Novel design of Multiband Slotted and Miniaturized Microstrip Patch Antenna for X and Ku -band Applications

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Abstract

This article takes a research on a novel design of a multiband slotted microstrip patch antenna. It depicts a multi ultra wideband compressed and developed antenna with double F- slots, four rectangular slots, and side corner cuttings on the patch using partial Ground. The proposed multiband microstrip patch antenna can resonate at six unique frequencies between 8 GHz and 19 GHz in X and ku bands and execute the reflected power of -23.8351 dB, -32.9380 dB, -14.6726 dB, -22.2810 dB, -19.0592 dB, and -18.8137 dB at 8.6181 GHz, 12.3116 GHz, 14.1960 GHz, 15.6281 GHz, 18.1910 GHz, and 18.9447 GHz, respectively. The gained voltage standing wave ratio (VSWR) is less than 1(0.3918). A maximum directivity and gain of 6.9104 dB and 6.3769 dB is achieved at the resonating bands. Moreover, the effectiveness of the proposed multi-band patch antenna has been verified through the radiation pattern and radiation efficiency of measured results. The low size, weight, and cost of the geometry of this antenna make it entice for Radar engineering, police radars for measuring the speed of the vehicles, for military applications, for navigation intentions, and in finding out the weather forecast and Satellite broadcast communication, space-crafts, wireless computer networks, etc.

1. Introduction

A milestone in wireless communication systems is the execution of the Microstrip patch antenna which is progressing to accomplish the challenging demands of the new breed of antenna technology. In present-day wireless communication systems antennas are broadly used because of their inherent proficiencies of a low profile, lightweight, consistent design, low cost, ease of fabrication, and ease of integration with circuits. Since wireless communication devices have become a crucial part of our daily communication life, the need for a low profile miniaturized multi- and wideband antennas has been developed. Communication systems that operate in the X-band are normally built engaging separate antennas for all bands. It is advisable to configure a single antenna that operates in multiple frequencies for multitasking, because it is fetching more and more essential to utilize such systems in one setting [1]. A microstrip patch antenna in its uncomplicated form comprises a radiating patch on one face of a dielectric substrate and a ground plane on the contrary. With respect to the shape, microstrip antenna patches can be usual or unusual. Common regular shapes are rectangular, square, circular, elliptic, and triangular, among others. These shapes have been generally carried out and the design approaches are well established. They are employed as consistent antennas for airplanes, cars, missiles, safeguard devices, and many other implementations. Commonly shaped antennas are more frequent, because they are easy to evaluate and normally present symmetric radiation patterns. The unevenly shaped patch antenna relates to a microstrip antenna whose patch measurement is configured to execute a specific antenna property such as compactness, wideband characteristics, and multi resonant operation [2]. The current spectrum assignment for ultra-wideband (UWB) radio communication has kindled and renewed interest in the subject of UWB antennas. Several designs have been latterly suggested for UWB antennas. However, traditional UWB antennas are "multi-narrowband" and, therefore, are not optimized to receive a single coherent signal across their entire operating bandwidth. Besides, higher-frequency cutoff performance is wanted for a UWB system to attain a better signal-to-interference ratio (SIR), with the growing demand for higher-frequency in data communications so as to bring down the interference from other indoor radio frequencies. On the other hand, the UWB antenna's performance and behavior must be stable and foreseeable over the matching band. Moreover, the denigration of escalating and contortion of the pulse, sufficient impedance matching, gain planeness and linear phase all over the entire-bandwidth are requirements of successful transmission and reception of UWB pulses. The size of the antenna, which must be retained small without compromising performance is the main another account in the design [3]. The Federal Communications Commission (FCC) systems admit the UWB wireless communication band operates at 3.1–10.6 GHz, with acutely low power ejection levels, is simply interceded with nearby communication systems such as the 3300–3600 MHz WiMax communication system, the 5150–5820 MHz and 5720–5870 MHz WLAN system, X-band between 7250–8400 MHz, Wi-Fi between

