Broadcast Traveling Wave Antenna with Azimuthal Beam Tilt Optimization

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Abstract *– Antenna beam tilt is a powerful parameter for pattern optimization and has a direct impact on shaping the boundaries of the reception service area. It has been common practice in broadcast to use mechanical beam tilt or vary the electrical beam tilt in different azimuth directions in order to optimize coverage, especially in areas where the height above average terrain changes drastically around the tower. Mechanically tilting the entire antenna results in an uncontrolled variation of beam tilt around the azimuth. In order to control the beam tilt around the azimuth, implementation has been limited to phased array panel antennas with multiple faces pointed in different directions. Since each panel is fed by a corporate power dividing system, the phase taper on each face can be easily made different, thus supplying different electrical elevation plane beam tilts in different azimuthal directions. Slotted coaxial "pylon" antennas have many advantages over traditional broadband panel antennas including much smaller size and wind load, higher reliability, and a greater degree of azimuth pattern flexibility. The use of "Beam Tilt Management" to optimize coverage with a slotted coaxial pylon antenna has been limited to either mechanical beam tilt in one direction and/or simple constant electrical tilt in all directions. This paper will explore a new novel slotted pylon antenna design which provides differential electrical beam tilting around the azimuthal plane, a technique which up until now was limited to complicated panel antennas. The new technology has all the benefits of standard slotted pylon antennas plus the ability to control the beam tilt in different directions from the tower.*

INTRODUCTION

Antenna beam tilt is defined as the angle of the main beam below the horizontal plane (Figure 1).

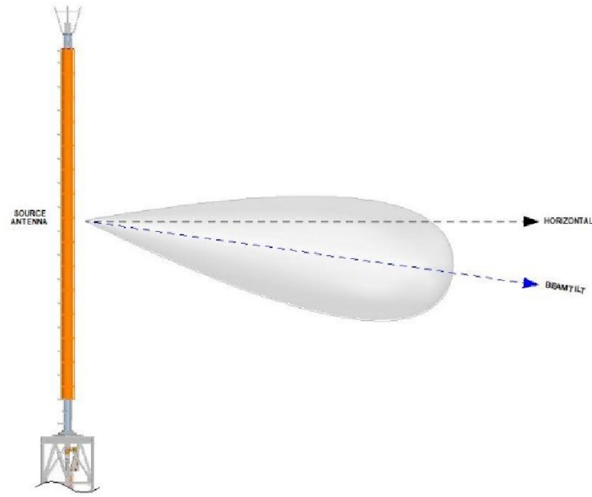

Figure 1: Antenna Beam Tilt.

There is always an optimum value for beam tilt, at least in a particular direction, which depends on the antenna's average height above terrain (HAAT) and the main beam width which is a function of gain. The typical rule of thumb in determining the beam tilt which provides the most even coverage within the radio horizon is depicted in Figure 2. The peak of the main beam in the elevation plane is pointed downward until the relative field strength at the radio horizon reaches 95% [1].

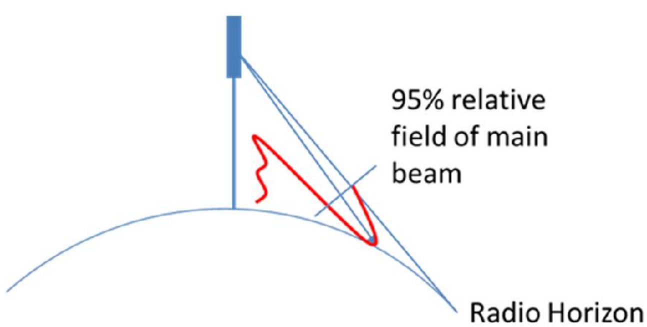

Figure 2: Beam tilt location for best overall coverage.

Using the rule of thumb, the recommended beam tilt can be expressed as (1) [1]:

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

Where r is the effective earth radius or 4/3's times the earth radius, 27,871,360ft., h is the height above average terrain and G is the elevation gain of the antenna relative to a half wave dipole.

