Antenna Technology for ATSC 3.0 – Boosting the Signal Strength

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ABSTACT

U.S. broadcasters planning for the upcoming re-pack must choose a new antenna system from a variety of available designs. Coinciding with the re-pack is an anticipation of a next generation broadcast standard, ATSC 3.0, which utilizes higher data rates and more channel capacity for improved quality of service. By merging broadcasting with the internet it promises more platforms, more flexibility, more services and more robust delivery. All of this "more" comes with a price. It requires more bits to be delivered to more places which requires more signal strength. This paper investigates the signal strength requirements for specific services and details methods to achieve those strengths. Through example, the impact of the different signal boosting techniques will be analyzed. Finally, antenna criteria which plays a major rule in defining necessary signal strength will be discussed.

ATSC 3.0 SIGNAL STRENGTH - SERVICE

So how much signal strength will be required? It should be noted that the purpose of this paper is not to determine actual planning factor numbers for next generation systems but to establish a signal strength baseline and show that antennas can efficiently deliver the needed signal strength. To help bracket the range of signal strengths needed for next generation broadcasting services, a good starting point is the FCC ATSC A/53 minimum field strength requirement of 41dBu. The ATSC Planning Factors are based on a fixed outdoor antenna at a height of 30 feet and a gain of 6dB for UHF (10dBd gain with 4dB down lead loss) and a C/N of 15dB [1]. From here, appropriate corrections can be made and applied to defined services. The commonly assumed loss due to antenna height reduction is given by [2]:

$$Loss\ (dB) = \left(\frac{A}{6}\right) * 20log_{10}\left(\frac{h}{30}\right) \quad (1)$$

Where h is the receive antenna height in feet and $1.5 \leq h \geq 40$ with A given as:

Zone	VHF (dB)	UHF (dB)
Rural	A=4	A=4
Suburban	A=5	A=6
Urban	A=6	A=8

For UHF service, reducing the antenna height from 30 feet to 6 feet causes an average reduction in signal strength of 18.6dB in urban areas and 9.3 dB in rural areas. Building penetration depends on the wall construction and attenuations of 5 to 28dB have been reported [3]. Smaller inefficient antennas such as those used in or on handhelds have typical gains on the order of -3dBd for integrated and 0dBd for external configurations. There is no simple way to place a good planning factor number to indoor fading, but numbers of 1-3dB have been published and used as an AWGN to Rician or Rayleigh dynamic multipath adjustment [4][5]. Finally, a location variability correction of 9 dB from 50% to 95% and 13 dB to 99% has been used for terrestrial services in the UHF TV band [6].

FCC ATSC A/53 minimum field strength	**41 dBu**
Reduce antenna height 30ft. to 6ft. (Suburban)	14 dB
Building wall attenuation (5-28 dB)	8 dB
Smaller inefficient receive antenna gain (-3 dBd)	9 dB
Multipath (AWGN to Ricean / Rayleigh) (1-3 dB)	3 dB
Location correction F(95%,fade margin)	9 dB
Estimated minimum required field strength for an indoor NG broadcast service to support a data rate based on 15 dB C/N	**84 dBu**

After converting to ATSC 3.0, broadcasters will be their own bit managers with the ability to define services on multiple PLP's that fit their business model. It is also important to note that old school thinking of designing for coverage will be replaced by designing for service. Focus will be placed on the number of consumers served. For the purpose of this paper, six possible types of services will be considered along with associated bit rates and required carrier to noise ratios. See Table 1.

		Type of Service					
	Inputs	Deep indoor mobile HD 25 Mbps	Fixed indoor Gateway HD 25 Mbps	Indoor Nomadic - Portable 10 Mbps	Outdoor mobile 5 Mbps	Outdoor fixed HD 25 Mbps	Rural Auto Bootstrp
FCC ATSC A/53 minimum field strength (dBu)	41	41	41	41	41	41	41
Reduce antenna height factor 30 to "X" ft. (dB)	14 Suburban X=6'	19 Urban X=6'	17 Urban X=8'	17 Suburban X=4.5'	14 Suburban X=6'	3 Rural X=18'	10 Rural X=5'
Building wall attenuation (dB)	8	15	5	15	N/A	N/A	N/A
Smaller inefficient receive antenna gain factor (dB)	9	9	6	6	9	3	6
Dynamic multipath - AWGN to Ricean/Rayleigh (dB)	3	3	3	3	3	1	3
Location correction F(95% or 99%,fade margin)	9	9	9	9	9	9	13
Required C/N (dB)	15	14	14	10	4	14	-10
C/N Correction (dB)	-15	-15	-15	-15	-15	-15	-15
Total - Required signal strength at 30' (dBu)	84	95	80	86	65	56	48

