Development and Performance Analysis of Dual-band Non-uniform Amplitude Pentagram-Hexagram Star Array Antenna

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Abstract

This paper presents a newly configured dual- band non-uniform amplitude pentagram-hexagram six (6) elements Star array antenna at VHF and UHF frequency bands for multipurpose applications. The pentagram-hexagram (Penta-Hexa)gram Star array has been designed to control it radiation characteristics by properly selecting the amplitude distribution of the elements. The design was set out to achieve a very few side lobes and a higher directivity Star array antenna. This antenna was constructed based on the design specifications using an Aluminum sheet. Both Pentagram and Hexagram star shapes were assembled together to form the Star array. The field pattern of each element and that of the array were determined and plotted using MatlabR2014a. The Performance analysis of the array shows a Dolph-Tschebyscheff field pattern with main lobes maximum at 0° and 180° and very few smaller side lobes. Further evaluations give the half- power beamwidth (HPBW) of the array to be 4.5° and directivity to be 11.72dB.The Star array shows good performance in the horizontal plane when compared with the standard antenna at UHF band. The test performance of the Star array antenna over the dual- band shows that the (Penta-Hexa)gram Star array antenna is very versatile for multipurpose applications.

Keywords: Antenna, Amplitude, Array, Beamwidth, Directivity, Nonuniform, Pentagram-hexagram, Star.

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1. INTRODUCTION

Antennas are a very important component of communication systems. By definition, an antenna is a device used to transform a Radiofrequency (RF) signal, traveling on a conductor, into the electromagnetic wave in free space [1] and [3]. Antennas demonstrate a property known as reciprocity, which means that an antenna will maintain the same characteristics irrespective of its transmitting or receiving. Antennas are of various types and various applications e .g. wire antennas, aperture antennas, microstrip antennas, reflector antennas, lens antennas, and array antennas. Array antennas are used in applications that require radiation characteristics that may not be achievable by a single element. It may, however, be possible that an aggregate of radiating elements in an electrical and geometrical arrangement (an array) will result in the desired radiation characteristics. The arrangement may be in such a way that the radiation from the elements adds up to give a radiation maximum in a particular direction or directions, minimum in others, or otherwise as desired. The increasing demand for efficient wireless communication services in recent times has necessitated the need for antennas capable of operating at a broadband frequency range [1] and [3]. Hence, in this study, the new configuration of pentagram-hexagram (Penta-Hexa)gram Star array antenna that operates at dual-band frequencies of

VHF (88.5MHz-108MHz) and UHF (900MHz-2000MHz) has been developed.

2. Materials and Methods

In the design of any antenna array system, the most important design parameters are usually the number of elements, the spacing between the elements, excitation (amplitude and phase), half-power beamwidth, directivity, and side lobe level [6]. The (Penta-Hexa)gram star array has been designed to control its radiation characteristics by properly selecting the phase and amplitude distribution of the elements (figure1). In the course of this design some of the parameters were determined through the following steps;

Step 1:UHF (Penta-Hexa)gram Star Array Boundary Conditions Design:

The initial boundary conditions for the design of the (Penta-Hexa)gram Star Array antenna at the dual bands' frequency was deduced as shown in Table 1.

Table1: Initial Boundary Condition of the (Penta-Hexa)gram Star Array

	Initial Boundary conditions			
Frequency Band	Lower Frequency	Upper Frequency	Bandwidth	Center Frequency
VHF	88MHz	108MHz	1.22	98MHz
UHF	900MHz	2000MHz	2.22	1450MHz
Dual-band Star Array	88MHz	2000MHz	22.72	1044MHz

Step 2: (Penta-Hexa)gram Geometrical Structural Design Procedure:

The structural geometrical design of the (Penta-Hexa)gram Star Array was developed using the fundamental formula for wire antenna length determination given by [2], [3], [4], and [9] as;

$$L = \frac{v}{f} \quad (\mathrm{m}) \tag{1}$$

f is the frequency, v is the speed of light ($3 \times 10^8 m/s$ and L is the geometric length of the antenna.

