Solutions White Paper

For

In-Building Systems

Helpful Design, Regulatory, Implementation & Optimization Techniques

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EMR Corporation
EMR Corp. Solutions Paper
- In-Building Systems-

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EMR Corp. In-Building System utilizing Multiple BDA's in Pima County, AZ Courthouse

...Built Over 25 Years Ago...

1. Much to Think About

There is much to think about when designing and deploying an In-Building System. This solutions white paper is intended to uncover, define and address the many issues and aspects involved with these highly specialized systems. Over the years, “BDA” has become a generic term bandied about to describe bi-directional signal boosters that are used to improve RF coverage inside buildings. Many times the phrase is repeated particularly in the cellular industry where the devices are cavalierly utilized wherever signal coverage is weak or non-existent.

The cellular and PCS bands, with 39 to 60 MHz of Uplink to Downlink frequency separation can facilitate the use of BDA's. With the sufficient frequency separation between radiating elements, achieving isolation is much easier than in the Low, MID VHF, UHF, 220, 380-470, and 470-512 MHz bands with separations as close as .1 MHz at VHF and as little as 3 MHz at 470 MHz. Uplink to Downlink Isolation is more difficult to achieve at closer spacings. Also, in some instances coverage enhancement isn't required in both directions so a UDA- (Uni-directional amplifier) might be utilized. For instance, coverage into the building from the repeater is adequate but “Uplink” back to the repeater is not strong.

The 150 MHz VHF through 960 MHz bands are our area of specialization where precision filters are needed to achieve required isolation along with highly BDA/UDA linear amplifiers.

2. In-Building Systems Can Significantly Improve Coverage

As land-mobile specialized mobile radio (SMR) systems gained popularity in the 1980s and high-performance portable radio transceiver units for these systems became available, an upsurge of usage took place. However, it was quickly found that buildings, tunnels, and areas that were deeply RF shaded from the base station site suffered from intermittent to a complete lack of coverage.

The primary use of these In-Building systems for First Responders is to improve poor coverage inside buildings. Wireless carriers use the devices to improve coverage and provide better customer satisfaction. Wireless carriers have driven the use of band-limited, or channelized systems to improve coverage for their customers but not for those of the competition.

The use of unidirectional or bi-directional filter-amplifiers, to enhance coverage, has provided an effective, yet relatively simple, answer to the problem but implementation requires careful planning.
3. Government Mandated Coverage

Many government entities (cities, counties and states) mandate coverage levels to ensure that First Responders can communicate inside a structure. In general, The In-Building System involves bi-directional amplifiers, splitters, dividers, cable, indoor and directional antennas for the Common Air Interface (CAI). RF/FO converters may be involved to achieve system objectives if great distances are involved between the booster and antennas in remote areas on a campus. The 800 MHz Public Safety System for City of Irvine, CA; City of Burbank, CA; City of Boston; City of Fort Lauderdale and many other Fire & Police regulations of cities and counties throughout North America have implemented regulations that mandate coverage particularly in common areas where First Responders may require two-way radio coverage. REF: http://www.bicsi.org/uploadedfiles-Conference_Websites/Fall_Conferences/2011/presentations/Understanding_New_Wireless_Codes.pdf

4. Business Case

There is a business case for building owners and operators, beyond coverage being mandated, to embrace the many benefits from the installation of In-Building systems. These include:

- Safety & Security of lessee, tenants, owners & occupants
- Safety for First Responders- Fire, Police & EMS- may be mandated in city and/or county
- Marketing & Selling feature/benefit for leasing company & owner
- Operational efficiency and productivity gains
- Responsiveness- the ability to respond quickly to tenant calls; wireless coverage in parking garage and stairwells, and improved mechanisms to track and record service calls in real time.
- Security systems and GPS location systems can also increase the value of an in-building installation

5. Multiple Bands are Possible

Systems can be designed for more than one band including: 150, 450, 700, 800 & 900 MHz, but they're more complex and generally more expensive. Keep in mind that propagation differences exist for each band- e.g.: a 150 MHz indoor antenna may cover 150 ft. while a 900 MHz indoor antenna will cover less; perhaps half the distance! Customized engineering is required on virtually every system that is configured and furnished so we recommend getting us involved from the onset of your project.

The basic system consists of placing an antenna array in the clear, aimed at the donor radio site to provide access to the communications system (also known as the common air interface or CAI). The BDA amplifier assembly is placed in a secure location as close as possible to the external antenna. From this point coaxial cable feeding line taps and antennas or lossy radiating cable is installed throughout the structure. Note: radiating cable is best used in a mine or tunnel type application. Using lossy radiating cable and/or coaxial transmission line with properly located splitters, dividers, line taps, and indoor antennas throughout the coverage areas represents the basic distribution aspect of the system. For longer runs, fiber-optic backhaul and/or distributed antenna systems provide distribution of the desired signal.

The use of RF/fiber-optic converters to extend system range in a campus application or for use over great distances is increasing typically where a line-of-sight path does not exist, the RF signal is low, or interference is an issue, such as in an urban area. Note that interference may also present obstacles to using a common air Interface for accessing the remote repeater(s) or system rather than a direct connection via fiber or coaxial cable directly on site to the repeater.

An in-building system can use either coaxial RF or optical technology; possibly both. These are often referred to as a DAS (Distributed Antenna System).
6. What is Timeframe for Project...who owns the System?

There are several operational and technical aspects to consider when working with management to implement an in-building system. For instance, what is the timeframe for the project and who is the purchaser of the system? What entity will act as the project developer—a builder, homeowners’ association, a private corporation, a government entity, a cellular/PCS operator, or a neutral host (NH) service provider? (Knowing who will be paying for the NH systems can be particularly challenging.)

7. Numerous Markets for In-Building Systems

Here are examples of locations where in-building systems have been implemented:

a) Public Safety- Any building over “X” square feet, with common areas or where city/county mandated “First Responder” two-way radio-coverage
b) College campuses and public/private schools- grammar, middle and high schools (this market is rapidly growing due to student safety, increasing school violence and discipline issues)
c) Medical- Hospitals, Medical Centers, Diagnostic Groups, Convalescent Care Centers; Clinics
d) Enterprise Markets. Industrial complexes; manufacturing plants, chemical and oil refining plants (this is a large market opportunity for radio dealers)
e) Military installations, airport hangers and related facilities
f) Stadiums and sports arenas
g) Malls- department stores, BIG BOX Stores (Wal-Mart, K-Mart, Sears, etc.)
h) Mines- underground and pit mines
i) Airports, transportation hubs, package sorting facilities (UPS, FedEx, USPS) and terminals- Domestic & International
j) Correctional facilities including detention centers, jails and prisons.

Additionally, neutral host systems are being used in casinos, airports, convention centers, hospitals and shopping malls, while office buildings, tunnels and public transportation are both public-safety and neutral-host applications.

The National Public Safety Telecommunications Council’s in-building working group technology committee noted that, “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.”

8. There are Many Important Questions

Who will ultimately own and maintain the system after implementation? Is the in-building system part of a new construction? It is often assumed that running cables or fiber is easier when the building doesn’t have the walls or ceiling in place. While this is true for the most part, there may be project management, contractor (union hall) and sub-contractor issues to consider.

If the system is going into an existing building, logistics will be a major concern. Installers might have to work after normal business hours or be especially mindful of not interrupting those conducting business, and issues might exist when working in restricted access areas.

1On the technical side, running coaxial cables can be quite challenging in existing buildings, without drop ceilings, particularly when they have to go through firewalls. In contrast, fiber-optic (FO) transport allows the transmission of the signal over great distances with minimal loss. However, such systems require optical to-RF converters that require AC/DC power, power back-up, and a corresponding antenna system.
FO/RF systems also need a secure location for the converter rack so there are maintenance and additional power operating costs.

9. Challenges

1.2 The requirement for proper “Antenna Site Engineering” on a case by case/site by site basis is essential for maximizing your overall In-Building Systems performance. Using a “Cookie Cutter” approach isn’t acceptable and could result in compromises in terms of systems range, coverage, systems capacity and interference. These are all interactive elements and you will need people in place that thoroughly understand this subset- The RF Antenna System. If it is properly designed, manufactured, and installed it will provide the best possible coverage and capacity for the users. Unfortunately, there are few experienced “Radio Guys” left in our industry that truly understand RF; most have been replaced or usurped by the “IT Department” due to the computerization of most of these systems. The interesting implication is that the RF Antenna System Peripherals’ Subset, while only representing a small percentage of the systems cost (1 to 10% depending on configuration) can have profound implications on the systems overall performance...getting it right is extremely important to all stakeholders and those involved as OEM's in the design, manufacture, and deployment of same.

The thrust of this solutions white paper is as follows:

1Technical/Engineering

1. Practical Design- Cost effective, well engineered systems, with proven RF hardware, alarm monitoring, with battery stand-by backup that are properly installed and optimized, result in reliable, long term operation. Doing it correctly the first time eliminates reworking and an extensive optimization effort. Many systems are in operation for more than 25 years.

2. Class A vs Class B Boosters are classified by the FCC in two categories- Class A “Channelized” and Class B “Broad Band”. While it can be argued that one approach is superior to the other depending on the RF environment, the bottom line is that a Class A Channelized Booster that utilizes IF conversion techniques, increase systems “group delay” that could affect digital systems operation, affects BER and will generally cost more than a Class B Booster with a 75 Khz Window Pass Band Filter or a Class B which may be required in Pass Band exceeds 75 Khz; perhaps 2-3X more cost.

3. FCC Regulation Summary on Signal Boosters

According to Michael Higgs Esquire: “Part 90 Signal Boosters are a type of Industrial Signal Booster, designed to improve coverage of land/mobile radio (LMR) networks authorized under Part 90 of the Commission’s rules. Part 90 covers non-cellularized radio communications systems primarily used to create private networks for public safety, transportation, and business and industrial entities”,

“Subject to the exceptions detailed below, Part 90 licensees are permitted to install compliant signal boosters at their discretion anywhere within their protected service contour. Non-licensees that seek to operate Part 90 signal boosters must obtain the consent of the licensee[s] whose signals they intend to amplify. Additionally, licenses, system integrators and installers must consider the potential adverse effects of the increased noise floor on LMR systems and establish additional emission limits to reduce the interference potential of signal boosters.”

Class A - Narrowband

“Part 90 signal boosters are separated into two classes, A and B. Class A signal boosters are designed to retransmit signals on one or more specific channels. A signal booster is deemed to
be a Class A signal booster if none of its passbands exceed 75 kHz. Part 90 licensees may deploy Class A (narrowband) signal boosters in both fixed and mobile environments provided that they do not cause interference to other licensed services in the band."

**Class B – Wideband**

“Class B signal boosters are designed to retransmit any signals within a wide frequency band. A signal booster is deemed to be a Class B signal booster if it has a passband that exceeds 75 KHz. Mobile deployment of Class B signal boosters is prohibited, but fixed deployments are permitted with registration.”

“Fixed Class B signal boosters must be registered directly with the FCC before being used. The Commission’s Class B signal booster registration system is expected to be available by November 1, 2013. By creating a permanent record of all Class B signal booster installations in a searchable database, licensees will be able to search online for signal booster installations if they experience interference or other degradations to their system. This will allow licensees to identify and shut down signal boosters causing harmful interference as necessary.

“Licensees and signal booster operators are required to register existing Class B signal booster installations with the FCC by November 1, 2014. After November 1, 2014, operation of an existing, unregistered Class B signal booster will be unauthorized and subject to enforcement action. Any new Class B signal booster installed after November 1, 2014 must be registered prior to operation. To encourage compliance with this new requirement, registration will be free of cost to the operator and/or licensee”.

