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Exploration of Dielectric SUPERSTRATES on the Square MICROSTRIP Patch Antenna

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ABSRACT:
Present paper demonstrates, the effect of dielectric superstrates on the performance of coaxial probe fed square patch microstrip antenna with and without dielectric superstrates. The antenna can be designed at 2.4 GHz(ISM band) frequency using transmission line model. In this paper experimentally studied the effect of dielectric superstrates on the parameters such as bandwidth, beam-width, gain and resonant frequency, Input impedance and VSWR etc. Measured results shows when placing the superstrate material above the substrate the antenna parameter will be changed and antenna resonant frequency will be shifted lower side, while other parameters have slight variation in their values. In particular, the 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 gain decreases with the dielectric constant of the superstrates.

Key words: Square patch microstrip antenna, dielectric superstrates, Bandwidth, Beam-width, Gain, VSWR and resonant frequency.

1. INTRODUCTION:

Microstrip antenna consists of radiating patch on the one side of the substrate having the ground plane on ther side. The major advantages are light weight, low profile, conformable to planar and non-planer surfaces and easy to fabricate. The antenna is suitable for high speed vehicles, aircraft's, space crafts and missiles because of low profile and conformal nature of characteristics[2].The different way of methods on the square patch microstrip antennas is investigated by many researchers [1] - [17]. Among them radome or superstrate were studied by few researchers [2]-[15]. The dielectric superstrate protects the patch from climatic conditions and environmental hazards and improve the antenna performance [7]. Among the few researchers [4], [5], 6] have investigated the input impedance of square patch with dielectric superstrate (radome) . But they have not studied thoroughly the effect of superstrates on the patch antenna by varying various thickness and dielectric constants. We have been designed the antenna based on the transmission line model. The effect of dielectric superstrates on the parameter such as Bandwidth, Beam-width, Gain, Resonant frequency, Input impedance and VSWR etc. The obtained results shows that the resonant frequency will be shifted to lower side by placing superstrate above substrate, while other parameter 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 increase, however bandwidth and gain decreases with the dielectric constant of the superstrates.

2. ANTENNA SPECIFICATION AND SELECTION OF SUBSTRATE MATERIALS:

The geometry of a probe fed square patch microstrip antenna is shown in Figure 1 to Figure 6. The antenna under investigation is a patch of width (W) is 33.6mm, length (L) is 33.6mm, center frequency is 2.4GHz and feed point location is X=0 and Y=10.0mm is shown in Table 3, fabricated on Arlon diclad 880 dielectric substrate, whose dielectric constant (ϵ_{r1}) is 2.2, loss tangent (tanδ) is 0.0009, thickness (h_1) is 1.6mm and substrate dimension is 100mm×100mm. The superstrate material can be used in the design of square microstrip patch antenna such as (1) Arlon Diclad 880 whose dielectric constant (ϵ_{r2}) is 2.2, loss tangent (tanδ) is 0.0009 and thickness (h_2) is 1.6mm. (2) Arlon Ad 320 whose dielectric constant (ϵ_{r2}) is 3.2, loss tangent (tanδ) is 0.003 and thickness (h_2) is 3.2mm. (3) FR4 whose dielectric constant (ϵ_{r2}) is 4.8, loss tangent (tanδ) is 0.02 and thickness (h_2) is 1.6mm. (4) Arlon Ad 1000 whose dielectric constant (ϵ_{r2}) is 10.2, loss tangent (tanδ) is 0.0035 and thickness (h_2) is 0.8mm. The selection of substrate materials play important role for antenna design is shown in Table 1, Table 2. Dielectric substrate of appropriate thickness and loss tangent is chosen for designing the square patch microstrip patch antenna. A thicker substrate is mechanically strong with improved impedance bandwidth and gain [10]. However it also increases weight and surface wave losses. The dielectric constant (ϵ_r) is play an important role similar to that of the thickness of the substrate. A low value of ϵ_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.

