Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Amendment of Parts 1, 2, 22, 27, 90 and 95 of	)	WT Docket No. 10-4
the Commission's Rules to improve Wireless	)	
Coverage Through the Use of Signal Boosters	)	

COMMENTS REGARDING NOTICE OF PROPOSED RULE MAKING (NPRM)

Jack Daniel, dba Jack Daniel Company, pursuant to the Commission's Public Notice of April 5, 2011,[1] hereby respectfully submits its comments in the above-referenced proceeding.

Jack Daniel is the sole proprietor of The Jack Daniel Company, a provider of consultation services, training programs, system design and materials specializing in in-building communications enhancement nationwide. Jack Daniel is a nationally recognized authority on public safety use of signal boosters with over 25 years experience in that field, preceding the first FCC certified signal booster in 1985.

Jack Daniel has spoken on the subject of signal boosters, in-building communications and codes that call out a requirement for public safety ino0door wireless coverage before such notable organizations such as the Association of Public-safety Officials, International (APCO),

[1] DA 10-14, released January 6, 2010 and extension of filing time released June 20, 2011.

National Public Safety Telecommunications Council (NPSTC), National Fire Protection Association (NFPA), International Code Council (International Fire Codes), International Wireless Communications Expo (IWCE), Institute for International Research (IIR), American Conference Institute (ACI) DAS Council, Enterprise Wireless Alliance (EW A) Institute as well as before many local public safety agencies and their associations.

Jack Daniel is a Life member of the Association of Public-safety Officials, International (APCO) Fellow of the Radio Club of America (RCA) and member of National Fire Protection Association, International Code Council (ICC), Association of Police Chiefs International (IACP) and Association of Fire Chiefs (IAFC).

Jack Daniel was vice-chair of the National Public Safety Telecommunications Council (NPSTC) In-Building Communications Best Practices committee, and a contributor to the in-building codes developed by the National Fire Protection Association (NFPA) and International Code Council (ICC) International Fire Code (IFC) section.

Signal booster applications that Jack Daniel has contributed to include communication systems used in major international airports, high-rise buildings, subway systems, nuclear power plants and U.S. military applications.

Like APCO and other public safety organizations, Jack Daniel supports and engages in the process of local authority adoption of fire and building codes that require signal booster in structure for the benefit and protection of first responders. He was an advisor to the first in-building code in the United States[2].

Jack Daniel focuses on implementing highly reliable and survivable, life saving wireless communications capability to Fire, Law Enforcement and Emergency Medical Services within structures and confined areas.

Jack Daniel in involved in the recommendation, sale, system design and implementation of both Class A and Class B signal boosters from various manufacturers.

While it could be more profitable to only promote the sale of Class A signal boosters, I believe profit is secondary to my responsibilities as a responsible member of the public safety community.

I. SUMMARY

These comments are in support of the excellent work of the Commission as reflected in the Notice of Proposed Rulemaking.

[2] Re. City of Burbank Ca, Ordinance No. 3265, effective September 21, 1991.

The intent of Jack Daniel is the same as the Commission's; minimize any additional burdens upon the Commission and to regulate any interference that degrades the operation of a licensees authority, especially public safety communications.

Jack Daniel is providing discussion of topics that require additional emphasis in light of the 720 filings made to date on this proceeding.

Jack Daniel has relationships with multiple manufacturers of all types and classes of wireless coverage enhancement products, including both Class A and Class B signal boosters, RF Over fiber optics, back-up power systems and other devices used in the current art.

Jack Daniel's purpose for commenting is to assure public safety licensees have competitive choices of hardware, including signal booster classes, needed to assure reliable and cost effective wireless communications within obstructed areas such as buildings, basements, subways, mines, canyons, etc.

Jack Daniel's comments are focused upon Part 90 licensees only and comments on subscriber-based services are only made when necessary for that focus.

II. Class B Signal Booster Use

Some commenters have suggested Class B broadband signal boosters be removed from these rules. Class B signal boosters are more applicable to public safety licensees than those few commenters may understand.

Some commenters may also seek restrictive regulations that could provide them with an unfair competitive advantage over others due to the commenters lack of skills or products.

It is important to recognize the enormous success the spectrum users have had with Class B Signal boosters. With over two million[3],[4] Class B signal boosters in use today, most installed by consumers with no technical skills or test equipment, the relatively small percentage of instances of Interference overall is surely unexpected if you rely on the exaggerated interpretations of Class B interference by some.

It is unfortunate that some would condemn all Class B signal booster operations as problematic due to the commenter's limited experience with how these are used successfully in buildings nationwide.

[3] See Wilson Petition for Rulemaking filed November 3, 2009, page 4 para 1.
[4] See Nextel comments dated February 5, 2010 section V, line 3;" … thousands of small scale … nearly 1000 large scale…solutions."

For example, most subway systems use Class A channelized signal boosters for outside over-the-air interface to the internal signal distribution System. When examined closer this is a very specialized requirement necessitated when the radio frequency environment includes an overly abundant quantity of undesired frequencies in use within the subway and the over-the-air (donor) antennas are often located at low elevations, in the vicinity of countless outside radio frequency signal sources and receivers, many transitory, at street level. The use of signal boosters within the New York subway system is such a one-of-a-kind situation.

The Commission's rules must address universally applied signal booster rules and subways are definitely not the norm for all other signal booster usage. A few other uncommon signal booster applications, such as nuclear plants, exist as well but their uniqueness should not be the basis for any universal rulemaking.

Although the countless value of saving one first responders is immeasurable the reality of costs will temper the use of signal boosters. In the case of tax based applications such as government buildings, subways or airports, there is less cost sensitivity than that of a building owner that is required to install an in-building wireless coverage system for first responders. Building owners must pay for signal booster systems and until such time there is no price advantage of Class B signal boosters over Class A signal boosters, demanding more expensive Class A signal boosters be used unnecessarily will drive the building owners to seek ways to contest and otherwise defer that expense. In the mean time the structure remains a hazard to all first responders regardless of intent of the Commission and others.

III. **Enhanced Interoperability**

In some instances the wider bandwidth of Class B signal boosters offer assistance to public safety interoperability. For example, an agency may allow the use of Class B signal boosters that will amplify the complete 3 MHz NPSTC band although the agency is only active on some portion of these channels when there are no emergencies. However when mutual aid is needed as in the case of a major fire, earthquake. hurricane or terrorist event, the signal booster may provide coverage for the assisting agencies with no re-programming of radio channels, switching channels or other human intervention.

As 700 MHz exclusive use public safety band plans are implemented similar Class B interoperable capability will be desired in that band.

IV. **Class B signal booster availability does not restrain the use of Class A Signal Boosters.**

Part 90 licensees who desire to use Class A signal booster are not restricted from doing so because Class B signal boosters also exist . Many thousands of others should not be forced to use Class A signal boosters simply because they exist.

V. Interference

There are no comparable interference metrics available for Class A versus Class B signal boosters due to the low historic number of Class A signal booster users to date driven mostly by cost and partially due to a limited number of sources in some frequency bands. Some versions of Class A signal boosters have been available as long as Class B signal boosters, starting with the first crystal filtered Class A signal booster FCC certificated on July 28 1986 to TX RX Systems[5].

The first FCC Certificated signal booster in the United States was a Class B signal booster TX RX Systems[6], now a division of Bird Technologies, certified six months earlier on December 30, 1985.

It has been erroneously suggested Class A signal boosters are less prone to cause interference than Class B signal boosters. Regardless of availability or cost, Class A signal boosters RF emissions and potential oscillations must obey the same laws of physics as Class B signal boosters.

It is disingenuous for Class A signal booster proponents to require increased bandwidth to reduce group delay problems while saying any oscillations and noise would be restricted to their single channel. For example, other earlier commenters[7] have agreed a Class A signal

[5] Reference FCC Certification database, certification ID EZZ5PI851101
[6] Reference FCC Certification database, certification ID EZZ5PI860701
[7] Canam Technologies comments dated February 5,2010, APCO, etc.

booster that must handle an FCC assigned 12.5 KHz digital channel will need approximately six to eight times the Commissions authorized channel bandwidth to operate properly.

Should such excessive passbands in a Class A signal booster could go into oscillation condition as easily as a Class B signal booster when there is insufficient isolation between inside and outside antennas. The typically random interference generated by a defective Class A signal booster installation could impact six or more adjacent channels that may be assigned by the Commission to other licensees and at higher power levels.

Class A signal boosters are promoted as having higher output power levels [8],[9]which makes it more difficult to obtain the necessary isolation between antennas.

Canam Technologies[10] states the gain of their channelized product can be as high as 120 dB, which is not unusual for Class A signal boosters. Using the lowest level of accepted best practices isolation, signal booster gain plus 15 dB[11], the minimum antenna to antenna isolation needed is 135 dB. This is not an isolation that is easy to obtain or maintain, even in subways near passenger loading platforms where stray signals from outside the subway are an additional problem.

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[8] Canam Technology, product specifications at www.canam-technology.com/ing/MarkIV_CHOLC.html, next to last line, "20 watts".
[9] Futurecom Group, product specification at http://www.futurecom.com/uploaded/tiny_mce/File/Product_PDFs/CMD800.pdf, "1 t0 30 watts"
[10] Same source as footnote 8, above.
[11] See Appendix A, NPSTC Best Practices. This standard practice is also cited in NFPA codes.

It should be pointed out that the vast majority of interference complaints were caused by subscriber-based service signal boosters interfering with public safety licensees. Very few cases of interference between two public safety licensees' signal boosters, or originating from within a public safety installation have been reported.

Major public safety licensees also frequently have exclusive licensee use channels within their operating area which further reduces co-channel interactions between signal boosters.

In any event, interference to life safety mission communications is unacceptable and it is Jack Daniel's intent to promote Commission rules that provide meaningful reductions of interference through regulation and technology.

Public safety MUST employ a reasonable 'no tolerance' policy towards interference caused to any of their wireless communications systems including interference from *both* Class A and Class B signal boosters.

VI. Untrained and ill-equipped installers are the root of signal booster Interference

Regardless of any arguments, signal booster malfunction due to inept installers it is an unacceptable condition. It has been proven in practice installations Class B signal boosters do NOT interfere when designed installed and maintained by skilled and trained individuals.

VII. Interference amongst Public Safety Licensees

There are sound reasons that interference from or between public safety licensee Class B signal boosters is less.

Unlike consumer installed signal boosters, public safety signal booster systems are designed using higher grade signal boosters and implemented by trained professionals with proper test equipment.

Technical competence for public safety applications has also become a requirement in new Emergency Communications Systems codes issued by the National Fire Protection Association (NFPA)[12] and International Fire Code (IFC)[13], requiring FCC General Radio Operator Licenses (GROL), certified factory training and/or other technical qualifications of the personnel involved.

It is no small matter that these two nationally accepted codes are being adopted and, like preceding local codes[14], these codes will drive the use of public safety signal boosters more extensively nationwide. As two examples, the State of California and State of Massachusetts fire authorities have already adopted these codes as statewide standards. In presenting training to hundreds on these codes to national groups[15] there is a great desire to utilize these new codes.

[12] Re NFPA72 2010, Chapter 24, Emergency Communications Service. This document cannot be duplicated here due to copyrights. The document can be purchased at www.NFPA.org

[13] Re IFC 2009 Section 510, Emergency Responder Radio Coverage. This document cannot be duplicated here due to copyrights. The document can be purchased at www.iccsage.org.

[14] For a partial list of local codes requiring in-building communications for first responders see www.RFSolutiuons.com/ords.htm.

[15] Jack Daniel has made presentation at national and conferences and symposiums held by APCO, IFC, NFPA, DAS Congress, CPRA, NAPCO, Comtronics Code Training (Boston), and other public safety events.

VIII. Cost Considerations

With today's severely limited public funds it is more important than ever to get the most performance out of the least expensive alternatives. Class B signal boosters have provided public safety licensees reliable and non-intrusive communications for over 15 years.

Codes mandating In-building communications for first responder codes require the building owners to pay for any in-building signal enhancements that may be required. In some cases this no small cost to the building owners and responsible public safety agencies have partnered with building owners to get the most affordable systems, and that is the use of Class B signal boosters when appropriate. If forced to only use more expensive Class A signal boosters more building owners will balk and delay the implementation of life critical in-building communications systems[16].

It must be noted public owned facilities, such as subway systems, are funded by a public agency which in the past has had more funds available for this purpose than a typical building owner. Economic conditions dictate competent local agencies must consider, and employ, Class B signal boosters when possible.

Additional information relating to Class A and Class B signal booster operation may be found in Appendix A, Best Practices for In-building Communications by National Public-safety Communications Council's "Best Practices for In-Building Communications" white paper.

[16] Re comments made to Jack Daniel by stakeholders upon presenting a lecture on NFPA and IFC codes at the Distributed Antenna System (DAS) Congress in Las Vegas, May 15, 2011.

IX. Transmit Power

I concur with the Commission conclusion that a maximum of 5 watts ERP is proven to be adequate for all signal booster installations.

However the current rule refers to an *average* power of 5 watts without specificity to over what period this average is taken. This is important as this method may allow much higher momentary power levels depending upon the averaging time period.

I suggest a more consistent requirement of *peak* power per channel. This criteria may be subject to the same argument as to what is the time period of *peak* power because there are digital modulation artifacts that generate higher than normal instantaneous power 'spikes' that are generally sub-microsecond in duration and not measureable on much common test equipment.

Therefore I submit anything that cannot be measured with a common spectrum analyzer should be inherently exempt.

Those seeking higher power levels for signal boosters have already been accommodated within the Commission's rules. They simply must license the site the same as any repeater site.

Motorola in their February 5, 2010 comments, page 10 stated; " A 35 watt ERP-based Class A booster will serve as a full substitute for an additional base site ……", a confirmation that the intent of using higher power outdoor signal boosters is functionally similar to a site licensed base station.

The licensing process would require frequency coordination to assure higher powers do not cause encroachment into co-channel licensees approved coverage area(s). If not coordinated,

power levels above 5 watts per channel would make frequency coordination ineffective, unpredictable and unmanageable.

X. Passive InterModulation in Signal Booster Systems

Although beyond the scope of this proceeding, the use of higher signal boosters has brought to light another sources of interference which can be misinterpreted as Class B signal booster generated when high power levels are used; uplink pollution caused by passive intermoduation (PIM). In recent years base station sites have been found to have levels of PIM that when reduced dramatically increased the usefulness of the radio site. In-building systems are not immune to PIM effects as well and when PIM occurs within the uplink passbands, sometimes called “uplink pollution”, the result can appear as signal booster noise to inexperienced investigators.

The distribution systems in subways and structures can be a complex web of cabling, connectors and non-linear devices. The primary source of PIM needs ferric materials to generate low level IM signals.

Subways have the additional potential of PIM due to the existence of massive ferric masses that are uncommon in most buildings. (For this discussion I will not include the uplink pollution caused by electrical trains and arcing of poor power insulators)

Class B signal boosters typically exhibit very low levels of uplink pollution from PIM sources simply because the downlink power is much less than many Class A signal boosters.

When comparing a 35 watt power level from a Class A signal booster to a 200 milliwatt signal from a Class B signal booster, the difference in the potential magnitude of PIM and uplink pollution, caused by high power Class A uplink signal boosters glaring.

XI Signal Booster Classifications

In reviewing the comments filed before this NPRM and in discussion with other professionals with extensive experience in the use of both Class A and Class B signal boosters there is great difficulty and confusion in applying current classifications.

Consider the following examples of operation of both classes;

1. Class A signal boosters are well known to require widening of the band of frequencies to be amplified beyond one authorized channel to accommodate newer digitalized voice and other digital data transmissions.

2. Canam proposes a maximum of 60 KHz (+/- 3dB) passband[17].

3. Motorola commented on page 9 of their February 5, 2010 filing stated, " With Class A boosters, however, the frequency coverage and *channel occupancy* is identical to that of a mobile or base station radio. Thus with the consent of the licensee and under the direction of professional installers, the increase to 35 watts per channel is

[17] Canam comments filed February 2, 2010, page 7.

appropriate and will not cause an increase in interference to the licensee or *adjacent channel licensees*". (italics added for emphasis on important details)

Clearly Motorola defines a Class A signal booster as one which has passbands equal to the licensees authorized channel bandwidth occupancy. In other words, no intentional widening of passbands for the purpose of reducing data destructive group delay distortion would be allowed under their definition of a Class A signal booster.

Based on proprietary tests of complex data waveforms of all current and anticipated public safety modulations, The minimum 3 dB passbands were three (3) to five (4) times the authorized channel bandwidth.

Jack Daniel proposes to define signal boosters as;

1. A Class A signal boosters 3 dB passband will not exceed more than eight times authorized channel bandwidth as may be required to assure reliable communications as demanded by public safety especially.

2. Additionally, all Part 90 signal boosters must suppress OOBE a minimum of 60 dB +/- 1 MHz from the passband edge 3 dB points.

3. A Class A signal booster may also have its 3 dB passband expanded to include a multitude of contiguous channels authorized to one licensee and no other licensees frequencies without explicit approval.

4. A Class B signal booster passband may be reduced to pass only those frequencies of one licensee if the authorized channels are a multitude of contiguous channels. In referring to item 1 above, it is within the capabilities of some Class B signal boosters to have a 100 KHZ +/- 3 dB passbands. Class B signal boosters operating under this rule are afforded the same privileges as a Class A signal booster with the pass bandwidth(s).

5. With the availability of 700 MHz channels for public safety exclusively, and potentially 10 more megahertz in a D Block assignment, a single authorized channel bandwidth could be 10 megahertz or greater.

6. When the 'authorized channels only' test is applied to a Class A signal boosters operating on subscriber-based service channel groups, the passband more often will be the total bandwidth of the licensees total assigned bandwidth, such as PCS channel B, etc. , subscriber-based frequency band signal boosters could be classified as either Class A or Class B.

Therefore, Class A "channelized" signal boosters could have a passband requirement that varies from 12.5 KHz (one authorized channel) to eight times for one authorized digital channel or even 10 MHz or more.

Many current signal booster products can be adjusted or programmed to be either class adding further confusion about the current definitions.

For the above and other reasons, I submit the current Class A and Class B classifications have become more operational than technical. The purpose of these classifications was to manage interference. There is good reason to maintain these classifications but they must be brought up to the current state of the art.

XII. Over the Air Communications by Signal Boosters

The Commission in its NPRM dated April 6, 2011, para 67, states it proposes to "Make clear that Class B devices must be limited to confined areas such as buildings, tunnels, parking structures, etc. but allow Class B signal boosters to be connected to external; antennas that can communicate with base stations. ".

HOWEVER, permission to use external antennas was not included in the proposed rules.

This is a very crucial oversight and must be corrected and if left standing would render almost every Class B signal booster installation useless.

Those who oppose the use of Class B signal boosters on the basis of (1) interference and (2) transmission of signals not belonging to one licensee argue against themselves. I have shown when a Class A signal boosters pass bandwidth has to be increased many channels wider to be functional, they have no advantage over a Class B signal booster with an equal pass bandwidth.

Any argument against Class B signal boosters using external antennas is simply unrealistic and self-serving in some fashion and should be set aside by the Commission.

Proposals that only allow Class B emissions to the outside of a confined area provided every licensee in the passband approve of the operation is only a device intended to deny the use of Class B signal boosters. I challenge the Class A proponents to pass the same test.

The Commission has wisely included the ultimate and most appropriate regulation of *all* signal booster usage; Cease operation of any signal booster causing objectionable interference to licensed communications. No more is needed.

XIII. Summation

In summation of my preceding comments, I submit a mark-up revision of the commission's NPRM rules for Part 90 below.

Conventions used: Deletions are shown as strikethrough and Additions are underlined.

XIV. Definitions

The Commission refers many times to "subscriber-based services' without a clear definition which would be clearly understood by consumers who are not familiar with the language of the Commission's rules. To prevent misunderstanding of Part 90 rules I submit the following additions to 90.7 is in order;

Subscriber-based services. Communications systems which offer services to the public for profit such as cellular and CMRS (i.e. Sprint-Nextel and others). Public safety and Industrial communications systems are not in this category.

Donor Antenna. The antenna used in signal booster systems that communicates between the distant base station and the location of the signal booster, typically roof mounted antennas.

Service Antenna. The antenna(s) used in signal booster systems that communicates between the signals booster and radios in an otherwise blocked area, such as inside a building, a canyon, etc. This is the antenna inside the vehicle in mobile applications.

XV. <u>Proposed Part 90 NPRM text, edited to include comments made in this filing.</u>

PART 90—PRIVATE LAND MOBILE RADIO SERVICES

11. The authority citation for Part 90 continues to read as follows:

AUTHORITY: Sections 4(i), 11, 303(g), 303(r), and 332(c)(7) of the Communications Act of 1934, as amended, 47 U.S.C. 154(i), 161, 303(g), 303(r), 332(c)(7).

12. Section 90.7 is revised by adding a definition for signal amplifier and amending the definition of signal booster to read as follows:

§ 90.7 Definitions.

Signal amplifier. A device that is installed between a radio transmitter and an external antenna, which amplifies the outgoing signal.

Signal booster. A device that automatically receives, amplifies, and retransmits on a bi- or unidirectional basis, the signals received from base, fixed, mobile, or portable stations, with no change in frequency or authorized bandwidth. Signal boosters may be either ~~narrowband~~ channelized (Class A) or wideband (Class B). Class A ~~narrowband~~ channelized signal boosters may be deployed at fixed locations or as mobile devices, and amplify signals only on those channels authorized to the licensee. Class B wideband signal boosters are restricted to fixed deployments ~~in enclosed areas- such as buildings, underground parking garages, and transit tunnels,~~ and amplify all signals across an entire frequency band.

Subscriber-based services. Communications systems which offer services to the public for profit such as cellular and CMRS (i.e. Sprint-Nextel and others). Public safety and Industrial radio services are not in this category.

Donor Antenna. The antenna used in signal booster systems that communicates between the distant base station and the location of the signal booster, typically roof mounted antennas.

Service Antenna. The antenna(s) used in signal booster systems that communicates between the signals booster and radios in an otherwise blocked area, such as inside a building, a canyon, etc. This is the antenna inside the vehicle in mobile applications.

Section 90.219 is revised to read as follows:

§ 90.219 Use of signal boosters.

