to a faulty amplifier or because you forgot to change the test power after a previous low power test, the IM3 produced by the PIM standard will be reduced by 7.5 dB. (2.5 dB/dB PIM slope x -3 dB change in power = -7.5 dB change in measured PIM) If this happens…STOP! Check the test equipment power setting. Also check to make sure that the correct IM order has been selected. If these settings are correct, your instrument needs service and should not be used for site testing.

2.3.2 CHECK RETURN LOSS

In order for a PIM test to be valid, both PIM test signals and the IM product being measured must be able to pass completely through the system under test. If the test signals are blocked by a RF filter, tower mounted amplifier (TMA), mechanical damage to the coaxial cables or an open connector in the system, PIM will not be tested beyond the point of blockage. To verify that the system will pass both Tx frequencies and the IM product frequency, a return loss test should be performed prior to PIM testing. The return loss level should be a minimum of -10 dB to ensure that less than 10% of the power is reflected back to the test instrument. If the reflected power exceeds this level, use distance-to-fault (DTF) to isolate the location of the reflection and perform the necessary repairs. If the high reflection is caused by a frequency limiting device such as a filter or TMA, by-pass that component with a short RF jumper while performing PIM tests.

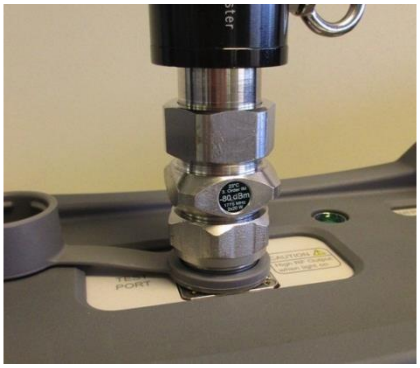

Figure 2.4 PIM standard attached to the RF output port of a PIM test instrument

2.3.3 CHECK FOR EXTERNAL INTERFERENCE

If there is active mobile traffic in the area transmitting at the same IM3 frequency used for testing, the mobile traffic may be at a high enough level to interfere with the PIM measurement. A noise level measurement should be performed prior to PIM testing to verify that mobile traffic in the area is below the pass/fail threshold for the system under test. This test can be performed using a spectrum analyzer attached to the system or by using the PIM test equipment itself, with the test instrument receiver active and the test tones turned off.

If high mobile traffic is seen during this measurement, adjust either the F1 or F2 test frequencies to move the IM3 frequency to a clear channel. A good practice is to choose test frequencies that intentionally place the IM3 product to be measured in a guard band frequency in the uplink band.

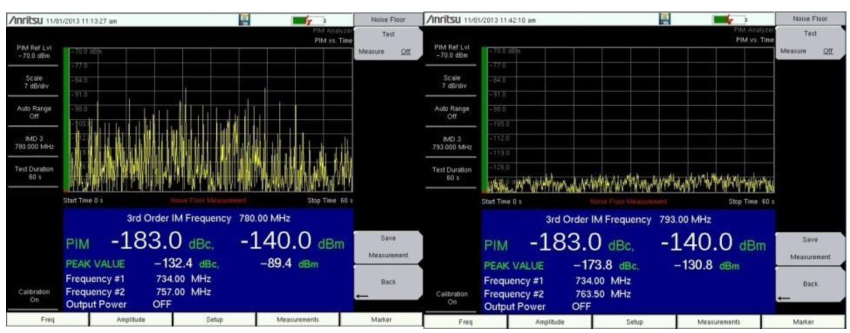

Figure 2.5 showing >40 dB noise reduction by moving the IM3 frequency to a guard band frequency

2.3.4 STATIC PIM TEST

“Static” means “without movement.” Perform an initial PIM test to determine the level of PIM generated by the site. If the static PIM is below the customer’s pass/fail threshold, proceed to “dynamic” testing. If the PIM level is above the customer’s pass/fail threshold, repairs are required.

Two methods exist for determining the location of static PIM faults. The first is dynamic testing, which will be described. PIM sources are often located at RF connections and dynamic testing will identify the location in need of repair. In other cases, the PIM source may be located somewhere inside the RF cable (away from the connectors) or located beyond the antenna. To isolate these PIM sources a low PIM load must be inserted into the system and methodically moved backwards toward the test equipment until the PIM source is isolated.

If the static PIM source is located beyond the antenna, additional measurements are required to prove this condition. First, a measurement is required with a low PIM termination installed at the end of the feed line. If this measurement passes, it indicates that the PIM source is not inside the feed system. Second, a measurement is required with the feed line re-attached to the antenna with the bottom antenna bracket disconnected and the antenna pointed upward toward the sky. If this measurement passes, it indicates that the feed system plus antenna are good and that the PIM source must be located beyond the antenna.

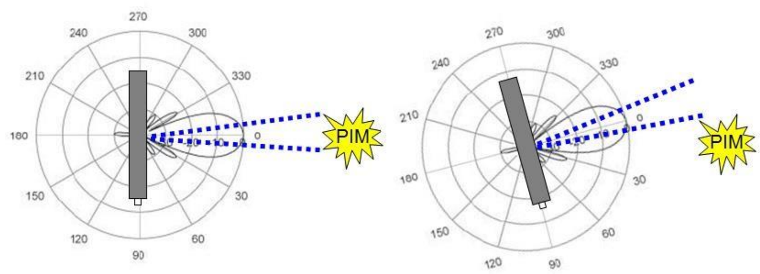

Figure 2.6 Rotating the antenna skyward on its mount can help isolate external static PIM sources

Some PIM test equipment is equipped with a test mode that measures the electrical length between the instrument and the PIM fault and displays this information to the user. A distance-to-PIM (DTP) test mode (referred to as Range-to-fault (RTF) or Distance-to-Faulty PIM by some manufacturers) provides a static test tool for identifying the approximate location of PIM faults, both inside the feed system as well as beyond the antenna.

