Design of Modified Patch Antenna Using Inverted U-Slot and L-slot for X, Ku and K-Band Applications

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***Abstract*—This paper presents the design of microstrip patch antenna for multiband applications. The designed antenna can be used for X, Ku and K band applications. The multiband antenna is achieved by cutting U and L slots in the rectangular patch. The designed antenna has width of the patch, W_p= 49.4mm and length of the patch, L_p = 41.4mm. Taconic TLY-5 dielectric substrate is used as a substrate layer which has dielectric constant of 2.2 and height of dielectric substrate is 1.6mm. The advantages of the resultant configurations are a) design is simple b) Inset feed is used for proper impedance matching c) the structure remains single layer and single patch. The designed antenna can be used for number of applications like in X-band it can be used for military communication and wideband global satellite communication systems (WGS), for Ku-band it can be used for terrestrial microwave and radar, specially police traffic speed-detector and for K-band it can be used in airport surface detection equipment (ASDE). The antenna is designed and simulated using Agilent's ADS (Advanced Design System) 2009.**

Keywords—Multiband,Uslot,Lslot,Inset feed,X-band,Ku-Band, K-Band,PIFA

I. INTRODUCTION

Many a times systems such as satellite, GPS(Global Positioning System), Galileo ,Radar need to be operated at different frequencies apart too far from each other. So the design of small antenna suitable for multiband operation is of great interest and microstrip patch antenna can be designed as multiband antenna using number of techniques [1][2].Microstrip patch antenna having numerous advantages like small size, lower weight , lower cost, ease of installation and aerodynamic profiles which enables it to use in high performance air craft, satellite and missile applications [3].However conventional microstrip patch antennas have some limitations also such as narrow bandwidth, lower gain, large ohmic losses and polarisation purity which is difficult to achieve[4]. Many researchers have worked and presented the techniques for getting multiband operation using multistack patches [5]. Using U-slot loaded patch stacked with H-shaped parasitic elements [6]. In [7] an annular ring patch is loaded with a slot, where the loaded slot makes the design capable for dual band operation. Two asymmetric horizontal strips are used as additional resonator to produce the lower and upper resonant modes [8]. Although U-slot patch antenna is used is concerned with broadband capabilities, however since the U-slot introduces another resonance; a dual band antenna can be obtained, to obtain triple band a second slot is needed [9]. Multi frequency operation can also be achieved using spiral printed antennas, Bowtie patches loaded with slots, multiple patches, cutting rectangular patch with L-shaped slit, U-slot and inserting slits [1][2][10][11]. PIFA (planar inverted F structures antenna) structures can be used for multiband applications [12]. Dual frequency operation in Ku band is achieved loading notches and slits in antenna patch [13]. In [14] new design technique of microstrip patch antenna with E-slot and a slot at the edge of radiator is presented for Wi-Max applications. The goal of this paper is to design a single layer multi band antenna which can work for X, Ku and K-band. Firstly single layer rectangular patch antenna is designed for ISM band and then to obtain the multi frequency operation a U-slot and two L-slots are etched on the patch. The purposed single layer multi band antenna uses inset feed and operating at seven different frequencies in X, Ku and K bands. The main applications of X, K and Ku bands are radar, high performance aircrafts, spacecrafts and satellite based communications systems.

II. ANTENNA MODEL

Primarily the microstrip patch antenna has 3 layers namely i) metallic layer as a radiating element ii) dielectric substrate iii) metallic layer as a ground plane. The rectangular patch antenna is made onto Taconic TLY-5 dielectric substrate which has dielectric constant of 2.2 and height of dielectric substrate is 1.6mm. The Width and length of the patch is 49.4mm and 41.4mm respectively. Here the Agilent's ADS (advanced design system) 2009 is used to design and simulate the antenna. For an efficient radiation the practical width of the rectangular patch becomes [3] [4]

$$W_p = \frac{1}{2fr\sqrt{\varepsilon_0\mu_0}} \times \sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

and the length of the rectangular patch becomes [3][4]

$$L_p = \frac{1}{2fr\sqrt{\varepsilon_{eff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L_p \qquad (2)$$

Where

$$\Delta L_p = 0.41h\,\frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258} \times \frac{\frac{W_p}{h} + 0.264}{\frac{W_p}{h} + 0.8} \qquad (3)$$

And

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12\frac{h}{W_p}}} \qquad (4)$$