1. **Coaxial vs Fiber DAS**- The Distributed Antenna System or DAS can be configured as a coaxial cable design, a RF/FO fiber optic system or a hybrid combination of both coaxial and FO together. In general, with RF/FO, fiber cables can be run much farther than with coaxial cables due to coaxial cable loss factors of typically 3 dB/100 feet, so a 1200 ft run is going to take away 36 dB of signal WITHOUT splitter, divider, connector, jumpers or line tap loss leaving you with about 24 dB for distribution from the typical 60 dB SYSTEMS GAIN BDA...not much.

2. Fiber optics, in comparison, will let you easily double distances from the head end but will require both DC power at the FO/RF antenna port along with AC/DC power and back up at origination end. **FYI, a fiber splitter has 3 dB optic loss; 6 dB RF loss. Also, FO Systems will generate system noise so the need for additional FO/RF filtering may be required.** While nominal, this too adds a maintenance and operational costs for upkeep. Additionally, for Fiber-Optic Systems, it’s safe to anticipate that additional users and operators will eventually want to piggyback onto most in-building systems, particularly if it will be a neutral Host system designed to accommodate multiple carriers, such as cellular, PCS, and SMR. In this circumstance, fiber -optic distribution may be an easier way to add different services.

3. **System Noise**- If systems are co-located: IT-LAN, WiFi, Two-Way Radio, Cellular/PCS mobiles sending their signals will raise the noise floor at the site. This phenomena, along with ever changing near/far power levels of the carriers' cell phones could potentially cause RX desense of the co-located receivers of systems. This RF energy must be filtered/managed so as to assure satisfactory system performance. This is a critical aspect that could compromise range, in-building penetration while exacerbating interference potential, if the antenna systems design, placements and combining systems network are done in a haphazard manner. For example, the background noise situation at 150 and 450 MHz is getting much higher; in Washington, DC and probably just about everywhere else. Background S-meter levels on pre-2000 amateur and scanning radios run around S4-S6 on average in this area on those two bands. This corresponds to 6-10 dB of S/N erosion for BDA/UDA customers and I believe this is a justification for increasing the FCC's BDA ERP limit from 5W to 50W and their -40 dBm noise.
floor to -30 dBm.

4. **Systems Optimization**- Optimizing and troubleshooting BDA systems is challenging at best. You may be able to stop the ring around that is caused by a booster amp by repairing the N connectors to the AMP and adding attenuation...YES, you heard that correctly. Many problems are created by having TOO MUCH GAIN!

5. **Interference Considerations** -
   
a) GPS Interference- definite issue for Cell, PCS and LMR Sites  
b) IM Considerations- Intermodulation Mixes can compromise performance  
c) Passive IM- Antennas, filters, transmission cables, lightning suppressors, rusty fences, poor grounding, etc. can be susceptible to “Passive Intermodulation”  
d) Co-location on the existing site- is interference manageable or insurmountable background noise to PS BB.  
e) Most of the non-TX related noise in these areas is from IT LAN equipment and cabling plus LED lighting. The LED noise can be extremely high at VHF high band and 220 MHz (as much as 10-15 dB excess over terrestrial in a 16 Khz measurement bandwidth). Both the LED interference and the LAN interference are pretty easy to see on a spectrum analyzer with 0-500 MHz sweep in 100 Khz measurement bandwidth. More detail on this aspect in the addendum below.  

f) **Elusive Interference**- Other sources of this noise could be some unidentified antennas found near the installation of the Distributed Antenna System- DAS that could be causing major problems for the operator/customer. Managing potential interference proactively rather than reactively, will avoid pratfalls.  
g) **Radiating Cable- Keep it AWAY from BDA's**! At least 50’ to 75’ of radiating cable from the amplifier otherwise RF oscillation can occur, so use regular coaxial cable from output of BDA DAS port. Sections of radiating can also be damaged during installation which can cause poor performance. In a particular instance, the entire section running from the BDA to its terminus was compromised starting from the splitter and running through a critical area of required coverage.  
h) **General**- These could be caused by poor connectors, misaligned center pins of the connector, damaged cables, etc. could wreak havoc with your In-Building system.

**Operational**-

1. **Choose the correct SME's**- Subject Matter Experts and/or Consultants that understand RF thoroughly; there are not many in the Land-Mobile industry compared to the past. **Those that collaborated on this solutions paper are very familiar with the Land-Mobile business.**  

2. **Select someone with a RF understanding of both Land-Mobile and Mobility (cellular/PCS) systems and their systems structures.**

**Legal Compliance**-

1. In many areas of the country, compliance with local In-Building Coverage ordinances, including or excerpting portions of NFPA and/or IFC regulations is being mandated. An example is from Orange County, CA where there is an ordinance in place that relates to common areas of buildings where “First Responders” may have to enter and have two-way radio coverage on their wireless network.  

2. Local fire codes often require amplification of Fire, Police or EMS “First Responder” Two-Way radios throughout the buildings. The two primary codes are NFPA1-annex o and IFC.

We have provided our configuration suggestions for 700 & 800 MHz combined In-Building Systems on a common distribution DAS input and output for insights. These designs will vary dependent on specific...
customer RF coverage and interference considerations.

As you can see, the approaches taken to assuring maximum performance of In-Building Systems and co-located transmitters in your Network is complicated. Doing so will result in cost effective savings, rapid deployment and safety/security for First Responders, administrators and the entire Public Safety community.

Paying attention to the RF Peripherals, while a relatively inexpensive system element, will result in beneficial systems range, coverage; overall In-Building performance. This is how you can “Leverage” the performance of your overall wireless system. Let us help you by sending an email to: info@emrcorp.com or call us on 623-581-2875 for immediate assistance.

10. An Overview on In-Building Solutions

Just as there are many variables to consider when deciding where and how to implement an in-building system, there are myriad steps that must be taken to bring the project to completion.

1. 1 A minimum of -65 dBm signal strength on the rooftop where the donor antenna is placed is simply a rule of thumb, figure of merit. A bidirectional system works best when LOS to the repeater(s) exists and this is when coverage is typically something you can be assured of prior to installation of the BDA/UDA and DAS. In some circumstances a lower signal level can be useable.

2. These figures originate from some base numbers and typical situations

3. Consider that typical Public Safety communication systems function at 100 - 200 watts ERP.

4. Figure that:
   a) The furthest a site will "typically" be from the repeaters is about 20 miles.
   b) System gain is runs about 60 dB.
   c) Typical building square footage is about 75,000 square feet.
   d) Cable used is 1/2". 800 MHz is used as the baseline as signal loss is greater through the cable at 800 MHz.

5. 100 watts ERP, 20 miles, LOS, means that signal to the BDA roof mounted antenna is going to be -72 dBm. A 10 dBd gain antenna gets that to -62 dBm. 100' of 1/2" cable between the antenna and the BDA is right about -65 dBm to the head-end of the BDA.

6. 60 dB gain means -5 dBm out of the BDA.

7. 75,000 square feet on two floors means a building that's about 140 x 140' should have four antennas per floor. Cable loss and splitter loss from the BDA to the "furthest" antennas would then be about 16 dB.

8. This would in a worst case scenario situation put any portable radios within 75' of any antenna. Free space path loss would be around 55 dB.

9. Pending material attenuation, multi-path, body absorption (greatest at VHF due to body emulating size of wavelength at those frequencies), poor antenna performance, low battery, etc..., there would be a downlink signal to the portable radio of -76 dB. Typically, there is 10 dB of absorption which leaves a -86 dBm to the portable.

10. Assuming that the portable is typically going to be 14 dB down from the base station unit, and there is reciprocity in the signal path (because there is line of sight) then we would see -100 dBm to the repeater receiver.

11. If these numbers aren't met we would look at a system upgrade to higher 80 dB gain offering; recommending a monopole or tower which gets better height to achieve LOS, or strongly caution that a BDA may not be the solution.

12. Cost Relativity- VHF BDA Systems tend to be MOST expensive; UHF BDA Systems can be moderate in cost while 700, 800 or 900 MHz tend to be lower in cost. This is due to the following factors- VHF does NOT have a logical and ordered CH plan; frequencies can be all over the board.
UHF is moderate in cost due to an ordered CH plan, closer CH groupings, 5 MHz TX to RX spacing. Costs on UHF can **will more than DOUBLE** if both bands (450 & 460 MHz) are to be amplified or if stop bands decrease. The Uplink to Downlink Spacings are at least 30 MHz in the 700, 800 or 900 MHz which results in the complexity and cost being lower; this can change upwardly, for example, if 700 & 800 MHz are required in the system.

13. Combining Cellular/PCS with Land-Mobile Public Safety Systems is **generally NOT** a good practice due to interference and propagation differences. It can be done but there will be disparities of coverage and systems bandwidth/capacity that could compromise mission critical communications. LTE will add to the quandary and exacerbate the issues.

14. Co-location of the BTS (base stations and/or repeaters) with the In-Building System/DAS can be done. Customized combining to “Front End” the DAS is available based on traditional combining system methods. As these applications are typically for In-Building, On-Site & Local area coverage, an EMR Corp. SYS Compact Combining System may be an ideal solution; conventional combining systems may also be required depending on frequencies, power levels, and site characterization. More on this approach follows in this paper.

15. A bidirectional system **requires repeater pairs** to prevent oscillation between the uplink and downlink branch.

16. It is important that the jurisdiction/agency understands the ramifications of what they are requesting and then be shown a **compromise to something that is more reasonable**. For example, if they just enhanced the 151/159 MHz repeater pair, it’s an uncomplicated system at a lowest cost.

17. Generally, VHF Simplex channels cannot be enhanced through use of a bidirectional system. However, there have been some developments towards accomplishing this objective. The options for the simplex channels- **Amplify in either the uplink OR the downlink direction. Alternatively, run separate uplink and downlink DAS using UDA’s- Unidirectional Amplifiers.** This solution is not a box that prevents oscillation but two boxes that have to be sufficiently physically isolated at each antenna in the DAS and elsewhere to prevent oscillation. **This scheme is heavily reliant on the experience of the installer, a great deal of testing during installation, and manipulation of the system to provide coverage without oscillation.** Normally, this is all handled in the BDA (bidirectional system) but must be done in separate boxes as UDA’s.

18. ERP of repeaters for calculating path loss between the donor LMR/Repeater site and building to be covered.

19. Distance between the repeaters and the building being covered.

20. **Signal levels on the roof of the building to be covered from the donor site** where the Yagi, Corner Reflector or Parabolic Antenna is placed.

21. To-scale layout prints of the building; Indicating on “marked-up” building “to scale” drawing prints the building, indicating where coverage inside the building is needed. You may use a scale to show signal coverage- rate from a level of 0 to 5 with 0 being non-existent and 5 being strong signal.

22. Identifying **specific locations in the structure that are considered crucial** will greatly aid system design and engineering.

23. Being aware of any city/county/federal regulations that require minimum RF coverage for first responders and having a copy of the pertinent specification will help the Systems Engineer know what must be provided. Any building code requirements for signal level, system qualification; IFC or NFPA Annex O for compliance.

