Substrate material effect on MPA design parameters

KEYWORDS BW, Directivity, Gain, MPA, Substrate Material, Simulator, VSWR

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ABSTRACT In this paper we present the effect of substrate material on Microstrip Patch Antenna design parameters and also demonstrate dielectric constant and tangent loss according to the different type of materials. Comparative analysis of Return-loss, BW, VSWR, Directivity and Gain of MPA design using different substrate materials are specified according to the simulation results.

I. INTRODUCTION

The rectangular patch antenna is approximately a one-half wavelength long section of rectangular Microstrip transmission line [1-3]. When air is the antenna substrate, the length of the rectangular Microstrip antenna is approximately one-half of a free-space wavelength [1-3]. The length of the antenna decreases as the relative dielectric constant of the substrate increases [1-3]. The resonant length of the antenna is slightly shorter because of the extended electric "fringing fields" which increases the electrical length of the antenna slightly [1-3].

The major advantage of MSA includes (i) reduction of size and weight (ii) easy to handle and inexpensive (iii) possibility of large scale fabrication (iv) topological considerations [1, 7]. It also suffers from some draw backs like (i) narrow bandwidth (ii) low gain (iii) large ohmic loss (iv) excitation of surface waves (v) radiation from the feed (vi) low polarization purity (vii) low power handling capacity [1, 7].

1) Frequency of operation (fr) [1, 7]

The resonant frequency of the antenna must be selected appropriately. The ISM Systems uses the frequency band 6-9 GHz. The resonant frequency selected for my design is 7.5GHz.

2) Dielectric constant of the substrate (εr) [1, 7]

The dielectric constant of substrate material plays an important role in the patch antenna design. A substrate with a high dielectric constant reduces the dimensions of the antenna but it also affects the antenna performance. So, there is a trade-off between size and performance of patch antenna. The dielectric constant of the substrate selected for my design is 4.3, 2.33 and 2.1.

3) Height of dielectric substrate (h) [1, 7]

For the Microstrip patch antenna to be used in communication systems, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate should be less. The height of the substrate selected for my design is 1.6 mm.

4) Gain [1, 7]

The gain of an antenna is defined as the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.

5) Radiation pattern [1, 7]

The radiation pattern is defined as a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates.

6) Antenna efficiency [1, 7]

It is a ratio of total power radiated by an antenna to the input power of an antenna.

7) VSWR [1, 7]

Voltage standing wave ratio is defined as VSWR=Vmax/Vmin. It should lie between 1 and 2.

8) Return loss

Return loss is the reflection of signal power from the insertion of a device in a transmission line. Hence the RL is a parameter similar to the VSWR to indicate how well the matching between the transmitter and antenna has taken place.

9)Bandwidth [1, 7]

The most serious limitation of the Microstrip antenna is its narrow BW. The bandwidth could be defined in terms of its VSWR or input impedance variation with frequency or in terms of radiation parameters. Bandwidth is presented more concisely as a percent where $\%BW$ $(\Delta f/fo)\times 100$

II. DESIGN STRUCTURE AND FOOTPRINT EQUATION

The height, width controls the bandwidth, impedance matching respectively [1-4]. The length of the antenna is responsible for determining the resonant frequency and the inductance of the antenna increases as the length increases [1-4].The width of the strip effects on the anti-resonance and increase the bandwidth. Similarly, the feed position from the short strip also affects the resonance frequency and bandwidth of the antenna is shown in figure 1 [1-4].

1)Calculation of Width (W) [4]

For an efficient radiator, practical width that leads to good radiation efficiencies is, the width of MPA is given as [1-3]

$$W = \frac{C}{2f0\sqrt{\frac{\varepsilon r+1}{2}}} \quad (1)$$

Whwre C is the free space velocity of light [4].

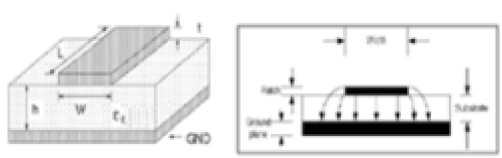

Figure 1: Antenna structure

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2) Calculation of Effective Dielectric Coefficient (ε_{reff}) [4]
The effective dielectric constant is given as [1-3]

$$\varepsilon reff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (2)$$

3)Calculation of Effective Length (L_{eff}) [1-3]

$$Leff = \frac{c}{2f0\sqrt{\varepsilon reff}} \quad (3)$$

4)Calculation of the Length extension (ΔL) [1-3]

$$\Delta L = 0.412h\frac{(\varepsilon reff+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon reff-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

5)Calculation of actual Length of Patch (L) [4]
The actual length of radiating patch is obtained by [1-3],

$$L = Leff - 2\Delta L \quad (5)$$

As per above design steps and footprint equations we were simulated antenna using structural simulator at 7.5GHz frequency and got results in term of return loss, VSWR, BW, Gain and Directivity and it is shown in section III as per antenna design geometry and structure shown in table 1 and figure 2.

