Optimizing the Sidelobe Level of a Two-Way Antenna Array Pattern by Thinning the Receive Aperture

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***Abstract*— The maximum sidelobe level of a two-way antenna array pattern of a radar is usually considered to be the product of the maximum sidelobe level of the transmit array time the maximum sidelobe level of the receive array. This paper shows that a thinned receive array can be synthesized in order to place nulls of the receive pattern in the directions of the peak sidelobes of the transmit pattern to get even lower two-way maximum sidelobe levels. The two-way pattern is synthesized using a genetic algorithm to find a thinned receive aperture that minimizes the maximum two-way sidelobe level with a uniform transmit array.**

Keywords*— *antenna array; phased array; radar; genetic algorithm; optimization; low sidelobes; two-way pattern

I. INTRODUCTION

Radar designers suppress sidelobes in the radiation pattern of a phased array antenna in order to avoid picking up objectionable amounts of ground clutter and other spurious signals [1]. Sidelobe suppression is usually in the form of an amplitude taper applied to the elements in the array. The amplitude taper can be in the form of a thinned array in which the amplitude taper is quantized to one bit. Elements towards the center of the array are active while passive elements are inserted in the array lattice at increasing frequency towards the array edges. Thinning can be optimized to yield the lowest possible sidelobe levels using a global optimization method, such as a genetic algorithm [2][3][4].

A low sidelobe taper on the transmit aperture reduces efficiency because not all the T/R modules transmit at full power. Using attenuators to produce the amplitude taper produces power dissipation problems. Changing the bias in the transmit amplifier causes mismatch problems. Making the transmit aperture uniform provides the maximum EIRP while eliminating amplitude taper implementation problems on the transmit array. Using a uniform transmit array means that the two-way pattern peak sidelobes are primarily determined by the receive pattern sidelobes [5].

Sidelobe levels of the two-way antenna pattern are important in many applications, such as SAR [6][7] and meteorological radar [8]. In general, the approach to two-way pattern synthesis is to synthesize the transmit and receive patterns separately, then multiply them to get the two-way pattern. The approach in [9] synthesized a two-way pattern using a gradient-based optimization to find a phase taper for the uniform transmit array and an amplitude and phase taper for the receive array. One report provided three approaches to generate low sidelobes in the two-way pattern when the transmit pattern is uniform and the receive pattern has low sidelobes [10]:

1. Make the transmit aperture smaller than the receive aperture, so that the first null of the transmit and receive patterns are at the same angle.
2. Split the uniform transmit aperture into two then steer both subapertures until their peak sidelobes are at the first nulls of the receive pattern.
3. Place a quadratic phase taper on the uniform transmit pattern.

The first approach produced the best results, while the last approach did not work well at all. It is possible to improve on the first approach by using a genetic algorithm to optimize the receive amplitude taper in order to get the lowest possible two-way peak sidelobe levels.

This paper presents the synthesis of low sidelobe two-way patterns radar planar arrays with a uniform transmit array and thinned receive array. T/R modules are located at all the active elements, while inactive receive elements only have transmit modules. Section II introduces the antenna array model. Section III demonstrates the traditional approach to synthesizing a two-way pattern. Section IV explains the logic behind this new two-way pattern synthesis approach. Section V introduces a new approach to two-way array pattern synthesis. The results show that the two-way pattern maximum sidelobe level can be lowered approximately 6.5 dB by optimizing the two-way pattern rather than the transmit pattern and the receive pattern separately at the expense of reduced gain.

II. ARRAY MODEL

Assume that the radar has an *N*-element planar array lying in the x-y plane with a square lattice as shown in Fig. 1. The transmit array factor when all the elements are uniformly weighted is given by

$$AF_{tx} = \sum_{m=1}^{N_y} \sum_{n=1}^{N_x} e^{-jk\left[(n-1)d_x \sin\theta\cos\phi+(m-1)d_y \sin\theta\sin\phi\right]} \qquad (1)$$

where

$N_x =$ number of elements in x-direction

$N_y =$ number of elements in y-direction

$k = 2\pi/\lambda$

$\lambda =$ wavelength

$d_x =$ element spacing in x-direction

$d_y =$ element spacing in y-direction

$\theta =$ angle measured from z-axis (elevation)

$\phi =$ angle measured from x-direction (azimuth)

The thinned receive array factor is written as

$$AF_{rx} = \sum_{m=1}^{N_y} \sum_{n=1}^{N_x} w_{m,n} e^{jk\left[(n-1)d_x \sin\theta\cos\phi+(m-1)d_y \sin\theta\sin\phi\right]} \qquad (2)$$

where

$$w_{m,n} = \begin{cases} 1 & \text{element turned on} \\ 0 & \text{element turned off} \end{cases}$$

