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Design and Analysis of Microstrip Patch Antennas for Narrow Band Communication Applications

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Abstract- Microstrip antennas are low-profile antennas. A metal patch mounted at a ground level with a dielectric material in between constitutes a Microstrip or Patch Antenna. These are very low- size antennas having low radiation. The patch antennas are popular for low-profile applications at frequencies above 100 MHz, these antennas consist of a very thin metallic strip placed on a ground plane with a dielectric material in-between. Usually, the antennas are chosen to be circular or rectangular in shape for ease of analysis and fabrication. These antennas are employed at ultra-high frequencies and higher frequencies. This paper aims to design and analysis of microstrip patch antennas for Narrowband Communication Applications by the analysis on antenna parameters such as Voltage Standing Wave Ratio (VSWR), S11 Parameters, Radiation Pattern and Gain. Dielectric materials FR4 Epoxy, RT Duroid 5880, RT Duroid 6006 and RT Duroid 6010 are considered whose permittivity is 4.4, 2.2, 6.15 and 10.2. The antennas are simulated at 900 MHz frequency using Ansys Electromagnetic Suite (HFSS) software and the resultant graphical analyses of the parameters are plotted. The antennas are also fabricated with the above dielectric materials and are tested for practical values using a network analyser using Midas software. The results show that RT-Duriod 6006 gives better values when compared to the other substrate materials. The gain observed is 12.6 dB with a VSWR of 1.65. From the obtained results, it can be concluded that the antenna made from this substrate material (RT-Duriod 6006) are best suited for narrow band communication applications.
Keywords- Voltage Standing Wave Ratio (VSWR), Return Loss (RL), Dielectric Constant, Gain, High Frequency Structure Simulator (HFSS)

I. INTRODUCTION

In narrow-band communication applications, there is a two-way wireless transmission between the cellular phone handset and the base station tower. The cell phone converts the audio signal into electrical form using a microphone. This information is imposed on higher frequency carrier signals by the process of modulation. The modulated carrier signals by the process of modulation. The modulated carrier is radiated into free space as an electromagnetic wave which is picked up by the base station tower. This is one of the typical examples of a wireless communication system that uses free space as a medium to transfer information from the transmitter to the receiver. A key component of a wireless link is the antenna which efficiently couples electromagnetic energy from the transmitter to free space and from free space to the receiver. The microstrip antenna can be called a printed antenna which means an antenna fabricated using photolithographic techniques on a printed circuit board (PCB). They are mostly used at microwave frequencies. An individual microstrip antenna consists of a patch of metal foil of various shapes (a patch antenna) on the surface of a PCB (printed circuit board), with a metal foil ground plane on the other side of the board. There are many parameters measuring the performance of the antenna, Some of them are the dimensions (form factor), Voltage Standing Wave Ratio(VSWR), Return Loss(RL), Gain, Directivity, Operating Frequency, the substrate material (the dielectric constant of the material), the height of the substrate material, type of feed, feeding position. There were many works done previously to determine the effect of factors like feeding type, feeding position, and operating frequency on the parameters of the antenna. The following work shall be considered to find the effect of the substrate materials on the parameters of the antenna. Since the paper aims to find the effect of substrate materials on antenna parameters, all the other parameters are kept constant for all the antennas. The frequency of operation is fixed to be 900 MHz; the feeding type is a microstrip input feed. Four dielectric materials named FR4 Epoxy, RT-Duroid 5880, RT-Duroid 6006, and RT-Duroid 6010 are considered whose dielectric constants are 4.4, 2.2, 6.15, 10.2 with heights of 1.6mm, 1.5748mm,1.905mm and 1.574mm. These antennas are simulated using Ansys Electromagnetic Suite (HFSS) and the resultant graphical analyses of the parameters are plotted. The antennas are also fabricated with the above dielectric materials and are tested for practical values using a network analyser using Midas software.

II. PREVIOUS LITERATURE

First work was done in 1989 by varying the height of the substrate and the dielectric constant of the substrate [9]. Better results are observed when the substrate height is more than 0.02 λ (wavelength). Theoretically the models generated at this frequency have given the best results [9]. The work in the year 1992 has concentrated on the software used for simulation of antenna [6]. Using software, the users had the freedom to select the required pattern which can be calculated by the theoretical formulae or by the previous works done [6]. Since the beginning of the use of antennas the size of the antenna and the band width of the antenna were of great concern. The size of the antenna depends on two major factors

The operating frequency

The Di-electric constant of the substrate material used.

