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PERFORMANCE ANALYSIS OF RECTANGULAR MPA USING DIFFERENT SUBSTRATE MATERIALS FOR WLAN APPLICATION

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Abstract
In this paper, a rectangular microstrip patch antenna (MPA) is designed using different substrate materials for analyzing the performance of the MPA. Alumina (Al_2O_3), Bakelite, Beryllium oxide (BeO), Gallium Arsenide (GaAs), RT-Duroid and Flame Retardant 4 (FR-4) are the six different substrate used in the design. The size of the rectangular microstrip patch antenna varies according to the dielectric constant of substrate materials used. The operating frequency taken for this analysis is 5.8 GHz. The proposed design provides the study on the performance of rectangular microstrip patch antenna for different substrate materials using the same frequency. This study conveys that which substrate material provides better performance. Moreover, this comparative study conveys that which substrate material provides better performance. The simulation parameters are investigated using HFSS.

Keywords:
Rectangular Microstrip Patch, Substrate Materials, Al_2O_3, Bakelite, BeO, GaAs, RT-Duroid and FR-4 and HFSS.

1. INTRODUCTION

MPA is a simplest form of antenna configuration has advantages such as small size, low-cost of fabrication process, low profile, light in weight, ease of installation and integration with many feed types [1]. But has a major limitations like low gain, less efficient, poor polarization purity, narrow bandwidth, etc.MPA become more essential for the next-generation communication systems where several wireless application. WLAN can be operated with the MPA at the operating frequency of 5.8GHz. WLAN is a wireless broadband solution that offers a rich set of features with a lot of flexibility in terms of deployment options and potential service offerings. WLAN can provide up to 600Mbps for fixed stations [2].

A microstrip patch antenna consists of a dielectric substrate which contain of a conducting medium mounted on the either sides of the substrate. Substrate plays a main role in microstrip it sets the radiating range and the size of the antenna structure etc. The upper side of the substrate is the patch which is the radiating part of the MPA and a lower conducting material is placed as a ground plane which is equal to the geometry of the substrate. The dielectric constant of the substrate decides the size of the patch placed in the MPA. There are different shapes of patch evolved such as hexagonal, circular, square and rectangular. Here, a rectangular shape of patch is taken under account and the MPA has been designed. The rectangular shape of patch also provides a good performance compared to other shapes. The electrical and physical size is mainly depends on substrate thickness and dielectric constant.

For the performance evaluation different substrates used here are Alumina, Bakelite, Gallium Arsenide, RT-Duroid, FR-4 and Beryllium Oxide. The size of the substrate determines the performance of the micro strip patch antenna. In an antenna design, thicker substrates containing low dielectric constant is used to increase the antenna efficiency and bandwidth. But, the size of the antenna is increased to a larger one. Thus, it cannot be used in other smart application. So, there are thinner substrates are used for higher dielectric constant which provides a small antenna size, but comparatively the antenna efficiency and bandwidth will be reduced. And so, an optimized antenna design should be made on considering the application where the antenna is being used.

2. LITERATURE REVIEW

In [3], Shukla studied the effects of various substrate material and their properties. They compared five different substrates like FR4-epoxy, Duroid, Roger 4350, Benzo-cyclobutane and Bakelite based in the multiband utilization, reflection coefficient and operating frequency. Hence, it is concluded that Bakelite provides a satisfactory parameters compared to other substrates. Srivastava et al. [4] compares different substrate materials for fulfilling the requirements of the MPA. They analyzed the return loss and 3D polar chart of the MPA designed with different substrates and frequencies. Since, they described that Roger RO4003 provides best results compared to other substrates.

Kaur and Goyal [5] compared the parameters of the antenna made from two different substrates like Epoxy Kevlar and FR4_epoxy for four different frequencies using HFSS tools. Thus, it is concluded that the resonant frequency and the band width decreases with increase in dielectric constant.

