Design of a Microstrip Patch Antenna with High Bandwidth and High Gain for UWB and Different Wireless Applications

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***Abstract*—We propose square shape patch antenna in this research work. Focus of the work is to obtain large bandwidth with compact ground plane for wireless applications. The proposed antenna is designed using dielectric material of FR4 having height of 1.6 mm and having ϵ_r of 4.4. We simulated the proposed antenna in CST Microwave Studio. Simulation results show that the proposed antenna achieved bandwidth from 2.33 GHz to 12.4 GHz with radiation efficiency more than 90% in ultra-wideband range. The proposed antenna covers the range of ultra wideband from 3.1 GHz to 10.6 GHz, the range of local area network, wide area network, and also covers the range of satellite communications (for both uplink and downlink).**

***Keywords*—High bandwidth, patch antenna, low profile, linear polarization**

I. INTRODUCTION

Antenna is one of the basic building blocks of wireless applications. Antenna plays an important role in telecommunication industry and is used to transmit and collect electromagnetic (EM) waves. Antenna is a metallic device acts as transducers, which transfers and also receives EM waves. Antennas are present everywhere; at homes, automobiles, roads, houses, police stations, radar system, parks, satellite communications buildings, and military devices. Television antennas in early days are manufactured to receive the air broadcast signals; those signals are transmitted having frequency at about 41 MHz to 250 MHz in very high frequency and also 470 MHz to 960 MHz in ultra-high frequency ranges among different countries.

In the end of 20^{th} century, scientists were able to do many inventions like computers, mobile phones, laptops, local area network, bluetooth, routers, jammers, military missile applications, aircraft, satellites communication, and rockets. For the reason of those inventions, scientists need such an antenna which is light in weight, cheap in cost, having good performance, portable, and easy to fabricate. Microstrip patch antenna can be printed on circuit boards. Microstrip patch antennas are mostly used in mobiles phones and laptops, etc. Patch antennas are cheap in cost, having low profile, and easy to fabricate. Patch antennas have three parts−patch, substrate, and ground. Substrate is composed of dielectric materials such as Arlon, FR4, foam, polystyrene, and roger. Ground and patch are made from metals.

The patch antennas are a famous type of the antennas from the frequency range of 1 GHz to 11 GHz. Deschamps suggested the idea of microstrip patch antennas in 1953. On the other hand, in early 1970, Howell and Munson were able to design a practical antenna. The antennas they designed have dual dimensional arrangements and are normally identified as patch antennas. The common arrangement of patch antenna can be made up of a radiator on front side of the substrate while a ground plane on the back side of patch antenna. There are various shapes of patch antennas for example square, rectangular, circular, triangular, dipole, and elliptical. A lot of advantages of those antennas such as lesser volume, easy to integrate, and also have the ability to handle both linear and circular polarization, and to permit double and triple frequency operations. Feed lines and matching circuits can be fabricated jointly with the antennas design.

Patch antennas have some limitations as well such as its bandwidth is very small and gain is also not good. Thus, different techniques are developed to increase its bandwidths and gain. In this letter, the proposed antenna is square in shape, which operates in the range of 2.33 GHz to 12.4 GHz; thus, accomplishing the UWB bandwidth improvement. UWB range is from 3.1 GHz to 10.6 GHz, which is officially certified by federal communication commission at America in 2002.

The proposed antenna covers the ultra wideband range, also achieves the range of worldwide interoperability for microwave access (WIMAX-1(2.300-2.400GHz), WIMAX-2(2.496 to 2.690), WIMAX-3(3.300 to 3.800), and WIMAX-4 (5.25-5.85 GHZ)), local area network band (wifi-1(2.412 to 2.4835), wifi-2(4.9 to 5.9)) works in personal area network (Bluetooth(2.402 to 2.480)), also works in satellite communications bands for both downlink (3.7 to 4.2 GHz) and uplink (5.925 to 6.425 GHz).

Rest of the paper is organized as follows: Section II discusses problem statement, literature review, and outlines contributions of the work, Section III explains basic structure of the proposed antenna design, while Section IV shows its simulation results from CST Microwave Studio.

