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Original Article

Effect of the Substrate Material and Thickness on the Performance of the Rectangular Patch Microstrip UWB Antenna

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Abstract *- The demand for broadband antennas has increased significantly in recent years. High-frequency and high-speed data networking are found to be commonly used. The factors affecting the bandwidth of a microstrip antenna are discussed in this article. The antenna extension is regulated by two major parameters. The thickness of the dielectric substrate is one, and the material of the substrate is another. This study assesses the performance characteristics of a rectangular patch microstrip antenna with varying substrate thickness and material. The resonant frequency, bandwidth, and return loss characteristic impacts are all affected by changing one of the parameters while keeping the other unchanged. The rectangular patch microstrip antenna designed for the microstrip feed line operates at 6.85 GHz (UWB).*

Keywords *- Bandwidth, Microstrip antenna, UWB, Return loss, Resonant frequency.*

1. Introduction

The antenna is a significant component of the communication system. There is a great deal of creativity in the construction of antennas. One of the cost-effective, easy-to-incorporate, and need-based antennas is the microstrip patch antenna. It also offers successful outcome-oriented methods [1]. In recent years a number of wireless communication engineering systems have shown a leap and related development and the comprehensive need for the future. This scenario involves the enhancement of the current system and the production of new technologies in order to satisfy demand and requirements [2]. As a new area of research and creativity, the usefulness and demand of the ever-increasing application unleash the antennas. The printed antennas are conveniently housed in the system box because they are economical. The best types of printed antennas are microstrip antennas. Their usefulness and demand lie in their certain characteristics that include lightweight, smaller size, large bandwidth, low cost, and integrated circuits [3, 4]; although these antennas have disadvantages such as low gain and narrow bandwidth [5], recently approved ultra-wideband communication systems operating in the frequency range from 3.1 to 10.6 GHz Federal Communication Commission (FCC) [6]. This band demands that the antennas satisfy the need to minimize the communication equipment's size and weight. Antenna bandwidth is an important antenna parameter that meets the desired antenna characteristics over a range of frequencies. On the basis of return loss or VSWR, antenna bandwidth is defined. The impedance bandwidth is the frequency range over which the antenna's input impedance is precisely matched to the feeding transmission line's characteristic impedance.

Antenna bandwidth is a significant antenna parameter over a frequency range that matches the desired antenna characteristics. On the basis of return loss or VSWR, the antenna bandwidth is defined. Impedance bandwidth is the frequency range over which the antenna's input impedance is precisely matched to the feeding transmission line's characteristic impedance. The fractional bandwidth at a 10dB point is the most common type of antenna bandwidth to be used in the microstrip antenna. Proper impedance matching is needed to optimize impedance bandwidth [7]. This requires that the feed at the antenna's driving point should usually be 50 ohms.

For matching enhancement, some researchers [8] implement a half-cut printed monopole technique. In its modern form, wireless communication includes extensive use of numerous microstrip antenna modifications [9, 10]. Many researchers have recently introduced the design aspect [11, 12, 13], but the emphasis was on designing a particular antenna in these areas. In [14], a simplification microstrip rectangular antenna with a bandwidth of 133.33 percent and a gain of 1.5-4.8 dB for UWB applications was incorporated to use a defective ground structure (DGS) with different locations of the enlarged patch in the ground. In [15], a microstrip antenna design based on the defective ground structure (DGS) and horizontal patch gap to achieve bandwidth and performance goals (HPG) was presented. The antenna's gain was 2.8 dBi, and its bandwidth was 764.4 MHz. Raviteja et al. [16] studied the performance of U and Quad L-shaped slots, as well as L-shaped DGS and U-shaped dual parasitic components. The gain of this antenna is 7.2 dB, and the bandwidth is 1.40 GHz. A contemporary semi-circular ultra-wideband antenna [17] with a wide bandwidth of 130.3 percent from