Licensees authorized to operate radio systems in the frequency bands above 150 MHz may operate signal boosters subject to the following conditions:

(a) General requirements. Signal boosters may only retransmit an amplified signal on the exact frequency (or frequencies, if applicable) of the originating base, fixed, mobile, or portable station. Signal boosters may only be used to fill in weak signal areas within an authorized licensees area and cannot extend the system's signal coverage area. The minimum measured isolation between the donor antenna and any service antenna shall not be less than the gain setting of the signal booster plus 15 dB.

(b) Class A requirements. Class A (~~narrowband~~ channelized) signal boosters must be capable of being adjusted or programmed to amplify only one authorized bandwidth, such as 12.5 KHz. Class A signal boosters may be used at fixed locations or as mobile devices, and may amplify signals only on those channels authorized to the licensee. In the event the signal booster is adjusted or programmed so that the passband passes frequencies other than those of the licensee the operation shall become that of a Class B signal booster subject to the requirements of 90.219 (c). Class A boosters must include automatic level control circuitry with a minimum of 60 dB Dynamic gain adjustment range. Class A boosters must not exceed ~~an average~~ a peak effective radiated power (ERP) of 5 watts per channel. Class A boosters must meet the out-of-band

emission limits of § 90.210 for each narrowband channel the booster is designed to amplify. Class A signal boosters shall attenuate all emissions +/- 1 MHz from the upper and lower edges of each 3 dB passband a minimum of 60 dB.

(c) Class B requirements. The maximum passband of a Class B signal booster shall be limited to that of service band(s) authorized to the licensee. Example; a signal booster cannot be designed or operated with public safety frequencies and subscriber-based service frequencies in the same signal booster. Class B (wideband) signal boosters are restricted to fixed deployments ~~in enclosed areas such as buildings, underground parking garages, and transit tunnels mines,~~ and amplify all signals across an entire frequency band. Class B signal boosters may be connected to external antennas that can communicate with base stations. Class B boosters must not exceed ~~an average~~ a peak ERP of 5 watts for each authorized channel that the booster is designed to amplify. Class B boosters must include automatic level control circuitry with a minimum of 60 dB dynamic gain adjustment range. Class B boosters must meet the emission limits of § 90.210 for frequencies outside of the booster's designed passband. Class B signal boosters shall attenuate emissions +/- 1 MHz from the upper and lower edges of each passband by 60 dB or greater.

(d) Operating authority. Part 90 Licensees are authorized to operate certificated signal boosters without separate authorization from the Commission. Individuals and non-individuals may only operate certificated signal boosters on Part 90 frequencies that are used for the provision of subscriber-based services subject to the conditions enumerated in subpart M, part 95 of this

chapter. Non-licensee operation of signal boosters for other radio services, such as public safety frequencies, require written consent of the licensee . Only certificated equipment may be operated, and the operator must comply with all applicable rules.

(e) Interference remediation. Licensees and other operators of signal boosters must correct any harmful interference that the equipment may cause to other systems. Normal co-channel transmissions will not be considered harmful interference. Interference resolution is subject to the conditions in § 90.173(b).

(f) Implementation of Part 95 Subpart M rules. Part 95 subpart M rules will become effective within 30 days of the effective date of these rules. No further repairs or installation of existing signal boosters that do not meet the requirements of Part 95 Subpart M may be made after 30 days of the effective date of these rules. Operation of existing signal boosters that do not meet the requirements of Part 95 Subpart M must be removed from service within 24 months of the effective date of these rules. Continued operation can result in fines and/or seizure of illegal equipment.

(g) National Signal Booster Clearinghouse. All fixed installations of signal boosters shall be registered using an on-line data base provided by the Commission. This registration will require;

1. The Call sign of the licensee for whom the signal booster is deployed. Note you cannot install a signal booster without the written approval of the existing licensee.

2. The common street name where the signal booster is located. In rural areas, relationship top nearest cross roads or city limits, etc.

3. The coordinates of the signal booster location. In the format: DD-MM-SS.S North and DDD-MM-SS. West.

4. The name and 24 hour telephone number of the person responsible for the operation of the signal booster, such as the building supervisor, contracted servicing party, etc.

The information in this database is open to public access.

XVI. Conclusion

Class A and Class B signal boosters are both needed under Part 90 rules. For the reasons stated in this filing and other reasons, Jack Daniel seeks a ruling by the Commission favorable to these conclusions.

Respectfully submitted,

(signature)

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Date: July 24, 2011

APPENDIX A

National Public Safety Telecommunications Committee (NPSTC)

Best Practices for In-Building Communications

NPSTC

National Public Safety Telecommunications Council

Best Practices for In-Building Communications

National Public Safety
Telecommunications Council (NPSTC)
In-Building Working Group

Stu Overby, Chair
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November 12, 2007

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1 Executive Summary and Background

The need for reliable communications does not stop at the door of a building. Increasingly, public safety entities, commercial wireless service providers, and wireless users require reliable communications inside buildings and, where applicable, inside tunnels. For public safety, reliable coverage is often essential throughout a broad jurisdiction, including coverage on-street, in-building, and in-tunnels. In such cases, there is no substitute for a properly designed dedicated mission-critical communications system with sufficient transmit sites to provide the level of signal required for reliable coverage anywhere within the jurisdiction, whether on-street or indoors.

However, where other limitations, e.g., lack of spectrum or inadequate funding prevent the deployment of such ubiquitous coverage throughout a jurisdiction, there are ways to supplement the outdoor coverage in specific buildings with a variety of “in-building” coverage solutions. These include bi-directional amplifiers (BDAs), off-air repeaters, PicoCell/Microcells, fiber-based Distributed Antenna Systems (DAS), or temporary deployable communications systems at a specific incident scene. Also, coverage deep in a subway tunnel may require the use of bi-directional amplifiers and specialized antenna systems such as “leaky coax,” regardless of the level of signal above ground. Deployment of solutions for reliable in-building or in-tunnel coverage must consider the spectrum environment, building or tunnel parameters, and the users’ operational needs. This paper covers the basics of in-building systems, techniques to minimize the risk of interference, and engineering best practices to provide robust in-building coverage.

Some jurisdictions have enacted ordinances to help ensure that construction of commercial buildings includes provisions for radio coverage of public safety signals within the building as a condition of occupancy and some of the methods noted above are usually allowed to meet these ordinances. In addition, initiatives are underway to develop and implement nationwide model codes that address public safety in-building communications. Sample local ordinances and the overall elements of national level codes under discussion are addressed herein.

The increasing business and consumer demand for wireless service also requires that commercial wireless systems increasingly provide in-building coverage. In-building systems boost both the signal to be received by a wireless device and the transmit signal from that device. To minimize interference, these systems must be properly designed and properly installed. A wide range of in-building systems are on the market, from high-quality units to low-cost consumer grade units with little if any filtering. In addition, installation practices vary, especially between knowledgeable and expert companies and consumers who often have minimal knowledge of proper installation and interference mitigation techniques.

This environment has led to the following trends:

- In-building deployments for public safety have grown in number and continue to do so.
- Commercial building owners/managers and commercial wireless service providers are also increasing their focus on the value propositions of in-building coverage for both commercial and public safety.
- Some local governments are addressing in-building coverage for certain types of buildings. While there are common elements across various ordinances adopted, there is not yet a common set of parameters invoked nationwide.
- Efforts are underway to develop and implement national level model codes for public safety in-building communications.

- The growing requirement to meet local codes regarding public safety communications as well as the need to serve customers on commercial systems are converging to increase interest in “neutral host” systems aimed at addressing both applications as one option to consider.
- Reports of interference from “rogue” (uncoordinated/unapproved) deployments have been relatively few in number but are cause for great concern to all mobile network operators and public safety entities, as they can be devastating when they do occur.

These trends have led to the need to examine the various in-building solution options, address interference concerns, define best-practices for the design and implementation of in-building systems, and develop recommended regulatory actions. The NPSTC In-Building Working Group has undertaken this initiative and the paper herein provides the preliminary results of this examination. The In-Building Wireless Alliance (IBWA), an organization which is evaluating the benefits of in-building wireless services for both commercial and public safety needs, has also been instrumental in partnering and coordinating with the NPSTC In-Building Working Group.

2 Attaining In-Building Coverage

There are three primary approaches to achieving in-building coverage: 1) Increasing the signal level through deployment of additional antenna sites within the jurisdiction; 2) Supplementing coverage in a specific building with a permanent system that boosts the signal level received from and transmitted to the outside; and 3) Using deployable systems which can boost coverage in a building for a specific incident scene on a temporary basis. There are tradeoffs across each of these approaches and it is likely that a combination of all three will be used in any given jurisdiction.

2.1 Increasing Signal through Deployment of Additional Antenna Sites

There is no substitute for a properly designed dedicated mission-critical communications system with sufficient transmit sites to provide the level of signal required for reliable coverage anywhere within the jurisdiction, whether on-street or indoors. With the exception of sub ground level floors, a properly designed and funded system can provide in-building coverage across multiple buildings within a jurisdiction for which it is designed. However lack of spectrum, inadequate funding, and/or the inability to approve sufficient transmitter sites can prevent the deployment of such ubiquitous coverage throughout a jurisdiction. Also, there is simply no 100 percent foolproof radio system. In a majority of urban environments even the best radios and radio networks cannot always penetrate high-rise buildings, subway tunnels, and other difficult subterranean environments. Coverage on underground floors or deep in a subway tunnel may require the use of other options regardless of the signal level available above ground.

2.2 Supplementing Coverage in Specific Buildings

The focus on in-building communications has spurred the use of “in-building” coverage solutions. These solutions include bi-directional amplifiers (BDAs), off-air repeaters, PicoCell/Microcells or fiber-based Distributed Antenna Systems (DAS), which are permanently installed and supplement coverage in a specific building. Such systems are particularly useful to provide day-to-day coverage in an underground parking garage or a subway tunnel where public safety entities need to communicate. The primary tradeoff of such systems is that they must be installed in each building where coverage is needed. As discussed more fully in this paper, these in-building systems also must be properly designed and installed to avoid interfering with other communications systems.

The following diagram provides a depiction of a very simple in-building system:

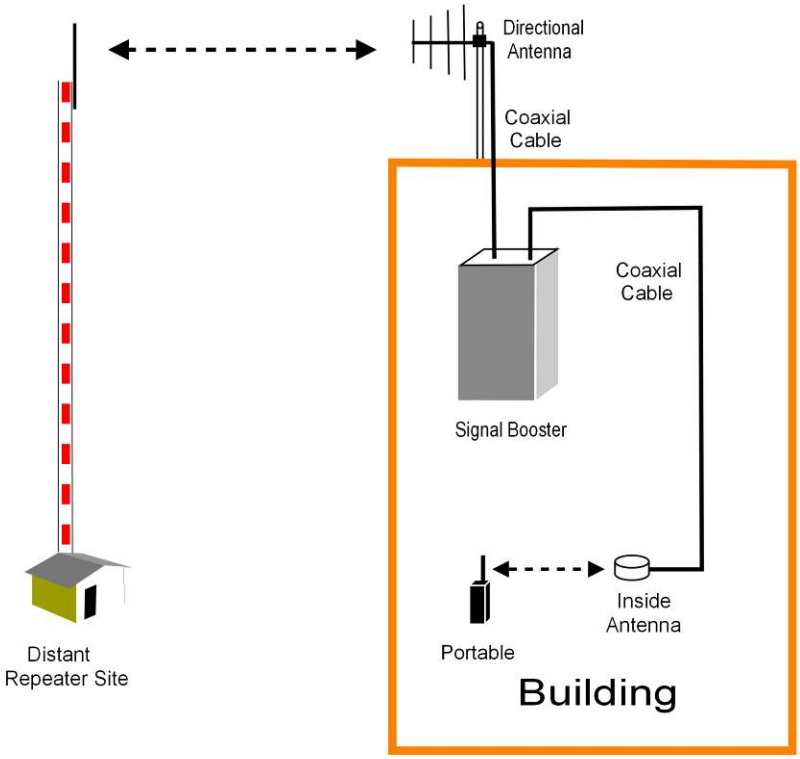


Figure 1 Simple In-Building System

2.3 Using Deployable Communications Systems

Many large urban fire departments do not rely solely on fixed repeater networks or tactical simplex channels for direct unit-to-unit use communications among each other at a fire scene. Supplementing these approaches with deployable systems provides increased reliability when land mobile portables are used in high-rise buildings or subterranean environments where coverage is challenging to maintain. Deployable solutions that normally consist of the land mobile portables familiar to firefighters through day-to-day use, along with high-powered transportable radios are designed to fit in a specially designed hard-shell case light enough to be carried by fire personnel arriving at a scene. Such transportable systems normally have a self-contained power source and can be used at any assigned post within a high-rise building or underground location.

Building and tunnel fires can damage the critical components of a communications network such as antenna lines and power lines. Lightweight deployable systems have the advantage of not relying on any pre-set infrastructure. This minimizes the concern about infrastructure that may have been damaged at the incident scene or may not have been properly maintained by a third party since a previous incident. During an emergency, crews can move these deployable repeaters to the scene of an incident to provide a dynamic communications solution for public safety personnel. The incident commander could also utilize mobile repeaters to support communications at the site and to link up with the rest of the network, providing a communications path to an operations center. Such deployable systems give agencies the potential to improve radio coverage in any location on short notice and can also serve as a useful backup when other systems have been damaged.

3 Ordinances and Codes for In-Building Communications

3.1 Local Ordinances and Codes

A number of jurisdictions have enacted or are considering enactment of local ordinances and codes which require a requisite level of public safety communications reliability in building as a condition for occupancy. The specifics of these ordinances and codes vary, but most include:

- A minimum signal strength limit;
- Application of the limit over a specified percentage of each floor;
- A specific level of reliability;
- A specified frequency band or bands for public safety coverage;
- Testing requirements and procedures;
- Provisions for penalties; and
- Provisions for waivers of the requirements.

Sample of Local Ordinances and Codes re In-Building Communications for Public Safety:

Local Jurisdiction	Ordinance Reference	Key Provisions
Boston, MA	- Fire Dept. In-Building Radio Spec. - 5/21/01	• Min signal -95 dBm, 95% of each floor • UHF band
Broward County, FL	- Ord. 99-22 - 5/25/99	• No interference to public safety comm. • Add'l facilities at no cost to county
Burbank, CA	- Ord. 3265, Sec 7-616.1 - Effective 9/21/91	• Min signal -107 dBm, 85% of each floor • 90% reliability factor • UHF band
Folsom, CA	- City Code - Chapter 14.18	• Min signal -95 dBm, 90% of each floor • 100% reliability factor • 800 MHz band • 12 hour battery backup
Grapevine, TX	- Ord. No. 109.2	• Min signal -107 dBm, 95 % of each floor • 800 MHz band • Adjacent band filtering • 8 hour battery backup
Roseville, CA		• Min signal -95 dBm, 90% of each floor • 100% reliability factor • 800 MHz band • Adjacent band filtering • 12 hour battery backup
St. Petersburg, FL	- Draft under development	• Min signal level -100 dBm 95 % of each floor; -95 dBm in stairwells & below grade

Local Jurisdiction	Ordinance Reference	Key Provisions
		• 90% reliability • 800 MHz now • 700 MHz band by 1/2/2012 • 12 hour battery backup
Scottsdale, AZ	- Section E, 810-90	• Min signal level -107 dBm, 85% of each floor • 90% reliability factor • 800 MHz and VHF bands • 2 hour battery backup
Tempe, AZ	- Ord. 2001.25 - Chapter 9 - Section 9-21 to 9-32 - 9/13/01	• Min signal level -107 dBm analog; -93 dBm digital, 85% each floor • 8 hour battery backup

More recent local ordinances have acknowledged and included provisions for 800 MHz rebanding system capabilities, 700 MHz expansion capacity, use of factory-certified suppliers, and remote alarms and control of active devices such as signal boosters.

3.2 National Model Code Initiatives

The growing acceptance of and need for in-building wireless communications has recently spurred initiatives to develop national model codes by such authorities as the National Fire Protection Association (NFPA) and the International Code Council (ICC). The NFPA and the ICC already have an established process and record of developing codes used by various jurisdictions. Codes issued by these groups include the National Fire Code, National Electrical Code, International Fire Code, and International Building Code. Almost every city and county in the United States subscribes and complies with one or more of these codes.

The NFPA and ICC are in the process of developing national level model codes focused on in-building public safety communications. There is still much work to be done and the first issuance of such a national level code is expected in 2009. NPSTC endorses the concept of these overall national level model code initiatives as they are beneficial to public safety. The result of these national level model code initiatives will help enable every jurisdiction to implement in-building wireless requirements without developing a new local code for each jurisdiction. National level model codes should also lead to standardization of the quality of equipment and to additional qualified in-building system engineers and installers. Because these NFPA and ICC code initiatives are designed to be technology neutral, they will also encourage continued innovation by the communications industry that also will benefit public safety users.

The NFPA and ICC national level model in-building code development is being driven primarily by fire jurisdictions. However, the initiatives are expanded to involve all public safety, including law enforcement and emergency medical services. The NFPA and ICC initiatives are separate but complementary. While the precise provisions of the draft codes vary between the two code development groups, key specifications involve significant commonality across the two initiatives. In addition, all the features of existing local codes are permissible under the new draft national level code framework. Each jurisdiction can “customize” the national level model code to meet any unique local requirements such as frequencies, donor levels, maximum acceptable delay, documentation, etc.

Key elements under discussion in the national level in-building code initiatives include the following:

- Equipment flexibility – No specific technology is favored or endorsed. Technical specifications do restrict the use of problematic consumer grade signal boosters for public safety installations that meet code.
- Environmental specifications – The draft code specifies splash tight NEMA-rated cabinets to prevent equipment failure resulting from wash-downs during a fire event.
- Minimum indoor coverage signal levels – Building owners will be given the choice of using wireless instead of wired fire communications in most situations. Using wireless may reduce costs to the building owner. Coverage is classified in "critical" and non-critical areas and different percentages of coverage are required. Additional details regarding coverage are under development.
- Redundancy and Reliability – 12 hour battery back up would be required as part of the code. In addition, the draft code requires supervised alarms for signal booster fault, AC Failure, DC Charger Failure, and Low DC battery conditions. These alarms are required on every signal booster, amplifier, battery charger, etc. regardless of how many devices may be installed in the structure. Note "supervised" in fire terminology means the alarm connecting circuits must be monitored for opens or shorts continuously. In one version of the draft code, the alarms will be wired to a fire type wireless alarm annunciator panel in the fire control room. The wireless alarm panel may or may not be connected to the central fire annunciator panel. Note that the wireless alarm panels must be powered by the 12 hour battery back up. Typically the central fire annunciator panel has much less back-up time.
- Interference to the public safety wireless system by other wireless devices in the structure is prohibited and must be corrected immediately upon detection. This code especially applies to shared commercial/public safety RF distribution systems which, if not properly designed, may distribute signals that interfere or degrade the public safety system performance.
- No public safety amplifiers, signal boosters, etc. may be installed without agency approval. This provides an opportunity to qualify the equipment quality. Also, the jurisdiction must approve any revision or change in an existing wireless distribution system and the results must be retested for continued code compliance.
- Building owners are informed that frequency changes may be dictated by changes in FCC rules, acquisition of additional bands or channels, etc. 800 MHz rebanding is specifically cited as a known process that involves frequency changes in the public safety community.
- A standardized methodology of testing coverage, interference, and antenna isolation is included, leading to more accurate and repeatable performance testing.
- All new systems must be compatible with both analog and digital modulations.
- FCC equipment certifications and compliance to all applicable FCC rules is required.
- Personnel must be certified for in-building wireless communications by a nationally recognized training organization or manufacturer.
- Maintenance response time is cited.

NPSTC believes these new standards and model codes will further the objectives of public safety to have reliable communications wherever first responders operate and therefore

supports these national level code initiatives. These nationwide model codes should have benefits for building owners and managers as well. First and foremost, owners and managers will have the benefit of providing a safer environment for their tenants and first responders. In turn, this may also help reduce any losses if a building incident does occur and moderate insurance rates. In addition, having a national level code that provides a common framework across all jurisdictions should help provide improved efficiencies in both the building design and permit process.

4 The Value Proposition of In-Building Wireless

A significant amount of work has been done by the In-Building Wireless Alliance (IBWA) to address the value proposition of in-building wireless for the commercial real estate management community. This is relevant to public safety because commercial real estate recognition of the benefits of in-building wireless may also lead to a cooperative environment that assists public safety attain in-building coverage as well. Therefore, it is important to understand motivations and benefits the commercial real estate community attaches to in-building wireless, even though the specific frequencies for public safety mission-critical use and commercial services are distinct.

The following are some of the key benefits that can be attained for building owners and operators:

- Operational efficiency
- Ability to respond quickly to tenant calls
- Improved tenant safety and security (e.g., wireless coverage in parking garage and stairwells)
- Improved mechanism to track and record service calls in real time
- Wireless sensors for building equipment
- Reduced cost of installs and cabling
- Reduced energy costs by monitoring and controlling energy usage
- Marketing differentiation of an “information-enabled building”

The reduction in energy costs by monitoring and controlling energy usage is very significant, especially as government and industry take steps to implement environmentally responsible “green” buildings which reduce energy usage. A June 2007 IBWA presentation at Realcomm in Boston indicated that operation of commercial buildings account for 70 percent of the electricity consumption in the U.S., and that with improved monitoring and control could provide a 30 percent savings in that consumption.

Tenants of these building, i.e., the primary customers of the building owners and operators, also can see the following benefits from in-building wireless:

- Productivity gains
- A mobile workforce enabled to be responsive to their customers
- Seamless mobility and coverage from car to office
- Single phone number for business use
- Decreased cost of cabling

The IBWA is currently conducting a pilot building test of the benefits of in-building wireless at a commercial office building in Washington, D.C., and preliminary results already indicate the value of in-building wireless to the building operator and its tenants.

For public safety, in-building communications can help save the life of a firefighter, police officer, emergency medical responder, or the public they all serve, a value which cannot adequately be quantified in terms of dollars. The IBWA, which also includes a public safety working group, assisted NPSTC with 1) a 2006 survey for public safety to determine the priorities among various in-building wireless uses, and 2) a subsequent draft matrix summarizing a "Public Safety Scorecard" which indicates a number of ways in which in-building communications can assist public safety and the public. Some of these benefits are obvious today and others provide a future perspective. This Public Safety Scorecard is still being finalized based on input from the public safety community and should be available at a future date.