DTP test

DTP test modes do have limitations that should be taken into account by users. Accuracy is dependent on selection of the correct cable velocity factor for the system under test, which may be difficult when multiple cable types are used in the system. In addition, electrically long devices, such as filters and TMA’s can create a large difference in electrical length compared to physical length. DTP algorithms are not able to cope with large interfering signals or large variations in PIM magnitude during the measurement window. If these conditions are present, DTP results may be highly inaccurate, and therefore should not be used as a pass/fail test. However, even with these limitations, DTP has proven to be a useful tool for identifying the location of static PIM sources in the field

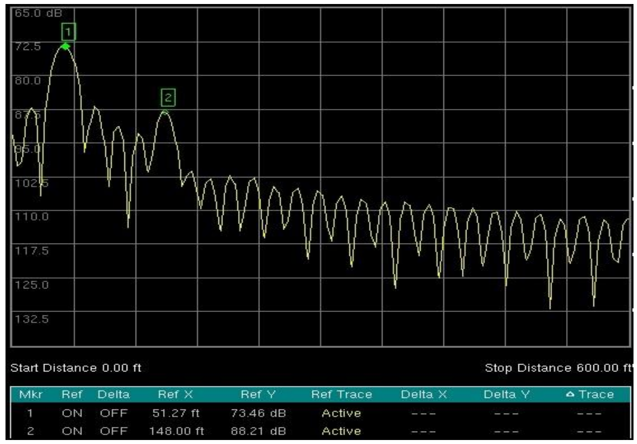

Figure 2.7 Distance-to-PIM measurement showing the location of static PIM sources

Accurately identifying the location of PIM sources beyond the antenna still requires additional testing when using DTP technology. The preferred method is to place a strong PIM source, such as a bag of steel wool, on the antenna random and record the electrical distance to the antenna radiating aperture. Next, remove the strong PIM source from the antenna random and measure the electrical distance to the largest “site” PIM source. If the site PIM source is electrically further away than the antenna aperture PIM, the site PIM source is beyond the antenna. If the site PIM source is electrically closer than the antenna aperture PIM, then the site PIM source is inside the antenna or inside the antenna feed system.

2.3.5 DYNAMIC PIM TEST

‘’Dynamic” means “with movement.” A dynamic PIM test involves measuring PIM while lightly tapping or flexing RF connections and RF components in the system. Since PIM sources are often caused by loose metal-to-metal contacts, lightly tapping or flexing RF connectors can cause small mechanical changes at contacting surfaces. Even very small changes at RF current carrying interfaces can result in PIM magnitude variation on the order of 60 dB. As discussed in Section 2.3.4, watching for this this variation while performing a PIM test is a useful tool for isolating PIM sources. Once all static PIM sources are repaired, the entire system must be dynamically PIM tested to ensure robust construction.

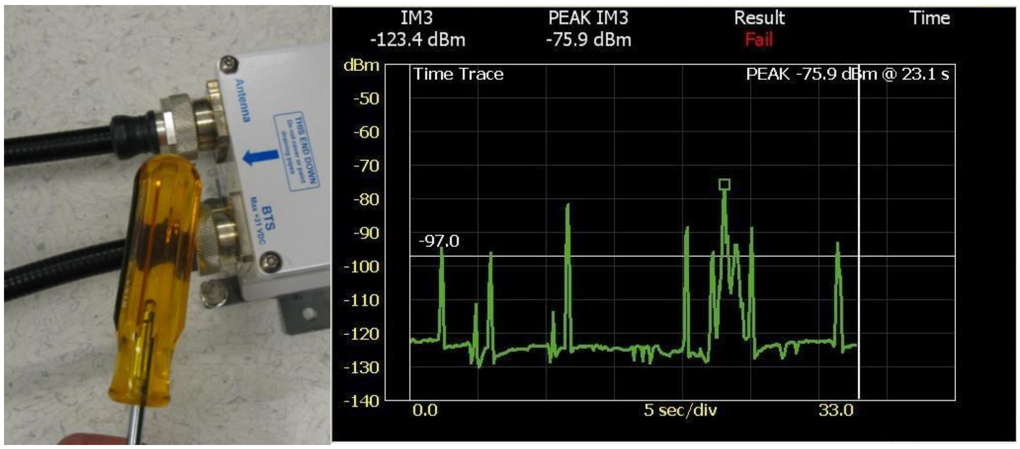

Figure 2.8 Dynamic PIM test showing large variation in PIM magnitude while tapping

Specification dynamic PIM testing guidelines for RF components such as filters, antennas, cable assemblies and RF connectors, when tested in a factory environment. Many of these tests are impractical, however, for field testing. A generally accepted field guideline is to incorporate the "**tap test**". The specification describes, "…tapping the assembly with an instrument that will not damage the surface of the assembly, such as a length of nylon rod or a hard rubber hammer." While the level of stress applied by this test is somewhat subjective, it is a quick, practical method to test assemblies in the field for PIM stability. Guidelines to follow while performing a dynamic PIM test in the field are:

- Monitor the peak PIM level while performing the test. If the peak PIM level exceeds the pass/fail limit at any time while performing the dynamic test, the test is a failure.
- Tap on RF connectors and RF components only.

CHAPTER - 3

PIM DETECTION

3. INTRODUCTION

The result of poor linearity is ultimately noise rise in the uplink band of the cellular system. Though other interference sources can also increase noise, the techniques discussed here can be used as tools to distinguish noise caused by Passive Inter modulation (PIM) from noise caused by other sources. These techniques do not precisely quantify the linearity of the system under test, but are useful for showing if that system is being impacted by PIM from the transmit channels you can control. Once PIM has been identified as the likely source of interference, a crew will still need to be dispatched to the site to find and repair the potential PIM issues using PIM test equipment

3.1 TEST METHODS

The impact of PIM can be detected by monitoring the receive noise power on a sector while manually changing the transmitted power level between high and low settings. If the Rx noise power increases significantly as the transmit power is changed. If the Rx noise power does not change significantly as the transmit power level is changed, PIM is not the likely source of interference. For LTE and UMTS systems, transmit power levels can be manually increased and decreased by changing OCNS (Orthogonal Channel Noise Simulator) or CPICH (Common Pilot Channel) power levels. In cases where the offending IM product is generated by a combination of different operating bands, both bands will need to be exercised during this test. As an alternative, turning one transmitter completely off while monitoring the receive level in the impacted band during normal traffic conditions can achieve the same result.

