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Passive Inter-modulation Sources and Cancellation Methods

Contents

1 Introduction

Both the user equipment (UE) and the base station (BS) are very important for achieving very high data rates. These are expected to be multimode and multiband to support transmission. However, especially on the UE side, there are restrictions in terms of power consumption, cost, and size. Transmission quality depends on signal quality and wireless system factors, so interference issues should be minimized. Defects in the wireless system architecture cause interference and are caused by technical limitations of the components. This is especially problematic for BS, where large amounts of current flow through the structure and affect the linearity of its components. These high performance systems require the signal path to be highly linear. Otherwise, defects will occur due to non-linear operation. These non-linearities can cause defects in the system, such as intermodulation distortion (IMD).

Intermodulation (IM) is an event that appears when one or more transmit (Tx) signals, with single and multiple frequencies or carriers, are given to a nonlinear system. The output is the inverse spurious frequency caused by the compound of input tones. This produces frequency components within and adjacent to the harmful band. These undesired spectral emissions, called spurious emissions, occur in the receiver band (Rx) and can interfere with the required receiver signal. If the nonlinear system that produces these new frequency elements is a passive linear element of high power systems like transmission lines, connectors, interconnects, or just a metal part, this event is called passive intermodulation distortion (PIM).

An optimal behavior is sought in any RF communication system, which translates into components with linear relationships. Due to the presence of modest intrinsic nonlinearities, it is unfortunately inescapable. Nonlinearities like this cause interference, intermodulation, and harmonic distortion. Intermodulation occurs when a sum of frequencies input signal travels through a nonlinear system, resulting in new frequency content. When the fundamental frequencies are mixed, additional frequency components are created that are integer multiples of the input signal's frequencies [1, 2, 3].

When the IM frequencies generated by the circuits fall into the receiver bands near the transmitter signals in the RF spectrum, intermodulation becomes an interference concern. The input signal Vi is made up of two tones with frequency f1 and f2, as well as corresponding amplitudes A1 and A2 which can be defined as:

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

The signal is subsequently passed via a non-ideal and thus nonlinear current-voltage (I-V) system, whose transfer function is represented by an nth-order power series with coefficients K1, K2, K3,... The nonlinear system's output signal, Vo, can be described as follows:

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

The stronger the K th coefficient in the series (1.2), the more dominating the nonlinear term, i.e., the larger the nonlinear contribution. Additional terms with new frequencies are formed by combining both equations and expanding the series terms using the trigonometric identity and the Binomial theorem [4, 5]. These erroneous frequency components are either harmonics (multiples) of the original signal or the consequence of adding or subtracting the frequencies of the original signal. The IM products, or frequencies that follow the relationship, are the additions and subtractions of the original frequencies f1 and f2.

$$f_{IM} = n f_1 \pm m f_2 \tag{1.3}$$

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where the coefficients n and m are integers. The order of the IM product is determined by adding the absolute values of these coefficients. Despite the fact that some of the higher and lower products may be easily filtered out, odd order IM frequencies are of particular concern because they are often near to the original signals (if the original frequencies in the original signal are close, which is common for multicarrier signals). Figure 1.1 shows an example of an output spectrum that shows the entire range of this occurrence in frequency. In general, the proposed approach can be expanded to multiple frequency components; for example, if three frequency components mix in a nonlinear system, the corresponding third-order IM products (IM3) would be $f_1 \pm f_2 \pm f_3$.
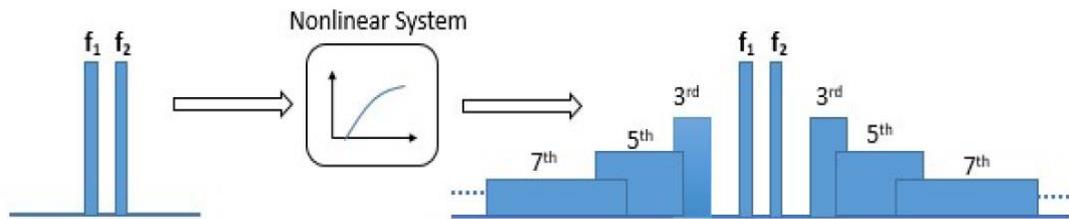