BEAM TILT MANAGEMENT

Beam tilt management is a tool used by RF consultants to either optimize a coverage area with challenging terrain features or to place a deep null in the azimuth pattern at the horizontal in order to meet interference criteria. Placing a deep null in a particular direction at the horizontal can usually be accomplished with a simple mechanical tilt and can be implemented with either a slotted coaxial pylon antenna or a panel antenna. Mechanically tilting the entire antenna results in an uncontrolled varying of the beam tilt around the azimuth. The beam tilt verses azimuth direction of a mechanically tilted antenna can be calculated using equation (2), where E is the electrical beam tilt, M is the mechanical tilt and Ø is the azimuth direction.

$$BT_{\emptyset} = E - Tan^{-1}[Tan(M)cos\emptyset] \quad (2)$$

This in turn influences the azimuth pattern at different elevation angle cuts and distances form the tower. The following example illustrates the result. Figure 3 shows the azimuth and elevation patterns of a typical 24 layer omni directional slotted coaxial pylon antenna with .7 degrees electrical beam tilt. Note the azimuth pattern will remain constant at all depression angles and distances from the tower. In Figure 4, the same antenna is tilted 1.7 degrees toward the east. This places the first null of the elevation pattern above the main beam at the horizontal which creates a very deep null to the east at the horizontal in the azimuth pattern. This is a standard technique used to protect a direction of interference. Note that in this case, over the main coverage area, (typically elevation angles between .5 and 1.5 degrees depending on the HAAT), the azimuth pattern loses its shape and thus coverage to the west as well. The effect is commonly known as "peanutting".

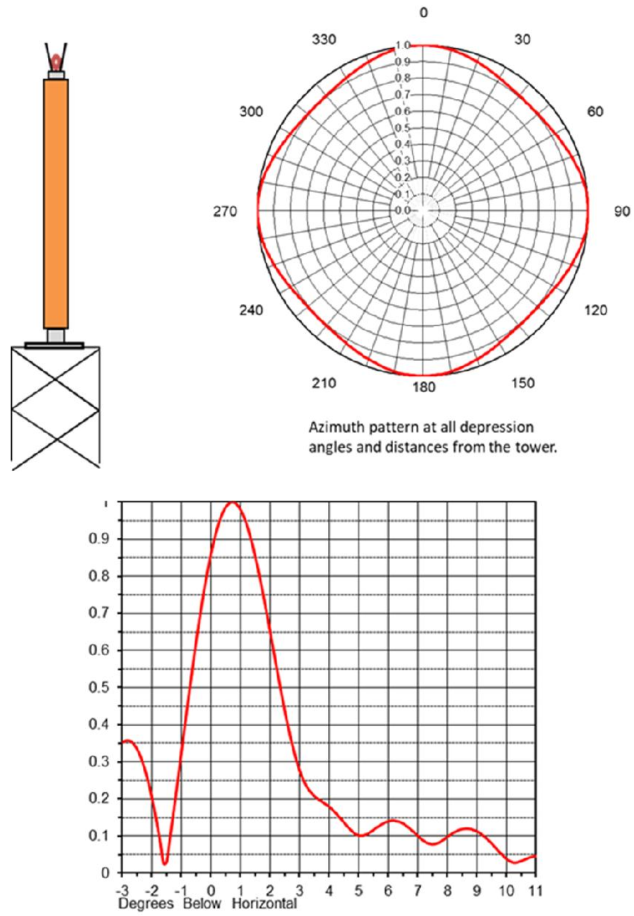

Figure 3: Typical 24 layer omni directional slotted coaxial pylon antenna with .7 deg. electrical beam tilt.

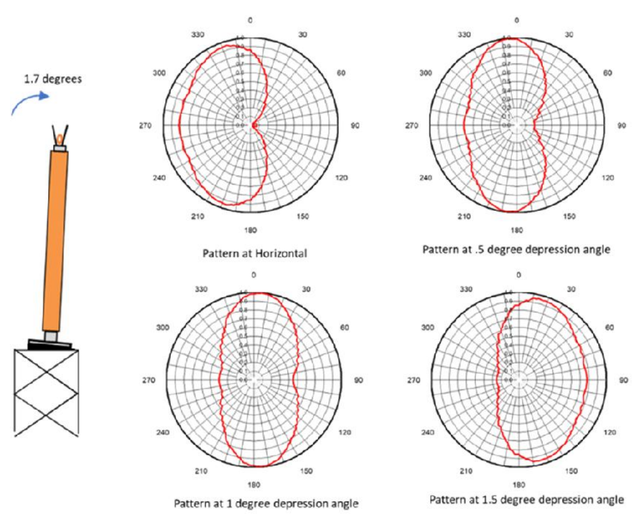

Figure 4: Antenna in Figure 3 tilted 1.7 deg. towards the east.

