Low Sidelobe Polarization Tapers for Planar Arrays

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Abstract: This paper presents a technique that optimized the orientation of each dipole in an array to minimize the sidelobes in the co-polarization pattern. A genetic algorithm calls a planar array cost function modeled using Feko Suite 5.1. The technique is demonstrated with a 6 by 6 and 10 by 10 planar arrays.

Keywords: planar array, genetic algorithm, low sidelobe, polarization, and antenna array.

1. Introduction

The textbook design of an antenna array assumes that all the elements have the same radiation pattern, and no mutual coupling exists. Thus, the resultant far field array pattern is the array factor multiplied by a single element pattern [1]. A planar array of dipoles (Fig. 1) with $N_x$ elements spaced $d_x$ apart in the x direction and $N_z$ elements spaced $d_z$ apart in the z direction has a far field pattern given by,

$$FF(\theta, \phi) = \cos \left( \frac{\pi \cos \theta}{2 \sin \theta} \right) \sum_{n=1}^{N_x} \sum_{m=1}^{N_z} w_{m,n} e^{j[k[(m-1)d_x \sin \theta \cos \phi + (n-1)d_z \cos \phi]]}$$

(1)

where

$$\cos \left( \frac{\pi \cos \theta}{2 \sin \theta} \right) = \text{Half wave dipole antenna pattern}$$

$N_x, N_z =$ Number of elements in x, z direction, respectively

$w_{m,n} =$ Single element amplitude

$k =$ Wave-number

$d_x, d_z =$ Element spacing in x, z direction, respectively

In order to take into account the mutual coupling between elements, Feko Suit 5.1 [2] is used to model two uniform planar arrays as seen in Fig. 2 and Fig. 3. Both arrays, have elements spaced $\lambda / 2$ apart, wire radius of $\lambda / 500$, and center fed with a voltage amplitude of one and zero phase.

Fig. 2a is a 36 element 6 by 6 array. The array is $\theta$-polarized with a maximum gain of 17.5 dB (Fig. 2b). The maximum sidelobe level (SLL) is 12.9 dB below the main beam. There is no cross-polarization as seen in Fig. 2c. Fig. 3a is a 100 element 10 by 10 array. The array is $\theta$-polarized with a maximum gain of 22.0 dB (Fig. 3b). The maximum SLL is 13.1 dB below the main beam. There is no cross-polarization as seen in Fig. 3c.
Fig. 1. Geometry of a planar array lying in the x-z plane.

Fig. 2. The 6 by 6 uniform array has a maximum gain of 17.5 dB with a sidelobe level of 12.9 dB below the main beam. (a) 6 by 6 uniform planar array. (b) $\theta$-polarized gain of a 6 by 6 array. (c) $\phi$ - polarized gain of a 6 by 6 array.
2. Planar Arrays with Tilted dipoles

Rather than weighting or non-uniformly spacing the dipoles to obtain low sidelobes [3], this section shows how to tilt the dipoles in Fig. 2a and Fig. 3a to minimize the sidelobe level for the co-polarized far field pattern while minimizing the entire cross-polarization pattern. The dipoles are tilted about their center in the x-z plane from \( \theta = 0 \) to \( \theta = 360 \) degrees (Fig. 4a.). Tilting a dipole in an array changes its polarization. For instance, when the dipole is parallel to the z-axis, it receives a \( \phi \)-polarized signal. As \( \theta \) increases, the dipoles ability to receive \( \theta \)-polarized signals decreases while the dipoles ability to receive \( \phi \)-polarized signals increases (Fig. 4a.). Thus, the amount of signal a linear dipole receives is a function of its tilt.

As will be seen in the following section, the planar arrays are optimized to receive a \( \theta \)-polarized signal. Therefore, the center four dipoles of the array are polarization matched at \( \theta = 0 \). The rest of the dipoles display the symmetry as seen in Fig. 4b. The reason for this symmetry is to create a maximum \( \theta \)-polarized array and a minimum \( \phi \)-polarized array when looking along the y-axis. From inspection, the electric fields add in phase in the z direction, and out of phase in the x direction.
3. Optimized Tilt of the Dipoles

Through the use of a genetic algorithm [4] the dipole tilt angles were found to minimize the maximum sidelobe level. The cost function calculates the co-polarization and cross-polarization antenna patterns over the range of $\phi = 0$ to $\phi = 90$ and $\theta = 0$ to $\theta = 90$. First, the co-polarization maximum SLL is found. Second, the maximum of the cross-polarization pattern is found. The cost is then the larger of the two values. This results in the co-polarization maximum SLL equaling to the cross-polarization maximum gain with the main beam oriented at $\phi = \theta = 90$.

Optimizing the elements in the 6 by 6 element array (Fig. 5a) results in a maximum gain of 15.5 dB with a maximum SLL of 17.0 dB below the main beam. Fig. 5b is the $\theta$-polarized gain of the array. It is seen that the maximum sidelobe levels have gone down significantly compared to Fig. 2b. Fig. 5c is the $\phi$-polarized gain of the array. Since the dipoles are now tilted the $\phi$-polarized pattern exists as compared to Fig. 2c. Comparing these results to that of a uniform array (Fig. 2) the maximum gain went down by 2.0 dB and the SLL decreased by 4.1 dB after optimization.

Optimizing the elements in the 10 by 10 element array (Fig. 6a) results in a maximum gain of 19.9 dB with a maximum SLL of 19.4 dB below the main beam. Fig. 6b is the $\theta$-polarized gain of the array. It is seen that the maximum sidelobe levels have gone down significantly compared to Fig. 3b. Fig. 6c is the $\phi$-polarized gain of the array. Since the dipoles are now tilted the $\phi$-polarized pattern exists as compared to Fig. 3c. Comparing these results to that of a uniform array (Fig. 3) the maximum gain went down by 2.1 dB and the SLL decreased by 6.3 dB after optimization.
Fig. 5. The 6 by 6 optimized array has a maximum gain of 15.5 dB with a sidelobe level of 17.0 dB below the main beam. (a) 6 by 6 optimized planar array. (b) $\theta$ - polarized gain of a 6 by 6 array. (c) $\phi$ - polarized gain of a 6 by 6 array.

Fig. 6. The 10 by 10 optimized array has a maximum gain of 19.9 dB with a sidelobe level of 19.4 dB below the main beam. (a) 10 by 10 optimized planar array. (b) $\theta$ - polarized gain of a 10 by 10 array. (c) $\phi$ - polarized gain of a 10 by 10 array.
4. Conclusion

This paper presents results from minimizing the maximum SLL of the co-polarized pattern while minimizing the entire cross-polarized pattern through tiling the dipoles in a uniformly spaced planar array. This concept can be applied to various other antennas with linear polarization such as patches. Further improvements in the sidelobe level are possible by combing polarization tapering with other low sidelobe design techniques.

5. References