BROADCAST ANTENNA DESIGN TO SUPPORT FUTURE TRANSMISSION TECHNOLOGIES

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Summary

It doesn't matter what future television transmission technology is being discussed for the new ATSC3.0, they all have one thing in common, the need for higher data rates and more channel capacity. Broadcasters will become "Bit Managers" knowing that more power equates to higher quality of service (QoS). With broad industry consensus, assumptions can be made about next generation systems. In general they will be based on orthogonal frequency division multiplexing (OFDM) synchronous single frequency networks (SFN) limited within the current coverage footprint as defined by the FCC and will have the flexibility to support capacity growth. As a result of post-auction repack there is likely to be more co-located channel sharing requiring broadband antenna systems with the central high power antenna retaining full ERP status. The use of physical layer pipes (PLP's), a new concept to US broadcasters will allow for business models to evolve and to tailor areas for fixed (rooftop reception), nomadic (stationary or slow moving reception at a variety of locations), and mobile (fast moving, vehicular reception) services within the coverage umbrella. In order to take full advantage of these efficiencies, the antenna must be able to adapt to provide the necessary signal strength in the desired locations.

Introduction

Wireless communications is based on frequency re-use and capacity is usually defined by the number of users a system can support. Serving large coverage areas with a single high power antenna mounted on a tall tower makes it impossible to re-use the same frequencies throughout the system. One way wireless operators "future proof" their antennas is to have them equipped with remote electrical tilt or RET. When a cell is no longer able to provide an acceptable quality of service, cell splitting can be employed to increase system capacity. This is typically done by increasing the beam tilt at one site in order to reduce the amount of coverage area and thus the amount of traffic within that cell and avoid inter-cell interference with neighboring cells. New groups of sites are then installed to fill in the gaps. The smaller cells allow for a greater level of frequency re-use providing more channels per unit coverage area.

Although the method will be different, the idea of future proofing a high power broadcast antenna in anticipation of next generation broadcast requirements should be considered. In any of the proposed next generation systems, the digital bandwidth is not limited by the number of users, but by the data rate supported within a given carrier to noise ratio (C/N). Increasing the capacity is not done by reducing the traffic, but by increasing the amount of throughput that can be delivered. The design objective for next generation broadcast antennas may encompass the need to provide a system that is capable of controlling the signal strength and thus the C/N versus the distance from the tower. This will allow for service specific robustness to be delivered to selected areas within the coverage range.

Multi – PLP Business Models

Physical layer pipes (PLP) allow the broadcaster to offer a variety of business models within the licensed coverage area. Since every PLP can have its own modulation and forward error coding (FEC), different levels of robustness and quality of service (QoS) can be broadcast within the channel. For example, the channel can be split into 3 PLP's, one for HD/ Data services, a second for nomadic SD services and a third for mobile services. See Figure1. 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 deliver variable C/N. To approximate 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. When considering indoor reception, the receive antenna height and gain, building wall attenuation and small scale fading must all be taken into account. 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. Studies have found that by reducing the antenna height from 30 feet to 8 feet caused an average reduction in signal strength of 6.7dB.[1] Building penetration depends on the wall construction and attenuations of 10 to 28dB have been reported[2]. 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. Indoor environments experience more dynamic multipath and small scale fading which produces more variability in the signal versus time and motion thus further reducing the carrier to noise ratio. Actual signal strength variability numbers depend on the complexity of the environment, the motion of the receiver and the type of transmission, circular or linear polarization. There is no simple way to place a good planning factor number to indoor fading. DVB-T studies have suggested a 9dB increase in C/N is required when using a time varying Rayleigh model over Ricean.[4] By summing these basic assumptions, one could argue the minimum required field strength for an indoor next generation broadcast service to support a data rate based on a 15 dB C/N is 94dBu.

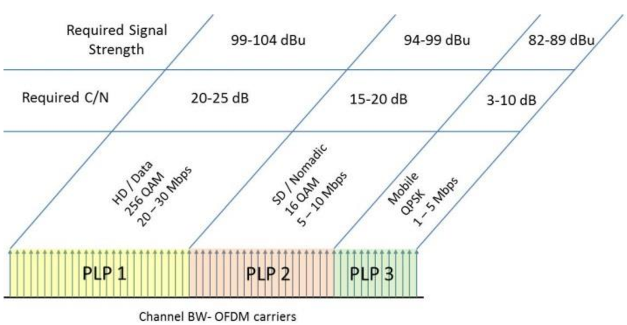


Figure 1: Physical layer pipes (PLP)

As shown in Figure 1, it is clear that in each case the bit rates for each PLP within the channel are different and will require different corresponding carrier to noise ratios (C/N's). In order to tailor the desired service to specific locations within the coverage area, the signal strength versus distance from the tower must be a controllable feature of the antenna.

