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NEW MODULATION Raise PIM

PASSIVE-INTERMODULATION DISTORTION IS BECOMING A SYSTEM- AND COMPONENT-LEVEL ISSUE THAT IS ONLY GROWING AS DASs AND SMALL CELLS CARRY THE BURDEN OF HIGH DATA TRAFFIC.

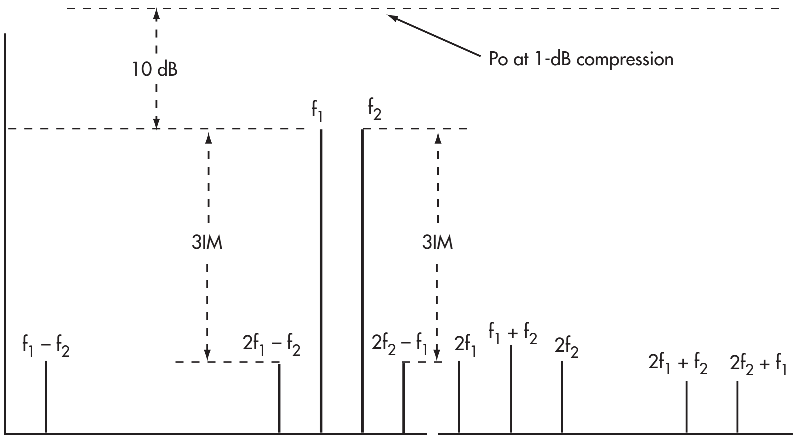
Consumers and industrial users are demanding higher rates of wireless connectivity and uninterrupted connections. This would imply the need for a very complex system of transmitters and receivers distributed throughout common environments and in industrial facilities. Such demands require transceiver systems with very high throughput capability across many different frequency bands. The latest modulation standards, such as LTE-Advanced (LTE-A) and WiGig, are designed to meet these demands in the busiest of thoroughfares or facilities.

In the meantime, however, the legacy challenge of dealing with modulation distortions caused by passive components has increased wireless system costs, decreased system performance, and raised the standards of component construction. Passive-intermodulation (PIM) distortions decay data rates, block frequency bands, and are highly costly to pinpoint and repair. Distributed antenna systems (DASs) and small cells are more susceptible to PIM interference than large stand-alone antenna systems. Understanding PIM's broad-spectrum effects and developing best practices to guard against may become a necessity for complex antenna systems.

By definition, passive-intermodulation distortion is a complex frequency response that occurs when multiple frequency tones exist along the same signal path and encounter nonlinear junctions. PIM differs from the harmonic products of mixing, as they are usually closer to the frequency band of reception. Modulation-distortion products are a known problem with active nonlinear devices like mixers, circulators, and amplifiers. These components are rigorously designed to limit their distortion products. The material properties of structures used in the construction of RF/microwave components also can produce nonlinear effects at certain frequencies and under certain conditions. When these nonlinear junctions are present in the signal path of an RF/microwave signal, the signals combine and produce PIM. Mathematically, PIM can be explained using a power series with sinusoidal signals. Eq. 1 is a power series of an amplitude product and an electric signal:

$$E_{out} = \sum_{i=0}^{N} K_i E_{in}^i \quad (1)$$

The output of such a power series is a simple solution, as indicated in Eq. 2.:



1. The harmonic and non-harmonic products of frequency mixing appear in the spectrum at fixed multiples of the mixed frequencies.

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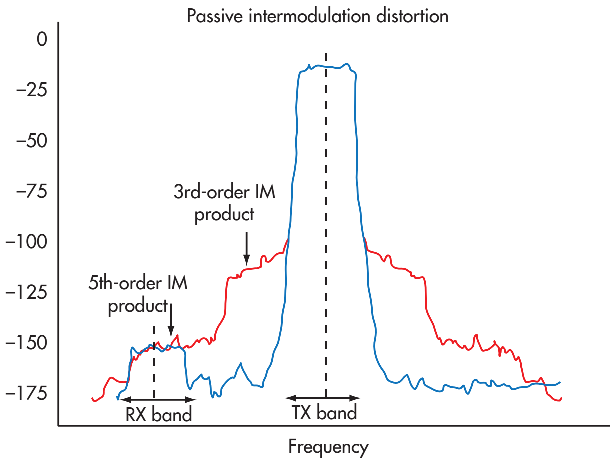


