Spiral-Shaped Monopole antenna for mobile communication

by

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A comprehensive project report has been submitted in the fulfillment of the requirements for the degree of

Bachelor of Technology

in

ELECTRONICS & COMMUNICATION ENGINEERING

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May, 2018

CERTIFICATE OF APPROVAL

This is to certify that the project titled "**Spiral-shaped monopole antenna for mobile communication**" carried out by

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for the partial fulfillment of the requirements for B.Tech degree in **Electronics and Communication Engineering** from **Maulana Abul Kalam Azad University of Technology, West Bengal**is absolutely based on his own work under the supervision of **Mr.Nandan Bhattacharyya**. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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DECLARATION

"We Do hereby declare that this submission is our own work conformed to the norms and guidelines given in the Ethical Code of Conduct of the Institute and that, to the best of our knowledge and belief, it contains no material previously written by another neither person nor material (data, theoretical analysis, figures, and text) which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text."

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Place: Kolkata

CERTIFICATE of ACCEPTANCE

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Name of the Examiner Signature with Date

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ABSTRACT

A planar monopole antenna consisting of a printed metal strip of rectangular spiral shape is studied. The spiral generates two resonance modes and radiates at two frequency bands. A simulation design is given where the lower operating band covers the GSM900 band, and the upper operating band covers DCS1800 and wifi standards. This multi-band antenna is compact and lightweight and it can be fabricated at very low cost by etching the spiral on an FR4/Epoxy substrate and feeding with a 50 ohm microstrip line.

CONTENTS

LIST OF ABBREVIATIONS

GHz	**GigaHertz**
HPBW	**Half-Power Beamwidth**
GPS	**Global Positioning System**
RHCP	**Right Hand Circularly Polarized**
RFID	**Radio Frequency Identification**
CD	**Compact Disc**
LHCP	**Left Hand Circularly Polarized**
IC	**Integrated Chip**
PCB	**Printed Circuit Board**
HFSS	**High Frequency Structure Simulator**
HPC	**High Performance Computing**
RF	**Radio Frequency**
VSWR	**Voltage standing Wave Ratio**

LIST OF FIGURES

Chapter 1

Introduction

Spiral antennas belong to the class of "frequency independent" antennas; these antennas are characterized as having a very large bandwidth. The fractional Bandwidth can be as high as 30:1. This means that if the lower frequency is 1 GHz, the antenna would still be efficient at 30 GHz, and every frequency in between.

Spiral antennas are usually circularly polarized. The spiral antenna's radiation pattern typically has a peak radiation direction perpendicular to the plane of the spiral (broadside radiation). The Half-Power Beamwidth (HPBW) is approximately 70-90 degrees.

Applications

Spiral antennas are widely used in the defense industry for sensing applications, where very wideband antennas that do not take up much space are needed. Spiral antenna arrays are used in military aircraft in the 1-18 GHz range. Other applications of spiral antennas include GPS, where it is advantageous to have RHCP (right hand circularly polarized) antennas.

Features Include

- ***Signal Gain:*** Inputs from multiple antennas are combined to optimize available power required level of courage.
- ***Interference rejection:*** Antenna pattern can be generated toward co-channel interference sources, thus improving the signal-to-interference of the received signals.
- ***Spatial diversity:*** Composite information from the array is used to minimize fading and other undesirable effects of multipath propagation.
- ***Power efficiency:*** It combines the inputs from multiple elements to optimize available processing gain in the downlink (toward the user).

Motivation

The world is changing rather developing with every passing second, so is the lifestyle and requirements of the coming generation with high reliability, durability and portability. Keeping the need of the masses and several industrial, communicational and defence mechanism in mind.We, as engineers often called as problem solvers thought the need of reduction in communication gap is of utmost importance and that antenna theory could be the best backdrop for this purpose.

Background

In the 1890s, there were only a few antennas in the world. These rudimentary devices were primarily a part of experiments that demonstrated the transmission of electromagnetic waves. By World War II, antennas had become so ubiquitous that their use had transformed the lives of the average person via radio and television reception. The number of antennas in the United States was on the order of one per household, representing growth rivaling the auto industry during the same period.

