A HEXABAND SLOTTED PATCH ANTENNA

Submitted by

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In partial fulfillment for the award of the degree of

BACHELOR OF ENGINEERING

in

ELECTRONICS AND COMMUNICATION ENGINEERING

COLLEGE OF ENGINEERING, GUINDY

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DECEMBER 2022

APPENDIX 2

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BONAFIDE CERTIFICATE

Certified that this project report **A HEXABAND SLOTTED PATCH ANTENNA** is the bonafide, work of **GOWTHAM N** who carried the project work under my supervision.

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ACKNOWLEDGEMENT

First and foremost, we thank God for an abundance of grace and has countless blessings in making this work a great success.

We also express our sincere gratitude to our Head of the Department **Dr.M.MEENAKSHI**, Professor, Department of Electronics and Communication Engineering for her enthusiastic encouragement and support throughout the project.

We present our sincere thanks and gratitude to our project supervisor, **Dr.M.SHANMUGAPRIYA**, Assistant Professor, Department of Electronics and Communication Engineering for his wholehearted support, patience, valuable guidance, technical expertise and encouragement in our project.

We thank all the teaching and non-teaching staff of Department of Electronics and Communication Engineering, for their kind help and co-operation during the course of our project.

ABSTRACT

In this Project, a Hexaband Slotted Patch Antenna is proposed for 5G (3.0 GHz), GPS L5 (1.17 GHz), Cordless Telecommunication (1.9 GHz), Wireless Local Area Network (WLAN) IEEE 802.11b/g/n (2.4 GHz), LTE (Long Term Evolution) (0.7 GHz) and Radio navigation (1.3 GHz) applications. Here, the patch antenna is optimized to resonate at 0.7, 1.17, 1.9 and 2.4 GHz respectively, being fed by a single microstrip feed line. Also, additional hybrid modes are made to resonate at 1.3 GHz and 3.5 GHz. A rotated and inverted S-shaped slot is etched on the patch metal to split surface currents of each of the modes into two orthogonal and 90◦ phase-shifted versions, enabling the antenna to radiate Circularly Polarized waves. While supporting CP operation, the proposed antenna is simply proximity-fed by a single microstrip line, which omits the need for external feeding networks and reduces the cost and complexity. The proposed antenna gain ranges from 2.71 dB to 3.98 dB over the operating bands.

CHAPTER 1
INTRODUCTION

1.1 MOTIVATION:

The development of modern wireless electronic devices' abilities to meet the significant growth of communication systems has become vital. One of the most important characteristics of the new electronic devices is the multiband operation, which enables modern devices to seamlessly operate across different communication standards while meeting tight design requirements, such as low cost and ease of fabrication. Since antennas play an essential role in modern communication devices, various techniques of multiband antennas were developed. In this project, developing a multiband antenna operating at various communication platforms, including the global positioning system (GPS) bands, is considered. GPS plays a unique role in smart cities, transportation, agriculture, communications, sensing, and safety applications. In this context, GPS has been integrated into many multiband antennas supporting cellular phones applications, Internet-of-Things applications, unmanned aerial vehicles, intelligent transportation systems, handheld devices, and wearable devices. Although multi-GPS bands provide an effective correction of ionosphere errors in real-time kinematic, many multiband antennas operate only in a single GPS band.

The multiband operation comes from a configured monopole antenna with an open-loop hexagonal ring radiator. The antenna resonates at GPS and LTE bands. On the other hand, linearly polarized (LP) multiband antennas that operate in GPS bands have been presented. However, CP operation at GPS bands provides multipath mitigation, polarization mismatch losses elimination, and less sensitivity to the transmitter/receiver angle mismatch. In an LP multiband monopole antenna loaded with one frequency-reconfigurable composite right/left-handed unit cell is studied. The antenna resonates at multiple LTE bands as well as GPS bands.

The antenna radiates CP waves at four different bands, including GPS bands. In this

Project, a Hexaband CP antenna fed by a single microstrip line is designed. It is composed of a slotted patch antenna which is optimized to excite the modes TM_{100}, TM_{110}, TM_{210}, andTM_{220} at 0.7, 1.17, 1.9 and 2.4 GHz respectively.

The feeding microstrip line is tuned to excite two hybrid modes EH_1 and EH_3 resonating at 1.3 GHz and 3.0 GHz. Meanwhile, a rotated and inverted s-shaped slot with optimized dimensions is etched into the patch metal to split surface currents of each of the modes TM_{110}, TM_{210}, EH_3, and EH_4 into two orthogonal and 90◦ phase shift versions, enabling the antenna to radiate CP waves at 1.17 and 3.5 GHz bands. Thus, the overall antenna structure operates at six bands with CP operation, offering availability of operation over more communication standards than many recent works. Also, the proposed antenna does not require any external feeding or power divider networks as compared to the work in.

1.2 SOFTWARE REQUIREMENT:

CST STUDIO SUITE

1.3 SOFTWARE OVERVIEW:

The designs and simulations in this project are based on the Computer Simulation Technology (CST) microwave Studio suite which is a high performance electromagnetic simulation software. There are two basic solver modules provided: time domain solver and frequency domain solver. The two solvers are totally different. Time domain solver is used for non-resonant structures and frequency domain solver contains alternatives for highly resonant structures. Beside frequency domain solver has the option of utilizing tetrahedral mesh that can discrete the structure better which is not available with in time domain solver. In addition, time domain solver is only for normal incidence but frequency domain solver can be used for off–normal incidences. CST contains several different simulation methods, including the finite integration technique(FIT), finite element method (FEM), transmission line matrix (TLM), multilevel fast multiples method(MLFMM) and particle in cell(PIC),as well as Multiphysics solvers for other domains of physics with links to electromagnetics.

CHAPTER 2

LITERATURE SURVEY

2.1.1 A Hexaband Quad-Circular-Polarization Slotted Patch Antenna

In this paper, it was inferred that using an inverted s-slot circular polarization operations can be performed while enabling multiband operation and using a proximity feeding technique hybrid modes can be produced.

2.1.2 The Versatile U-slot Patch Antenna

In this paper, it was inferred that by using different slot configurations based on U slot, multiband operation can be achieved, by increasing substrate thickness, bandwidth can be increased and increasing slot width, frequency of operation is shifted to lower values.

2.1.3 Feed Analysis of a Proximity Coupled Microstrip Patch Antenna

In this paper, the length of the feedline in a proximity coupled microstrip patch antenna was investigated. It is found that the length of the feed line has a direct influence on the resonant frequency and that the antenna resonates at a higher frequency when the length of the feedline is increased.

2.1.4 Multi Rectangular Slotted Hexa Band Micro-strip Patch Antenna for Multiple Wireless Applications

In this paper, it was observed that using fractal approach, multiband operation can be achieved and the effective length and bandwidth of antenna can be increased. It was studied that multi-layer dielectric may be used for bandwidth enhancement. Different combination of material can be used for substrate layer and modify thickness to increase the bandwidth of antenna.

2.1.5 Proximity-Coupled Stacked Patch Antenna for Tri-Band GPS Applications

In this paper, it was observed that while designing the AMC connector for exciting the feedline, the outer conductor should be connected to ground in order to prevent unwanted backward reflections. It was inferred that using proximity-coupled feed technique, the thickness of the antenna can be reduced while supporting hybrid modes.

2.1.6 Wideband and Low-Cross-Polarization Planar Annual Ring Slot Antenna

In this paper, it was observed that introducing a short circuit in the antenna, the impedance bandwidth can be further improved by inspiring a further resonant point. It was studied that adding arc-shaped slots at the circular aperture to cut the circular current vectors around the aperture, improves the cross-polarization level at the whole impedance bandwidth.

CHAPTER 3
SIMULATION DESIGN METHODOLOGY AND RESULTS

3.1 PROPOSED ANTENNA STRUCTURE:

To get modes at the resonant frequencies, the length, the width, and the height of the antenna upper substrate are obtained using cavity model of the patch antenna given below.

$$f_{r,mnp} = \frac{1}{2\pi\sqrt{\mu\epsilon}}\sqrt{(\frac{m\pi}{d_x})^2 + (\frac{n\pi}{d_y})^2 + (\frac{p\pi}{d_z})^2}$$

Using the above formula, the dx*dy*dz dimensions are obtained. The parameters of the antenna is shown in table 1.

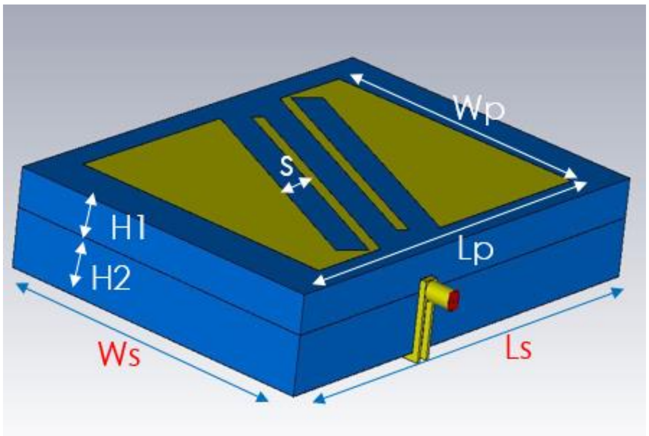


Figure 1 Antenna design

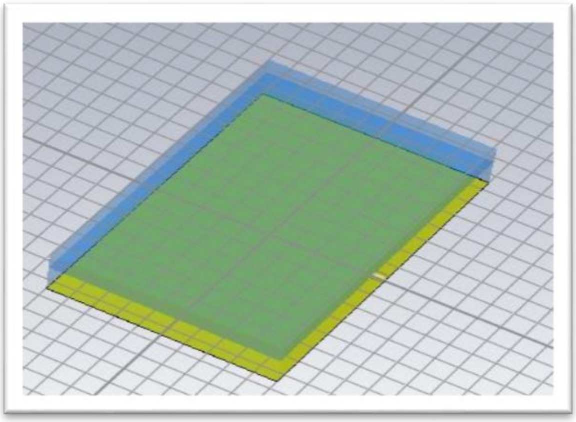
The proposed antenna structure consists of two main parts, as shown in Figure. 1, the first part is the radiating slotted patch antenna and the second part is microstrip feed line. Each of the slotted patch antenna and the feeding microstrip line is printed upon stacked FR4 substrates. A rotated and inverted S-shaped slot is etched into the patch metal to perturb the surface currents of certain excited modes and enable the CP operation. The dimensions of the antenna structure are shown in Table 1.

Table 1: Antenna dimensions

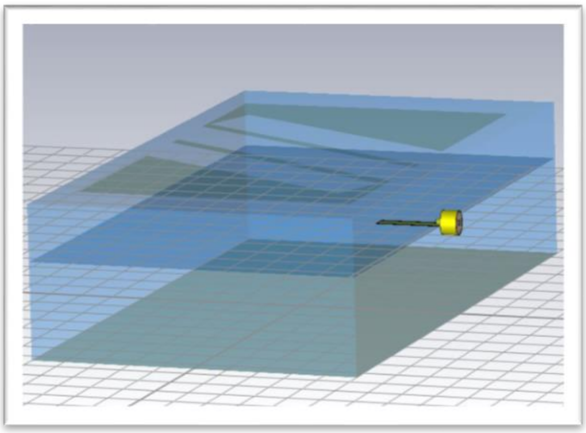
PARAMETERS	**VALUES(mm)**
ANTENNA SIZE	150 x 100 x 30.47
Ws	100
Ls	150
Wp	84.9
Lp	116.4
H1	11.2
H2	19.2

By using the theoretically calculated dimensions as initial values, the dimensions' values are fine-tuned using CST MWS to have the resonances at 0.62, 1.2, 1.7, and 2.4 GHz.