Figure 1.1 Inter-modulation of Two Carries

If the signals are modulated, the bandwidth (Bw) of the IM products formed, not only the center frequency, must be taken into account. The bandwidth of IM products is greater than the bandwidth of the original signals, and it scales with the order of IM. If both input signals are 1 MHz wide, for example, 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 [6]. As a result, assuming both original signals have the same bandwidth, the IM product bandwidth can be calculated as the original signal bandwidth multiplied by the IM product order number. The different amplitudes of the IM products are another crucial aspect. If the input power on the signals is low, IM products have modest amplitudes; but, if the input power is large (as in radio systems), the amplitudes will also grow. If the input signal is increased by 1 dB to achieve the necessary output power, the IM3 product amplitude increases by 3 dB, according to the mathematical equations presented in [4, 5, 7]. Finally, IMD is an event defined by the transmitted signals combined in the nonlinear device, such as relative carrier frequencies, bandwidth, and power.

2 Origins of Intermodulation Distortion

PIM has long been recognized as a potential source of interference in radio communications systems, with the first investigations reaching back to 1989-90 [5, 8]. However, because to the rising saturation of the frequency spectrum and the adoption of wideband multicarrier communications, the PIM problem has resurfaced in recent years. PIM distortion can be divided into three types: design PIM, assembly PIM, and rusty bolt PIM, according to [9]. This classification is based on several nonlinear trigger mechanisms that cause PIM interference, which necessitates a distinct solution. Design PIM refers to the decisions made by designers while selecting layout members, or picking components based on size, power, rejection, and PIM performance trade-offs. Based on the quality (materials, robustness, stability, interface) of the components and surrounding environment, assembly PIM indicates the interference caused by the degradation of the installed system over time. Rusty bolt PIM is linked to downlink frequency reflections towards the uplink in metallic objects in the beam's propagation path (rusty fence, barn, etc.). Any interference signal that can couple into the radio receiver and has a substantial strength difference from the desired received signal might cause receiver desensitization.

It's helpful to divide PIM sources into two categories: internal and external. PIM sources such as coaxial cables, connectors, waveguides, antennas, filters, and other internal PIM sources [5, 6, 8]. External PIM points out sources outside of the antenna that re-radiate the detrimental spurious emission towards the Rx, such as support structures, towers and masts, wire fences, and surrounding metallic objects.

2.1 Internal PIM Sources

PIM is caused by several physical mechanisms, including electron tunneling and thin dielectric layers between metallic contacts, micro discharge between microcracks and across voids (multipactor discharge), nonlinearities associated with dirt and metal particles on metal surfaces, high current densities, nonlinear resistivity of materials used, nonlinear hysteresis (memory effects) due to ferromagnetic and ferrimagnetic materials, and electro-thermal (ET) cohesion.

Until recently, contact mechanisms in RF components were thought to be the primary source of internal PIM in radio system elements such as filters, antennas, and connectors [1, 10, 11, 12]. ET research, on the other hand, surfaced and was recognized as another significant contributor to PIM production in internal sources. Dirt particles and corrosion (contamination) are still a significant source of PIM, and they are a concern that must be addressed in radio systems. The description of the triggers will center on contact mechanisms and ET because the physics of contact mechanisms explains why corrosion can also generate PIM.

2.1.1 Contact Nonlinearities

The nonlinearities in metal contacts, as previously indicated, are one of the key mechanisms responsible for PIMP formation. The metal-insulator-metal (MIM) and metal-metal (MM) scenarios are two types of physical contact that can occur. Each of these physical structures, MIM and MM contacts, has numerous nonlinear mechanisms of its own. Electron tunneling, thermionic emission, and corona discharge are all more likely in MIM structures. Due to variations in metal work functions and nonlinear contact resistances caused by thermal processes such as expansion and thermal fluctuation, MM structures can form diode-like junctions [1]. These two contact types can occur in a variety of ways, especially as they are influenced by terrain and pressure on both ends of the contact.

