Antenna Contributions to Amplitude and Phase Variation Across a Broadcast Channel

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***Abstract*—Antenna amplitude and phase patterns, differential amplitude, differential phase, and group-delay are compared for end-fed and center-fed array configurations.**

***Index Terms*—Antenna Arrays, Radiation Patterns, Differential Gain, Differential Amplitude, Differential Phase, Group Delay.**

I. Introduction

Television broadcasting makes use of several types of antenna arrays. Antennas are required to handle large amounts of power and produce patterns that will provide good quality signal coverage of large areas. Linear arrays of slots in a coaxial cylinder often serve as the antenna to meet these demands.

The configuration of these slotted arrays affect the quality of the transmitted signal and coverage of the desired area. The amplitude and phase of the radiation pattern varies with frequency, and these variations in turn affect the signal available to the receiver [1]. Differential amplitude, differential phase, and group-delay for end-fed and center-fed array configurations are compared.

II. Elevation Pattern Synthesis

2.1 Elevation Pattern Synthesis

The radiated fields of an antenna are related to the distribution of fields at the antenna aperture. For arrays of discrete elements, the aperture distribution is related to the fields at each element. Given the amplitude and phase of each radiating element, α_i, β_i respectively, and the known (linear) array geometry, d_i, the array factor may be computed by the following equation [2],

$$AF(\theta) = \sum \alpha_i e^{j(kd_i \cos\theta + \beta_i)} \quad (1),$$

where k is the propagation constant and θ is the elevation angle. If the array consists of similar elements, the product of the array factor and the pattern of one element produce the elevation pattern. The separation of the antenna patterns into element and array factors provides insight into key differences of various array configurations. Note that the quantity computed by Equation (1) is a complex number, providing both amplitude and phase of the elevation pattern.

2.2 End-Fed Resonant Arrays

Typical arrays used for television broadcasting are series-fed, resonant arrays of slots in a large coaxial cylinder [3]. Although a great variation exists among these antennas, a realistic array to consider may consist of 24 elements, each separated by approximately one wavelength. Because the power is fed into the array at one end, these are denoted as end-fed arrays.

Elements in the end-fed array have little restriction on element spacing, and typical aperture distributions and patterns are shown in Figure 1 and 2 respectively. Because elements in the end-fed array may be freely positioned there are no discontinuities in the aperture distribution, of the element amplitude or phase. Such discontinuities are present center-fed arrays discussed below and bring rise to important pattern characteristics.

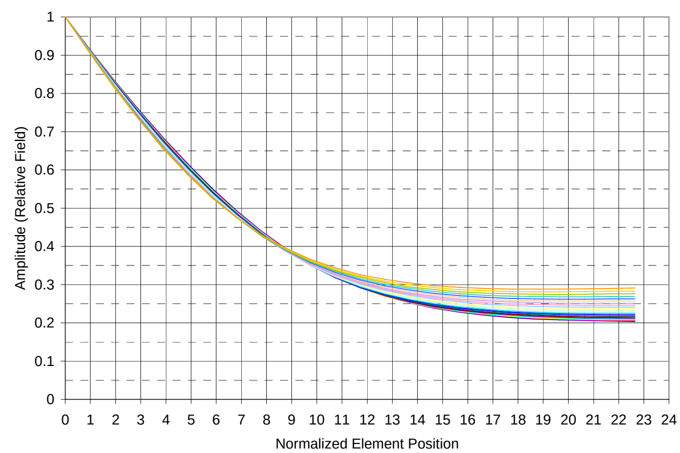

Figure 1a: Amplitude Aperture Distribution of End-Fed Array

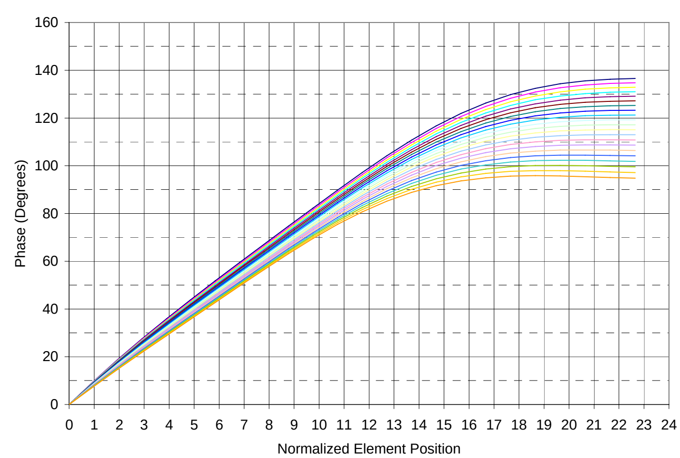

Figure 1b: Phase Aperture Distribution of End-Fed Array

The side-lobe structure of the antenna may be interpreted by considering the vector interference of the fields at the edges of the aperture. The side-lobes of an end-fed array are generally high and the respective nulls are heavily filled (Figure 2a). This may be understood by the fact that the two edges of the aperture have very different amplitudes (Fig. 1a). When the two vectors interfere constructively (in-phase) the large sidelobe peaks occur, and when they interfere destructively the heavily filled nulls occur.