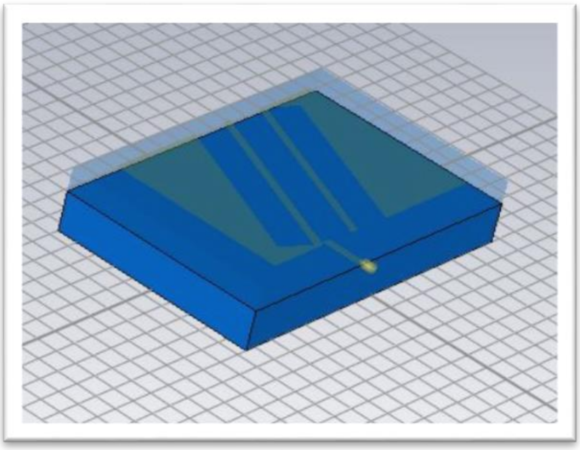
To get hybrid modes the lower substrate height is modified and the proximity feed length is varied and observed. The Figure 2 shows the detailed design of the antenna. Wp, Lp corresponds to patch width and length respectively, Ws, Ls corresponds to substrate length and width. The height of lower substrate is H2 and upper substrate is H1 S gives slot width and antenna size is provided.



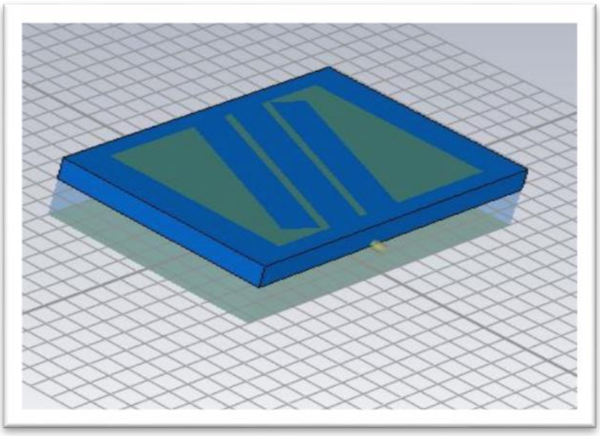
Ground



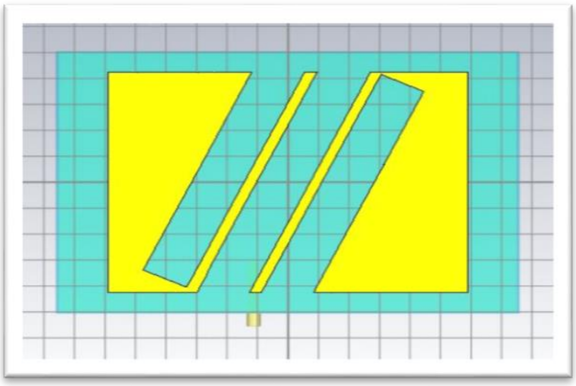
Feed line with Port



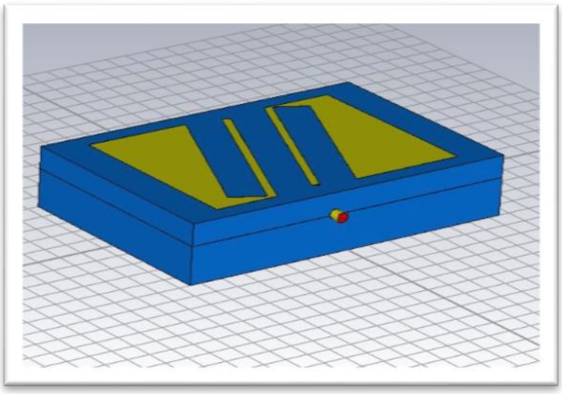
Lower Substrate



Upper Substrate



Inverted S-slot patch



Whole Design

Figure 2 Detailed Design

3.2 CST PROCEDURE:

Create Ground surface by using a new brick and set the copper as material. Set the dimensions length, width in y length and x length and set 0.035 as height in z length.

Design a lower substrate with the same length and width and height starting from z_{max} of ground plane and set z_{max} of the lower substrate to have the derived height value for the lower substrate. Design an upper substrate with the same length and width as that of the lower substrate and starting from z_{max} of lower substrate set the zmax of the upper substrate to have the derived height value for the upper substrate. Set the material for both the lower and the upper substrate to be FR4 substrate.

Now to design the patch on top of the upper substrate, use new block with copper material and use the lengths and widths specified in table1.To impose the inverted s slot, first use a slot container of same parameters as patch with only width different enough to have the slot. Then introduce two more bricks on the slot container and have the length and width as to provide an s shape to the slot. Use Boolean operations to remove the newly added from the slot container and then remove the slot container from patch. Rotate the obtained slot to 340deg counter clockwise. The resultant will be the desired inverted slot antenna. Next is to design the feed of thickness of 0.035 which is proximity to the patch.

The feed should be designed in such a way that excites the patch properly and should be impedance matched. The feed has height of 0.035 starting from the lower substrate z_{max} to upper substrate z_{min}. To include feed without inserting into the upper substrate, the upper substrate z_{min} is modified to start from 0.035+lower substrate z_{max} to include feed. The feed material is copper. The face of the feed where the supply will be given is selected and a waveguide port is constructed on the selected face. After waveguide port is constructed, Simulation is started.

This sequence of steps are carefully followed to get the desired design of the antenna. The parameters for each brick should be given a variable so that the parameter sweeps can be performed easily. At first, only the waveguide port is constructed and the analysis are done whether the derived parametric values are suitable to get the results.

But practically a SMA (Sub Miniature version A) connector is used to provide supply. The SMA connector is semi precision coaxial RF connectors developed as a minimal connector interface for coaxial cable with a screw-type coupling mechanism. The results will be varied when SMA connector is used due to noise and the load impedances.

3.3 ANALYSIS USING WAVE GUIDE PORT:

The S_{11} plot shows how return loss occur at the resonant frequencies. The desired level of return loss at resonant frequencies is that it should be less than or equal to -10dB. The Figure 3 shows the S_{11} result when analyzed using wave guide port.

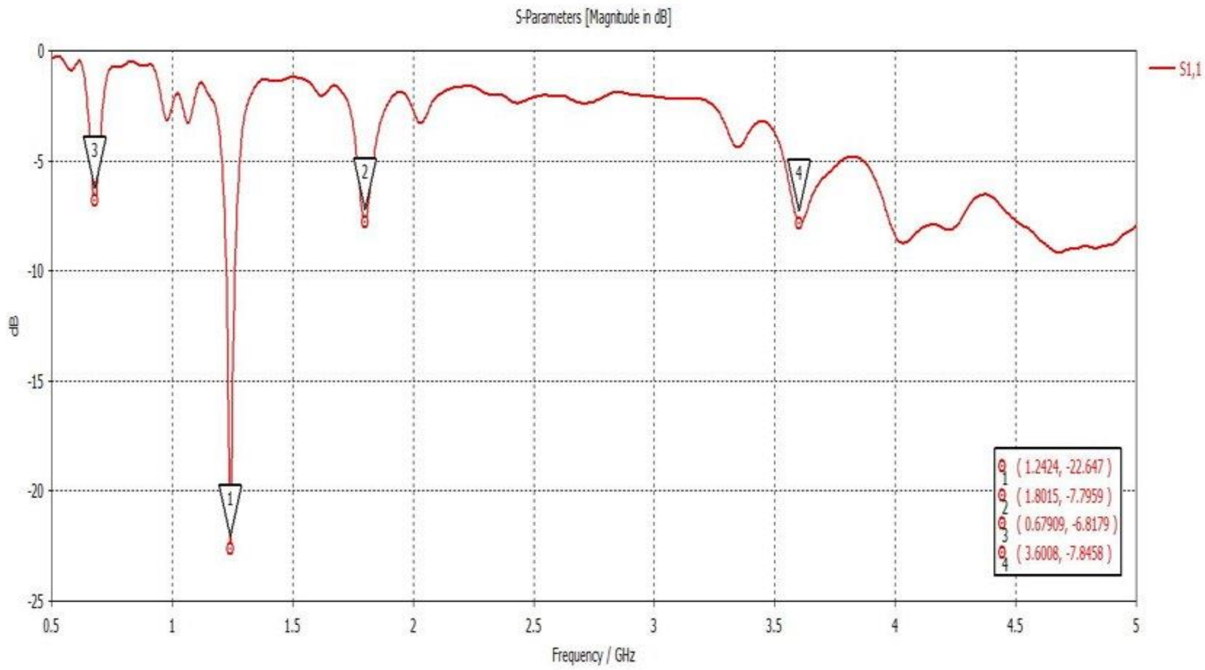


Figure 3a S_{11} plot with no slots on patch

The Figure 3a shows that at 1.24 GHz where only at this the S_{11} is –30dB which implies that only at this frequency the power transmitted to the antenna is radiated with some losses and at other frequencies there is no radiation and all the power is reflected back. This resonant frequency is due to the length, width of patch and height of the substrate. But five more resonant frequencies are desired so an inverted s-slot on the patch was introduced.

