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Depiction and Analysis of a Split P-shaped Microstrip Patch Antenna for S, C, X, and Ku-band Applications

Md. Jubaer Alam[1,*]

[1]Department of Electrical and Electronic Engineering,
IUBAT—International University of Business Agriculture and Technology, Dhaka, Bangladesh
*corresponding author Email: jubaer.alam@iubat.edu

ABSTRACT: In *this paper, a split P-shaped multiband microstrip patch antenna is designed and its measurement results in terms of different parameters are given. This patch antenna is designed to support models with resonances at 3.48 GHz, 5.85 GHz, 9.4 GHz, 12.91 GHz, 15.93 GHz and 19.06 GHz. FR-4 (lossy) is used as a substrate to design the recommended antenna which has a firm dimension of 18×20 mm2. This antenna operates at S, C, X, and Ku band with moderate bandwidth because of its design and feedline. This mixed quadrilateral shaped multiband antenna has directivity gain of 2.61dBi, 5.78dBi, 3.04dBi, 0.97dBi, 3.42dBi and 7.47dBi at resonating frequencies and is suitable for a modern communication system. The proposed split multiband antenna results are obtained in terms of Return Loss, Voltage Standing Wave ratio, Gain and Radiation Pattern which have admissible values of return loss less than -10 dB, Efficiency more than 80% at each resonant frequency and Gain more than 5 dB. A suitable radiation pattern and an emerging gain make the recommended antenna suitable for the use in a modern communication system.*

KEYWORDS: *Multiband; Microstrip Antenna; Split gap; Modern communication;*

Introduction

Given the recent advance of modern modes of communication, there is need for antennas that are small in size, compact in shape, and low cost and that can provide good output characteristics over a large frequency range. In early 1970s, the microstrip patch antenna (MPA) was introduced and it has initiated a revolution in antenna design. Designing optimal MPAs has attracted the attention of researchers attempting to reduce further the size of the antenna. Microstrip antennas cover much of the wireless system, such as Bluetooth, Wi-Fi, WLAN, WiMAX applications.

MPAs are known as low profile antennas. They are used in planar and nonplanar surfaces. They are being used widely because they are simple and inexpensive to fabricate. MPAs have a frequency range above 100 MHz [1]. They are fabricated on a dielectric substrate. The advantage of this conformable structure is the ability to integrate the antenna into various telecommunication systems. Designing an optimum MPA requires experimentation with different designs: the splits, gaps and spaces among the element determine the resonant frequency of the antenna. The most important decision is the choice of spacing. Gaps and spaces play a vital role in the MPA. They determine the resonance at different frequencies. So these splits and gaps need to channelize perfectly. But tuning the MPA in a particular position may make the structure complex. A coupling problem occurs with the reduction of the structure. Sometimes, increased spacing creates the possibility of uncertain convexity in the substrate [2-9]. A handful of researchers has worked to design better patch antennas keeping in mind the goal of smaller size and better operation in several discrete frequencies. In spite of complexities regarding the design of multiband antennas, researchers have discussed the schematic composition of MPAs that have operating frequencies in more than one band.

A lot of research has been done on the layout of MPAs. A double G-shaped planar multiband antenna of 40×30mm2 has been designed for WLAN, WiMAX, and HIPERLAN2 [10]. A 50×50 mm2 slot ring antenna integrated with capacitive patch has been proposed, which is able to function at frequencies related to WLAN and WiMAX applications [11]. Coplanar Waveguide (CPW)-fed slotted patch antennas of 23×30 mm2 designed to operate in 2.4–2.63, 3.23–3.8 and 5.15–5.98GHz bands [12], and 25×25mm2 to cover 2.14–2.85, 3.29–4.08, and 5.02–6.09GHz bands [13] have been developed. The two-U slot-shaped patch antenna of 40×50mm2 with three resonant frequencies of 2.7, 3.3 and 5.3GHz has been implemented to cover tri-band wireless system [14]. Alam et al. worked on this microstrip antenna in recent past. They proposed a combined double H-shaped microstrip antenna for X-band operation [15] and a split quadrilateral shaped antenna for C, X, Ku, and K-band (multiband) applications [16]. The gain of the H-shaped antenna was more than 5 dB, but it covered only X-band, whereas the split quadrilateral antenna covered multiband with gain around 3 dB. The main concern of the researchers on the above-mentioned proposals and designs was to design multiband antennas with minimum concession to either higher fabrication cost or larger effective electrical area. The parameters of concern are steady radiation performance, gain or efficiency. There remains scope for researchers to build low profile MPAs with better gain, radiation patterns, and efficiency. On the basis of the background study, a low profile, multifunctional, small sized MPA is proposed in this paper with highly tolerable FR-4 material as the substrate. The slit P-shaped multiband patch antenna has an area of 18×20mm2. After fabrication, this patch has been compared with other similar antennas on different performance criteria. This slit quadrilateral shaped MPA that produces multiple bands resonating at 6.3GHz, 7.2GHz, 7.5GHz, 8.7GHz, 12.8GHz, 17GHz and 21.3GHz with excellent return loss. The frequencies accessible with the proposed antenna cover C, X, Ku and K bands, which have many applications in wireless communications such as GSM (Global System for Mobile communications), DCS (Distributed control system), CDMA (Code-division multiple access), PCS (Personal Communications Service).

