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The occurrence of passive intermodulation and troubleshooting in Thailand mobile industry

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Abstract

This paper describes the problem of the passive intermodulation (PIM) in mobile communications. We focus on the problem occured between the transmitter and antennas. The paper starts from the theory of intermodulation,mathematics concept and effect in mobile channels. The problem occured when two or more signals frequencies are transmitted at the same time in the same passive device. The non-linear behavior produced spurious signals where the frequencies were linear combinations of the frequencies of the original signals. When PIM level occurred,we measured such level and find out the methods to reduce PIM level. Finally,we got some methods in reducing PIM level to meet IEC 62037 standard.

Keywords: Passive Intermodulation (PIM), impedance, linearity
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1. Introduction

1.1. What is passive intermodulation (PIM)

The Passive Intermodulation (PIM) is a growing issue for cellular network operators. PIM issues occur as existing equipment generation when co-locating new carriers or when installing new equipment. PIM is a particular issue when overlaying (diplexing) new carriers into old antenna runs. PIM can create interference that will reduce a cell's receive sensitivity or even block calls. This interference can affect both the cell that creates it as well as other nearby receivers. PIM is created by high transmitter power so on-site PIM testing needs to be done at or above the original transmitter power levels to make sure that the test reveals any PIM issues. PIM is a serious issue for cellular operators wanting to maximize their network's reliability, data rate, capacity, and return on investment. It is worth noting that PIM testing does not replace impedance-based line sweeps but it completes line sweeping which is now more important than ever. High-speed digital data communications make PIM testing critical. As cell usage and throughput grows, the peak power produced by the new digital modulations increases dramatically which contribute heavily to PIM problems. On-site experiments have shown significant decrease in download speed. Drive tests have revealed an approximate 18% drop in download speed while residual PIM level was increased from –125 dBm to –105 dBm. [1]

1.2. Impedance versus linearity

The PIM test is a measure of system linearity while a Return Loss measurement is concerned with impedance changes. It is important to remember that they are two independent tests, consisting of mostly unrelated parameters that are testing opposite performance conditions within a cellular system. It is possible that a PIM test passes while Return Loss fails, or that PIM test fails while Return Loss passes. Essentially, PIM test will not find high Insertion Loss and Return Loss will not find high PIM. Line sweeping and PIM testing are both important. Some cable faults show up best with a PIM test. For example, if an antenna feed line has a connector with metal chips floating around inside, it is highly likely that a connecter test will fail PIM test while the line sweep passes. The antenna run most certainly passess nearly ideal impedance characteristics, but the presence of metal flakes bouncing around will cause the failling PIM test. It is also an indication that the connector was not fitted correctly. Another possible cause of PIM test failure is braided RF cables. These cables will test perfectly in a Return Loss or VSWR test, but

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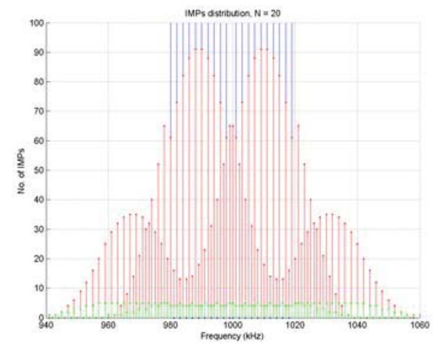

Figure 1: PIM in many orders.

generally possess only average PIM performance. The braided outer conductor can act like hundreds of loose connections that behave poorly when tested for PIM, particularly as they age. For permanent installations, braided cables are not recommended. Low PIM precision test cables are available commercially and they perform well, although they are very expensive. Some cable faults show up best in a Return Loss or VSWR test. A good example is a denoted or pinched main feeder cable, which will have an impedance mismatch at the point of damage, but may still be linear. Return loss testing will quickly spot this sort of damage, while PIM testing cannot. With the rollout of spread-spectrum modulation techniques, such as W-CDMA, and OFDM technologies like LTE and WiMAX, it has become essential to test both PIM and impedance parameters accurately.

2. Mathematical Background

2.1. Mathematics equations related to PIM

When two or more modulated signals are transmited into the same non-linearity media such as transmission cable,the signals will interference called Passive Inter Modulation (PIM). The results are interference signals in many orders. Figure 1. shows PIM in many orders. In this figure, two modulated signals are transmited at frequencies 150 MHz and 151 MHz with the same power. PIM creates interference at 3 , 5 ,7 , 9 orders on both sides of the spectrum. The most significant order that interferes a system is 3rd order because it has the highest power.