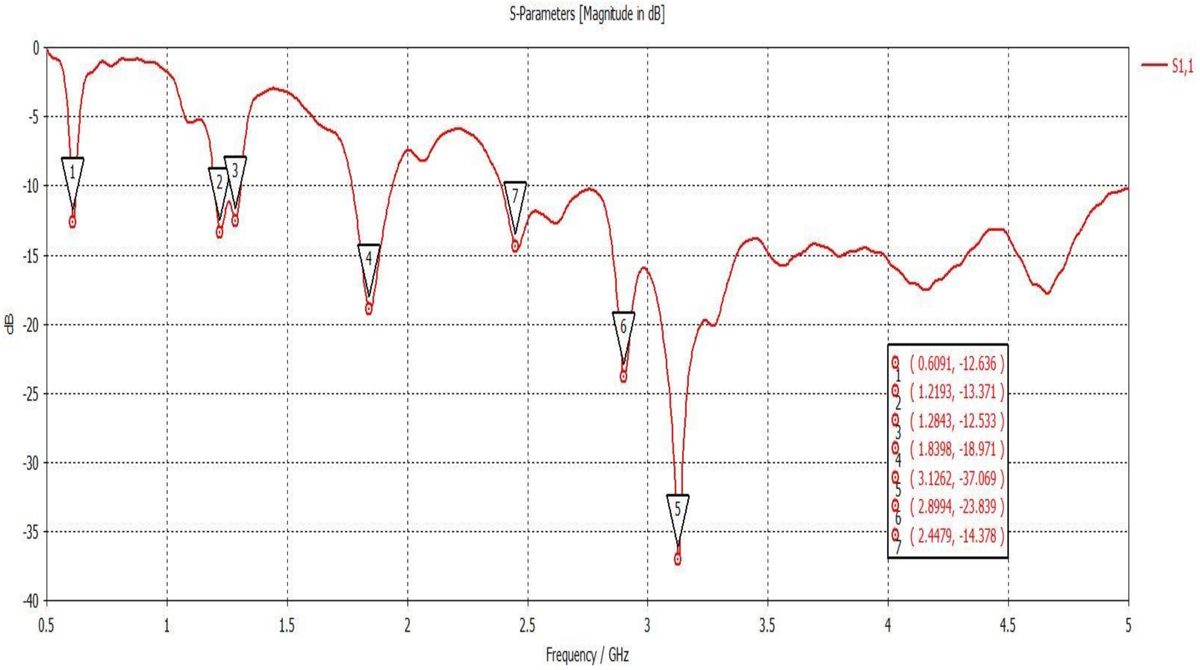
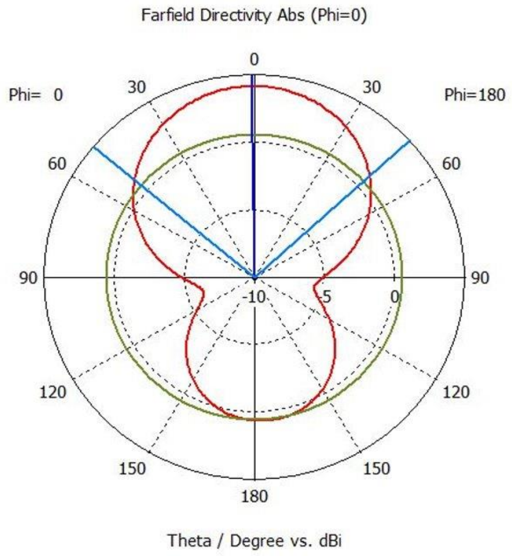
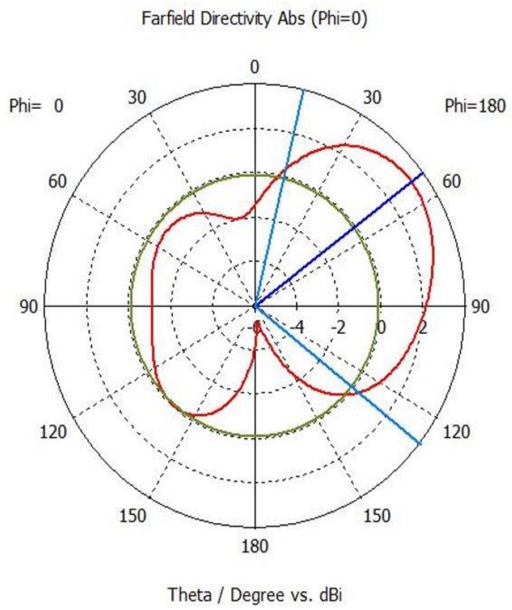
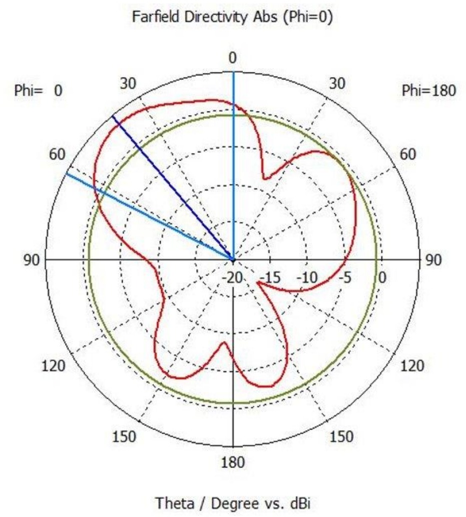
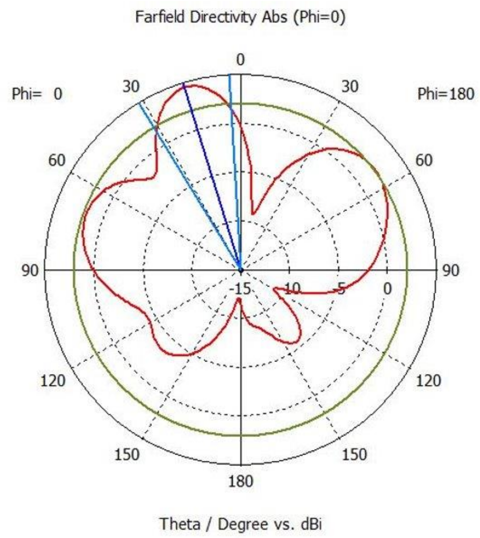


Figure 3b S_{11} plot with s-slot

The above Figure 3b shows the obtained seven resonant frequencies where S_{11} is less than –10dB. The frequencies are 0.609, 1.2193, 1.28, 1.839, 3.12, 2.89 and 2.44 GHz and out of these four of the desired resonant frequencies of operation are obtained. Two more resonant frequencies at 1.57 GHz and 3.5 GHz should be obtained. For that proximity feed technique is to be used. The purpose is that using a feed in between ground plane and the patch makes the distance of separation between the E-plane at the top on patch and at the bottom to small, making the E-field and H-fields at other four faces to get closer to produce hybrid modes where both E-field and H-field are transverse to the propagating direction of EM wave. This will produce additional resonant frequency of operation for the antenna. The radiation pattern obtained for the four frequencies obtained shown in Figure 3b are included below in table 2.

Table 2: Radiation plots

	→ Frequency : 0.62GHz → Gain : 2.64 dB → Directivity : 2.057 dB → HPBW : 97.4º → Efficiency : 69.7 %
	→ Frequency : 1.2 GHz → Gain :1.52 dB → Directivity : 1.13 dB → HPBW : 115.2º → Efficiency : 66.7 %

<table>
<tr>
<td>
</td>
<td>→ Frequency : 2.8 GHz
→ Gain : 4.35 dB
→ Directivity : 6.75 dB
→ HPBW : 63º
→ Efficiency : 67.5 %</td>
</tr>
<tr>
<td>
</td>
<td>→ Frequency : 3.12 GHz
→ Gain : 5.05 dB
→ Directivity : 5.03 dB
→ HPBW : 27.8º
→ Efficiency : 61.66 %</td>
</tr>
</table>

The table 2 shows the radiation pattern obtained for the four resonant frequencies of operation which tell about the gain obtained, the directivity, the Half Power Beam Width and Efficiency for each resonant frequency. The Half Power Beam Width (HPBW) which tells in which direction half of the maximum power transmitted is focused which in turn shows the direction where the radiated power can be received, is in different direction for the four resonant frequencies.

The Figure 4 shows the current density at each portion of the antenna when excited. It is observed that the introduction of slots, produced circular polarization. Circular polarization is produced when two modes are orthogonal and separated by a small distance. It makes the radiated waveform to travel tracing a spiral path which helps when the direction in which the transmitter or receiver is positioned is unknown and prevents loss in data.

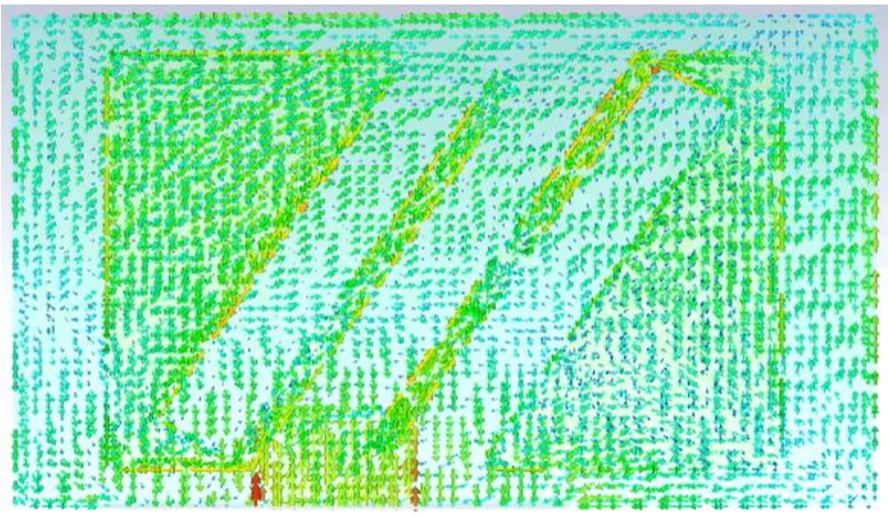


Figure 4 Surface Current Density

VSWR stands for Voltage Standing Wave Ratio. VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna. For a radio (transmitter or receiver) to deliver power to an antenna, the impedance of the radio and transmission line must be well matched to the antenna's impedance. The parameter VSWR is a measure that numerically describes how well the antenna is impedance matched to the radio or transmission line it is connected to. Figure 5 is VSWR plot which indicates that at the resonant frequencies, the reflected power is less within acceptable range less than 2.

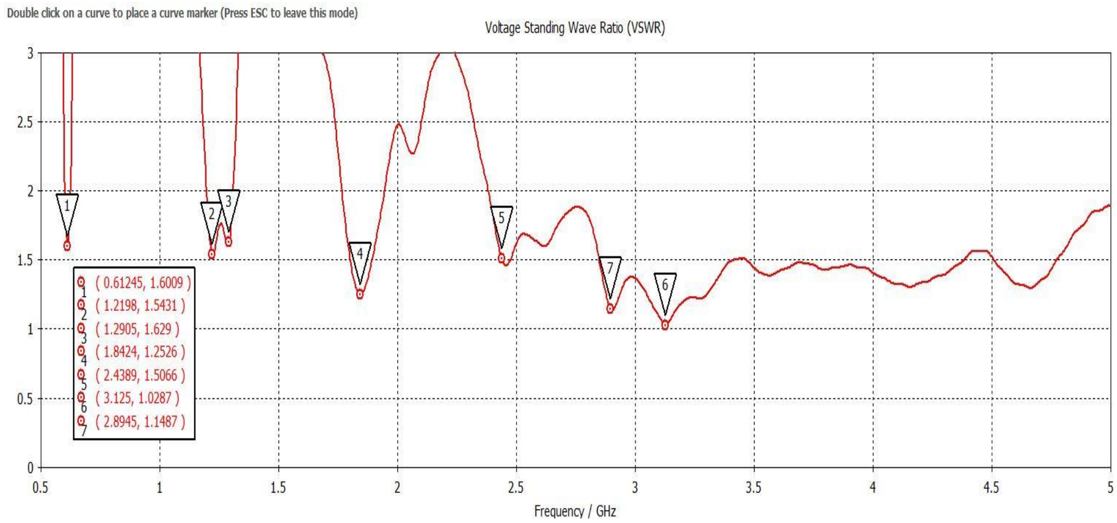


Figure 5 VSWR plot

3.4 ANALYSIS USING SMA CONNECTOR:

The SMA connector has to be connected to the feed line to provide excitation to the antenna. The SMA connector has three hollow cylinders. Inner Cylinder is of type copper and has inner radius 0.6 and outer radius 1.6. Middle Cylinder is of type Teflon and has inner radius 1.6 and outer radius 2. Outer Cylinder is of type copper and has inner radius 2 and outer radius 2.4. In CST, cylinder is used to construct SMA connector for each layer of different radii. The outer cylinder must be connected to the ground. So, the bricks are used to connect the outer cylinder to the ground. Only inner cylinder must touch the feed. Figure 6 and Figure 7 shows the design.

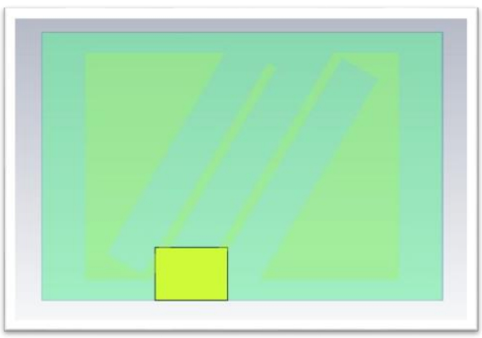


Figure 6 Feed

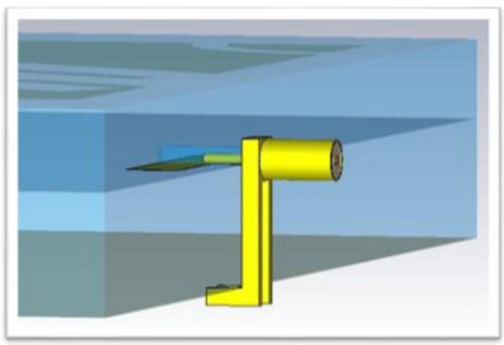


Figure 7 Proximity feed with SMA connector

The length and width of the feedline plays an important role in proximity feed technique. A wrong value would result either in wrong resonant frequencies or in no excitation. So a parameter sweep was done on the length and width of the feed and observed for which set of values the desired result was obtained.