The survey of priorities targeted to public safety entities, in which some NPSTC members participated, revealed the following results. From a public safety perspective, it showed that voice communications is the highest priority and already has the highest capability in place. The survey showed that wideband or broadband data, still images, and video are viewed as a somewhat lower priority than voice but that these are areas with the largest gap in current capabilities. Therefore, such advanced features are more likely to be desirable if basic voice needs are already met.

NPSTC believes that this gap could be closed in major urban areas as a new nationwide system supporting broadband data, still images, and video is implemented in the 700 MHz band. The rules have been finalized for use of the 700 MHz spectrum and the nationwide broadband system. These rules call for a hybrid broadband system serving both public safety and commercial entities. The system is to be deployed in a combination of public safety and commercial 700 MHz spectrum segments. The system will be developed under a public/private partnership between a nationwide Public Safety Broadband Licensee (PSBL) and the auction winner of the adjacent D block 700 MHz band spectrum. The system requirements will be negotiated between the PSBL and the D block auction winner. Closing the gap on in-building coverage for data, imaging, and video of course will require the system specification to call for the coverage and data rates necessary to do so.

The Federal Communications Commission (FCC) rules require that the Network Sharing Agreement and system parameters be finalized by the PSBL and the D block winner within 6 months of the auction close. The 700 MHz auction is scheduled to begin on January 24, 2008, and is expected to take up to several weeks to conduct. Therefore, the Network Sharing Agreement and system requirements should be finalized by the August/September 2008 timeframe. As in other bands, system coverage may need to be supplemented on a specific building-by-building basis by the use of 700 MHz bi-directional amplifiers, distributed antenna systems, and temporary deployable systems at incident scenes, etc.

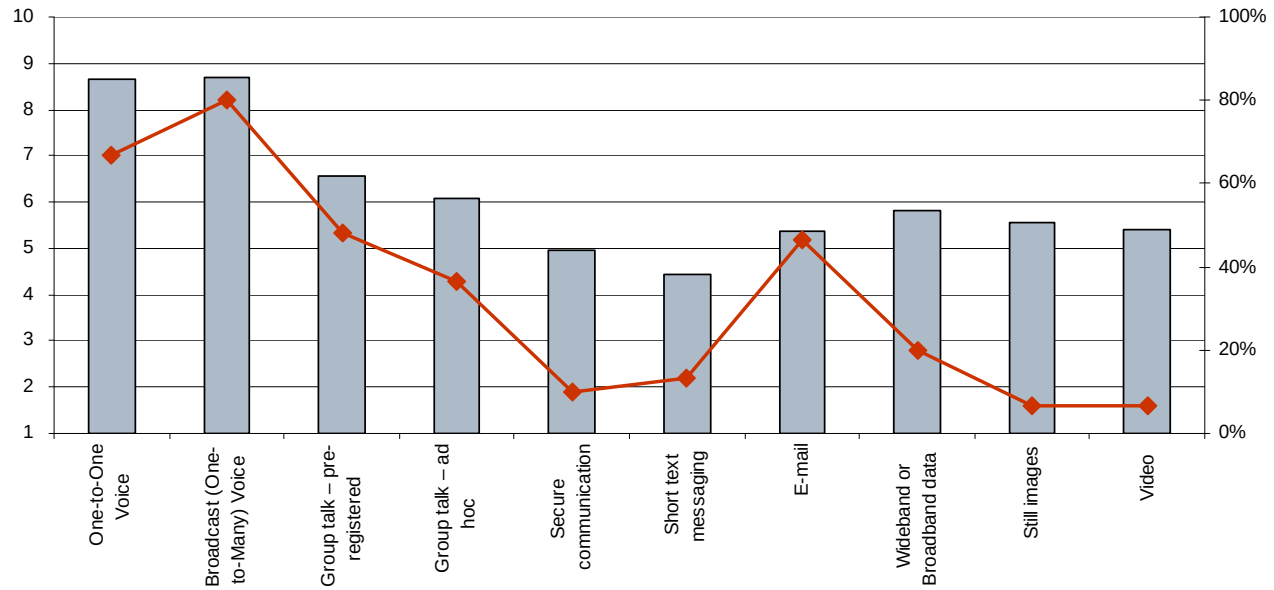


Figure 2 Bar graph shows level of importance per respondents; Red line shows percent respondents who already have this capability

Another area that has significant interest, especially from the fire community, is in-building location services. While GPS location is prevalent outdoors, GPS signals emanate from a satellite and are generally of insufficient signal strength to penetrate into buildings on a reliable basis. Furthermore, GPS provides location in the horizontal plane, but not the vertical plane, i.e., it would not show the floor where a firefighter is located. Therefore, some additional means are needed to help locate firefighters in a building. The IBWA conducted a preliminary review of various technologies for in-building location as summarized in the attached chart. The chart shows there are tradeoffs among the various location technologies. Overall, no in-building location technology has yet emerged that fully meets public safety expectations and needs. However, as various in-building location technologies mature, performance improvements should be possible. There may also be some synergies with technology development expected to occur as a result of increased requirements for E911.

Technology	Description	Precision	Strengths	Challenges
Infrared	Infrared sensors placed throughout a building can be used to detect a person wearing a device	Few meters	• Low cost	• Requires visual line of sight to function • Not very accurate • Cannot work if the device is in a pocket
Ultrasound	Beacons send signals to a receiver allowing the device to calculate its location based on proximity	~1 foot	• Can achieve high accuracy to the point of determining target orientation	
Basic RF	Target transmits low power RF signal which is detected by receivers strategically placed around the building	2-3 meters	• Does not require line of sight to function	• Signal strengths at higher frequencies are very sensitive to conditions (e.g. people, furniture) • Resolution may be limited
WiFi	Determine which users are being served by a particular base station	~50 meters	• Can be a low-cost solution	• Weak resolution
Bluetooth	Very short range RF standard	1-3 meters	• Increasing popularity of the standard	• Requires target to be within very short range

At a recent major in-building conference focused primarily on building owners, the National Institute of Standards and Technology (NIST) and others discussed a potential for on-scene building automation systems monitoring by fire agencies. This would provide an incident commander with wireless access to HVAC, security, power, and other data upon arriving at a commercial building location.

The NPSTC In-Building Working Group notes that one means of such access might be through the use of broadband 4.9 GHz systems that are tied into the building automation systems. Relatively small unobtrusive 4.9 GHz access points could be placed on the outside of the building so that public safety personnel, both fire and police, could access building information as they arrive at an incident scene. The 4.9 GHz band is limited to public safety use and with proper authentication techniques could provide public safety responders a secure link over which to access information from inside the building, including video from security cameras, location of elevators, temperatures at various locations, etc. Such information could be very useful in a fire or hostage situation, as well as some terrorist event or other disaster. As of November, 2007, over 1,200 public safety agencies in the U.S. have obtained 4.9 GHz licenses.

Hospital wireless systems providers are also interested in the possibility of adding patient monitoring, hospital administration and security to an in-building RF distribution system. The specific design of the system would need to be matched to the hospital requirements.

As noted above, the IBWA, under its own Public Safety Working Group is in the process of developing a “Public Safety Scorecard” for public safety in-building wireless use. The purpose of the scorecard is to address benefits and the value proposition of in-building wireless for public safety in a number of operational areas and, where possible, propose the use of quantitative data to assess improvements in operations from in-building wireless services. These areas include department education/training, preparedness, situational awareness, response time, cost per incident, lives saved/lives lost, and customer productivity lost due to an incident.

5 Interference Concerns and Regulation

There have been some instances of interference from in-building deployment of bi-directional amplifiers (BDAs), although the number of known interference cases is relatively low compared to the estimated 20,000 BDA deployments. The Jack Daniel Company previously distributed a survey to help gain insight to the degree and types of interference being experienced. The survey, which was not scientific, was targeted primarily to public safety and private radio systems. The survey questions are contained in Appendix A in the Addendum to this paper. The results of the survey to date are:

- The Jack Daniel Company estimates that the survey was viewed by approximately 1,500 to 2,000 such entities.
- A total of 57 responses have been received as of October 17, 2006.
- Fifty-four of the respondents reported they had experienced some interference.
- Twelve of the 57 responses relate to different events reported by the same person, a cellular service provider technician.
- Forty-seven of the 54 responses (87 percent) indicated that “oscillating” BDAs were the cause of the interference.
- Only 6 percent of the responses indicated that noise was the cause of the interference.
- All of the respondents reporting interference said Internet sales to consumers should be stopped.

- All of the respondents reporting interference expressed the opinion that voluntary BDA registration was unworkable.
- Sixteen respondents said BDA installations should be licensed; 10 said they were undecided.

The low number of initial responses to the survey makes any solid conclusions speculative at this time. Note that instructions for the surveys sent early in the process requested a response only if interference had been experienced. Based on the low number of responses, NPSTC believes that a large percentage of the universe exposed to the survey either (1) had no interference, (2) did not know they had interference, or (3) did not consider it severe enough to report. On the other hand, one respondent suggested some users were so frustrated by interference experienced that they did not think the survey would accomplish anything. With regard to Internet sales, some of those responding compete with Internet sales, which might skew the survey results.

Since the termination of the survey, several more cases of oscillation type interference have been reported, indicating this is a continuing and growing problem. In at least two cases, the FCC levied fines on the signal booster owners.

FCC RULES

The FCC rules address the deployment of BDAs. These rules rely primarily on the licensee to authorize and police any BDA use. Following are the rules from 47CFR, sections 90.7 and 90.219 that apply to public safety use of signal boosters:

Sec. 90.7 Definitions

***

Signal booster. A device at a fixed location which automatically receives, amplifies, and retransmits on a one-way or two-way basis, the signals received from base, fixed, mobile, and portable stations, with no change in frequency or authorized bandwidth. A signal booster may be either narrowband (Class A), in which case the booster amplifies only those discrete frequencies intended to be retransmitted, or broadband (Class B), in which case all signals within the passband of the signal booster filter are amplified.

***

Sec. 90.219 Use of signal boosters.

Licensees authorized to operate radio systems in the frequency bands above 150 MHz may employ signal boosters at fixed locations in accordance with the following criteria:

a) The amplified signal is retransmitted only on the exact frequency(ies) of the originating base, fixed, mobile, or portable station(s). The booster will fill in only weak signal areas and cannot extend the system's normal signal coverage area.

b) Class A narrowband signal boosters must be equipped with automatic gain control circuitry which will limit the total effective radiated power (ERP) of the unit to a maximum of 5 watts under all conditions. Class B broadband signal boosters are limited to 5 watts ERP for each authorized frequency that the booster is designed to amplify.

c) Class A narrowband boosters must meet the out-of-band emission limits of Sec. 90.209 for each narrowband channel that the booster is designed to amplify. Class B broadband signal boosters must meet the emission limits of Sec. 90.209 for frequencies outside of the booster's design passband.

d) Class B broadband signal boosters are permitted to be used only in confined or indoor areas such as buildings, tunnels, underground areas, etc., or in remote areas, i.e., areas where there is little or no risk of interference to other users.

e) The licensee is given authority to operate signal boosters without separate authorization from the Commission. Certificated equipment must be employed and the licensee must ensure that all applicable rule requirements are met.

f) Licensees employing either Class A narrowband or Class B broadband signal boosters as defined in Sec. 90.7 are responsible for correcting any harmful interference that the equipment may cause to other systems. Normal co-channel transmissions will not be considered as harmful interference. Licensees will be required to resolve interference problems pursuant to Sec. 90.173(b).

[61 FR 31052, June 19, 1996, as amended at 63 FR 36610, July 7, 1998

The potential for interference is not confined to public safety in-building systems. The interference from improperly installed or adjusted systems in the cellular industry has been reported by the CTIA-The Wireless Association (CTIA) to the FCC. The impact of oscillating signal boosters can have a devastating impact on cellular like infrastructure. Both the public safety and commercial wireless communities have a common interest in eliminating interference. The CTIA document, entitled “White Paper on the Harmful Impacts of Unauthorized Wireless Repeaters” dated May 1, 2006, is available from CTIA, 202-785-0081 or www.ctia.org.

Also, on November 2, 2007, CTIA filed a petition with the FCC asking the agency to prohibit the sale and use of cellular jammers and the unauthorized sale and use of wireless boosters and repeaters. Notably, public safety users in Florida have also experienced interference from the deployment of rogue BDAs onboard boats being used to boost commercial cellular signals.

In addition to oscillation and noise interference, there is the potential of interference in shared service systems due to frequency conflicts and minimal filtering. The most common example of this is the relationships between 800 MHz private systems and cellular channels. Cellular band A is adjacent to the current National Public Safety Planning Advisory Committee (NPSPAC) band and filtering is usually insufficient to prevent interaction. This is especially true with the more popular fiber optic fed cellular devices. Even after 800 MHz rebanding is completed, the new public safety downlinks may interfere with the cellular B band uplink channels. This is true of all future in-building systems. One solution is to implement parallel systems with separated antennas. A paper on this subject can be found at www.rfsolutions.com/nh-wp.pdf.

NPSTC believes any instances of interference have the potential to escalate into severe consequences to public safety. Such consequences could occur as a result of interference to commercial systems, as well as to dedicated public safety mission-critical systems, since the general public increasingly relies on commercial wireless systems to make 911 calls. Therefore, the severity and reach of the interference that does occur may be even more important than the number of cases occurring.

One such situation involved interference to a wireless carrier in the New York City Metro area. A customer of the carrier had incorrectly installed a BDA, causing the BDA to self oscillate, i.e., to act as a transmitter radiating an interfering signal back out to the receiver antenna located outside the building. This interfering signal impacted a large number of cell sites as shown in the following map in Figure 3. The wireless carrier and the BDA manufacturer worked diligently to resolve the problem. However, the user had to be tracked and located so power from the BDA could be removed. In addition to impacting the quality of service during this period of time, the resolution process consumed significant resources by the wireless carrier and the BDA

manufacturer that could have otherwise been better spent. This was a situation in which the BDA was well designed, but improperly installed by an end user with little technical knowledge and it underscores the need for proper deployment as well as design to minimize interference risks.

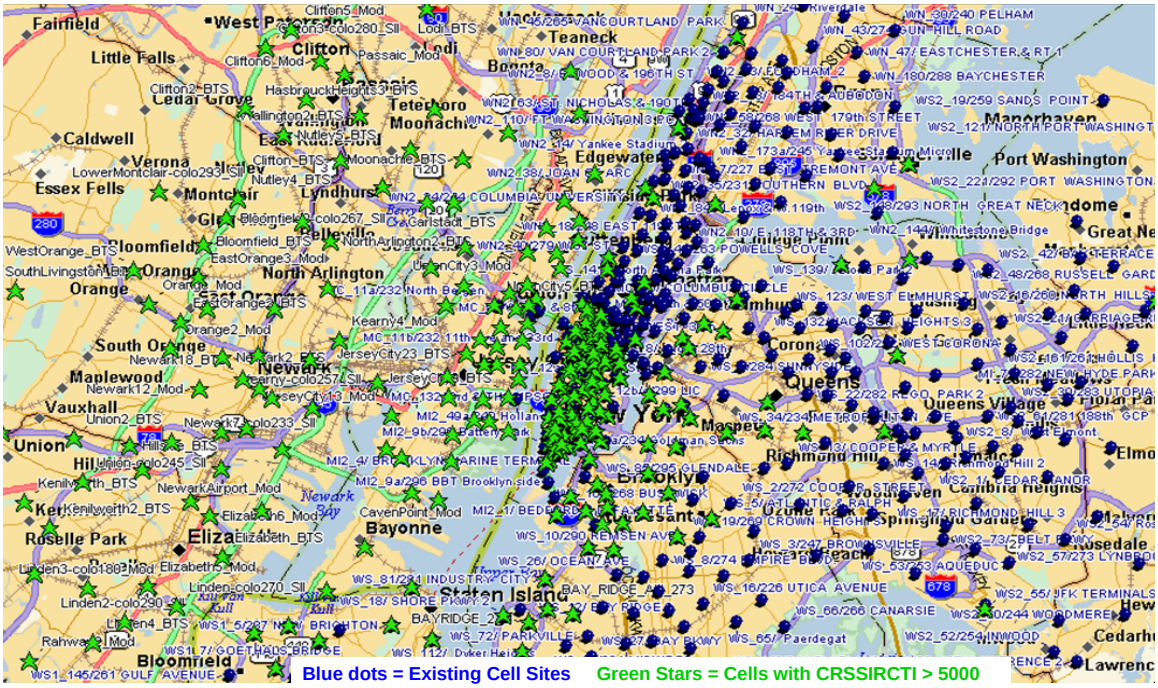


Figure 3 Effects of Interference from a Self-Oscillating BDA – Sample Case

6 Engineering an In-Building System

Deployment of solutions for reliable public safety in-building or in-tunnel coverage must consider the spectrum environment, building or tunnel parameters, and the users' operational needs. As with most systems for public safety, whether indoor or outdoor, reliable solutions require customization, high-quality products, good systems engineering, and proper installation and maintenance. Reliable public safety in-building systems are not a "cookie cutter" design with one size fits all. There are a number of options for solutions, each with their own tradeoffs and applications depending on the particular scenario involved.

NPSTC is fortunate to have the participation of industry experts in the development of this paper. Appendix B in the Addendum provides valuable information regarding the elements of in-building systems, as well as mechanisms to minimize interference and provide a reliable system. Appendix C in the Addendum covers the considerations, technology options, and tradeoffs that are part of a successful in-building design and implementation for robust coverage. We urge those involved in specifying and contracting for public safety in-building systems to take advantage of the wealth of information these two appendices provide.

In addition, public safety entities should consider the following generic requirements for successful deployments. These general requirements are technology neutral and relate primarily to the spectrum and building environment.

6.1 Site Survey

A site survey presents the opportunity for the designer/integrator to get a hands-on perspective of the facility. The primary goal is to identify a methodology to marry up a conceptual design with the realities of what is practical inside the facility.

Before starting a site walk, it is important to attempt to acquire “to-scale” floor plans in advance. While on the site survey, it is valuable to take the on-site information and correlate it to what the floor plans are illustrating. There are standard items to look for in any site walk. These include:

a) Donor Antenna Placement and Type

Several elements go into selecting the proper donor antenna placement and consequent mounting. The building manager/owner needs to be involved at this step because it needs to be determined where, if any, existing rooftop presentations are located. Ideally, the donor antenna will be in close proximity to limit the donor cable run and, consequently, its associated RF loss characteristics.

If an entry point can be identified, that will go a long way in getting the donor signal into the building. Existing penetrations should be utilized because every time you drill a hole in a roof for rack mounts or wiring you create the potential for leaks.

Flashing should encase roof penetrations and waterproof caulking should be used for smaller penetrations. Sometimes “sleds” or existing pipe fixtures can be utilized for antenna mounting. Mounts on the side of buildings are also possibilities.

Rubberized roofs present a unique challenge and the building owner will need to contact the contractor who installed the roof. This is done to either identify available penetrations for cabling use or to have the roofing contractor provide a quote to do the actual work in order to keep the roof under the terms of the warranty.

The building manager/owner will need to have a clear understanding of where the antenna should be and the pros/cons of having it in different locations. The customer may desire the donor antenna to be camouflaged or its footprint reduced (e.g., fewer elements in a yagi antenna).

Another factor to consider when choosing a location is identifying where the donor site is located. A clear of line of sight to where the donor signal originates is mandatory. In urban environments, it is important to be cognizant of the noise floor differences between near street level mounts and roof tops of high rises.

Typically, the noise floor increases by a large magnitude at a higher vantage point. This may have an impact on where the donor antenna is located. Placement in close proximity to other antennas is also something that needs to be avoided so as not to create any unnecessary intermod products in the antenna’s near field propagations.

Particular care needs to be used when microwave dishes are in use on a given rooftop to avoid any unnecessary RF exposure. The use of a NARDA meter will go a long way in warning a person conducting a site walk of unseen RF dangers.

b) Cable Runs

After the outside surveying is complete, the next order of business is identifying a vertical chase that will get the cable runs from floor to floor. Once this has been identified, a network closet/IT room where the booster equipment can be parked must be located. Ideally, you would want the two elements; the vertical chase and the network closet/IT room to be as close to each other as possible – if not one and the same.

A walk through the facility should allow the DAS designer to begin to see potential cable runs in certain locations more so than others. Certain areas should jump out that would be better locations for internal antennas. These areas should be hallway juncture points and areas that are in need of strong coverage (e.g., manager's office, security office, etc.) consistently. This would mandate a dedicated internal antenna within close proximity.

Another item to look for is the method of transport for the cabling. Are there dedicated cable trays? Is conduit required? Does the local fire code mandate plenum ratings on the cable? If fiber is the method of delivering RF, is there any dark fiber available to use? If so, what type is it? Is the fiber of the single mode or multimode variety?

What do the ceilings look like? False ceilings? Hard lid ceilings? A mix? The amount of labor to get through different ceiling types will vary as will the time/cost. Ceiling types will have a huge impact on which antenna to use.

In some cases, the end customer may want the antennas out of view. Examples of what the antenna looks like should be presented to the customer for approval from a cosmetic perspective. How high are the ceilings? Will a hydraulic lift be required to gain access for antenna installation? These are items that need to be considered when doing the site walk.

An area where core drilling is required is an important cost/time consideration that can be identified during a thorough site survey. Firewall locations need to be identified as they require special prep work for penetrations and pulling cable from one side to the other.

c) Power of Systems

While examining the room where the booster will be installed, a survey of potential power sources should be identified. Will the outlet have power in case of a blackout? If not, it may mandate a dedicated UPS power back up module.