Table 1: Six possible types of services and required signal strength at 30' above ground

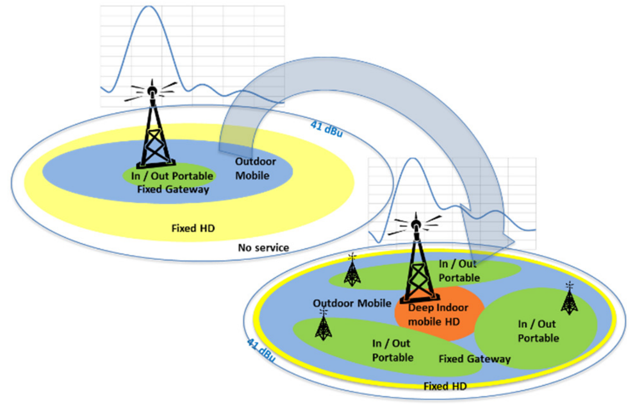


Figure 1: Saturate from main antenna and add SFN sites to boost the signal strength and provide targeted data intensive services.

BOOSTING THE SIGNAL STRENGTH

There are four basic methods to boost the signal strength in selected areas within the defined FCC 41 dBu contour.

1. Increase transmitter power.
2. Increase null fill or beam tilt.
3. Add a single frequency network (SFN).
4. Provide diversity gain though MISO.

At this point, introducing MISO (Multiple Input Single Output) diversity is beyond the scope of this paper and will be the focus of future work. Note that three of the four methods are antenna related. It must also be noted that in many areas data intensive services will require a 10 dB or more increase in signal strength making increasing the transmitter power an unrealistic solution. Increasing the beam tilt increases the signal strength near the tower since the energy is concentrated to a smaller region. Unfortunately for broadcasters with higher gain antennas with narrow main beams radiating from much higher elevations then other wireless services, this is a very inefficient method to produce broad saturation [1].

ADDING NULL FILL AND FUTURE PROOFING

In anticipation of ATSC 3.0 services, future proofing should be considered if purchasing an antenna now. The use of predetermined illuminations with broadband panels or limited bandwidth slotted coaxial pylon antennas that are modifiable in the field can provide the flexibility to customize the null structure at a future date. In order to design an antenna for variable null fill, one must be able to change the illumination. For television broadcast antennas, the method must be simple and have a short conversion time due to their height and inaccessibility on large towers with high power feed systems. It can be shown mathematically that introducing an out of phase excitation approximately 5/8's of the way from the bottom of an array consisting of an illumination with a constant amplitude and linear phase taper provides null fill in the first three nulls below the main beam. Refer to Appendix A [1]. If the phase excitation at this point is 180 degrees, the starting beam tilt is unaffected, thus meeting the goal of close-in signal strength improvement with minimum loss in the far regions. With this in mind, illuminations have been developed by Dielectric "FutureFill" program which allow for very high null fills to be obtained through a simple illumination adjustment [1].

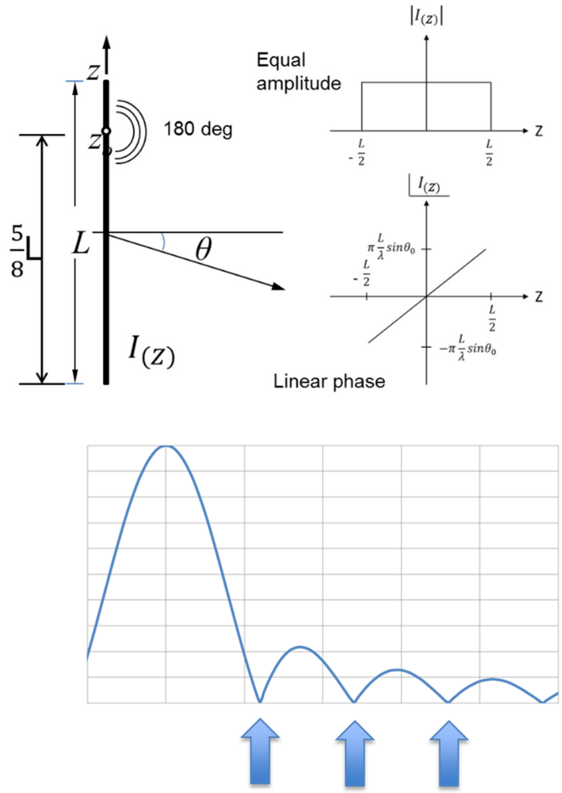
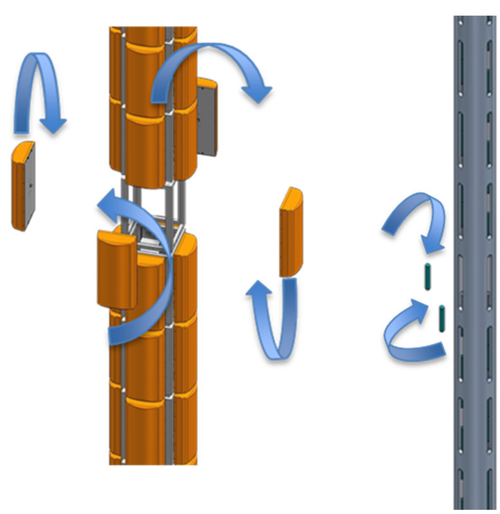