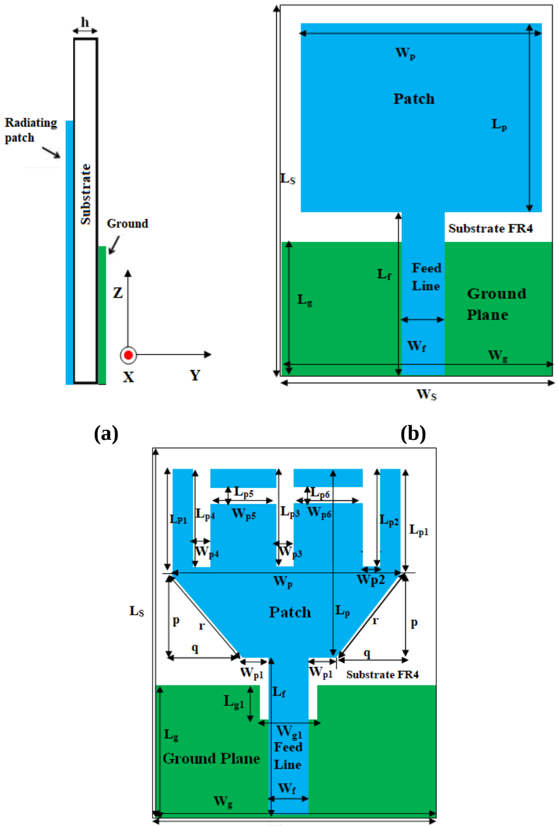
3.16 to 15 GHz and gain ranging from 4.9 dB to 10.9 dB was described for broadband applications. D. Gopi1 et al. [18] exhibited a small low-monopole circular-shaped patch antenna for ultra-wideband applications based on a defective ground structure. The impedance bandwidth of the antenna ranges from 2.5 to 10.6 GHz. The gains are 8.4 dBi and 8.2 dBi for the two resonant frequencies, respectively. In [19], the air gap method was used to develop a rectangular microstrip patch antenna for gain enhancement. The gain is enhanced from 6.907 dB to 9.179 dB based on the simulation results. Double-side planar periodic structures to fabricate a miniaturized enlarged bandwidth UWB microstrip antenna [20] used metamaterial (MTM). The antenna has a 3.2 to 23.9 GHz bandwidth and a maximum gain of 6.2 dB. The antenna has a frequency range of 3.2 to 23.9 GHz and a maximum gain of 6.2 dB at 8.7 GHz. J. Vijayalakshmi et al. [21] characterized a compact high-gain (MHG) ultra-wideband (UWB) unidirectional monopole antenna with a defective ground structure (DGS) for ultra-wideband applications. This antenna has a high gain of 7.20 dB, a high efficiency of 95%, and a frequency range of 3.2 to 10.6 GHz. A compressed mace-shaped ground plane customized circular patch antenna was designed for ultra-wideband applications [22]. The maximum gain and fractional bandwidth of this antenna, according to simulation results, are 3.2dB and 118 percent (3.1 to 12.13 GHz), respectively. In [23], the study presented a small stepped slot antenna for ultra-wideband (UWB) applications. The simulation resulted in an impedance bandwidth ranging from 3.05 to more than 12 GHz. The researchers examined the notched-band characteristics of a very tiny ultra-wideband (UWB) slot antenna with three L-shaped slots [24]. The antenna has a voltage standing wave ratio (VSWR) of less than 2 and an impedance bandwidth ranging from 2.65 to 11.05 GHz. [25] illustrated an innovative and insightful analysis of a compact-size ultra-wide-band (UWB) microstrip antenna for DS-UWB applications. The simulation analysis reveals a 109 percent impedance bandwidth. On an FR4 substrate, [26] intended a modified UWB antenna with gain improvement for wireless applications. According to the observation, a maximum gain of more than 6.5 dB is achieved with an impedance bandwidth ranging from 2.2 GHz to more than 12 GHz, or 138 percent fractional bandwidth.