Some times while using a material with higher di-electric constant, some of the parameters might be affected, leading to undesirable values of the required parameters like VSWR or the return losses. The increase in the dielectric constant of the increase the band width of the operation, but the other parameters might get disturbed [15]. One of the ways to achieve this is the use of the concept of “External substrate perforation” [2]. The goal is to achieve desirable effects parameters of antenna, while eliminating the undesirable effects of the antenna. The work done was generated by the finite-difference time-domain (FDTD) technique. The change in effective dielectric constant has effectively reduced the unwanted interference pattern. For the first time computers were involved in analysis and design of antennas and microwave components in the year 2000 [5]. The major reason being the availability of high power computers and the development of simulation software’s. The work in the year 2004 [7] gives the importance of proper feed network and the impendence matching. This work deals with the importance of the various factors of an antenna on the performance of the antenna. This paper even discussed the importance of proper position for terminating the feed. The feed used here was coaxial feed. One of the major works in the year 2008 in the field of antennas was to find the changes when a microstrip patch antenna was immersed in a external dielectric material [12]. For the ease in conducting the experiment the authors have used dielectric powder to observe the effect. From the experiment conducted, the conclusion was that when a microstrip antenna was immersed in a external dielectric material the VSWR was less than 2:1, but the other parameters like the gain and the bandwidth and efficiency have been disturbed, but the form factor (size) is reduced significantly, so when the reduction in size of the antenna is the major concern and the other parameters can be compromised, this technique is best suited [12]. In 2011 work was done to understand the effect of higher dielectric materials on the higher power of the antenna [4]. In this experiment three classes of high dielectric materials were developed.

Major concern was that the selected materials must be capable of withstanding higher voltages; the built materials are applications which are to be used in the frequency bands of VHF and UHF. The materials which are intended to work in the VHF band are classified as MU45, MU100 and MU550 [4]. In 2012 a research was intended to understand the effect of dielectric constants on parameters of microstrip patch antenna [13]. The materials used are Bakelite, FR4 Glass Epoxy, RO4003, Taconic TLC and RT Duroid. Taking a cue from the work done in the year 1989 [9], the effect of the di electric constant at a frequency of 2GHz was considered [1]. Different materials were used to reduce surface wave losses [1]. The software used is Sonnet [1]. In the same year (i.e., 2013), one of the easy and efficient way of producing microstrip patch antennas on flexible materials was introduced [16]. In the same work focus was on design, fabrication and testing of flexible. In 2014 research was intended to find the combined effect of height and the dielectric permittivity on microstrip antenna [3]. The feed type was microstrip feed and the shape of the patch was rectangular shape. The increase in the permittivity has seen a decrease in the return loss (RL), the band width also [3]. The next year (i.e., 2015) saw two important researches when antennas was concerned,

- One was the upgraded version of the work in the year 2014 [3], Similar to the work in the year 2014 [3] in 2015 work was done to find the effect of changing the substrate material and the thickness on the parameters microstrip patch antennas with inset type feeding [14]. This work was carried out in the software with advanced design system (ADS) 2009 momentum 3D planar electromagnetic simulator. This is one of the simulations software’s to do the analysis on antennas [5] [6].
- The other work carried in the same year was to find out the effect of height of the substrate material and the width of the patch on performance of antenna [15]. Height of the substrate material and the width of the patch play an important role in maximizing the radiation efficiency and increase the bandwidth [15]. For increase in the bandwidth the width must be around 1.5 times the length [15].

In 2018, the work was done on Ansoft High Frequency Structure Simulator [5] [6] to simulate a antenna working in the UWB frequencies [8]. In 2017, the work done in 2012 [13], 2015 [14], 2014 [3] and 2013 [1] was upgraded using the results in the paper [11], to find the efficiency of antenna [17]. In this work the 3 different materials used were polyethylene, silicon Dioxide and Silicon with the di-electric constants in the year 2.0 to 3.99, 4.0 to 6.0 and 6.0 to 12.0 respectively. In this work the dimensions were kept same and the dielectric materials were kept changing [17].