24. Review any local building code requirements in place for plenum-rated cables as some fire codes may also **specify fire-retardant cable.**

25. Location of roof mounted “Yagi, Corner Reflector or Parabolic” Antenna

26. Location of BDA in the building; telephone closet, equipment room, etc.

27. Location of vertical chases within the building

28. Any requirements for alarm and monitoring of the system

29. Any requirements for UPS and battery backup of the system in the event of primary power failure
30. Primary power available 115 VAC?
31. If you need high gain (80 dB) due to off-air signal strength or link budget considerations due to long cable runs; alarm and monitor upgrade, UPS/battery backup upgrade could increase the cost.
32. Does Line of Sight (LOS) exist between the roof mounted directional antenna and the repeater site? This is crucial due to path fade margin considerations.
33. Define critical areas:
   a) Exit Pathways
   b) Stairwells
   c) Common areas
   d) Lobbies
   e) Areas of public gathering in an emergency
   f) Code compliance drawings noting coverage needs
   g) Fire and Pump Control Rooms
   h) Where ever the fire inspector wants
   i) Areas critical to life safety (caustic materials handling, dangerous manufacturing processes, etc)
   j) Areas of potential crimes requiring law enforcement coverage (banks, jewelry stores, etc)

11. Commissioning and live signal test
   a) AHJ may dictate testing procedure
   b) If not, commission the BDA using manufacturers’ procedure
   c) Be sure to filter out unwanted signals
   d) Test the worst areas to verify before calling for inspection
   e) Inspector usually does the 20 grid test
   f) Only one can fail and that gives you 95% coverage
   g) They can stand anywhere within that grid space (see graph below in NFPA regulation)

12. Cost Considerations

2,9 When a need for in-building coverage is uncovered, invariably the topic of cost will come up and will become a big factor in system design. A plethora of variables will affect system cost, starting with the complexity of the design.

The following represent some of the issues that must be considered; there may be more.

1. Vertical risers for penetrating floors add labor cost.
2. Avoid using horizontal offset cable runs when going floor to floor.
3. Plenum-rated cables will greatly increase material costs.
4. Multiple bands and services can greatly increase installation cost.
5. Cost breakdown typically will be 1/3 for equipment and 2/3 for installation and systems optimization.
6. Costs can range from $0.30 to $5.00 per square foot, or more. For example, a 100,000-square foot building that is essentially open manufacturing or warehousing with few walls and partitions, and which achieves amplification using a single UHF frequency pair could cost $30,000. In contrast, a 400,000 square-foot office complex with multiple bands and services may cost $1 million or more.
7. Larger systems for airports, shopping malls, hospitals and entertainment venues are among the costliest installations.
8. Multi-building campuses such as hospitals, colleges, universities and military installations, etc. require much more planning and design before price can be established.
13. In-Building Design Thumbnail

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<th>BDA/DAS IN-Building Systems Design Thumbnail- TABLE A</th>
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<td>These figures originate from some base numbers and typical situations. A Signal Level of -65 dBm at BDA is simply a rule of thumb.</td>
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<tr>
<td>2. 10 MILES Typ MAX RADIO RANGE- The furthest a site will &quot;typically&quot; be from the repeaters is on the order of 20 miles for Public Safety &amp; LMR Systems.</td>
</tr>
<tr>
<td>3. 80 dB GAIN- BDA System Gain typically about 80 dB; 60 dB gain is ~5 dBm to/from the BDA.</td>
</tr>
<tr>
<td>4. CABLE- Used is 1/2&quot; (LMR600); loss is ~3 dB per 100' at 800 MHz. LMR400 is ~3.75 dB per 100' at these frequencies.</td>
</tr>
<tr>
<td>5. 700/800/900 MHz Systems are HIGHEST LOS- Use of 800 MHz as the baseline as signal loss is greater through the cable at 800 MHz.</td>
</tr>
<tr>
<td>6. EFFECTIVE RADIATED POWER- 100 watts ERP - 20 miles, LOS, so signal to the BDA once 72 dBm. 10 dB gain antenna = 42 dBm. 100' of 1/2&quot; cable to antenna- BDA-65 dB at the BDA.</td>
</tr>
<tr>
<td>7. BUILDING SIZE- 75,000 square feet on two floors- building that’s about 194 x 194’ = four antennas per floor. Cable loss &amp; splitter loss from the BDA to the “furthest” antennas is about 16 dB.</td>
</tr>
<tr>
<td>8. INDOOR ANTENNA RANGE- to portable radius 75' of any antenna worst case. Free space path loss would be on the order of 55 dB.</td>
</tr>
<tr>
<td>9. OTHER LOSSES- Material, multi-path, body (greatest at VHF) poor antenna performance, low battery, etc. reduces downlink signal to -76 dB; + 10 dB body absorption =-86 dBm at the portable.</td>
</tr>
<tr>
<td>10. MATCHED UP &amp; DOWNLINK- Assuming portable is typically going to 14 dB down from the base station unit, for reciprocal signal path (line of sight exists) = -100 dBm to the repeater receiver.</td>
</tr>
<tr>
<td>11. LINK BUDGET- May require higher 80 dB gain offering; recommending a monopole or tower to get better height to achieve LOS, or strongly caution that a BDA may not be the solution.</td>
</tr>
<tr>
<td>12. NOTE: A bidirectional system works best when LOS exists back to the repeater</td>
</tr>
<tr>
<td>13. CONFIRM COVERAGE- Coverage is typically something that can be assured by Field Testing prior to installation of the BDA, UDA and/or DAS.</td>
</tr>
</tbody>
</table>

14. DAS Template for Collecting Data

6 We furnish the following templates for your VHF, UHF (illustrated below) or 700/800/900 MHz In-Building Systems applications. Send an email to sales@emrcorp.com to request the template.
## Uni- or Bi- Directional Signal Enhancement Systems

**Company:**

**Contact:**

**Address:**

**City / State / Country:**

**Phone:**

**Email(s):**

**EMR Global Quote #:**

**EMR Global ID:**

**System Block Attached:**

**List Value:**

**Net Value:**

**Direct and/or Distributor**

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### Co-Located

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<thead>
<tr>
<th>Co-located Freqs on this Page</th>
<th>Base to Donor</th>
<th>Donor to Base</th>
<th>Stop Band</th>
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<tbody>
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<td><strong>Y / N</strong></td>
<td>Down-Link</td>
<td>Up-Link</td>
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<td>1)</td>
<td>(Base Station to Portables – Repeater Tx)</td>
<td>(Portables to Base Station – Repeater Rx)</td>
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### Fiber Interconnect(s):

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<th>Fiber Interconnect(s)</th>
<th>to Doner:</th>
<th>DAS:</th>
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### Site Designation:

- Distributor

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### Base to Donor

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### Signal Path(s) and Strength:

- **Direct or Obstructions:**
- **Base to Donor Distance:**
- **If Not Known, Specify -65 dBm Min. on Quote**

### Enclosure:

- **NEMA-4**
- **Other NEMA**
- **Size:**
- **Rack/Cabinet/Free Standing**

### For a Building DAS Application

- **Desired location of BDA:**
- **Donor Antenna Location:**
- **Distance:**
- **Building Material:**
- **Cable/Coax to be used:**
- **Utility AC or DC Power:**
- **Square feet per Floor:**

### For a Restricted or Tunnel DAS Application

- **Desired BDA Location:**
- **Cable/Coax to be used:**
- **Utility AC or DC Power:**
- **Obstruction(s):**

### City, County or State Codes or requirements

- **NFPA Exceptions:**
- **Back-Up Power/UPS:**
- **Hours:**

---

**EMR Corp.**

17431 N. 25th Avenue
Phoenix, AZ 85023 USA

**www.emr.com**

Tel: 623-581-2875; 1-800-796-2875
15. Key Steps for Engineering an Effective In-Building System

1. Complete the EMR DAS Information Template (request from: sales@emrcorp.com). Supply as much information as possible.
2. Identify signal levels (in dBm) at the outside pickup antenna location, typically on the roof.
3. Does LOS exist between the repeater and the donor site? If not, the system may not work reliably and consistently due to path fade considerations during the day.
4. Identify the transmitter output power and the distance to the donor site. (The FCC license should contain this information.)
5. Determine whether any barriers exist between the transmitter antenna and the site (e.g., buildings, structures, hills, or mountains).
6. Provide building diagrams and layouts that are "marked-up" with current and desired signal levels, in dBm, at crucial In-Building Locations (i.e.: -85 dBm is typical)
7. Define the footprint of the building, particularly the number of floor(s) to be covered.
8. Identify construction materials used in the building (e.g., concrete/reinforced concrete, wood/plywood) and the type of window glass (reflected, mirrored, dual pane).
9. Advise if the BTS base station or repeaters are going to be co-located.

**TYPICAL BI-DIRECTIONAL ENHANCEMENT SYSTEM**

![Diagram of Bi-Directional Enhancement System]

*Diagram Courtesy of EMR Corp.*
16. Selective Filters are Essential in BDA Systems

17. BDA's & UDA's are DIGITAL Compatible

ANY DIGITAL Format- DMR, MOTOTRBO; P25; iDAS, NXDN; MPT-1327, TETRA (Analog, too.)

18. In-Building Systems may Require Emergency Back-Up

In-building systems designed for public safety and carrier operation may require emergency back-up power including the optical-to-RF converter rack, if Fiber-DAS is used, to assure uninterrupted interoperation. 12 hours of Emergency Power Back-Up is a common NFPA requirement; NOTE: the IFC Regulation specifies 24 hours.

19. In-Building Systems may Require Monitoring

If jurisdiction calls out that BDA must be compliant per NFPA Annex O- O.3.7 An automatic-monitoring system — with a dedicated panel in the emergency command center of the building — is required.

20. In-Building Solutions Installation

BDA or Bi-directional amplifier systems take signal from a donor site or tower and amplify that signal in the building. From a “Link Budget” perspective, your objective is to have sufficient gain to offset the loss once you go into the building. Overdriving signal causes potential damaging oscillations, or a “feedback loop” which is like holding a wireless microphone up to an active audio speaker...the screeching is very annoying until you remove the excess signal amplification or gain.

You will also have to identify the closest site if multiple sites are involved such as in a multi-site or simulcast system. In an example, the BDA (amp) is on the 7th floor of a building with a total of 10 stories of which 2 are below grade. Six levels are amplified. This configuration is odd since the first 100 ft of feed cable has only 2.4 DB loss. Signal is less on lower floors and may be non-existent in the basement. We'll be
assisting you in designing the system, with your very important input on signal levels, LOS back to the donor site along with signal levels outside the building along with the azimuthal heading so you correctly point the directional Yagi, Corner Reflector or Parabolic antenna toward the repeater/donor site.

You should have an idea of RF theory. The amp would most likely be placed on the 1st floor but could also be located in an available equipment closet or telephone room somewhere on a mid-floor in the structure.

Installation Issues to remember

1. Is a building permit required?
2. Do the plans require a Professional Engineer to review stamp?
3. File plans with Fire Marshall/AHJ
4. Check cable fire rating requirements
5. A set of construction plans that shows cable routing and component part numbers are useful to the installer.
6. CW Test First
   a) Connect signal generator to DAS input with level at calculated per channel power from BDA
   b) At each antenna check signal level with analyzer (e.g. at 8ft @800Mhz free space loss is 38.6dB)
   c) If projected output at each antenna is -10dBm, should be seeing -48.6 on spec-an, give or take a couple dB
   d) Check the signal strength in the farthest, most distant shielded locations, generally the stairwells. You should have at least -95 dB.

It is much easier to install antennas in drop ceilings than in solid ceilings. Having an equipment or telephone closet that is in line top to bottom facilitates installation. Observe the cable hole or raceway; will it accommodate the 1/2” cable that runs from the roof to the amp? When you test a building with incomplete walls being inside the elevator is always a good acid test. Metal does tend to impede RF, but 700/800/900/1800 MHz does sneak into cracks; standing near the elevator door opening may help.

NOTE: If you have readings in the high 90 dB level or are unsure, head for the elevator where signal will be shielded and lower strength. Stairwells are also difficult and require to be covered by fire codes.

