Electronically Steerable planer Phased Array Antenna

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***Abstract*- A planar phased-array antenna has been constructed from a 15x15 square grid of z-directed monopoles with a length of 0.475 λ, element spacing of 0.29 λ, average directivity of 20.0 dBi across all scan angles, an average H-plane HPBW of 37 degrees, an average E-plane HPBW of 23 degrees, and an efficiency of 99.6%. Two current distributions are tested: uniform and binomial. The binomial current distribution is selected to minimize the side lobe level.**

***Keywords*- Phased array, Electronically steerable, Current Distribution**

I. INTRODUCTION

Phased array antenna is a multiple-antenna system in which the radiation pattern can be reinforced in a particular direction and suppressed in undesired directions. The direction of phased array radiation can be electronically steered obviating the need for any mechanical rotation. These unique capabilities have found phased arrays a broad range of applications since the advent of this technology. Phased arrays have been traditionally used in military applications for several decades. Recent growth in civilian radar-based sensors and communication systems has drawn increasing interest in utilizing phased array technology for commercial applications. Phased array antennas are common in communications and radar and offer the benefit of far-field beam shaping and steering for specific, agile operational conditions. They are especially useful in modern adaptive radar systems where there is a trend toward active phased arrays and more advanced space time adaptive signal processing. In phased arrays all the antenna elements are excited simultaneously and the main beam of the array is steered by applying a progressive phase shift across the array aperture.

II. PHASED ARRAY ARCHITECTURE

The phased array antenna has an aperture that is assembled from a great many similar radiating elements, such as slots or dipoles, each element being individually controlled in phase and amplitude. Accurately predictable radiation patterns and beam pointing directions can be achieved. A phased array is an array antenna whose beam direction or radiation pattern is controlled primarily by the relative phases of the excitation coefficients of the radiating elements. Physically it is composed of a group of individual elements that are arranged in a linear or two dimensional (typically planar) spatial configurations.

A. Phased Array Principle

The block diagram of an N-element phased array is shown in Fig. 1 "N" identical antennas are equally spaced by a distance "d" along an axis. Separate variable time delays are incorporated at each signal path to control the phases of the signals before combining all the signals together at the output. A plane-wave beam is assumed to be incident upon the antenna array at an angle of θ to the normal direction. Because of the spacing between the antennas, the beam will experience a time delay equal to Eqn. 1 in reaching successive antennas.

$$\Delta\tau = 2\Pi\, d \sin(\Theta)/\lambda \qquad (1)$$

Here, λ is the wavelength of the signals. Hence, if the incident beam is a sinusoid at frequency ω with amplitude of A, the signals received by each of the antennas can be written as Eqn 2.

$$S_i = Ae^{-jn\Delta\tau} \qquad (2)$$

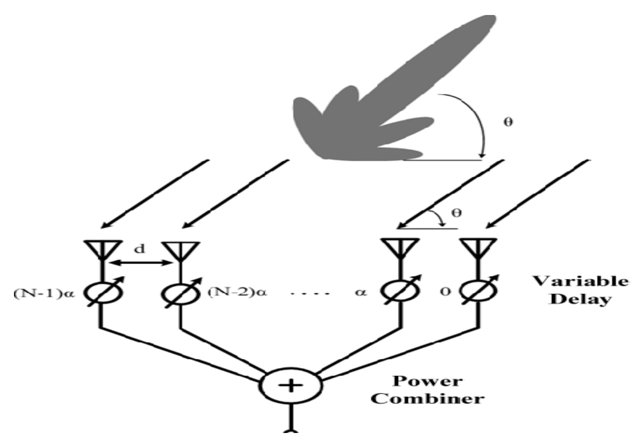

Fig 1. Block Diagram of N-element Phased Array

The plane wave incident at an angle upon the phased array experiences a linear delay progression at the successive antenna elements. Therefore, the variable delay circuits must be set to a similar but with reverse delay progression to compensate for the delay of the signal arrived at the antenna elements. In linear arrays, variable time delays are designed to provide uniform phase progression across the array. Therefore, the signal in each channel at the output of the variable delay block can be written as Eqn. 3.