Generally in Microstrip patch antenna feed line impedance is 50 ohm as compare to the radiation resistance of the patch at edge, which is of few hundred ohm depending on the patch dimension and substrate used. The performance of the antenna is affected due to this mismatch since the maximum power is not being transmitted .The typical method of achieving such an antenna is using an inset feed [15]. The inset feed distance Y_0 can be calculated such that feeding edge of the antenna can be matched to the characteristic impedance of the transmission line. The input resistance for the inset fed patch is given by [3]

$$R_{in}\,(Y = Y_0) = \frac{1}{2(G_1 \pm G_{12})} Cos^2\left(\frac{\pi}{L} Y_0\right) \qquad (5)$$

Where

$$G_1 = \frac{1}{90}\left(\frac{W_p^{\,2}}{\lambda_0^{\,2}}\right) \qquad W_p << \lambda_0 \qquad (6)$$

And

G_{12} is mutual inductance which is negligible with respect to G_1 for microstrip patch antenna.

Where f_r (in Hz) is resonant frequency, λ_0 is the wavelength, h (in mm) is the height of the substrate, ε_r is relative dielectric constant, W_p and L_p are the width and length of the patch in mm respectively.

III. ANTENNA DESIGN

Firstly a simple ISM band antenna is designed by selecting 2.4 GHz frequency. The dimensions of the antenna are calculated using equations 1 to 6 and can be viewed in Table 2. also. The input impedance can be reduced if the patch was fed closer to the center. One method of doing this is by using an Inset feed, so we have used the Inset feed to feed the antenna. The antenna is designed and simulated using Agilent's ADS (Advanced Design System) 2009. The designed antenna is shown in figure 1.It radiates in ISM band with return loss of - 46dB. The simulated return loss is shown in figure 2. in which it can be clearly seen that it radiates on 2.4 GHz frequency. The current distribution which shows the average strength of the current for purposed rectangular patch antenna is shown in figure 3. And hence this particular antenna can be used for ISM band applications. The optimized antenna parameters for this ISM band are shown in Table 1.