Cable and Loss

1. LMR 600 or 1/2” cable is used for the feed from the rooftop mounted directional yagi, corner reflector or high gain parabolic antenna to the BDA, depending on link budget considerations.
2. The codes and plans will dictate the choice and size of cable. 1/2” inch cable loses 2.4 db at 800 MHz per 100 ft. 3db = 50% loss. LMR400 loss is 3.8 db per100 ft.

Testing Equipment Needs & Experience

1. Line sweeper for reflected power or checking connectors
2. Signal strength meter for 150-900 MHz; Most have wider bandwidth – Ref: Anritsu E-Series Spectrum Master™, Cell Master™, and Site Master™
3. Experience with coaxial cables, connectors; fiber-optic connectors, too. You must have proper crimp tools.

21. Typical In-Building System Hardware

As mentioned earlier, the correct filtering, combining, cross band coupling; antennas, splitters, line taps and amplification are all essential.

NOTES:

1. If NFPA Annex O- O.3.7 System monitoring is mandated, an automatic-monitoring system with a dedicated panel in the emergency command center of the building, is required.
2. A UPS- Uninterrupted Power Supply Battery Back-up may be mandated.
3. VHF, UHF, 700/800/900 MHz BDA & UDA offerings are available.
4. Custom Band Widths and Dual Band 700 & 800 MHz BDA & UDA's are offered.
5. Most EMR 800 MHz BDA's CAN BE RETUNED FOR REBANDING; CONTACT FACTORY.
6. Contact sales@emr.com with your project requests and for additional details.
7. Use our In-Building Systems Design Template to help configure your In-Building System.
22. Base Station or Repeater Co-location

The **SYS Compact Combining Solutions** for most LMR & PMR applications where high insertion loss is not a major system detriment. *Ideal for Base Station or Repeater Co-Location as a “Front-End” to an In-Building/DAS System.*

These offer the most practical approach to full duplex combining in mobile and base station applications. These are single antenna systems. Each model includes transmitter combiner, receiver multicoupler and antenna duplexer.

The systems are delivered ready for operation with no on-site tuning or adjustment needed.

The SYS is available as 25 Watt (SYS-25), 50 Watt (SYS-50) & 100 (SYS-100) Watt versions. By using hybrid/ferrite technology a greater variety of difficult to combine frequencies can be used in the same compact system. Standard components provide economical products with reliable, uniform performance and quick delivery times. The limitations to the SYS approach are where frequencies must be within a 1 MHz pass band and have a 4 MHz stop band. The pass band is 600 Khz with a 4.6 MHz stop band if 100 Watt input is required.

Contact the factory for systems in different frequency bands, with narrowed or expanded filter bandwidths and complex specialized combining.

**Product Features**

Available for up to 100 W Power Applications: VHF, UHF, 700 & 800 MHz

Up to 8 CH: For 25 W, 5 CH for 50 &-100 W; VHF or UHF; Adjacent Channel Possible. Even 6.25 KHz Spacing!

Suited for In-Building Systems; On-Site and Local Area: Industrial Applications for local area coverage.

Compact Size: Starting at only 3 RU Height.

Full Duplex: Ideal for Digital RF Repeater Systems including: P25, iDAS, MOTOTRBO, DMR, NXDN; MPT-1327, TETRA.

**Reduced Cost**

Costs Less Than $1,700 List Per repeater pair (4 CH 25 W Full Duplex System)! Contact Factory for Details: sales@emr.com
23. Detailed DAS System Design Example

24. UHF BDA Example
26. **“The 50 Ohm Enigma”- for Leveraging RF Performance**

Here's where it gets interesting. You can **LEVERAGE** RF Performance by following some important practices to achieve an excellent impedance match.

The “RF Antenna Peripherals” of the wireless system are typically a relatively low cost systems element; perhaps only 1% or 2% of a system and rarely as much as 10% on a smaller base station system. They include: Amplifiers, Antenna, Transmission Line, Lightning Suppression Devices, Isolators, IM Panels, Combiners, Cross-band Couplers, Duplexers, RX Multicoupers; In-Building Systems/DAS, too. Yet, these items are often cavalierly treated and dismissed as being un-important in the overall scheme of the system...WRONG! We have repeatedly optimized, retuned, re-cabled, re-designed combining systems networks that have been provisioned as part of a larger system and with little concern about their operation within a larger network..."Cookie-Cutter" if you will. The OEM got a good deal on the package or summarily dismisses the implications of a well “Impedance Matched” RF network.

Some years ago, Bill Lieske, Sr., Founder of EMR Corp. wrote the White Paper “The 50 Ohm Enigma” which captures the essence and importance of impedance matching in an RF network. Common assumptions, even by those that claim to be in the know, are that the amplifier, antenna, transmission lines, isolators, IM panels, combiners, RX multicoupers, duplexers, etc. are designed to be 50 ohms so what’s the big deal? It is a big deal because every transition from one element to another is a “Critical Impedance Match” point and requires a critical length cable (ie: jumper between antenna and transmission line, etc.) to maximize RF energy transfer.

---

**Example 1:**

![Critical Impedance Match Points Diagram](Diagram)
Critical Impedance Match Points


Based on the mediocre coverage and in-building performance of typical cellular/PCS mobility networks, it appears that most widely deployed systems have never taken critical length cables; constant impedance configurations into consideration. By picking up an additional 6 dB of RX system return loss can have perceptible improvements in systems range, in-building coverage; perhaps even fewer base station sites or simulcast stations which could reduce capital outlay and recurring costs. Imagine how much improved In-Building Coverage could be realized with a precise impedance match!

27. 4.6 NFPA & IFC Regulation Information

4 NFPA ANNEX O

O.3.1 General: The document requires that the BDA operate without causing interference to other parts of the public-safety radio system and that technologies be employed that are compatible with the public-safety radio system. Most BDA’s employ an over-the-air broadband BDA at the donor antenna. These devices are notorious for causing harmful interference, especially if there is poor isolation between donor and coverage antennas (there should be 15 dB more decoupling than the BDA system gain minimum). Annex O envisions a permitting process whereby the system design must be submitted to the authority having jurisdiction (AHJ) for approval before it can be installed.

O.3.2 Radio coverage: Two types of building areas are defined: critical areas and general building areas. Critical areas include emergency command centers, fire pump rooms, exit stairs, exit passageways, elevator lobbies, standpipe cabinets and other areas deemed critical by the AHJ. Critical areas must have 99% coverage, while general building areas must have 90% coverage.

O.3.3 Signal strength: Minimum inbound and outbound signal strengths of -95 dBm are required. Note that a typical 12.5 kHz FM radio will operate satisfactorily at -102 dBm in multipath fading. When measuring signal strength at the repeater site, the gain of any amplifiers between the antenna and receiver must be used to translate the -95 dBm threshold to an equivalent carrier-to-noise ratio at the receiver.

Although not stated in the document, we must presume a building that meets the requirements of O.3.2 and O.3.3, without enhancement, does not require a BDA. Similarly, enhancements only should be required on floors or in areas that do not meet radio-coverage requirements.

O.3.4 System frequencies: The BDA must be capable of retransmitting all relevant public-safety frequencies, and these frequencies are to be provided by the public-safety agency through the AHJ.

O.3.5 System components: Signal boosters, including BDAs, shall have FCC type acceptance and must be operated in accordance with commission rules (for example, see CFR Title 47, Part 90.219, Use of Signal Boosters).

O.3.6 Power supplies: A building on fire likely will lose its prime power source, so a strict standard for secondary power is necessary. Annex O requires either 12-hour battery backup for the RES, or an automatic-starting generator and storage batteries dedicated to the generator capable of at least two hours of operation at 100% capacity. (As many of our readers can attest, generators sometimes fail to start automatically and require manual intervention.)

O.3.7 System monitoring: An automatic-monitoring system — with a dedicated panel in the emergency command center of the building — is required. The system must signal an alarm in the event of an antenna malfunction or signal-booster failure. Power supply systems must, at a minimum, signal an alarm when AC power is lost, when the battery charger fails and when the battery has a low charge (defined as 70% of capacity).
O.3.9 Testing: There are three types of testing specified in the document ref: System commissioning testing (performed by the building owner) Acceptance testing (under the supervision of the AHJ) and Annual testing.

510 IFC

SECTION 510 EMERGENCY RESPONDER RADIO COVERAGE

510.1 Emergency responder radio coverage in new buildings.
All new buildings shall have approved radio coverage for emergency responders within the building based upon the existing coverage levels of the public safety communication systems of the jurisdiction at the exterior of the building. This section shall not require improvement of the existing public safety communication systems.

Exceptions:

1. Where approved by the building official and the fire code official, a wired communication system in accordance with Section 907.2.13.2 shall be permitted to be installed or maintained in lieu of an approved radio coverage system.
2. Where it is determined by the fire code official that the radio coverage system is not needed.
3. In facilities where emergency responder radio coverage is required and such systems, components or equipment required could have a negative impact on the normal operations of that facility, the fire code official shall have the authority to accept an automatically activated emergency responder radio coverage system.

510.2 Emergency responder radio coverage in existing buildings.
Existing buildings shall be provided with approved radio coverage for emergency responders as required in Chapter 11.

510.3 Permit required.
A construction permit for the installation of or modification to emergency responder radio coverage systems and related equipment is required as specified in Section 105.7.5. Maintenance performed in accordance with this code is not considered a modification and does not require a permit.

510.4 Technical requirements.
Systems, components, and equipment required to provide emergency responder radio coverage system shall comply with Sections 511.4.1 through 511.4.2.5.

510.4.1 Radio signal strength.
The building shall be considered to have acceptable emergency responder radio coverage when signal strength measurements in 95 percent of all areas on each floor of the building meet the signal strength requirements in Sections 510.4.1.1 and 510.4.1.2.

510.4.1.1 Minimum signal strength into the building.
A minimum signal strength of -95 dBm shall be receivable within the building.

510.4.1.2 Minimum signal strength out of the building.
A minimum signal strength of -95 dBm shall be received by the agency’s radio system when transmitted from within the building.

510.4.2 System design.
The emergency responder radio coverage system shall be designed in accordance with Sections 510.4.2.1 through 510.4.2.5.

510.4.2.1 Amplification systems allowed.
Buildings and structures which cannot support the required level of radio coverage shall be equipped with a radiating cable system, a distributed antenna system with Federal Communications Commission (FCC)-certified signal boosters, or other system approved by the fire code official in order to achieve the required adequate radio coverage.

510.4.2.2 Technical criteria.
The fire code official shall maintain a document providing the specific technical information and requirements for the emergency responder radio coverage system. This document shall contain, but not be limited to, the various frequencies required, the location
2. Signal boosters shall be tested to ensure that the gain is the same as it was upon initial installation and acceptance.

1. In-building coverage test as described in Section 510.5.4. Following:

510.6.1 Testing and proof of compliance.

The emergency responder radio coverage system shall be inspected and tested annually or whenever structural changes occur that could materially change the original field performance tests. Testing shall consist of the following:

1. Each floor of the building shall be divided into a grid of 20 approximately equal test areas.

2. The test shall be conducted using a calibrated portable radio of the latest brand and model used by the agency talking through the agency’s radio communications system.

3. Failure of a maximum of two nonadjacent test areas shall not result in failure of the test.

4. In the event that three of the test areas fail the test, in order to be more statistically accurate, the floor shall be permitted to be divided into 40 equal test areas. Failure of a maximum of four nonadjacent test areas shall not result in failure of the test. If the system fails the 40-area test, the system shall be altered to meet the 90 percent coverage requirement.

