PIM Test Power Levels

For Mobile Communications Systems

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Table of Contents

1. Abstract:

In 1999, the International Electro-technical Commission (IEC) released Standard 62037 providing the wireless industry a consistent test method for measuring Passive Intermodulation (PIM) in RF components and systems. Over the next 12 years, wireless technology evolved from 2G systems serving primarily voice traffic to 4G systems serving high-speed data users. These 4G systems require new network architectures with broadband modulation schemes to achieve the required increase in network capacity. This paper reviews the applicability of IEC 62037 for qualifying components, subsystems and systems used in today's commercial telecommunications infrastructure and specifically addresses whether or not there is technical merit in increasing PIM test power levels from 20W to 40W.

2. Why Do We Measure Passive Intermodulation (PIM)?

PIM occurs when two or more high power RF signals encounter non-linear electrical junctions or materials in an RF path. These non-linear junctions behave like a mixer causing new signals to be generated at mathematical combinations of the original RF inputs. If these signals fall in a network operator's receive band, the noise floor rises causing reduced data rates and decreased service quality.

PIM is often caused by inconsistent metal-to-metal contacts in high current density regions such as inside transmission lines, inside RF components, or outside the system but in the main beam of an antenna. Common sources of PIM are:

- Contaminated or oxidized RF surfaces
- Inadequately torqued RF connectors
- Loose screws or rivets inside RF components caused by transportation shock and vibration
- Metal flakes or shavings inside RF connections
- Poorly prepared RF terminations due to improper tooling, or incorrect assembly procedures
- Metal flashing or rusty vent pipes in front of antennas on roof-top sites

PIM testing identifies the presence of these defects using RF transmission as the stimulus and highly sensitive receivers to detect and measure the response. PIM testing is the ultimate measure of construction quality of RF components, subsystems and systems. It will identify mechanical, as well as material defects in workmanship that may go undetected by more conventional techniques such as visual inspection or s-parameter measurement.

3. The International Electro-technical Commission (IEC), Technical Committee 46, Working Group 6:

In the early days of commercial telecom, it was understood, based upon experiences of other communications systems and most particularly satellite communications, that PIM could produce interference conditions that were performance impacting. Recognizing this, mobile operators and OEMs impressed upon their component suppliers (manufacturers of antennas, cables, connectors, filters, lightning protectors, etc.) the need to provide "Low PIM" solutions. However, there was very little guidance of what "Low PIM" meant.

Left to their own devices, component manufacturers around the world began specifying the PIM performance of their products using varying and inconsistent parameters. Some manufactures only conducted PIM tests in their engineering laboratories claiming that their products were “Low PIM” by design. Others conducted PIM tests on each unit produced to verify not only the design but also assembly workmanship. Some certified higher order PIM products such as IM5 or IM7 depending on the end-user’s band of operation. And finally, some manufacturers specified peak PIM while applying mechanical stimulus (dynamic testing) while others measured the best case PIM achieved with the DUT at rest (static testing.)

This arbitrary and haphazard approach made it impossible to compare products and performance. To establish consistency, IEC Technical Committee 46, Working Group 6 was formed to create an industry standard for Passive Intermodulation testing. The PIM Working Group was comprised of OEMs, component manufacturers, universities, and national standards organizations.

4. Developing the Recommended Test Standard:

In the beginning, there were many energized debates among the working group constituents that ranged from academic, to practical, to sometimes political. There were arguments about how many carriers should be used, how much power was needed, what IM products to measure, how to define repeatable and meaningful dynamic tests, and whether PIM testing was even necessary since only high order IM products could land in the operator’s own receive band.

After considerable analysis, experiments and discussion, IEC Standard 62037 was finalized and released in the fall of 1999. The specification defined technical requirements for PIM testing apparatus as well as provided key recommendations to enable consistency in PIM performance comparisons. Two key recommendations from the original specification were:

- *PIM comparisons should be conducted at the same power level; 2 x 20 Watts recommended for Mobile Communications applications*

- *Third order IM products typically represent the worst case condition of unwanted signals; therefore measuring IM3 characterizes the DUT*

An update to IEC-62037 was published in May 2012 with more specific instructions for testing of antennas, connectors, cables, cable assemblies, and filters. This new revision contains the same fundamental recommendations as the original specification; measure IM3 using 2 x 20W test tones and adds clarity regarding a third key requirement for PIM tests:

- *Devices should be subjected to impact or movement while PIM testing*

In 1996, Brad Deats and Rick Hartman formed Summitek Instruments (now Kaelus) to develop simple to operate, integrated PIM test solutions to deliver the test capability recommended by the IEC specification. Deats and Hartman participated in the original working group and the PIM analyzers they developed have become the de facto world standard instrument for performing this test.