Mahamine et al. [6] analyzed the effect of different substrate on rectangular microstrip patch antenna for S-Band. They have used six different substrate materials namely FR-4, Polystyrene, Ceramic, Quartz, Styrofoam and Glass-pyrex. It has been finalized that Polystyrene substrate provides an improved antenna parameters.

Kiani et al. [7] analyzed four different substrates in a U patch antenna which is used for wireless communication system. This paper says that the higher permittivity substrates will provide more size reduction which is useful for WLAN, GSM and radio satellite applications. Bano [8] designed a rectangular microstrip patch antenna with a co-axial feed for the operating frequency of 1.9GHz and simulated the design on various dielectric substrates using Sonnet software. This provides an output that the Roger TMM6 and Silicon give a good output values.

Ingale et al. [9] compared different dielectric material in an H-shaped microstrip patch antenna for the operating frequency of 2.4GHz using HFSS software. It conveys that FR-4 substrate provides a good return loss value. Venkatrao [10] studied the performance analysis between two different dielectric substrates using rectangular microstrip patch antenna for the operating frequencies 2.4, 3.0, 3.5 and 4.0GHz. Thus, it concludes that the FR-4 is suitable for the given operating frequencies.

Mukherjee [11] analyzed performance of the rectangular microstrip patch antenna by varying the height of the substrate and frequencies. Mane [12] compared seven different dielectric substrate materials and observed results are good for FR-4 substrate. From the study, it is noticed that there are different substrates compared to know which substrate provides a good and preferable for the microstrip patch antenna used in different applications.

In this paper, the performance of Rectangular microstrip patch antenna using different substrates is presented. The paper is organized as follows: Section 1 discuss the introduction about the MPA and WLAN. Section 2 describes the antenna designs which consist of patch, substrate and Ground plane. Section 3 brings out simulated results of the rectangular MPA for each substrate. Section 4 concludes the merits of the paper based on the antenna parameter.

3. DIELECTRICSUBSTRATES

The antenna design is made under the platform of HFSS software. The patch of the antenna feed through a microstrip. Because, microstrip feed provide a good impedance matching between the patch and transmission line. Here, there six different substrates used to compare the performance of the each. The length and the width of the patch vary according to the substrate and the length and width of the ground plane will be equal to the substrate. The design process of the proposed antenna has a 0.04mm thicker rectangular patch with a microstrip feed is mounted on a substrate layer of thickness of 1.6mm, a dielectric constant varies according to the substrate used and ground plane of 0.04mm is attached to the other side of the substrate [13]. The descriptions of the different substrate materials and their dielectric constants with a detailed description are explained in Table.1.

3.1 GALLIUM ARSENIDE

Gallium Arsenide is a semiconductor with relative insensitive to heat owing to their wider band gap. GaAs provide a dielectric constant of 12.9. It is a high cost, highly resistive and high efficient material. It is used in the manufacture of Gunn diodes, computer chips, detectors and solar cells. The size of the antenna using GaAs for 5.8GHz is 19.4×16.4×1.68mm.

3.2 ALUMINA

Alumina is an electrical insulator with high thermal conductivity and corrosion resistance. It provides low electrical conductivity, high strength, and resistance to chemical attacks. It has a dielectric constant of 9.6. It is used in high performance applications such as integrated circuit, spark plug insulators, compact fluorescent lamps, bone and dental implants, grinding wheels, refractory linings and also in cosmetic industries etc. The size of the antenna using Alumina for 5.8GHz is 20.9×17.5×1.68mm.

3.3 BERYLLIUM OXIDE

Beryllium oxide is an electrical insulator with a higher thermal conductivity, semiconductor and good thermal conductivity parts. It is a stable ceramic used in rocket engines, gas lasers, vacuum tubes, radio equipment and microwave devices as protective over-coating. The size of the antenna design using Beryllium oxide for 5.8GHz is 22.7×19.0×1.68mm.

