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A Novel Microstrip Slotted Patch Antenna using Different Dielectric Substrates for Multiple Applications

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Abstract

In this work, investigation of the effect of different substrate materials on the performance of Ultra Wideband Antenna is presented. The characteristics of an antenna depend on substrate properties such as its dielectric constant, loss tangent etc. The proposed antenna is designed on three different substrates, FR4-epoxy $(\varepsilon_r = 4.4)$, RODGER $(\varepsilon_r = 3.66)$ and Bakelite $(\varepsilon_r = 4.78)$ with a substrate thickness of 1.6mm and the performance are obtained by using CST Microwave Studio. The simulated antenna shows multiband characteristics and an operational bandwidth from 2.2 to 10.3 GHz with a maximum gain of 5.64 dB. By changing the value of relative permittivity with substrate material, Bakelite is found to be the best substrate for a given microstrip patch antenna. The antenna offers application in WiMAX IEEE802.16 (3.30-3.80 GHz) and UWB range especially for X-band downlink satellite system (7.1–7.9 GHz), C-band (4-8 GHz) applications in Satellite communication and also for medical uses to detect cancers and tumors where the safe frequency range for human tissues is 4 GHz - 9.5 GHz.

Keywords: Microstrip Patch Antenna, Ultra wide band antennas, Return loss, slots.

INTRODUCTION

In recent years, the demand for compact handheld communication devices has grown significantly. Devices having internal antennas have appeared to fill this need. Wireless communication systems require small size and compact antennas which have wider bandwidth than conventional antenna design [2]. Antenna size is a major factor that limits device miniaturization. For the past few years, new designs based on the Microstrip patch antennas (MSPA) are being used for handheld wireless devices because these antennas have low-profile geometry and can be embedded into the devices. New wireless applications requiring operation in more than one frequency band are emerging.

Dual-band and tri-band phones have gained popularity because of the multiple frequency bands used for wireless applications. Multiband antennas can be designed by feeding techniques [1–3], etching slots [4–6], adding multi-branched strips, fractals etc. Slots create some sort of discontinuity in the electric current path leading to positive impact on input impedance thereby creating additional resonance frequencies. Research shows that cutting slots and slits in radiating patch and ground plane [8-12] shift the operating frequency and increase resonating frequencies.

In this paper, the effect of different substrate materials on the performance of the proposed Ultra Wide Band (UWB) antenna is presented. The proposed antenna is designed on three different substrates, FR4-epoxy $(\varepsilon_r = 4.4)$, RODGER $(\varepsilon_r = 3.66)$ and Bakelite $(\varepsilon_r = 4.78)$ with a substrate thickness of 1.6mm and the performance are obtained by using CST Microwave Studio. Here substrate Bakelite is found to be the best material regarding utilization of multiband, resonance frequency and return loss.

The proposed antenna works in the WiMAX IEEE802.16 (3.3 to 3.8 GHz) and UWB range especially for X-band downlink satellite system (7.1–7.9 GHz). This structure can also be used for C-band (4-8 GHz) applications in Satellite communication and also for medical uses to detect cancers and tumors where the safe frequency range for human tissues is 4 GHz - 9.5 GHz.

ANTENNA DESIGN

The microstrip antenna consists of a very thin conducting patch placed above a grounded dielectric substrate with reliability, mobility and good efficiency [11-12]. The conducting patch can be of any shape but in practice rectangular, circular and triangular are commonly used shapes because these shapes are less complex and effective. They are most suitable for aerospace and mobile applications.

In this work, a rectangular patch with slots is selected for the analysis. Although the transmission line model yields less accurate results, it is a very simple model and provides a good physical insight of the basic antenna performance. Among the various feeding methods, microstrip line feed is chose as it is simple to model and easy to fabricate.

Design of Rectangular Patch

The model of Microstrip Antenna can be represented by two slots of width (W) and height (h) separated by transmission line of length (L). The width of the patch can be calculated from the following equation [7].

