Phase-Only Optimization of Beam Efficiency for a Large Scanning Reflectarray

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***Abstract*—A fast and efficient method for synthesizing element excitations for very large reflectarrays is presented to be used on a Configurable Reflectarray for Electronic Wideband Scanning Radiometry (CREWSR). CREWSR is a tri-band scanning reflectarray that contains three lattices of antenna elements, each containing 120,000 to 480,000 elements. Applying the fast Fourier transform and the alternating projection method allows for an optimization algorithm that achieves phase-only synthesis, targeting side lobe levels to increase beam efficiency.**

I. Introduction

In applications such as space-based weather radiometry, reflectarrays are an attractive alternative to traditional phased array antennas. In addition to their lower size, weight, and power requirements, it is possible to achieve higher gain and resolution by increasing the number of elements in the reflectarray. The Configurable Reflectarray for Electronic Wideband Scanning Radiometry (CREWSR), in development at MIT Lincoln Laboratory, is one such example of a large reflectarray [1]. CREWSR allows tri-band sensing by interleaving lattices of antenna elements, one for each of the three frequency bands it operates in. The three lattices each contain 120,000 to 480,000 elements (connected to separate reflective 4-bit phase shifters), that enable independent beamsteering on each band. However, the inherent size of CREWSR and other very large reflectarrays present a challenge in implementing optimization and synthesis procedures.

Widely used optimization and synthesis algorithms were designed for much smaller arrays; computation burden tends to scale dramatically as the number of array elements increase. In addition, reflectarrays are restricted to phase-only synthesis – each of CREWSR's lattices are illuminated by separate horn antennas – which limits the algorithms that can be used. For these reasons, these algorithms tend to be computationally impractical for large reflectarrays.

This paper investigates a method to quickly synthesize element excitations for very large reflectarrays. It has been shown in [2] that it is possible to apply the properties of the Fourier transform to quickly synthesize patterns for planar array antennas with periodic element spacing. By modifying the algorithm described in [3], it is possible to extend this method to the reflectarray on the CREWSR platform to optimize beam efficiency.

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CREWSR's mission is to measure atmospheric factors such as temperature and humidity – in other words, the antenna is detecting noise in the atmosphere. It is therefore important to minimize noise from outside of the target area, which is why we are interested in optimizing CREWSR's beam efficiency. As beam efficiency is related to side lobe level we optimize on beam efficiency through manipulating side lobes. [4] defines beam efficiency (BE) as

$$BE = \frac{\iint_{mainbeam} P(\theta, \phi)\, \sin\theta d\theta d\phi}{\int_{4\pi} P(\theta, \phi)\, \sin\theta d\theta d\phi} = \frac{\Omega_M}{\Omega_A} \tag{1}$$

where $P(\theta, \phi)$ is normalized antenna power pattern, Ω_M is the main beam solid angle, and Ω_A is the antenna beam solid angle. Using half power beamwidth (HPBW), we define the main beam as

$$\text{main beam} = 2.5 \cdot \text{HPBW}. \tag{2}$$

II. Optimization Algorithm and Application

Referring to Fig. 1, this algorithm achieves side lobe suppression using the fast Fourier transform (FFT) and the alternating projection method (APM). The array factor is used to represent the radiated far fields.

A. Challenges

Convex optimization problems are relatively straightforward to solve. They have small computational runtimes that grow gracefully with problem size. Local search algorithms can be used on these optimization problems, since by definition local minimums will also be global minimums. Most antenna synthesis problems (notably when phase and magnitude are variable) are convex and have well documented algorithms.

However, phase-only synthesis is a non-convex problem, which is less efficient to solve. To fully solve these types of problems, alternative techniques must be employed (e.g. global search or genetic algorithms), many of which require larger and larger amounts of computational time as array size increases. At CREWSR's scale, this problem is intractable with these brute force approaches. However, by exploiting certain properties of reflectarrays, it is possible to mitigate these problems.