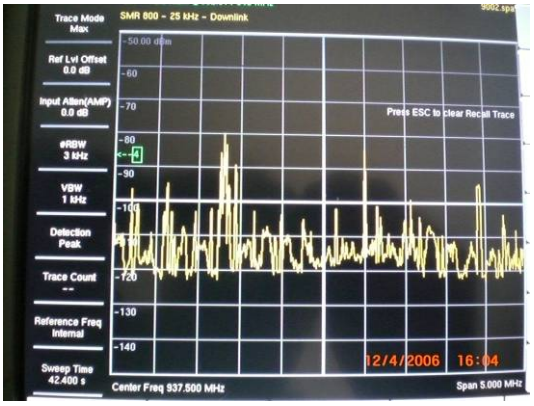
d) Wall Construction and Attenuation Factors

The building materials used in the construction of the building and walls should be scrutinized closely. What is the makeup of the walls? Drywall, sheetrock, cement blocks, brick? Is there any metal? In hospital environments, lead will be present in the walls near radiology units. What about insulation or ductwork? Metallic backing on certain types of insulation will strongly attenuate RF signals from propagating. Metal duct work will also have an impact on a RF signal.

6.2 RF Survey and Spectral Analysis

For an RF survey, it is mandatory that the exact frequencies that need to be supported are obtained. The advantage of having that data allows the person who is conducting the survey to examine the ambient signal strength where the donor antenna will be located. A sweep on a spectrum analyzer may reveal potential interferers that the intended public safety frequencies that need to be supported are going up against.

Identifying the RF environment will allow the person conducting the survey to complete post-survey research to identify the owner (starting with matching the frequency with those in the FCC database) of those frequencies. The RF environment information also may lead to the selection of a particular system design to match that environment.



Taking various measurements on a rooftop may identify a stronger donor signal in one area as opposed to another. This could be due to shadowing or multipath environments in one location. An attempt to get the strongest signal with the most direct line of sight is the ultimate goal for a proper RF design.

The importance of obtaining the signal strength for the required carriers cannot be understated. This is the foundation upon which an RF link budget is built. While the frequencies that need to be supported are important, it is just as vital to identify the number of channels. The rationale being that the BDA/booster's resources will need to be shared across all the channels that pass though its input port. This translates into the power per channel (the true performance characteristic in comparison to composite power) equivalent to the composite power minus 10*log(# of channels).

If there are multiple donor sites available to choose from, the site with the clearest line of sight and strongest signal strength should prevail. Also, if separate signals from different donor sites are present – and they have different signal strengths, it may prove relevant to feed each into a separate BDA/booster to balance out the signals through gain/attenuation adjustments inside the BDA/booster. This will allow the signal for each donor site to have similar coverage patterns inside the facility.

Monitoring the integrity of the donor signal for a mild duration is also advisable. This may help to identify if the signal varies due to multi-path or fading situations. If possible, allowing the spectrum analyzer to sit and collect data over a reasonable amount of time will allow for more confidence in the acquired data.

Inside the facility, it may require a test setup of a signal generator at a defined frequency and power level while measuring that test signal at different points on the same floor and above and below it to get a better feel for how RF will penetrate through the various building materials. Drywall/sheetrock typically will have a 3 dB to 4 dB attenuation impact, while cement/brick can have attenuation characteristics of 10 to 14 dB and more.

6.3 Scope of Work Development

A detailed scope of work sets the correct expectations that both the building tenants and the entity providing the solution can agree on. These expectations must have a baseline performance to be measured against. This can be a rudimentary description of existing coverage or a more thorough grid testing pattern to verify existing signal strength and delivered

audio quality (DAQ) readings in defined intervals. This baseline testing can then provide a fair comparison for when the system is turned up.

Assumptions about what signal strength will be delivered to what percentage of the facility is notated here. An example would be a signal strength of at least -90 dBm or stronger through at least 95 percent of the facility. Other assumptions should include whether stairwells, restrooms, or elevators will or will not be covered as part of the scope of work. Any union labor, hydraulic lifts, asbestos hazards, conduit, 1st/2nd/3rd shift requirements, etc. should also be extensively detailed in this section.

A final component of a scope of work should be a matrix of responsibilities between what is expected of the building owner, the network operator, the vendor, and the contractor. An example may be who is responsible for materials on site. Will an area be designated to house these? Will it be secured? Items of this nature are typically covered here.

6.4 Engineering of Systems

The foundation of any system engineering is a RF link budget. This will account for all the gains and losses in a given system to give a reasonable expectation for what the coverage prediction should look like.

An elementary link budget will at the very least, account for the following terms:

RxP = TxP + TxG - TxL - FSL - ML + RxG - RxL

Where:

- RxP = received power (dBm)
- TxP = transmitter output power (dBm)
- TxG = transmitter antenna gain (dBi)
- TxL = transmitter losses (coax, connectors...) (dB)
- FSL = free space loss or path loss (dB)
- ML = miscellaneous losses (fading, body loss, polarization mismatch, other losses)
- RxG = receiver antenna gain (dBi)
- RxL = receiver losses (coax, connectors) (dB)

Once the link budget foundation is understood, the designer can implement a more comprehensive computer-based design tool. The advantages of a tool of this ilk are several. Essentially, it makes a link budget come alive to show the user what coverage should look like if the initial data was correctly input. The time tested saying of “garbage in, garbage out” is especially relevant.

A detailed bill of materials can also be generated with the entry of to scale floor plans. This allows ancillary part (cable runs, for example) ordering to be more precise. Special items to be considered in the engineering include an intermodulation analysis of existing frequencies to determine if harmful intermodulation products will be generated with the current RF environment.

Internal antenna placement is important also. It is important to treat the in-building situation as a macro environment. Coverage enhancements in the facility should not bleed out into the outside world. This means keeping internal antennas at least 50 feet away from windows so as to

eliminate the possibility of a regenerative feedback loop between service and donor antennas which ultimately can cause oscillations, spurious emissions, and cripple the macro network.

Ambient coverage environments in a high-rise building should also play a part in the engineering. Typically, coverage is present on upper floors but not so on the floors near street level. This assumption, along with the RF noise floor, needs to be taken into account. Understanding this information allows the designer to know how much power needs to be delivered to the antennas on various floors.

Donor antenna selection should also be determined at this time. Front-to-back ratios, gain, horizontal/vertical beam widths, and physical appearance should all be considered when selecting the correct antenna.

Isolation in a RF sense is very important. In all instances, the micro/in-building environment should be completely separate from the macro/outdoor coverage. It is widely accepted that 15 dB more than the gain of the booster/BDA is an adequate level of separation between the two systems. An example would be a 90 dB gain booster/BDA; the ideal isolation situation would be at least 15 dB more than or 105 dB of isolation.

In-building system design software is also available which will generate coverage patterns, equipment and antenna placement diagrams, materials lists, etc.

6.5 Acceptance Test Procedure (ATP) Development

The agency deploying the coverage solution should develop a mutually agreed upon ATP or Acceptance Test Plan between the vendors that will supply the system and users of the system to ensure that it will meet system performance specifications. There are two types of coverage measurements when evaluating in-building systems—the Signal Strength Test and Voice Quality Test. The Signal Strength Test is cost effective with downlink RSSI signal measurements, and the Voice Quality Test is a subjective performance test of Delivered Audio Quality or DAQ.

The ATP should be developed by both the deploying agency and the customer/user to verify RF coverage based on such measurements. The procedure provides an accurate, statistically valid, repeatable, objective, and cost-effective method to verify all customer/user coverage requirements are met. A definition of coverage by signal strength or DAQ figures, which define the audio qualify of a wireless systems' performance, should be accomplished so that all parties involved understand the overall objective and so that proposals and systems designs are in line with this ultimate objective.

6.6 Testing Process

A reliable, accurate wireless test device such as a spectrum analyzer in conformance with industry standards should be defined as a baseline to measure coverage performance and produce repeatable measurement. The wireless test equipment should include one antenna that will be mounted on a handcart 3-4 feet in height to replicate the portable at the hip-level location. The GPS receiver will be disconnected.

Prior to taking signal strength measurements, each site must be audited to verify that the radio system is operating properly. The audits will verify the antenna configuration, the power into the antenna, the antenna installation, and the frequency of the test transmitter.

It is important to define in the ATP how the "customer" (agency buying the in-building solution) is going to test the performance of the system. Included is, of course, the decision of signal strength and/or DAQ but also type of test equipment used, settings on equipment, locations of

measurements within the building, and so on. This clear and comprehensive definition will make for fewer post-deployment problems.

First, proper design and installation of BDA systems requires a site survey/audit. A site survey and audit should identify the following parameters:

- Number of users in building
- Number of “foreign” networks, i.e., networks other than the one for which the BDA system is being installed
- Density of walls and ceilings
- Proximity of windows relative to the parent system donor site
- Existing signal strength in the building
- A floor plan with accurate building dimensions
- Complexity of the in-building environment

Once the site survey and audit is completed, design can be conducted. This includes:

- Spectrum analysis and coordination
- System design and engineering
- Installation and implementation
- Record and catalog site specifics

Coverage extension systems are also used in tunnels. A key element in the proper design and installation of tunnel systems is the “leaky coax,” normally used to help distribute the wireless signal. In some cases, in-tunnel systems have not performed as planned because existing leaky coax which had deteriorated over time was used as part of a “new” system. Agencies issuing Requests for Proposals (RFPs) for in-tunnel systems should seriously consider an evaluation of any existing leaky coax and replacement if necessary as part of the system implementation.

7 Best Practices

Based on the information collected for this report, the NPSTC In-Building Working Group recommends the following “Best Practices” with respect to the deployment of in-building communications systems.

1. Given the increased need for and benefits of in-building communications, public safety agencies should ensure that coverage for in-building operation is strongly considered when specifications for system RFPs are drafted and issued.

2. Where ubiquitous in-building coverage throughout a jurisdiction cannot be funded or provided yet, in-building coverage on a building-by-building basis should be considered through the use of properly designed and installed bi-directional amplifiers, distributed antenna systems, etc. Deployable systems can also be considered to provide temporary in-building coverage at a given incident scene when needed.

3. Jurisdictions may be able to increase in-building communications by adopting ordinances that require its implementation. Based on a number of sample ordinances already adopted, NPSTC recommends that new ordinances specify the minimum signal strength over a defined percentage area of each floor, stairwell or below-grade area, a reliability factor, testing procedures to ensure conformance to the requirements at the outset and on a periodic basis thereafter, and provisions for battery backup power.

Going forward, provisions to accommodate 800 MHz rebanding and adding coverage for the new 700 MHz band will also be important considerations.

4. Agencies should also monitor initiatives underway to develop national level model codes and standards supporting public safety in-building communications and consider providing support to these initiatives as appropriate.

5. The public safety community should continue to liaison with the commercial real estate interests as in-building coverage provides benefits to both parties. This liaison is already established primarily between the NPSTC In-Building Working Group and the In Building Wireless Alliance and should be continued.

6. Parties deploying in-building bi-directional amplifiers should seriously consider the tradeoffs of various system designs and related equipment with respect to coverage extensions of the parent system, costs, interference abatement, etc.

7. Parties deploying in-building bi-directional amplifiers should adhere to defined good engineering practices for the deployment of such systems. These practices are addressed in the previous section and in Appendices B and C of the Addendum to this document.

8. Agencies adding in-tunnel wireless extensions to existing systems should evaluate the condition of any existing coax, including radiating coax, planned for use because coaxial cable can deteriorate over time, especially in harsh tunnel environments.

9. Any instances of interference should be reported to both NPSTC and the FCC so interference trends can be tracked. The NPSTC website could include an interference reporting template (to be developed).

10. NPSTC recommends the FCC aggressively address any interference that occurs to public safety or commercial operations. NPSTC also recommends the FCC closely track interference trends to determine if any changes to the marketing and certification regulations regarding the availability and use of lower quality booster amplifiers are warranted.

11. Provisions for backup battery power or emergency power sufficient to support the in-building system during expected emergency durations are recommended.

12. When sharing a “neutral host” type of system designed to extend commercial and unlicensed services in a structure, public safety agencies should develop a binding agreement that includes the following minimum conditions:

    - No other wireless service can be permitted to interfere with or diminish public safety coverage;
    - Public safety coverage must include basements, utility rooms, stairwells, etc.;
    - Once installed, changes to the system must have concurrence from public safety prior to implementation.

8 Summary

In-building coverage is increasingly important for both public safety and commercial communications requirements. The communications needs of first responders and the general public do not stop when they enter a building. NPSTC, with assistance from industry, has developed this white paper to help bring focus to the multiple aspects being addressed to improve in-building coverage while minimizing any interference.

9 Addendum: (Separate Document)

Appendix A: Interference Survey

Appendix B: Introduction to In-Building Wireless Signal Distribution for Public Safety

Appendix C: Providing Robust In-Building Coverage in Public Safety Wireless Networks

Appendix D: Optimizing FCC Class B Band Selective (Broadband) Signal Boosters for Urban Use

Appendix E: Optimizing Class FCC Class A Channel Selective (channelized) Signal Boosters

NPSTC

National Public Safety Telecommunications Council

Best Practices for In-Building Communications

Appendices A through E

National Public Safety
Telecommunications Council (NPSTC)
In-Building Working Group

Stu Overby, Chair
Stu.overby@motorola.com

November 12, 2007

Appendix A: Interference Survey

The attached interference survey was developed and has been distributed to the public safety community by the Jack Daniel Company.

The following is a survey to gather information and statistics concerning any interference from BDAs (bi-directional Amplifiers) you may have experienced.

This survey will be used in support of petitions requesting the FCC update and revise rules for BDAs.

One such petition may be viewed at: http://www.rfsolutions.com/bird-fcc.pdf. The intent is to get the FCC to open the rules for public input of changes needed regardless of whether you agree with the Bird petition or not.

Please email comments, questions or suggestions about this survey to: JackDaniel@RFWise.com

1. Has BDA OSCILLATIONS (not noise) caused you any problems ? No Yes

2. If you answered YES to question 1, how many different BDA installations in the last 5 years ? (1 to 10+)

3. Has broadband NOISE (not oscillations) from BDAs caused you any problems (such as receiver desense) ? No Yes

4. If YES to question 3, how many different BDA installations were focused on the same donor site ? (1 to 10+)

5. Do you think internet BDA sales to consumers should be stopped ? No Yes

6. Do you think 'voluntary' registration of BDA installations would work ?
No Yes

7. Should the FCC enforce existing BDA (signal booster) rules better ?
No Yes

8. Should FCC rules be updated and made more restrictive ? No Yes

9. Should BDA installations be licensed similar to control stations ?
No Yes

10. Is there any place else this survey should be posted ?
(Feel free to distribute to other groups)

12. May we supply your name to the FCC with this survey ?
The FCC pays more attention to specific reports than anonymous sources.
No Yes Contact me first

Appendix B

Introduction to in-Building Wireless Signal Distribution for Public Safety

A General Design Overview and Installation Guideline.
(See notice on last page)

© 2005, 2007 Jack Daniel Company
Tel: 800-NON-TOLL
email: JackDaniel@RFWise.com

Note: NPSTC Received Permission from Jack Daniel to include this copyrighted document.

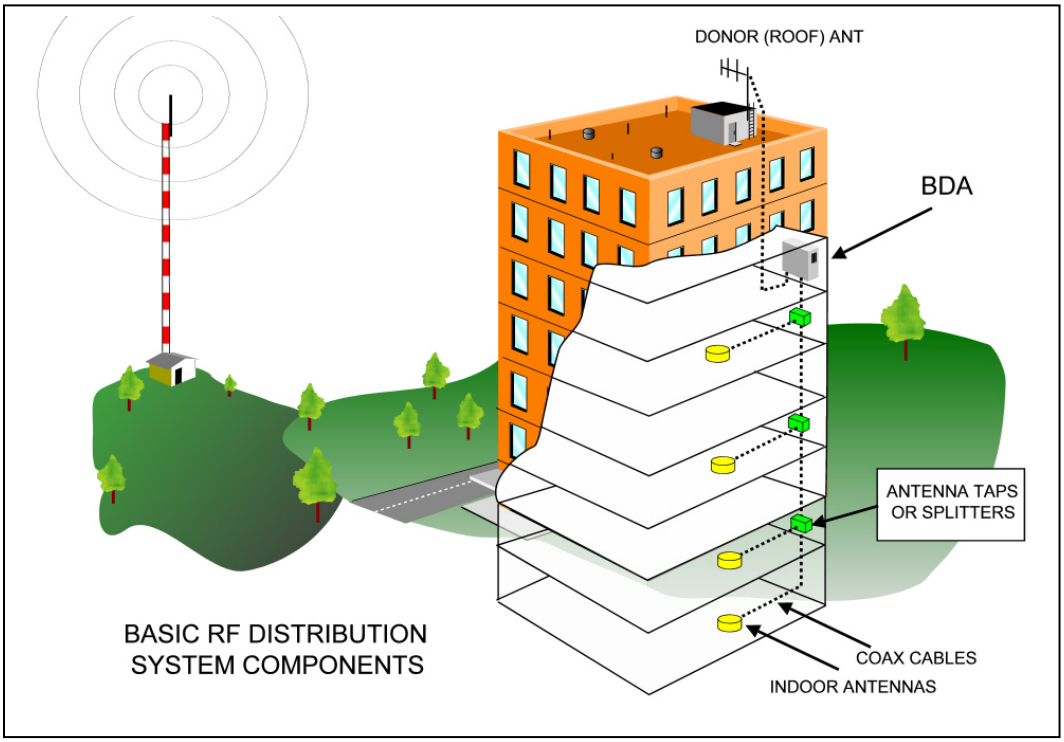
Introduction:
Wireless users expect and rely on communications wherever they go, including inside large structures, high rise buildings, underground parking, malls, basements, subways, etc.

When wireless radio frequency (RF) signals pass through any material they lose strength and when the RF signal levels fell below a given amount, communications becomes unreliable or completely stops.

Whenever the area needing radio coverage is below grade (underground) it is almost certain a RF distribution system will be needed.

The following discussion of RF (radio frequency) distribution systems is intended as an introduction to the various solutions being used to improve RF signal levels when necessary.

The primary components of an amplified RF Distribution system are identified below:



1. Donor (roof) antenna. This is called the "DONOR" antenna. It is usually mounted on the roof, or a side of the structure, where a clear line-of-sight path exists to the distant radio tower. The distant site is also known as the "Donor".

This is a two way interface;
- the DOWNLINK" is the RF signal direction going INTO the structure.
- the "UPLINK" is the RF signal being sent back OUT of the structure.

2. BDA (Bi-Directional RF Amplifier). A very specialized RF amplifier which selects what frequencies are to be amplified in the downlink and uplink paths (they are different) and increases the RF signal strength in both directions. The FCC calls these amplifiers 'signal boosters' and there are very specific federal rules on their operation that should be followed by the system designer.

3. The RF distribution network.
The most common method is to use coaxial cables. The coaxial cables fall into two classes; standard (non-radiating) and radiating.

Standard (Non-radiating) **coaxial cables** route RF signals to multiple indoor antennas placed in areas where radio operation is needed.

Special devices that take a portion of the RF signal out of the main coax cable to feed multiple antennas may be used. There are several types of these devices and they may be called **"taps", "splitters" or "decouplers"**, all serving the same purpose.

"Radiating" coaxial cables (sometimes called 'leaky coax') intentionally allows low level RF signals to 'leak' in and out along the path of the cable. The ideal location for radiating cables is in passageways, tunnels etc.

The RF signal looses strength going through coaxial cable. These losses increase with length and RF frequency. In most cases, the maximum usable length of a coaxial cable is less than 1000 feet.

Coaxial cables used for RF distribution must be 50 ohm (not 75 ohm) type.

Indoor antennas can be placed at the end of a coaxial cable or 'tapped' into a coaxial cable to allow multiple antennas along the coaxial cable route. This method is called Distributed Antenna System or "DAS". 800 MHz antennas are typically small and unobtrusive, some looking similar to smoke detectors.

Ideally, the indoor antennas will be located where they are optically visible from every location you wish to communicate, however RF signals can travel through 2 - 4 wood or drywall walls but the signal will be weakened.

In parking garages, low profile (2" thick, 6 " diameter) antennas are sometimes glued to the lower side of overhead structural beams with construction adhesive.

Locations of antennas sometimes follow the layout for video surveillance cameras, with both often serving the same area.

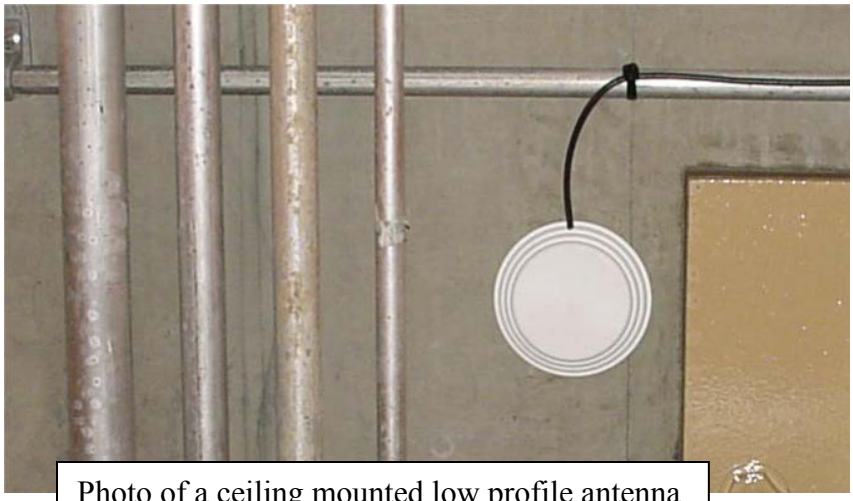


Photo of a ceiling mounted low profile antenna.

"RF-Over-Fiber" Fiber Optic cables

When a long coaxial cable would be required to connect antennas inside a larger structure, a long tunnels or adjacent buildings, it may be more practical to use 'RF-over-fiber' technology. Instead of using coaxial cables, the signals are converted to light and transported over fiber optic cables. On longer distances, fiber often offers less cost and easier installation. Use of fiber optic cables is explained further later.

Mixed RF distribution type designs:
All three types of cable may be combined as required by each project by the distribution system designer.