Next Generation Networks

Service area specific robustness can be achieved through the use of PLP's and signal strength concentration methods provided by the antenna. Consider an urban broadcast site located in the heart of a dense population. With the increasing expectation of high indoor QoS, the future goal will be to provide as much signal strength as possible in the immediate coverage area, providing high data rates with sufficient building penetration. Moving beyond the metropolitan area, where building penetration may not be required, nomadic services maybe preferred. Outside of this area, mobile services using a lower level of modulation for reliable reception can be considered. In order to accommodate high data rate services outside of the immediate coverage area, on-channel gap filling repeater sites can provide pockets of high signal strength. See Figure 2.

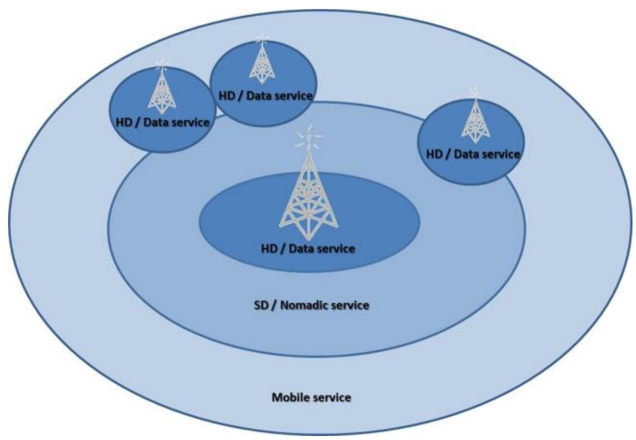


Figure 2: Example of a next generation network plan.

Effect of Beam Tilt with High Gain Antennas

As mentioned earlier, the use of RET is common practice in today's wireless industry to reduce coverage area. Increasing the beam tilt also increases the signal strength near to 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, this is a very inefficient method to produce immediate vicinity saturation. Figure 3 helps to illustrate the effect of increasing the beam tilt with a high gain antenna. A simple exponential amplitude taper and progressive phase taper is used to vary the beam tilt of a typical 24 layer broadcast antenna.

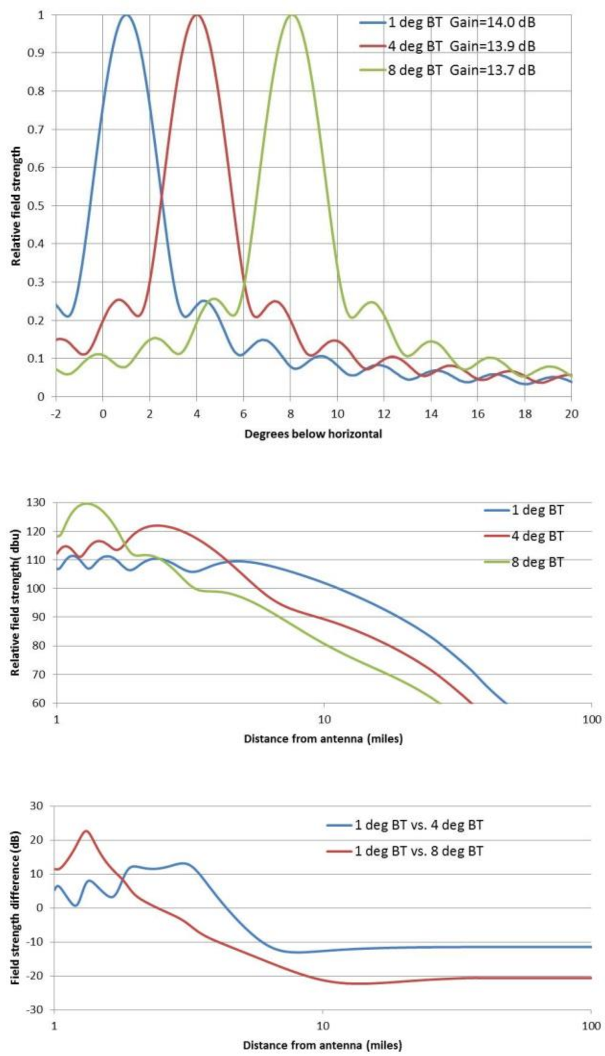


Figure 3: Beam tilt effect on coverage for high gain antenna. Field strength is based on 1MW ERP at a HAAT of 1000' using the FCC 50, 90 curves for UHF.

