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The Effect of Substrate Material on Microstrip Patch Antenna

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Abstract: ***This paper shows that how antenna performance like Gain, return loss and beam width changes accordingly on varying substrate material. Various substrates like RT_duroid, Rogers, Epoxy and FR4 are used to achieve better gain and beam width. In addition effect of substrate thickness is also analyzed. If the designer has a clear conception about the effect of changing substrate material on the performance of the antenna, it will be easier to design an antenna. The designed inset feed rectangular microstrip patch antenna operates at 3 GHz.***

Keywords: Inset Feed, Dielectric Constant, Return Loss, Gain, Directivity, Substrate thickness, beam width**.**

1. Introduction

Microstrip patch antennas consist of a metallic patch on a grounded substrate. The microstrip patch antenna first took form in the early 1970's and interest was renewed in the first microstrip antenna proposed by Deschamps in 1953[1].Microstrip patch antennas have attracted a huge area of interest and have been widely used in satellite communications, aerospace, radars and many more applications. The microstrip patch antennas are well known for their performance and their low cost, light weight, robust design and fabrication. Although it is used rectangular shaped patch but the radiating patch can be of any geometrical configuration like square, rectangle, circular, elliptical, triangular, E-shaped, H-shaped, L-shaped, U shaped etc [2]. When changes the substrate material of microstrip antenna, it changes the antenna performance. Therefore, in order to introduce appropriate correctness in the design of the antenna, it is important to know the effect of changing dielectric substrate material. Simulation and measurements of inset feed rectangular patch antenna on different substrate material like RT_duroid, roger, epoxy and FR-4 is presented in this research paper. The design, simulation and measurements are performed by advanced design system (ADS) 2016 momentum.

2. Feeding Technique

Microstrip patch antennas can be fed by a variety of methods. Mainly these methods are classified into direct contact and indirect contact. Some popular feeding techniques are m line feed, coaxial probe feed, inset feed, aperture coupling, proximity coupling, coupled (indirect) fed etc. The selection of feeding technique for a microstrip patch antenna is an important decision because it directly affects the return loss and Gain [3] [7]. We chose Inset feed technique because it can be easily fabricated and simplicity in modeling as well as impedance matching [4].The fig.1 shows the layout of inset feed rectangular microstrip patch antenna with requires dimensions. Where, A = width of patch, B = Length of patch, C = inset depth, E = width of feeder and F = length of feeder.

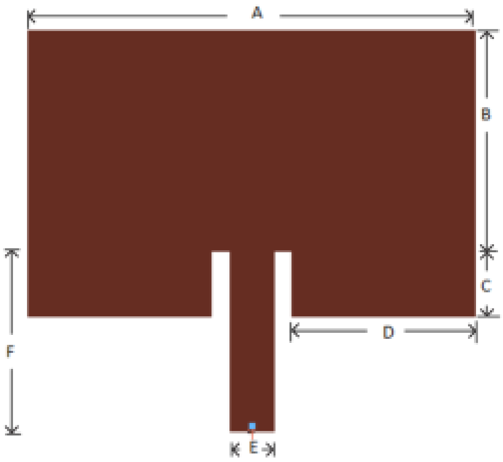

Figure 1: layout of inset feed microstrip patch antenna

3. Design of Microstrip Patch Antenna

In the typical design procedure of rectangular Microstrip patch antenna, three essential parameters are [5]:

- Resonance frequency, fr
- Dielectric constant, εr
- Thickness of substrate, h

The usual methods to calculation dimension of patch antenna are given as follows.

Step 1: Calculation of width of patch, W

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

Where, C = Velocity of Light = 3×10^8 m/s

f_r = Resonance Frequency

ε_r = Dielectric Constant

W = Width of Patch

Step 2: Calculation of effective dielectric constant,

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \qquad (2)$$

Step 3: Calculation of effective length of patch,

$$L_{eff} = \frac{c}{2 f_r \sqrt{\varepsilon_{eff}}} - 2\Delta L \qquad (3)$$

Step 4: Calculation of length extension,

$$\Delta L = 0.41h * \frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258} \times \frac{\frac{W}{h} + 0.264}{\frac{W}{h} + 0.8} \qquad (4)$$

Step 5: Calculation of actual length of patch,

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

Where, L = Length of Patch

The geometry of the proposed patch antenna is shown in Figure 1.