In this paper, the background has been explained in section I. Section II explains the design of the antenna. Section III is based on results and discussion of different parameters like VSWR, directivity, surface current etc. And finally, section IV provides a conclusion.

Methodology

The geometry and layout of the proposed split P-shaped MPA are highlighted in Figure 1. Table 1 shows the summary. This antenna consists of three layers: a patch, substrate and ground. All measurements are in mm scale. In this antenna, FR-4 (lossy) is used as a dielectric substrate. This substrate has a thickness of 1.6 mm and a relative dielectric constant (εr) of 4.4 and loss tangent tan δ=0.02. The dimensions of the substrate are 18×20×1.67 mm3. Copper annealed is used as the patch and ground material. When there is a little change in the feed line, there is a remarkable change in resonances. It is the shape of the antenna that makes it possible to resonate at different frequency ranges.

Figure 1: The geometry of the proposed MPA

(a) Front view of the prototype

(b) Front view of the design

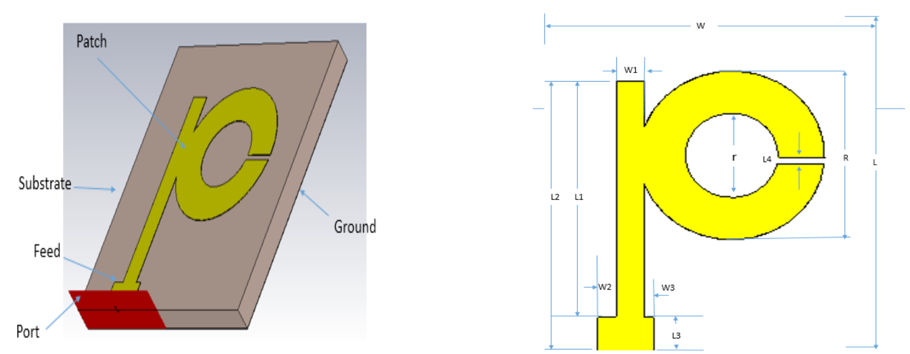


Table 1: Antenna Parameters

Parameter	Optimum value (mm)	Parameter	Optimum value (mm)
L	20	W1	1.5
W	18	W2	1
L1	14	W3	0.5
L2	16	R	5
L3	2	r	2.5
L4	0.38		

Figure 2: Prototype of the MPA

(a) Front view (b) Back view

Figure 2 illustrates the prototype of the MPA. Here, the Length of the antenna L is 11mm and width of the antenna Wg is 15mm. All antenna parameters are tabulated in Table 1 and the antenna was simulated with commercially available Finite Integration Technique (FIT) based on Computer Simulation Technology (CST) microwave studio software.

