FM Boosters 2.0 – It's Not Your Father's SFN

Rich Redmond – GatesAir
Hal Kneller – Geo Broadcast Solutions

Abstract - FM broadcasters around the world, and specifically in the United States, have long been able to license FM boosters or Single Frequency Networks (SFN) to augment the coverage of their main FM transmitting systems. In early implementations the coverage enhancements predicted appeared beneficial, however many have found the actual results range from underwhelming to something close to a signal jammer. In recent years significant advances have been made in sold state, digitally modulated FM transmitters, real time adaptive precision time delay control and software coverage planning tools which have closed the gap from paper to reality. In this paper we will review the types of signal issues that properly designed boosters can address, improvements in system design, simplification of implementation and real-world results including synchronizing translators. We will examine the new opportunities the improved coverage and ratings impact these SFN networks bring to radio broadcasters, network operators and the listening public.

Background

FM Broadcasters have long enjoyed a very good delivery system that includes good audio fidelity, clear reception in the service area, good in-building reception, and great in-car reception. FM overcame many of the reception issues that impacted the AM broadcast band, however FM is generally a line of sight service where the receiver needs a clear view of the transmitter site. While ideally sited FM's have very good coverage typically from a tall tower or high mountain top, the impact of terrain such as mountains, ridges, or even man-made structures such is as city buildings can cause shadows impacting what would otherwise be areas of usable reception. (See Figure 1) In some cases, relocating the main FM transmitter site can improve reception in the areas impacted, it often creates new areas of subpar coverage – almost every move is a tradeoff. In other cases, a station may be limited to their current site due to co or adjacent channel spacing with other broadcasters making a site move impossible. Sometimes stations attempt to serve a market from outside, commonly known as 'rimshots' whose protected contour may encompass the primary city desired but the signal, in reality, is not competitive.

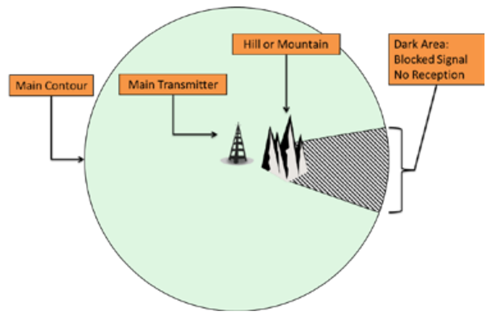


Figure #1

The use of on-channel boosters or a single frequency network to provide improved coverage in cases of signal impairment is one that has been available to broadcasters for many years. In principle the concept is simple - provide the same content on two different transmitters and lock the transmitters to a common reference, today typically GPS, creating seamless coverage. In practice, the real-world results have ranged from very good to the creation of new interference and impaired coverage to the point many boosters have been turned off after many attempts to "dial it in." In most cases the interference came from significant overlap of RF signals from the main FM transmitter and the booster. (See Figure 2)

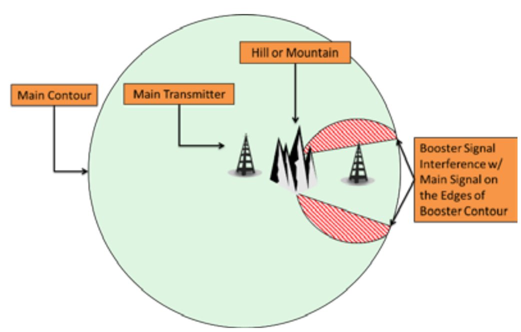


Figure #2

What has Changed

With the advent of multiple global digital radio and television standards along with the advancements in broad deployment of mobile telephony networks, we now have further understanding of interaction between transmitters in a network, proper network design, and the criticality of system timing. Planning software has also improved immensely. While these other digital standards have specific physical layer capabilities of the COFDM modulation that make single frequency networks simpler and more robust, many principles can be applied to analog FM systems, despite the single carrier nature. Technology evolution in IP networks and advances in RF device technology have allowed broadcast equipment manufacturers to make significant improvement in the size, cost and flexibility of transmitters and transport products.

