Detecting and Locating Interference from Bidirectional Amplifiers

White Paper

Bidirectional amplifiers or "signal boosters" are frequently used to improve cellular coverage within buildings by amplifying both downlink and uplink signals. Oscillation caused by insufficient path loss between a BDA's donor and serving antennas is one of the most common and most serious forms of interference in cellular networks. This white paper provides a general overview of how BDAs work, the conditions leading to oscillation, and practical information for identifying and locating oscillating BDAs.

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Paul Denisowski
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ROHDE&SCHWARZ

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1 INTRODUCTION

One of the main ways that cellular network operators differentiate themselves is through the coverage they provide to their subscribers. In the most general sense of the word, “coverage” is the geographical area in which a cellular network operator provides service to its subscribers, either directly or through roaming agreements. Today the term “coverage” not only means the area of coverage but also implies the quality of service available in a given area, which can be quantified using key performance indicators such as the rate of dropped calls, voice quality and data throughput, for example.

As most subscribers are well aware, coverage can vary tremendously within the areas nominally covered by a network operator. The level and quality of received signals and the related performance are a function not only of the density of base stations but also the radio-frequency environment at a specific user location. This is particularly evident inside buildings, where the difference between having “full bars” and “no coverage” may be as little as the length of a conference room or a walk to the nearest window. While outdoor coverage issues are relatively easy to address through things such as antenna tilt or power level adjustments, excellent indoor coverage has remained one of the greatest challenges for cellular network operators.

Having subscribers simply walk outside or move closer to a window is a very common way of dealing with poor in-building coverage, but often this is not practical. The solution in many cases is to improve the coverage inside the building. This can be done in a variety of ways, deploying femtocells (very small cellular base stations), for example. But by far the most common way of improving in-building coverage is by using bidirectional amplifiers.

2 WHAT ARE BIDIRECTIONAL AMPLIFIERS?

As the name implies, a bidirectional amplifier (BDA) is a device that amplifies signals in two directions simultaneously. In cellular systems, a bidirectional amplifier uses a *donor antenna* to receive downlink signals from a nearby cellular base station, then amplifies and retransmits these signals into the building through one or more *serving* or *service antennas*. These same antennas receive the uplink signals from the user equipment (phones, data cards, etc.), amplify them and retransmit them through the donor antenna back towards the base station. In this way, coverage can be extended into areas where it would otherwise be poor or non-existent, most commonly within buildings or other indoor structures.

Figure 1: A typical bidirectional amplifier installation

This approach is technically very straightforward and relatively low-cost: a consumer-grade BDA system – including the repeater itself, antennas, cabling, etc. – can be purchased in stores or on-line for as little as several hundred dollars. Since they are simply RF amplifiers, there is no monthly charge or other recurring cost associated with operating a BDA. And while these systems may be professionally installed by the network operators themselves, self-installation by the building owner or end user is very common.

Although self-installation of BDAs is illegal in many countries, the United States Federal Communications Commission (FCC) has historically allowed consumers to purchase, install, and operate bidirectional amplifiers (which they refer to as “signal boosters”) without a license or approval from either the FCC or the relevant cellular network operator. However, in response to the large number of interference issues caused by BDAs, the FCC issued a new Report and Order [FCC 13-21] to address this situation. These new regulations, which take effect on March 1, 2014, specify equipment changes (intended to minimize potential interference) and registration of all installed BDA systems. Despite this new FCC order, there is still some question as to whether there will be widespread compliance.. According to various estimates [NYT, AT] there are between one to two million bidirectional amplifiers being used in the United States today, and the FCC’s own consumer advisory [FCC2] states that “the FCC likely will not pursue enforcement against current or prospective signal booster users unless it involves an instance of unresolved interference.”

3 INTERFERENCE FROM BIDIRECTIONAL AMPLIFIERS

When properly installed and operated, bidirectional amplifiers can improve in-building coverage without adversely affecting the operation of the cellular network. However, in some instances BDAs can create serious, service-affecting interference to the cellular network in a number of ways, most of them due to a phenomenon called *oscillation*.

In order for a BDA to work properly, there must be sufficient separation between the donor (outside) and serving (inside) antennas. Failing to sufficiently isolate these two antennas can lead to a situation in which the amplified signals (uplink and/or downlink) from one antenna are fed into the other, creating a feedback loop that causes the BDA to oscillate. Various industry groups and manufacturers [NPSTC, Bird, etc.] specify that the attenuation (or path loss) between the two antennas should be 15-20 dB more than the gain of the amplifier (e.g. a BDA system with a gain of 80 dB should have at least 95-100 dB of isolation between antennas). In some cases, such as when BDAs are installed in vehicles, on boats, etc., there may be limits to the achievable physical separation between antennas. If sufficient physical separation is not possible, it may be necessary to lower the gain of the amplifier and/or change the configuration and placement of one or both antennas.