Even though signal levels can be increased 5 to 10 dB in a limited region close to the immediate coverage area, losses of more than 10 dB are observed after reaching a few miles from the antenna. Since the constant phase taper technique used to increase the beam tilt allows the gain of the antenna to remain relatively constant (within .3dB in the example), this loss in signal strength in the far region is purely a function of the narrow beam width and lack of signal on the upper side of the main beam. This will not be acceptable in the described next generation network plan since a small amount of receivers would experience stronger signal and a large amount of "gap fillers" would be required to increase the signal strength levels outside of the immediate coverage area. The goal needs to be to increase the signal strength in the immediate coverage area with a minimum amount of loss in the far regions.

Convertible Null Fill Antenna

The null fill of an antenna is defined by the spacing between radiating elements and their illumination or relative amplitude and phase of each radiator in the elevation plane. Illuminations can be as simple as a single point where all the amplitudes and phases are the same for each radiator to very complicated where each radiator has a unique characteristic. Figure4.

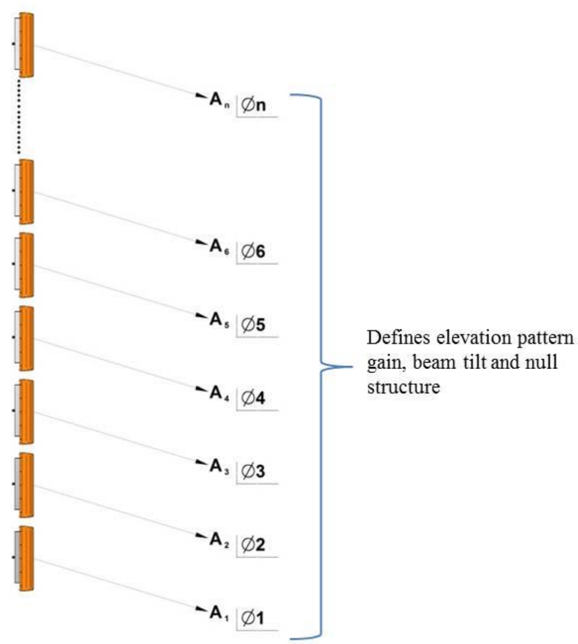


Figure 4: Illumination is the amplitude and phase of each radiator which defines the characteristics of the elevation pattern.

In order to design an antenna to have variable null fill, one must be able to change the illumination. For television broadcast antennas, the method must be simple due to their height and inaccessibility on large towers with expensive 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. 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 which allow for very high null fills to be obtained through a simple illumination adjustment.

As mentioned earlier, the future of broadcasting will most likely see more co-location and antenna sharing which will drive antenna designs towards broadband panel configurations. Individual panels in a panel array are fed through a series of power dividers and feed lines which determine their relative amplitude and phase and thus defining the illumination. Since antennas fed with equal amplitude and linear phase are of little value to the broadcaster since they provide zero null fill, custom illuminations have been developed that react positively to the theory discussed in the mathematical appendix. To illustrate how the use of a field convertible panel illumination can simply be adjusted to increase null fill, 4 scenarios are presented using a 24 layer antenna consisting of a 12 panel vertical array producing the elevation pattern with standard null fill shown in Figure 5.

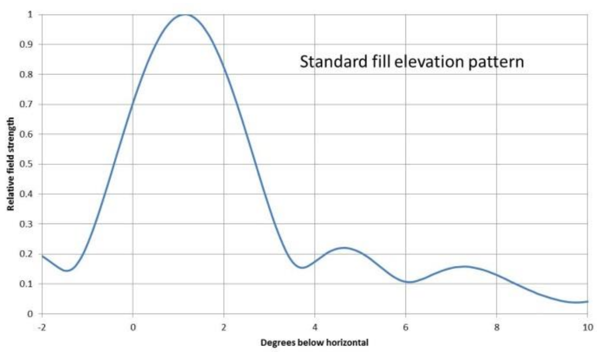


Figure 5: Starting design elevation pattern of a typical 24 layer (12 panels), antenna.