In this design, the Pentagram element has 10edges and 5 pointed angles while the hexagram element has 12edges and 6 pointed angles. Each edge is assumed to be a dipole of point source and the vertex line between two edges represents the amplitude. Hence, each pentagram and hexagram elements have 10 and 12 points sources, and the Length was designed using $L = \lambda/10m$ for pentagram and $L = \lambda/12$ m respectively. The uniform spacing between each element was obtained using $d = \lambda/2$m. The designed geometrical structural dimensions for the six-elements Star array is as shown in table 2.

Table 2: Designed (Penta-Hexa)gram Star Array Structural Dimensions

	VHF (3)Elements			UHF (3) Elements			Star Array
	1st	2nd	3rd	4th	5th	6th	
(λ) m	3.4	3.06	2.77	0.33	0.21	0.15	0.17
(L) m	0.34	0.25	0.27	0.027	0.021	0.013	1.313
(d) m	0.078						

Figure 1: The constructed Pentagram-hexagram Star Array Antenna

Step 3: (Penta-Hexa)gram Star Array Field Pattern Analysis

In antenna theory, the field pattern of electrically small antennas of any shape (circular, elliptical, rectangular, square, etc) are similar to that of an infinitesimal dipole with a null perpendicular to the plane of the loop and with maximum along the plane of the loop [4], [7], and [8]. Hence, the field pattern of this new configured Pentagram-hexagram Star Array is also likened to infinitesimal dipoles with the edges behaving like small linear dipoles of constant current I_o and length l. This antenna is configured as nonuniform amplitude distributions with uniform spacing

The total field E_n from even number of sources is expressed as Even Fourier series is given by [9] as;

$$E_{ne} = 2\sum_{k=o}^{k=N-1} A_k cos\left(\frac{2k+1}{2}\psi\right) \qquad (2)$$

where $\psi = \frac{2\pi d}{\lambda} sin\theta = d_r sin\theta$ and $N = \frac{n_e}{2}$; $k = 0, 1, 2, 3, \dots\dots\dots$, A_k is the amplitude of the individual point source.

Hence the six elements Star Array (figure 1) has 66 point sources; 32 VHF and 34 UHF point sources.

The VHF (32) point sources total field (E_{ne}) is deduced from (2) as;

$$E_{32} = 2A_0 COS\left(\frac{1}{2}\psi\right) + 2A_1 COS\left(\frac{3}{2}\psi\right) + 2A_2 COS\left(\frac{5}{2}\psi\right) + ---+ 2A_1 COS\left(\frac{31}{2}\psi\right) \quad (3)$$

Furthermore, the UHF 34 point sources total field E_{ne} is deduced from (2) as;

$$E_{34} = 2A_0 COS\left(\frac{1}{2}\psi\right) + 2A_1 COS\left(\frac{3}{2}\psi\right) + 2A_2 COS\left(\frac{5}{2}\psi\right) + ---+ 2A_{16} COS\left(\frac{33}{2}\psi\right) \quad (4)$$

The dual-band (Penta-Hexa)gram Star Array 66 point sources total field E_{ne} is deduced as;

$$E_{66} = 2A_0 COS\left(\frac{1}{2}\psi\right) + 2A_1 COS\left(\frac{3}{2}\psi\right) + 2A_2 COS\left(\frac{5}{2}\psi\right) + ---. +2A_{33} COS\left(\frac{65}{2}\psi\right) \quad (5)$$

The field pattern of an even number of sources is a Fourier series but one which has no constant term and only odd harmonics. The coefficients are arbitrary and express the amplitude distribution [9]. In a non-uniform amplitude array antenna, the length of the line of each point source is proportional to the amplitude [5]. Therefore, to determine the Array amplitude (A_k) of this new configuration; the amplitude (coefficients) of the first element (pentagram) of the Star array was deduced as [9];

$$2A_0 = 2A_1 = 2A_2 = 2A_3 = 2A_4 = 1 \qquad (6)$$

Other elements amplitude were determined starting from second to the sixth through the designed structural dimensional parameters ratio of table 2 and the values are as shown in (7) to (11).

$$2A_5 = 2A_6 = 2A_7 = 2A_8 = 2A_9 = 2A_{10} = 0.78 \qquad (7)$$

$$2A_{11} = 2A_{12} = 2A_{13} = 2A_{14} = 2A_{15} = 0.5 \quad (8)$$

$$2A_{16} = 2A_{17} = 2A_{18} = 2A_{19} = 2A_{20} = 2A_{21} = 0.389 \qquad (9)$$

$$2A_{22} = 2A_{23} = 2A_{24} = 2A_{25} = 2A_{26} = 0.278 \qquad (10)$$

$$2A_{27} = 2A_{28} = 2A_{29} = 2A_{30} = 2A_{31} = 2A_{32} = 0.167 \qquad (11)$$

