Appendix D: Optimizing FCC Class B Band Selective (broadband) Signal boosters for Urban use

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The FCC signal booster Class, A and B, are operational designations and should not be confused with the commonly used technical classifications of amplifier designs used within the signal booster. For example, FCC Class B signal boosters usually use technical class A amplifier circuits to provide high linearity. FCC Class A signal boosters may be using any of the technical classes of amplifier circuit. Reference: FCC part 90.219.

The Code of Federal Regulations part 47 section 90.7 and 90.219 details the definitions and limits for the use of RF signal boosters in Land Mobile Radio networks. These rules are included in Section V of this Best Practices paper.

Within this paper FCC Class B signal boosters are called 'broadband' amplifiers or better clarity.

Effects of multiple channels and Composite Power

Broadband amplifiers are used in FCC Class B signal boosters to amplify multiple channels within a given bandwidth. To be a FCC Class B signal booster the broadband amplifier's passband is wider than one channel bandwidth and may be many channel bandwidths wide. The FCC rules permit the amplification of both licensees and others within the passband of a Class B signal boosters.

These amplifiers used in Class b signal boosters are very linear amplifiers to minimize distortion and intermodulation generation. To assure the amplifier operation remains within the linear region while operating at maximum usable output power, a feedback circuit reduces the amplifier gain so the maximum output is relatively stable. This also assures the out of band emissions are within the FCC limitations, which is currently -13 dBm.

Since the bandwidth of a broadband amplifier allows amplification of more than one communications channel, the total power of all the channels together is called the "composite power". A power measurement of the total power out of a broadband amplifier is the sum of all the carriers within that passband, not any one single channel. A more accurate measurement of 'power per channel' can be made using a spectrum analyzer.

The end result of the feedback driven gain adjustment is the output power per *channel* can vary in direct proportion to the input power per channel when operating at maximum *composite* power output .

The impact of multiple channels on the power per channel

Example relationships are illustrated in Table 1 on page 2 when comparing the power level per channel when the signal boosters composite output power level is fixed at maximum.

Table 1
Effect of composite power when signal booster is operating at maximum design output level
In this illustration, the input carriers are all 0.001 mW (-30 dBm) and the maximum composite output power is 1 watt (+30 dB).

Number of Input channels	Input Power per channel mW	Input Power Composite input (mW)	Input Power Composite Input (dBm)	Effective Gain *	Output Power per channel dBm	Output Power per channel mW	Output Power composite output (w)
1	0.001	0.001	-30.00	60.00	30.00	1000.000	1
2	0.001	0.002	-26.99	56.99	26.99	500.000	1
3	0.001	0.003	-25.23	55.23	25.23	333.333	1
4	0.001	0.004	-23.98	53.98	23.98	250.000	1
5	0.001	0.005	-23.01	53.01	23.01	200.000	1
6	0.001	0.006	-22.22	52.22	22.22	166.667	1
7	0.001	0.007	-21.55	51.55	21.55	142.857	1
8	0.001	0.008	-20.97	50.97	20.97	125.000	1
9	0.001	0.009	-20.46	50.46	20.46	111.111	1
10	0.001	0.010	-20.00	50.00	20.00	100.000	1
20	0.001	0.020	-16.99	46.99	16.99	50.000	1
30	0.001	0.030	-15.23	45.23	15.23	33.333	1
40	0.001	0.040	-13.98	43.98	13.98	25.000	1

* Effective gain is signal booster gain after feedback control (AGC)

Obviously, the more input channels, the less power out per channel. Good engineering practice is to assume worse case based on the spectrum activity within the signal boosters passband.

For example, it is practice to assume 40 equal level carriers could occur in the worse case in downtown Los Angeles, so the coverage is designed around a per carrier power level of 25 mW or +14 dBm. When there is less activity the coverage will improve.

Although the input filter's bandpass may be wide enough to pass more than 40 channels, that is seldom the real spectrum seen out of the donor (roof top) directional antenna. Directional antennas reduce the level of undesired channels that are not in the main gain lobe of the antenna.

It is true that a very strong signal within the passband can 'dominate' the power per channel and have the same effect as multiple undesired channels. The most extreme cases may require the use of FCC Class A channelized signal boosters, with the engineers awareness of other potential undesirable tradeoffs that may occur when using channelized signal boosters.

Exceptionally strong undesired adjacent channels may not be attenuated sufficiently by the channel selective filter to prevent negative impacts on a channelized amplifier. For example, a channelized signal booster's filter may attenuate adjacent channels by 40 dB and if the offending adjacent channel signal is 40 dB higher than the desired channel level this is the same as having two channels within the channelized signal boosters amplifiers. In real applications, a distant donor site may be delivering a -90 dBm signal to the signal booster while a nearby cell site is delivering -50 dBm, a 40 dB overdrive by the undesired signal.

High level input signals can exceed the capability of the AGC circuits and/or the 3rd order intercept point of the input amplifiers in any type signal booster, leading to excessive IM products and out of band emissions. The solution is the same as for all designs: anticipate these conditions in the system design and set signal booster gains accordingly.

