WHITE PAPER

Passive Inter-modulation Sources and Cancellation Methods

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Abstract

When nonlinearities or time variation in a system create amplitude modulation of signals with two or more distinct frequencies, it is known intermodulation distortion (IMD). When frequency components intermodulate, additional components are formed at frequencies that are not only at harmonic frequencies (integer multiples) of either, as is the case with harmonic distortion, but also at the original frequencies' sum and difference as well as at sums and differences of multiples of those frequencies. Though it can also be found in passive wireless components like filters, transmission lines, connectors, antennas, attenuators, and so on, particularly when transmit power is rather large, IMD is most frequently found in active circuits of radio systems. In the latter case, the IMD is referred to as passive intermodulation (PIM) distortion. The maximum capacity of a radio network may be hampered by PIM interference, which is becoming more and more apparent because of the progress in the development of radio systems and the limited availability of radio spectrum. In this paper, the PIM sources in BS radio systems are divided into two groups: internal and external sources. The radio' s passive parts, such as filters, connectors, transmission lines, antenna, and so forth, are considered internal sources. External sources, on the other hand, are passive components like corroded and metallic objects in the antenna near eld that are positioned outside the BS antenna, but inside the RF signal path. For both kinds of sources, the high power current passing through these passive components might result in nonlinear behavior and IMD. In this paper, PIM mitigation strategies are also reviewed.

1 Introduction

In order to achieve very high data rates, both the base station (BS) and the user equipment (UE) are critical components. In order to facilitate transmission, these are anticipated to be multimode and multiband. Nevertheless, there are limitations with regard to size, cost, and power consumption, particularly on the UE side. As wireless system parameters and signal quality affect transmission quality, interference problems should be kept to a minimum. Technical limits of the components lead to interference produced by defects in the architecture of the wireless system. This is particularly troublesome for BS, as high current flows through the structure and alter the linearity of its constituent parts. Highly linear signal paths are required for these high performance systems. In the absence of this, however, non-linear operation will lead to faults. Intermodulation distortion (IMD) is one type of system flaws that can be brought on by these non-linearities [1].

When one or more transmit (Tx) signals with single or multiple frequencies or carriers are applied to a nonlinear system, a phenomenon known as intermodulation (IM) occurs. The inverse spurious frequency resulting from the combination of input tones is the output. This generates frequency components both inside and outside the dangerous band. The required receiver signal may be interfered with by these unwanted spectral emissions, also known as spurious emissions, which happen in the receiver band (Rx). This phenomenon is known as passive intermodulation distortion (PIM) if the nonlinear system generating these new frequency elements is a passive linear component of high power systems such as transmission lines, connectors, interconnects, or simply a metal component [1].

Any RF communication system seeks an ideal behavior, which translates into linearly related components. Sadly, it is unavoidable due to the existence of tiny intrinsic nonlinearities. Intermodulation, harmonic distortion, and interference are all caused by such nonlinearities. When a nonlinear system receives an input signal with a sum of frequencies, intermodulation takes place, producing new frequency content. Additional frequency components that are integer multiples of the frequencies of the input signal are produced when the fundamental frequencies are combined [1, 2, 3, 4].

Intermodulation becomes an interference problem when the IM frequencies produced by the circuits are located in the receiver bands close to the transmitter signals in the RF spectrum. The two tones with corresponding frequencies, f_1 and f_2, and their respective amplitudes, A1 and A2 constitute the input signal Vi(s) as below [1]:

$$V_i(s) = A_1 \cos(2\pi f_1 t) + A_2 \cos(2\pi f_2 t) \tag{1.1}$$

A non-ideal and hence nonlinear current-voltage (I-V) system is then used to pass the signal. Its transfer function can be represented as an nth-order power series with coefficients K1, K2, K3,... In this case,the output signal Vo(s) of the nonlinear system can be represented as follows [1]:

$$V_o(s) = K_1 V_i + K_2 V_i^2 + K_3 V_i^3 + ... \tag{1.2}$$

The nonlinear term in the equation (1.2) becomes more dominant, or the nonlinear contribution gets higher, when the Kth coefficient gets stronger. Combining the two equations and utilizing the trigonometric identity and the Binomial theorem to expand the series terms results in additional terms with new frequencies [1, 5, 6]. These incorrect frequency components result from either adding or subtracting the original signal' s frequencies, or their harmonics (multiples) of the original signal. The original frequencies f_1 and f_2, which are added and subtracted, result in the IM products, or frequencies that follow the relationship [1]:

$$f_{IM} = kf_1 \pm lf_2 \tag{1.3}$$

where k and l are integer coefficients. The absolute values of these coefficients are added to establish the order of the IM product. Odd order IM frequencies are specially concerning since they are frequently close to the original signals (assuming the original frequencies in the original signal are close, which is usual for multicarrier signals), even though some of the upper and lower products may be readily filtered out. An example of an output spectrum that displays the whole range of this occurrence in frequency domain is depicted in Figure 1.1 [2]. Generally, the proposed approach can be expanded to include multiple frequency components. In a nonlinear system, for instance, the corresponding third-order IM products (IM3) would be $f_1 \pm f_2 \pm f_3$, if three frequency components are combined.