1) Turning 1 panel off.

This requires only removing one power divider and connecting a single line to a panel with a short correctly phased jumper. With the slight power division created by inactivating one panel and the gap left in the vertical array taken into account, the new pattern is shown in Figure 6. The average increase in the null structure from 3.5 to 9 degrees below horizontal is 4.22dB with a gain reduction of only .5dB with respect to the original pattern shown in Figure 5.

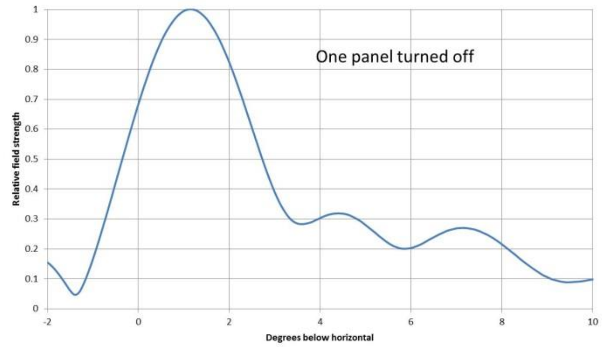


Figure 6: Effect of turning one panel off using a custom illumination designed for field modification to high null fill mode.

2) Re-phasing one panel by 180 degrees.

Since the only phase offsets relative to the rest of the array that will not alter the original beam tilt are 0 and 180 degrees, a panel can simply be turned upside down to achieve the desired effect. In this case for the example given, the average null fill increase is 8.15dB with a gain reduction of 2.1dB with respect to the original standard null fill elevation pattern. Figure7.

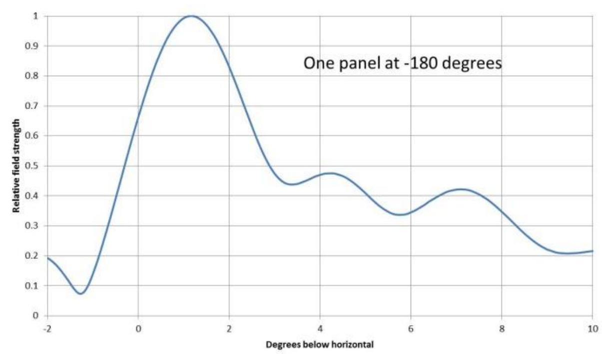


Figure 7: Effect of turning one panel upside down using a custom illumination designed for field modification to high null fill mode.

3) Turning one panel off and re-phasing one panel by 180 degrees.

The combination of turning off one panel and turning one panel upside down produces the new pattern as shown in Figure 8. Note here the average increase in null fill form 3.5 to 9 degrees below horizontal is 9.42dB with a gain reduction of 2.7dB.

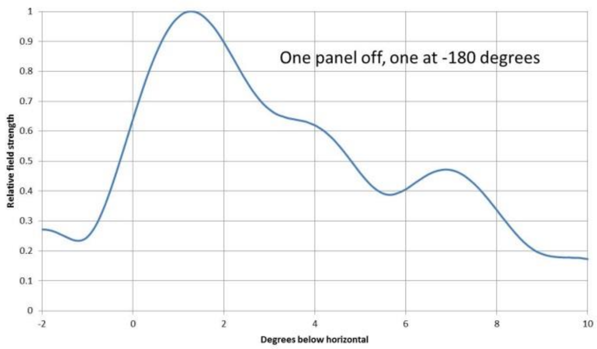


Figure 8: Effect of the combination of turning one panel upside down and turning one panel off using a custom illumination designed for field modification to high null fill mode.

4) Re-phasing two panels by 180 degrees.

The effect of re-phasing 2 two panels by 180 degrees by physically turning them upside down is shown in Figure 9. The average null fill increase is 11.4dB with a gain reduction of 4.3dB.

