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Performance Analysis of Rectangular Patch Antenna for Different Substrate Heights

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Abstract: Height of the dielectric substrate material for a microstrip patch antenna is utterly important in terms of controlling bandwidth as well as surface wave. In this paper we have presented a comparative study of effect of height in the performance parameters of Rectangular Shaped Microstrip Patch antenna. The antennas were simulated for purpose of the application of wireless LAN for resonance frequency 2.45GHz. Five antennas with different heights were designed using same dielectric substrate material with relative permittivity of 2.84 for the analysis of their performances. Coaxial Probe-feed methods are used for feeding techniques. This paper along with the comparison of performance parameters like VSWR, Reflection coefficient, Bandwidth, Impedance, Mismatch loss, Directivity, Gain and Field, also presents the effect of substrate height in design parameters like width, length, feed point location, ground dimension for each patch antenna. This study was carried out by using FEKO, Electromagnetic solver software which uses Method of Moments (MoM) technique.

Keywords: Microstrip, Fringing field, Reflection coefficient, VSWR, FEKO

I. INTRODUCTION

In this paper basic structure of Microstrip patch antenna was taken under design consideration. A microstrip patch antenna consists of a conducting patch of any planar or non-planar geometry on one side of a dielectric substrate with a ground plane on other side. It is a printed resonant antenna that is very popularly required for wireless links of narrow-band microwave because of its semi-hemispherical coverage. Microstrip Patch antennas are low cost, low profile, light weight, mechanically robust, easy to fabricate and analyse. Compact size, radiation pattern and selective range of resonance frequency draw major attractions. The microstrip antenna radiates a relatively broad beam broadside to the plane of the substrate. Thus the microstrip antenna has a very low profile, and can be fabricated using printed circuit (photolithographic) techniques. This implies that the antenna can be made conformable, and potentially at low cost [1]. The feeding method that has been considered is pin feed using a coaxial probe. Pin-fed patch on a finite substrate includes pin offset which gives the best impedance match to a 50Ω system at length equals to approximately one-half wavelength of microstrip transmission line. One important consideration in designing microstrip patch antenna is the fringing fields. Fringing field is a function of effective dielectric constant. Along the width of patch, fringing fields can be modeled as radiating slots, increasing electrical length (vitually) of patch than physical length [2,3].

II. DESIGN CONSIDERATIONS OF PATCH ANTENNA

Microstrip antennas are also referred to as patch antennas because of the radiating elements photo-etched (patches) on the dielectric substrate. This radiating patch may be square, rectangular, circular, elliptical, triangular, and any other configuration. In this work, rectangular microstrip patch antennas are taken under consideration. The patch dimensions of rectangular microstrip antennas are usually designed to maximize the pattern so that it is normal to the patch. The rectangular microstrip antennas are made of a rectangular patch with dimensions width, W, and length, L, over a ground plane with its width Wg, length Lg and substrate thickness h and dielectric constants εr of the dielectric material.

A. *Frequency of Operation (f_o)*

The antennas were designed for the application of wireless LAN that uses frequency of 2.45GHz as per IEEE 802.11 standards. The resonant frequency selected for design is 2.45GHz for wireless LAN network.

B. *Selection of Dielectric material*

Selection of dielectric material is based on the following parameters:

- Relative Dielectric Constant εr or permittivity

- Height of the substrate material h
- Loss Tangent, tan δ

Selection of dielectric material with appropriate dielectric constant is important as it has a major role in antenna performance. It directly affects gain, bandwidth, shift in operating frequency, radiation loss [4]. Also dielectric constant controls the fringing field which is the main cause of radiation in microstrip patch antenna. The lower will be εr, the wider will be the fringes which in turns results into the better radiation and also increased bandwidth and efficiency. Hence a dielectric material Nylon (610) with dielectric constant 2.84 and a loss tangent 12e-3 was used.

The height of the substrate is important in terms of controlling bandwidth and surface waves [5]. Height for the substrate is also responsible for inductive impedance. Based on these considerations dielectric material with height 2.54, 3.81, 4.75, 5.08 and 6.35 were taken into account to include a wide variety of heights into this study.

