A Particle Swarm Approach to Grating Lobe Suppression in an Aperiodic Vivaldi Array

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***Abstract*—To avoid grating lobes, periodic array elements must be $\lambda_o/2$ apart. For wideband arrays, sparsity in array element sparsity is unavoidable. This paper explores using particle swarm optimization to create an aperiodic spacing between Vivaldi elements to help suppress grating lobes from 2-40 GHz.**

I. Introduction

Designers use electrically scanned array (ESA) antennas for radar, space communication and radio astronomy. Conventionally, radiating elements are one-half of a free space wavelength apart to avoid generating grating lobes in the far field radiation patterns. Grating lobes are images of the main beam that appear in other portions of the radiation pattern as you steer the main beam off boresight. A sparser element spacing at a given frequency generates more grating lobes in the hemispherical radiation pattern even for steering angles of 0°.

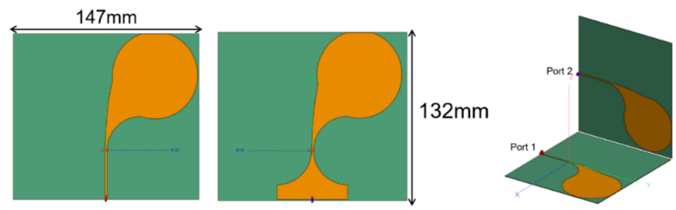
For wideband ESAs, as frequency increases λ_o decreases which means sparsity between radiating elements in the ESA increases with frequency. In an ESA spanning 2-40 GHz, radiating elements $\lambda_o/2$ apart at 2 GHz are $10\lambda_o$ apart at 40 GHz because λ_o is 20 times smaller at 40 GHz than at 2 GHz.

Non-uniform, quasi-aperiodic, and aperiodic ESA geometries are studied in the literature as a technique to reduce grating lobes [1-2]. For example, with a minimum inter-element spacing of $0.9\lambda_o$, using the triangular spacing scheme achieves grating lobe suppression levels -4.0 dB below the main lobe peak for a 1x16 linear ESA [2]. One can also use an overlapped subarray approach to maintain desired inter-element spacing in an ESA geometry, resulting in reduced grating lobe levels [3].

We simulate 8 dB grating lobe suppression in an 8x8 dual-polarized Vivaldi ESA that spans 2-40 GHz by optimizing element spacing with particle swarm optimization (PSO). PSO suppresses grating lobes better than deterministic taper distribution functions such as Gaussian, triangular and raised cosine. Furthermore, our PSO technique achieves similar grating lobe suppression regardless of the ESA bandwidth.

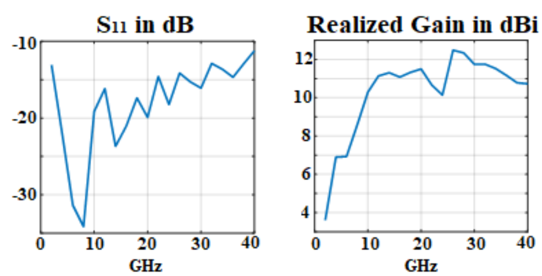
II. Dual Polarized Antipodal Vivaldi Element

We consider the design of a circular dual-polarized antipodal Vivaldi antenna element based on that of Muniyasamy and Rajakani [4]. The design utilizes a dielectric substrate having a thickness of 0.4 mm and a dielectric constant of 4.3. We show the circular Vivaldi in Fig. 1 with a footprint of 147x132 mm^2. The Vivaldi is an end-fire antenna requiring a balanced feed to two arms fed 180° out of phase and covers 2-40 GHz. The two arms exist on the top and bottom of a single dielectric substrate as shown in Figs. 1a and 1b. We create a dual-polarization antenna with the design shown in Fig. 1c. We simulate all antenna results using FEKO.



(a) **(b)** **(c)**

Fig. 1: a) Top, b) bottom and c) dual-polarization views of the 2-40 GHz Vivaldi.



(a) **(b)**

Fig. 2: a) S_{11} and b) realized gain of the 2-40 GHz Vivaldi.

The simulated S_{11} and realized gain versus frequency results of Figs. 2a and 2b show the performance of the antenna from Fig. 1. The antenna achieves an S_{11}<-10 dB across the whole bandwidth and a realized gain of 3.5-12.5 dBi.