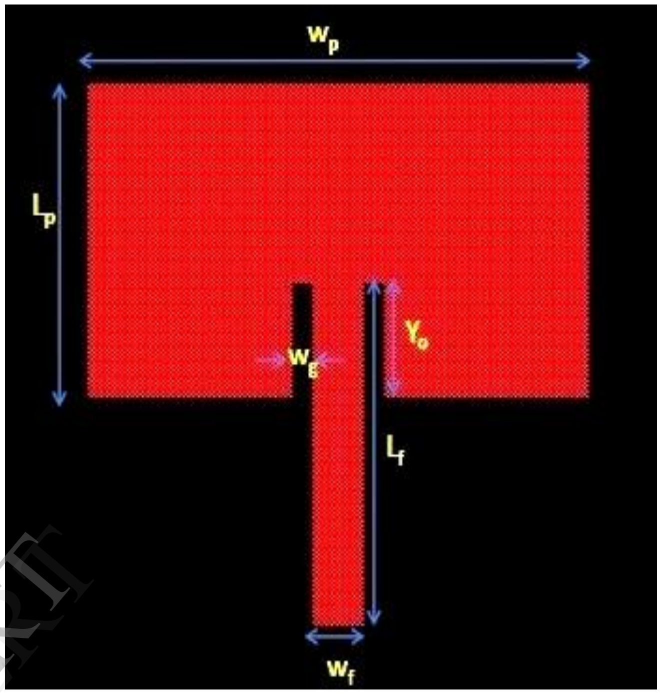

Figure 1. Purposed rectangular patch antenna

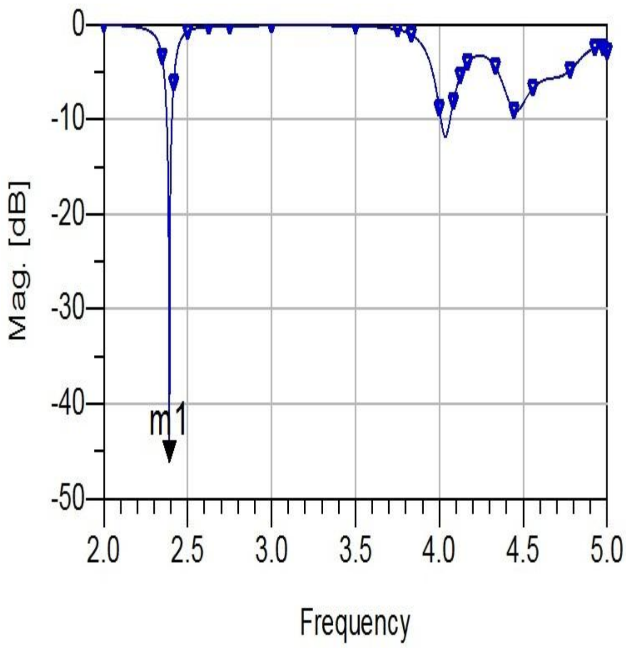

Figure 2.Return loss of purposed rectangular patch antenna

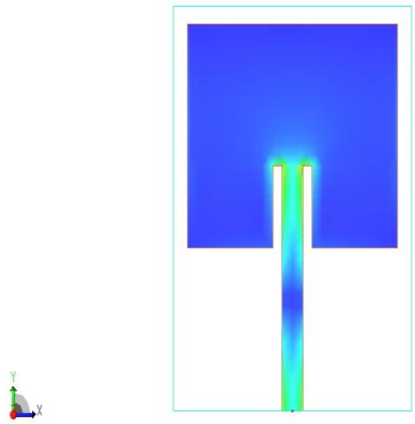

Figure 3. Current distribution in colour showing the average strength of the current for purposed rectangular patch antenna.

Table 1. Antenna parameters for the puposed rectangular patch antenna

Performance Parameter	Value
Power Radiated (Watts)	0.0488667
Effective Angle (Steradians)	2.00162
Directivity (dB)	7.97828
Gain (dB)	7.58269
Maximum intensity (Watts/Steradians)	0.0244136

A. Modifications in the purposed rectangular patch antenna to get multiband antenna.

Now to get the multiband operation from this purposed rectangular patch antenna we have cut the U-slot and two L-slots of particular dimension on the patch as described in Table 2. The Overall dimensions of this modified rectangular patch antenna are shown in Table 2.

Table 2. Detailed dimensions of the modified rectangular patch antenna.

Parameter	Dimensions (mm)	Parameter	Dimensions (mm)
W_P	49.4	Y_o	15.1
L_P	41.4	d	2
h	1.6	W_u	31.2
W_f	5	L_u	9.1
L_f	45.3	W_l	11.1
W_g	2	L_l	9.1

Firstly inverted U-slot is etched on the patch and then two L-slots are etched on the upper part of the patch to both left and right corner. These etched slots introduce other resonant frequencies so by choosing their dimensions appropriately a multiband antenna can be designed [9]. The introduction of the slots in the proposed design also improves the return loss properties of the antenna as they changed the effective length and width of the antenna so resonant frequency of the antenna was also changed. These slots also change the patch antenna's shape and it acts as compact patch. This modified rectangular patch antenna with U-slot and L-slots is as shown in figure 4.