Basic Single Structure application;

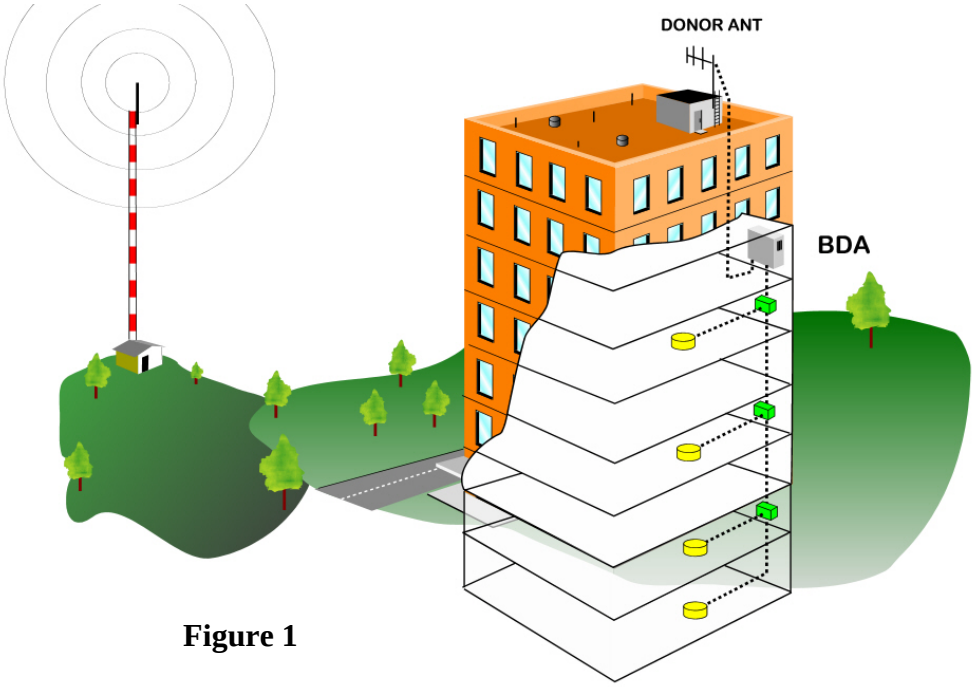


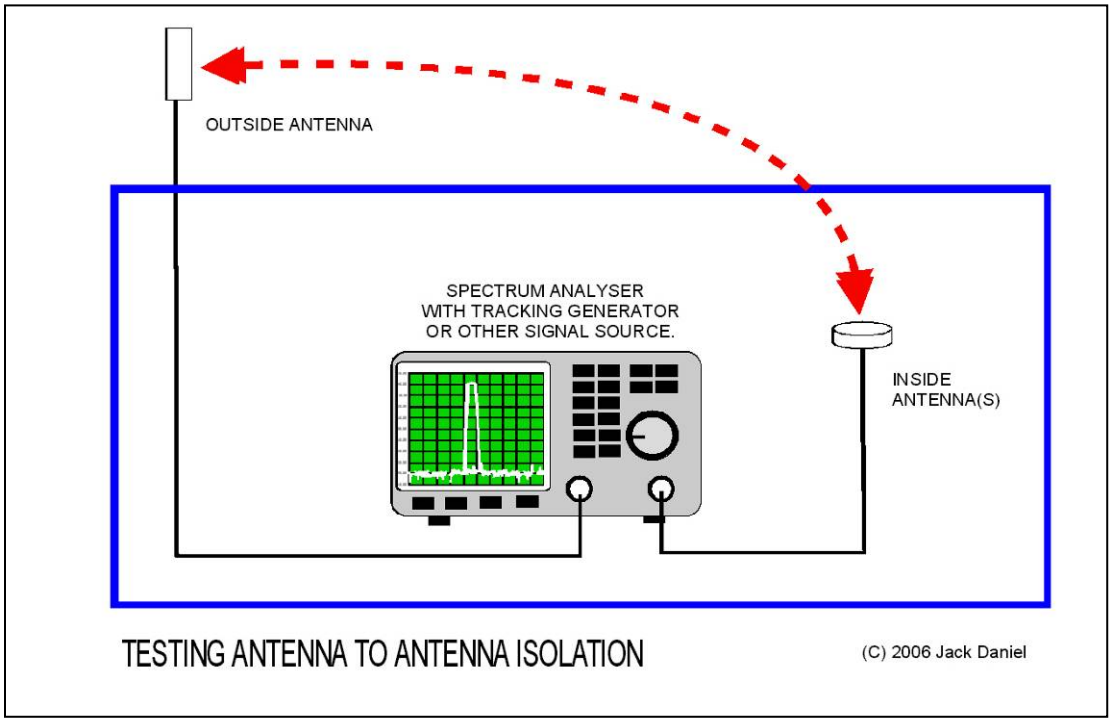
Figure 1

In this example, a directional roof top antenna (Donor Antenna) is positioned so it has a line-of-sight path to the appropriate distant radio tower. A non-radiating coaxial cable connects the donor antenna to the BDA RF amplifier.

SPECIAL NOTE:
The most frequent problem with an in-building installation is inadequate isolation (path loss) between the roof antenna and those within the building. When insufficient the system 'oscillates' and causes interference to yourself and others. It is illegal to operate a signal booster that oscillates. Reduce gain settings to prevent oscillations.

The industry standard for minimum antenna to antenna isolation uses this formula; BDA gain + 15 dB.

Example, 80 dB BDA gain + 15 dB = 95 dB minimum ant – ant isolation.



Excessive gain does not improve performance and may present excessive noise to nearby receivers. Always use the minimum reliable gain setting.

It is VERY important that the gain setting of the BDA be adjusted by a qualified radio technician. Factory certified technicians are recommended when available. Contact the signal booster manufacturer for a list of certified technicians in your area.

Remember, the Federal Communications Commission (FCC) can impose fines and confiscate equipment that causes interference.

The other side of the BDA connects to the internal RF distribution system.
In the example, a Distributed Antenna System (DAS) approach is used.
The black lines are non-radiating coaxial cables.

The green boxes are decouplers which take off a portion of the RF signal on each floor. The decoupled signal is routed through coaxial cable to an indoor antenna (yellow discs)

In real applications, the system is designed to have sufficient RF coverage from each inside antenna. Other devices, such as power dividers and antenna taps, may be used to place multiple antennas on each floor.

Single structure Fiber Optic application.

In some structures it may be better to use "RF-over-fiber" technology to overcome long coaxial cables which lose too much RF signal, are harder to install and often more expensive. Unlike coaxial cables, fiber distribution includes low level RF amplification which results in zero distribution loss.

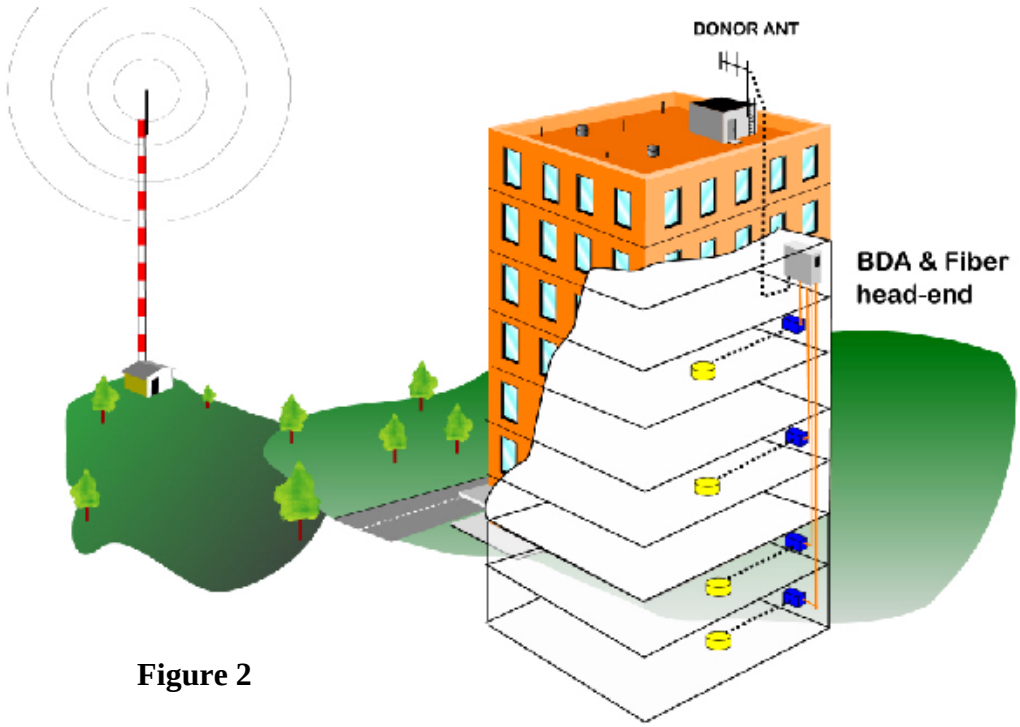


Figure 2

Orange cables are 2 fiber single mode cables
Blue boxes are Remote Hubs.

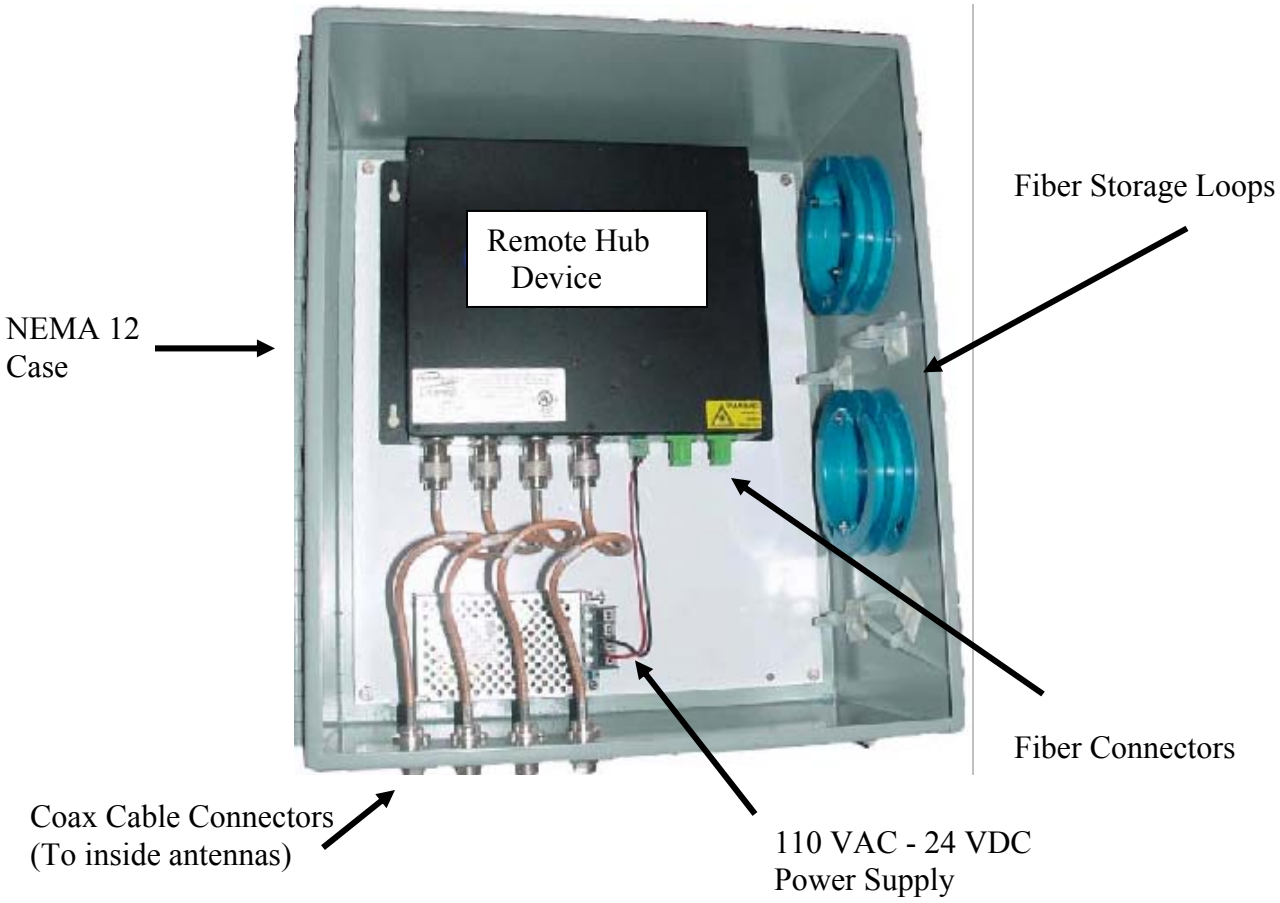
A fiber installation is similar to coaxial cables EXCEPT each fiber run between the BDA and each inside antenna is a separate 'home run' type path. In practice a 4 to 6 fiber single mode fibers is installed for each path; 2 are in use and the rest are spares. Multimode fibers cannot be used for this application.

The fiber device near the inside antennas is called a 'remote hub' and can serve as many as 4 inside antennas per remote hub.

The inside antennas are connected to the remote hub with non-radiating coaxial cable. The exact combination of remote hubs, inside antennas and length of coaxial cables is designed by an in-building distribution engineer.

Note: A combination splice tray and fiber patch panel is recommended at the BDA to manage the various fiber cable runs. Fiber cable terminations and short fiber jumpers are required at each remote hub as well as a 110 VAC 1 Amp power source.

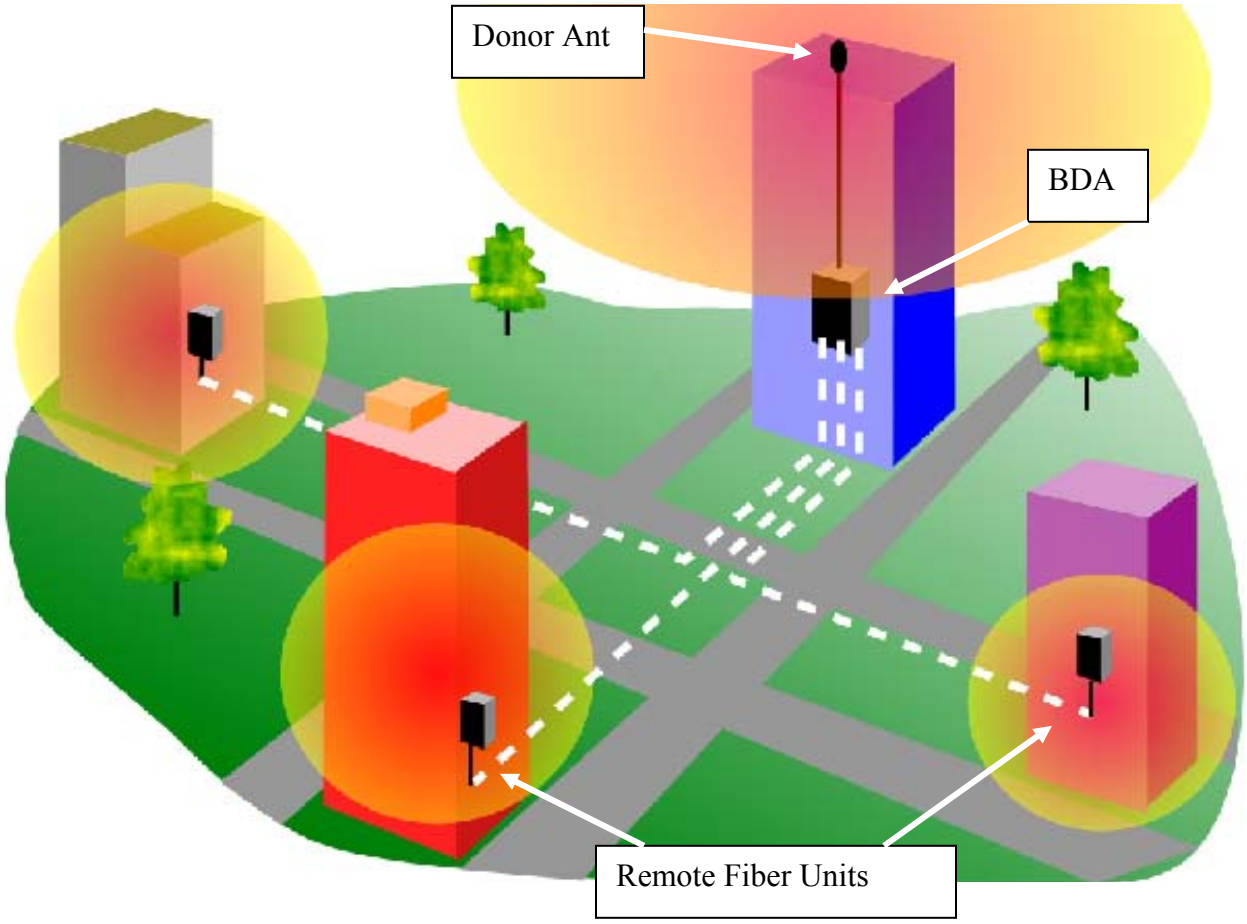
In exposed areas, such as parking garages, all this and a DC power supply is often mounted inside a small NEMA 12 utility box. These are normally fabricated by the integrator to match the system requirements. See 800 MHz example below. (Bands below 800 MHz and multi-band remotes are much larger)



Multiple structure 'Campus' application.

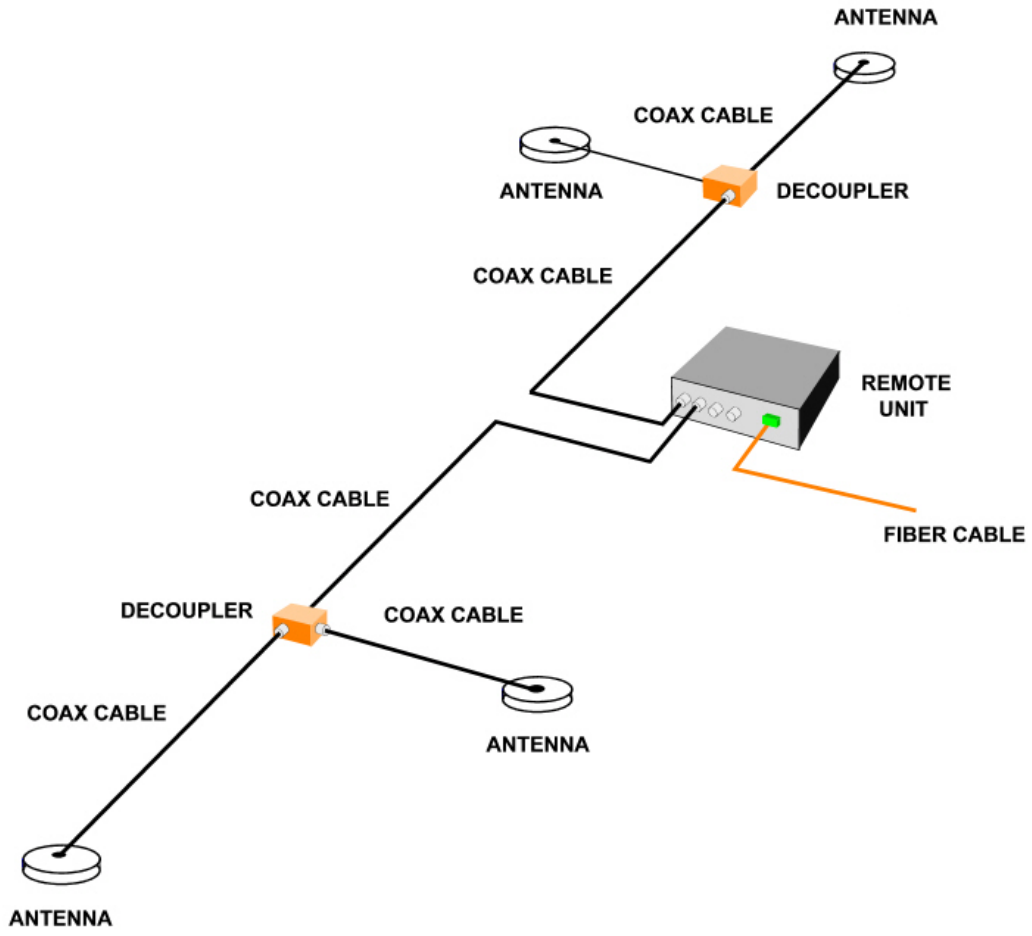
This application is very similar to a single structure fiber optic distribution system.
The only difference is a multiple fiber single mode finer cable is ran from the BDA to distant buildings. On the distant buildings a patch panel is installed to break out the smaller fiber cables ran to the remote fiber units in that building.
Remote fiber units and inside antennas can also be placed in the same structure as the BDA.

The result is one pair of fibers from every remote fiber unit being ran (home run) to the BDA.



In this illustration, BDA located in the 'main equipment room' is used to feed the RF distribution in that building as well as fiber remote units in 3 others. If there are more than one remote fiber unit in a distant building, a larger fiber optic cake may be used between the buildings and a "patch panel" used to separate the 2 fiber runs in the distant building.

ALWAYS use short fiber optic jumpers between the end of the permanent fiber optic cable and the RF equipment. This reduced the possibility of damaging the ends of the permanent cable which are difficult to repair.



EXAMPLE OF RF DISTRIBUTION ON ONE FLOOR

Typical RF distribution on a single floor:

In the example above, 4 distributed antennas serve a single floor. Some remotes only have one RF connection and external power dividers (splitters) may be added.

The Fiber cable is 2 or more fibers and connects to the Base unit in another location.

In the example, only two of the 4 RF outputs of the remote units are used, the remaining 2 reserved for expansion and additional antennas.

A decoupler (or "tap") may be placed in-line to the coax cables. This takes a portion of the signal to one antenna and passes the remaining signal to a more distant antenna(s). More than one decoupler and antenna may be inserted in a coax cable, depending on the amount of RF signal power available.

The exact locations of antennas and the quantity of antennas is determined by the system engineering.

Code Compliance:
Local building and safety codes must be met, most being the same as IBC 2003 and NEC2005 - NFPA 70 codes.