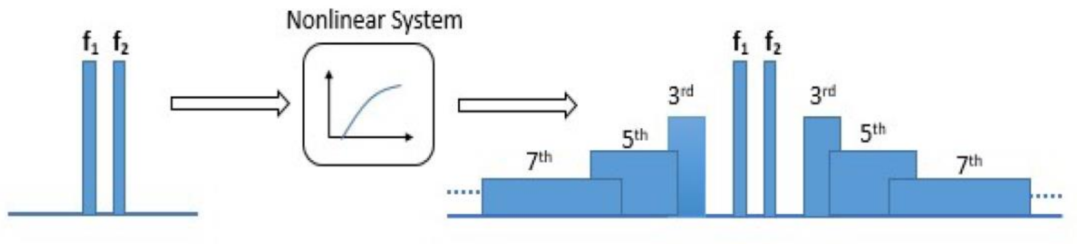

Figure 1.1 Inter-modulation of Two Carries f_1 and f_2

In the event that the signals are modulated, both the center frequency and the bandwidth (Bw) of the IM products that are created must be considered. IM products have a bandwidth that increase with the order of IM and are larger than the original signals' bandwidth. The third-order product will have a bandwidth of 3 MHz, the fifth-order product will have a bandwidth of 5 MHz, and so on, if both of the input signals are, for instance, 1 MHz wide [7]. Thus, the bandwidth of the IM product can be computed by multiplying the bandwidth of the original signals by the IM product order number, provided that both original signals have the same bandwidth. An other important consideration is the varying amplitudes of the IM products. IM products will have moderate amplitudes when the input power on the signals is low; nevertheless, if the input power is exteremely high (as in radio systems), the amplitudes will also get much bigger. The IM3 product amplitude increases by 3 dB if the input signal is raised by 1 dB to provide the required output power, as per the mathematical formulas shown in [5, 6, 8]. Ultimately, the transmitted signals coupled in the nonlinear device — such as relative carrier frequencies, bandwidth, and power — define the event known as IMD.

2 Origins of Intermodulation Distortion

PIM has been investigated since 1989–1990, and it has long been known that it could cause interference in radio communications systems [1, 6, 9]. However, the PIM issue has returned in recent years due to the increasing frequency spectrum saturation and the adoption of wideband multicarrier communications. According to [1] and [10], PIM distortion can be categorized into three types: design PIM, assembly PIM, and rusty bolt PIM. Based on multiple nonlinear trigger processes that result in PIM interference, this classification calls for a unique solution. When choosing layout members, or choosing components based on size, power, rejection, and PIM performance trade-offs, designers make judgments that are referred to as design PIM. Assembly PIM highlights the interference produced by the installed system' s gradual degradation over time that is based on the quality (materials, robustness, stability, interface) of the component parts and the surrounding environment. The rusty bolt PIM [10] is associated with downlink frequency reflections in metallic objects in the beam' s propagation path, such as rusty fences and barns, that face uplink. Receiver desensitization may result from any interference signal that couples with the radio receiver and differs significantly in strength from the intended received signal. So, splitting PIM sources into internal and external groups is useful [1]. Internal PIM sources include sources like filters, waveguides, coaxial cables, connectors, and antennas [1, 6, 7, 9]. The external PIM identifies sources, such as nearby metallic objects, wire fences, towers and masts, and support structures, that re-radiate the harmful spurious emission towards the Rx.

2.1 Internal Origins of PIM

Electron tunneling and thin dielectric layers between metallic contacts, micro discharge between microcracks and across voids (multipactor discharge), high current densities, nonlinear resistivity of materials used, nonlinear hysteresis (memory effects) due to ferromagnetic and ferrimagnetic materials, and electro-thermal (ET) cohesion are some of the physical mechanisms that cause PIM [1].

Internal PIM in radio system components like filters, antennas, and connections was previously considered to be mostly produced by contact mechanisms in RF components [1, 2, 11, 12, 13]. On the other hand, ET research emerged and was accepted as another important source of PIM construction between internal sources. In radio systems, dirt particles and corrosion (contamination) remain as a major source of PIM and need to be taken serious in radio system design. Because the physics of contact mechanisms explains why corrosion can also generate PIM, the trigger description will focus on contact mechanisms and ET.

2.1.1 Contact Nonlinearities

As mentioned before, a major factor behind PIMP creation is the nonlinearities in metal interactions. There are two possible types of physical contact: metal-insulator-metal (MIM) and metal-metal (MM). MIM and MM contacts are two physical structures that each has a variety of unique nonlinear mechanisms. MIM structures have a higher probability of corona discharge, thermionic emission, and electron tunneling. MM structures can create diode-like junctions as a result of differences in metal work functions and nonlinear contact resistances brought on by thermal processes including expansion and thermal fluctuation [2]. There are many different ways that these two sorts of contacts can happen, because terrain and pressure at both ends of the contact can specifically affect them.

