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An Introduction to PIM

What Is PIM?

In recent years passive intermodulation (PIM) has become a major concern for wireless service providers and those responsible for building and maintaining wireless networks. The increase in awareness around PIM comes with the increasing complexity of how spectrum is utilized. The push to increase spectral efficiency in wireless networks by utilizing technologies like higher order modulation, channel aggregation and MIMO makes keeping an eye on sources of PIM in current and next generation wireless systems increasingly important. PIM in antennas, circuits and transmission lines can place limits on the performance of wireless communication systems but also sensor, radar and navigation systems.

It is accepted and even expected that active components generate nonlinearities in systems, and different approaches have been developed to improve the performance of active devices in the presence of non-linear responses. But passive devices can also introduce non-linearity into a system

PIM can occur when passive devices are exposed to two (or more) high power signals. PIM products are formed by the signals mixing at a nonlinearity in the component. A signal amplitude increases so does the effect of the nonlinearity - PIM can often only manifest at increased power, leading one to conclude on inspection at lower powers that a device is linear and functioning appropriately.

Nonlinearities

A nonlinearity in a passive component can act like a diode, and diodes can be used to make a simple mixer. In fact looking at how mixers work can help us understand the mechanisms behind PIM and some of the effects it can have on our system.

In a mixer the desired function, which is usually to provide the sum and difference of the two inputs, relies on a nonlinearity. A simple diode based mixer works with the nonlinear response of the diode, in that the response (current) is not linear with the input (voltage). If the response current is then run through an external load (say a resistor) the resulting voltage does not look like the input voltage and the behavior permits the frequency modulation that the mixer designer is after.

We can look at this another way. We know the output

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voltage of the diode in this mixer is non-linear. So we can expect the output to be the sum of the two inputs plus a series of non-linear terms, and we can describe a non-linear output voltage this way:

$$v_0 = (v_1 + v_2) + \frac{1}{2}(v_1 + v_2)^2 + \cdots$$

Where v0 is the output voltage, v1 and v2 are the two inputs and we have truncated the series to the quadratic term.

Let's say that the voltages are sinusoids:

$$v_0 = (\sin(at) + \sin(bt)) + \frac{1}{2}(\sin(at) + \sin(bt))^2 + \cdots$$

Expanding the second term and using some handy trigonometric identities we find that the output voltage has a terms that include tones whose frequencies are the sum and difference of the original frequencies a and b:

$$v_o = \cos\big((a - b)t\big) + \cos\big((a + b)t\big) + \cdots$$

So nonlinearities can create additional tones that are the sum and difference of the input tones. In Mixers this is expected and good, but in passive components in the form of PIM this can be detrimental to the performance of the system.

PIM Arithmetic

Let's look at a system that is exposed to two frequencies a and b. These could be the transmit/receive in a FDD based wireless system, for example. The bandwidth of each is c. Now if we take the sum and difference we get a+b and a-b, which are well above and below the operating bands of the system. But what if we encounter mixing with the harmonics of these frequencies? We would see (for example) 2a-b and 2b-a. If the math works such that these tones are close enough to a and b to cause interference, then we could have a problem. Take for example 716MHz and 734MHz:

a = 734MHz

b = 716MHz

a - b = 18MHz, not a problem

a + b = 1450MHz, not a problem (for this system at least)

2a - b = 698MHz, only 18MHz away from a, so could be an issue if c (bandwidth) is large enough

2b - a = 752MHz, only 18MHz away from b, so again could be an issue if c (bandwidth) is large enough

The degree to which PIM impacts a system has a lot to do with the two input tones a and b and how the system is set up to tolerate interferers that close to the signals of interest. However having to account for PIM in a systems spectrum planning can become a major source of difficulty, especially if the sources of PIM are not accounted for beforehand.

Avoiding PIM

In system components there are a range of causes for PIM inducing non-linearities. Common sources include the use of ferromagnetic materials, since their hysteresis leads to non-linear behavior (some Mixers are based on ferromagnetic core inductions), defects in metal interconnects and material impurities. Some of these effects can be mitigated by overplating but if your goal is to reduce sources of PIM in your system from components like capacitors it is best practice to eliminate contributing materials wherever possible. Knowles has engineered a range of alternatives to the traditional approach that can help you avoid PIM in your next system design.

Traditional surface mount multilayer ceramic capacitors are supplied with a nickel barrier finish as industry standard. This consists of a base layer over plated with nickel, which provides solder leach resistance, followed by a plated top layer of pure tin to maintain a readily solderable finish. Nickel however has undesirable properties in PIM sensitive applications in addition to magnetic properties which are unacceptable for certain medical applications.

Historically, the industry solution for a non-nickel termination material was silver/palladium (Ag/Pd), however the solder leach resistance of this termination type is inferior to that of the nickel barrier, the raw material costs are also high. In addition this option requires the use of low melting point solders, typically lead-based, doped with a small amount of silver to prevent silver leaching out of the termination, these solders are not compatible with regulations such as RoHS.

To meet the demands of these applications for non-nickel components, the engineers at Knowles Precision Devices have developed a non magnetic range of MLCC products. The devices are constructed using selected non-magnetic dielectrics and a nickel free copper barrier plated finish ensuring RoHS compliant and compatible soldering properties. Available in both class 1 and class 2 dielectrics and in high power form factors this renders the ranges ideal for both magnetic sensitive medical and PIM critical applications.

When designing a system with PIM in mind, consider the material composition of the individual components. For help with selecting capacitors specifically designed to minimize contributions to PIM, contact a Knowles Precision Devices to learn how their solutions can help you keep PIM under control.