The two-way antenna pattern is just the product of (1) and (2)

$$AF_2 = AF_{tx} \times AF_{rx} \qquad (3)$$

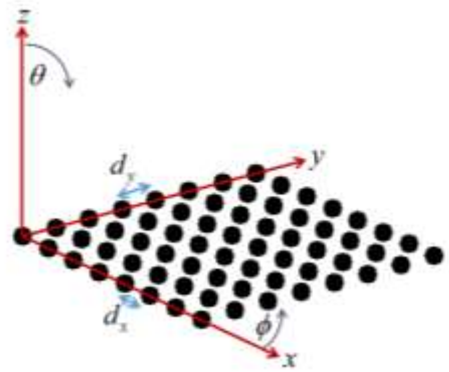

Fig. 1. Planar array model.

In this paper, we assume the array has 32 by 32 elements that are spaced $\lambda/2$ apart in the x- and y-directions for a total of N = 1024 elements. The transmit array is assumed to be uniform, so its array factor is shown in Fig. 2. It has a directivity of 35.1 dB and a peak sidelobe level that is 13.3 dB below the main beam.

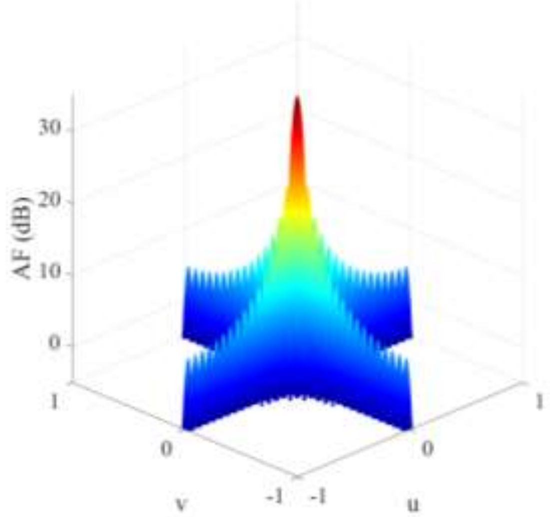

Fig. 2. Transmit uniform array factor.

III. Traditional Approach to Synthesizing a Two-Way Antenna Pattern

The traditional approach to synthesizing a two-way pattern would thin the receive array aperture in order to minimize the maximum sidelobe level of the receive array factor. In this case, a genetic algorithm minimizes the cost function given by

$$\text{cost} = sll_{rxpeak} \qquad (4)$$

where sll_{rxpeak} is the peak sidelobe level of (2). The genetic algorithm used for this problem is found in [9]. The corresponding receive pattern is then substituted into (3) to yield the two-way pattern.

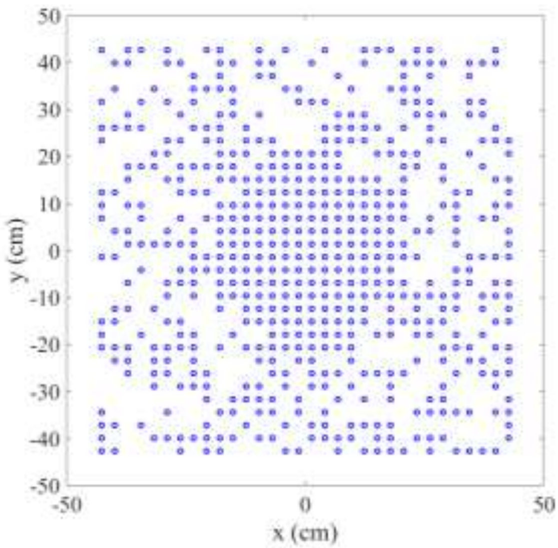

Fig. 3. The two-way pattern resulting from a uniform transmit and a uniform receive pattern for an 8 element linear array.

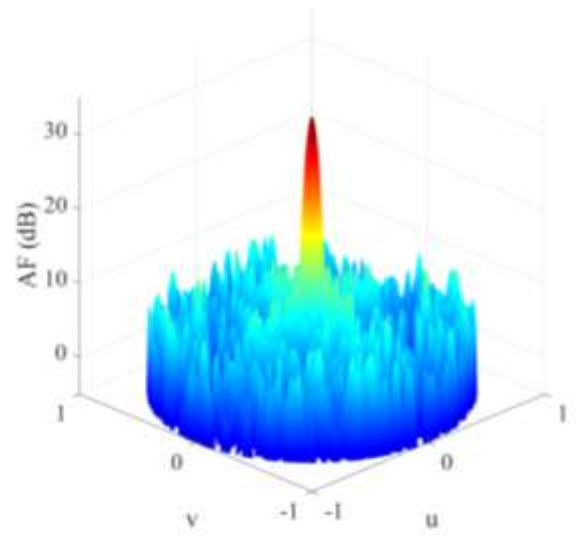

Fig. 4. Optimized thinned receive array factor.

