



Passive Intermodulation Measurement System

Hüseyin Anıktar^{1*}

^{1*} Tübitak Bilgem, P.K. 74, 41470, Gebze, Kocaeli, Turkey, (ORCID: 0000-0001-9659-8446), huseyin.aniktar@tubitak.gov.tr

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Abstract

The Passive Intermodulation (PIM) phenomenon occurs because of non-linearities in antennas or passive components. When data rates are increasing in next generation communication systems like in 4G, 5G and 6G, PIM is getting even crucial and costly problem. Unwanted harmonics and intermodulation products might occur in communication band and this can take down the communication network. This work presents PIM mechanisms, and PIM measurement test setups for any communication standards (4G, 5G and 6G).

Keywords: Passive intermodulation, Non-linear behavior PN junctions, high speed wireless communication, 4G, 5G, 6G.

Pasif İntermodülasyon Ölçüm Sistemi

Öz

Pasif intermodülasyon (PIM), iki veya daha çok sinyalin birleşerek yeni bir sinyali oluştururken ortaya çıkan girişime denir. GSM baz istasyonları, uydu haberleşme istasyonları gibi çoklu frekans kullanılan iletişim sistemlerinde sinyal kalitesini ve alıcı hassasiyetini etkileyen, bazı durumlarda iletişimi kopma noktasına getiren girişim olarak adlandırılmaktadır. Lineer olmayan malzemeler ve metalik yapılarıdaki düzgün olmayan temaslar PIM oluşumunda en büyük etkenler arasında yer almaktadır. GSM sektöründe yüksek hızlı haberleşme (4G, 5G ve 6G) ve yüksek sinyal kalitesi istekleri PIM testini zorunlu bir hale getirmektedir. Bu yayında PIM ölçüm teknikleri ile ilgili yapılan çalışmalar sunulmuştur.

Anahtar Kelimeler: Pasif intermodülasyon, lineer olmayan jonksiyonlar, yüksek hızlı veri iletişimi, 4G, 5G, 6G.

* Corresponding Author: huseyin.aniktar@tubitak.gov.tr

1. Introduction

Non-linear behavior of passive RF structures (connectors, adapters, cables, flanges, antennas, etc.) in communication systems causes passive intermodulation (PIM). Especially in satellite and new generation high-speed communication systems such as 4G, 5G, and 6G, the intermodulation frequencies arising from passive intermodulation, and the intermodulation frequencies coming from their multiplications with each other, fall into the working band. It causes drops and even the system to be disabled after a certain point.

Non-linear behavior of passive components occurs with contacts such as two metals touching each other, screwing, etc. The behavior of these contacts causes the formation of a PN junction or non-linear resistance between the two metals, due to factors such as the metals touching each other being made of different materials, oxidation, how rough the metal surfaces are. RF signals passing through this structure generate harmonics and intermodulation frequencies due to non-linear behavior.

The detailed formation of the PIM mechanism is given in the second part. In the third part, the measurement setup and the comparative results are shared. The presentation of this study is completed with the conclusion and references.

2. PIM Mechanism

Any two metals touching each other (metal-metal contact) or corroded metals cause a junction. We can model this effect with a non-linear resistor (Rusty Bolt effect) in its simplest form [1, 2, and 3]. The current-voltage relationship (I-V) on this resistor is given in Equation 1.

$$I(V_{NL}) = a_1 V_{NL} - a_3 V_{NL}^3 \quad (1)$$

a_1 and a_3 are constant coefficients of the nonlinear resistance. V_{NL} is the voltage across the non-linear resistor. This voltage is a sinusoidal voltage due to the operating frequency. As can be seen from the equation, since the third order force of the sinusoidal voltage will be more dominant, the frequencies of metal-metal contacts, corroded metals or the interaction of two different metal materials will be more dominant (the third harmonic and intermodulation frequencies). The mathematical expressions of interaction of these contacts are given in more detail in the given references.

In Figure 1, some PIM frequency values for two-tone stimulation are presented. The third order harmonics are $3f_1$ and $3f_2$, the third order PIM values are $2f_1-f_2$ and $2f_2-f_1$. The fifth-order PIM values are $3f_1-2f_2$ and $3f_2-2f_1$. Seventh order PIM values can be given as $4f_1-3f_2$ and $4f_2-3f_1$. The ingredients given are the strongest ones, other ingredients are not given. In Figure 2, images of some RF components that can be PIM sources are shared. PIM measurements of these and similar RF components used in communication systems should be determined that they meet the standards and they should be used in the systems in this way.

3. PIM Measurement Setup

In multi-frequency systems, many components can be the cause of PIM. For this reason, the components used in the infrastructure must be tested and meet the requirements. Generally, connection apparatus and/or intermediate apparatus

not being tightened with a certain force, old/corroded antennas or rusted subsystem components appear as the cause of PIM. PIM testing is a solution to see how the antenna system responds to high power and multi-frequency signals. Although there is no PIM test standard yet published worldwide, the most well-known is the IEC62037 standard [4]. PIM test can be evaluated in two separate groups as antenna and other passive component tests. All test equipment used in PIM measurement should have a low PIM value ($<-160\text{dBc}$). The components in the test setup were selected according to the "Low PIM" feature.