$$S_i' = Ae^{-jn\Delta\tau}e^{-jn\alpha} \qquad (3)$$

In this equation, α denotes the difference in phase shift provided by two successive variable time delay blocks. Therefore, array factor which is equal to the sum of all the signals normalized to the signal at one path can be written as Eqn. 4.

$$F=\sum_{n=1}^{N} e^{-jn(\Delta\tau-\alpha)} \qquad (4)$$

According to Eqn. 1.4, the peak of the array factor occurs at an incident angle which can be determined by Eqn. 5.

$$2\Pi\, d \sin(\Theta)/\lambda = \alpha \quad \text{Or} \quad \Theta = \arcsin\left(\frac{\alpha}{2\Pi d}\right) \qquad (5)$$

At this incident angle, which is called scan angle, the linear delay progression experienced by the wave arriving at the successive antennas is perfectly compensated with the time delays incorporated at each path resulting in all the signals being coherently combined at the output of the receive array. The array factor can also be shown as Eqn.6.

$$F = \frac{\sin^2\left[\frac{N}{2}\left(\frac{2\Pi d}{\lambda}\sin(\Theta_{in}) - \alpha\right)\right]}{\sin^2\left[\left(\frac{2\Pi d}{\lambda}\sin(\Theta_{in}) - \alpha\right)\right]} \qquad (6)$$

At the scan angle "θ", the array factor has a maximum value of N^2. For other angles of incident, the array factor will be lower than this value indicating spatial selectivity of phased array. In addition to the spatial filtering, one of the main capabilities of phased array is that the peak gain of the array, according to Eqn. 5, can be controlled by electronically tuning the variable time delays eliminating the need for any mechanical rotation of antenna array.

It should be also noted that the benefits of using phased array is increased as the number of elements in the phased array is increased. As mentioned before, the maximum value of array factor N^2 is directly proportional to the number of array elements. Furthermore, the beam width of the array can be decreased by increasing the number of array elements in order to enhance the spatial selectivity of phased array.

B. Classification of Phased Arrays

(1) Scanning methods. (2) Radiator feed methods. (3) Positioning of radiators in the array.

The main scanning methods are phase scanning and frequency scanning. It is the phase scanned arrays that are referred to as phased arrays. From the viewpoint of feed methods, arrays are divided into constrained feed arrays and space fed arrays, the latter taking the form of reflect arrays or transmission arrays. With regard to element positioning, phased arrays are divided into uniformly spaced and unequally spaced arrays. They provide the radar with flexibility and adaptation to the assigned task, ability to change beam position in space almost instantaneously (electronic scanning), generation of very high powers from many sources distributed across the aperture, high directivity and power gain possibility of synthesizing any desired radiation pattern (including formation of pattern nulls in the directions of undesired interference sources) capability of combining search, track, and recognition functions when operating in multiple target and severe interference environments (including jamming), enhanced target throughput capability, and compatibility with digital computers and digital signal processing algorithms.

III. ANALYSIS

This antenna design attempts to find the optimal combination of several properties: element distribution, element type, element spacing, efficiency, current distribution, and phase requirements. A MATLAB simulation is also created to demonstrate the effectiveness of the design.

A. Element Arrangement, 2-Dimensional Square Array

Element arrangement is the first factor we consider in this design. An array factor expression that meets the directive angle requirements is required. Therefore, we consider an arrangement of concentric circles, a 2-dimentional rectangular planar array, and a 3-dimentional placement of dipoles as possible element arrangements. We were not able to consider the concentric circles or 3-dimensional arrangement because the required mathematical analysis involved is lengthy and our design time is limited. In addition, 3- dimensional arrays add extra mechanical complexity to the design, and a goal of this project is to trade mechanical complexity for electrical complexity. Therefore, only the 2-dimensional square array is considered. Two dimensional rectangular arrays are much easier to analyze. Although we expect to lose some degree of accuracy azimuthally, a rectangular array seemed like an effective tradeoff between design complexity and performance.

