THE CHARACTERISTICS OF RECTANGULAR AND SQUARE PATCH ANTENNAS WITH SUPERSTRATE

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ABSTRACT

This paper compares the characteristics of rectangular and square patch antennas with and without dielectric Superstrates. The proposed antennas were designed to operate at 2.4GHz and behavior is explained through parameter study using Finite Element Method based on EM- Simulator (High Frequency Structure Simulator). The antennas have been formulated using transmission line model. In this paper, we measured experimentally various characteristics of rectangular and square patch microstrip antennas with and without dielectric Superstrates. The effect of dielectric Superstrate thickness on the antenna characteristics such as resonant frequency, Bandwidth, Beam- width, Gain, Input impedance, Return –loss and VSWR etc. are measured experimentally and compared the characteristics of both antennas. The effect of microstrip patch antenna with dielectric Superstrates results in antenna resonant frequency being shifted to lower side, while other parameters have slight variation in their values. In particular, the resonant frequency increases with the dielectric constant of the Superstrates thickness. In addition, it has also been observed that return loss and VSWR increases, however bandwidth and gain decreases with the dielectric constant of the Superstrates thickness. Input Impedance increases as Superstrate become thick.

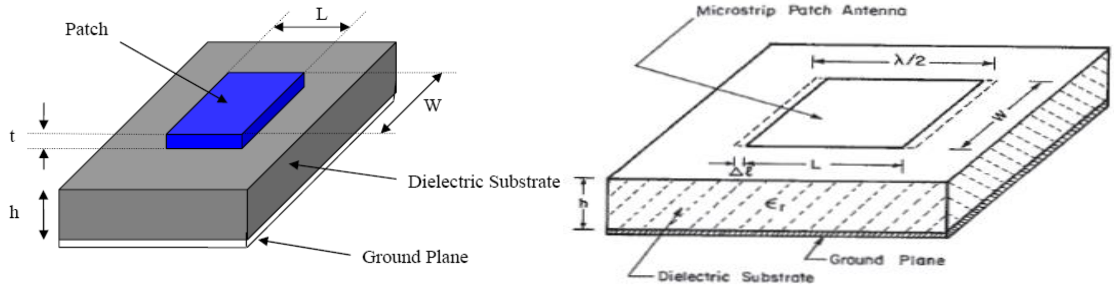
KEYWORDS: *Microstrip antenna, dielectric Superstrates, Bandwidth, Beam- width, Gain, Resonant frequency etc.*

I. INTRODUCTION

Microstrip antenna consists of radiating patch on the one side of the substrate having the ground plane on other side. The major advantages are light weight, low profile, conformable to planar and non-planar surfaces and easy to fabricate. The antenna is suitable for high speed vehicles, aircrafts, space crafts and missiles because of low profile and conformal nature of characteristics [1], [2], [3]. The dielectrics Superstrate protects the patch from climatic conditions and environmental hazards and improve the antenna performance [7]. The researchers [3], [4], [5], 6] have investigated the input impedance of circular and square patch with dielectric Superstrate (radome). The different circular and square patch microstrip antennas are investigated by many researchers. K.M.Luk et al, [8] has reported the investigation of the effect of dielectric cover on a circular microstrip patch antenna. The resonant frequency of patch is decreased while bandwidth is slightly varied. Hussain.A et al, [9] has discussed the microstrip antenna performance covered with dielectric layer. He found the simulated results which show that the antenna resonant frequency is reduced as the dielectric layer thickness is increased; however the gain is decreased as dielectric layer thickness is increased. R.K.Yadav et al, [10] has observed that the resonant frequency lowers and shift in resonant frequency increases with the dielectric constant of the Superstrates, in addition, it has also been observed that return –loss and VSWR increases, however bandwidth and directivity decreases with the dielectric constant of the Superstrates. Hussein Attia et al, [11], discussed that a microstrip patch antenna can be designed to achieve the highest possible gain when covered with a Superstrate at proper distance in free space. The transmission line analogy and cavity model are used to deduce the resonance conditions required to achieve the highest gain. Samer Dev. Gupta et al, [12] has discussed the design of multi dielectric layer based on different thickness and permittivity of the Superstrate layer has significant effect in gain and efficiency. The proper choice of thickness of substrate and Superstrate layer results in significant increase in gain. Mohammed Youness et al, [13], have discussed a parametric study of rectangular microstrip antenna at frequency ranging from 0.6 to 0.8 THz with and without Superstrate. The matching bandwidth and maximum radiation gain has been obtained by them but they have not studied thoroughly the effect of Superstrates on the patch antenna by varying various thickness and dielectric constants. We have designed the rectangular and square patch microstrip antenna based on the transmission line model .The substrate and Superstrate material are of same dielectric constant. The effect of dielectric Superstrates thickness on the parameter such as bandwidth, beam-width, gain, resonant frequency, input impedance, return loss and VSWR etc. has been investigated. The obtained results show that the resonant frequency will be shifted to lower side by adding Superstrate above substrate, while other parameters have slight variation in their values. In particular, the resonant frequency increases with dielectric constant of the Superstrates. In addition, it has also been observed that the return loss and VSWR increases, however bandwidth and gain decreases with the dielectric constant of the Superstrates. Input Impedance is increased as Superstrate becomes thick.

