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U-SLOT MULTIBAND ANTENNA WITH PRUNED EDGES FOR WLAN, WI-MAX, X AND KU BAND APPLICATIONS

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Abstract

In this paper a novel planar micro-strip antenna is presented for quad band applications. The antenna structure is composed of symmetrically step slotted (pruned) rectangular patch at the right and left edges with a U-slot etched inside the patch along with a partial ground to achieve multiband operation. The proposed antenna is simulated on an FR-4 substrate of dielectric constant of 4.3, loss tangent 0.02 and 50Ω micro-strip feed line. The simulation and optimization results are carried out using CST software 2014. The antenna topology occupies an area of 23×22×1.5mm^3. The antenna operates at four different resonant frequencies 2.5GHz (2.36GHz-2.70GHz), 5.1GHz (4.85GHz-5.33GHz), 9.95GHz (9.64GHz-10.31GHz) and 14.6GHz (13.83GHz-15.89GHz) which meet the requirements of the Wi-Max, WLAN, X-band and Ku-band. The impedance bandwidths are 13.49%, 9.4%, 6.64% and 14.07% for the 2.5GHz, 5.1GHz, 9.95GHz and 14.6GHz bands respectively. The antenna shows good return loss, VSWR and radiation pattern characteristics in the desired frequency range.

Keywords:

Quad Band, Wi-Max, WLAN, Ku-Band, VSWR

1. INTRODUCTION

Rapid developments in the wireless communication require novel antenna designs with more than one frequency band to integrate multiple wireless communication systems [1]. For multiband operations micro-strip antennas are most suitable due their low profile, low cost, light weight, ease in fabrication and integration with different circuits. The micro-strip antenna should operate for more than one band to save space and cost of the system. Several dual-, tri-band and quad band antennas have been explored [2]-[7]. These antennas can be used for multi-functional systems in wireless communication applications like RADAR, Satellite, mobile phones, computers and many more.

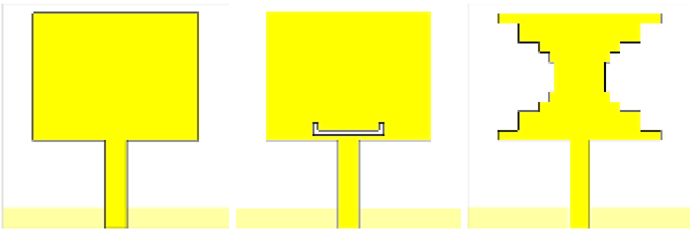
Antenna parameters like radiation intensity, return loss, directivity significantly depends upon the geometry, dimensions and type of dielectric substrate used [8]. A number of micro-strip antennas with different geometries have been presented to reduce the size for WLAN/Wi-Max applications. The fork shape antenna [9], tree house shape design [10] and antenna with multiple slots in patch [11] results in different geometric manipulation to achieve multi band performance which makes geometry complex and difficult to fabricate. The size of antenna is another important factor as an antenna design should occupy less space. Nowadays with accelerating popularity of hand held and portable gadgets compact antennas are major design concern. Employing high dielectric constant substrates results in size reduction but it shows narrow bandwidth. Different multiband antenna have been implemented which are large in size as compared to the proposed antenna thus acquiring large spaces. In [12] antenna with E-shaped stubs has overall dimensions of 47×45.5×0.76mm^3 for WLAN, Wi-Max and GSM. In [13] it uses L-slots in patch and have dimensions 47mm×48mm×0.8mm while [14] presented antenna design with slots and spur lines with size of 40mm×30mm×0.508mm to achieve more than one resonant frequency.

In order to generate multiple bands, half- wavelength ring resonators with defected ground is realized in [15] while two U shaped parasitic elements near patch is used in [16]. In [17] the antenna consists of two upright chairs like shaped slots of the same size that are etched on a rectangular patch to achieve multiband operation along with a defected ground plane. This paper explains the design of novel quad band rectangular micro-strip antenna. It occupies an area of 23×22×1.5mm^3. The proposed antenna consists of simple shape and geometry and is also compact in size in comparison to antennas reported in same frequency ranges [18] [19] which is highly desired for WLAN and Wi-Max communication standards.

The proposed antenna details are organized as following sections. Section 2 elaborates antenna design, section 3 provides parametric analysis and results detailing, section 4 shows measured result and finally topic is concluded in section 5.

