Article

Design of Octagonal Fractal Array Antenna for Side Lobe Reduction with Morse-Thue Fractal Density Tapering Technique

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Abstract: Fractal array antennas are multiband arrays having ultra wide band and space filling facility. But Side lobe levels and large number of antenna elements are the major designing challenges of these arrays. In this paper, design and analysis of octagonal fractal array antenna is investigated with Morse-Thue fractal density tapering technique (MTFDT). Due to the proposed technique, a remarkable improvement has observed in Side lobe levels and thinning of the elements can also be attained at the various iterations of octagonal fractal array antenna. These arrays are analyzed and simulated by MATLAB-15 programming.

Keywords: fractal array antenna; density tapering; side lobe level

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1. Introduction

When a meticulous purpose insists superior gain, a fine directive pattern, steerability of the main beam, or other concert that a single element antenna cannot afford, an antenna made up of an array of discrete antenna elements may offer a clarification to the trouble [1]-[4]. Wide band and multi band performance of antennas and antenna arrays plays a crucial job in advanced communications and related systems. This type of antenna behaviour can be achieved by both fractal antennas and antenna arrays. Like conventional antenna arrays, fractal array antennas are also divided into three basic types. They are fractal linear, planar and conformal array antennas. One of the famous fractal linear arrays is cantor linear array [5], [6], it was generated with cantor set. Cantor ring array is also generated by Cantor set like Cantor linear array, Cantor ring arrays has also been investigated to achieve a thinned array and achieve multiple operating frequency bands [7]. Sirepinski carpet and triangular antenna arrays are best examples for fractal planar antenna arrays. Wide band and multi band performance of fractal antenna arrays can be depend on their number of iterations (P) and scaling factor (S). These two key factors can depend on design methodology of the fractal array antenna. Concentric circular ring sub array generator is one of the famous design methodologies for the generation of fractal array antennas. Using this methodology any polygon shape can be produced. Fractal square, triangular, hexagonal, heptagonal and octagonal arrays are finest examples of this design methodology [8], [9]. Three dimensional fractal array antennas can also be produced by concentric sphere array generators. Menger sponge fractal antenna array, 3-D Sierpinski gasket fractal antenna array has generated using this three dimensional methodology [10].

Fractal arrangement of array elements can create a thinned array and achieve multiband performance [11]. Current and phase excitations play a very important role in the formation of required radiation patterns. Uniform, binomial and triangular are meticulously used current

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distributions for array antennas [2]. This article investigated octagonal fractal array antenna with fractal Morse-Thue distribution of currents. Like fractal shapes, fractal number progressions also obeying self-similar nature. A large variety of fractal sequences are available, for this report, a three valued fractal sequence proposed by Morse and Thue is considered [12]. The considered series can be extended up to infinite set of values. Reports on the application of fractal excitation of current to octagonal fractal array antennas are relatively less or no more. In some reports various fractal distribution of currents, atomic functional and Fibonacci sequences are considered as current amplitudes to reduce side lobe levels in fractal arrays [13]-[16]. The rest of this article organized as follows: Section 2 explains the generation of MTFDT technique. Section 3 explains the design equation and iteration process of octagonal fractal antenna array. Section 4 discusses the results of proposed method and finally conclusion of this article draws in section 5.

2. Morse-Thue Fractal Density Tapering Technique

A fractal series is a number sequence which follows the property of self-similarity nature. Fractal sequences are also repeats again and again with different values like fractal geometrical shapes. An extensive range of fractal sequences are available, this report considered three valued fractal sequence proposed by Morse and Thue [12], this cycle can be extended to infinite set of values. Depending on this sequence MTFDT technique proposed and applied to the octagonal fractal array antenna. The generalized three-valued Morse-Thue fractal sequence is,

0 (Kernel)

0 1 2 (1st iteration)

0 1 2 1 2 0 2 0 1 (2nd iteration)

0 1 2 1 2 0 2 0 1 1 2 0 2 0 1 0 1 2 2 0 1 0 1 2 1 2 0 (3rd iteration)

0 1 2 1 2 0 2 0 1 1 2 0 2 0 1 0 1 2 2 0 1 0 1 2 1 2 0 1 2 0 2 0 1 0 1 2 2 0 1 0 1 2 1 2 0 0 1 2 1 2 0 2 0 1 2 0 1 0 1 2 1 2 0 0 1 2 1 2 0 2 0 1 1 2 0 2 0 1 0 1 2 0 1 2---------------------- (nth iteration)

Any Morse-Thue sequence starts with “0”, this is the kernel of that sequence. Generation of the sequence should depend on the expansion factor of the sequence. If the expansion factor of the sequence is two then first iteration should be “0 1” and the expansion factor of the sequence is three then first iteration should be “0 1 2”. In second iteration “0” should be replaced by “0 1 2”, “1” should be replaced by “1 2 0” and “3” should be substituted by “2 0 1”. By this progression, series can be extended to nth iteration. Of course, this paper cannot show the complete cycle, it is infinite. In this paper from first iteration to sixth iteration has considered for excitation of antenna elements of the considered fractal array.

