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The Effect Of Dielectric Loss Tangent On Radiation Characteristics Of Co-Axial Feed Rectangular Patch Antenna

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ABSTRACT: ***The substrate permittivity and loss tangent are critical parameters in controlling band width, efficiency and radiation pattern of micro strip patch antenna. Present paper rectangular patch antenna is designed using a wide range of dielectric materials having same permittivity but with different loss tangent values. A comprehensive study of radiation characteristics of this rectangular patch antenna is investigated. Results such as resonance frequency, bandwidth, gain, return loss, input and impedance are presented.***

Keywords**:** dielectric constant, loss tangent, rectangular patch antenna, co-axial feed,

Introduction

Generally a dielectric substrate is defined by its two prime parameters, one is its permittivity (It denotes the tendency of a material to polarize) and another is its loss tangent (It denotes the dissipation of electromagnetic energy), defined by the equation $\varepsilon=\varepsilon_r\varepsilon_0(1-j\tan\delta)$. Loss tangent includes dielectric damping loss and conductivity loss of material and it is frequency dependant.

For a material with conductor loss and dielectric damping loss, its defining equation are [1, 2, 3]

$$\begin{aligned} \nabla \times \overline{H} &= j\omega\overline{D} + \overline{J}_c \\ &= j\omega\epsilon\overline{E} + \sigma\overline{E} \\ &= j\omega\epsilon'\overline{E} + (\omega\epsilon'' + \sigma)\overline{E} \\ &= j\omega(\epsilon' - j\epsilon'' - j\frac{\sigma}{\omega})\overline{E} \\ &= j\omega[\epsilon' - j(\epsilon'' + \frac{\sigma}{\omega})]\overline{E} \end{aligned}$$

The imaginary part of above equation explains loss of material. Including dielectric damping loss (ϵ''), the conductive loss (σ/ω).

$$\begin{aligned} \nabla \times \overline{H} &= j\omega[\epsilon' - j(\epsilon'' + \frac{\sigma}{\omega})]\overline{E} \\ &= j[\omega\epsilon' - j(\omega\epsilon'' + \sigma]\overline{E} \end{aligned}$$

In microwave engineering, the materials are defined with

$$\begin{aligned} \epsilon &= \epsilon' - j(\epsilon'' + \frac{\sigma}{\omega}) \\ &= \epsilon'[1 - j(\frac{\omega\epsilon'' + \sigma}{\omega\epsilon'})] \\ &= \epsilon'[1 - j\tan\delta] \end{aligned}$$

complex permittivity for loss less materials there is no loss tangent ($\tan\delta=0$) then the permittivity is real ($\varepsilon=\varepsilon_r\varepsilon_0$) [8]. Present paper different dielectric materials of same permittivity with different loss tangent were considered. Height of substrate is 1.56mm (common for all simulations).

I. MICROSTRIP PATCH ANTENNA DESIGN

The structure of rectangular patch antenna consists of dielectric substrate backed with optically planar reflecting metal ground plane, on other side consists of radiating element.

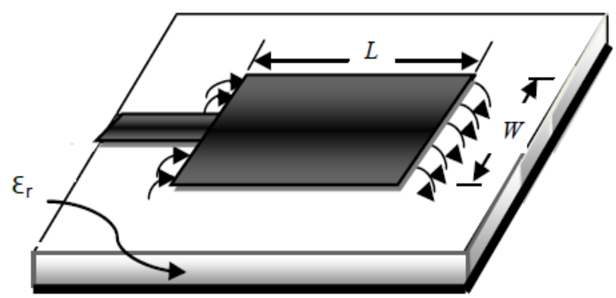

Fig 1: Rectangular Patch Antenna

The length of patch (L) is about $\lambda_g/2$ (λ_g is effective wave length) and substrate height (H) is of order of $\lambda_g/20$. Due to very small space between radiating element and ground plane main power is radiated towards broad side. The fringing fields effectively increase the length (ΔL) of patch need to be accounted in determine resonance frequency [4].

The most commonly used design equations of antenna [5, 6] are:

a) Effective dielectric constant

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

b) Length extension is

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

c) Effective Length

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

d) Actual length of patch

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

e) Patch width

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

f) Ground plane dimensions

$$L_g = 6h + L$$

$$W_g = 6h + W$$

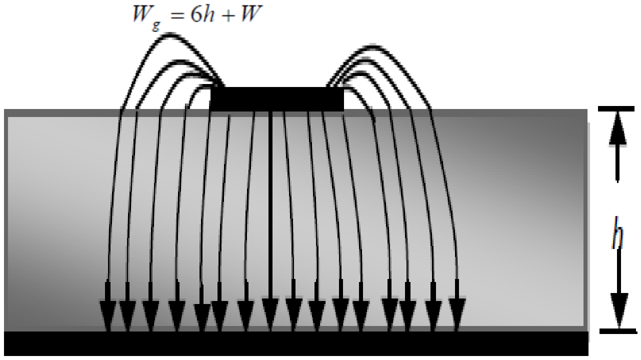

Fig 2: Electrical Field Lines(Side View)

II. CO-AXIAL PROBE FEED

This is common feed technique, where outer conductor is connected to ground plane and the inner conductor of co-axial connector extends through dielectric and is soldered to patch.