The phase pattern of the end-fed array, shown in Figure 2b, is lobed and smooth, much like the amplitude pattern. These characteristics arise from the smooth phase taper of the aperture distribution (Figure 1b) and the lack of restrictions in positioning the elements of the end-fed array, allowing the array to operate with a single phase center. In contrast, the center-fed phase pattern contains many phase reversals in the same region (Figure 5b).

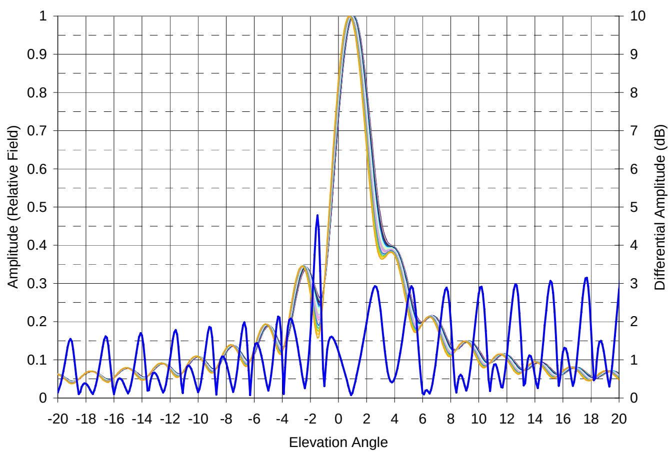

Figure 2a: Amplitude Pattern of End-Fed Array

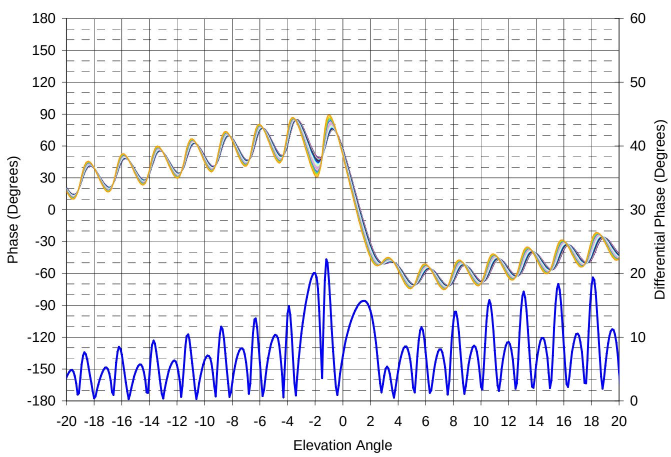

Figure 2b: Phase Pattern of End-Fed Array

The Differential Amplitude of the pattern is the amplitude variation of the antenna pattern amplitude across the 6MHz channel bandwidth, also known as Differential Gain or somewhat ambiguously as "Frequency Response." The Differential Phase is the phase variation across the channel. These differential quantities are plotted in Figure 2.

Group Delay, t_d, is defined by,

$$t_d = \frac{\partial \phi}{\partial \omega} \quad (2),$$

where ϕ is the (radian) phase and ω is the natural frequency. This is directly proportional to the discrete computation of Differential Phase. The Group Delay is shown in Figure 3.