In this example, in order to eliminate peanutting and maintain coverage to the west, but still obtain a deep null to the east at the horizontal, mechanical tilt must be replaced by differential electrical beam tilts around the azimuth. To illustrate this, shown in Figure 5, a 4 around omni panel antenna is analyzed using the same elevation pattern as in Figure 3.

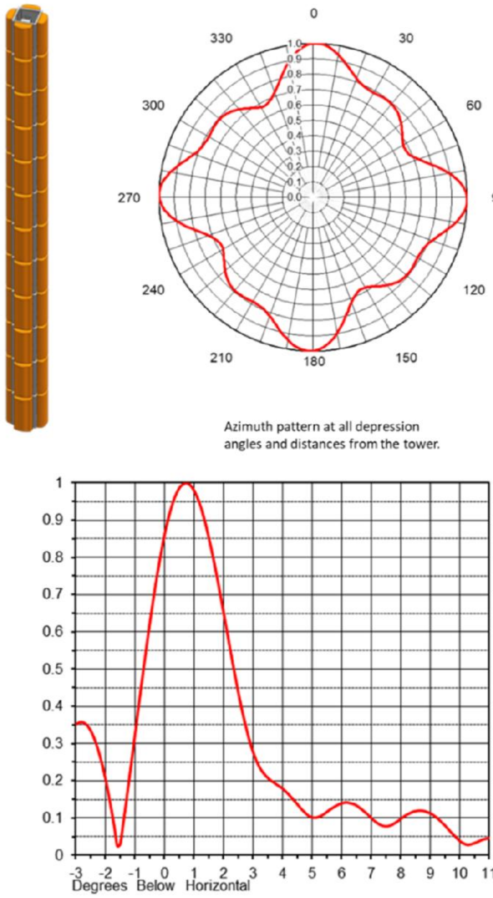

Figure 5: Typical 24 layer omni directional panel antenna with .7 deg. electrical beam tilt.

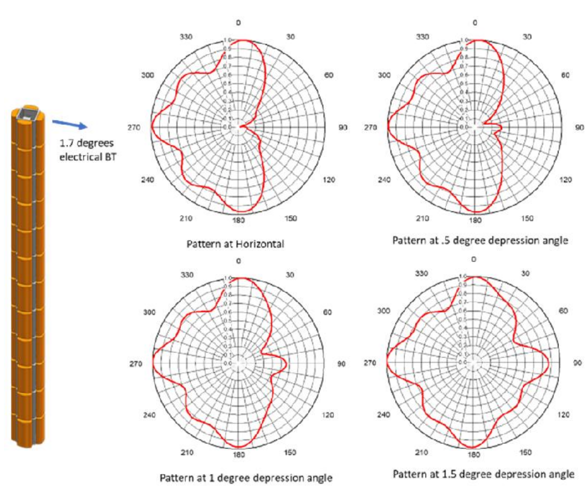

Figure 6: Antenna in Figure 5 with 1.7 deg. electrical tilt on the east face.

In Figure 6, the same panel is phased such that the east face has an electrical beam tilt of 1.7 degrees. This again places the first null above the main beam of the elevation pattern at the horizontal, which creates a very deep null to the east at the horizontal in the azimuth pattern. Note that replacing the mechanical tilt with electrical tilt in the east direction eliminates the peanutting effect.

Up until now, the only option for producing differential electrical beams around the azimuth of an antenna was to use a phased array panel antenna with multiple faces pointed in different directions. Since each panel is fed by a corporate power dividing system, the phase taper on each face can be easily modified, thus supplying different electrical elevation plane beam tilts in different azimuthal directions. New technologies are now making it possible to apply differential electrical beam tilt to slotted coaxial pylon antennas.

INTRODUCTION OF THE TRAVELING WAVE PYLON ANTENNA

The slotted coaxial traveling wave antenna was first introduced in 1955 when Robert Masters from the Ohio State University filed for a patent on the concept. RCA engineers soon adapted the concept to a practical application in high band VHF broadcast (Figure 7).