C. Calculation of Width (W)

For an effective radiator, practical width that leads to good radiation efficiencies is given by [6]:

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

Where c0 is the free-space velocity of light i.e. 3×10¬8 m/s and εr is the dielectric constant of material. Calculated width for different dielectric material has been given in the Table1.

D. Calculation of Effective Dielectric Constant ε_{reff}

The value of effective dielectric constant is less than dielectric constant of the substrate, because of the fringing fields is not confined in dielectric substrate around the periphery of the patch only, but is also spread in the air. The value of this effective dielectric constant is given by [7]:

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

Where h and W are the height and width of substrate material for an antenna respectively.

E. Calculation of Length (L)

The length of the patch determines the resonance frequency thus it is a critical factor for narrowband patch. Since it is not possible to accurately account the fringing field the results are not definite. Below is the equation to calculate the length of the patch.

$$L_{eff} = \frac{c_o}{2f_o\sqrt{\varepsilon_{reff}}} - 2dL$$

Where dL is the length extension because of fringing field, which can be calculated as follow:

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

F. Table Captions

Tables must be numbered using uppercase Roman numerals. Table captions must be centred and in 8 pt Regular font with Small Caps. Captions with table numbers must be placed before their associated tables, as shown in Table 1.

G. Calculation of Ground Dimensions

The ground dimension for the antenna can be calculated as below:

Width of the ground is given as: Wg = W + 6h
Length of ground is given as: Lg = L + 6h.

H. Feeding Technique & Location

The most common technique Coaxial-probe feeding was used for Microstrip patch antennas. This feeding scheme is advantageous in terms of free and desired placement location in order to match with the input impedance [7]. The impedance match will depend on its feed point location on the patch. An improved impedance match results in improve performance like increase the bandwidth and less return loss.Hence the feed point locations in order to match 50 ohm impedance were calculated using the following equation [8]:

Along the width of patch:

$$X_f = \frac{W}{2}$$

Along the length of patch:

$$Y_f = Y_0 - dL$$

$$\text{Where} \quad Y_0 = \frac{L}{\pi}\cos^{-1}\sqrt{\frac{50}{Z_0}}$$

$$Z_0 = \sqrt{50 * Z_{IN}}$$

$$Z_{IN} = 90 * \frac{{\varepsilon_r}^2}{\varepsilon_r - 1}\left(\frac{L}{W}\right)^2$$

This equation gives an approximation and can be considered the starting point, however to work out the exact co-ordinates for best match of impedance it is a very much iterative process. But for the sake of comparative study we have assumed this location to be final location for the feed point.

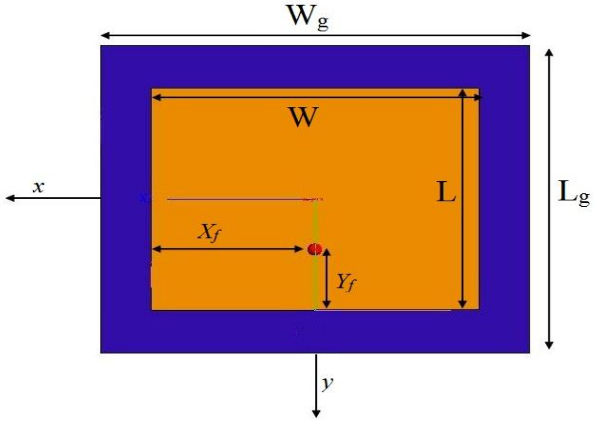

Fig. 1. Upper view of model of Microstrip patch antenna

I. Comparison of Design Parameters

Based on the techniques mentioned in previous section for calculation of design parameters, the patch width and length, width and length of ground and feed location were calculated. The table below shows the comparison of those design parameters.