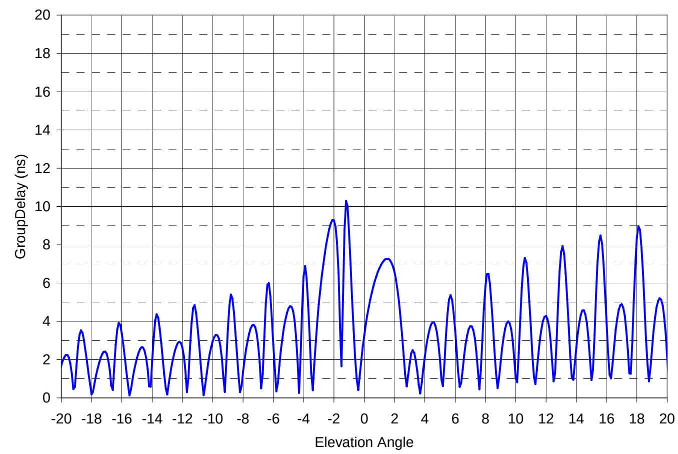

Figure 3: Group Delay of End-Fed Array

2.3 Center Fed Resonant Arrays

Center-fed arrays are composed of two end-fed, resonant arrays, joined together with a power divider. The amplitude of the power division may be typically considered equal and the phase unequal to induce some tilt of the beam. The resulting aperture distributions are shown in Figure 4. Note that the top half of the array produces amplitude and phase distributions typical of an end-fed array.

Because the aperture distribution has lower amplitudes at each end of the array, the magnitude of the side-lobes produced in the pattern (Figure 5) are lower than those produced in the end-fed case. The nulls are also lower because the amplitude of the edge fields is nearly equal at the ends of the center-fed array, adding destructively in the nulls. Low side-lobes and deep nulls combine to produce large differential amplitudes across the broadcast channel (Figure 5a).

The sub-array structure of the center-fed array also limits the possible beam tilt of the array. If the beam-tilt of the center-fed array were increased from that shown in Figure 5 (the typical maximum of 0.5 deg.) to one similar to the end-fed example in Figure 2 (1.0 deg.) the patterns of Figure 7 are produced. The sub-array pattern is also shown, an array of two elements separated by approximately 12 wavelengths and phased to produce 1.0 deg. of beam tilt. The main beam region is formed by this sub-array pattern, and the large lobe above the horizon becomes too large at beam tilts larger than 0.5 deg.