5. The Question of Testing at Higher Carrier Powers:

New entrants to the PIM test equipment market have claimed that PIM testing should be conducted at 40W rather than the IEC recommended 20W level in order to “spot problems that cannot be seen on a 20W PIM tester.” Further claims are made that 40W is the correct power level to use since it is more representative of “real world” BTS operating conditions.

To determine whether or not there is validity to these arguments, first consider the claim that PIM testing should represent “real world” BTS conditions. As seen in the table below, PIM test parameters have very little to do with the particular air interface, number of carriers, or power level deployed at a site. Rather, the test parameters were selected to define an accurate method to measure the degree of non-linearity present in an RF path. Presented further in this document, 20W is more than enough power to accurately measure non-linearity in RF components as well as in completed feed systems.

	PIM Measurement	Typical BTS
Carrier Modulation	CW	Various: GSM, UMTS, CDMA, LTE
Number of Carriers	2	1, 2, 3, 4 or more
Bandwidth per Carrier	5 kHz	>5 MHz for LTE
Carrier Power	20W	20W, 40W, 60W, 80W & higher
IM Product of Concern	IM3	IM5, IM7, IM9 & higher

If the goal were to simulate the actual BTS environment the required test equipment would need to transmit 100’s of watts (not 40W) to capture the full range of base station transmit levels. Test equipment would need to transmit multiple carriers rather than just two and would need to transmit GSM, wideband CDMA or LTE waveforms rather than CW test tones. The resulting test equipment would be significantly larger, heavier, more expensive, and would pose safety risks to technicians performing the test. In addition this equipment would need to be replaced every few years to keep up with the ever changing wireless industry (2G, 3G, 4G, etc.) Great news for the test equipment industry but not a practical solution for RF equipment manufacturers, or network operators forced to continually invest additional CAPEX to keep up with a continuously changing specification.

These are exactly the same issues that the IEC working group faced back in 1999! Their challenge was to develop a test that was “fit for purpose” and not constantly changing based on individual manufacture’s claims. The IEC team analyzed this problem (over several years) and produced the test specification that the industry has relied on ever since.

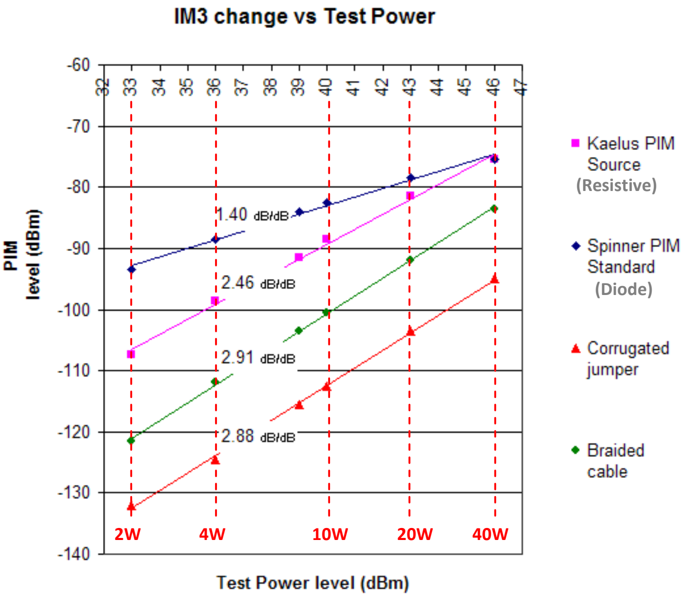
To address the claim that higher test power will unveil PIM problems that cannot be seen using the industry standard 20W test, one must understand how PIM behaves with increasing test power as well as consider the test as a whole rather than by its individual components.

The magnitude of PIM produced by a given defect is dependent on the physical characteristics of that defect. Looking at the data below, one can conclude that the

Spinner PIM standard (produced using a diode in its construction) creates the highest level of PIM and that the corrugated jumper cable (constructed with solid copper conductors with soldered connections) produces the lowest level of PIM at any given test power.

OBSERVATIONS

- The more severe the defect, the higher the PIM for a given test power
- As test power increases, PIM level increases
- PIM level increases linearly on a dB scale with increasing test power
- The rate of PIM level increase vs. test power is different for each PIM source



One will also notice that as the test power changes over the range of 2W to 40W the magnitude of the PIM produced by each defect also changes. In theory, IM3 is expected to change 3dB for every 1dB change in test power and is expected to be linear over a wide range of test powers. In practice, this rate of change is typically lower and varies based on the physical characteristics of the defect causing the PIM. In the example above the "PIM slope" varies between 1.4 and 2.9dB/dB for the components tested and, as expected, remains very consistent over the full range of powers tested.

This means that if we know the magnitude of PIM produced by a defect at one test power level and we know the PIM slope, we can accurately estimate the magnitude of the PIM that will be generated at a different test power. Using this knowledge, we can see that nothing new or unexpected is revealed by increasing the test power. The PIM magnitude is higher at 40W than it is at 20W, but it is higher by a predictable amount.