Figure 2: Superimposing an out of phase excitation in custom illuminations provides heavy null fill in the elevation pattern.

For panel antennas, the practical method of adding an out of phase disturbance to the antenna array is to simply flip a set of panels at the correct elevation level upside down. For slot coaxial pylon antennas, the pole can be pre drilled to allow for the reversal of the internal couplers to the opposite side of the slot. Both methods produce a 180 degree phase shift without any effect to the VSWR performance.



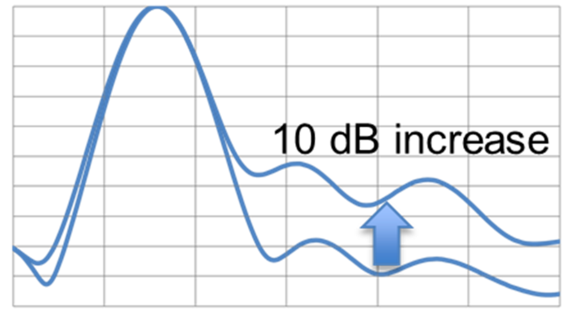


Figure 3: Methods to introduce a 180 degree phase reversal in antenna arrays and resulting increase in null fill.

PLANNING THE ATSC 3.0 NETWORK

The new ATSC 3.0 standard will continue to utilize “main stick” existing infrastructure in the form of high power and tall tower sites. This is especially important in the U.S. market where these sites are the backbone of the industry as it exists today. In addition, the goal of a SFN is to provide extended, robust coverage to consumers outside the reach of the main antenna or in urban areas where terrain shadowing is an issue. This is accomplished using a network of smaller or lower power antennas distributed throughout a coverage area. By overlapping the coverage of each individual antenna a defined contour can be more efficiently covered than with a single high power antenna. In order to illustrate the effectiveness in boosting the signal strength through the use of adding high null fill to the main antenna, adding a SFN or a combination of both, an example case study will be discussed. The software tool used in this example is PROGIRA PLAN. The basic assumptions used in the study are as follows:

- CRC (Communication Research Center, Canada) will be used as the propagation model. It is more realistic then the more common broadcast industry standard, Longley-Rice since it incorporates true clutter data.
- The services, associated bit rates and received signal strengths (RSS) needed at 30’ above ground used for comparison will be as described in Table 1.
- The network area will be limited within the FCC 41 dBu contour or 103 km from the main antenna as described in 47 CFR 73.626 – DTV distributed transmission systems.
- When searching for adequate SFN towers, it will be assumed that all towers are available and only

those that lie inside 10 km of the 103 km circle will be considered.

- Acceptable SFN towers will be restricted to heights greater than 60m

CASE STUDY – WNUV, BALTIMORE

The basic goal of the case study was to boost the signal strength and provide more services to more people. This is accomplished by providing deep indoor mobile HD services to highly populated areas, providing indoor portable services in targeted areas, and by expanding outdoor mobile service capability. WNUV is an 845 kW ERP omni directional service at 1200’ above average terrain in the Washington, Baltimore area and is owned and operated by Sinclair Broadcast Group. The case study will assume that the main antenna is replaced with a field convertible null fill antenna during re-pack. This new antenna will retain full ERP and its current height above average terrain. It is also assumed that the station can strategically add SFN sites to coverage areas using existing towers. Figure 4 is a map of the WNUV existing 41 dBu contour as well as the overlaid 103 km radius. Also represented are all the available towers meeting the criteria lists above.

