On the Gain Loss of Wide-Angle Scanning Phased Arrays with Narrow- and Wide-beam Element Patterns

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***Abstract*—Gain loss and gain fluctuation are significant contributors to pattern degradation for wide-angle scanning phased arrays. To counter this, phased arrays can utilize various element types with large half-power beamwidths (HPBW) that increase the available scanning range. There are also a multitude of array structures that increase radiation in the endfire direction to extend the array scanning range. This paper attempts to address the gain loss and gain fluctuation for a scanning linear phased array for cases in which narrow- and wide-beam elements are utilized. Multiple scan angles are viewed for each element case, and the gain losses are determined.**

Keywords*— *Phased arrays; wide-angle scanning; element pattern.

I. Introduction

Phased array antennas are heavily utilized partly due to their flexible beam-forming and incredible beam-scanning capability. Scanning bounds of phased arrays created with standard elements, such as microstrip patches, normally have viable scanning ranges of approximately ±50° off-broadside [1]. As the beam of the array scans away from broadside, the maximum of the array factor and the maximum of the element pattern are no longer collocated, which in turn causes overall gain loss in scanning arrays. Gain loss as a function of the scan angle can be reasonably modeled by a cosine to the power of 1.5 [2]. Normal values of gain fluctuations from broadside to the edges of the normal ±50° scanning bounds range between 4-5 dB [1].

Reducing gain loss at large scan angles can be accomplished by using elements that have a very large half-power beamwidth (HPBW). Many element types utilized for wide-angle scanning applications inherently have wide element patterns such as half-mode substrate integrated waveguide (HMSIW) slot elements [3] or microstrip magnetic dipole elements [4]. Some methods and array designs can artificially widen the antenna element pattern by increasing the amount of generated endfire radiation such as introducing vertical metal walls around the radiating element [5] or employing parasitic elements at the edges of the array [4]. This paper models the gain loss phenomenon with increasing scan angle by investigating both wide- and narrow-beam element patterns using a 25-element uniformly illuminated linear array with a half-wavelength element spacing. The computed results show the benefit of electing for a wider element pattern for wide-scanning angle applications and highlights the ramifications of utilizing elements with narrower patterns.

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II. Formulation of the Element and Array Patterns

For simplicity and without the loss of generality, the narrow- and wide-beam element patterns are modeled herein using a power of the cosine. Each element pattern is given by:

$$E(\theta) = \cos^n(\theta) \tag{1}$$

where E is the total electric field radiated by the element, n is a positive real-valued number that determines the "wideness" of the element pattern, and θ is the conventional spherical coordinate. As n increases, narrower element patterns are generated. For this paper, n = 12 and n = 0.85 were used for creating the narrow- and wide-beam element patterns, respectively. The HPBW of the narrow-beam pattern is 27.36°, and that of the wide-beam pattern is 96.48°.

The overall array pattern is obtained by the multiplication of the element pattern and the array factor. The general array factor expression for a uniform, broadside, linear array whose elements are distributed along the x-axis is given by:

$$AF(\theta,\phi) = \sum_{n=1}^{N} e^{j\frac{2\pi}{\lambda}d(n-1)\sin\theta\cos\phi} \tag{2}$$

where d is the element spacing and ϕ = 0° is assumed to scan the main beam in the θ direction. Fig. 1 shows a plot of the element pattern, array factor, and the resulting array pattern steered to broadside for the cases of a narrow-beam and wide-beam element pattern. It is notable that the narrow-beam element pattern causes a near-complete cancellation of the minor lobes beyond ±40°.

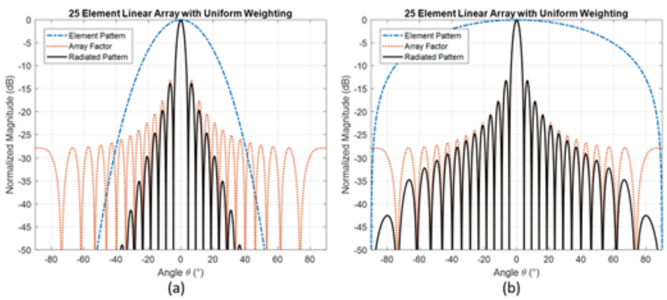

Fig. 1. Radiation patterns of a broadside, uniformly-excited, 25-element linear array with the element patterns of (a) n=12 and (b) n=0.85.

