Fall 8-2011

Design of a Uniform Circular Phased-Array Smart Antenna for 2.4 GHZ Applications

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DESIGN OF A UNIFORM CIRCULAR PHASED-ARRAY SMART ANTENNA FOR 2.4 GHZ APPLICATIONS

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Electrical Engineering
Department of Electrical Engineering

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College of Engineering and Computer Science

The University of Texas at Tyler
August 2011

The University of Texas at Tyler
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APRIL 14, 2011
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Acknowledgements

I am heartily thankful to my husband Ratna Dandamudi and my daughter Siri Mallika for their love, support, patience and encouragement in facing this challenge. I would like to express the deepest appreciation to my advisor Dr. Hector A. Ochoa for his encouragement, patience, supervision and constant support from preliminary to the concluding level. Without his guidance and persistent help this thesis would not have been possible. And I would also like to thank my mother Adilakshmi and father Rangarao for helping and supporting me to finish my degree.

I would like to thank my committee member Dr. Ron J. Pieper for taking time and reviewing my work. I am grateful to Dr. Mukul Shirvaikar for supporting and guiding me throughout my Master's. I would like to thank the entire EE department and the University of Texas at Tyler for supporting me throughout my Master's. Finally, I would like to thank all those who supported me in any respect during the completion of the thesis.

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Abstract

DESIGN OF A UNIFORM CIRCULAR PHASED-ARRAY SMART ANTENNA FOR 2.4GHZ APPLICATIONS

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May 2011

Antennas are devices which detect electromagnetic signals. An antenna is a transitional structure between free-space and a guiding device. Different types of antennas have different properties in terms of its radiation characteristics, directivity and gain. One of the antennas, which play an important role in advanced wireless communication systems, is the smart antenna. One of the most remarkable properties of a smart antenna is that it is capable of directing its main beam towards the direction of an individual user and the nulls in the direction of interfering signals.

An array of transmitting antennas is required to achieve good adaptive properties for a smart antenna. There are different configurations for smart antennas and the decision about which configuration will perform the best depends on the desired application. One of these configurations is the Uniform Circular Array Antenna (UCA). One of the main characteristics of the UCA structure is that it does not possess edge

elements. Also, the radiation pattern obtained from this antenna can be electronically rotated in the plane by modifying the phase of the current at each dipole. One of the most relevant works for this research is the one performed at Auburn University, wherein they studied the properties of a Dual Excited Planar Circular Array Antenna for Direction Agile Applications. The radiation pattern of the UCA is electronically steered in the azimuthal plane by modifying the position of the driven elements and by dynamically adding and removing reflectors and directors. The Auburn design consists of 17 elements composed of driven elements, reflectors and directors placed on a hollow cylindrical ground structure. The simulations were conducted by changing the excited elements in the array and dynamically adding and removing reflectors and directors. For each simulation there were only nine active elements, which provide the beam in the desired direction. However, the continuous change of the driven elements is not a very efficient procedure. In this research, it is proposed to steer the radiation pattern of a uniform circular array antenna in the azimuthal plane by keeping the driven elements in the same position and dynamically adding and removing reflectors and directors. For simulation purposes, the analysis of the radiation pattern for the proposed smart antenna was verified using 4NEC2 software. 4NEC2 is a windows based tool used to design, view, optimize and check 2D and 3D style geometry structures and simulate near and far field radiation patterns. The proposed design is composed of a total of 25 elements arranged in two concentric circles. Of the 25 elements 8 are used as directors, 14 as reflectors and 3 as fixed driven elements. The 8 directors are spread in the outer circle, and the remaining 14 reflectors are spread over the inner circle. The driven elements are placed on the diameter of the inner circle. The simulation results showed that the proposed system is capable of steering the radiation pattern in every direction by keeping the driven elements fixed and by dynamically adding and removing reflectors and directors.

Chapter One

Introduction

An antenna is a transducer that converts an electric current into electromagnetic waves which are then radiated into space. In modern wireless communication systems, different types of antennas are used to direct the energy from the radiation pattern in some specific directions and suppress it in other directions. Antennas are widely used in television broadcasting, radio, wireless LAN, cell phones, radar and aerospace communications.

1.1 Types of Antennas

Antennas are mainly classified into three categories: wire, aperture and micro strip antennas. Wire antennas are the most common type of antennas. They can be seen on automobiles, buildings, ships, aircraft, spacecraft and many other places. Some examples of different types of wire antennas as presented by Balanis [1] are shown in Figure 1.

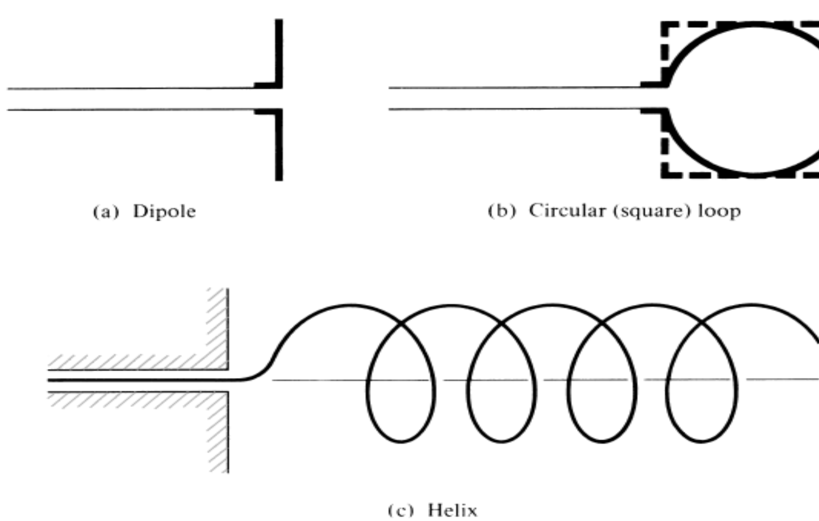

Figure 1. Various types of wire antennas [1]

Aperture antennas are mainly used in aircraft and spacecraft applications. Some examples of aperture antennas are the pyramidal horn, the conical horn and the rectangular waveguide antennas. Microstrip patch antennas are mainly used for government and commercial applications. Rectangular and circular microstrip patch antennas are the most used antennas because of their low cross-polarization [1].

1.2 Antenna Parameters

The performance of an antenna depends on many parameters like: radiation pattern, directivity, antenna efficiency, beam-width and gain**.** The radiation pattern is a parameter that plays a very important role on the performance of an antenna. The radiation pattern is a graphical representation of the radiation properties of an antenna in terms of space coordinates. The coordinate system used to analyze the radiation of antennas is shown in Figure 2 [1].

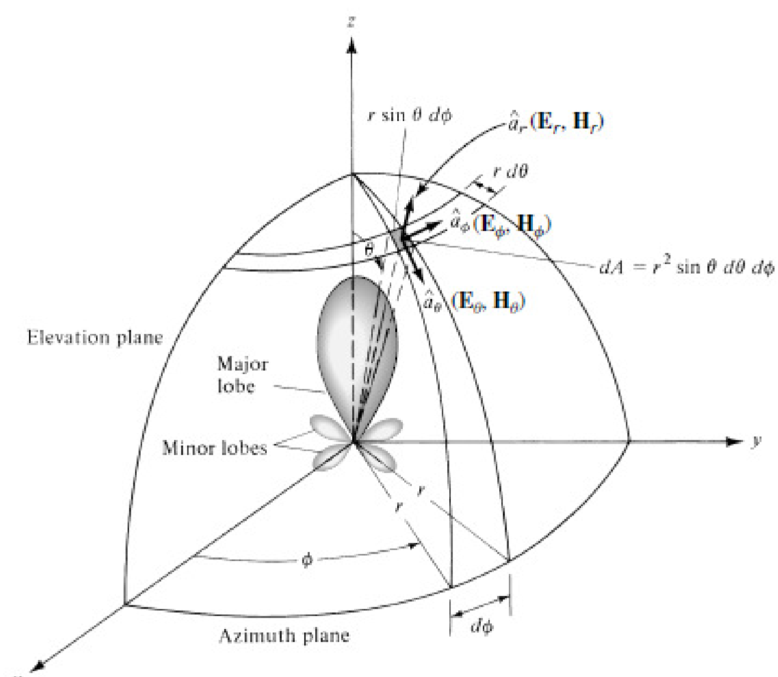

Figure 2. Coordinate system for antenna analysis

Most radiation patterns are composed of a major lobe, minor lobes and back lobes. The major lobe or main lobe is the maximum radiation lobe and it is typically pointing in the $\theta = 0$ direction. The back lobe is the lobe located at an angle of 180 degrees with respect to the main lobe, and a side lobe is next to a major lobe, seen in the direction of the main beam. Half Power Beam Width (HPBW) is the angular separation between the half power points on the antenna radiation pattern, where the gain is one half the maximum value. First Null Beam width (FNBW) is the angular width between the first nulls on either side of the main beams. All these parameters for the radiation pattern are presented in Figure 3.