Two different methods are typically used to monitor Rx levels while changing the transmit power:

Method 1. Involves monitoring the Receive Signal Strength Indicator (RSSI) or Receive Total Wideband Power (RTWP) through a network operation center. An advantage of this method is that the test can be automated to evaluate multiple sectors each day without physically visiting the site.

Method 2. Involves directly viewing the receive spectrum using a spectrum analyzer connected to a receive monitor port at the BTS while the transmit power is changed. This technique provides real-time feedback of the noise being generated, which can sometimes be used with dynamic testing to locate PIM sources that are within reach.

Both methods record Rx power from interference sources, such as PIM, as well as power from UEs in the sector. It is therefore preferred to perform these tests during network quiet hours to minimize power fluctuations caused by mobile traffic.

3.2 ACCEPTANCE LEVELS

Because these tests are looking at average receive power levels over a period of time, changes in receive level need to be significant to conclusively determine that PIM is the source of interference. Therefore, an average noise rise of 3 dB or greater is often used as a pass / fail threshold for these tests. However, even small increases with strong correlation to transmit power level changes should be investigated, as they imply that users are being impacted. With strong correlation to transmit power level changes should be investigated, as they imply that users are being impacted.

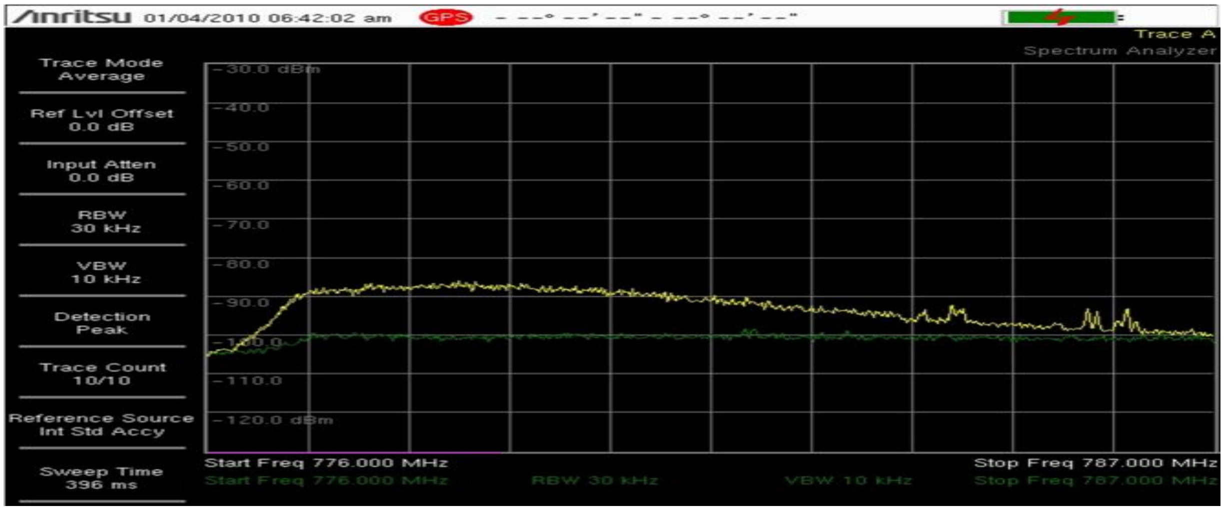

Figure 3.1 Noise rise in LTE system due to PIM observed with OCNS enabled

CHAPTER - 4

IN-BUILDING SYSTEM

4. INTRODUCTION

For the purpose of defining "best practices" a neutral host DAS supporting multiple frequency bands (e.g., 700MHz, 800MHz, 1900MHz, and 2100MHz) and multiple air interfaces (e.g., GSM, CDMA, UMTS, and LTE) is assumed. In this scenario, it is highly probable that IM3 and IM5 signals will impact one or more operators sharing the DAS. The DAS must therefore be constructed using low PIM materials and using proper assembly techniques to minimize PIM interference.

4.1 COMPONENT CONSIDERATIONS

RF power distribution components used in a DAS installation, including hybrid couplers, RF splitters and tappers, must be selected with PIM performance in mind. Careful consideration of the connector type should be conducted and include not only initial purchase costs but future costs related to PIM reliability and site visits required to ensure compliant performance. For many designs the higher initial cost of low PIM connectors, such as DIN, "mini-DIN" or connectors is offset by lower construction and test costs and fewer maintenance calls that may occur with Type-N connectors.

Hybrid couplers, both 2x2 and 4x4, are often used at high RF power points in the DAS. Unused high power ports may require low PIM terminations to meet system performance requirements. Low power ports may be able to be terminated with resistive terminations without the creation of harmful PIM.

Plenum rated cabling requires careful selection of connecters and diligent care in cable preparation and cleanliness due to the use of air as a dielectric. Metal flakes and foreign material can fall into the cable during the cable attachment process and become sources of PIM. The use of tubing cutters is required to avoid loose metal particles from being formed and the cable should be held with the opening facing downward during all processes. Compressed air is not to be used to clean connectors as this also can transfer contamination into the cable. Alcohol wipes and a small vacuum should be used instead to remove contamination.

4.2 TEST METHODOLOGY

The nature of the RF path in a distributed antenna system requires more RF connections, each of which may generate PIM if not properly designed and constructed. It is recommended that PIM tests be performed during the construction phase of a project rather than waiting until after construction to perform the test. Table 4.1 presents the trade-offs to be considered when deciding on a testing methodology.