B. Element Spacing

In general, increasing element spacing allows for finer beam widths, but element spacing greater than half-wavelength results in undesired grating lobes. These grating lobes are shown for a separation of 0.8 wavelengths along the x- and y-axis elements:

We chose a uniform element spacing of 0.29 wavelengths such that the beam width is moderately fine, does not produce grating lobes, and allows sufficient number of elements to fit on the circular mounting structure. This element spacing determines the total number of array elements due to restrictions in the maximum allowable array area. Since the maximum length of the square array is 0.707 the allowable diameter (50 inches), the number of elements allowed with a 0.29 wavelength element separation equals the following:

N or M max= (50 feet*12$\frac{inch}{foot}$ *2.54$\frac{cm}{inch}$)$/(0.29 * 240\ cm)$

N or M max=15.48 = 15

C. Element Type

Z-Directed monopoles were chosen over patch antennas for improved efficiency. The monopoles are z-directed to exploit the blind spot in the θ=0^0 direction, which falls outside of the design requirements (minimum θ=10^0).

A half-wave dipole is used in the simulation because this represents a realistic length, when compared to the ideal and short dipoles at 125MHz, and because larger structures are more resistant to changes in characteristics produced by rust and chemical erosion. In addition, the input impedance of such a dipole can be made real (70Ω) by shortening the dipole slightly to achieve resonance. Since our array consists of erect monopoles positioned directly normal to a PEC ground plane, the length of our array elements are only a quarter-wavelength (60cm). The actual length is slightly less than 60cm to achieve resonance when considering the extra effective length due to fringe field effects. The input impedance is half of that for the equivalent dipole, or 35Ω. The expected directivity is twice that for a half-wave dipole in free space or 5.16dB.

D. Current Distribution

In order to achieve the lowest side lobe levels (SLL) possible, we decided to use a binomial array amplitude distribution, which completely eliminates the side lobes. This has the effect of decreasing directivity and half-power angle in the E- and H-planes. The uniform pattern produces unacceptable SLL when the beam is positioned 10 degrees from the z-axis. The uniform and binomial distributions are shown in figure 2 and figure 3 below.

IV. SIMULATION RESULTS

We simulate the following change in variables for our rectangular array design:

1. Rectangular Array of size N x M
2. Arbitrary Element Spacing D_x and D_y
3. Uniform or Binomial current distribution
4. 0.5λ Dipoles or Isotropic Sources to simulate a pure Array Factor
5. phase distance α_x& α_y or beam direction φ_0 & θ_0

MATLAB Simulation displays the following data:

1. Normalized 3d meshgrid plot of the Total Radiated Pattern
2. HPBW-E (Present State, Max, and Simulation Average)
3. HPBW-H(Present State, Max, and Simulation Average)
4. Directivity (Assuming Dipole, Present State, Min, and Simulation Average.

Given: N = M = 15, D_x = D_y= .29,

Binomial Current Distribution

HPBW_E_MAX:56.1728^0 : HPBW_H_MAX:27.6654^0 : D_MIN:58.6124

HPBW_E_AVG:37.0722^0 : HPBW_H_AVG:23.7516^0 : D_AVG:101.6584

Since the beamwidths were so high we decided to see what kind of beamwidths we could have expected with uniform current distribution, despite its large sidelobes.

