Effect of Substrate relative dielectric constant on Bandwidth characteristics of Line feed Rectangular Patch Antenna

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Abstract: **Selection of proper substrate material is most important parameter when we design microstrip patch antenna. The limitations of micro-strip antenna such as low gain, low efficiency and high return loss can overcome by selecting a proper substrate material, because permittivity of substrate is critical parameter in controlling band width, efficiency and radiation pattern of patch antenna. The substrate materials have two basic properties i.e dielectric constant and loss tangent. Present paper is comparative study of various dielectric constants and its effect on radiation characteristics of rectangular patch antenna such as bandwidth and return loss. The micro-strip antenna consist of a planar resonant radiating element parallel to, but separated, from a ground plane by a thin dielectric substrate (t <<λ) was designed.**

Keywords: **Relative Dielectric constant, Rectangular Patch Antenna, Bandwidth, S11 Parameter,Gain & HFSS.**

I. INTRODUCTION

Microstrip antennas as shown in fig1, consist of a very thin ($t \ll \lambda_o$) metallic strip (patch) placed a small fraction of a wavelength ($h \ll \lambda_o$ usually $0.003\ \lambda_o \leq h \leq 0.05\ \lambda_o$) above a ground plane. The microstrip antenna is designed so its pattern is normal to the patch. This is accomplished by properly choosing the mode (field configuration) of excitation beneath the patch. End fire radiation can also be accomplished by judicious mode selection. For a rectangular patch, the length of the element is usually $\lambda_o/3 < L < \lambda_o/2$. The strip (patch) and the ground plane are separated by a dielectric sheet (referred to as a substrate). There are numerous substrates that can be used for the design of microstrip antennas, and their dielectric constants are usually in the range of $2.2 \leq \varepsilon_r \leq 12$. The once that are most desirable for antenna performance are thick substrates whose dielectric constant is in the lower range because they provide better efficiency, larger bandwidth, loosely bound fields for radiation in space but at the expense of larger element size. Thin substrates with larger dielectric constants are desirable for microwave circuitry because they require tightly bound fields to minimize undesired radiations and coupling, and lead to smaller elemental sizes, however, because of their greater losses; they are less efficient and have relatively smaller bandwidths. Since microstrip antennas are often integrated with other microwave circuitry, a compromise has to be reached between good antenna performance and circuit design.

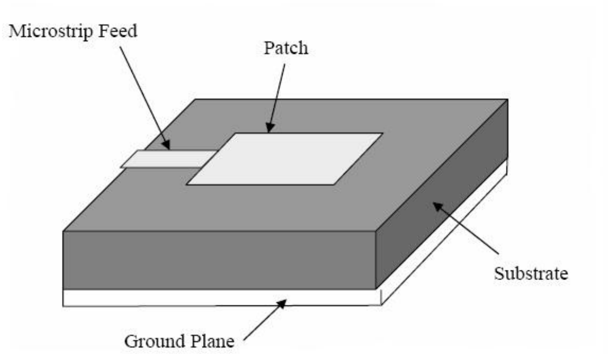

fig 1 microstrip antenna

II. MICROSTRIP PATCH ANTENNA DESIGN

The rectangular patch antenna consists of metalized pattern over a thin microstrip substrate. The back surface of substrate is known as ground palne. The substrate relative dielectric constant ε_r lies between 2.2 to 12. And an effective dielectric constant (ε_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line. The value of ε_{reff} is slightly less then ε_r because the fringing fields around the periphery of the patch.

The expression for ε_{reff} is given as:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2}$$

Where

ε_{reff} = Effective dielectric constant

E_r = Dielectric constant of substrate

h = Height of dielectric substrate

W = Width of the patch

The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically by as:

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

Since the length of the patch has been extended by ΔL on each side, the effective length of the patch is now

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

For a given resonant frequency the effective length is given by

$$L_{eff} = \frac{C}{2f_o\sqrt{\varepsilon_{reff}}}$$

The resonant frequency for any rectangular micro-strip patch is given as

$$f_o = \frac{C}{2\sqrt{\varepsilon_{reff}}}\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{w}\right)^2\right]^{1/2}$$

Where m,n are the modes for L and W respectively.