Table 1: Antenna design geometry

Block	Substrate	Feed Line	Patch	Ground Plane	Boundary
Position	0, 0, 0	L-(w/2), 0, 0	L/2, W/2, 0	0, 0, -H	-5, -5, -5-H
X axis	2L	w	L	2L	≥ 2L
Y axis	2W	W/2	W	2W	≥ 2W
Z axis	-H	0.05	0.05	-0.05	10+H

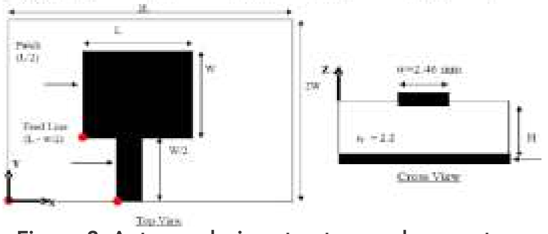

Figure 2: Antenna design structure and geometry

III.SIMULATION RESULT AND DISCUSSION

Considering the trade-off between the antenna dimensions and its performance, it was found suitable to select a thin dielectric substrate with low dielectric constant as presented in simulation result was Teflon [1-4]. Thin substrate permits to reduce the size and also spurious radiation as surface wave, and low dielectric constant for higher bandwidth, better efficiency [1-4] and low power loss which was presented in simulation results shown in figure 3, 4, 5 and 6 were found satisfactory as per design structure and geometry. The comparative analysis of input and output parameters are presented in table 2 and 3.

Table 2: Input parameter for MPA design

Material	Dielectric constant	Loss tangent	Substrate height (mm)	Patch length (mm)	Patch width (mm)
Fr-4	4.3	0.025	1.6	8.98	12.28
Rogers Rt5870	2.33	0.0012	1.6	12.14	15.49
Teflon (PTFE)	2.1	0.0002	1.6	12.75	16.06

Table 3: Output parameter for MPA design

Material	Return loss	VSWR	BW (%)	Gain	Directivity
FR4	-16.7861	1.3385	6.92	4.8	6.4
Rogers (RT5870)	-22.5029	1.1620	6.02	7.1	7.4
Teflon	-23.1586	1.1494	5.46	7.665	7.768

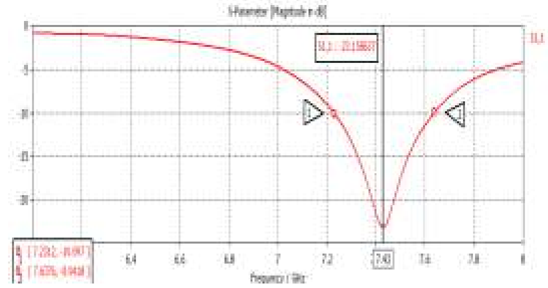
Figure 3: return loss and bandwidth plot for Teflon (PTFE)

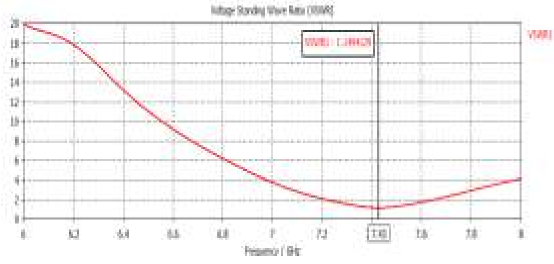
Figure 4: VSWR plot for Teflon

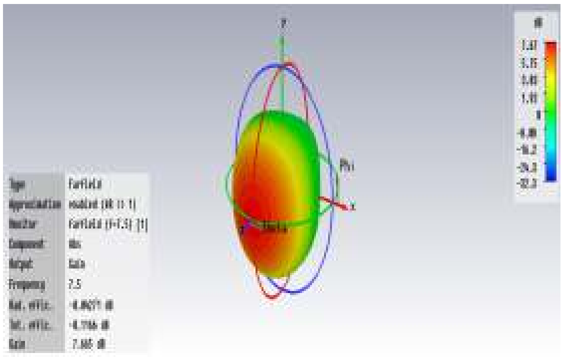
Figure 5: 3D plot for Gain for Teflon

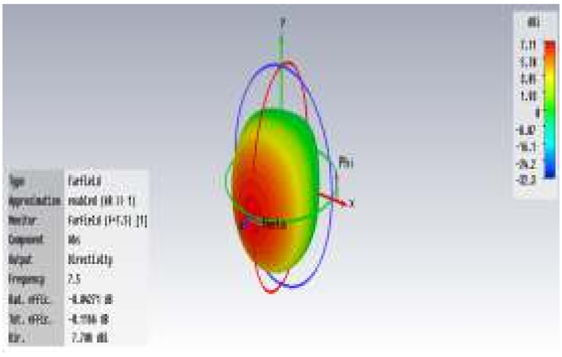
Figure 6: 3D plot for Directivity for Teflon

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IV.CONCLUSION

Finally we concluded that Teflon material is suitable for MPA design as per simulation results and return loss improved by 1dB compare to RT5870 & 7dB compare to FR4 material, VSWR improved by 0.02dB compare to RT5870 & 0.2dB compare to FR4 material and Gain improved by 0.6dB compare to RT5870 & 2.8dB compare to FR4 material but BW is reduced by 0.5% compare to RT5870 & 1.5% compare to FR4 material. The Bandwidth may be enhancing by different shapes and slits in MPA design structure.

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