2. The spectral response of the mixing of powerful tones can produce odd-order modulation products in the reception bands of a duplex standard, such as LTE.

$$E_{out}=K_1E_{in}^1+K_2E_{in}^2+K_3E_{in}^3+\ldots \quad (2)$$

When a single sinusoidal signal is added to the input of the system, more complex products are produced. The expansion in Eq. 3 demonstrates a harmonic response that grows in frequency as integer multiples of the input sinusoidal signal frequency.

$$\begin{aligned} E_{out} &= \sum_{i=1}^{N} K_i E_{in}^i \cos(i\omega t) \\ &= K_1E_{in}^1\cos(\omega t)+K_2E_{in}^2\cos(2\omega t)+K_3E_{in}^3\cos(3\omega t)+\ldots \end{aligned} \quad (3)$$

The input signal in Eq. 4 is a compound signal of two sinusoidal tones.

$$E_{in}=a\cos(\omega_1 t)+b\cos(\omega_2 t) \quad (4)$$

When two tones are input into a power series, the response is a progression of multiple-order products. This progression is shown in Eq. 5 with only the odd-order products up to the ninth order. The order is determined by the addition of the integers multiplied by the frequency. The amplitude of the signal also is a function of the progression, and decreases as the order increases.

$$\begin{aligned} E_{out} &= \ldots + \\ &\langle \text{3rd Order}\rangle A_3\cos(2\omega_1 t-\omega_2 t)+A_3\cos(2\omega_2 t-\omega_1 t)+ \\ &\langle \text{5th Order}\rangle A_5\cos(3\omega_1 t-2\omega_2 t)+A_5\cos(3\omega_2 t-2\omega_1 t)+ \\ &\langle \text{7th Order}\rangle A_7\cos(4\omega_1 t-3\omega_2 t)+A_7\cos(4\omega_2 t-3\omega_1 t)+ \\ &\langle \text{9th Order}\rangle A_9\cos(5\omega_1 t-4\omega_2 t)+A_9\cos(5\omega_2 t-4\omega_1 t)+\ldots \end{aligned} \quad (5)$$

In Eq. 5, for example, the integer multiplied by frequency one is 2. The integer multiplied by frequency two is 1. The combination of these two integers is the designation for the third-order intermodulation distortion. These products occur at the combination frequencies and at various power levels. For two tones, the frequencies at which these products occur is dictated by Eq. 6, where m is 1 less than n *(Table 1)*.

$$\begin{Bmatrix} f_{IM-} \\ f_{IM+} \end{Bmatrix} = \begin{Bmatrix} nf_1-mf_2 \\ nf_2-nf_1 \end{Bmatrix} \quad (6)$$

The power of these unintended signals decreases as the order of the product increases. This is represented mathematically in Eq. 7.

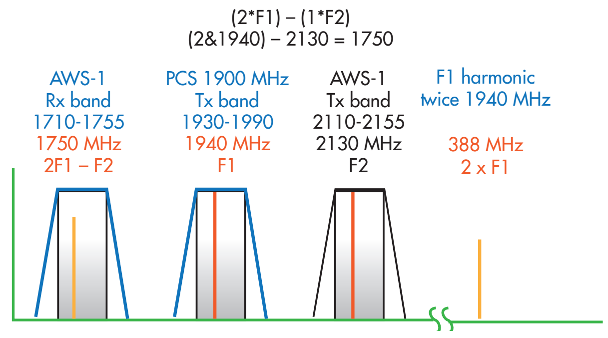
$$\begin{Bmatrix} P_{IM-} \\ P_{IM+} \end{Bmatrix} = \begin{Bmatrix} nP_1+mP_2-2{*}IIP(n+m) \\ nP_2+mP_1-2{*}IIP(n+m) \end{Bmatrix} \quad (7)$$

Graphically, this appears as a series of impulses at the frequency combinations *(Fig. 1)*. The third-order product is often the product of concern, as it could potentially be of high enough power and within the reception band. This product also could increase the noise floor in the reception band and lower the signal-to-noise ratio (SNR). In doing so, it will directly degrade the throughput performance of high-speed data lines.