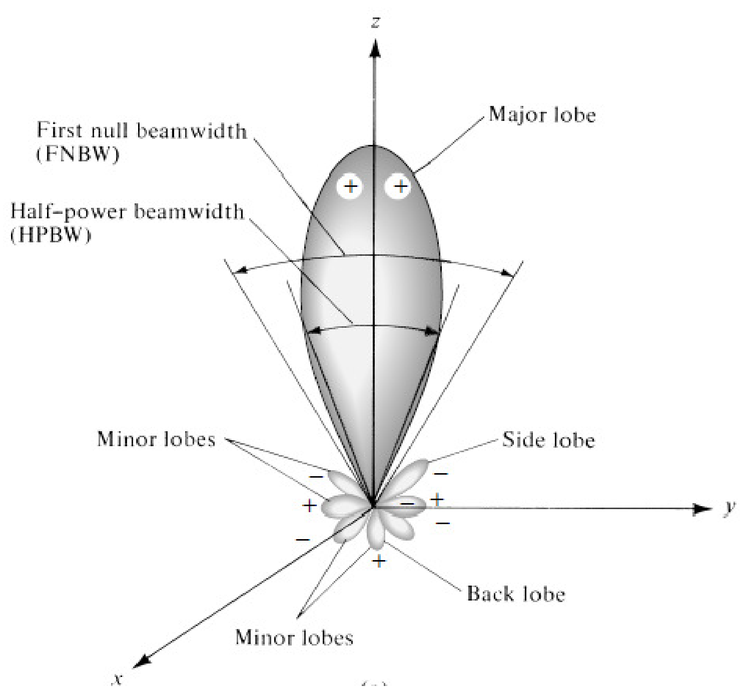

Figure 3. Radiation lobes of an antenna [1]

There are three different types of regions around the antenna. They are the reactive near field, radiating near field and far field regions. The reactive near field region is the region near to the antenna. D is the maximum dimension of an antenna. The boundary of this region is defined as

$$R < 0.62\sqrt{\frac{D^3}{\lambda}} \tag{1.1}$$

The radiating near field or intermediate field region is the region between the reactive near field and the far field region. This region is defined as

$$0.62\sqrt{\frac{D^3}{\lambda}} < R < \frac{2D^2}{\lambda} \tag{1.2}$$

The far field region is the region far from the antenna. This region starts at a distance

$$R > \frac{2D^2}{\lambda} \tag{1.3}$$

A pictorial representation of all these regions is shown in Figure 4.

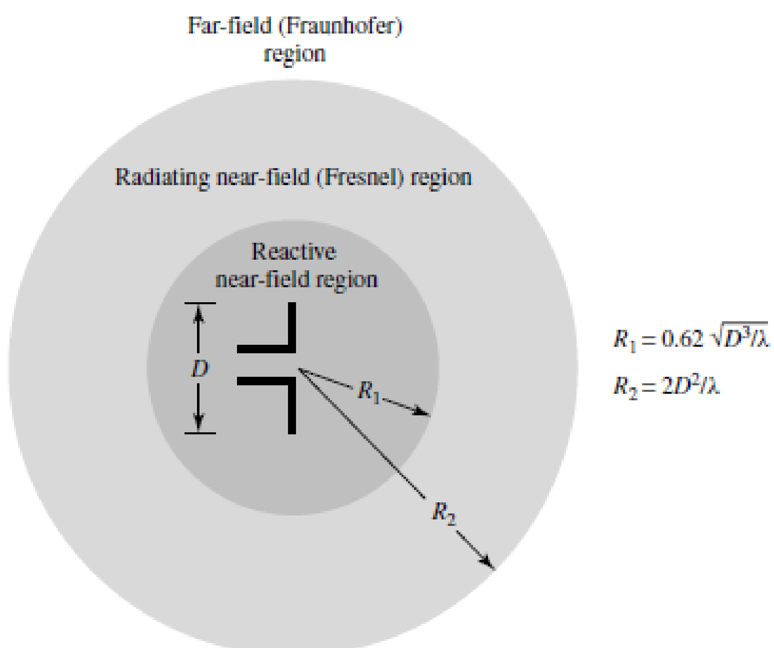

Figure 4. Field regions of an antenna [1]

1.3 Directivity, Antenna Efficiency and Gain

Directivity is the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions [1]. The direction of the maximum radiation intensity is defined as

$$D_0 = \frac{U_{\max}}{U_0} = \frac{4\pi U_{\max}}{P_{rad}} \tag{1.4}$$

where D_0 is the maximum directivity, $U_{\max}$ is the maximum radiation intensity, U_0 is the radiation intensity of a isotropic source and P_{rad} is the total radiated power.

Antenna Efficiency is the product of the conduction efficiency and the dielectric efficiency. The antenna radiation efficiency is defined as

$$e_{cd} = e_c e_d \tag{1.5}$$

where e_c is the conduction efficiency and e_d is the dielectric efficiency

Gain is defined as the ratio of the antenna radiated power density at a distant point to the total antenna input power radiated isotropically.

$$G = (\theta, \phi) = e_{cd}\left[4\pi \frac{U_{(\theta,\phi)}}{P_{rad}}\right] \tag{1.6}$$

where e_{cd} is the antenna radiation efficiency and U is the radiation intensity

1.4 Infinitesimal Dipole Antenna

An infinitesimal dipole $(L << \lambda)$ is a small element of a linear dipole that is assumed to be short enough; such that the current (I) can be assumed constant along its length L. The infinitesimal dipole is also known as Hertzian dipole [2]. The coordinate system used to define the electric field of an infinitesimal dipole is shown in Figure 5.

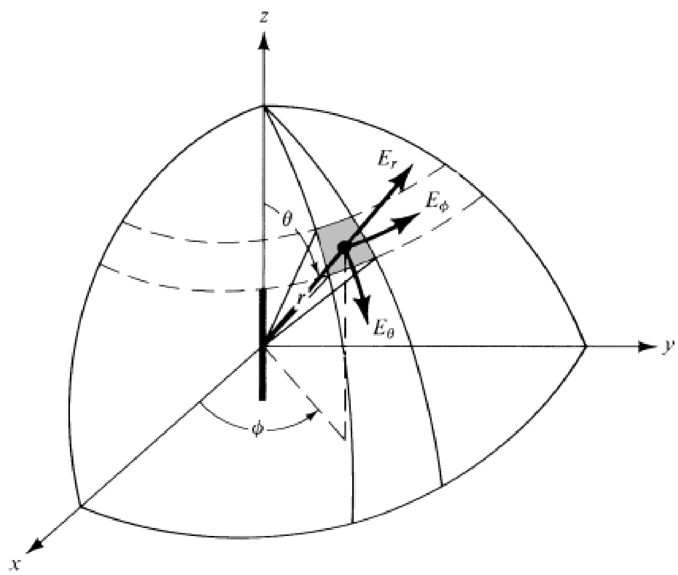

Figure 5. Electric field orientation [1]

The components of the electric field for an infinitesimal dipole are given by,

$$E_r = \eta \frac{I_0 l \cos\theta}{2\pi r^2}\left[1 + \frac{1}{jkr}\right]e^{-jkr} \tag{1.7}$$

$$E_\theta = j\eta \frac{kI_0 l \sin\theta}{4\pi r}\left[1 + \frac{1}{jkr} - \frac{1}{(kr^2)}\right]e^{-jkr} \tag{1.8}$$

$$E_\phi = 0 \tag{1.9}$$

where E_r, E_θ, E_ϕ are the electric fields of the electromagnetic waves radiated in the r, θ, ϕ directions.