III. Particle Swarm Optimization technique

We utilize a PSO approach to optimize the spacing between ESA elements to maximize the suppression of grating lobes across a 2-40 GHz bandwidth. Grating lobes are unlike side lobes and traditional amplitude tapering schemes have no effect on suppressing them. Fig. 3 shows how the PSO technique perturbs the position of each 8x8 element in the ESA to create an aperiodic arrangement of elements that will reduce grating lobe levels.

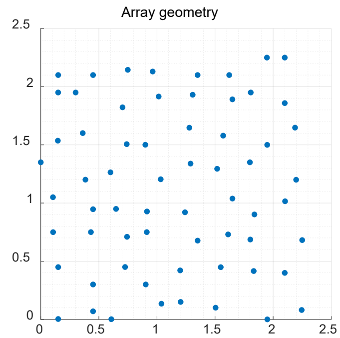


Fig. 3. Aperiodic ESA spacing for an 8x8 circular Vivaldi.

The PSO algorithm represents the positions of the elements as a complete set of perturbations. The PSO concept mimics the behavior of bees in search of the best location for food. The bees sample the space in a pseudo-random fashion at first. The initial randomness incorporates intelligence as follows: 1) bees report satisfaction with current position to each other; 2) bees remember personal best and global best of the swarm; 3) bees accelerate towards both in a pseudo-random fashion.

We calculate the cost value of each insect in the swarm as grating lobe level. We define a maximum threshold of -15 dB where grating lobes above the threshold have increasing cost. As the PSO algorithm reduces grating lobe levels, the cost value of that set decreases. In the end, the swarm converges to the best set of perturbations. Reference [5] provides in depth details on PSO as well as additional references.

IV. Simulated Grating Lobe Suppression

This section shows the simulated radiation patterns after combining the antenna design of Fig. 1 and the aperiodic ESA geometry of Fig. 3. Fig. 4 shows the resulting radiation pattern at 40 GHz of a uniformly spaced Vivaldi ESA where the array elements are $\lambda_o/2$ apart at 2 GHz. The maximum realized gain is 28 dBi for an 8x8 ESA, but we see the normalized pattern is full of grating lobes of nearly equal strength. Figs. 5a-5c show the same 8x8 ESA after we apply PSO aperiodic spacing to the elements. We see a grating lobe suppression of around 8 dB across the entire bandwidth.

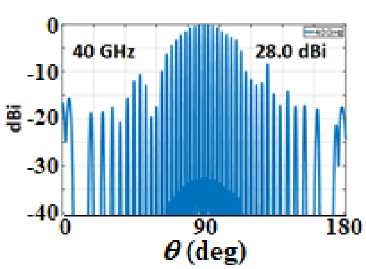


Fig. 4. Radiation pattern for a uniformly spaced Vivaldi ESA.

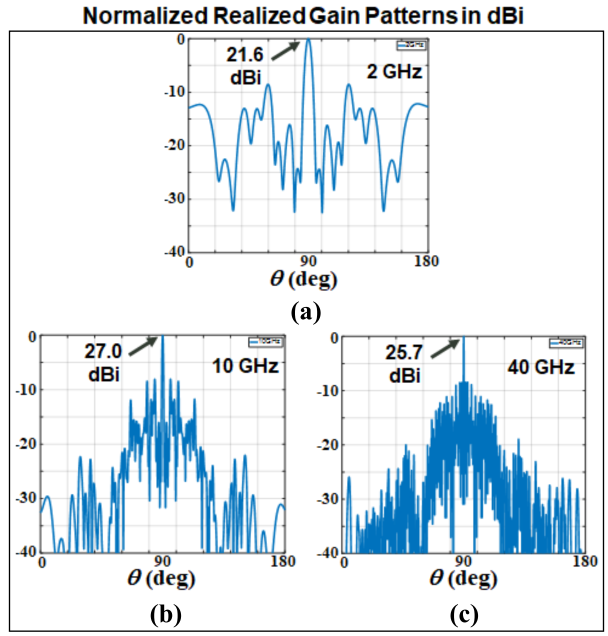


Fig. 5. Normalized radiation pattern for a PSO aperiodically spaced Vivaldi ESA at a) 2 GHz, b) 10 GHz and c) 40 GHz.

V. Conclusions

We propose the concept of using a PSO algorithm to generate aperiodic ESA element spacing to suppress grating lobes up to -8 dB for a Vivaldi 8x8 ESA spanning 2-40 GHz. We show simulated results exemplifying this improvement versus a uniformly spaced ESA of the same size comprising of the same Vivaldi element. Future work includes prototyping and measuring a smaller 4x4 version of this same array.

References

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