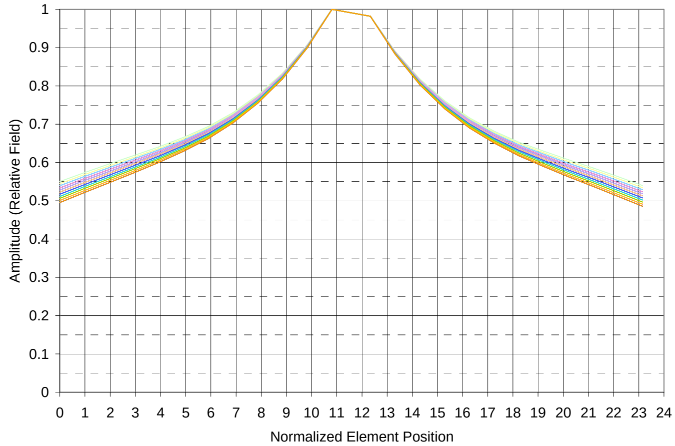

Figure 4a: Amplitude Aperture Distribution of Center-Fed Array

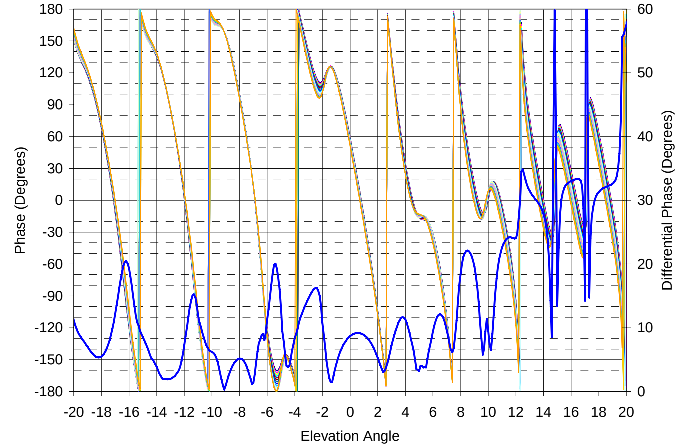

Figure 5b: Phase Pattern of Center -Fed Array

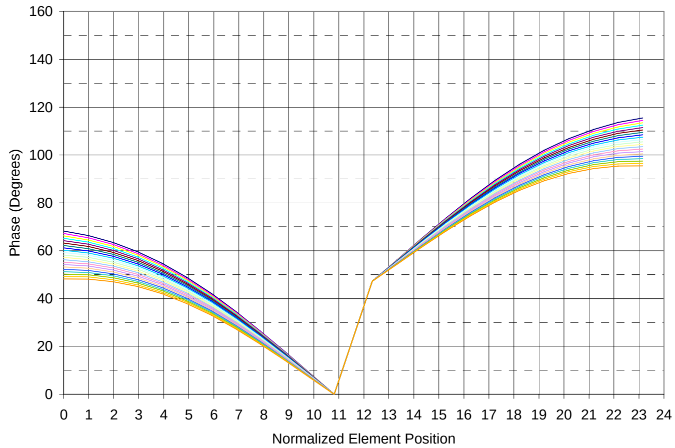

Figure 4b: Phase Aperture Distribution of Center-Fed Array

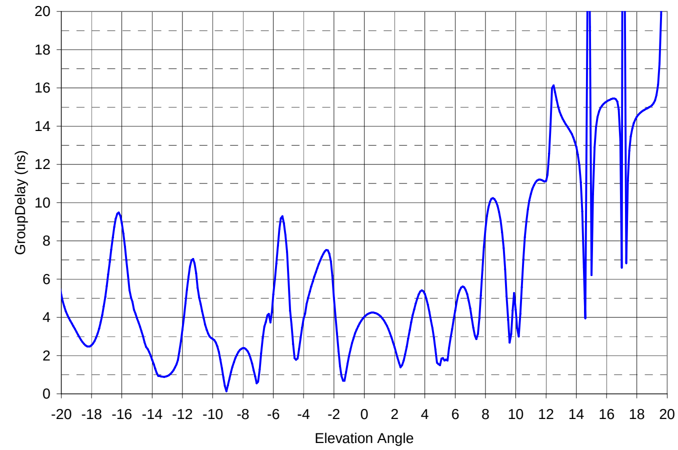

Figure 6: Group Delay of Center -Fed Array

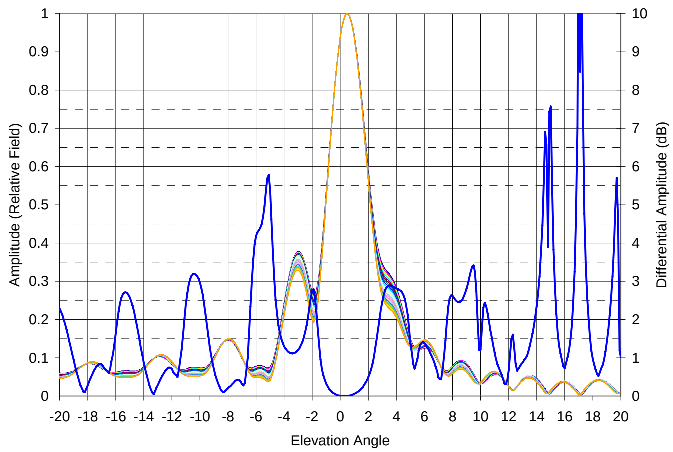

Figure 5a: Amplitude Pattern of Center-Fed Array

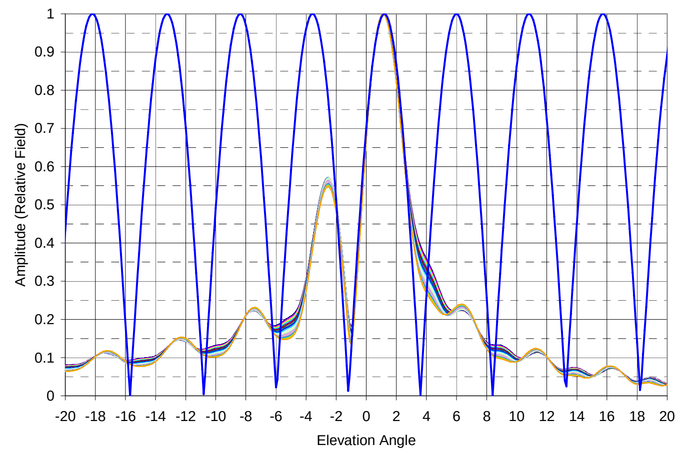

Figure 7: Sub-Array Pattern of Center -Fed Array

III. Conclusions

Comparisons of end-fed and center-fed array configurations indicate key differences in the two antenna types. The freely positioned radiating elements of the end-fed configuration yield near-ideal broadcast pattern performance with higher side-lobes, high null-fill, low differential amplitude and phase, and low group delay. The sub-array structure of the center-fed configuration yields lower side-lobes, deeper nulls, lower null-fill, and higher differential amplitude and phase, and higher group delay.

References

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[3] Wittaker, Jerry, ed., *NAB Engineering Handbook, 9th Edition,* Washingtion, DC, 1999

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