What is most likely the biggest change in the approach to implement a successful SFN network is a shift from thinking of booster sites as a small version of the main transmission facility to thinking about them as part of a planned network of RF sources more like a mobile network. Many of the principles that make a great FM main site, high placement of the antenna, great look angle to the intended market, broad coverage, maximum allowable power and so forth are in fact poor choices or requirements for successful booster sites as they are not conducive to focusing the RF coverage and often cause RF overlap with the main site. The culmination of these changes requires a holistic view of optimizing coverage to meet each station's market, format, and listener demographics. The best way to accomplish this is by developing a technical system of carefully aligned design, equipment, and implementation rather than the traditional approach of selecting components based on brand preference coupled with local engineering team implementation.

Importance of network design

One would rarely take on building a new house without architectural plans that had been through multiple reviews by clients, engineers, and local permitting officials to ensure the resulting home meets all the needs and complies with required codes. While all boosters go through some sort of regulatory approval, these are typically done to ensure a station is not exceeding their licensed coverage area and is not causing interference to other broadcasters. In addition, most RF consultants who are skilled in normal broadcast licensing are not experienced in SFN network design and as a result sites often meet regulatory requirements but fall short in meeting key network design criteria.

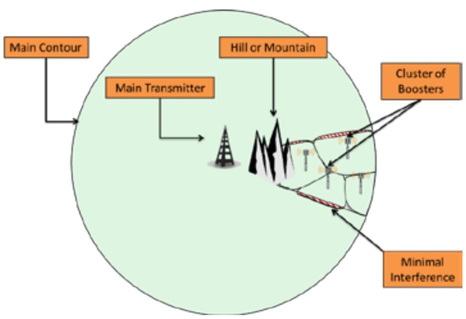
In many countries outside of North America, the approach of using multiple low power transmitters on a single frequency to create a targeted coverage is commonplace, especially in digital TV and radio using DVB-T/T2 and DAB/DAB+ modulations. This is also the case globally for mobile networks using GSM/LTE networks. As a result of these global deployments, advances in network planning and coverage software from companies not normally seen in typical FM coverage analysis provide a critical tool needed to properly design a successful SFN network. These planning tools allow for the mapping of interference at the RF level between multiple transmitter sites and are useful in crafting the appropriate antenna patterns needed for the booster sites to target the coverage and minimize interference. These tools also will calculate the timing offset required between multiple boosters within a network based on the RF propagation delay from each site to the area of overlap. One such provider of this advanced software is ATDI ICS Telecom which is based in France.

The importance of using these specialized planning tools is to ensure that the areas of planned coverage using the targeted transmission sites meet the station's required outcomes. In fact, these coverage planning maps can be overlaid with station-specific data including but not limited to addresses of known listeners, demographics and/or ethnicities of a station's target market, and even location by zip codes of Nielsen Portable People Meters in metered markets. An important first step in any coverage improvement project is meeting with the station management, sales team, programing team and so forth to understand areas of importance to these important stakeholders. It is far simpler to resolve differences in importance of coverage areas while the design is still on paper. The number of times a booster meets the technically planned coverage but missed the management, programming and sales desired areas is astonishing. While no system can meet every desire, and no engineering consultant is a miracle worker, ensuring everyone is aligned at the beginning of the project is critical.

Figure# 3 Typical MaxxCasting or ZoneCasting antenna array (Shively 6025 dual)

Precision RF design

Hand in hand with the concept of network planning tools is the need to develop a methodology that focuses the booster RF in the targeted area, while at the same time minimizing the amount of RF that overlaps in areas which already have coverage from the main FM transmitter. As we discussed earlier, the principles one would use to design a good main FM site would not be typically applicable to booster designs, and in the case of RF system design this is one of the most critical deviations. A significant advancement in this area has been pioneered by Geo Broadcast Solutions which is the concept of clusters of boosters employing mobile-cellular type antenna patterns to create a focused coverage of the desired area with little signal overlapping the main coverage. (See Figure 4) This has been commercially branded as MaxxCasting and is patented.