Uniform Current Distribution

HPBW_E_MAX:34.153^0 : HPBW_H_MAX:11.5014^0

HPBW_E_AVG:19.9463^0 : HPBW_H_AVG:10.1628^0

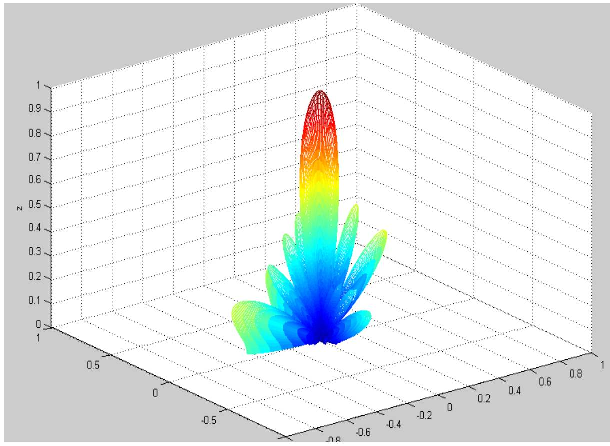

Fig 2. Uniform Distribution

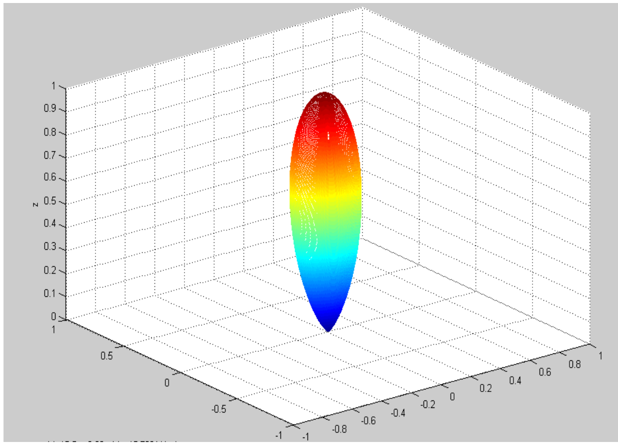

Fig 3. Binomial Distribution

A. Uniform Distribution in Planer Phased array antenna at different angles

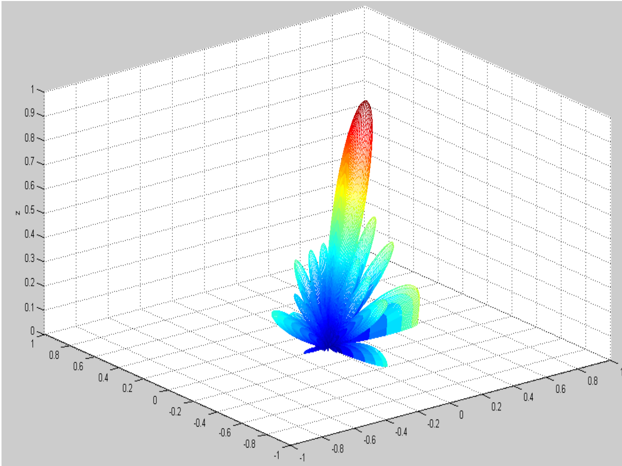

Fig 4. Antenna Pattern Θ(0) :10 ,ϕ(0): 0

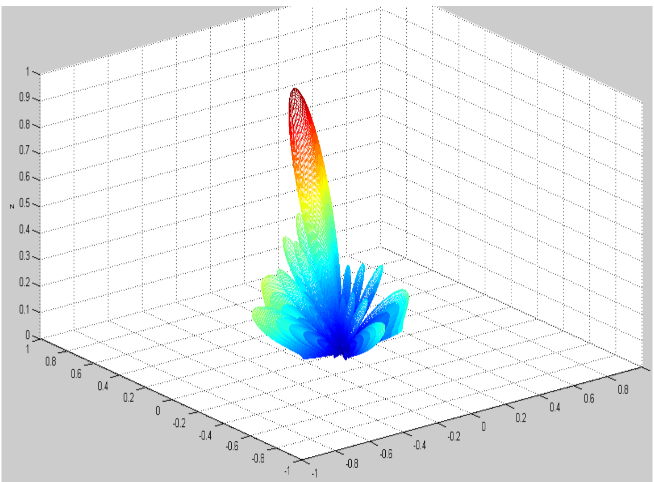

Fig 5. Antenna Pattern Θ(0) :10 ,ϕ(0): 90

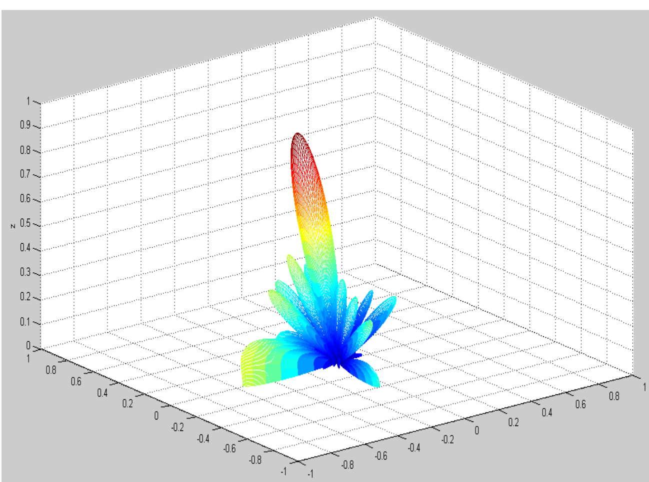

Fig 6. Antenna Pattern Θ(0) :10 ,ϕ(0): 120