Hence (3) becomes;

$$E_{32} = COS\left(\frac{1}{2}\psi\right) + COS\left(\frac{3}{2}\psi\right) + -- COS\left(\frac{9}{2}\psi\right) + 0.78COS\left(\frac{11}{2}\psi\right) + 0.78COS\left(\frac{13}{2}\psi\right) + -- +0.78COS\left(\frac{21}{2}\psi\right) + 0.5COS\left(\frac{23}{2}\psi\right) + 0.5COS\left(\frac{25}{2}\psi\right) + -- +0.5COS\left(\frac{31}{2}\psi\right) \qquad (12)$$

Also (4) becomes;

$$E_{34} = 0.389COS\left(\frac{1}{2}\psi\right) + 0.389COS\left(\frac{3}{2}\psi\right) + -- +0.389COS\left(\frac{11}{2}\psi\right) + 0.278COS\left(\frac{13}{2}\psi\right) + -- 0.278COS\left(\frac{21}{2}\psi\right) + 0.167COS\left(\frac{23}{2}\psi\right) + -- +0.167COS\left(\frac{33}{2}\psi\right) \qquad (13)$$

The 6 elements dual-band (Penta-Hexa)gram Array with 66 dipoles point sources in (5) becomes;

$$E_{66} = COS\left(\frac{1}{2}\psi\right) + COS\left(\frac{3}{2}\psi\right) + - - - + COS\left(\frac{9}{2}\psi\right) + 0.78COS\left(\frac{11}{2}\psi\right) + - - - + 0.78COS\left(\frac{21}{2}\psi\right) + 0.5COS\left(\frac{23}{2}\psi\right) + - - - + 0.5COS\left(\frac{31}{2}\psi\right) + 0.389COS\left(\frac{33}{2}\psi\right) + - - - + 0.389COS\left(\frac{43}{2}\psi\right) + 0.278COS\left(\frac{45}{2}\psi\right) + - - + 0.278COS\left(\frac{53}{2}\psi\right) + 0.167COS\left(\frac{55}{2}\psi\right) + - - + 0.167COS\left(\frac{65}{2}\psi\right) \quad (14)$$

Note: $\psi = \frac{2\pi d}{\lambda} sin\theta$; and d is taken to be $\lambda/2$.

The polar plot of the field pattern of the newly configured (Penta-Hexa)gram star array at $0 \leq \theta \leq 360$ were simulated using Matlab R2014 4a. and the results are as depicted in figure 2 to figure 4.

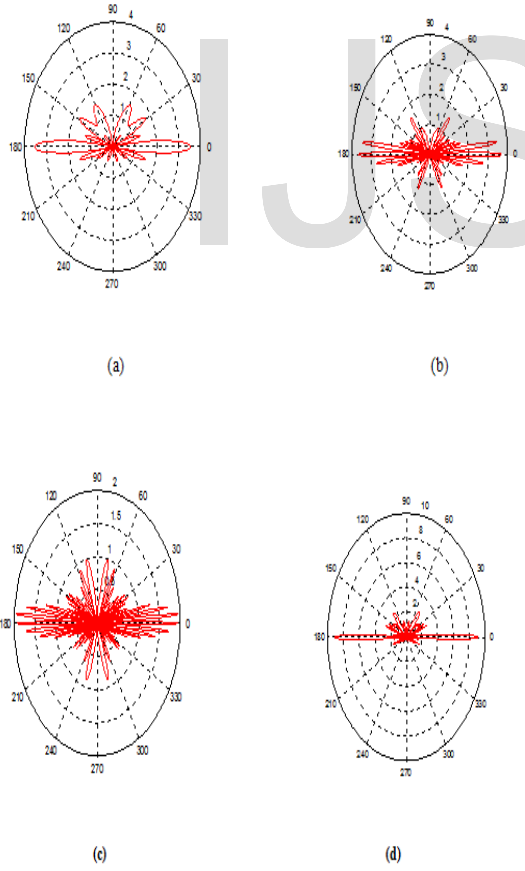


Figure 2: (a) First element (Pentagram) field pattern (b) Second element (hexagram) field pattern (c) Third element (Pentagram) field pattern (d) VHF (Penta-Hexa)gram field pattern