In general, achieving a completely smooth surface on the termination of radio components during the fabrication process is unachievable. When two radio components are coupled, both contact surface topographies have multiple peaks in random positions and a native oxide or sulfide layer covering them on a microscopic level. The thickness of this layer varies depending on the metals used, but it is often in the nanometer range. As a result, contacting two similar surfaces is similar to contacting needles of varying lengths. Based on these findings, one might deduce that the "actual" contact area is only a fraction of the macroscopic contact area, and that it only occurs in peaks making contact. Similarly, MM scenarios only arise at microasperities where the mechanical pressure was significant enough to induce the connection of the peaks due to surface defects. When the mechanical pressure is inadequate to pierce through the thin dielectric layer covering the metal's surface, the comparable MIM condition arises [1]. As a result of the topology of the surface, a contact can be viewed as a combination of both forms of structure. However, as pressure rises, mechanical deformation rises, increasing the size of the "actual" area by pushing more microasperities connections, allowing researchers to evaluate whether MM happens more frequently. Different models exist to characterize the nonlinearities that appear based on the parameters that define the type of structure, such as deterioration, metals used, and cleanliness. The physical situation described above, in which the current is confined to flow via the microasperities, is depicted in Figure 2.1. The presence of a thin dielectric layer between the microasperities or the emergence of corrosion in the empty zone determines whether the scenario is MM or MIM. The number of MM and MIM scenarios,

however, is dependent on the amount of pressure exerted. The PIM distortion formed at a junction can come from a variety of sources, including MIM and MM, but some contributions are more significant [1]. Because the applied pressure connecting two radio components can decrease in most radio systems, MIM regions are extremely likely to be the main source of IMD, especially since a large number of contacting zones can emerge.
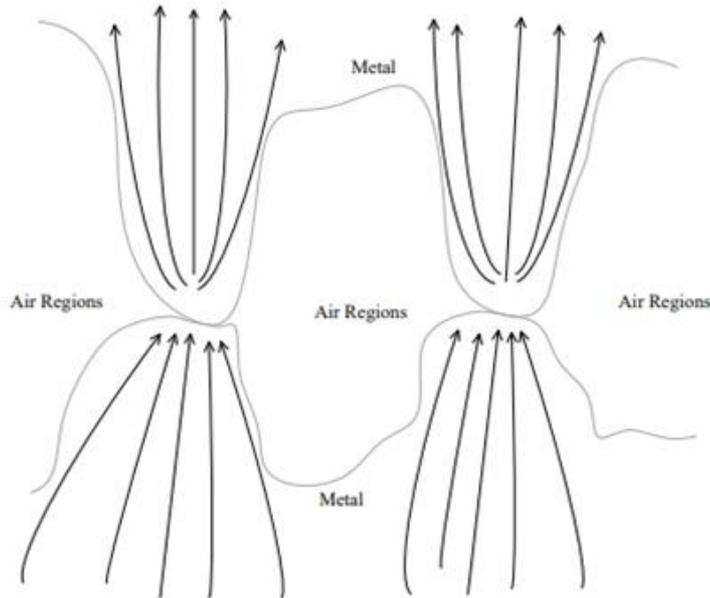

Figure 2.1 Constriction of current in the connection between microasperities

In conclusion, PIM interference can be caused by ferromagnetic materials and dirtiness in contacts. These mechanisms can be found throughout the RF network, including transmission lines, resonant structures, and antennas, in addition to contacts and junctions. Physical conditions incorporated in radio system components, on the other hand, generate PIM signals that can be accumulated across the system. In high-power BS radio systems, where the downlink signals that contribute to PIM formation are extremely powerful, these interferences become increasingly noticeable.

2.1.2 Electro-Thermal PIM Sources

High-power transmit signals might cause electro-thermal effects, which can lead to PIM. When modulated RF signals travel, the continual change in both the thermal and electrical domains causes time variant nonlinear conductivity, which is responsible for PIMP formation [1]. PIM generation due to ET conductivity is also one of the key contributions to exacerbating the problem in internal sources, as previously indicated, and its physics are explored in the following subsections. Electro-thermal effects caused by high-power transmit signals can also cause PIM. When modulated RF signals travel, the continual change in both the thermal and electrical domains causes time variant nonlinear conductivity, which is responsible for PIMP formation [1]. PIM production as a result of ET conductivity is also a major factor in exacerbating the problem in internal sources.