The genetic algorithm found the receive array thinning shown in Fig. 3. This aperture has a directivity of 32.6 dB with a taper efficiency of

$$\eta = \frac{N_{on}}{N} = 0.56 \tag{5}$$

where N_{on} is the number of active elements. Fig. 4 shows the resulting array factor that has a peak sidelobe level that is 21.1 dB below the main beam.

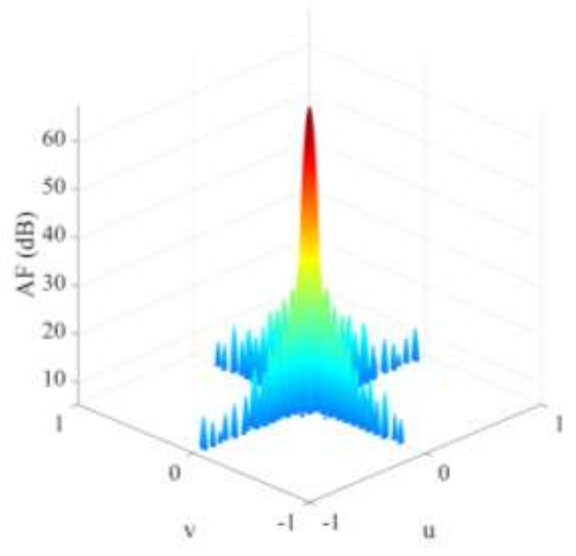

Fig. 5. The two-way pattern resulting from a uniform transmit and an optimized thinned receive array.

The two-way pattern is found by multiplying the synthesized thinned array factor by the uniform array factor. The resulting two-way array factor shown in Fig. 5 has a directivity of 67.6 dB with a maximum sidelobe level that is 34.3 dB below the main beam. Note that this two-way peak sidelobe level approximately equals the sum (in dB) of the peak sidelobe levels of the transmit and receive array factors.

IV. Synthesized Two-Way Pattern: Small Linear Array Example

In this section we present an illustrative example of optimizing a two-way sidelobe pattern through a small linear array. The linear array has 8 elements spaced $\lambda/2$ apart. The object is to place nulls of one pattern at the location of sidelobe peaks of the other pattern. Turning off two end elements is the optimum solution (Fig. 6) -- no genetic algorithm needed here. The 6 element receive pattern is superimposed on the uniform transmit patter in Fig. 7. Note that when one pattern has a null the other one has a peak. Forcing the receive pattern to have nulls at the same locations as the sidelobes of the transmit antenna results in a lower peak sidelobe level than the product of the transmit antenna pattern and a low sidelobe receive pattern. Fig. 8 is a plot of the optimized two-way pattern. Its two-way directivity is 16.8 dB with a peak sidelobe level that is 29.2 dB below the peak of the main beam. The two-way pattern of a uniform 8 element transmit and receive array has a directivity of 18.1 dB and peak relative sidelobe level of 26.4 dB. In this case, both the transmit and receive patterns have a maximum sidelobe level of 13.2 dB but a two-way pattern maximum sidelobe level greater than the combined 26.4 dB.

Fig. 6. The optimized receive and transmit arrays.

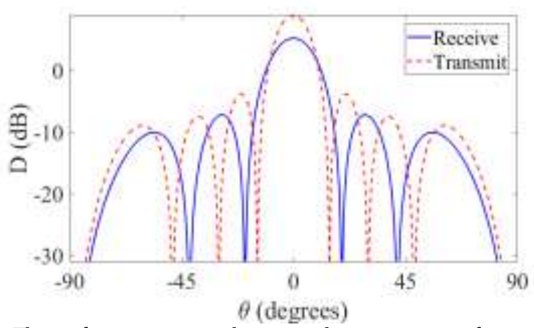

Fig. 7. The uniform transmit and optimized receive pattern for an 8 element linear array.

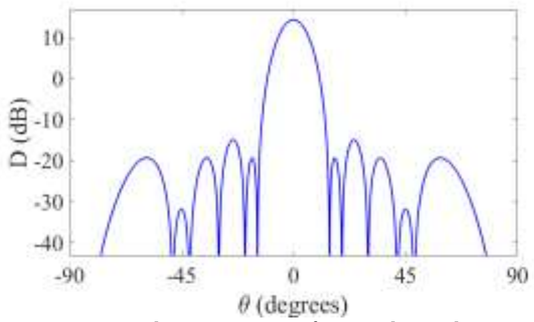

Fig. 8. Optimized two-way pattern for an 8 element linear array.

V. SYNTHESIZED TWO-WAY PATTERN: PLANAR ARRAY EXAMPLE

Rather than minimizing the maximum sidelobe level of the receive array factor, the genetic algorithm can minimize the peak sidelobe level of the two-way pattern using the cost function

$$\text{cost} = sll_{2peak} \tag{6}$$

where sll_{2peak} is the peak sidelobe level of (3).

