Optimizing 16 dB Capture Effect to Overcome Class A 'Channelized' Signal Booster Group Delay problems within Public Safety Communications Systems

July 30, 2008

Preface:

The radio spectrum in urban areas is overpopulated with various signals, some desired and others undesired, that will fall within the passband of a signal booster. Undesired signals can effect the performance of the signal booster, especially in the downlink path which is exposed to the outside environment.

Interest in deploying FCC Class A signal boosters (channelized) has reemerged recently, driven partially by the availability of 'channelized' signal boosters with digital bandpass filtering entering the marketplace. In principal, a channelized signal booster will only pass some quantity of single channel bandwidths which is the optimum selectivity if no other signal booster effects are considered.

However as these types of signal boosters are being deployed it has become evident there are other directly related interactions with the desired signal. The most notable is propagation delay which can degrade performance where the outside signal and boosted signals overlap. The amount of delay is directly proportional to the width of the passband, or selectivity, of the filters used.

Typical bandwidth related delays are:
12.5 KHz bandpass = 70+ microseconds delay
25.0 KHz bandpass = 40+ microseconds delay
35.0 KHz bandpass = 30+ microseconds delay
87.5 KHz bandpass = 20+ microseconds delay
150.0 KHz bandpass = <10 microseconds delay

Based on radio system manufacturers suggestions, the critical delay where degradation could occur is between 15 and 35 microseconds . Delays of less than 10 microseconds are considered acceptable at this time. Broadband signal boosters with passbands ~ 500 KHz have less than 5 microseconds delay and do not create destructive multipath conditions.

It is the 'differential' in the arrival of the direct signal from the donor site versus the delayed signal booster signal.

It is a well known fact that the longer propagation delay within a signal booster with 25 or 12.5 KHz bandwidths can be problematical. This delay can result in loss of communications in digital communications systems in areas where the direct signal and the delayed boosted signal overlap. A chart of the effects of different time differentials in overlapping signals in digital systems is published in TIA TSB-88B.

For the most current digital systems, it has been accepted practice to maintain the delay differential at 25 microseconds or less..

15 microseconds maximum delay differential should be used on current or proposed P25 Phase 2 systems.

Using channelized signal boosters for outdoor 'fill-in' coverage is especially impacted by this problem. (A separate white paper specifically addressing outdoor coverage challenges is available at: http://rfsolutions.com/outdoor.pdf)

The 16 dB signal dominance solution.

It has been know for many years that interaction between two or more signals presented to a FM receiver is mitigated when one of the signals is much more dominant than the others. This is commonly called the receiver 'capture effect'. The use of capture effect as an element of communications coverage design has been evident in simulcast systems for years.

In the past it was a general accepted practice, when using analog modulations, that the capture effect occurs when the differential between the desired signal and all undesired signals is 6 dB or greater.

TIA research document TSB-88B shows the ideal signal level differential to achieve the capture effect would be close to 20 dB but some manufacturers and in-building system designers are currently using 16 dB differential as the in-building design criteria to overcome unacceptable delays caused by narrow passband signal boosters.

The TIA TSB-88B Recommended Methodologies charts show the maximum differential *relative* delay for a analog and P25 Phase 1 systems is less than 33 microseconds to obtain a DAQ of 3.4. In P25 Phase 2 systems, the maximum delay is 15 microseconds.

The TIA charts also indicates when two signasl are present (outdoor and indoor) at the same time, longer delays maybe acceptable *provided* there is a greatsignal level differential in the two signal's levels with 20 dB being an ideal differential level.