1.4.1 Infinitesimal Dipole Antenna Parameters

The infinitesimal dipole antenna parameters are given in terms of the radiated power, directivity and maximum effective area. The antenna radiates its real power through radiation resistance. The power radiated by an infinitesimal dipole antenna is given by,

$$P_{rad} = \eta\left(\frac{\pi}{3}\right)\left|\frac{I_0 l}{\lambda}\right|^2 = \frac{1}{2}|I_0|^2 R_r \tag{1.10}$$

where R_r is the Radiation Resistance. The radiation resistance is determined by the geometry and of the antenna and is given by,

$$R_r = 80\pi^2\left(\frac{l}{\lambda}\right)^2 \tag{1.11}$$

The directivity of an antenna is the maximum value of the power radiated per unit solid angle to the average power radiated to the unit solid angle. The directivity of infinitesimal dipole is given by,

$$D_0 = 4\pi\frac{U_{\max}}{P_{rad}} = \frac{3}{2} \tag{1.12}$$

where $U_{\max}$ is the radiation intensity.

The maximum effective area of an antenna is the maximum area of the antenna which absorbs as much net power from the antenna. The maximum effective area covered by an infinitesimal dipole is given by,

$$A_{em} = \left(\frac{\lambda^2}{4\pi}\right)D_0 = \frac{3\lambda^2}{8\pi} \tag{1.13}$$

1.5 Half-wavelength Dipole Antenna

A half-wave dipole antenna is similar to a regular dipole antenna. The main difference between a regular dipole antenna and a half-wavelength antenna is in its length. The length of this antenna is equal to half the wavelength of the operating frequency. The electric and magnetic field components of a half wavelength dipole antenna are given by

$$E_\theta \simeq j\eta \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right] \tag{1.14}$$

$$H_\phi \simeq j \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right] \tag{1.15}$$

The total power radiated by a half wavelength dipole is given by,

$$P_{rad} = \eta \frac{|I_0|^2}{4\pi}\int_0^\pi \frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} d\theta \tag{1.16}$$

1.6 Research Objective

The goal of this research is to steer the radiation pattern of a uniform circular array antenna in the azimuthal plane by keeping the driven elements in the same position and by adding and removing reflectors and directors dynamically. The analysis of the radiation pattern for the proposed antennas was verified using 4NEC2 software. NEC stands for Numerical Electromagnetic Code used for antenna modeling. 4NEC2 software is a Windows-based tool used to design, view, optimize and to check 2D and 3D style geometry structures and simulate near and far field radiation patterns [3]. The proposed design is composed of 25 elements arranged in two concentric circles with directors, reflectors and three driven elements. The outer circle is composed only of directors, and the inner circle is composed of reflectors and three driven elements. By looking at the simulation results it can be concluded that the proposed system is capable of steering the radiation pattern in every direction.

1.7 Thesis Outline

The outline of this document is as follows. Chapter 2 describes smart antennas and the geometry of uniform circular array antennas. Chapter 3 discusses the design and simulation of a Uniform Circular Array Antenna using 4NEC2 software. Finally, chapter 4 provides the conclusions and discussion for future work.

Chapter Two

Smart Antennas

2.1 Introduction

The demand for mobile technology is growing rapidly in current wireless communication systems. This has led to an increase in channel capacity, larger coverage area and higher wireless traffic. One of the solutions to these problems is the implementation of smart or adaptive antennas. A smart antenna is an antenna that possesses the property of modifying its transmitting and receiving characteristics in order to improve its performance. In a smart antenna system, the dipole array is not smart by itself. It is the digital signal processing which makes the smart antenna really smart [1]. Although it might seem that smart antennas are a new technology, the fundamental theory behind them is not new [1, 4, 5]. These antennas were applied in defense related systems during World War II. In advanced wireless systems, smart antennas improve the system capacity, the coverage area and the data rate. Smart antenna systems are an extension of cell sectoring in which the sector coverage consists of multiple beams [6]. This is obtained by using antenna arrays and a number of beams in the sector [1]. The increase in beam directionality provides more capacity and coverage area. The smart antenna provides the maximum radiation pattern towards the intended user and nulls towards the direction of interfering signals [7]. Smart antennas have the properties of higher rejection interference and low bit error rate (BER) which creates a significant improvement in channel capacity [8]. Smart antennas are widely used in applications like mobile wireless systems and aerospace. In general, smart antennas are classified into two types: Switched Beam Array Systems and Adaptive Array Systems.

2.2 Switched Beam Array Systems

A switched beam array system consists of multiple fixed beams. When the mobile unit moves throughout the cell, the switched beam system detects the signal and chooses the predefined beam pattern. One of the disadvantages of this system is that the system does not provide protection from multipath components received from the directions near the desired signal. A switched beam array system is represented in Figure 6.

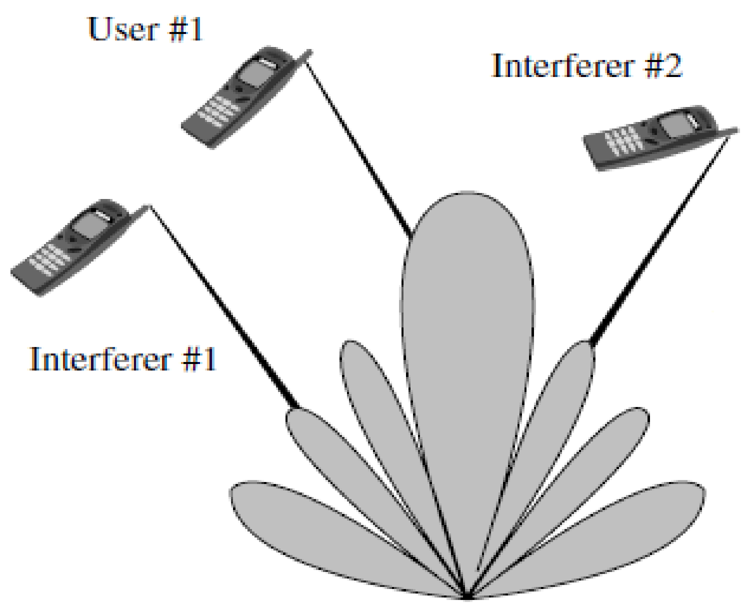

Figure 6. Switched Beam Array System [9]

2.3 Adaptive Array Systems

Adaptive array systems can locate and track signals and adjust the antenna pattern to improve reception while minimizing interference using digital signal processing algorithms. These systems can track Signal of Interest (SOI) and Signal Not of Interests (SNOI) by changing the amplitudes and phases of antennas. This system provides the maximum radiation pattern towards the individual user and nulls towards the interferer signals [10]. If the interference level is high, these adaptive array systems provide more interference rejection than switched beam systems [11]. The adaptive array system is represented in Figure 7.

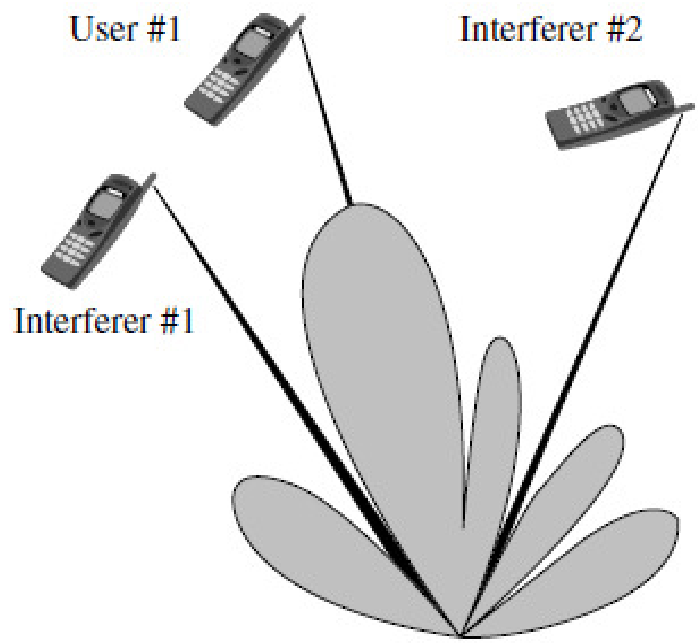

Figure 7. Adaptive Beam Array System [10]

2.4 Arrays

An array of antenna elements is needed to obtain good adaptive properties and more gain for a smart antenna. These antenna elements play an important role in shaping and scanning the radiation pattern [1]. There are different kinds of antenna elements to form an adaptive array. These include dipoles, micro strips, horns, reflectors and so on. In most cases the elements used to create the array are identical.

