Signal Boosters Are Not Plug And Play

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Signal boosters, also called bi-directional amplifiers, or BDAs, are becoming very popular as public safety agencies, among others, move to provide seamless in-building communications. Many places now have ordinances requiring building owners to provide facilities for in-building communications. The signal booster and distributed antenna system (DAS) are a very popular way to meet these requirements.

Signal boosters are available from several manufacturers and in different configurations. Wide-band boosters pass all of the signals within a given bandwidth through the use of window filters and high-gain amplifiers. Channelized boosters utilize DSP technology to pass only the channels of interest. Both technologies have their advantages, depending upon the application and environment.

Signal booster systems also have their own special set of problems. Many factors have to be considered when implementing a signal booster and distributed antenna system. Some of these factors include the amount of signal received from the donor site, the path loss back to the donor site, the losses within the DAS, the gain of the booster, and the isolation between the booster's input and output. Proper consideration of these parameters and others make signal booster systems something that should be designed and implemented by people who have the necessary experience in signal booster system design. These systems are not "plug and play." When improperly designed or installed, signal booster systems can be a significant source of interference both to the system they are trying to augment and to others.

At Bird, our Site Optimization Services department has chased many interference problems linked to improperly installed or adjusted signal boosters. On one job, I was speaking with a technician from the company that installed a booster found to be causing interference to a public safety system. The conversation went something like this; "What is the signal level from the donor site?" "I don't know." "What is the gain of the booster?" "I don't know." "What is the isolation between the donor antenna and the distributed antenna system?" "I don't know." To be fair to the poor guy, he was not stupid or incompetent. He simply lacked experience in signal booster systems. No one ever told him that these things mattered. Their approach to the booster system installation was "plug and play."

As seen in the 7/19/11 edition of the RF Globalnet (**www.rfglobalnet.com**) newsletter.

Figure 1: *Signal booster*

Oscillation

One of the biggest problems that plague booster systems is oscillation, which is also known as feedback or "ring around." This occurs when signal from one of the booster outputs, such as the uplink output, is received back into the corresponding input, in this case the uplink input, and the amplifier begins to oscillate, just like when the microphone of a public address system picks up energy from the speakers and creates the familiar feedback howl. The difference is, the booster oscillation occurs at RF frequencies and usually covers the total bandwidth of the booster's filters. If this occurs on the uplink, it results in severe wide-band interference to both the system associated with the booster and any other systems operating within that frequency band. Because the energy has a wide bandwidth, it is often confused with transmitter noise or other environmental noise being received at the victim receiver site.

To prevent or mitigate booster oscillation, it is absolutely necessary that the isolation, or loss, between the donor antenna and the DAS or inside antenna be significantly greater than the gain of the booster. Many booster systems have total gains of 80 dB or more. This requires a minimum of 100 dB of isolation between the donor antenna and the DAS or inside antenna to guarantee that oscillation will not occur. Why do we need 20 dB more isolation than system gain? The RF environment is never static. Signal levels change as the environment changes. As people and vehicles move within the RF fields, the isolation changes. The extra 20 dB helps ensure that even if the isolation dips a little, the booster system will not oscillate. The only thing more frustrating to locate than an oscillating booster is one that oscillates intermittently.

If you can't obtain antenna-to-antenna isolation that is 20 dB greater than the system gain, then it will be necessary to reduce the gain of the booster. This may have a negative impact on the system's in-building coverage, but an oscillating booster doesn't work well either.

Often, the key to good antenna isolation is placement of the donor antenna. The use of a directional antenna is strongly recommended. In addition, the antenna should have a good front-to-back ratio like a corner reflector, panel antenna, or Paraflector®[1]-type antenna. The donor antenna should be located with the DAS below and behind it to maximize isolation. In all cases, the antenna-to-antenna isolation between the donor antenna and the DAS should be measured to verify that adequate isolation exists to allow the system to operate with the necessary gain. If adequate isolation cannot be obtained, then either the gain of the system will have to be reduced or the design and placement of the antennas will have to be reviewed.

Overdrive

Another area where we often find problems is overdrive. This is where the booster is trying to produce more output power than the amplifiers are capable of making. This results in intermodulation (IM) and noise. This problem mostly affects broadband boosters, but channelized systems can have similar problems. Every amplifier has a maximum output limit beyond which it can create various forms of interference.