By the early 21st century, thanks in large part to mobile phones, the average person now carries one or more antennas on them wherever they go (cell phones can have multiple antennas, if GPS is used, for instance). This significant rate of growth is not likely to slow, as wireless communication systems become a larger part of everyday life. In addition, the strong growth in RFID devices suggests that the number of antennas in use may increase to one antenna per object in the world (product, container, pet, banana, toy, cd, etc.). This number would dwarf the number of antennas in use today. Hence, learning a little (or a large amount) about of antennas couldn't hurt, and will contribute to one's overall understanding of the modern world.

Log-Periodic Spiral Antenna

In 1954, Edwin Turnur started messing with a dipole antenna. Instead of leaving the arms straight, he wrapped them around each other, forming a spiral. This was the beginning of the spiral antenna. We can define the arms of a spiral antenna using simple polar coordinates and polar functions. The log-periodic spiral antenna, also known as the equiangular spiral antenna, has each arm defined by the polar function.

$r = R_0 e^{a\phi}$ [Equation 1]

In Equation [1], R_0 is a constant that controls the initial radius of the spiral antenna. The parameter a controls the rate at which the spiral antenna flares or grows as it turns. Equation [1], in English, states that the spiral antenna radius grows exponentially as it turns. In Figure 1.1, a plot of a planar Log-Periodic Spiral Antenna is shown.

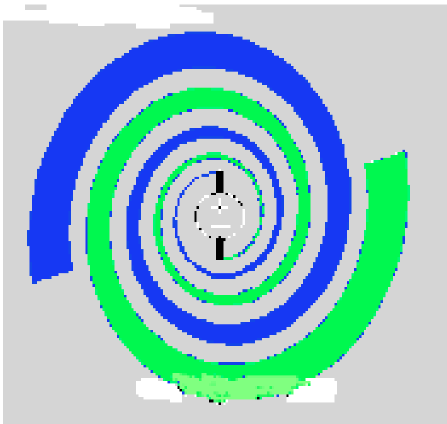


Figure 1.1- a planar Log-Periodic Spiral Antenna

The planar spiral antenna of Figure 1.1 will have peak radiation directions into and out of the screen (broadside to the plane of the spiral, in both the front and the back). The spiral antenna of Figure 1.1 will radiate Right Hand Circularly Polarized (RHCP) fields out of the screen, and Left Hand Circularly Polarized (LHCP) fields into the screen. The sense of the circularly polarized fields can be determined by placing your thumb in the direction of the fields, and curling your fingers in the direction of the spiral antenna (If your fingers curl the right way using your right hand, then it is RHCP. Otherwise, it is LHCP).
The parameters that effect the radiation of the spiral antenna include:

1. Total Length of the Spiral, or the outer radius (R_{end}) - This determines the lowest frequency of operation for the spiral antenna. The lowest operating frequency of the spiral antenna is commonly approximated to occur when the wavelength is equal to the circumference of the spiral:

$f_{low} = \frac{c}{\lambda_{low}} = \frac{c}{2\pi R_{end}}$ [Equation 2]

2. The Flare Rate (a) - The rate at which the spiral grows with angle is the flare rate. If it is too large, the spiral is tightly wrapped around itself. In this case, it will behave more like a capacitor, with closely coupled conductors, giving poor radiation. If the flare rate is too small, the spiral acts more like a dipole as it doesn't wrap around itself. A commonly used value is a = 0.22.

3. Feed Structure - The feed must be controlled with a balun so that the spiral has balanced currents on either arm. A commonly used balun for spiral antennas is the infinite balun. More importantly, the feed structure determines the high end of the operating band. How tightly you can wrap the spiral in on itself determines how small the wavelength can be that will fit on your spiral and still maintain spiral antenna operation. The highest frequency in the spiral antenna's operating band occurs when the innermost radius of the spiral (i.e. where the spiral starts after the feed structure) is equal to lambda/4 (one quarter wavelength). That is, the highest frequency can be determined from the inner radius (R_i in Equation [1]):

$$f_{upper} = \frac{c}{\lambda_{upper}} = \frac{c}{4R_i}$$ [Equation 3]

4. Number of Turns (N) - The number of turns of the spiral is also a design parameter. Experimentally it is found that spirals with at least one-half turn up to 3 turns work well, with 1.5 turns being a good number.