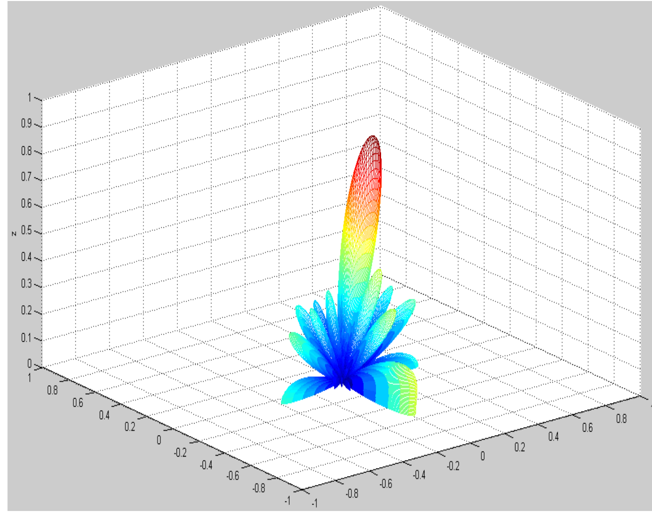

Fig 7. Antenna Pattern Θ(0) :10 ,ϕ(0): 180

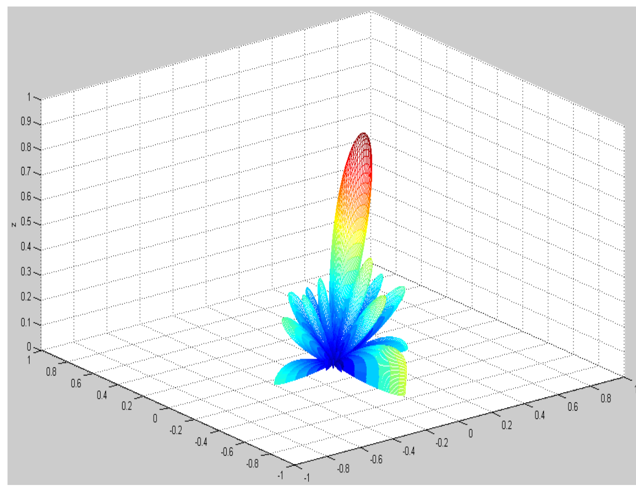

Fig 8. Antenna Pattern Θ(0) :10 ,ϕ(0): 270

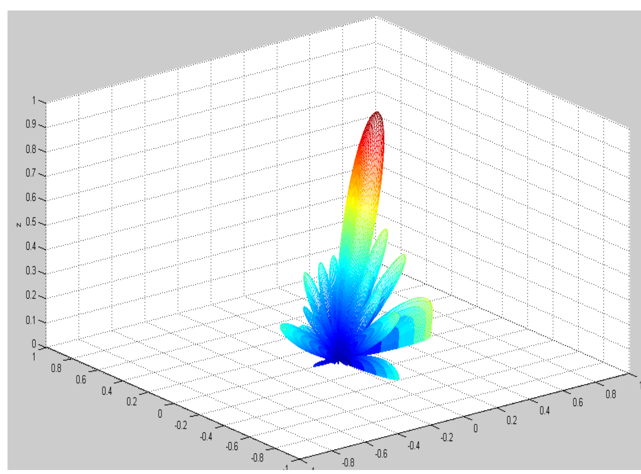

Fig 9. Antenna Pattern Θ(0) :10 ,ϕ(0): 360

B. Binomial Distribution in Planer Phased array antenna at different angles

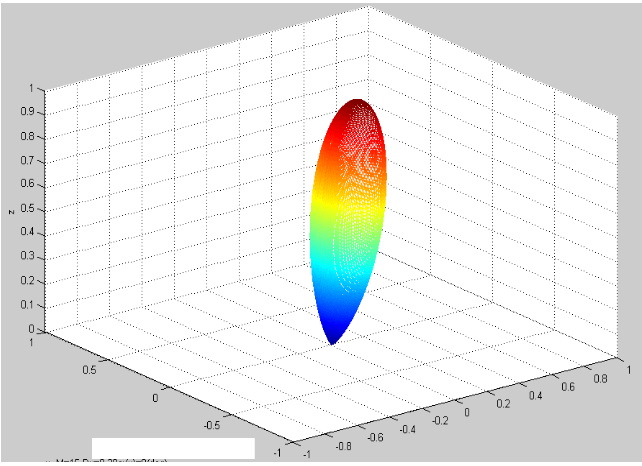

Fig10. Antenna Pattern Θ(0) :10 ,ϕ(0): 0

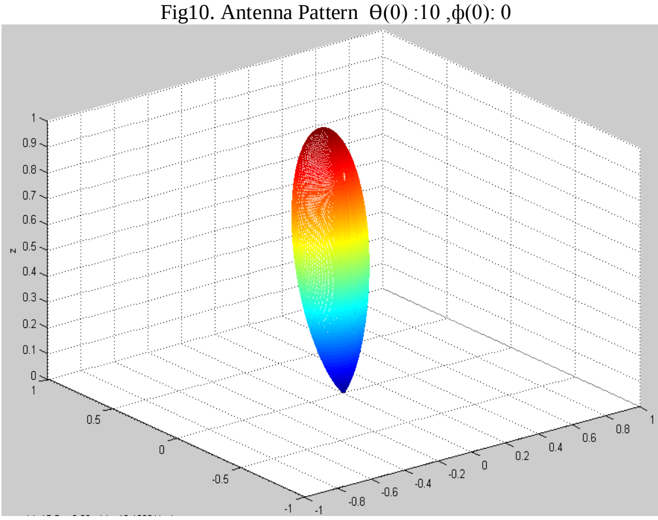

Fig 11. Antenna Pattern Θ(0) :10 ,ϕ(0): 90

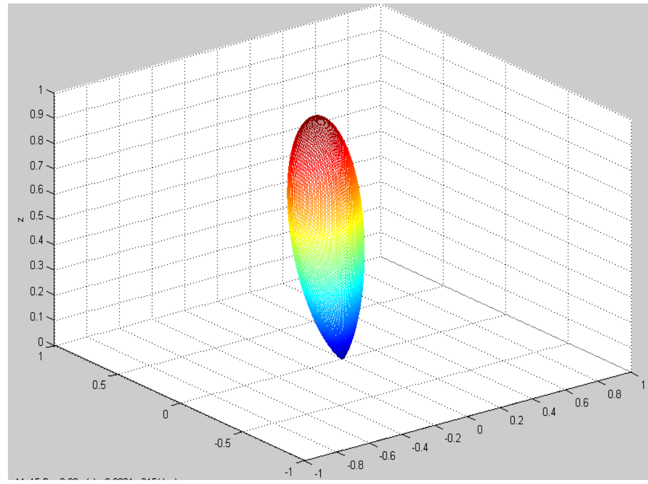

Fig 12. Antenna Pattern Θ(0) :10 ,ϕ(0): 120