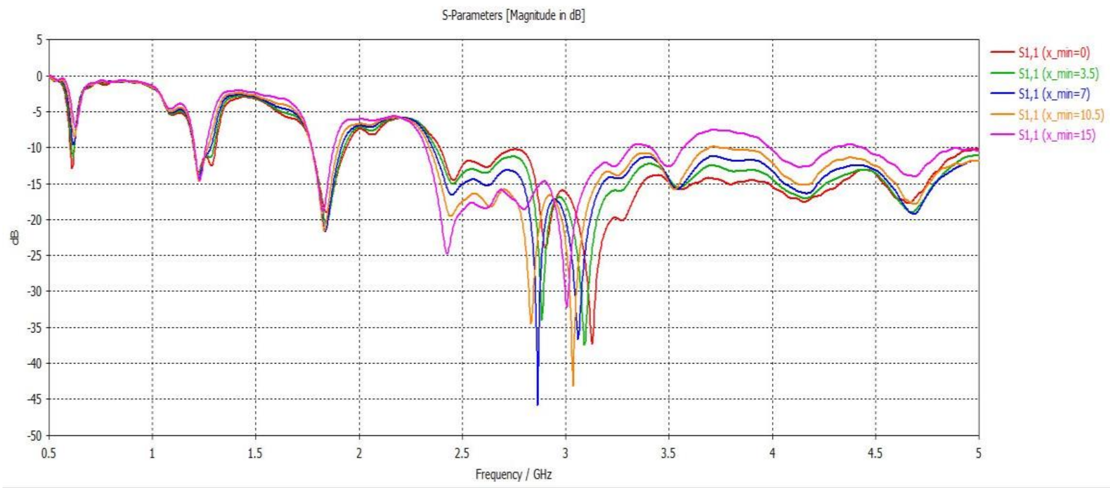


Figure 8. Varying width of feed line

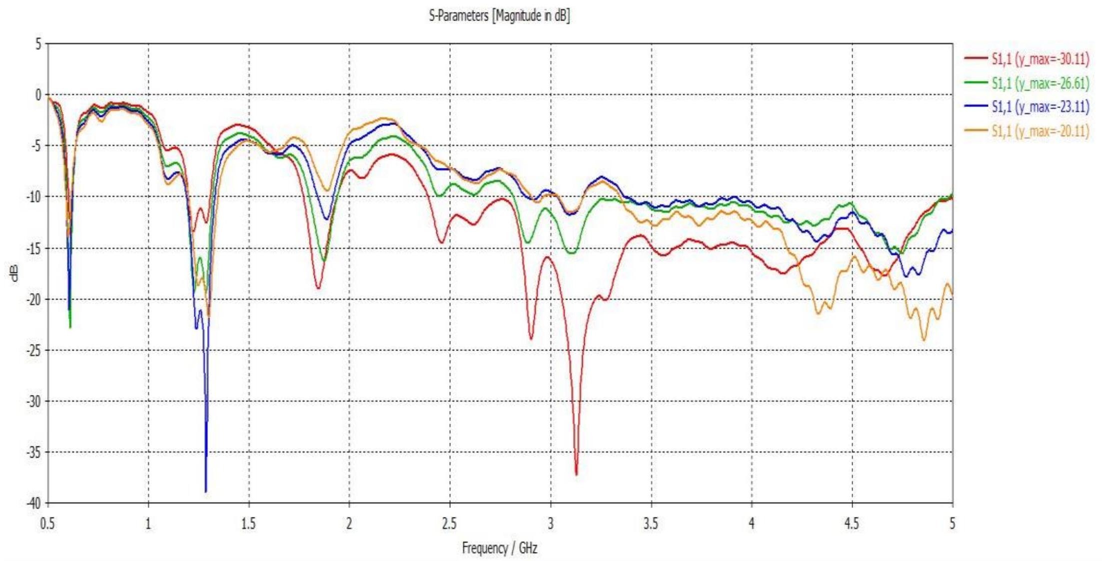


Figure 9. Varying length of feed line

Varying the width of the feedline the undesired band of frequencies greater than 3.5 GHz was able to be moved up i.e., at those high S_{11} was able to be obtained indicating higher ratio of reflected power. Varying the length of feedline the S_{11} was less indicating lesser ratio of reflected power at resonant frequencies. To make the band of frequencies greater than 3.5 GHz and to get desired resonant frequencies, an arc was introduced at two corners of patch. These arcs were designed using rings in CST. These arcs help to oppose radiation at those corners improving the HPBW and shifting the resonant frequencies. The new design is shown in Figure 10.

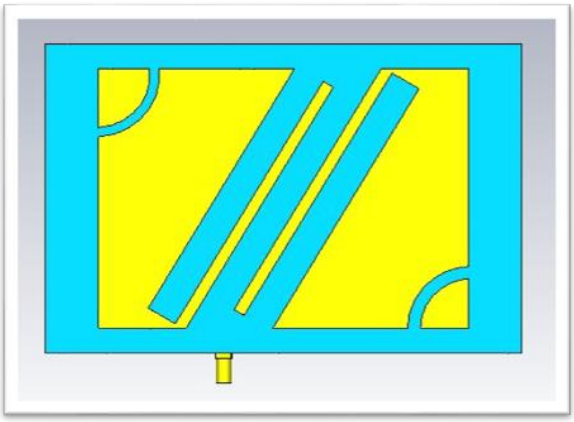


Figure 10 Updated design of antenna

Analysis on $S_{11}$by varying the slot width was done. The result is shown in Figure 11. The best slot width was considered and used to get the new design in Figure 10.

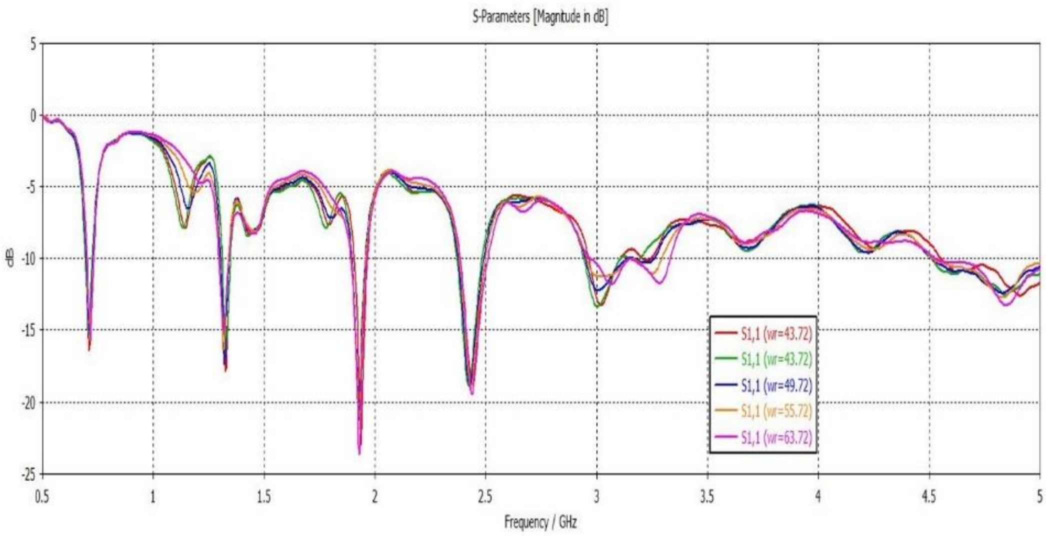


Figure 11 Varying width of slot

Analysis on varying the thickness of both the top and bottom substrates were done. Figure 12 shows the result of varying the thickness of upper substrate and Figure 13 shows the result of varying the thickness of lower substrate.

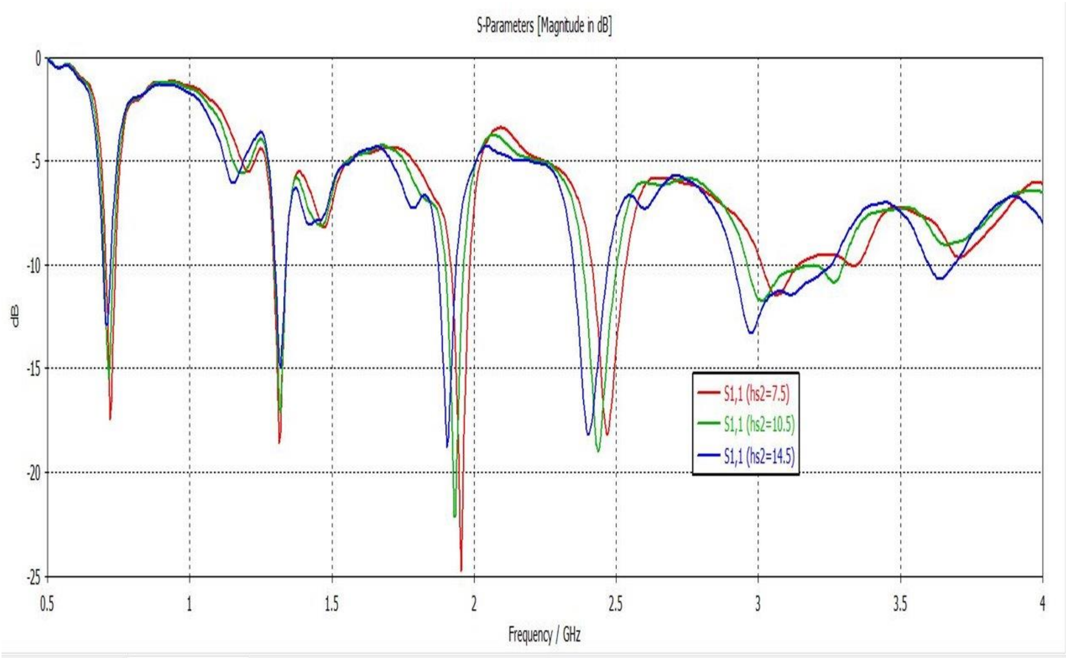


Figure 12 Varying thickness of upper substrate

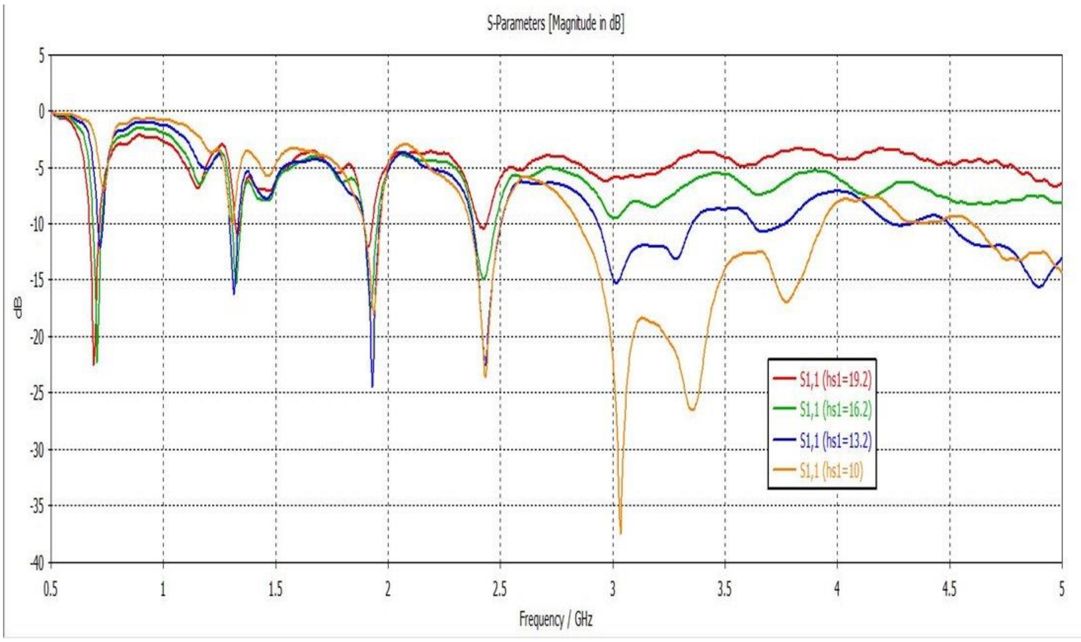


Figure 13 Varying thickness of the lower substrate

It was inferred that decreasing the height of substrate leads to closely coupled E-field and H-field leading to modes resonated at higher frequencies. So the resonant frequencies were shifted to right. Analysis on length and width of feedline for modified design is done.