Figure# 4

The use of highly directional antennas employing high front to back ratios are deployed in clusters focusing the RF energy specifically in the areas of desired coverage improvement. (See Figure 5) The relationship between antenna patterns, booster site selection, antenna elevation, booster ERP and the related timing between the sites are just some of the variables that are analyzed and optimized to create seamless coverage.

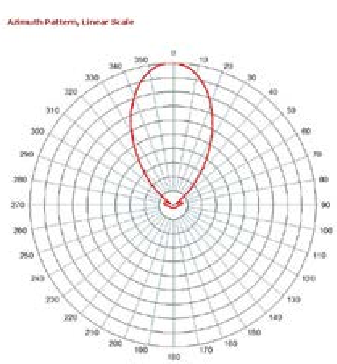


Figure 5

A good comparison to this design principle might be to think about the use of focused lights in a sports stadium for night games. The lights surround the field and are all focused on the playing field in a highly directional manner. Virtually no light emanates from the back side of the lights. This is similar to the concept of clustered designs. If we were to try to light the stadium using typical FM main transmitter principles we would place omnidirectional lighting of high intensity 500' above the playing field. This would provide ample lighting for the playing field, but it would also cover much of the parking lot and many neighbors' homes. It would also be energy inefficient. The concentrated patterns permit the use of much lower power transmitters in booster design.

By using the advanced planning tools now available, coupled with the clustered booster concept and the unique combination of multiple operating parameters, interference between boosters and the main transmitter is virtually eliminated. This is a very critical step in the process of taking a systems approach to boosters. While there are certain things that can be done using the adjustments in the system timing, also a critical step, timing alone cannot recover self-interference between boosters and the main transmitter. RF levels need to be carefully managed and a true network plan developed to ensure all the main and booster sites operate in concert.

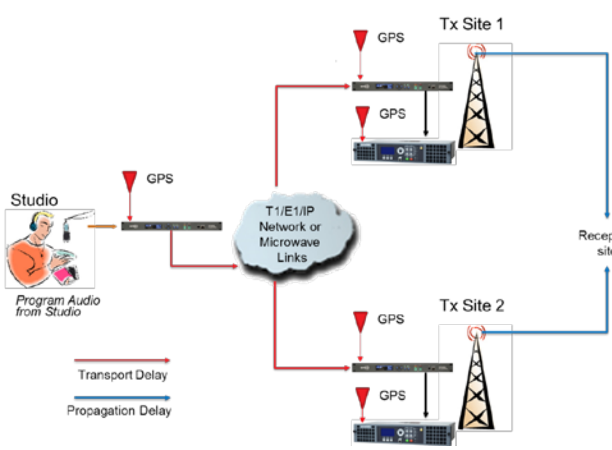
System timing

In all SFN systems there are multiple delays that must be managed to first align a system and then keep it in alignment to support continued smooth operation. The important concept is that in addition to the alignment of the frequency of each transmitter, the audio path needs precision alignment to ensure simultaneous arrival of the audio at the receive sites in the overlap area where a receiver would be getting signal from two or more transmitters. GatesAir's Intraplex SynchroCast system employs patented technology that provides real time adaptive delay to maintain precision control in an SFN system. The first delay that needs to be managed is the transport delay which accounts for the time to get the audio to each transmitter site using a variety of methods. In the past transport methods, we were limited to TDM links over public network or microwave and required over 1.5 Mbps of bandwidth to support the transport. Recent developments have allowed the use of IP networks which are often available at lower costs. In addition to the use of IP networks, the required bandwidth has also been reduced to 128 kbps which also increases the flexibility of the types of links that can be used and further reduces transport cost.

With the increase in flexibility comes in some cases increase in variability of latency in the delivery network. It is the variability of this network path that is of concern and must have real-time adaptive control of the network delay versus a simple fixed delay system. The Intraplex SynchroCast® system supports the ability to reference the transport payload to GPS signals at the studio and each transmitter site to be able to provide a solid refence to compare the variation in delays and compensate. Some customers even have had success using the public Internet for distribution when using the Intraplex IP Link 200.