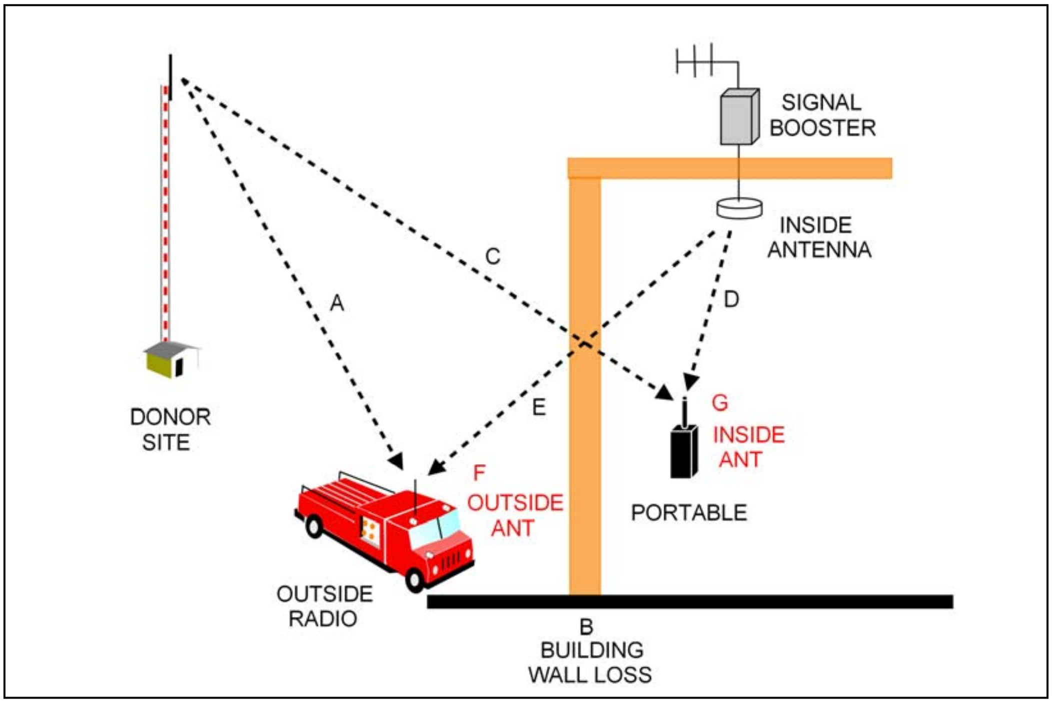
The potential problems caused by using FCC Class A (channelized) signal boosters with their inherent delay can be mitigated by either;
(1) Carefully designing the system coverage so that the desired signal is always at least 16 dB greater than any or all undesired signals at all locations where communications is required , and
(2) Increase the passband bandwidth of the a Class A channelized signal booster so as the signal booster becomes a broadband FCC Class B signal booster.

NOTE: FCC Class B (broadband) signal boosters delay is less than 5 microseconds, so there is no need to take special considerations for delay in system designs using Class B signal boosters..

Basic 16 dB Capture Concept:
Objective; Design the in-building system so as to assure 16 dB, or greater, differential between direct from donor site signals and the delayed signal booster signals, both inside *and outside* the structure.

It is important to remember the real delay differential includes ALL the in-building wireless distribution components in addition to the signal booster delay, such a coax and fiber delays, in-line amplifier delays, etc.

If the boosted signal is fully contained with the building, propagation delay is not a problem because there is no overlap with outside signals. However, in most applications overlap occurs both within the structure and outside the structure as signals transverse a wall or other separating medium. The basic concept of outside versus inside signals is illustrated below.



Path A= Donor to Outside ant.
Path C = Donor to Inside antenna
Path E = Booster to outside antenna
F = Outside antenna

B = Attenuating wall
Path D = Booster to inside antenna
G = Inside antenna

This basic model is used below to limit the number of calculations in the following charts. In real applications the signal losses can become very complex; multiple walls, doors, windows, etc.

The illustration focuses on the ground level as that is where the greatest potential exists for problems often overlooked in this type system design.

Potential signal differentials are estimated in the following charts. Any differential in column F or G that is greater than 16 dB will provide the desired capture effect. *All RED values are below the 16 dB requirement and communications may be unreliable.*

Given:
1. One common minimum service area signal level is used; the public safety accepted standard -95dBm in Table 1 as well as a higher level of -80 dBm in Table 2.

2. The direct from donor signal level is that expected outside the structure at ground level.

3. There is only one potential external signal source; direct from the donor site.

4. It is assumed the worse case of signal overlap will be in the vicinity of external walls of the structure, thus coverage through inner partitions is not a consideration in this exercise.

5. Changes in path lengths (direct versus through the wall) have minimal effect on the free space losses, so no adjustment was made for this paper.

16 dB analysis: See drawing for path identification 3/10/2008

Note the wall losses are within the ranges used in TIA-TSB-88-B, figs 20 & 21.