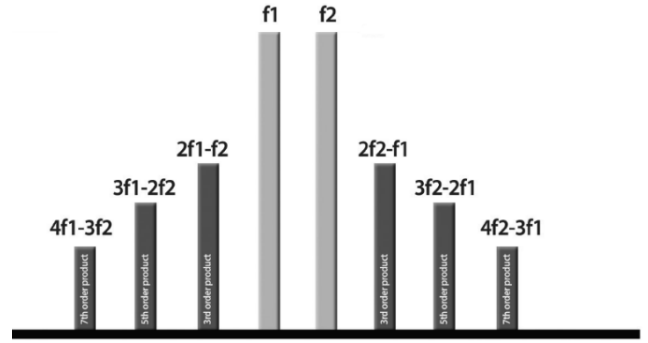


Figure 1. Some PIM values according to two tone excitation.



Figure 2. Some RF components which need PIM measurement.

Operating frequencies and harmonic/intermodulation frequencies for various communication systems are given in Table 1 [2, 3]. For any system, if the PIM requirement is not specified by a standard, this can be determined by calculating the system's receiver sensitivity or noise floor. The PIM value is expected to be below this level. For example, if the LTE communication system has 6 channels and each channel has a bandwidth of 180 kHz, the noise floor for this system can be determined by Equation 2:

$$F = -174\text{dBm} + \text{NF} + 10\log\text{BHz} \quad (2)$$

When Equation 2 is calculated, the noise floor is found approximately -113.66dBm . Bandwidth is taken as $6 * 180\text{ kHz}$, NF noise figure is taken as 0dB , if we take NF as 3dB , and the noise floor will be -110.66dBm . The higher the noise factor, the higher the noise floor. If the intermodulation signals are below this value (the noise floor), they will not be able to interfere with the system. In Table 2, the stimulation intensity and the required PIM values for the two-tone test are given.

Table 1. Frequencies of Communication Systems and Harmonic/Intermodulation Frequencies [5,6]

	f1	f2	2f2-f1	2f1-f2	3f2-2f1	3f1-2f2
LTE 700MHz	733	760	787	706	814	679
LTE 2600MHz	2620	2690	2760	2550	2830	2480
WCDMA 2100MHz	2110	2170	2230	2050	2290	1990
DCS 1800MHz	1820	1870	1920	1770	1970	1720
PCS 1900MHz	1930	1990	2050	1870	2110	1810
GSM 900MHz	935	960	985	910	1010	885

Table 2. Absolute and Relative PIM Power Levels

CW POWER LEVEL	f1 and f2 Test Signal Level	PIM=-118dBm	PIM=-110dbm
40W	2x20w (+43dbm)	-161dbc	-153dbc
25W	2x12.5w (+41dbm)	-159dbc	-151dbc
20W	2x10w (+40dbm)	-158dbc	-150dbc

The method to be applied for testing any component in the LTE 2600MHz communication system is to excitation two tones to the component with a power level of +43dBm for each tone at frequencies of 2620MHz and 2690MHz, and in the response of the component, at harmonic/intermodulation frequencies (2760, 2550, 2830, 2480, ...) should be below -160dBc, to meet the PIM requirement.

There are commercial products available for PIM testing. The products of Rohde&Schwarz, Anritsu, Kathrein are the most well-known. Each device of these companies have been developed for specific application. It's like a different device for the LTE2600, a different device for the LTE700. There is no broadband product that covers all band and wireless communication standards. The reason for this is that they cannot cover more than one band because the devices are portable and their output power is as high as 2x20W.

The test system we suggested in this study is a desktop system (not portable), it works with broadband because there is no heating and space problem, and it covers most wireless communication standards. Two separate test setups are recommended for antenna and passive components:

3.1. PIM Test Setup-Antenna

For antenna measurement, two tone signals (2x43dBm) are transmitted to the power combiner via amplifiers. Two tone signals are combined by the power combiner, after passing through the duplexer, signals reach the antenna, and the measurement is completed by measuring the level of the PIM signals returning over the same port [7, 8]. The setup used for antenna PIM measurement is given in Figure 3.

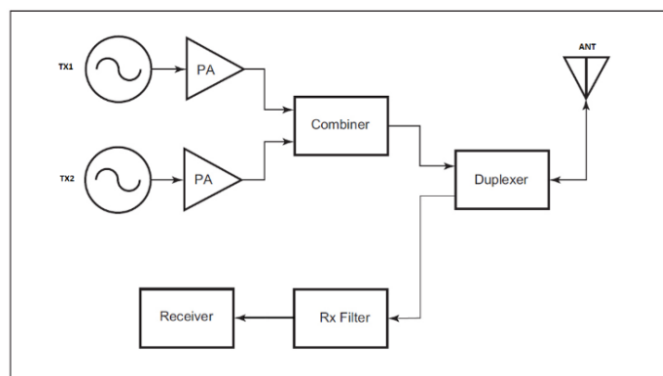


Figure 3. Antenna PIM test setup.