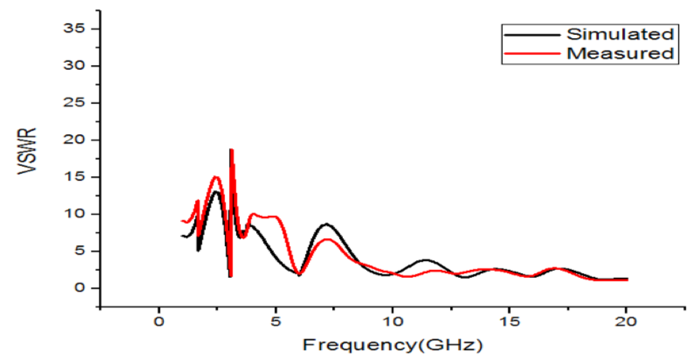
Results and Discussions

The performance of this split Quadrilateral shaped antenna is determined by CST software. The simulation has been done with ASUS A556U series. The Central Processing Unit is Intel Core i5-6200U, RAM- 8GB, HDD- 1TB. It took about 293 seconds for each simulation. The Satimo Starlab anechoic chamber was used for measuring different parameters.

The analysis is made on VSWR, Frequency, Directivity, Measured gain, Radiation on surface current, E and H field radiation pattern, with a frequency range of 1 to 20 GHz. This antenna shows resonance in four different bands. The analysis is illustrated below with figures.

Voltage standing wave ratio (VSWR) is used to measure the imperfections of the transmission line. It measures the ratio of the amplitudes of the maximum standing wave. In the case of a

Figure 3: Simulated and measured VSWR of the antenna



transmission system, this VSWR represents the efficiency of transferring RF power into the load via a transmission line from the power source. The implementation of the VSWR of the mentioned MPA in Figure 3 represents the measured impedance bandwidth of the antenna within the range of 1 to 20GHz for VSWR ≤ 2. Both simulated and measured results have a decent match. The inconsistency between the results of simulated and measured are predominantly due to deceptions in the process of fabrication. However, the inconsistency may be occurring due to the use of the connector during the measurement. But in the case of simulation, the microstrip feeding cable is not considered. In spite of these, the mentioned miniaturized MPA shows resonance at multiple bands.

On the other hand, reflection coefficient (S11) does similar activities like VSWR. It signifies the relationship between input and output ports in an electrical system. It represents the quality of the impedance match between the source and the measured load. And for any antenna, the value of (S11) is taken in account when it is less than -10dB.

The antenna has four resonant frequencies at four different bands and these resonant frequencies appeared in the range of 3 to 20 GHz. At resonant frequencies, return losses are quite similar. They fluctuate within a range of -10.7 dB to -22.24 dB. These resonant frequencies along with their corresponding bands and return losses are tabulated below.

Table 2 describes the return loss at different resonant frequencies. The bandwidth is quite impressive at those resonances. The fundamental resonance of the antenna is at 3.48GHz and its bandwidth is 53MHz. On the other hand, the highest resonant frequency is 19.06GHz and the bandwidth is 1890MHz. There, corresponding return losses are -22.24dB and -19.41dB.

Figure 4 describes the input impedance of the proposed MPA. It is evident from Figure 3 that the VSWR is much higher than 2 at lower frequencies and returns loss follows the same. Besides, at higher frequencies the -10dB bandwidth is much wider. This may occur due to the impedance mismatch over lower frequencies. As the input impedance of an electrical network is the quantity of restriction to current flow both static and dynamic in the electrical

TABLE 2: Return loss and bandwidth of the proposed MPA

Resonant Frequency (GHz)	Band covered	Return loss (dB)	Bandwidth (MHz)
3.48	S	-22.24	53
ce5.85	C	-16.21	221
9.4	X	-15.673	969
12.91	Ku	-14.30	1135
15.93	Ku	-14.29	1133
19.06	K	-19.41	1890

source, impedance matching is pretty important. From input impedance curve in Figure 4, it is observed hat the impedance fluctuates extensively in the frequency range of 0-20GHz. From 0 to 4GHz, reactance is quite high and has a peak value of around 2000Ω. Apart from that, the impedance remains close to 50Ω. A ground plane effect is there to create the input impedance mismatch to 50Ω.