Radiation occurs from the spiral antenna when the currents on the spiral's arms are in phase. As the spiral winds outward from the center, there will exist some region for each frequency (wavelength) where the currents add constructively and produce radiation. This radiation removes energy from the electric current on the spiral antenna; as a result, the magnitude of the current dies off with distance from the spiral antenna. Hence, there is little reflection of current from the end of the spiral antenna. How quickly the current decreases in magnitude away from the center of the spiral are a function of the geometry of the spiral antenna.

Impedance of Slot Antenna - Babinet's Principle

To estimate the impedance of the spiral antenna, we can recall Babinet's Principle, which was discussed with respect to slot antennas. Note that the Log-Periodic Spiral Antenna and its dual surface are identical. That is, if we rotate the Log.-Periodic Spiral by 90 degrees, we get the exact same shape, which is the dual of the spiral antenna. This unique property means has a nice consequence. Since the impedance of two antennas that are identically shaped must also be identical, we can obtain the impedance from Babinet's principle.

$$Z_C Z_S = Z_S^2 = \frac{\eta^2}{4} = \frac{377}{4}$$

$$\Longrightarrow Z_S = 188.5\Omega$$ [Equation 4]

That is, the Log-Periodic Spiral Antenna has a theoretical impedance of about 188 Ohms. In actual realizations of Spiral antennas the impedance tends to be less than this, in the 100-150 Ohm range.

Radiation Patterns

The radiation pattern of the Log-Periodic Spiral Antenna is approximately given by:

$$F(\theta) = \cos\theta$$ [Equation 5]

This pattern has two equal radiation peaks, both broadside to the plane of the spiral antenna (which lies in the z=0 plane, or x-y plane). One peak is above the planar spiral antenna and the other is below. The Spiral Antenna has circular polarization over a wide beamwidth, often for angular regions as wide as $\theta \leq 70^{\circ}$ angles of circular polarization for spiral antenna. This is a very broad beamwidth for circular polarization; this is one of the features that make spiral antennas very useful.

The Archimedean Spiral Antenna

Another common planar spiral antenna type is known as the Archimedean Spiral antenna. Each arm of the Archimedean spiral is defined by the equation:

$$r = a\phi \quad \text{[Equation 6]}$$

Equation [6] states that the radius r of the antenna increases linearly with the angle ϕ. The parameter a is simply a constant that controls the rate at which the spiral flares out. The second arm of the Archimedean spiral the same as the first, but rotated 180 degrees.