5. A test location approximately in the center of each test area shall be selected for the test, with the radio enabled to verify two-way communications to and from the outside of the building through the public agency's radio communications system. Once the test location has been selected, that location shall represent the entire test area. Failure in the selected test location shall be considered failure of that test area. Additional test locations shall not be permitted.

6. The gain values of all amplifiers shall be measured and the test measurement results shall be kept on file with the manufacturer of the equipment being installed.

510.4.2.4 Signal booster requirements.

If used, signal boosters shall meet the following requirements:

1. All signal booster components shall be contained in a National Electrical Manufacturer’s Association (NEMA) 4-type waterproof cabinet.

2. Battery systems used for the emergency power source shall be contained in a NEMA 4-type waterproof cabinet.

3. The signal booster system and battery system shall be electrically supervised and monitored by a supervisory service, or when approved by the fire code official, shall sound an audible signal at a constantly attended location.

4. Equipment shall have FCC certification prior to installation.

510.4.2.5 Additional frequencies and change of frequencies.

The emergency responder radio coverage system shall be capable of modification or expansion in the event frequency changes are required by the FCC or additional frequencies are made available by the FCC.

510.5 Installation requirements.

The installation of the public safety radio coverage system shall be in accordance with Sections 510.5.1 through 510.5.5.

510.5.1 Approval prior to installation.

Amplification systems capable of operating on frequencies licensed to any public safety agency by the FCC shall not be installed without prior coordination and approval of the fire code official.

510.5.2 Minimum qualifications of personnel.

The minimum qualifications of the system designer and lead installation personnel shall include:

1. A valid FCC-issued general radio operators license; and

2. Certification of in-building system training issued by a nationally recognized organization, school or a certificate issued by the manufacturer of the equipment being installed.

These qualifications shall not be required where demonstration of adequate skills and experience satisfactory to the fire code official is provided.

510.5.3 Acceptance test procedure.

When an emergency responder radio coverage system is required, and upon completion of installation, the building owner shall have the radio system tested to ensure that two-way coverage on each floor of the building is a minimum of 90 percent. The test procedure shall be conducted as follows:

1. Each floor of the building shall be divided into a grid of 20 approximately equal test areas.

2. The test shall be conducted using a calibrated portable radio of the latest brand and model used by the agency talking through the agency’s radio communications system.

3. Failure of a maximum of two nonadjacent test areas shall not result in failure of the test.

4. In the event that three of the test areas fail the test, in order to be more statistically accurate, the floor shall be permitted to be divided into 40 equal test areas. Failure of a maximum of four nonadjacent test areas shall not result in failure of the test. If the system fails the 40-area test, the system shall be altered to meet the 90 percent coverage requirement.

5. A test location approximately in the center of each test area shall be selected for the test, with the radio enabled to verify two-way communications to and from the outside of the building through the public agency's radio communications system. Once the test location has been selected, that location shall represent the entire test area. Failure in the selected test location shall be considered failure of that test area. Additional test locations shall not be permitted.

6. The gain values of all amplifiers shall be measured and the test measurement results shall be kept on file with the building owner so that the measurements can be verified during annual tests. In the event that the measurement results become lost, the building owner shall be required to rerun the acceptance test to reestablish the gain values.

7. As part of the installation a spectrum analyzer or other suitable test equipment shall be utilized to ensure spurious oscillations are not being generated by the subject signal booster. This test shall be conducted at time of installation and subsequent annual inspections.

510.5.4 FCC compliance.

The emergency responder radio coverage system installation and components shall also comply with all applicable federal regulations including, but not limited to, FCC 47 CFR Part 90.219.

510.6 Maintenance.

The emergency responder radio coverage system shall be maintained operational at all times in accordance with Sections 510.6.1 through 510.6.3.

510.6.1 Testing and proof of compliance.

The emergency responder radio coverage system shall be inspected and tested annually or whenever structural changes occur including additions or remodels that could materially change the original field performance tests. Testing shall consist of the following:

1. In-building coverage test as described in Section 510.5.4.

2. Signal boosters shall be tested to ensure that the gain is the same as it was upon initial installation and acceptance.
3. Backup batteries and power supplies shall be tested under load of a period of one hour to verify that they will properly operate during an actual power outage. If within the 1-hour test period the battery exhibits symptoms of failure, the test shall be extended for additional 1-hour periods until the integrity of the battery can be determined.

4. All other active components shall be checked to verify operation within the manufacturer’s specifications.

5. At the conclusion of the testing, a report, which shall verify compliance with Section 510.5.4, shall be submitted to the fire code official.

**510.6.2 Additional frequencies.**
The building owner shall modify or expand the emergency responder radio coverage system at their expense in the event frequency changes are required by the FCC or additional frequencies are made available by the FCC. Prior approval of a public safety radio coverage system on previous frequencies does not exempt this section.

**510.6.3 Field testing.**
Agency personnel shall have the right to enter onto the property at any reasonable time to conduct field testing to verify the required level of radio coverage.

### 28. In-Building Class B Part 90 Booster Registration Information

EMR Corp. manufactures Class B Signal Boosters which must be registered with the FCC. The FCC developed this tool to allow the registration of Part 90 Class B signal boosters within the United States.

All Part 90 licensees and signal booster operators must register existing Part 90 Class B signal boosters with the Commission by November 1, 2014-2015 In addition, any new Class B signal booster installed after November 1, 2014 must be registered prior to operation. (See 90.219(d)(5)1 of the Commission’s rules).

Excerpted from FCC 13-21 Report and Order, Adopted: February 20, 2013

**Section 165.** The Wireless Telecommunications Bureau will perform outreach regarding this registration requirement, including releasing a Public Notice detailing the specifics of the registration process once it is available. We require licensees and signal booster operators to register existing Class B signal booster installations with the Commission by November 1, 2014. We believe this period will allow sufficient time for public outreach, website development, and regulatory approval of this process. After November 1, 2014, operation of an existing, unregistered Class B signal booster will be unauthorized and subject to enforcement action. We note that any new Class B signal booster installed after November 1, 2014 must be registered prior to operation. To encourage compliance with this new requirement, registration will be free of cost to the operator and/or licensee.

In addition, we ask signal booster manufacturers and Part 90 licensees to assist in informing all relevant parties of our new registration requirements.

**Section 166.** We do not require operators to register Class A signal boosters at this time.

The public can use this tool to discover Part 90 Class B signal boosters that exist in their region. Licensees can use this tool to determine if a registered Part 90 Class B signal booster is causing interference to their other signals. This is also a good tool for knowing the key contacts, telephone and email #s at the entities as the detail is provided.


If you don't already have a “FCC Registration Number (FRN)” # you can create one at: [https://apps.fcc.gov/coresWeb/publicHome.do](https://apps.fcc.gov/coresWeb/publicHome.do)

Perhaps your customer should do his own registration, or use the **EWA- Enterprise Wireless Alliance** [http://www.enterprisewireless.org/sites/default/files/forms/ewa_signal_booster_form.pdf](http://www.enterprisewireless.org/sites/default/files/forms/ewa_signal_booster_form.pdf) so they can best manage any changes or modifications/changes to same. You may also offer registration assistance as a “Value Added” service of your company or to your Maintenance Agreement- M/A Customers

We will be including details for same in our Combined Times NEWSLETTER, on our website, in our BDA Brochure, Manual and products. Kindly furnish this information to your customers for their compliance. Ref: DA-14-15A1.pdf FCC Booster Details 0114 Public Notice for your information.
The following warning label appears in our BDA Brochure and inside the cabinet of our BDA and UDA products.

29. Qualifications for Technicians & Installers

Regarding certifications, the ETA- Electronics Technician Association and others, provide the training (much of it self-guided) and certifications from Associate to full DAS Certification on In-Building Systems. The NFPA specification in general, regarding NFPA and IFC Compliance which is "optional" depending on the AHJ- Authority Having Jurisdiction", city, borough, locality or count as to whether these specifications be used.

Section J103.23 of the NFPA

Minimum Qualifications of Personnel

1. A valid FCC General Radio Operators License (see FCC 13-4- no longer required for Land-Mobile---only for High Power/Maritime) and has been replaced by third party testing as part the CET Exam which is offered by ETA, and

2. Certification of in-building systems training issued by a nationally recognized organization or school or a certificate issued by the manufacturer being installed.

Further stated is that "the agency (aka- AHJ- Authority having Jurisdiction) may waive these requirements upon successful demonstration of adequate skills and experience satisfactory to the fire code official". These are done to purge those that are not competent to do these installs/optimization but do add cost and complexity to be paid/absorbed by the contractor.

We would refer candidates for Associate, Competency, Certifications and exam testing that encompass everything from general knowledge to specific applications such as DAS certifications. Details on the FCC regulation and available DAS Program Certification are provided in the following links:

Ref: www.DASpedia.com Training scheduled for January 11th, 2016 at University of California, Irvine, CA Campus
Ref: www.emrcorp.com BDA School

30. EMR Corporation Background

EMR Corp. engineers, designs and manufactures RF Communications and Antenna Systems Peripherals for Two-Way,
31. Appendices- Sources

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14 www.anritsu.com for Indoor Mapping, Site Master Tools

Appendix B – References

9 http://www.hol4g.com/webinars/
10 www.abiresearch.com “In-Building Wireless Systems Will Reach 500,000+ Buildings By 2013”
14 www.anritsu.com for Indoor Mapping, Site Master Tools

This solutions white paper was prepared in part, too, without the use of references, in some instances.

We would like to acknowledge and thank the consultants and In-Building Specialists for their important contributions to this solutions white paper. There is much information about the In-Building and Co-located Systems and their implications for the wireless industry that must be communicated in an impartial and complete manner. This paper is intended to capture the importance of a very essential subset- the RF Antenna Systems Peripherals that done properly can maximize performance. These are an inexpensive part of the overall system that can profoundly impact how the entire system operates if not configured properly. Hopefully this can become the blueprint for constructing excellent In-Building Solutions Systems in the future.
32. Addendum- LED RF Interference

Dave Dunford, RF Consultant, Kansas City, KS provided details on a topic I cited briefly above. According to Dave: “I’ve been working with the folks in Boone County, MO on their VHF high band public safety two-way radio system and we’ve recently run into an interesting technical snag. Last fall we began receiving reports of “no coverage” inside one of the new Zaxby’s restaurants in town. Traveling to the site we were able to identify that the background broadband RF noise was about 20 dB higher inside the building than outside. We began looking for electrical system issues but the facility cooked with gas and there was no heating or air conditioning in operation. Glazing was not suspect and cell/PCS phones worked fine inside. We couldn’t identify the problem, but did verify the effect”.

“Recently, we received a similar complaint, again “the radios don’t work” this time inside Panchero’s Mexican Restaurant on the west side of town. Again, we verified that the report was accurate – portables would talk out of the building but could not receive signals from the simulcast base station network. However, we did discover that the problem only manifested itself when the interior building lights were turned on. We contacted the manager who was very helpful and readily agreed to our conducting some on-site testing. We devised a simple RF probe setup which was a 6” VHF flexible portable radio antenna (BNC connector) linked by a run of RG-58 cable to our spectrum analyzer”.

“As it turns out, the restaurant uses two versions of LED lamps. There are overhead track lights with a series of pre-focused lamps and there are pendant lights, each fitted with a more spherical, globe shaped lamp. Please see photo of restaurant interior attached. We quickly discovered that the track lights produce no observable RF radiation. These are the GE lamps described as follows: 500 lumen output, model LED 10DP305830/20. We just as quickly discovered that the lamps inside the pendant lights are significant RF interference radiators. These are TCP PRO LED dim-able A-19 lamps”.