The second major type of delay that needs to be managed in an SFN system is the propagation delay of the RF signal from each transmitter site to the area of overlap. This delay ensures the audio accounts for the time it takes for the actual signal to propagate over the air. Adjustments of this portion of the delay allow a user to "move" the overlap seam one way or another away from a major highway, for example. Then, using the proper planning software tools discussed earlier in the paper, the propagation delay for each site can be determined to ensure proper system alignment.

In addition to the two major delays we have discussed, (See Figure 6) each piece of equipment in the signal path such as the exciter and transmitter has some form of delay that needs to be measured and accounted for in order to adjust the system to the overall delay needed. We have noted that different model exciters even from the same manufacturer may have different delay factors, internally. While we deal with microsecond delays through space, we deal with millisecond delays through the various equipment components in the network, all of which have to be considered in the timing calculations. The overall delay for each site will be different to account for all parameters and will be no shorter than the maximum delay of the longest transport path and propagation path plus some buffer to allow for the real time adaptive time control.

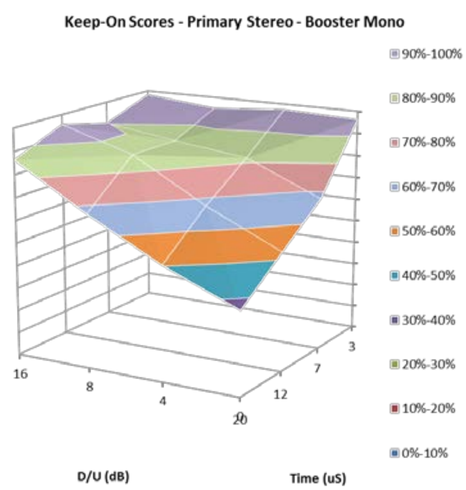


Figure# 6

Why delays matter

Whenever more than one signal reaches an analog receiver on the same frequency and they are not in perfect alignment, heavy multipath at best and signal cancellation at worst will occur. It creates an unlistenable signal. It is possible to set the launch timing of a booster so that the signals may be in perfect phase and otherwise properly synchronized, in one particular location. But move a few kilometers and you are no longer in synchronization. Various items come into play as to how much tolerance exists with talk programming versus music programming, mono, or stereo transmission, etc. The wider the spread in amplitude ratio (d/u), the more the timing of signal arrival can be off without deleterious effects due to the capture ratio of the receiver. As the amplitude of the arriving signals comes closer to being equal, the more critical the timing becomes. Noticeable interference manifests itself with as much as a 20dB d/u when synchronization is improper. Deployment of directional antennas is useful to minimize these overlaps, so booster signals do not travel to areas which will cause interference with the main signal (or at least cause it over unpopulated areas). Proper network design is how this interference is mitigated or even eliminated in many cases. And of course, we always need to maintain exact synchronization of the audio phasing, modulation level, pilot, and carrier frequency regardless of the launch delay timing. Thus, we have typically recommended that all exciters in the network be identical models or ensure that the modulation components of disparate equipment is adjusted to compensate the timing such that exciter latency is taken into consideration.

Listening tests conducted by NPR Labs and Towson University revealed for the first time, what listeners would tolerate in terms of misalignment under a wide variety of conditions. (See Figure 7) This drives the customized software for network design, using real-world data.



Figure# 7

Choices in transport

In recent years the options for the transport of audio to the transmitter sites have become more flexible in the type of methods used but also the types of signals transported. The migration from TDM to IP transport has increased the flexibility in links, as has the further development of audio data compression CODECS. Products such as the GatesAir Intraplex IP Link employing SynchroCast technology provide the needed program transport and precision timing control to enable the seamless coverage that today's booster systems can offer.

The GatesAir Intraplex product family provides numerous audio transport options for SFN applications using SynchroCast technology. The IP Link can transport analog and digital discrete left and right audio using a full range of compression and error mitigation options to tailor the delivery to the available network capacity. While traditional left and right audio transport was available in the older TDM systems, the IP Link MPX version can transport both analog and digital AES192 composite MPX audio. This is a significant breakthrough for SFN applications as it eliminates the use of multiple aligned stereo generators located at the transmitter sites and allows one to use the single stereo generator in the main processor. This approach ensures that the exact same signal is delivered, and time aligned for the requirements of each transmitter site.