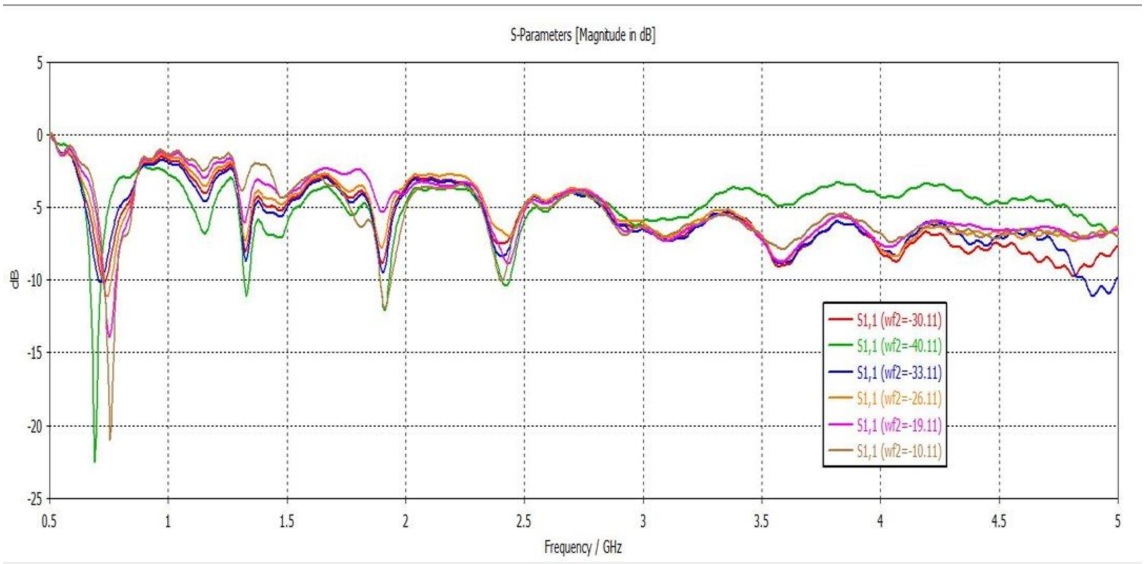


Figure 14 Varying width of feed line

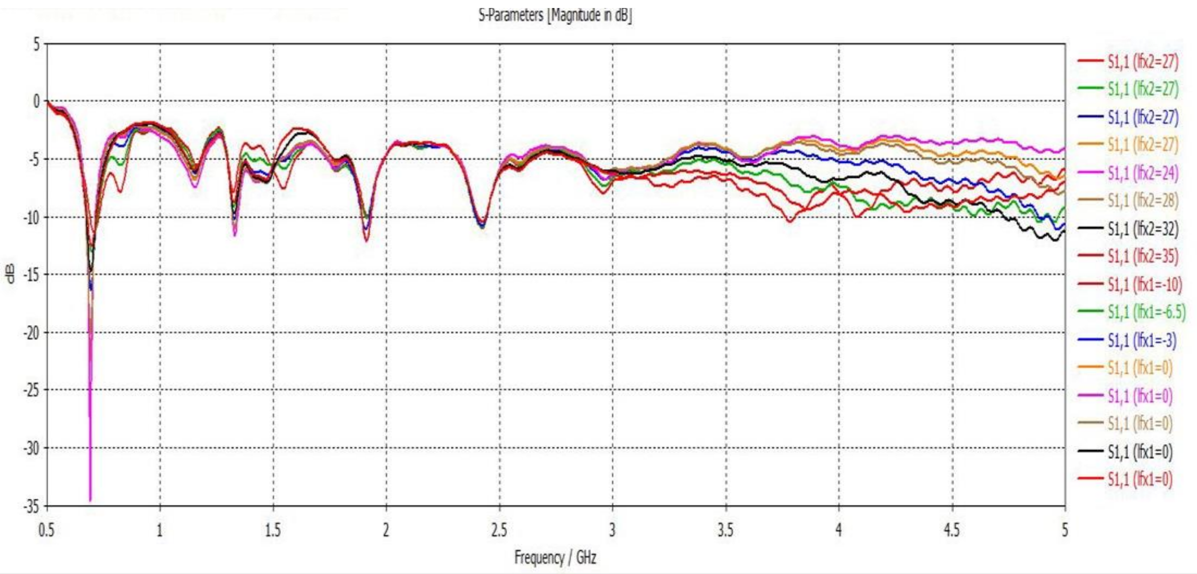


Figure 15 Varying length of feed line

Varying the length and width of feed line, the undesired bands are made to have high reflected power while making the desired resonant frequencies to have low reflected power.

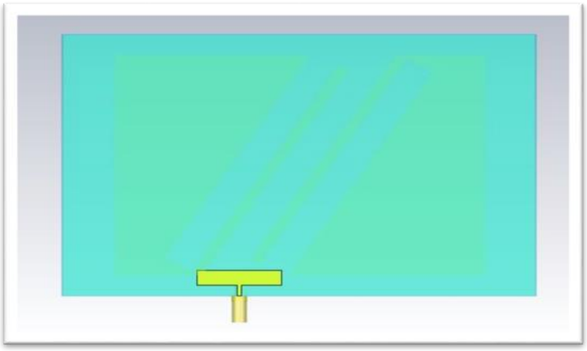


Figure 16 Updated feed line

By using the results from Figure 12 and Figure 13, the height of the upper substrate is reduced from 11.2 mm to 9.6 mm and the height of the lower substrate is reduced from 19.2 to 14.4. The updated parameters are displayed in table 3.

Table 3: Updated Antenna dimensions

PARAMETERS	VALUES(mm)
ANTENNA SIZE	150 x 100 x 24.105
Ws	100
Ls	150
Wp	84.9
Lp	116.4
H1	9.6
H2	14.4
S	9.906

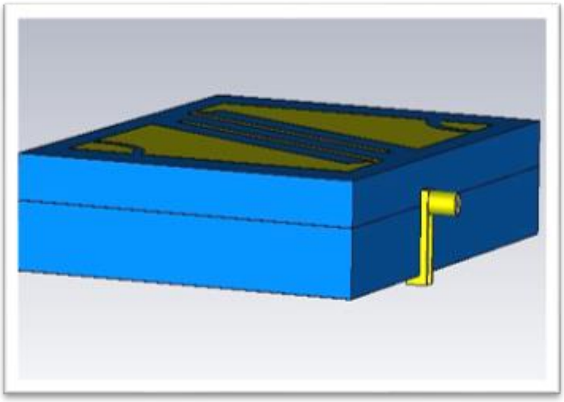


Figure 17 Antenna Design (final)

3.5 SIMULATION RESULT:

The new design shown in Figure 17 is the final design and the simulation is run to obtain S_{11}, VSWR plot and the radiation patterns.

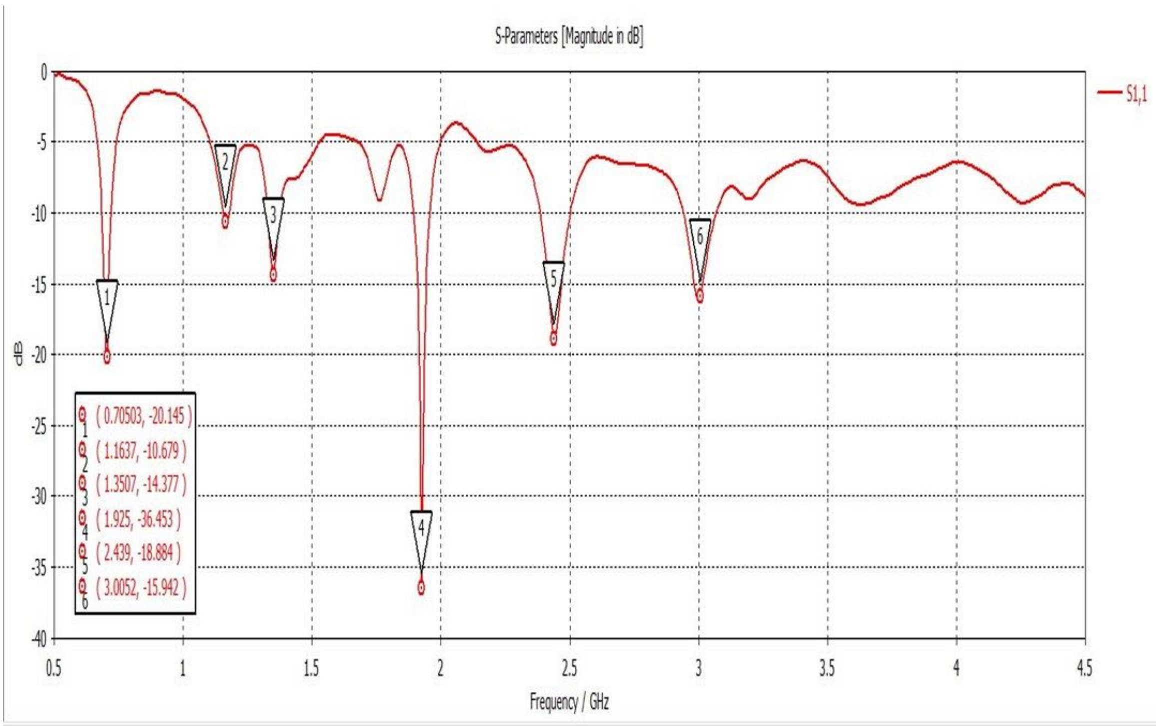


Figure 18. S_{11} plot

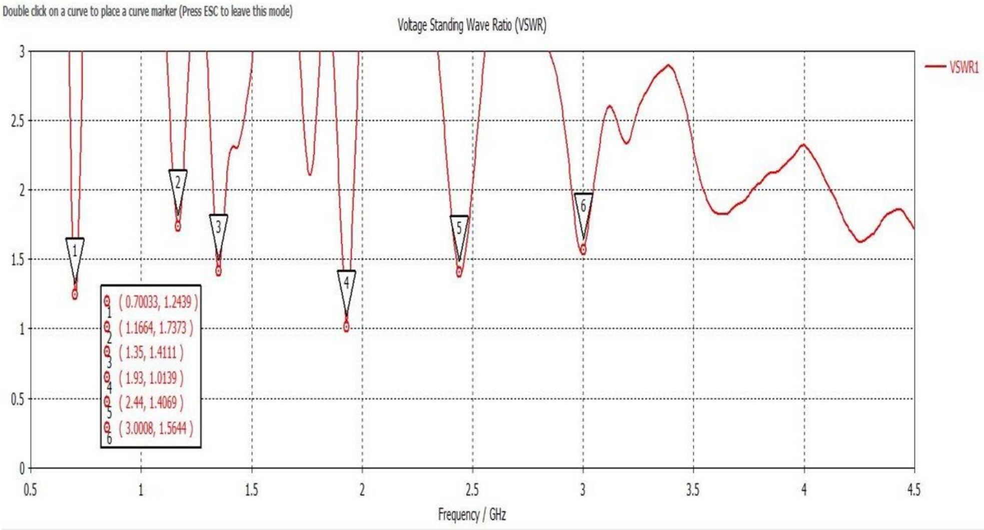


Figure 19. VSWR Plot

From the VSWR plot and S_{11} plot, it is observed that using the new design the desired resonant frequencies are obtained at 0.7, 1.16, 1.35, 1.9, 2.4 and 3 GHz and the undesired band of frequencies higher 3.5 GHz have higher reflected power. Hence this design is considered final and the radiation patterns are obtained to determine the gain, beam width and efficiency at each of these resonant frequencies.