III. Scanning Characteristics

The phenomenon of gain loss while scanning is caused by a mismatch between the array factor and the element pattern. This mismatch increases as the array scans farther off-broadside because of the drop-off in the element pattern. For narrower element patterns, the drop-off becomes steeper much quicker, causing large gain drops at smaller scan angles.

Array scan angle is accounted for in the array factor, and is realized by using complex-valued weights that contain the desired steer angle (θ_0, ϕ_0). In general, using complex weights in the array factor of (2) to scan the array yields:

$$AF(\theta,\phi) = \sum_{n=1}^{N} e^{j\frac{2\pi}{\lambda}d(n-1)(sin\theta cos\phi - sin\theta_0 cos\phi_0)} \quad (3)$$

where $\phi = 0°$ and $\phi_0 = 0°$ because the array is linear and can only scan in a single direction, thus simplifying the array factor to:

$$AF(\theta) = \sum_{n=1}^{N} e^{j\frac{2\pi}{\lambda}d(n-1)(sin\theta - sin\theta_0)} \quad (4)$$

To obtain the total array pattern, (4) is given a scan angle θ_0 and the result is multiplied by the pattern radiated from an individual element in the array. The gain loss results for the scan angles of $\theta_0 = 25°$and $\theta_0 = 60°$ are plotted in Figs. 2 and 3, respectively, for both the narrow- and wide-beam element cases.

As observed in Fig. 2, for the scan angle of 25° off-broadside, there is a 10 dB gain loss in the array that uses the narrow-beam elements; the array utilizing wide-beam elements only shows an approximate 0.5 dB in gain loss.

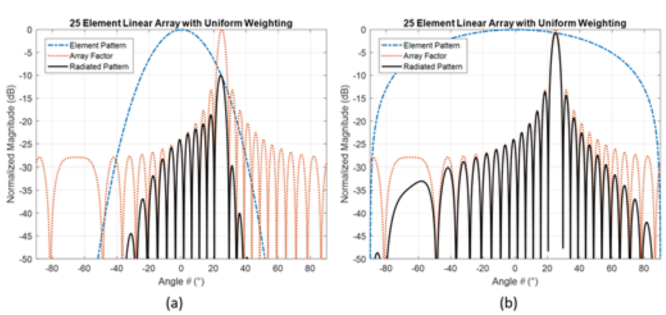

Fig. 2. Radiation patterns of a uniformly-excited, 25-element linear array steered to 25° off-broadside with the element patterns of (a) n=12 and (b) n=0.85.

The results for a wide desired scan angle of 60° off-broadside are shown in Fig. 3. As observed, the main lobe is completely cancelled for the narrow-beam element due to the array factor maximum being outside the range of the element pattern. On the contrary, the wide-beam element array only suffers approximately 5 dB in gain loss which is a reasonable amount considering such a wide scan angle.

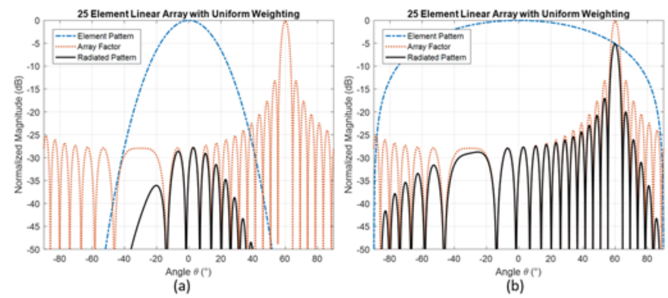

Fig. 3. Radiation patterns of a uniformly-excited, 25-element linear array steered to 60° off-broadside with the element patterns of (a) n=12 and (b) n=0.85.

IV. Conclusion

Gain degradation due to the mismatch of the element pattern and array factor while scanning is discussed. Gain loss for scanning phased arrays can be significantly improved by using elements that have wide HPBWs. However, increasing the HPBW can lead to a higher sidelobe level (SLL), but this can be alleviated by incorporating tapered amplitude distributions. The maximum gain values of the narrow-beam and wide-beam elements are compared at the scan angles of $\theta_0 = 0°$, $\theta_0 = 25°$, and $\theta_0 = 60°$. Based on the simulation results, elements with inherent or artificially created wide-beam element patterns are integral in minimizing gain degradation in scanning phased arrays, especially for wide-angle scanning applications.

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