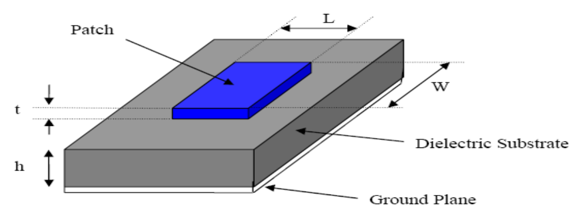

Figure 1: Schematic of square patch microstrip antenna

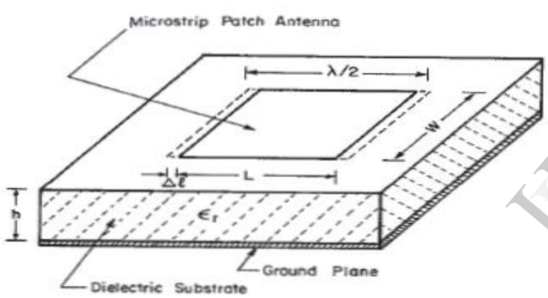

Figure 2: Square microstrip patch antenna geometry

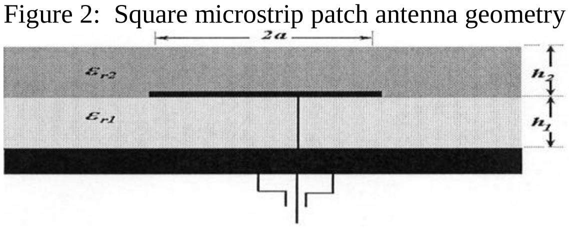

Figure 3: Microstrip antenna with superstrate geometry

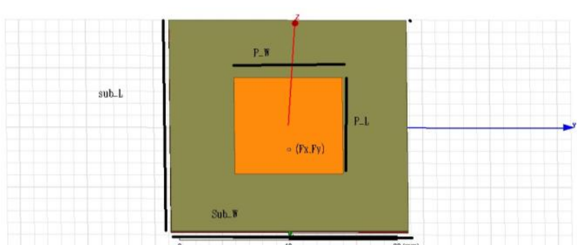

Figure 4: Geometrical structure of square patch antenna

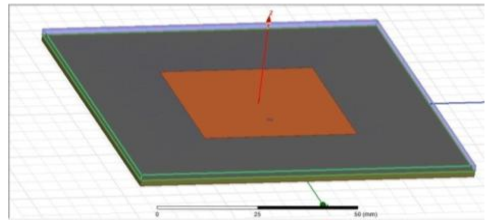

Figure 5: Square patch antenna with superstrate

3. DESIGN OF SQUARE PATCH ANTENNA:

In the most basic form, a square microstrip patch antenna consists of a radiating patch on one side of the dielectric substrate, which has ground plane on the other side and ground plane and radiating patch separated by dielectric substrate is shown inFigure 1, Figure 2. The resonant length of the antenna can determine its resonant frequency. In fact the patch is electrically a bit larger than its physical dimension. The patch antenna can be designed at 2.4GHz and fabricated on Arlon diclad substrate, whose dielectric constant(ϵ_{r1}) is 2.2.The substrate and superstrate dimension is 100×100mm of the patch antenna.

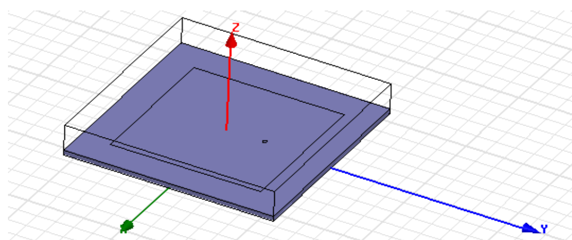

Figure 6: The structure and design parameter of the square

The coaxial probe feeding is given to the at particular location of the point where input impedance is approximately 50 Ω, is shown in Figure 4, Figure 6. 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. The proposed antenna has been designed using the following expression [1], [4].

The effective dielectric constant has values in the range of $1 < \epsilon_{reff} < \epsilon_r$. For most applications where the dielectric constant of the substrate is much greater than the unity ($\epsilon_r \gg 1$), the value of ϵ_{reff} will be closer to the value of the actual dielectric constant ϵ_r of the substrate[12].

$W/h > 1$

$$\epsilon_{ref} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \qquad (1)$$

The dimensions of the patch along its length have been extended on each end by distance ΔL, which is a function of the effective dielectric constant ϵ_{reff} and the width-to-height ratio[12]

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

The effective length of the patch is now

$$L_{eff} = L + 2\Delta L \qquad (3)$$

For an efficient radiator, a practical width that leads to good radiation efficiencies is [15]

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r + 1}} = \frac{\vartheta_0}{2f_r}\sqrt{\frac{2}{\epsilon_{r+1}}} \qquad (4)$$

The actual length of the patch can now be determined by solving (14-5) for L, or

$$L = \frac{1}{2f_r\sqrt{\epsilon_{reff}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L \qquad (5)$$

The conductance of the patch can be represented as[12]

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

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

$$Z_{in} = \frac{1}{Y_{in}} = R_{in} = \frac{1}{2G_1} \qquad (7)$$

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

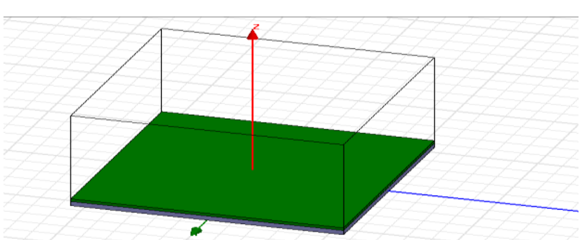

Figure 7: Structure of square patch antenna with dielectric superstrates

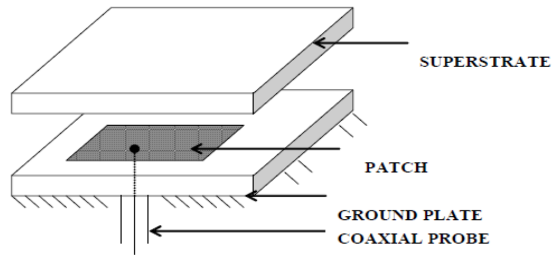

Figure 8: Structure of square patch with substrate and dielectric superstrates.