For efficient radiation the width (W) is given by:

$$w = \frac{C}{2f_o\sqrt{\frac{(\varepsilon_r+1)}{2}}}$$

Where

f_o= Resonant frequency.

C =speed of light in free-space.

III. MICROSTRIP LINE FEED

This model represents the microstrip antenna by two slots of width W and height h, separated by a transmission line of length L. The microstrip is essentially a non homogeneous line of two dielectrics, typically the substrate and air. Figure 2 illustrates this.

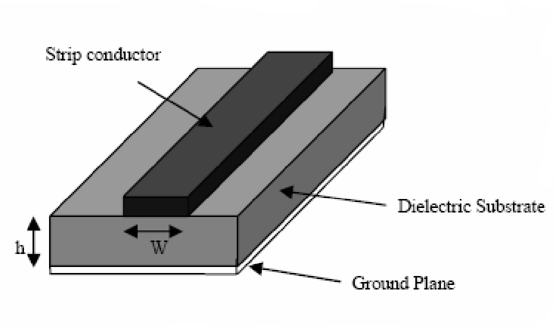

fig 2 microstrip line

IV. DIELECTRIC MATERIAL DATA

Present thesis I have consider different type of dielectric material whose relative dielectric constant i.e ε_r are lie between ranges 4 to 4.4 are listed below.

TABLE I
DIELECTRIC CONSTENT

S.NO	Material Name	Relative Permittivity	Loss Tangent
1.	Polymide Quartz	4	0
2.	Silicon dioxide	4	0
3.	Arlon AD410	4.1	0.003
4.	Arlon AD430	4.3	0.003
5.	Polyamide	4.3	0.004
6.	FR 4	4.4	0.02

V. DESIGN SPECIFICATIONS FOR RECTANGULAR PATCH

The essential parameters for the design of a rectangular microstrip Patch Antenna are listed below.

TABLE II
DESIGN SPECIFICATIONS

S.NO	Resonant Frequency (fr) in GHz	Substrate Height (h) in mm	Relative permittivity (ε_r)	Length of patch in mm	Width of patch in mm
1.	10	1.5	4	6.81	9.48
2.	10	1.5	4.1	6.72	9.39
3.	10	1.5	4.3	6.56	9.21
4.	10	1.5	4.4	6.48	9.12

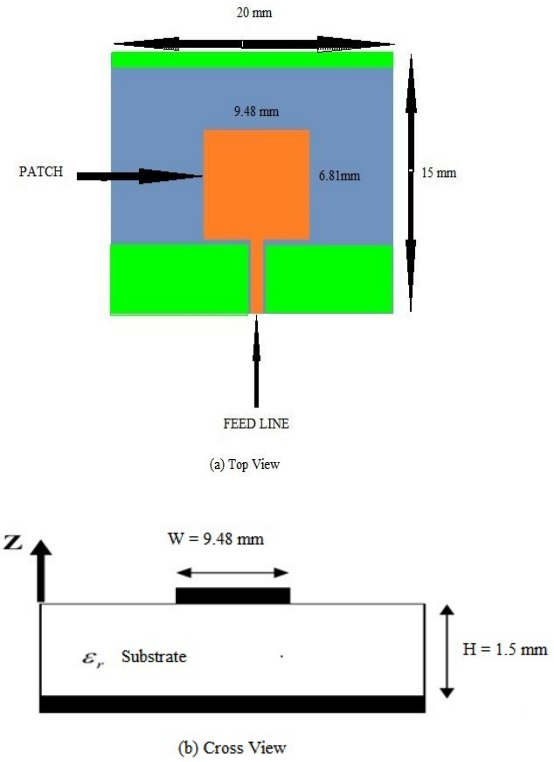

fig 3 (a) Top View of rectangular patch antenna (b) Cross View of rectangular patch antenna

VI. SIMULATION SETUP

Present project work of microstrip line feed rectangular patch antenna was designed with above given specification in Ansoft HFSS software. And result of Return loss, gain in 3D Polar, and bandwidth were presented.

