

WHAT YOU DON'T KNOW ABOUT BDAs & DASs CAN HURT YOU

BY GREGORY GLENN

As cellular users expect “more bars in more places,” the use of in-building signal enhancement systems is becoming more prevalent. New BDA (bi-directional amp) and DAS (distributed antenna system) infrastructures are being installed daily across the U.S. These systems, designed to support cell phones, can cause serious degradation to existing 800 MHz public safety radio systems.

Government entities that have adopted the National Fire Protection Agency’s code (Part 72-2010), those that have in-building signal ordinances and those that operate in the 800 MHz SMR/NPSPAC band need a general understanding of how these systems operate.

AMPLIFICATION

The first thing to know: A BDA will always amplify thermal noise, even if there’s no outside signal applied to the amplifier’s input. Without giving a dissertation, *thermal noise* is the electronic noise generated by the agitation of electrons within a conductor and exhibits equal power throughout the spectrum. In other words, it exists by nature.

Noise power (NP) can be calculated using the equation: $NP = k \times T \times B$, where k is Boltzmann’s constant, T is the absolute temperature in Kelvin, and B is the bandwidth in Hertz. NP equals -174 dBm/Hertz at room temperature. For this discussion, we’ll use a channel bandwidth of 30 kHz. Thus, the thermal noise within a 30 kHz channel is -130 dBm. For those of you interested in converting this to a 25 kHz value subtract .7 dB from all the 30 kHz values ($-174 + 10 \log 30000$).

Let’s examine a few typical carrier-grade DAS amplifiers. A carrier grade amp usually exhibits 80–85 dB of gain. It will have a mechanical filter that’s fairly wide, and a DSP (digital signal processor) to determine frequency pass band. Note

that amps designed to support Sprint Nextel and A Block cellular will amplify thermal noise well into the NPSPAC portion of the SMR band.

The amplifier depicted in Fig. 1 (p. 40) is being used with a low-end DAS system in a major airport here in the U.S. This amplifier is driving a DAS system that has about 19 dB of downlink gain. As a result, the thermal noise depicted in the figure is amplified by about 19 dB at the service antenna. Also note that this system supports 1900 MHz PCS, so antenna density is high with a radiation radius of about 55 feet.

Now, let’s look at some characteristics of this Sprint Nextel approved amplifier. This sweep is the amplifier’s downlink output noise crown with donor input terminated with a 50 Ω load (see markers, Fig. 1). Markers 1 and 2 indicate the programmed pass band for this amplifier. Note that Sprint Nextel-approved amplifiers can be programmed with multiple pass bands. Eighteen MHz is the wide-band side, covering 851–869 MHz, and the narrow filter is 7 MHz, covering 862–869 MHz. Other pass bands are available and vary by manufacturer. I haven’t seen any approved Sprint Nextel amp that filters out upper NPSPAC 866–869 MHz.

The amplifier in Figure 1 is programmed to pass 862–869 MHz, as can be seen by the noise crown between Markers 1 and 2. Note the NP between Markers 3 and 1. The area just to the right of Marker 3 is the new NPSPAC band, 851–854 MHz, as well as the interleaved portion of the 800 MHz band. After rebanding, this is where public safety users will be in 800 MHz spectrum.

The amplifier in Figure 1 is programmed for 50 dB of gain. As discussed earlier, thermal noise is about -130 dBm in a 30 kHz channel. The indicated NP using a 30 kHz bandwidth filter is approximately -45 dBm within the DSP pass band and -55 dBm outside its programmed DSP pass band.

Let’s do some math: If $-45 - X = -130$, then $X = 85$. The math indicates the amplifier is running about 85 dB of gain. In reality, the amplifier is running about 80 dB of gain and has a 5 dB noise figure. So why does the noise crown indicate that the amplifier is running 80 dB of gain when it’s programmed for 50? Because manufacturers reduce “system” gain by placing an attenuator on the amplifier’s input side. Although an economical way to create the look and feel of lowering gain, it breaks a cardinal rule when engineering an amplification system: It’s never a good idea to reduce the input signal only to make it up with excessive gain. Good design practice would dictate the removal of a gain stage rather than reducing the input signal level prior to the first stage of amplification.