II. BACKGROUND AND CONTRIBUTIONS

A. Problem Statement

The main limitation of microstrip patch antenna is the lower bandwidth, which effects wireless communication applications. Bandwidth of microstrip antenna can be improved by increasing the height of substrate by using the transmission line model. At the same time, increasing height of the substrate also increases the surface waves, which move from end to end around the substrate and spread at the curves of the radiating patch, which adopts apart of energy of the signal;

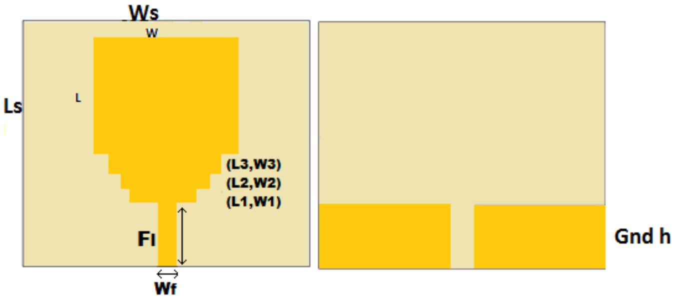

Fig. 1. Design of the proposed antenna.

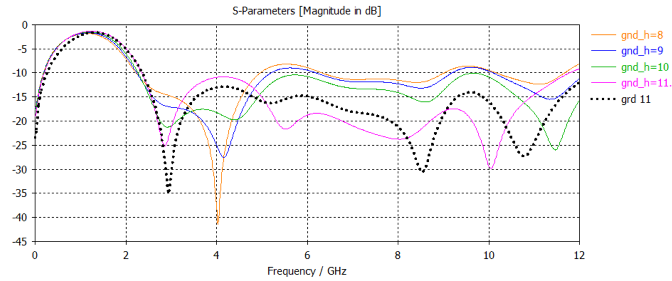

Fig. 2. Simulated return loss in dB against frequency for different length of ground plane.

thus, declining the the antenna's performance. In order to avoid this problem, different techniques are used such as air gap technique in which surface waves are not produced. Further, length of patch plays important role in bandwidth of antenna. Antennas having minimum possible size are considered efficient.

B. Related Work

Different antennas have been studied in the literature for illustration such as antenna having ring slot of square shape [1], antenna of dual band [2], planar antenna with single, dual, and triple-band notched characteristic [3], CPW-fed with SRR loaded UWB antenna [4], MIMO antenna for UWB applications [5], SRR loaded UWB circular monopole antenna [6], new planar antenna for UWB applications [7],and a printed circular monopole disc antenna [8].

In the literature, several methods are suggested to rise the bandwidth of antenna such as meandered ground plane method [9], patch antenna with integrated band pass filter [10], matching network of optimally designed, and gap-coupled feed [11]. All those methods are proposed to enhance the bandwidth of patch antenna. The proposed methods have advantage as well dis-advantages. Some methods are costly, some methods have very low gain and efficiency.

For the proposed antenna, all the advantages are collected and summarized to design a new antenna for wireless communications.

C. Contributions

- The proposed antenna bandwidth is improved, which is suitable for ultra wideband devices. The proposed antenna works in additional band and also achieved multiband characteristics.
- The proposed antenna is easy to fabricate, voltage standing wave ratio is also less than two, and gain is in the acceptable range.
- The proposed antenna has smaller size, lower profile in weight, and linearly polarized.

III. Structure of the Proposed Patch Antenna

The basic antenna design is shown in Fig 1. For the proposed antenna, FR4 dielectric material is used for substrate having value of 4.4 and height of 1.6 mm. Our proposed antenna consists of two rectangular shapes patches—one large rectangular patch and another small rectangular patch, which also works as a feed line for the antenna. The substrate length and its width are denoted by *Ls* and *Ws*, respectively. The feed line is represented by *Fl*. Patch antenna is present on front side of the substrate while ground is also on the same side of the substrate. The ground plane is indicated by Gnd h as presented in Fig.1. CST Microwave Studio is used for antenna simulation in order to obtain more accurate results. All the dimensions of the antenna design are presented in Table I.

