

A Note on the Effects of Broadcast Antenna Gain, Beam Width and Height Above Average Terrain

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Dielectric L.L.C. Raymond, ME 30 September 2014

Abstract

With channel re-pack looming in the broadcasters' future, and also a possibility of a new modulation scheme, it seems appropriate to re-fresh a topic so important to antenna system design. This paper will examine the effect that antenna gain, beam width and height above average terrain has on the coverage and signal strength of the next generation broadcast system.

Introduction

U.S. broadcasters planning for the re-pack must make choices about a new antenna system from a variety of designs available. Coinciding with the re-pack is an anticipation of a next generation broadcast system with higher data rates and more channel capacity all leading towards more power equating to higher quality of service. The next generation system will most likely use physical layer pipes (PLP's) allowing for the tailoring of service area robustness. This technology will require the antenna to provide areas of high signal saturation in order to support the PLP's carrying data rate intensive services. [1]

Elevation Pattern Gain and Efficiency

Gain requirements for the new ATSC3.0 depend on transmitter power, and necessary field strength as determined by the data rate to support the services in a given area. By the very basic definition, achieving a given effective radiated power (ERP) is a choice between using a low power transmitter and high gain antenna or vice-versa. However, the use of a high gain antenna requires some special considerations since the higher gain results from narrowing the main beam, hence reducing local field strengths and increasing the field strength near and at the horizon. For the purpose of this discussion, gains and directivity are defined on an RMS basis, thus will be a function of the elevation pattern only. The gain of the antenna is equal to the product of the directivity and the antenna efficiency.

$$G = \eta D \quad (1)$$

The elevation gain is a function of the number of radiating elements, their spacing and the illumination or relative radiated amplitude and phase. In order to provide continuous coverage for as far as possible, the elevation pattern must be shaped with null fill and beam tilt by varying the illumination. This of course requires additional energy and thus reduces the aperture efficiency. 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. Figures 1 and 2.

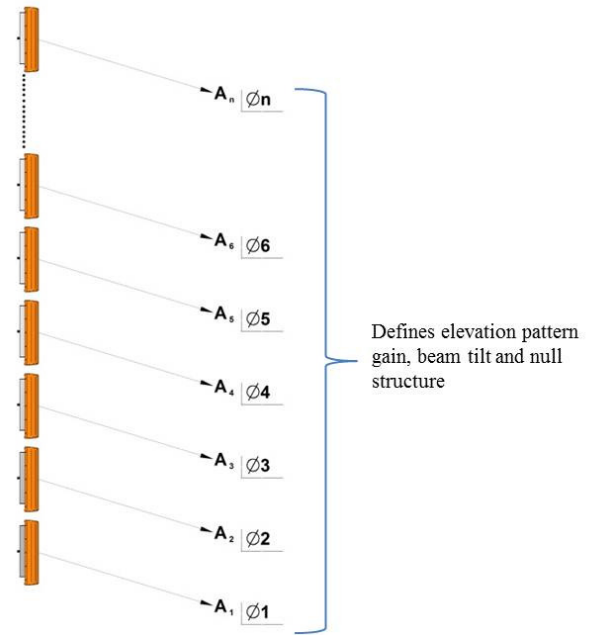


Figure 1: Illumination is the amplitude and phase of each radiator which defines the characteristics of the elevation pattern.

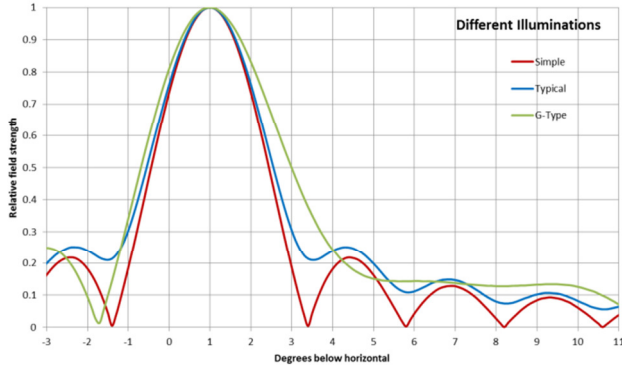


Figure 2: Different illuminations produce different null structure and elevation beam width.