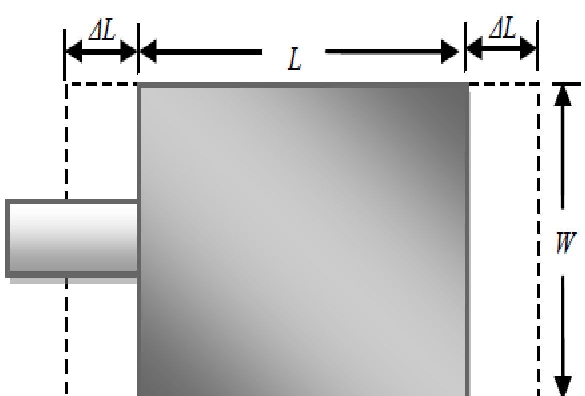

Fig 3: Physical & Effective Lengths of Patch

Inner conductor of co-axial cable transfers the power from strip line to micro strip antenna from slot in the ground plane. Placing of feed position is important in order to have best matching with input impedance. Here feed is applied at (0mm, 9.2mm). It provides narrow bandwidth performance and it is difficult to design for thick substrates [7, 8].

IV. DIELECTRIC MATERIALS

TABLE I : DIELECTRIC LOSS TANGENT

Material Name	Permittivity	Loss Tangent
Rubber_hard	3	0
Roger RO3003	3	0.0013
Arlon AD300A	3	0.002
Neltec NH 9300	3	0.0023
Rogers Ultralam 1300	3	0.003

V. NUMERICAL DESIGN

The proposed co-axial feed rectangular micro strip patch antenna is operating at 1.7616GHz having physical dimensions of radiating patch length L=47.4mm along Y-axis, width W=56.5mm along X-axis (here width of patch W is maintained higher than length L because of wider operating band width).

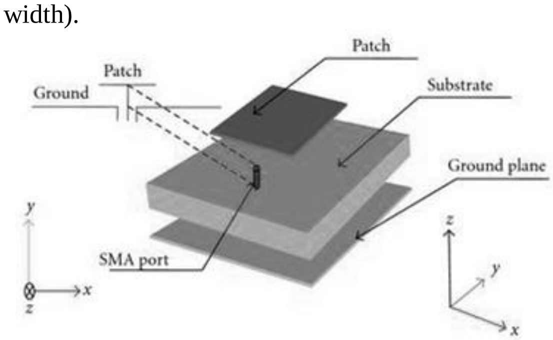

Fig 4: Top view of micro strip patch antenna

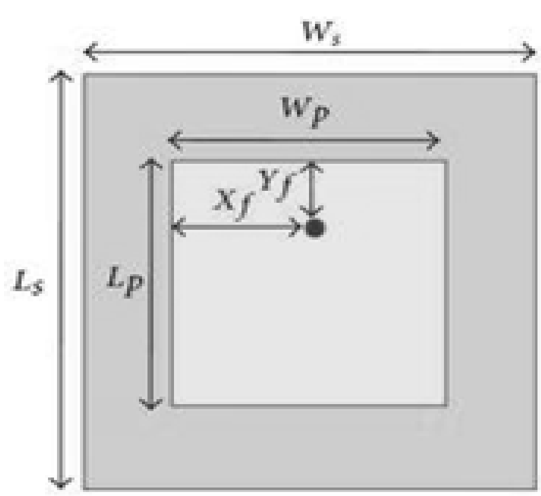

Fig 5: Coaxial feed micro strip antenna

VI **Simulation Setup**

The ANSOFT HFSS software is utilized here for execution of current proposal of coaxial feed rectangular micro strip antenna. And results of return loss, gain and band width are presented.

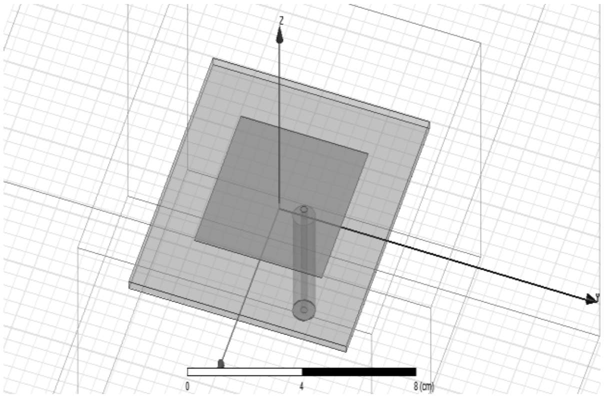

Fig 6: Simulated Antenna Model

VII. **Results & Discussion**

A. Return loss

According to maximum power transfer theorem, maximum amount of power will be transferred when there is a perfect matching between input and output. If load is mismatched, the power is not delivered to load and there is a return of power that is called loss. Hence it is called return loss and is given as -20log|Γ| where Γ is the reflection coefficient. The response of magnitude of S11 verses frequency curve clearly explains return loss as shown in Figure 7.