2. DESIGN OF PROPOSED ANTENNA

The design consists of modified structure of a conventional rectangular patch antenna with stepped slots added symmetrically at left and right sides of radiating patch and a U-slot etched just above the 50Ω feed line. In order to improve the impedance bandwidth and radiation characteristics and to minimize the size of conventional rectangular antenna, stepped cuts at left and right edges are added to the radiating patch. The steps in the design process of proposed multiband antenna is shown in the Fig.1(a)-Fig.1(c). The Fig.1(a) shows conventional rectangular patch, rectangular patch with a U-slot inserted just above the feed line in Fig.1(b) and a step slotted patch at the radiating edges in Fig.1(c).



(a) (b) (c)

Fig.1(a). Simple rectangular antenna (b) rectangular patch with U-slot (c) antenna with stepped slots

As shown in Fig.2, for the proposed antenna configuration, the conventional rectangular monopole can provide the fundamental resonant band at 2.5GHz and a wideband at around

13.8GHz-17.5GHz. It is found that by incorporating steps symmetrically at right and left edges of the radiator patch, additional resonance frequency at 5.1GHz is excited with modified wideband of conventional patch. Hence much wider impedance bandwidth with multi-resonance characteristics can be achieved, especially at the higher band. The insertion of U-slot on the other hand generates an additional resonance band at 9.95GHz besides 2.5GHz band and modified wideband generated by conventional patch.

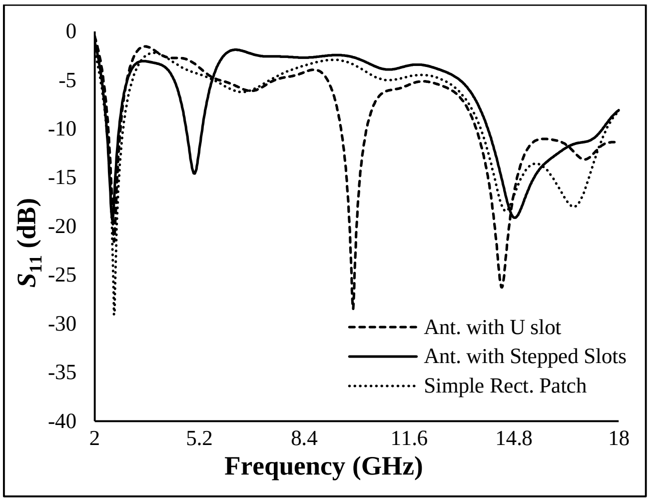


Fig.2. Comparison of return loss for different antenna designs

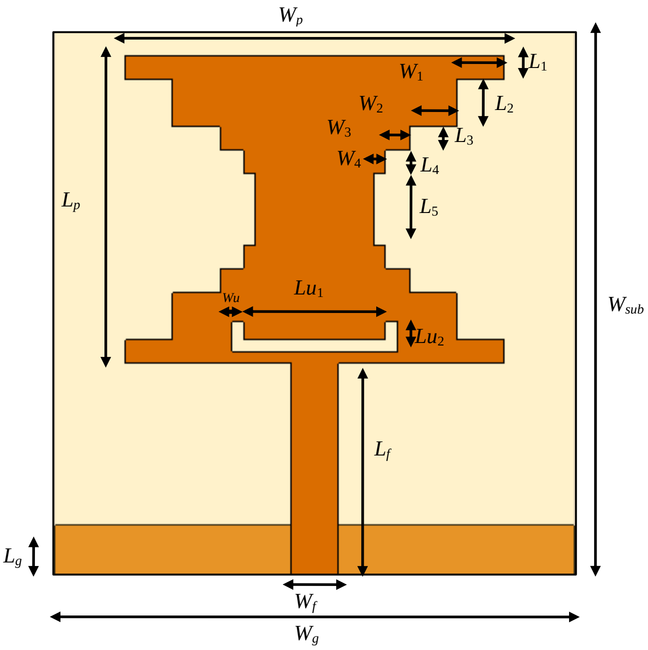


Fig.3. Front view of proposed antenna

The radiating patch has a length L_p and a width W_p. The W_f and L_f are the width and length of the feed line, which connect the patch with SMA connector. On the other side of the substrate, a conducting partial ground plane is placed. The dimensions of the partial ground plane are width W_g and length W_g. The width of U-slot is W_u and total length is given by ($Lu_1 + 2Lu_2$) (see Fig.3). The width of the micro-strip feed line is fixed at 2 mm. The antenna is printed on a 23×22×1.5mm^3. The parameters are optimized for optimal antenna performance [20] (Table.1).