2.1.3 Distributed PIM Sources

In current radio systems, passive nonlinearities are divided into two types: lumped, in which PIM is generated by a single major source, often metal-to-metal contacts, and distributed, in which the sources are dispersed across the infrastructure. In current base stations, weak passive nonlinearities due to ET effects that operate like PIM sources are disseminated throughout the system, similar to the MIM situation. According to [1], the

temperature's influence on conductivity causes significant electrical distortion in microwave elements. As a result of the electro-thermal phenomena, distributed PIM distortion is commonly described as a nonlinear transmission line (NTL). This model can be used to describe PIM production in passive components such as coaxial cables and microstrips due to ET conductivity. In a radio system, these elements, along with contact terminations (lumped components), play a critical role in generating PIM. The PIM distortion in the NTL model is caused by singular elements of a nonlinear transmission line. The total of nth order PIM outage power owing to ET effects is the sum of all the impacts reproduced by the cells. The reader is directed to [1] for a thorough explanation of how PIM is formed in each tiny element. To recapitulate, a nonlinear electric field (E) of IM products is generated in a line component by the nonlinear current (J) generated by variable heat dissipation (Q). The PIM signal is the sum of the electric fields that have accumulated down the line as a result of several components. In essence, each line element is a nonlinear generator whose signal power is proportional to its impedance (varies throughout the line). It's worth noting that each point generates two electric fields, one forward and one reverse. However, the latter is minimal due to destructive interference after line length z = /4. PIM can, however, flow backwards by reflecting the forward PIM signal at the line's termination. A illustration of PIM creation from the NTL model is shown in Figure 2.2. In conclusion, it is possible that the many resistive parts through which the current travels contribute to PIM distortion due to ET conductivity.
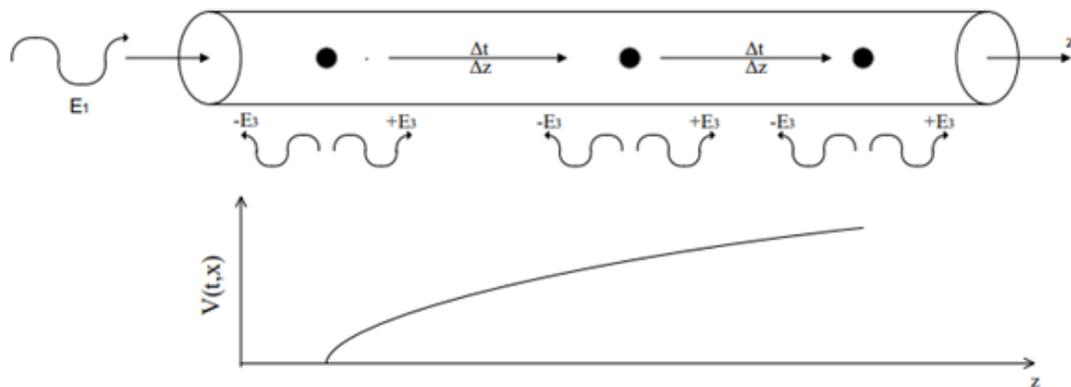

Figure 2.2 PIM's signal strength sequential increase due to the generated fields in nonlinear consecutive points in the transmission lines

2.2 External PIM Sources

The focus of the discussion thus far has been on nonlinear triggers of internal PIM sources; nevertheless, the PIM problem extends beyond the radio system's internal components. External sources of PIM can sometimes be unpredictable and unmanageable. In either situation, indoor or outdoor, resolving site interference concerns reveals the challenges related with PIM from external sources. The author of [13] conducted a study on the challenges that a site faces. It was established that non-linear objects in the RF path, such as sheet metal vents, metal flashing, ceiling tile frames, street lamps, and so on, might generate IM products and re-radiate them into the system. The "Rusty Bolt" effect is a frequent name for this effect. As a result, antenna position and orientation are critical for removing external sources from the system's RF path. The way energy couples with the nonlinear item and how it is received back into the Rx is also affected by antenna polarization. Varying antenna linear polarization (+45 and 45, respectively) leads to different degrees of third order IM products created externally by stacking metal sheets, as illustrated also in [13]. Tx and Rx functions are combined into one antenna in a conventional FDD radio system, while various antennas and bands perform simultaneously in a co-site scenario where multiple radios from the same or separate operators are installed. Intermodulation distortion of

signals is a serious challenge in site integration. Internal causes like as contact nonlinearities (described and quoted in 2.1.1), material nonlinearities, and electro-thermal nonlinearities [1, 5, 10] are commonly blamed for PIM interference in antennas. PIM can, however, be generated externally (outside the base stations), in simple metallic components, as discussed in section 2.2. PIM products can be generated or reflected by simple objects in the RF path, such as rusted junctions or metal structures, and are captured by the antenna as noise [5]. Tx and Rx functions are combined into one antenna in a conventional FDD radio system, while various antennas and bands perform simultaneously in a co-site scenario where multiple radios from the same or separate operators are installed.