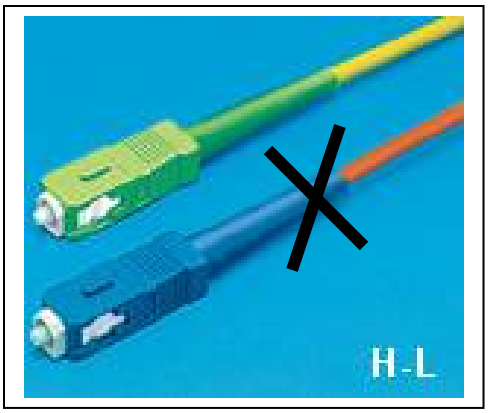
Specific recommendations:

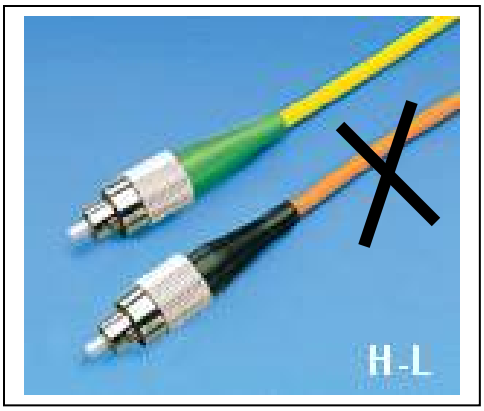
Recommended coaxial cable type (per NEC-2005 article 820) 820.113 "CATVP";
- 1/2 inch dia., 50 Ohm (75 ohm not acceptable). "N" male type RF connectors only. Verticals and long laterals.
- 1/4 inch dia., 50 Ohm (75 ohm not acceptable). "N" male / "SMA" male type RF connectors. Remote unit to nearby inside antenna, short runs.

Recommended fiber cable type (per NEC-2005 article 770) 770.113 "OFNP".
Fiber optic cable connectors are either "SC-APC" or "FC-APC", as specified otherwise by the system designer. Non "APC" connectors are NOT acceptable.

A minimum of 4 fibers per remote fiber unit is recommended. (2 in use, 2 spares)

Never use orange connectors or orange jacketed fiber cables.





Top: "SC-APC" = Use if specified Top: "FC-APC" = Use if specified Bottom: "SC" = DO NOT USE Bottom: "FC" = DO NOT USE

Conduits:
Fiber Cables: 2 - 4 fibers per fiber remote unit; 1 inch I.D. Min. bending radius = 6 inches. No more than two bends between breakouts.

Coaxial cables up to 5/8" diameter; 2 inch conduit. Min bending radius = 12 inches. No more than 3 bends between breakouts.

Coaxial cables up to 1 " diameter, 4 inch conduit. Min bending radius = 24 inches, No more than 2 bends between breakouts.

Note: Normally risers to roof are 4". Unless the local code specifies otherwise, Coaxial cable risers do not have to be in conduit. 4" core drillings in vertically stacked equipment rooms are common practice.

Note: Always use cable manufacturers specifications.
Note: Do not run radiating coaxial cables over 10 ft inside metallic conduit.

Misc. Fiber items:
Head-end Hardware:

2 each, 36 inch ¼" dia. cable jumpers with N-male and SMA-male connectors .
Connects BDA to Fiber head end unit.

1 each, 110 VC in 24 VDC output power supply. Typically 1 amp per 8 remote hub connections.

RF-to-Fiber Head end units. Each unit serves 4 or 8 remote hubs according to model. Maybe expanded to approximately 64 remotes

Fiber patch panels for SC-APC or FC-APC connectors. (connectors match Head end connectors) 2 connectors per remote hub.

Typical Head-end (Main Equipment room) Patch Panel

Fiber Jumpers: 36" or 1 meter signal mode fiber with SC-APC or FC-APC (connectors match head-end equipment), 2 jumpers per remote unit.

Miscellaneous: Standard 19" inch equipment mounting rack. Will house rack mounted BDA, Fiber head-end, patch panel, DC power supply, interconnecting cables, etc.

Typical Remote Fiber Unit Hardware;
1 each, Fiber remote unit.
1 each, DC power supply

If installed in open area, (see picture on page 9) add;
1 each, NEMA12 type case. Approx 16 x 16 x 10 inch for 800 MHz.
NOTE: For lower bands and multiband systems case will be larger.

1 each, Small 2 to 6 fiber patch box. 2 are in-service and others are spares.
2 each, 36" single mode fiber jumpers with SC-APC or FC-APC connectors.
RF jumpers will be required if the assembly is fabricated in the field.

Antennas:
1 each, Donor rooftop antenna:
(10 dB typical gain directional antenna for 800 MHz.)

1 each, Roof antenna mast and 1-1/2 inch antenna mount pipe.
Iinclude roof penetration considerations!

Indoor antennas. Surface mount, unity gain with N-male connector.
Up to 4 per remote hub. OPTIONAL: Radiating coax.

Antenna 'taps", splitters, etc. as specified by system designer.

Antennas and Hardware for frequencies below 800 MHz.
Different components are usually required for each radio frequency band.
Some combinations of frequency bands, such as public safety and cellular bands, may not be compatible or require special and additional hardware.
Consult the system designer for additional information

NOTICE:
This information is supplied as an educational document only and does not include all possibilities of designs nor does it contain adequate information to complete a proper design. This may serve as a general installation guideline for contractors. In all cases, experienced in-building integrator or system designer is highly recommended. Only detailed analysis can determine exact antenna placements. Factory certified in-building integrators are recommended.

Appendix C

Providing Robust In-Building Coverage in Public Safety Wireless Networks

By Gary Grimes, Dekolink Americas

1. *INTRODUCTION*

It is well known that most mobile wireless communications in urban environments terminate in an indoor environment. Because of this, it is not only desirable but, more and more, legally mandated that upgraded and new public safety networks guarantee a level of in-building coverage for first responders. Until relatively recently, wireless public safety networks have been deployed with the goal that in-building coverage will be provided to whatever extent possible by the outdoor network of high sites.

It is now widely recognized that this approach leaves many crucial highly populated areas in high-rise office buildings, shopping malls, hospitals, government buildings and tunnels with severely limited coverage for emergency services. To fill in this coverage with additional, very expensive high sites is economically impractical.

To meet these requirements, there is a range of in-building coverage solutions available that can solve these coverage problems economically. These solutions extend the coverage of the outdoor network to the indoor environment through the use of a bi-directional RF signal booster. One RF port of the booster is connected to an outdoor directional antenna that pulls the signal in from a nearby high site, which acts the "donor" site. The other RF port of the booster is connected to an indoor antenna or indoor distributed antenna system (DAS) that is designed to provide uniform coverage within the building.

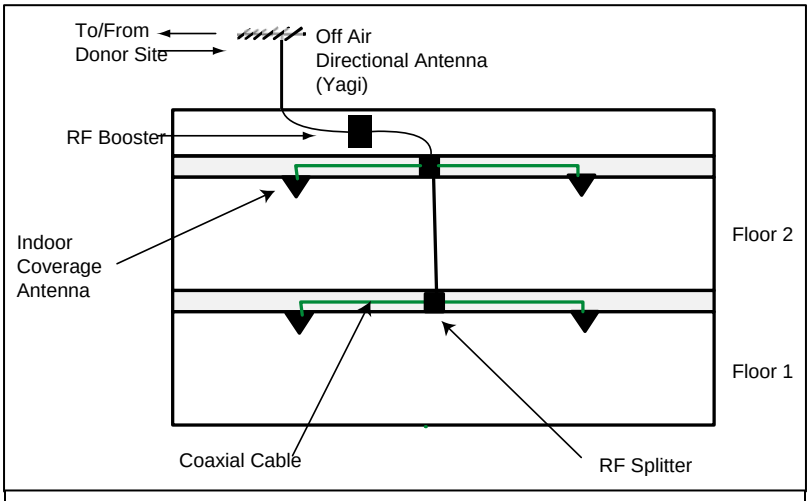


Figure 1. In-Building Coverage System.

RF Boosters range from low power, low cost, wideband devices to state-of-the-art multichannel digital RF boosters. The available products trade off cost with features and performance. The latest digital boosters are specifically designed for Public Safety networks to provide the simplest and most reliable set up in any network as well as performance and

features that guarantee robust coverage even in real emergencies.

Most of the products approved by the network OEMs will provide the needed coverage but only if they are deployed as part of a well-engineered site. Hasty installations of low-cost RF boosters usually cause more serious problems than they solve. Because of the nature of public safety networks, designing and deploying in-building coverage systems for these networks requires more engineering care and skill than for commercial wireless networks. Even small sites should be designed and deployed by experienced and licensed engineers.

In choosing RF booster performance, features and technology, Public Safety users have options between simple, low cost Class B only technologies and higher cost technologies that can be configured as Class B, Class A or a mix as necessary. To summarize, Class B technologies retransmit an entire band or large segment of a band. Class A technologies select only the desired channels to retransmit. Small indoor coverage sites may only warrant a low cost solution. On the other hand, if interference with other sites cannot be mitigated by such low cost solutions, then no indoor solution will be effective(except fiber fed or a micro base station). Indoor coverage systems for large buildings can cost well over several hundred thousand dollars in engineering services and installation alone so a high performance multichannel solution that costs $10k to $30k would be the choice to ensure the most robust coverage for the money.

2. *FCC 47 CFR 90.219 USE OF SIGNAL BOOSTERS*

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.

3. *AVAILABLE TECHNOLOGIES*

3.1 Bi-directional Amplifier (BDA)

Although this is the common terminology that has been used in the two-way industry for years, some of the major manufacturers are re-educating the market so as to differentiate the various technologies.

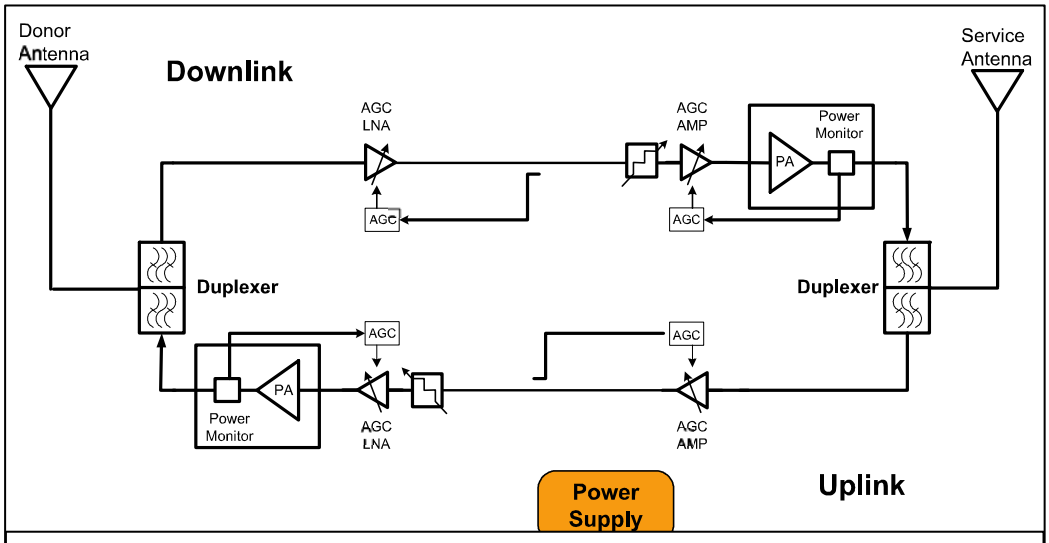


Figure 2. Bi-directional amplifier. All of the filtering is handled by the duplexers.

Figure 2 shows the block diagram for a BDA. There is no heterodyning (internal frequency conversion). All of the filtering is handled by the duplexers. Although this is the simplest architecture, the BDA has a number of limitations. The main ones are:

1. *Poor out-of-band rejection*: when filtering at the higher frequencies, it is difficult to achieve very sharp roll off in the filter response. These are usually full band devices. The poor roll off characteristics have caused problems for Cellular carriers for years.
2. *Fixed filtering:* To get a different frequency range, the entire unit must be replaced.

3.2 Analog RF Boosters

This architecture starts with the BDA then adds an internal heterodyned section.

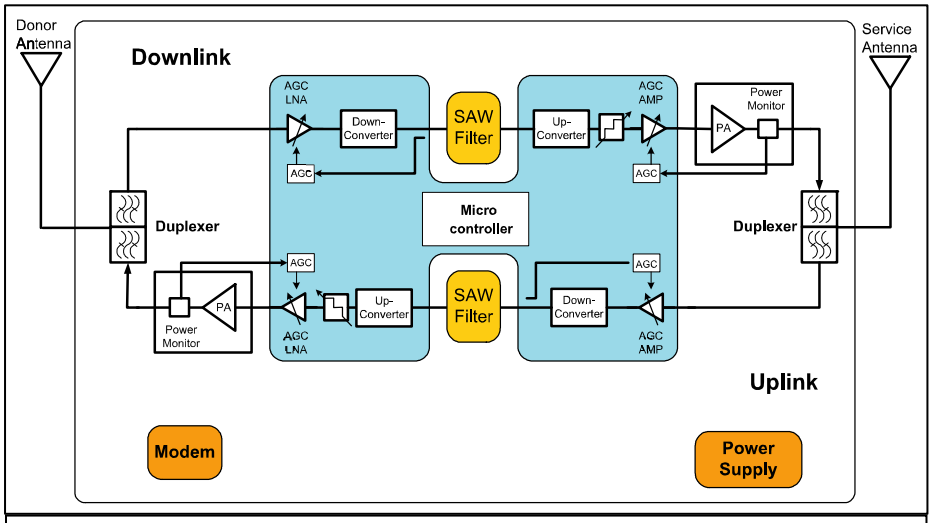


Figure 3. Analog RF Booster includes an internal RF down/upconversion that permits adding additional filtering at a lower Intermediate Frequency (IF).

This architecture has a number of significant advantages over the basic BDA.

1. *Better filtering:* At the lower IF, low cost filters with very sharp roll offs are available. These can be crystal filters or SAW (surface acoustic wave). The sharp roll off filters permit the realization of channel selective filtering or any number of sub bands.
2. *Tunable:* the down- and upconversion process permits tuning of the pass band anywhere within the full band of the duplexer.
3. *Multiple bands:* Splitting the IF path allows for multiple sub bands.

The components and processes needed for this architecture are produced in high numbers so add very little cost to the basic BDA design but result in a much higher performing product with better features.

3.3 Digital Filter RF Booster

This booster has the same architecture as the analog booster except that the SAW or crystal filter is replaced by a digital filter. Here, the IF signal is sampled by a high speed A/D converter. The filtering is done in the digital domain on this data stream with digital signal processing. The processed data is converted back to analog RF by a high speed D/A converter.

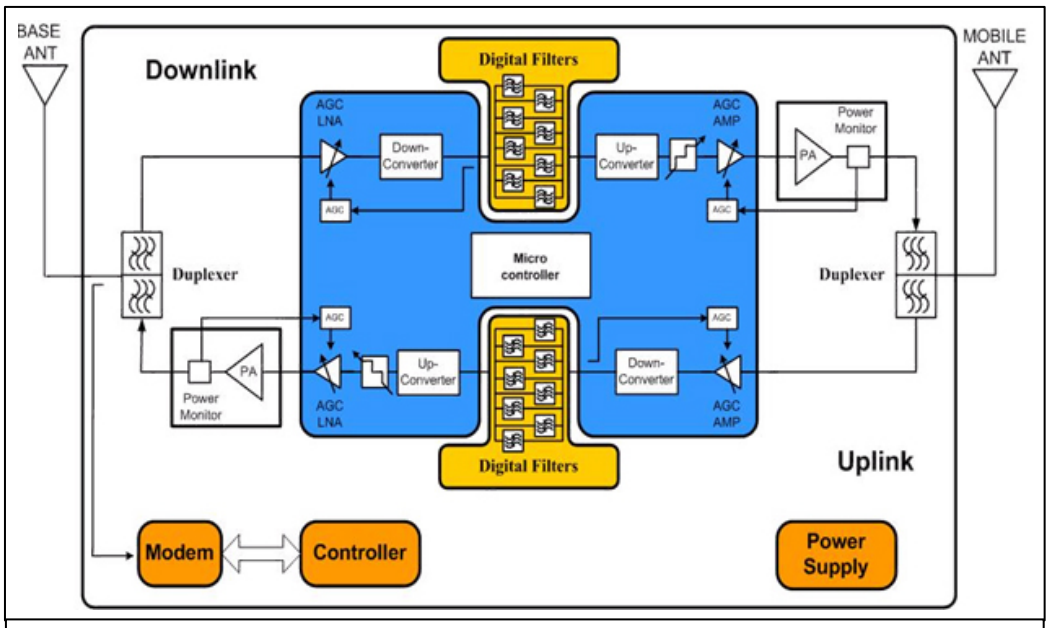


Figure 4. Digitally filtered RF Booster.

With the filtering handled by digital signal processing, the range of possibilities of this architecture is vast. A wide range of filter types can be stored in the library with differing bandwidth, roll off, delay times and general transfer functions. The unit can be configured with many filters, each of which is independently selected and tuned. The newest versions permit selection of up to 24 filters which can be a mix of single and multiple channel pass bands. Because of this, it is more accurate to refer to this architecture as “spectrum selective” rather than channel selective.

4. *CHARACTERISTICS OF EACH DESIGN*

4.1 Time Delay

There is much discussion about the time delay through a Class B booster versus that through a Class A booster. The concern is that there can be signal quality degradation in areas where there is overlap between the primary signal directly from the base station and the delayed version of the signal through an RF booster. This is discussed in detail in section 7 below. At this point, note that the delay through a filter is inversely proportional to its bandwidth and directly proportional to the filter "order", that is, the number of sections that determine the sharpness of the roll off and the flatness across the pass band. This is the same no matter how the filter is implemented, i.e.; no matter whether it is analog or digital. So, a filter that is narrow band with a sharp roll off will have a higher time delay than will a wide band filter with a soft roll off. For filters wider than about 200 kHz, the delay through the booster is determined by the delay through the electrical components, typically around 5 μsec. However, as the filter bandwidth is increased, the adjacent channel signal rejection is reduced. The proper tradeoff of these factors for the spectrum environment encountered is part of the professional system design needed to optimize operation.

4.2 Gain

- **Preventing Feedback Oscillations**

  It is important to design and deploy an RF Booster site such that there is sufficient electrical isolation between the donor and coverage antennas. If they are too close to each other, the system will go into feedback oscillation similar to holding a microphone too close to the PA speaker. The rule of thumb is to ensure the total isolation is at least G + 15 dB where G is the gain of the RF booster.

  The required gain is determined by the coverage area needed and the available signal from the donor site as well as the antenna gains. This is the same for any RF booster, Class A or B. Therefore, either class A or class B systems that are properly designed and installed can provide the necessary isolation to avoid feedback.

  For outdoor coverage, the donor and coverage antennas are often mounted on a tower with a vertical separation. Antenna manufacturers provide data for the attenuation of the directional antenna gain away from the main beam. This data is used to calculate the needed separation between the antennas. Often, the needed isolation is achieved by placing the antennas on opposite sides of a physical structure such as a building. For in-building applications, the building provides the needed isolation between the outdoor donor antenna and the indoor coverage antennas. The standard practices used by qualified installers ensure sufficient isolation.

- **Automatic Gain Control (AGC)**

  Most RF Boosters employ an AGC circuit that automatically limits the RF output power to the "rated" power of the booster. The rated output power is the maximum output power that ensures that all transmitted spurious signals and intermodulation products will be less than the FCC limit. This level is typically approximately 10 dB lower than the output 1 dB compression point of the booster.

  If a large RF signal is received such that, if the gain remained unchanged the output would exceed the rated power, the AGC automatically reduces the gain to prevent this. When the input level drops, the AGC restores the gain to its original setting.

- **Microprocessor-Controlled AGC**

  In some RF boosters, manufacturers have implemented "smart" gain control circuits in addition to the standard AGC. There three primary advantages of these circuits.

  1. *Automatic Gain Optimization during set up:* It is often difficult to know the correct gain setting during set up. This is due to the fact that, when on site RF measurements are made, all of the available channels in the network are not on. The "smart" circuits monitor the network and make the necessary gain adjustments until the proper gain is discovered.
  2. *Oscillation Prevention:* If the antenna isolation changes temporarily because of, say, nearby construction that causes the system to feedback, these circuits will automatically reduce the gain to stop the oscillation. When the source of the oscillation has been removed, the system will return to the original gain setting. It is not true that these circuits cause a "bursty" oscillation problem. Instead, the gain will simply remain below the oscillation threshold until the isolation problem is removed. The condition is reported by the unit locally and over the remote monitoring connection (if deployed).
  3. *Long Term Maintenance:* these circuits will make small adjustments as necessary to maintain the proper booster gain if the donor link changes over time. Changes might occur from misalignment of the donor or a change in the donor link multipath due to new construction in the area. This eliminates the need for service personnel to revisit the site.

4.3 Uplink Noise

All FCC-approved boosters have limits on transmitted out-of-band noise. The limits are defined in 47 CFR 90.210. There are two possible problems with the transmitted uplink noise that must be addressed in any site design.

1. *Base Station Desense:* if the booster uplink gain is set too high, the noise from booster can reduce the sensitivity of the base station. This causes a reduction in the base station coverage area for all portables and mobiles. Note that this problem can be caused by improper deployment of any booster whether low power or high power. It is not true that channelized boosters have inherently higher output noise than broadband boosters. If a particular product has a higher out of band noise

characteristic, this is due to the manufacturer's design and not because of any problem inherent with channelized architectures.

2. *Other Services Desense:* with broadband boosters, one must be careful not to desense other services with base stations located within the donor antenna beam width but closer than the desired base station. A gain setting that is correct for the desired service will be high for the other service and will jam their signal. There have been cases where the initial set up was good but a new service deployed a site nearer the booster that was then jammed by the out of band noise from booster. In this case, either a more directional antenna or a narrowband booster must be used.

5. *PRACTICAL CONSIDERATIONS*

5.1 Digital RF Booster specifications

The newest digitally filtered, spectrum selective RF boosters are designed specifically for Public Safety networks. The primary specifications for the 700/800 MHz versions are:

Frequency	700 + 800 MHz or 800 MHz band only
Composite Downlink RF Power	2W or 10W
Number of Filters	up to 24
Filter Bandwidth range	12.5 kHz to 12 MHz
Time Delay	5 µsec to 100 µsec depending on filter
Per Filter AGC	60 dB range

Note that the digital booster can function as a Class B booster or Class A or a mix as necessary. There are enough filters to handle most Public Safety networks even if each filter is for a single channel. The per channel AGC selectively squelches any large, transient signal from, say, a passing high power mobile so that the wideband AGC is not activated which would desense all of the channels. All of these features make the digital booster somewhat more expensive than a Class B booster but the flexibility and guaranteed non-interfering, robust coverage in real environments make this the preferred choice in many applications.