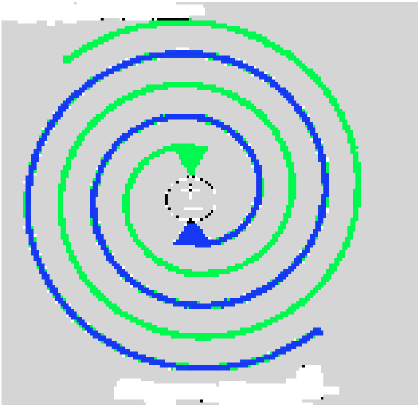


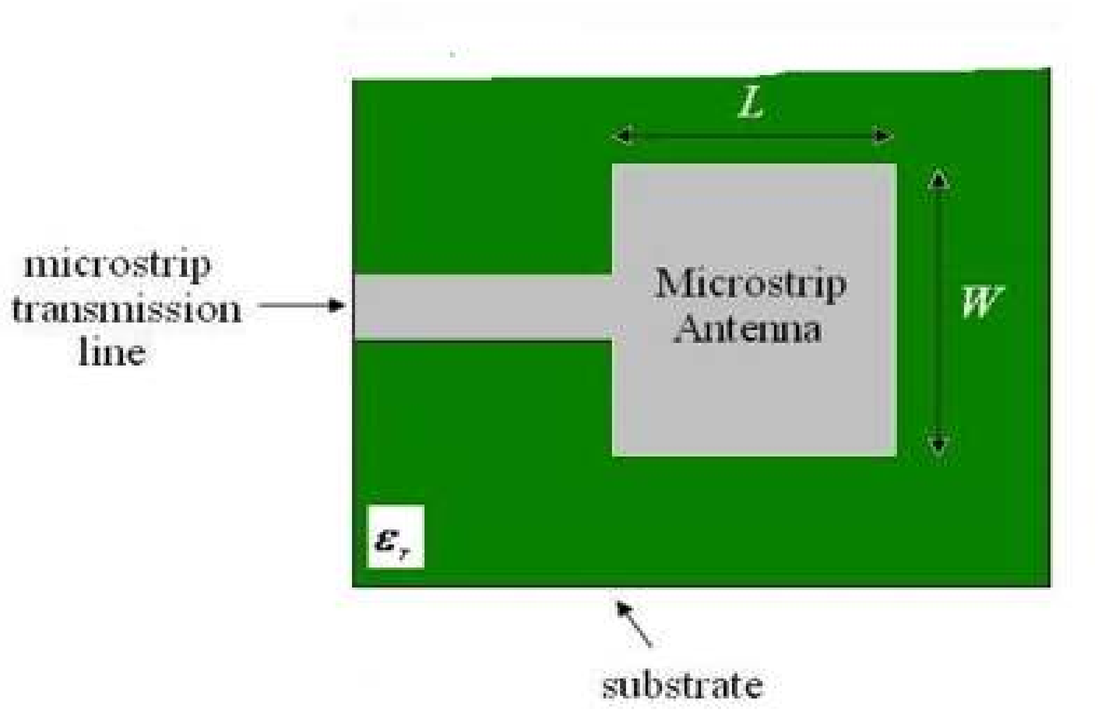
Figure 1.2-Archimedean Spiral Antenna, with a=0.2

In Figure 1.2, we have two arms of the Archimedean spiral antenna flaring away from the center, as defined by Equation [6]. The feed of the antenna (the voltage source), is placed directly across between the two arms of the spiral - the positive end to one arm and the negative end of the feed to the second spiral arm.

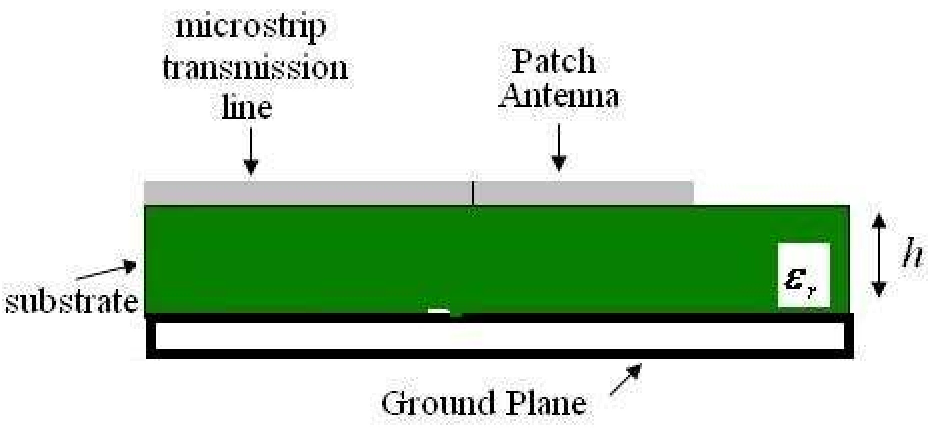
Rectangular Microstrip Antenna

Microstrip or patch antennas are becoming increasingly useful because they can be printed directly onto a circuit board. Microstrip antennas are becoming very widespread within the mobile phone market. Patch antennas are low cost, have a low profile and are easily fabricated.

Consider the microstrip antenna shown in Figure 1, fed by a microstrip transmission line. The patch antenna, microstrip transmission line and ground plane are made of high conductivity metal (typically copper). The patch is of length *L*, width *W*, and sitting on top of a substrate (some dielectric circuit board) of thickness *h* with permittivity ε_r . The thickness of the ground plane or of the microstrip is not critically important. Typically the height *h* is much smaller than the wavelength of operation, but not much smaller than 0.05 of a wavelength or the antenna efficiency will be degraded.



1.3-Top View of Patch Antenna



1.4-Side View of Microstrip Antenna

The frequency of operation of the patch antenna of Figure 1 is determined by the length *L*. The center frequency will be approximately given by:

$$f_c \approx \frac{c}{2L\sqrt{\varepsilon_r}} = \frac{1}{2L\sqrt{\varepsilon_0 \varepsilon_r \mu_0}}$$

The above equation says that the microstrip antenna should have a length equal to one half of a wavelength within the dielectric (substrate) medium.