TABLE I
Design parameters for different substrate materials

DESIGN PARAMETERS	HEIGHTS OF THE SUBSTRATE(mm)				
	2.54	**3.81**	**4.75**	**5.08**	**6.35**
RELATIVE PERMITIVITY	**2.84**	**2.84**	**2.84**	**2.84**	**2.84**
LOSS TANGENT	**12e-3**	**12e-3**	**12e-3**	**12e-3**	**12e-3**
PATCH WIDTH (mm)	**44.18**	**44.18**	**44.18**	**44.18**	**44.18**
PATCH LENGTH (mm)	**35.2568**	**34.496**	**33.88**	**33.667**	**32.7996**
GROUND WIDTH (mm)	**59.42**	**67.04**	**72.68**	**74.66**	**82.28**
GROUND LENGTH (mm)	**50.4968**	**57.356**	**62.38**	**64.147**	**70.8996**
FEED LOCATION (mm)	**(22.09, 9.16)**	**(22.09, 7.24)**	**(22.09, 6.55)**	**(22.09, 6.31)**	**(22.09,5. 36)**

Observing the Table 1, it can be noted that with the increase in dielectric constant the size of the antenna reduces. This very well validated the previously established concepts. Some other important conclusions have been based on the simulation results also have been discussed in the next section.

III. RESULTS

The simulation results for all the antennas have been tabulated. Table II presents the performance parameters of antennas for different heights of dielectric substrate materials.

Some general observations from the comparative results in Table II are:

- With increase in the height of the dielectric substrate the resonance frequency shifts towards the desired operating frequency.
- Gain increases that with increase in the height of the dielectric substrate.
- Bandwidth increases up to the height of 4.75mm then decreases. Increase in bandwidth can be understood with the concept that more height acquired in space results into increased bandwidth, but further increase in height results into decrease in bandwidth as more height allows surface waves to travel within the substrate.
- VSWR, Reflection-coefficient and impedance increases with increase in height.
- Half power beam width decreases with increase in the height of the dielectric substrate. This can be exploited in case of requirement of directivity.

TABLE III
Comparison of performance parameters

PERFORMANCE PARAMETERS	HEIGHTS OF THE SUBSTRATES (mm)				
	2.54	**3.81**	**4.75**	**5.08**	**6.35**
RESONANCE FREQUENCY (GHz)	**2.29224**	**2.33573**	**2.35224**	**2.34525**	**2.37575**
GAIN (dBi)	**3.36453**	**3.99538**	**4.2138**	**4.27716**	**4.47657**
IMPEDENCE (Ω)	**48.4472**	**58.5511**	**49.9828**	**54.8093**	**67.8197**
VSWR (ABSOLUTE VALUE)	**1.06336**	**1.11352**	**1.0555**	**1.36558**	**1.83228**
REFLECTION COEFFICIENT (dB)	**-30.255**	**-25.399**	**-31.372**	**-16.219**	**-10.637**
-3 dB BANDWIDTH (MHz)	**223.327**	**370.387**	**440.586**	**391.516**	**416.17**
-10 dB BANDWIDTH (MHz)	**73.660**	**119.320**	**139.668**	**112.564**	**53.537**
-3 dB HALF POWER BEAM WIDTH (Deg)	**88.404**	**83.850**	**80.926**	**80.172**	**76.967**

The graphs of the simulation results shown below depict the variation in performance parameters for different heights of substrate material.

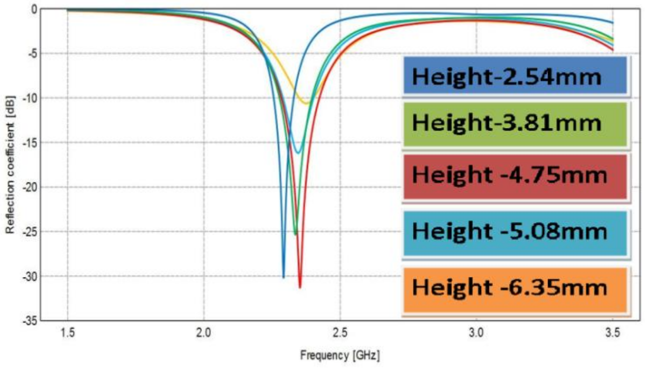

Fig. 2. Magnitude of Reflection Coefficient (in dB)