3.4 BAKELITE

Bakelite is highly resistant to electricity, heat and chemical action. Bakelite has a dielectric constant of 4.8. It is made using synthetic components which are easily available and not flexible. It can be molded easily and used in electronics, electrical, power generation, automobile and aerospace industries. The geometry of the rectangular MPA design made using Bakelite for 5.8GHz is 24.8×20.9×1.68 mm.

3.5 FLAME RETARDANT - 4

Flame Retardant-4 is an electrical insulator with good mechanical strength, high pressure thermo-set plastic which provides a good strength to weight ratios. It is used in printed circuit boards, transformers, switches, relays, etc. FR4 is used as an electrical insulator possessing with mechanical strength. The size of the antenna using FR-4 for 5.8GHz is 25.3×21.4×1.68mm.

3.6 RT-DUROID

RT-Duroid composites are designed for exacting strip line and micro strip circuit applications. The RT-Duroid is a low density, low electrical loss, highly reliable, low moisture absorption and lightweight materials with dielectric constant of 2.2. It provides a wide frequency range. It is used in military radar system, space satellite transceivers, ground and airborne based radar system. The size of the antenna design using RT-Duroid is 5.8GHz 30×26.1×1.68mm.

Table.1. Specifications of different substrate

Substrates	Dielectric constant	Loss Tangent
GaAs	12.9	0
Alumina	9.6	0.0003
BeO	6.8	0
Bakelite	4.8	0.002
FR-4	4.4	0.02
RT-Duroid	2.2	0.0009

4. ANTENNA DESIGN

The antenna is designed for the operating frequency (f_r) of 5.8GHz which of is an ISM frequency used for WLAN application, the length and width of the MPA is calculated using the height and dielectric constant of the substrate. Thus, the height of the patch is 0.04mm and the height of the dielectric substrate (h) is 1.6mm [14, 15].

Patch Width (*W*):

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

where, *c* is the velocity of light, *W* is the width of the patch for the operating frequency f_r and dielectric constant ε_r.

Effective Dielectric Constant (ε_{reff}): Effective dielectric constant is sufficient for finding the length of the patch. In practice, the antenna's field will not lie inside the length and width of the antenna dimension due to fringing effect. Due to effect of fringing field along the edges of the antenna patch, Effective dielectric constant ε_{reff} is evolved.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-1/2} \quad (2)$$

Patch Length Extension (Δ*L*): Due to the fringing effect on the other side or at the end of the patch, an additional line length is needed. Thus, patch length extension is evolved.

$$\Delta L = 0.412h\left(\frac{\varepsilon_{reff} + 0.3}{\varepsilon_{reff} - 0.258}\right)\left(\frac{\frac{W}{h} + 0.264}{\frac{W}{h} + 0.8}\right) \quad (3)$$

Effective Patch Length (L_{eff}): Effective Patch Length is the actual length of the antenna design which includes the length of the antenna and twice the length extension.

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \quad (4)$$

Patch Length (*L*):

$$L = L_{eff} - 2\Delta L \quad (5)$$

Substrate Width (W_s) and Ground plane Width (W_g):

$$W_s = W_g = 6h + W \quad (6)$$

Substrate Length (L_s)and Ground Plane Length (L_g):