Note that for antenna-to-antenna isolation the value that should be used should be the gain setting of the signal booster plus 15 dB. In the example above, this would be 60 dB + 15 dB for a total isolation requirement of 75 dB or more.

The impact of lower level channels on Channel Power

When doing a spectrum analysis it is not uncommon to see many low level 'undesired' channels within the signal booster's passband. The best place to insert the spectrum analyzer is after the input filter. The downlink path is usually the most active. The result on the spectrum analyzer will now be a true representation of the input spectrum after the improvement caused by the input filter by reducing out-of-band channels as well as the directivity of the donor (roof top) antenna.

It has become common practice to ignore undesired signals that are 20 dB or more below the desired channels. Table 2 demonstrates the insignificant impact of as many as 40 undesired channels upon the output level of the desired channels.

Table 2
Impact of undesired channels 20 dB below desired channels
In this illustration, the desired channels are -30 dBm, the undesired channels are -50 dBm and signal booster output set at +30 dBm composite

Number of desired channels	Composite desired channels (dBm)	Number of undesired channels	Undesired channel levels	Composite undesired channels	Channel dBm without undesired	Channel dBm with undesired	Net dBm reduction impact
1	-30.00	0	none	none	30	30.00	0
1	-30.00	10	-50.00	-40.00	30	29.54	0.46
1	-30.00	20	-50.00	-37.00	30	29.24	0.76
1	-30.00	40	-50.00	-33.00	30	28.24	1.76
10	-20.00	0	none	-20.00	20	20.00	0.00
10	-20.00	10	-50.00	-40.00	20	19.96	0.04
10	-20.00	20	-50.00	-37.00	20	19.91	0.09
10	-20.00	40	-50.00	-33.00	20	19.79	0.21
20	-17.00	0	none	none	17	17.00	0.00
20	-17.00	10	-50.00	-40.00	17	16.98	0.02
20	-17.00	20	-50.00	-37.00	17	16.91	0.09
20	-17.00	40	-50.00	-33.00	17	16.89	0.11
40	-14.00	0	none	none	14	14.00	0.00
40	-14.00	10	-50.00	-40.00	14	13.99	0.01
40	-14.00	20	-50.00	-37.00	14	13.98	0.02
40	-14.00	40	-50.00	-33.00	14	13.95	0.05

Best Practices for Donor Antennas

From Table 2 it can be recognized that undesirable channels that are much lower than the desired channels have minimal impact. The 'donor' antenna is typically the outside roof antenna. Careful choices of antennas types and mounting can improve the desired channel levels and reduce undesirable channel power levels.

Obviously, an antenna with high directivity and high front-to-back rations should always be used. This includes locations where the benefits of the antenna gain is not important because we are looking for the directivity.

The following illustrations demonstrate several important methodologies.

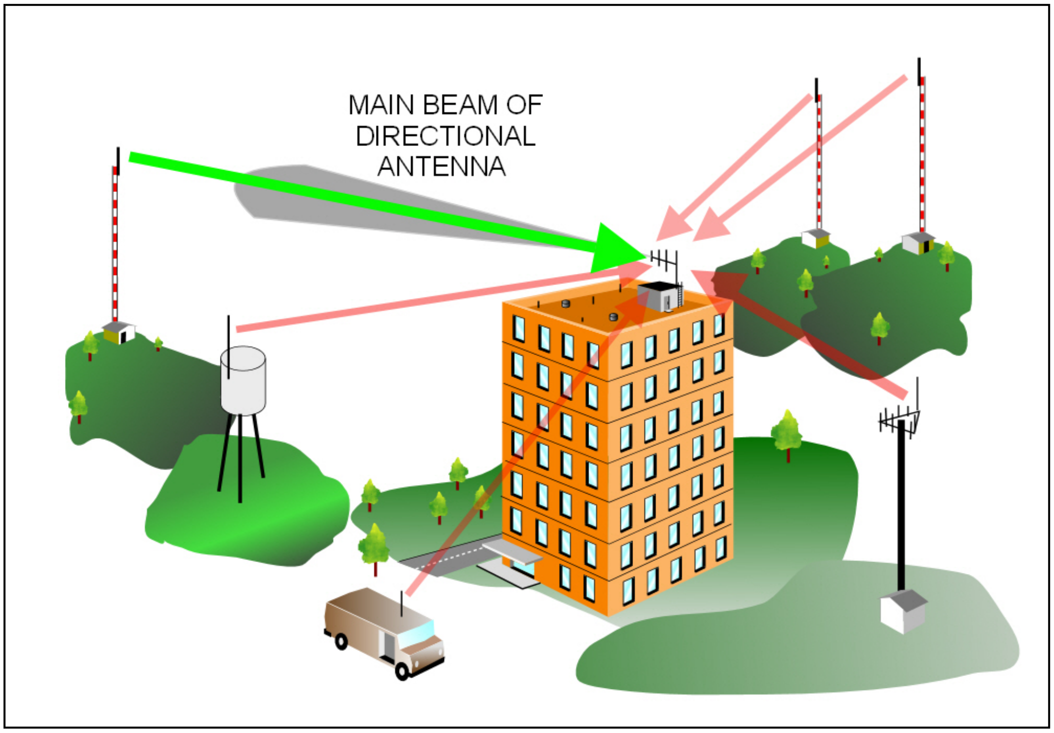
Using the structure itself to reduce undesired channels:

Many roof tops have elevator and HVAC rooms that may provide additional blockage of undesired channels. Instead of placing the antenna above these rooms, place the antenna on the side of the room, putting the attenuation of the room between you and potential undesired channel locations. This approach can be used on the face of buildings as well.