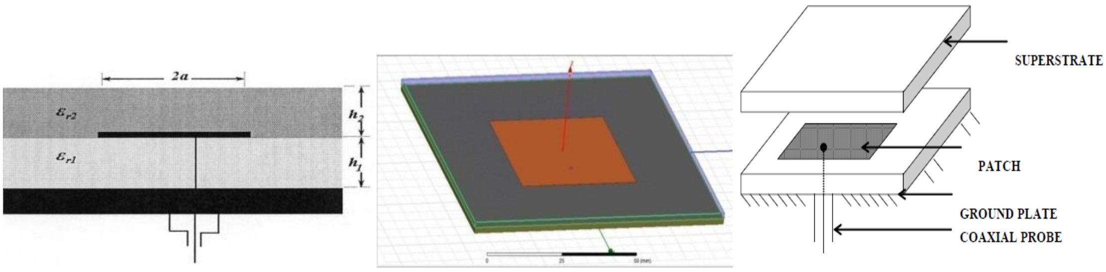
II. SPECIFICATION AND SELECTION OF SUBSTRATE MATERIALS

The geometry of a coaxial probe fed rectangular and square patch microstrip antenna is shown in Figure 1, Figure 2.The antenna under investigation the rectangular patch antenna width (W) = 49.4mm, length (L) = 40.3mm and feed point location (F) = 10.5mm, the square patch antenna (W×L) = 33.6mm and feed point location (F) = 10.0mm.. The antennas designed center frequency is 2.4GHz is shown in Table 3, fabricated on Arlon diclad 880 dielectric substrate, whose dielectric constant($\in_{r1}$) is 2.2, loss tangent(tanδ) is 0.0009, thickness (h_1) is 1.6mm and substrate dimension is 100mm×100mm [1]. The Superstrate material can be used same as substrate with same specification in the design of rectangular and square patch microstrip antenna [2], is shown the Table 1 and Table 2. The selection of substrate materials play important role for antenna design [1], is shown in Table 1, Table 2. Dielectric substrate of appropriate thickness and loss tangent is chosen for designing the rectangular and square patch microstrip patch antenna [1]. A thicker substrate is mechanically strong with improved impedance bandwidth and gain [10],[14][15]. However it also increases weight and surface wave losses. The dielectric constant ($\in_r$) is play an important role similar to that of the thickness of the substrate. A low value of $\in_r$ for the substrate will be increase the fringing field of the patch and thus the radiated power. A high loss tangent (tanδ) increases the dielectric loss and therefore reduce the antenna performance. The low dielectric constant materials increase efficiency, bandwidth and better for radiation [17].