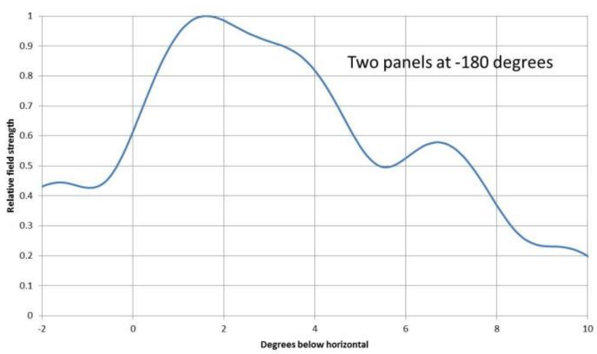


Figure 9: Effect of turning two panels upside down using a custom illumination designed for field modification to high null fill mode.

To better understand the average null fill increase vs. the gain reduction, the field strength vs. distance from the antenna can be plotted. For comparison purposes a height above average terrain of 1000’ using the FCC 50, 90 curves for UHF are used to compare the original design pattern with the effect of turning off one panel in conjunction with physically flipping one panel upside down to achieve a 180 degree phase difference. The elevation patterns for these cases are shown in Figures 5 and 8. The ERP’s based on the elevation gains of each pattern are 1000kW and 537kW respectively, assuming constant power to the antenna. The resulting expected field strength and field strength difference are shown in Figure 10. The reduced ERP and resulting loss of service at or near the horizon can be overcome several ways. It may be possible to plan on and increase transmitter power. As alluded to earlier, it may be possible to change the FEC for a resulting offset of lost gain to maintain the service area with corresponding reduction in useful data bandwidth. In the context of a next generation system, the ability to overlay SFN or on-channel gap filling repeaters may provide the desired service area signal levels.

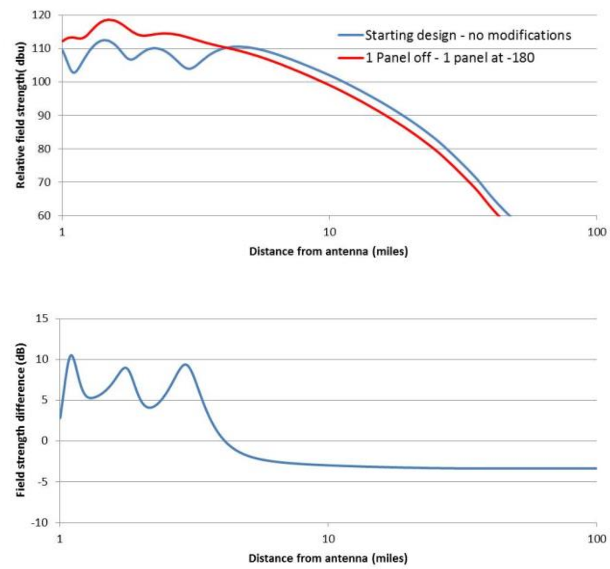


Figure10: Comparison in field strength of the original design vs. the new high null fill mode that can be achieved with a minimal adjustment to the antenna.

When comparing the effect on coverage of electrical beam tilt as shown in Figure 3 to the effect of increasing the null fill from Figure 10, it becomes obvious that increasing the null fill is the preferred method for immediate area signal saturation.

Direction Specific Service

Broadcast panel antennas provide the capability of customizing the elevation pattern differently on difference faces of the azimuthal array. This in turn can add another level of flexibility to next generation networks as shown in Figure 11.

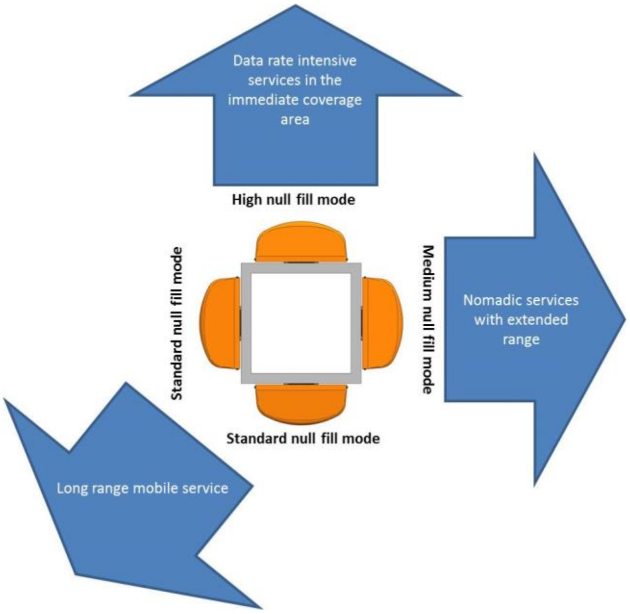


Figure 11: Panel antenna supporting direction specific services though null fill variation on different faces.