It is generally impossible to get a perfectly smooth surface on the termination of radio components during the fabrication process. When two radio components are connected, the contact surface topographies of each contain several peaks at random locations, and a microscopic level native oxide or sulfide layer covers them. Depending on the metals employed, this layer' s thickness varies, although it is often in the nanoscale range. Touching two identical surfaces is therefore analogous to touching needles of different lengths. These results lead one to conclude that the "actual" contact area only occurs in peaks making contact and constitutes only a small portion of the macroscopic contact area. In a similar mechanism, MM scenarios only occur at microasperities where surface imperfections have caused enough mechanical pressure to cause the peaks to link. The analogous MIM scenario occurs when the mechanical pressure is insufficient to break through the thin dielectric layer that covers the metal's surface [1, 2]. A contact can be thought of as a compound of the two types of structure as a consequence of the surface topology. On the other hand, mechanical deformation increases with pressure increase, which increases the actual area size by forcing more microasperities connections, letting researchers think if MM occurs more frequently or not. Various models are available to describe the nonlinearities that arise according to some parameters which specify the kind of structure, like corrosion, the metals utilized, and cleanliness. Figure 2.1 [1] shows the physical scenario mentioned above, where the current is limited to flowing via the microasperities. Whether the scenario is MM or MIM is decided by either the appearance of corrosion in the empty zone or the presence of a thin dielectric layer between the microasperities. The count of scenarios for MM and MIM, nevertheless, depends on how much pressure is applied. Although MIM and MM are two of the many

many possible sources of the PIM distortion created at a junction, some origins are more important than others [1, 2]. MIM areas are very likely to be the primary source of IMD because, in most radio systems, the applied pressure connecting two radio components might drop, especially because a significant number of contacting zones can arise.

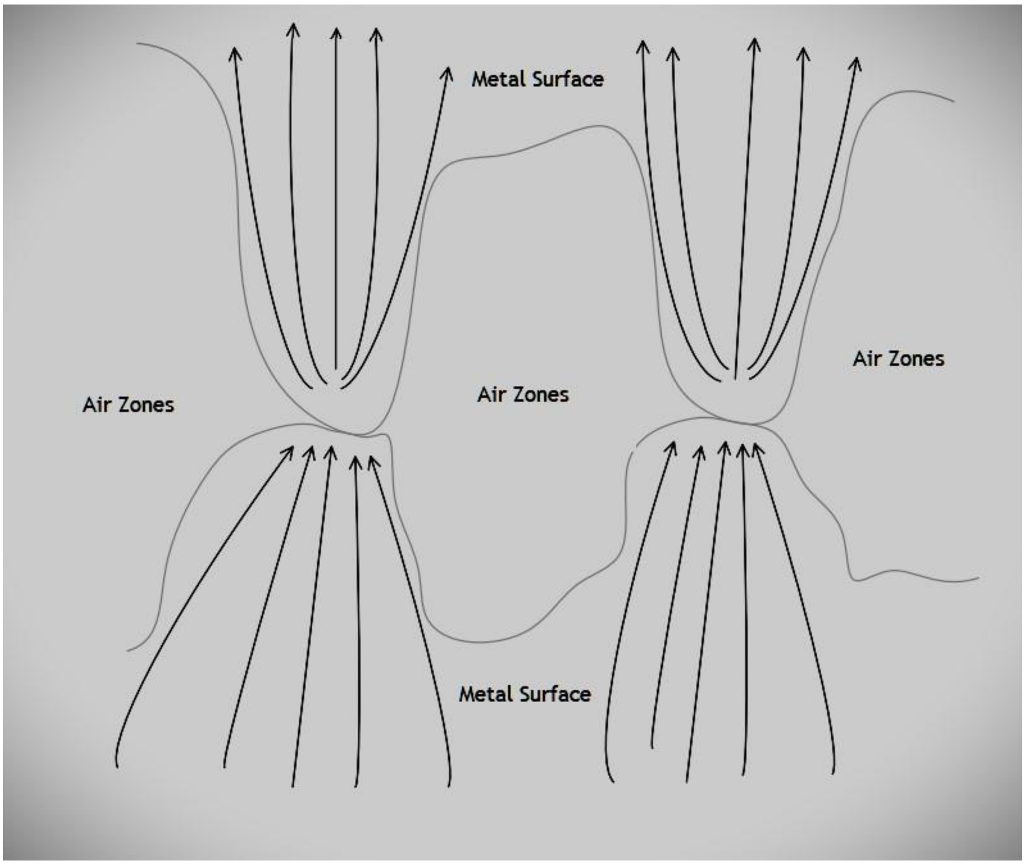

Figure 2.1 Restriction of Current in The Microasperity Connection

In conclusion, ferromagnetic materials and dirtiness in contacts might result in PIM interference. In addition to contacts and junctions, these mechanisms exist in all parts of the radio frequency network, such as antennas, resonant structures, and transmission lines. On the other hand, PIM signals are resulted by physical characteristics built into radio system components and can be summed throughout the system. These interferences become more visible in high-power BS radio systems, where the downlink signals that lead to PIM creation are quite strong.