(a) Square patch antenna [17] **(b)** Rectangular patch antenna [17]

Figure 1: Schematic of rectangular and square patch microstrip antenna



(a) Rectangular patch [16] **(b)** Square patch **(c)** Substrate and Superstrate Setup [16]

Figure 2: Microstrip antenna with Superstrate geometry

III. DESIGN OF RECTANGULAR AND SQUARE PATCH ANTENNA

The rectangular and square patch microstrip antenna can be designed at frequency of 2.4GHz using transmission line model and fabricated on Arlon Diclad 880 substrate, whose dielectric constant($\in_{r1}$) is 2.2. The Superstrate material can be used same as substrate and whose dielectric constant ($\in_{r2}$) =2.2, substrate and Superstrate dimension is 100×100mm for designing of patch antennas. The rectangular patch antenna width (W) =49.4mm, length (L) =40.3mm and feed point location (F) is X=0, Y=10.5mm, the square patch antenna W×L =36.5mm and feed point location (F) is X=0, Y=10.0mm is calculated using equation (4), (5) and (7). The coaxial probe feeding is given to a particular location of the point where input impedance is approximately 50 **Ω** [16] is shown in Figure 2. The main advantages of the feeding technique are that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and also has low spurious radiation [15].

3.1 Design Equation Of Rectangular And Square Patch Antenna

The effective dielectric constant has values in the range of $1 < \in_{reff} < \in_r$. Where the dielectric constant of the substrate is much greater than the unity ($\in_r \gg 1$), the value of $\in_{reff}$ will be closer to the value of the actual dielectric constant $\in_r$ of the substrate [2].

$$W/h > 1$$

$$\in_{ref} = \frac{\in_r+1}{2} + \frac{\in_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \tag{1}$$

The dimensions of the patch along its length have been extended on each end by distanceΔL, which is a function of the effective dielectric constant $\in_{reff}$ and the width-to-height ratio [1], [2]

$$\frac{\Delta L}{h} = 0.412\frac{(\in_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\in_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{2}$$

The effective length of the patch is now

$$L_{eff} = L + 2\Delta L \tag{3}$$

For an efficient radiator, a practical width that leads to good radiation efficiencies is [1], [2]

$$W = \frac{1}{2f_r\sqrt{\mu_0\in_0}}\sqrt{\frac{2}{\in_r+1}} = \frac{\vartheta_0}{2f_r}\sqrt{\frac{2}{\epsilon_{r+1}}} \tag{4}$$

The actual length of the patch can now be determined by [2]

$$L = \frac{1}{2f_r\sqrt{\in_{reff}}\sqrt{\mu_0\in_0}} - 2\Delta L \tag{5}$$

The conductance of the patch can be represented as [2]

$$G_1 = \begin{cases} \frac{1}{90}\left(\frac{W}{\lambda_0}\right)^2 & W \ll \lambda_0 \\ \frac{1}{120}\left(\frac{W}{\lambda_0}\right) & W \gg \lambda_0 \end{cases} \tag{6}$$

The total input admittance is real, the resonant input impedance is also real, or

$$Z_{in} = \frac{1}{Y_{in}} = R_{in} = \frac{1}{2G_1} \tag{7}$$

$$R_{in} = \frac{1}{2(G_1 \pm G_{12})} \tag{8}$$

IV. SUPERSTRATE (RADOME) EFFECTS

When rectangular and square patch microstrip antenna with the dielectric Superstrate or Radom is shown in Figure 2 .The characteristics of antenna parameters change as a function of the dielectric Superstrate layer. The properties of a microstrip antenna with dielectric Superstrate layer have been studied theoretical formulation using the transmission line [1]. The resonant frequency of a microstrip antenna covered with dielectric Superstrate layer can be determined when the effective dielectric constant of the structure is known. The change of the resonant frequency by placing the dielectric Superstrate has been calculated using the following the expression [1] [2].

$$\frac{\nabla f_r}{f_r} = \frac{\sqrt{\in_e} - \sqrt{\in_{eo}}}{\sqrt{\in_e}} \tag{9}$$

If $\in_e = \in_{eo} + \nabla\in_e$ and $\nabla\in_e \leq 0.1 \in_{eo}$, then

$$\frac{\Delta f_r}{f_r} = {}^1\!/_2 \frac{{}^{\Delta\in_e}\!/_{\in e_o}}{1 + {}^1\!/_2 {}^{\Delta\in_e}\!/_{\in e_o}}$$

