End Fed vs. Center Fed Slotted Coaxial Broadcast Antenna

Not a Choice of Preference

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Abstract – *The advantages of center feeding a slotted coaxial, high power broadcast antenna have been presented and marketed for over 50 years. There are also manufactures who claim end fed antennas have the advantage. The truth is that both center fed and end fed broadcast antenna designs need to be in the product portfolio. The choice should not be dictated by preference but rather by technical limitations and decisions. This paper will discuss those limitations and define the center fed – end fed criteria that dictates the best choice, or in many cases, the only choice of antenna design.*

Introduction

The vast majority of UHF broadcast antennas used in the US are slotted cylinder "pylon" designs. It is their pattern versatility and low wind load that have made them the antenna of choice. Top mount pylon antennas are designed to feed the RF power from the bottom of the antenna since it is mechanically convenient. In 1966 RCA introduced the "J" type pylon antenna which incorporated a triaxial center feed arrangement. This revolutionary idea allowed a top mounted broadcast antenna to be electrically center fed but mechanically fed from the bottom.

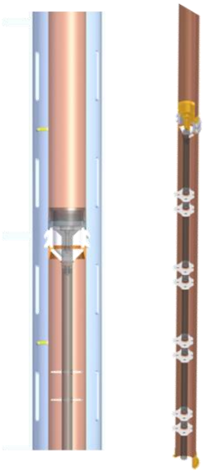

Figure 1: Internally center fed harness pylon slotted coaxial broadcast antenna

Historical Background - The Advantages of Center Feeding

References such as "Slotted Cylinder Antenna Design Considerations for DTV" and "New DTV Antenna Technology" [1] and [2], among others have examined and evaluated the frequency response performance as well as the beam tilt and null fill variation between end fed and center fed antennas. Unlike the days of analog broadcast, ATSC 1.0 and upcoming ATSC 3.0 treat the entire channel with equal importance. Clearly it is better to have a flat channel response than a non-flat response so that receivers will not need to equalize. This of course is only true in a perfect world. The RF world we live in has imperfect antennas, frequency depended scatter off towers and terrain multi-path, all contributing to variability vs. frequency in the received signal. Historically, center fed antennas gained popularity due to their inherently flat channel response. This is a function of opposite phase tapers progressing in opposite directions from the feed point resulting in an insignificant beam sway with frequency. It also allows the use of symmetrical, mirror image illuminations which are known for smooth stable null fill.

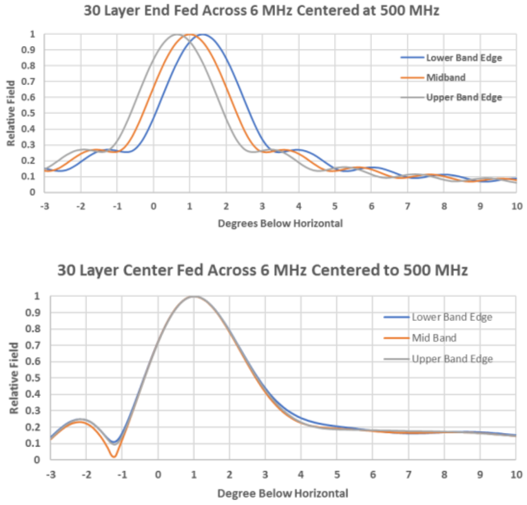

Figure 2: Elevation pattern of a 30-layer end fed antenna design vs. a 30-layer center fed design.

Affect on Performance - Elevation Pattern Frequency Response

To understand the effect that the elevation pattern frequency response has on coverage it helps to plot the elevation pattern in terms of signal strength vs. distance from the antenna. For illustration, the field strength is based on 1MW ERP at a height above average terrain (HAAT) of 1000’ and using the FCC 50, 90 curves for UHF. The radio horizon at a HAAT of 1000’ is calculated to be 44.7 miles. A comparison of coverage is shown in Figure 3 using the elevation patterns from Figure 2.