5470–5725 MHz and C-band between 3700–4200 MHz [4]. In [5] V. Bhanumathi and S. Swathi, has established an Inverted L-Shaped patch which is configured on the top of the substrate and a U-Slot is engraved in the infinite ground plane and it is detected to be obtaining maximum return loss -24dB at the frequency range of 5 to 8GHz with a compact size of $24 \times 36 \times 1.6$ mm having altered ground structure which is determined to be appropriate for UWB applications. In [6] Kumar Gautam and et.al has been proposed Inverted L-Shaped Slotted Microstrip Patch Antenna with DGS for X-Band Applications attains a return loss value of -18.16 dB and -30.55 dB for a frequency of 8.15 GHz and 10.84 GHz respectively with a compact size of $16 \times 18.02 \times 1.6$ mm having ground structure 16×18.2 mm which can be applicable for UWB applications. [7] Janvi Meena and et.al have been suggested Slotted Patch Antenna with the resonating frequencies of 9.0 GHz and 10.14 GHz having return loss values of -15.92 dB and -14.84 dB respectively, with a peak gain of 7.50 dB and bandwidth 1.41 GHz with a reduced size of $30 \times 30 \times 1.6$ mm having ground structure 30×30 mm for X-band applications. [8] Brijesh Mishra and et.al have been introduced Gap Coupled Swastika-Shaped Patch Antenna for X and Ku Band Applications which resonates in the frequency range of (10.25–12.4) GHz, (11.74–13.52) GHz, and (10.74–13.63) GHz with resonating frequencies of 11.3 GHz, 12.6 GHz, and 12 GHz; peak gains of 3 dBi, 5 dBi, and 5.13 dBi; and maximum radiation efficiencies of 88.4%, 89.2%, and 87.2%, respectively with substrate dimension $20 \times 20 \times 1.6$ mm having ground plane 20×20 mm. [9] Shahid Ullah and et.al have been presented a simple z-shaped meander monopole antenna having high efficiency and super ultra-wide bandwidth. It enhanced a wide bandwidth of 19.9 GHz (2.8 GHz to 22.7 GHz). The notion of transformer is utilized for finest matching in a special microstrip feeding line and is also adequate to reach wide bandwidth with substrate dimensions $38 \times 35 \times 1.57$ mm. Microstrip Patch Antenna (MPA) employing hybrid fractal slot (Koch-Minkowski and Koch-Koch) along with partial ground plane for wideband applications. The deficiency of these above antenna review holds that the size of the ground plane and thickness of the substrate is wide and therefore antenna loss turns high and radiation efficiency becomes less. To reduce the antenna's loss and enhance the radiation efficiency is carried out by the reduction of the size of an antenna not only in the patch but also in the ground. Our paper is designed based on this idea and the simulation results show the best enhancement in radiation efficiency and lower in return loss with multi band with respect to the above analysis. The main focus being reduction and enhancement of radiation efficiency with multi-band which causes multi- task. In our novel antenna, different approaches at size reduction in the patch have been proposed such as placing double F shapes and four rectangular slots in the bottom of the patch and also having cuts on the corner of the patch left and right sides to workout multiband functions .The simulated and improved outcomes are weighed up in terms of return loss, VSWR, Gain, Directivity, and radiation efficiency. The benefit of this approach is that the return loss of the antenna gets reduced, and the radiation efficiency of the antenna gets enhanced with multi-bands. The statistical study of various antenna design variables is carried out to achieve optimum Radar and Satellite applications.

2. Antenna Design And Theory

The proposed antenna is possessed of a double F-Slotted patch with four rectangular slots in the bottom of the patch, cuts at left and right corners of the patch and it is fed with the microstrip line to attain 50-ohm impedance for better impedance suit. Substrate FR4-epoxy of dielectric constant 4.4 has been selected for this proposal. The height of the substrate is $h = 1.43$ mm.

The length and width of the substrate ($L_s \times W_s$) are $40\text{mm} \times 26\text{mm}$. Measurements of the partial ground plane ($L_g \times W_g$) is $16.2\text{mm} \times 12.12\text{mm}$. Diverse specifications surveyed for this novel design are designated below in table 1. The antenna design is configured with double F slots having a partial Ground to encounter the essentials for the Radar and ku band implementation. This antenna has a wideband operating in the frequency range of 8-19 GHz.