2.2.1 External Sources as PIM Antennas

The physics behind IM produced products of reflections in metallic objects, which is based on the TDPO technique, was described in the previous subsections. It works by inducing a nonlinear current that radiates an electric field with the frequency of the IM products back to the BS antenna, which can then couple with the receiver chain. In fact, the TDPO method may be used to determine the scattered EM fields of dielectric substances and huge reflector antennas. However, when a reflector antenna, such as a parabolic reflector, is illuminated by high-power microwave radiation, the principal cause of false signal radiation is electron tunneling in the MIM junctions, which is known as the "Rusty Bolt" phenomenon. Nonlinear currents originating from two or more transmitters are induced in the reflector surface and flow through the object in this situation. MM or MIM junctions are formed when the local current encounters connectors, slits, or cracks during this process. Across tunneling events and corona discharge of the two or more currents running through the junction, nonlinear I-V characteristics emerge, which generate and radiate IM products. The produced IM products are subsequently radiated back at the transmitting antenna, where they may interfere with Rx bands. External sources can be seen as PIM antennas based on this research.

The physics of PIM from internal sources, specifically MIM sjunctions, are the key contributors to radiate PIM towards the Tx antenna, even when the sources are beyond the antenna, e.g., are external to the radio. It is defined by its parameters, just like any other antenna, but these cannot be measured. The strength of the current induced and how it flows in the surface determine the radiation pattern, polarization, directivity, and gain. Furthermore, many MIM junctions and reflections from a single external source might contribute to the radiation of IM products. Dielectric coating and incoming wave polarization are two unpredictable elements that can alter this generation. As a result, it's reasonable to predict that different PIM antennas should be expected based on the external source met by the broadcast tones.

3 Passive Intermodulation Distortion in Radio Systems

PIM is a type of radio interference that has the potential to reduce the efficiency of a cell site, consequently influencing the performance of a radio network directly. Furthermore, the problem of PIM interference is aggravated by the cohabitation of numerous communication systems in the same areas, and it is becoming more of a concern as network complexity and deployments rise. As a result, it is a problem with a growing influence on networks. Intermodulation concerns are exacerbated in broadband radio systems where bandwidth is expanded to obtain higher data rates, especially when CA is used, because PIM interference is a problem in the RF spectrum. However, active narrowband systems such as GSM are susceptible to PIM interference. Because of the

nonlinear generating techniques, passive intermodulation is frequently seen as an installation issue, most commonly seen in high-power cell sites. However, this is only a surface consideration, as interference issues are frequently caused by a saturated RF spectrum. PIM has become a volatile concern as a result of the constant updating and expansion of network systems, and its effects on RF systems will continue to worsen. This is especially true in 5G, where the seamless integration of several base station technologies is becoming more common.

3.1 Passive Intermodulation in Broadband Radio Systems

Most literature describe and analyze PIM based on two unmodulated carrier signals. As it is explained in section 2.1, in this case, the resulting PIM products are also narrow carriers spurs. However, in broadband radio systems like UMTS and LTE, the signal is modulated over a wider bandwidth and can be transmitted through several bands of the RF frequency, especially with the employment of features like CA. Furthermore, the combined modulated signals can be both narrowband or broadband at the same time. Hence, consider a general noncontiguous dual-carrier CA FDD transceiver whose Tx signal is represented as

$$x[n] = x_1 e^{jf1} + x_2 e^{jf2} \qquad (3.1)$$

This signal is made up of two component carriers (CCs), denoted by x_1 and x_2 and respective frequencies f_1 and f_2 ($f_1 < f_2$). Mixing occurs and IM components appear when this noncontiguous Tx signal travels via a nonlinear passive source.