Table-1

<table>
<tr><th></th><th>Build then Test</th><th>Test While Building</th></tr>
<tr><td rowspan="3">Advantages</td><td rowspan="3">-Lower testing cost if few PIM defects are present</td><td>- Contractor is able to identify common defects early and take corrective action before replicating defects throughout the project:
*Environmental PIM
*Manufacturer defects
*Technique errors
*Faulty equipment</td></tr>
<tr><td>- Assurance that construction is correct before moving on in restricted access situations</td></tr>
<tr><td>- Project % completion easy to verify as sections of the DAS are completed</td></tr>
<tr><td rowspan="4">Disadvantages</td><td>-Many PIM problems to locate and repair if there were assembly technique problems or material quality problems during construction.</td><td rowspan="4">-Higher up-front testing cost</td></tr>
<tr><td>-Locating PIM problems is more difficult from the head end of the DAS vs. testing smaller sections.</td></tr>
<tr><td>-Schedule risk due to un-planned time to find and repair PIM failures</td></tr>
<tr><td>- May be difficult to arrange repeated access to restricted areas of the building to perform repairs.</td></tr>
</table>

Table 4.1 Build then Test versus Test while Building

4.3 ANTENNA LEVEL TESTING

The small, low gain antennas often used in DAS construction tend to illuminate external PIM sources near the antenna. These PIM sources are often behind the antenna, making them difficult to locate. Optimal antenna locations can be determined by PIM testing the antenna at its design location to evaluate external PIM sources. Moving the antenna within a few meters of the design location typically will have little impact on coverage, but may have a significant impact on PIM results.

Antenna location PIM tests are typically conducted at low power levels (+10 dBm to +20 dBm) that more accurately simulate actual use conditions. In addition, antenna location tests should be conducted at the lowest frequency planned for use in the DAS. The near field region around an antenna is largest at the lowest frequency, exciting PIM sources farther away from the antenna than would be excited at higher frequencies.

Antenna location PIM tests can be conducted using a “PIM friendly” antenna support, typically plastic or fiberglass, at test powers similar to those expected in the operational system at the antenna input. The antenna support should be able to accommodate expected antenna types and allow placement as close as possible to the final installation location, as shown in Figure 4.2. Even at very low power levels PIM sources near antennas can be severe enough to generate harmful interference. Small movement of the antenna away from the primary PIM source, usually within a 1m diameter circle, resolves most external PIM problems while maintaining desired coverage.

After the antenna is installed, perform a post-installation test of the antenna by itself as final verification.

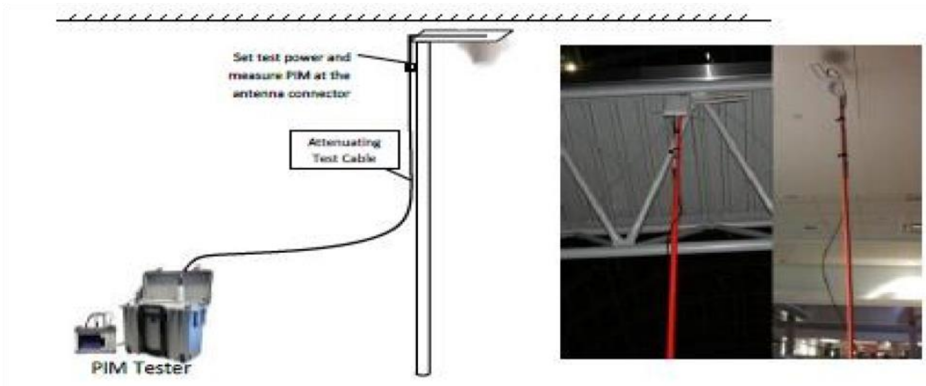

Figure 4.2 Test set and support and two example test photographs.

4.3.1 BRANCH LEVEL TESTING:

RF path construction and PIM testing of a branch should proceed from the input towards the last output connection. By terminating the branch with low PIM loads, external PIM sources are eliminated. The RF power distribution system can now be tested independently to verify low PIM construction. Best practice is to add one splitter at a time with its output cables terminated into a low PIM loads. Each new RF connection should be dynamically PIM tested as you go to verify low PIM construction. Often, a high power PIM test (2x 43 dBm) is used at this step, with the same pass fail criteria as outdoor site testing, to identify construction defects that might go un-noticed with a lower power test. Lower PIM test levels must be used if the DAS components in the branch are not designed to withstand 40W average power. Continue this progresses until all output ports of the branch are in place and terminated (Figure 4.3).

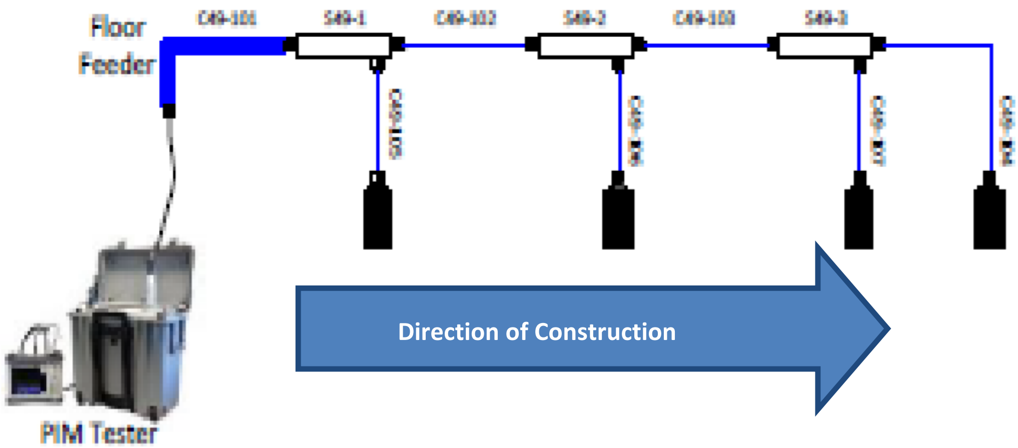

Figure 4.3 Construction and PIM test of a branch closed with low PIM loads.

When the branch RF distribution system is complete, it is now time to replace each RF termination with an antenna. Before attaching the antenna, it is good practice to perform an insertion loss measurement to verify the system design. If the loss from the branch input to the antenna output is incorrect, check the tappers installed on the branch for correct coupling value and for correct installation orientation. After all antennas on the branch are connected, perform a branch level PIM test to verify that the connections between each antenna and the feed network are low PIM. Branch level PIM tests, with the antennas attached, should be conducted at a low power level (below 33 dBm) to simulate in-use conditions. Higher test levels may damage components (e.g., antenna), pose an RF hazard, or generate excessively high PIM levels due to external PIM sources that would not be experienced in actual use conditions. Figure 4.4 indicates a fully tested and reported branch. Time is saved by testing in this method because the test set location remains fixed while each branch is assembled and tested.