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

The effective dielectric constant of the substrate can be calculated as follows,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12\frac{h}{W}}} \quad (2)$$

The actual length of the antenna is different from the calculated L since the fringing field also needs to be considered here. The actual length is calculated by subtracting the excess lengths from both the sides of the patch. The length of the Patch Antenna L is given by,

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 0.824h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (3)$$

Higher values of permittivity allow a shrinking of the Patch Antenna. Particularly in cell phones, the designers are given very little space and want the antenna to be a half-wavelength long. One technique is to use a substrate with a very high permittivity. The actual length of the Patch Antenna is given by,

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (4)$$

The length (L_g) and the width (W_g) of a ground plane are calculated using the following equations,

$$L_g = 6h + L \text{ and } W_g = 6h + W \quad (5)$$

Hence, if the permittivity is increased by a factor of 4, the length required decreases by a factor of 2. Using higher values for permittivity is frequently exploited in antenna miniaturization. All of the parameters in a Rectangular Patch Antenna design (L, W, h, permittivity) control the properties of the antenna. Table 1 gives the design specifications of a standard rectangular patch with FR4 substrate.

Table 1: Design Specifications of Rectangular Patch

Substrate materials used	FR4 (εr=4.4)
Thickness between ground and fed patch (h)	1.6 mm
Length of the rectangular patch (L)	38 mm
Width of rectangular patch (W)	29 mm
Width of the ground plane (Wg)	59 mm.
The length of the ground plane (Lg)	76 mm.

Design of Proposed Antenna

Initially a rectangular patch antenna for a particular frequency is designed. The parameters of rectangular patch are modified to obtain the dimensions of the proposed antenna structure. There are various parameters, which can be used to tune the antenna. The major among them are the slot length, slot width, feed line width and position of the patch relative to the slot. In this paper a rectangular patch with different slots, with different substrate materials is analyzed.

PARAMETRIC STUDY OF RECTANGULAR PATCH ANTENNA

The performance parameters such as return loss, bandwidth and radiation patterns of standard rectangular antenna are discussed below. The basic structure is that of a Rectangular Patch Antenna shown in Figure.1.

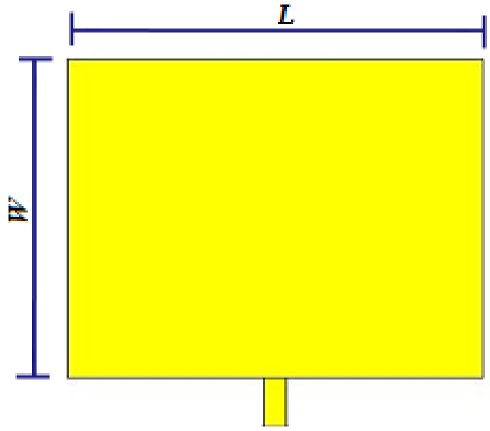

Figure.1. Rectangular Patch Antenna

Return Loss

The response S_{11} shows in Figure. 2 and the antenna resonates at 2.45 GHz with a Return Loss of -36 dB.

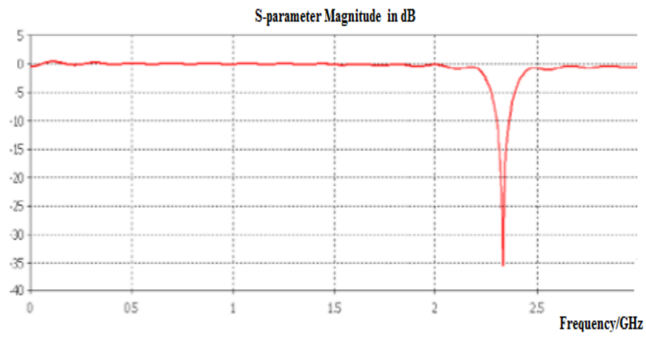

Figure.2. Plot of S_{11} Parameters versus Frequency

Radiation Pattern

The Radiation property of any antenna can be analyzed to understand the distribution of power around the orientation. The simulated gain pattern of the antenna shows (Figure.3) that the antenna has a gain of 5.66 dBi.

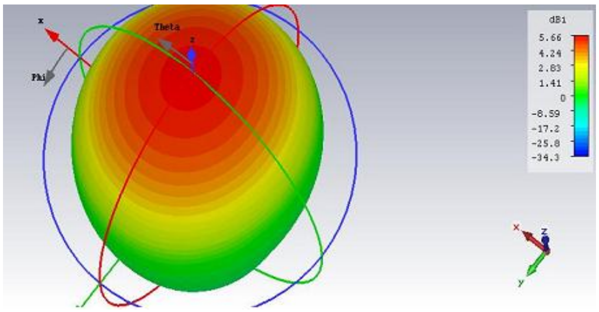

Figure 3. Radiation Patterns at 2.45 GHz

Figure 4 shows the polar radiation pattern of the standard Rectangular patch antenna. It has main lobe magnitude of 5.66 dBi in the direction 2.0 degree.