There are different types of array configurations like linear, planar and circular arrays. An array of identical elements with identical magnitude and each with progressive phase is called as a uniform array. A smart antenna system has the property to reuse the frequency efficiently. This feature makes some developments in the field of digital signal processing by providing maximum beam towards the intended user and nulls towards the interferer. Until now, the investigation of smart antennas in wireless applications has mainly focused on Uniform Linear Arrays (ULAs) and Uniform Rectangular Arrays (URAs) [12]. However there are many methods and algorithms used to find the direction of arrival of signals. One of the antenna models to find the direction of arrivals is through Uniform Circular Arrays (UCAs) and Uniform Planar Circular Arrays (UPCA). Furthermore, not as much interest has been shown in circular array topologies despite their ability to offer many advantages [12]. An obvious advantage is due to the symmetry of UCA structure. Since a UCA does not have edge elements, radiation patterns provided by this configuration can be electronically steered in the azimuthal plane [13].

2.5 Geometry of Circular Array Antennas

In the circular array, the elements are placed in a circular ring with N number of equally spaced elements. In current wireless communications, circular arrays have been proposed for the smart antenna applications. These circular arrays have the ability to scan a beam azimuthally through 360° with little change either in the beam width or side lobe level [12]. The geometry of an N-element circular array antenna is shown in Figure 8.

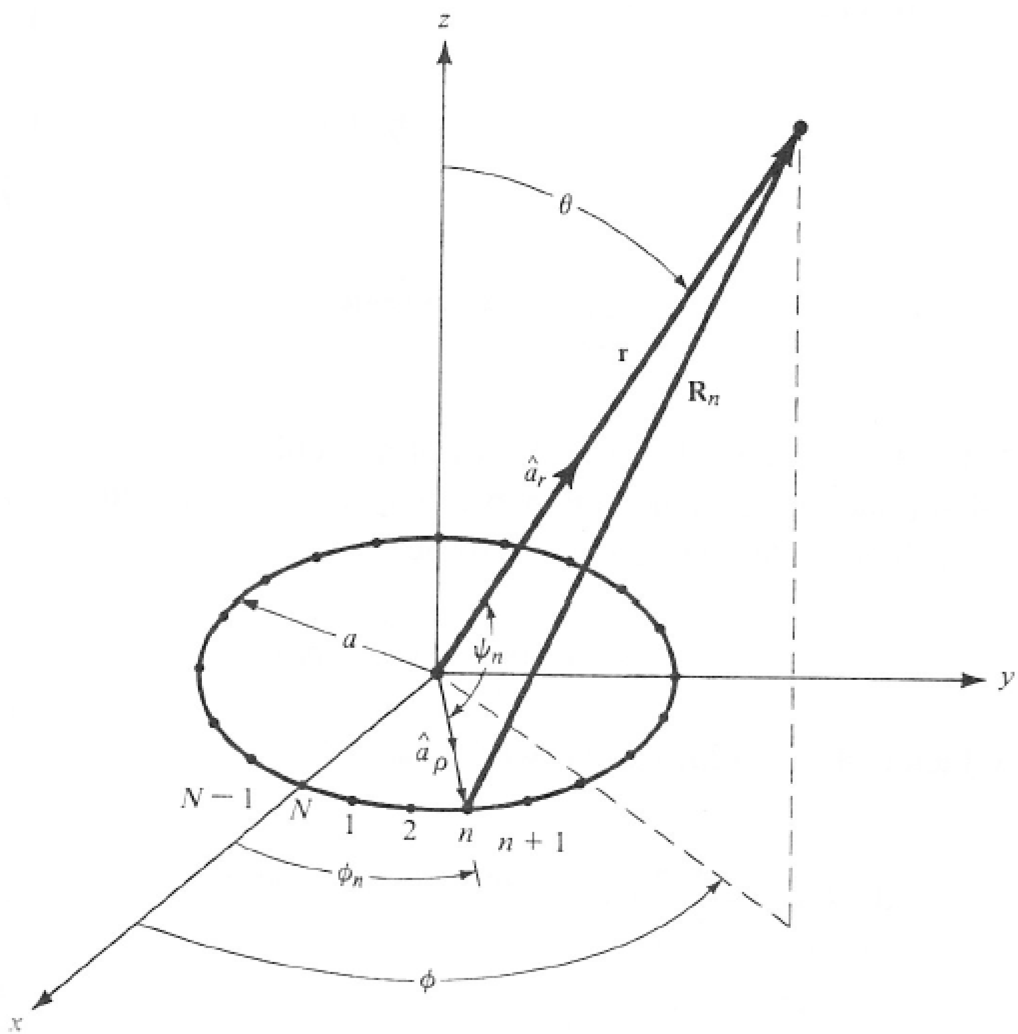

Figure 8. Geometry of an N-element circular array [1]

The circular array consists of N isotropic elements that are equally spaced on the x-y plane along a circular ring of radius a. The normalized field of the array can be given as

$$E_n(r,\theta,\phi)=\sum_{n=1}^{N}a_n\frac{e^{-jkR_n}}{R_n} \tag{2.1}$$

where R_n is the distance from the nth element to the observation point.

$$R_n = r - a\sin\theta\cos(\phi-\phi_n) \tag{2.2}$$

Assuming that for amplitude variations $R_n \simeq r$, then the equation for E_n is

$$E_n(r,\theta,\phi) = \frac{e^{-jkr}}{r} \sum_{n=1}^{N} a_n e^{jka\sin\theta\cos(\phi-\phi_n)} \tag{2.3}$$

$$E_n(r,\theta,\phi) = \frac{e^{-jkr}}{r} \left[AF(\theta,\phi)\right] \tag{2.4}$$

where a_n is the excitation coefficients of the nth element, ϕ_n is the angular position of the nth element on x-y plane and $AF(\theta,\phi)$ is the array factor of the circular array of N equally spaced elements. Array Factor can be written as

$$AF(\theta,\phi) = \sum_{n=1}^{N} I_n e^{j[ka\sin\theta\cos(\phi-\phi_n)+\alpha_n]} \tag{2.5}$$

where I_n is the amplitude excitation of the nth element, α_n is the phase excitation of the nth element. In order to direct the peak of the main beam in the (θ_0, ϕ_0) direction, the phase excitation of nth element can be written as

$$\alpha_n = -ka\sin\theta_0 \cos(\phi_0 - \phi_n) \tag{2.6}$$

Thus the array factor can be written as

$$AF(\theta,\phi) = \sum_{n=1}^{N} I_n e^{jka\left[\sin\theta\cos(\phi-\phi_n)-\sin\theta_0\cos\left(\phi_0-\phi_n\right)\right]} \tag{2.7}$$

$$AF(\theta,\phi) = \sum_{n=1}^{N} I_n e^{jka\left[\cos-\cos\psi_0\right]} \tag{2.8}$$

When the radius of the array becomes large, the directivity of a uniform circular array approaches the value of N , where N is equal to the number of elements [1].

2.6 Past Work on Circular Array Antennas

As discussed in the previous section, the uniform circular array antenna is similar to the Yagi-Uda antenna. The Yagi-Uda antenna is designed using an array of dipoles which consists of reflectors, driven elements and directors. From the article "Dual Excited Planar Circular Array Antenna for Direction Agile Applications" [14], the radiation pattern of the UCA is electronically steered in the azimuthal plane by modifying the position of the driven elements and by dynamically adding and removing reflectors and directors. The previous research design was made using 17 elements placed on a hollow cylindrical ground structure. Of the 17 elements, 16 elements were placed in two concentric circles and one more element was placed in the center of the ground structure. Two driven elements are placed 135 degrees apart on the inner ring. The elements placed diagonally opposite to the excited elements are grounded to act as reflectors. The elements behind the excited elements in the outer ring, the element at the center are also grounded and the remaining elements are removed from the system. In their work, for each simulation there were only 9 active elements which provide the beam in the desired direction. Simulations were conducted by changing the excited elements in the array and dynamically adding and removing reflectors and directors.

Chapter Three

Design and Simulation of Uniform Circular Array Antennas

In this chapter the design of a Circular Array Antenna is discussed. For simulation purposes the radiation pattern of the proposed design is verified using 4NEC2. The basic analysis used by 4NEC2 relies on the “method of moments,” a mathematical technique that subdivides an antenna into segments and displays the radiation pattern by calculating the properties, loadings and ground effects [3]. As discussed in the previous chapter, the design of a circular array antenna is similar to the Yagi-Uda antenna. In 1926, Dr.Shintaro Uda and Dr.Hidetsugu Yagi of the Tohoku Imperial University invented a directional antenna system consisting of an array of dipoles and parasitic elements [15]. The design of a Yagi-Uda Antenna involves driven elements, reflectors and directors [16]. The driven element is the excited element in which the transmitting source is applied. The reflector element is important in determining the front-to-back ratio of an antenna. The size and spacing of the directors have a large effect on the forward gain, backward gain and input impedance and are considered critical elements of the array antennas [1]. Typically the reflecting element is placed behind the driven element and the directors are placed in front of the driven element. The distance between the driven element and the reflector should be smaller than the driven element and the nearest director. When these elements are designed properly, these antennas produce directional beams [17]. Yagi-Uda antennas are lightweight, low –cost and simple antennas which are used in many applications. A pictorial representation of these antennas is shown in Figure 9.