4. SQUARE PATCH MICROSTRIP ANTENNA WITH DIELECTRIC SUPERSTRATE:

4.1 Superstrate (radome) effects:

When square patch microstrip antenna with the dielectric superstrate or Radom is shown in Figure 3, Figure 5, and Figure 7 to Figure 9. 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 analysis. 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].

$$\frac{\nabla f_r}{f_r} = \frac{\sqrt{\epsilon_e} - \sqrt{\epsilon_{eo}}}{\sqrt{\epsilon_e}} \qquad (8)$$

If $\epsilon_e = \epsilon_{eo} + \nabla\epsilon_e$ and $\nabla\epsilon_e \leq 0.1\ \epsilon_{eo}$, then

$$\frac{\Delta f_r}{f_r} = {}^1/_2\frac{{}^{\Delta\epsilon_e}/_{\epsilon e_o}}{1 + {}^1/_2{}^{\Delta\epsilon_e}/_{\epsilon e_o}}$$

Where,

ϵ_e= Effective dielectric constant with dielectric superstrte

$\epsilon\ e_o$=Effective dielectric constant without dielectric superstrate

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

Δf_r =Fractional change in resonance frequency

f_r =Resonce frequency

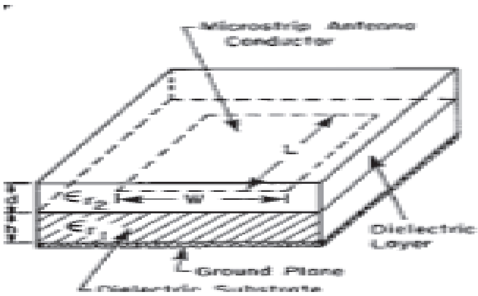

Figure 9: Square microstrip patch antenna with dielectric superstrate.

5. RESULT AND ANALYSSIS:

5.1 Experimental measurement:

The geometrical structure under consideration is shown in Figure 1 to Figure 6. A square patch antenna, designed patch width (W) = 33.6mm and length (L) = 33.6mm was fabricated on thick dielectric substrate whose dielectric constant (ϵ_{r1}) is 2.2, loss tangent is 0.0009, thickness (h_1) is 1.6mm and the dielectric superstrate is same substrate specification. The patch was fed through probe of 50Ω cable. The location of feed probe had been found theoretically and chosen as X=0, Y= 10.0mm.Then the patch was placed with different dielectric substrate materials. The dielectric superstrate materials such as (1) Arlon Diclad 880 whose dielectric constant (ϵ_{r2}) is 2.2, loss tangent $(\tan\delta)$ is 0.0009 and thickness (h_2) is 1.6mm. (2) Arlon Ad 320 whose dielectric constant (ϵ_{r2}) is 3.2, loss tangent $(\tan\delta)$ is 0.003 and thickness (h_2) is 3.2mm. (3) FR4 whose dielectric constant (ϵ_{r2}) is 4.8, loss tangent $(\tan\delta)$ is 0.02 and thickness (h_2) is 1.6mm. (4) Arlon Ad 1000 whose dielectric constant (ϵ_{r2}) is 10.2, loss tangent $(\tan\delta)$ is 0.0035 and thickness (h_2) is 0.8mm. The impedance characteristics were measured by means of HP 8510B network analyzer is shown in Figure 10. The radiation pattern measurements were performed in the anechoic chamber by the use of automatic antenna analyzer.

Figure 10: Fabricated microstrip antenna measurements

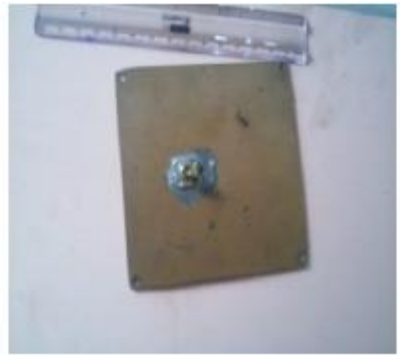

Figure 11: Fabricated Porto type square patch with feed point location

Figure 12: Dielectric substrate (ϵ_{r1}) is 2.2 and superstrate materials(ϵ_{r2}) is 2.2

Figure 13: Dielectric superstrate(ϵ_{r2}) is 3.2 and superstrate materials(ϵ_{r2}) is 4.8

Figure 14: Dielectric superstrate(ϵ_{r2}) is 10

6. RESULT OF SQUARE PATCH ANTENNA:

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 is shown in Figure 11 and corresponding the results are shown in Figure 15, Figure 20 and Figure 25. The obtained results show that the value of VSWR is 1.466 and Bandwidth is 4.6GHz, the Gain is 4.8dB and half power beam-width is108.16^0 in horizontal polarization and 105.45^0 in vertical polarization, input impedance is 36.744Ω and return-loss is -8.907dB.The corresponding data Table is tabulated is shown in Table 4, Table 7, Table 9 and Table 10.

7. RESULT OF SQUARE PATCH ANTENNA WITH VARIOUS DIELECTRIC CONSTANTS:

In order to observe the effect of dielectric supersrtrates on the antenna characteristics such as bandwidth, beam-width, gain and resonant frequency etc. The proposed antenna has been analyzed using various dielectric superstrates of dielectric constant (ϵ_{r2}) is 2.2, 3.2, 4.8, 10.2, corresponding frequency will be shifted 2.38GHz, 2.34GHz,2.35GHz,2.36GHz The obtained charactestics are shown in Figure 16 to Figure 37. The input impedance is varying from 33.480Ω to 37.404Ω, the resonant frequency is varying from 2.36GHz to2.40GHz, the gain is varying from 3.4dB to 4.2dB, the bandwidth is varying from 4.5GHz to 4.7GHz, the HPBW is constant in both polarization i.e around 108.16^0 in horizontal polarization and 86.93^0 in vertical polarization, the VSWR is varying from 1.45to 1.56 and return-loss is varying from -8.149dB to -12.392dB, corresponding data are tabulated in Table 5, Table 6, Table 8 and Table 10.