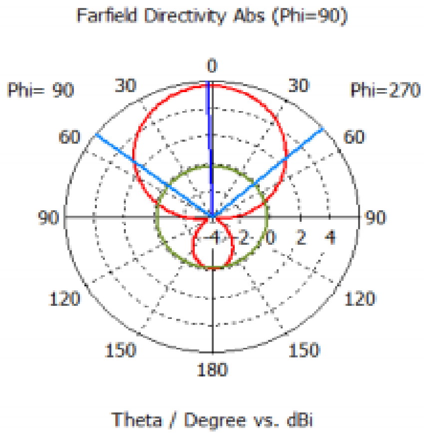

Figure.4. Polar plot at 2.45 GHz

PARAMETRIC STUDY OF PROPOSED ANTENNA USING DIFFERENT SUBSTRATES

In the proposed antenna, a basic rectangular patch is designed at 2.45 GHz. Different kinds of slots are incorporated in the patch and the effect of different substrate materials on the performance of the proposed Ultra Wide Band (UWB) antenna is analyzed. The proposed antenna is designed on three different substrates, FR4-epoxy $(\varepsilon_r = 4.4)$, RODGER $(\varepsilon_r = 3.66)$ and Bakelite $(\varepsilon_r = 4.78)$ with a substrate thickness of 1.6mm. The structure of proposed Antenna is shown in Figure.5.

Table 2: Design Specifications of Proposed Antenna

Length of sides of the patch	$L_1 = 28$ mm
	$L_2 = 19$ mm
	$L_9 = L_{10} = 5$ mm
Length of inner slots	$L_3 = L_4 = 10$ mm
	$L_5 = 5$ mm
	$L_6 = L_{11} = 2$ mm
Width of Microstrip line (L_7)	2 mm.
Length of Microstrip line (L_8)	4.5 mm

Table 2 gives the design specifications of the proposed patch with different substrates such as FR4 epoxy, RODGER and Bakelite.

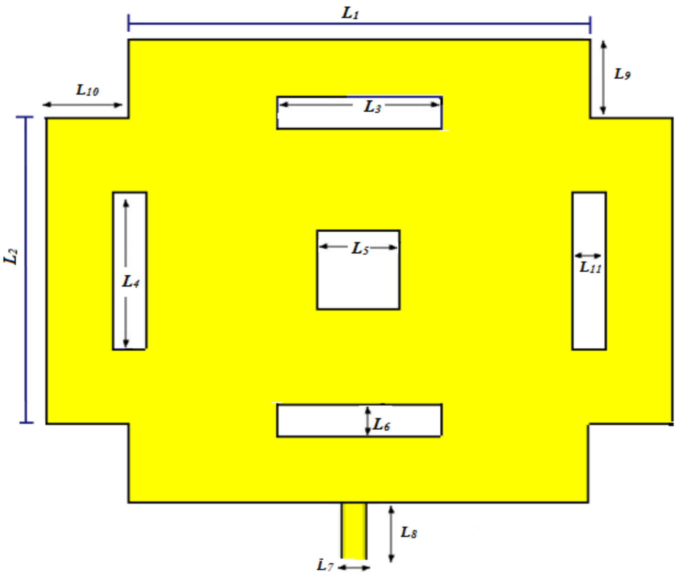

Figure.5. Proposed Antenna

FR4-epoxy Substrate

The proposed structure is simulated on FR4-epoxy substrate material with dielectric constant $(\varepsilon_r = 4.4)$ and the simulation results are observed.

Return Loss

The response S_{11} in Figure 6 shows that by using FR4-epoxy as the substrate, the proposed antenna resonates at two frequencies 7.7 GHz and 8.9 GHz with Return Loss of -11 dB and -14 dB respectively.