As we vary the substrate material and the substrate thickness of the microstrip UWB antenna, the performance of the system changes. Therefore, it is important to know the effect of changing dielectric substrate material and substrate thickness in order to incorporate sufficient correctness in the design of the antenna.

This paper presents a series of simulations of a microstrip feed rectangular patch microstrip UWB antenna on a variety of substrate materials, including Rogers RT/duroid 5880(tm), Taconic RF-30 (tm), and FR-4, as well as FR-4 substrate thicknesses.

2. Proposed Antenna Design

The geometry of the microstrip fed UWB antenna without a slot, used as a reference antenna in our research, is depicted in Fig.1 (a) and (b). The antenna is constructed on a low-cost FR4 epoxy substrate with a dielectric constant of 4.4, a thickness of 0.8 mm, a dielectric tangent loss of 0.02, and dimensions of 30 mm × 20 mm (Ls × Ws). The conducting patch and ground plane are made of copper. The rectangular patch is the base of the monopole radiator, which is embedded with the dimensions $L_P \times W_P$ on the FR4-epoxy substrate and is supplied by a simple 50 Ω microstrip line with the length L_f and the width W_f. The microstrip feed line is used to reduce return loss, resulting in highly efficient antenna gain. A partial ground plane is printed on the FR4 epoxy substrate with the dimensions of $L_g \times W_g$. The width of the partial ground plane (W_g) is equal to the width of the substrate (Ws). As shown in Fig. 1(c), several slots, such as right-angle triangular and rectangular slots, are inserted on the patch, and a single rectangular slot is added on the ground plane to enhance the antenna's gain-bandwidth and impedance matching in the UWB. HFSSv15 simulator software is used to optimize and investigate the proposed antenna. In Table, I, the values for the proposed antenna with different parameters are shown.



(a) (b)

(c)

Fig. 1 Design of the proposed antenna (a) Side view, (b) Ordinary Patch Antenna, and (c) Final design

3. Simulation Results and Discussion

The discussion is focused on the two observation sets. The influence on bandwidth by changing the thickness of the substrate is seen in the first case of observation, while the thickness of the substrate is kept constant in the second case, and the material of the substrate varies to observe the variation in bandwidth.

Table 1. Parameters values of the proposed antenna

Parameters	Values (mm)	Parameters	Values (mm)
$W_s= W_g$	20	L_{p1}	8
L_s	30	$L_{p5}=L_{p6}=W_{p2}=W_{p3}=W_{p4}$	0.5
H	0.8	$L_{p2}=L_{p3}=L_{p4}$	7
W_p	18	$W_{p5}=W_{p6}$	6.5
$L_p= L_g$	14	L_{g1}	3
L_f	15	L_{p1}	8
$W_f =W_{g1}= W_{p1}$	2	p = q	6
L_{g1}	3	r	8.48

3.1. Effect of Variation of Substrate Thickness (h)

Under this observation set, the graph shown below in Fig. 2 shows the effect of the variation in substrate thickness of the proposed antenna structure on the performance of its covered resonant frequency bandwidth. Substrate thickness is gradually increased in three stages from h = 0.65 to 0.8 mm. It is found that the bandwidth increases from 13.65 GHz to 19.7 GHz when the substrate thickness (h) is increased from 0.65 mm to 0.8 mm. Thus, the bandwidth can be enhanced by increasing the substrate thickness. But, the thickness of the substrate cannot be increased to an extent because it would overpower surface waves. To reach higher bandwidth requires an accurate selection of substrate thickness. In the instant case, this verifies the selection of substrate thickness, h = 0.8 mm, because it results in a wide bandwidth. If substrate thickness is changed, this leads to other parameters shown in Table II being changed.