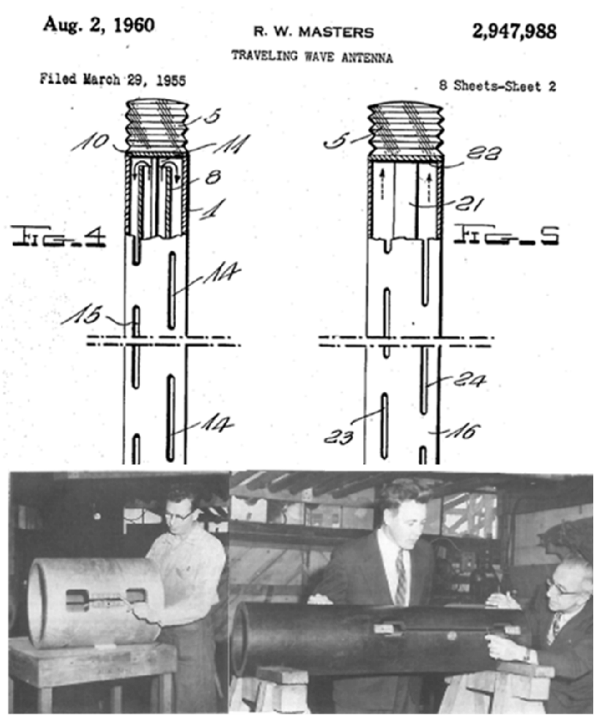

Figure 7: Master's traveling wave antenna patent filed in 1955. RCA Engineering working of VHF prototype.

RCA's Traveling Wave Antenna was extremely popular due to the simplicity and reliability properties discussed above. More than 500 were manufactured and placed into operation between 1958 and 1990. The basic concept is to produce a uniformly attenuated wave along the coax in which the attenuation created by the slot coupling results in radiation. This is done by matching each slot to the pipe's intrinsic impedance. Each layer is a matched load and therefore any number of layers of slots can be stacked on top of each other to produce elevation gain. Since a traveling wave has a linear phase characteristic, the excitation of each successive radiator will be lagging from the previous one by an amount which depends upon the spacing between layers. It is this lag that defines the antenna electrical beam tilt. If no beam tilt is employed, the relative phase along the whole aperture is zero. To add beam tilt, the spacing can be adjusted according to equation (3).

$$D = \lambda \left[\frac{1 - \frac{\beta}{360}}{sin\phi + 1} \right] \quad (3)$$

Where β is the phase delay through a layer caused by coupling, λ is the wavelength and ∅ is the desired beam tilt. The combination of the exponential distribution of power with linear phase taper along the aperture produces an extremely smooth, null free elevation pattern.

DIFFERENTIAL BEAN TILT UHF TRAVELING WAVE PYLON ANTENNA

Individual small pipe traveling wave pylon antennas can be bundled into a common pylon aperture and used as an azimuthal array in order to produce a desired coverage much like panel antennas. Referring to the common aperture pylon traveling wave with differential beam tilt as the "DBT" antenna, the beam tilt in any plane or direction can be varied by changing the layer to layer spacing in that plane relative to the other planes producing a differential beam tilt around the azimuth (Figure 8).

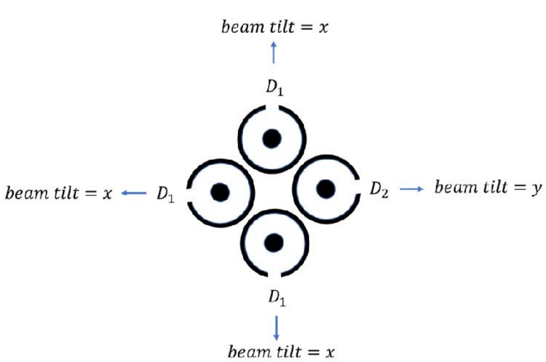

Figure 8: Differential beam tilt around the azimuth of a pylon DBT-TW antenna.

The power is fed into the antenna inputs at the bottom of each individual pipe through a coaxial tee. The stub at the bottom of each tee is shorted with spokes, which are locked to both the inner and outer conductor. This provides both water drainage and support for the inner conductor. Refer to Figure 9.

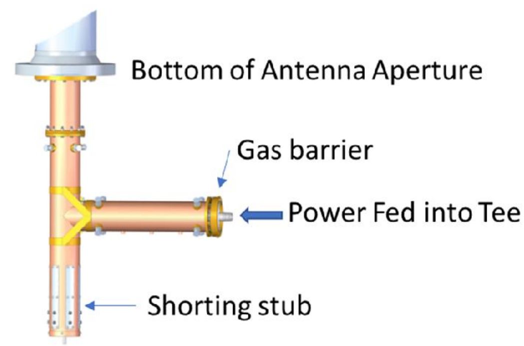

Figure 9: Input feed of one pipe of a DBT antenna.