Table.1. Parameters of proposed quad band antenna

Parameter	Value (mm)
L_g	2.15
W_g	22
L_{sub}	23
W_{sub}	22
T_{sub}	1.5
L_f	9
W_f	2
L_p	13
W_p	16
L_1	1
W_1	2
L_2	2
W_2	2
L_3	1
W_3	1
L_4	1
W_4	0.5
L_5	3
Lu_1	6
Lu_2	1.25
W_u	0.5

3. RESULTS AND DISCUSSIONS

This section presents the performance results of the proposed antenna at WLAN, Wi-max, X band and Ku band communication system frequencies at 2.5GHz, 5.1GHz, 9.95GHz and 14.6GHz. The performance results such as return loss, VSWR, surface current density and radiation pattern at the desired frequencies are analyzed.

3.1 OPTIMUM RETURN LOSS (PARAMETRIC ANALYSIS)

It has been noticed in the simulation that the operating bandwidth and resonant frequencies of the antenna is dependent on the length (Lu_2) of U slot. So these parameters have to be optimized for optimum return loss for proposed antenna. After parametric analysis we obtain the optimum return loss for the proposed antenna.

3.1.1 Effect of Length Lu_2 of U-Slot:

Major shift in frequency is seen for third resonant band when we vary the length Lu_2. As we increase the parameter Lu_2, the third resonant band is shifted towards lower frequencies. On varying the length of U-slot, the return loss shifts downwards to a more negative value for the fourth resonant frequency. There are minor variations for the first and second resonant frequency bands. So for optimum value of Lu_2 = 1.25mm, the third resonant frequency is 9.95GHz that is in X band.

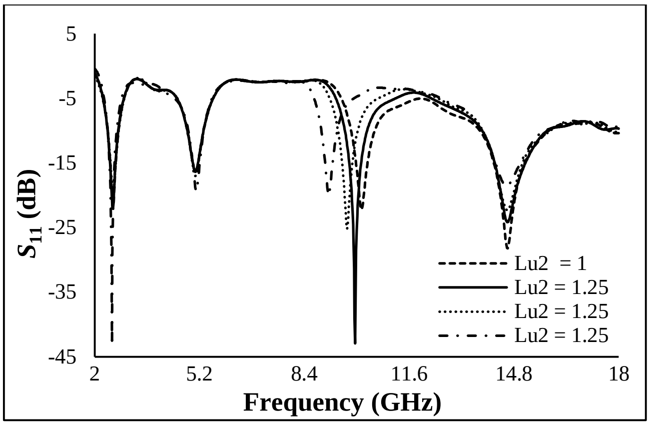


Fig.4. Effect of length Lu_2 of U-slot on Return Loss

3.1.2 *Effect of Width W_u of U-Slot*:

The increase in width W_u results in downward movement of S_{11} towards more negative value for third resonant band (Fig.5). Minor frequency shift towards lower frequencies for fourth frequency band while there are almost no variations for first and second resonant frequency bands on varying width of U-slot. So the optimum value of W_u = 0.5mm for which third resonant frequency is 9.95GHz. Hence there is no major influence of width of U-slot on return loss.

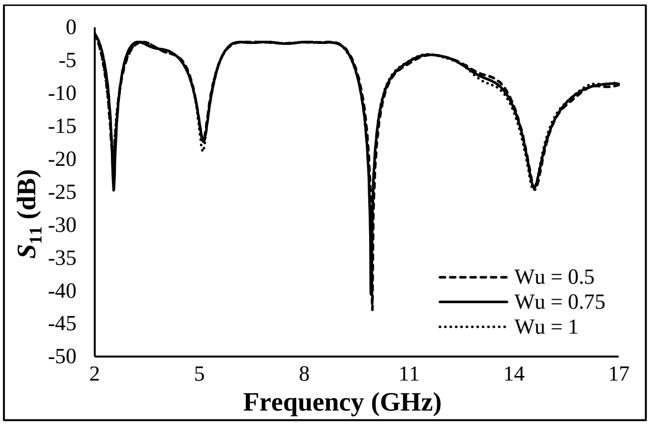


Fig.5. Effect of width W_u of U-slot on Return loss

The results of the parametric studies indicate that third resonant frequency depends most strongly on the length Lu_2 of the U-slot. After parametric analysis the optimum values for S_{11} are -20dB, -17.28dB, -42.9dB and -24.6dB for resonant frequencies 2.5GHz, 5.1GHz, 9.95GHz and 14.6GHz respectively as can be seen in Fig.6.