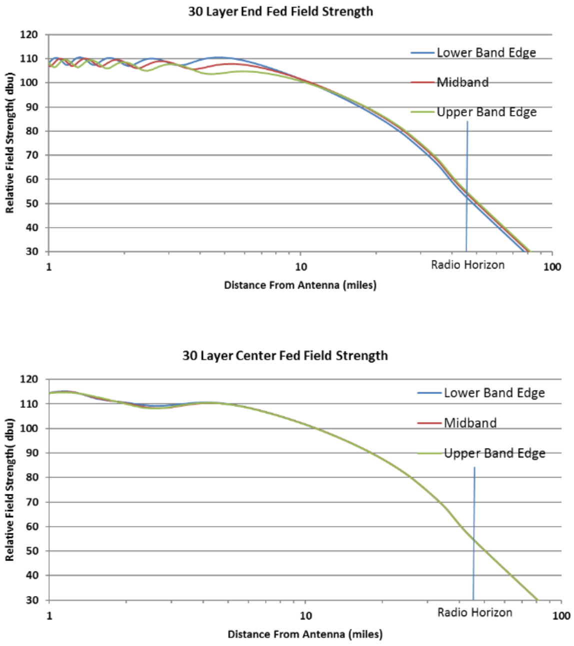

Figure 3: Signal strength across a 6 MHz band. Comparison between a 30 layer end fed and center fed antenna.

Since knowledge of the antenna frequency response in addition to the ERP are essential in defining the actual service, it should be clear that the resulting elevation pattern used to define the service should be based on the minima across the occupied bandwidth at every elevation angle rather than at mid band alone. In Figure 4, the midband coverage prediction is compared to the minimum at any frequency. It should be noted that the FCC ATSC A/53 minimum field strength requirement is 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 [4].

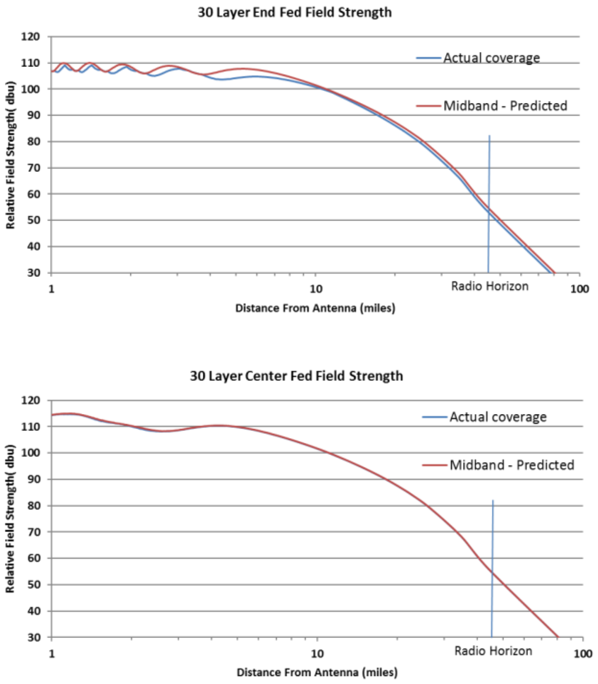

Figure 4: Midband predicted coverage vs. the actual coverage based on the minimum field strength at any frequency in the occupied bandwidth.

As can be seen in Figures 3 and 4, the requirement is well beyond the radio horizon and would indicate that the slope imposed on the incoming signal will not imply a coverage penalty. This is not necessarily true since the analysis is based on antenna response only and is prior to being subjected to multipath and interference. Even though the frequency response only becomes an issue when the signal strength is near the receiver threshold, the fact is that center fed antennas will reduce the overall frequency response variation.