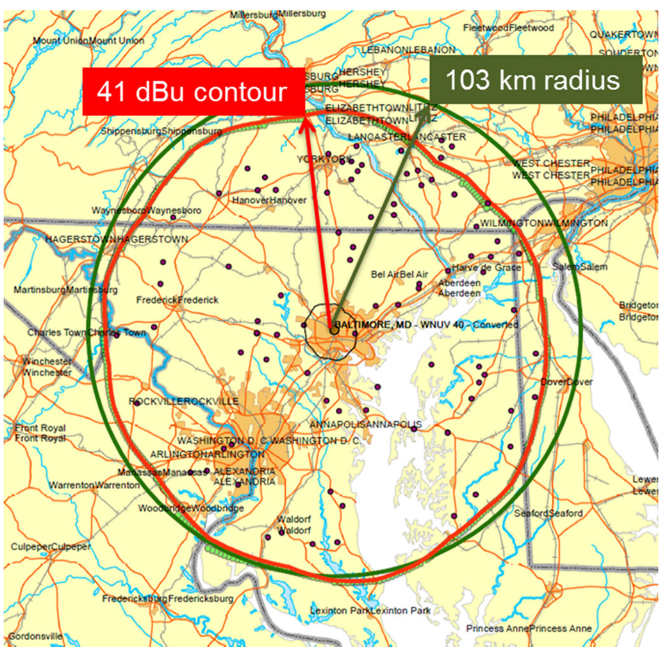


Figure 4: WNUV 41 dBu contour and 103 km radius. The small dots represent all available towers within a 93km radius that are greater than 60m tall.

The benchmark of the analysis is based on the population served by each defined service from the existing main antenna after the ATSC 3.0 switchover. This data is shown in Figure 5 and listed Table 2. For reference, the total population residing within the 103 km radius is 7.9M people. Note that all services are inclusive, meaning that if signal strengths levels are able to provide deep indoor mobile HD, then it is automatically assumed outdoor mobile is also available.

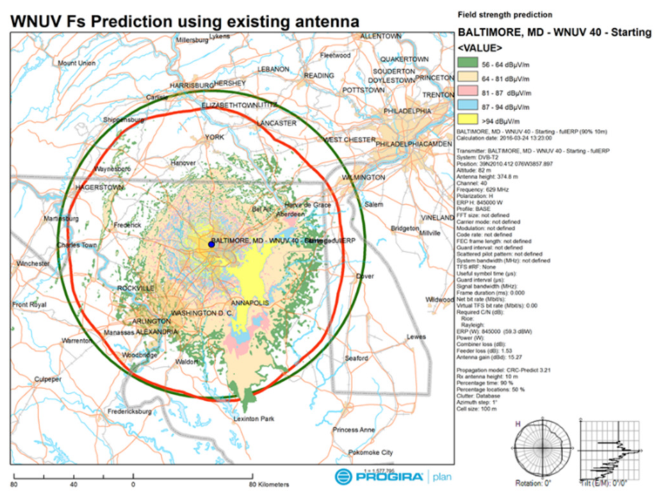


Figure 5: WNUV example using existing antenna for ATSC 3.0

Service	RSS (dBu)	Existing Main Antenna Population Served
Bootstrap	48	6,121,162
Outdoor fixed HD	56	4,940,909
Outdoor mobile	65	3,788,584
Fixed indoor gateway HD	80	1,905,382
Indoor nomadic-portable	86	1,429,098
Deep indoor mobile HD	95	658,493

Table 2: WNUV example. Benchmark populations using existing antenna after ATSC 3.0 switchover.

REPLACING THE WNUV ANTENNA WITH A FIELD CONVERTIBLE HIGH NULL FILL ANTENNA

Now assume that the main existing main antenna was replaced with a field convertible high null fill (FutureFill) antenna during the re-pack process and switched to the high null fill mode. The resulting changes in the populations served by the defined services after increasing the null fill by the simple conversion as described in Figure 4 are shown in Table 3.

Service	RSS (dBu)	Existing Main Antenna Population Served	Future High Null Fill Converted Population Served	% Change	Population Change
Outdoor fixed HD	56	4,940,909	4,847,172	-2%	-93,737
Outdoor mobile	65	3,788,584	3,716,684	-2%	-71,900
Fixed indoor gateway HD	80	1,905,382	1,896,801	0%	-8,581
Indoor nomadic-portable	86	1,429,098	1,527,028	7%	97,930
Deep indoor mobile HD	95	658,493	1,001,992	52%	343,499

Table 3: WNUV example. Comparison of number of people served by each defined ATSC 3.0 service after converting to a high null fill mode.