Another observation from Fig. 1 is in the frequency response of the amplifier’s mechanical filter. The filter’s skirts aren’t very steep, and the 3 dB points on the filter are at about 848 MHz and 872 MHz. So although touted as an SMR amplifier, this amp will create noise well into the cellular A Block on the downlink side, as well as into the cellular B Block on the uplink side. But, more important to the public safety user, this amp will generate thermal noise across the entire SMR downlink.

I’ve confronted three amplifier manufacturers on the attenuator subject, and two of them actually told me, “We do it because everyone else does it that way.” My 13-year-old daughter knows that reason doesn’t hold any water with me. This practice is causing major problems in the industry—not necessarily to the carriers, but to the others using spectrum around them. *The good news:* There are manufacturers that design amplifiers with attenuators in the proper places, and I include a spectral picture later.

Now, let’s talk about the effects this amplifier will have on the public safety

Effect



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user, first looking at the upper NPSPAC band, 866–869 MHz. The thermal noise out of the amplifier in Fig. 1 is about -45 dBm. *Do the math:* Free space loss is calculated by this equation: $36.6 + 20 \log(f) + 20 \log(d)$, where f = frequency in MHz and d = distance in miles. (Note that this formula should be used in cases of 10λ or greater distance from the antenna. At 800 MHz, that's about 10 feet.) *The numbers:* $36.6 + 58 - 54 = 40.6$ dB. Thus, free space loss at 10 feet equals 41 dB; loss at 20 feet equals 47 dB; loss at 40 feet equals 53 dB; and loss at 80 feet equals 56 dB.

Assuming we would like to see a 16 dB faded signal to noise ratio (S/N) (maybe a bit less for P25 narrowband CPQSK), the signal level inside a building necessary to overpower this amplifier's noise output would have to be (more math): -45 dBm out of the amplifier, 40.6 dB of free space loss at 10 feet + 16 dB S/N capture. So $-45 - 41 + 16 = -70$ dBm at 10 feet. At 20 feet, signal must be -76 dBm. At 40 feet, signal

must be -82 dBm. And at 80 feet from the antenna, signal from the public safety system must be -88 dBm to be reliable.