Chart 1: Using -95 dBm inside signal level standard

A	B	C		D	B	E		F	G
Donor Outside	Wall Loss	Donor Inside		Service Inside	Wall Loss	Service Outside		Difference Outside	Difference Inside
-100	-5	-105		-95	-5	-100		0	10
-100	-10	-110		-95	-10	-105		5	15
-100	-15	-115		-95	-15	-110		10	20
-100	-16	-116		-95	-16	-111		11	21
-100	-20	-120		-95	-20	-115		15	25
-100	-25	-125		-95	-25	-120		20	30
-100	-30	-130		-95	-30	-125		25	35

Continued….

-95	-5	-100		-95	-5	-100		5	5
-95	-10	-105		-95	-10	-105		10	10
-95	-15	-110		-95	-15	-110		15	15
-95	-16	-111		-95	-16	-111		16	16
-95	-20	-115		-95	-20	-115		20	20
-95	-25	-120		-95	-25	-120		25	25
-95	-30	-125		-95	-30	-125		30	30

-90	-5	-95		-95	-5	-100		10	0
-90	-10	-100		-95	-10	-105		15	5
-90	-15	-105		-95	-15	-110		20	10
-90	-20	-110		-95	-20	-115		25	15
-90	-25	-115		-95	-25	-120		30	20
-90	-30	-120		-95	-30	-125		35	25

-85	-5	-90		-95	-5	-100		15	-5
-85	-10	-95		-95	-10	-105		20	0
-85	-15	-100		-95	-15	-110		25	5
-85	-20	-105		-95	-20	-115		30	10
-85	-25	-110		-95	-25	-120		35	15
-85	-30	-115		-95	-30	-125		40	20

-80	-5	-85		-95	-5	-100		20	-10
-80	-10	-90		-95	-10	-105		25	-5
-80	-15	-95		-95	-15	-110		30	0
-80	-20	-100		-95	-20	-115		35	5
-80	-25	-105		-95	-25	-120		40	10
-80	-30	-110		-95	-30	-125		45	15

-75	-5	-80		-95	-5	-100		25	-15
-75	-10	-85		-95	-10	-105		30	-10
-75	-15	-90		-95	-15	-110		35	-5
-75	-20	-95		-95	-20	-115		40	0
-75	-25	-100		-95	-25	-120		45	5
-75	-30	-105		-95	-30	-125		50	10

Chart 2: Using -80 dBm inside signal level

A	B	C		D	B	E		F	G
Donor Outside	Wall Loss	Donor Inside		Service Inside	Wall Loss	Service Outside		Difference Outside	Difference Inside
-100	-5	-105		-80	-5	-85		-15	25
-100	-10	-110		-80	-10	-90		-10	30
-100	-15	-115		-80	-15	-95		-5	35
-100	-16	-116		-80	-16	-96		-4	36
-100	-20	-120		-80	-20	-100		0	40
-100	-25	-125		-80	-25	-105		5	45
-100	-30	-130		-80	-30	-110		10	50
-95	-5	-100		-80	-5	-85		-10	20
-95	-10	-105		-80	-10	-90		-5	25
-95	-15	-110		-80	-15	-95		0	30
-95	-16	-111		-80	-16	-96		1	31
-95	-20	-115		-80	-20	-100		5	35
-95	-25	-120		-80	-25	-105		10	40
-95	-30	-125		-80	-30	-110		15	45
-90	-5	-95		-80	-5	-85		-5	15
-90	-10	-100		-80	-10	-90		0	20
-90	-15	-105		-80	-15	-95		5	25
-90	-20	-110		-80	-20	-100		10	30
-90	-25	-115		-80	-25	-105		15	35
-90	-30	-120		-80	-30	-110		20	40
-85	-5	-90		-80	-5	-85		0	10
-85	-10	-95		-80	-10	-90		5	15
-85	-15	-100		-80	-15	-95		10	20
-85	-20	-105		-80	-20	-100		15	25
-85	-25	-110		-80	-25	-105		20	30
-85	-30	-115		-80	-30	-110		25	35
-80	-5	-85		-80	-5	-85		5	5
-80	-10	-90		-80	-10	-90		10	10
-80	-15	-95		-80	-15	-95		15	15
-80	-20	-100		-80	-20	-100		20	20
-80	-25	-105		-80	-25	-105		25	25
-80	-30	-110		-80	-30	-110		30	30
-75	-5	-80		-80	-5	-85		10	0
-75	-10	-85		-80	-10	-90		15	5
-75	-15	-90		-80	-15	-95		20	10
-75	-20	-95		-80	-20	-100		25	15
-75	-25	-100		-80	-25	-105		30	20
-75	-30	-105		-80	-30	-110		35	25

Observations from above analysis:

- Statistically, 50% of the 'difference' values from the above charts are 16 dB or greater and 50% of the difference values are less than 16 dB. This clearly indicates each site should be individually engineered and the use of generalizations may lead to unexpected performance.