The results show a slight loss of 174,000 potential consumers (indicated by the blue cells) using lower RSS services in the outer coverage areas. It also shows a substantial gain of 441,000 in potential consumers that may use data intensive services in the near in coverage areas. The data from Table 3 is plotted in Figure 6 to better illustrate the effect of increasing the null fill.

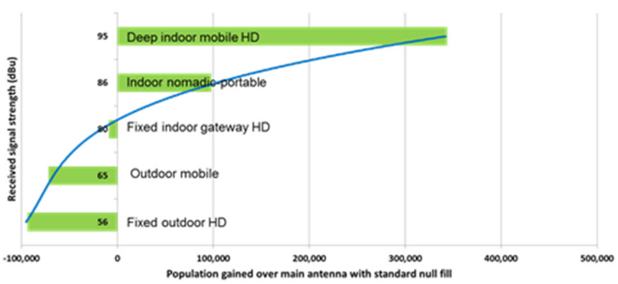


Figure 6: WNUV example. Comparison of number of people served by each defined ATSC 3.0 service after converting to a high null fill mode.

ADDING SFN SITES TO THE EXISTING WNUV ANTENNA SYSTEM

Next, the effect of strategically placing four optimized 50 kW ERP SFN sites within the limits of the FCC contour will be analyzed. In the process, each site begins as an omni directional azimuth pattern. Power reductions are then performed in all directions to meet the FCC limitations. The results predict the best theoretical azimuth pattern to be applied at each site. Figure 7 is a map of the locations chosen for each SFN site and Figure 8 depicts the optimized theoretical patterns generated for each site.

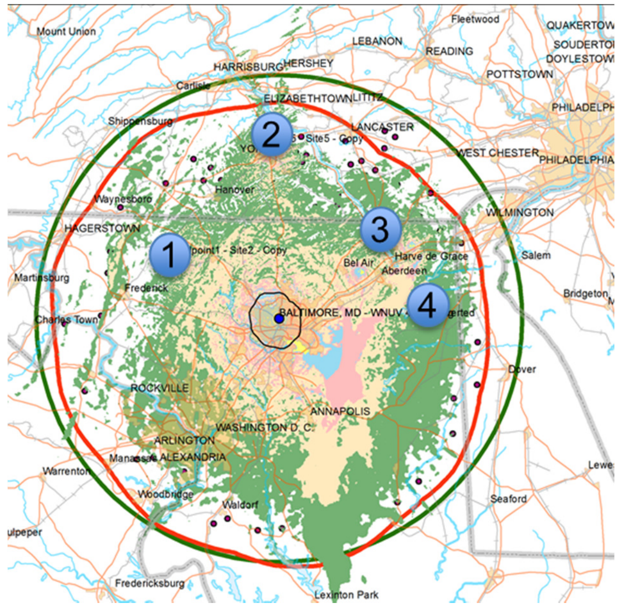


Figure 7: WNUV example. Four tower locations chosen for the SFN sites to be added to the existing main antenna to create the full ATSC 3.0 network.

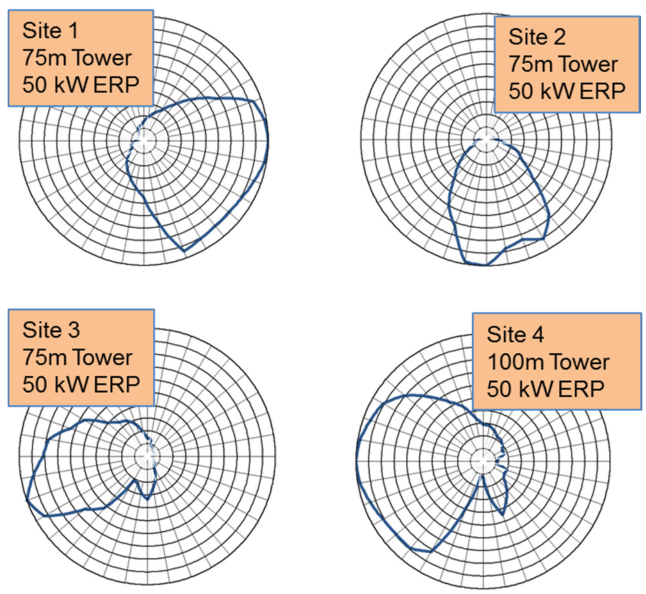


Figure 8: WNUV example. Best fit optimized theoretical azimuth patterns chosen for each site based on power reductions to meet FCC limits.

The effect on populations served by the previously defined ATSC 3.0 services by adding four theoretical SFN sites to the existing main antenna with standard null fill are listed in Table 4 and plotted in Figure 9.