A rectangular microstrip patch antenna is presented with novel deformity inserted in the patch using a partial ground plane. Fig .1(a) shows a microstrip patch antenna with the partial ground without any change in the patch. In Fig.1 (b) double F slots are combined with the radiating patch, with four rectangular slots at the bottom of the patch, two at the lower edge of the left side and two at the lower edge of the right side whose lengths and widths are upgraded to execute good consequences in antenna characteristics and preferred results. To create advances in the characteristics of the suggested antenna, additionally, two cuts at the left and right corners are made in the antenna. Figure .1(c) shows the front view of the presented antenna with a partial ground to attain X and Ku-band characteristics and to bring nearer a standard return loss and to elevate the radiation efficiency of the antenna. The upgraded proportions of all the antenna parameters are declared in Figure 1.(a), 1.(b), and 1.(c). are referred to in the table.1

Table 1. Measurements of depicted Microstrip Patch Antenna (MPA)

Antenna design parameters	Designed Values (mm)
Substrate material	FR4-epoxy
Substrate Thickness (h)	1.43
Length of the substrate	40
Width	26
Length of the patch	19.3
Width of the patch	19.27
Length of the ground	16.2
Width of the ground	12.12
Feed length, L	19.2
Feed Width, W	3
Vertical Right & Left Slot1 length	3.14
Vertical Right & Left Slot1 width	1.1
Vertical Right & Left Slot2 length	3.91
Vertical Right & Left Slot2 width	1.1

2.2. Effects of Slots and Cuts to the Patch Shape

In terms of return loss, VSWR, gain, directivity, radiation efficiency, various patch configurations put forwarded an antenna performance. We interpose the slots on the patch, so as to get an affirmative impact on outcomes. At various stages of design limitations, the illustrated layout model is exhibited and validated. Fig. 2(a), (b), and (c) represent the design limitations at various junctures. Above Fig. 2(a) oulinining the antenna structure that incorporates a simple patch with the partial ground without any slot inserted in it. It resonates at triple-band frequency 8.9 GHz, 13.175 GHz, 17.75 GHz with return loss of -20.8362 dB, -29.8018 dB, -13.9266 dB, with the gain of 2.9046dB, 2.8959 dB, 4.0926 dB and with the radiation efficiency of 84%, 87%, 94% respectively. Also with the insertion of double F Slots in Fig2.(b), causes it to resonate in three frequency bands 8.9 GHz, 13.175 GHz, 17.75 GHz with the better outcomes of return loss -20.5978 dB, -32.5549dB, -13.892dB, gain 2.6291dB, 2.628dB, 4.5043dB and radiation efficiency 81%, 88%, 96%

respectively. In fig 2.(c), by interposing the double F shaped slots with left and right side corner cuts and small slots in the bottom of the patch on the left and right side, the five multiple bands 8.75GHz, 12.05 GHz, 13.325 GHz, 15.275 GHz, 17.975 GHz has been obtained with the return loss of -20.6945, -11.6413, -32.518, -21.2814, -18.8097. Finally, the two slots are included at the left and right bottom of the patch which enhances the antenna characteristics in fig.2(c) that makes it to resonate six multiple bands 8.6181 GHz, 12.3116 GHz, 14.1960 GHz, 15.6281 GHz, 18.1910 GHz, and 18.9447 GHz with the return loss of -23.8361 dB, -32.9380 dB, -146726 dB, -22.2810 dB, -19.0592 dB, -18.8137 dB, gain 2.97 dB, 3.89 dB, 3.06 dB, 5.34 dB, 6.02 dB, 6.37 dB, radiation efficiency 89%, 79%, 84%, 81%, 94%, 92% respectively.

Table.2 Proposed Micro strip Patch Antenna

Patch	Return Loss (S11)	VSWR (dB)	Gain (dB)	Directivity (dB)	Resonant Frequency (GHz)	Radiation Efficiency(%)
Patch with partial ground	-20.8362	1.5821	2.9046	3.6173	8.9	84
	-29.2560		2.8959	3.4587	13.25	87
	-13.8835	0.5622	4.0926	4.3281	17.6	94
Double –F Slotted	-20.5978	1.1026	2.6291	3.4935	8.9	81
	-32.5978		2.6280	3.1822	13.17	88
	-13.8920		4.5043	4.6444	17.75	96
Proposed design	-23.8351	1.1186	2.9757	3.3307	8.6181	89
	-32.9380	0.3918	3.8395	4.8116	12.3116	79
	-14.6726		3.0622	3.6372	14.1960	84
	-22.2810	1.3854	5.3433	6.5220	15.628	81
	-19.0592	1.9440	6.0244	6.3752	18.1910	94
	-18.8137		6.3769	6.9104	18.9447	92