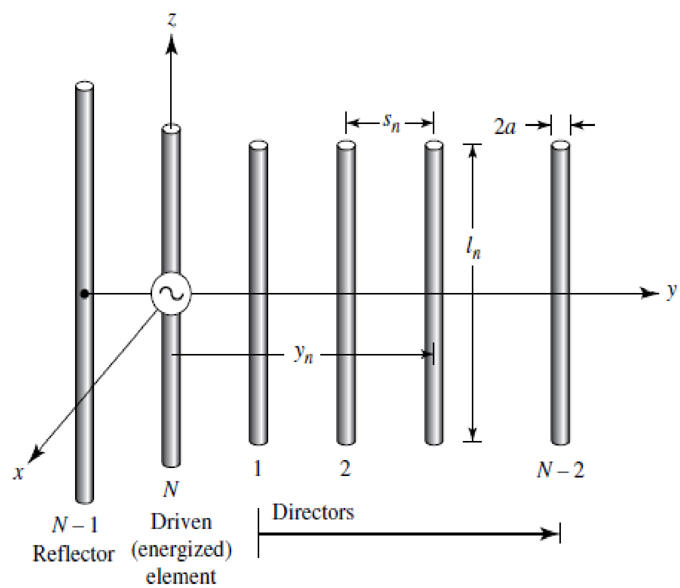

Figure 9. Configuration of Yagi Uda Antennas

There are two types of formulation methods for the Yagi-Uda antenna. The first formulation is the Pocklington's Integral Equation which is used to determine the equivalent line-source current of the wire, and the current density of the wire by knowing the incident field on the surface of the wire. At any point in space, the total electric field is the sum of the incident and scattered fields. The field equation is given as

$$E^t(r) = E^i(r) + E^s(r) \tag{3.1}$$

where $E^t(r)$ is the total electric field, $E^i(r)$ is the incident electric field and $E^s(r)$ is the scattered electric field.

The Pocklington's integral equation is given by

$$\int_{-l/2}^{+l/2} I_z(z')\left[\left(\frac{\partial^2}{\partial z^2} + k^2\right)G(z,z')\right]dz' = -j\omega\varepsilon E_z^i \tag{3.2}$$

where $k^2 = \omega^2\mu\varepsilon$ and $I_z(Z')$ is equivalent line to source current from the z axis.

For small diameter wires the current on each element can be approximated by a finite series of odd-ordered even modes. Thus, the nth element can written as a Fourier series expansion of the form

$$I_n\left(Z'\right)=\sum_{m=1}^{M} I_{mn}\cos\left[(2m-1)\frac{\pi z'}{l_n}\right] \tag{3.3}$$

where I_{mn} is the complex current coefficient of mode m on element n and l_n is the corresponding length of the n element. Thus, the Pocklington's integral equation reduces to

$$\sum_{m=1}^{M} I_{nm}\left\{(-1)^{m+1}\frac{(2m-1)\pi}{l_n}G_2\left(x,x',y,y'/z,\frac{l_n}{2}\right)+\left[k^2-\frac{(2m-1)^2\pi^2}{l_n^2}\right]\right.$$

$$\left.\times\int_0^{l_n/2}G_2\left(x,x',y,y'/z,z_n'\right)\cos\left[\frac{(2m-1)\pi z_n'}{l_n}\right]dz_n'\right\}=j4\pi\omega\varepsilon_0 E_z^t \tag{3.4}$$

where

$$G_2\left(x,x',y,y'/z,z_n'\right)=\frac{e^{-jkR_-}}{R_-}+\frac{e^{-jkR_+}}{R_+} \tag{3.5}$$

$$R_\pm=\sqrt{\left(x-x'\right)^2+\left(y-y'\right)^2+a^2+\left(z\pm z'\right)^2} \tag{3.6}$$

where n=1, 2, 3,…..,N , N=total number of elements and $R_\pm$ is the distance from the center of each wire radius to the center of any other wire.

The method of moments is useful in obtaining the complex current coefficient I_{mn}. Each wire element is subdivided into M segments to obtain the solution for the equation. On each element the matching is done at the center of the wire and E_z^t vanishes at each matching point of each segment. On the driven element the matching is done on the surface of the wire, and E_z^t vanishes at M-1 points. The M th equation on the feed element is given by

$$\sum_{m=1}^{M} I_{nm}\left(z^{'}=0\right)\Big|_{n=N} = 1 \tag{3.7}$$

where I_{nm} is the current coefficient of mode m on element n

The second type of formulation is the Far-Field Pattern. Once the current distribution is found, the total field of the entire Yagi-Uda array is obtained by summing the contributions from each. The far-zone electric field generated by the M modes of the n th element is given by

$$E_{\theta n} \simeq -j\omega A_{\theta n} \tag{3.8}$$

$$A_{\theta n} \simeq \frac{-\mu e^{-jkr}}{4\pi r}\sin\theta \int_{-l_n/2}^{+l_n/2} I_n e^{jk(x_n \sin\theta\cos\phi + y_n \sin\theta\sin\phi + z_n^{'}\cos\theta)} dz_n^{'} \tag{3.9}$$

where x_n, y_n represent the position of the n th element. The total field is then obtained by summing the contributions from each of the N elements, and it is given by

$$E_{\theta} = \sum_{n=1}^{N} E_{\theta n} = -j\omega A_{\theta} \tag{3.10}$$

$$A_{\theta} = \sum_{n=1}^{N} A_{\theta n} = -\frac{\mu e^{-jkr}}{4\pi r}\sin\theta \sum_{n=1}^{N}\left\{e^{jk\left(x_n \sin\theta\cos\phi + y_n \sin\theta\sin\phi\right)}\right.$$

$$\left.\times\left[\int_{-l_n/2}^{+l_n/2} I_n e^{jkz_n^{'}\cos\theta} dz_n^{'}\right]\right\} \tag{3.11}$$

For each wire, the current is represented by

$$I_n(Z^{'}) = \sum_{m=1}^{M} I_{nm}\cos[(2m-1)\frac{\pi z^{'}}{l_n}] \tag{3.12}$$

$$\int_{-l_n/2}^{+l_n/2} I_n e^{jkz_n^{'}\cos\theta} dz_n^{'} = \sum_{m=1}^{M} I_{nm} \int_{-l_n/2}^{+l_n/2} \cos\left[\frac{(2m-1)\pi z_n^{'}}{l_n}\right] e^{jkz_n^{'}\cos\theta} dz_n^{'} \tag{3.13}$$

Since the cosine is an even function, the equation is given by

$$\int_{-l_n/2}^{+l_n/2} I_n e^{jkz_n^{'}\cos\theta} dz_n^{'} = \sum_{m=1}^{M} I_{nm} \left\{ \int_{0}^{+l_n/2} \cos\left[\frac{(2m-1)\pi}{l_n} + k\cos\theta\right] z_n^{'} dz_n^{'} \right.$$

$$\left. + \int_{0}^{+l_n/2} \cos\left[\frac{(2m-1)\pi}{l_n} - k\cos\theta\right] z_n^{'} dz_n^{'} \right\} \tag{3.14}$$

$$\int_{-l_n/2}^{+l_n/2} I_n e^{jkz_n^{'}\cos\theta} dz_n^{'} = \sum_{m=1}^{M} I_{nm} \left[\frac{\sin(Z^{+})}{Z^{+}} + \frac{\sin(Z^{-})}{Z^{-}}\right] \frac{l_n}{2}$$

with

$$Z^{+} = \left[\frac{(2m-1)\pi}{l_n} + k\cos\theta\right] \frac{l_n}{2} \tag{3.15}$$

$$Z^{-} = \left[\frac{(2m-1)\pi}{l_n} - k\cos\theta\right] \frac{l_n}{2} \tag{3.16}$$

Thus, the total field is given by

$$E_\theta = \sum_{n=1}^{N} E_{\theta n} = -j\omega A_\theta \tag{3.17}$$

$$A_\theta = \sum_{n=1}^{N} A_{\theta n} = -\frac{\mu e^{-jkr}}{4\pi r} \sin\theta \sum_{n=1}^{N} \left\{ e^{jk(x_n \sin\theta\cos\phi + y_n \sin\theta\sin\phi)} \right.$$

$$\left. \times \sum_{m=1}^{M} I_{nm} \left[\frac{\sin(Z^{+})}{Z^{+}} + \frac{\sin(Z^{-})}{Z^{-}}\right] \right\} \frac{l_n}{2} \tag{3.18}$$

where x_n, y_n is the position of the nth element and l_n is the corresponding length of the n element

3.1 Design of Circular Array Antennas

For simulation purposes, the design of the proposed smart antenna was performed using 4NEC2 software. The design was made using circular array antennas which are similar to Yagi-Uda antennas but the geometry is in a circular arrangement. The performance of a Yagi-Uda antenna depends on the arrangement of the reflectors and the driven elements, the number of directors and the driven elements. The design of the antenna in a three dimensional plane is shown in Figure 10.