III. THE MATHEMATICAL FORMULAS

The basic patch antenna equations to determine the length and width of the antenna are as follows

$$\text{Width}=\frac{c}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} \quad (1)$$

$$\epsilon_{reff}=\frac{\epsilon_r+1}{2}+\frac{\epsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{w}\right)}}\right] \quad (2)$$

$$\text{Length}=\frac{c}{2f_0\sqrt{\epsilon_{reff}}}-0.824 \text{ x } h\frac{(\epsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{\epsilon_{reff}-0.3)(\frac{w}{h}+0.8)} \quad (3)$$

Where

C – Speed of light (3 x 10^8) m/s

f_o- Operating Frequency (Hz)

ϵ_r- Di-Electric Constant

ϵ_{reff}- Effective Di-electric Constant

h- Height of the Di-Electric Substance (m)

w- Width of the Patch (m)

l- Length of the Patch (m)

The resultant values of length and width of the antennas for different dielectric materials are tabulated as follows.

Table1 Dimensions of the Patch for different material

Substrate Material	Permittivity (ϵ_r)	Width (in mm)	Length (in mm)
FR4 Epoxy	4.4	91.22	71.26
RT Duroid 5880	2.2	118.5	100.4
RT Duroid 6006	6.15	79.28	60.30
RT Duroid 6010	10.2	63.34	46.93

IV. ANALYSIS

A. FR4 Epoxy

The material is very low cost and has excellent mechanical properties, making it ideal for a wide range of electronic component applications [17]. FR4 is unlikely to be viable for antenna feeding structures due to its high losses. However, for high density microwave circuits where path lengths are short and for broadband antenna elements, where losses and absolute dielectric constant values are less critical [17]. The designed FR4 Epoxy antenna can be seen in the Fig 1.The gain can be seen in the Fig 2. The Figure 3 is the Radiation Pattern of the FR4 Epoxy in the network analyser and Midas Software.

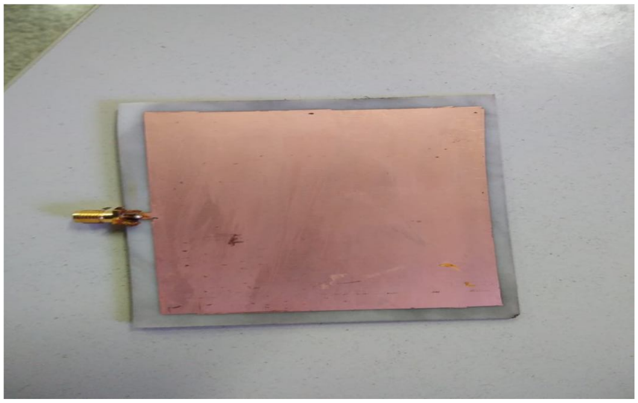

Fig. 1 Antenna built using FR4 Epoxy material

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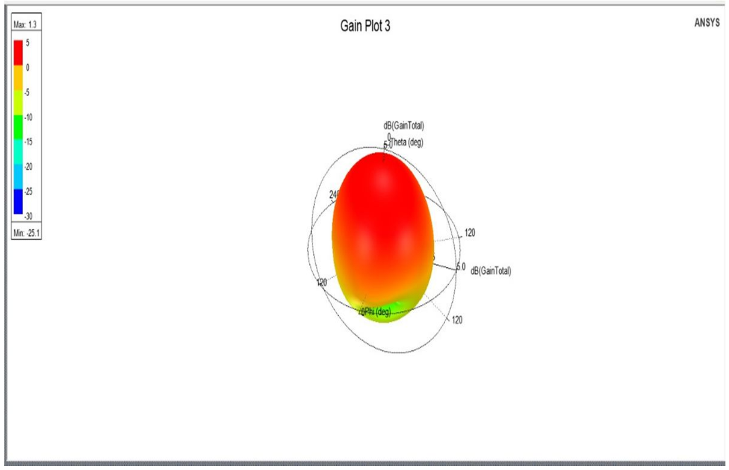