There are other less common ways that BDAs can create interference in cellular networks. Being wideband amplifiers, BDAs will pick up and repeat both the desired cellular signals as well as undesired signals. For example, low-level spurious emissions found within a building can be picked up by the serving antenna, amplified, and then transmitted back towards the base station. Furthermore, BDAs can generate and repeat intermodulation products from other transmitters, especially in urban areas.

4 SPECTRAL CHARACTERISTICS OF OSCILLATING BDAS

Bidirectional amplifiers are designed to amplify signals across one or more frequency ranges (or “bands”) used by cellular network operators. BDAs which go into oscillation will therefore typically raise the noise floor over the entire frequency range of the amplifier. Note that although most BDAs are nominally designed to work over a given set of cellular frequencies, the range of frequencies amplified by BDAs will vary between manufacturers and may depend on the specific installation as well (especially if filters are used).

Most commonly, the noise caused by an oscillating BDA takes the form of a wide “bump” or rise in the noise floor, often from 10-40 MHz wide. For this reason one should always start with a wide frequency range / span when examining noise issues in cellular uplink bands (it is much easier to identify BDA-related interference when the entire “bump” can be seen). The edges of the “bump” may be well-defined or trail off, possibly asymmetrically.

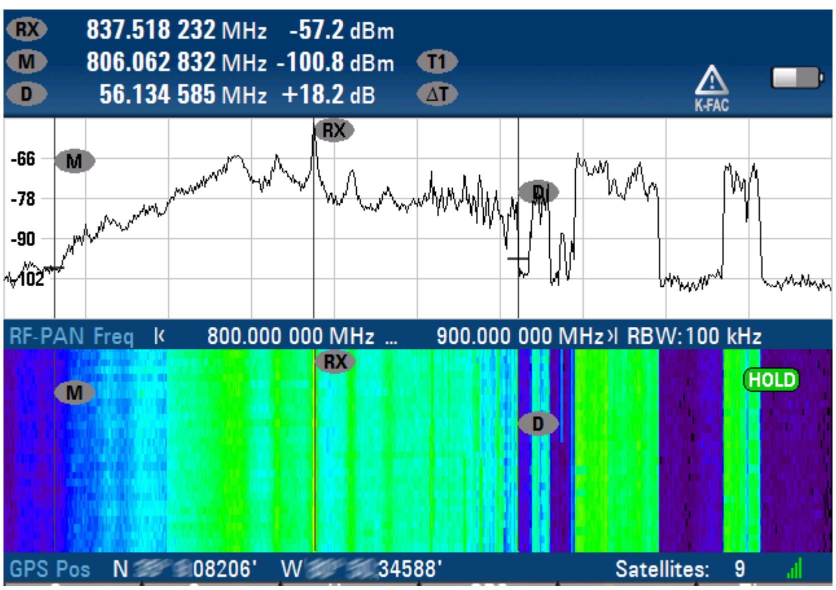

Figure 2: Wide noise increase (“bump”) generated by an oscillating BDA

The oscillation may also create many narrowly-spaced carriers across the affected frequency range.

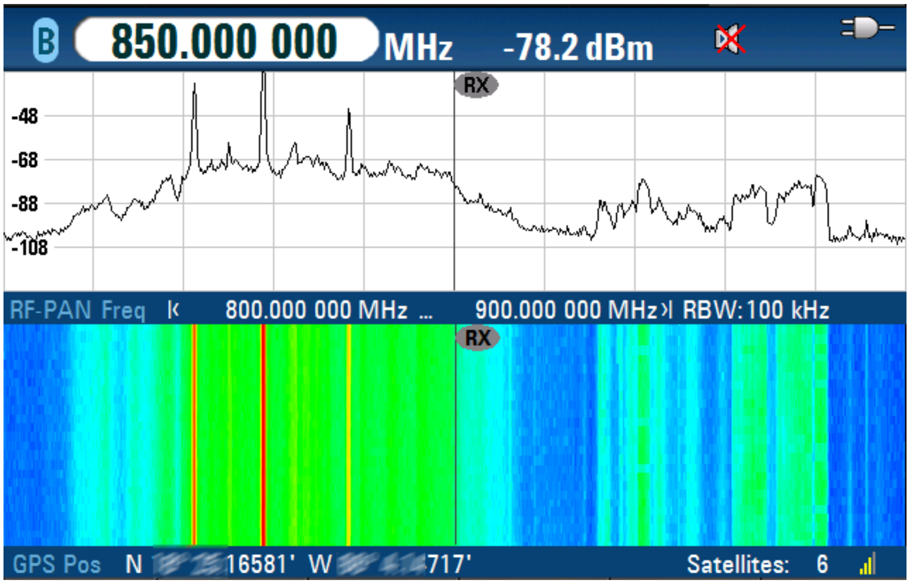

Figure 3: Narrowband noise generated by an oscillating BDA

Although it is difficult to make generalizations, the narrowband-carrier pattern is much less common than the broadband-noise pattern, the former usually being caused by very high levels of coupling between antennas (i.e. very poor antenna isolation).