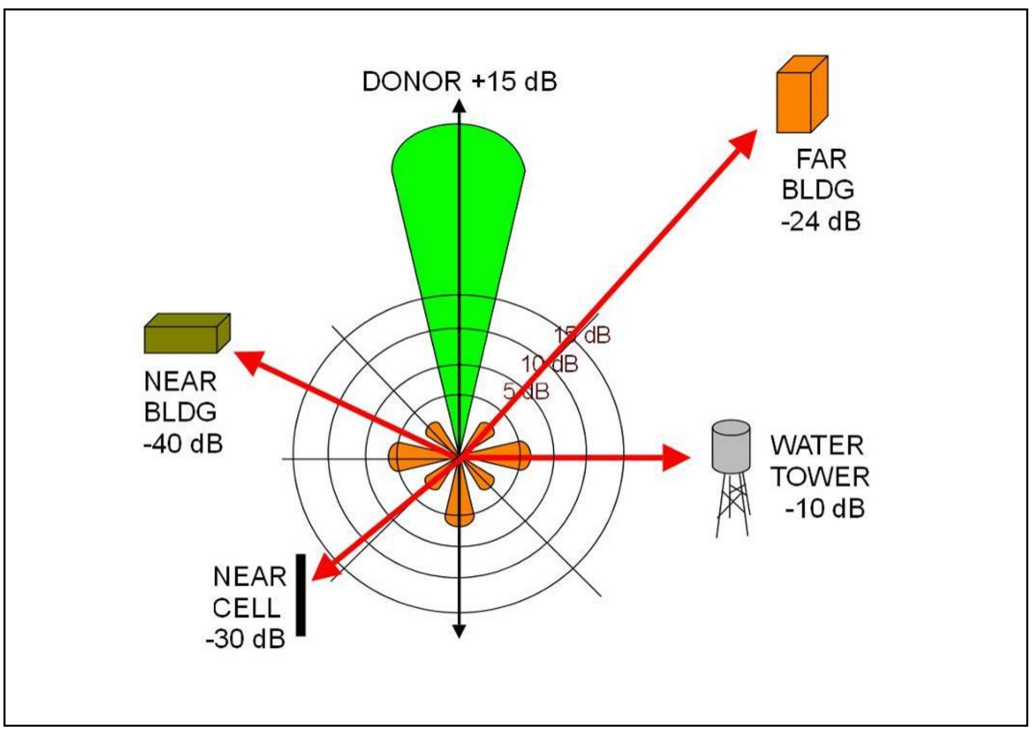
High donor antennas also 'see' more sites in the distance. The antenna elevation should be as low as practical an still maintain a line of sight path. Below are pictures of actual public safety installations using this approach:

Donor Antenna on
side of structure.
Blocking nearby
Nextel site

Panel Donor Antenna at
street level.
(Downtown Los Angeles)



The above illustration shows the importance of a directional antenna in reducing the levels of potential undesirable interferers. Note the vehicular source also.



This illustration shows the practice of slightly rotating a directional antenna 'off center' so that the offending sources fall with the low gain side lobes of the antenna. This effect is most noticeable in Yagi type antennas.

Broadband bandpass filter optimization:

It is a common error to think input and output filters are simple duplex filters. While the function of duplexing the downlink and uplink channels does occur, high performance filters are required to prevent interactions due to the high gains within the signal booster itself and the reduced guardbands that are more demanding than common duplexers.

The passbands of public safety rated signal boosters can usually be ordered to match the requirements. Consumer grade products usually come with one maximum bandwidth choice. The type of filter includes cavity, combine, saw and digital with each having its advantages and disadvantages. By providing the system designer with the exact operating frequencies, site coordinates and known power levels, they can determine which choices bets fit the application. There may be more than one solution.

Summation: Class B broadband signal boosters have a long record of successfully providing reliable in-building coverage for public safety agencies. Although the basic concepts were developed several years ago, these products are under constant improvements in performance and functionality.

System engineers and client agencies are cautioned to evaluate the real design dynamics of their environment in making their system design and equipment selections. While Class B signal boosters satisfy many public safety requirements, the use of Class A may be needed in some situations to address undesirable in-band interferers. There are many considerations and trade-offs the system designer must handle when planning and installing a public safety in-building system, whether class A or B.