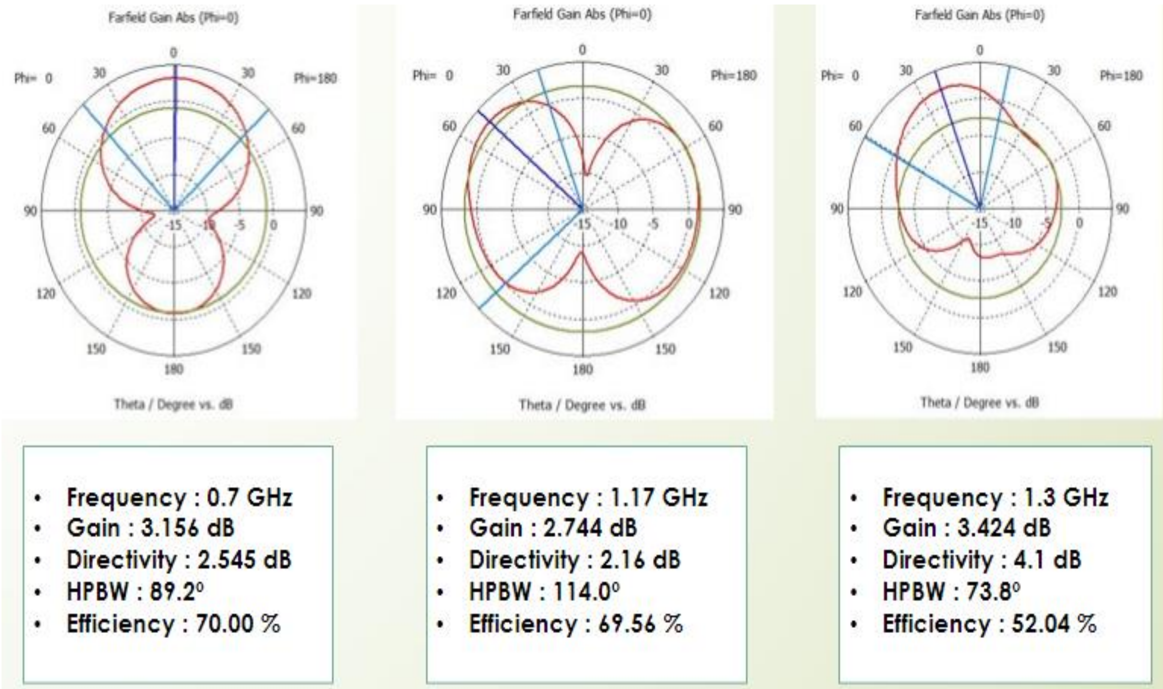


Figure 20a Radiation patterns

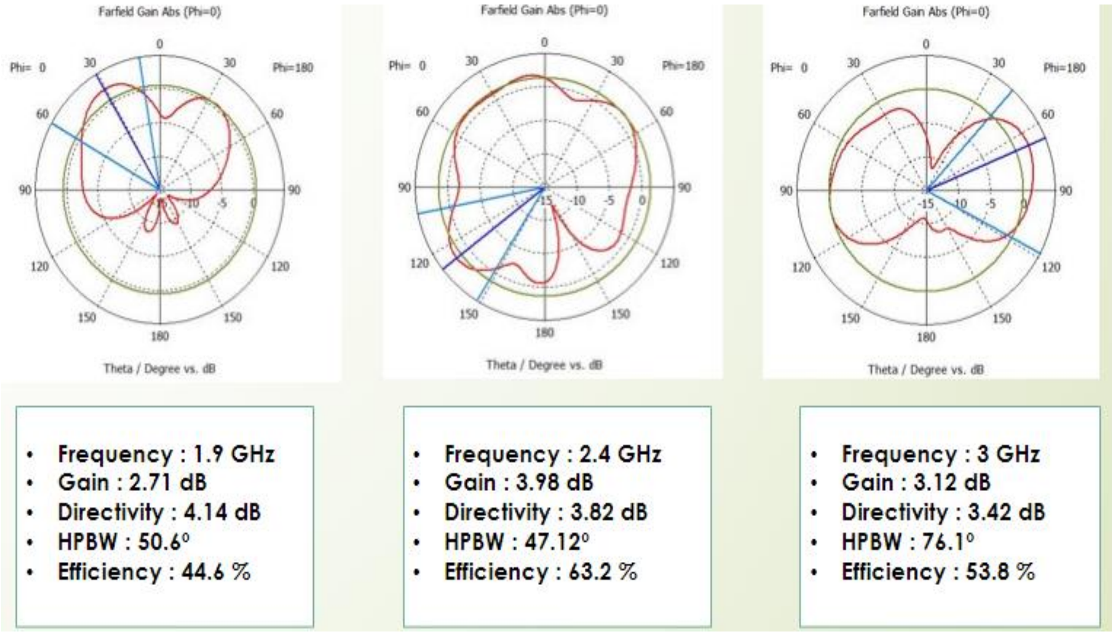


Figure 20b Radiation patterns

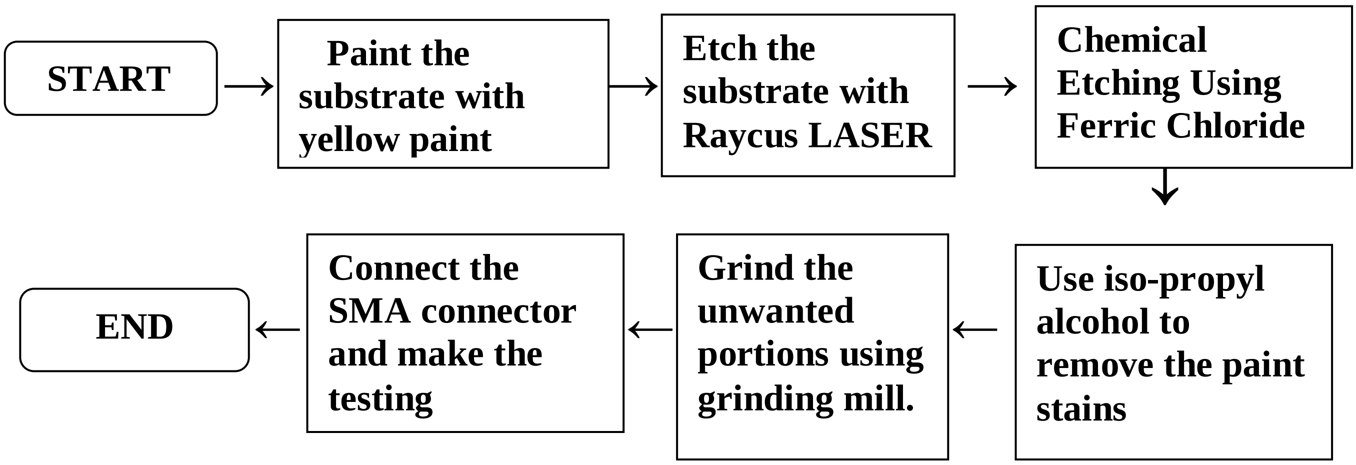
The designed antenna is used and simulated to get the required six resonant frequencies for six different application which is the main motive of this project. Next step is the fabrication process and to analyze using the fabricated product which will be discussed in the following chapter.

CHAPTER 4

FABRICATION PROCESS

4.1 LASER CUM CHEMICAL ETCHING

This chapter discusses the various techniques used for antenna fabrication. The antennas fabricated using different techniques were then compared for their performance, to identify the most suitable fabrication methodology.



4.1.1 LASER ENGRAVING:

Laser engraving is a process that vaporizes materials into fumes to engrave permanent, deep marks. The laser beam acts as a chisel, incising marks by removing layers from the surface of the material. The laser hits localized areas with massive levels of energy to generate the high heat required for vaporization. Laser engraving sublimates the material surface to create deep crevices. This means that the surface instantly absorbs enough energy to change from solid to gas without ever becoming a liquid. To achieve sublimation, the laser engraving system must generate enough energy to allow the material's surface to reach its vaporization temperature within milliseconds.

Figure 21a RAYCUS LASER

Figure 21b IPG LASER

Using the EZCAD software, the image is imported. X and Y coordinates of the design are given as inputs from which many passes are run to etch the design.

Figure 22a Feeding input to laser

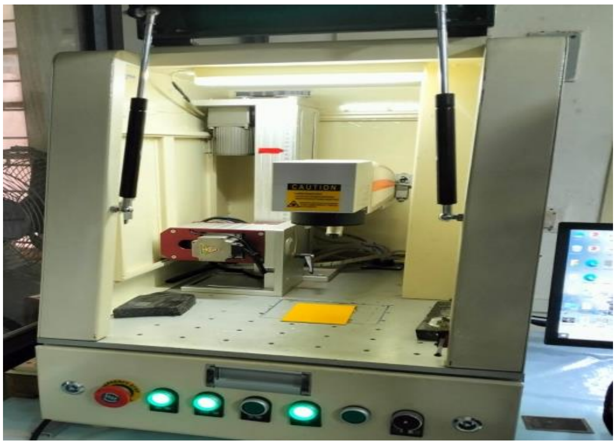


Figure 22b Placement of Substrate

Figure 23a Before etching

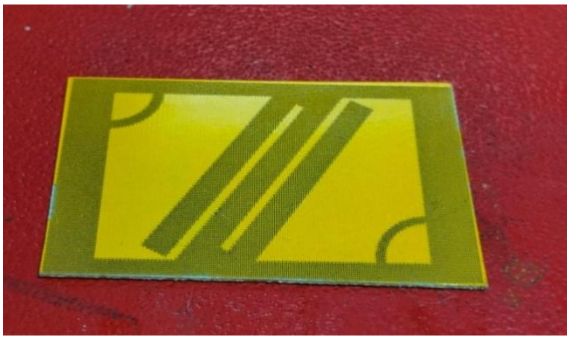


Figure 23b After LASER etching

4.1.2 CHEMICAL ETCHING:

The chemical etching process works by printing a component design on to photo resist which is laminated onto metal. The areas of photo resist which have not been printed are removed, exposing the metal, which is subsequently etched away. Chemical etching, also known as chemical milling or photo etching, is a subtractive sheet metal machining process which uses chemical etchants to create complex and highly accurate precision components from almost any metal. Photo-etched components are burr and stress-free with no mechanical force or heat used, leaving material properties unaltered. Ferric chloride is one of the most widely used etchants in the field of chemical etching. It is commonly used to etch steel and stainless steel parts, but it is also capable of etching copper. One of the reasons it is so popular is because of its versatility.

$$\mathbf{FeCl_3 + Cu \xrightarrow{\triangle} CuCl_2 + FeCl}$$

Here the Copper of the substrate reacts with the Ferric Chloride and dissolve in the solution as CuCl2.In a solution the Ferric chloride and distilled water are mixed in 1:1 ratio to get the perfect etching of the copper.

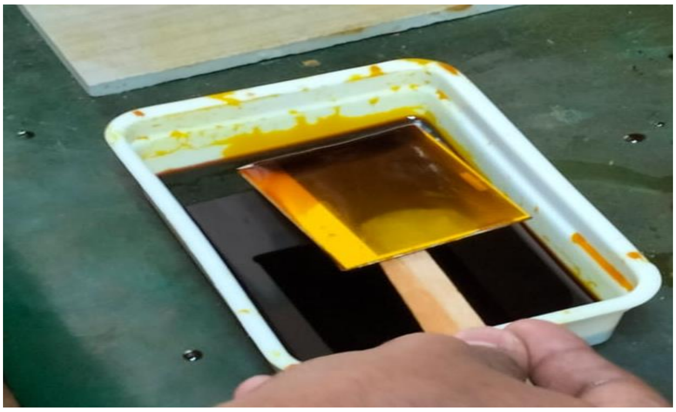


Figure 24 After reaction with $FeCl_3$

4.2 FINAL PREPARATIONS:

After the chemical etching of the laser fabricated material the paint stains in the material is removed using the Isopropyl alcohol. Isopropyl alcohol (rubbing alcohol) liquefies the oldest paint. Wet paint thoroughly and cover with plastic to prevent evaporation. Paint will wash off with water after a short time.