The elevation patterns in Figure 2 are all 24 layers of vertical elements spaced one wavelength apart and phased for one degree of beam tilt. Special notice should be given to the “G-Type” illumination which was developed specifically for DTV operation. It provides smooth null fill with lower gain, wider beam width and flat output response over a wide bandwidth. With reference to the three cases shown in Figure 2, antennas with these types of illuminations used by today’s broadcasters are compared in elevation gain for a given number of layers. Refer to Figure 3.

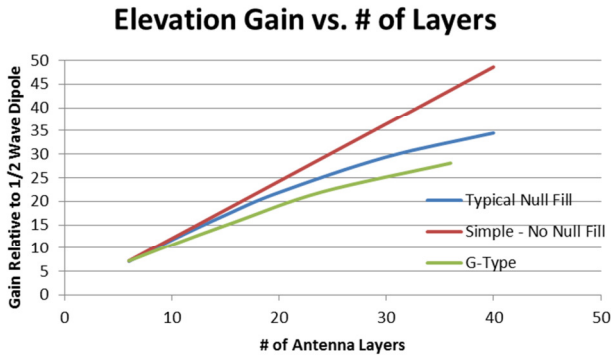


Figure 3: Gain vs. number of layers for no null fill, typical null fill and G-Type illuminations.

Two observations can be made from Figures 2 and 3. First, with the addition of null fill, the aperture efficiency decreases with increased number of layers. Second, the elevation pattern beam width can be significantly increased through control of the aperture illumination.

Elevation Pattern Beam Width

The directivity, based on an estimate of the beam area from the half power beam widths of the patterns in the two horizontal and vertical planes is given by equation 2. [2]

$$D = \frac{41,253}{\theta \phi} \quad (2)$$

Where θ and ϕ are the half power beam widths expressed in degrees. It can be stated that the antenna gain and beam width in the vertical plane are simply inversely proportional. Doubling the vertical beam width reduces the gain to half.

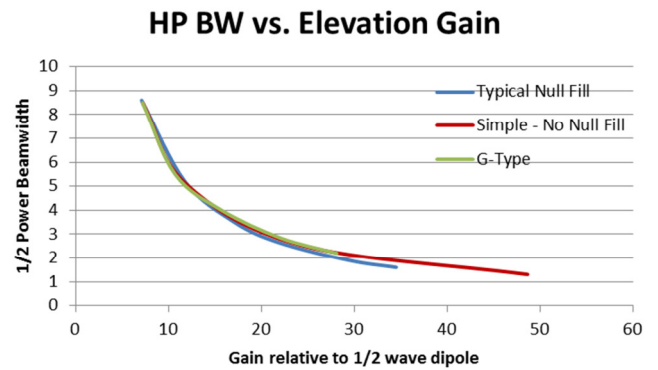


Figure 4: Elevation pattern half power beam width vs. elevation gain.

Figure 4 reveals an interesting result. As null fill is applied by variations in the illumination, the half power beam width is only a function of the resulting reduction in gain.

Antenna Height Effects on ERP

The plane earth model assumes a 2-ray coherent addition of the direct and the ground reflected signals as shown in Figure 5.

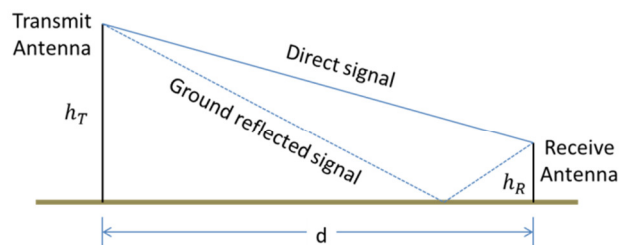


Figure 5: Plane earth ray model.