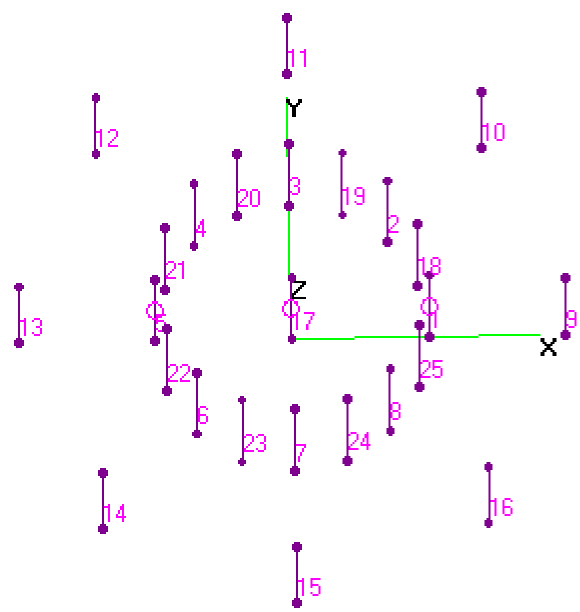

Figure 10. Design of a Circular Array Antenna in 3D plane using 4NEC2

The antenna was designed to operate at 2.4 GHZ and is composed by a total of 25 elements arranged in two concentric circles. Of the 25 elements 8 are used as directors, 14 as reflectors and 3 are fixed driven elements. The 8 directors are spread in the outer circle and the remaining 14 reflectors are spread over the inner circle. The driven elements are placed over the diameter of the inner circle. The radius of the inner circle and outer circle are taken as 0.2667λ and 0.5334λ [14]. The reflectors are arranged in the inner circle, each at an angle of 22.5 degrees. The directors are arranged in the outer circle at an angle of 45 degrees. The lengths of the driven elements are taken as 0.49λ. The lengths of the reflector elements are greater than the driven elements which are taken as $\frac{\lambda}{2}$. The lengths of the director elements are smaller than the driven elements which are taken as 0.45λ [1].

3.2 Simulation

In this section the results obtained by applying the different phases to the driven elements and by modifying the configuration of the reflectors and directors will be discussed. In order to emphasize the importance of the results obtained from this research the radiation pattern for the array antenna with no directors and reflectors will be presented. The simulations are made by changing the phases of the current for each driven element. The results obtained for the array antenna with phases of $(0^\circ, 0^\circ, 0^\circ)$; $(0^\circ, 20^\circ, 40^\circ)$; $(0^\circ, 40^\circ, 80^\circ)$ and $(0^\circ, 60^\circ, 120^\circ)$ are shown from Figure 11 through Figure 14. It is evident by looking at the figures that the radiation pattern is composed not only of the main lobe but also has a major back lobe. In order to suppress the back lobes from the radiation pattern, the topology of a uniform circular array antenna can be effective. This is one of the reasons, why smart antennas are playing an important role in the advanced wireless communication systems.

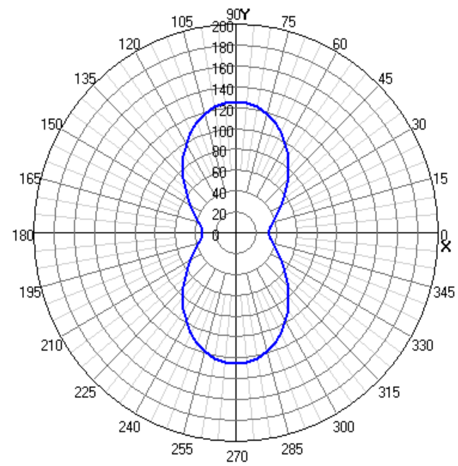

Figure 11. Radiation pattern of 3-element dipole antenna with no reflectors and directors for (0˚, 0˚, 0˚) phase

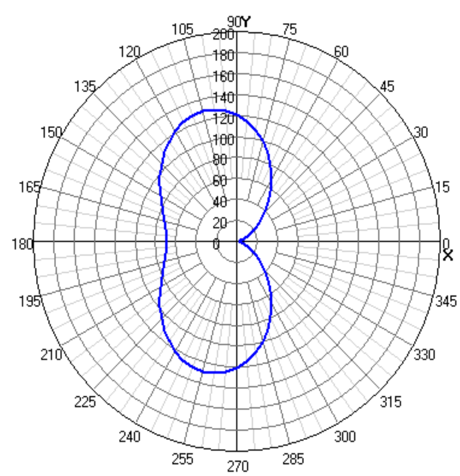

Figure 12. Radiation pattern of 3-element dipole antenna with no reflectors and directors for (0˚, 20˚, 40˚) phase

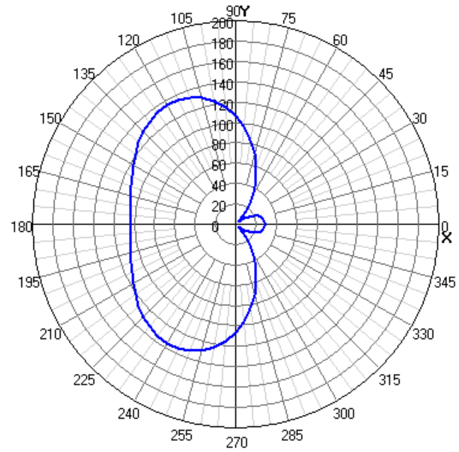

Figure 13. Radiation pattern of 3-element dipole antenna with no reflectors and directors for (0˚, 40˚, 80˚) phase

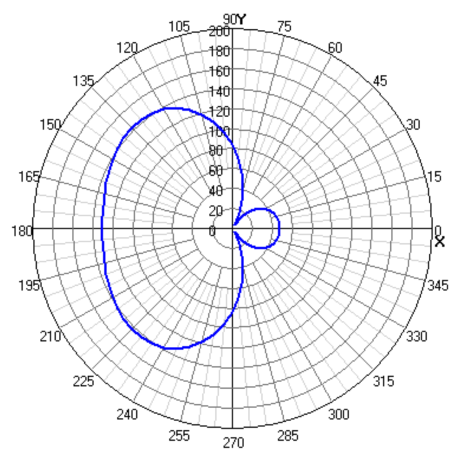

Figure 14. Radiation pattern of 3-element dipole antenna with no reflectors and directors for (0˚, 60˚, 120˚) phase

The uniform circular array configuration for smart antennas is used to suppress the back lobes and to control the radiation pattern in every phase by keeping driven elements in the same position and dynamically adding and removing reflectors and directors. For the $(0^{\circ}, 0^{\circ}, 0^{\circ})$ phase, the reflectors 20, 3 and 19 are removed from the system and the directors 12, 11 and 10 remain in the system. For the $(0^{\circ}, 20^{\circ}, 40^{\circ})$ and $(0^{\circ}, 40^{\circ}, 80^{\circ})$ phases, the reflectors 2 and 19 are removed from the system and the directors 9, 10 and 11 remain in the system. For the $(0^{\circ}, 60^{\circ}, 120^{\circ})$ phases, the reflectors 2 and 18 are removed from the system and the directors 9, 10 and 11 remain in the system. The 4 NEC2 design for the phases $(0^{\circ}, 0^{\circ}, 0^{\circ})$, $(0^{\circ}, 20^{\circ}, 40^{\circ})$, $(0^{\circ}, 40^{\circ}, 80^{\circ})$ and $(0^{\circ}, 60^{\circ}, 120^{\circ})$ are shown in Figures 15-17. Since the geometry of the circle is symmetrical, the radiation patterns obtained for every direction is shown in Figure 18 through Figure 31.