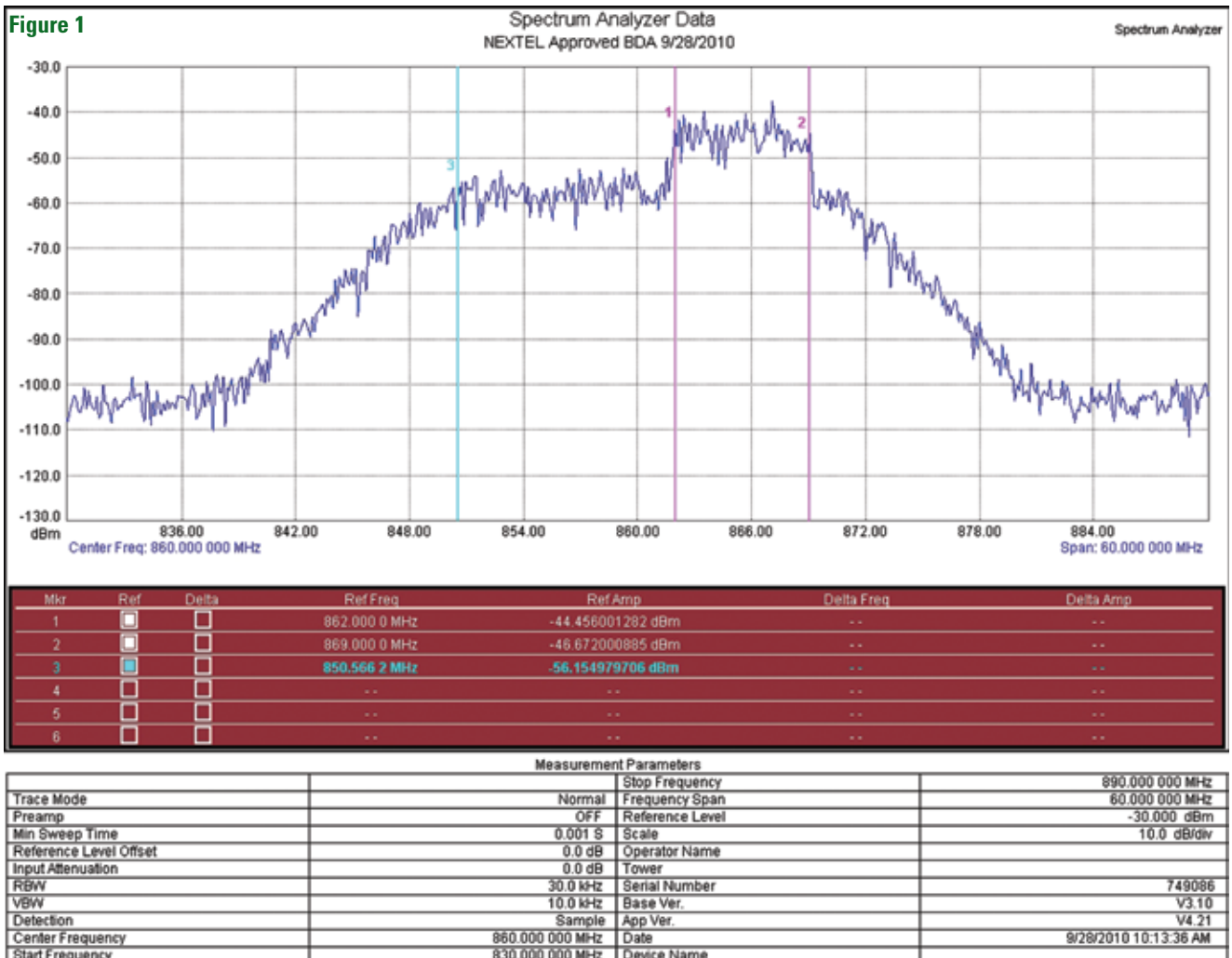
Let's assume we have a building that complies with a -95 dBm signal (most ordinances, as well as NFPA, use this as a target signal value) from the local public safety radio system. High-TEK Cellular Company installs a BDA in this building. What used to be good coverage in this building is now marginal or unusable in large areas of the building. The problems only get worse when you add a fiber DAS because it will increase the noise by 17–20 dB, typically.

Using the NP outside the DSP/SAW band pass, we have about 11 dB less noise, so we would need a -79 dBm signal to overtake the noise at 10 feet from the service antenna. Again, a -95 dBm signal would also be marginal in this environment.

Next, we can look at a popular cellular BDA on the market. This amplifier (Fig. 2, opposite) is "approved" by most

major carriers, Verizon and AT&T included. This amplifier has pretty good characteristics. Again, we can see that the mechanical filters start to roll off well into the NPSPAC portion of the 800 MHz band. The 3 dB point of the mechanical filters looks to be about 866 MHz. Also, this spectrum shot was taken using a 10 kHz resolution bandwidth. So we must apply a correction to any mathematical models we use to compare it to the amplifier used in Fig. 1 (below). The actual NP in a 30 kHz channel will be about 4 dB higher than indicated in this spectrum shot.

The average NP indicated in Figure 2 is about -72 dBm, with the correction factor of -68 dBm. *Do the math on the noise:* $-68 \text{ dBm} - 40.6 \text{ dB} = -108.6 \text{ dBm}$. A -95 dBm signal would adequately overpower this amplifier's noise if you were right at the service antenna. However, if this were applied to a fiber DAS with 17–20 dB of gain, the numbers change.