Service	RSS (dBu)	Existing Main Antenna Population Served	Standard Elevation Pattern + SFN Population Served	% Change	Population Change
Outdoor fixed HD	56	4,940,909	5,405,598	9%	464,689
Outdoor mobile	65	3,788,584	4,189,184	11%	400,600
Fixed indoor gateway HD	80	1,905,382	2,157,756	13%	252,374
Indoor nomadic-portable	86	1,429,098	1,702,093	19%	272,995
Deep indoor mobile HD	95	658,493	734,238	12%	75,745

Table 4: WNUV example. Comparison of number of people served by each service under ATSC 3.0 when adding four SFN sites to the existing main antenna with standard null fill.

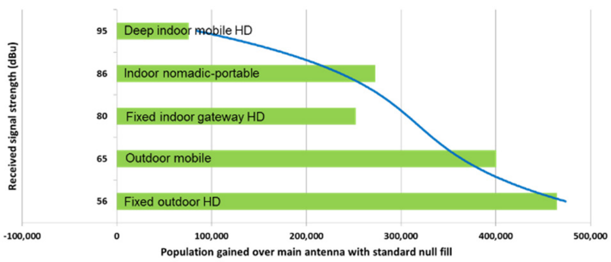


Figure 9: WNUV example. Comparison of number of people served by each service under ATSC 3.0 when adding four SFN sites to the existing main antenna when standard null fill.

As seen by the data, 1,460,000 possible consumers have been gained throughout the coverage area. Figure 9 illustrates a slight gain in consumers serviced by data intensive services while showing a significant gain in consumers serviced by lower bit rate services.

ADDING SFN SITES TO THE WNUV ANTENNA CONVERTED TO HIGH NULL FILL

The next scenario to be analyzed is theoretically replacing the existing antenna with a FutureFill field convertible design for re-pack and adding SFN sites. Table 5 and Figure 10 display these results.

Service	RSS (dBu)	Existing Main Antenna Population Served	Future High Null Fill Converted + SFN Population Served	% Change	Population Change
Outdoor fixed HD	56	4,940,909	5,283,509	7%	342,600
Outdoor mobile	65	3,788,584	4,099,525	8%	310,941
Fixed indoor gateway HD	80	1,905,382	2,142,988	12%	237,606
Indoor nomadic-portable	86	1,429,098	1,760,761	23%	331,663
Deep indoor mobile HD	95	658,493	1,077,222	64%	418,729

Table 5: WNUV example. Comparison of number of people served by each service under ATSC 3.0 when adding four SFN sites to a new field convertible high null fill main antenna.

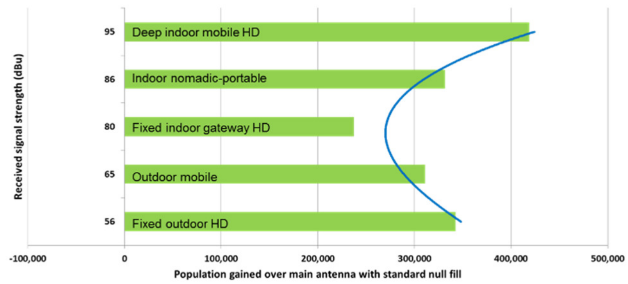


Figure 10: WNUV example. Comparison of number of people served by each service under ATSC 3.0 when adding four SFN sites to a new field convertible high null fill main antenna.

Overall, 1,640,000 new possible ATSC 3.0 consumers have been added. This scenario results in a significant gain in consumers serviced by both lower and higher data rate services. From the data, a much more even distribution in populations served by all services is observed compared to just using the existing antenna for ATSC 3.0 delivery and adding an SFN.

REPLACING THEORETICAL ANTENNA PATTERNS WITH REAL DESIGNS

The next logical step in the ATSC 3.0 network planning process is to replace the best fit theoretical azimuth patterns generated by the planning software with real designs. A combination of panel and slotted coaxial antenna designs were used to replicate the theoretical patterns shown in Figure 8. The overlay comparison is shown in Figure 1.