3. Design Equation and Geometry of Octagonal Fractal Array Antenna

In this paper, octagonal fractal antenna array generated by concentric circular ring sub array generator is considered. The generalized array factor for fractal array of this type can be expressed as [8]:

$$AF_P(\theta,\phi) = \prod_{P=1}^{P} GA(S^{P-1}(\theta,\phi))$$

(1)

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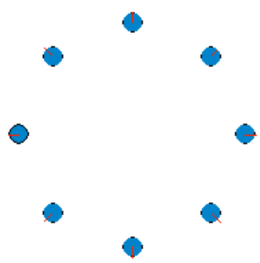
where P signifies number of iterations; it can be extended to infinite set of values. S is the scale (or) expansion factor that governs how large the array grows with each recursive application of the generating sub array. G.A. represents array factor associated with generating sub array is given by [5],

$$G.A(\theta,\phi) = \sum_{m=1}^{M}\sum_{n=1}^{N_m} I_{mn} e^{jkr_m \sin\theta\cos(\phi-\phi_{mn})+\alpha_{mn}} \tag{2}$$

where M is the total number of concentric rings; Nm is the total number of elements on the mth ring; Imn is the excitation current amplitude of the nth element on the mth ring ;k=2π/λ; rm is radius of the mth ring; θ is the angle between positive section of y axis and observation point in space; φ is the angle between positive section of x axis and observation point in space; φmn = 2π(n-1)/Nm; αmn is the excitation current phase of the nth element on the mth ring. Substitute (2) in (1) for the resultant array factor of "n" element fractal array generated by concentric circular ring sub array generator. Octagonal fractal antenna array is a self-similar two dimensional antenna array as shown in Fig.1and array factor is exemplified in (3) and (4). This array can also generated up to infinite extent, but in this paper results calculated up to four iterations having same distance between the elements (d= λ/2) [10].

$$\mathrm{AF_P} = \frac{1}{8^P}[\prod_{P=1}^{4}\{\sum_{n=1}^{8} I_n e^{j2^{p-1}\pi((\sin\theta\cos(\phi-\phi_n))-\sin\theta_0\cos(\phi_0-\phi_n))}\}] \tag{3}$$

$$\varphi n=(n-1)(2\pi/8) \tag{4}$$



Stage:1

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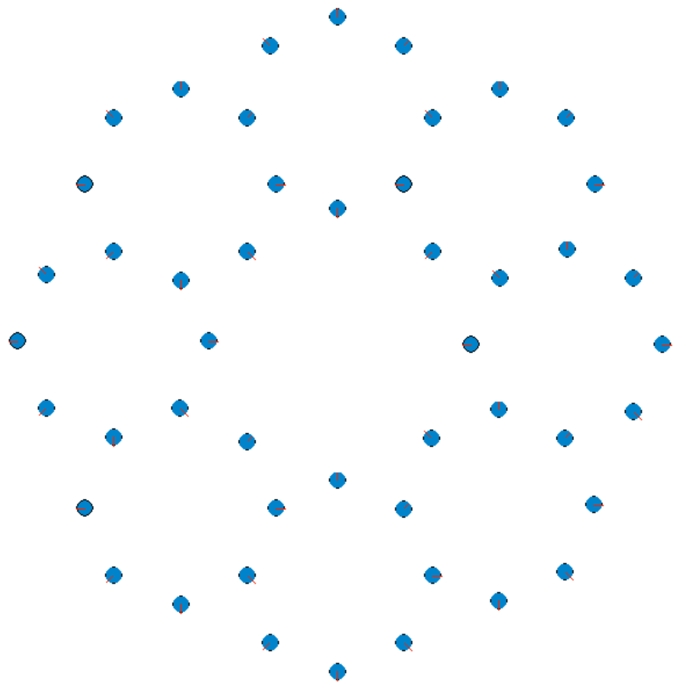

Stage:2

Figure 1. Octagonal Fractal array antenna for three successive iterations (P=1, 2). [10]

4. Results and Discussion

This paper expresses the application of MTFDT technique for the side lobe reduction of octagonal fractal array with isotropic antenna elements. The performance of this fractal antenna arrays is compared with fully populated octagonal fractal antenna array. As mentioned in chapter 2 and 3, octagonal fractal array generated for four successive iterations (P) with uniform and Morse-Thue fractal distribution of currents and their array factor behaviour are represented in Figs.2 and 3 respectively. Figure 2 explains that side lobe level and beam width decreases with each successive iterations and wide side lobe level angles achieved at first and second iterations of the fully-populated fractal antenna array. Figure 3 depicts that side lobe levels decrease with each successive iterations as in the case of fully-populated array but abated side lobes observed than Fig.2 except in the case of third iteration. But here better side lobes achieved with nearly same beam width and side lobe level angle. Due to the nature of this distribution function nearly one third of the antenna elements switched off in each iteration and proposed MTFDT technique with four iterations of octagonal fractal array antenna are tabulated in Table 1.