Consider an FDD system in which signals are broadcast from several bands. Consider two channels, B2 and B21, that transmit from band 2 and band 21, respectively. The transmitting carrier has a center frequency of 1940 MHz and a bandwidth of 10 MHz, while the band 2 DL runs from 1930 to 1990 MHz. The transmitting carrier has a central frequency of 2130 MHz and a bandwidth of 10 MHz, while the band 21 DL runs from 2110 MHz to 2155 MHz. PIM products are created during transmission due to a nonlinearity on a passive device. Consequently, because they are focused around 1750 MHz, one of the created spurious 3rd order and fifth order IM products will overlap with the B21 receiver spectrum, which spans 1710 MHz to 1765 MHz. Furthermore, because the B2 carrier's bandwidth extension is big enough to fall within this Rx band, the OOB 5th order product overlaps with B15 UL. Even if the false emission is more detrimental, both possibilities lead to a potential danger of interference. The preceding situation is depicted in Figure 3.1.
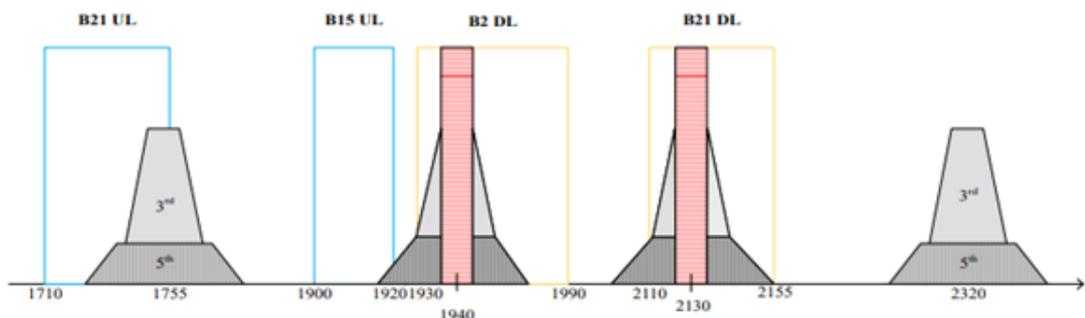

Figure 3.1 Spectral regrowth given the spurious and OOB emission due to IM of carriers from B2 and B21 that can lead to interference in B15 and B21s

Spectral regrowth is typical in active broadband base stations, where the carriers merged at the source are from multiple frequency bands. The scenario is known as cross-band PIM when the CCs engaged in PIM generation are from multiple bands, as in the example above. In the same way, if all of the carriers are from the same band, the scenario is known as in-band PIM. The refarming of RF spectrum, such as new DL bands and interband
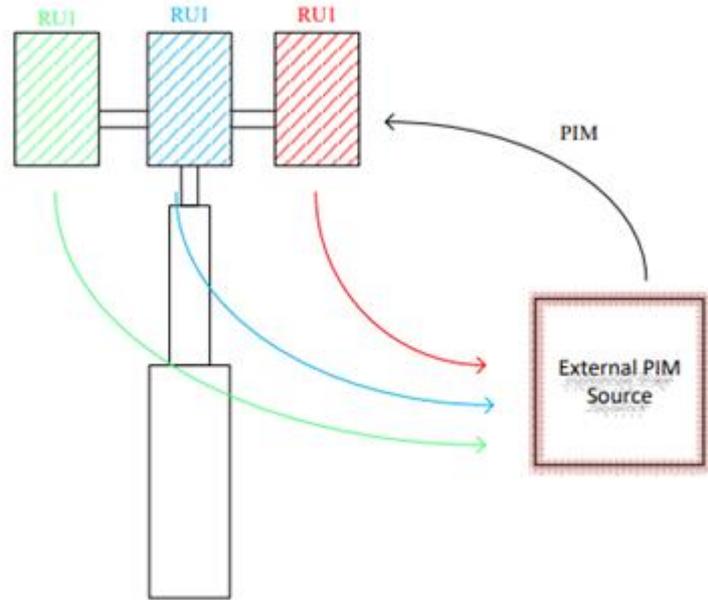
Figure 3.2 Cross-PIM scenario involving three radio units, RU1, RU2 and RU3 and an external source close to the BS

CA, as well as the increasing complexity of the BS, are exacerbating cross-band PIM. Furthermore, because the number of external sources in which the carriers can mix is rising, cross-band PIM is a contemporaneous scenario in modern radio systems. Figure 3.2 illustrates this scenario.