$$L_s = L_g = 6h + L \quad (7)$$

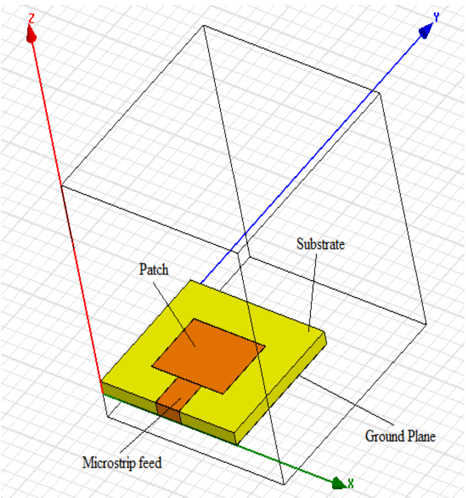

Fig.1. Design of rectangular microstrip patch antenna

The above Eq.(1) to Eq.(7) describe the calculation of width and length of the rectangular patch antenna for different substrate. The Table.1 shows the dimensions of rectangular MPA for different substrate. From the equation, it is known that the size of the antenna is depends upon the dielectric constant and height of the substrate used in the antenna design. Here, there are six different substrates used for performance analysis. The dielectric constant varies from one substrate to other but the height of all the substrate remains same. Each substrate has some tangential loss made in the surroundings. The thickness of the patch and ground plane is 0.04mm and substrate is 1.6mm [16, 17]. The design of the proposed antennas is made using the dimensions of the patch antenna as in the Table.2. The dimensions of the rectangular MPA will be varied according to the substrate materials used.

Table.2. Dimension of rectangular MPA

Substrates	**Patch (mm)**		**Substrate and Ground plane (mm)**	
	Width (W_P)	Length (L_P)	Width (W_s)(W_g)	Length (L_s)(L_g)
GaAs	9.8	6.8	19.4	16.4
Alumina	11.3	7.9	20.9	17.5
BeO	13.1	9.1	22.7	19.0
Bakelite	15.2	11.3	24.8	20.9
FR-4	15.7	11.8	25.3	21.4
RT-Duroid	20.4	16.5	30.0	26.1

5. SIMULATION RESULTS

The parameters of the antenna design are obtained through the HFSS software for the operating frequency of 5.8GHz. The simulated antenna parameters are explained below.

5.1 GALLIUM ARSENIDE

The Fig.2 denotes that the return loss and the bandwidth values of designed antenna with Gallium Arsenide substrate is -15.964dB and 200MHz respectively at the operating frequency of 5.8GHz. Also, it provides a VSWR value of 1.3785 as shown in Fig.3.

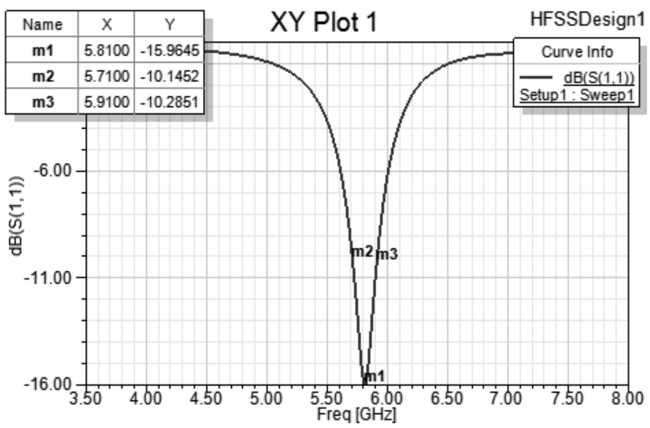

Fig.2. Return loss and Bandwidth of GaAs

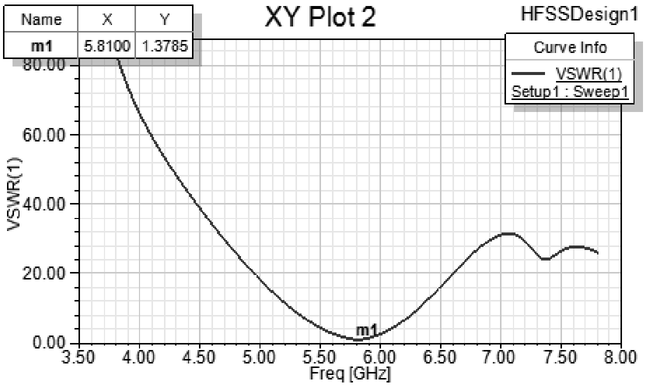

Fig.3. VSWR of GaAs

5.2 ALUMINA

The antenna design Alumina substrate provides the return loss and the bandwidth value -19.079dB and 210MHz respectively for the operating frequency of 5.8GHz and provides a VSWR value of 1.2502 as shown in Fig.4 and Fig.5. Alumina is resistive to chemical attacks with more strength.