We assume the non-linear transfer function is characterized by a third order polynomial

$$y = a_1 x + a_2 x^2 + a_3 x^3 \tag{1}$$

where x and y represent instantaneous input and output respectively.

In PIM testing procedure, IEC 62037 standard, we use two tests input signals with unit amplitude at closely spaced frequencies which cause PIM. The input x is composed of two signal or carriers $\cos\omega_1$ and

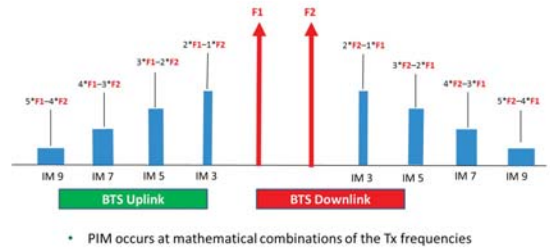

Figure 2: PIM in many orders and their calculated frequencies.

$\cos\omega_2$ in the equation (2). [2]

$$x(t) = \cos\omega_1 t + \cos\omega_2 t \tag{2}$$

Where ω_1 and ω_2 are angular frequencies of carriers . Then we substitute equation (2) in equation (1). We get .

$$\begin{aligned} y(t) &= a1(\cos\omega_1 t + cos\omega_2 t) \\ &+ a2[1 + (1/2)\cos 2\omega_1 t \\ &+ (1/2)\cos 2\omega_2 t + (1/2)\cos(\omega_1 + \omega_2)t \\ &+ (1/2)\cos(\omega_1 - \omega_2)t] \\ &+ a3[(5/4)\cos\omega_1 t + (5/4)\cos\omega_2 t \\ &+ (1/4)\cos 3\omega_1 t + (1/4)\cos 3\omega_2 t \\ &+ (1/2)\cos(2\omega_1 + \omega_2)t \\ &+ (1/2)\cos(2\omega_1 - \omega_2)t \\ &+ (1/2)\cos(2\omega_2 + \omega_1)t \\ &+ (1/2)\cos(2\omega_2 - \omega_1)t] \end{aligned} \tag{3}$$

The output y is consisted of many harmonics such as ω_1 , ω_2 , $2\omega_2$ - ω_1 , $2\omega_2 + \omega_1$, $\omega_1 - \omega_2$, etc. For PIM interference of mobile industry, we are interested in the third order $2\omega_1 - \omega_2$ on the lower spectrum and $2\omega_2 - \omega_1$ on the upper band because they have the highest power. In the deep research of next generation mobile system likes 5G when the bandwidth and transmission speed become greater, we will calculate PIM more than third order. In this paper, we focus on third order of PIM of which their frequencies are shown in equation (4).

3rd order PIM (Hz) = 2F1–F2 at lower spectrum

and 3rd order PIM(Hz) = 2F2–F1 at higher spectrum (4)

Figure 2 illustrates IM3 , IM5 , IM7 , IM9 (3^{rd} order , 5^{th} order , 7^{th} order and 9^{th} order) and their calculated frequencies on both side of the spectrum.

The basic problem of PIM is nonlinearity of transmission media. The nonlinearity can happen from many phenomena at the junction such as poor connector termination, metal flakes, metal folded, loose copper, etc. This will cause the nonlinearity in the contact surface in transmission line [3].

The other effect beyond PIM that can degrade the signal is impedance. We must matching the

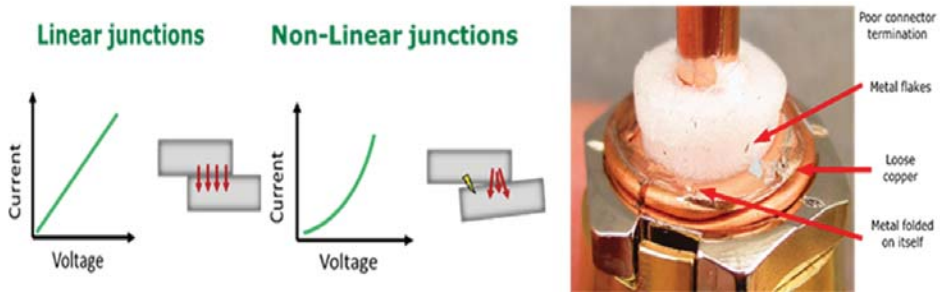

Figure 3: Nonlinearity phenomena in metallic contact.