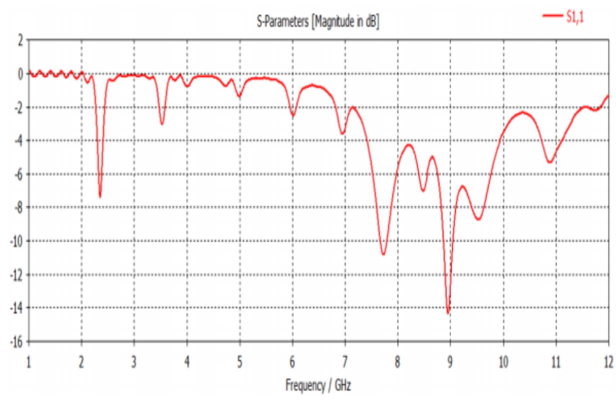

Figure.6. Plot of S_{11} Parameters versus Frequency

Radiation Pattern

The simulated gain pattern of the antenna shows (Figure.7) that the antenna has a gain of 5.64 dBi.

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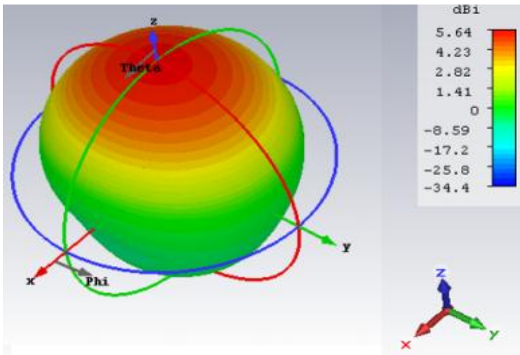

Figure.7. Radiation Patterns at 7.7 GHz with gain 5.64 dBi

RODGER Substrate

The proposed structure is simulated on RODGER substrate material with dielectric constant $(\varepsilon_r = 3.66)$ and the simulation results are observed.

Return Loss

The response S_{11} in Figure 8 shows that by using RODGER as the substrate, the proposed antenna resonates at two frequencies 2.7 GHz and 10 GHz with Return Loss of -18 dB and -35 dB respectively.

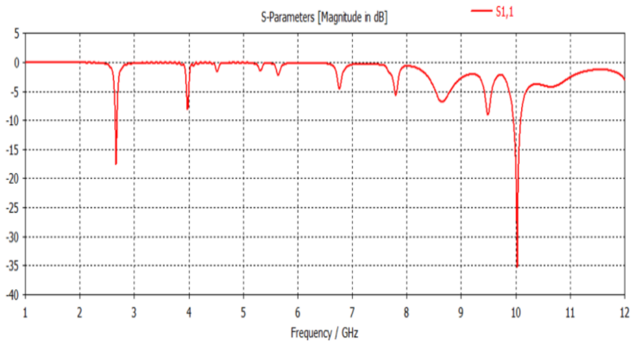

Figure.8. Plot of S_{11} Parameters versus Frequency

Radiation Pattern

The simulated gain pattern of the antenna shows (Figure.9) that the antenna has a gain of 5.62 dBi.

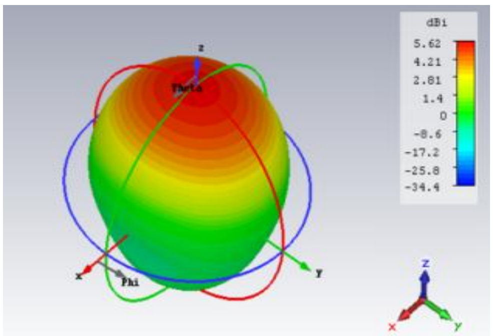

Figure.9. Radiation Patterns at 10 GHz with gain 5.62 dBi

Bakelite Substrate

The proposed structure is simulated on Bakelite substrate material with dielectric constant $(\varepsilon_r = 4.78)$ and the simulation results are observed.

Return Loss

The response S_{11} in Figure 10 shows that by using Bakelite as the substrate, the proposed antenna resonates at five frequencies 2.2 GHz, 3.3 GHz, 6.7 GHz, 8.1 GHz and 10.3 GHz with Return Loss of -16 dB, -18 dB, -14 dB, -24 dB, and -15 dB respectively.