Here is a link to these lamps:


I’ve attached a photo of a sample TCP lamp that is causing the interference. As can be seen, I believe they have even stamped it with the “FCC” approval logo (these can be bogus fakes from offshore or domestic sources).
“Please find attached two photos of spectrum analyzer displays. Horizontal scale is 10 MHz per division. The first Figure A labeled 2015 BOONE BASEBAND is exactly that – building lights off, reading taken inside the dining area. The analyzer is centered on 155.310 MHz which is our ‘Main Boone County Law’ talk-out frequency. Throughout the building we were seeing levels on our test probe of -80 to -84 dBm when the 155.310 MHz transmitter was keyed which would normally yield a solid received signal. However, when the interior lights were turned on, there was a considerable rise in the background RF noise.

In the second photo, Figure B, Broadband noise Levels of -70 to -72 dBm were readily observed. Please refer to illustration where the influence on about anything RF from 90 MHz up through about 190 MHz is devastating (Aviation, Amateur, Public Safety, NOAA/NWS, Federal Government & Business Enterprise Bands). We conducted some additional testing and it appears that this RF interference occurs most intensely below about 220 MHz. UHF 450-470 MHz UHF and cell/PCS service do not appear affected.

Figure A...2015 BOONE BASEBAND

Figure B...2015 BOONE LED INTERFERENCE
“One possible solution would be to increase system talk out signal strength by 10-15 dB in an effort to overcome the interference by brute force, but then our signals would probably also be strong enough to cover the state of Missouri! Alternately, we could publicly announce (and decry) the particular brand and model of “interfering” lamps – which could well have opposite the desired effect: criminals would want light bulbs that disrupt police radios!”

Dave asked for advice from the FCC on how to proceed mitigating this problem. Overarching concerns are that (1) there are plenty more of these type devices out there, (2) the established testing protocols may not be discover this RF emission problem and (3) unscrupulous importers/vendors may be ignoring this aspect of their products and cloak themselves in the “green-ness” of LED lighting. THIS A growing CONCERN!
EMR Corporation

Class B Signal Booster School
Chapter I

by: Douglas B. Ferrini
VP Systems Engineering
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EMR Corp Class B Signal Booster School- Chapter I

1. Bidirectional (BDA) Broadband Repeater Basics

A BDA is a device used to improve portable or mobile radio communications into areas which are otherwise shaded from the fixed repeater(s) and have either poor or no coverage due to distance, building materials, terrain shielding, or other problems resulting in attenuation of the desired RF signal to-and/or-from the repeater.

The use of two-way amplifiers requires that the base or repeater station be full duplex or half-duplexed, and that the separation between the repeater transmit and receive frequencies be sufficient to achieve high enough isolation to prevent oscillation between the repeater amplifier branches.

Non-Heterodyne, or Broadband Repeater Amplifiers are ones that utilizes linear amplifiers with Uplink (UL) and Downlink (DL) filters that restrict pass bandwidth to some specified frequency range. No frequency conversion processes are involved in the BDA's operation. Filter pass bandwidth can range from 75 KHz to several MHz. Non-heterodyne amplifiers are less complex and expensive than heterodyne repeater amplifiers (channelized BDA's); providing a cost-effective solution to communication problems.

2. Two Way Repeater Detail

*Figure 1: Non-Heterodyne two way repeater amplifier system flow diagram.*

Broadband repeater amplifiers typically consist of the following basic elements:

1. Linear amplifiers which provide the RF gain and output power
2. Power control or Gain control circuitry
3. UL and DL filters
4. Power supply
5. A rack, cabinet, or enclosure
Typical options include

i) Battery backup
   1. 12 Hour
   2. 24 Hour

j) Alarm and monitoring
   1. Modem
   2. SNMP
   3. NFPA72

k) Red Paint

**Linear Amplifiers**
Required for their ability to amplify signals without creating output distortion products. This is a primary consideration in non-heterodyne repeater amplifier systems because of the need to amplify multiple signals on different frequencies. This makes Class-A linear amplifiers a natural choice for this kind of service due to their excellent linearity and predictable behavior. Typical linear amplifiers used in BDA's have an average gain of 20 dB per stage and will have 3 to 5 amplification stages.

Understanding the difference between power and gain in a bidirectional system can be difficult. While a BDA may be capable of 5 watts out of the amplifier the actual power output is a function of the input signal level, the number of carriers, the amplifiers power control limits, the PA input and output filter losses, and the gain of the amplifier. In most BDA applications it is rare for the DL or UL signals to drive the PA into power control.

-50 dBm of signal to the donor antenna from the repeaters is about average. With a 65 dB gain BDA, a single RF carrier would exit the BDA system at +15 dBm; which is far below the 5 watts that the PA is capable.

**Gain Control**
Amplifier gain requirements will vary from one application to another. The BDA gain is set and fixed when shipped from the factory and is determined either by the system design or as indicated by the customer. The gain listed in the BDA specifications represents the sum of all the individual stage gains in each branch, minus the input and output filter losses. Depending on the model, the gain can be reduced by means of the PIN diode attenuator on the driver amplifier, by means of fixed RF attenuators, or by variable attenuators. The gain can be further reduced at the factory, if necessary, by bypassing low-level stages.

Power control is required and included in every EMR BDA but output power per carrier must be kept below a specified maximum (0 dBm) as the Power control circuitry has a maximum 30 dB dynamic range and if exceeded will result in damage to the PA.

**Filters**
In one-way (Unidirectional (UDA)) systems, input filters reject undesired signals in order to minimize the potential for interference and minimize the spectrum amplified by the PA. UDA output filters attenuate spurious out-of-band amplifier noise.
In two-way BDA systems, the input and output filters in adjacent amplifier branches provide sufficient selectivity, attenuation, and cross-over depth in order to insure stability between the UL and DL amplifiers. To assist with a mental visualization of a Broadband or Channelized BDA filter scheme, we can liken them to two duplexers and two amplifiers. Now, the reality is, this is a very simple means to illustrate the basic electrical flow that occurs within a bidirectional signal booster. The reality is that the BDA's filter scheme must be far more complex and take into account more demanding performance than that of a simple duplexer. A BDA's filters must capable of preventing oscillation due to the high gains associated with the BDA's UL and DL amplifiers.

Often, the frequencies that are to be supported by the BDA require more than two branches. Stable operation of the amplifiers can only be achieved with filter designs that provide sufficient isolation between all possible branch pairs. In this filter scheme it may help to visualize the BDA as being a combiner a multicoupler which are then duplexed to a common port. This latter is often used in VHF and UHF BDA's because of the repeater frequencies that are required to be supported having interleaved repeater TX and RX frequencies.

In both of the BDA filter schemes discussed above, ordinary notch or pseudo-bandpass (pass/notch) duplexers are not suitable for repeater amplifier applications as they provide high isolation at narrow frequency ranges and result in flyback. Flyback results in too little isolation which will then result in oscillation between the UL and DL amplifiers. The predominant filter response characteristic in a BDA must, therefore, be band pass in nature.

The BDA filter design can be comprised of one, or a combination, of different filter types and design combinations. The BDA filter design chosen will depend on the frequency range, frequency separation, bandwidth, and gain of the required amplifier branches. Quarter wave cavities, hog out filters, helical resonators, SAW filters, crystal filters, and combline filters are all within the purview of the BDA design engineer.

**Power Supplies**
BDA's are equipped with an internal AC power supply and DC regulator or converter to provide 12 VDC bias voltage to the BDA amplifiers. Mission critical, life safety communications supported by the BDA's mean that careful attention was paid to selecting the most reliable method of supplying power to the BDA. Due to mission-critical, life safety concerns, BDA power supplies have transient suppression at the AC input, current foldback and overvoltage protection, and many BDA's are supplied with an upgrade to include batteries on a float charge to maintain communications in the event of primary power failure.

DC-to-DC switching converters may be supplied on request for applications where an uninterruptible DC supply of some kind is already available. 12 to 48 VDC input voltages can be accommodated.

In applications where multiple bidirectional systems are utilized to implement coverage, for example in a tunnel, DC bias voltage can be supplied through the coaxial cable. Iso-tees are
required at each BDA to keep DC and RF isolated while maintaining sufficient input-to-output RF isolation. This is not a viable approach in systems where several BDA amplifiers require several amperes of current. Also consider that lengthy cable segments will result in large DC voltage drops which can require higher voltage to the cable input.

**Enclosures**
Standard BDA’s are housed in painted steel enclosures rated to NEMA 4X standards. Some BDA’s are so large that housing them in such enclosures can be cost prohibitive. In such cases BDA’s are configured for 19” EIA rack mount and housed in either a cabinet or open relay rack. High-quality, weatherproof cabinets with sealed heat sinks to prevent exposure of the equipment to environmental extremes are available upon request.

![Figure 2: Non-Heterodyne two way repeater amplifier system.](image-url)
3. Mandated Battery Backup

Depending on the Regulatory Environment, the Authority have Jurisdiction for the city, town, county, township, may mandate battery backup. EMR provide an optional 12 or 24 hour battery backup. The batteries and charger are housed in a separate NEMA 4 enclosure to prevent damage to the BDA in the event of catastrophic failure of the battery.

![Figure 3: 12 hour battery backup.](image)

4. Mandated Alarm and Monitoring

Depending on the Regulatory Environment, the Authority have Jurisdiction for the city, town, county, township, may mandate alarm and monitoring. Currently there are three monitoring upgrades available for monitoring of the BDA systems: modem, SNMP, and SNMP - NFPA72 fully compliant. Each of these monitoring options are microprocessor-controlled units capable of monitoring the Primary AC, Power Supply/Battery DC Voltage, and the DC Current for up to four RF amplifiers used in any EMR Signal Enhancement System. BDA monitoring features vary depending on the relevant hardware configuration. This documentation covers features which are common to most users.

**Product Features Modem and SNMP versions:**

1. Monitoring for up to four RF Power Amplifiers
2. Programmable using a web browser (SNMP version) or standard terminal program (modem version)
3. SNMP Trap (SNMP version)
4. User programmable alarm set points
5. 1 Relay Output Contact Closure
6. Auto Dialer and 9600 Baud Modem (modem version)
7. LED Status Indicators
8. Door Alarm
9. AC Alarm
10. IP/DNS Configuration (SNMP version)
11. E-mail notification for up to five address (SNMP version)
12. Web access (SNMP version)

System Requirements Modem and SNMP versions:
1. EMR Signal Enhancement Bi-Directional System
2. IBM compatible computer with Com Port (modem version)
3. HyperTerminal or similar communication software package (modem version)
4. Standard Serial Cable (modem version)
5. NIC card (SNMP version)
6. Web Browser (SNMP version)

SNMP - NFPA72 compliant
The Relay Output Port (J11) is a DB25 Male connector typically located on the bottom right panel of the BDA. A label of the pin-outs is also located inside of the door of the BDA. A DB25 Female connector (with hood hardware) is supplied with the unit for the Install Technician to connect to the Alarm Panel.

Note: Pin Numbers are written on the DB25 Connectors

There are 7 alarm relays available, these will supply contact closure (Supervisory Signal) to the fire alarm panel for the following alarm:
(1) AC Power Failure
(2) Signal Booster Failure
(3) Battery Charger Failure
(4) Low-battery capacity
(5) Power Supply Failure
(6) Antenna Malfunction
(7) Signal Booster Trouble

5. BDA Applications

Buildings:
Office buildings, schools (kindergarten through college campuses), casinos, jails, court houses, police stations, hospitals, water treatment facilities, manufacturing facilities, shopping malls, parking structures, power plants (nuclear, coal), hotels, apartments, condos, and golf courses. In effect any large building is a candidate especially those having floors which are below grade.

