Design Validation of Prototype Ultra-wideband Linear Polyfractal Antenna Arrays

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I. Introduction

The need to create more agile antenna systems has inspired a considerable amount of research over the years to develop robust design methodologies for ultra-wideband arrays. Nevertheless, design techniques for wideband arrays have remained elusive. Recently a new design methodology has been developed that utilizes a genetic algorithm [1] to optimize solutions that incorporate both ordered and periodic properties in their geometries. These arrays, called polyfractal arrays, are capable of substantially lower sidelobe levels over ultra-wide bandwidths [2-4]. Figure 1 illustrates the array layout and radiation pattern for an example of a 1924-element polyfractal array, operating at a 20λ minimum (46.06λ average) interelement spacing [2]. This array has a peak side-lobe level (SLL) of -15.97 dB at a frequency where a standard periodic array would radiate 40 grating lobes. Moreover, Figure 2 demonstrates the wide bandwidth low-sidelobe performance exhibited by the array up to a minimum element spacing of 20λ . Because the peaks and nulls of subarrays tend to overlap in large sized polyfractal arrays, arrays consisting of large numbers of elements are generally capable of better bandwidth performance than less populated arrays. However, to prove the concept, arrays consisting of small numbers of elements are required in order to reduce the costs associated with fabrication and testing. This paper focuses on the design, construction, and testing of two prototype 32-element, ultra-wideband polyfractal antenna arrays and compares their performance with numerical simulations.

II. Array Designs for Proof of Concept

The two prototype arrays are designed to operate over a 4:1 bandwidth spanning a minimum interelement minimum spacing of $\frac{1}{2}\lambda$ to 2λ , corresponding to frequencies f_o and $4f_o$, respectively. Figure 2 shows plots of the maximum sidelobe level vs. minimum element spacing for prototypes A and B. Two arrays were chosen because one has lower SLL at the lower operating frequency f_o while the other has lower SLL at the upper operating frequency $4f_o$. The operating frequencies were chosen to be $f_o = 5$ GHz and $4f_o = 20$ GHz. Each prototype array was constructed twice, once per operating frequency to avoid wideband radiator and matching network issues. In addition, each full array was split into four subarrays to fit on size-restricted printed circuit panels. Arrays were constructed of square patch radiating elements and a microstrip corporate feed network on 0.031" thick Rogers RT/Duroid 5880 material.

III. Array Simulation

Each array was created and simulated in Ansoft Designer v2.2. In addition, each full array was split into corresponding subarrays as well for direct comparison to the experimental data. Figures 3 and 4 illustrate the differences in prototype A between simulation with a full array and pattern multiplication with simulated subarrays, the main difference being the lack of additional transmission line when in subarray fashion.

Figures 6 through 9 show the radiation patterns for the prototypes after simulation in subarray form and application of pattern multiplication. Side-lobe levels are similar to the (isotropic radiator) predictions shown in Figure 2.

IV. Experimental Results

The arrays were constructed and tested by JEM Engineering of Laurel, MD. Testing was done in a 14' x 14' x 46' tapered anechoic far-field chamber. Figures 5 and 6 show photographs of the fabricated subarrays that comprise array A for the 5 GHz and 20 GHz cases, respectively. Subarray patterns were combined in the same manner as discussed in Section III to yield the radiation patterns shown in Figures 6 through 9. Simulations are also provided for comparison with the measured results. We note that the microstrip feed radiation effects observed in simulation at 5 GHz have a more pronounced effect at 20 GHz. In addition, slight "warping" of the panels occurred due to the relatively thin substrate used for fabrication. This warping tends to produce a broadening in the main beam of the measured radiation patterns compared to predictions. Side-lobe levels for the prototype arrays are similar to predictions, yielding -16.3 dB and -14.2 dB at 5 GHz and -5.39 dB and -5.44 dB at 20 GHz for arrays A and B, respectively.

V. Conclusions

The beneficial properties of ultra-wideband linear polyfractal arrays have been validated through design, fabrication, and testing of two prototypes. Even with non-ideal influences such as feed line radiation and antenna panel warping, the 32-element prototypes maintain their low sidelobe levels over a 4:1 bandwidth. Conversely, conventional periodic structures would have developed grating lobes at 10 GHz.

References

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Figure 1: 1924-element Linear Polyfractal Array Radiation Pattern and Layout at 20λ Minimum Spacing

Figure 2: Ideal Isotropic 32-Element Prototypes and 1924-Element Polyfractal Array Performance

Figure 3: Array A at 5 GHz Near Main Beam

Figure 4: Array A at 5 GHz

Figure 5: Subarrays of Array A at 5 GHz

Figure 6: Subarrays of Array A at 20 GHz

Figure 6: Array A at 5 GHz

Figure 7: Array A at 20 GHz

Figure 8: Array B at 5 GHz

Figure 9: Array B at 20 GHz