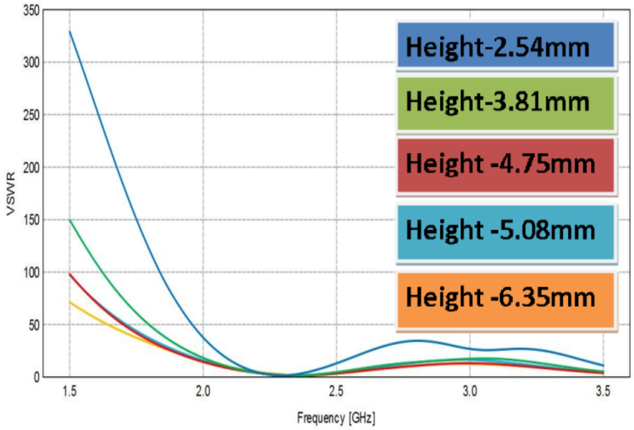

Fig. 3. Absolute value of VSWR

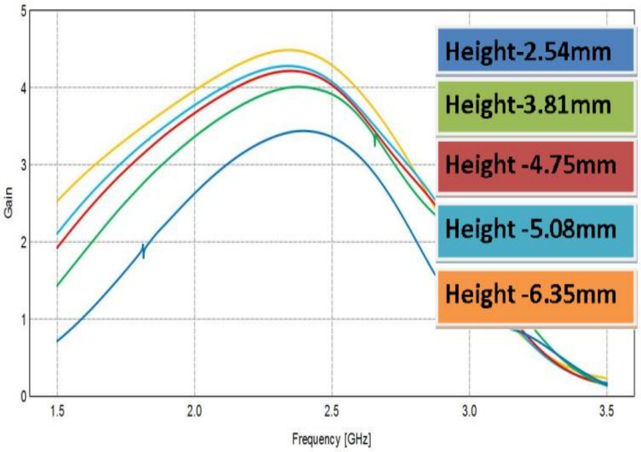

Fig. 4. Gain of the different antennas

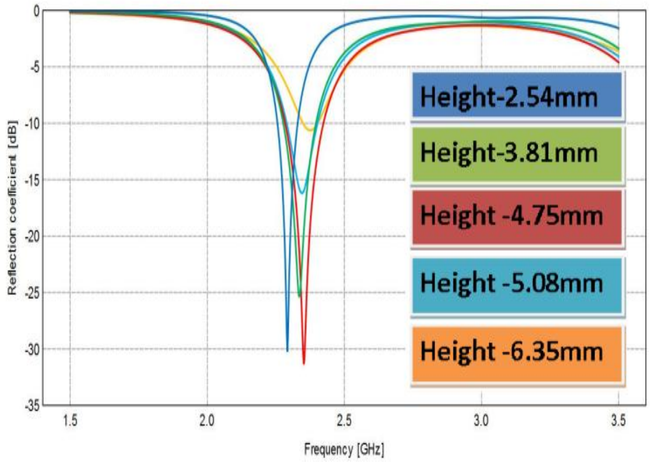

Fig. 5. -3dB bandwidth of antennas with different heights

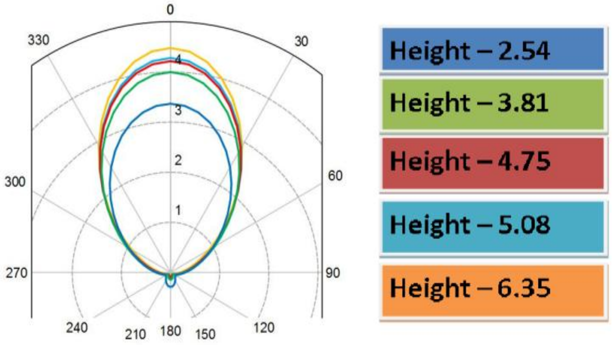

Fig. 6. *Polar plot*

IV. CONCLUSION

Generalized observation of the results obtained by the simulation of co-axial fed rectangular shaped microstrip patch antenna can help us to draw some conclusions regarding the tradeoff and design parameters. Increasing the height of the dielectric substrate is advantageous in increasing the bandwidth of microstrip antenna, which is desirable in compact antenna application. However increasing height of the dielectric substrate also results in expansion of the size of antenna, increased return loss and VSWR. But substrate with greater height can be used to achieve better directivity.

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