Fig. 2 Gain of FR4 Epoxy

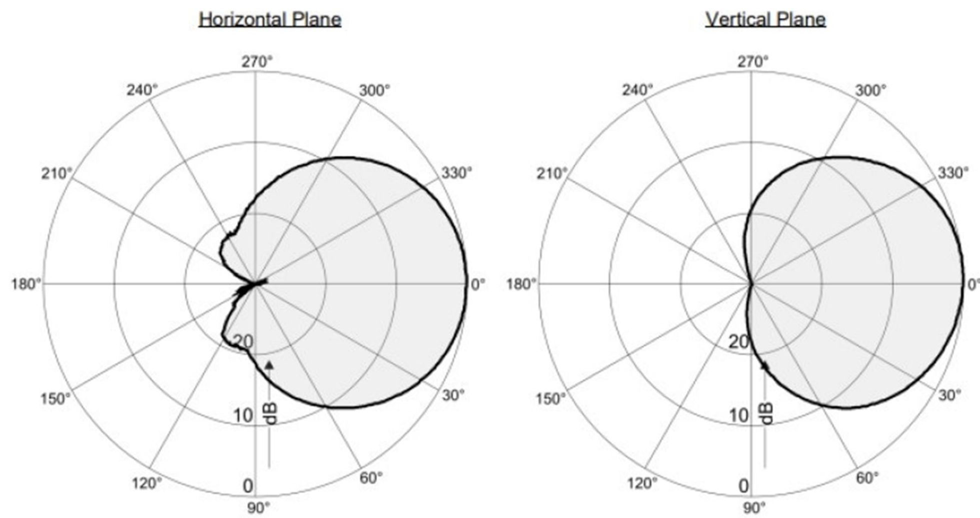

Fig. 3 Radiation Pattern of FR4 Epoxy

B. RT-Duroid 5880

This material has uniform electrical properties over wide frequency range. It is resistant to solvents and reagents used in etching or plating edges and holes. Major the advantage of the material is ideal for high moisture environments. The Di-Electric Constant (ϵ_r) of this material is 2.2. The Figure 4, 5 shows the RT-Duroid 5880 antenna and its Gain respectively. The Figure 6 is the Radiation Pattern of the RT-Duroid 5880 in the network analyzer and Midas Software.

Fig. 4 Antenna built using RT-Duroid 5880 material

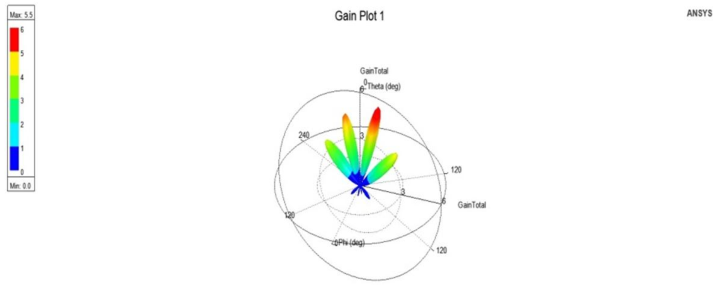

Fig. 5 Gain of RT-Duroid 5880

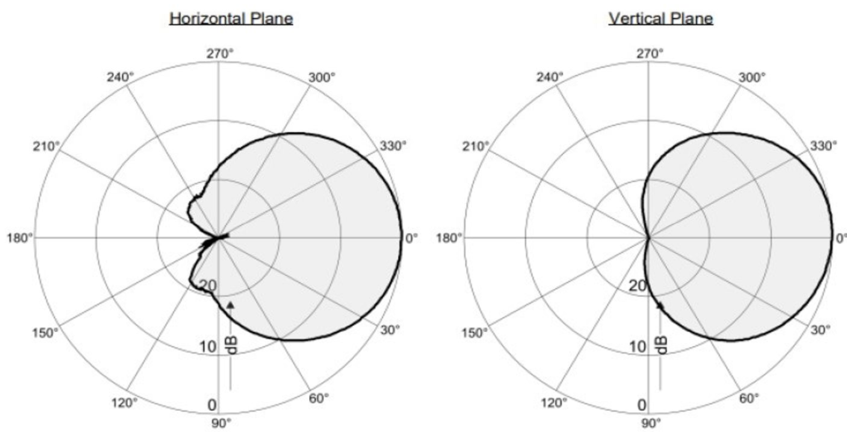

Fig. 6 Radiation Pattern of RT-Duroid 5880

C. RT-Duroid 6006

It has high dielectric constant for circuit size reduction. It has Low loss, ideal for operating at X-band or below.. Major the advantage of the material has low moisture absorption. The Di-Electric Constant (ϵ_r) of this material is 6.15. The Figure 7, 8 show the RT-Duroid 5880 antenna and its Gain respectively. The Figure 9 is the Radiation Pattern of the RT-Duroid 5880 in the network analyzer and Midas Software.