- Increasing the service area signal level did not improve the *percentages* of go/no-go situations. However, service area power distribution management may resolve specific problem areas.

(*Simplified formula for estimating isolation (i.e. wall loss) required between outdoor and indoor signal levels: The difference between the outdoor signal level (dBm) and the indoor signal level + 16 dB*.)

The simple model used above probably does not reflect all situations. Additional considerations are;

1. More than one donor site may serve the same structure. This can occur when a secondary donor site is used for back-up. As the azimuth between sites increase the greater the need for separate engineering for all sites.

2. Donor site(s) locations may be changed or donor sites added over time. If the azimuth or the signal levels of the donor site(s) changes it may require modifications to the inside antenna locations and adjustment of indoor signal levels.

3. Multi-band systems, i.e. 800 MHz PD/450 MHz FD, may have different donor locations and/or indoor signal levels. This requires analysis of all bands when a common indoor distribution system with broadband indoor antennas are used.

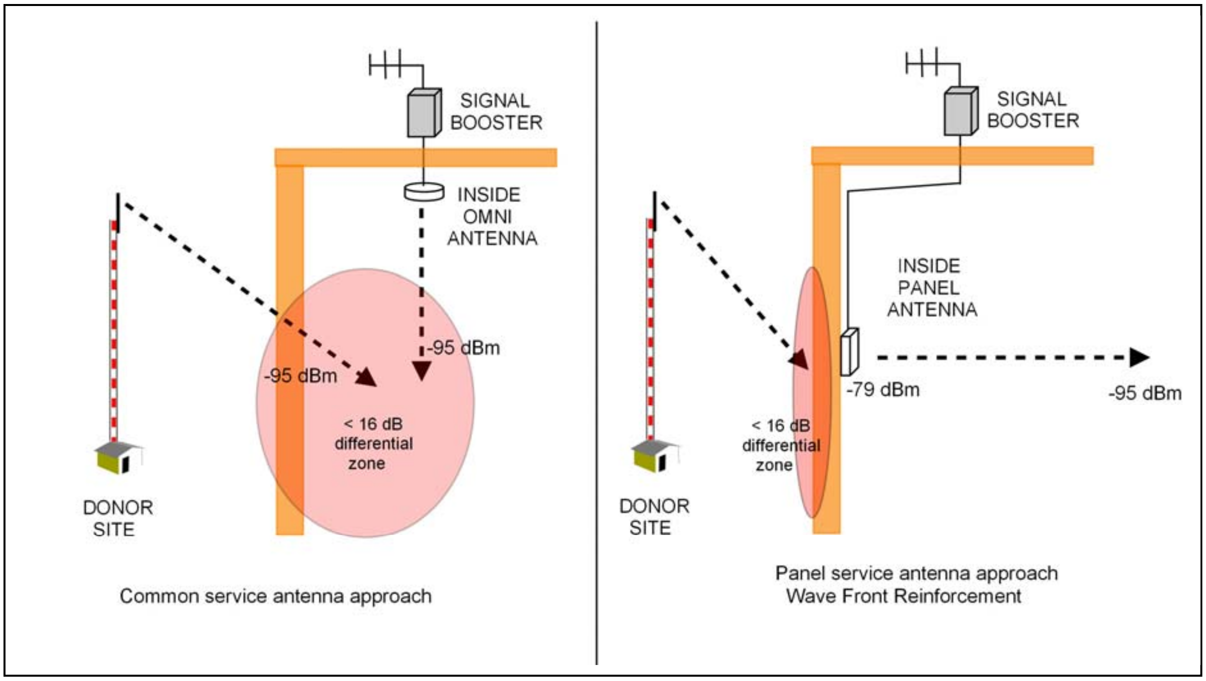
4. The 'wall loss' can be different in the vicinity of windows, doorways and other entrances such as ramps leading to underground parking. The system engineering should design to worse case positioning of indoor antennas in such areas.

5. System engineering should include considerations peculiar to the structure. For example: a metal lined jail may inherently have sufficient shielding. A fire station or loading dock may have varying signal levels when large overhead doors are opened and closed. A hospital may have limitation on the maximum RF levels inside the building, limiting the flexibility in adjusting power levels to assure 16 dB capture.