As most signals broadcast from telecommunication antennas are not perfect tones, the PIM and harmonic responses are not impulses. The responses are spread more widely through

TABLE 1: INTERMODULATION PRODUCTS FOR A TWO-TONE SIGNAL

IM3-	IM3+	IM5-	IM5+	IM7-	IM7+	IM9-	IM9+
2F1 – F2	2F2 – F1	3F1 – 2*F2	3*F2 – 2*F1	4*F1 – 3*F2	4*F2 – 3*F1	5*F1 – 4*F2	5*F2 – 4*F1



3. An interference product is produced from a duplex frequency standard in the reception band by the transmission signal mixing with another duplex standard.

the frequency spectrum *(Fig. 2)*. This aspect suggests that the PIM product doesn't need to be exactly within the reception band to cause distortions. Rather, it must be within the receive filter's passband *(Fig. 3)*.

As the LTE and LTE-A standards require higher-throughput data, maintaining a low noise floor is a chief concern. Telecommunications systems in less dense spectrum may only consider third-order intermodulation distortion as significant. This is not the case with very dense spectrum, as the other-order products could be within the reception band of neighboring carriers. Other-order products also may increase the noise floor throughout the system, as they may be retransmitted. *Tables 3 and 4* (online only) show commonly used cellular telecommunications bands that are affected by PIM products beyond just third-order intermodulation distortion. The antenna front ends and antennas for these complex digital modulation standards also are increasing in frequency performance and density.

For example, increased frequency-handling capability is being designed into the latest mobile antennas. These antennas transmit and receive efficiently at many different bands and switch between these bands rapidly. This approach would not cause enhanced PIM issues in an isolated system. When these antenna systems are distributed throughout an environment to ensure good signal reception, the proximity of these

TABLE 2: INTERMODULATION PRODUCTS FOR A THREE-TONE SIGNAL

F1	F2	F3	A–	A+	B–	B+
—	2F2-F3	2F2-F1	2F1-F2	2F3-F2	2F1-F3	2F3-F1

* See Fig. 2

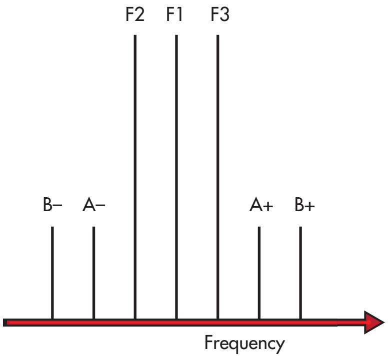
antennas decreases. This densification of antennas and broadcast frequencies has led to a scenario in which the redundant transmission of the antennas could induce significant PIM levels within their companion structures. PIM then extends beyond the simple two-tone frequency case and multiplies the frequencies mixing throughout the signal environment *(Fig. 4)*.

The products for multi-tone frequency mixing are more numerous than with just two tones. In a two-tone mixing, there are only two third-order intermodulation-distortion odd-order products that are considered of primary concern. With three-tone mixing, there are four third-order intermodulation-distortion odd-order products of similar power levels *(Table 2)*. Modulation schemes that use the same frequency for transmit and receive (like time-domain LTE and WiGig, for example) could exhibit degraded performance with multi-tone PIM generators nearby.

This problem is compounded when considering DASs, which are predominantly used for commercial and industrial areas, where enclosed spaces limit larger cell broadcasting. These areas are often more prone to having PIM generators in the environment and near the antennas. PIM generators could be any material that is electrically responsive in the environment—with either nonlinear properties or the potential for such properties when in contact with other materials.

PIM generators include ferromagnetic materials, galvanic contacts, solder joints, screw connections, conductive coatings, rust, and antenna systems. Such concerns have driven manufacturers of RF/microwave passive components to design low PIM-performing products. mw

Editor's Note: To read the full version of this article, visit www.mwrf.com/passive-components/new-modulation-schemes-raise-pim.



4. Multiple tones have the capability of mixing and creating modulation products that can cause unpredicted distortions.