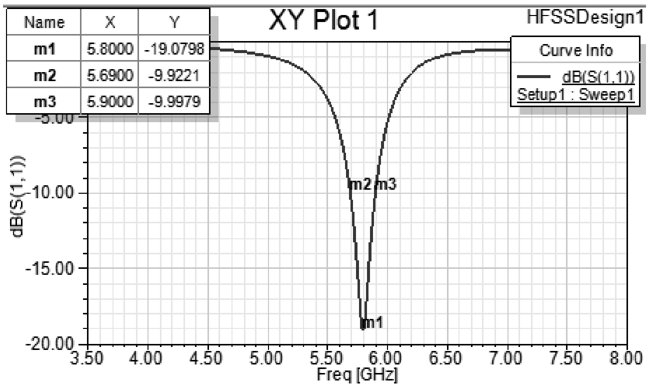

Fig.4. Return loss and Bandwidth of Alumina

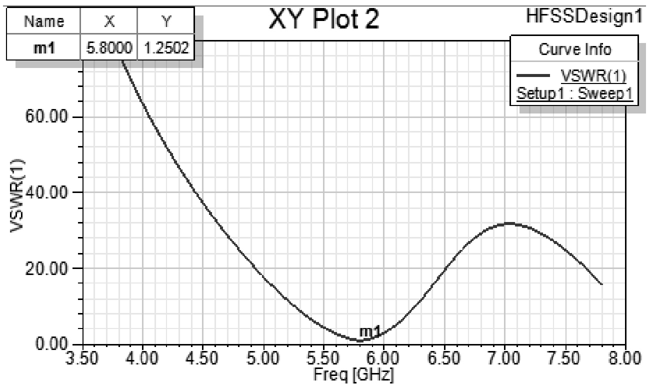

Fig.5. VSWR of Alumina

5.3 BERYLLIUM OXIDE

Beryllium oxide provides a return loss value of -21.370dB and band width of 240MHz at the operating frequency of 5.8GHz as shown in Fig.6. Then, the VSWR value of the substrate is 1.1868 which is represented in Fig.7.

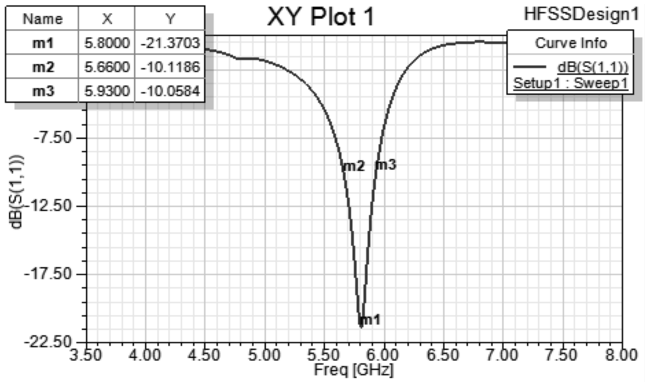

Fig.6. Return loss and Bandwidth of Beryllium oxide

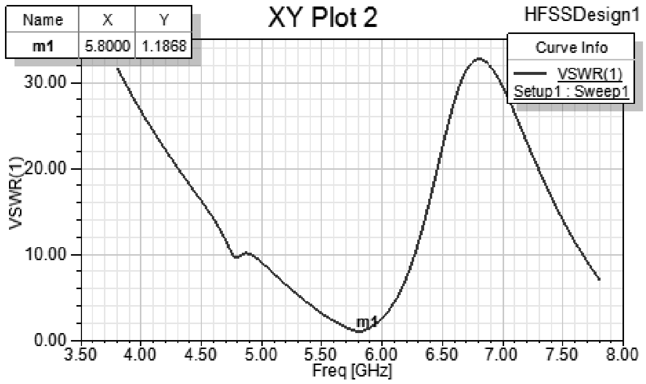

Fig.7. VSWR of Beryllium oxide

5.4 BAKELITE

The Fig.8 shows the return loss and the bandwidth value of Bakelite substrate is -22.729dB and 260MHz respectively at 5.8GHz. The Fig.9 represents the VSWR value of 1.1576. This substrate provides a 7dB reduction in return and wider increase in bandwidth for 60MHz.

