

Design & Development of Multiband Antenna for Consumer Applications



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2017

Developer's Submission

This report is being submitted to the Department of Electrical Engineering of the National University of Computer and Emerging Sciences in partial fulfillment of the requirements for the degree of BS in Electrical Engineering.

Developer's Declaration

We take full responsibility of the project work conducted during the Final Year Project (FYP) titled "*Design & Development of Multiband Antenna for Consumer Application*". We solemnly declare that the project work presented in the FYP report is done solely by us with no significant help from any other person; however, small help wherever taken is duly acknowledged. We have also written the complete FYP report by ourselves. Moreover, we have not presented this FYP (or substantially similar project work) or any part of the thesis previously to any other degree awarding institution within Pakistan or abroad.

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Abstract

A planar antenna possessing multiband characteristics is numerically modeled and experimentally characterized. The proposed antenna, 120 mm in height and 64 mm in width is fabricated, and the obtained bandwidth covers the global system for mobile communication-GSM (890-960 MHz), personal communication system (1850-1990 MHz), wireless local area network-WLAN (2.45GHz) and TV cable band (includes VHF & UHF bands) respectively. Details of the simulated design and obtained experimental results are presented and discussed. Furthermore, demonstrations of two possible consumer applications at WLAN (2.45 GHz) and TV cable band (UHF & VHF) are briefly explained.

Acknowledgement

For the success of this project we would like thank our supervisors, our lab staff and all the wonderful people whose support and encouragement was instrumental throughout. We would like to thank our FYP supervisor Dr. Babar Kaleem Minhas, who gave us continuous guidance and assistance and inspired us even in difficult times to achieve promising results.

In the end, we would especially like to extend our gratitude towards National Institute of Electronics (NIE) for allowing us to use their testing facility free of cost and also microwave laboratory incharge at NIE Sir Babar, who was gracious enough to spare time to help us with familiarization of the computational electromagnetics software (HFSS & CST microwave) and lab equipment Vector Network Analyzer-(VNA).

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Chapter 1

Introduction

1.1. Background Information

An antenna is a transducer which converts electric power into radio waves and vice versa. It is an important part of radio equipment. It can be considered as an impedance matching that can transport signals between vacuum and electronic devices. Antennas are mostly used in radio equipment that include electronic devices like mobile phones, tablets and personal digital assistants (PDAs). Moreover, they're also used in wireless communication technologies, for example Worldwide Interoperability for Microwave Access (WiMAX), Wireless Local Area network (WLAN), Global Positioning Systems (GPS) and television broadcasting etc [1].

Microstrip patch antennas are gaining popularity because they can be printed directly on printed circuit board (PCB) making them easier to fabricate. The most common types of microstrip patch antennas are circular and rectangular patches. Microstrip antennas are widely used because they are easy to fabricate and they are compatible with integrated circuit technology. Active and passive elements can also be etched on the same dielectric substrate as the patch antenna. However, these antennas also have some major drawbacks such as low efficiency, low power, false feed radiation and a narrow bandwidth [1], [2].

Modern day wireless systems require a device to be operated at multiple frequencies simultaneously. A multiband antenna is designed when we want an antenna to be active for multiple bands of frequency at the same time. The gains of these antennas are lower than the average gains of single-band antennas [3]. These types of antennas are not expected to match a given line on all bands of frequencies on which we intend to be use them on. A short length antenna may work as a multiband antenna given that the loading for each frequency band is suitable [4]. A block diagram is given in figure 1.1, which shows how our multiband antenna can be utilized and the possible applications of the designed multiband antenna.

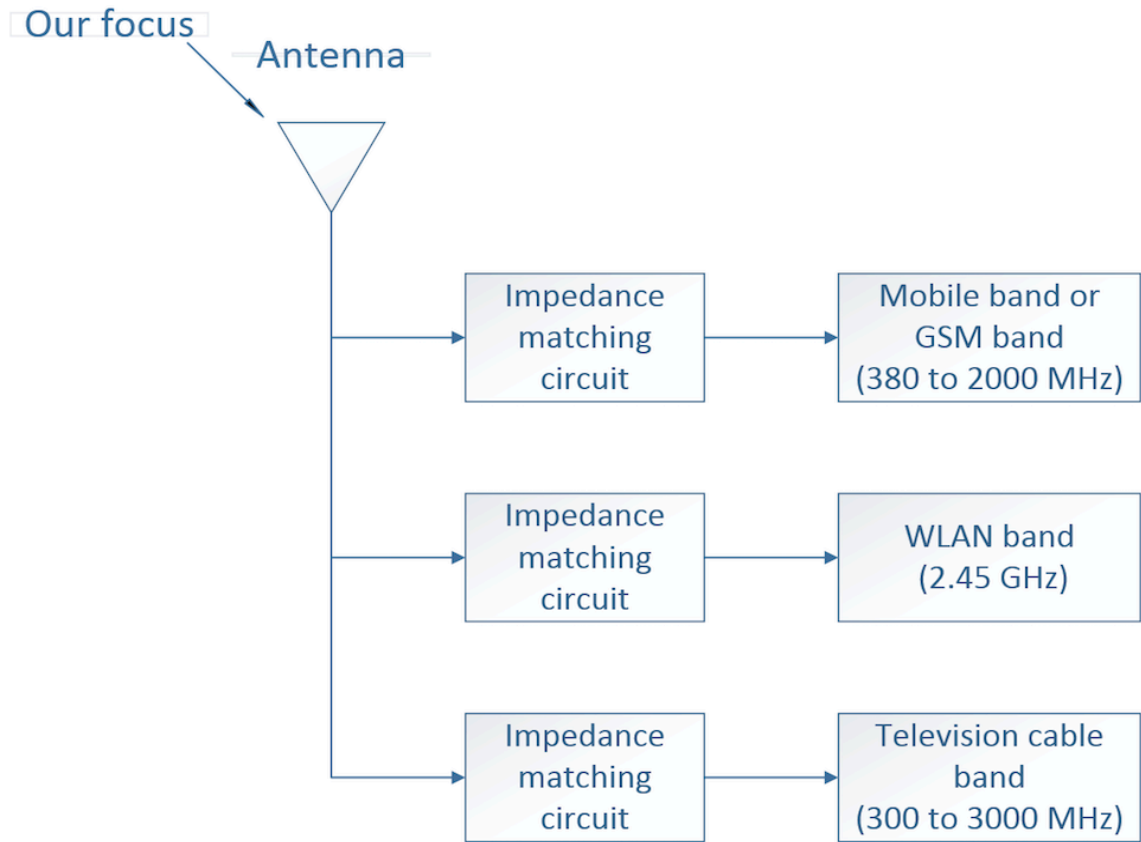


Figure 1.1 – Block diagram of where multiband antenna can be utilized.

1.2. Problem Statement

In the recent years, the electronic devices that are developed require multiple bands of frequency to be covered concurrently. Those bands may include Global Systems for Mobile (GSM) band, GPS band, WLAN band and television cable band. Instead of designing separate antennas for each frequency band, we have designed a single multiband antenna that covers multiple frequency bands simultaneously. Hence instead of separate feeds for each antenna, single feed will be required thereby reducing cost and complexity.

Chapter 2

Solution/Design/Implementation

This chapter contains the project description, different types of antennas and different antenna parameters that help in understanding antennas. Moreover, this chapter also contains the literature review of different papers related to multiband antennas, project block diagrams and flow chart along with the explanation of their modules. It also explains the designing, fabrication and testing procedure for patch antenna and multiband antenna.

2.1 Project description

A multiband antenna is designed and fabricated, which covers GSM, television cable and WLAN bands simultaneously. The fabricated antenna is tested and the results were used to determine the performance of the antenna. The multiband antenna is successfully tested to demonstrate consumer applications, which include transmitting a WLAN signal as well as transmitting a television cable signal wirelessly

2.2 How an antenna radiates

Whenever a time-varying current passes through a conducting wire or there is acceleration of charge through a conducting wire, it radiates. When there is no motion of charge or uniform velocity of charges along a straight wire, it does not radiate.

Antenna is a device that is designed to radiate and receive electromagnetic waves. Radiation process of antenna can be explained with help of sinusoidal voltage source connected to a transmission line. Thus, changing (sinusoidal) accelerating charges produce an electric field, which in turn, according to Maxwell's equations, gives rise to changing magnetic field hence, we have electromagnetic radiation. Since the source is sinusoidal, electromagnetic waves are created

continuously and these travel through the transmission line, through the antenna and radiate into the free space [18]. In figure 2.1, it is shown that a voltage source is connected to an antenna through a two-conductor transmission line.

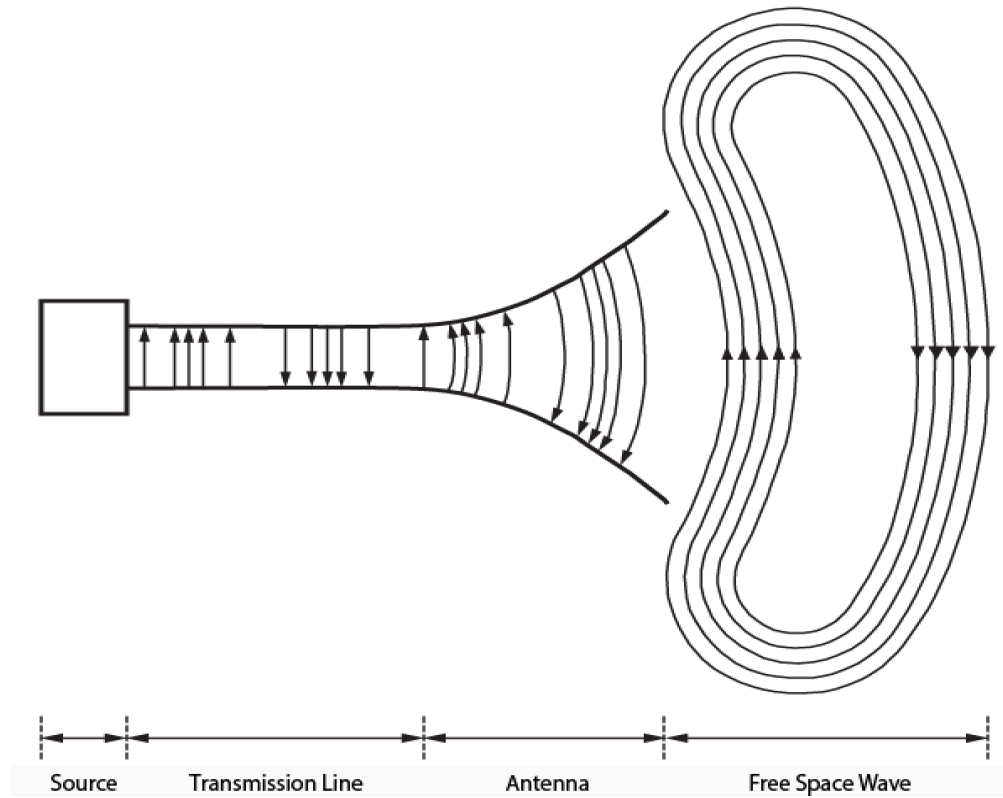


Figure 2.1: Radiation from an antenna.

2.3 Antenna performance parameters

2.3.1 Radiation Pattern

Radiation pattern is a graphical representation of the radiated electric field ($\mathbf{E}$) of an antenna in the far –field as a function of space coordinates given by the elevation angle θ and the azimuth angle ϕ . For a maximum value of unity for the field expression, it is normalized, which can be done for a z-directed source that only has θ - component of $\mathbf{E}$ as follows:

$$F(\theta, \phi) = \frac{E_{\theta}}{E_{\theta}(\max)}$$

Where $F(\theta, \phi)$ is the normalized field pattern and $E_{\theta}(\max)$ is the maximum value of the magnitude of E_{θ} [19]. A typical radiation pattern is shown in figure 2.2 as a polar plot [19].

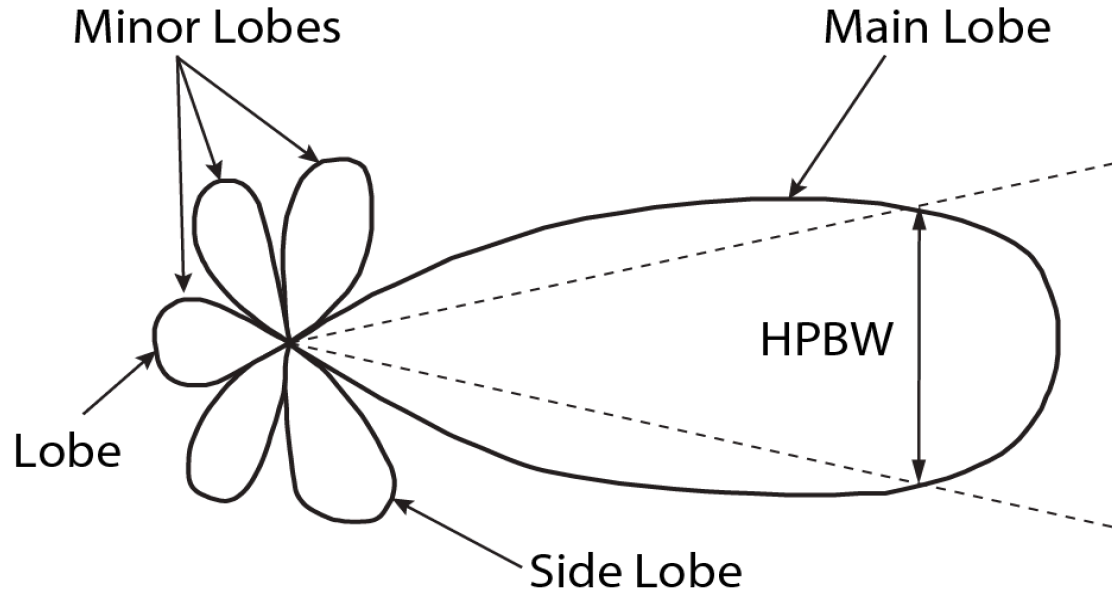


Figure 2.2: Radiation pattern of a generic omni-directional antenna.

- HPBW: The half power beamwidth is defined as the angle between half-power points of the main lobe.
- Main Lobe: The lobe, which contain the maximum direction of radiation.
- Minor Lobe: Every other lobe in the radiation pattern apart from the main lobe is referred as minor lobe, which is undesirable.
- Back Lobe: The minor lobe, which is at a 180° angle with the main lobe.
- Side Lobes: All the minor lobes, which are neither the main or the back lobe are the side lobes.

2.3.2 Poynting Vector

The Poynting vector associated with an electromagnetic wave is defined as:

$$\mathbf{S} = \frac{1}{2} \text{Re}(\mathbf{E} \times \mathbf{H}^*)$$

Where $\mathbf{S}$ is the instantaneous Poynting vector with units watts per square meter (W/m^2), $\mathbf{E}$ is the instantaneous electric-field intensity with units volts per meter (V/m) and $\mathbf{H}$ is the instantaneous magnetic-field intensity with units amperes per meter (A/m) [19].

2.3.3 Radiation Intensity

Radiation intensity is defined as the power radiated in a specific direction per unit solid angle. Solid angle is the two-dimensional angle subtended by an object in a three-dimensional plane. It has units watts per square radian (or steradian, sr), which can be defined as follows:

$$U(\theta, \phi) = \frac{1}{2} \text{Re}(\mathbf{E} \times \mathbf{H}^*) \cdot \hat{\mathbf{r}} r^2 = S(\theta, \phi) r^2$$

Where $U(\theta, \phi)$ is the radiation intensity, $S(\theta, \phi)$ is the magnitude of Poynting vector and r is the radius of the circle. It can also be expressed as:

$$U(\theta, \phi) = U_m |F(\theta, \phi)|^2$$

Where U_m is the maximum radiation intensity and $|F(\theta, \phi)|^2$ is the power pattern normalized to a maximum value of unity [19].