The difference in path length between the rays add differently depending on the distance (d). As the distance increases the summation passed through a number of amplitude cycles until the path difference is less than a half wave. At this breakpoint distance d_b , given by equation (3), the fields decay asymptotically [3] [4]. Beyond the breakpoint, the overall path loss (L) becomes a function of only the antenna heights and the distance between them and is independent of frequency.

$$d_b = \frac{4h_T h_R}{\lambda} \quad (3)$$

$$L = \frac{d^4}{(h_T h_R)^2} \quad (4)$$

Therefore it can be stated that in the region beyond the breakpoint the effective radiated power (ERP) is proportional to the square of the transmitting antennas height above average terrain (HAAT).

$$ERP \propto h_T^2 \quad (5)$$

It is noted that from this relationship, a doubling of the antenna height produces a 6dB increase in ERP. This calculation can be used as a rule of thumb and correlates well with the FCC (50,90) curves as shown in Figure 6.

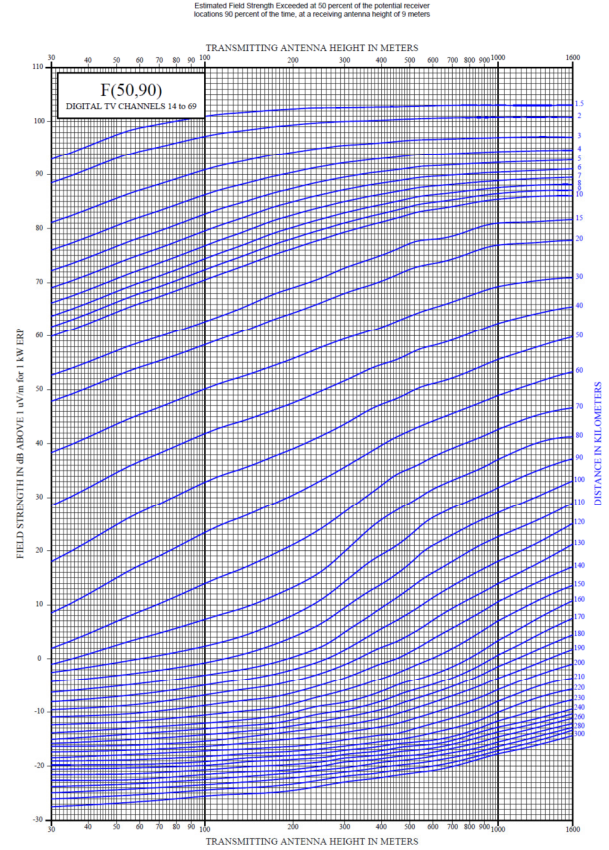


Figure 6: FCC (50,90) curves for UHF channels 14-69.

Using the elevation pattern shown in Figure 7, a comparison of field strengths based on 1MW ERP at heights of 500' and 1000' using the FCC (50,90) curves for UHF is shown in Figure 8. Here it can be clearly seen that after the 6.5 mile breakpoint, the increase in ERP corresponds well with our rule of thumb of 6dB. Using the same elevation pattern, the same scenario is evaluated in Figure 9 for increased height from 1000' to 2000'. Again after the breakpoint of 13.1 miles, the ERP is boosted on the order of 6dB. Note that the breakpoint calculations are based on a receive antenna height of 30' as described by the ATSC Planning Factors.

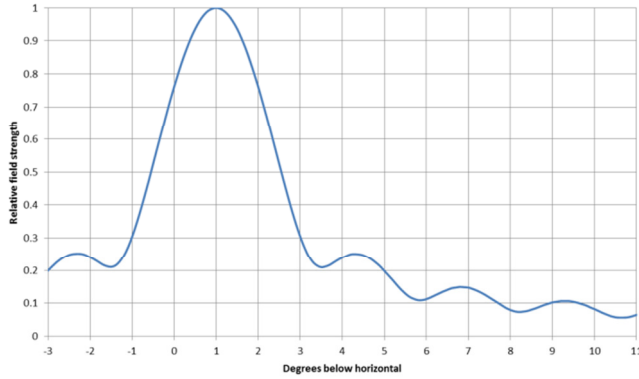


Figure 7: Typical elevation pattern of a 24 layer antenna.