TABLE I. Dimensions of the Proposed Antenna

Parameter	Value(mm)	Parameter	Value(mm)
Sub. height	1.6	L1	3.2
Ls	40 (FR4)	L2	2.4
Ws	43	L3	1.2
Gnd h	11	W1	1. 6
Wf	3	W2	3.6
Fl	11.9	W3	6
Er	4.4	Ls	43 (other materials)

IV. Simulation Results of the Proposed Patch Antenna

A. Return Loss, S11

Simulated return loss of an antenna with different ground planes is shown in Fig.2. The proposed antenna is tested and its results are checked with five different ground planes widths starting from ground width equal to 8 to 11.5. From Fig.2 it is clear that ground plane having width of eleven gives better results than all other. Antenna with ground plane of eleven gives resonant frequencies at 2.94 GHz, 5.18 GHz, 8.54 GHz and 10.78 GHz through return loss of -35.056 dB, -16.335 dB, -30.589 dB and -27.27 dB. Patch of length L, ladder steps at bottom of patch and also ground plane creates those frequencies.

The frequencies for the reason that of the footsteps at the lowermost part of rectangular patch, the rapid changes in the geometry of patch antennas indications to a cutout in the microstrip line [12]. Due to the technique wider bandwidth is obtained, which produces capacitive coupling between the ground plane and patch of the antenna [13]. Magnetic and electric field spreading are altered nearby the discontinuity when the geometry of antenna ups and downs. Thus, the incoherence due to footsteps can be symbolized as corresponding circuit as three times of spilt LC circuit as shown in Fig. 3. Quasi static computation equations from (1) to (7) can be used to express the variables [12].

$$A = 0.00137\frac{\sqrt{\epsilon_{re1}}}{Zom1}(1-\frac{W2}{W1})h\frac{(\epsilon_{re1}+0.3)}{(\epsilon_{re1}-0.258)} \quad (1)$$

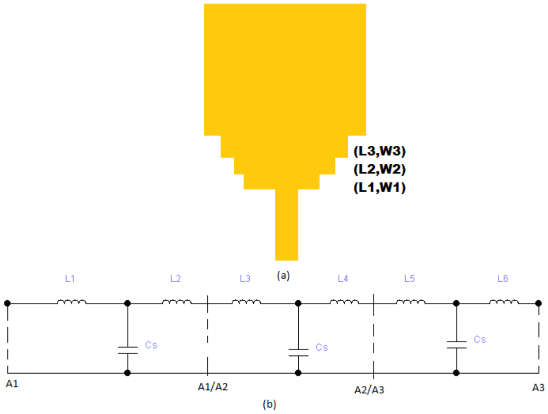

Fig. 3. (a) Micro-strip 3 steps pattern; (b) Corresponding circuit.

$$B = \frac{(\frac{W1}{h} + 0.264)}{(\frac{W1}{h} + 0.8)} \quad (2)$$

$$Cs = A \times B \quad (3)$$

$$L1 = \frac{Lw1}{(Lw1 + Lw2)} Ls \quad (4)$$

$$L2 = \frac{Lw2}{(Lw1 + Lw2)} Ls \quad (5)$$

$$Lwi = \frac{(Zom\sqrt{\epsilon_{re}})}{C}(H/m) \quad (6)$$

$$Ls = 0.000987h(1 - \frac{Zom1}{Zom2}\sqrt{\frac{(\epsilon_{re1}}{\epsilon_{re2})}})^2(nH) \quad (7)$$

Where, Lwi is on behalf of i = 1, 2, 3 point towards inductance per unit length of microstrip of widths *W1*, *W2* and *W3*. ϵ and *Zom* point towards the dielectric constant and microstrip patch line characteristic impedance and also the substrate size h is in mm [12].