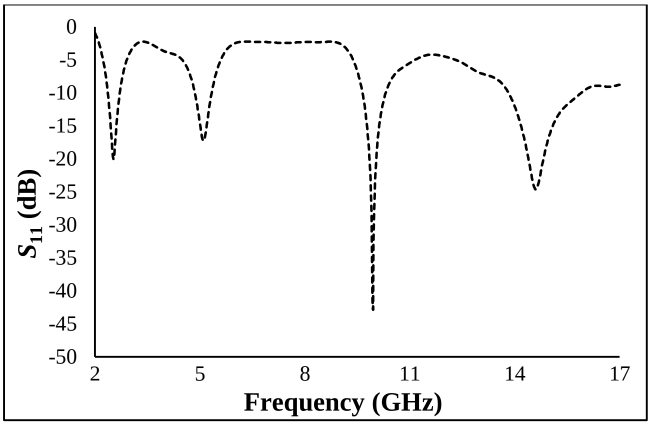


Fig.6. Return Loss of proposed antenna

3.2 VOLTAGE STANDING WAVE RATIO

The value of VSWR < 1.5 for all the four resonant frequencies resulting in less reflection and provides adequate matching.

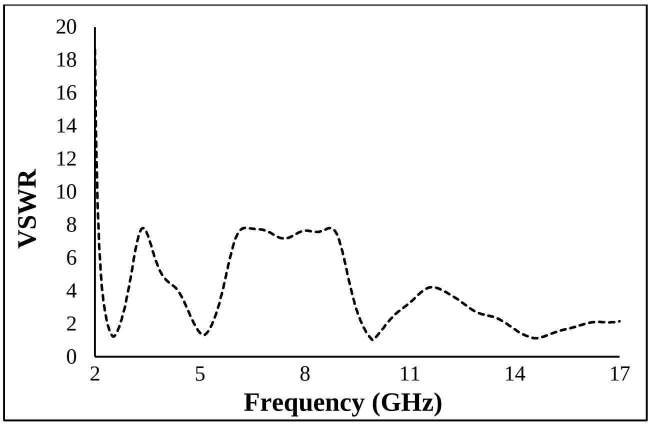
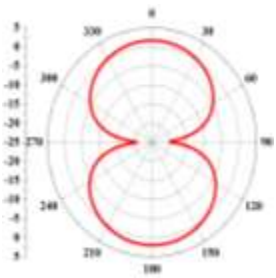


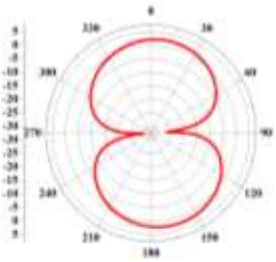
Fig.7. VSWR for proposed antenna

3.3 RADIATION PATTERN

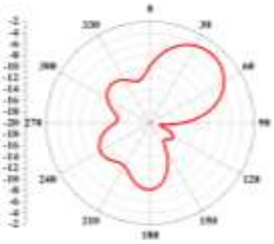
Radiation fields show bidirectional patterns for the first two lower frequencies of 2.5GHz and 5.1GHz. The next two higher center frequencies of 9.95GHz and 14.6GHz exhibit directional far field patterns with 3dB bandwidths of 55.5° and 46.5°, respectively. The Fig.8(a)-Fig.8(d) shows radiation patterns in polar form while Fig.9(a)-Fig.9(d) shows them in 3D form.