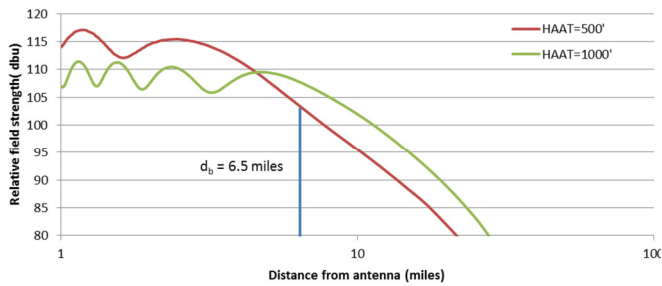


Figure 8: Field strength vs. distance from the antenna using the elevation pattern as shown in Figure 7, based on 1MW ERP and HAAT's of 500' and 1000'.

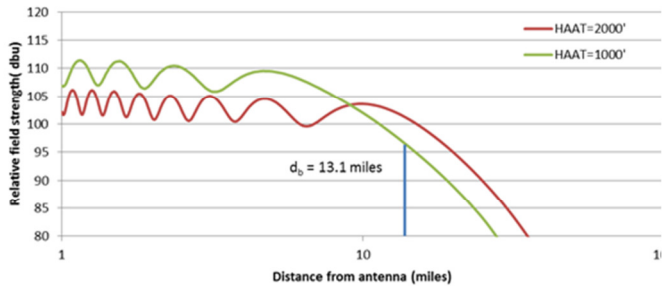


Figure 9: Field strength vs. distance from the antenna using the elevation pattern as shown in Figure 7, based on 1 MW ERP and HAAT's of 1000' and 2000'.

Calculating the Recommended Beam Tilt vs. Antenna Height

The typical rule of thumb in determining the beam tilt to provide the most even coverage within the radio horizon is depicted in Figure 10. The peak of the main beam in the elevation plane is pointed downward until the relative field strength at the radio horizon reaches 95%.

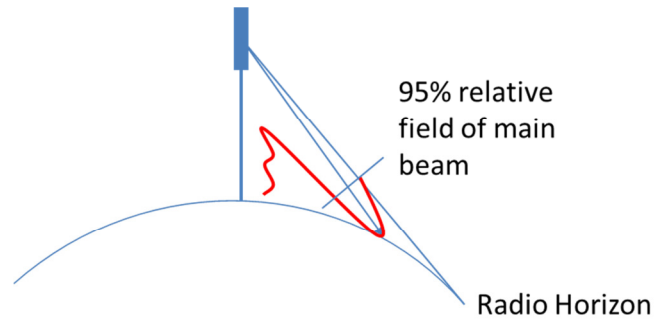


Figure 10: Beam tilt location for best overall coverage.

The radio horizon angle can be calculated by equation 6, where r is the effective earth radius or $4/3$'s times the earth radius (3959 miles) and h is the antenna height above average terrain.

$$a_h = \cos^{-1} \left(\frac{r}{r+h} \right) \quad (6)$$

Using the rule of thumb, the recommended beam tilt can be expressed as:

$$BT_r = a_h + .19HPBW \quad (7)$$

The half power beam width as plotted in Figure 4 can be estimated by:

$$HPBW = \frac{60}{G} \quad (8)$$

Therefore:

$$BT_r = \cos^{-1} \left(\frac{r}{r+h} \right) + \frac{11.4}{G} \quad (9)$$

Where $r = 27,871,360$ ft., h is the height above average terrain and G is the elevation gain of the antenna relative to a half wave dipole.