Buildings require a three-dimensional signal distribution system to provide coverage of multiple floors including open spaces, stairwells, corridors, and elevators. The high gain BDA provides the interface between the remotely located repeaters and the interior of the building. The Distributed Antenna System (DAS) deployed within the building to support the BDA will consist of multiple
branches routed through low loss coaxial cable and/or radiating cable and/or fiber optic cable via splitters or line taps which will, in turn, feed signal to a number of omni-directional antennas

**Tunnels:**
Tunnels are long, narrow underground or interior spaces.

Some examples include: Mine shafts and tunnels, railway and vehicular tunnels, underground passageways, maintenance and utility shafts, metros, and subways.

RF signals do not propagate well in narrow tunnels which are often comprised of high RF loss walls resulting in poor performance from a DAS supported with a number of omni-directional antennas. Instead, a DAS featuring radiating cable transmission line would be a better choice to better support uniform RF coverage inside such tunnels.

The basic configuration of a BDA in "tunnel" communication system requires the head-end amplifier installed, usually at one end of the tunnel, a high-gain directional antenna provides the air interface with an external repeater, a length of coaxial cable on both the source and distribution sides of the BDA, and a radiating coaxial cable carries the desired RF signals to-and-from the portable radios inside the tunnel. The far end of the cable is terminated with either a suitable omni-directional unity gain antenna or a 50-ohm RF load resistor to assure proper impedance matching.

The head-end amplifier boosts desired signals to insure there is sufficient signal strength to provide reliable communication over the radiating cable distribution system. Additional BDA boosters can be positioned along the radiating cable to overcome the high longitudinal loss of the radiating cable to support communications in very long tunnels.

**Shadowed Areas**
Shadowed areas which impede RF communications due to absorption or reflection from either terrain or man-made structures can be covered with a BDA using two antennas. A highly directional antenna links the BDA with the repeater. The other antenna, also directional, is aimed at and provides RF coverage to portables and mobiles within the shadowed area. To prevent amplifier instability due to input-to-output feedback, the two antennas must be carefully position to provide a minimum of 15 dB greater decoupling than there is system gain within the BDA amplifier. Stable, reliable antenna isolation in excess of 70 dB is very difficult to achieve limiting the system gain of a BDA to between 55 to 60 for this type of application. Accordingly, this implies that there be relatively short distances between the repeaters and the BDA amplifier site, between the BDA and the shadowed area, and that Line of Sight (LOS) between the repeater and BDA antennas.
6. Real-World Applications

Typical applications will usually contain elements of two or even three of the above listed applications. Courthouses will have large open Court rooms best covered with discrete omni-directional antennas. The Courthouse is often connected to the jail through long underground passages which are better covered with a radiating cable DAS.

7. FCC Signal Booster Class Definitions

A BDA is currently classified by the FCC as either narrowband Class A (retransmit signals on one or more specific channels) or as broadband Class B (retransmit any signals within a wide frequency band). The FCC rules specifically limit a Class A (channelized) Signal Booster bandwidth to no more than 75 KHz.

The FCC also makes distinction between Industrial versus Consumer BDA’s. Signal enhancement products manufactured by EMR Corporation are Industrial Boosters.

Class B BDA’s

1. A signal booster that amplifies multiple channels with a bandwidth greater than 75 KHz and could be many megahertz wide.
2. Uses broadband amplifiers with common output power amplifiers.
3. Composite output power.
4. Automatic Gain Control.
5. Maximum 5 watts output power per channel.
6. Gain typically between 50 and 80 dB.
7. Very low digital group distortion and propagation delay, typically less than 5 microseconds.
8. Much lower cost per channel.
9. Must comply with Human RF Exposure limits. Rule of thumb is to limit ERP of any single in-building antenna to +28 dBm composite power.
10. Requires less power, making backup systems smaller and less costly.

8. Requirements for Class B BDA implementation

1. The FCC requires that non-licensees who seek to operate signal boosters must first obtain the consent of the licensee whose signals they intend to amplify. consent may be reflected, for example, by "a letter, email or other record sent from a licensee or agent of a licensee to an operator, owner, or installer of the Class B BDA acknowledging that the [Industrial Signal Booster] will retransmit the specified frequency bands of the licensee.
2. The FCC requires that both new and existing Class B signal boosters be registered through the FCC Signal Booster Registration website. www.fcc.gov/signal-boosters/registration. Unregistered Class B signal boosters after November 1, 2014 will be subject to FCC enforcement action.
3. The FCC prohibits a single Class B signal booster device from amplifying both commercial services (such as Cellular Carriers) and Part 90 Land Mobile and Public Safety Services. This does not apply to the DAS as it involves a level of design and implementation in order to address the needs of each service.

9. Effects of Multiple Channels Composite Power on Class B Signal Boosters

BDA's are used to amplify multiple channels within a given pass bandwidth. As a Class B signal booster the BDA's UL and DL passbands are wider than a single channel's modulation bandwidth and may be many channels wide.

The FCC rules do permit the amplification of both licensees, and others, within the passband of a Class B signal booster.

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 (Power Control) reduces the amplifier gain so the maximum output level of the PA is not exceeded resulting in damage to the amplifier. Power Control also assures that the out of band emissions are within the FCC limitation of -13 dBm.

Since the bandwidth of a Class B signal booster allows for amplification of more than one communications channel, the total power of all the channels together is referred to as "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. The end result of the feedback driven gain adjustment is that the output power per channel will vary in direct proportion to the input power per channel when operating at maximum composite output power.

Obviously, the more channels incident on a Class B Signal Booster, the less power out per channel. For example, it is reasonable to assume that 20 equal level carriers could occur in downtown Phoenix, so the coverage would be designed around a per carrier power level of 50 mW or +17 dBm. When there is less activity the coverage will improve.

Although the input filter's pass bandwidth may be wide enough to pass more than 20 channels, that is rarely the spectrum seen downstream of the BDA donor mounted on the roof of the building. A directional antenna reduces the level of undesired channels that are not in the main lobe of the antenna. A very strong signal within the pass band can dominate the amplifiers power and have the same effect as multiple undesired channels.

The most extreme cases may require the use of FCC Class A channelized signal boosters, which have their own inherent undesirable tradeoffs. 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. If the offending adjacent channel signal level is 40 dB greater than the desired channel level; this is the same as having two channels within the channelized signal booster 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 of signal booster leading to excessive IM products, out of band emissions, or even amplifier failure.

Note that donor antenna - to - DAS antenna isolation should be at least 15 dB greater than the gain of the Signal Booster to prevent system oscillation. The basic EMR BDA gain is typically 60 dB meaning there needs to be a minimum of 75 dB of decoupling between the roof mounted donor antenna and the interior DAS antennas.

10. 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 that fall within the BDA's operational pass bandwidth. The best place to insert the spectrum analyzer is after the downlink input filter providing an accurate representation of the input spectrum seen by the amplifier after the spectrum shaping provided by the input filters and the narrowed aperture of the directional antenna. It is 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.

11. Donor Antennas

Carefully choosing the donor antenna and mounting position can improve the desired channel levels and reduce the undesirable channel power levels. It cannot be said enough but, an antenna with high directivity and high front-to-back ratios should always be used. This includes locations where the benefits inherent in the gain of the antenna are not important because we are looking for the directivity and resulting narrowing of the antennas aperture.

A 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 understand that the noise floor will be different between mounting the antenna near street level versus that of the roof top of a multi-story building.

Many roof tops have elevator and HVAC rooms that may provide needed 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.

Placement of the BDA donor antenna in close proximity to other RF antennas is also something that needs to be avoided so as not to create any unnecessary intermod (IM) products in the antenna’s near field propagations.
12. Distributed Antenna Systems - DAS

The main focus so far has been on the BDA or head-end. The correct donor antenna also plays a significant role in the overall function of the installed BDA as does the Distributed Antenna System. Poor design, implementation, or installation of any one of these three system elements will result in poor system performance.

A DAS can be classified as either active or passive. An Active DAS is one which employs amplification of the UL and DL signals; the vast majority of deployed DAS are active systems. A passive DAS is a viable approach under the correct set of circumstances. A passive approach can be considered when the repeaters are located close to the building or underground space requiring coverage, and the area needing coverage requires very few antennas to support communications to portables within that space.

Coaxial DAS

Coaxial cable is the common approach used to enhance coverage to portables operating in buildings. In a coaxial DAS scheme coaxial cable is routed from floor-to-floor and throughout the building in support of several antennas located within the building.

Products used to implement a coaxial DAS:

1. Splitters. These can be 2 way, 3 way, or 4 way splitters. These are meant to split power equally to each port: 50%/50% for a 2 way, 33%/33%/33% for a 3 way, and 25%/25%/25%/25% for a 4 way.

2. Line taps. These can support splitting power unequally to 2 or more ports. From as much as 25%/75% to as little as 0.025%/99.975%.

3. Antennas. While there are instances where a high gain directional antenna could be a good choice, most applications will deploy omni directional antennas. EMR manufactures a 1/4 wave omni with a ground plane and a dipole antenna. The application and design will determine which is a better choice. Antennas need to be...
located below any metal: ducting, conduit, etc. Locate antennas to minimize the chance of damage.

4. Coaxial cable. Larger diameter cable will present lower longitudinal loss which can be an advantage. However, larger cable means high cost per lineal foot, wider bend radius, and more difficult to route through standpipes and conduit. 1/2” coaxial cable provides a good compromise between insertion loss, cost per foot, and ease of installation.

Other considerations when installing a coaxial DAS:
1. Building code. Cable runs through building plenums should utilize plenum rated cable.
2. Jumpers will be needed from the coaxial cable to antennas, splitters, donor antenna, and the BDA.
3. Concentrate cable runs and antenna locations to soft ceiling areas such as hallways.
4. Ideally locate the BDA head-end within 100’ of the donor antenna.

Radiating Cable DAS
Radiating cable is commonly used in applications that are typically long, with limited narrow coverage areas. Radiating cable DAS is similar in approach to a coaxial cable DAS and utilizes the same components to route signal throughout the desired coverage area. Typically, DAS designs incorporating radiating cable will have the portables operating within 10’ of the cable.

Considerations when installing a radiating cable DAS are similar to those of a coaxial DAS with a few added concerns.
1. Do not use radiating cable within 50’ of the BDA head-end system. The cable between the donor antenna and the BDA will be coaxial as will the first 50’ from the BDA to the DAS.
2. If boosters are used to extend coverage, the radiating cable needs to once again transition to double-shielded coaxial cable on either side of the booster.
3. Proper coverage from a radiating cable DAS does require that the cable be installed per the manufacturers specification; which usually leaves the cable about 2” from the wall or ceiling to which the cable is attached.
4. While it is acceptable to terminate the end of the radiating cable with a load termination. Using the available RF energy by means of an antenna, instead of converting RF energy to heat, makes more sense.
Fiber Optic Cable DAS

A Fiber Optic (FO) DAS is another viable means to implement a coverage solution. Typical applications where a fiber DAS would be considered are campus applications. Such applications have several buildings which are located within fairly close proximity and they already have "dark" fiber connecting each of these buildings. One building functions as the RF over-the-air repeater interface which then feeds these other buildings through the existing dark fiber. Again, many of the stem elements in a FO DAS are common to those of the coaxial DAS. An RF-FO DAS makes use of the following additional system elements.

1. FO transceiver head-end and remotes. These devices directly amplitude modulate the optical emitter with the RF frequency. Modules are available for using 2 FO cables, one UL and one DL, or a single FO cable where the UL is done at one wavelength, and the DL at a different wavelength. Typical FO transceivers are designed for a maximum RF level of 0 dBm in/out.