2.3.4 Directivity

Directivity is defined as the ratio of the radiation intensity in a specific direction to the ratio of directivity averaged on all other directions. It is determined by the radiation pattern of an antenna. In order to find antenna directivity expression, we first need to find average power per steradian.

$$U_{ave} = \frac{1}{4\pi} \iint U(\theta, \phi) d\Omega = \frac{P}{4\pi}$$

Where P is the input power, the directivity is given as:

$$D = \frac{U_m}{U_{ave}} = \frac{U_m}{P / 4\pi}.$$

Where D is the directivity of the antenna. An antenna that radiates equally in all directions is called an isotropic antenna, which has $U_m = U_{ave}$. It would have directivity of 1 or in decibels 0 dB. It is not practically realizable but it is used as a reference for calculating practical antenna parameters [19].

2.3.5 Gain

Antenna gain is antenna's performance parameter, which incorporates antenna's directivity and efficiency. Gain is used to quantify how efficiently an antenna transforms available power into radiated power. In case of a 100% efficient antenna, or a lossless antenna, the antenna gain equals the antenna directivity.

$$G(\theta, \phi) = \xi D(\theta, \phi).$$

Where $G(\theta, \phi)$ is the gain of the antenna, ξ is the efficiency of the antenna and $D(\theta, \phi)$ is the directivity of the antenna [19].

2.3.6 Equivalent Circuit

The equivalent circuit of a transmitting antenna is shown in figure 2.3:

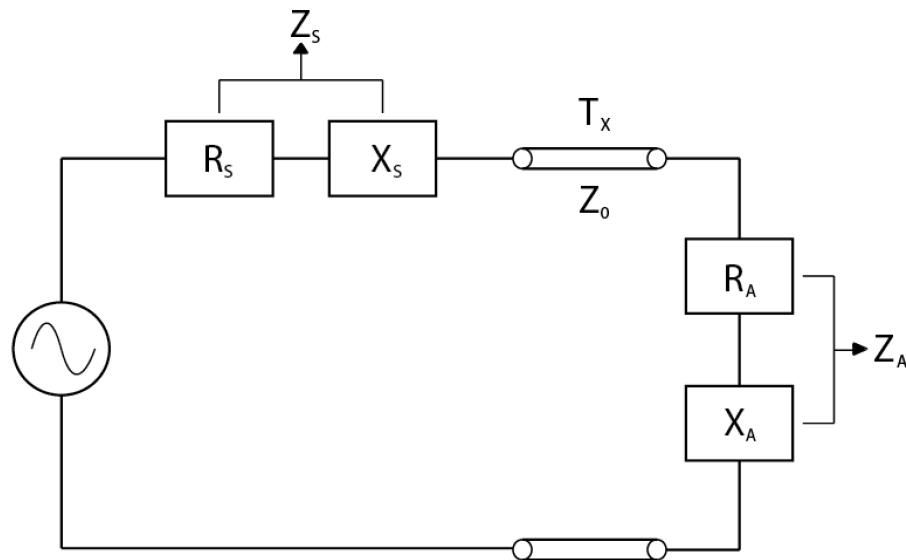


Figure 2.3: Equivalent circuit of transmitting antenna.

Where $Z_s = R_s + jX_s$ is the source impedance connected through a transmission line T_x of characteristic impedance Z_0 to the transmitting antenna with an impedance of $Z_A = R_A + jX_A$ [19].

2.3.7 Voltage Standing Wave Ratio

When the condition of matching is not satisfied, reflection of power takes place, which result in the creation of standing waves. These standing waves can be characterized by a parameter Voltage Standing Wave Ratio (VSWR) given by:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}.$$

$$\Gamma = \frac{Z_A - Z_o}{Z_A + Z_o}.$$

Where Γ is the reflection coefficient, Z_A is the impedance of antenna, Z_o is the characteristic impedance of the transmission line. A VSWR of less than 2 is acceptable for antenna design [18].

2.3.8 Return Loss

Return loss is a measure of how much power is reflected back at the antenna due to mismatch from the transmission line.

$$RL = 20 \log_{10} |\Gamma| \quad (\text{dB})$$

In case of perfect matching, $\Gamma = 0$ and $RL = \infty$ indicating that there is no reflection of power. In case all of the incident power is reflected, $\Gamma = 1$ and $RL = 0$. A return loss of less than -10 dB is acceptable for antenna design, which shows that the VSWR is less than 2 [12].

2.3.9 Impedance Bandwidth

Impedance bandwidth simply is the range of frequencies over which the antenna VSWR remains less than 2. The bandwidths of narrowband and wideband antennas are given as:

$$BW_{broadband} = \frac{f_H}{f_L}$$

$$BW_{narrowband}(\%) = \left[\frac{f_H - f_L}{f_c} \right] \times 100$$

Where f_H is the upper frequency, f_L is the lower frequency and f_c is the center frequency of the antenna. Lower frequency is defined as the lowest frequency on the return loss plot over which the antenna return loss is less than or equal to -10 dB. Similarly, high frequency is defined as the highest frequency on the return loss plot over which the antenna return loss is less than or equal to -10 dB. When $f_H/f_L = 2$ an antenna is considered to be broadband [12].

2.4 Antenna Types

Antenna designs vary based on their shapes, sizes and purposes. Some of the antenna designs that are commonly used are mentioned below:

2.4.1 Dipole and Short Dipole Antennas

A dipole antenna is simply a center fed open-circuit as it consists of two metal rods with a length which is approximately quarter to the operating wavelength at operational frequencies. In figure 2.4, a dipole antenna is shown.

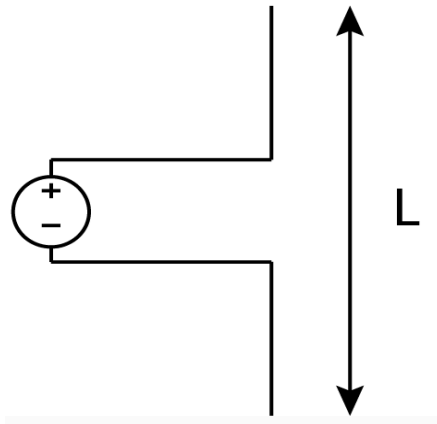


Figure 2.4: Dipole antenna.

A short dipole antenna is a type of dipole antenna which has a length that is less than $\lambda/10$. A short dipole antenna oriented along z-axis, centered at $z = 0$ has a current distribution given by:

$$I(z) = I_0 \left(1 - \frac{2|z|}{L} \right)$$

The antenna directivity can be calculated to be 1.76 dB. This antenna has a linear polarization and is described as vertically polarized when assessed in x-y plane. The radius of the dipole dictates its input impedance [13].

2.4.2 Half-Wave Dipole Antenna

A half-wave dipole antenna is a special case of dipole antenna, which has a length that is equal to $\lambda/2$, where λ is the free space wavelength corresponding to the operating frequency. In figure 2.5 a simple half-wave dipole antenna is shown.

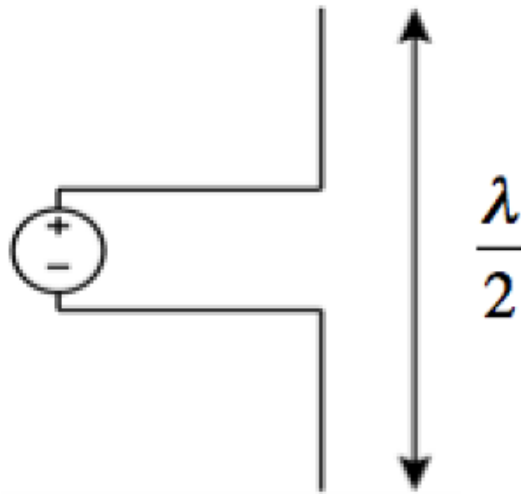


Figure 2.5: Half-wave dipole antenna.

The input impedance of half-wave dipole antenna is $Z_{in} = 73 + j42.5$ ohms and the directivity is 2.15 dB [14]

2.4.3 Log-Periodic Dipole Array Antenna

A log-periodic dipole array antenna is a multi-element, directional narrow beam antenna, which has a wide bandwidth. Active and passive regions characterize this antenna. The directivity of these kinds of antennas is a function of radiation intensity. In figure 2.6 a simple design of a log periodic array antenna is shown.

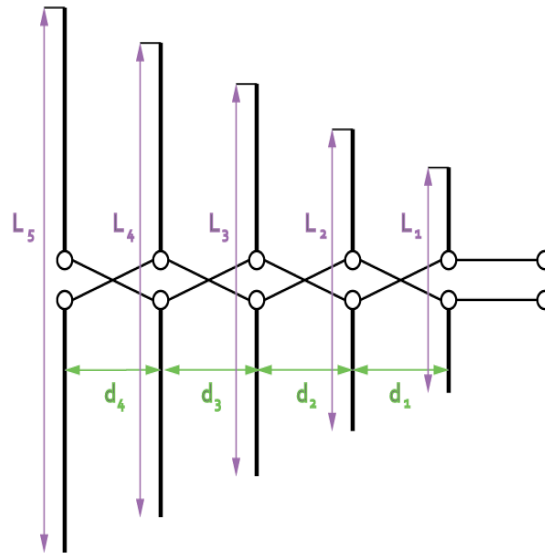


Figure 2.6: Log-Periodic Dipole Array Antenna

The length and spacing of elements reduce logarithmically from back end to the front end. The length and spacing between the elements of the antenna are represented by this equation [15]:

$$\frac{L_{n+1}}{L_n} = \frac{d_{n+1}}{d_n} = k$$

2.4.4 Monopole Antenna

A monopole antenna is a variation of dipole antenna, which consists of a straight rod-shaped conductor mounted perpendicularly on top of a conducting ground plane. The impedance of the monopole antenna is half of that of their dipole counterparts [16].

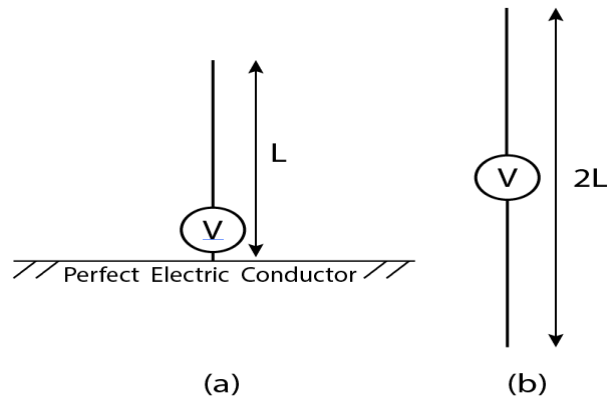


Figure 2.7: Monopole Antenna.

Figure 2.7 (a) shows a monopole antenna mounted over a ground plane and figure 2.4 (b) shows the dipole counterpart of the monopole antenna.

2.4.5 Microstrip Patch Antenna

A microstrip patch antenna is widely used because they can be directly printed onto a circuit board. These antennas are very popular because they are low cost, low profile and easy to fabricate. The height of the antenna is dictated by the thickness of the substrate onto which the antenna is printed.

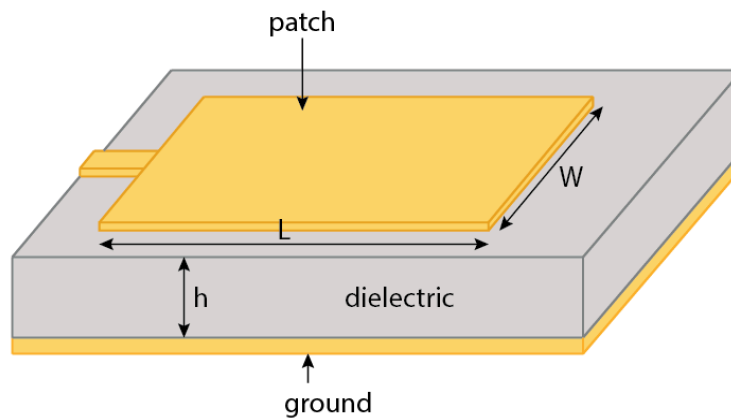


Figure 2.8: Microstrip patch antenna.

The width of the microstrip antenna controls the input impedance and the microstrip line is normally designed for 50 ohms. As the width of the microstrip line increases, the input impedance is reduced [17].

2.5 Literature Review of Existing Approaches

2.5.1 Paper 01 [5]

This paper discusses the designing of the planar broadband antenna, using a combined elliptical structure to achieve the broadband performance, while maintaining a compact structure. It consists of a pair of symmetrical elliptical patches; one is printed on the topside of the substrate-FR4, which has a dielectric constant $\epsilon_r = 4.4$, the other is printed on the bottom side of the substrate. Reason for combining elliptical patch is because this design can not only operate at very low frequency, but can also match input impedance of the SubMiniature Version A (SMA) connector over a wide range of frequencies with a small size. The measured results of the fabricated antenna have shown -10 dB return loss for a very broad bandwidth. The desired bands, UHF band for TV signals, GSM signals and WLAN signals can be operated simultaneously. Making the antenna feasible to be used in wireless portable devices.

2.5.2 Paper 02 [6]

In this paper, a printed circular disc monopole fed by a microstrip line is analyzed, which showed that this type of an antenna could yield an ultra-wide bandwidth. The proposed circular disc monopole antenna has a 50 Ω microstrip feed line printed on one side of the dielectric substrate like FR4 ($\epsilon_r = 4.4$) and the other side has conducting ground plane that covers the portion of microstrip feed line. The ground plane serves as an impedance matching circuit. This paper shows that the operational bandwidth of antenna is highly dependent on the feed gap due to impedance matching. It is also noted that the width of the ground plane plays a significant role because the main distribution of current is along the ground plane. The radiation pattern is omnidirectional, which resembles that of monopole antennas and this design is suitable for ultra-wideband (UWB) applications.

2.5.3 Paper 03 [7]

In this paper, basic design principles and techniques of multiband microstrip dipole antenna are described using a parallel stripline structure. Unlike typical microstrip antennas, which use one side of the slab as the ground plane, the microstrip dipole simply uses the dielectric slab as the host material. The dipole length is usually half wavelength long to provide considerable resonance. In order to operate antenna at higher frequency band and to stretch the bandwidth, a relatively large dipole width is used. However, ideally size of the ground plane should be infinite. Therefore, less-than-perfect performance from the antenna was expected. Measured reflection coefficients conform to simulation predictions and exhibit low return loss in desired communication bands. Relatively wider dipole provided wide bandwidth coverage, including 1.8 GHz, 1.9 GHz GSM bands and the 2.4 GHz WLAN band. Lastly, they examined the antenna transmission patterns on azimuthal plane in each band.

2.5.4 Paper 04 [8]

In this paper, planar elliptical ultra-wideband antennas are examined, which offer good dipole performance over two octaves in frequency band. It is noted that elliptical antenna has less return loss over the element size and typically exhibits -10 dB return loss for this design. Moreover, unlike other planar antennas, the efficiency of this type of antenna is generally never below 50% for smaller element size. This type of antenna has a gain of around 2.0 dB, as expected of a dipole. It is also noted that increasing eccentricity of antenna improves the matching but compromises azimuthal pattern.

2.5.5 Paper 05 [9]

In this paper the proposed novel low-profile planar multiband antenna is successfully implemented to meet the frequency requirements of 900-MHz GSM band, 1800-MHz Digital Communication System (DCS), 1900-MHz band Personal Communication System (PCS) and 2050-MHz band Universal Mobile Telecommunication System (UMTS) cellular systems. The antenna has planer rectangular radiating patch of dimensions $10 \times 60 \text{ mm}^2$ in which slit is inserted in order to split patch in two halves, one is use for operating in quarter wavelength

structure and other is in both quarter and half wavelength. The measured return loss of the antenna agreed with the simulated results of wide operating bandwidth.