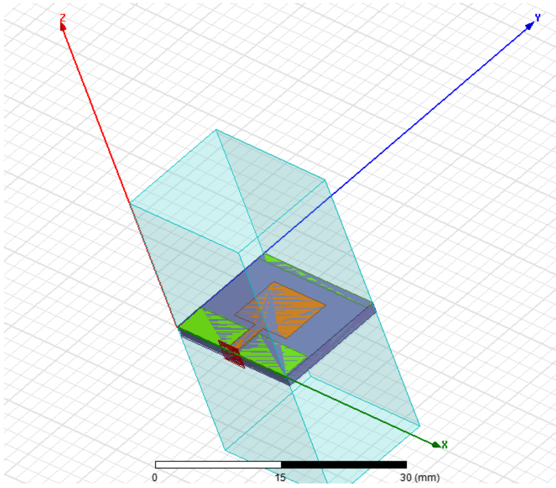

fig 4 simulated Antenna Model

VII. RESULT & DISCUSSION

A HFSS simulation software is use to analysis the performance of microstrip antenna and evaluate the various parameter of antenna like return loss , bandwidth and radiation pattern etc.

A. Return Loss

This is important to calculate the input and output of signal source, Because if load is mismatched the whole power is not delivered to load and there is a return of power that is called loss, since this loss is returned hence is called return loss. The response of S11 versus frequency curve clearly explain return loss.