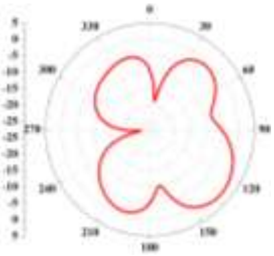
(a) *f* = 2.5GHz



(b) *f* = 5.1GHz

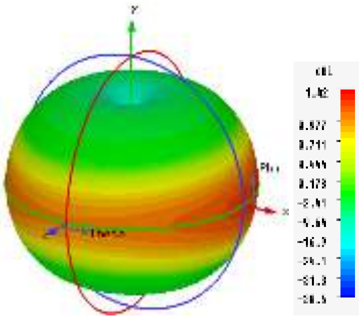


(c) *f* = 9.95GHz

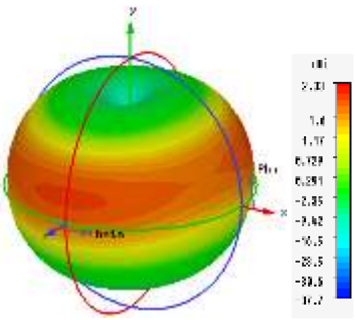


(d) *f* = 14.6GHz

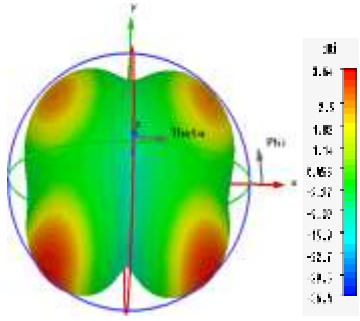
Fig.8. Radiation pattern in polar form



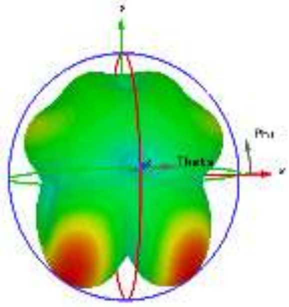
(a) *f* = 2.5GHz



(b) *f* = 5.1GHz



(c) *f* = 9.95GHz

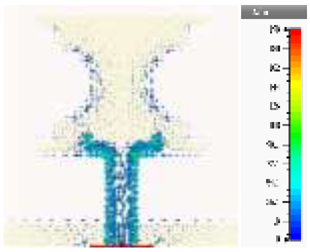


(d) *f* = 14.6GHz

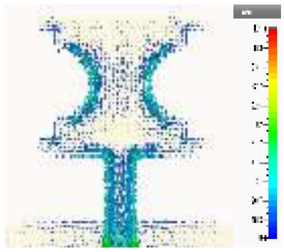
Fig.9. 3D Radiation pattern

3.4 SURFACE CURRENT DENSITY

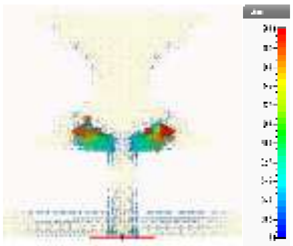
Among the four resonant bands 2.5GHz and 14.6GHz are the lowest and highest operating frequencies of the proposed antenna respectively. We can see, the currents at 5.1GHz mostly concentrate on the slots at left and right sides of patch which clearly indicates that these stepped slots generate the second resonant frequency at 5.1GHz together. The third resonance frequency is generated by insertion of a U-slot on the patch thus leading to multiband behavior. The inner length of the U-slot is about half the wavelength of the 9.95GHz resonant frequency, which is established in [21]. The surface currents for the four resonant frequencies can be seen in the Fig.10(a)-Fig.10(d).



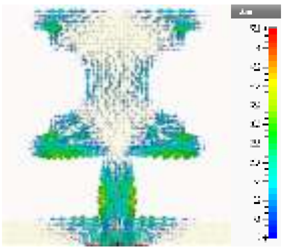
(a) *f* = 2.5GHz



(b) *f* = 5.1GHz



(c) f = 9.95GHz



(d) f = 14.6GHz

Fig.10. Surface current density

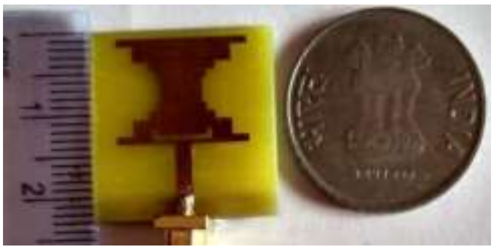
The summarized simulated parameters are given in Table.2 in terms of -10dB bandwidth, fractional bandwidth (FBW) and designed antenna applications.