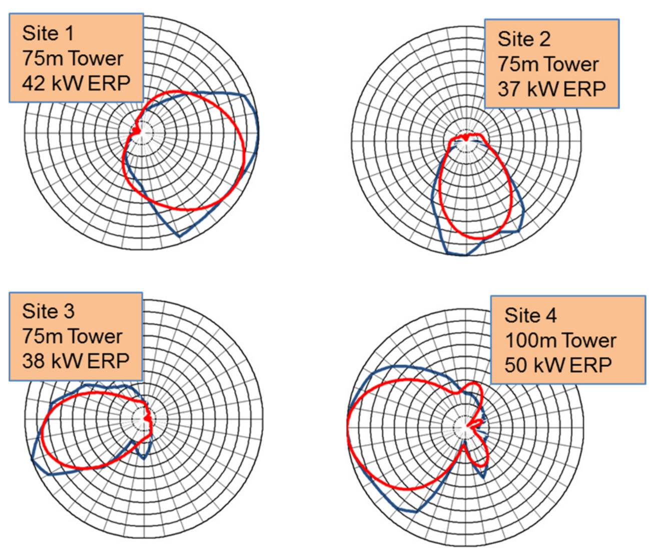


Figure 11: WNUV example. Real antenna design azimuth patterns (shown in red) used to replicate the optimized theoretical azimuth patterns (shown in blue).

Note that in most cases, the ERP had to be reduced from 50 kW to remain within the theoretical pattern footprint. The impact of replacing the best fit theoretical patterns with real antenna design are shown in Table 6.

Service	RSS (dBu)	Existing Main Antenna Population Served	Future High Null Fill Converted + Real Ant. SFN Population Served	% Change	Population Change
Outdoor fixed HD	56	4,940,909	5,276,767	7%	335,858
Outdoor mobile	65	3,788,584	4,095,082	8%	306,498
Fixed indoor gateway HD	80	1,905,382	2,123,632	11%	218,250
Indoor nomadic-portable	86	1,429,098	1,742,929	22%	313,831
Deep indoor mobile HD	95	658,493	1,065,715	62%	407,222

Table 6: WNUV example. Comparison of number of people served by each service under ATSC 3.0 when adding four SFN sites with real antenna designs to a new field convertible high null fill main antenna.

As can be seen from the data comparison between Table 5 and Table 6, with careful antenna design, a loss of only 60,000 possible ATSC 3.0 consumers out of 1,640,000 is observed. This translates to a minimal 4% loss.

WHAT TYPE OF ANTENNAS WILL BE BEST SUITED FOR ATSC 3.0 SFN NETWORKS

Different types of broadcast antennas have different advantages and disadvantages. For example, slotted coaxial pylon antennas are much smaller in size thus have substantially less wind load then panel arrays with the same gain. They also exhibit higher reliability due to the fact that slotted coaxial antennas have less connections and less parts. Another feature of slotted antennas is their pattern versatility. Elevation patterns can be shaped by discretely controlling the amplitude and phase emanating from each vertical layer. The azimuth patterns can also be tailored to meet even the most difficult coverage requirements by changing the pipe size, the number and orientation of slots around the pipe, the power division between those slots and through the addition of fins and directors. The disadvantage to slotted antennas that a slot radiator is inherently narrow band and thus has limited channel range. Panel antennas on the other hand are broadband and are an excellent choice for co-located shared SFN sites. They too exhibit excellent pattern flexibility, by varying the array radius, number of panels around, their location and orientation as well as their amplitude and phase. Another choice that will be considered for future ATSC 3.0 SFN sites are slot cavity antennas. They are basically a cross between a panel and a slotted coaxial design, providing panel bandwidth in a pylon package. In short, there will be no “one size fits all” antenna solution for ATSC 3.0 SFN’s. A combination of panel, slot and broadband slot cavity antennas will be required.

CONCLUSION

It is clear that ATSC 3.0 services will require a new definition of received signal strengths. By planning ahead and through the use of innovative antenna design as well as advanced SFN planning tools, these required signal strengths can be achieved.

APPENDIX A

In can be shown mathematically that superimposing an out of phase excitation approximately 5/8’s of the way from the bottom of an array consisting of an illumination with a constant amplitude and linear phase taper provides null fill in the first three nulls below the main beam. If the phase excitation at this point is 180 degrees, the starting beam tilt is unaffected, thus meeting the goal of close-in signal strength improvement with minimum loss in the far regions.

A continuous source distribution can be used to approximate linear arrays of discrete elements. The far field pattern of a continuous line source having a uniform amplitude and linear phase taper is given in equation (1).

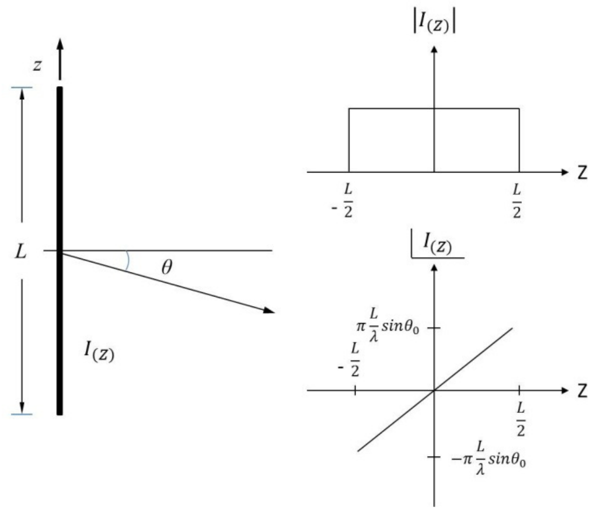


Figure 1: Continuous line source with equal amplitude and linear phase taper.