Fig. 7 Antenna built using RT-Duroid 6006 material

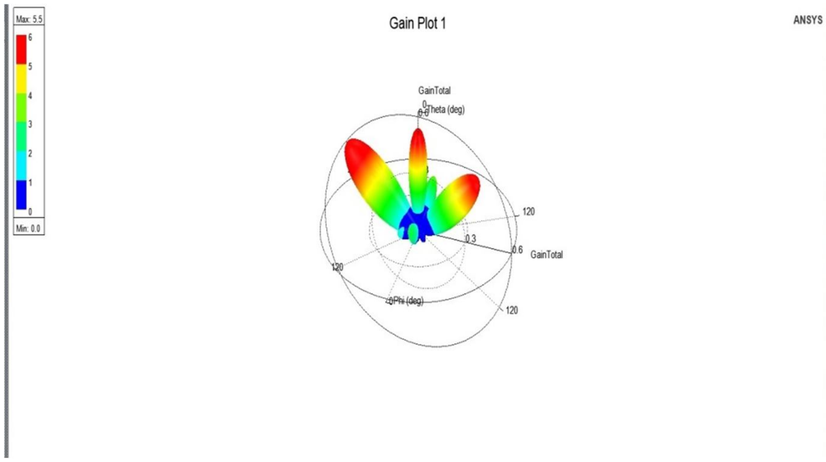

Fig. 8 Gain of RT-Duroid 6006

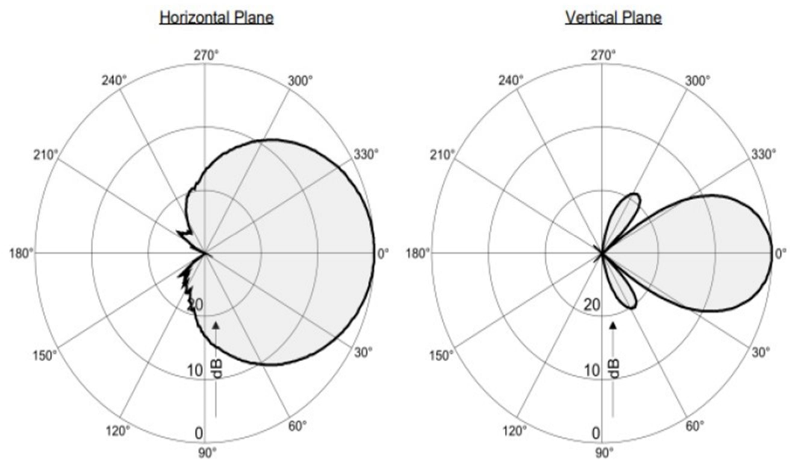

Fig. 9 Radiation Pattern of RT-Duroid 6006

D. RT-Duroid 6010

This material is filled PTFE (random glass or ceramic) composite laminates for use in high reliability, aerospace and defence applications. The Di-Electric Constant (ϵ_r) of this material is 10.2. The Figure 10, 11 show the RT-Duroid 5880 antenna and its Gain respectively. The Figure 12 is the Radiation Pattern of the RT-Duroid 5880 in the network analyzer and Midas Software.