B. Algorithm

The alternating projection method (APM) is an iterative optimization technique used to find a point that satisfies multiple constraints simultaneously. It operates by iteratively projecting the current point onto each constraint set, alternating between them until convergence. In each iteration, the method computes the projection of the current point onto one constraint set while keeping it fixed with respect to the other sets, gradually moving towards a solution that satisfies all constraints.

The inverse fast Fourier transform (IFFT) can quickly synthesize the array factor of antenna arrays with periodic structure. It transforms a matrix of magnitude/phase weights of each array element to an array factor. The fast Fourier transform (FFT) does the reverse - it maps the far field array factor to the near field element excitation.

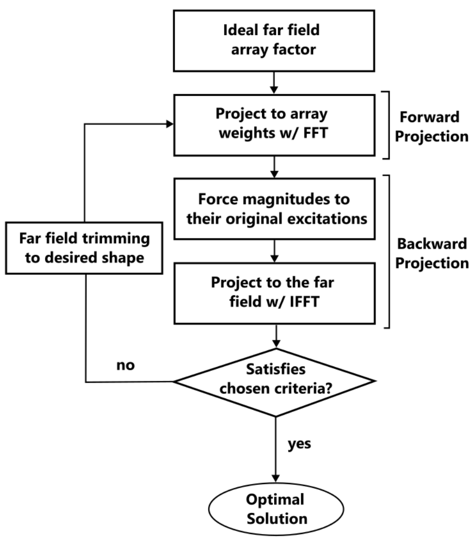

Fig. 1. Optimization Algorithm Flowchart

In this paper, the algorithm takes advantage of these methods. As in Fig. 1, the algorithm starts with a set of possible array weights and a set of desired sampled far field points. The desired far field points are transformed between both sets using the IFFT and FFT. When an intersection occurs, the algorithm has found a solution that satisfies all desired criteria. Otherwise, the algorithm converges to a state where the two sets are the closest – this state is the most optimized solution possible.

III. Reflectarray Optimization and Results

In a reflectarray, a feed antenna illuminates each element unevenly. Therefore, the illumination of each element by the feed is calculated and integrated into the algorithm, represented by the step "Force magnitudes to their original excitations" in Fig. 1.

CREWSR employs a 4-bit phase shifter on each element, which means that all possible phases are limited to 16 different values. The results in Fig. 2 show the results of the algorithm being run for 15 iterations on a 57 by 57 element array (the size of CREWSR one panel). The beam efficiency for this array starts stabilizing and converging towards 94% after 5 iterations. For reference, our baseline panel single beam efficiency is calculated to be around 89-90%.

The normalized phases of the optimized excitations give a fairly uniform phase distribution, with most phases being close to 0°. The effects of the algorithm are most apparent along the edge elements of the array, with excitations anywhere between -180° and 180°.

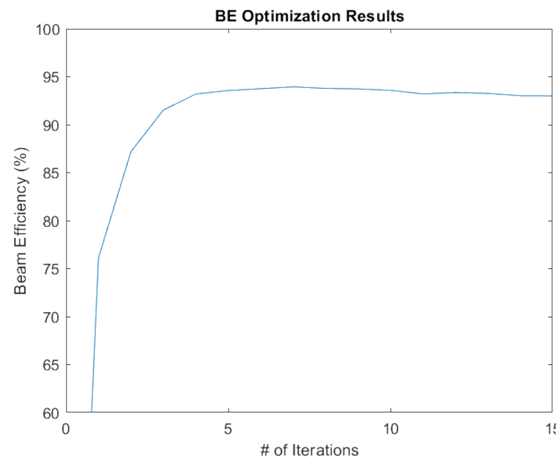

Fig. 2. Plot of Beam Efficiency vs. Algorithm Iterations for a Planar Array

IV. Conclusion

A phase-only synthesis algorithm to quickly optimize element excitations for the large reflectarray on the CREWSR platform has been presented. High beam efficiency is optimal for weather radiometry applications, and by trimming its side lobes, the CREWSR reflectarray is optimized on beam efficiency. Applying a combination of techniques, such as using FFTs and APM, allows optimization to efficiently occur when applied to antenna arrays with a large number of elements. Future work includes applying a smarter method of trimming side lobe levels.

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