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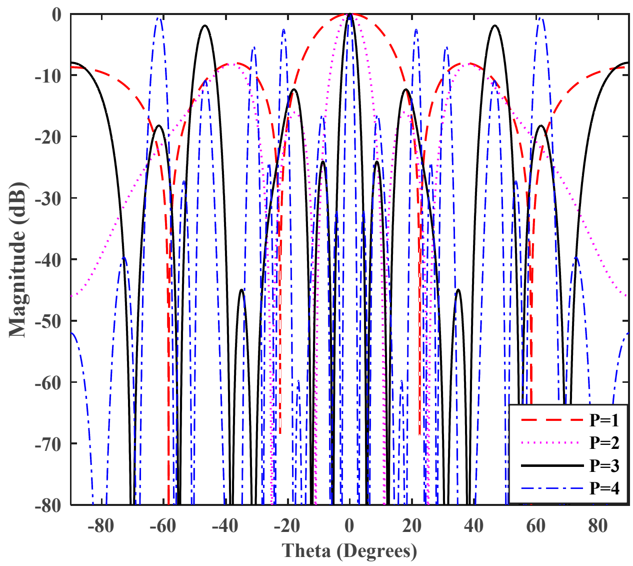

Figure 2. Array factor (P=1, 2, 3, 4) of fully-populated octagonal fractal antenna array.

Table 1. Array factor properties of octagonal fractal antenna array with uniform and MTFDT technique

Ite.(P)	Octagonal fractal antenna array					
	Uniform distribution of current			MTFDT Technique		
	SLL (dB)	HPBW (Deg.)	SLL Angle (Deg.)	SLL (dB)	HPBW (Deg.)	SLL Angle (Deg.)
1	-8.0	20.6	37.0	-∞	26.4	-
2	-16.1	7.4	18.0	-21	7.6	18.0
3	-24.3	3.0	9.0	-23.0	3.0	9.0
4	-32.5	1.2	4.5	-34.1	1.2	4.2

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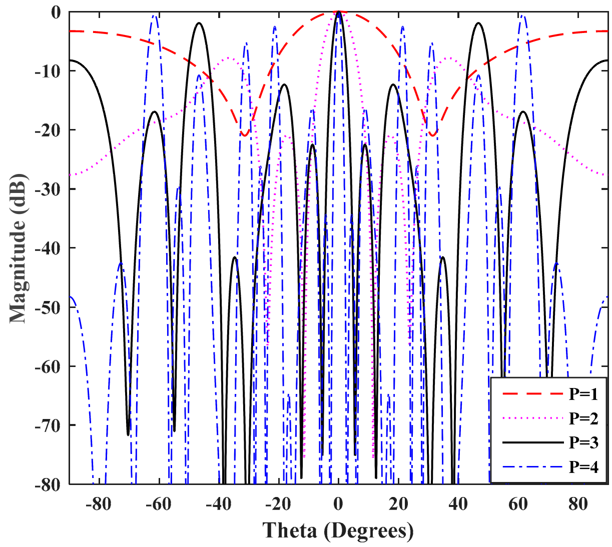

Figure 3. Array factor (P=1, 2, 3, 4) of octagonal fractal array antenna with MTFDT technique

5. Conclusions

Octagonal fractal antenna array for side lobe reduction with MTFDT technique have been presented. Nearly one third of antenna elements switched off and except in the third iteration side lobe level reduced in each iteration than its original counterparts. In the forth iteration of octagonal fractal antenna array with MTFDT technique -34.1 maximum side lobe level achieved with very narrow beam width of 1.2^0 and 4.2^0 of side lobe level angle. The association shows a momentous improvement for side lobe level with significant reduction in the number of antenna elements by proposed technique. This will decrease the price of designing the fractal antenna arrays considerably.

Author Contributions

V. A. Sankar Ponnapalli wrote the majority of this paper. Structural and technical advice as well as editing was provided by P. V. Y. Jayasree.

Conflicts of Interest:

The authors declare no conflict of interest.

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