Antenna Isolation Testing for Systems With Multiple Radios

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Why isolation testing matters

If your product has more than one radio and at least one of them is a transmitter, your device is at risk of intermittent radio performance problems. To ensure this does not happen, or the affects of it are limited, proper antenna isolation testing needs to be performed during the design of your product. Your product may even pass type approvals or certification testing, however your customers and users may still experience device communication issues, which ultimately can lead to market rejection.

The issue – transmitting antennas drown each other out

Whenever two antennas are physically close together, radio frequency isolation decreases between those antennas and the antennas can “hear” each other better. The problem occurs when one of those antennas is transmitting, while the other antenna is receiving or transmitting. In situations where, the antennas are both receiving only, there is usually no problem. The challenge is if one antenna or more is a transmitter. In this scenario, the transmitter(s) degrade receiver performance, and can interfere with other radio systems and/or cause certification problems such as radiated spurious emissions (RSE).

At a very basic level, you can think of a radio receiver as an extremely sensitive ear trying to listen to transmitters on its frequency that are very “far” away. “Far” is defined as more than three meters away from the co-located transmitter antenna. The co-located transmitter antenna (the one that’s transmitting) is a bit like a fighter jet at full throttle right next to you. You can’t hear the quiet transmitter you want, because of the loud transmitter you don’t want.

Factors affecting isolation

The main factor affecting isolation is the proximity of the antenna elements. The further apart they are, the better the isolation. In systems made up of separate antenna elements, spacing those antennas wisely can avoid problems with isolation entirely. By keeping the antennas separated, the radios won’t interfere with each other. How far those antennas have to be separated is a simple question with a complex answer.

A second factor is related to the losses in the transmission lines used to connect antennas to their respective radios. At GHz frequencies, transmission lines of any significant length (more than 3 feet) can present losses that impact system performance and isolation. The loss in the transmission line hurts link budget

performance because power is being dissipated as heat in the transmission line. That same loss however, lowers the power that gets to a transmit antenna and further decreases the power coming back to a radio from the receive antenna. For this reason, it's critical to include the actual transmission line losses for both transmitter and receiver when calculation or measuring isolation.

Another factor to bear in mind is that there is also a filter-like effect because most antennas are efficient radiators only at certain frequencies. This situation creates a weak, passive bandpass filter behavior and that bandpass effect can amount to an overall meaningful suppression of out-of-band signals, especially when the frequencies are very different.

Impacts of poor isolation

Front end de-sense

Front end de-sense is caused when there is a strong enough RF signal presented to the first amplifier in the receive chain to cause it to go into gain compression. The frequency of the signal itself is not of concern; only that the signal amplitude is significant enough to cause gain compression. It's common for this situation to arise where the transmitting signal is out of band to the receiver. In compression, the effective gain of the amplifier goes down, and the net effect is that the receiver's sensitivity is significantly degraded, often to the point of not functioning. In extreme cases, there can be permanent damage to that first amplifier.

This situation is very common when there is a transmitting antenna located close to a receiving GNSS antenna. This is because the satellite GNSS antennas typically have sensitive low noise amplifiers built-in. Any transmitter can cause this problem, but generally, the closer the frequency is to the receiver's operating frequency and the higher the power is, the likelihood of problems increases. Cellular and Wi-Fi transmitters are typical examples of technologies that can cause problems for receivers with nearby antennas.

This situation is not limited to active antennas like those used for GNSS or indeed TV/FM reception. This problem can happen with completely passive antennas and any type of radio receiver. The dictating factor is how much energy gets to the LNA in the receive chain.

Baseband de-sense

Baseband de-sense occurs when you've built a linear receive chain and the interference signal is just so strong it blows through the filters and winds up being stronger than the desired signal at baseband. The net effect is that now any desired signal must be stronger than the interference at baseband - or the interferer drowns the signal out completely. The effective sensitivity of the receiver is degraded, making your product "deaf," so it can't hear the desired transmitters. In these situations, users complain about poor range. This scenario is common for Wi-Fi devices in the presence of high-quality, high-power frequency hopping radios designed for outdoor long-range use. This situation happens most often with in-

band interference, but it can also happen with out of band signals as well, if they're strong enough.

Inter-modulation distortion and radiated spurious emissions

Inter-modulation distortion (IMD) and radiated spurious emissions (RSE) can be produced whenever a strong RF signal hits an active semiconductor device. This device does not need to be an RF part, in fact spurious emissions can be generated by IGBTs, power MOSFETs, small signal diodes, even LEDs. When a nonlinear system element is presented with a very strong signal, this situation can create mixing products that are re-radiated out through the antenna. This scenario is typically observed as the harmonics of the fundamental transmitter frequency.

RSE is fundamentally an RF immunity issue. If your electronics, regardless of their function, are sufficiently immune to the incident RF radiation in your normal use-case, then there's no problem. It's only when your electronics create unintended emissions that challenges occur. In these cases, it's because the emissions are subject to a large electro magnetic field radiating from an efficient antenna.