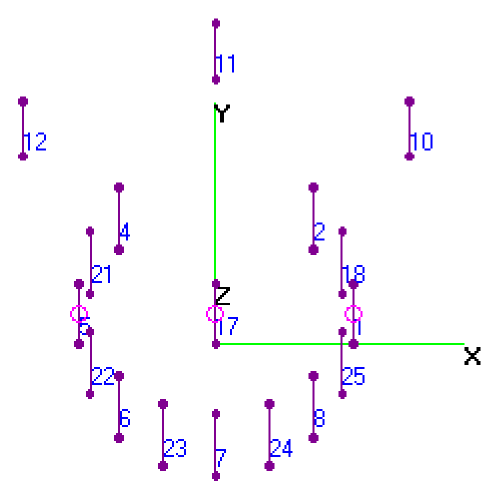

Figure 15. 4NEC2 design for the $(0^{\circ}, 0^{\circ}, 0^{\circ})$ Phase

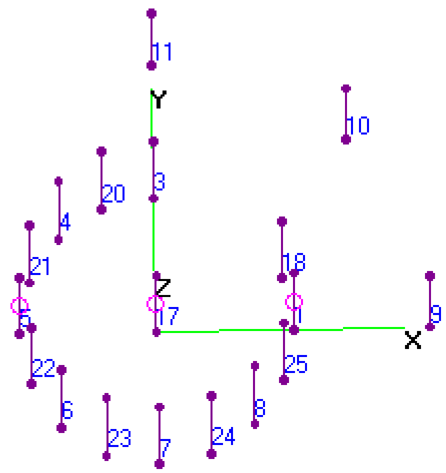

Figure 16. 4NEC2 design for (0°, 20°, 40°) and (0°, 40°, 80°) Phases

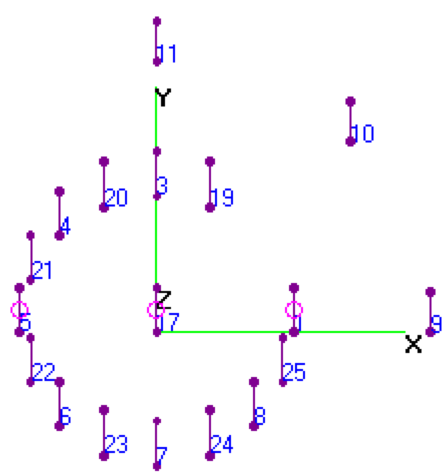

Figure 17. 4NEC2 design for the (0°, 60°, 120°) Phase

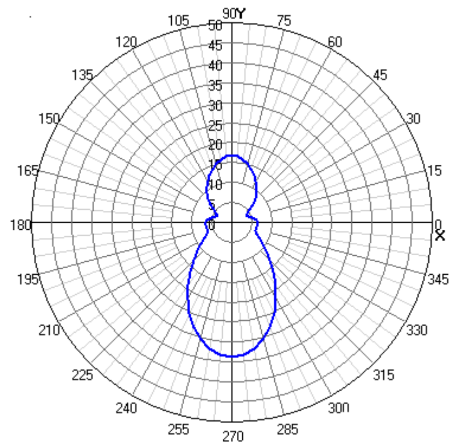

Figure 18. Radiation pattern of (0˚ , 0˚ , 0˚) Phase without 20, 3 and 19 reflectors and with 10, 11 and 12 directors

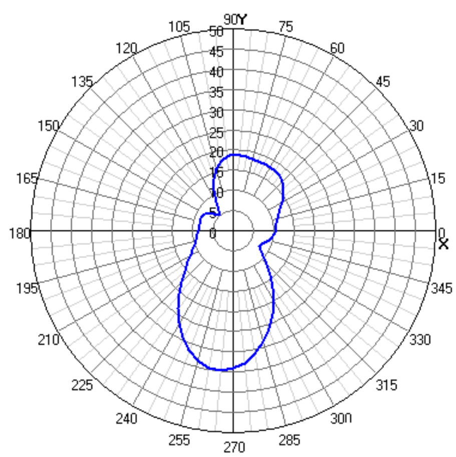

Figure 19. Radiation pattern of (0˚ , 20˚ , 40˚) Phase without 4 and 20 reflectors and with 11, 12 and 13 directors

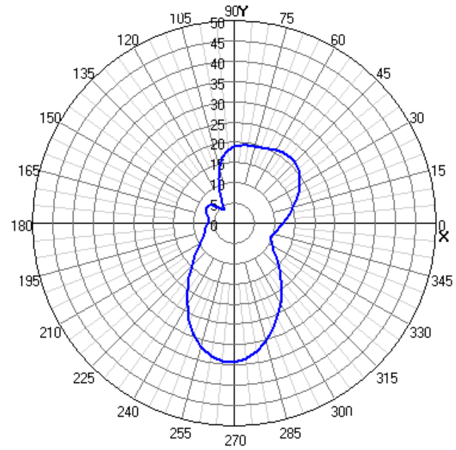

Figure 20. Radiation pattern of (0°, 40°, 80°) Phase without 4 and 20 reflectors and with 11, 12 and 13 directors

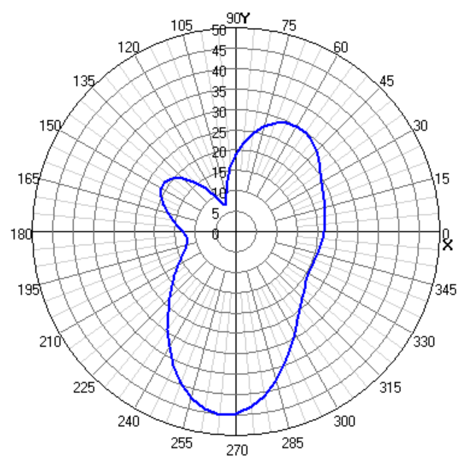

Figure 21. Radiation pattern of (0°, 60°, 120°) Phase without 21 and 4 reflectors and with 11, 12 and 13 directors

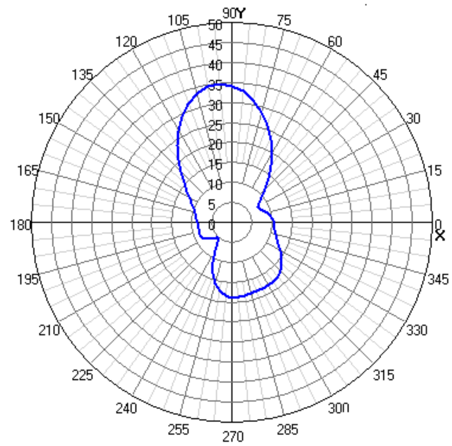

Figure 22. Radiation pattern of (0˚, 20˚, 40˚) Phase without
6 and 23 reflectors and with 13, 14 and 15 directors

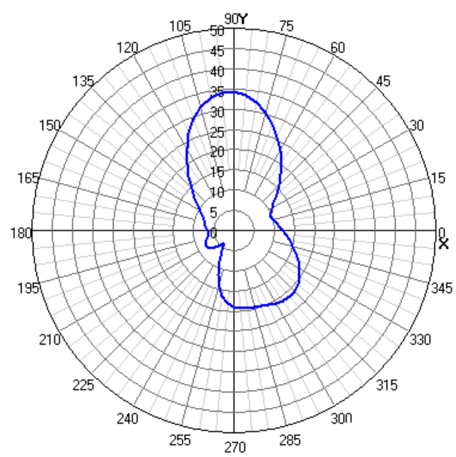

Figure 23. Radiation pattern of (0˚, 40˚, 80˚) Phase without
6 and 23 reflectors and with 13, 14 and 15 directors

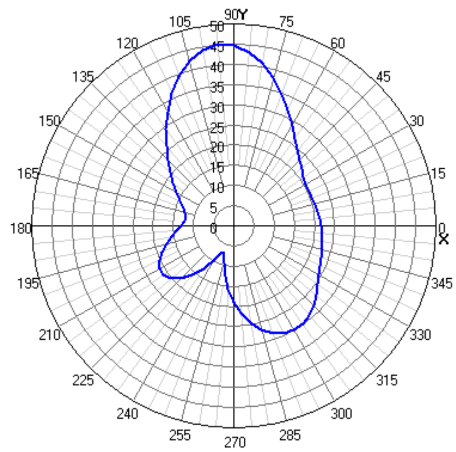

Figure 24. Radiation pattern of (0˚, 60˚, 120˚) Phase without 22 and 6 reflectors and with 13, 14 and 15 directors