Table.2. Simulated and measured parameters of the proposed antenna

Antenna Parameter	Resonance Frequency (GHz)	-10dB BW (GHz)	FWB (%)	Application
Proposed Antenna	2.5	2.36-2.70	13.49	Wi-Max
	5.1	4.85-5.33	9.4	WLAN
	9.95	9.64-10.31	6.64	X band
	14.6	13.8-15.9	14.07	Ku band

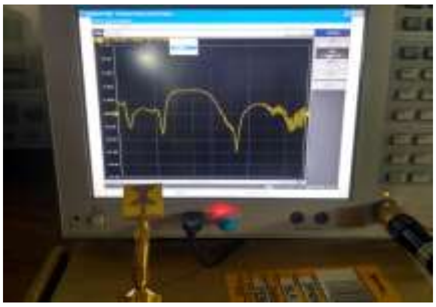
4. MEASURED RESULTS

The fabricated antenna was tested by connecting the SMA connector to a Vector Network Analyzer to measure the S_{11} for different frequencies falling within the antenna's range.



(a)

(b)



(c)

Fig.11. Fabricated multiband antenna: (a) Front view (b) Back view (c) VNA setup for measurement

Reasonable agreement was obtained between the simulated and experimental results. The discrepancies between simulated and measured results are due to the fabrication tolerance of the fabricated antenna prototypes. The Fig.11 shows the measured and simulated return loss of the quad band antenna.

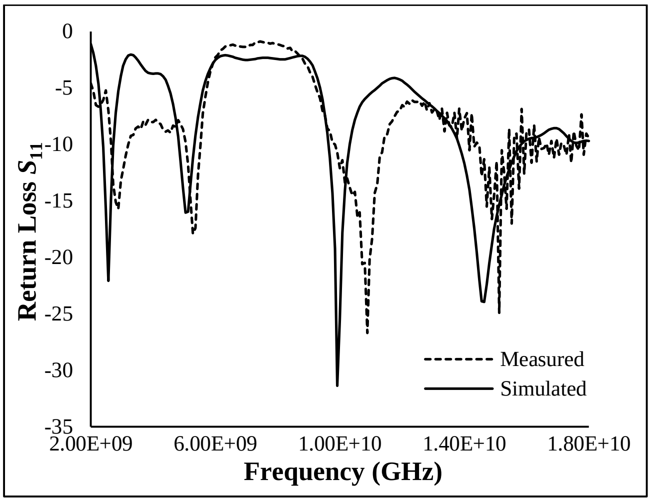


Fig.12. Comparison of simulated and measured return loss of designed antenna

The comparative study between the proposed antenna and reported antennas is tabulated in Table.3.

Table.3. Comparative performance analysis of proposed antenna with existing antennas

Methods	Antenna Size (mm^2)	Frequency Band (GHz)	Applications
[9]	45×45×1.575	3.3 - 3.69	Wi-Max
		5.15 - 5.2	WLAN
[10]	30×32×1.6	2.06, 10.92, 16.30, 24.24	NA
[12]	47×45.5×0.76	0.8 - 1.037	GSM
		3.459 - 3.549	Wi-Max
		2.329 - 2.575 4.93 - 5.64	IEEE 802.11b and 802.11g IEEE 802.11a (WLAN)

[13]	47×48×0.8	0.93 - 0.98	NA
		2.18 - 2.27	
		3.29 - 3.42	
		4.85 - 4.94	
[14]	40×30×0.508	2.63 - 3.3	WLAN Wi-Max
		3.3 - 3.72	
		3.96 - 4.58	
		5.29 - 5.43	
[15]	30.5×30×1.6	3.80 - 3.90 4.10 - 5.20 11.2 - 11.5 12.5 - 14.0	WLAN
			Wi-Max
			C
			Ku

5. CONCLUSION

In this paper, a compact structure of multiband microstrip antenna is presented. To realize multiband characteristics, a U-slot is etched on a rectangular patch with its right and left edges slotted in stepwise manner on both sides symmetrically. The values of return loss are -20dB, -17.28dB, -42.9dB and -24.6dB respectively. X-band frequencies have an advantage that is less affected by rain. Printed microstrip slot antennas are not only used extensively for radar and satellite applications but the popular wireless applications**.** Hence it can be concluded that antenna has compact size and simple geometry that generates satisfactory values for return loss (S_{11} < -10dB) and good radiation features in multiband category.

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