The public safety system producing a -95 dBm signal won't overcome the thermal noise generated by the DAS.

Let's discuss uplink noise rise, which can creep up on a system, chewing away portable coverage 1 dB at a time. If you refer back to our free space loss formula, you'll see that a 6 dB rise of noise at the receive site will cause a 50% radius drop in coverage. This can be a huge issue! Let's say a receive site is designed to provide portable coverage for a three-mile radius, and the noise floor is raised by 6 dB. Under normal conditions, this site will provide roughly 28 sq. miles of coverage. Now drop the radius by 50% (6 dB) to 1.5 miles. The site coverage has dropped to about seven sq. miles or 25% of the original coverage area.

Figure 3 is a spectrum shot from an amplifier that was offending a public safety site in California. *The math:* -52 dBm of thermal noise into the donor antenna. Donor line loss was about 1.5 dB, and antenna gain was 11 dB. The thermal noise power at the donor antenna was -43 dBm. A quick calculation says that this thermal noise will affect any site up to 2,400

feet, the noise floor will be raised by 3 dB, assuming no gain on the public safety base station antenna system.

The offended site was using 10 dB gain omni-directional antennas and was approximately 1,000 feet away. Needless to say, this BDA rendered receivers at this site useless. If this amplifier had been equipped with the proper mechanical filter, there would have been no issue.

All of these demonstrations are a result of actual field complaints about loss of coverage by public safety in areas where they once had coverage.

PROTECT YOUR AGENCY

So what can you as a public safety entity do to protect against such occurrences?

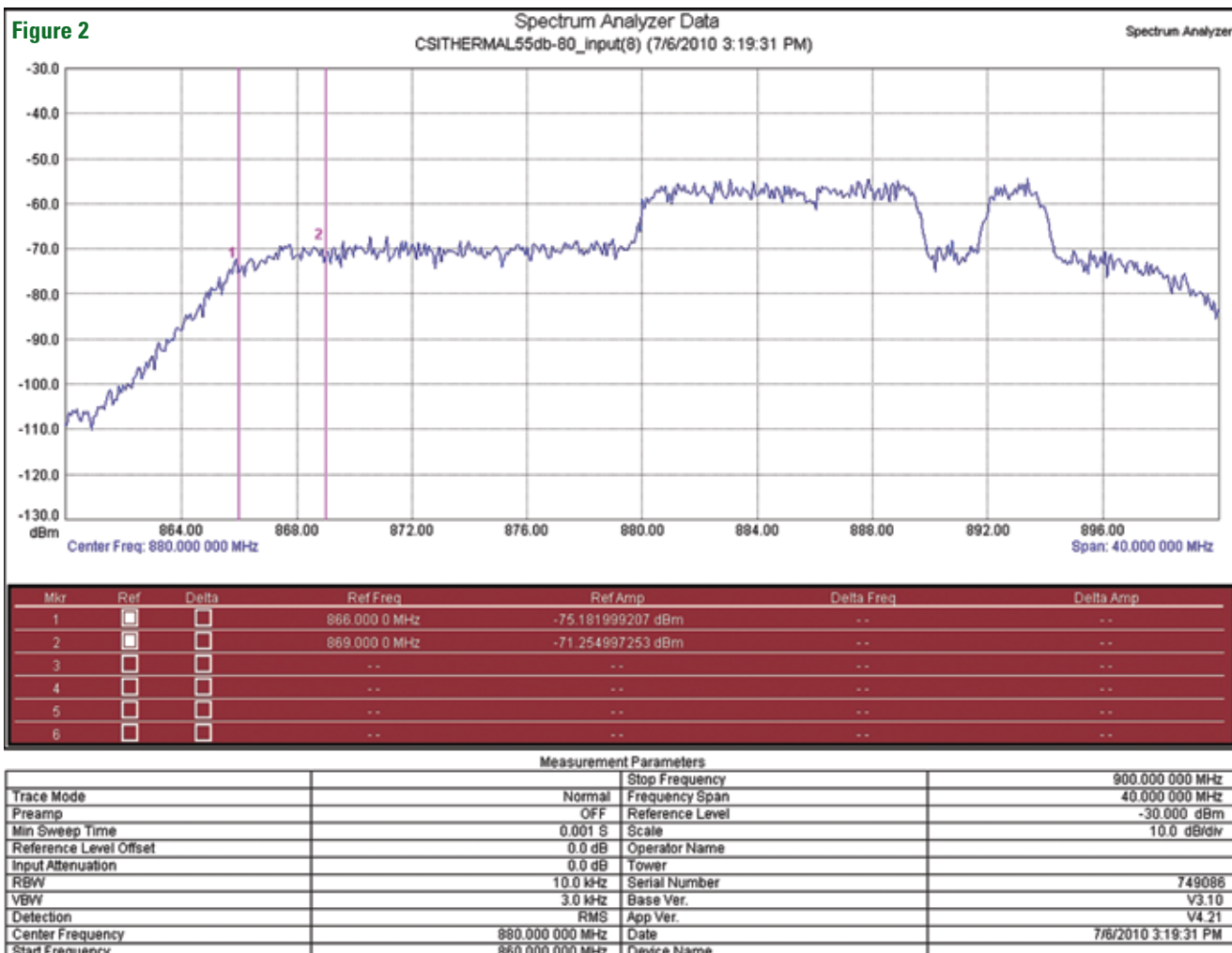
1) *Require all DASs to be permitted.* Most cities and counties with ordinances require the integrator to pull a permit to install a public safety DAS. This low-voltage system should require a permit to be installed. Have a qualified "special inspector" verify the plans and check the system after it's installed. This person can