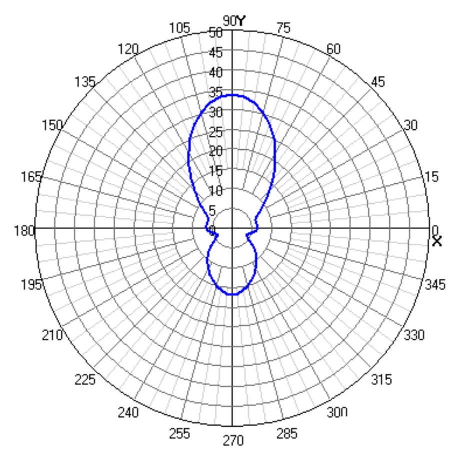

Figure 25. Radiation pattern of (0˚, 0˚, 0˚) Phase without 23, 7 and 24 reflectors and with 14, 15 and 16 directors

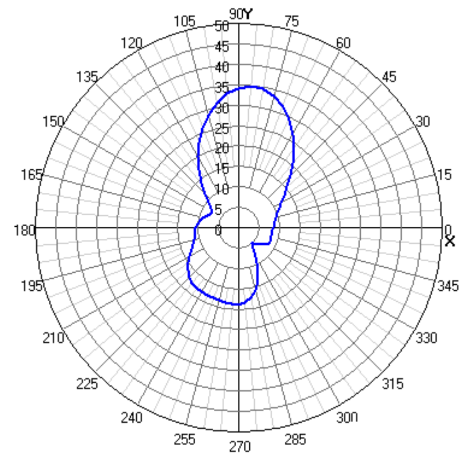

Figure 26. Radiation pattern of (0˚, 20˚, 40˚) Phase without
8 and 24 reflectors and with 16, 15and 9 directors

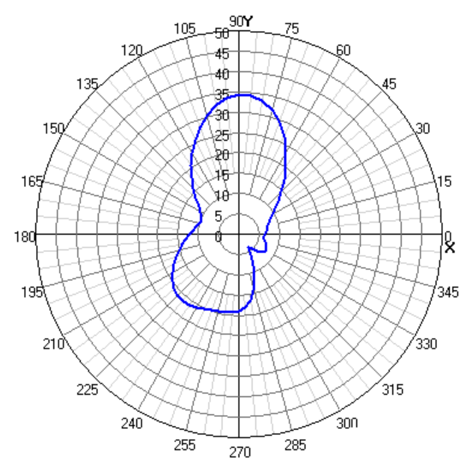

Figure 27. Radiation pattern of (0˚, 40˚, 80˚) Phase without
8 and 24 reflectors and with 16, 15 and 9 directors

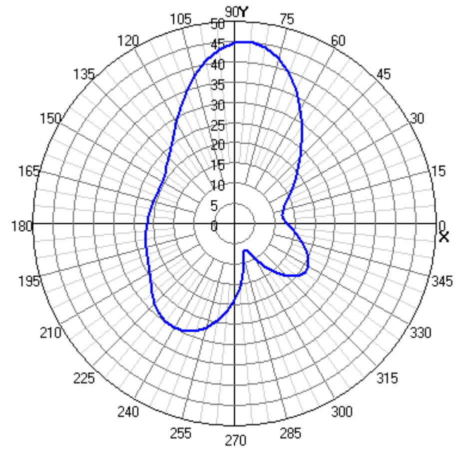

Figure 28. Radiation pattern of (0°, 60°, 120°) Phase without 25 and 8 reflectors and with 16, 15 and 9 directors

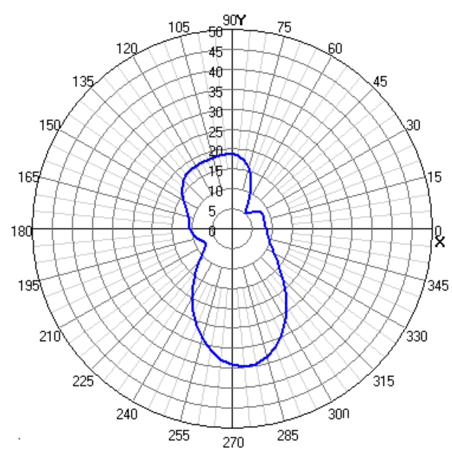

Figure 29. Radiation pattern of (0°, 20°, 40°) Phase without 19 and 2 reflectors and with 9, 10 and 11 directors

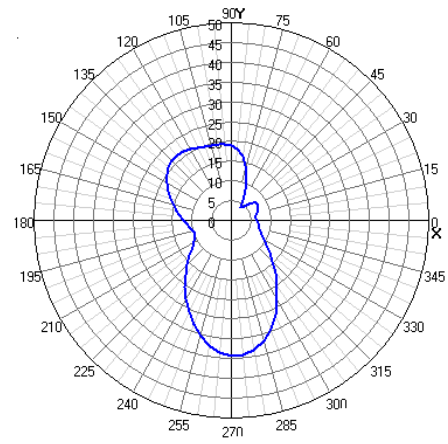

Figure 30. Radiation pattern of (0˚, 40˚, 80˚) Phase without 19 and 2 reflectors and with 9, 10 and 11 directors

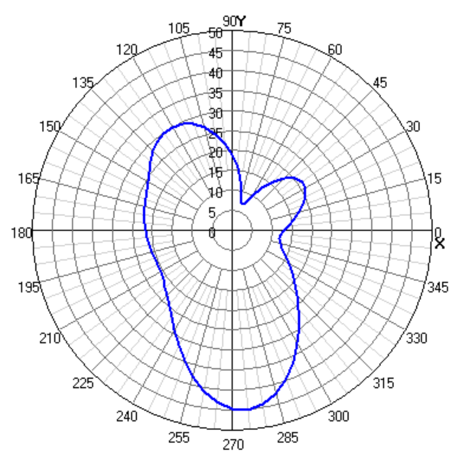

Figure 31. Radiation pattern of (0˚, 60˚, 120˚) Phase without 18 and 2 reflectors and with 9, 10 and 11 directors

For the remaining phases, if we observe the 3-element dipole antenna with no reflectors and directors shown in Figure 14, the shape of the main beam is changing and it is forming the lobe like a circle. A larger structure is needed to get better directivity for the remaining phases. In order to clarify the point, a 5-element dipole antenna with no reflectors and directors is considered. For a larger structure, the main beam of the antenna forms a lobe. This indicates that a larger structure is needed for the remaining phases. The radiations patterns for the remaining phases can be obtained by taking the larger structure and by dynamically add and remove reflectors and directors. The radiation pattern of 5-element dipole antenna with no reflectors and directors for the phase $0^{\circ}, 60^{\circ}, 120^{\circ}$ is shown in Figure 32.

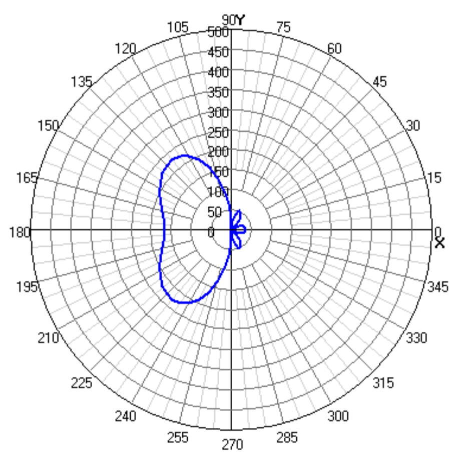

Figure 32. Radiation pattern of 5-element dipole antenna with no reflectors and directors for ($0^{\circ}, 60^{\circ}, 120^{\circ}$) phase

Chapter Four

Conclusions and Future Work

4.1 Conclusions

In this research a Uniform Circular Phase Array Smart Antenna was proposed. One of the major characteristics of this antenna is the capability of steering the radiation pattern without modifying the position of the driven elements and by dynamically adding and removing reflectors and directors. The radiation pattern of this antenna was verified using 4NEC2 software.

From the results it is evident that it is possible to modify the radiation pattern of the antenna and direct most of its energy to predefined positions. This can be clearly seen from in Figures 11 through 14 and from Figures 18 through Figure 32. The back lobes are suppressed by dynamically exciting specific elements in the array. This is of great advantage for systems in which it is desired to eliminate any external interference and achieve the maximum gain from the desired signal.

4.2 Future Work

Further work is needed to obtain radiation patterns for the remaining phases from the results shown in Figure 14 and from Figure 32, it is clear that for the five element dipole antenna with no reflectors and directors, the beam is forming a lobe. This proves that a larger structure is needed to obtain a good radiation pattern by dynamically adding reflectors and directors.

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