If we examine some typical booster specifications, we might see that the unit is specified to have 1 watt or +30 dBm of output. This is the single carrier maximum output the unit can produce while still meeting FCC specifications for spectral purity. If the system is configured so that when a single carrier is present the amplifier is producing 1 watt, then what happens when a second signal appears at the same level? Common sense would tell us that the amplifier will have to produce 2 watts, and based on true power over time, that would be correct. However, the problem is with the instantaneous peak power, and this is really a voltage problem. The peak voltage of an RF signal can be determined by the equation:

$$E_P = 1.414 * \sqrt{(P * R)}$$

Inserting the number for our 1-watt signal in a 50-ohm system we get:

$$E_P = 1.414 * \sqrt{(1 * 50)} = 10 \text{ Volts}$$

So a 1-watt signal has a peak voltage of 10 volts. If two 1-watt signals are present on the same transmission line, there will be times when the two peaks are aligned. Now statistically it doesn't happen often, but in an 800-MHz system you have over 800 million peaks per second so "not often" is really a relative term, and the peaks will still align many times per second. When the peak voltages of the waveforms align, they add together to produce 20 volts. Converting the 20 volts peak back to RMS by multiplying by .707 we obtain:

$$20 \text{ Volts}_{Peak} * .707 = 14.14 \text{ Volts}_{RMS}$$

[1] Paraflector is a trademark of Kathrein Inc.

To convert the RMS voltage back to power, we use the equation:

$$P = E^2 / R$$

$$P = 14.14\text{Volts}_{RMS}^2 / 50 \text{ Ohms} = 4 \text{ Watts}$$

So instead of trying to produce 2 watts, our poor 1-watt amplifier is actually trying to produce 4 watts every time the voltage peaks align. At this point, the amplifier is into severe distortion and is producing not only distorted versions of the two fundamentals but all of the sum and difference products we call intermodulation (IM).

If we take a step back for a moment, we see that in order to keep the amplifier operating within its design limits when amplifying two signals, the gain of the system has to be reduced not by 3 dB (1/2 power), but by 6 dB (¼ power) so that each carrier produces only 250 milliwatts. If you try to obtain more output than this, the booster will produce harmful levels of IM, and in the worst case, may suffer component failure in the final amplifier.

The amount of power per carrier that a booster can produce is based on the capabilities of the final amplifier and the number of expected carriers. The power output limit per carrier, based upon the amount of interference that might be created, can be determined by using a formula documented within the TIA specification PN2009. The formula takes into account the capability of the amplifier expressed as the “output third-order intercept” (OIP3) and the number of expected carriers, “N”.

$$P_{dBm} = (2/3)*[OIP3 + 0.409 - 24.75\text{Log}_{10}N + 1.437(\text{Log}_{10}N)^2]$$

On the uplink side, this is usually easy to compute as the number of uplink carriers will be equal to the number of channels in your system. On the downlink side, it can be more difficult as the number of carriers will depend upon the bandwidth of the booster’s filters and the density of the RF environment. Careful observation of the downlink environment is highly recommended to identify how many carriers might be present within your required bandwidth. Rogue carriers, not part of your system, can have a significant impact on your in-building coverage when they cause the booster to go into overload and roll back the gain.

When installing and optimizing a signal booster, it is necessary to determine the number of carriers and the maximum signal level. Then, adjust the gain of the system so that each carrier only produces the output level defined by either PN-2009 or the booster manufacturer’s manual.

All boosters, in order to be approved by the FCC, will have some kind of automatic level control. At Bird, we call it the OLC or “output level control.” While this circuit ensures that the booster is never overdriven to the point of creating harmful interference, it should not be used to regulate the gain in normal operation. Whenever the OLC reduces the gain of the booster, the level of signals through the amplifier is reduced. While this may not be a problem for the high-level carrier that causes the gain reduction, it can hurt coverage for other, weaker signals also using the system. This type of operation can result in sporadic poor coverage and be perceived as a problem with the booster, or the associated communications system, when in reality, the unit is simply working as designed.

In conclusion, signal booster systems can be a valuable tool in providing improved coverage in buildings, tunnels, or other difficult locations, but they are not “plug and play,” and the systems need to be designed, installed, and, most of all, optimized by people with the necessary experience to ensure proper interference-free operation.

About The Author

Alfred T. Yerger II is an RF engineering specialist for Bird Technologies Group, specializing in field engineering for the land mobile industry, including antenna site design, noise and interference, and communications system coverage issues.

Mr. Yerger has been working in the radio communications and broadcast industries since 1974, including 18 years with Motorola Communications. He joined Bird Technologies Group in January 2005, after running his own business, Antenna Site Technology Inc., for 6 years. He is the senior engineer in Bird’s Site Optimization Services (SOS) department. In this position, Mr. Yerger is responsible for supporting Bird’s spectrum monitoring and noise measurement services, interference mitigation, and training for the land mobile communications industry.