As seen in Figure 10, each of the tees are then linked together by a main power divider which provides a single input to the antenna array.

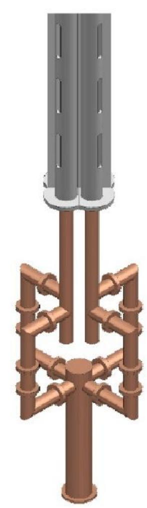

Figure 10: Differential beam tilt pylon antenna feed system.

The simplicity of this technique is evident when comparing the 24 layer, 4 around differential beam tilt pylon feed system to an equivalent panel system such as the one shown in Figure 6. The panel array will require over 200 connections, most of which are not accessible if failure were to occur as shown in Figure 11. Since the corporate feed system of a panel array requires close to equal length paths to each panel, long drip loops are usually required below the tower top to make up the length.

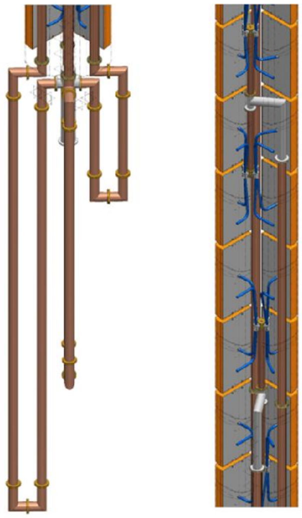

Figure 11: Feed system of a typical 24 layer, 4 around panel system.

In comparison, the differential beam tilt pylon will have 21 connections, all of which are completely accessible below the tower top. It also does not require long drip loops since the equal phase location is at the input to each individual pipe. It should also be noted that each individual panel has many parts, connections, and small hardware internally. The slot in a pylon antenna is fed by a simple coupling bar attached to the inside wall of the outer pipe, typically with 3 bolts as shown in Figure 12.

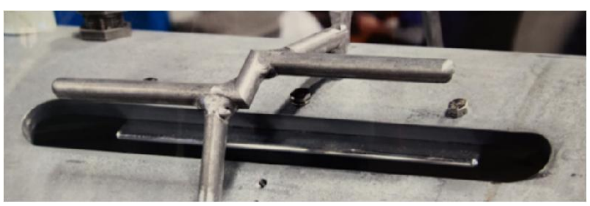

Figure 12: Pylon antenna slot coupling.

Failure rate is defined as:

$$\lambda = \sum_{i=1}^{n} N_i \lambda_i \pi_{Qi} \quad (4)$$

Where n is the number of part categories, N_i is the quantity of the ith part, λ_i is the failure rate of the ith part and π_{Qi} is the quality factor of ith part [2]. From equation 4, one can conclude that reliability is directly proportional to parts count. Looking at equation 4 and considering the difference in parts count between the DBT pylon and a panel antenna, this inherently makes the DBT pylon design many times more reliable than an equivalent panel design.

Since the first, or bottom. layer of the antenna receives the highest power and each layer above that successively extracts the remaining power from the traveling wave, an exponential amplitude radiation taper is formed along the aperture. Typical traveling wave pylon designs will attenuate approximately .5dB or about 10% of the power per layer. This translates to half of the total power being dissipated after only 6 layers of aperture. It is for this reason that the slot spacing drift, as shown in Figure 13, from one plane to another, which produces the differential beam tilt with azimuth direction, has very little effect on the fundamental azimuth pattern. It is not until farther up from the bottom of the antenna that the drift becomes significant causing a space phase offset in the azimuth plane, but by then the asymmetry has little effect due to the low power levels.

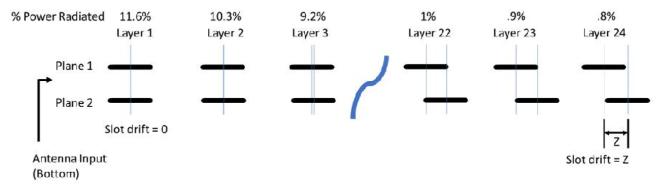

Figure 13: Slot spacing (D) drift.

When the signal reaches the top of the antenna, all but a few percent of the energy has been extracted and radiated. The remaining energy is radiated by an end load. Besides contributing to the radiation, the end load also provides a proper termination for the main aperture [3].