2.1.2 Electro-Thermal PIM Sources

PIM may result from electro-thermal effects brought on by high-power transmit signals. The time variation nonlinear conductivity that results from the continuous change in both the thermal and electrical domains during the transmission of modulated radio frequency signals is what leads to PIM creation [1, 2]. As previously mentioned, PIM formation due to ET conductivity is also one of the main factors aggravating the issue in internal sources, therefore, the physics of this phenomenon are discussed in the subsequent subsections.

2.1.3 Distributed Origins of PIM

Passive nonlinearities in modern radio systems are classified into two categories: distributed, where the sources are scattered across the infrastructure, and lumped, where PIM is produced by a single main source, frequently metal-to-metal contacts. Similar to the MIM scenario, weak passive nonlinearities resulting from ET impacts that function as PIM sources are distributed across the current base station system. As per the findings of [1, 2], the impact of temperature on conductivity leads to notable electrical distortion in microwave elements. Distributed PIM distortion is sometimes referred to as a nonlinear transmission line (NTL) due to the electro-thermal phenomenon. Because of ET conductivity, this model can be used to explain PIM creation in passive components like microstrips and coaxial cables. These components, in conjunction with contact terminations (lumped components), are essential for producing PIM in a radio system. A nonlinear transmission line' s singular elements are what give rise to the PIM distortion in the NTL model. The total of all the affects that the cells replicate is the total of the nth order PIM outage power caused by ET effects. For a comprehensive explanation of how PIM is generated in each microscopic element, the reader is referred to [1, 2]. To summarize, the nonlinear current (J) produced by changing heat dissipation (Q) generates a nonlinear electric field (E) of IM products in a line component. The electric fields that have built up along the line as a result of various components are combined to form the PIM signal. All of the line elements are essentially nonlinear generators, with signal power that changes with line impedance. Note that there are two electric fields produced by each point: a forward and a backward electric field. Destructive interference following line length $\Delta z = \lambda/4$, however, causes the latter one to be ignored. Nonetheles, PIM can travel both ways by reflecting the forward PIM signal at the line' s termination. Figure 2.2 provides an example of how PIM is created using the NTL paradigm [1]. In summary, PIM distortion resulting from ET conductivity may be influenced by the numerous resistant components that the current passes through.

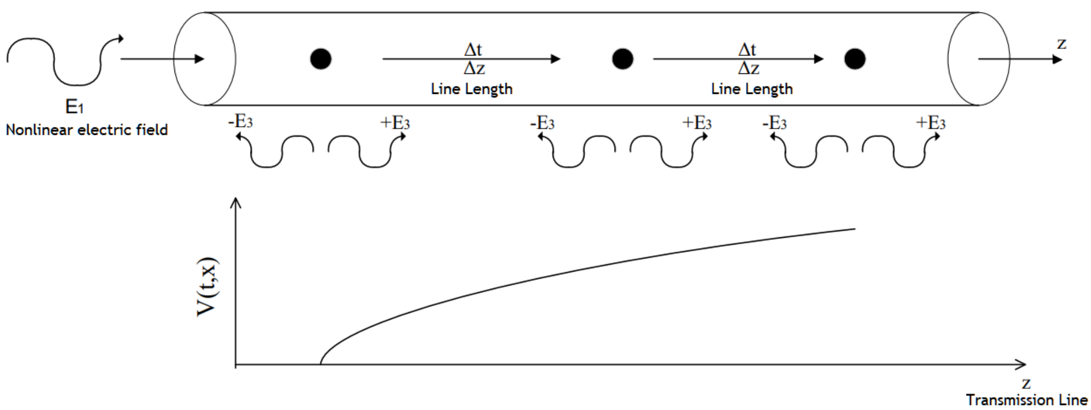

Figure 2.2 PIM' s signal intensity sequential increase because of the generated fields at nonlinear successive sites in the transmission lines

2.2 External Origins of PIM

Although nonlinear triggers of internal PIM sources have been the main topic of this study thus far, the PIM issue is not limited to the internal parts of the radio system. There are instances where PIM from external sources is unanticipated and uncontrollable. Either indoors or outdoors, addressing site interference issues highlights the difficulties associated with PIM from outside sources. The author of reference [14] performed a research on the difficulties a site encounters. It has been determined that non-linear items in the radiofrequency path, such as metal flashing, sheet metal vents, ceiling tile frames, street lamps, and the like, may produce IM products and reradiate them back into the system. This effect is often referred to as the "Rusty Bolt" effect. Consequently, in order to exclude outside sources from the system' s radio frequency path, antenna position and direction are crucial. Antenna polarization also affects how energy couples with the nonlinear item and is received back into the Rx (Receiver). As demonstrated in [14] also, varying antenna linear polarization (+45 and 45, respectively) results in varying degrees of third order IM products produced externally by stacking metal sheets. In a traditional FDD radio system, Tx and Rx functions are merged into a single antenna, but in a co-site scenario, where numerous radios from the same or different operators are placed, different antennas and bands function simultaneously. A significant obstacle to site integration is signal intermodulation distortion. PIM interference in antennas is frequently linked to internal causes such as material nonlinearities, contact nonlinearities (explained and mentioned in 2.1.1), and electro-thermal nonlinearities [1, 2, 6, 11]. However, PIM can be generated externally, that is, outside of base stations, in simple metallic components. Simple items in the RF path, like rusty junctions or metal buildings, can create or reflect PIM products, which are then detected by the antenna as noise [6].