In this design subtract thickness is taken as 0.06 inch and Z_0 is calculate using LineCalc Tool in ADS 2016.The dimension of microstrip patch antenna can be calculated from Table 1.

Table 1: Dimensions of microstrip patch antenna

Parameter	*Size of patch (mm)*
A	W/0.8127
B	L/1.2825
C	W/1.9888
D	L/4.4
E	Z_0
F	15.2-20.2

4. Effect of Changing Substrate Material

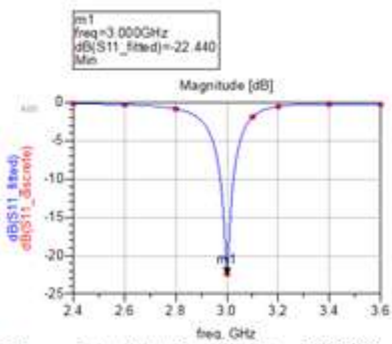

Figure 2: |s11| for RT_Duroid5881

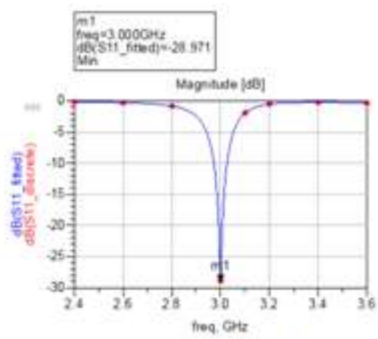

Figure 3: |s11| for RT_Duroid6002

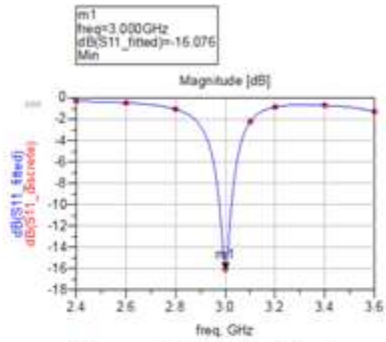

Figure 4: |s11| for FR_4

Antenna Parameters

Frequency (GHz)		3
Input power (Watts)		0.00248575
Radiated power (Watts)		0.0021435
Directivity(dBi)		7.84967
Gain (dBi)		7.20634
Radiation efficiency (%)		86.2318
Maximum intensity (Watts/Steradian)		0.00103963
Effective angle (Steradians)		2.06178
Angle of U Max (theta, phi)	2	90
E(theta) max (mag,phase)	0.885055	-24.5769
E(phi) max (mag,phase)	0.00142575	124.832
E(x) max (mag,phase)	0.00142575	-55.1682
E(y) max (mag,phase)	0.884516	-24.5769
E(z) max (mag,phase)	0.030888	155.423

Figure 5: Gain for RT_Duroid5881

Antenna Parameters

Frequency (GHz)		3
Input power (Watts)		0.00249683
Radiated power (Watts)		0.0020048
Directivity(dBi)		7.24382
Gain (dBi)		6.29063
Radiation efficiency (%)		80.2937
Maximum intensity (Watts/Steradian)		0.000845751
Effective angle (Steradians)		2.37043
Angle of U Max (theta, phi)	2	90
E(theta) max (mag,phase)	0.798272	-12.0792
E(phi) max (mag,phase)	0.00130177	-32.5385
E(x) max (mag,phase)	0.00130177	147.462
E(y) max (mag,phase)	0.797786	-12.0792
E(z) max (mag,phase)	0.0278593	167.921

Figure 6: Gain for RT_Duroid6002

Antenna Parameters

Frequency (GHz)		3
Input power (Watts)		0.00243829
Radiated power (Watts)		0.00130124
Directivity(dBi)		6.51448
Gain (dBi)		3.78722
Radiation efficiency (%)		53.367
Maximum intensity (Watts/Steradian)		0.000464085
Effective angle (Steradians)		2.80389
Angle of U Max (theta, phi)	2	90
E(theta) max (mag,phase)	0.591328	-37.4485
E(phi) max (mag,phase)	0.000997023	99.7246
E(x) max (mag,phase)	0.000997023	-80.2754
E(y) max (mag,phase)	0.590968	-37.4485
E(z) max (mag,phase)	0.020637	142.551