8. MEASUREMENT ANALYSIS:

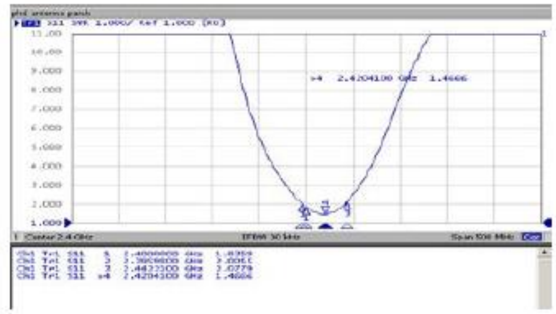

Figure 15: Experimental calculated VSWR plot without superstrate only at substrate(ϵ_{r1}) is 2.2

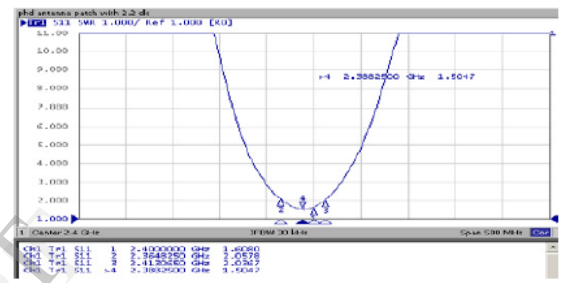

Figure 16: Experimental calculated VSWR plot with superstrate (ϵ_{r2}) is 2.2

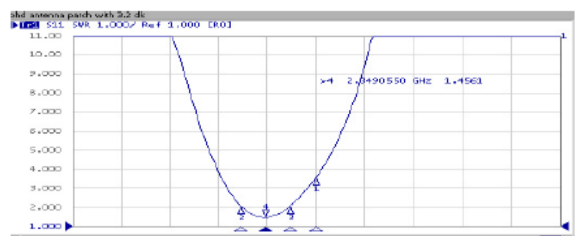

Figure 17: Experimental calculated VSWR plot with superstrate (ϵ_{r2}) is 3.2

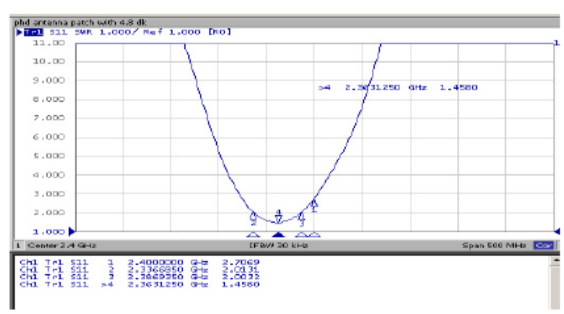

Figure 18: Experimental calculated VSWR plot with superstrate (ϵ_{r2}) is 4.8

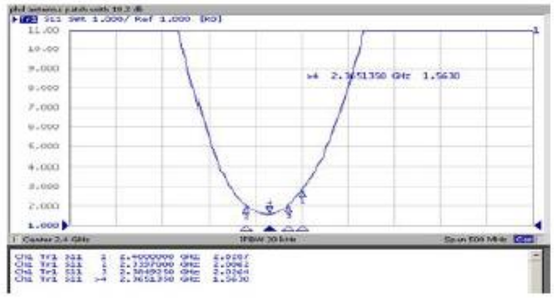

Figure 19: Experimental calculated VSWR plot with superstrate (ϵ_{r2}) is 10.2

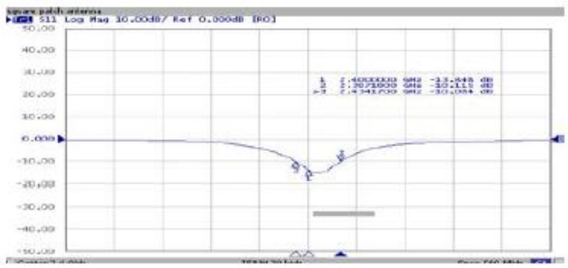

Figure 20: Experimental calculated return loss plot without superstrate only at substrate(ϵ_{r1}) is 2.2

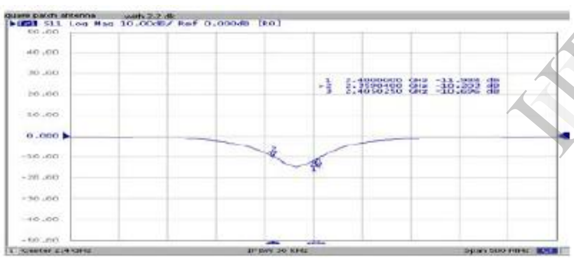

Figure 21: Experimental calculated return loss plot with superstrate (ϵ_{r2}) is 2.2