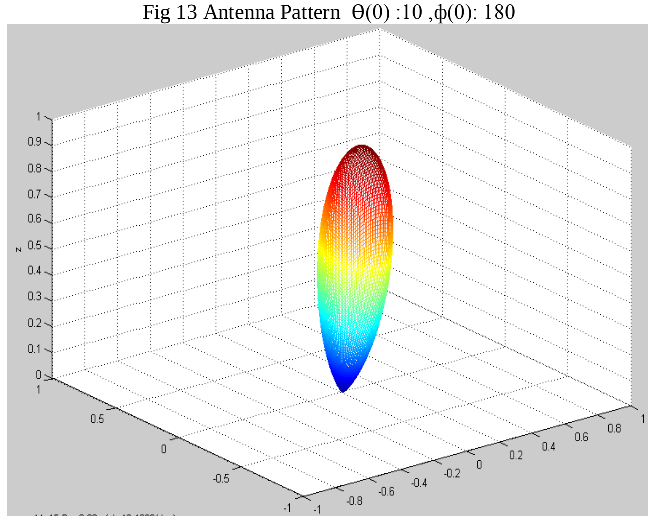

Fig 13 Antenna Pattern Θ(0) :10 ,ϕ(0): 180

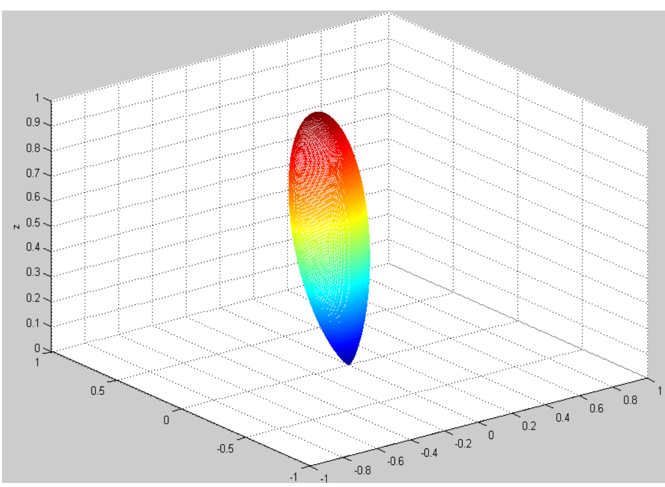

Figure 14. Antenna Pattern Θ(0) :10 ,ϕ(0): 270

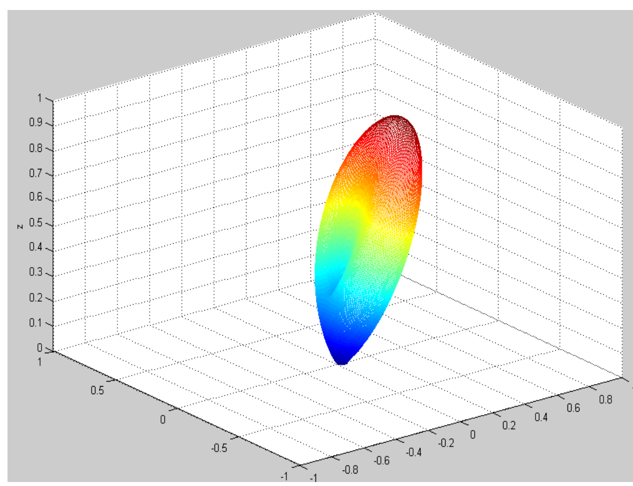

Figure 15. Antenna Pattern Θ(0) :10 ,ϕ(0): 360

CONCLUSION

Phased array, capable of providing a directional beam that can be electronically steered, can significantly enhance the performance of sensors and communications systems. The directional beam of a phased array also allows for a more efficient power management. In addition, the spatial filtering nature of the phased array systems alleviate the problem of multipath fading and co-channel interference by suppressing signals emanating from undesirable directions. Unfortunately, side lobe levels on the uniform distribution are above the -20dBi requirement. The uniform distribution experiences significantly reduced beam width than the binomial distribution; however, directivity for each case exceeds the specified requirement (20 dBi). By using Dolph Chebyshev current distribution we can reduces HPBW while maintaining -20dBi sidelobes relative to the main beam.

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