3. Results And Discussion

Figure 3, shows the correlation plots of the simulated return loss curves against frequency for various patch configurations. Return loss specifies the amount of power reflected back. The above figure ensures the course of action of the reduced patch with the partial ground which enhances the antenna to envelop an X and Ku-band range. To upgrade radiation efficiency by reducing the return loss of the antenna, F shapes and rectangular slots are inserted in the patch which covers X band (8– 12 GHz) for radar applications and ku band (12– 18 GHz) for satellite applications. Designed microstrip patch antenna characteristics are shown as follows

3.1 Return Loss of prosed Antenna

When simulated return loss is plotted on Y-axis with respect to the frequency on X-axis, Fig 4 shows that the suggested antenna reveals X and Ku-band behaviors. We minimize the return loss, by interposing double F- shape, the two rectangular slots both left and right sides in the bottom of the patch and corner cuttings, which makes it to resonate six multiple bands 8.6181 GHz, 12.3116 GHz, 14.196 GHz, 15.6281 GHz, 18.1910 GHz, and 18.9447 GHz with the return

loss of -23.8351, -32.9380, -14.6726, -22.2810, -19.0592, and -18.8137 respectively. Thus, the HFSS simulation result confirms that the return loss for the aimed multiband has been attained.

3.2 VSWR of designed antenna

VSWR is an essential requirement for the proper function of the antenna which implies the impedance matching between the source and the feed is optimum. It depicts the pattern and behavior of the antenna. In figure 5, the VSWR investigation has been shown. The VSWR obtained at the favored multiband is 1.11 at frequency 8.61 GHz, 0.39 at frequency 12.31 GHz, and 1.33 at frequency 15.62 GHz, 1.94 at frequency 18.19 GHz respectively. Thus, the proposed antenna is capable of providing the coveted VSWR outcomes.

3.3 Gain of the proposed Antenna

The power radiation in a given direction is revealed by the antenna gain. Figure 6(a), 6(b), 6(c), 6(d), 6(e), 6(f) shows the 3D view of the broadband gain of the designed antenna which varies with respect to the frequency. The achieved gains are 2.9757 dB, 3.8395 dB, 3.0622 dB, 5.3433 dB, 6.0244 dB, 6.3769 dB at the resonated multiband frequency is 8.6181 GHz, 12.3116 GHz, 14.1960 GHz, 15.6281 GHz, 18.1910 GHz, and 18.9447 GHz respectively. The highest attainable gain for the suggested antenna is 6.3769 dB at a frequency of 18.9447 GHz which means the antenna is more efficacious at this frequency, while a low gain of 2.9757 dB at a resonant frequency of 8.6181 GHz which means the antenna is lesser effective at this frequency. The designed antenna exhibits the peak gain of 6.3769 dB is obtained at 18.9447 GHz frequency which makes the antenna advantageous for Satellite communication applications.

3.4 Directivity of the proposed Antenna

Fig (7) shows the directivity of the suggested microstrip patch antenna versus frequency. The potential of an antenna that improves energy in a specific direction when transmitting energy better from a particular direction when receiving such as revealing by directivity. It exhibits 3.3307 dB, 4.8116 dB, 3.6372 dB, 6.5220 dB, 6.3752 dB, and 6.9104 dB at the resonated multiband frequency of 8.6181 GHz, 12.3116 GHz, 14.1960 GHz, 15.6281 GHz, 18.1910 GHz, and 18.9447 GHz respectively. We come to know from the directivity plot that the maximum amount of radiation intensity which is equivalent to 6.9104 dB is attained at a resonant frequency of 18.9447 GHz. Table (4) which is given below reveals the Return loss, VSWR Gain, Directivity, and radiation efficiency for different resonant frequencies of the proposed antenna

Table (4) presents the characteristics of the proposed microstrip patch antenna.

<i>Resonance frequency(GHz)</i>	<i>Return Loss(dB)</i>	<i>VSWR</i>	<i>Gain(dB)</i>	<i>Directivity(dB)</i>	<i>Radiation efficiency (%)</i>
8.6181	-23.8361	1.1186	2.9757	3.3307	89
12.31116	-32.9380	0.3918	3.8395	4.8116	79
14.1960	-14.6726		3.0622	3.6372	84
15.6281	-22.2810	1.3386	5.3433	6.5220	81
18.1910	-19.0592	1.9440	6.0244	6.3752	94
18.9447	-18.8137		6.3769	6.9104	92

3.5 Radiation Pattern

The 3D radiation patterns for the elevation and azimuthal plane respectively of the proposed antenna is illustrated in figures above. The radiation pattern indicates the graphical portrayal of the radiation properties of the antenna as a

function of space. The radiation pattern reports how an antenna causes energy radiation into space and reception.