Co-modulation

Another form of IMD RSE, co-modulation, happens when one transmitter's signal hits a second transmitter's output amplifier. In some cases, this situation can cause a mixed product of the two transmit signals, i.e. co-modulation, which gets radiated from the incident transmitter's antenna. Again, this problem is fundamentally an RF immunity issue that's normally dealt with using filters. In this case, they would have to be high power filters that you could run sufficient transmit power.

What do you need to test?

It is important to test the isolation between each antenna pair in a system. For each antenna that transmits, you want to measure the isolation between that antenna and all the other antennas. As mentioned earlier, if you have two antennas that are only receiving, you don't need to worry about the isolation between those two antennas.

Isolation is typically measured with a network analyzer. A sweep is performed from the lowest transmit frequency in the system to the highest receive frequency in the system. Receivers are not subject to interference at frequencies below the lowest transmit frequency. The network analyzer is set up in a way whereby the transmit port (S1) is on the transmitting antenna, and the receive port (S2) is on the other antenna. It is important that any active antenna circuitry present in the antennas themselves is powered properly. For instance, you may need to power an active GNSS antenna with a bias tee and account for the gain of its amplifier when setting the stimulus power. For this test, you want the stimulus power to be low enough that it doesn't cause front-end de-sense as the goal is to measure isolation. This situation may mean turning the stimulus power down as low as -30dBm in order to measure the in-band part of the isolation, while turning the power up to measure the out-of-band isolation.

From these measurements, isolation vs. frequency plots can tell you clearly what isolation level you have between any two antennas and at which frequencies.

How good is good enough?

How much antenna isolation is required depends on several factors:

1)The linearity of the receive chain for each receiver

2)The effectiveness of the filtering (at the frequency of the interfering transmitter) on each receiver

3)For co-modulation, the effectiveness of any filtering after the last power amplifier of each transmitter

4)For co-modulation, how sensitive the power amplifier is to the incident RF

As you can see, “good enough” depends heavily on the radios involved. Many radio products, especially narrowband licensed radios, list specifications for out-of-band signal rejection in their transmitter and receiver specifications. Other products expect to be the only radio around or simply neglect these specifications. In many cases, it is necessary to measure the performance of the radios in your system to get this information.

For this discussion, we’ll define receiver out-of-band signal rejection as how strong the out-of-band signal can be in dBm, while not affecting the receiver’s sensitivity. As mentioned earlier, there are several possible failure modes for the receiver chain - some of which can lead to IMD RSE problems and degraded sensitivity.

Once you have numbers for rejection of the radios, you simply build a link budget with your isolation values as the path loss.

i.e., Receive sensitivity (TX Power – isolation – rejection) = isolation margin.

All values are positive - except sensitivity, which should be a negative number.

Tx power	33	dBm
Isolation	44	dB
Rejection	70	dB
Sensitivity	-100	dBm
Margin	-19	dB

If your margin comes out negative, it means when the transmitter is on, the receiver is degraded with the transmitter at that specific power level. You can do the same process for the transmitter when it comes to co-modulation producing mixing products.

What do you do about it?

The easy answer is move the antennas further away from each other, using physical separation. This solution has little to no impact on individual radio performance other than improving isolation and lowering interference. Every doubling of the distance gives 6dB more isolation, so the first three feet make the biggest difference.

This solution is not always practical in small electronic products, so the next answer is to add filtering. If you have the ability to add filtering to the receive path before the first LNA then there are various small, low-cost, highly effective filter types like SAWs. BAWs, ceramic dielectric and LC filters also can deliver effective results. These filters have minimal impact on total receiver performance and make the product much more robust against interference. If you have to transmit through the filter, your options are limited to filters that are compliant with your transmit power. Various types of ceramic dielectric, LC, machined cavity, comb and inter-digital filters can take high transmit powers and provide good performance. The trade off is that they are physically bigger and sometimes, more expensive.

One option is to turn the transmit power down on the offending transmitter. This solution obviously impacts the system link budget, but in some cases, you can turn the transmitter power down a little and find a compromise between interference and link budget. In cases where the radio type involved does not allow for turning the power down, an alternative is to increase the loss between radio and antenna. This situation is even worse for the link budget because it impacts both receive and transmit performance, but in some situations, it may be the only choice.

There are times when you can exploit the radiation patterns of antennas to create additional isolation between them. A common example of this is placing vertically polarized omni-directional antennas on a tower directly above/below each other. Such antennas have a null in the radiation pattern directly up and directly down, which can be exploited to get 20dB or even 30dB of additional isolation for a given separation distance. You can exploit high directivity antennas like Yagi, panel and dish antennas in a similar way.

Addressing isolation early on makes for happier customers and less headaches

Don’t let isolation be something you address after the fact. Addressing isolation early on helps mitigate problems down the road. With careful planning at the system level, your radio systems will work together more coherently and efficiently. Like anything done well, it looks easy. Nothing is on fire, no phone calls about intermittent communication problems in the field. Just happy customers and increasing sales.

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