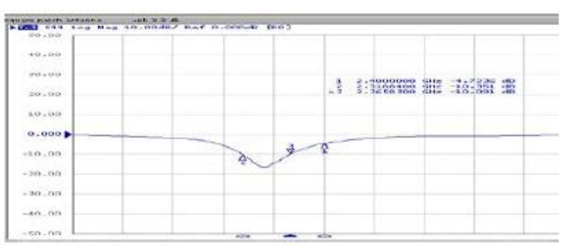

Figure 22: Experimental calculated return loss plot with superstrate (ϵ_{r2}) is 3.2

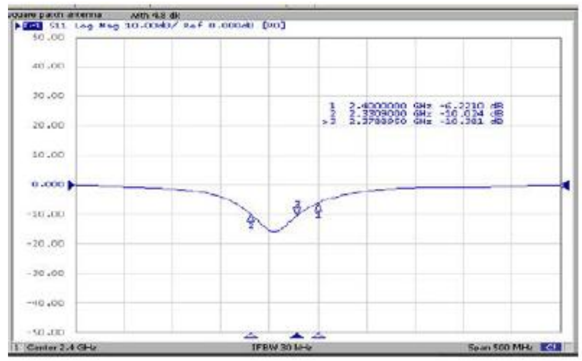

Figure 23: Experimental calculated return loss plot with superstrate (ϵ_{r2}) is 4.8

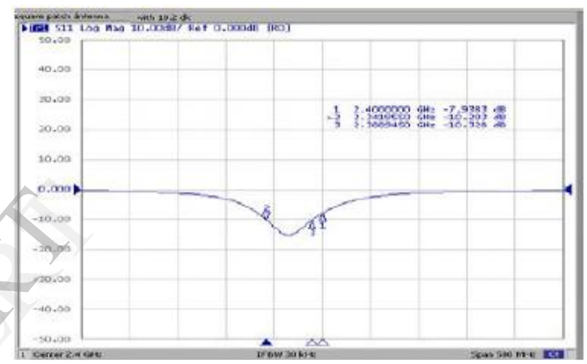

Figure 24: Experimental calculated return loss plot with superstrate (ϵ_{r2}) is 10.2

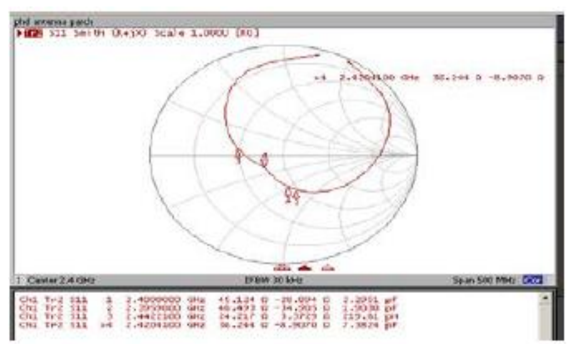

Figure 25: Experimental calculated smith chart (impedance) plot without superstrate only substrate (ϵ_{r1}) is 2.2

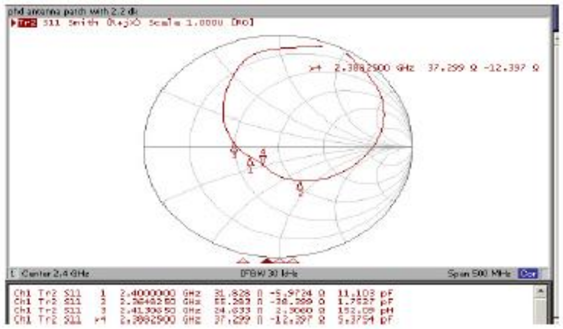

Figure 26: Experimental calculated smith chart (impedance) plot with superstrate (ϵ_{r2}) is 2.2

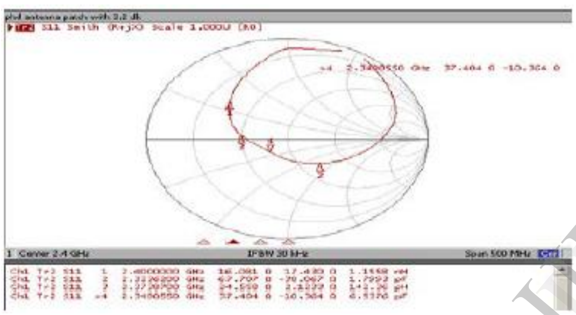

Figure 27: Experimental calculated smith chart(impedance) plot with superstrate (ϵ_{r2}) is 3.2

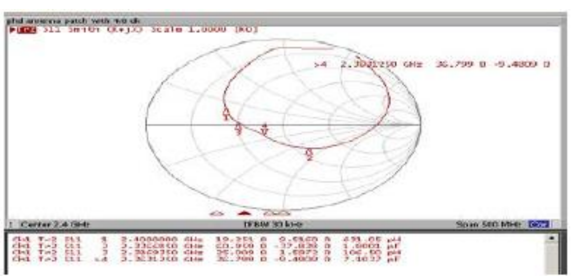

Figure 28: Experimental calculated smith chart(impedance) plot with superstrate (ϵ_{r2}) is 4.8

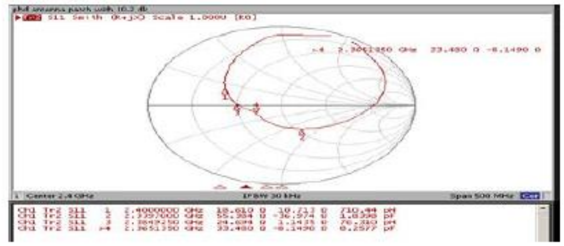

Figure 29: Experimental calculated smith chart(impedance) plot with superstrate (ϵ_{r2}) is 10.2