be an internal RF engineering resource or an outside source. Make sure a full set of engineering drawings is submitted and depicts service antenna locations, as well as a list of all the active equipment to be used.

2) *Ensure any 800 MHz public safety system is part of the same DAS if that DAS is carrying Sprint Nextel 800 MHz or any 800 MHz cellular.* This tactic, which is already being used in some jurisdictions, is a good solution because the cost of a good quality public safety grade amplifier is minimal as it relates to total project cost.

3) *Only allow the use of high-grade equipment in your jurisdiction.* There are good amplifier and fiber DAS manufacturers that use proper filtering, as well as good engineering practices, to develop their products. Unfortunately, public safety users are going to have to drive this step.

4) *Only pass the frequencies needed to accomplish the task.* There's no reason to use an 18 MHz wide amplifier in most public safety applications. The cost to build a two-window downlink amplifier is marginal as it compares to the total cost of



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a properly installed DAS. Most 800 MHz public safety users don't need to pass 861–865 MHz, and all it does is eat up the amplifier's composite power.

5) *Do not use more gain than necessary to accomplish the task.* Make sure your amplifier or DAS manufacturer places attenuators in their systems so they don't dramatically increase the system's noise figure. Although it's cheap to run a monoblock amplifier with an attenuator on the amplifier input, it's a poor practice and leads to noise problems.