Figure 7: Gain for FR_4

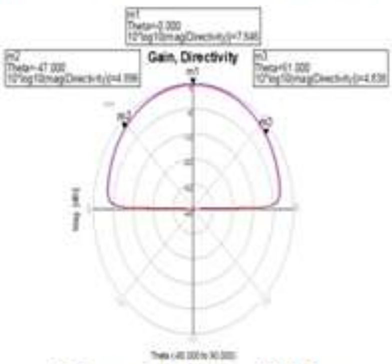

Figure 8: Beam width for RT_Duroid5881

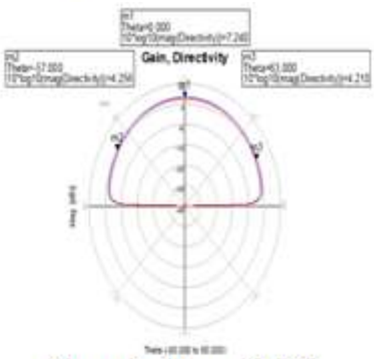

Figure 9: Beam width for RT_Duroid6002

Figure 10: Beam width for FR_4

Table 2: Variation in patch antenna parameters as a function of changing substrate material

Substrate Material	Dielectric Constant ε_r	Tan D	Width of patch W(mm)	Length of patch L(mm)	Directivity D(dB)	Gain G (dB)	Return Loss R(dB)	Beam-Width
RT_Duroid5881	2.17	0.0009	39.69	33.13	7.84	7.2	-22.44	98
RT_Duroid5880	2.2	0.0009	39.5	32.9	7.85	7.2	-22.7	100
RT_Duroid5870	2.33	0.0012	38.72	32.01	7.67	6.92	-21.07	104
RT_Duroid6002	2.93	0.0013	35.6	28.6	7.24	6.29	-28.97	120
Rogers_RO3003	3	0.0013	35.33	28.3	7.13	6.15	-26.59	126
Roger_RO3203	3.02	0.0016	35.24	28.21	7.1302	6.09	-23.83	127
Roger_RO4003	3.55	0.0022	33.13	26.06	6.85	5.6	-22.00	111
Rogers_RO4350	3.66	0.004	32.73	25.67	6.919	5.23	-20.72	146
Epoxy Fiberglass	4.2	0.015	30.99	23.99	6.65	3.32	-26.91	155
FR_4	4.6	0.01	29.86	22.93	6.51	3.78	-16.08	159

Changing the substrate material means the changing the dielectric constant (εr). Although, wide variety of substrate materials have been found to exist suitable for microstrip antenna design. In this paper different substrate materials like RT Duroid 5881, RT Duroid 5880, RT Duroid 5870, RT Duroid 6002, Rogers_RO3003, Rogers_RO3203, Rogers_RO4003, Rogers_RO4350, Epoxy_Fiberglass and FR_4 are used whose dielectric constants are 2.17, 2.2, 2.33,2.93,3,3.02,3.55,3.66,4.2 and 4.6 respectively for the same antenna configuration (fr=3GHz & h=0.06").

For different substrate materials the antenna performance parameters are determined as resonance frequency, directivity, gain, return loss, BeamWidth as well as the dimension of patch of the antenna (length and width of patch). These antennas are designed and simulated by using advanced design system (ADS) 2016 momentum simulator. Table 2 shows the antenna parameters variation summary with changing substrate material. From the Table 2, it can be said that as dielectric constant (εr) increase the dimension of patch, inset depth (d), Directivity (D) and Gain (G) decreases but 3-dB BeamWidth at phi 90^0 is increase.

Figure 11 shows the graphical representation of the antenna gain and directivity which are given in table 2 with respect to dielectric constant. From figure 11 it can be said that as dielectric constant increase the antenna gain and directivity decrease.