2.2.1 External Origins of PIM as Antennas

The preceding subsections covered the physics of IM generated products of reflections in metallic objects, which is based on the time domain physical approach (TDPO) method [1]. The BS antenna can couple with the receiver chain by means of an electric field that is radiated back to the antenna at the frequency of the IM products by means of an induced nonlinear current. This electric field can then couple with the receiver chain. Actually, the scattered electromagnetic fields of dielectric materials and massive reflector antennas may be found using the TDPO approach. However, electron tunneling in the MIM junctions — also referred to as the "Rusty Bolt" phenomenon — is the main source of undesired signal radiation when a reflector antenna, like a parabolic reflector, is irradiated by high-power microwave radiation. In this case, the object is subject to nonlinear currents that originate from two or more transmitters and are induced in the reflector surface. When the local current comes into contact with connectors, slits, or fractures during this process, MM or MIM junctions are created. Nonlinear I-V characteristics arise across tunneling events and corona discharge of the two or more currents passing through the junction, producing and radiating IM products. After being created, the IM products radiate back toward the transmitting antenna, where they could potentially cause interference in the Rx bands. This research [1] suggests that external sources can be viewed as PIM antennas.

Even in cases where the sources are outside the antenna, such as when they are external to the radio, the physics of PIM from internal sources, more precisely MIM junctions, is what mostly contributes to the PIM' s radiation toward the Tx antenna. Like every other antenna, it is defined by its parameters, which are unmeasurable. The radiation pattern, polarization, directivity, and gain are determined by the intensity of the induced current and its flow characteristics at the surface. Furthermore, the emission of IM products may be attributed to several MIM junctions and reflections from a single external source. Two unpredictabilities that can change this generation are dielectric coating and incoming wave polarization. Therefore, it makes sense to assume that, depending on the external source that the broadcast tones meet, different PIM antennas should be anticipated [1, 4].

3 Passive Intermodulation Distortion in Radio Systems

PIM is one kind of radio interference that can decrease a cell site' s efficiency, which could directly affect a radio network' s performance. Moreover, PIM interference is a growing trouble as network complexity and deployments increase, and it is getting worse by the coexistence of multiple communication systems in the same locations. Thereby, networks are more and more affected by this issue. Because PIM interference is an issue in the RF spectrum, intermodulation difficulties are getting worse in broadband radio systems where bandwidth is increased to achieve faster data rates, particularly when carrier aggregation (CA) is utilized [1]. However, PIM interference can affect active narrowband systems like GSM too. Passive intermodulation is often viewed as an installation problem due to nonlinear producing processes; this is especially true for high-power cell sites. This, however, is merely a surface consideration, since a saturated RF spectrum often leads to interference problems. The ongoing development and expansion of network systems has made PIM a nonvolatile issue, and it will exacerbate its consequences on RF systems. This is particularly true for 5G, as it is becoming more typical to integrate multiple base station technologies seamlessly [1, 2].

3.1 Passive Intermodulation in Broadband Radio Systems

The majority of published works use two unmodulated carrier signals to describe and evaluate PIM. In this situation, the resultant PIM products are likewise narrow carrier' spurs, as described in section 2.1. However, the signal is modulated across a larger bandwidth and can be carried through multiple RF frequency bands in broadband wireless systems like as UMTS and LTE, especially when features like CA are used. Moreover, the merged modulated signals may simultaneously be broadband or narrowband. Thus, let us examine a generic noncontiguous dual-carrier CA FDD transceiver, where the transmitted signal is denoted by: [1]

$$y[n]=y_1e^{jf1}+y_2e^{jf2} \tag{3.1}$$

Two component carriers (CCs), represented by the symbols y_1 and y_2, and their corresponding frequencies, f_1 and f_2 ($f_1 < f_2$), make up this signal as this noncontiguous Tx signal passes via a nonlinear passive source, mixing takes place and IM components become visible.

Think of an FDD system that broadcasts signals from several bands. Let us examine two channels that originate from band 2 and band 21, respectively: A2 and A21 [1]. A2 DL spans from 1730 to 1790 MHz, and the transmitting carrier has a central frequency of 1740 MHz and a bandwidth of 10 MHz. The A21 DL extends from 1910 MHz to 1955 MHz, and the transmitting carrier has a central frequency of 1930 MHz and a bandwidth of 10 MHz. PIM products are produced by a nonlinearity on a passive device during transmission. One of the generated spurious third- and fifth-order IM products will therefore overlap with the A21 receiver spectrum, which runs from 1510 MHz to 1565 MHz, due to its emphasis around 1550 MHz. Moreover, the out of band (OOB) 5th order product overlaps with A15 UL since the A2 carrier' s bandwidth expansion is large enough to fit inside this Rx band. Both scenarios raise the risk of interference. This scenario is shown in Figure 3.1 [1].