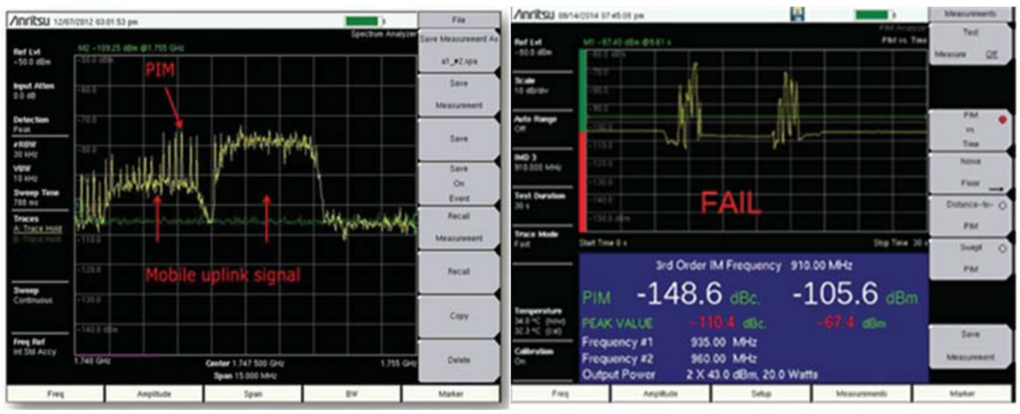

Figure 4: PIM spectrum display.

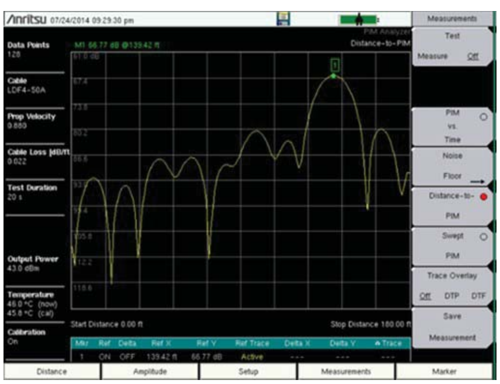

Figure 5: Distance to PIM (DTP) Measurement.

impedance between any junctions in the transmission lines or networks.

2.2. *Mathematics of power measurement in decibel unit*

A Decibel is a subunit of a larger unit called the bel. As originally used, the bel represented the power ratio of 10 to 1 between the strength or intensity ,i.e., power, of two sounds, and it was named after Alexander Graham Bell. Thus a power ratio of 10:1 = 1 bel, 100:1 = 0.01 bels. It is readily seen that the concept of bels represents a logarithmic relationship since the logarithm of 100 to the base 10 is 2 (corresponding to 2 bels), the logarithm of 1000 to the base 10 is 3 (corresponding to 3 bels), etc. The exact relationship is given by the formula

$$\text{Bels} = \log(\text{P2}/\text{P1}) \tag{5}$$

where $P2/P1$ represents the power ratio. Since the bel is a rather large unit, its use may prove inconvenient. So, a smaller unit, the Decibel or dB, is used. 10 decibels make one bel. A 10:1 power ratio, 1 bel, is 10 dB; a 100:1 ratio, 2 bels, is 20 dB. Thus the formula becomes

$$\text{Decibels (dB)} = 10\log(\text{P2}/\text{P1}). \tag{6}$$

It should be clearly understood that the term decibel does not in itself indicate power, but rather is a ratio or comparison between two power values. It is often desirable to express power levels in decibels by using a fixed power as a reference. The most common references in the world of electronics are the milliwatt (mW) and the watt. The abbreviation dBm indicates dB referenced to 1.0 milliwatt. One milliwatt is then 1.0 dBm. Thus P1 in equations (5) or (6) becomes1.0 mW. Similarly, the abbreviation dBW indicates dB referenced to 1.0 watt where P2 being 1.0 watt. Thus one watt in dBW is one dBW or 30 dBm or 60 dBμW. For antenna gain, the reference is the linearly polarized isotropic radiator, dBLI. Usually the “L” and/or “I” is understood and left out. **dBc** is the power of one signal referenced to a carrier signal, i.e.

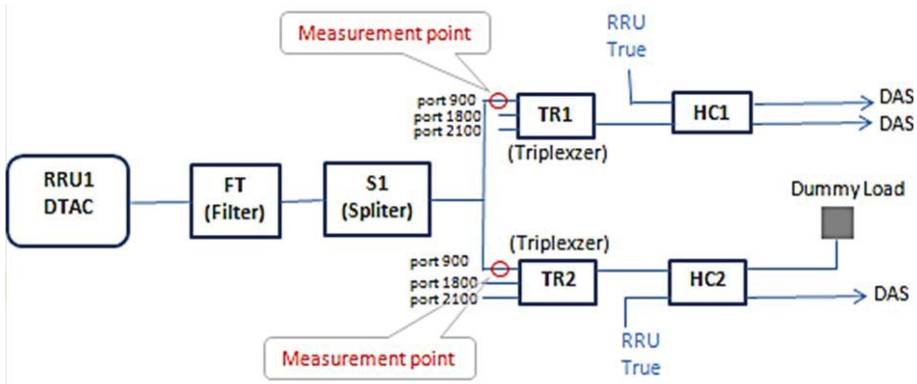

Figure 6: Diagram of DTAC mobile network at a simple site.