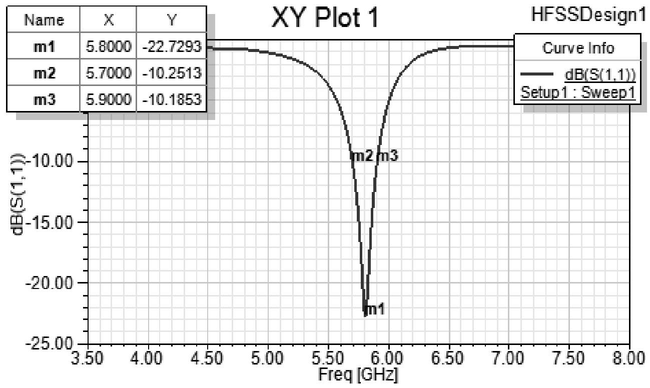

Fig.8. Return loss and Bandwidth of Bakelite

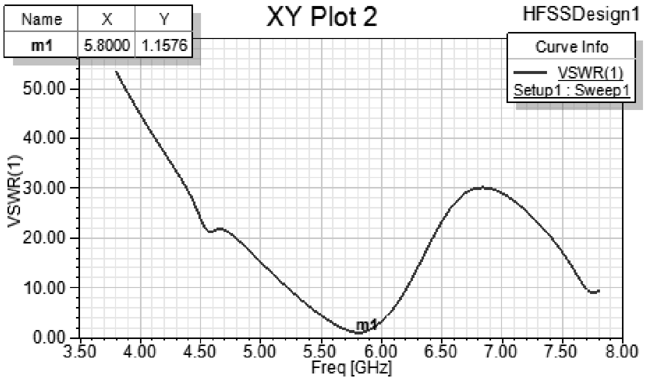

Fig.9. VSWR of Bakelite

5.5 FLAME RETARDANT - 4

FR-4 substrate provides a return loss value of-25.883dB and band width of 260MHz at 5.8GHz as shown in Fig.10. The Fig.11 represents the VSWR value of 1.1070. It provides a better reduction in return loss value of 5dB and 60MHz increase in bandwidth.