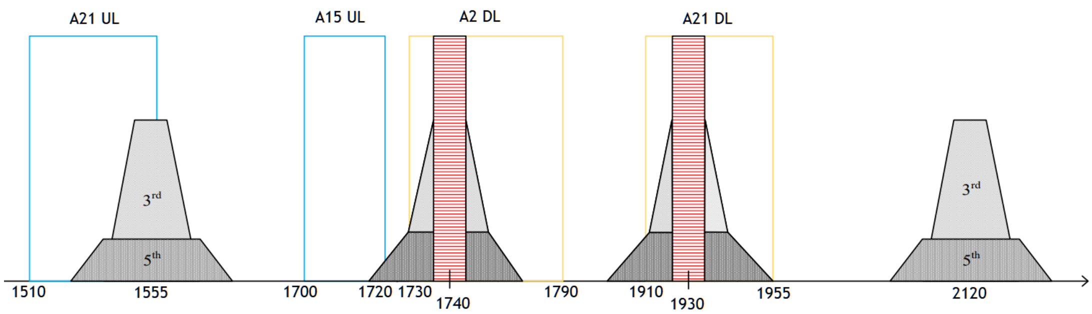

Figure 3.1 Spectral regrowth in light of the OOB and spurious emission resulting from the IM of A2 and A21 carriers, which may cause interference in A15 and A21

In active broadband base stations, when the carriers combined at the source are from several frequency bands, spectral regrowth is common. When the CCs involved in PIM

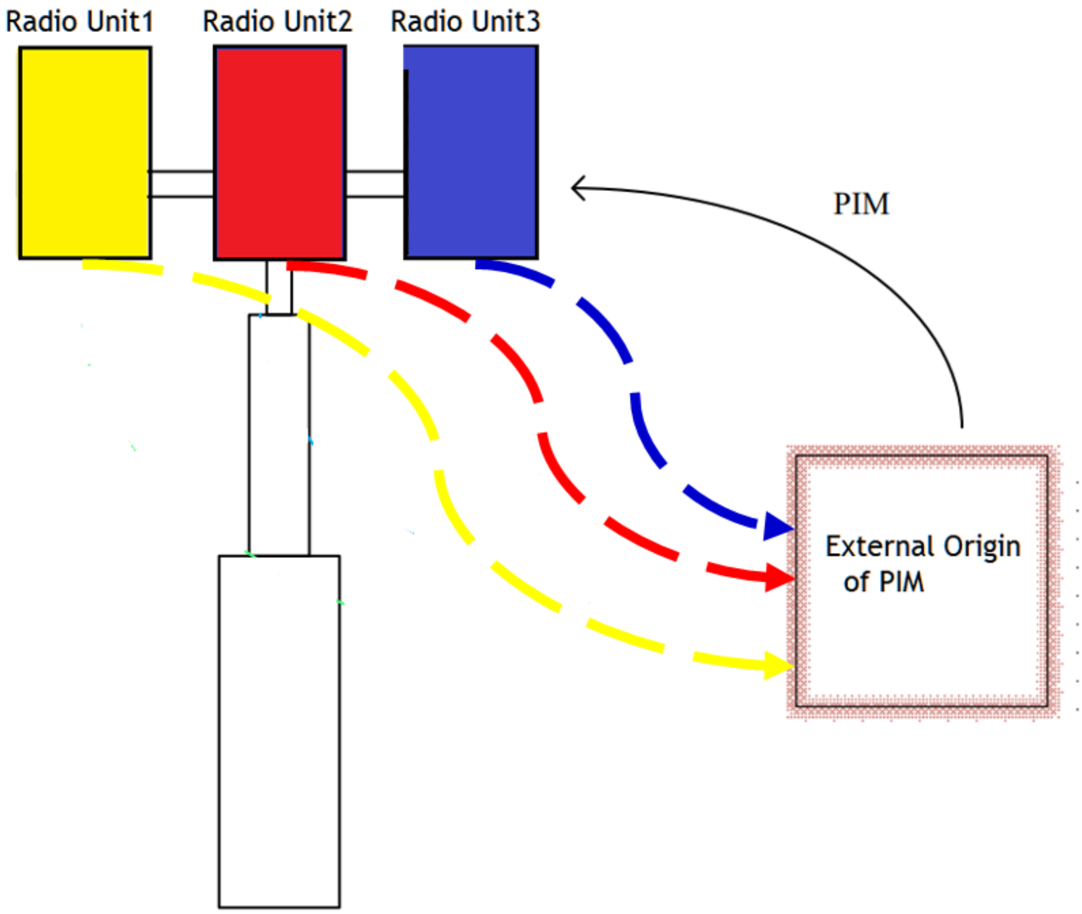

Figure 3.2 Cross-PIM scenario with an external source near the BS and three radio units, Radio Unit1, Radio Unit2, and Radio Unit3.

production come from several bands, as in the example Figure 3.1, the situation is referred to as cross-band PIM. In a similar scheme, the situation is referred to as in-band PIM if every carrier is from the same band. Cross-band PIM is getting worse by refarming of the RF spectrum, which includes new DL bands and interband CA, in addition to the BS' s growing complexity. Furthermore, cross-band PIM is a common scenario in today' s radio systems due to the increasing number of external sources in which the carriers can combine. Figure 3.2 depicts this possible outcome [1].