Conclusion

Next generation ATSC3.0 broadcast technology will be based on OFDM single frequency networks with the flexibility to support capacity growth. More co-located channel sharing will become necessary, driving broadband antenna solutions. The use of PLP's will allow for the tailoring of service area specific robustness making the future broadcasters "Bit Managers". In anticipation of this new broadcast technology and the launch of new services, the ability to easily tailor the antennas signal strength to take full advantage of PLP's should be considered if purchasing an antenna now. To accomplish this, the use of predetermined illuminations with broadband antennas that are modifiable in the field can provide the flexibility to customize the null structure at a future date.

Mathematical Appendix

Summary

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.

Point Source Disturbance

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).

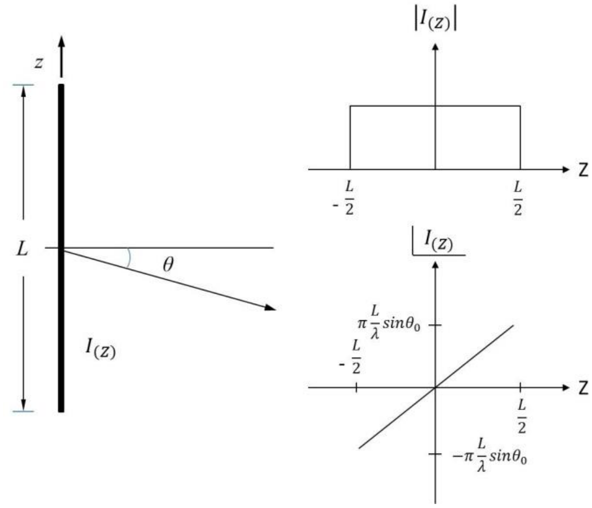


Figure 1: Continuous line source with equal amplitude and linear phase taper.

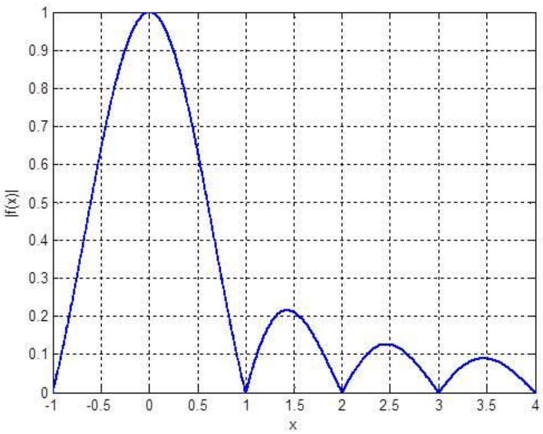
$$F(\theta) \sim \frac{\sin \pi\frac{L}{\lambda}(sin\theta - sin\theta_0)}{\pi\frac{L}{\lambda}(sin\theta - sin\theta_0)} \quad (1)$$

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.

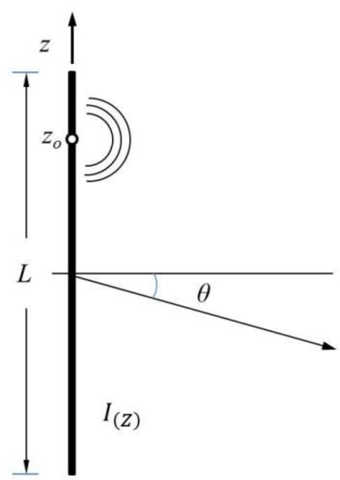


Figure 2: Point source placed along the continuous line source.

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.

References

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[2] TV Technology: "DTV in the House, Part1", Doug Lung, Sept 5, 2007

[3] IEEE Transactions on Broadcasting (Impact Factor 2.09) 04/2009 "Analysis of DVB-T signal variation for indoor portable reception", A Martinez, D. Zabala, I. Pena, P. Angueira, M. Velez, A Arrinda, D.de la Vega, J.L. Ordiales

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