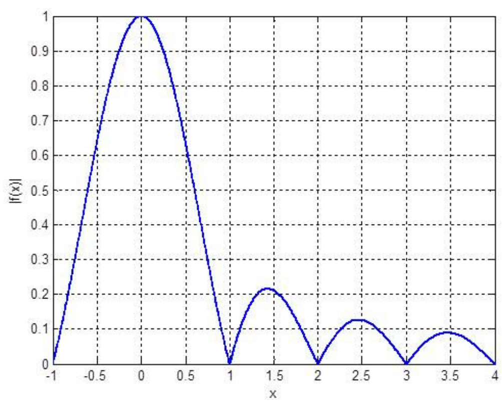
$$F(\theta) \sim \frac{\sin \pi \frac{L}{\lambda}(\sin\theta - \sin\theta_0)}{\pi \frac{L}{\lambda}(\sin\theta - \sin\theta_0)} \qquad (1)$$

Letting

$$x = \frac{L}{\lambda}(sin\theta - sin\theta_0) \quad (2)$$

$$F(\theta) \approx \frac{sin\ \pi x}{\pi x} \quad (3)$$

The pattern maximum or beam tilt is located at $\theta = \theta_0$ and the nulls located by at x = +/-1, +/-2, +/-3,….



A point source is placed along the Z axis at location Z_0 as shown in Figure 2.

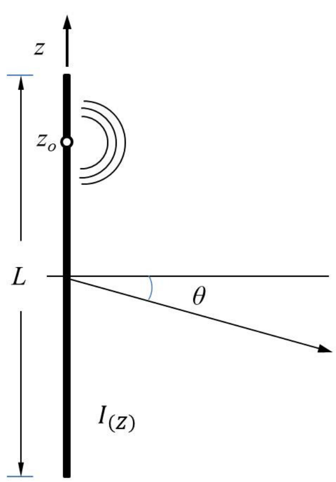


Figure 2: Point source placed along the continuous line source.

The far field pattern of the point source at point Z_0 is given by equation (4).

$$F_p(\theta) = Qe^{j\phi}e^{-j2\pi\frac{Z_0}{L}x} \quad (4)$$

Q is the amplitude and ϕ the offset of the feed phase of the point source relative to the line source at the same location.

$$\phi = \phi_{pt} - \phi_{line}(z_0) \quad (5)$$

In choosing the phase offset between the point source and the line source, one must consider that the objective is to have the beam tilt remain at $\theta = \theta_0$ and be unaffected by the addition of the point source. For this to be true the only two choices are the point source to be in phase or 180 degrees out of phase from the line source at the point sources location. Choosing ϕ = 180 will be considered at this point.

The total pattern is the coherent sum of the line source and point source and is represented by equation (6).

$$F(\theta) \approx \frac{sin\pi x}{\pi x} + Qe^{j\pi}e^{-j2\pi\frac{Z_0}{L}x} \quad (6)$$

By placing the fields of the line source and the point source in phase quadrature at a defined location in the far field will ensure cancellation cannot occur and thus null fill is obtained. The phase angle of the point source is readily determined from the exponential of the second term in equation (6).

$$\pi - 2\pi\frac{z_0}{L}x \quad (7)$$

Setting the point source in phase quadrature with the line source and solving for the location of the point source to achieve null fill centered around the first three null or x=2 produces the following result.

$$\pi - 2\pi\frac{Z_0}{L}x = \frac{\pi}{2}\ at\ x = 2$$

$$\frac{z_0}{L} = .125 \quad (8)$$

Note that this location is .125L above the array centerline or approximately 5/8 L from the bottom of the array.

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Acknowledgement

A special thank you to good friend Dan Janning for his personal help in formulating the mathematical basis to support the null fill technique described in this paper. Dan is currently an Electronics Engineer, AFRL/RYMD
Air Force Research Laboratory Sensors Directorate,
Multi-Spectral Sensing and Detection Division,
RF Technology Branch

The author would like to also thank Andy Whiteside and Bill Soreth for their contributions.