4 Passive Intermodulation Mitigation Techniques

In general, PIM-generated spurious signals that interfere in the Rx bands are highly erratic. As previously described, the surroundings of the site, the RF infrastructure, internal and external sources, as well as the specified bands and employed frequency channel, all influence the spurious signals. The strength of the interfering signals is often determined by the nonlinear characteristics of the PIM generating source. Moreover, dielectric coating from outside sources is an unpredictable element. Consequently, handling any interference from PIM becomes challenging. The complexity of PIM mitigation increases even further when one takes into account ongoing improvements to the radio system, such as smaller cells, higher performing services, and radio configuration along the RF route. However, a number of mitigation strategies have been used in the past to address PIM interference; these are briefly covered here.

The two main categories of PIM mitigation techniques are physical approaches and radio integrated techniques. Physical mitigation approaches refer to methods or modifications that are applied to RF equipment, infrastructure, and the surrounding environment in order to reduce or eliminate PIM interference. These procedures often require a detailed understanding of the physics involved, as they are specific countermeasures to the PIM generation mechanisms previously mentioned. Digital mitigation strategies employ digital signal processing techniques and are incorporated into the signal' s path to prevent PIM interference.

4.1 Physical Mitigation of Passive Intermodulation Interference

As PIM sources can be internal or external, this section should also be separated into two subsections to address the steps that are taken to reduce each type of source.

4.1.1 Steps for Mitigation of Internal Origins of PIM

To reduce internal origins of PIM in radio systems, it is necessary to prevent the effects explained section 2.1. Over the last twenty years, the following rules have been mostly adhered to:

- Reduce the amount of metallic contacts and connectors to ensure that loose contacts and rotating joints are avoided;
- Reduce the amount of thermal variation in the radio system' s components;
- Reduce the amount of current densities in the conduction paths by using larger conductors or larger contact areas, such as MM contacts;
- Maintain all joints tightly and cleanly, ideally using materials coated or made of less oxidizing materials.
- PIM can never completely be eliminated from a system, but it can be greatly reduced with careful planning, excellent craftsmanship, and frequent system maintenance [1, 5, 6].

Low electronic conductivity materials are presently employed in the manufacture of radio system components since electro-thermal phenomena have been shown to be the primary internal PIM causes. This technique makes sure that there may be very few thermal fluctuations even while using high power currents passing through the base station' s RF components [1].

4.1.2 Steps for Mitigation of External Origins of PIM

Compared to internal origins, these are more difficult to handle. One fundamental and widely used recommendation when setting up a site is to scan the surrounding area, or RF path, for probable nonlinear sources that can create PIM and then remove them. These scanners attempt to identify the source by searching for primary test tones that produce IM products. However, mitigation is a challenging task since objects in the radiation path of the antenna are unpredictable and uncontrollable. The distance from these sources also affects the severity of the distortion they produce; in certain circumstances, they might even be the main PIM cause [1].

All radio systems have PIM, hence digital signal processing techniques are utilized to minimize PIM [1, 14]. Nevertheless, base station complexity —specifically, antenna count— increases in tandem with radio network complexity. As previously mentioned, PIM relies heavily on antennas in MIMO systems, which are now widely used. Any enhancement that increases the transmission link' s power (dB) is significant because their sensitivity is dropping.

The efforts that co-site base stations make to prevent excessive interference (PIM) and enhance link quality are referred to as antenna isolation. The physical space between antennas, both horizontally and vertically, antenna polarization, emission pattern, and the antenna' s surrounding environment all affect the amount of isolation that is achieved. When the distance between the antennas and the electrical down tilt (azimuth) angle increases, the mitigation of IM interference generally gets better.