4.2.1 PHOTO POLYMERIZATION:

A negative acting photo polymerizable film resist in which a photopolymerizable layer is sandwiched between a temporary support film and a temporary cover film. This film has gained widespread usage in the manufacture of printed circuits in which the cover film is removed, the photopolymerizable layer is laminated by heat and pressure to the surface, e.g., copper, of a substrate to be permanently modified, the layer is image wise exposed to actinic radiation, the film support is removed, the unexposed areas of the layer are removed by solvent washout (development), and the resultant bared area of the copper surface is permanently modified, such as by etching or deposition of metal.

4.2.2 TINNING:

Tinned copper is primarily used for protection against oxidation and corrosion. In climates where copper has long-term exposure to water, the oxygen will combine with the metal and form copper oxide, weakening the bonds of the metal. It is worse if the wire is in contact with salt water.

Figure 25 During tinning process

4.2.3 GRINDING:

Finally the fabricated antenna is grinded using the grinding machine .Grinding machine Grinds the unwanted area in the antenna. Grinding is used to avoid unnecessary losses in the substrate while cutting the antenna.

Figure 26 During Grinding process

4.3 INDUSTRIAL FABRICATION:

4.3.1 FILM FORMING:

In all the above fabrication methods there is no need of Gerber file. In the industrial fabrication process there is a need of Gerber file of each layer of the antenna. We imported the Gerber file of our antenna and send it to the industrial. They will form the film based on the Gerber.

Figure 27 Film of patch

4.3.2 TARGET FIXING:

In order to fix the layer of the substrate to be fixed without shaking for drills are made on the substrate using screws and the substrate is fixed tightly. The machine used the film to make holes on the substrate

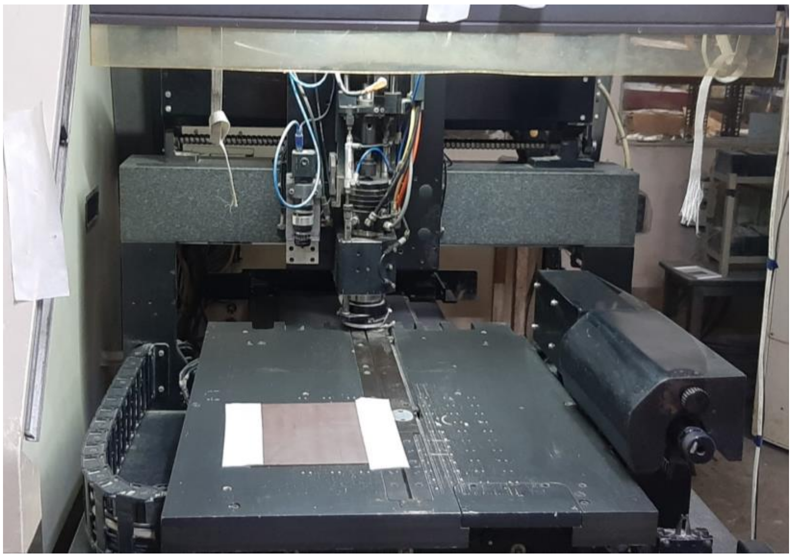


Figure 28 Target fixing

4.4 FABRICATED ANTENNA FROM INDUSTRY:

During stacking of antenna a non conducting glue is used and pressed the stacks.So that it won't affect radiation pattern.

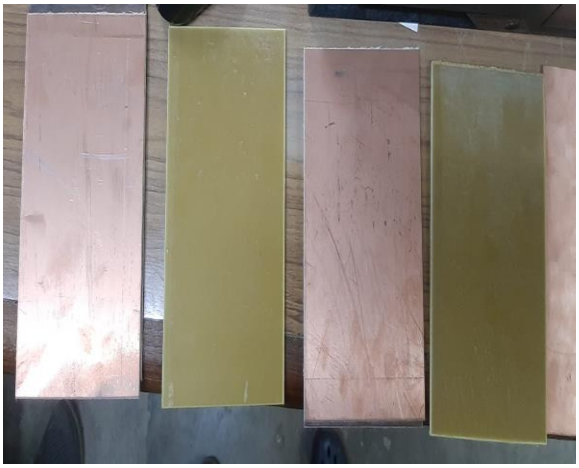
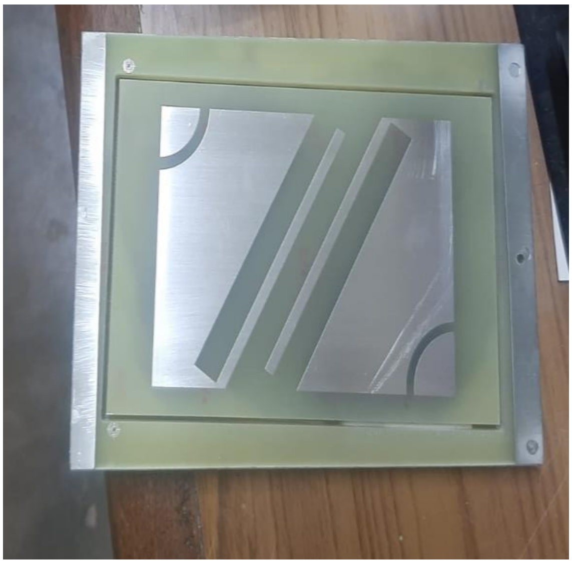


Figure 29a Before fabricating

Figure 29b After fabricating



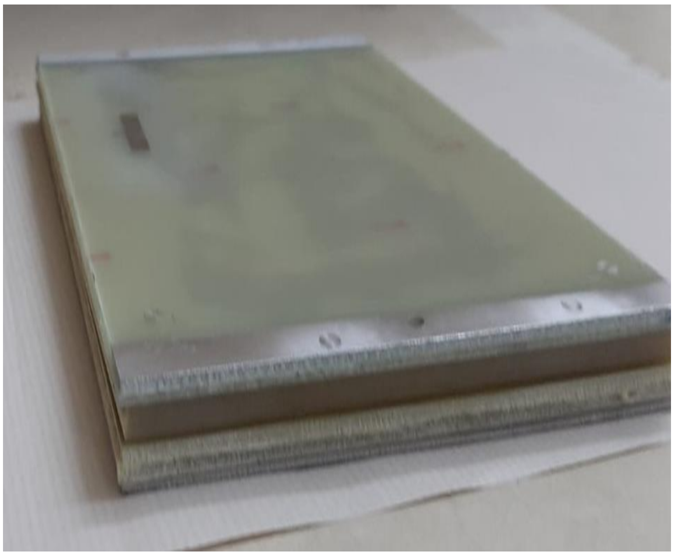
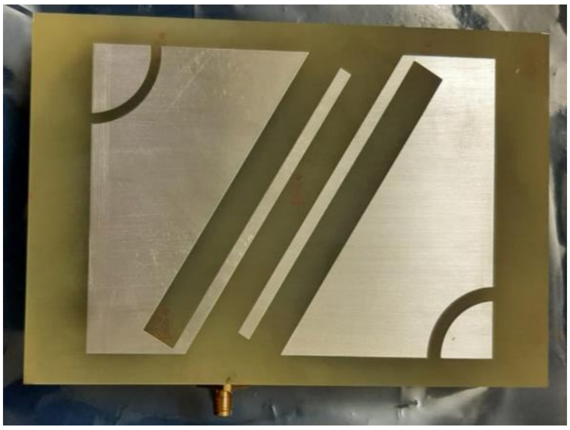


Figure 30a Front view of the antenna Figure 30b Stacked substrates

The stacking of antenna using bonding is a tedious process and it so costly also glue based stacking so as to reduce the cost of fabrication without affecting the radiation pattern.

4.5 FINAL FABRICATED ANTENNA:

The SMA connector with 14.4 mm is unavailable .So a copper wire is used to connect the SMA connector with the ground plane.



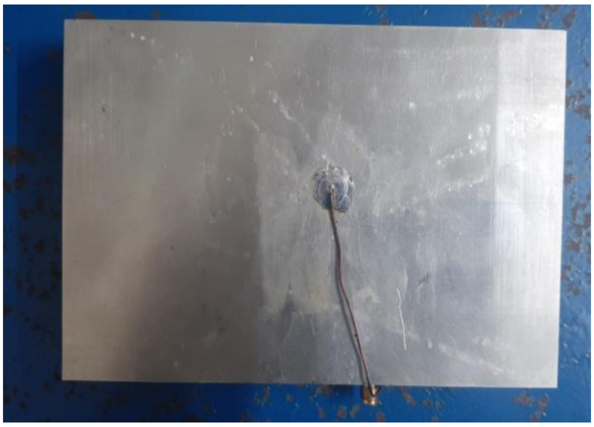


Figure 31a Top view

Figure 31b Back view

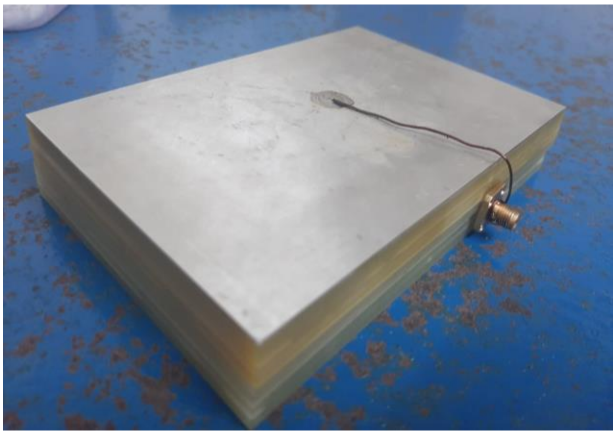


Figure 32a Side View

Figure 32b Side View

4.6 NETWORK ANALYSER:

A network analyzer is an instrument that measures the network parameters of electrical networks. Today, network analyzers commonly measure S parameters because reflection and transmission of electrical networks are easy to measure at high frequencies, but there are other network parameter sets such as y-parameters, z-parameters, and h-parameters. Network analyzers are often used to characterize two-port networks such as amplifiers and filters, but they can be used on networks with an arbitrary number of ports. A VNA (Vector Network analyzer) is a form of RF network analyzer widely used for RF design applications. A VNA may also be called a gain–phase meter or an automatic network analyzer.

4.6.1 CALIBRATION KIT:

Calibration kit is used to remove the noise which were present in the previous simuation. It contains three port namely OPEN, SHORT, LOAD .These three ports were connected to the measuring tube and the noises where removed. CALKIT 85220A is used for testing.

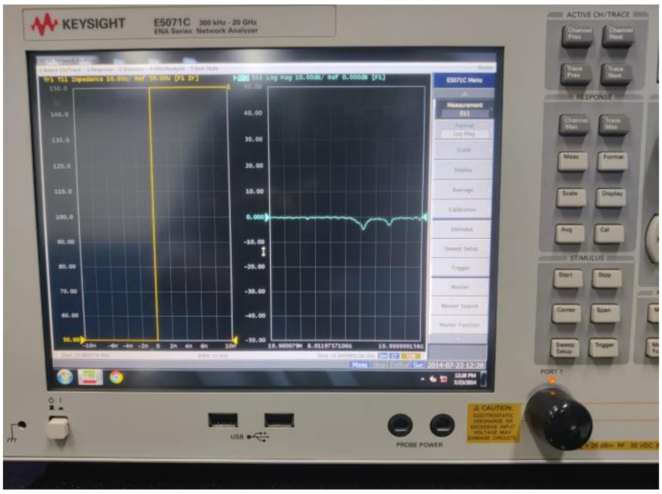


Figure 33a Calkit 85220A

Figure 33b Vector Network Analyzer

4.6.2 SMA CONNECTOR:

SMA (*SubMiniature version A*) connectors are semi-precision coaxial RF connectors developed in the 1960s as a minimal connector interface for coaxial cable with a screw-type coupling mechanism. The connector has a 50 Ω impedance. SMA was originally designed for use from DC (0 Hz) to 12 GHz, however this has been extended over time and variants are available to 18 GHz and 26.5 GHz. There are also mechanically compatible connectors such as the K-connector which operate up to 40 GHz. The SMA connector is most commonly used in microwave systems, hand-held radio and mobile telephone antennas and, more recently, with WiFi antenna systems and USB software-defined radio dongles. It is also commonly used in radio astronomy, particularly at higher frequencies (5 GHz+).