The main concern of an antenna is its directivity or radiation pattern. It explains the direction of a particular antenna at which the radiation is directed. It is measured by the ratio of two radiation intensities; one is in the particular direction and the other is the overall direction. Figures 5 and 6 show the radiation pattern of the antenna at resonant frequencies in E and H plane. The figures are shown from the relevant pattern from $\phi = 0$ and $\phi = 90^{\circ}$. For

Figure 4: Simulated input impedance of the MPA

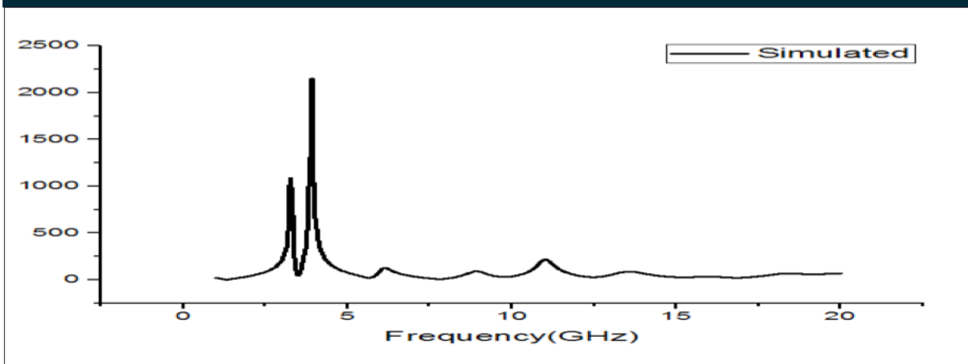


Figure 5: Simulated and measured radiation patterns at 5.85GHz in (a) Elevated plane and (b) Horizontal

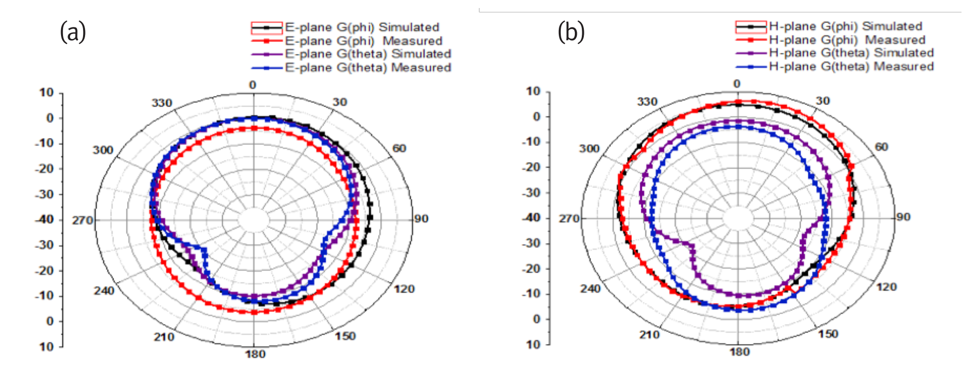
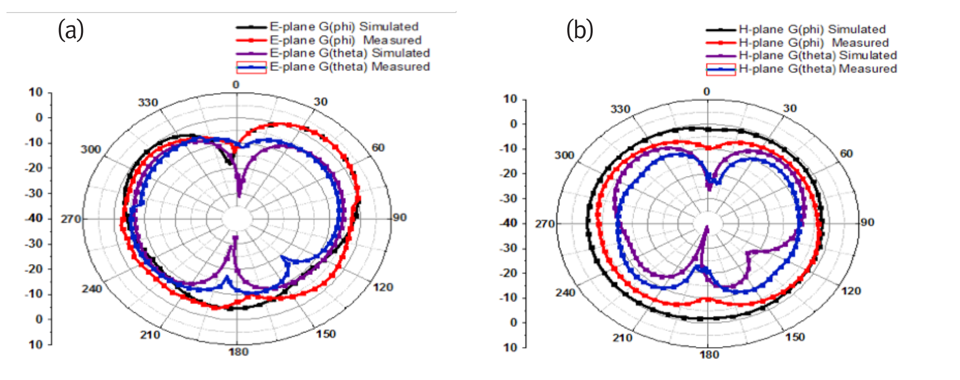


Figure 6: Simulated and measured radiation patterns at 12.91GHz in (a) Elevated plane and (b) Horizontal plane



the proposed antenna at resonant frequencies, the directivities are shown in Table 3.