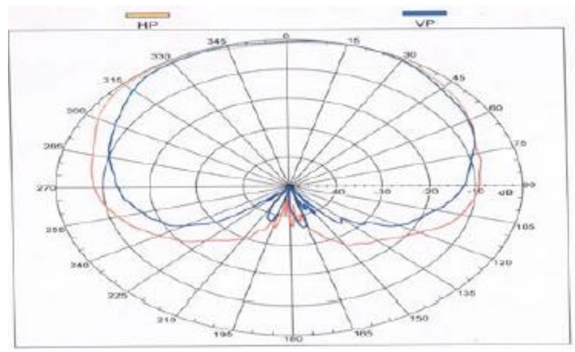

Figure 30: Experimental calculated far field amplitude of 2.4GHz radiation pattern plot with and without superstrate(radome) at VP and HP

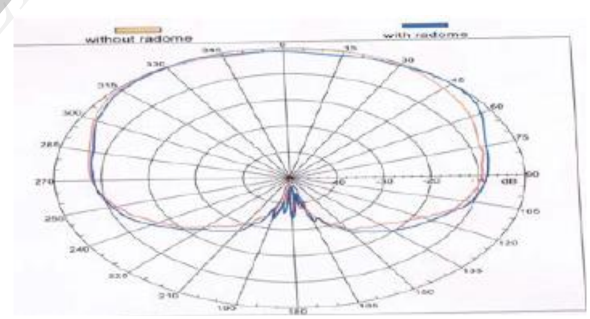

Figure 31: Experimental calculated far field amplitude of 2.4GHz radiation pattern plot with and without superstrate (radome) at (ϵ_{r2}) is 2.2 at HP

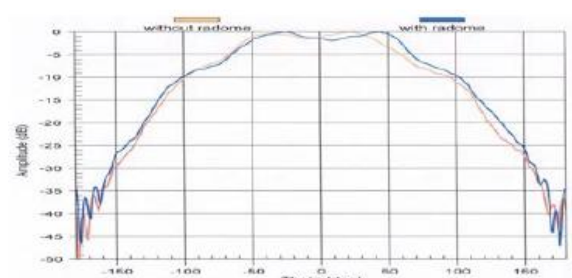

Figure 32: Experimental calculated far field amplitude of 2.4GHz radiation pattern plot with and without superstrate (radome) at (ϵ_{r2}) is 2.2 at HP

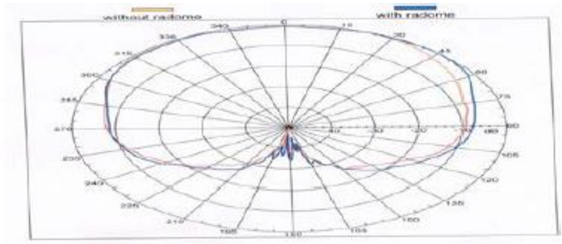

Figure 33: Experimental calculated far field amplitude of 2.4GHz radiation pattern plot with and without superstrate (radome) at (ϵ_{r2}) is 3.2 at HP

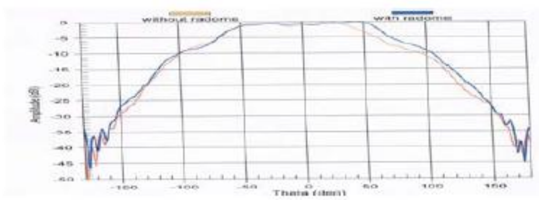

Fig33. Experimental calculated far field amplitude of 2.4GHz radiation pattern plot with and without superstrate (radome) at (ϵ_{r2}) is 3.2 at HP

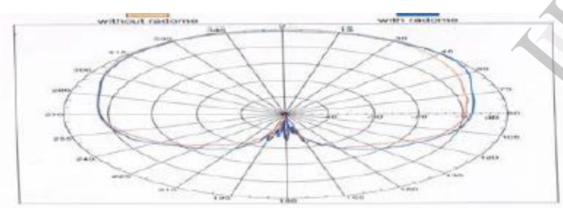

Figure 34: Experimental calculated far field amplitude of 2.4GHz radiation pattern plot with and without superstrate (radome) at (ϵ_{r2}) is 4.8 at HP

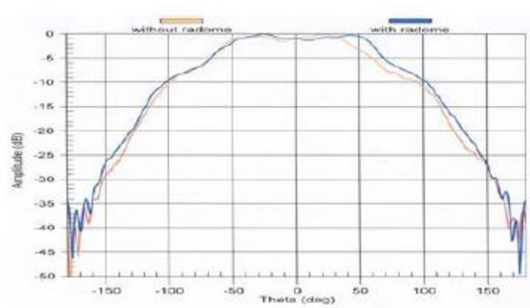

Figure 35: Experimental calculated far field amplitude of 2.4GHz radiation pattern plot with and without superstrate (radome) at (ϵ_{r2}) is 4.8 at HP