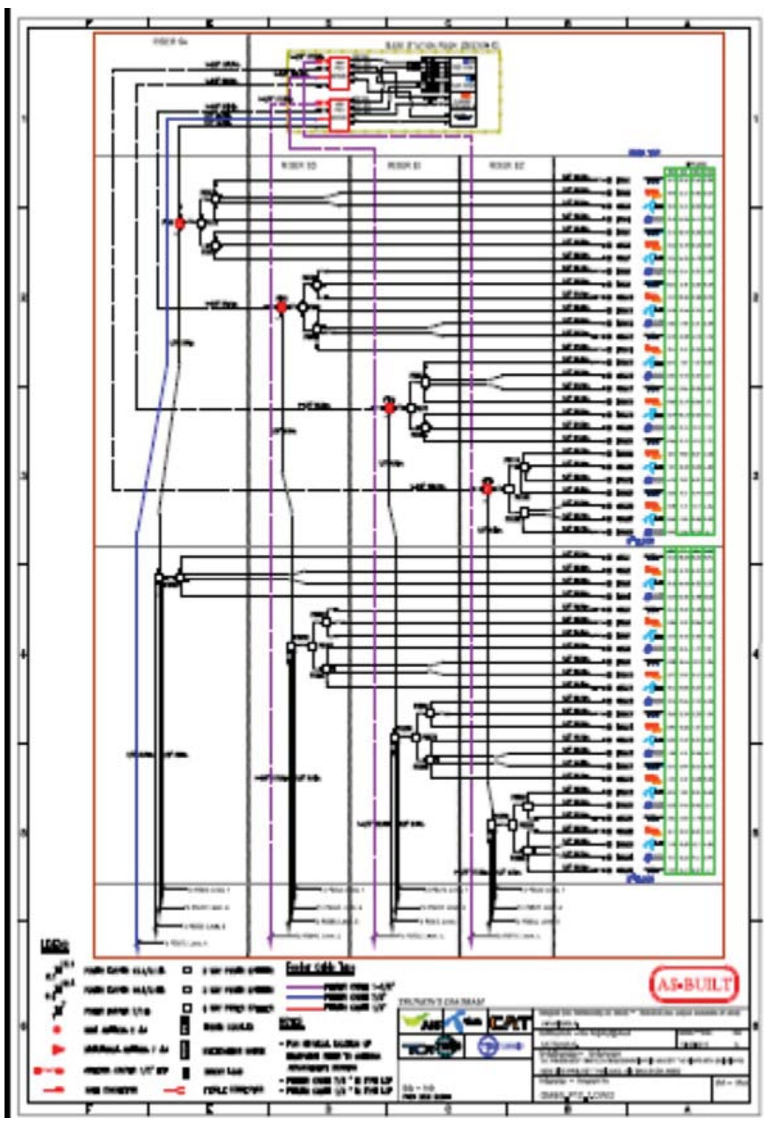

Figure 7: Trunking diagram of network.

Figure 8: Antenna install to the ceiling and too long of inner conductor, one of high PIM value problems.

Table 1. PIM report form

Output	To	Cores	Floor	Coverage	PIM	
					dBc	DTP Meter
1	PT2C	3	4	4,3,2,1	-114	45.1
2	PT1C	4	9	9,8,7,6,5	-96.7	46.4
3	PS69C	3	9	9,8,7,6,5	-118	32.2
4	PS67C	4	4	4,3,2,1	-125.1	48.4
1	PT3C	1	9	9,8,7,6,5	-134.0	24
2	PT4C	2	9	9,8,7,6,5	-126.5	20
3	PS73C	1	4	4,3,2,1	-142.0	37.2
4	PS77C	2	4	4,3,2,1	-119.5	27.6
1	PT3C	1	9	9,8,7,6,5	-134.0	24

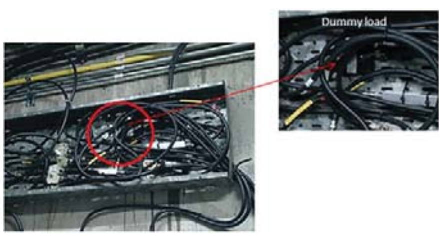

Figure 9: Dummy load can cause PIM.