3.2. PIM Test Setup-Passives

The main reason for presenting two separate arrangements for antennas and passives is that the antenna element is single-ported, while the other passive elements consist of two ports. As in antenna measurement, two different tone signals (2x43dBm) are transmitted to the power combiner via amplifiers. The two tone signals collected with the power combiner reach the passive element (dut – device under test) to be measured after passing through the duplexer, unlike the antenna measurement, the second port of the passive element is terminated with a load [9]. The measurement is completed by measuring the level of the PIM signals returning from the first port in the same way. The setup used for PIM measurement of passive elements is presented in Figure 4.

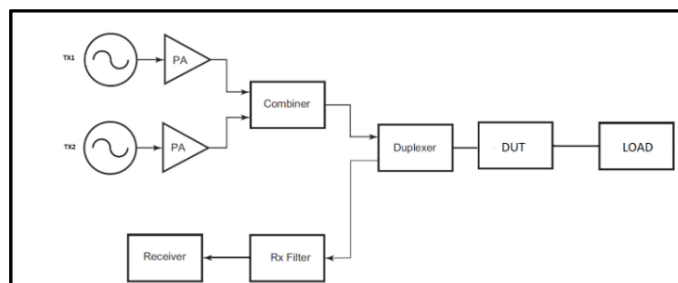


Figure 4. Passive components PIM test setup.

The PIM measurement setups presented in Figure 3 and Figure 4 can measure PIM in a wide frequency range 700MHz-2700MHz. With this performance and frequency range, it covers the function of four of the commercially available narrowband stand-alone PIM meters at the same time. But on the other hand, commercially available PIM meters are portable and it gives possibility to take measurements on site.

In the measurement setup, NI PXIe-5652 was used as two tone signal sources (TX1 and TX2) and NI PXIe-5601 products were used as receivers. To reach +43dBm power level, ZHL-4W-422+ power amplifier from Mini-Circuits was used. Microlab's D2-85FN product with low PIM was used as the power combiner/splitter. MECA ANM-F-M01 load with low PIM value was used as PIM load and Microlab FZ-30N attenuator with low PIM value was used as attenuator. All products used in the setup were selected as "PIM free".

4. Results

Some measurements were taken to confirm the accuracy of the measuring setup and these measurements were compared with the results of commercial products. In this study, one of these measurements is presented for the standard LTE antenna.

The standard LTE antenna used for measurement has an operating frequency band of 0.79 – 2.7GHz. Two tone signals were applied at frequencies of 821MHz and 795MHz. The PIMpro-800C device of the CCI company was used as a commercial test device (See Figure 5) [10]. In the measurement made with this device, the PIM value of the antenna was measured as -128dBc (Yellow colored region). The green zone, which we can say pass for PIM, will show intermodulation signs below -140dBc, but this antenna is not PIM compatible.

When the same antenna was measured using the measurement setup given in Figure 3, it was measured as -130.7dBc. Therefore, the antenna did not pass the PIM test.

5. Conclusion

In this study, information about passive intermodulation formation mechanism is given and PIM measurement setups are presented. The offered PIM measurement setups are broadband and cover 2G, 3G and 4G communication bands, and PIM measurements of the components used in this band can be made precisely. Work continues to prepare a measurement setup for 5G; specifically, the lower frequency band of 5G is targeted for this measurement setup. Especially in new generation communication systems, PIM issue becomes more critical as data rate and bandwidth increase.

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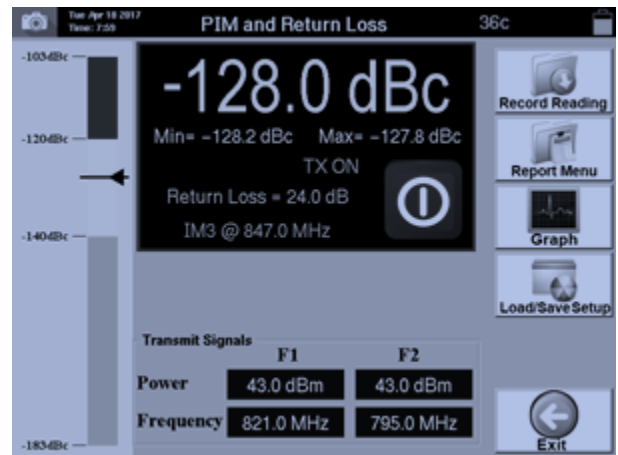


Figure 5. Commercial equipment PIM test result.