4.2 Radio Integrated Reduction of Passive Intermodulation Interference

In general, physical PIM mitigation solutions are not able to completely eliminate PIM interference. As a result, as shown by [1, 5] and other sources, interest in digital PIM mitigation strategies has recently increased. Generally speaking, the block diagram shown in Figure 4.1 serves as the foundation for the digital PIM cancelation technique. Based on adaptive filter theory, the basic idea of this model is to remove PIM-induced IM products from the receiving signal chain (after I/Q conversion and duplexer) by forecasting them based on the broadcasting signal. The main problem with digital

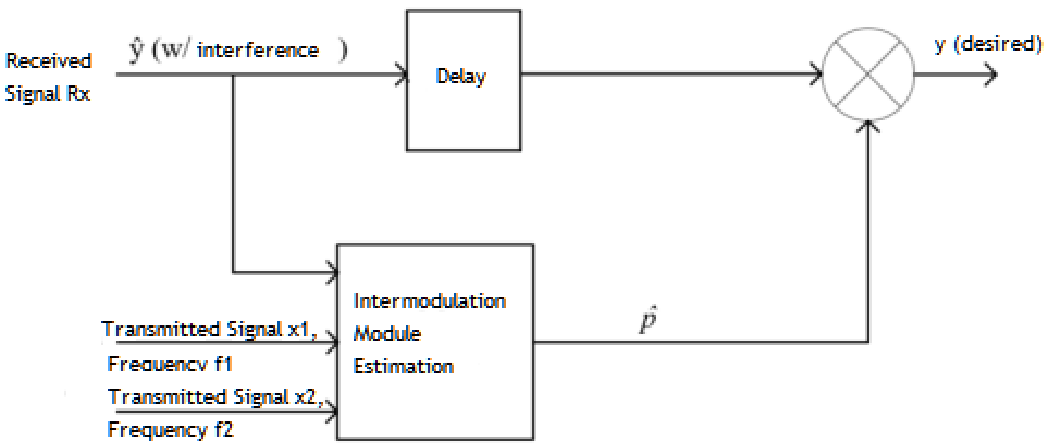

Figure 4.1 Block Diagram for an Adaptive Cancellation PIM Algorithm

cancelation, however, is that PIM products' amplitudes, phases, and delays are not constant and change according to the RF components used (power amplifier, duplexer, etc.). The model used to estimate IM products becomes more sophisticated because while the transreceiver system is offline, the parameters need to be updated or checked. This digital cancellation' s main benefit is that it may be used to reduce the amount of internal IM products that are produced after the Tx filtering. Another often employed strategy is frequency or resource planning. The allocation of available channels for each tier in this system is done using a channel spacing rule. A quick channel allocation is implemented to reduce the amount of spurious interference signals. Network superimposition can be achieved by either block assignment or frequency banning.

- The first stage distributes channel blocks to the two networks, making sure that transmission within the cell is not interfered by any possibly IM product.
- There are three steps in the second stage:

- o Finding the channel combinations in each cell that generate dangerous IM products;
- o Refraining from using those most popular channel combinations; and
- o Employing frequency hopping to recompense for the decrease in capacity (count of channels).

Unlike other systems, frequency planning completely removes the PIM issue, guaranteeing a channel free of PIM. This approach, however, may lead to a decrease in throughput as it hinders the complete use of already available resources. You can also employ unconventional tactics, whereas they will cost higher. As a result of PIM power being proportionate to Tx power, decreased transmit power, for instance, can lessen PIM. Less coverage is the price for this, though. A further example is to increase Rx sensitivity when PIM is about to happen. Neverthless, users located on the cell-edge and therefore interconnect with BS via a lower power level might have their signals suppressed [1, 2].

5 Conclusion

When two or more high-power tones are sent over passive devices (cables, antenna, and the like), PIM occurs. Also, when two or more high-power tones combine at nonlinearities in the device, like dissimilar metal junctions or metal-oxide junctions, such as loose, corroded connectors, the PIM is generated. Even if the system initially seems to be linear and incapable of producing intermodulation, the effect of the nonlinearities becomes more noticeable at higher signal amplitudes, and the intermodulation is more prominent [1, 4, 5].

PIM is a significant issue in today' s communication systems when a single antenna is utilized for both high power transmission and low power reception signals. The passive intermodulation signal is generally on the same order of magnitude as the receive signal power, despite the fact that its strength is sometimes many orders of magnitude lower than the transmit signal power. Consequently, passive intermodulation that enters the receive path is unfilterable and unisolable from the received signal. PIM mitigation strategies can be in a variety of forms, including radio-integrated and physical solutions [1, 14]. Numerous countermeasures have already been put into place as a consequence of extensive research into physical generating mechanisms when it comes to physical mitigation tactics. However, because of this extensive research, PIM is a persistent and unmanageable issue. Therefore, radio integrated mitigation strategies are essential for managing uncertainty. Up until now, the approach for these kinds of methods has focused on predicting spurious frequency emissions; however, new strategies are needed since the spectrum gets saturated. In recent years, digital canceling algorithms have appeared as a reasonable solution, although more performance needs to be achieved. To improve things, continuously data is gathered and analyzed [1, 2]

6 About Yupana

Yupana is a highly dynamic and fast growing company founded in 2011 in the San Francisco Bay Area. Working closely with the wireless carriers tailored engineering services are developed and products are customized allowing customers to build the networks of tomorrow.

Yupana team of highly skilled technicians and engineering bring an unprecedented level of quality and expertise to all field activities, combined with passionate and ambitious team of UTRAN engineers and project managers, and software developers. Yupana leverages many years of international experience managing projects and programs in Tier 1 MNOs, along with world class Engineering expertise.

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