2.5.6 Paper 06 [10]

This paper discusses a square planar monopole antenna with a double feed (SPMDF). The author describes that double feed is used to generate vertical current distribution and to avoid horizontal currents, which causes deterioration in important features of antenna such as polarization properties and impedance bandwidth. A feed network, under its infinite ground plane, excites the antenna at two symmetrical points of its base. A VSWR of less than 2 is desired when an antenna is designed so the bandwidth according to VSWR goes from 1.3 to 6.9 GHz for the SPMDF. Hence, the new feed improves the impedance bandwidth. The bandwidth can further be improved using a bevel on both corners of square patch antenna, referred as bevelled SPMDF. It is noted that using this method, polarized bandwidth is not enhanced enough when compared to SPMDF. So, using SPMDF an enhanced bandwidth and better cross-polarization levels within impedance bandwidth are obtained

2.5.7. Comparison of Different Designs

	Antenna Type	Frequency Band
Paper 01	Planar broadband antenna	470 MHz to 3.8 GHz
Paper 02	Printed circular disc monopole antenna	2.78 to 9.78 GHz
Paper 03	Multiband microstrip dipole antenna	1.8 to 2.4 GHz
Paper 04	Planar elliptical ultra-wideband dipole antenna	1 to 5.5 GHz
Paper 05	Planar monopole antenna	890 MHz to 2.17 GHz
Paper 06	Square planar monopole antenna with double feed	1.3 to 6.9 GHz

Table 2.1: Comparison of different antenna design in literature review.

2.6 Proposed Solutions

For the designing and development of wireless multiband antennas, our first step was to learn the use of and to familiarize ourselves with computational design software of the antenna, either using High Frequency Structural Simulator (HFSS) and Computer Simulation Technology (CST) Studio Suite, by initially designing, testing and fabricating a microstrip patch antenna, which is the most common type of microstrip antenna [11]. The basic patch antenna has a metallic patch printed on a grounded dielectric substrate like FR4 or RT duroid. This type of antenna is generally popular for narrow-band microwave wireless coverage [1].

After familiarization with the whole antenna modeling process, we moved on to design two different types of multiband antennas that cover the UHF (300 MHz to 1 GHz), WLAN (2.45 GHz) and GSM (380 MHz to 1.9 GHz) bands. Out of many possible approaches, we opted to design monopole antenna and planar antenna.

Based on the summaries of different research papers, we modified the proposed designs mentioned in [5] and [6] according to our frequency band requirements. In paper [5], the planar broadband antenna exhibits broadband characteristics and the return loss defines the frequency band to be similar to the one we desire. In paper [6], the circular disc monopole antenna works at a higher frequency band than our desired frequency band. Hence, we intend to scale the frequency band of this particular design according to our requirements.

In final phase of the project, we fabricated one of the multiband microstrip antennas for consumer applications, that is, for transmitting and receiving purposes. Selection of the antenna is based on to parameters like impedance bandwidth and gain.

2.7 Block Diagram

The step-by-step procedure of our project is explained in the block diagram given in figure 2.9. We started our project with initially designing the patch antenna for the better understanding of Computational Electromagnetic Software (CEM). We then fabricated and tested our patch antenna to get familiar with the entire antenna design process. After that we designed, fabricated and tested multiband antenna. Our last step was to demonstrate two consumer applications using our designed antennas.

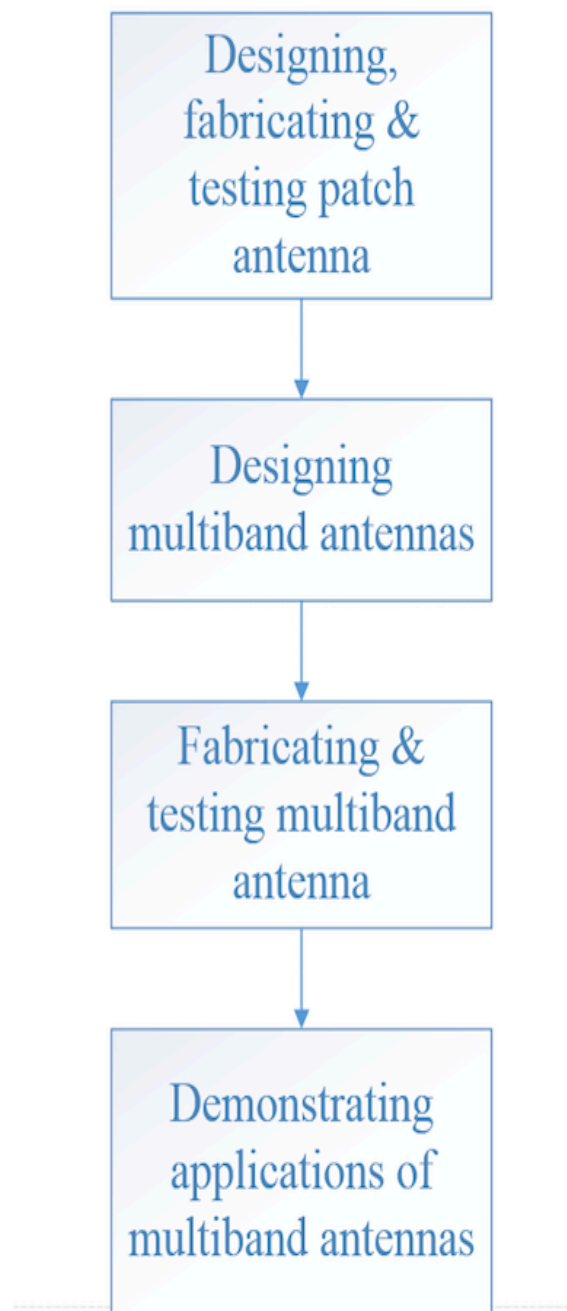


Figure 2.9: Project block diagram.

2.8 Designing, Fabricating and Testing Patch Antenna on HFSS

First of all we started designing patch antennas in Computational Electromagnetic Software (CEM), which in our case was High Frequency Structural Simulator (HFSS). In order to get familiar with the antenna design software, we initially designed patch antenna, centered at 2.45GHz, which is the most commonly used antenna because it can easily be printed onto a circuit board. We chose a substrate RT-duroid for the fabrication of the antenna as it has a low loss tangent.

2.8.1 Design Specifications

The three main components for designing a rectangular microstrip patch antenna are:

- Frequency of operation (f_o): The main component in the patch antenna is the resonant frequency at which the return loss is centered. We designed the patch antenna for WLAN so the resonant frequency we selected was 2.45 GHz.
- Dielectric constant of the substrate (ϵ_r): The dielectric material we selected for our design is RT-duroid, which has a dielectric constant of 2.2. We chose this substrate because it has a lower loss tangent for a more efficient antenna.
- Height of the dielectric substrate (h): The height of the substrate is also kept under consideration while selecting it because we don't want a large design for a patch antenna. Hence, the substrate we selected has a height of 1.57 mm.

2.8.1.2. Equations Used for Designing of Patch Antenna [12]

In figure 2.11 the top view of the patch antenna is shown along with different dimensions like feed point location (X_f, Y_f), width of patch (W), length of patch (L), width of ground plane W_g and length of ground plane L_g

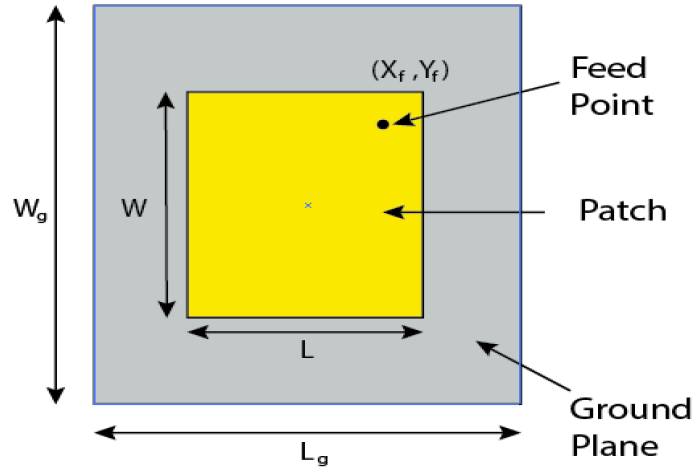


Figure 2.10: Top view of the patch antenna.

- **Step 1: Calculation of the Width (W)**

$$W = \frac{c}{2f_0 \sqrt{\frac{\epsilon_r + 1}{2}}}$$

Substituting $c = 3 \times 10^8 \text{ ms}^{-2}$, $\epsilon_r = 2.2$ and $f_0 = 2.45 \text{ GHz}$

$$W = 49.8 \text{ mm}$$

- **Step 2: Calculation of Effective Dielectric Constant (ϵ_{reff})**

$$\epsilon_{\text{reff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}}$$

Substituting $\epsilon_r = 2.2$, $W = 49.8 \text{ mm}$ and $h = 1.57 \text{ mm}$

$$\epsilon_{\text{reff}} = 2.1$$

- **Step 3: Calculation of the Effective Length (L_{reff})**

$$L_{\text{reff}} = \frac{c}{2f_0 \sqrt{\epsilon_{\text{reff}}}}$$

Substituting $c = 3 \times 10^8 \text{ ms}^{-2}$, $f_0 = 2.45 \text{ GHz}$ and $\epsilon_{\text{reff}} = 2.1$

$$L_{\text{reff}} = 42\text{mm}$$

- **Step 4: Calculation of the Length Extension (ΔL)**

$$\Delta L = 0.412h \frac{(\epsilon_{\text{reff}} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{\text{reff}} - 0.258) \left(\frac{W}{h} + 0.8 \right)}$$

Substituting $\epsilon_{\text{reff}} = 2.1$, $h = 1.57\text{mm}$ and $W = 49.8\text{mm}$

$$\Delta L = 0.8285\text{mm}$$

- **Step 5: Calculation of the Actual Length of Patch (L)**

$$L = L_{\text{reff}} - 2\Delta L$$

Substituting $L_{\text{reff}} = 42\text{mm}$ and $\Delta L = 0.8285\text{mm}$

$$L = 39.2\text{mm}$$

- **Step 6: Calculation of the Ground Plan Dimension (L_g and W_g)**

$$L_g = 6h + L = 6(1.57) + 39.2 = 50\text{mm}$$

$$W_g = 6h + W = 6(1.57) + 49.8 = 58\text{mm}$$

2.8.3 Feeding Methods

There are two methods of patch antenna feeding:

- Patch antenna fed with a microstrip feedline
- Coaxial fed patch antenna

We opted to design a coaxial fed patch antenna by following the steps given in reference [12]. In coaxial feed method, we need to calculate the width and length of patch as well as the ground plane. In coaxial feed method, there is a feeding point through which the patch is fed. We want the input impedance to be 50 ohms for the resonant frequency so we must locate a feed point on the patch. In order to do that, we use a trial and error method to locate the feed point. We compare the return loss at different feed point locations and that location of feed point is selected

where the return loss is most negative. We chose our feed point to be (12,0) as the return loss is minimum at this point. In table 2.2, return loss against different feedpoint locations are given.

No.	Feed Location (X_f , Y_f) (mm)	Center Frequency (GHz)	Return Loss (RL) (dB)
1	(5,0)	2.41	-3.88
2	(6,0)	2.41	-5.43
3	(7,0)	2.42	-7.36
4	(8,0)	2.43	-9.93
5	(9,0)	2.43	-12.81
6	(10,0)	2.42	-16.31
7	(11,0)	2.45	-22.3
8	(12,0)	2.45	-29.25
9	(12.5,0)	2.45	-25.07
10	(13,0)	2.46	-25.52
11	(14,0)	2.46	-20.94
12	(15,0)	2.46	-18.13
13	(16,0)	2.47	-16.4
14	(17,0)	2.48	-15.54
15	(18,0)	2.48	-15.01
16	(19,0)	2.48	-14.81

Table 2.2: Varying feedpoint location.

2.8.4 Design

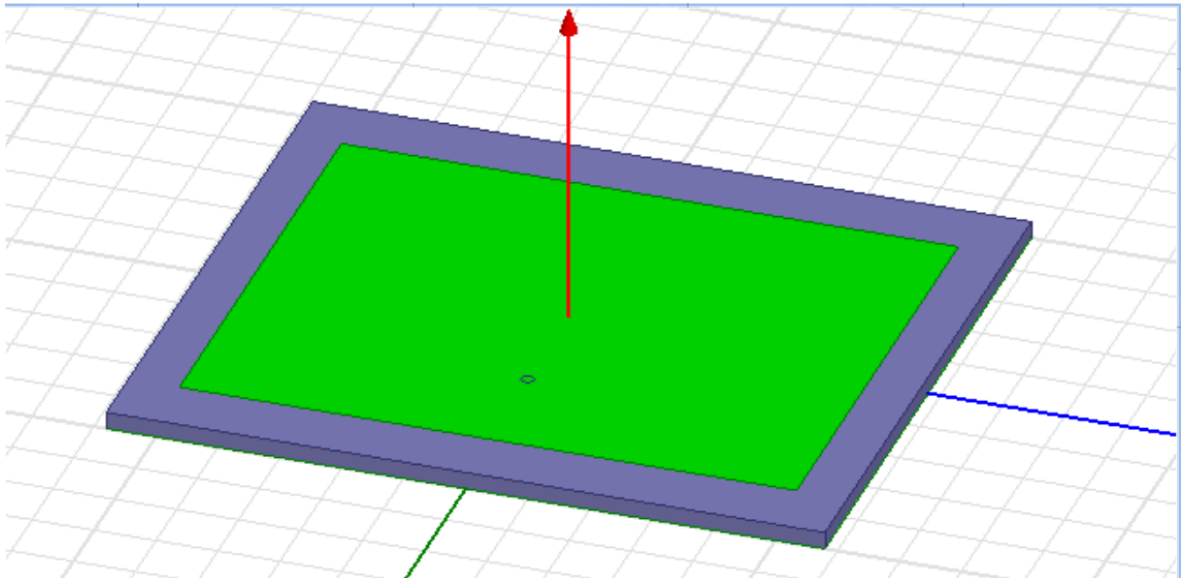


Figure 2.11: Coaxial fed patch antenna.

2.8.5 Result of S11 – Return Loss:

In this design, return loss is -29.79 dB centered at 2.45 GHz, which is according to our requirement so we opted for this design for fabrication of the antenna and it is shown in figure 2.12.

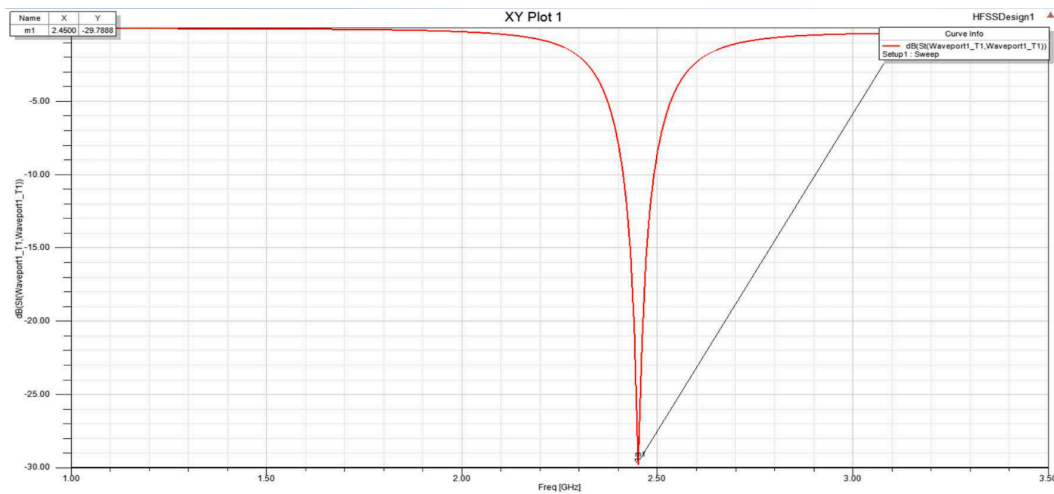


Figure 2.12: Return Loss of patch antenna.

2.8.6 Fabricated Antenna

Figures 2.13 and 2.14 displays the front and back side of the fabricated antenna.



Figure 2.13: Front side of fabricated antenna.



Figure 2.14: Back side of fabricated antenna.

2.8.7 Fabricated Antenna Results

The return loss of the fabricated antenna is found using Vector Network Analyzer (VNA) and it has a value of -9.28 dB at a frequency of 2.46 GHz and it is shown in figure 2.15.