Figure# 8

The IP Link can use multiple classes of IP networks to deliver synchronized audio to support the SFN program delivery and has simplified the system by providing the option for a low cost integrated GPS receiver to support link timing.

If IP connectivity is an issue at your transmitter site, several new options are available. The GatesAir Intraplex HD link, a 950mHz STL system, can also support SynchroCast technology and is ideal for sites with limited wired connectivity. These in fact can be mixed and matched with IP links in a single network. In some cases, commodity wireless IP radios in both the licensed and unlicensed bands can be deployed to support SFN operation. The SynchroCast technology can adapt to the non-deterministic nature of these radios and continue to deliver reliable perfectly timed audio.

Simplified Transmission

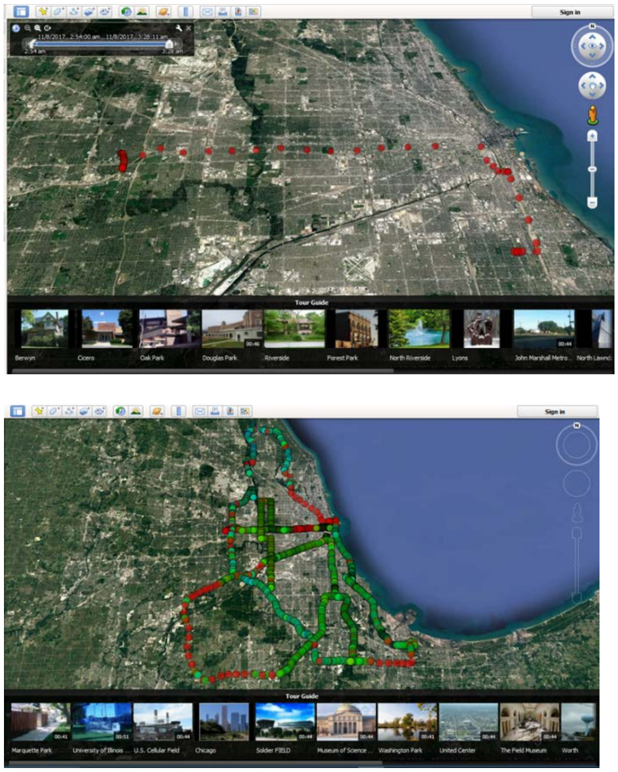
FM broadcast transmitters have evolved over the past 20 years converging the capability of digital FM exciters, integrated GPS receivers, and the latest 50-volt LDMOS technology. In the past once you needed a transmitter beyond 50 watts or so, the transmitter became a combination of exciter, control system, some form of amplification, which could be tube or solid state, and outboard lowpass filtering. All of these systems combined often required a dedicated cabinet to hold the electronics needed to provide relatively low powers. The size of such systems, and the requirement in some cases for three phase power connections made site selection difficult for booster applications.

Recently GatesAir has developed the Flexiva FAX line of solid state, digitally modulated FM transmitters which offer high power density and a very compact footprint. The FAX 3.5K can produce up to 3850 watts in a small 4 rack units of space. Beyond the compact nature of the unit is the ultra-stable digital modulator-exciter which is at the core of the system, and critical for successful SFN operation. The combination of technology, integrated capabilities such as GPS, and the world-class digital exciter can thus support SFN boosters in today's space constrained environments.