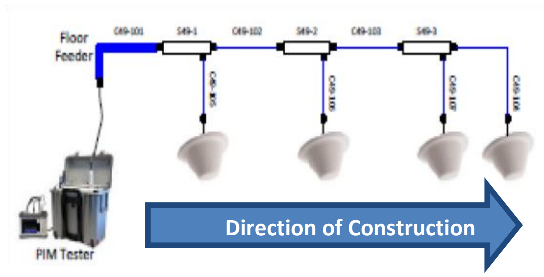

Figure 4.4 Final PIM test of a branch terminated in antennas.

4.3.2 FLOOR LEVEL TESTING

When all branches are complete and ready for the next level of integration (e.g. a floor) a process similar to the construction and test of a branch is used. The floor divider network is built piecewise with low PIM loads and tested in process. At the completion of the floor divider network each branch is added individually until the floor, or sector, is complete. Floor construction and testing is depicted in Figure 4.5. When floor tests are complete, the RF connector input should be capped to prevent entry of contamination before the next level of integral. As with macro site testing, the BTS or remote radio unit transmitters can be used to perform a system level PIM verification test on a completed system. If a noise rise is observed in the Rx path when the BTS transmitters are activated at full power, a PIM problem likely exist

For active DAS systems, first, verify that the uplink and downlink gain is balanced correctly. Cases have been observed where high PIM signals were incorrectly compensated for by adding excess attenuation to the uplink path. This excess attenuation must be removed in order to resolve PIM issues. Next, verify low PIM performance of the passive components between the output of the BTS and the input to the active DAS hardware. In a typical system, this can be accomplished by observing system noise with the uplink connection to the passive hardware disconnected. If high noise is observed with the uplink connection from the active hardware disconnected, PIM problems exist in the passive components feeding the DAS. If the passive feed components are not causing the noise rise, re-connect the uplink connection and individually disconnect the optical fibers feeding remote radio units to identify the branch(s) causing the noise rise. Once identified, a PIM test analyzer can be used at the remote locations to identify and resolve PIM problems in the RF path beyond the remote radio unit.

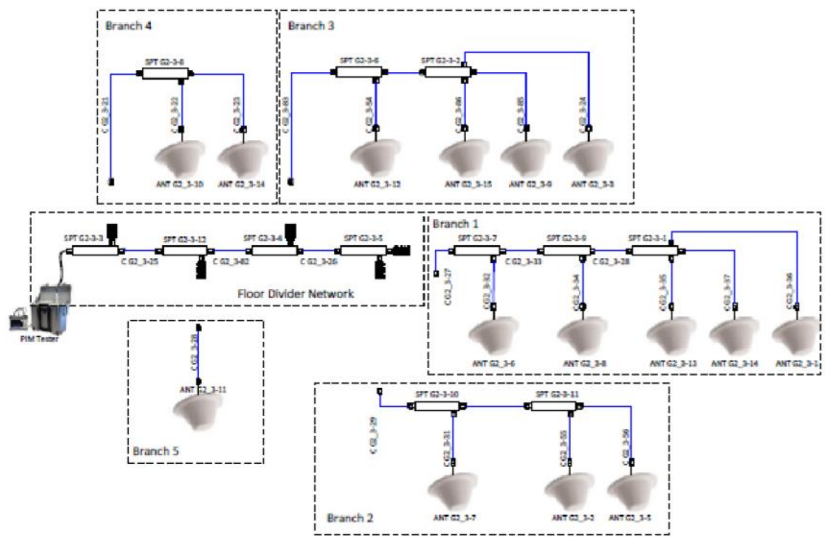

Figure 4.5 Progression of floor divider network PIM tests.

4.5 DESIGN FOR TEST (DFT)

During the DAS design phase it is recommended that the physical plant follow a "Design for Test" (DFT) methodology to obtain potential project cost savings. The DFT methodology is supported by the following practices:

- Organize the DAS vertically (by floor) and horizontally (on floor)
- Plan for construction and testing to be conducted on a per floor basis
- Centralize the location of splitters to minimize test set movement
- Design with five or fewer antennas per branch or introduce sub-branches to limit the number of low PIM loads required for closed (without antennas) tests to less than five.

The DFT methodology inserts milestones for construction and test into the project schedule and allows for contractors to work in parallel on multiple floor installations. Quality issues are identified earlier and hard to access areas are better managed. Figures 4.6 through 4.9 show “good” and “bad” DAS designs from a DFT perspective.