In order to prevent oscillation, some BDAs incorporate a form of automatic gain control, in which the BDA will automatically decrease gain if it detects that oscillation is occurring. The latest FCC standard [FCC13-21] mandates that BDA manufacturers incorporate this kind of automatic gain control. Many manufacturers have already implemented this feature in their amplifiers. Note that the speed and granularity of this gain control varies between manufacturers. Figure 4 shows a BDA which goes into significant oscillation in approximately ten second intervals due to a very slow-acting automatic gain control.

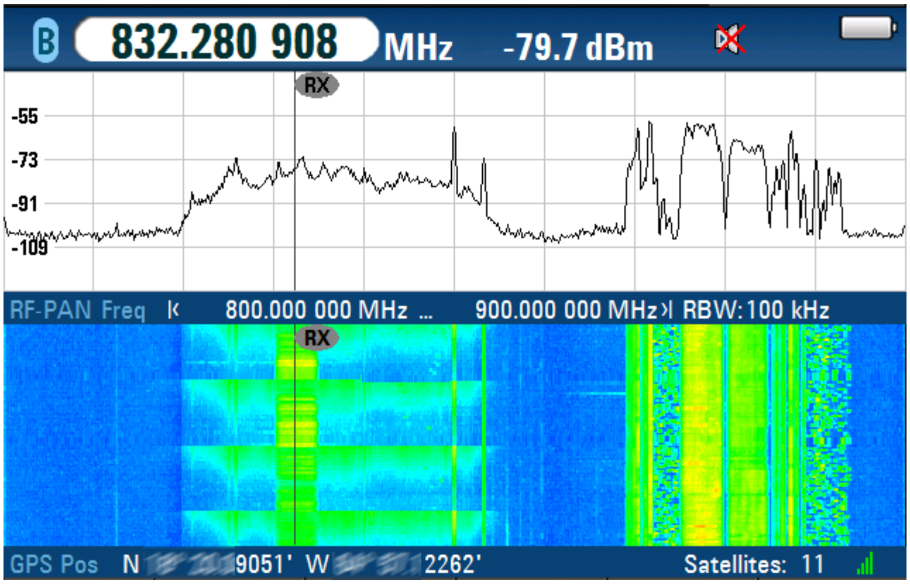

Figure 4: BDA with very slow-acting gain control

Although it is not uncommon for BDAs to operate on multiple bands (e.g. 850 MHz and 1900 MHz), oscillation in one band is not a reliable indicator of oscillation in other bands. However, if an oscillating BDA is detected, checking the other cellular bands for interference is highly recommended.

5 Locating BDAs in the field

If the spectral characteristics of interference are similar to those of a BDA, the next step is to physically locate the BDA and contact its owner.

The fact that BDAs usually have an externally (outside) mounted donor antenna can be a tremendous help in locating them. In most fixed-location installations, such as on buildings or residences, the donor antenna will be some form of directional antenna, such as a yagi, log-periodic, panel, etc. Since the antennas of cellular base stations are vertically polarized, a properly-installed donor antenna will also have vertical polarization. In mobile installations on campers, RVs, boats, etc. a vertical or omnidirectional donor antenna is normally used. There are also some systems which have a panel-type donor antenna, often attached to a window. A pair of binoculars is often helpful when inspecting antennas mounted on rooftops or the upper floors of buildings. Keep in mind that small directional antennas can be used for a variety of purposes; i.e., not every rooftop yagi is connected to a BDA. Familiarity with common donor antennas can also help one more easily identify potential BDA installations.

Figure 5: Yagi used as a donor antenna

Figure 6: Omnidirectional vertical used as a donor antenna

Figure 7: Roof-mounted panel antenna used as a donor antenna

The composition of a building can also be an important clue when trying to determine whether or not an attached antenna is a BDA donor antenna or not. Buildings that are made out of solid concrete, metal, etc. and/or buildings with few windows will more heavily attenuate cellular signals and thus be good candidates for a BDA installation. The intended function of a building can also be a valuable clue. Most movie theaters or churches, for example, would not be interested in improving in-building reception, whereas a restaurant without decent cellular coverage would be at a serious disadvantage. Cellular phone retailers will sometimes install BDAs in order to ensure that their customers have “full bars” and very good data throughput while inside the store, regardless of the normal (non-amplified) signal levels.

Figure 8: Small yagi on a metal building – possible BDA installation

From a spectral point of view, it is usually fairly easy to determine whether a given antenna is the source of interference by examining the *uplink* frequencies in close proximity to the antenna. In many cases, this may require building / rooftop access or a ladder.