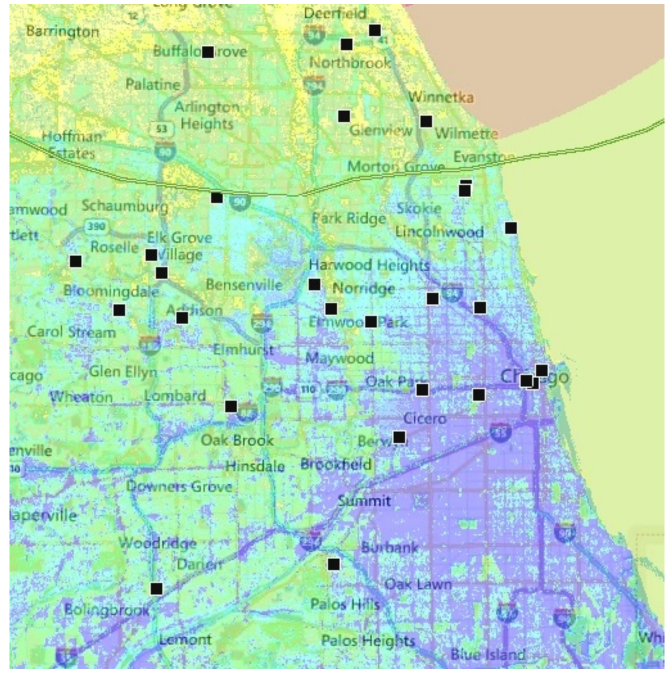
Figure# 9

Changes in Ratings Methodology

Ratings information used to be gathered by telephone calls or diaries which selected listeners filled out. Today, most of the larger Nielsen markets are using PPM (Portable People Meters). Scoring the station's decoded watermarked PPM signal is vital to the ratings being reported. Poor signal areas where people struggle to listen (or worse yet, tune out) means the station does not receive credit. Even a weak signal significantly detracts from the ability of the unit to decode. Thus, boosters in the right place and lack of interference (which would also impede decoding) can be a very viable solution. System testing at WIIL (Union Grove, WI) shows field and PPM measurements of the signal level using the main only (red dots equal no decoding), and the use of additional synchronized low power transmitters (co-channel FM translators in this case). Figure 10 shows the drive on one of the main routes in Chicago before the Maxxcasting system is deployed, and more extensive drive testing once the system was turned on creating significant signal improvement.



Figure# 10



Figure# 11a:

WIIL Union Grove, WI Station Coverage

Figure# 11b:

Additional Coverage w/Translators

PPM field viability measurements are possible by use of an instrument created by 25-Seven (a Telos Alliance company) called the TCV-15, still in prototype stage. This was used along with a WorldCast Systems Navigator to measure the effective decoding levels above.

Synchronizing Translators

While the discussion in this paper has largely been about boosters (which under FCC rules are located inside an FM station's protector contour), Geo Broadcast Solutions has undertaken a number of translator projects which involve much of the same technology but are OUTSIDE the station's protected contour. In these cases, the translator is co-channel (same channel) with the main station and is used to extend coverage beyond the station's contour, something a booster is not permitted to do. In all ways, the technology being used is identical to what we do with boosters inside the contour. The PPM measurements in Figure 11 on station WIIL, Union Grove, WI are an example of co-channel translator implementation. In this case, two co-channel translators are situated south of the main station's contour to serve portions of the Chicago market.