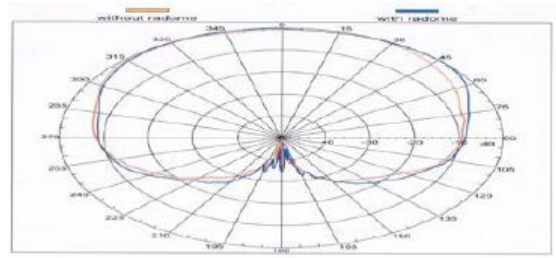

Figure 36: Experimental calculated far field amplitude of 2.4GHz radiation pattern plot with and without superstrate (radome) at (ϵ_{r2}) is 10.2 at HP

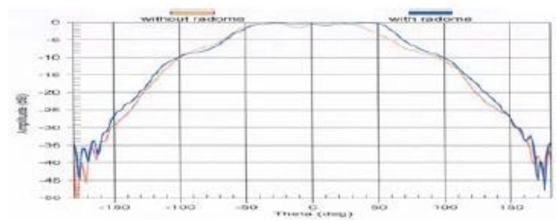

Figure 37: Experimental calculated far field amplitude of 2.4GHz radiation pattern plot with and without superstrate (radome) at (ϵ_{r2}) is 10.2 at HP

9. EXPERIMENTAL CALUCLATED DATA:

TABLE 1: Specification of substrate material for square patch antenna design:

Substrate Material	Dielectric Constant (ϵ_{r1})	Loss Tangent $(Tan\delta)$	Thickness of Substrate ,(h_1),mm
Arlon diclad 880	2.2	0.0009	1.6

TABLE 2: : Specification of superstrate material for square patch antenna design:

Superstrate Material	Dielectric Constant (ϵ_{r2})	Loss Tangent $(Tan\delta)$	Thickness of Superstrates (h_2), mm
Arlon diclad 880	2.2	0.0009	1.6
Arlon ad 320	3.2	0.003	3.2
FR4	4.8	0.02	1.6
Arlon ad 1000	10.2	0.0035	0.8

TABLE3:**Caluclated data of patch, width, length, feed point location forsquare patch design:**

Type of Patch	Width (W),mm	Length (L),mm	Feed Point (F),mm
Square patch	33.6	33.6	10.0

TABLE 4: **Experimental data for Gain, Bandwidth, HPBW of square patch antenna without superstrate:**

ϵ_{r1}	f_0,GHz	BW(GHz	Gain dB	HPBW HP,(Deg)	HPBW (Deg)
2.2	2.410675	0.04699	4.8	108.16	105.45

TABLE 5: **Experimental data for Gain, Bandwidth, HPBW of square patch antenna with superstrate:**

ϵ_{r2}	(f_0),GHz	(BW),GHz	Gain (dB)	HPBW (HP),Dg	HPBW (VP),Dg
2.2	2.3820325	0.0455985	4.2	108.16	86.93
3.2	2.342335	0.04699	3.4	108.16	86.93
4.8	2.3548975	0.047995	3.6	108.16	86.93
10.2	2.36545	0.04699	3.4	108.16	86.93

TABLE 6: Experimental data for return- loss of square patch antenna with superstrate:

Superstrate(ϵ_{r2})	Frequency(GHz)	Return-loss(dB)
2.2	2.3882500	-12.397
3.2	2.3490550	-10.364
4.8	2.3671250	-9.4809
10.2	2.3651350	-8.1490

TABLE 7: Experimental data for return- loss of square patch antenna without superstrate:

Substrate(ϵ_{r1})	Frequency(GHz)	Return-loss(dB)
2.2	2.4204100	-8.9070

TABLE 8: **Experimental data for VSWR of square patch antenna with superstrate:**

Superstrate(ϵ_{r2})	Frequency(GHz)	VSWR
2.2	2.3882500	1.5047
3.2	2.3490500	1.4501
4.8	2.3631250	1.4580
10.2	2.3631250	1.5630

TABLE9: Experimental data for VSWR of square patch antenna without superstrate:

Substrate(ϵ_{r1})	Frequency(GH)	VSWR
2.2	2.4204100	1.4666

TABLE10: Experimental data of impedance of square patch antenna with superstrates:

Substrate(ϵ_r)	Frequency(GHz)	Impedance(Ω)
2.2(without)	2.40	36.744
2.2	2.388	37.299
3.2	2.349	37.404
4.8	2.363	36.799
10.2	2.365	36.744

10. MEASURED RESULTS AND DISCUSSIONS:

The measurement results carried out for the square microstrip patch antenna designed at 2.4GHz and fabricated on Arlon ad 880 sbstrate, whose dielectric constant (ϵ_{r1}) is 2.2. In this paper experimentally carried out with and without dielectric superstrates on the parameter such as Gain, Bandwidth, Beam-width, resonant frequency, input impedance, return loss and VSWR etc. The result obtained only microstrip patch without superstrate is Gain is 4.8dB, Bandwidth is 4.6GHz,Half Power Beam-Width(HPBW) is 108.16^0 and 105.45^0, input impedance is 37.404Ω, Voltage Standing Wave Ratio(VSWR) is 1.466 and return loss(RL) is -8.907dB. The microstrip patch with superstrates, the frequency will be shifted lower side from 2.4GHz to 2.38 GHz, Gain varying from 0.47dB to 3.43dB, the Bandwidth varying from 1.0GHz to 2.6GHz, VSWR is varying from 1.45to1.56, return loss varying from -10.196 dB to -13.635 dB and Half Power Beam- Width in vertical and horizontal polarization is constant i.e 108.16^0 in horizontal polarization and 86.93^0 is in vertical polarization. The highest gain is obtained at microstrip patch with $\epsilon_{r2}$is 2.2 i.e. 4.2dB and return loss is -12.39 dB is shown in Figure 15 to Figure 37, however the corresponding data Table is shown in Table 4 to Table 10.