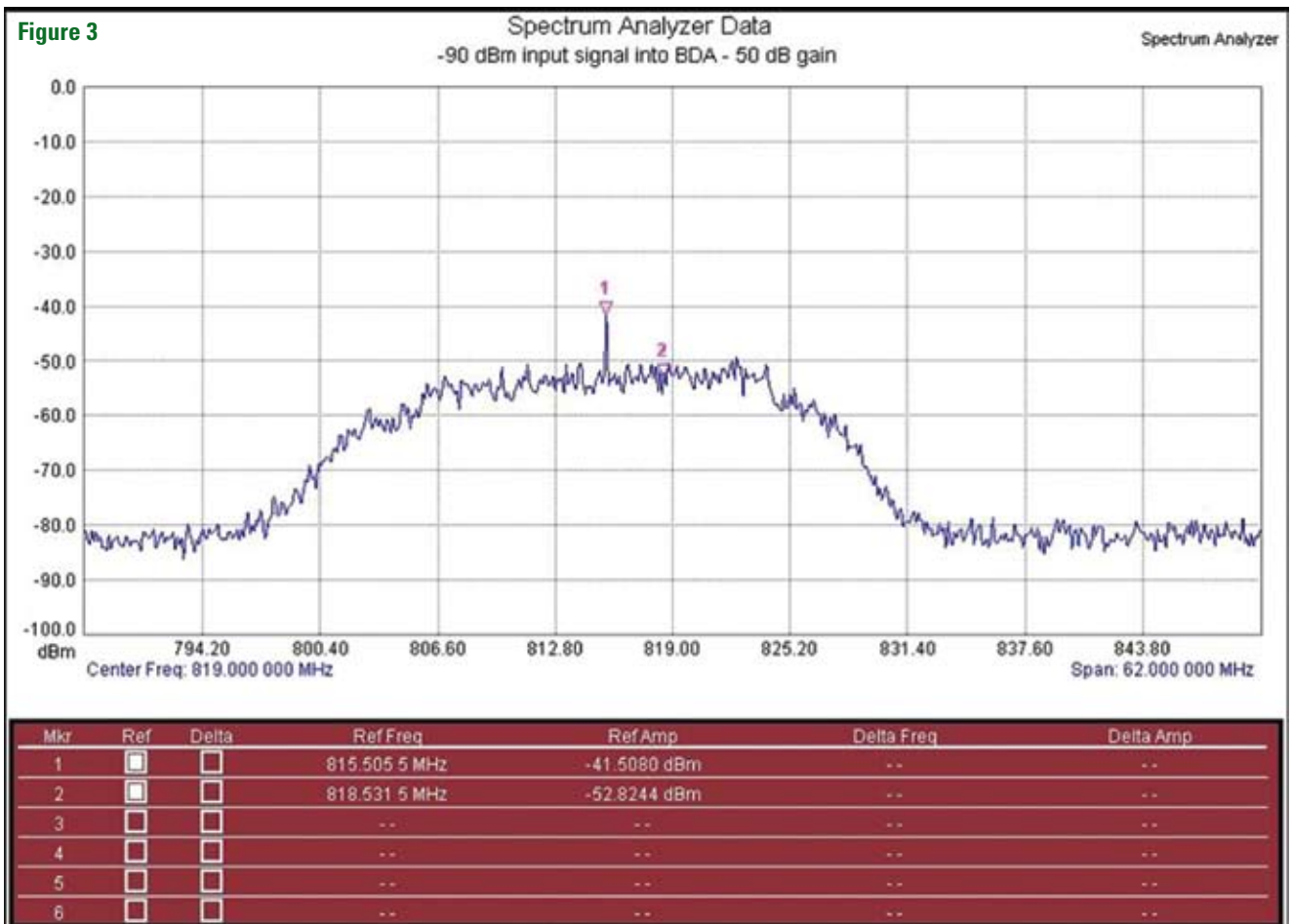
6) *Don't participate in the "channelized systems are the way to go" debate.* Although there is a place for everything, DSP, SAW or crystal filtering doesn't usually help keep amplifiers from interfering

with users outside their programmed pass bands. Notice I didn't say channels. If an amplifier were truly channelized (i.e., it had the same bandwidth performance as the channel it was passing), the output signal would be distorted to such a point that it would be unusable. "Channelized" is a marketing term used to describe amplifiers capable of very narrowband passes by using DSP technology. Very narrowband passes *will* cause time domain problems that can't be overcome.