5.2 Need for External Combiners and Multicouplers

This only applies to the high power, narrowband UHF and VHF boosters that are employing a common transmit/receive for each of the donor and coverage antennas. Unlike the 700/800 MHz band where the transmit and receive channels are assigned to separate frequency blocks, transmit and receive channels for UHF are interleaved. UHF transmit and receive channel pairs are separated by 5 MHz, but a low level receive channel for one service may be adjacent to a high power transmit channel from another. Although the booster itself may be channelized using either analog or digital filtering, combining all of the transmit and receive channels to and from the base station onto a single antenna requires a separate rack of cavity filters and combiners that is custom for every site. The same applies to the coverage antenna or DAS port.

5.3 Filter Selection and Rebanding

A number of analog RF booster designs with internal heterodyning are configured with either switchable bands or replaceable plug-in filter sections. Manufacturers may offer a

selection of filter bandwidths that may be configured. This simple approach can be effective in many applications. Often, the optimum filter choice is not available from the standard SAW filters offered. In these cases, the digital filter may be the best or only choice. Digitally filtered boosters will come with a standard library of filter choices. If the optimum filter for a given installation is not included in the standard library, the manufacturer can usually e-mail the needed filters that can then be downloaded into the digital filter.

This same flexibility can be a big advantage if there are changes in the network channel plan either because of added capacity or Rebanding. Although Rebanding has been implemented in some areas, there are many areas where it has not and will not be for some time. This is especially true near the borders with Canada and Mexico where the changes involve negotiations with those countries.

Finally, it is important to note that Rebanding eliminates most of the adjacent channel interference issues with Sprint/Nextel and SouthernLinc but there are still many different emergency services and SMR services that share the remaining band.

Note that any broadband filter solution deployed in a pre-Rebanding area will have to be retuned or replaced after the Rebanding. This is because a broadband booster will often have to cover the entire 800 MHz band to accommodate channels scattered throughout the band. After Rebanding, the booster must be changed to pass only the non-ESMR services. The digital filtered boosters need reprogramming of the filters. And if the booster is deployed with remote monitor and control, this reprogramming can be accomplished without having to visit the site physically.

6. *PROVIDING ROBUST COVERAGE IN A REAL EMERGENCY*

Many in-building network engineers design and verify in-building coverage systems for two-way radio the same way they do for commercial cellular systems. That is, they design to guarantee a certain downlink signal level, usually -85 dBm, over some percentage of the building, and then verify the actual coverage with a simple walk through with a portable.

In fact, Public Safety networks have several major differences that must be taken into account.

1. *No power control:* commercial mobile handsets have automatic power control so they always transmit just enough power to maintain the needed signal quality. Two-way radio mobiles and portables have manual power settings only. Because of this, the coverage system for a Public Safety network must be able to accommodate nearby high power portables and mobiles.
2. *Two-way radio networks are unbalanced:* commercial networks balance the transmit power with the receive sensitivity automatically. Two-way radio networks are almost never balanced since there is no automatic power control. Because of this, the optimum gain settings may be different for the uplink and downlink paths.
3. *The loading environment is very different during a real emergency:* The primary purpose of a Public Safety network is to function during a real emergency. Designing and verifying an in-building system for operation when there may be one or two security guards present does not reflect how the system will perform during an emergency when

there are a high number of portables and mobiles in operation in the area from first responders.

6.1 Accommodating Additional Services

Some literature has claimed that broadband boosters are preferable during real emergencies because they can accommodate other first responder services that are not otherwise in use. First, if a broadband system has been designed to provide coverage for certain services, adding channels to this system will require that the booster gain be reduced so as not to overdrive the booster. This would result in a loss in overall coverage area. So, in order to accommodate these additional services, the system would have to be designed from the beginning to anticipate the additional loading. Also, additional donor antennas would have to be included in the initial design that point towards the relevant donor sites for these additional services. These same considerations then apply to any booster design, Class A, Class B or mixed.

6.2 Transient High Power Mobiles

One crucial advantage of the new digital boosters for Public Safety is the per filter AGC feature. If the filters selected are single channel, then this feature becomes a per channel AGC. In a real emergency, high power mobiles or even high power portables can pass close to the coverage antennas. This is especially the case for systems that include outdoor coverage or coverage in parking garages where mobiles in emergency vehicles could go. With a broadband uplink power amplifier on the analog or digital booster, this high level signal can cause the broadband amplifier AGC to reduce the gain which then reduces the uplink sensitivity. This can cause a reduction in signal quality or complete loss of signal for the portables at the edge of coverage at the emergency site. The per channel AGC selectively squelches the large signal so that none of the other channels are affected.

A broadband booster can be relatively unaffected by high power transients if the unit features a high power uplink amplifier. For in-building coverage where only portables and not mobiles are expected, adding sufficient RF loss by designing the DAS with enough cable and RF splitters to multiple antennas will also minimize this problem.

7. CLASS A OR CLASS B OR MIXED?

The decision to use a Class A, Class B or mixed class, spectrum selective booster at a given site depends on several factors.

1. *Economics:* is the higher cost of a digital or analog Class A or spectrum selective booster supported by the available budget?
2. *Uplink Interference:* Can the donor site be isolated or mostly isolated from other services by selecting a narrow beam donor antenna? If so, a broadband booster could be used. If not, it may be that services in adjacent channel can be filtered using narrow, but not necessarily channel selective filters. In this case, a digital filtered spectrum selective booster provides the simplest solution.
3. *Site Size and Importance:* Larger buildings and facilities for government and crucial services may necessitate the most robust coverage during actual emergencies when a high number of first responders are present. In this case, a narrowband or mixed class,

programmable, multichannel spectrum selective digital booster with per channel AGC is the safest choice.

4. *Futureproof and Accessibility:* An easily reprogrammed digital multichannel spectrum selective booster may be the best choice if network changes for Rebanding are expected. Broadband units in urban areas are also vulnerable to interfering with new sites that fall in the donor antenna beamwidth. Also, sites that are located in difficult to reach locations can be much better served by boosters that can be reconfigured via remote connection. On the other hand, a remote, rural installation may not have much adjacent channel interference so a Class B approach with a low power requirement for a dedicated fuel cell or solar power may be the best choice.

7.1 Number of Channels and Composite Power

Even if there are other services within the donor antenna beamwidth, a broadband booster can be set up to accommodate this by setting the gain such that the composite output power does not exceed the rated power of the booster. The more channels that must be accommodated, the lower the available power per channel will be. For example, a booster that can provide 27 dBm/channel for 2 channels will provide 24 dBm/channel for 4 (equal) channels, 21 dBm/channel for 8 equal channels, and so on. Especially in urban areas, one must regularly monitor any changes in the other networks or the addition of any new services that could adversely affect the coverage.

7.2 Uplink Interference - The Main Concern

Incorrect interpretation of the FCC rules as well as lack of knowledge about the functioning of two-way radio networks, has led many to believe they can always use a broadband booster for indoor coverage. This is especially the case for small buildings where many assume that, since the coverage area requires just a small, low power booster, it cannot possibly harm the network.

This simply is not true. A small, low power broadband booster improperly deployed can cause just as much damage to the network as a high power unit. One problem was discussed previously, namely improper uplink gain settings. But a complete knowledge of the location and channel plans for other services is required to assure a non-interfering deployment of any booster as required by the FCC.

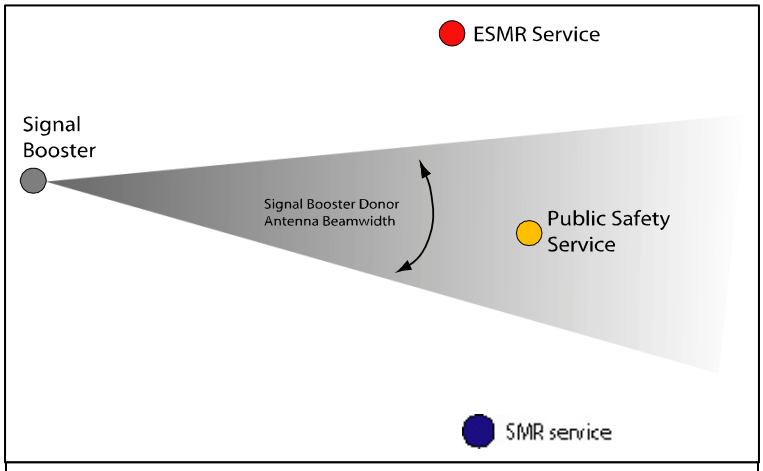


Figure 5. A narrowband donor antenna isolates the desired donor site. A broadband booster is OK.

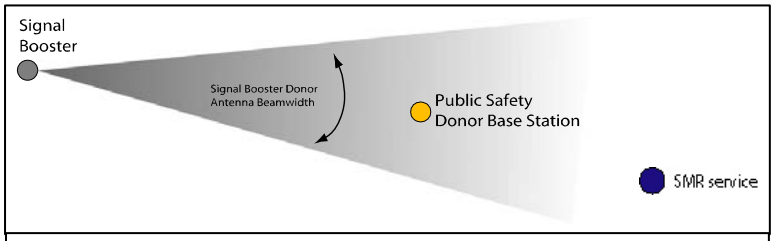


Figure 6. The only other services within the donor antenna beam width are far away. A broadband booster will work.

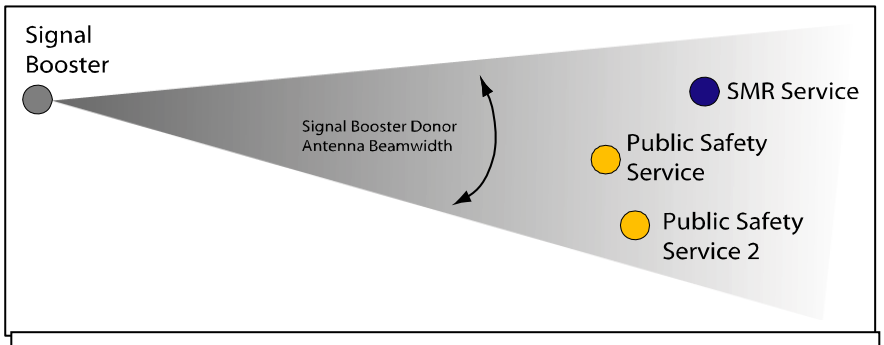


Figure 7. There are other services near the desired service not closer to the booster site. A broadband booster could be used if planned carefully since the channels from the other services will mix with the channels from the desired service. Also, any excess out-of-band noise or spurious could jam the other services. A spectrum selective booster could be easier to set up and more reliable if the additional cost is within the budget.

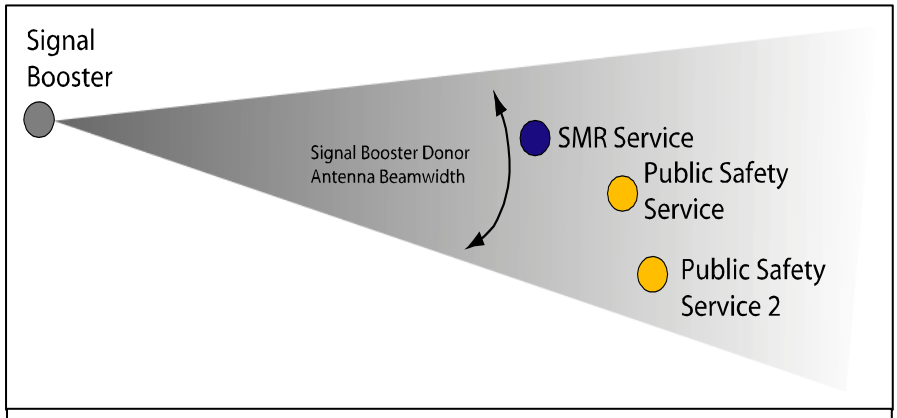


Figure 8. Other services have donor sites closer to the booster site than the desired site. A broadband booster cannot be used since the uplink noise would jam the other services. A Class A or spectrum selective booster must be used.

8. *PROPAGATION DELAY*

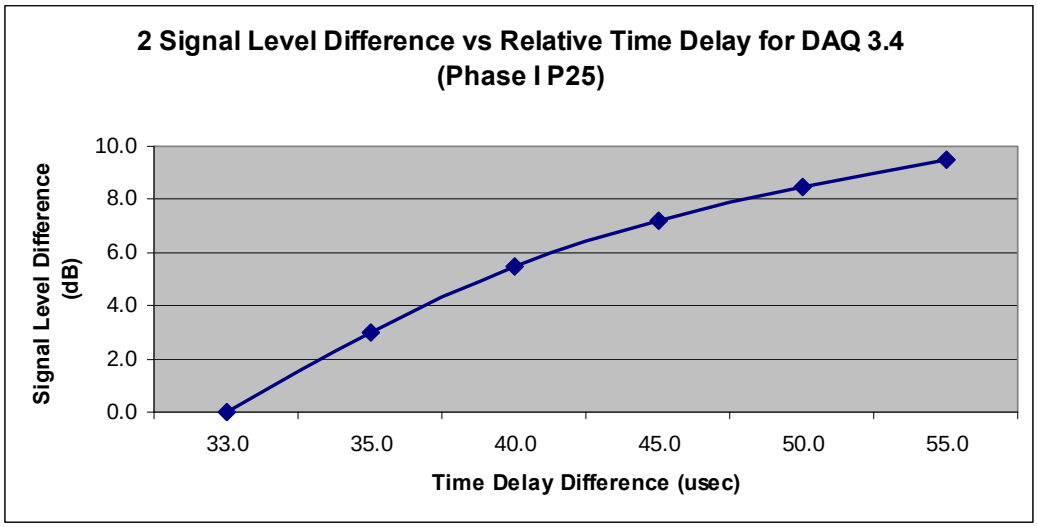
Some industry analysts have depicted the propagation delay through RF boosters as a universally bad thing. In fact, propagation delay is simply a part of the device physics and must be factored into any properly engineered coverage solution.

8.1 Time Delay in RF Boosters

The propagation delay through any filter, whether it is implemented digitally or in the analog domain, is inversely proportional to the bandwidth and (roughly) directly proportional to the order (number of sections) of the filter which determines the filters flatness across the pass band and sharpness of the roll off at the filter's edges. For filters with bandwidths greater than about 200 kHz, the delay is limited by the electrical delay through the components. This is typically approximately 5 μsec.

8.2 TDI (Time Domain Interference)

It is well known from simulcast network design that signal quality degradation can result from the overlap of a signal and a delayed version of the same signal. The worst case occurs in areas where the two signals are the same level. The analysis from the TIA TSB-88B Recommended Methodologies shows that, under these conditions, the maximum *relative* delay that can be tolerated to maintain a DAQ 3.4 is 33 μsec. For P25 Phase 2 systems, this value is expected to be 15 μsec. When one signal is stronger, higher relative delays can be tolerated. This is shown in Figure 9 below.



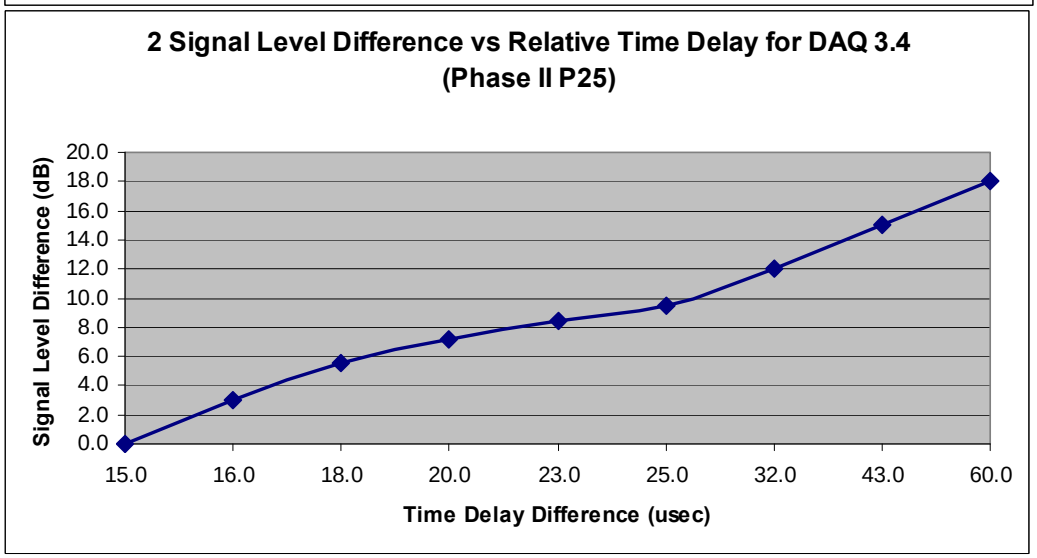


Figure 9. These plots show the maximum allowable relative time delay as a function of relative signal strengths.

8.3 Design to Minimize BOTH Adjacent Channel Interference and TDI

If it is determined that a narrowband analog or digital filtered booster is required or preferred, the coverage system must be designed so as to minimize both adjacent channel interference and time domain interference. More severe adjacent channel interference calls for narrower filters, which introduces more time delay. The coverage design must then ensure that delay does not cause signal degradation.

- ### Step 1: Select the Donor Antenna

  The first step in proper design to mitigate interference is to select a donor antenna that has a beam width narrow enough to eliminate as many adjacent channel services as possible. In many cases, it is desirable to select an antenna with a beam width narrower than needed to guard against possible future sites. It is important to consider the site where the antenna is to be installed as this could pose physical limitations either in size or aesthetics.

- **Minimize Coverage Overlap**

  If narrowband filters are to be used, the coverage design must minimize the overlap with the primary signal from the base station. For outdoor coverage sites, the service or coverage antenna should have a beam width just wide enough to cover the area in question but no more. The proper use of downtilt for the coverage antenna often helps confines the coverage as well.

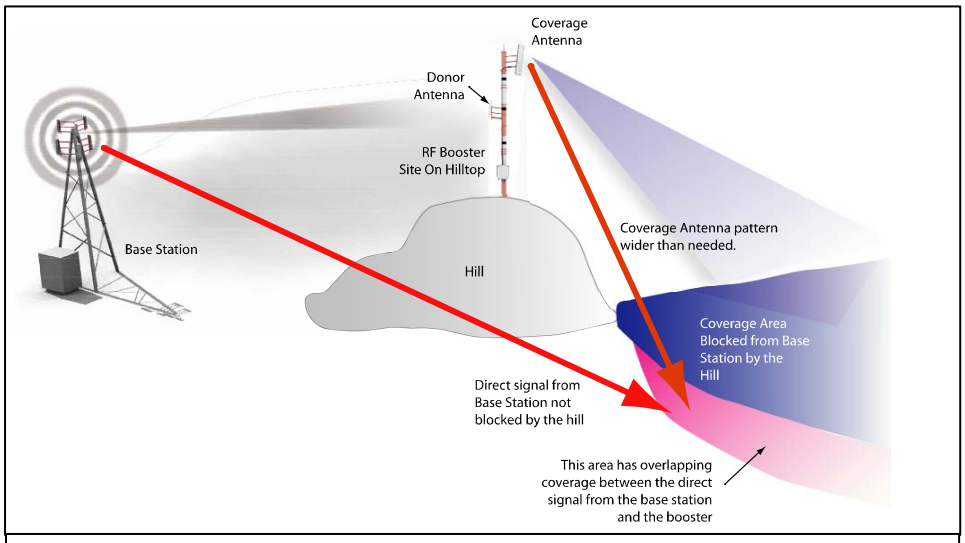


Figure 10. Here, an RF booster is deployed on a hilltop to fill in coverage behind the hill. The coverage antenna beam width is wider than needed to provide the coverage so there is an area of overlap between the direct signal from the base station and the delayed signal through the booster. If the relative time delays of the two signals in this area is > 33 µsec, there will be some signal degradation in this area.

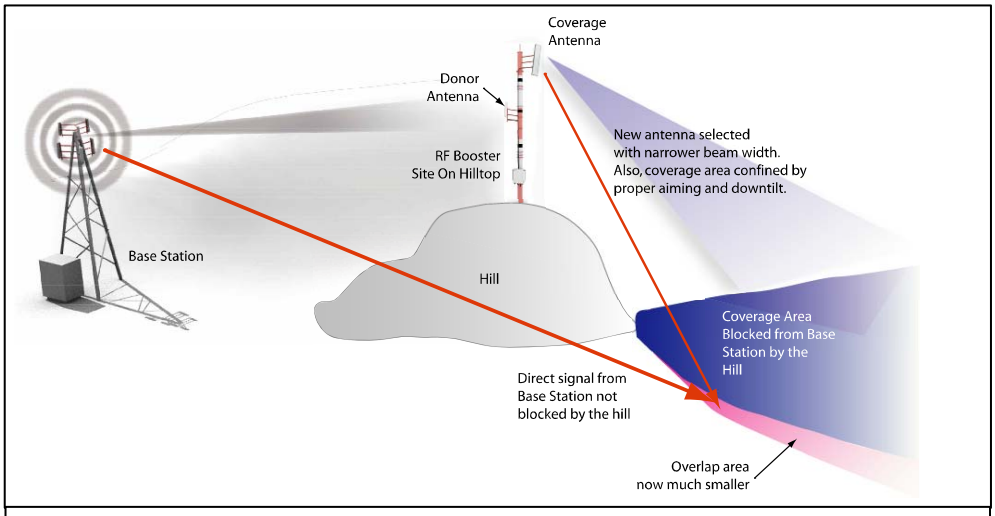


Figure 11. Same as before but a coverage antenna has been selected with a narrower beam width to cover only the area needed. Also, the antenna alignment has been optimized and downtilt has been employed to better focus the coverage. Now, the coverage overlap area has been minimized. Any signal degradation occurs only in a small strip.

- ## Minimizing Overlap for Indoor Coverage

The signal penetrating a building from the outdoor network can be quite spotty and irregular depending on the building layout and materials as well as the nearby obstructions outside the building.

If a building were located in an isolated place with no nearby obstructions, the signal from the nearest high site would still be much higher at the upper floors because of the characteristics of RF propagation over the earth's surface. The signal level difference between the ground level and 100 feet higher can be over 20 dB. In real environments, there are additional attenuations that affect the lower floors from terrain, nearby buildings and even trees.