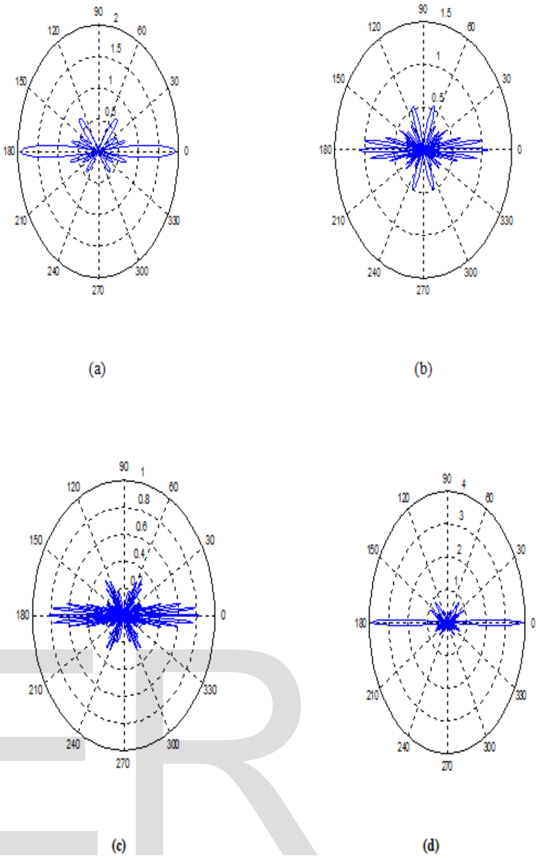


Figure 3: (a): Fourth element (Hexagram) field pattern (b) Fifth element (Pentagram) field pattern (c) six-element (Hexagram) field pattern (d) UHF (Penta-Hexa)gram field pattern

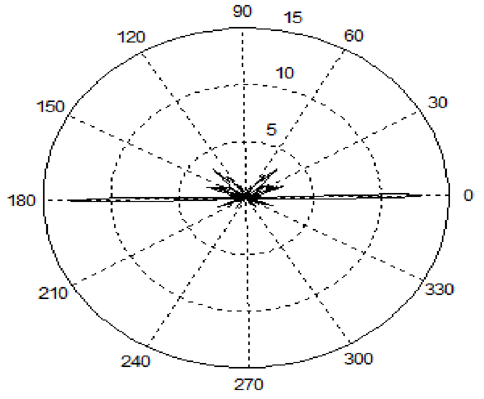


Figure 4: Total field pattern of the dual-band Star Array

The half-power beamwidth and the directivity of the newly configured (Penta-Hexa)gram Star Array antenna was deduced from figure (4) as 4.5° and 11.72dB respectively using (15), (16), (17) and (18) given by [5] and [10] as;

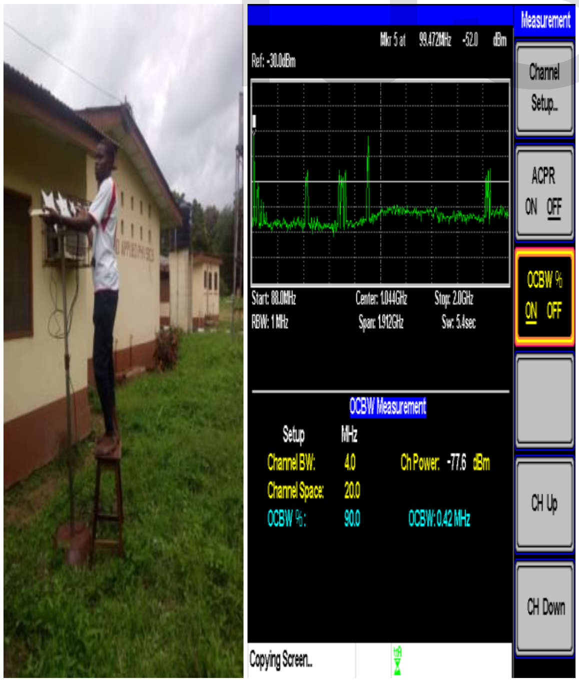
$$\Theta_h = \cos^{-1}\left[\cos\theta_o - 0.443\frac{\lambda}{(L+d)}\right] - \cos^{-1}\left[\cos\theta_o + 0.443\frac{\lambda}{(L+d)}\right] \quad (15)$$