Heading Into Repack

The FAA restricts the overall height on top mounted antennas. Going down in frequency and keeping the same overall aperture height equates to post repack antennas having less gain. It is also true that going down in frequency requires less gain for the same coverage due to the dipole factor used in field strength calculations.

$$P_r = P_t \frac{G_t G_r \lambda^2}{(4\pi R)^2} \qquad (1)$$

From equation (1), the ratios of received powers is simply the ratio of the pre-repack channel frequency divided by the post repack channel frequency squared.

$$ERP\ Reduction\ \% = \left(\frac{f_{pre-repack}}{f_{post-repack}}\right)^2 \qquad (2)$$

For example, a 1 MW channel 49 station being repacked to channel 25 will have a new ERP of 622 kW. Lower gain antennas will inherently have wider elevation pattern main beams. The wider beam widths are less sensitive to variation in differential gain caused by beam sway and thus the concern over beam sway is not as large as they were in post repack days.

ATSC 3.0 and Elevation Pattern Frequency Response

In reference [7], the penalty on the available carrier to noise ratio imposed by the equalizer at the receiver due to frequency distortion is the passb0and in an ATSC 1.0 HDTV channel is given by equation (3).

$$P_p(dB) = 10Log\left[\frac{1}{f_B}\int \frac{df}{|H(j2\pi f)|^2}\right] \qquad (3)$$

It is noted that while the exact magnitude of the noise power penalty depends on the choice of equalizer, equation (3) defines the worst case. Instead of relating frequency response to power penalty as suggested in reference [7], it would be better to understand the effect it has on bit error rate. The reason is that the relationship between the signal to noise ratio (SNR) and Bit error rate (BER) is a non-linear function. In fact, with the LDPC codes used in ATSC 3.0, the bit error rate curve is very steep. The difference between 0 errors and 100% errors is typically < 0.1 dB of SNR.

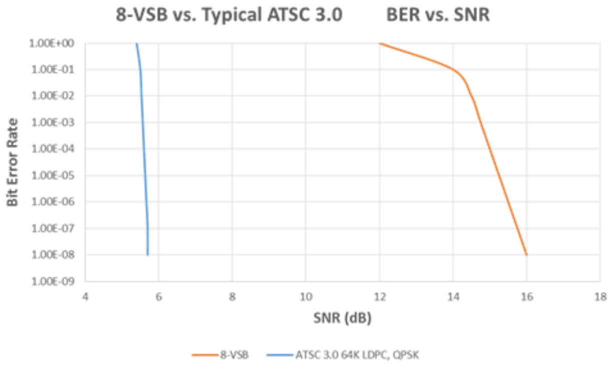

Figure 5: Comparison of BER vs. SNR for 8-VSB and a typical ATSC 3.0 case [5], [6].

Essentially, the signal is compromised if the strength in any portion of the occupied band drops below the desired service threshold. This is of course a very simplified analysis. To find the actual effect on a particular channel response, you would need to do simulations with the exact ATSC 3.0 parameter set that would be used. The reason is that the system has interleaving, both in the time and frequency domain. The time interleaving is to help with time-varying channels and impulse noise and the frequency interleaving is meant to help offset the problem of different parts of the channel having different SNR levels.

ATSC 3.0 Readiness – Future Fill / Higher PAPR

It is clear that ATSC 3.0 services will require a new definition of received signal strengths. Signal strengths of 48 dBu to 95 dBu have been discussed depending on the desired service [8]. When depending on these higher signal strengths, the importance of a flatter frequency response becomes more apparent.

The idea of future proofing a high power broadcast antenna in anticipation of next generation broadcast requirements should be considered. To accomplish this, the use of predetermined illuminations in center fed antennas that are modifiable in the field to provide the flexibility to customize the null structure at a future date, can be used [9]. The technique known as Future Fill, is simple for center fed slot coaxial pylon antennas. The outer pipe can be pre-drilled to allow for the reversal of the internal couplers to the opposite side of the slot [8]. This increases the null fill 7-10dB, while only reducing the peak ERP 1.5dB to 2dB. In conjunction with the addition of SFN's, an even distribution of high signal strengths can be achieved throughout the coverage area. Unfortunately, the technique is not compatible with end fed antennas, although it is true that end fed antennas typically start with higher null fill.