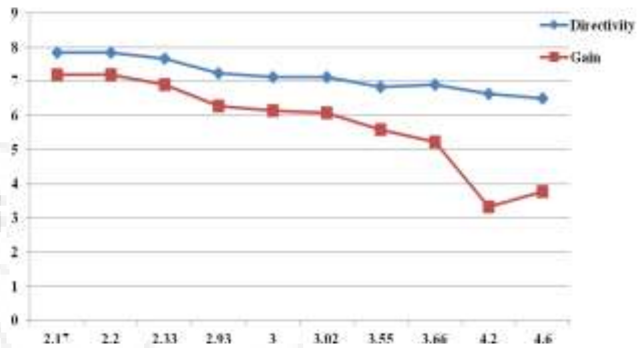

Figure 11: Dielectric constant Vs Gain and Directivity

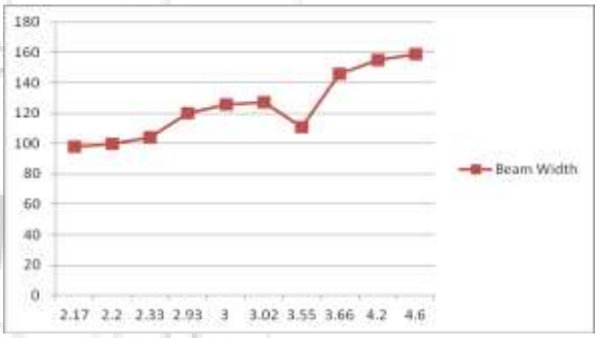

Figure 12: Dielectric constant Vs Beam Width

Figure 12 shows the graphical representation of the antenna Beamwidth which are given in table 2 with respect to dielectric constant. From figure 12 it is said that as dielectric constant increases the antenna Beamwidth is also increase.

5. Effect of Changing Substrate Thickness

Table 3: Variation in patch antenna parameters as a function of changing substrate Thickness

Substrate Thickness (inch)	Width of patch W(mm)	Length of patch L(mm)	Resonance Frequency f_r (GHz)	Directivity D(dB)	Gain G (dB)	Return Loss R(dB)	Beam-Width (phi-90^0)
0.01	35.64	29.13	3	7.098	2.94	-23.049	118
0.02	35.64	29.06	3	7.14	5.35	-19.686	118
0.03	35.64	28.97	3	7.16	5.94	-31.824	119
0.04	35.64	28.86	3	7.19	6.19	-24.093	120
0.05	35.64	28.75	3	7.21	6.244	-25.195	119
0.06	35.64	28.63	3	7.24	6.29	-28.971	120
0.09	35.64	28.22	3	7.33	6.24	-14.955	118
0.1	35.64	28.07	3	7.36	6.21	-12.729	118

Selection of proper substrate thickness is important in microstrip patch antenna design. Here, the antenna parameters by varying substrate thickness (h) from 0.01 inch to 0.1 inch for an inset feed rectangular microstrip patch antenna. The measured data are show in table 3. RT Duroid 6002 substrate with dielectric constant εr=2.93 used for this analysis. From the table 3, it is seen that with increasing the substrate thickness, the Gain and directivity increases but the antenna dimension decreases.

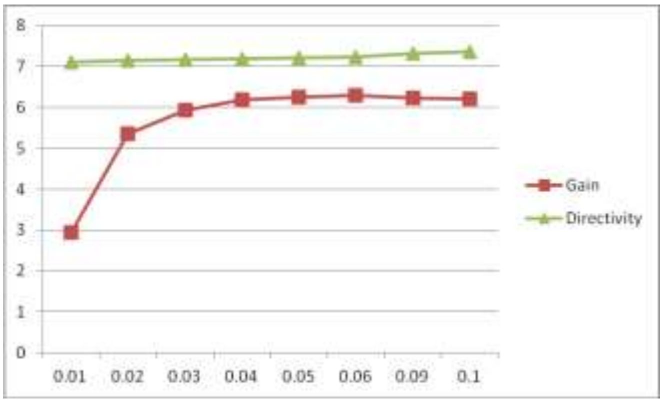

Figure 13: Substrate Thickness Vs gain and Directivity

Figure 13 Shows the graphical representation of the antenna parameters which are given in table 3 with respect to substrate thickness (h). From figure 13 it can be say that as substrate thickness increase the antenna gain and directivity also increase.

6. Conclusion

The performance of the antennas was measured for 3 GHz operating frequency using inset feeding technique with advanced design system (ADS) 2016.From the table 2, the use of substrate material with higher dielectric constant in microstrip patch antenna design, size of the antenna reduces and beam Width is increase but decreasing the dielectric constant, the antenna Gain and Dielectric constant increase. Form table 3, as subtract thickness increases size of patch antenna is reduce but gain and directivity is increase.

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