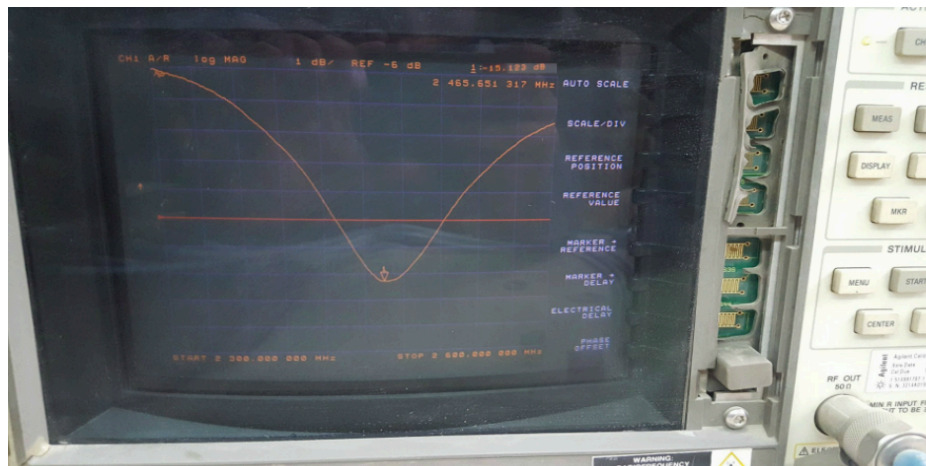


Figure 2.15: Return Loss of fabricated antenna.

2.8.8 Fabrication of the Patch Antenna

We fabricated the antenna in an external facility. We had to use an external facility because the resources for antenna fabrication are not available in our university. We fabricated as well as tested our antenna using Vector Network Analyzer at the external facility. The substrate we used for antenna fabrication was RT-duroid because of its low loss tangent. For fabrication of antenna, the method that was used was milling. The steps involved in milling include:

- Software used for milling: CircuitCAM
- Design that is to be printed onto the substrate is made on the software
- PCB milling machine: LPKF ProtoMat H60
- Universal cutter with 0.2 mm end mill used initially
- Other cutters used are 1 mm and 3 mm end mills

These tools mill out excess copper from the undesired area. Figure 2.16 shows the fabrication process.

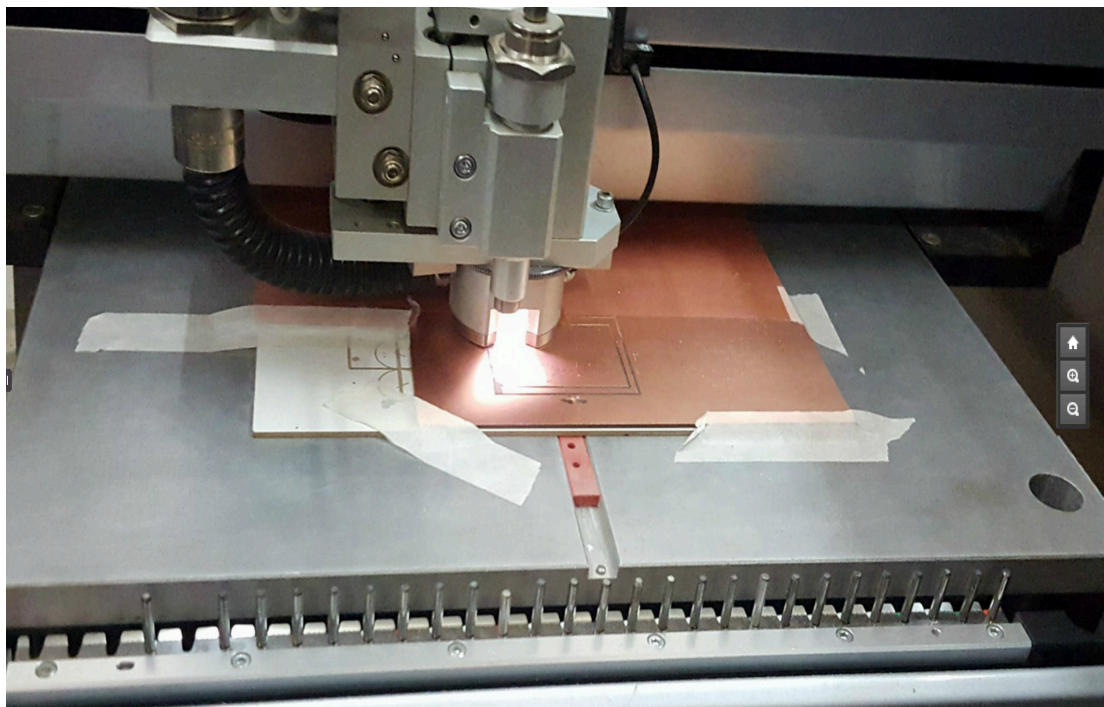


Figure 2.16: Fabrication process.

2.9 Designing Multiband Antenna

We designed two antennas using the antenna designs given in [5] and [6] and made changes to the design according to our frequency band requirements. We designed the antenna by varying antenna design parameters to achieve required return loss as a function of frequency. We kept in mind that the gain is satisfactory in the region of our frequency of interest. For the desired range of frequencies, the antenna return loss should be less than or equal to -10 dB or the VSWR should be less than 2. We did so by varying antenna parameters.

After designing both the antennas, we chose the antenna design suggested in paper [6] for fabrication. We chose this design because we achieved the desired frequency band for our application with this design. We fabricated the designed antenna on RT-duroid.

We then tested the fabricated antenna using an external antenna testing facility, i.e., National Institute of Electronics for finding out the return loss and VSWR. The method used for multiband fabrication was etching. After fabricating and testing, we compared the simulated and the experimental results. We compared the return loss and gain of our simulated and fabricated design. After that, the designed antenna was tested the antenna for demonstrating consumer applications. We were successfully able to demonstrate two consumer applications.

For designing of multiband antenna, we used CST Studio Suite. We used this software because it was easier to use and the results of CST Studio Suite are closer to those of the fabricated antenna. Hence, in order to achieve equivalent results experimentally and practically, it was more convenient for us to use CST Studio Suite instead of HFSS for multiband antenna design. Figure 2.17 shows the flowchart for our antenna design project.

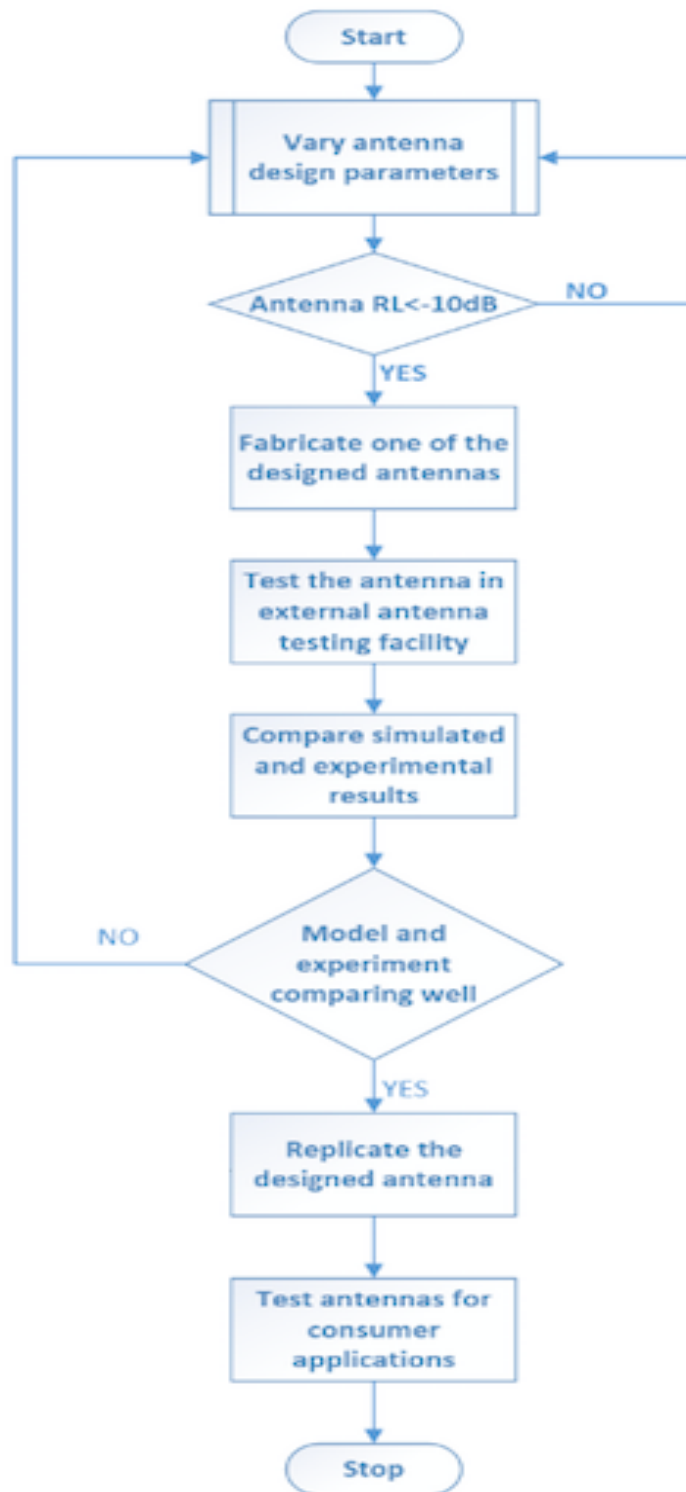


Figure 2.17: Flow Chart of the project.

2.9.1 First Design

The first design consists of a circular disc of radius R fed by a $50\ \Omega$ feedline of a dielectric substrate RT-duroid with a relative permittivity of 2.2. This antenna consists of a circular patch fed by a microstrip feedline, which has an impedance of $50\ \Omega$. The geometry of the proposed design is shown in figure 2.18 in which L and W denote the length and width of the dielectric constant. L_1 denotes the length of the ground plane at the backside of the antenna, $h+L_1$ is the height of the microstrip feedline and W_1 represents the width of microstrip feedline. The height and width of the microstrip feedline is designed in such a way that it has an impedance of $50\ \Omega$. The frequency band that is covered in the paper [6] is from 2.78 to 9.78 GHz but our desired frequency band covers lower band of frequencies. Multiple iterations were made in the design so that we could scale down the frequency band. We successfully designed the antenna but we were unable to scale down the frequency band. In figure 2.18, the geometry of first design is shown.

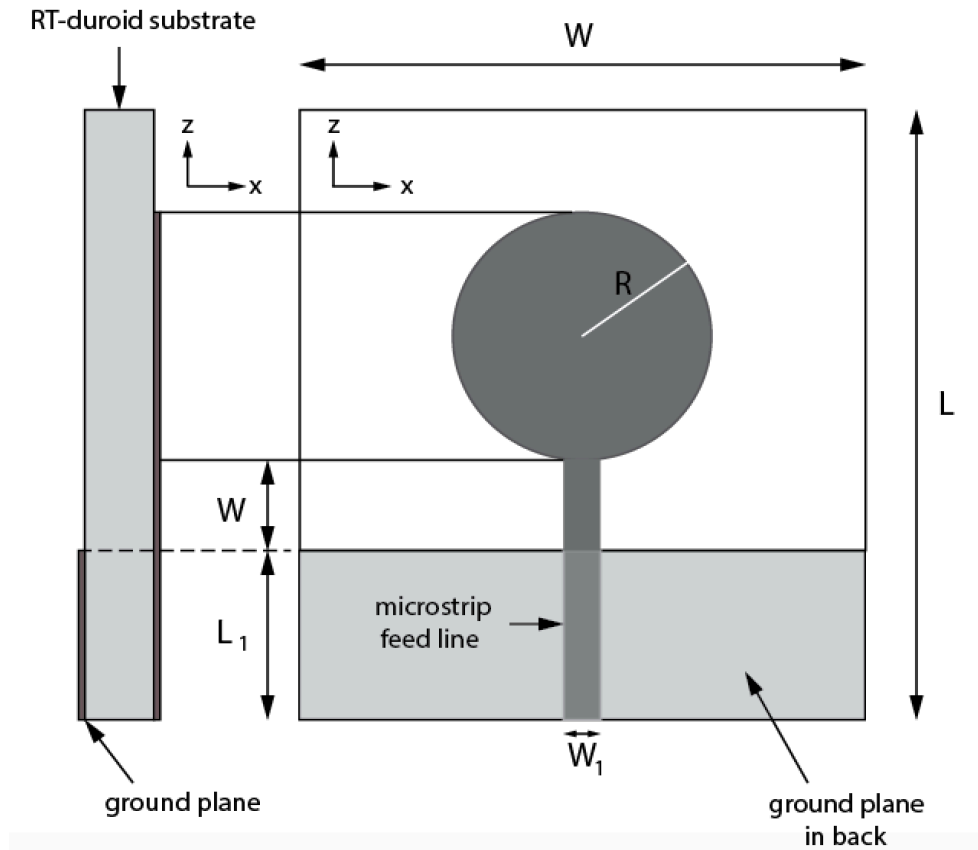


Figure 2.18: Geometry of the first design.

2.9.1.1 Design of Circular Disc Monopole Antenna

In figure 2.19 and 2.20, the front and back side of the antenna that is designed on the software is given.

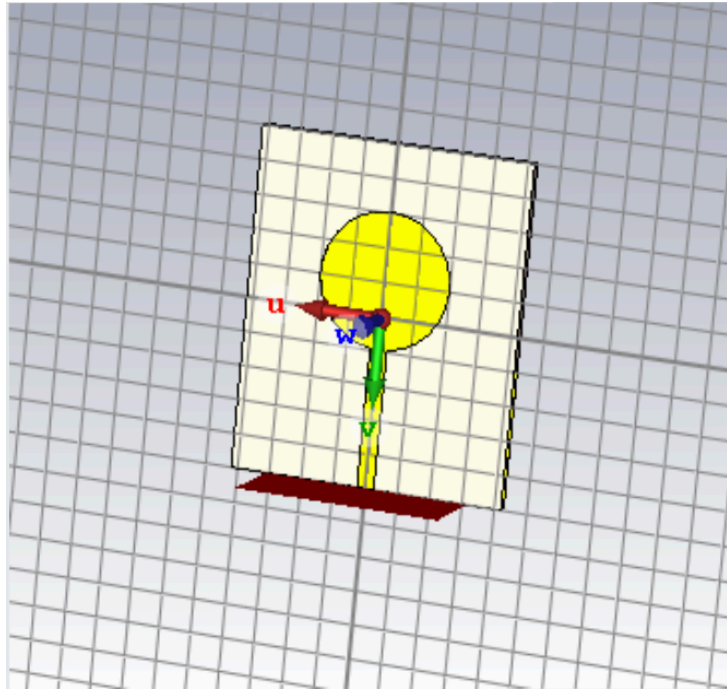


Figure 2.19: Front side of circular disc monopole antenna.

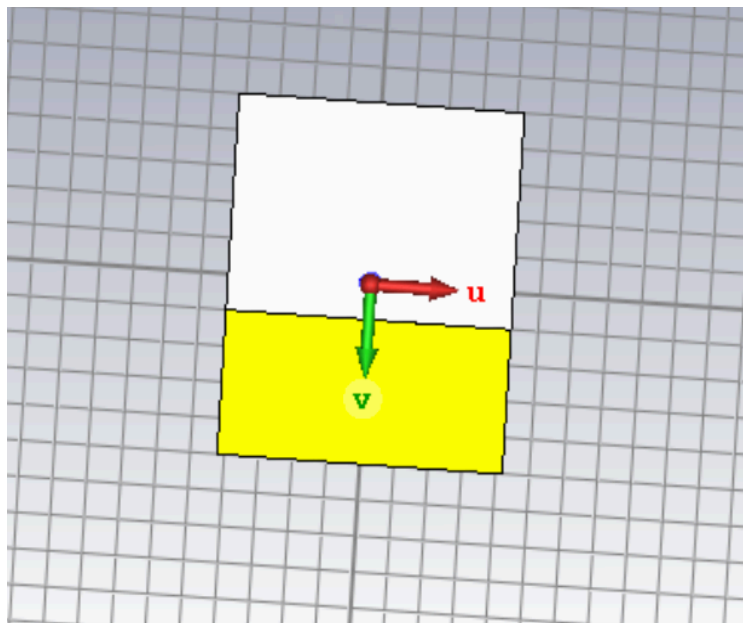


Figure 2.20: Back Side of circular disc monopole antenna

2.9.1.2 Varying Parameters

In order to scale down the frequency band, multiple iterations were made in the design. We changed the parameters h , R and W and obtained the results discussed below.