In order for the claim to be true that 40W PIM testing will "spot problems that cannot be seen on a 20W PIM tester," one of the two following conditions must be true:

- *The test instrument does not have sufficient receiver sensitivity to yield a 10dB signal to noise ratio for the PIM signal being measure*

Or

- *The PIM level increases in a non-linear fashion (on a dB scale) as the test power level increases*

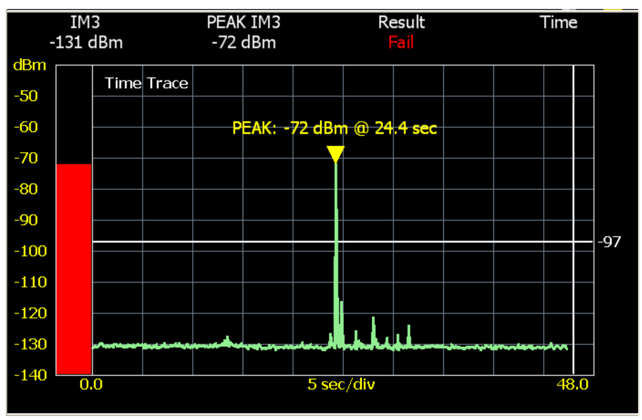
High quality PIM test instruments manufactured today typically achieve a receiver noise floor level on the order of -130dBm. Since the IM3 level that is required to measure is on the order of -150dBc (-107dBm) for factory tests and -140dBc (-97dBm) for field tests, the typical signal to noise ratio achieved is between 23 to 33dB. This means the PIM signal level is already 20 to 200 times stronger than the 10dB minimum signal to noise ratio required for an accurate measurement. Increasing the test power does not create a useful benefit in measurement accuracy yet does increase the personal safety risk to test personnel.

The data presented in this paper shows that IM3 increases linearly on a dB scale with increasing test power. This is true for the vast majority of defects found in RF components and in typical cell site installations. Similar results have been demonstrated across a wide range of test powers and test frequencies by other investigators. [1], [2]

6. The Importance of Dynamic Testing:

It is important to emphasize that all elements of a PIM test are important and must be used together to ensure the quality of the system under test. Accurately controlling the test power alone does not ensure a trouble free system, regardless of the test power level used.

To demonstrate the importance of dynamic testing, metal flakes were inserted inside an RF connection and the system was tested using the required 20W power level. Without mechanical movement (static testing) the PIM performance appeared very good. When connection was lightly tapped (dynamic testing) the PIM level jumped more than 50dB clearly indicating that a problem exists.



Dynamic testing identifies loose metal-to-metal connections as well as contact surface defects that might cause arcing at higher power levels. Without dynamic testing these defects could go unnoticed until activated by wind loading, tower vibration or stresses caused by temperature changes.

Recently, claims have been made by test equipment manufacturers new to PIM testing that using 40W test power rather than 20W eliminates the need for dynamic testing. It would be wonderful if this was true, but unfortunately this claim is false! There is no single test power that by itself will sufficiently stress a system to identify defects. Applying mechanical stress while the PIM test is in process is the only way to ensure that the system is robust. If simply increasing the test power would have eliminated the need for dynamic testing, the IEC working group would not have spent the last 10 years fine tuning dynamic PIM test requirements for RF components such as jumper cable assemblies, RF connectors, filters and antennas. Details of this work can be found in the newly released versions of the IEC 62037 PIM test specification.

Summary:

The existing PIM test standard was developed through a lengthy process of analysis, measurement and debate by a respected group of engineers, scientists and managers from the commercial telecommunications market: OEMs, component manufacturers, standards organizations and Summitek Instruments as the only participating company exclusively committed to providing PIM test solutions.

The test standard produced has been used globally for more than a decade. Component manufacturers, OEMs and network operators have built their quality procedures and performance requirements around measuring IM3 with 2 x 20W test tones while applying dynamic stimulus. As shown by the example of the metal flakes inside a connector, dynamic stimulus is a critical component of the PIM testing process for identifying faults that are not visible under static conditions.

As demonstrated in this document, there is no technical justification for changing the power level used for PIM tests to 40W or any other power level (higher or lower.) Nothing has changed since the specification was first released in 1999 to invalidate the IEC's original, well considered recommendations.

References:

[1.] P.L. Lui, "Passive intermodulation interference in communication systems", Electronics & Communication. Engineering. Journal, vol. 2, June 1990, pp. 109-118.

[2] M. Bayrak and F. A. Benson, "Intermodulation products from nonlinearities in transmission lines and connectors at microwave frequencies", Proceedings of IEE, vol. 122, pp. 361-367, April 1975.

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