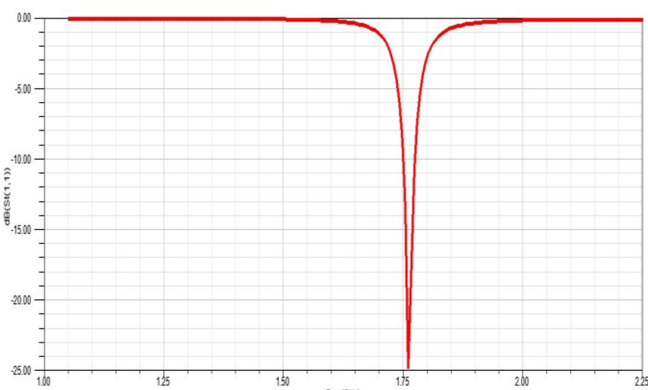

Fig 7 : Return loss

TABLE II
RETURN LOSS

Substrate	Return loss	Operating Frequency(GHz)
Rubber_hard	-18.1618	1.7616
Roger RO3003	-20.9417	1.7616
Arlon AD300A	-22.5992	1.7616
Neltec NH 9300	-23.3269	1.7616
Rogers Ultralam 1300	-24.8394	1.7616

We can see that as the loss tangent of dielectric material increases the return loss value decreases. This indicates that more amount of power is forwarded and very less amount of power is reflected back.

B. Bandwidth:

It can be defined as the range of frequencies over which gain is constant. In software simulation this value is taken at intersecting points of -10db line on return loss curve.

Table III : Band Width

Substrate	Band width (MHz)	Operating Frequency(GHz)
Rubber_hard	22.5	1.7616
Roger RO3003	22.5	1.7616
Arlon AD300A	22.5	1.7616
Neltec NH 9300	22.5	1.7616
Rogers Ultralam 1300	22.5	1.7616

The loss tangent of substrate does not affect the operating bandwidth of antenna.

C. Impedance:

The impedance is not effected by loss tangent of substrate

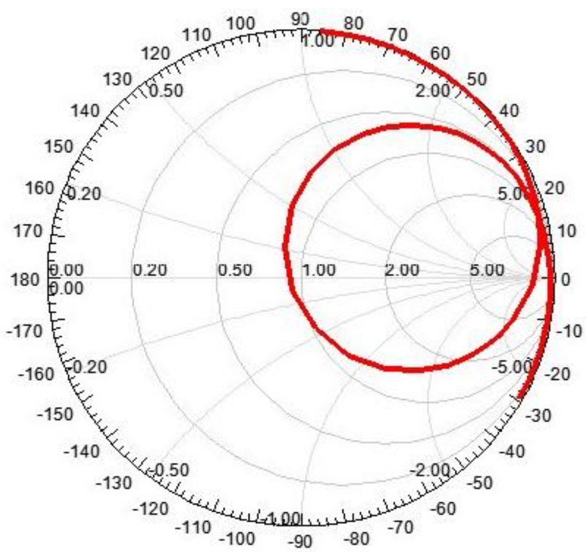

Fig 8: Impedance

D. Gain

Gain explains figure of merit of antenna which combines antenna's directivity and electrical efficiency.

VIII. Antenna Parameters

Tabe Iv:Antenna Parameters

Parameter/Substrate	Rubber Hard	Roger RO3003	Arlon AD300A	Neltec NH 9300	Rogers Ultralam 1300
Max U	0.004063	0.0037	0.0036	0.0036	0.00348

	3 (w/sr)	989 (w/sr)	672	126	85
Peak Directivity	5.231	5.2288	5.2285	5.2284	5.2276
Peak Gain	5.2428	4.864	4.6823	4.6082	4.443
Peak Realized Gain	5.1571	4.8216	4.6544	4.5851	4.4276
Radiated Power	0.0097641	0.0091301	0.008814	0.008683	0.008386
Accepted Power	0.0097394	0.0098149	0.0098422	0.0098515	0.009867
Incident Power	0.0099012	0.0099012	0.0099012	0.0099012	0.0099012
Radiation Efficiency	1.0023	0.93023	0.89553	0.88139	0.84991
FBR	26.57	26.57	26.573	26.577	26.432

The gain, directivity and radiation efficiency are decreasing as the loss tangent of substrate is increasing.

IX CONCLUSION

The dielectric materials provide mechanical strength to patch antenna design. To have effective radiation characteristics it is better to consider a dielectric material with a low loss tangent. But loss tangent will not affect the operating band width.

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