$$f = 1 + 0.636\left\{\frac{2}{R_o}\cosh\left[\sqrt{(\cosh^{-1}R_o)^2 - \pi^2}\right]\right\}^2 \quad (16)$$

$$\text{HPBW} = \Theta_h \times f \quad (17)$$

$$\text{Directivity} = \frac{2R_o^2}{1+(R_o^2-1)f\frac{\lambda}{L+d}} \quad (18)$$

L is the length of the array and d is spacing,, f is the array beam broadening factor ;R_o is the major to minor lobe ratio.



Mkr 5 at 99.472MHz -52.0 dBm
Ref: -30.0dBm
Start: 88.0MHz Center: 1.044GHz Stop: 2.0GHz
RBW: 1 MHz Span: 1.912GHz Sw: 5.4sec

OCBW Measurement

Setup	MHz	
Channel BW:	4.0	Ch Power: -77.6 dBm
Channel Space:	20.0	
OCBW %:	90.0	OCBW:0.42 MHz

(a) (b)

Figure 5: (a)Experimental setup (b) (Penta-Hexa)gram Star Array Test Responses

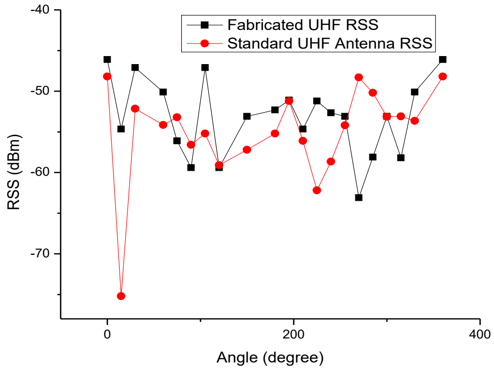


Figure6: (Penta-Hexa)gram Star Array comparison with standard Antenna at UHF band

4. Results and Discussion

Figure 2a, figure 2b figure 2c and figure 2d represent the field pattern of the first, second, third, and VHF elements of the (Penta-Hexa)gram Star Array antenna. The two nulls are at 90° and 270° respectively. The first element field pattern (figure 2a) shows some variations in its side lobes, the result shows a little broadside lobe in the range of 30° to 60° and 120° to 150°. The second and third elements (figure2b and figure2c) show broadside Dolph-Tschebyscheff field patterns with multiple main and side lobes which imply non-directive scenarios. Figure 2d shows the VHF combined (Penta-Hexa)gram three elements array field pattern with minor side lobes. This combination of the VHF elements will be versatile in higher directivity VHF applications. Figure 3a, 3b, 3c, and 3d represent the field pattern of fourth, fifth, sixth, and combination of the (Penta-Hexa)gram UHF elements Figure 3a has few side lobes and fairly directional compared to the figure 3b and figure 3c that show broadside Dolph-Tschebyscheff field pattern. Figure 3d has minor side lobes and will be suitable for highly directional UHF antenna Array applications. Figure 4 specifically shows the field pattern of the (Penta-Hexa)gram 6 elements Star Array antenna. This depicted a smaller and scanty side lobes field pattern of highly directional Star Array antenna with a half-power beamwidth of 4.5° and directivity of 11.72dB. The performance analysis shows that as the number of elements increases the array becomes more directional, which is in agreement with the literature. Figure 6 shows that the newly developed (Penta-Hexa)gram Star array antenna has a good quality of signal reception when compared with a standard antenna at UHF band.

5. Conclusion

In this work a newly configured 6 elements dual-band (Penta-Hexa)gram Star array antenna of non-uniform amplitude and uniform spacing have been realized and characterized. The dual band (Penta-Hexa)gram Star array antenna has demonstrated higher directivity with few side lobes, good quality of received signal strength, and ability to received signals simultaneously at the dual-band frequencies. The test performance of this Star Array antenna over the dual-band has shown that it is versatile for multipurpose applications particularly for simultaneous radio, television, and mobile network receiver in automobiles and homes.

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