Table. (5) Comparison of performance of the antenna introduced in previous literature's with the existing work

Published Antenna	Antenna size (mm)	Height (mm)	Ground (mm)	Return Loss (dB)	Maximum Gain (dB)	Resonant Freq [GHz]	Radiation Efficiency%	Applications
Ref.[5]	24x36	1.6	24x20	-21.7911 -33.6083 -23.0760	3.01	4.92 4.99 5.02	-	UWB band
Ref.[6]	30x30	1.6	30x30	-26.85 -16.13	6.27	9 10.35	-	X band
Ref.[7]	30x30	1.6	30x30	-15.92 -14.84	7.5	9 10.14	-	X band
Ref.[8]	20x20	1.6	20x20	-23 -14 -13	5.13	11.3 12.6 12	89.2	X and Ku bands
Ref.[9]	38x35	1.57	34x34	-38 -19 -16 -12	6.4	5.5, 8.5 12.5 20	93	X and ku bands
Proposed Antenna	40x26	1.43	16.2x12.12	-23.83 -32.93 -14.67 -22.28 -19.05 -18.81	6.37	8.61 12.31 14.19 15.62 18.19 18.94	94	X and ku bands

From the above table (5), we come to know that the proposed antenna has similar characteristics which are as per with the already suggested antenna's. Based on the popular microstrip antenna parameters such as size, resonant frequencies, return loss, and radiation efficiency, a fair comparative analysis is presented with the other considered antennas. The antenna performance lies in the X and ku frequency band.

The main focus of our designed antenna is to achieve "Size reduced", "multiband resonant frequencies" and hence can be taken up for multi commercial purposes. This antenna has been profitably executed after numerous modeling and simulations by Ansoft HFSS 13.0 software to get the best solution of the parameters for overall performance. After getting good results from the simulated and measured parameters, the target was achieved.

Conclusions

In this research work, with the insertion of the slots, the effective patch size is marginally reduced but the performance of an antenna is significantly improved which causes multi-band resonant frequencies, very less return loss, and excellent radiation efficiency. The proposed compact rectangular microstrip patch antenna designed with double F Slots, four rectangular slots, side cuttings, and partial ground which covers multiple frequencies range between 8 GHz and 19 GHz which is found to be suitable for X and ku band applications. It is more efficient which achieves 96% efficiency. Due to the high radiation efficiency, ultra-wideband (UWB), reasonable gain, stable radiation pattern, less return loss ensures that the proposed antenna could be more suitable for radar, microwave imaging, satellite wireless communication applications and etc.

Declarations

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Not Applicable

***Conflicts of interest/Competing interests**

Not Applicable

Availability of data and material (data transparency)

Not Applicable

***Code availability (software application or custom code)**

Not Applicable

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Not Applicable

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Figures

Figure 1

Antenna Geometry (a) Microstrip patch without modifications (b) Microstrip Patch with modifications (c) Final design with partial ground

Figure 2

Antenna Modification (a) Simple patch with partial ground (b) Double F-Slots Interposed (c) Interposition of double F-Slots with Corner cuttings and Single slots at right and left side (d) Proposed antenna

Figure 3

Return curves for different patch geometries.

Figure 4

Graph showing Return Loss Vs Frequency

Figure 5

Graph showing VSWR Vs frequency

Figure 6

(a) Gain of proposed antenna at 8.6181 GHz (b) Gain of proposed antenna at 12.3116 GHz (c) Gain of proposed antenna at 14.1960 GHz (d) Gain of proposed antenna at 15.6281 GHz (e) Gain of proposed antenna at 18.1910 GHz (f) Gain of proposed antenna at 18.9447 GHz

Figure 7

Graph showing Directivity of the proposed microstrip patch antenna (a) at 8.6181 GHz (b) at 12.3116 GHz (c) at 14.1960 GHz (d) at 15.6281 GHz (e) at 18.1910 GHz (f) at 18.9447 GHz

Figure 8

Radiation pattern in 3D of proposed patch antenna, (a) At 8.6181 GHz, (b) At 12.3116 GHz, (c) At 14.196 GHz, (d) At 15.6281 GHz, (e) At 18.1910 GHz, (f) At 18.9447 GHz.