4 Passive Intermodulation Mitigation Techniques

PIM-generated spurious signals interfering in the Rx bands are generally quite unpredictable. The spurious signals are based on the site's environment, RF infrastructure characteristics, external and internal sources, as well as configured bands and used frequency channel, as previously explained. The nonlinear features of the PIM producing source usually determine the strength of interfering signals. Furthermore, there is the uncontrollable factor of dielectric coating in external sources. As a result, dealing with any PIM interference becomes a difficult task. When considering continual radio system enhancements, such as higher performing services, smaller cells, and radio configuration in the RF route, the complexity of PIM mitigation becomes even more. Nonetheless, PIM interference has been addressed in the past using a variety of mitigation approaches, which are briefly discussed below.

Physical techniques and radio integrated techniques are the two primary kinds of PIM mitigation techniques. Physical mitigation techniques are processes or changes to RF equipment, infrastructure, and the surrounding environment that can be used to correct or minimize the level of PIM interference. These processes are frequently particular countermeasures to the previously described generation mechanisms, and thus necessitate a thorough grasp of the physics involved. To prevent PIM interference, digital mitigation mechanisms are included into the signal's path and use digital signal processing techniques.

4.1 Physical Mitigation of Passive Intermodulation Interference

Because PIM sources can be internal or external, this section should be divided into two subsections to account for the physical activities taken to minimize both sorts of sources.

4.1.1 Guidelines for Mitigation of Internal Sources

Counteracting the effects indicated in section 2.1 is required to mitigate internal sources of PIM in radio systems. For the past two decades, the following guidelines have generally been followed:

• Minimize metallic contacts and connectors, ensuring that loose contacts and rotating joints are avoided;
• Keep thermal variations in the components of the radio system to a minimum;
• Keep current densities low in the conduction paths by using larger conductors or having bigger contact areas, e.g., MM contact;
• Minimize metallic contacts and connectors, avoiding loose contacts and rotating joints;
• Keep thermal variations in radio system components to a minimum;
• Keep all joints clean and tight, preferably made or coated with materials less prone to oxidation; Although no system is fully free of PIM, careful planning, quality craftsmanship, and a high degree of system maintenance are all necessary to significantly reduce its level [4, 5].

Since electro-thermal effects have been established as the main internal PIM sources, low electronic conductivity materials are currently being used in the production of radio system components. While using high power currents flowing through the RF components of the base station, this practice ensures that thermal changes are maintained to a minimal.

4.1.2 Guidelines for Mitigation of External Sources

These are more harder to deal with than internal sources. Scanning the surroundings, or RF route, for potential nonlinear sources that can cause PIM and then deleting them is a basic and common guideline used when setting up a site. These scanners look for primary test tones that generate IM products in order to pinpoint the source. Objects in the antenna's radiation path, on the other hand, are unexpected and uncontrollable, making mitigation a difficult task. The strength of the distortion generated by these sources is also depending on how far away they are located, and they may even be the primary PIM source in some situations.

Because PIM is inherent in all radio systems, digital signal processing techniques are used to reduce PIM. However, as radio networks become more complicated, so does the complexity of base stations, particularly the number of antennas. As previously explained, MIMO systems are currently in place, with antennas playing a key role in PIM. Because their sensitivity is decreasing, any improvement that enhances the transmission link's power (dB) is important.

Antenna isolation refers to the considerations that co-site base stations make in order to avoid excessive interference (PIM) and improve link quality. The amount of isolation obtained is influenced by a number of elements, including the physical horizontal and vertical separation distance between antennas, antenna polarization, radiation pattern, and the antenna's surrounding environment. In general, the mitigation of IM interference improves as the distance between the antennas and the electrical down tilt (azimuth) angle increase.