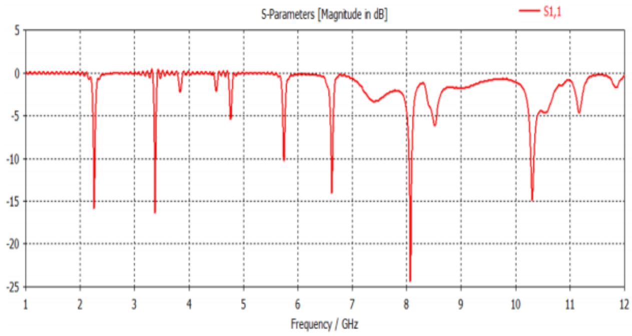

Figure.10. Plot of S_{11} Parameters versus Frequency

Radiation Pattern

The simulated gain pattern of the antenna shows (Figure.11) that the antenna has a gain of 5.62 dBi.

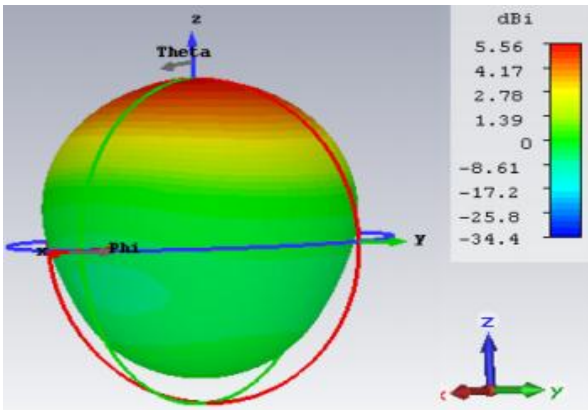

Figure.11. Radiation Patterns at 10 GHz with gain 5.56 dBi

COMPARATIVE STUDY

Table 3 shows the comparison of conventional rectangular patch antenna and the proposed patch antenna with slots on FR4-epoxy substrate material with dielectric constant $(\varepsilon_r = 4.4)$ in terms of operating frequency, return loss and gain.

Table 3: Comparison with standard patch antenna

Substrate used	Structure	Resonating Frequency (GHz)	Return Loss (dB)	Gain (dBi)
FR4 $(\varepsilon_r = 4.4)$	Rectangular Patch Antenna	2.45	-36	5.66
	Proposed Antenna	7.7	-11	5.64
		8.9	-14	

From the result it is observed that the proposed antenna with slots shows multiband behavior characteristics with improved bandwidth.

Table 4 shows the comparison the proposed patch antenna with different dielectric substrate material in terms of operating frequency, return loss and gain.

Table 4: Comparison of proposed antenna with different dielectric substrate materials

	Substrate used	Resonating Frequency (GHz)	Return Loss (dB)	Gain (dBi)
Proposed Antenna	FR4-epoxy $(\varepsilon_r = 4.4)$	7.7	-11	5.64
		8.9	-14	
	RODGER $(\varepsilon_r = 3.66)$	2.7	-18	5.62
		10	-35	
	Bakelite $(\varepsilon_r = 4.78)$	2.2	-16	5.56
		3.3	-18	
		6.7	-14	
		8.1	-24	
		10.3	-15	

CONCLUSION

In this work, the aim was to investigate the effect of different substrate materials on the performance of proposed Ultra Wideband Antenna. Three different substrate materials and are selected and simulated. The simulated results of the proposed antenna using FR4 substrate are compared with the conventional microstrip rectangular patch antenna. A comparative study on the behaviour of proposed antenna with different substrate material is also done. The designed antenna shows multiband characteristics and an operational bandwidth from 2.2 to 10.3 GHz with a maximum gain of 5.64 dB. From the results it is observed that changing the value of relative permittivity with substrate material, Bakelite is found to be the best substrate for a given microstrip patch antenna. Using FR-4 and RODGER as the substrate material, the antenna shows dual band characteristics. But by replacing the substrate with Bakelite, the antenna resonates in five frequencies with improved bandwidth. It can be justified that the proposed antenna is suitable for offers application WiMAX IEEE802.16 (3.30-3.80 GHz) and UWB range especially for X-band downlink satellite system (7.1–7.9 GHz). This structure can also be used for C-band (4-8 GHz) applications in Satellite communication and also for medical uses to detect cancers and tumors where the safe frequency range for human tissues is 4 GHz - 9.5 GHz.

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