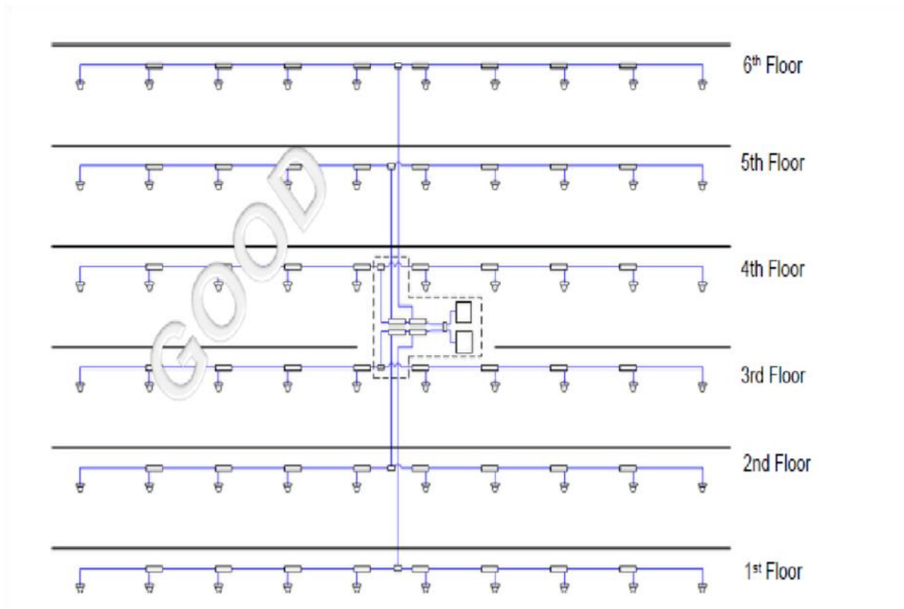

Figure4.6 Vertical design by floor allowing testing from central locations

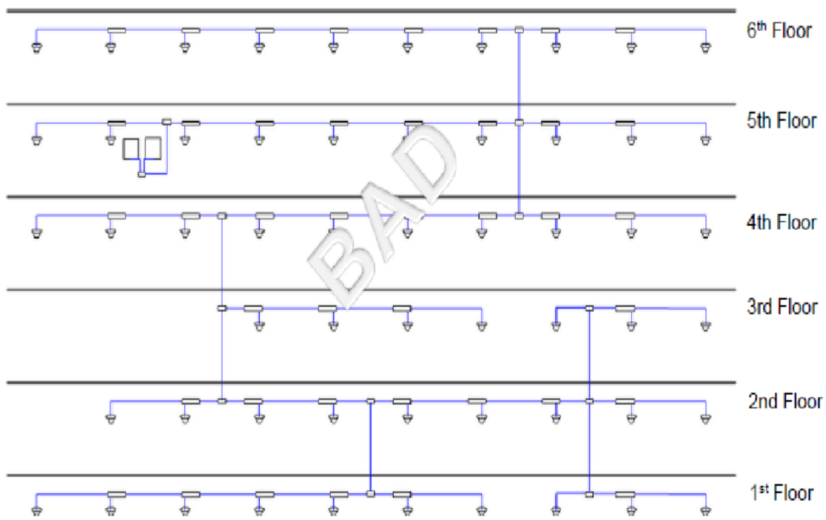

Figure 4.7 Poor vertical design complicates testing with branches covering multiple floors

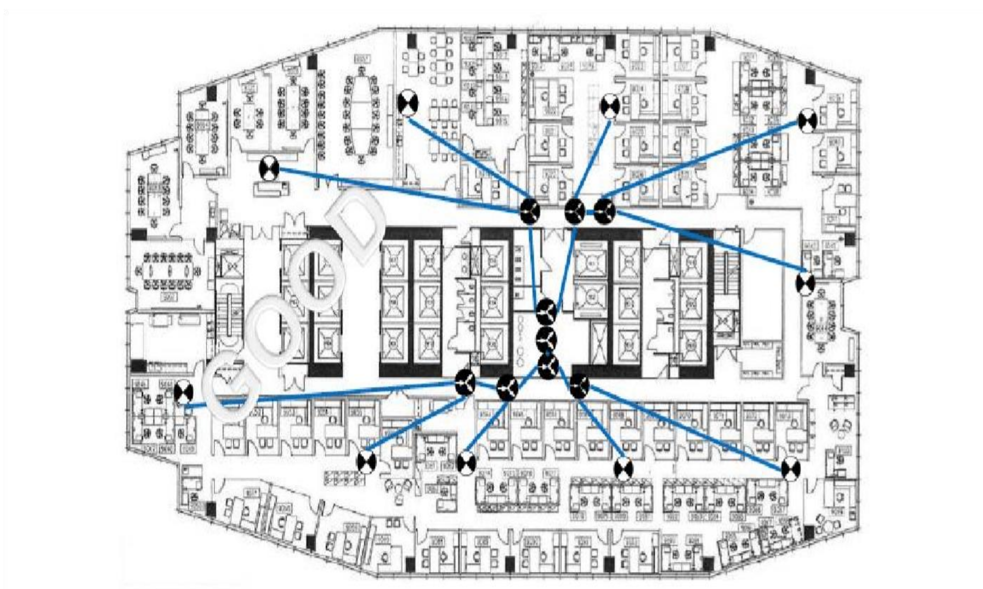

Figure 4.8 Good horizontal (floor) design supports Design for Test

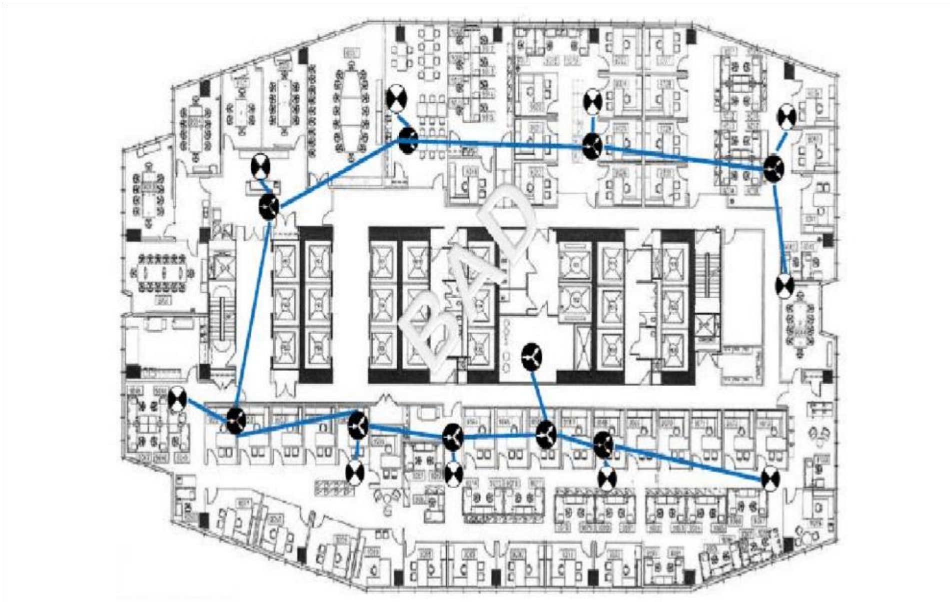

Figure 4.9 Decentralized horizontal (floor) plan spreads power dividers and increases test time

4.6 CONSTRUCTION BEST RF ACTICES

During construction, care must be taken to avoid mechanical stresses on RF connections so that they do not create PIM sources over time. Proper mounting of components to a support structure and the use of stress relief in the cabling will assist in long term PIM performance. By way of example, the two photographs below indicate an initial and improved construction of a section of a MIMO RF path. The initial construction did not embrace a Design for Test methodology, had components mounted by cable ties to dry wall anchors, had no stress relief and had poor tool access. Testing was difficult and the dry wall anchors were not strong enough to properly secure the components and cables when assembly torque was applied. As a result, the anchors pulled-out, leaving the components hanging by the RF cables, introducing stresses to the RF connections. PIM proved to be erratic for this construction.