Differential Beam Tilt Traveling Wave Pylon Application Example

Figure 14 shows the azimuth and elevation patterns of a 4 around DBT pylon antenna with a designed .7 degrees electrical beam tilt built into each of the pipes. Note the azimuth pattern will remain constant at all depression angles and distances from the tower.

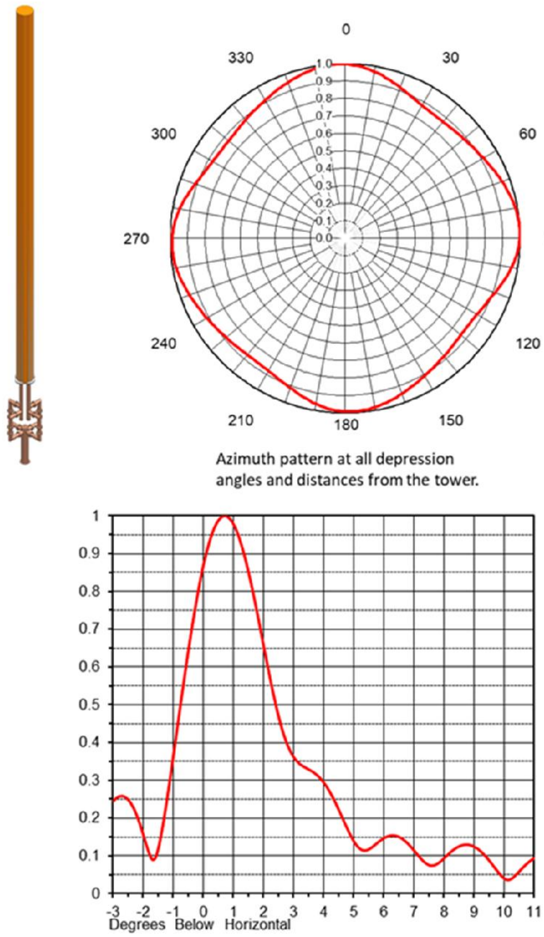

Figure 14: 24 layer x 4 around omni DBT pylon antenna with .7 deg. electrical beam tilt in all pipes.

In Figure 15, the same DBT antenna is designed with the east pipe having a 1.7 degree beam tilt while keeping the other 3 pipes designed at .7 beam tilt. Like the previous examples, this places the first null of the elevation pattern above the horizontal at the horizontal which creates a very deep null to the east at the horizontal in the azimuth pattern.

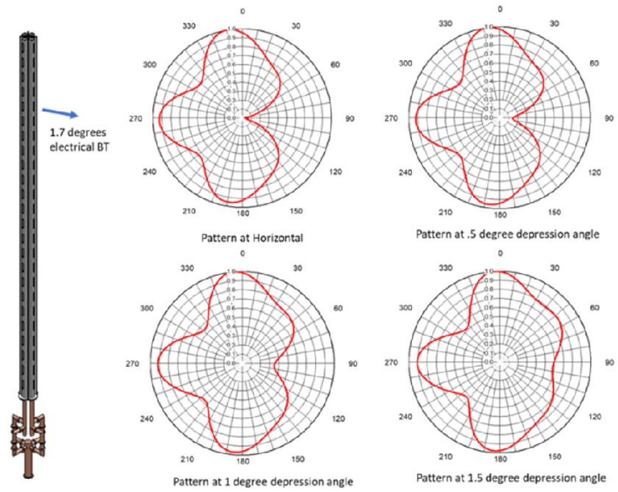

Figure 15: Antenna in Figure 14 with 1.7 deg. electrical beam tilt in the east pipe.

Note that by using DBT with differential beam tilt, the same type of response, with no peanutting effect, is observed as was previous demonstrated by a panel antenna.

CONCLUSIONS

The use of “Beam Tilt Management” to optimize coverage with a slotted coaxial pylon antenna that can vary the beam tilt in different azimuth directions has been discussed. The new DBT pylon technology has all the benefits of standard slotted pylon antennas including low windload and proven reliability with the added benefit of being able to vary the azimuthal beam tilt in a specified direction, a feature which historically could only be found in complicated panel antennas.

REFERENCES

[1] Schadler J.L., “A Note on the Effects of Broadcast Antenna Gain, Beam Width and Height Above Average Terrain”, Technical resources, https://www.dielectric.com/technical-resources/

[2] MIL-217 Standard

[3] Siukola, M.S. “Traveling Wave Antenna”, *Broadcast News, RCA Vol. No. 94, April 1957*