The OFDM based modulation of ATSC 3.0 will present higher peak to average power ratios than are currently observed in the 8-VSB standard we know today. The weak point for voltage breakdown in a slotted coaxial pylon antenna is typically between the inner conductor and the slot coupling [10]. Refer to Figure 8. Since center fed antennas split the input power between the upper and lower half of the antenna, the highest power slots see half the power in the first slot compared to an end fed antenna. This provides more voltage headroom needed to support the higher PAPR's associated with ATSC 3.0

Higher Order Modes in Coaxial Lines

Coaxial lines usually operate in the principal TEM mode. Higher order waveguide modes can also exist but only if excited at a frequency above the cutoff frequency for that given mode [3].

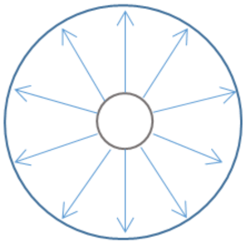

Figure 6: TEM mode in coaxial transmission line

At frequencies below the cutoff, the higher order modes can be excited at a discontinuity source but will attenuate rapidly with distance.

The cutoff frequency is defined by the size of the coaxial inner and outer conductor and can be approximated by the mean diameter between them [3].

$$f_c(MHz) = \frac{11802.76}{\left(\frac{D+d}{2}\right)\pi} \qquad (4)$$

Where D is the ID of the outer conductor and d is the OD of inner conductor. The attenuation of any mode in the cutoff region is given by equation (5) [3].

$$\alpha\ (dB/length) = \frac{54.6}{\lambda_c}\sqrt{1-\left(\frac{\lambda_c}{\lambda}\right)^2} \qquad (5)$$

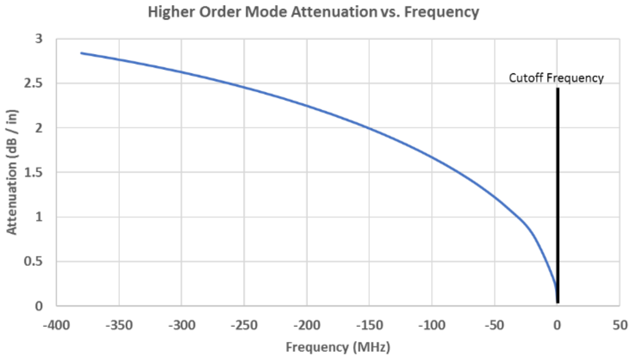

Figure 7: Higher order mode attenuation in dB per inch vs. frequency below cutoff for a design frequency of 600 MHz

Higher Modes in Coaxial Antennas

Slotted coaxial antennas are meant to operate with energy propagating internally in the principle TEM mode. The slots loading and radiation characteristics are well defined when they are fed with the symmetrical TEM mode. This is the only mode condition that ensures a predictable performance from each slot and each layer in the array.

To create a potential difference across the slot which provides current flow on the outside of the pipe, a coupling structure must be mounted internally. This coupling structure will by nature excite a higher order mode as fields tend to align to the object.

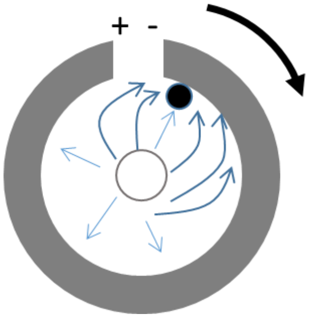

Figure 8: Internal coupling structure inside a slotted coaxial antenna.