The width *W* of the microstrip antenna controls the input impedance. Larger widths also can increase the bandwidth. For a square patch antenna fed in the manner above, the input impedance will be on the order of 300 Ohms. By increasing the width, the impedance can be reduced. However, to decrease the input impedance to 50 Ohms often requires a very wide patch antenna, which takes up a lot of valuable space. The width further controls the radiation pattern. The normalized radiation pattern is approximately given by:

$$E_\theta = \frac{\sin\left(\frac{kW \sin\theta \sin\phi}{2}\right)}{\frac{kW \sin\theta \sin\phi}{2}} \cos\left(\frac{kL}{2} \sin\theta \cos\phi\right) \cos\phi$$

$$E_\varphi = -\frac{\sin\left(\frac{kW \sin\theta \sin\phi}{2}\right)}{\frac{kW \sin\theta \sin\phi}{2}} \cos\left(\frac{kL}{2} \sin\theta \cos\phi\right) \cos\theta \sin\phi$$

In the above, *k* is the free-space wavenumber, given by $2\pi / \lambda$. The magnitude of the fields, given by:

$$f(\theta, \phi) = \sqrt{E_\theta^2 + E_\phi^2}$$

Advantages and Disadvantages of Microstrip Antenna

Microstrip antenna offers certain advantages as:

- ***Easy to handle and inexpensive:*** as it is small and light
- ***Low power-handling capability*** of printed circuits
- ***Topological Considerations:*** Integral with other circuit devices,hence,improving system reliability.
- ***Reduction in Size:*** printed circuits are thin and thus require less volume than their waveguide or coaxial line counterparts.
- ***Large-Scale Fabrication:*** once the designer has developed the basic circuit pattern, realized a circuit, and tested it successfully, additional copies can be produced rapidly and consistently in large mass production.

On the other hand, it suffers from some disadvantages as:

- Narrow bandwidth
- Low gain
- Large ohmic loss in large feed network.
- Radiation from feeds contributes to the radiation pattern.
- Excitation of surface waves.
- Low polarization purity.

Broadband Dipole Antenna

A standard rule of thumb in antenna design is: an antenna can be made more broadband by increasing the volume it occupies. Hence, a dipole antenna can be made more broadband by increasing the radius *A* of the dipole. These antennas are also known as wideband dipoles**.**

1.1 Problem definition

To design a spiral-shaped monopole antenna for mobile communication.

1.2 Problem statement

The objective is to achieve two operating bands; a lower band around 900 MHz to cover GSM900 (890-960 MHz) and a higher band from 1.7 to 2.1 GHz to cover DCS1800 (1710-1880 MHz) and wifi standards.We conducted the analysis and design using HFSS commercial software.

1.3 Software Required:ANSYS HFSS

ANSYS HFSS software is the industry standard for simulating high-frequency electromagnetic fields. Its gold-standard accuracy, advanced solvers and high-performance computing technologies make it an essential tool for engineers tasked with executing accurate and rapid design in high-frequency and high-speed electronic devices and platforms. HFSS offers state-of the-art solver technologies based on finite element, integral equation, and asymptotic and advanced hybrid methods to solve a wide range of microwave, RF and high-speed digital applications.

HFSS delivers 3-D full-wave accuracy for components to enable RF and high-speed design. By leveraging advanced electromagnetic field simulators dynamically linked to powerful harmonic-balance and transient circuit simulation, HFSS breaks the cycle of repeated design iterations and lengthy physical prototyping. With HFSS, engineering teams consistently achieve best-in-class design in a broad range of applications including antennas, phased arrays, passive RF/mW components, high-speed interconnects, connectors, IC packaging and PCBs.

Design sign-off accuracy is provided by HFSS through its groundbreaking and industry-leading adaptive meshing technology. Its powerful meshing and solver technologies enable you to design with confidence, knowing the results provided by HFSS can be relied on. Other tools simply give answers without any feedback regarding the accuracy of the solution, leading to uncertainty. When combined with ANSYS HPC technologies, like domain decomposition or distributed frequencies, HFSS can simulate at a speed and scale never before thought possible, further allowing you to more fully explore and optimize your device’s performance. With HFSS you know your designs will deliver on their product promise.