2. Fiber optic cable. Single mode fiber optic cable is suitable for RF applications. Multi-mode cable is not a viable choice for RF systems at this time.

3. Fixed or variable attenuators. Attenuators are required between the BDA head-end and the FO transceiver to set the gain levels so that the BDA does not damage the FO transceiver and conversely the FO transceiver does not damage the BDA.

4. FO connectors. Typical connectors used for RF FO applications are either FC-APC or SC-APC

13. Details needed to Design the BDA

The information listed is needed to determine whether a bidirectional system is a viable solution or if additional information is needed to determine what may need to be changed to make a BDA solution possible. Once it's determined that a BDA is viable, the information below will be instrumental in determining the head-end filter scheme, the gain required to implement coverage, and the optional upgrades required to meet the needs of the application.

1. Repeater transmit frequencies
2. Repeater receive frequencies
3. Location of sites where repeaters are located in relation to the building to be covered.
4. Repeater ERP
5. Distance between the repeater and the building to be covered
6. Signal level on the roof of the building to be covered
7. Loss = -36.6 - 20log (frequency MHz) - 20 log (distance in miles)
8. Gain of the BDA required to implement coverage, provided by customer, or from the DAS design.
9. Knowledge of local building code requirements which the BDA and DAS must meet.
10. Nearby, in band repeater transmitters that are within 20 dB of the signal level of the desired repeater transmit frequencies.
11. Gain of the directional antenna to be used in dBi.
14. Details Needed to Design the DAS

1. Cable to be used for the application. Often determined during the DAS design.
2. pdf of the building to be covered by the BDA and DAS.
3. Distances specified on the drawing to determine an accurate scale.
4. The pdf should show where hallways and passageways are located.
5. Note where the BDA head-end is to be located within the building.
7. Building materials used in the construction of the building and walls.
8. Knowledge of special rooms within the building requiring special care; such as radiology units in a hospital.
9. Make note of any metallic backing on ceiling tiles, wall paper, or plaster board.
10. Note areas within the building that do not require coverage.

15. Commissioning the System

Many applications require that the system undergo compliance testing as the installed BDA system and DAS represent a significant investment. Even if not required base line system readings should still be taken. Doing so will make future trouble shooting of the system easier as well as aiding in redesign of the DAS due to building remodeling or expansion.

The ideal of 100% coverage and 100% reliability is not practical economically and almost impossible to achieve. It is appropriate to use minimum signal level values similar to what is acceptable for outside coverage. Most ordinances set RF signal levels near -95 dBm, which is sufficient to approach 95% reliability.

There are two types of coverage measurements when evaluating in-building systems Delivered Audio Quality (DAQ) and Signal Strength Test (SST).

While many agencies consider DAQ as a suitable for acceptance testing it is a subjective performance test. DAQ definitions follow:

1) Unusable, speech present but unreadable.
2) Understandable with considerable effort. Frequent repetition due to noise/distortion.
3) Speech understandable with slight effort. Occasional repetition required due to noise/distortion.
3.5) Speech understandable with repetition only rarely required. Some noise/distortion.
4) Speech easily understood. Occasional noise/distortion.
4.5) Speech easily understood. Infrequency of noise/distortion.
5) Speech easily understood.

16. RF Coverage Confirmation

RF coverage based on RF signal strength measurements provides an accurate, statistically valid, repeatable, objective, and cost-effective method to verify that user coverage requirements are met by the installed BDA and DAS. To conduct DL testing, the wireless test equipment should consist of a single antenna mounted to a handcart 3 - 4 feet in height. This is a suitable simulation of a portable radio carried at the hip. A suitable Spectrum Analyzer, Network Analyzer, SSI, or other
suitable, calibrated test equipment capable of accurately reading signal strength to \(-100\) \(\text{dBm}\) or less. To conduct uplink testing, a signal strength measurement can be taken from an unused receiver multicoupler port, or by means of a directional coupler or "tap" at the receive port.

Many agencies already employ a suitable testing procedure for acceptance testing within the area covered by the BDA and DAS. The following is representative of what may already be in place however, in the event there is no established requirement it would be advisable to adopt something similar for base line testing of the installed system.

Each floor of the building shall be divided into a grid of approximately 20 equal areas. A maximum of 1 of these 20 equal areas will be allowed to fail the test. In the event that two of the areas fail the test, the floor will then be divided into 40 equal areas. Now, a maximum of 2 of the 40 equal areas will be allowed to fail the test. After the 40-area test, if the system continues to fail, it will require the BDA or DAS to be altered to meet the 95% coverage requirement. The test should be conducted using an agency approved calibrated portable talking through the agencies radio communications system as specified by the agency.

The BDA UL and DL system gains should also be verified against the factory data and then documented. Drive the port labeled "Source" on the BDA with the frequencies from the repeater transmit with a maximum signal strength of \(-50\) \(\text{dBm}\). Read the signal strength from the port labeled "Distribution" and the gain should match the Data Specification Sheet sent with the BDA. Then, drive the port labeled "Distribution" on the BDA with the frequencies from the repeater receive with a maximum signal strength of \(-50\) \(\text{dBm}\) and read the signal strength from the port labeled "Source".

17. Maintenance

The BDA should be checked annually to verify operation of all active components of the in-building radio system, including but not limited to amplifiers, power supplies, and back-up batteries.

1. Amplifiers shall be tested to insure that the gain is the same as it was upon initial installation and acceptance. The original gain shall be noted and any change in gain shall be documented.
2. If supplied with back-up batteries and power supplies these shall be tested under load for a period of one hour to verify that they will operate during an actual power outage.
3. Active components shall be checked to determine that they are operating within the manufacturer’s specifications for their intended purpose.
4. Maintain documentation of all tests performed.

18. Self-Test Questions for Certification

1. A Class B Booster is a “Non-Hetrodyning” Device- T or F
2. The maximum power output of a BDA is how many \(\text{dBm}\)?
3. How frequently must a BDA be checked?
4. Is documentation of all tests required?
5. What is “minimum” desired Signal Level at the rooftop where the donor antenna is placed?
6. Should the donor antenna have a clear unobstructed path back to the donor site?
7. Which system is harder to design? VHF or 800 MHz
8. Why would it be harder to design?
9. What does AHJ mean?
10. If you have more than ONE signal passing through the BDA, what affect does it have on ALL the signals?
11. What happens to BDA Booster Performance if you can't obtain a minimum of -65 dBm at the donor input port?
12. What happens when multiple BDA's are cascaded on a site for range extension?
13. How much range can each indoor antenna be expected to cover at VHF?
14. How much range can each indoor antenna be expected to cover at UHF?
15. How much range can each indoor antenna be expected to cover at 700, 800 or 900 Mhz?
16. What is the optimal transmission cable diameter for coaxial DAS Systems?
17. Which is easier to deploy in an already constructed building? Coaxial or Fiber-Optic
18. What is the maximum sq. ft size for coverage of a building?
19. What is the function of a “Line Tap” or coupler?
20. If you set a line tap at 6 dB “down” from the thru line port how much % of signal would there be at the antenna point?
21. How close could you place a radiating cable to a booster in ft.?
22. What is maximum recommended length of transmission line between the BDA and the donor antenna? 25, 50 or 100 ft.?
23. What would cause a BDA to “oscillate”? a) Too much gain b) too little separation between the input and the output of the BDA c) AGC not working properly d) all the above
24. What is the most likely “Fail Point” in a booster?  Power Supply
25. What is MAX frequency “Pass Band” and MIN “Stop Band” for our standard BDA offerings? a) 500 Khz PB; 4.5 MHz SB b) 1 MHz PB, 4.0 MHz SB c) 1.5 MHz PB, 3.5 MHz SB
27. EMR Corp. has been building BDA/UDA’s since 1985?  T or F
28. Our EMR Corp. main competition for Public Safety VHF, UHF, 700/800/900 MHz Signal Boosters?
29. The City of Boston Fire Fighter Communications System Current Revision # is: 16

30. A permit request for a Fire Fighter Communication System, must be submitted to: Boston Fire Department Communications Section 59 Fenway Boston, MA 02115 Fax # 617-343-3060. T or F

31. Does the City of Boston endorse or recommend BDA manufacturers or suppliers?

32. Regarding IFC Section 510.4.2.3 Secondary power. Emergency responder radio coverage systems shall be provided with an approved secondary source of power. How many hours must secondary power operate?

33. Ideally locate the BDA head-end within X' of the donor antenna?

34. Most ordinances set RF signal levels near -X dBm?

35. Which is sufficient to approach X% reliability.

36. Regarding Coverage Confirmation, each floor of the building shall be divided into a grid of approximately 20 equal areas. A maximum of 1 of these 20 equal areas will be allowed to fail the test. T or F?

37. Radiating cable is commonly used in applications that are typically long, with limited coverage areas? Would these by Wide or Narrow areas?

38. Typically, DAS designs incorporating radiating cable will have the portables operating within X' of the cable?

39. Once it's determined that a BDA is viable, the information below will be instrumental in determining the head-end filter scheme including: the gain required to implement coverage? T or F?

40. What are the optional upgrades required to meet the needs of the application? Power Monitoring, Battery Back-up, additional gain

41. Repeater transmit frequencies? T or F

42. Repeater receive frequencies? T or F

43. Why is the location of sites where repeaters are located in relation to the building to be covered, important?

44. Repeater ERP- is why is this important?

45. Distance between the repeater and the building to be covered. Why do you need this information?

46. Signal level on the roof of the building to be covered- Loss = -36.6 - 20log (frequency MHz) - 20 log (distance in miles)

47. Gain of the BDA required to implement coverage, provided by customer, or from the DAS design. Both information is needed.

48. A knowledge of local building code requirements which the BDA and DAS must meet? T or F?

49. Nearby, in band repeater transmitters that are within 20 dB of the signal level of the desired repeater transmit frequencies. Why is this important?

50. Why is the Gain of the directional antenna to be used in dBi important?

51. The more channels incident on a Class B Signal Booster, the more power out per channel. T or F

52. For example, it is reasonable to assume that 20 equal level carriers could occur in downtown Phoenix, so the coverage would be designed around a per carrier power level of 50 mW or +17 dBm. When there is less activity the coverage will improve. T or F
53. Why do you have to know the cable to be used for the application? To determine systems losses & link budget calculation.

54. Often determined during the DAS design. T or F
55. Is a .pdf of the building to be covered by the BDA and DAS required? T or F
56. Distances specified on the drawing to determine an accurate scale. T or F
57. The pdf should show where hallways and passageways are located. T or F
58. Note where the BDA head-end is to be located within the building. Why? To calculate distances and cable types to use.
59. Knowing the location of vertical chases within multi-story buildings. To determine where to run cables between floors.
60. Why do you have to know the building materials used in the construction of the building and walls? To calculate link budget; losses?
61. Why must you have a knowledge of special rooms within the building requiring special care; such as radiology units in a hospital? Additional antennas inside area or additional BDA’s may be used.
62. Why make note of any metallic backing on ceiling tiles, wall paper, or plaster board? To calculate link budgets.
63. Why note areas within the building that do not require coverage? To save money and installation time.
64. For NFPA-72 Monitoring, there are 7 alarm relays available, these will supply contact closure (Supervisory Signal) to the fire alarm panel for the following alarm. Name each one:
   (1) AC Power Failure
   (2) Signal Booster Failure
   (3) Battery Charger Failure
   (4) Low-battery capacity
   (5) Power Supply Failure
   (6) Antenna Malfunction
   (7) Signal Booster Trouble