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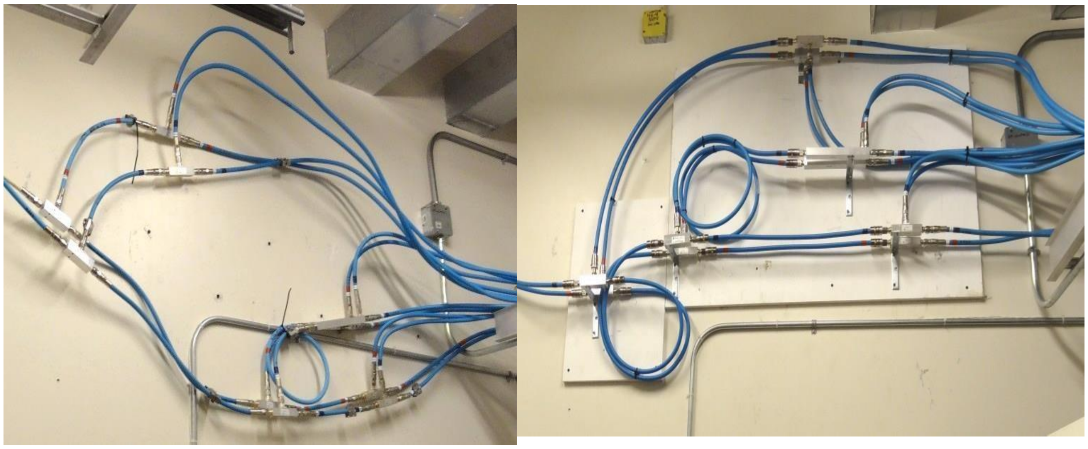

Figure 4.10 Initial and improved installation to reduce stress on RF connections and improve testability.

CHAPTER - 5

SMALL CELL PIM TESTING

5. INTRODUCTION

Small cell deployments often utilize existing structures such as street lamps and telephone poles to provide coverage at street level. These low sites can provide increased capacity in a small area or provide fill-in coverage in areas not served by macro sites. External sources of Passive Inter Modulation (PIM) are a significant concern in small cell applications. Metal objects, such as lamp fixtures, guy wires, power lines and metal support structures, are often located near the site antennas. Since Omni-directional antennas are often used for these applications, the metal objects near the antenna are likely to be illuminated with RF power and likely to generate PIM.

Figure 5.1 External PIM sources at small cell installation

5.1 TEST METHOD

The best method to avoid PIM at these sites is to reduce the amount of RF energy reaching the nearby PIM sources. This can be accomplished by deploying directional panel antennas instead of Omni-directional antennas, or by deploying quasi-Omni antennas when Omni-directional coverage is required. A quasi-Omni antenna is made by phasing three panel antennas together, 120° apart. The radiation pattern for this style antenna has maximum gain on the bore site of each panel and reduced gain between panels. Due to the large amount of scattering in the street level environment, the nulls in the azimuth pattern have little impact on site coverage. However, rotating this style antenna after installation provides a method to “steer” the azimuth nulls in the direction of external PIM sources and improve site performance. If illumination of PIM sources in the installed location is unavoidable, reducing the site transmit power may be the only available recourse. PIM decreases approximately 3 dB for every one dB reduction in transmit power. PIM testing at small cells can be conducted using the same process defined in Section 2.0. Since a bucket truck will likely be used during construction and testing, it is important to lower the bucket well below the site antenna while performing PIM tests. A long, non-conducting rod will be required for dynamic PIM testing to keep the operator out of the view of the site antenna.

Figure 5.2 Bucket truck in use at quasi-Omni, small cell installation

Note that the safe distances presented above are human exposure limits and do not indicate the required size of the PIM free zone around an antenna to achieve valid PIM test results

PIM

Source

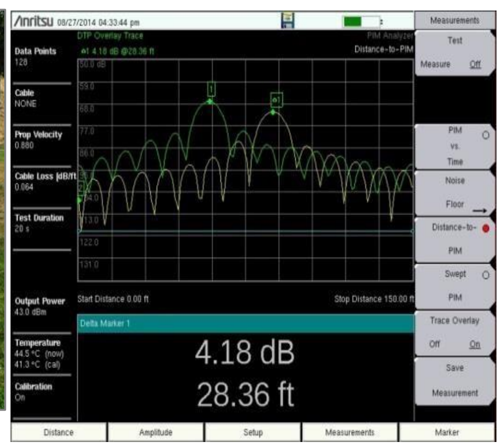

Figure 5.3 PIM source 30 ft (9.1m) in front of an antenna

Figure 5.4 Distance-PIM-overlay showing distance

In the Distance-to-PIM (DTP) overlay (Figure 5.5) the green trace is a stored measurement with steel wool taped to the antenna random to create a "PIM Marker" at the antenna surface. The yellow trace is a measurement with the steel wool removed, revealing the distance to the external PIM source in front of the antenna. A delta marker shows the relative distance between peaks, confirming the PIM problem to be 28 ft in front of the antenna. Similarly, when testing a low gain, Omni-directional antenna, a PIM source was able to be detected at distances much farther away than the safe exposure distance. In the experiment below, a PIM source was positioned progressively closer to the Omni-directional antenna while measuring PIM. Tests were repeated at each distance using a variety of test power levels ranging from 43 dBm to 22 dBm.