This radiation pattern is formed based on the Elevated plane (E-plane) and Horizontal plane (H-plane). The design is made in such a way that the XY plane has become the Elevated one and YZ plane as the horizontal one. Figures 5 and 6 show the comparison between measured and simulated far-field radiation patterns in E-plane and H-plane at resonant frequencies. For E-plane, ϕ is kept zero to measure gain phi [G(ϕ)] and gain theta [G(θ)] And for the H-plane, ϕ is kept at 90 to measure G(ϕ) and G(θ). Only a little deviation is found between the measured results and the simulated results. This may happen because of the cable loss which is the connector between controller and antenna. Apart from that, the results are quite impressi,ve and over the resonating frequencies, the radiation patterns are quite steady. In the case of G(ϕ) radiation for both E and H plane are essentially symmetric. But in the case of G(θ), the patterns are quite similar at the operating frequencies.

Figure 7 and 8 represent the 3D radiation patterns at 5.85GHz and 12.91GHz. The study is made on “xy”, “yz” and “zx” planes to compare the radiation. Two different resonant frequencies are taken to observe the activity in two different bands. As expected, these phase patterns have a helical profile with a 2π phase change in one turn. Therefore, the proposed antenna adequately radiates a circularly polarized electromagnetic wave [18]. It is seen from the Figure 7 and 8 is the main lobe directions are ϑ and main lobe magnitudes are 5.79dBi and 7.15dBi respectively for 5.85GHz and 12.91GHz Table 3 describes the value of the directivity at different resonating points in E and H plane respectively. In the case of the E-plane, the highest directivity is found at 19.06GHz. On the other hand, for H plane, the highest value is also at 19.06GHz. Even the radiation patterns are also impressive at these resonant frequencies.

Figure 7: Simulated 3D radiation pattern at 5.85GHz in (a) xy, (b) yz and (c) zx plane

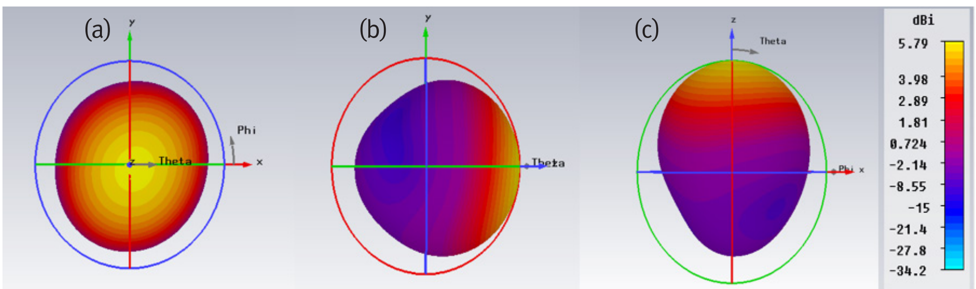


Figure 8: Simulated 3D radiation pattern at 12.91GHz in (a) xy, (b) yz and (c) zx plane

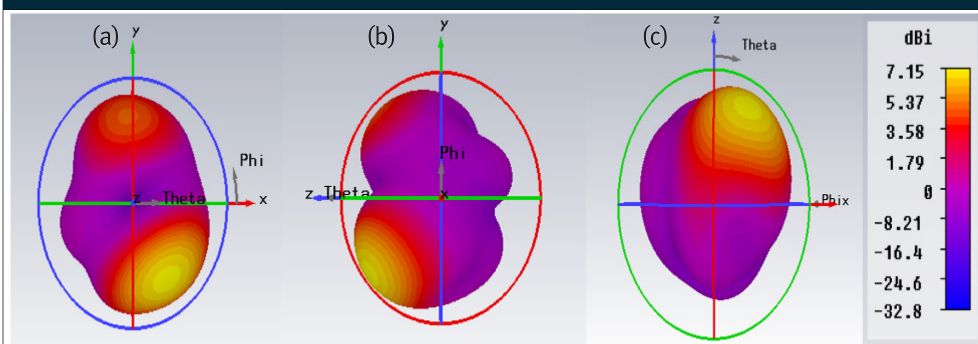
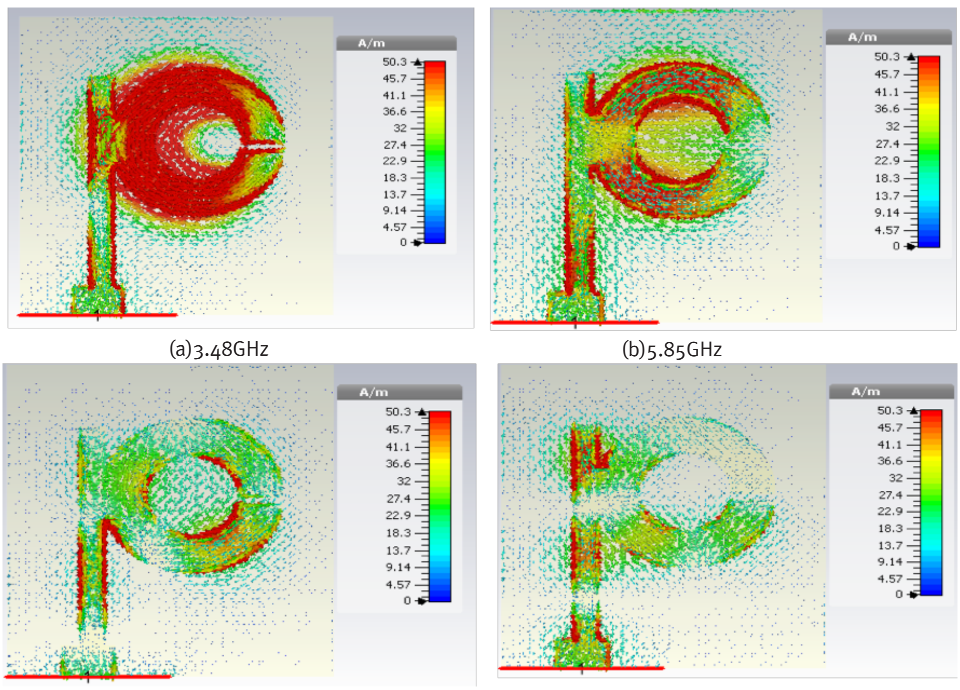