Where,

$\in_e$= Effective dielectric constant with dielectric superstrte

$\in e_o$=Effective dielectric constant without dielectric Superstrate

$\Delta\in_e$= Change in dielectric constant due to dielectric superstrate

Δf_r =Fractional change in resonance frequency

f_r =Resonce frequency

V. RESULT AND ANALYSIS

5.1 Experimental Measurement

The impedance characteristics were measured by means of HP 8510B network analyzer is shown in Figure 3. The radiation pattern measurements were performed in the anechoic chamber by the use of automatic antenna analyzer [18] [19].

(a) Measurement setup **(b)** Prototype **(c)** Dielectric substrate **(d)** Superstrate

Figure 3: Microstrip patch antenna – Prototype, dielectric substrate, Superstrate material and measurement setup

5.2 Result of Rectangular and Square patch Antenna without Superstrate

In order to present the design procedure of antenna achieving impedance matching for the case, the first prototype of the antenna was designed using Arlon diclad 880 substrate resonating at 2.4GHz as shown in Figure 3. The obtained results from rectangular patch microstrip antenna without Superstrate is that the Gain is 7.3dB, Bandwidth is 2GHz, Half power beam-width (HPBW) in horizontal and vertical polarization is 88.36^0 and 90.20^0 respectively, Input impedance is

36.796+j6.0508, return loss is -13.635dB and VSWR is 1.5706 is shown in Figure 4 and corresponding data Table is tabulated as shown in Table IV. The obtained results from square patch microstrip antenna without Superstrate is that the value of VSWR is 1.466 and Bandwidth is 4.6GHz, the Gain is 4.8dB and Half power beam-width is 108.16^0 in horizontal polarization and 105.45^0 in vertical polarization, Input impedance is 36.744Ω and return-loss is -8.907dB is shown in Figure 4, and corresponding data Table is tabulated as shown in Table IV.

Result of Rectangular and Square patch Antenna with Superstrate thickness

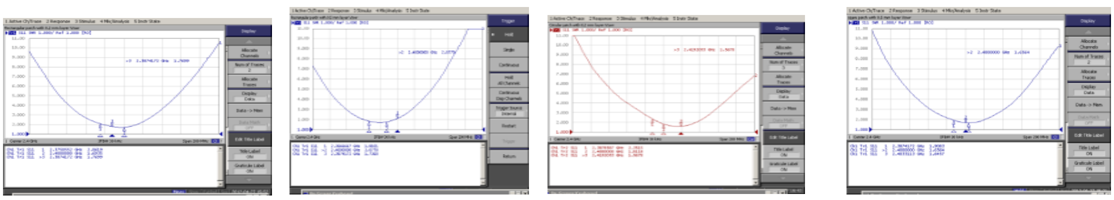
The proposed Rectangular microstrip patch antenna has been analyzed using various thicknesses of the Superstrates from 0.2mm, 0.5mm, 0.8mm, 1.3mm, 1.5mm, 2.2mm, 2.4mm, 3.2mm and corresponding frequency has shifted from 2.40GHz to 2.38HGz. The gain has increased from 3.3db to 6.22db, bandwidth is varied from 2.4GHz to 5.4GHz, half power beam-width (HPBW) is varied from $84.69^0$to 91.50^0 in horizontal polarization, half power beam-width(HPBW) is varied from $67.91^0$to 77.63^0 in vertical polarization, input impedance has varied from 24.370Ω -j785.85Ω to 47.950Ω -j32.106Ω, return loss (RL) is changed from -9.205dB to -11.560dB, VSWR is varied from 1.758 to 3.076 as shown in Figure 5 to Figure 12 and corresponding data is tabulated in Table V.
The proposed Square patch antenna has been analyzed using various thickness of the Superstrates from 0.2mm, 0.5mm, 0.8mm, 1.3mm, 1.5mm, 2.2mm, 2.4mm, 3.2mm and as a result of which the corresponding frequency has shifted from 2.40GHz to 2.36HGz. The Gain has varied from 0.47db to 3.43db, Bandwidth is varied from 1.5GHz to 2.6GHz, Half power beam-width (HPBW) is varied from $95.41^0$to 105.33^0 in horizontal polarization, half power beam-width (HPBW) is varied from $74.86^0$to 90.20^0 in vertical polarization, Input impedance has been varied from 25.387Ω -j16.696Ω to 53.759Ω -j45.307Ω, return loss (RL) is changed from -7.582dB to -12.857dB, VSWR is varied from 1.567 to 5.581 as shown in Figure 5 to Figure 12 and corresponding data is tabulated in Table VI.