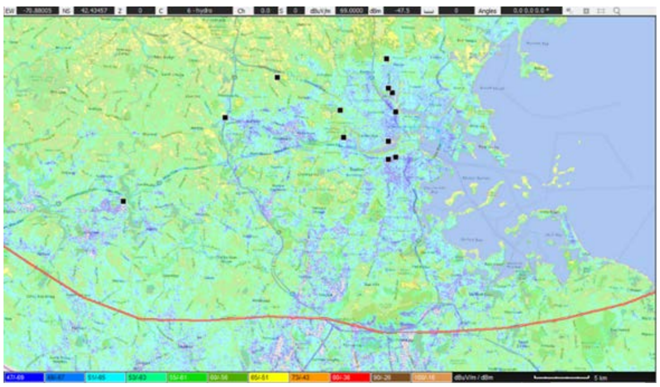
Real world results

Los Angeles

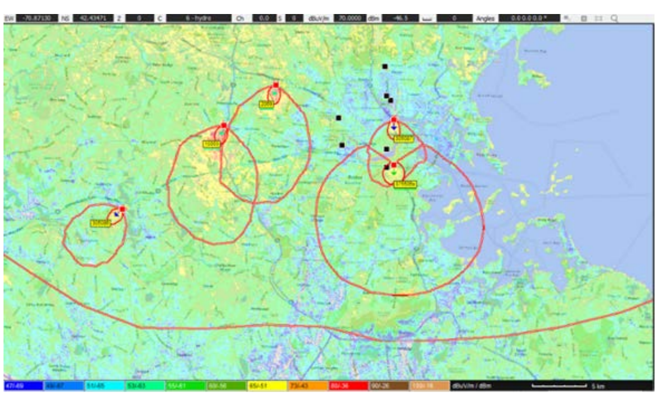
Station KPCC (Pasadena, California) is an NPR member station and operates with a mere 600 watts ERP but from the top of Mt Wilson with 891 Meters HAAT. While height is an advantage, the low ERP and the distance of travel to the station's 60 dBu contour provides a less than desirable signal with poor building penetration. KPCC deployed MaxxCasting technology and the results have been noticeable in the ratings. The ratings were typically 1.5 AQH Share Age 6+ Monday – Sunday 6 am to Midnight prior to MaxxCasting. In the time since, the ratings have been rather consistent at 1.9.

Boston

WXRV (Andover, Massachusetts) is a full power FM Class B station which desires to serve the Greater Boston market from the north. Due to rolling hills in the western suburbs of Boston and both slight terrain blockage into downtown Boston and the presence of high power FM transmitters on top of tall buildings in the downtown area, the WXRV signal was significantly compromised.



Figure# 12a:
WXRV Coverage before MaxxCasting



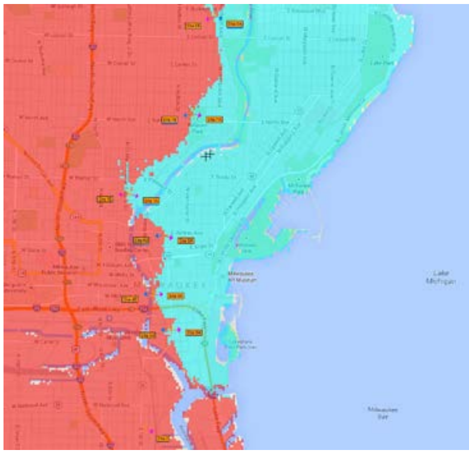
Figure# 12b:
WXRV Coverage with MaxxCasting

The results have been greatly increased listenability throughout the areas of the MaxxCasting nodes and a consequential ratings boost. (See Figure 12) Prior to MaxxCasting, WXRV was typically at a 1.5 AQH share, 6+ Monday – Sunday 6 am to Midnight. Since MaxxCasting, the ratings are up in October and November of 2017 showing 2.1. But further into the rating analysis, WXRV is now ahead of its head-to-head competitor, WBOS, who has dropped from 2.1 down to 1.8. WBOS transmits from downtown Boston, operating as a full Class B on WXRV's 2nd adjacent (92.5 for WXRV, 92.9 for WBOS)!

Another form of Booster Use – ZoneCasting™

Traditionally, boosters have been used to mitigate signal problems within an FM station's protected contour and have thus presented identical programming compared to the main FM transmitter. Geo Broadcast Solutions has developed, patented and branded ZoneCasting which has a different purpose – to divide an FM station's coverage area into two or more "zones" where the boosters would play out separate content from the main FM signal for certain portions of an hour or even hours in a day.

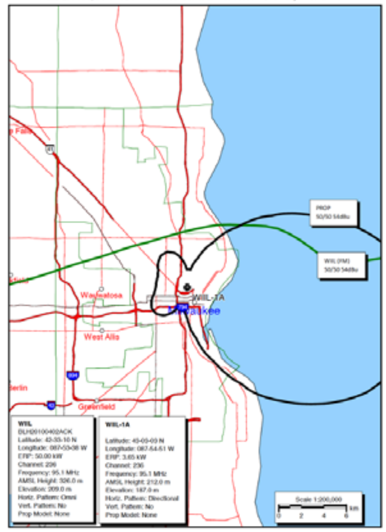
Most engineers would think this to be impossible with regard to interference being created over extremely wide areas. However, in the fall of 2016, a technical trial was authorized by the FCC in Milwaukee, WI over station WIIL (Union Grove, WI). Portions of downtown Milwaukee were separated out from the main station's signal to form a zone where separate programming could be aired. This trial was conducted using an Experimental Authorization as part of a pending Rulemaking at the FCC. What is unique about this trial was the antenna configuration. (See Figures 13 and 14) Using highly directional Shively 6025 dual log periodic antennas arranged in a back-to-back arrangement, facing west was a simulcast (synchronized with the main FM station) and facing east was a duplicated set of antennas broadcasting different content, synchronized within the zone. The results were such that interference/transition zones were contained within 1 to 1.5 city blocks and no deleterious effects existed beyond that. Interference mappings and audio samples were sent to the Commission for evaluation.