Figure 34 SMA Connector

CHAPTER 5

FABRICATION RESULTS

5.1 ANALYSIS USING MINIATURIZED ANTENNA DESIGN:

The proposed antenna design is first analyzed with dimensions reduced. The length is reduced to 60 mm from 150 mm and width is reduced to 40 mm from 100 mm. Without stacking the substrates, analysis were made to observe only the effect of slots in patch.

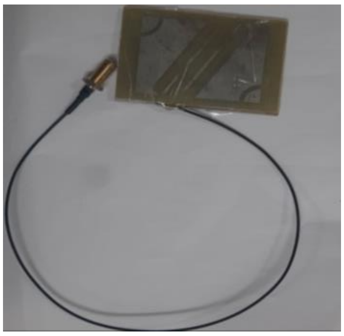


Figure 35 60 X 40 mm Antenna with SMA connector

The patch length is reduced to 48 mm and patch width is reduced to 35 mm. The thickness of upper substrate and lower substrate is 1.6 mm. The results obtained are shown below.

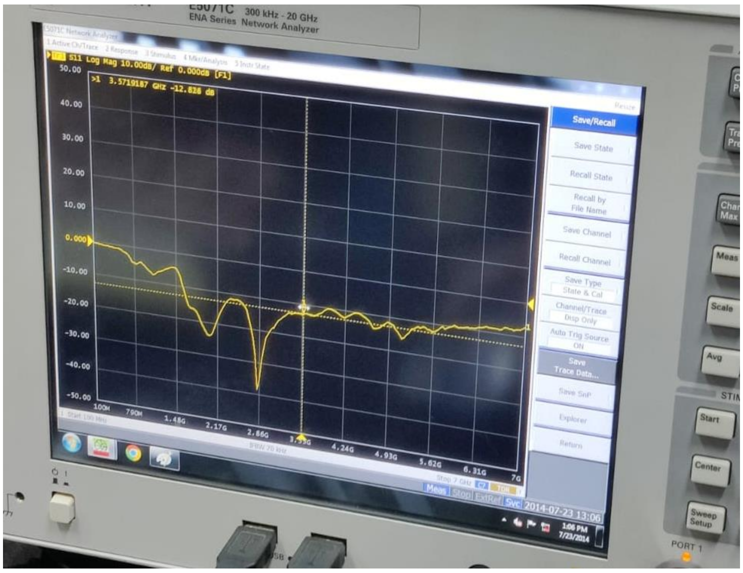


Figure 36 S_{11} plot

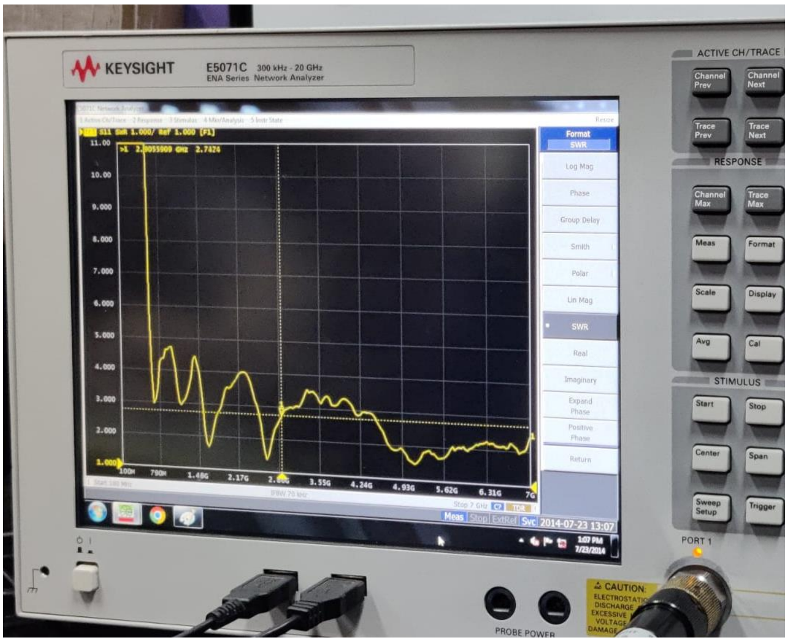


Figure 37 VSWR plot

From the VSWR plot and S_{11} plot, it was observed that using the designed patch, the antenna is able to resonate at two frequencies 1.9 GHz and 2.8 GHz. This miniaturized antenna did not have the effects of the proximity coupled feed technique and the desired frequencies don't have high S_{11} magnitude values. So, the substrates are stacked and using the parameters finalized in simulation stage, the antenna is fabricated and analyzed in the following section.

5.2 NETWORK ANALYZER RESULTS:

The Antenna fabricated in industry is tested and analysis are made using Vector network Analyzer. Following Figure shows the S_{11} of the fabricated antenna.

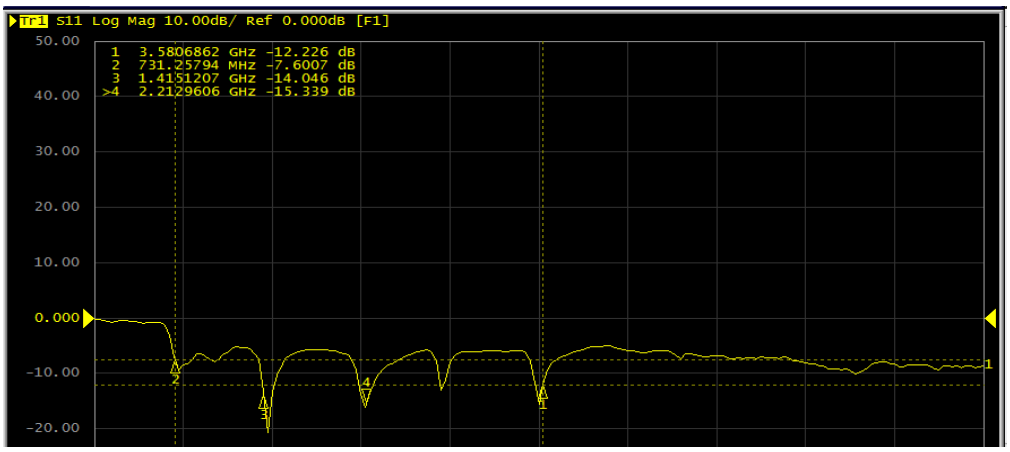


Figure 38a S_{11} plot

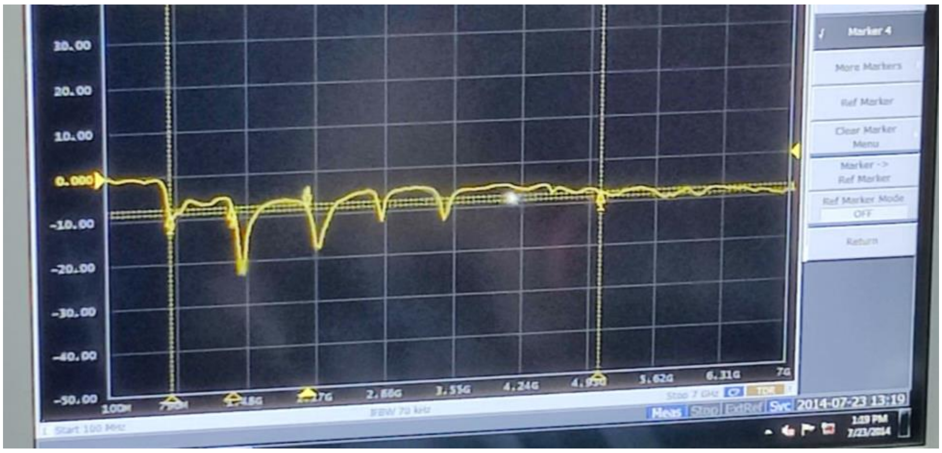


Figure 38b S_{11} plot

The resonant frequencies are 0.7, 1.17, 1.4, 2.2, 2.8 and 3.5 GHz which vary a little from the required resonant frequencies obtained in simulation process due to accidental errors in stacking and cable losses that occur when measured using network analyzer. But the antenna is able to produce six resonant frequencies which are required to meet the operations of six applications.

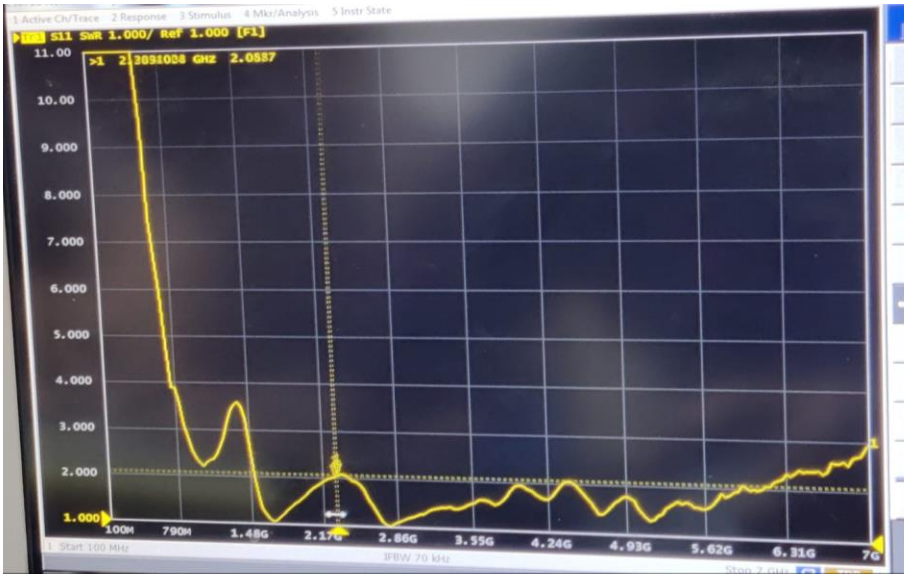


Figure 39 VSWR result from network analyzer

From the VSWR plot, it is deduced that the impedance is matched well between feedline and antenna at the six resonant frequencies as VSWR values are within acceptable range (<3) at those frequencies.

CHAPTER 6

CONCLUSION

In this Project, a Hexaband antenna has been designed, simulated and fabricated for which multiband operation has been achieved with a rotated and inverted S-shaped slot by substrate stacking and proximity coupled feeding technique. The designed antenna supports LTE at 0.7 GHz with a gain of 3.156 dB and efficiency of 70%, GPS L5 at 1.17 GHz with a gain of 2.74 dB and efficiency of 69.56%, Radio Navigation at 1.3 GHz with a gain of 3.42 dB and efficiency of 52.04%, Cordless Telecommunication at 1.9 GHz with a gain of 4.14 dB and efficiency of 44.6%, WLAN at 2.4 GHz with a gain of 3.98 dB and efficiency of 63.2% and 5G (Sub 6 GHz band) at 3 GHz with a gain of 3.12 dB and efficiency of 53.8%. Through several iterations and parametric analysis, the effects of varying length and width of slot and feed line, thickness of substrates and proximity coupled feeding technique were studied and as a result, thickness of the antenna has been reduced from 30.47 mm to 24.105 mm, patch slot width has been reduced from 15.48 mm to 9.906 mm. From experimental results, the S_{11} parameters and VSWR plots are reported and it is concluded that the suggested design can be used for mentioned applications supporting multiband operation.

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