Experimental Measured Plot

(i) VSWR **(ii)** Impedance **(iii)** VSWR **(iv** Impedance

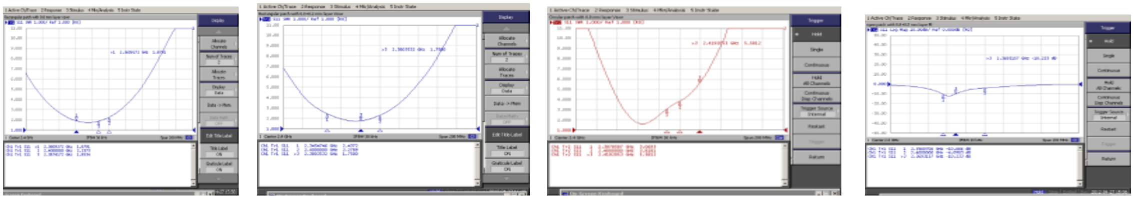
(a) Rectangular patch antenna **(b)** Square patch antenna

Figure 4: Comparison result of experimentally measured VSWR and Input impedance plot of rectangular and square microstrip patch antenna without dielectric Superstrates whose dielectric constant at $\in_{r1}$= 2.2



(i) 0.2mm **(ii)** 0.5mm **(iii)** 0.2mm **(iv)** 0.5mm
(a) Rectangular patch antenna **(b)** Square patch antenna

Figure 5: Comparison result of experimental measured VSWR plot of rectangular and square microstrip patch antenna with dielectric Superstrates thickness 0.2mm and 0.5mm



(i) 0.8mm **(ii)** 1.0mm **(iii)** 0.8mm **(iv)** 1.0mm

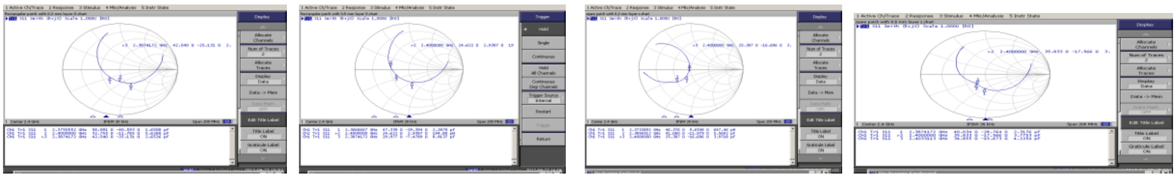
(a) Rectangular patch antenna **(b)** Square patch antenna

Figure 6: Comparison result of experimental measured VSWR plot of rectangular and square microstrip patch antenna with dielectric Superstrates thickness 0.8mm and 1.0mm

(i) 1.3mm **(ii)** 1.5mm **(iii)** 1.3mm **(iv)** 1.5mm

(a) Rectangular patch antenna **(b)** Square patch antenna

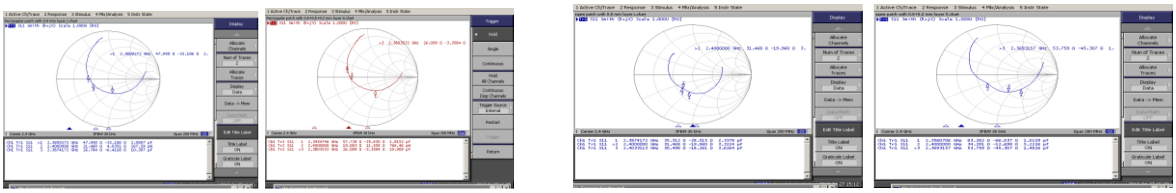
Figure 7: Comparison result of experimental measured VSWR plot of rectangular and square microstrip patch antenna with dielectric Superstrates thickness 1.3mm and 1.5mm.