4.2 Radio Integrated Mitigation of Passive Intermodulation Interference

Physical PIM mitigation techniques, in general, cannot entirely resolve the PIM interference problem. As a result, digital PIM mitigation measures have lately sparked interest, as evidenced by [4] and others. In most cases, the digital PIM cancellation method is based on the block diagram presented in Figure 4.1. The fundamental idea behind this model, which is based on adaptive filter theory, is to forecast PIM-induced IM products based on the transmitting signal in order to remove them from the receiving signal chain (after I/Q conversion and duplexer). However, the fundamental issue with
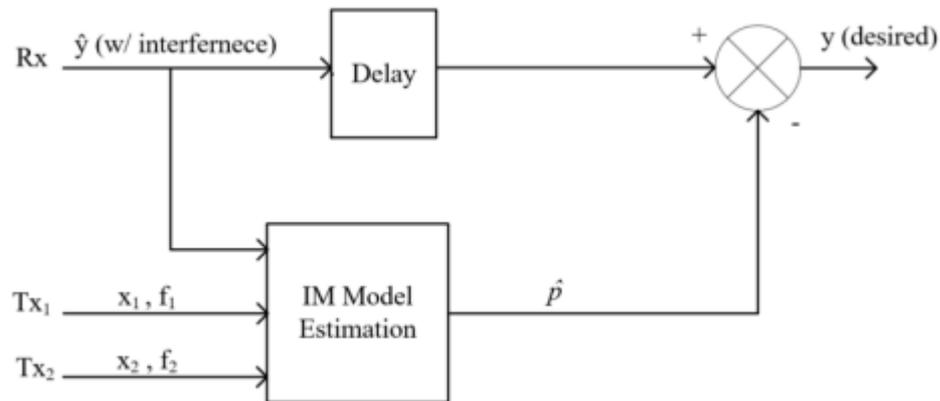
Figure 4.1 Diagram block for an adaptive cancellation PIM algorithm

digital cancellation is that the amplitudes, phases, and delays of PIM products vary dependent on the RF components employed (PA, duplexer, etc.) and are not constant. Because the parameters must be updated or examined when the transreceiver system is offline, this adds to the complexity of the model used to estimate IM products. The key advantage of this digital cancellation is that it can be utilized to minimize the internal IM products generated after the Tx filter. Frequency or resource planning is another often used method. In this method, a channel spacing rule is used to determine the allocation of available channels for each tier. The channel allocation is made hastily in order to minimize spurious interference signals. The process of superimposing the networks can be accomplished through block assignment or frequency banning.

- The first allocates channel blocks to both networks, ensuring that no potentially IM product interferes with transmission within the cell.
- The second stage consists of three steps:
    - Identifying the channel combinations that produce hazardous IM products in each cell;
    - Avoiding the most popular channels in the combinations; and
    - Using frequency hopping to compensate for the reduction in capacity (number of channels).

Frequency planning, unlike other systems, totally eliminates the PIM problem, ensuring a PIM-free channel. This method, on the other hand, prevents full utilization of existing resources and can result in lower throughput. Unusual strategies can also be used, although they come at a higher cost. Reduced transmit power, for example, can minimize PIM because PIM power is proportional to Tx power. However, this comes at the expense of lesser coverage. When PIM is imminent, another example is to boost Rx sensitivity. However, users on the cell-edge, who will be interacting with BS at a low power level, may have their signals blocked.

5 Conclusion

PIM happens when two or more high-power tones are sent through passive equipment (such as cables, antennae, and so on). The PIM product is created when two (or more) high-power tones mix at nonlinearities in the device, such as dissimilar metal junctions or metal-oxide junctions, such as loose corroded connectors. The effect of the nonlinearities is more obvious at greater signal amplitudes, and the intermodulation is more prominent — even if the system appears to be linear and unable to generate intermodulation at first glance.

When a single antenna is used for both high power transmission and low power receive signals, PIM is a serious challenge in current communication systems. Although the

strength of the passive intermodulation signal is often many orders of magnitude lower than the power of the transmit signal, it is frequently on the same order of magnitude (if not higher) than the power of the receive signal. As a result, passive intermodulation that makes its way into the receive path cannot be filtered or isolated from the receive signal. There are many types of PIM mitigation techniques deployed, including as physical and radio integrated solutions. In terms of physical mitigation approaches, various countermeasures have already been implemented as a result of considerable research into physical generating mechanisms. However, PIM is a persistent and uncontrollable problem as a result of this vast research. As a result, radio integrated mitigation approaches are critical for coping with unpredictability. Until far, the strategy for these types of techniques has been concentrated on anticipating spurious frequency emissions; however, as the spectrum becomes saturated, new tactics are required. Digital cancellation algorithms have emerged as a feasible option in recent years, but they still need to be improved for greater performance. Data collection and analysis are used to make improvements.

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.

For more information, please contact:

E-mail: info@yupanatech.com

Web: www.yupanatech.com

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