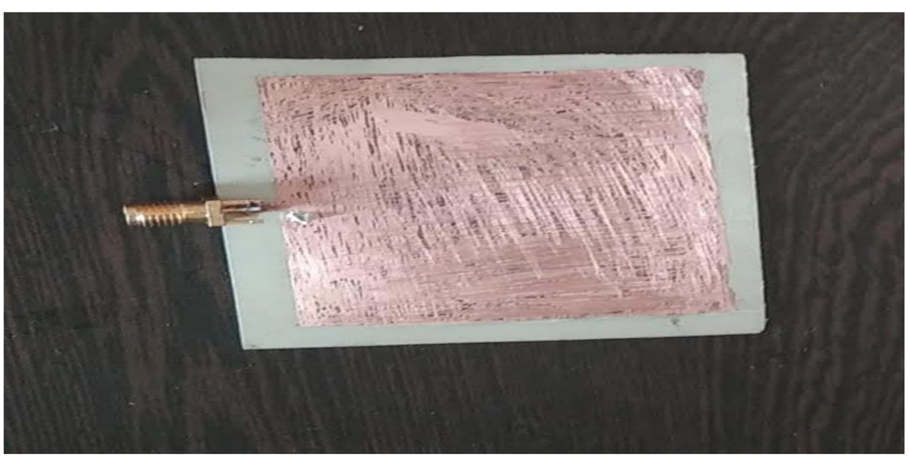

Fig. 10 Antenna built using RT-Duroid 6010 material

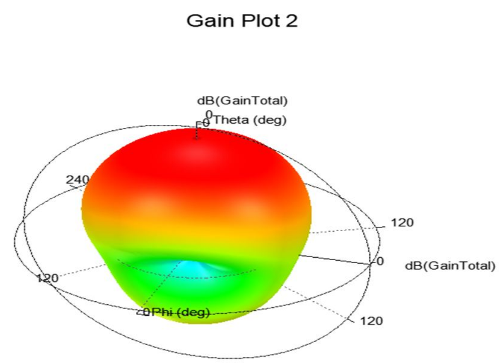

Fig. 11 Gain of RT-Duroid 6010

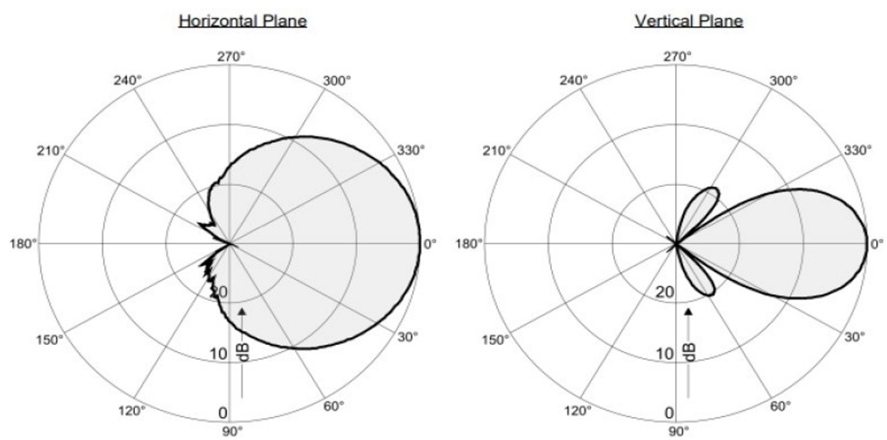

Fig. 12 Radiation Pattern of RT-Duroid 6010

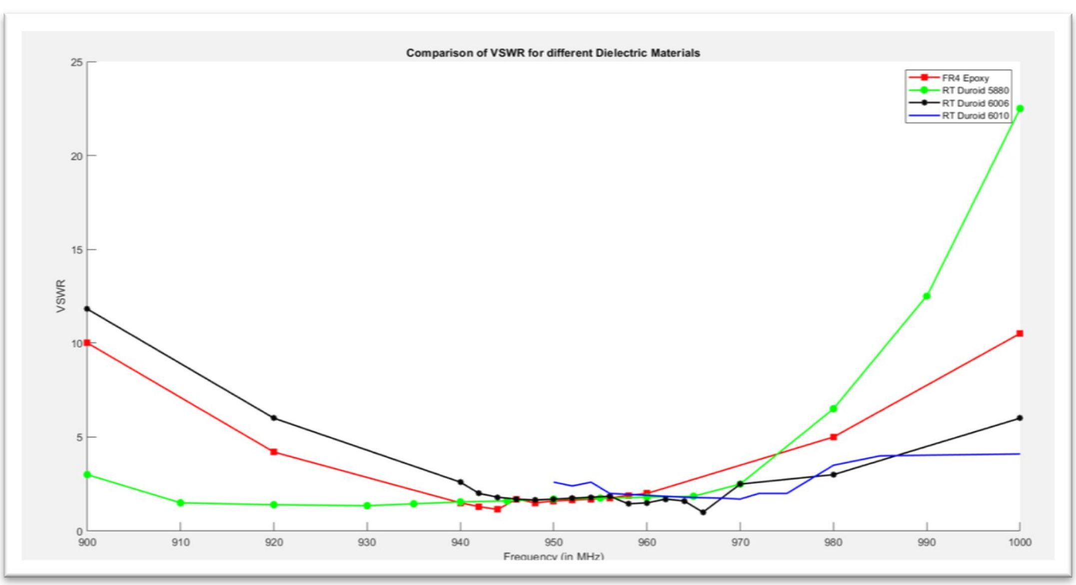

Fig. 13 VSWR Plot

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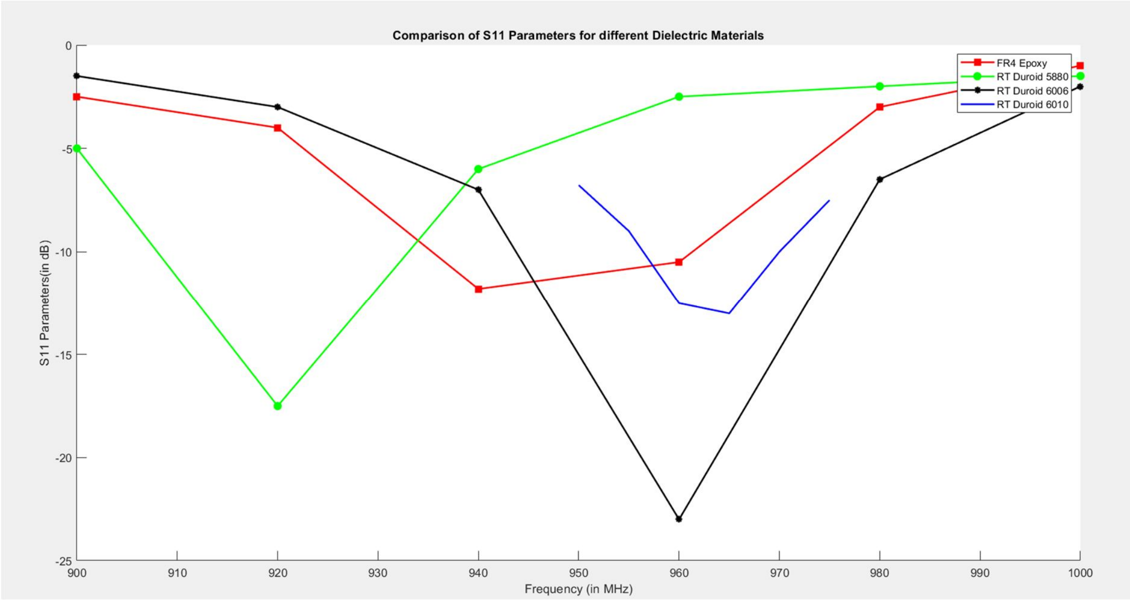

Fig. 14 Return Losses Plot

The VSWR and RL are plotted in figures 13 and 14. The simulation results and the experimental results are in the tables 2 and 3. Table 4 describes the comparison between both experimental and practical values.

Table 2 Simulated Values for Different Materials

Substrate Material	VSWR	Return Loss (dB)	Gain (dB)
FR4 Epoxy	1.6	-11	5
RT Duroid 5880	1.62	-17.5	6
RT Duroid 6006	1.59	-23	6
RT Duroid 6010	1.51	-12.5	

Table 3 Experimental Values for Different Materials

Substrate Material	VSWR	Return Loss (dB)	Gain (dB)
FR4 Epoxy	1.7	-10	5.5
RT Duroid 5880	1.8	-15	5.7
RT Duroid 6006	1.65	-20	12
RT Duroid 6010	1.52	-12	10

Table 4 Comparison between Experimental Values and Simulated Values for Different Materials

	VSWR		Return Loss(dB)		Gain(dB)	
	Simulation	Experiment	Simulation	Experiment	Simulation	Experiment
FR4 Epoxy	1.6	1.7.	-11	-10	5	5.5
RT Duroid 5880	1.62	1.8	-17.5	-15	6	5.7
RT Duroid 6006	1.59	1.6	-23	-20	6	12
RT Duroid 6010	1.51	1.52	-12.5	-12	6	10

V. CONCLUSION

In this project the microstrip patch antennas are first simulated by using ANSYS HFSS, and then they are designed and fabricated using the materials, and tested by a network analyzer and software Midas. The following are the conclusions.