(i) 0.2mm **(ii)** 0.5mm **(iii)** 0.2mm **(iv)** 0.5mm

(a) Rectangular patch antenna **(b)** Square patch antenna

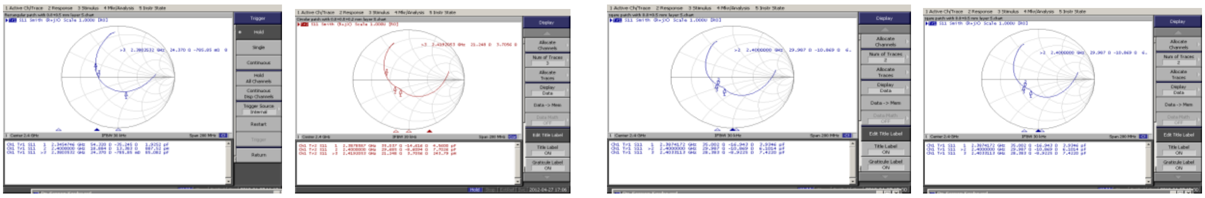
Figure8: Comparison result of experimentally measured input impedance plot of rectangular and square microstrip patch antenna with dielectric Superstrates thickness 0.2mm and 0.5mm



(i) 0.8mm **(ii)** 1.0mm **(iii)** 0.8mm **(iv)** 1.0mm

(a) Rectangular patch antenna **(b)** Square patch antenna

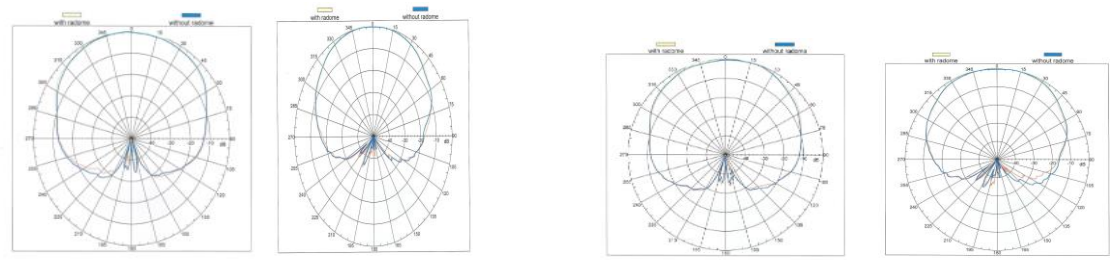
Figure9: Comparison result of experimentally measured input impedance plot of rectangular and square microstrip patch antenna with dielectric Superstrates thickness 0.8mm and 1.0mm



(i) 1.3mm **(ii)** 1.5mm **(iii)** 1.3mm **(iv)** 1.5mm

(a) Rectangular patch antenna **(b)** Square patch antenna

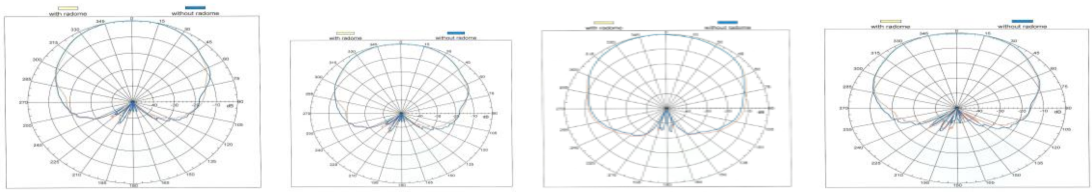
Figure10: Comparison result of experimentally measured input impedance plot of rectangular and square microstrip patch antenna with dielectric Superstrates thickness 1.3mm and 1.5mm