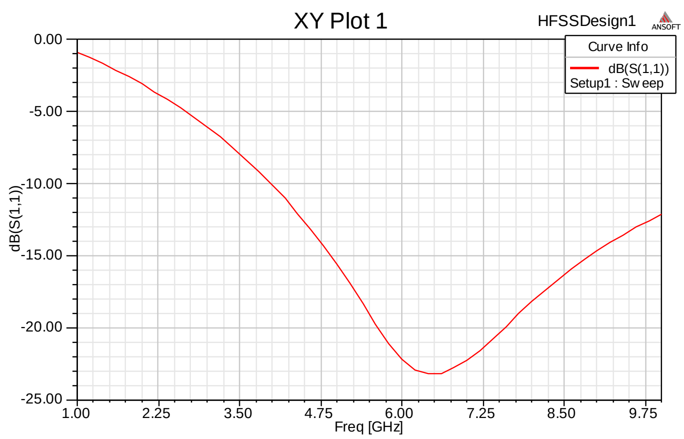

fig 5(a) Return loss curves for Silicon dioxide

fig 5 (b) Return loss curves for polyimide quartz

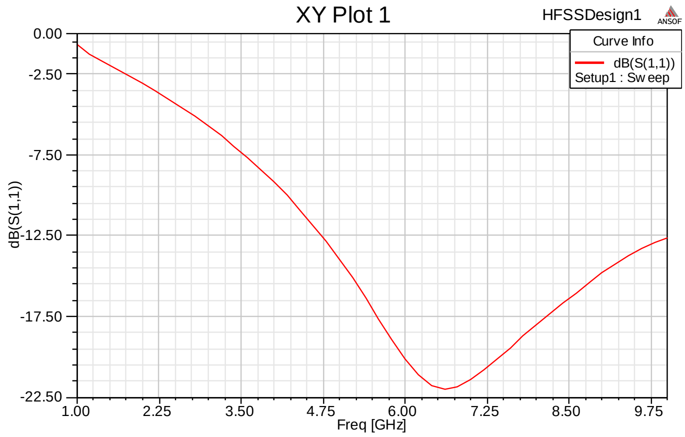

fig 5(c) Return loss curve for Arlon AD 410

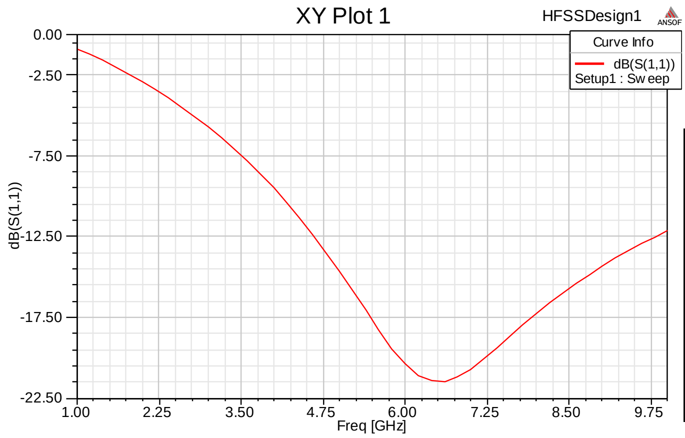

fig 5(d) Return loss curve for Arlon AD 430

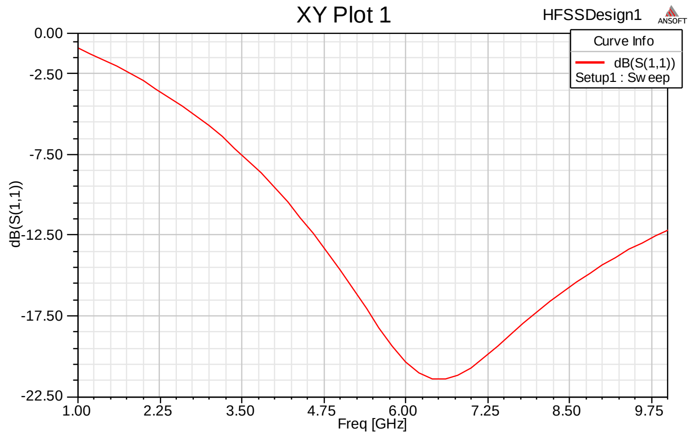

fig 5(e) Return loss curve for Arlon AD 430

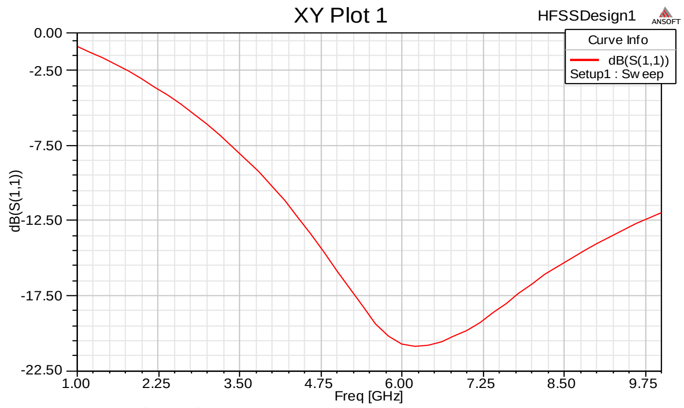

fig 5 (f) Return loss curves for FR4-Epoxy

TABLE III
RETURN LOSS

Substrate	Dielectric constant ε r	Return loss	Operating frequency (GHz)
Silicon dioxide	4	-23.24	6.4
Polyimide quartz	4	-23.24	6.4
Arlon AD 410	4.1	-21.99	6.6
Arlon AD 430	4.3	-21.45	6.6
Polymide	4.3	-21.45	6.6
FR4-Epoxy	4.4	-21.43	6.6

By observation of table III we can conclude that as we increase the relative dielectric permittivity of the substrate of antenna then return loss is increasing hence very les amount of power is forwarded to radiating element hence radiating characteristics can be degraded. It is also observe that if substrate material are different but have same relative dielectric constant then return loss is remain same for both materials.

B. Bandwidth

In microstrip patch antenna the bandwidth is inversely proportional to the square root of the dielectric constant of the substrate.

S11 response of patch antenna is used for calculation of bandwidth. From the figure 5(a), frequency f1 is taken as 4GHz and f2 is taken as 10 GHz. Therefore maximum bandwidth is obtained after doing calculation as 85.7%.

TABLE IV
BANDWIDTH

Substrate	Dielectric constant εr	Frequency (f1)GHz	Frequency (f2)GHz	Bandwidth= $\frac{f_2-f_1}{f_c}\times 100$ %
Silicon dioxide	4	4	10	85.70%
Polyimide quartz	4	4	10	85.70%
Arlon AD 410	4.1	4	10	85.70%
Arlon AD 430	4.3	4.2	10	81.69%
Polymide	4.3	4.2	10	81.69%
FR4-Epoxy	4.4	4.2	10	81.69%

By observation of table IV we can conclude that as we increase the relative dielectric permittivity of the substrate of antenna the bandwidth of antenna is decreases.