The excited higher order modes **must** be either attenuated or canceled out so that the only mode remaining and allowed to feed the next layer in succession is the TEM mode. Failing to do so will result in an unpredictable layer impedance and radiation characteristics making the complete antenna unusable. Slotted coaxial antenna designs such as omni directional and peanut patterns employ symmetrical internal coupling devices which naturally cancel higher order modes. This occurs due to the generation of pairs of equal and opposite higher order modes.

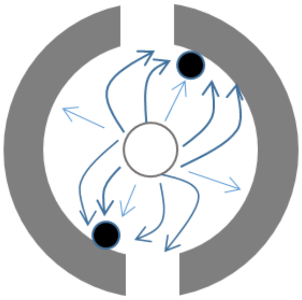

Figure 9: 4 Equally spaced excited slots. The equal and opposite higher order modes are canceled naturally.

Because internal symmetry acts as a natural mode canceler, slotted coaxial antennas such as an omni or peanut azimuth pattern that make use of this geometry can predictably operate in the higher order mode region, thus are not restricted by the inner and outer pipe size. Directional antennas, such as the one shown in Figure 8, which demand a non-symmetrical slot configuration such a skull, cardioid, tri-lobe and other custom azimuth designs must use outer and inner sizes that allow for enough higher order mode attenuation such that each successive slot is feed with a clean TEM mode.

Higher Order Mode Design Criteria

As earlier indicated, internal slot coupling structures excite higher order modes. The question becomes, "On non-symmetrical coaxial antenna designs, how much attenuation is enough to practically assume predictable performance?" It has been shown though experimentation and experience that antenna designs should allow for at least 20 dB of higher order mode attenuation between coupling voltage peaks. For reasons beyond the scope of this paper, slotted coaxial antenna coupling structures are typically placed at either one or half wavelength aperture intervals. If the coupling structures, such as the one shown in Figure 8, are placed either one wavelength or half wavelength apart axially, then the frequency cutoff criteria to ensure predictable full antenna design can be determined by equation (5). The proper choice of inner and outer diameters can then be determined using equation (4).

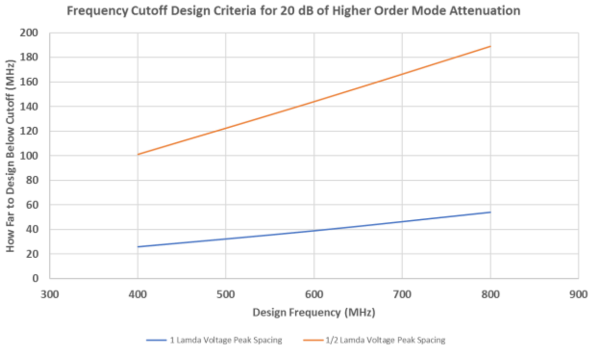

Figure 10: How far from higher order mode cutoff frequency one should design the proper inner and outer combination for either full or half wave voltage peak spacings.

Making the Decision – Center Fed or End Fed?

One should start to see that the choice between a center fed and end fed slotted coaxial broadcast antenna is usually not a preference but dictated by a technical road map consisting of power, size, pattern and performance criteria. For example, when top mounting a pylon antenna, center feeding will offer the best frequency response and least amount of beam sway. If the azimuth pattern is omni directional, power handling is not an issue since a large harness inner can be placed inside a large structural outer without concerns of higher order modes propagating. This is due to the ability to place symmetrical slots radially thus always exciting equal and opposite higher order modes which cancel. If the desired azimuth pattern is directional requiring non-symmetrical slots, high power center feeding with a harness is not an option. Since the outer pipe and inner conductor need to be relatively small in order that higher order modes attenuate, the only method to get the power into the antenna is through end feeding.

Conclusion

Although there are a multitude of considerations in determining the best top mount slotted coaxial antenna design, the one general case which drive the necessity for end fed pylon antennas is the combination of high power and a directional azimuth pattern. The bottom line is that there is no one size fits all. Both center fed and end fed broadcast antenna designs need to be in the product portfolio in order to provide a full range of technical solutions.

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