Table 2. Effect of substrate thickness on bandwidth

h (mm)	ε_r	RL (dB)	O.B.W (GHz)	B.W (GHz)
0.65	4.4	-27.98	3.40-17.05	13.65
0.7	4.4	-36	3.55-22.80	19.25
0.8	4.4	-28.35	3.15-22.85	19.7

Here, h = Substrate thickness, ε_r = Dielectric constant,
RL = Return loss, O.B.W = Operating bandwidth,
B.W = Bandwidth

3.2. Effect of Variation of Substrate Material

In this observation, The physical dimensions parameters and other parameters in the proposed antenna change as the dielectric material of the substrate varies, as indicated in Table III. The simulated return loss results are obtained using the HFSS tool at a resonant frequency of 6.85 GHz for various cases are given. The return loss of the designed antenna varies for various dielectric substrates with the same dielectric thickness. From Fig. 3 and Table III, it is clear that the dielectric constant decreases as the bandwidth increases and as the dielectric constant increases as the bandwidth decreases. However, this has negative effects on the reduction of antenna size since a microstrip antenna resonant length is shorter for higher dielectric constant substrates. Additionally, this antenna can be easily used for various substrate materials in other frequency bands.

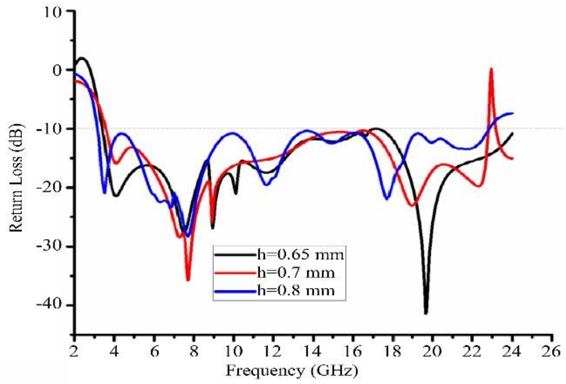


Fig. 2 Effect of variation of substrate thickness of the proposed antenna structure

Table 3. Comparison of different substrate materials

h (mm)	Substrate Material Name	ε_r	RL (dB)	O.B.W (GHz)	B.W (GHz)
0.8	FR4_epoxy	4.4	-28.35	3.15-22.85	19.7
0.8	Taconic RF-30(tm)	3	-26.99	3.28-23.54	20.26
0.8	Rogers RT/duroid 5880(tm)	2.2	-36.98	3.60-more than 24	More than 20.4

Here, h = Substrate thickness, ε_r = Dielectric constant,
RL = Return loss, O.B.W = Operating bandwidth,
B.W = Bandwidth

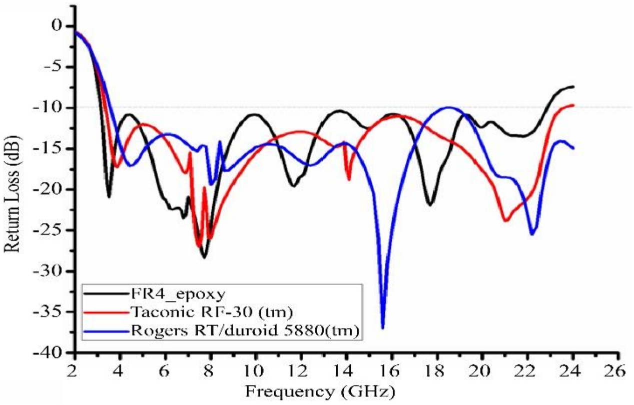


Fig. 3 Effect of variation of substrate material of the proposed antenna structure

4. Conclusion

According to the results of the above study, using a substrate material with a higher dielectric constant in the design of a rectangular patch microstrip UWB antenna degrades antenna efficiency while reducing antenna size. The resonance frequency and bandwidth increase with increasing substrate thickness (h). This requires an accurate selection of the substrate thickness to achieve higher bandwidth. In the present case, this verifies the choice of substrate thickness, h=0.8mm, as this results in a wide bandwidth. The performance of the antennas was calculated at an operating frequency of 6.85 GHz using a combination of a microstrip feed line, slotted partial ground plane, and multi-slotted patch techniques with the HFSS simulator.

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