1.4 Antenna Details

Figure 1.4.1 shows the generic structure of the spiral-shaped planar monopole antenna, which is composed of a spiral radiating element, a microstrip feedline, a substrate and a ground plane. In practice the radiating element and the feedline may be formed by etching on a standard substrate. Note that the 50 Ω microstrip feedline is printed on the same surface of the substrate but the ground is on the opposite surface of the substrate and only below the microstrip line, as indicated by the shaded rectangular region. In other words, the radiating element is positioned in the extended region of the substrate above the ground plane. There is a transition taper between the feedline and the antenna element, to allow for different microstrip and antenna strip widths. It is well known that multi-arm spiral antennas can offer broad bandwidth and they are normally excited at the inside terminal. In these antennas, the antenna element is similar to a single-arm rectangular-spiral antenna but the feedline is connected to the outside terminal of the spiral. This structure can excite several modes and radiate at multiple frequency bands. For the example design, the ground plane was selected to be 40 × 39 mm. We also chose an FR4/Epoxy substrate with a thickness of 0.8 mm and a relative permittivity of 4.4 due to their general availability. The other dimensions of this antenna are: s1=24.0 mm, s2=22.75 mm, s3=17.0 mm, s4=18.25 mm, s5=12.5 mm, s6=13.75 mm, s7=8 mm, s8=9.25 mm, wf=1.5 mm, wp=3.0 mm. The lower operating band of this antenna (with better than 1:2.5 VSWR) is about 90 MHz wide and it covers the GSM900 band (890-960 MHz). Its upper operating band is 460 MHz wide (1.71-2.17 GHz) and it covers the DCS1800 (1710-1880 MHz), PCS1900 (1850-1990 MHz), and UMTS2000 (1920-2170 MHz) bands.

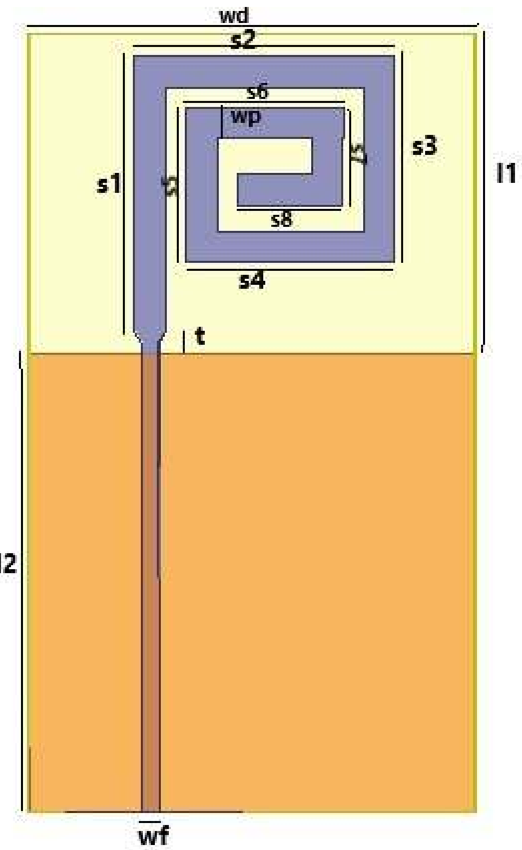


Figure 1.4.1-Antenna Design

1.5 Design and Result Analysis

- A feature we can note from the result is that the upper resonance frequency of the antenna in 1b can be tuned by changing the gap width, without affecting the lower resonance frequency.
- The lower resonance frequency is primarily determined by the length of the spiral strip.
- The bandwidths are not affected significantly as a result of substrate thickness variation as long as the FR4 substrate is at least 0.8mm thick.

1.6 Outcome

- An S11 versus Frequency graph is obtained for the designed antenna
- 3Dradiation pattern which shows approximately omnidirectionality of the designed antenna
- For 125 mm radiator length, the antenna resonating frequencies are found to be 700 MHz, 1.6 GHz, and 2.8 GHz.
- At these frequencies the antenna length is approximately λ/4, λ/2 and λ.