The genetic algorithm found the receive array thinning shown in Fig. 9. This aperture has a directivity of 32.3 dB with a taper efficiency of $\eta = 0.53$. Fig. 10 shows the resulting receive array factor that has a peak sidelobe level that is 19.2 dB below the main beam.

The two-way pattern is found by multiplying the synthesized thinned receive array factor by the uniform transmit array factor. The resulting two-way array factor shown in Fig. 11 has a directivity of 67.4 dB with a maximum sidelobe level that is 40.8 dB below the main beam. This two-way peak sidelobe level is 8.3 dB less than the sum (in dB) of the peaks sidelobe levels of the transmit and receive array factors and 6.5 dB less than that obtained by optimizing only the receive pattern.

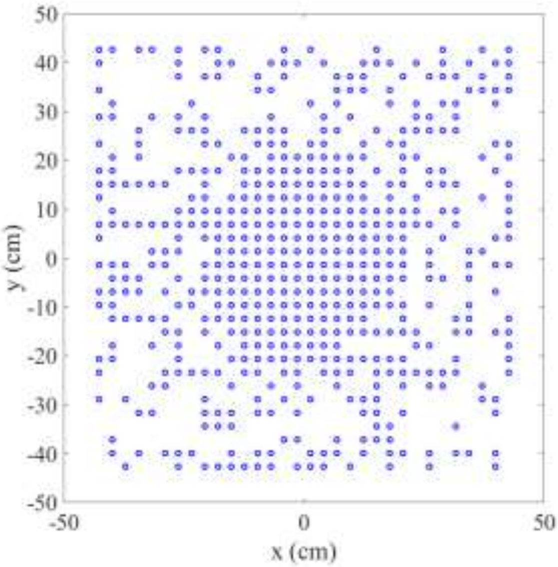

Fig. 9. Thinned receive array optimized for a minimum maximum 2-way sidelobe level.

VI. CONCLUSIONS

In the traditional approach to synthesizing a two-way pattern, the peak sidelobe level of a two-way pattern equals the peak sidelobe level of the receive pattern times the peak sidelobe level of the transmit pattern. This idea was confirmed by multiplying a uniform transmit pattern by a thinned receive array pattern in which the thinning minimized the peak sidelobe level of the receive pattern. The approach advocated in this paper finds a thinning for the receive array that minimizes the peak sidelobe level of the two-way pattern. Although the receive pattern in this approach has a 1.9 dB higher peak sidelobe level than the traditional approach, the two-way pattern has a peak sidelobe level that is 6.5 dB less than the traditional approach at a cost of losing 0.2 dB in the maximum directivity. Other optimization methods will yield similar results. There is not a unique solution.

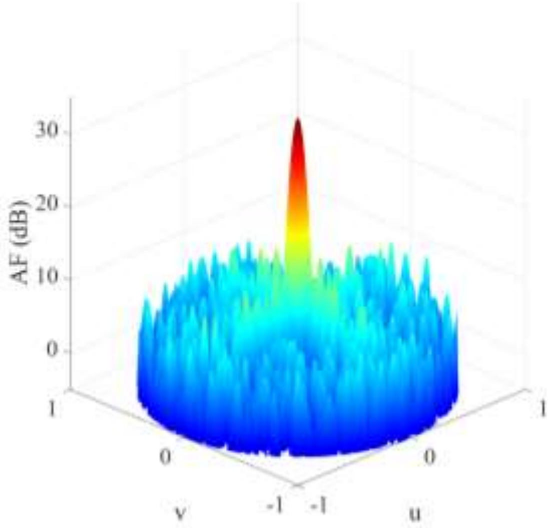

Fig. 10. Receive array factor corresponding to Fig. 9.

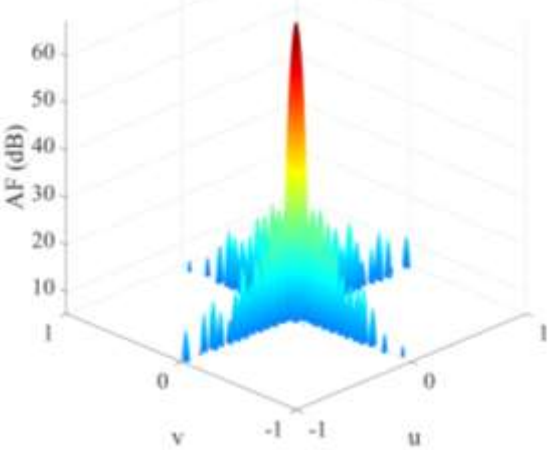

Fig. 11. The optimized 2-way array factor.

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