If the signal levels are good at the higher floors, one could take the approach of providing a full indoor coverage system for the lower floors and just the stairwells and elevators shafts for the upper floors. Another approach is to cover the entire building and shape the coverage so that the indoor coverage signal dominates over any signal from the outside. One way to accomplish this is to design a DAS with directional antennas at the corners of each floor. This way, the indoor coverage signal can immediately be dominate over signals coming through the walls and windows without leakage to the outside (Figure 13).

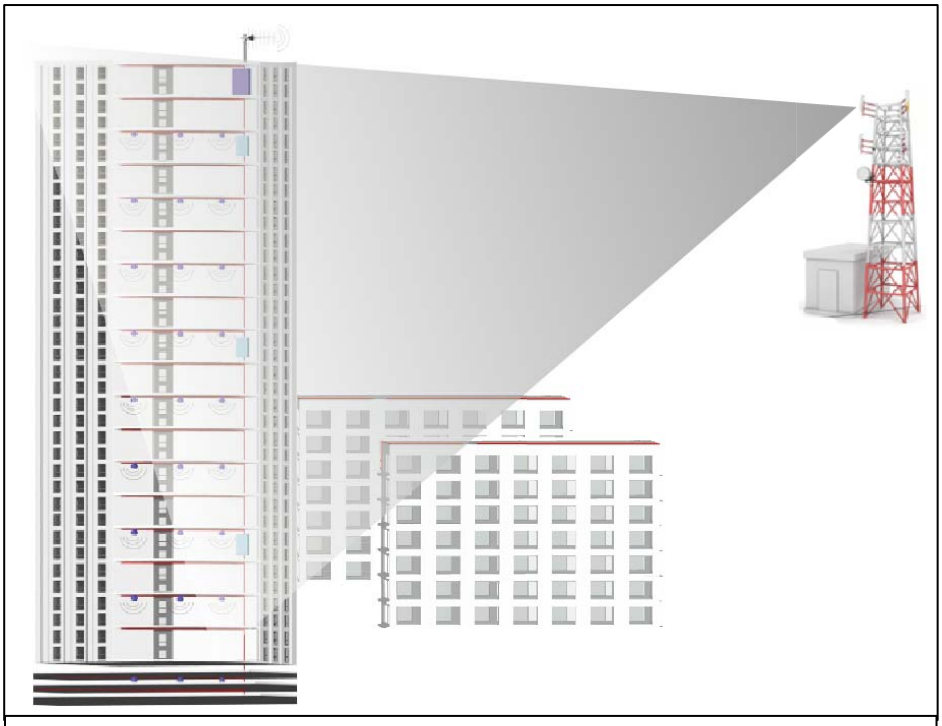


Figure 12. In-building coverage from the outside network will generally be much worse for the lower floors. The actual coverage may be spotty throughout. The best solution is a DAS design that ensures a dominant indoor signal

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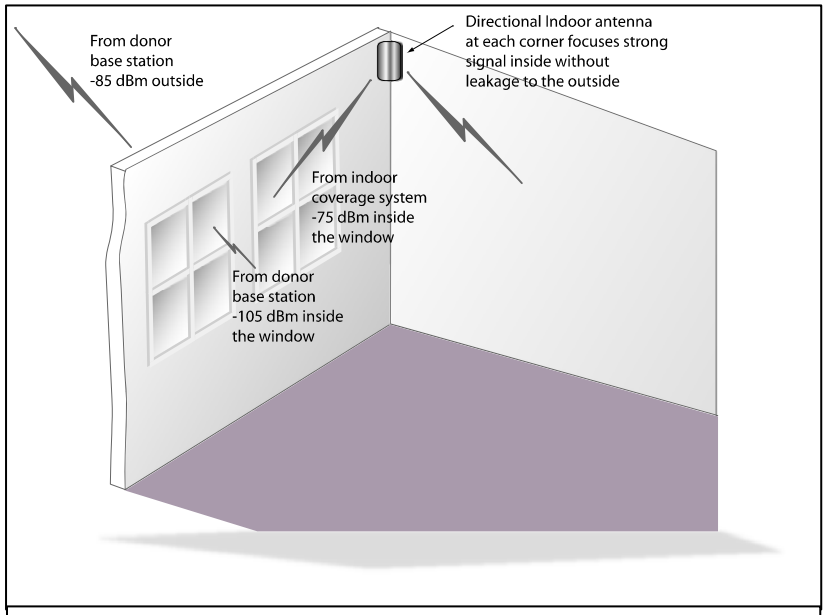


Figure 13. A DAS design with directional corner antennas can ensure capture of the indoor signal without leakage to the outside.

Select filters with maximum BW that give the needed adjacent channel rejection

A detailed knowledge of the adjacent channel services being picked up by the donor antenna allows the design engineer to select filters in the booster that are as wide as possible but still provide the required adjacent channel rejection.

In the worst case, one or more of the filters may have to be selected that pass one or more adjacent channel services. Accommodating a few additional channels is still far easier and more controllable than accommodating 30 additional channels in a broadband booster.

9. RF BOOSTERS IN SIMULCAST NETWORKS

Somewhat more care must be taken deploying narrowband and spectrum selective boosters in a simulcast network. Broadband boosters generally have time delays of around 5 µsec so can be deployed without time delay concerns. If narrowband or spectrum selective boosters are to be deployed in the capture area of one site of a simulcast network, the same methodology described above for a non-simulcast network applies. If the in-building site is located in an area covered by more than one donor, all of the same procedures for minimizing both adjacent channel and time domain interference apply, however the donor site used must be the one nearest and with the most dominant signal and one must take extra care to "shape" the indoor coverage as discussed previously to ensure capture of the portables with that donor site.

10. SUMMARY

RF signal boosters are the cost-effective way to fill in crucial coverage in Public Safety networks. There is a range of available solutions from simple broadband boosters to analog narrowband boosters to digital multichannel spectrum selective boosters that can be configured as Class A, Class B or a mix as necessary. All of these solutions can provide coverage that is as robust as the rest of the network if the coverage solution is engineered properly. Similarly, any in-building system regardless of class, configuration, size and cost that is deployed with little planning or poor engineering can cause network performance problems. Every site is different and requires a thorough knowledge of the services in that area and a carefully planned design by qualified engineers.

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

By Jack Daniel, Jack Daniel Company

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.

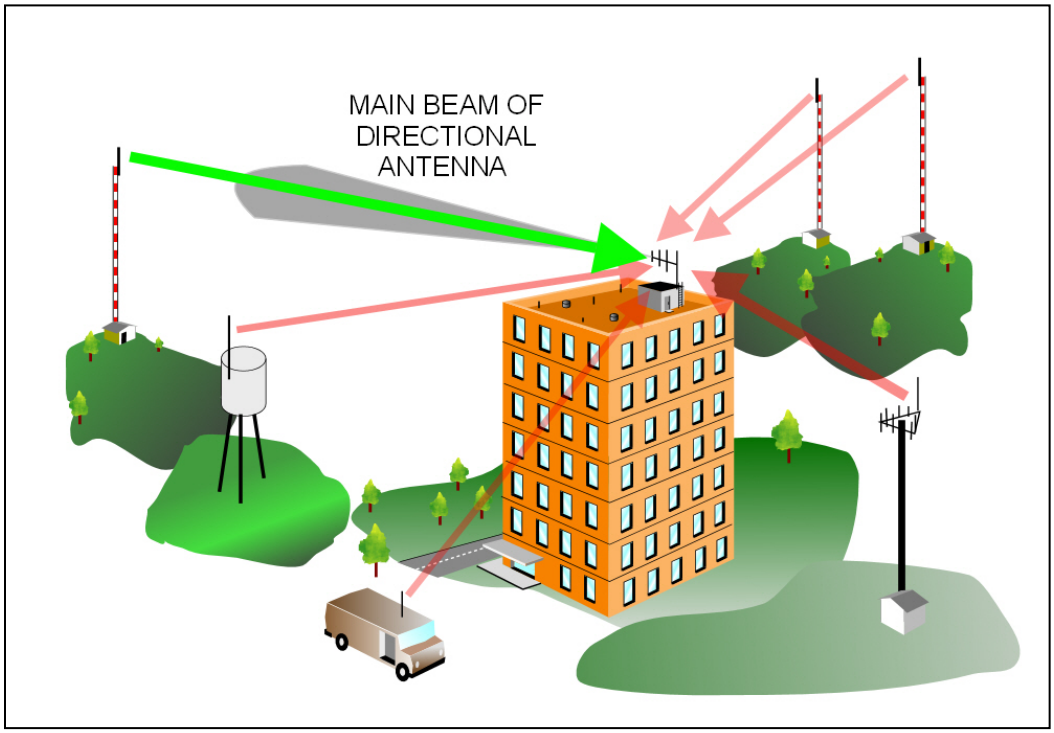
Using the structure itself to reduce undesired channels:

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.

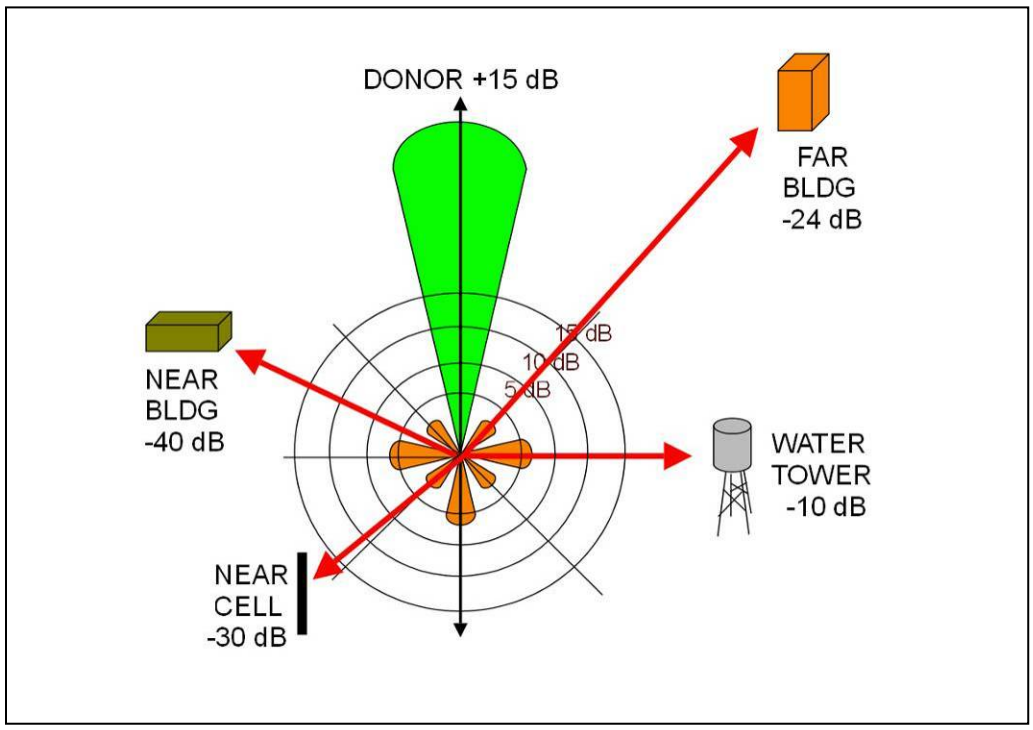
High donor antennas also 'see' more sites in the distance. The antenna elevation should be as low as practical an still maintain a line of sight path. Below are pictures of actual public safety installations using this approach:

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.

Appendix E: Optimizing FCC Class A Channel Selective (channelized) Signal boosters

By Jack Daniel., Jack Daniel Company

The FCC signal booster Classes, 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 circuits. 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 A signal boosters are called 'channelized' amplifiers for better clarity.

Types of Class A signal boosters

Class A signal boosters have been available for over 15 years with different, newer technologies and bands appearing over the years. There are four types available today and because of operational differences each type may require different configurations and optimizations. The following is a very minimal description of the different types.

These types will be cited throughout this document when the types has different characteristics relative to the subject being discussed.

Type 1: Crystal filter type: This is the original type and it is only available currently at VHF frequencies. These are not programmable and generally limited to 4 channels per signal booster. Except for bandwidth these are the same as Class B signal boosters. Since the signal booster only passes one channel the composite power effect in broadband signal boosters does not exist. These types are the most economical of all channelized amplifiers.

Type 2: Single Channel heterodyne. These are perhaps the most programmable of all Class A signal boosters. These are always channelized as the passband bandwidth is restricted and cannot be reprogrammed to operate as a Class B broadband signal booster. Selectivity is achieved by down converting the input to a narrow IF filter then up converting the output back to the input frequency. These closely resemble a standard repeater, with good input sensitivity and fixed output power regardless of input level. Repeater activation thresholds are programmable and squelch operation can be none, CTCSS or Digital squelch activated. This type is capable of up to approximately 30 watts output per channel. The number of channels are unlimited as each channel is a stand alone rack mounted module and scaleable as required. Remote status monitoring, alarming and complete programmability capability is standard.

Type 3: Multiple channel heterodyne. This design uses a wideband down conversion of the input band (i.e. block conversion) into a bank of multiple parallel "IF" sections, combines the IF outputs into a composite output, then up coverts the composite signal into a common output power amplifier. Each IF is programmable so each may select an individual channel. The number of channels per signal booster is determined by the number of Ifs used, with 4 and 8 channel versions being most common.

Due to the common input amplification and common output power amplifier this type does exhibit the composite power effect common to Class B signal boosters. (a discussion of composite power and optimization of composite power effects can be found in Addendum E, Optimizing Class B Signal Boosters) The potential output power per channel varies greatly from model to model due to many output power amplifier choices. Remote alarming and channel programmability is available as an option in some models. Since this type does not use baseband demodulation, CTCSS or Digital squelch control is not currently offered.

Type 4: Functionally, this type is similar to Type 3 but uses digital signal processing to perform the channel bandwidth and frequency selection. This is sometimes referred to as 'digital filtering'. Current standard models have 4 to 8 channel capacity per signal booster. This type can allow programmability of gain per channel, which may be beneficial when input signals are from different remote sites. The output power per channel varies from model to model and high power (25 to 60 watt) amplifiers are available. Note the power amplifier is amplifying the composite power of the number of active channels, therefore the power per channels is less than the overall power rating of the output amplifier.
Remote status monitoring, alarming and complete programmability capability is standard. Since this type does not have normally include baseband demodulation, CTCSS or Digital squelch control is not currently offered.

Note: Type 4 has passband programmability which allows the passband to be more than one channel's bandwidth. When operating in this mode, the signal booster becomes a FCC Class B, broadband signal booster and has more composite power effects.

Number of Channels:
Type 1 is limited to approximately 4 VHF channels and is typically 1 channel.

Type 2 has no limits on the number of channels, however conventional low power transmit combiners are required and that places practical limits on how many channels can be combined while retaining adequate power per channel. In in-building applications where low power distribution is preferred the combining loses are more acceptable.

Most current Type 3 and type 4 models have hardware limitations of up to 8 channels per signal booster. (up to 16 channel capacity is under development)
When the primary system utilizes more channels than the capacity of one signal booster additional signal booster inputs and outputs may be combined using hybrid combiners or other commonly available devices. Normal combining losses will reduce the power per channel accordingly.

Interoperability Considerations:

The number of channels in a Class A signal booster is intentionally fixed to those specific channels used by the system it normally communicate with. The main function of a Class A signal booster is to prevent other undesired channels from interacting with the desired channels passing through the signal booster.

The system planner should consider the channel requirements when the signal booster should also serve mutual aid and other outside agencies during an emergency event. This is an extension of interoperability.

When additional channels should be processed by a channelized signal booster temporarily, one or more approaches may be used to accommodate them.

(a) The Class A signal booster is installed with all the expected interoperability channels in addition to the normal channels being used. If the number of channels exceed the capacity of one Class A signal booster, more are added in parallel until a sufficient number of channels is provided. The system designer must also anticipate the composite power effects if the 'emergency' channels are only activated during an event.

(b) The channels within the Class A signal booster are reprogrammed to accommodate interoperability channels. In this method the system designer must predetermine what normally processed channels within the signal booster will be made inactive during the event. The channel change is most effectively implemented using remote programming access circuits.

(c) If the new channels are close to existing channels, the passband bandwidth of one or more channels may be widened. When this approach is used, the system designer should prepare a plan then, based on the levels of all the channels that will pass through each window, recalculate the output power. This is because the composite power effect comes into play when any passband allows more than input channel to be amplified by the same output amplifier. The passband bandwidth change is most effectively implemented using remote programming access circuits. This choice is currently limited to type 4 signal boosters.

In scenarios (b) and (c) preplanning is required to have fast reprogramming response capability during the emergency. It would not be practical to dispatch a trained person to each structure to implement changes at the signal booster's physical location. A centralized remote site is optimal. The requires the system designer to include circuits for remote control to the appropriate structures. There are many circuit options available to the system designer, such internal data networks, dedicated or dial up telephone circuits, etc. Naturally the most dependable method is preferred and the public internet is never recommended.

The remote reprogramming effort is similar to the methods used in 'dynamic regrouping' methodology. As many emergency scenarios as possible are matched with the radio channel changes that would be required in each scenario, limited by the channel capacity of the Class A signal booster(s). The results are entered into a program that allows non-technical personnel to activate the reprogramming based on the event type.

Propagation Delay

When signals pass through a signal booster they are delayed by the signal boosters internal circuits. The amount of delay varies with design but overall is relative to the passband bandwidth. The narrower the passband, the greater the propagation delay.

Propagation delay becomes a consideration in public safety applications where the direct signals from the repeater site and the delayed signals from the signal booster overlap. When the signal booster delay is small it has no effect on system operation.

Manufacturers experience with overlap (or multipath) in simulcast system designs has established maximum signal booster delays relative to the type or brand of radio system used. Digital modulations have reduced the acceptable signal booster delay and the system designer should anticipate the worse case to facilitate current and future system requirements without replacing or reprogramming signal boosters.

Currently, the most severe digital modulation type radio system delay recommendation is 15 microseconds or less. Analog systems may operate with longer delays, dependent upon each radio each system design.
Current Class A signal boosters cannot achieve much less than 50 microseconds propagation delay while maintaining a single channel passband bandwidth.

If deployed in a tunnel or other situation where no overlap with the outside signal can exist, signal booster propagation delay is not a consideration. (Although not part of this in-building discussion, delay is a major problem when using a signal booster to fill-in for an outdoor area.)

It has also been established when a stronger signal 'captures' the receiver there will be no communication degradation caused by the lesser signal(s), regardless of delay. Again, digital modulations generate the most demanding specification. Recent evaluation has established digital receivers are captured by the signal that is 16 dB or greater than any other signal at the receiver input. The system designer can overcome the propagation delay challenge of Class A signal boosters by designing each in-building installation so as there are no overlap areas with less than 16 dB dominance of a signal from either the direct or delayed signal path.

Obviously, at some point the signals must approach equal levels and delay becomes detrimental to the operation of the system. The system designer should calculate the various looses to identify where the 16 dB rule is violated and make sure these locations are not in areas where communications is needed. This can be a complex issue because the effect wall and floor attenuations must be considered. As the signals pass through additional walls and floors the levels can change considerably in a few feet.

Reducing Class A signal booster delay:

Since delay is dominated by the passband bandwidth, the delay can be reduced by simply widening the passband bandwidth. At some point, usually 200 KHz or greater bandwidth, the delay in a Class A is reduced to an acceptable level. As the bandwidth is increased the Class A signal booster delay becomes closer to being a Class B signal booster, which has propagation delays of less than 5 microseconds.

When using a channelized signal booster with more than one channel passband in a trunked radio system, all the passbands should be increased equally to prevent unpredictable operation.

When operating as a Class B signal booster the composite power effects apply and the system engineer should anticipate the highest possible input levels from undesired signals that appear within the widened passbands. Margins to accommodate the potential output signal variations must be added. The system designer may also have to reprogram the ACG circuits to accommodate the effect of high level undesired signals on an AGC circuit normally handing one channel instead of many channels at the same time.

Output power considerations

Many Class A signal boosters have the capability of providing 5 watts or more output power per channel. While this may be desired, additional considerations arise at these power levels.

First, the FCC 90.219 rules for signal boosters limit the ERP per channel to 5 watts maximum under any conditions.

With gain roof top (donor) antennas it is easy to exceed this level on the uplink path. Since directional antennas with inherent high gain are desirable on the roof, the uplink output power should be reduced accordingly. For example, a net 10 dB antenna/coax gain roof antenna system, an input level of 500 milliwatts (+ 27 dBm) is maximum signal booster output under the FCC signal booster rules.

The limitation on power delivered to inside antennas is more compliance to OSHA Human RF Exposure limits than the FCC 5 watt ERP limit. It is easy to exceed these limits with high power output signal boosts, and, if allowed to occur, open civil liability issues in the event of a complaint. The system designer should establish the ERP for the highest ERP antenna and, using OSHA guidelines, adjust the signal booster power accordingly.

Although not endorsed here, the common compliance practice is to use cellular handsets as an acceptable power level reference, or 600 milliwatts (+27 dBm) maximum ERP at any indoor antenna. Remember, for exposure measurements, this is the maximum composite power measure and the power per channel in a multichannel system will be less. For example, the 600 mW composite power ERP for a 10 channel trunked system results in 60 mW (+17 dBm) maximum ERP per radio channel at any indoor antenna. This reduces the signal boosters output power requirements considerably.

Naturally, the system designer must also consider balance between the uplink and downlink coverage within the structure to prevent one sided communication attempts. In at trunked system this effect is usually caused by excessive downlink power levels.

Alternately, an ERP of over 5 watts is legal when each signal booster installation is coordinated and licensed as a separate fixed location base station. This may be desirable for outdoor fill-in applications of high power signal boosters but less suitable for in-door applications due to the human exposure limitations.

Power Consumption

Many in-building system specifications include some form of back-up power. In This is usually addressed using battery based DC power back-up devices and the most common requirement is 12 hours operation.

The system designer must anticipate the back-up power requirement, which can be considerable with high powered signal boosters. The system designer may use a lower operating power level but at the risk of someone later increasing power consumption beyond the back-up's capability. Alternately, ask the manufacturer for a lower powered unit to reduce the size and cost of the back-up system.

Conclusion

Class A signal boosters offer reduction of interactions caused by undesired channels and may provide higher power per channel in the finished system design as compared to Class B signal boosters. However, these benefits may come at additional cost. 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.