(i) 0.2mm **(ii) 1**.3mm **(iii)** 0.2mm **(iv)** 1.3mm

(a) Rectangular patch antenna **(b)** Square patch antenna

Figure11: Comparison result of experimental measured far field amplitude radiation pattern plot of rectangular and square patch microstrip antenna pattern with Superstrate (radome) thickness 0.2mm and 1.3mm in horizontal polarization and vertical polarization



(i) 2.4mm **(ii)** 3.2mm **(iii)** 2.4mm **(iv)** 3.2mm

(a) Rectangular patch antenna **(b)** Square patch antenna

Figure12: Comparison result of experimental measured far field amplitude radiation pattern plot of rectangular and square patch microstrip antenna pattern with Superstrate (radome) thickness 2.4mm and 3.2mm in vertical polarization

Table I: Specification of dielectric substrate materials used in the design of rectangular and square patch antennas patch antenna [1]

Dielectric constant(ε_{r1})	Loss tangent(tanδ)	Thickness (h_1),mm
2.2	0.0009	1.6

Table II: Specification of dielectric Superstrate materials used in the design of rectangular and square patch antennas [1]

Dielectric constant(ε_{r2})	Loss tangent(tanδ)	Thickness (h_2),mm
2.2	0.0009	1.6

Table III: Calculated data of patch, width, length, feed point location for rectangular and square patch antenna design

Type of Patch	Width (W),mm	Length (L),mm	Feed Point (F),mm
Rectangular patch antenna	49.4	40.3	10.5
Square patch antenna	33.6	33.6	10

Table IV: Experimental data for Gain, Bandwidth (BW), and Half power beam-width (HPBW) of rectangular patch and square patch antenna without dielectric Superstrate

Type of patch	Dielectric constant ($\in_{r1}$)	Center frequency (f_0)	Gain (dB)	BW (GHz)	HPBW (HP),Deg	HPBW (VP),Deg	IMP(Ω)	RL(dB)	VSWR
Rectangular patch	2.2	2.40	7.3	0.203	88.36	90.20	36.796 +j6.0508	-13.635	1.5706
Square patch	2.2	2.40	4.8	0.046	108.1	105.4	36.24 – j8.9070	-10.08	1.4666

Table V: Experimental measured data for Gain, Bandwidth (BW), half power beam-width (HPBW), Impedance (IMP), Return-loss (RL) and VSWR of Rectangular microstrip patch antenna with varying various dielectric Superstrates thickness (mm) on the patch antenna

Superstrate thickness($\in_{r2}$)	$\Delta f_r / f_r$(GHz)	Gain(dB)	BW(GHz)	HPBW(HP),Deg	HPBW(VP),Deg	IMP(Ω)	RL(dB)	VSWR
0.2mm	2.387	4.29	0.024	90.94	70.71	42.540 – j25.13	-11.560	1.769
0.5mm	2.40	3.97	0.033	89.80	73.29	24.622 +j2.938	-9.0884	2.077
0.8mm	2.36	3.85	0.039	84.77	76.88	47.950 – j32.10	-10.518	1.879
1.0mm	2.380	5.75	0.054	88.40	77.63	31.542 – j11.77	-11.214	1.758
1.3mm	2.380	6.12	0.054	84.69	67.91	24.370 – j785.8	-9.785	1.899
1.5mm	2.380	4.32	0.054	85.34	70.23	26.099 – j3.358	-10.205	3.076
2.2mm	2.234	3.33	0.051	91.50	71.80	25.234 – j12.34	-11.234	2.912
2.4mm	2.342	4.99	0.0432	90.34	78.23	45.243 – j12.34	-12.56	2.991
3.2mm	2.234	4.47	0.0523	95.20	90.20	48.231 – j23.34	-13.231	3.013

Table VI: Experimental measured result of resonant frequency, Gain, Half power beam-width (HPBW), Impedance (IMP), Return loss and VSWR for Square patch antenna with various dielectric Superstrate thicknesses