Serving antennas, on the other hand, are usually inconspicuous flat or domed antennas, most often mounted on (or in) the ceiling. The best way to determine whether a serving antenna is present and operating is by examining the *downlink* frequencies. Since the BDA is intended to improve coverage through amplification, one will typically see a very strong (-40 to -50 dBm) downlink signal level near the serving antenna. If the downlink signal level *increases* as you enter a building or a room, this is an excellent sign that a BDA is being used.

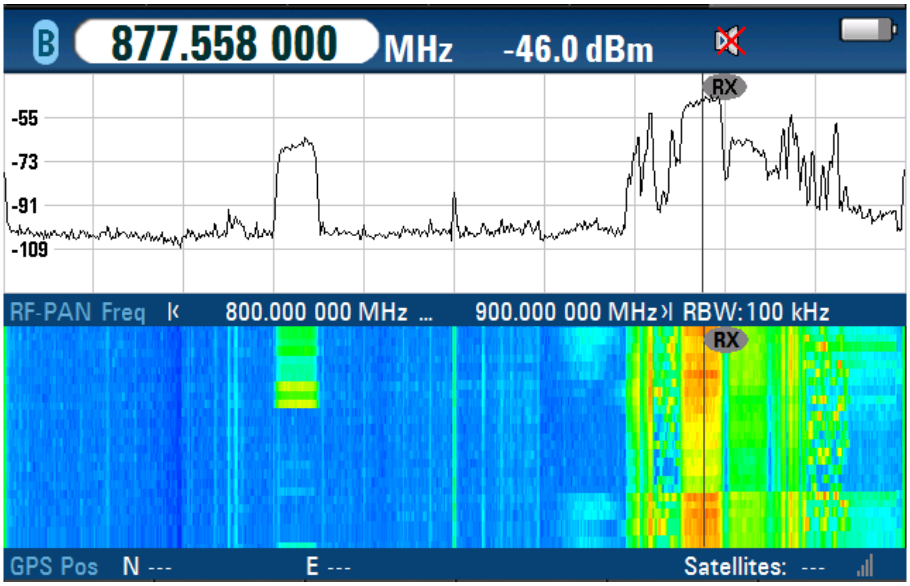

Figure 9: Very high downlink levels seen indoors due to installed BDA system

Figure 10: Ceiling-mounted panel antenna used as serving antenna

Figure 11: Ceiling-mounted dome antenna used as a serving antenna

The location of the BDA will vary from installation to installation, but often they are installed in back rooms, closets, etc. and will normally not be in plain sight. They will of course be powered and will have antenna cables leading to both donor and serving antennas. Here again, familiarity with the more common brands and form factors of commercially-available BDAs can be very helpful.

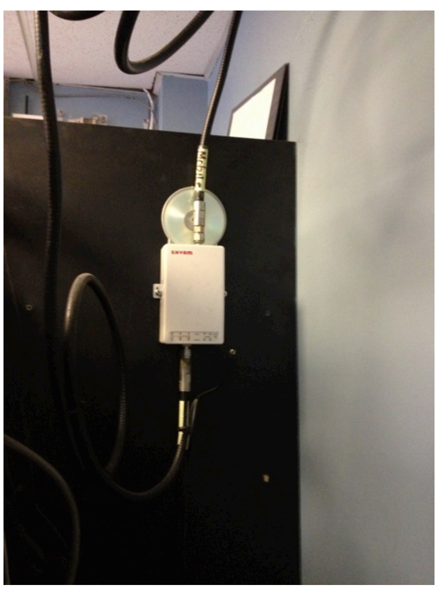

Figure 12: Bidirectional amplifier

Figure 13: Bidirectional amplifier

The best way to determine whether a BDA is the cause of interference is to power off the BDA and examine the spectrum and / or base station statistics. One thing to keep in mind is that some BDAs have a battery-powered backup and will continue to amplify and repeat signals even if their power supplies are disconnected.

One final note: often the day-to-day occupants of a building or vehicle are unaware of the presence, location, or purpose of a BDA. In fact, one of the challenges in locating BDAs is that the terms “BDA” or “bidirectional amplifier” are not widely known outside of the cellular industry. Asking whether someone has a “signal booster” or “cell phone repeater” is often more effective.

6 Conclusion

Bidirectional amplifiers can improve the coverage and performance of cellular networks when properly installed and operated. Interference from BDAs most often occurs when there is insufficient separation (path loss) between the donor and serving antennas, leading to oscillations and a broad increase in the noise floor over the entire operating range of the BDA. The spectral shape of noise from an oscillating BDA is normally easy to recognize, and both internal and external antennas provide strong clues as to the possible presence of a BDA.

7 References

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Figure 1: Courtesy of Wilson Electtronics.