TABLE 3: Directivity of E and H plane at operating frequencies.

Resonant Frequencies (GHz)	Directivity in E-plane (dBi)	Directivity in H-plane (dBi)
3.48	2.61	1.1
5.85	5.78	5.78
9.4	3.04	3.77
12.91	0.97	5.95
15.93	3.42	4.0
19.06	7.47	7.37

Figure 9: Surface Currents distribution of the antenna simulated at (a), (b), (c) and (d)GHz



(a)3.48GHz (b)5.85GHz

(c)9.4GHz (d)12.91GHz

In metallic antennas, the surface current is an actual electric current that is induced by an applied electromagnetic field. The electric field pushes charges around. Figure 9 illustrates the result of simulation of the current distribution of the proposed MPA for (a) 3.48 GHz, (b) 5.85 GHz, (c) 9.4 GHz and (d) 12.91 GHz.

It is visible from the figure that the feedline is carrying more current. The generated electric field has been found at this point [17]. It is also observed that the current distribution of the lower frequencies is more balanced than the higher or upper ones. In upper bands, the created electric field near the slot is quite legitimate. In lower frequencies, the current is distributed almost all over the patch. But with the higher frequencies, the current has to cover curvier paths than a straight one in lower frequencies. This is because of skin effect. Due to it, at higher frequencies, current flows through the surface of a conductor instead of its fundamental part. Hence, in the case of both the upper and lower band, excitation is quite strong in the entire parts of the MPA.