Installation techniques driven by 16 dB differential requirement.
The following techniques may be used to improve 16 dB differentials.

a. Adjust service area signal levels. This is an obvious exercise and requires no additional explanation. Attenuators and different antenna decoupling values can be used.

b. Indoor ("Service" area) antenna types and locations. When common omni-directional antennas and locations cannot provide 16 dB differential, one technique, 'wave front reinforcement', may be beneficial. The principle of this approach is based on the sharp front to back ratios of panel type antennas. The illustration below shows the reduction of the < 16 dBm differential levels achieved by using panel antennas mounted on the wall most adjacent to the donor site. The key is to have the panel antenna in the direct line between the donor and service area.

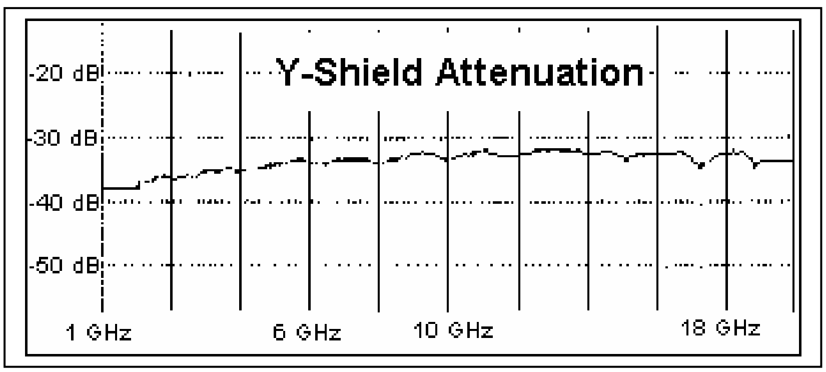


c. RF leakage through windows: Apply metallic films to increase losses through windows. Some experimentation may be required as RF attenuation is not a common window film specification. One RF rated material is

ScotchTint Shielding Performance				
Frequency	Attenuation		Frequency	Attenuation
30 MHz	24 dB		1 GHz	24 dB
100 MHz	22 dB		2.5 GHz	26 dB
300 MHz	22 dB		4.5 GHz	27 dB

Shading Coefficient .26 Emissivity .65 Glare Reduction 78%
Visible Light Reflected 58% Heat Gain Reduction 72% "U" Value .95
Visible Light Transmitted 19% Heat Loss Reduction 10% Visible Light Energy Rejected 77%

d. RF leakage through walls: Add shielding to walls on the donor side of the structure. One approach is to add a RF shielding undercoat paint. One type is Y-Shield.



Another approach is to apply shielding paint, such as "CuPro-Cote Paint " which provides > 75 dB attenuation (when grounded properly) from 1MHz to 1GHz.

RF shielding wall panels and wall papers are also available. BAE Systems manufactures "Stealthy Wallpaper" used by military and federal agencies.

VERY IMPORTANT NOTE: When shielding is added it will also attenuate signals other than your own. Mutual aid support may require the signal booster to also amplify other agencies signals in the structure.

Planning for now and the future

As noted previously, public safety systems are always subject to change as new communication requirements, new hardware and frequency band changes occur over time.

When designing an in-building system that requires the 16 dB capture effect due to the delays in FCC Class A (channelized or channel selective) signal boosters and delays within the wireless distribution system (cable and fiber delays) reserve isolation should be included.

Potential temporary situations, such as a command vehicle, or handhelds, operating adjacent to an outer wall during an emergency, should be anticipated. It is unacceptable to interfere with a command vehicle during an emergency.

Conclusion

Designing systems that provide 16 dB capture effect may be accomplished based upon extensive analysis of the characteristics of each structure and the proposed wireless distribution system. When a 16 dB or greater differential exists between the direct to donor site path and the boosted service area path, FCC Class A (channelized) signal boosters can be utilized.

In the event a 16 dB differential cannot be achieved or it is cost prohibitive to do so, the system designer may consider using FCC Class B (band selective) signal boosters which do not require 16 dB capture effect due to their inherent low delay.

Relative papers available on-line:

Optimizing Class A signal boosters: www.RFSolutions.com/classa-opt.pdf
Optimizing Class A signal boosters: www.RFSolutions.com/classb-opt.pdf

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