Acting on radiating and matching areas permits monitoring the impedance bandwidth. This slot presents a capacitive reactance, which counteracts with the inductive reactance of the feed. In fact, the technique of cutting the slot at the patch antenna is investigated widely [12]. The proposed antenna shows decent ultra wideband features in terms of return loss and impedance BW, with fractional bandwidth(FBW) of 136.59% in the simulated result. Furthermore, from return loss graph, we can see the proposed antenna gives better result when ground length is 11 mm.

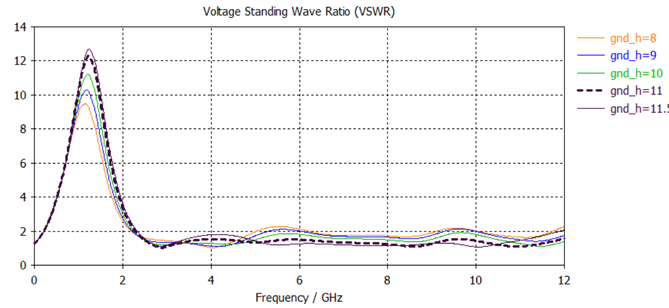

Fig. 4. Simulated VSWR against frequency.

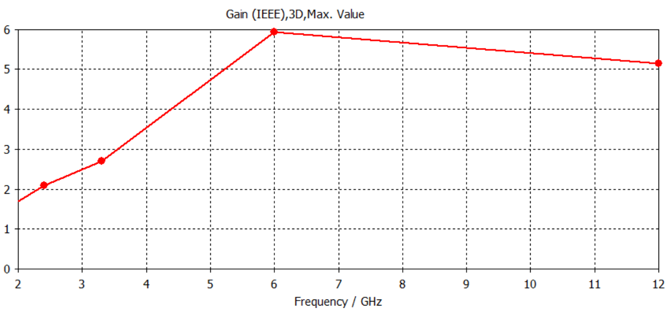

Fig. 5. Simulated result of Gain vs frequency (GHz).

B. Plot of Voltage Standing Wave Ratio (VSWR)

For different ground widths, the VSWR graph is checked against its frequencies. It is obviously understood that this graphs values are between one and three all the way through simulation frequency. For our attained results, the voltage standing wave ratio for ground width of 11 is good in which value is less than 2 all the way through the simulated frequency results as displayed in the Fig. 4.

C. Comparison of the Proposed Antenna

Table II gives a comparison of different antennas w.r.to their sizes, area and bandwidths achieved. The proposed antenna is simulated for different substrate materials and its results are checked and compared with different antennas as shown in Table II. All the antennas attained wideband properties. Now a day‘s, size of the antenna needs to be minimum due to invention of modern devices and bandwidth should be larger. The proposed antenna is not only smaller in size and area but also has larger bandwidth than all other antennas given in Table II. Gain (dBi) of an antenna is the ratio of power transferred by an antenna in a specified direction and the power transferred in that direction by a perfectly effective isotropic radiator in that direction. Fig. 5 shows the information about the gain along with frequency on horizontal side. It is noticed that the gain of antenna is positive and acceptable. Negative gain shows the losses of an antenna. Gain of the proposed antenna lies between 2 and 6 throughout the simulated frequency.

D. Radiation Pattern of an Antenna

E plane is the one at which the theta cuts of at 90^0 and H plane is that one at which phi cuts at 90^0. From Fig. 6, it can be seen that radiation patterns show a guiding performance