Note that if we were attempting to measure this antenna for a 5W small cell application, the "PIM free" zone would need to be >4.75 ft (>1.4 m), which is almost 3 times the safe exposure distance

5.2 ACCEPTANCE LEVELS

PIM test parameters for small cell installations are the same as macro site installations, with the exception that the test power should be adjusted to more closely match the transmit power level in use at the site. Site pass / fail levels can be scaled based on the power level assuming a 3 dB/dB change in PIM for every one dB change in power. Using a 5 W (37 dBm) small cell as an example:

- Pass / Fail level at 43 dBm (20 W) test power = -97 dBm
- Small Cell test power = 37 dBm (5 W)
- Delta test power = 43 dBm – 37 dBm = -6 dB
- Specification reduction due to change in power = 3 dB/dB x -6 dB = -18 dB
- New pass / fail level at 37 dBm (5 W) test power = -97 dBm + -18 dB = -115 dBm

Calculations

$EIRP_{dBm}$ = [Test tone power (dBm) + 3 dB + Antenna gain (dBi)] –

[Beam angle adjustment (dB) – Test cable loss (dB)]

$EIRP_W$ = (10^ ($EIRP_{dBm}$ / 10) / 1000)

MPE (W/m^2) = MPE (mW/cm^2) * 10

Safe Distance = SQRT ($EIRP_W$ / (4π * ($MPE_{(W/m^2)}$)

DEFINATIONS

$EIRP_{dBm}$ = Effective Isotropic Radiated Power in dBm $EIRP_W$ = Effective Isotropic Radiated Power in Watts $MPE_{(W/m2)}$ = Maximum Permissible Exposure in W/m^2

MPE $_{(mW/cm2)}$ = Maximum Permissible Exposure in mW/cm^2
Beam angle adjustment = Front-to-Side ratio or Front-to-Back ratio per antenna pattern

Safe Distance = Distance from antenna in which MPE is achieved

Table B.1 and B.2 show representative safe distances assuming test cable loss = 0.5 dB and Front-to-side

ratio =15 dB and Front-to-back ratio = 25 dB for 65° Panel Antenna.

Table-1

Antenna type	Frequency	Gain (dBi)	Test power (dBm)	Distance (front)	Distance (side)	Distance (rear)
65° Panel Antenna	700 – 900 MHz	15.5	43	4.5 m	0.8 m	0.3 m
65° Panel Antenna	1700 – 2100 MHz	17.5	43	4.0 m	0.7 m	0.2 m
Omni Antenna	700 – 900 MHz	12.0	43	3.0 m	N/A	N/A
Omni Antenna	1700 – 2100 MHz	12.0	43	2.1 m	N/A	N/A
Small Omni Antenna	700 – 900 MHz	3.5	37	0.6 m	N/A	N/A
Small Omni Antenna	1700 – 2100 MHz	5.0	37	0.5 m	N/A	N/A

Table: B.1 Approximate safe distances using General Public / Uncontrolled MPE levels

Table-2

Antenna type	Frequency	Gain (dBi)	Test power (dBm)	Distance (front)	Distance (side)	Distance (rear)
65° Panel Antenna	700 – 900 MHz	15.5	43	2.0 m	0.4 m	0.1 m
65° Panel Antenna	1700 – 2100 MHz	17.5	43	1.8 m	0.3 m	0.1 m
Omni Antenna	700 – 900 MHz	12.0	43	1.3 m	N/A	N/A
Omni Antenna	1700 – 2100 MHz	12.0	43	0.9 m	N/A	N/A
Small Omni Antenna	700 – 900 MHz	3.5	37	0.3 m	N/A	N/A
Small Omni Antenna	1700 – 2100 MHz	5.0	37	0.2 m	N/A	N/A

Table: B.2Approximate safe distances using Occupational / Controlled MPE levels

PIM Source

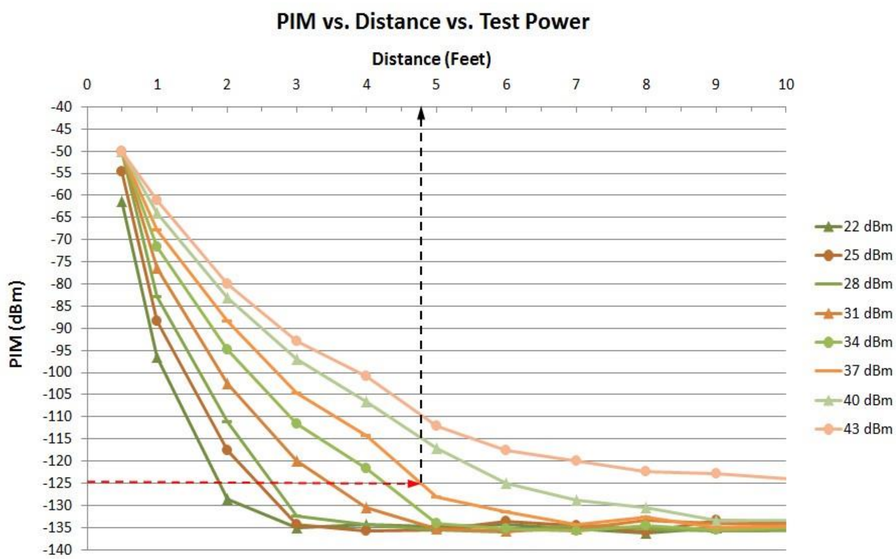

Figure 5.5: PIM source near antenna

Figure 5.6: PIM vs distance vs test power level

CHAPTER - 6

CONCLUTION

Conclusion:

Wireless technology continues to evolve at an accelerating rate. Developments such as the growth of small cell deployment, use of millimeter wave transmission and increasingly sophisticated modulation schemes add complexity to the design and maintenance of high capacity, high-availability networks. At the same time, cell towers are quickly becoming overcrowded as wireless service providers turn to co-location strategies in order to rein in costs. The issue and effects of PIM will only grow in importance. Although component vendors and wireless service providers appear to agree regarding PIM control during manufacturing, that same urgency and effort are not yet evident in the field. This can be seen by the number of known “good” RF components being assessed and returned as faulty. As an industry, we must do a better job of emphasizing the importance of proper connection practices and accurate PIM testing among installers and service technicians. Nevertheless, positive strides are being made. Comprehensive solutions such as PIM Site Audit and Avoidance are successfully driving PIM awareness through all parts of the network, from purchasing and systems design to field installation and testing. By taking advantage of proactive and comprehensive programs such as this, wireless service providers can successfully mitigate the effects of PIM while continuing to evolve their networks.

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