2.9.1.2.1 Varying Height of the Microstrip Feedline (h):

In this case we varied the height of the feedline while keeping radius of the circular disc and width of the microstrip feedline constant at $R = 10 \text{ mm}$ and $W_1 = 2.6 \text{ mm}$. Figures 2.21 to 2.24 show the results.

- For $h = 0.2 \text{ mm}$

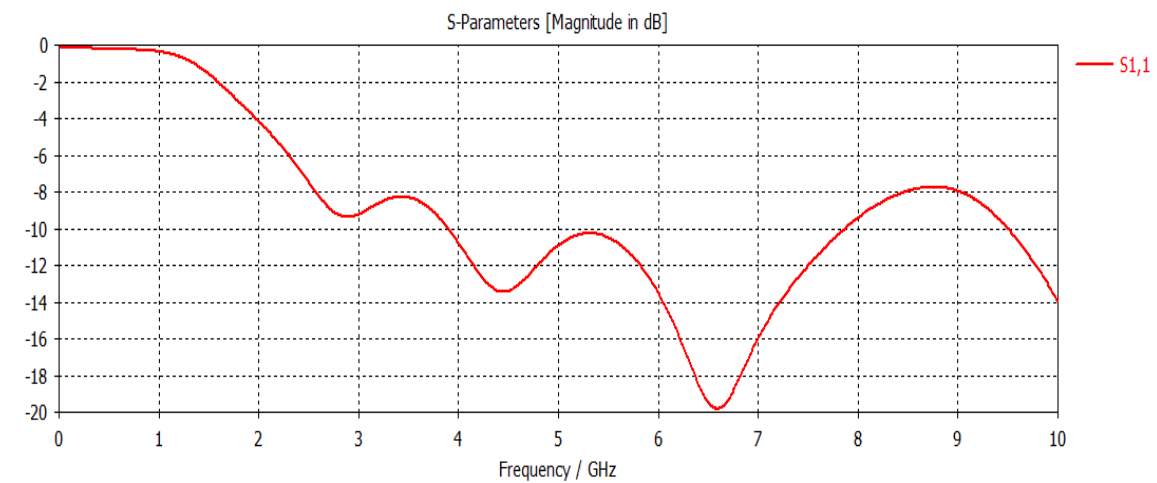


Figure 2.21: Return Loss plot for $h = 0.2 \text{ mm}$.

- For $h = 0.3 \text{ mm}$

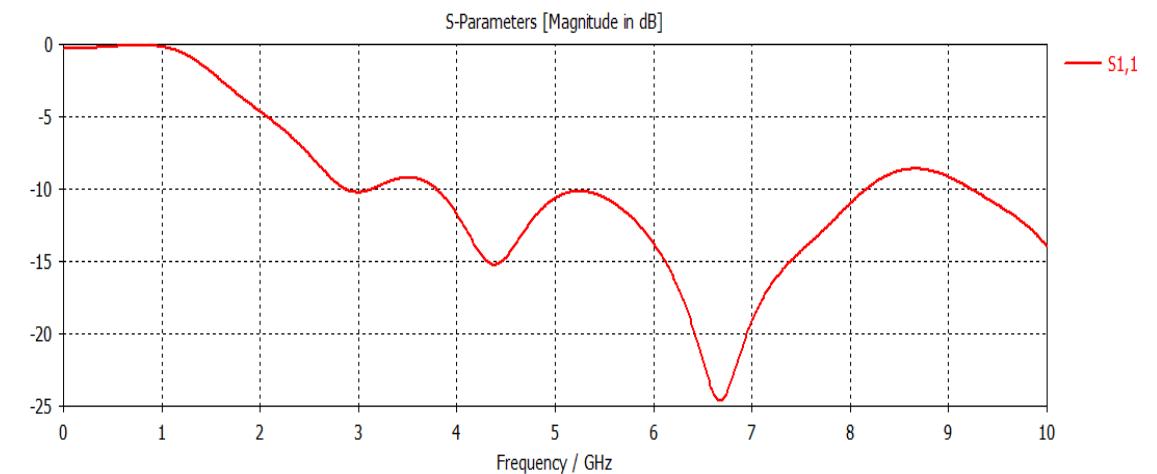


Figure 2.22: Return Loss plot for $h = 0.3 \text{ mm}$.

- For $h = 0.7 \text{ mm}$

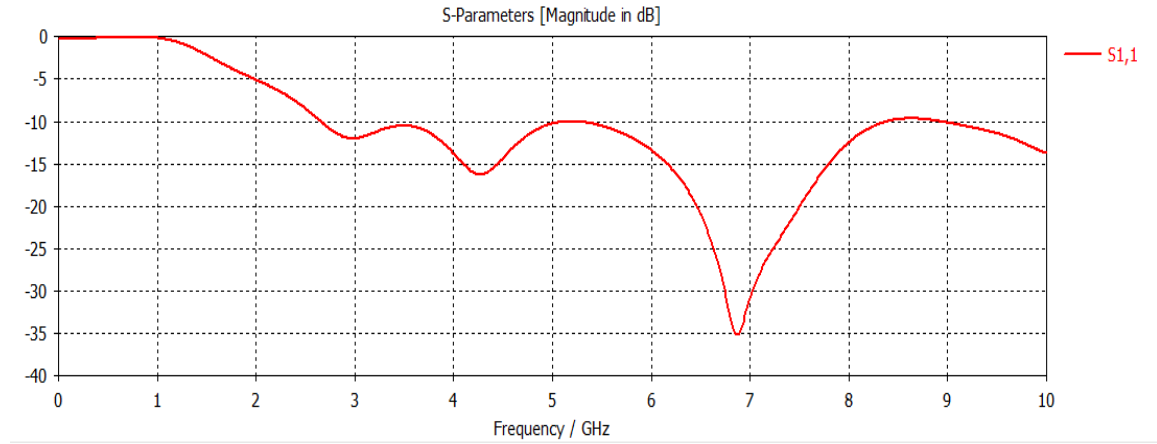


Figure 2.23: Return Loss plot for $h = 0.7 \text{ mm}$.

- For $h = 1.5 \text{ mm}$

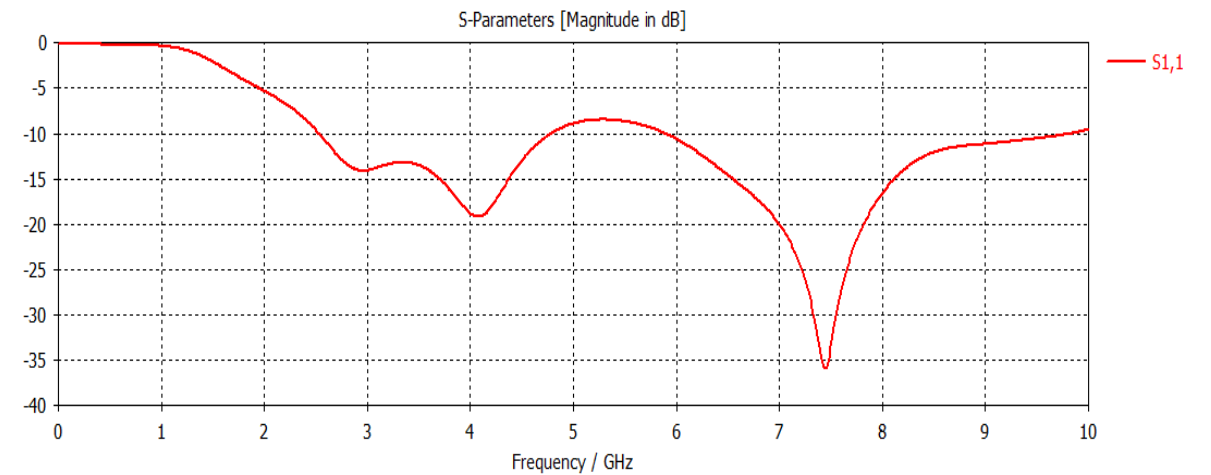


Figure 2.24: Return Loss plot for $h = 1.5 \text{ mm}$.

In the above iterations for the height, we notice that changing the height of the feedline varies the return loss but it still remains in the range of 3 GHz and 10 GHz and it is not scaled down to the frequency range we require. Hence, we try to vary other antenna parameters to achieve our desired frequency range.

2.9.1.2.2 Varying Width of the Microstrip Feedline (W_1):

In this case we varied the width of the feedline while keeping radius of the circular disc and height of the microstrip feedline constant at $R = 10 \text{ mm}$ and $h = 0.7 \text{ mm}$. Figures 2.25 to 2.28 show the results.

- For $W_1 = 1.6 \text{ mm}$

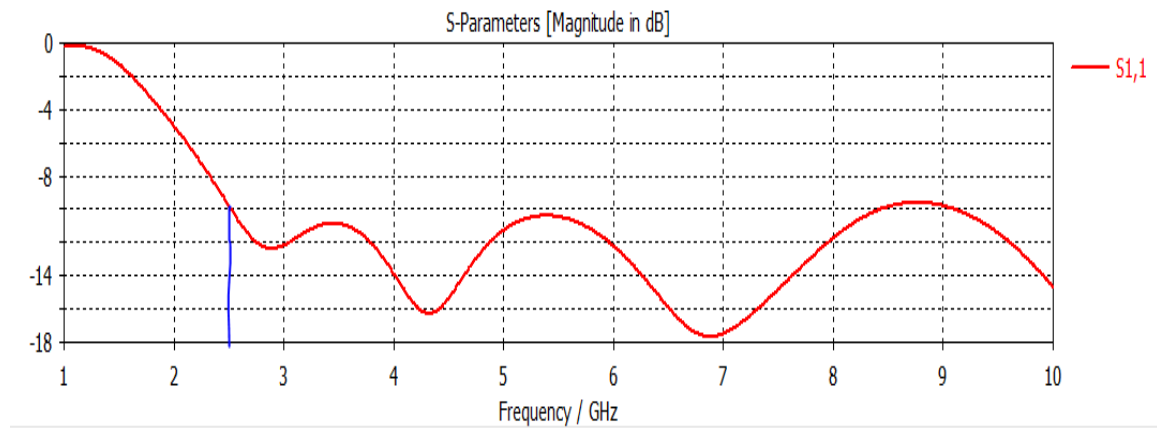


Figure 2.25: Return Loss plot for $W_1 = 1.6 \text{ mm}$

- For $W_1 = 2 \text{ mm}$

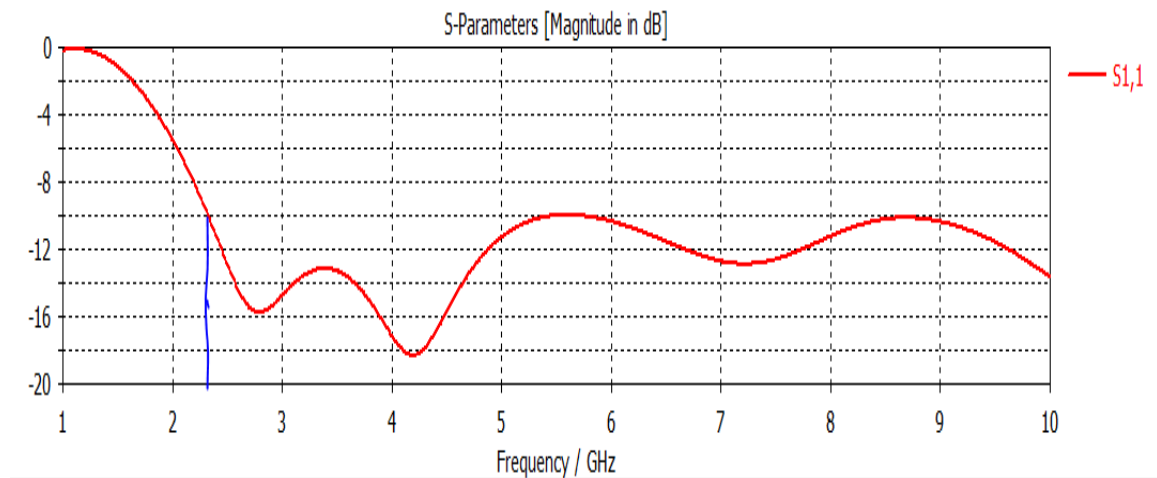


Figure 2.26: Return Loss plot for $W_1 = 2 \text{ mm}$.

- For $W_1 = 2.4 \text{ mm}$

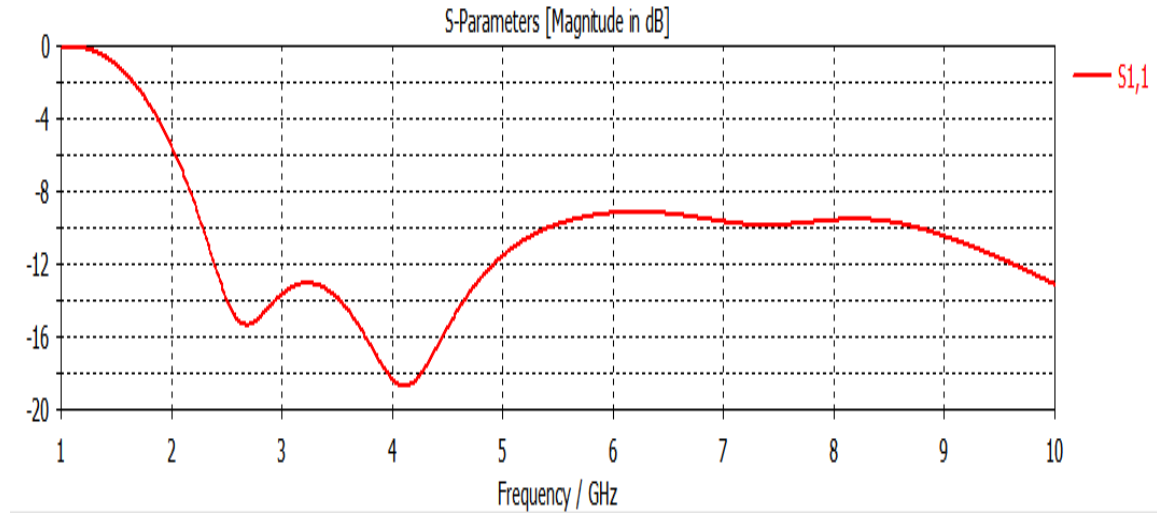


Figure 2.27: Return Loss plot for $W_1 = 2.4 \text{ mm}$.

- For $W_1 = 2.6 \text{ mm}$

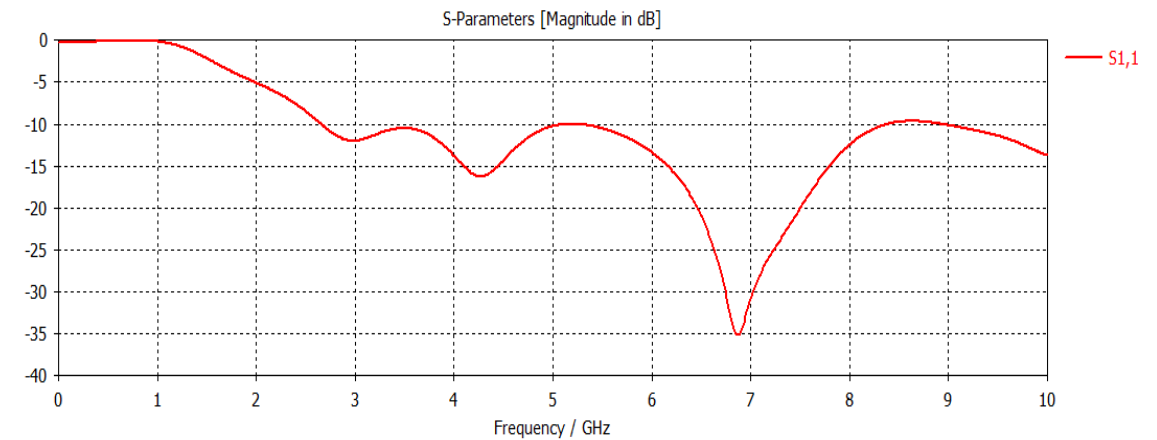


Figure 2.28: Return Loss plot for $W_1 = 2.6 \text{ mm}$.