11. CONCLUSION:

The design and development of square microstrip patch antenna with and without dielectric superstrates presented. In this paper experimentally studied the effect dielectric superstrates on the parameters such as bandwidth, beam-width, gain and resonant frequency. The experimental result carried out on the patch antenna without superstrate(only patch) and with superstrates. The result obtained only microstrip patch without superstrate is Gain is 4.8dB, Bandwidth(BW) is 4.6GHz, half power beam-width(HPBW) is 108.16^0 in horizontal polarization and 105.45^0 in vertical; polarization,voltage standing wave ratio(VSWR) is 1.570, input impedance is 37.404Ω and return loss(RL) is -13.635dB .The microstrip patch with superstrates, the frequency will be shifted lower side from 2.4GHz to 2.34 GHz, Gain varying from 3.4dB to 4.2dB, the Bandwidth varying from 4.59 GHz to 4.79 GHz, VSWR is varying from 1.57 to 3.43, return loss varying from -8.14dB to -12.397dB and half power beam- width is constant for both in vertical and horizontal polarization ie.108.16^0 in horizontal polarization, and 86.93^0 in vertical polarization. The experimentally results shows that the variation of VSWR with different dielectric superstrate (radome) thickness, as dielectric superstrate thickness increases, VSWR increases. The variation of the antenna gain at different dielectric superstrate thickness as dielectric superstrate thickness increases, the Gain decreases. The Bandwidth of the microstrip antennas can also increases with increasing thickness of the dielectric superstrate for low dielectric constant materials, and decreases for high dielectric constant of the substrate materials. Initially the return loss increases with increasing thickness of dielectric superstrates and then decreases.The antenna beam width in vertical and horizontal polarization is constant at various dielectric superstrates.

REFERENCES:

1. I J Bhal and P Bhartia, “Microstrip antennas”, Artech house, 1980.
2. R.Shavit,”Dielectric cover effect on Rectangular Microstrip Antennas array”. IEEE Trans. Antennas propagat.,Vol 40,. PP.992-995, Avg.1992.
3. Inder ,Prakash and Stuchly, “Design of Microstrip Antennas covered with a Dielectric Layer. IEEE Trans. Antennas Propagate. Vol.AP-30.No.2, Mar 1992.
4. O.M.Ramahi and Y.T.LO, ”Superstrate effect on the Resonant frequency of Microstrip Antennas”, Microwave Opt.Technol. Lett. Vol.5, PP.254-257,June 1992.
5. A.Bhattacharyya and T. Tralman, “Effects of Dielectric Superstrate on patch Antennas”, Electron Lett., Vol.24,PP.356-358, Mar 1998.
6. R.Afzalzadeh and R.N.Karekar, ”Characteristics of a Rectangular Microstrip patch Antenna with protecting spaced Dielectric Superstrate”, Microwave Opt. Technol. Lett., Vol.7, PP.62-66, Feb 1994.
7. I J Bahl P. Bhartia, S.Stuchly “ Design of microstrip antennas covered with a dielectric layer. IEEE Trans. Antennas Propogat. No. 30, PP. 314-318, Mar 1982
8. Odeyemi KO, Akande, D.O and Ogunti E.O.” Design of S-band Rectangular Microstrip Patch Antenna, European Journal of Scientific Research Volume 55, Issue 1, 2011
9. Bernnhard and Tousignant, “Resonant Frequencies of rectangular microstrip antennas with flush and spaced dielectric superstrates”, IEEE Trans. Antennas Propagat, vol.47, no.2, Feb 1999.
10. Hussain, A. Hammus, “ Radiation performance evaluation of microstrip antenna covered with a dielectric layer”, Eng& Tech Journal, vol.27, 2009.
11. P. Malathi AND Rajkumar” Design of multilayer rectangular microstrip antenna using artificial neural networks” International journal of recent trends in Engineering, vol.2, no.5, Nov. 2009.
12. Balanis, C.A., Antenna Theory: Analysis and Design, John Wiley& Sons.
13. Christopher J Meagher and Satish kumar Sharm “ A wide band aperture- coupled microstrip patch antennas employing space & dielectric cover for enhanced gain performance, IEEE Transaction on antenna and propagation, Vol.58, No.9, Sep. 2010.

14. Bahl, I.J, Stuchly, S.S, "Analysis of a microstrip covered with a lossy dielectric, IEEE Trans. Microwave Theory Tech., 28, pp.104-109.1980.

15. Alexopoulos N.G.Jackson, D.R. "Fundamental superstrate (cover) effects on printed antennas, IEEE Trans. Antennas Propagat.32, PP. 807-816.

16. R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, Microstrip Antenna Design Hand book, Artech House, Canton, MA, 2001

17. M..Younssi,A.Jaoujal" Study of MSA with and without superstrate for Terahz frequency', ISSR Journal, 2013