At the end of the day in actual application, most channelized amps are running a band pass filter programmed to pass much larger bandwidths than any channel bandwidths used today. Because most thermal noise problems are due to the final ampli-

fication stages of any system, they can be mitigated only by mechanical filters, as seen by Figures 1–3. A good integrator takes into account the RF environment and should recommend the best course of action. Although I will never say never—and I have used crystal filtered solutions in some VHF applications—in 99% of cases it isn't necessary and can be detrimental to use band pass filters tighter than 150 kHz. It should also be noted that DSP filters don't dismiss the necessity to use similar band passes in the mechanical filters.

Dealing with time domain and band pass ripple issues far outweighs designing in more antennae to mitigate one or two unwanted channels. There have been many times when channelized amplifiers



Measurement Parameters			
Trace Mode	Normal	Stop Frequency	850.000 000 MHz
Preamp	OFF	Frequency Span	62.000 000 MHz
Min Sweep Time	0.001 S	Reference Level	0.000 dBm
Reference Level Offset	0.0 dB	Scale	10.0 dB/div
Input Attenuation	20.0 dB	Operator Name	Tower
RBW	10.0 kHz	Serial Number	749086
VBW	3.0 kHz	Base Ver.	V3.08
Detection	Peak	App Ver.	V4.15
Center Frequency	819.000 000 MHz	Date	1/15/2010 1:07:09 PM
Start Frequency	788.000 000 MHz	Device Name	

have caused major problems in overlap areas, and the amplified channel became unusable. This simply wouldn't be a problem if system designers used their heads and the proper equipment for the job.

Figure 4 is a spectrum shot of a well-designed public safety BDA. This BDA is producing a composite power output level of 5 dBm and is driving a fiber DAS. This amp is designed to support public safety in both the 700 and 800 MHz bands. This amplifier is performing as it should be and has been designed with the proper filters and amplification for the job. This amplifier is driving a fiber DAS and is being used in a metropolitan area.

A few things to note: The amplifier has two windows in the downlink 851–861 and 866–869 MHz. It isn't necessary to amplify the area between 861 and 866 MHz because most, if not all, public safety entities in the U.S. don't use this spectrum. Sprint Nextel is predominant in this area and, in most cases, should be filtered. Also note that the amplifier's thermal noise floor is about -80 dBm, indicating an amp gain of about 50 dB.

This amplifier isn't running at 80 dB of gain and attenuating the input by 30 dB like many of the carrier-grade amplifiers, thus it doesn't exhibit the noise levels caused by this type of poor engineering.

Although I don't have a spectrum shot of the uplink side, the thermal noise crown is at about -80 dBm on this system. This means that any voting site would have to be less than 300 feet away to see any noise from this system. Yes, the public safety entity likes what it sees: No noise at its receive sites. Because this is using the proper mechanical filters, when the agency rebands, the 866–869 filter will be removed. There will be very little thermal noise generated by this amplifier in the band's Sprint Nextel portion.

CONCLUSION

In summary, DASs are being installed daily. Few integrators in the marketplace truly understand the needs of public safety and adhere to good engineering practices when installing these systems. Use the technical resources you have available to you. CPRA, APCO International's South-

ern California Chapter, has some of the best RF people in the industry. Seek out integrators that don't represent a particular DAS or BDA manufacturer. These folks can help you write requests for proposals, ordinances and system specifications.

Always test and question marketing claims on amplifiers and DASs. Ask for lab tests. If the manufacturers won't provide them, walk away.

If you'd like more information, contact me at greg.glenn@tripower.com. Jack Daniel is another excellent resource on the subject and can be reached via e-mail at jackdaniel@rfwise.com. **||PSC||**

GREGORY GLENN, an APCO International member, is director of RF Engineering at TriPower Group. He has more than 30 years of RF system design experience and has been involved in in-building signal enhancement since the late 1980s. About 90% of his system designs have a public safety component, and he has extensive experience in jails and other hardened applications. Glenn also holds a patent for work accomplished in gathering data in a mobile RF environment, General Class RadioTelephone license, as well as an amateur extra license.