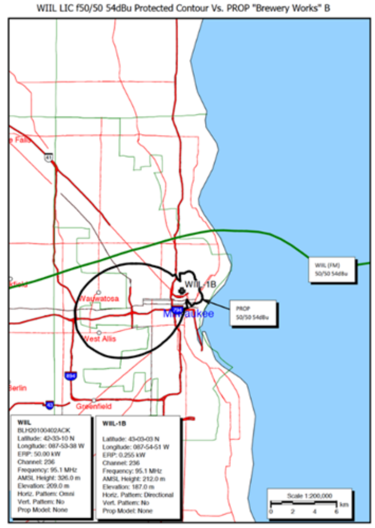
The red shaded area on the left indicates the main station's zone. The blue-green on the right is the ZoneCasting zone. The red dots on the map on the right indicate the antenna locations for the trial.

Figure# 13

WIIL LIC f50/50 54dBu Protected Contour Vs. PROP "Brewery Works" A



WIIL LIC f50/50 54dBu Protected Contour Vs. PROP "Brewery Works" B



WIIL LIC f50/50 54dBu Protected Contour Vs. PROP "SBA Tower" ASR 1060030

Figure #14

The FCC authorized a 90-day Experimental Authorization for WIIL creating a separate programming zone as shown in Figure 13. The station had a relatively poor signal in the area in which ZoneCasting was deployed, although it all was within the legal constraints of the station's 54 dBu contour. Ironically, despite the short trial period, station management reported ratings increases due to the greatly enhanced signal in both shaded areas which are rich in PPMs.

95 WIIL ROCK 95.1 FM

"In Milwaukee County, we saw a significant audience increase in males 18 and over from October to November. This is an important demographic for our Active Rock format, and we can directly attribute this increase to the MaxxCasting network lighting up more PPM units," said Karl Wertzler, WIIL general manager.

Figure# 15

Present FCC rules do not permit separate programming on booster facilities (although a rulemaking is being sought to permit this). And technology prior to now would not permit it without the aforementioned serious interference. The stability of the equipment available today such as the IP Link 200 with SynchroCast Key by GatesAir and the network design tools which GeoBroadcast Solutions has now permits this technology to become reality. Sometimes rules are behind advancing technology, but those rules had sound basis when first promulgated.

There are many reasons to consider separation of a zone from the main signal. Some stations have very large coverage areas thus emergency alerts may not be valid through the entire coverage area. News, weather, localized advertising, even separate sports broadcasts could be envisioned in these zones. Geo targeting is more and more relevant today when one thinks about how cable TV works with local insertions. Recently the Commission approved voluntary use of the ATSC 3.0 over-the-air television standard by US broadcasters which also supports geo-targeting. Advertisers are using IP address locations to target content geographically via the Internet. Direct mail has done it for generations, down to postal zip codes and now radio can do so as well.

Conclusion

Radio is at its heart local, mobile, and free, all excellent value propositions. However, if your listeners can't receive your station, even the best value proposition will fail. While the potential for FM boosters and SFN networks have long been regulatory options, the reality of a useful deployment escaped many who tried and resulted in years of belief that "boosters just don't work." With today's advances in technology and system design capabilities, boosters not only work, and work well, they can be an important tool for increased coverage, improved listener experience and better ratings. The ability to impact listeners and ratings translates to new revenue opportunities and improved profitability for broadcasters.

The authors would like to thank the following for their contributions to this paper; Chris Devine and Bill Hieatt – GEO Broadcast Solutions, Keyur Parikh – GatesAir Radio stations WILL - Alpha Media, KPCC and WXRV.

GATESAIR®