In the above iterations for the width, we notice that changing the width of the feedline varies the return loss but it still remains in the range of 2.7 GHz and 10 GHz and it is not scaled down to the frequency range we require. We were unable to scale down the frequency range using the feedline parameters so we tried to vary the radius of the circular disc.

2.9.1.2.3 Varying Radius of Circular Disc (R):

In this case we varied the radius of circular disc while keeping width and height of the microstrip feedline constant at $W_1 = 2.6 \text{ mm}$ and $h = 0.7 \text{ mm}$. Figures 2.29 to 2.31 show the results.

- For $R = 5 \text{ mm}$

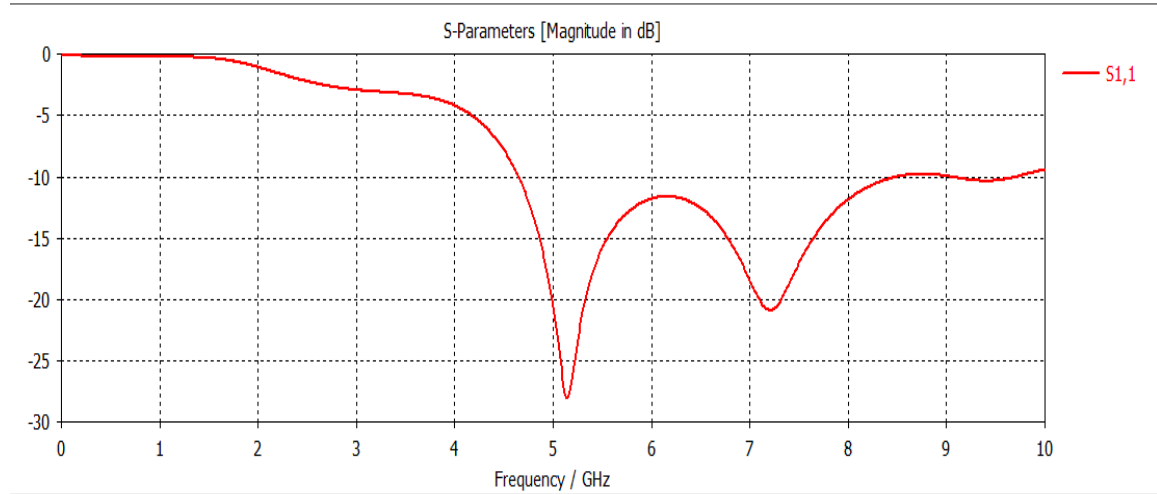


Figure 2.29: Return Loss plot for $R = 5 \text{ mm}$.

- For $R = 7 \text{ mm}$

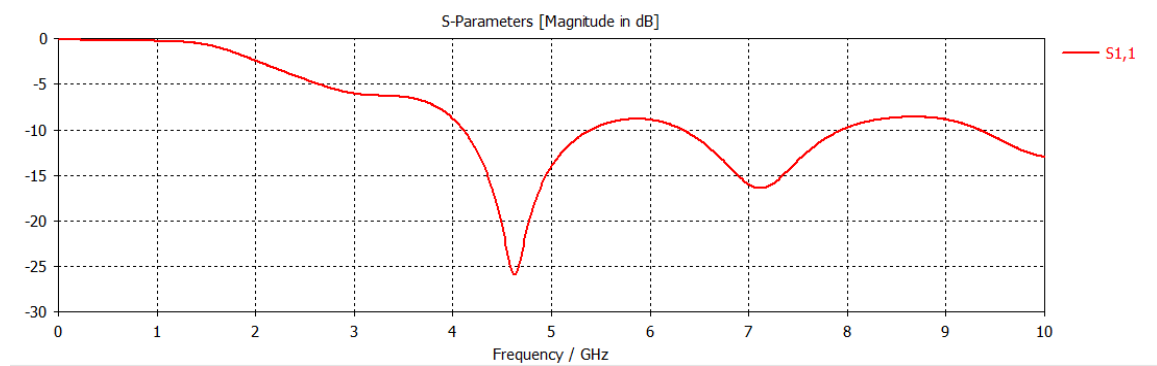


Figure 2.30: Return Loss plot for $R = 7 \text{ mm}$.

- For $R = 9 \text{ mm}$

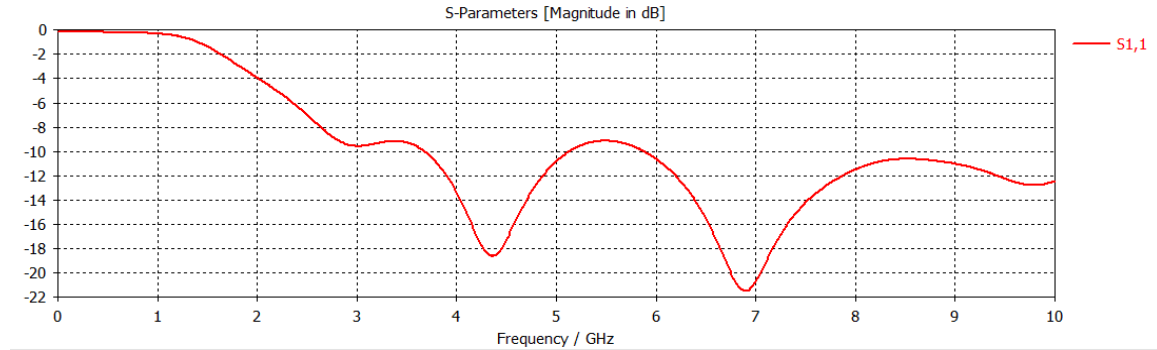


Figure 2.31: Return Loss plot for $R = 9 \text{ mm}$.

- For $R = 11 \text{ mm}$

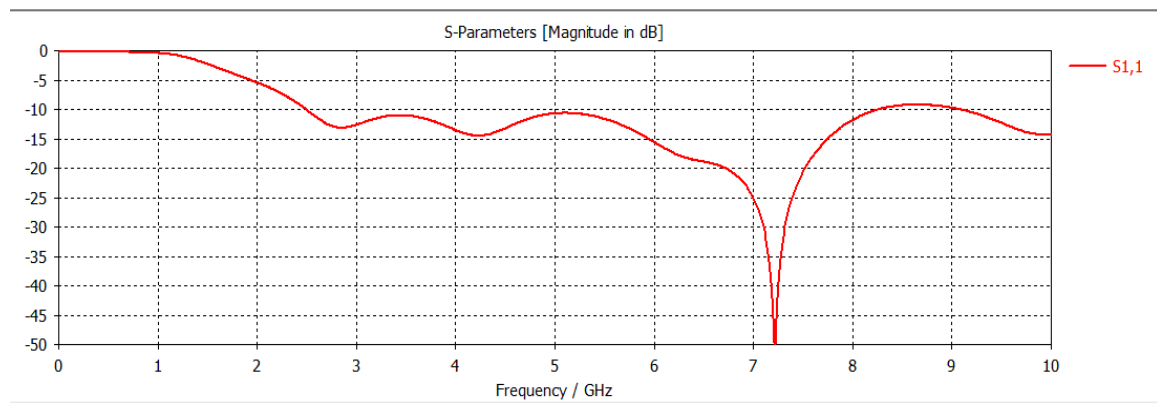


Figure 2.32: Return Loss plot for $R = 11 \text{ mm}$.

According to the iterations shown above, it is clear that we cannot scale this design below 2.5 GHz so we opted to choose a design, which can give us a lower frequency range

2.9.1.3 Final Design

The design we finally chose has the following parameters:

- Substrate: $L = 50 \text{ mm}$ and $W = 42 \text{ mm}$
- Radius of Circle: $R = 10 \text{ mm}$
- Width of microstrip feedline: $W_1 = 2.6 \text{ mm}$
- Height of the microstrip feedline: $h = 0.7 \text{ mm}$

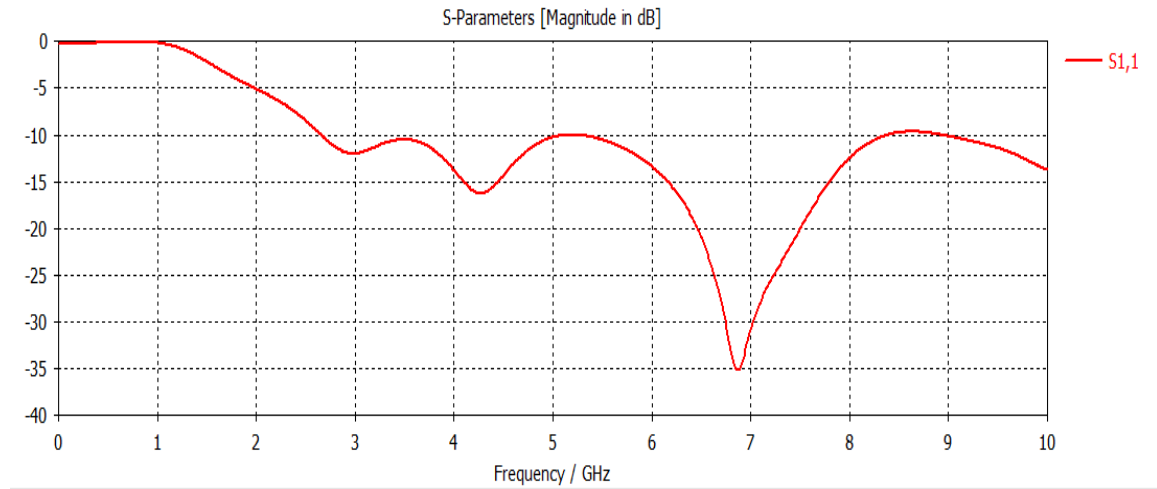


Figure 2.33: Return Loss plot of final design.

According to the return loss vs frequency plot shown in the figure 2.33, the frequency band of this design is approximately from 2.7 GHz to 11 GHz, which is not according to our requirements and does not cover the band of frequencies for the applications we wanted to demonstrate. Hence, we did not choose this design for fabrication.

2.9.2 Second Design

This design consists of one elliptical patch at the front side of the antenna and another elliptical patch with the same dimensions on the other side of the antenna. The geometry of the antenna is shown in figure 2.34. We used an elliptical patch design because it exhibits superior broadband performance at lower band of frequencies. The antenna is large in size because it covers lower band of frequencies. This antenna is a variation of an elliptical dipole antenna and the design rule for dipole antenna is $l = \lambda / 2$ and for calculation of wavelength $c = f\lambda$ is used, which shows an inverse relationship of frequency and wavelength. Hence, for lower frequencies, the wavelength is larger making the size of the antenna to be large [5].

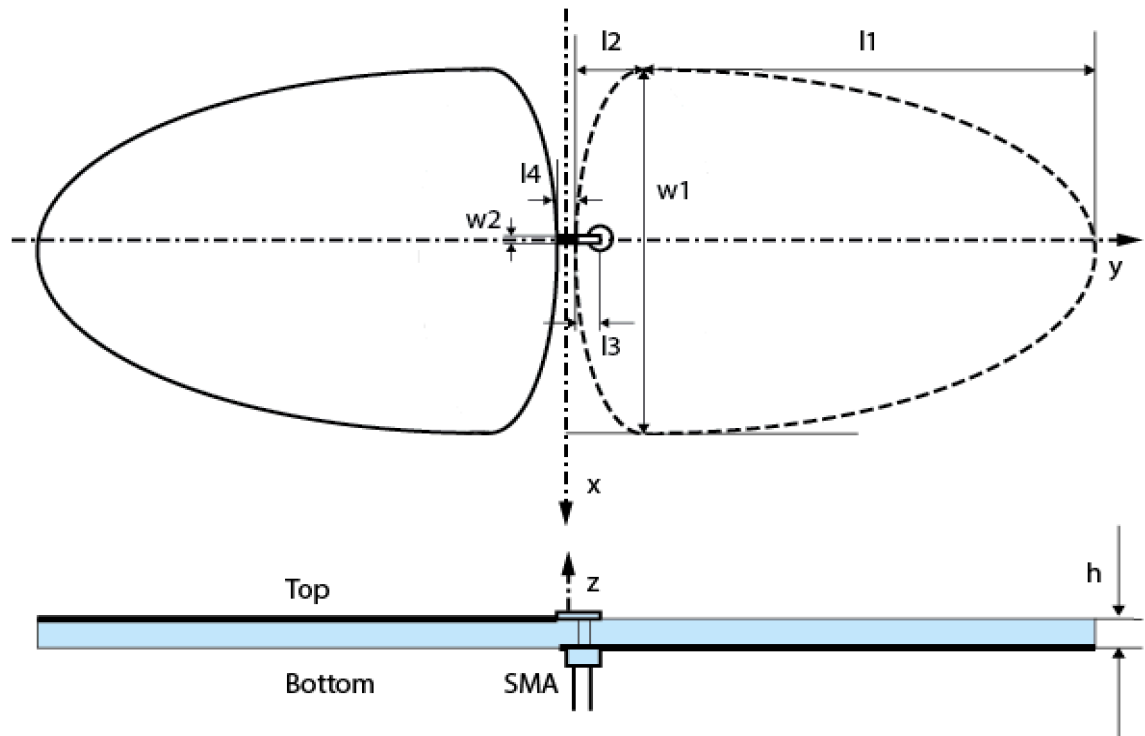


Figure 2.34: Geometry of the second design.

2.9.2.1 Antenna Dimensions

- Antenna dimensions:

Length	260 mm
Width	124 mm
Height	1.57 mm

- Elliptical patch dimensions:

l_1	107 mm
l_2	22 mm
l_3	3 mm
l_4	2 mm
w_1	124 mm
w_2	1.2 mm

2.9.2.2 Design of Planar Elliptical Broadband Antenna

Figures 2.35 and 2.36 show the front and back side of the planar elliptical broadband antenna.

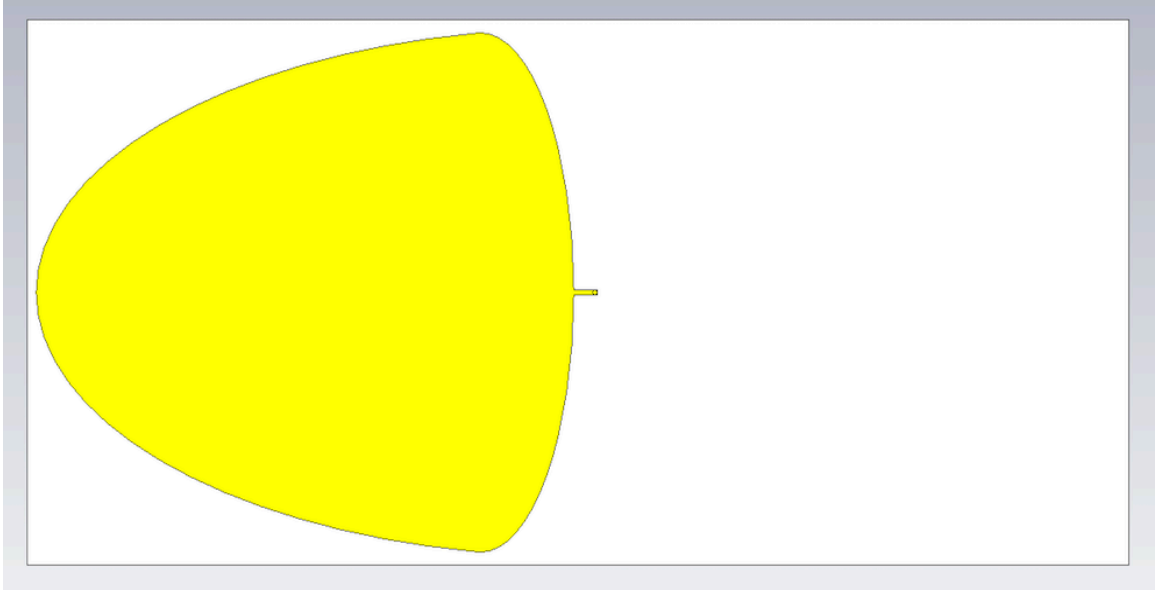


Figure 2.35: Front side of planar elliptical broadband antenna.