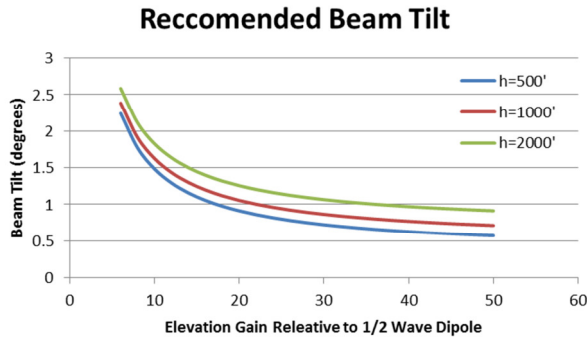


Figure 11: Recommended beam tilt vs elevation pattern gain for various heights above average terrain.

Figure 12 illustrates how using the recommended beam as given by equation (9) places the relative field of 95 % to be located at the radio horizon angle for a given height above average terrain.

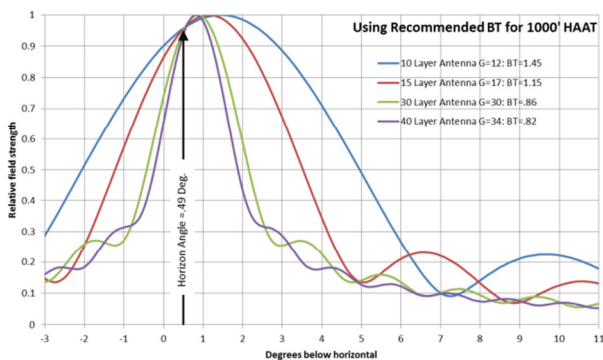


Figure 12: Elevation patterns for 10, 15, 30 and 40 layer antennas using the recommended beam tilt for a height above average terrain of 1000'.

When these patterns are plotted as relative field strength vs. distance from the antenna with the TPO adjusted for equal ERP as shown in Figure 13, it becomes apparent the effect the wider beam width has on the immediate coverage area.

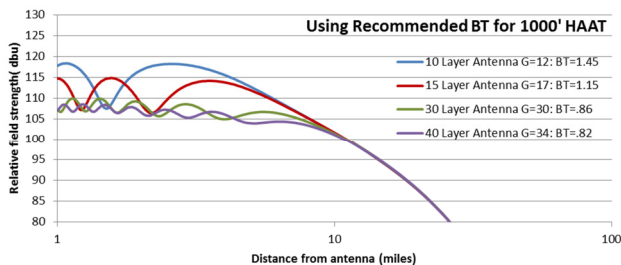


Figure 13: Relative field strength vs. distance from the antenna for elevations patterns of a 10, 15, 30, and 40 layer antenna using the recommended beam tilt with a height above average terrain of 1000'. The plots are based on a 1MW ERP using the FCC (50, 90) curves.

With the increasing expectation of high indoor quality of service, 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. Along with wider beam antennas, the addition of extreme null fill should be considered [1].

Conclusion

Some basic rules of thumb for relating antenna gain, beam with, ERP and height above average terrain have been discussed. First, the addition of null fill becomes less efficient for high gain antennas. Second, the antenna beam width and gain are inversely proportional. Doubling the vertical beam width reduces the gain in half. Third, the old saying in broadcast “Height is king” is very true. An increase in height has the same general effect as increasing the gain of the antenna. Fourth, the recommended beam tilt to provide the most even coverage within the radio horizon for a given height above average terrain and gain can be calculated from equation (9). Lastly, it has been shown that low gain antennas with wider beam widths should be considered to provide immediate coverage signal saturation for high data rate next generation services. Along with wider beam widths, the addition of extreme null fill should be considered.

References

- [1] 2014 NAB BEC Proceeding, “Broadcast Antenna Design to Support Future Transmission Technologies”, John L. Schadler
- [2] “Antennas”, McGraw-Hill Electrical and Electronic Engineering Series, John D. Kraus
- [3] IEEE Transactions on Vehicular Technology, VOL. 45, NO 2, May 1996 “Effects of Antenna Height, Antenna Gain, and Pattern Downtilting for Cellular Mobile Radio”, Edward Benner, Abu B. Sesay.
- [4] IEE Electromagnetic Waves Series 50, “Channels, Propagation and Antennas for Mobile Communications”, Rodney Vaughan and Jorgen Andersen