TABLE II. COMPARISON OF THE PROPOSED ANTENNA WITH DIFFERENT ANTENNAS

Ref.	Antenna type	Freq. (GHz)	ABW (GHz)	FBW	Material	Area (L×W)
[1]	Ring slot antenna	3-11	ABW = 8GHz	FBW = 114.2%	RO4003B ϵ_r = 3.4	12000m^2
[7]	Planar UWB antenna	3.1-10.6	ABW = 7.5GHz	FBW = 109.4%	RO4003 ϵ_r = 3.38	5850m^2
	Proposed antenna (using material RO4003)	2.35-13.5	ABW = 11.15GHz	FBW = 140.6%	RO4003 ϵ_r = 3.38	1849m^2
[3]	Planar antenna	2.5-12	ABW = 9.5GHz	FBW = 131.1%	RO3003h ϵ_r = 3	2500m^2
	Proposed antenna (using material RO3003)	2.38-13.82	ABW = 11.44GHz	FBW = 141.5%	RO3003 ϵ_r = 3.00	1849m^2
[4]	SRR-loaded UWB antenna	2.37-10.93	ABW = 8.56GHz	FBW = 128.7%	Taconic ϵ_r = 2.33	2500m^2
[6]	Circular monopole antenna	2.6-10.8	ABW = 8.2GHz	FBW = 122.3%	Taconic ϵ_r = 2.33	2500m^2
	Proposed antenna (using material Taconic)	2.4-14.55	ABW = 12.15GHz	FBW = 143.3%	Taconic ϵ_r = 2.33	1849m^2
[2]	Dual band antenna	2.8-10.6	ABW = 7.8GHz	FBW = 116.4%	FR4 ϵ_r = 4.6	1720m^2
[5]	MIMO antenna for UWB	3.1-12	ABW = 8.9GHz	FBW = 117.8%	FR4 ϵ_r = 4.4	1820m^2
[8]	Printed circular disc monopole	2.69-10.16	ABW = 7.47GHz	FBW = 116.2%	FR4 ϵ_r = 4.7	2100m^2
	Proposed antenna (using material FR4)	2.33-12.4	ABW = 10.064GHz	FBW = 136.5%	FR4 ϵ_r = 4.4	1720m^2

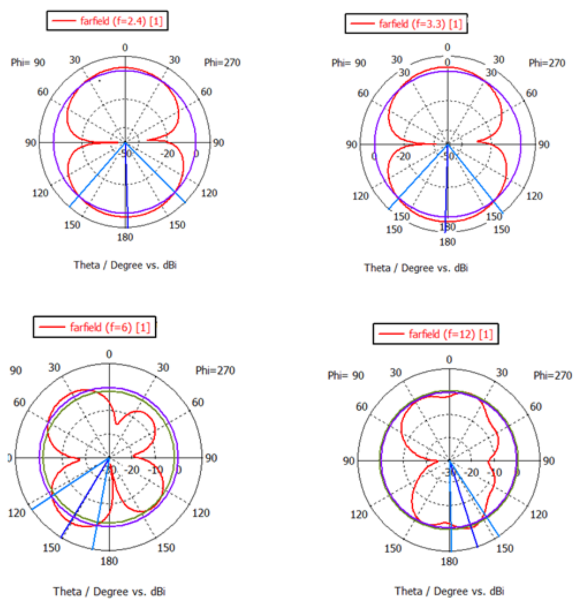

Fig. 6. Radiation patterns at phi cut of 0 degree and at theta cut of 90 degree at (a) 2.4 GHz, (b) 3.3 GHz, (c) 6 GHz, and (d) 12 GHz.

such as the core lobe direction is towards at 0^0 and 180^0. It means that absorption of the field concentrate on sides of patch of antenna. For time being, from the front and back part of the patch of an antenna lobe suppressed at 90^0 and 270^0 degree, respectively. Fig. 6(b) shows the same pattern as given in Fig. 6(a), while Fig. 6(c) and Fig. 6(d) display the central lobe direction at the front patch antenna from 0^0 to 180^0. More lobes are also observed at higher frequencies. The radiation pattern shows omni directional behavior at low frequencies and linear directional behavior at higher frequencies.

V. CONCLUSIONS AND FUTURE WORK

The proposed antenna showed good ultra wideband features, which have simulation results from 2.33 GHz to 12.4 GHz and fractional bandwidth of 136.59%. The proposed antenna also covers range of WIMAX, blue-tooth, wireless fidelity, and satellite communications for both uplink and downlink channels. The scale of VSWR is also less than 2 throughout the achieved bandwidth. The proposed antenna has small geometrical size and thus, is suitable for telecommunication applications. In future work, we will try to further increase the bandwidth and to add more communication bands for wireless applications such as global system for mobile communication and universal mobile telecommunications system.

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