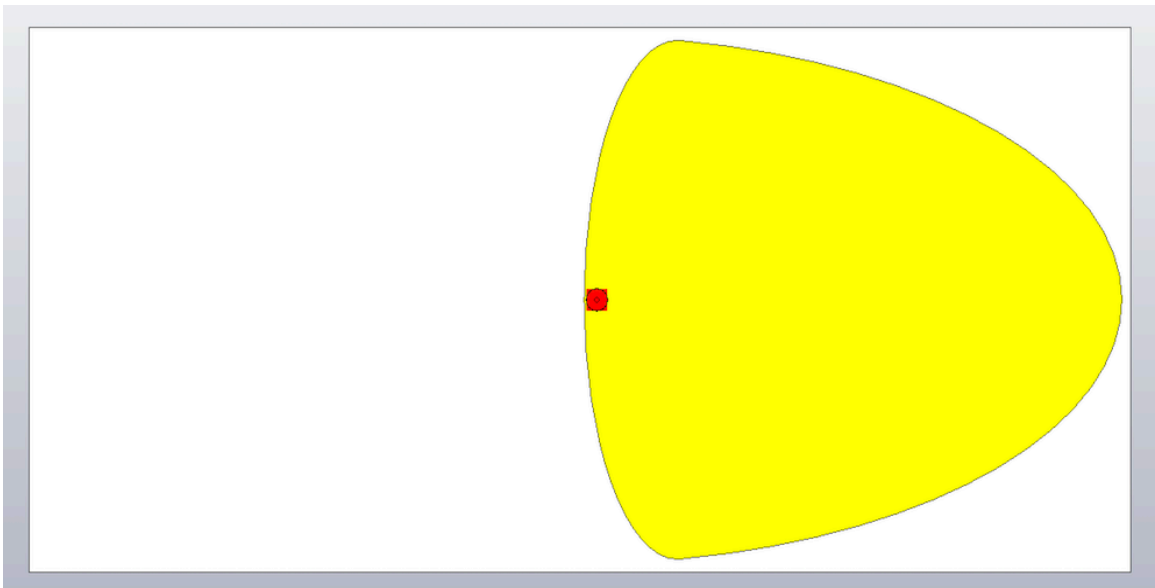


Figure 2.36: Back side of planar elliptical broadband antenna.

2.9.2.3 Varying Parameters

In this design, we only varied the radius of the inner ellipse (r), shown in figure 2.37, and radius of the outer ellipse (R), shown in figure 2.38, to cover our desired frequency band ranges.

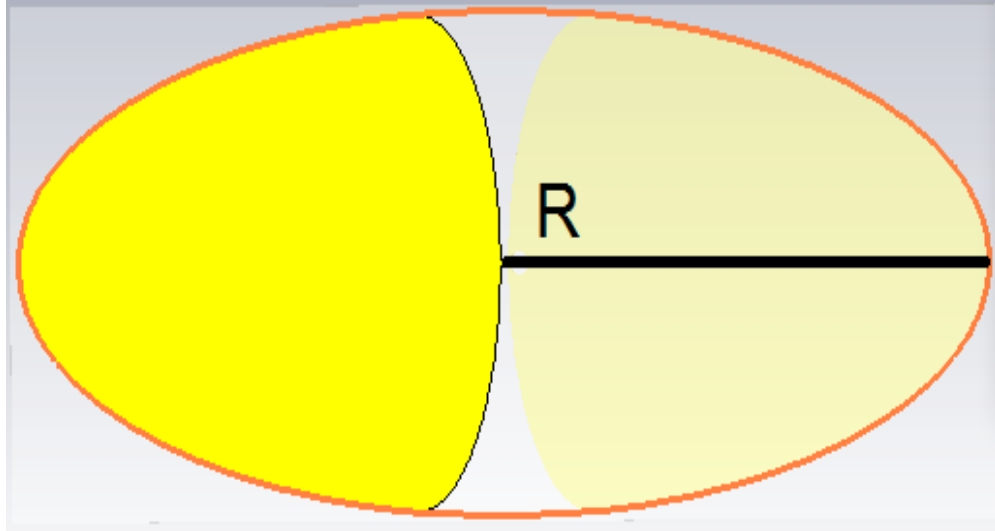


Figure 2.37: Major radius of outer ellipse.

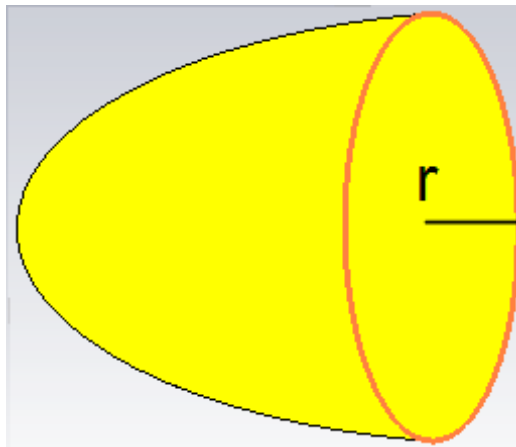


Figure 2.38: Minor radius of inner ellipse

Multiple iterations were made to the design by changing the values of r and R so that we could select a design that covers our desired frequency band which includes Wireless Local Area Network (WLAN) band, Global System for Mobile communications (GSM) band and cable television band.

2.9.2.3.1 Result of S11 – Return Loss

We varied the antenna parameters R and r to vary the return loss in our designed range of frequency. It is clear from figure 2.39 that when $r = 22 \text{ mm}$ and $R = 128 \text{ mm}$, the return loss is minimum, we chose this design as our final design.

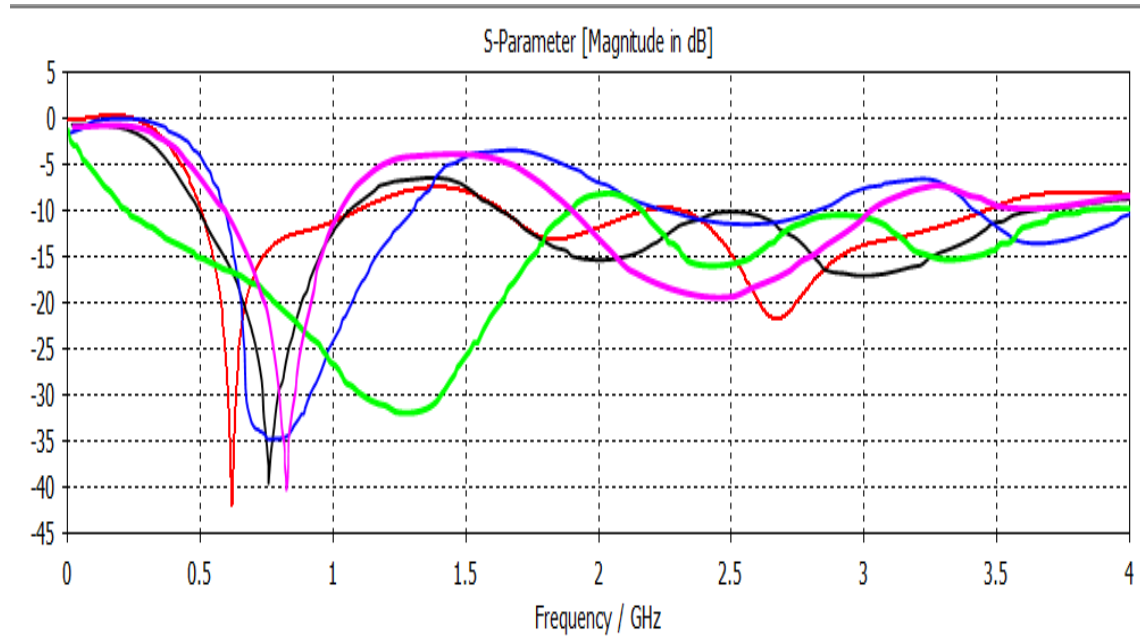


Figure 2.39: Return Loss plot for multiple iterations.

—	$r=22\text{mm}$	$R=128\text{mm}$
—	$r=20\text{mm}$	$R=128\text{mm}$
—	$r=18\text{mm}$	$R=120\text{mm}$
—	$r=10\text{mm}$	$R=128\text{mm}$
—	$r=16\text{mm}$	$R=110\text{mm}$

We were able to achieve our desired frequency band using this design so we fabricated this antenna for demonstrating consumer applications.

2.9.2.4 Simulated Results

2.9.2.4.1 Result of S11 – Return Loss

The return loss shows that the frequency range is in between 500 MHz and 3.2 GHz, as shown in figure 2.40. Hence, we were able to achieve our desired frequency range. The cable television comes in the VHF and UHF band and that is covered in this design as well. At 600 MHz the return loss is -23.482 dB, at 900 MHz the return loss is -13.127 dB, at 1800 MHz the return loss is -12.635 dB and finally at 2.45 GHz the return loss is -22.09 dB.

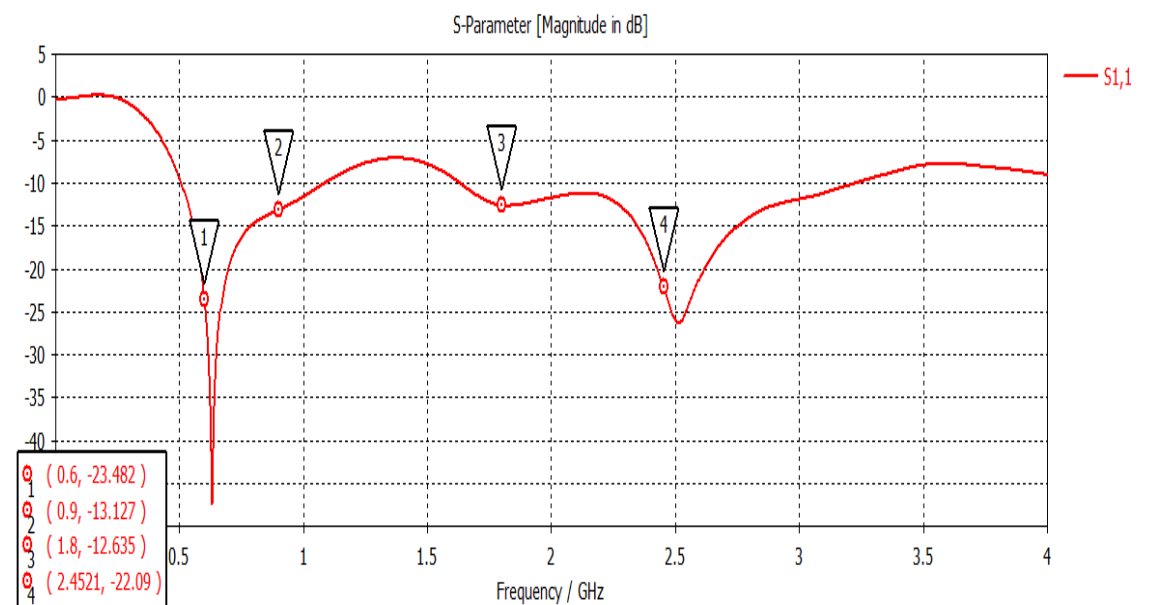


Figure 2.40: Return Loss vs Frequency curve.

2.9.2.4.2 2D Gain Plot

The 2D gain plot of the multiband antenna is shown in figure 2.41, which shows that at desired frequencies, the gain is high as well. At 611.5 MHz the gain is 2.55 dB, at 906 MHz the gain is 3.55 dB, at 1.8 GHz the gain of the antenna is 3.04 dB and lastly at 2.45 GHz the gain 4.06 dB. As we have higher gain at desired frequencies, it was easier for us to demonstrate consumer applications.

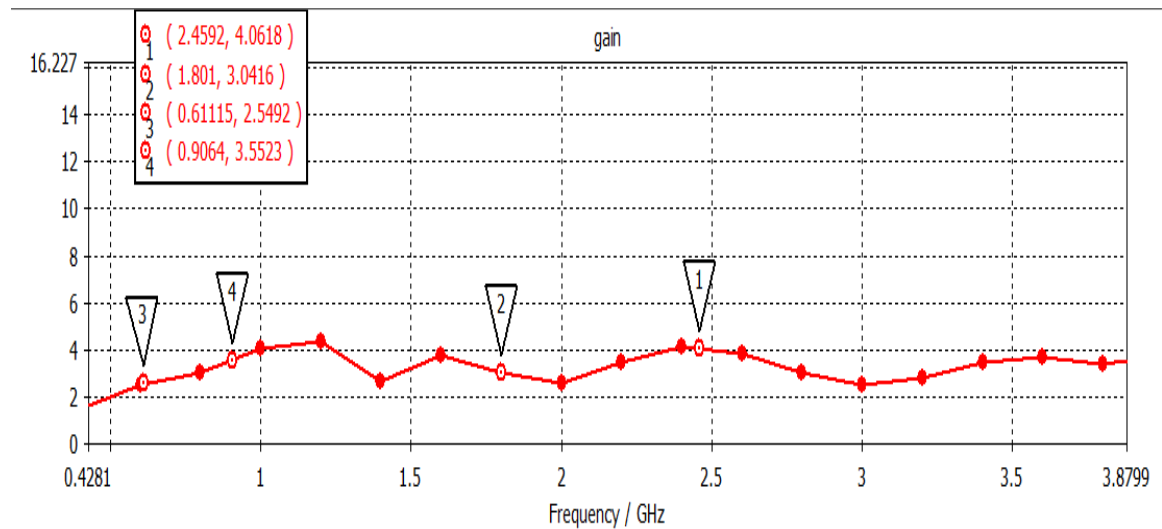


Figure 2.41: Gain plot.

2.9.2.4.3 Directivity

The farfield directivity of the designed multiband antenna at 2 GHz frequency is shown in figure 2.42. The directivity plot shows how directional the antenna is at 2 GHz. It is clear from the plot that the antenna is omni-directional at 2 GHz frequency.

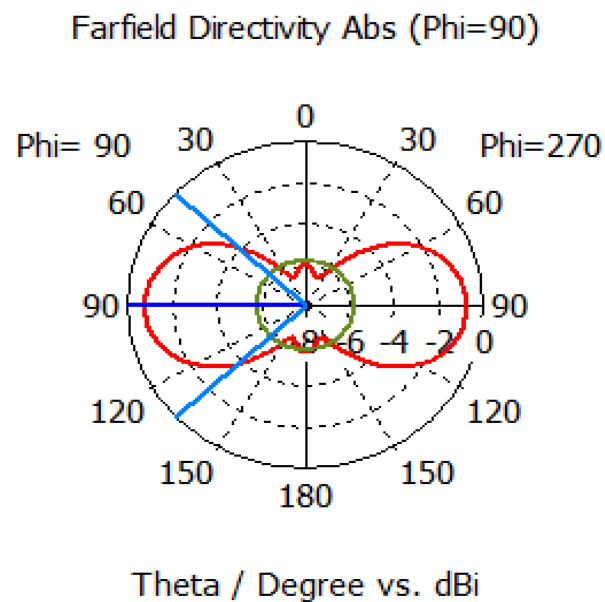


Figure 2.42: Farfield Directivity at 2 GHz.

2.9.2.4.4 Radiation Pattern

The 3D radiation pattern of the multiband antenna is shown below in figure 2.43, which indicates that that antenna is omni-directional. We also found out practically that the antenna is omni-directional by demonstrating in consumer applications.