Figure 10: Comparison between Simulated and Measured gain of the MPA

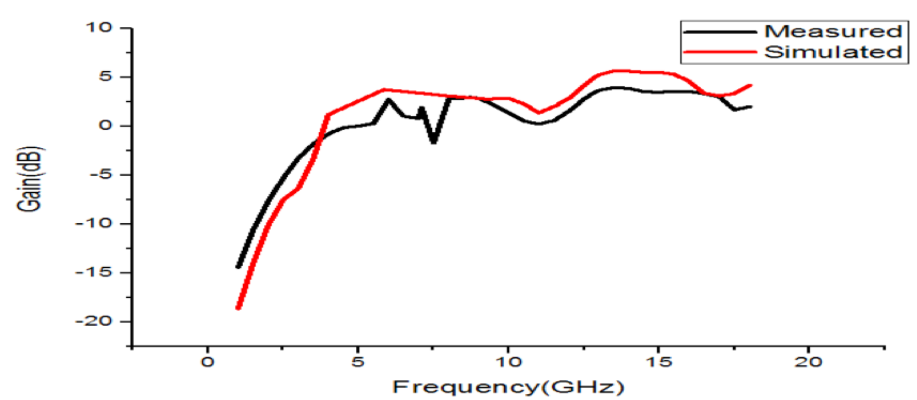


Figure 11: Comparison between Simulated and Measured efficiency of the MPA

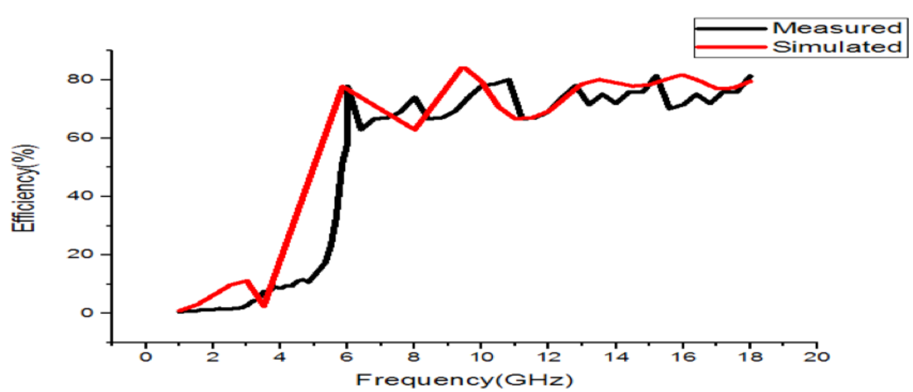


TABLE 4: Performance comparison between proposed antenna and some existing antennas.

Antenna	Dimension Area (mm^2)	Covered Bands	Bandwidth (MHz)	Application
[9]	20×20	S and C	360, 440, 1550	WiMax, C-Band
[10]	40× 30	L, S and C	140, 270, 675	WLAN, Blue-tooth, WiMAX, HIPERLAN2
[12]	23×30	S and C	290, 290, 700	WiFi/WiMax, C-Band
[13]	25×25	S and C	300, 500, 700	WiMax/ WLAN
[14]	40×50	S and C	180, 150, 170	Tri-band Wireless
Proposed	18×20	C, X, K and Ku	358, 537, 445, 1553, 1036, 2182	WLAN, C-Band, Satellite Communication

Antenna gain is a term that explains the amount of transmitted power in the direction of an isotropic source. It is the measurement of an antenna's ability to provide a direction to the radio frequency energy in a distinct pattern. This gain is measured by Satimo StarLab near-field measurement system. Figure 10 illustrates the gain of the MPA within 1 to 18 GHz. There is a negligible deviation between measured and simulated curve. And it is visible that the gain crosses the 5dBi line at 13.5 GHz. The highest gain is found between 19 and 20GHz where the value is almost 6dBi, but that is not included in the figure as the measurement could be made only up to 18GHz.

The efficiency of the patch is also done by Satimo StarLab near-field measurement system. Figure 11 illustrates the efficiency of the patch within range of 1 to 18 GHz. The highest efficiency is recorded at 81.35% with an average of 70%. In this figure, both measured and simulated efficiencies are compared within 18GHz as the Satimo StarLab near-field measurement system cannot measure more than 18GHz. The efficiency is not that high because the patch is designed for the high loss FR-4 dielectric substrate. Due to this reason, both efficiency and gain are deteriorated. The gain and efficiency of the proposed MPA can be upgraded by using expensive microwave substrate rather than low-cost FR-4.

The comparison of the proposed MPA with existing antennas based area and application are shown in Table 4. Though the related antennas are made of identical materials, there are definite resonant frequencies at different bands because of the various shapes of the antennas. After analyzing the detailed performance characteristics, the mentioned antennas are bigger in shape, cramped in bandwidth and cover fewer bands comparing to the proposed split quadrilateral shaped MPA.

Conclusions

In this paper, a small split P-shaped multiband microstrip patch antenna is proposed for the modern communication system, especially for wireless communication. For this antenna, the resonant frequencies are obtained in S, C X and Ku bands with satisfactory gain. Moreover, the directivity and gains are quite impressive. The perimeter of the designed MPA is quite small and compact for an antenna that gets resonant frequencies with four different bands. Despite using the FR-4 substrate, the antenna is only 1.67 mm thick. This design works well in wireless systems like WiFi, WLAN, WiMAX, etc.

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