C. Gain

Since antenna is a passive device the gain cannot be measured directly. Test antenna radiation is compared with the isotropic antenna.

Gain is a measure of power radiated per unit surface by test antenna in a given direction at any distance, the obtained result are compared with the result of isotropic antenna.

3D polar plot of gain for different substrate show in figure below.

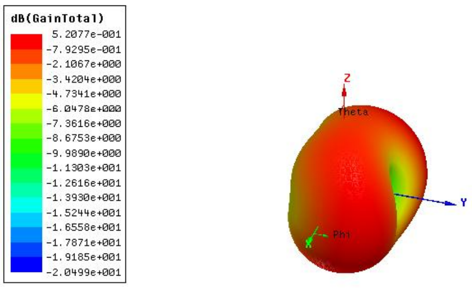

fig 6(a) 3D polar plot for silicon dioxide

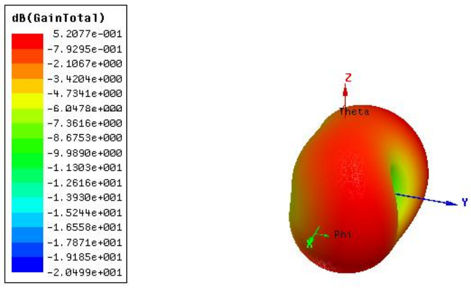

fig 6(b) 3D polar plot for Polymide Quartz

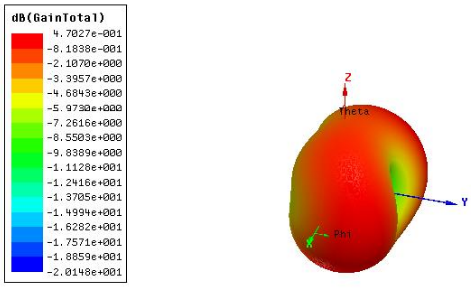

fig 6(c) 3D polar plot for Arlon AD 410

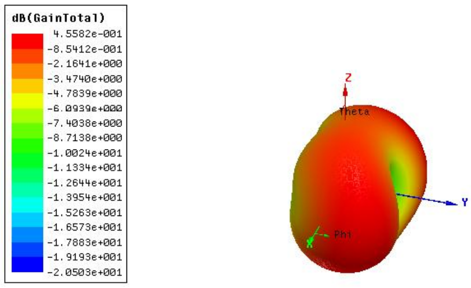

fig 6(d)3D polar plot for Arlon AD 430

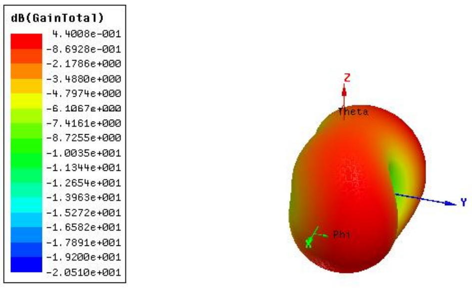

fig 6(e) 3D polar plot for Polyamide

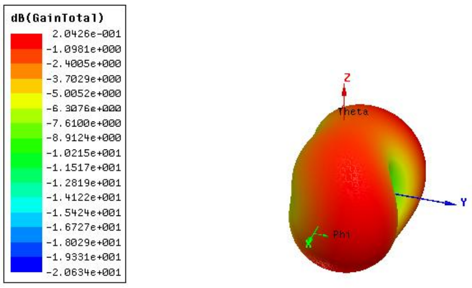

fig 6(f) 3D polar plot for FR4- Epoxy

By observation of above 3D polar plot we can conclude that as we increase the relative dielectric permittivity of the substrate of antenna the gain of antenna is decreases.

VIII. CONCLUSION

This research was aimed at designing and implementing rectangular microstrip patch antenna for different types of substrate material.

By care full observation of paper we can conclude that when we increasing the substrate dielectric constant in antenna design The performance characteristics of antenna like antenna bandwidth , gain and S11(Return loss) parameter are degraded from $\varepsilon_r = 4 \; to \; \varepsilon_r = 4.4$.

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