A. RT-Duriod 6010 has the smallest size when compared to other di-electric materials, due to high di-electric constant.
B. As the dielectric constant of a substrate material is increasing, the form factor of the antenna decreases, it can help in optimization of the antenna size.
C. The gain of the antenna is observed to be more in RT-Duriod 6006 and RT-Duriod 6010 when compared to the other substrate materials, because of the high dielectric constant of the material.
D. For narrow band communication application, the gain must be high, even though there is no fixed rule for the VSWR, so from the analysis it can conclude that RT-Duroid 6006 is the best suited among the four chosen materials.
E. These materials can be used in designing antennas for navigational applications, which can work under the frequency ranges below 2.4 GHz

VI. ACKNOWLEDGMENT

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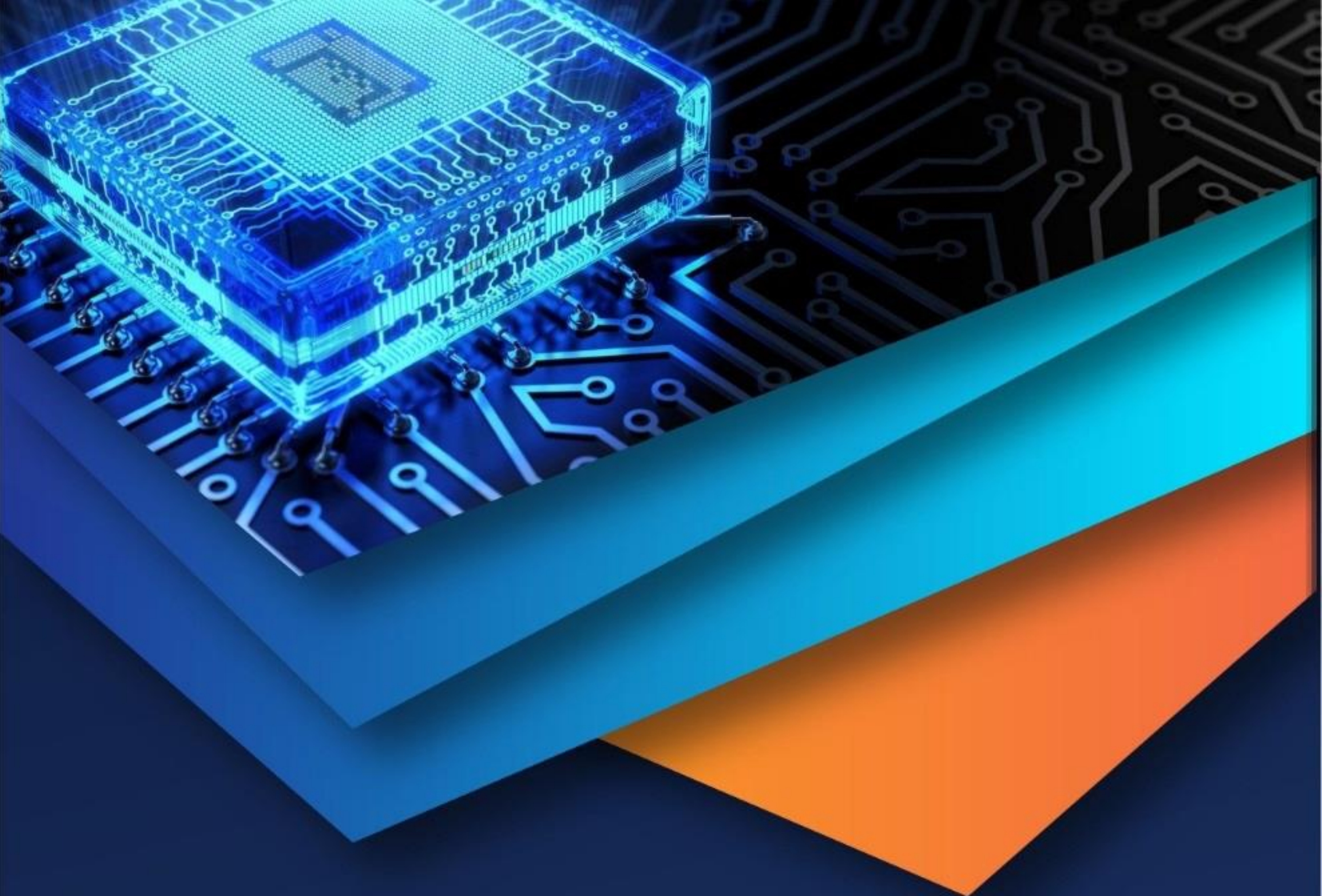

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