Superstrate thickness ($\in_{r2}$)	Δ_{fr} / f_r(GHz	Gain(dB)	BW (GHz)	HPBW(HP),deg	HPBW(VP), deg	IMP(Ω)	RL (dB)	VSWR
0.2mm	2.40	1.42	0.0267	98.16	90.20	25.387-j16.696	-8.286	2.253
0.5mm	2.40	0.93	0.0158	99.15	74.86	35.833-j17.566	-12.142	1.656
0.8mm	2.38	1.63	0.0158	95.41	77.56	31.468-j19.960	-10.054	1.916
1.0mm	2.369	2.01	0.0142	94.20	75.25	53.759-45.307	-10.233	2.206
1.3mm	2.387	1.83	0.0158	105.33	79.72	36.166-j10.869	-12.006	1.670
1.5mm	2.40	2.43	0.0249	107.23	80.56	29.987-j15.292	-10.991	1.786
2.2mm	2.37	3.43	0.0152	98.55	81.07	28.23+j23	-10.234	2.612
2.4mm	2.39	0.74	0.0142	107.56	77.30	29.23-j2.34	-12.231	2.991
3.2mm	2.39	0.47	0.0142	102.25	83.61	30.23+j6.2	-13.239	3.231

VI. RESULTS AND DISCUSSION

In this paper, the characteristic of rectangular and square patch microstrip antenna with and without dielectric Superstrates has been experimentally compared. The result of rectangular patch antenna without Superstrate has gain of 7.3dB, bandwidth is 2.0 GHz, input impedance is 36.796+j6.0508Ω, Half power beam-width (HPBW) is $88.36^0$and 90.20^0 in horizontal and vertical polarization, return-loss and VSWR is -13.635 and 1.5706 is shown in Table4. The result of square patch antenna without Superstrate has gain of 4.8dB, bandwidth is 4.6GHz, input impedance is 35.833-j8.9070Ω, half power beam-width (HPBW) is $108.1^0$and 105.4^0in horizontal and vertical polarization respectively, return- loss and VSWR is -10.08 and 1.4666 as shown in Table 4. The result of rectangular patch antenna with Superstrate is that frequency will be shifted from 2.40GHz to 2.234GHz, gain is increased from 3.33dB to 6.12dB, bandwidth is increased from 2.4GHz to 5.4GHz, half power beam-width (HPBW) is increased from 84.69^0 to 95.20^0 and increased from 67.91^0 to 90.20^0 in horizontal and vertical polarization respectively, return loss and VSWR is changed from -9.0888dB to

-13.231dB and 1.758 to 3.076 respectively, input impedance is increased from 24.370-j785.8 to 48.231-j23.34 as shown in Table 5. The result of square patch antenna with Superstrate is a shift in resonant frequency from 2.40GHz to 2. 38GHz, gain is increased from 0.47dB to 3.43dB, bandwidth is increased from 1.4GHz to 2.6GHz, beam-width is increased from 94.20^0 to $107.56^0$and 74.86^0 to 90.20^0 in horizontal and vertical polarization respectively, input impedance has increased from 25.387-j16.696 to 53.759-j45.307Ω, return loss and VSWR is increased from -8.286dB to -13.239dB and 1.656 to 3.231 respectively based upon the thickness of the dielectric Superstrate as shown in Table 6.

VII. CONCLUSIONS

A comparison of experimental results with dielectric Superstrate for rectangular and square patch microstrip antenna is presented in Table 5 and Table 6.The data refers that the return-loss first increases with increasing the thickness of the dielectric Superstrate and decreases further. The band width of microstrip antenna also increases with increasing the thickness of dielectric sheet for low dielectric constant materials, and decreases for high dielectric constant materials. The VSWR increases with increase in thickness of dielectric Superstrates and it is also observed that the resonant frequency f_r decreases monotonically with the increase in the Superstrate thickness of the Superstrate. The general trend of impedance characteristics is that both input impedance and the reactance are increased as Superstrate becomes thick. The HPBW become narrower or wider depending upon the dielectric constant and thickness of the Superstrate. The maximum gain of 6.12dB is obtained at thickness of 1.3mm for rectangular patch antenna and maximum gain of 3.43dB is obtained at thickness of 2.2mm for square patch antenna.

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