Figure 1.6.1- S11 versus Frequency graph

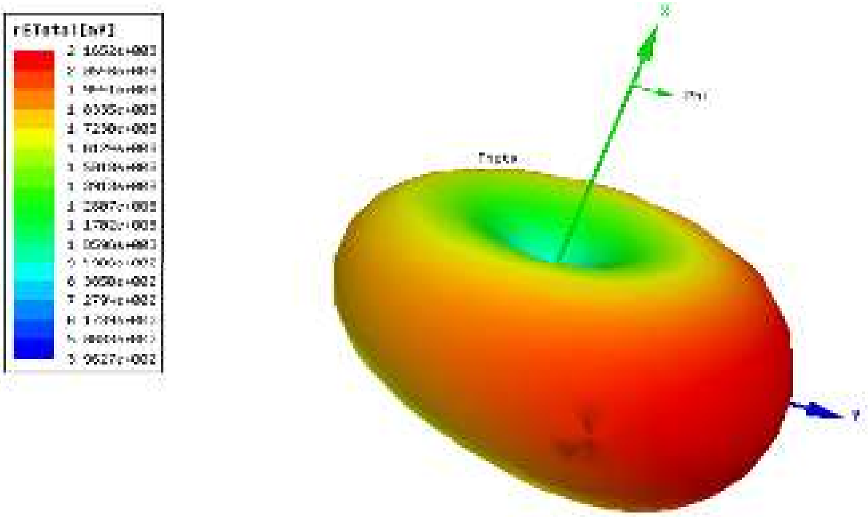


Figure 1.6.2-3d Radiation pattern for 0.7 GHz

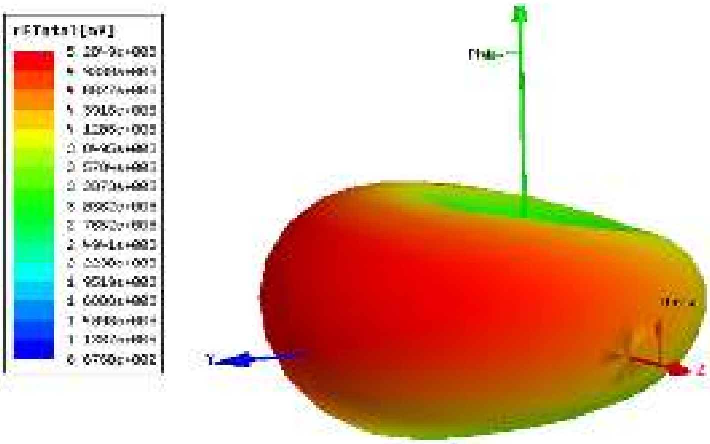


Figure 1.6.3-3D radiation pattern for 1.7 GHz

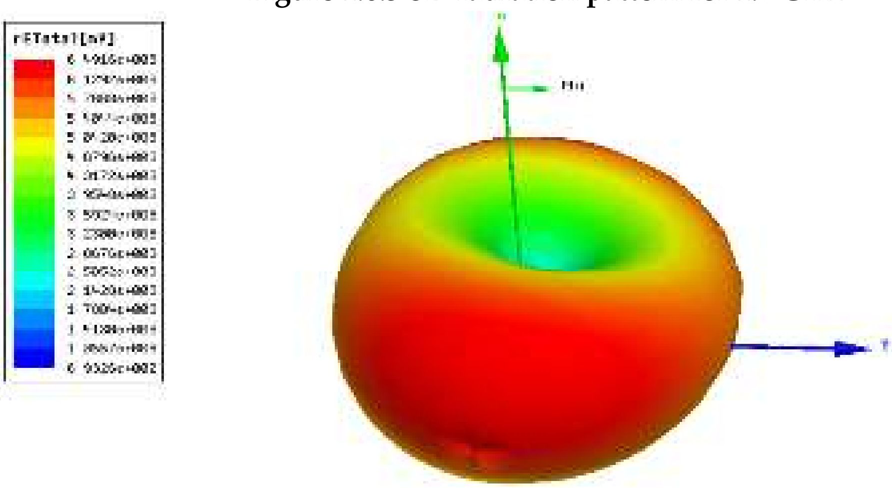


Figure 1.6.4-3D radiation Pattern for 2.8 GHz

Conclusion

The designed antenna could be used for multiband mobile communication. Though further optimization of antenna dimension is required to get the desired resonant frequency and to improve the return loss.

Reference

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