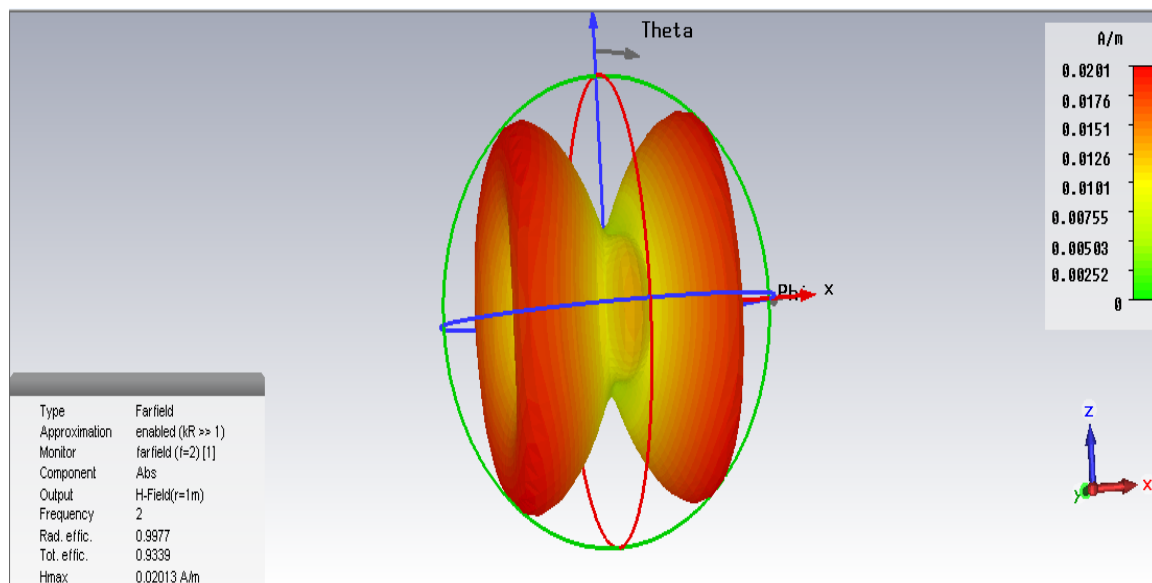


Figure 2.43: 3D Radiation Pattern.

2.9.2.5 Fabricated Antenna

Figures 2.44 and 2.45 shows the front and back side of fabricated antenna.

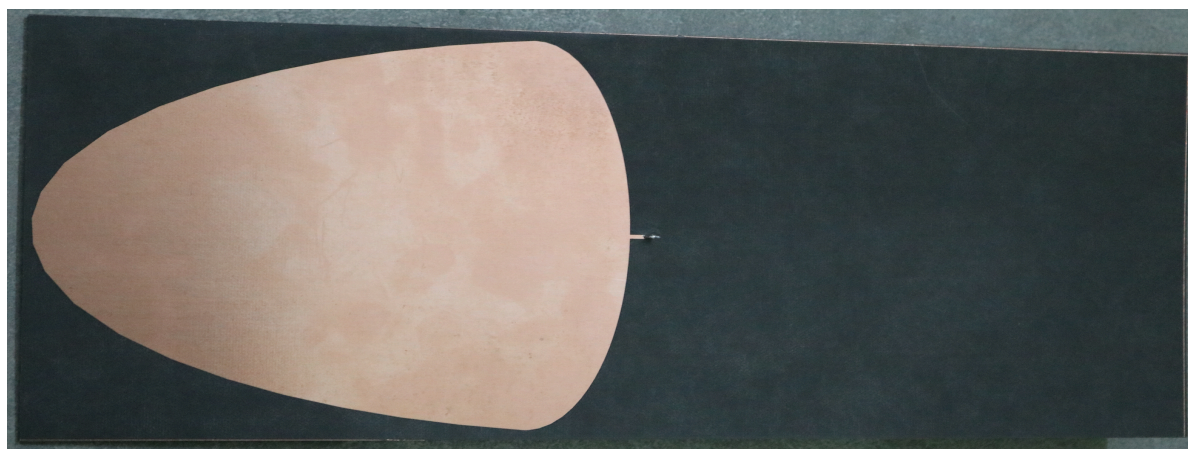


Figure 2.44: Front side of fabricated antenna.

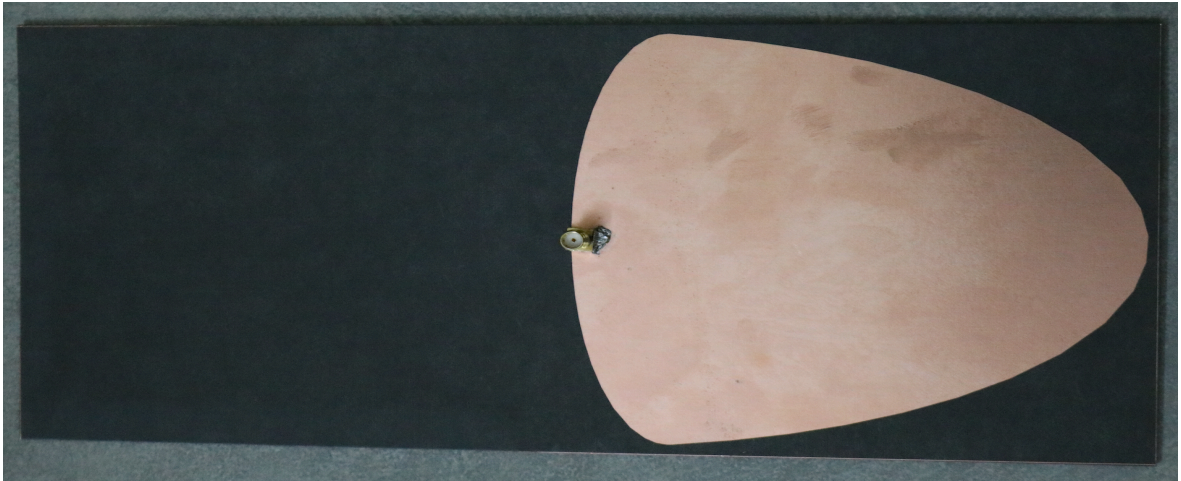


Figure 2.45: Back Side of fabricated antenna.

2.9.2.6 Fabricated Antenna Results

The return loss of the antenna is shown in figure 2.46 below. At 450 MHz the return loss is -9.56 dB, at 1.19 GHz the return loss is -9.615 dB and at 2.47 GHz the return loss is -9.593 dB. It may be noted that the model results and the experimental results are not exactly alike. This may be due to number of reasons which we were not able to investigate.

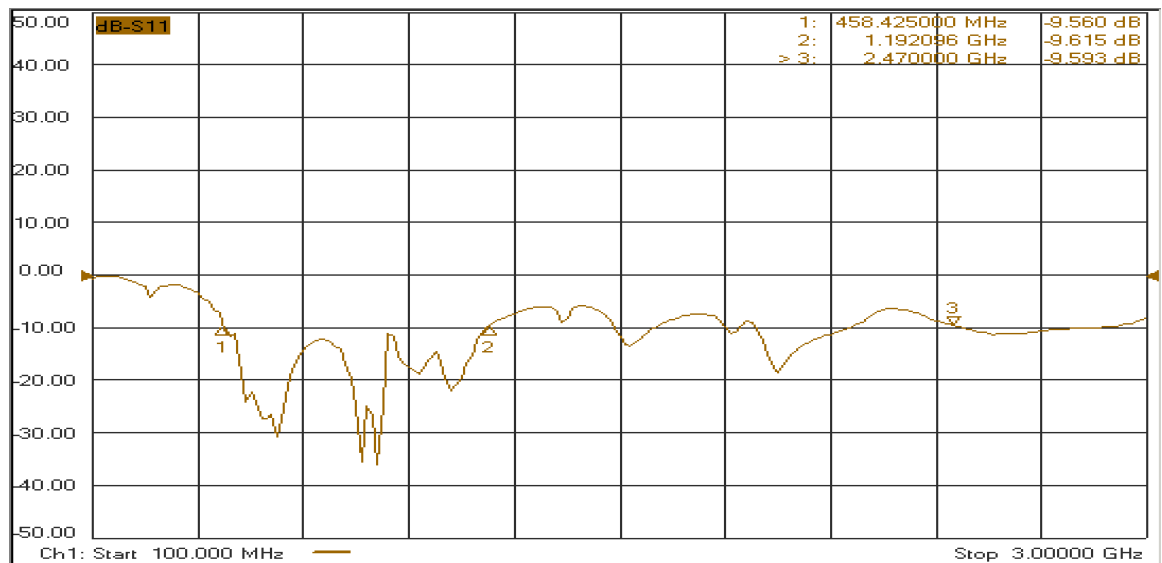


Figure 2.46: Return Loss Curve of fabricated antenna.

Chapter 3

Demonstrations/Conclusion/Future Work

This chapter has all the demonstration of consumer applications of the designed multiband antenna, conclusion and recommendations for future improvement that can be made in the antenna we have designed.

3.1 Demonstrations

After fabrication of the antenna, we demonstrated two consumer applications to show that the antenna is working properly for our desired frequency range. We successfully managed to transmit a WLAN signal as well as a cable television signal wirelessly. Fabricated antenna is demonstrated to perform two consumer applications.

3.1.1 Wireless Local Area Network (WLAN)

WLAN operates at 2.4 GHz providing wireless communications over short distances using radio signals instead of traditional network cabling. We constructed Wi-Fi local networks in ad-hoc mode. For this purpose, we used household Cisco 871 router and replaced its rubber duck antenna with our multiband antenna. Furthermore, we observed the signal-strength on our mobiles phones in the radius of 50 meters. Hence, our designed antenna can easily be used for WLAN signal transmission.

The demonstration of this application is shown in figures 3.1 and 3.2. In figure 3.1, the setup for demonstration is shown and in figure 3.2, the signal strength on the mobile phone is shown. The average signal strength of the router according to figure 3.2 is 3.9 Mbps on the mobile phone.



Figure 3.1: Transmission of WLAN Signal

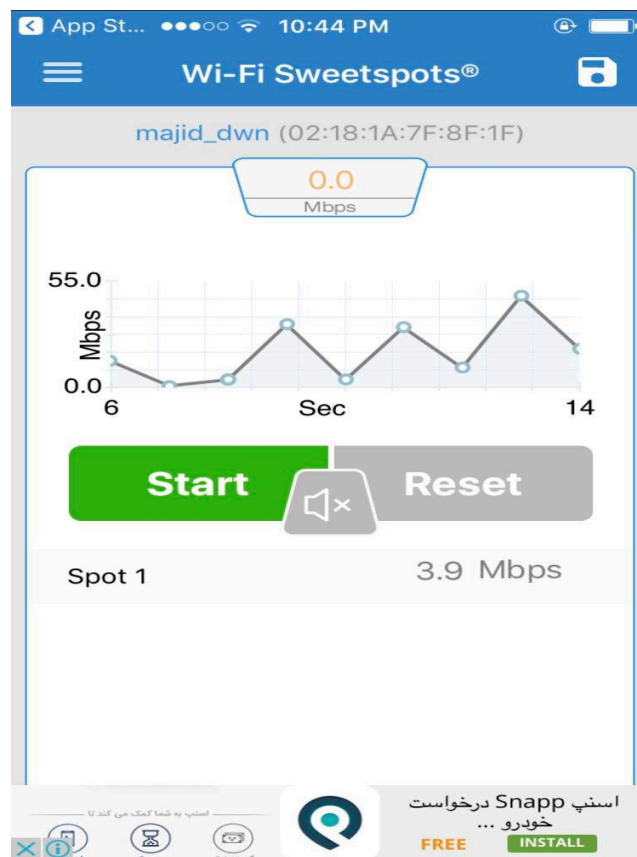


Figure 3.2: Signal Strength on Mobile Phone

3.1.2 Transmission of Television Cable Signal Wirelessly

TV cable signals occupy the VHF and UHF frequency bands. For this purpose, we used front-end cable signal amplifier, which can amplify the return loss upto -40 dB, male and female Bayonet Neill-Concelman (BNC) connectors, male and female SMA connectors, male and female cable connectors and impedance matching pad on the transmitting side attached to the cable. We used an impedance matching pad because we designed our antenna with an impedance of 50Ω while the cable has an impedance of 75Ω . Due to the use of connectors and impedance matching pad, there is insertion loss, which resulted in the reduction of the gain. In order to overcome the losses, a cable signal amplifier is used. On the receiving side, a rabbit ear antenna is attached to the television, to receive the signal from the multiband antenna. In the end uninterruptible transmission of various television channels is displayed on screen. The demonstration of this application is shown in figure 3.3.



Figure 3.3: Demonstration of wireless cable television signal transmission.

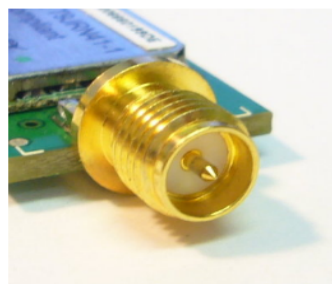
Although we were able to transmit cable television signal wirelessly, the resulting signal was very distorted. We believe that if the same antenna is used for the transmitting side as the receiving side, the signal quality can be improved.



Figure 3.4: Cable Signal Amplifier, Connectors and Rabbit Ear Antenna.



SMA Male



RP-SMA Female



SMA Female



RP-SMA Male

Figure 3.5: Different Types of SMA Connectors

In figures 3.4 and 3.5, all of the components that are used for the wireless transmission of cable television signal are shown, which include BNC connectors, SMA connectors, cable signal amplifier, impedance matching pad and rabbit ear antenna.

3.2 Conclusion

A planar elliptical broadband antenna is designed, which covers the frequency range of VHF, WLAN and GSM bands. We noted that the model results and experimental results are not matching. That may be due to some optimization error in the modeling of the design. We were not able to fully explore why the model and experimental results are not matching due to lack of time. As we have covered lower range of frequencies, the antenna size is larger because the antenna is a variation of an elliptical dipole antenna and the design rule for dipole antenna is that length is equal to half the operating frequency. It can be noted that the designed antenna has gain greater than 2 dB for desired frequencies. Furthermore, for WLAN demonstration, a $50\ \Omega$ line is required and for wireless cable transmission a $75\ \Omega$ line is required. Our design is for $50\ \Omega$ line so there were some problems in the transmission of wireless cable television signal.

3.3 Future Work

For future improvements in the antenna design, more iterations should be made in the simulation in order to achieve equivalent model and experimental results. Furthermore, the design should be of the same input impedance as the impedance required for the consumer application so there is no need for impedance matching pad as the use of an impedance matching pad results in insertion loss. Other than that, the signal quality of the cable signal can be improved if the designed antenna is replicated for the receiving side as well. An alternate way should be found to resolve the issue of difference in the input impedance of the antenna design and the input impedance of the consumer applications.

3.4 Budget

Table 3.1 displays our budget for this project.

Component	Type	Company	Cost (Rs.)
Substrate	RT-duroid	Roger's: https://www.rogers.com/	2000 (shipping cost only)
Amplifier	Cable Amplifier 40 dB	Shop number 78, Allied Electronics, College road, Rawalpindi	950
Connectors	Impedance Matching Pad	Shop number 78, Allied Electronics, College road, Rawalpindi	600
	BNC Connector Female	Shop number 78, Allied Electronics, College road, Rawalpindi	150
	BNC Connector Male	Shop number 78, Allied Electronics, College road, Rawalpindi	150
	SMA Connector Female to Male	Shop number 78, Allied Electronics, College road, Rawalpindi	250
	SMA Connector Male to Female	Shop number 78, Allied Electronics, College road, Rawalpindi	250
	SMA Connector Female to Female	Shop number 78, Allied Electronics, College road, Rawalpindi	250
	SMA Connector Female	Shop number 78, Allied Electronics, College road, Rawalpindi	300
Fabrication and Testing	Patch Antenna	Zeeshan Electronics: House no. 62, Service Road North, I-10/2, Islamabad	5000
	Multiband Antenna	National Institute of Electronics: Plot no. 17, Street 6, H-9/4 Islamabad	3500
Total			13,400

Table 3.1: Total budget of the project.

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