Figure 10: Loose or too tight connection.

if a second harmonic signal at 10 GHz is 3 dB lower than a fundamental signal at 5 GHz. Then , the signal at 10 GHz is -3 dBc.

3. PIM Measurement Methods

In the measurement fields such as the base station of each mobile operator nowadays , we use the PIM Analyzer as the test & measure equipment. We measure many parameter to clarify the PIM problems.

3.1. PIM versus time

This measurement tracks instantaneous PIM and also records Peak PIM levels throughout a fixed frequency PIM test. It is useful for dynamic PIM tests and provides a visual indication of the stability of the system under test. We measure in dBm and dBc unit. The test frequencies Tx1 and Tx2 power according from IEC 62037 are 20 watt or 43 dBm. If 3rd order PIM is -105.6 dBm then PIM in dBc unit is 148.6 according to equation (7)

$$\text{PIM (dBm)} - \text{Transmit Power(43 dBm)} = \text{PIM (dBc)} \quad (7)$$

Figure 4 on the left shows the PIM interference in the bandwidth of mobile uplink cell phone to base station. Figure 4 on the right shows PIM level that exceed the standard at -140 dBc.

3.2. Noise floor

Before measuring PIM level , we must test line sweep and impedance matching of the transmission lines or networks. The networks should have low VSWR or high return loss for good matching as table 1 below. The PIM power level in this section must be ≤ - 100 dBm , VSWR must be ≤ 1.3:1 and return ross ≥ 18

3.3. Distance to PIM (DTP)

When the PIM occure in our system we solve the problems by repair , tighten , replace or cleaning at the junctions that PIM occurred . This function let us know the distance from the test equipment to PIM and the problem is there. Figure 5 show DTP measurement function.

4. PIM Measurement and Troubleshooting

Thailand mobile industry has PIM problems more than in the past. The 4G networks use higher bandwidth , higher bit rate and so on. This mean PIM is a very sensitive parameter when new 4G equipments are installed in the base station or when the new 4G system is replacing the old 3G networks. Every operator in Thailand such as AIS , DTAC and TRUE measures and solves PIM problems in their networks.

We measured PIM by the methods in topic 3 then all the report forms as tabled. The forms consist of data such as PIM level in dBm or dBc, distance from the test instrument to PIM, junction names , floor and signal floor coverage. Before measuring, we study a networks diagram to see the junctions, the splitters, triplexers, etc. and their whereabouts.

Figure 6 shows a simple netwok diagram of DTAC at the site. DTAC used three groups of carriers as we see in the diagram below. The carriers are 900 MHz, 1800 MHz and 2100 MHz and TRUE share this simple network with DTAC via hybrid coupling circuit HC.

Table 2 shows PIM report form. It contains important data that use to improve PIM to acceptable level . From this table we found that PIM at output 3, core E1 , floor 4 is higher than the acceptable level(-140dBc). It appears at 37.2 meters from the PIM analyzer. We had checked the conjunction at that point. Figure 7 shows network trunking diagram. We adjusted PIM points by several methods based on the problems at those points. Figure 8,9 and10 show some PIM problems found in the networks. After resolving them, we remeasured PIM until they get to be at the acceptable level.

5. Conclusion

Signals send in nonlinear networks can degrade the receive sensitivity of a mobile system. This limits the reliability, data rate, capacity and coverage of the networks. PIM tests can troubleshoot these problems. PIM occur from two or more modulated signals mixing in a non-linear device. These non-linear devices, or junctions, occur in improperly tightened, damaged, corroded connectors or in damaged antenna. Rusty components, such as mounts and bolts, are also suspected when finding the sources of PIM. Troubleshooting PIM starts with quality transmission networks. The growing in capacity, new services, speed rate are all conducive towards this problem. PIM testing is becoming more important especially in the era of 5G mobile system .

References

[1] N. Cannon, Troubleshooting passive intermodulation problems in the field, Anritsu white paper (2010).
[2] E. K. Yin . Mathermatical problems arising from passive intermodulation interference in communications, ProQuest Dissertations and Theses (1979).
[3] R. Hartman, Passive intermodulation (PIM) testing moves to the base station, Microwave Journal (2011) 124.
[4] Z. Shi-quan *et. al.*, Analysis of passive intermodulation interference in GSM mobile communication antennas, in: IEEE International Symposium on Microwave, Antenna, Propagation, and EMC Technologies For Wireless Communications (2007) 1251-1254.
[5] Z.Shi-quan, G. De-biao, The generation mechanism and analysis 0f passive intermodulation in metallic contacts, CEEM Dalian (2006) 546-549.