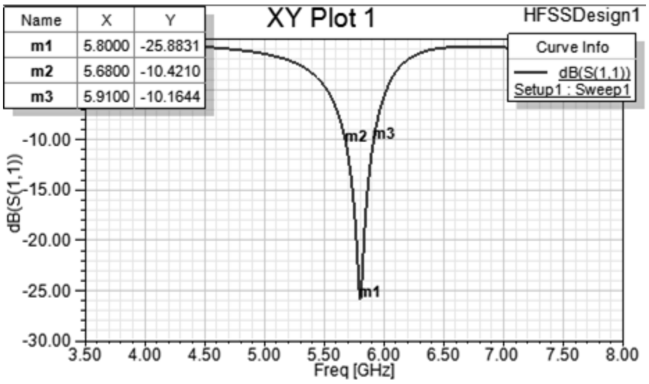

Fig.10. Return loss and Bandwidth of FR-4

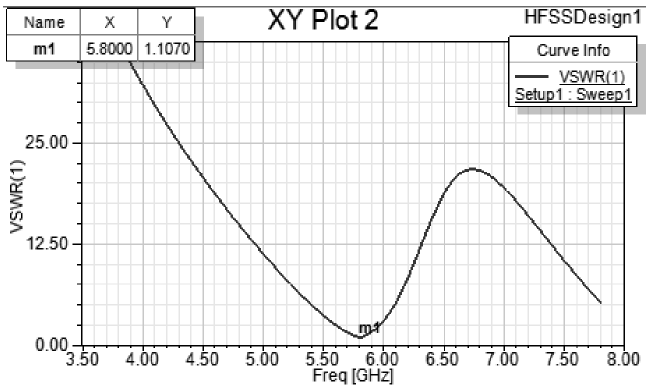

Fig.11. VSWR of FR-4

5.6 RT-DUROID

The Fig.12 shows that the FR-4 substrate provides a return loss value of -33.30dB and band width of 270MHz. The Fig.13 represents the VSWR value of 1.070.

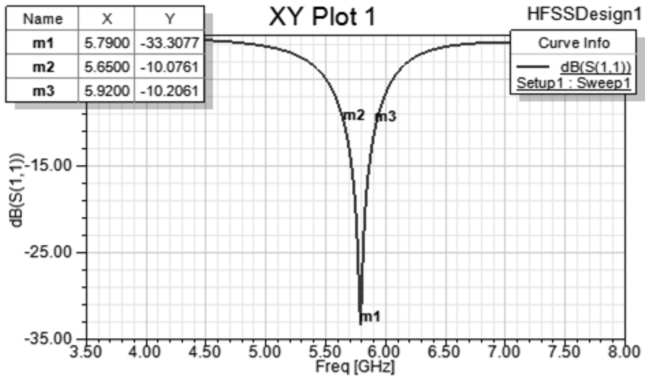

Fig.12. Return loss and Bandwidth of RT-Duroid

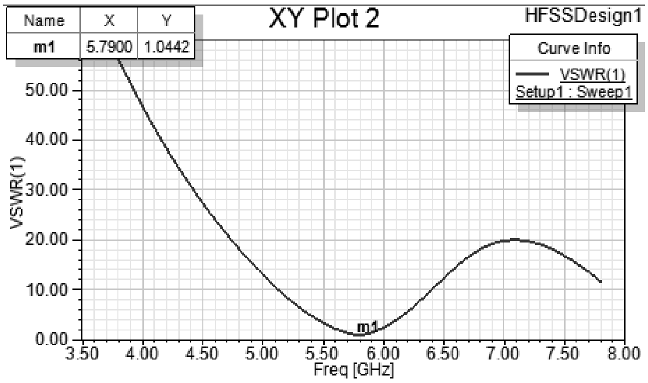

Fig.13. VSWR of RT-Duroid

Table.3. Simulation output for Different Substrates

Substrate	Return Loss (dB)	Bandwidth (MHz)	VSWR
GaAs	-15.96dB	200MHz	1.3785
Alumina	-19.07dB	210MHz	1.2502
BeO	-21.37dB	240MHz	1.1868
Bakelite	-22.72dB	250MHz	1.1576
FR-4	-25.88dB	260MHz	1.1070
RT-Duroid	-33.30dB	270MHz	1.0442

The Table.3 represents the return loss, VSWR and bandwidth values of the designed rectangular MPA for different dielectric substrates. The simulation results of the proposed antenna provide an improved performance for RT-Duroid substrate because of its reduced dielectric constant. Thus, it provides an improved return loss and bandwidth values compared to other substrates.

6. CONCLUSION

In this paper, a rectangular MPA is designed using different substrate such as Alumina, Bakelite, Gallium Arsenide, RT-Duroid, FR-4 and Beryllium oxide for the same frequency of 5.8 GHz frequency. Hence, the simulation outputs of the antenna design convey that the proposed antenna design provides best return loss and bandwidth for the substrate with reduced dielectric constant. Thus, this paper concludes that the rectangular MPA design made of RT-Duroid substrate provides 23% improved results compared to other substrates. Next to RT-Duroid, FR-4 substrate provides 19% increment in the simulation parameters. Therefore, a good MPA design made of substrates with lower dielectric constant brings potential benefits in terms of less, reflection co-efficient, wider bandwidth and good impedance matching.

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