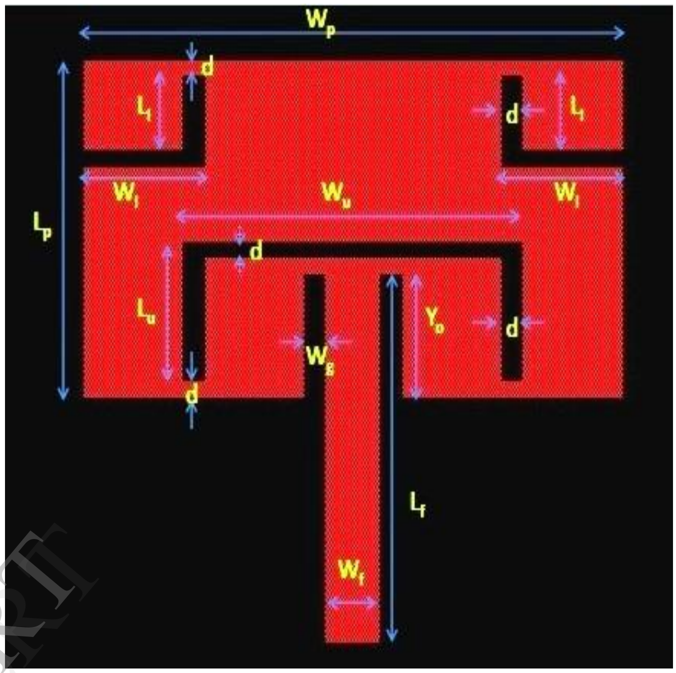

Figure 4. Modied Rectangular Patch antenna

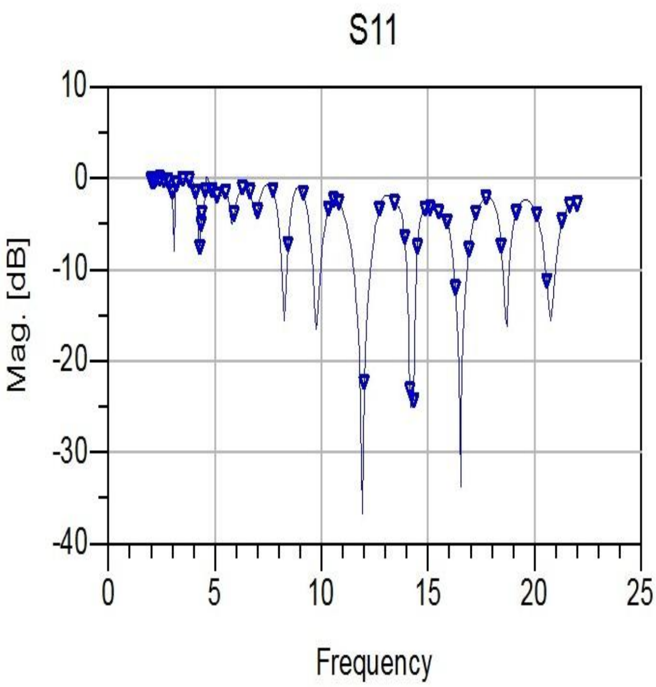

Figure 5. Return loss of the Modified Rectangular Patch antenna

The simulation process of this modified rectangular patch antenna is carried out using Agilent's ADS 2009.
From the simulation it is found that it resonates on seven different frequencies which are in X, Ku and K bands. For X-band it resonates on 8.25 GHz and 9.73 GHz with return loss of -15.604 dB and -16.514 dB respectively. For Ku-band it resonates on 11.93 GHz, 14.19 GHz and 16.52 GHz with the return loss of -36.738 dB, -25.036 dB and -33.755 dB respectively. For K-band it resonates on 18.7 GHz and 20.75 GHz with the return loss of -16.282 dB and -15.557 dB respectively. The simulated return loss for this modified rectangular patch antenna is shown in figure 5.The current distribution which shows the average strength of the current of this modified antenna is also shown in figure 6. The optimised antenna parameters are shown in table 4.

Table 3. Antenna Parameters for Modified Rectangular patch antenna

Performance Parameter	Value
Power Radiated (Watts)	0.00168554
Effective Angle(Steradians)	2.32783
Directivity (dB)	7.32258
Gain (dB)	6.17558
Maximum intensity (Watts/Steradians)	0.00072408

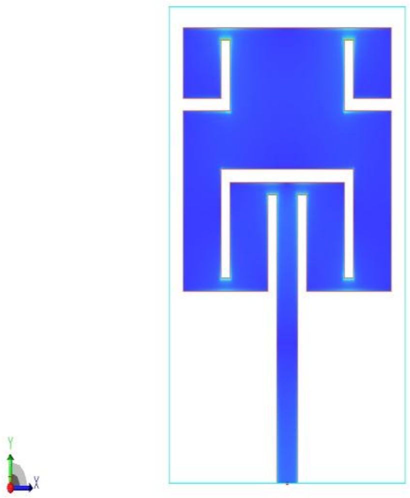

Figure 6. Current distribution in colour showing the average strength of the current for modified rectangular patch antenna.

IV. RESULTS AND DISSCUSSIONS

This modified rectangular patch antenna resonates in X, Ku and K band and its overall characteristics can be seen in Table 4. with return loss at each frequency. It also shows that there are seven resonant frequencies out of which two are falling in X-band, three in Ku-band and two in K-band. The return at various frequencies in X, Ku and K bands shows that the most of the power is radiated and only a liitle amount of power is reflected back, which means that designed antenna can be efficiently used in X, Ku and in K band.The multiband operation is achieved using slotting technique and we have used the U-slot and two L-slots in the patch.By choosing appropriate dimesnsions of the slots and thier postion we have got the good results for X, Ku and K bands.The various applications of this antenna in X-band are that, it antenna can be used in maritime civil and military navigation radars.This can also be used in X-band for spaceborne or airborne imaging radars based on synthetic aperture radar (SAR) both for military electronic intelligence and civil geographic mapping. Ku-band which is very popular in Europe has uplink frequency of 14 GHz and downlink frequency of 10.9 - 12.75 GHz. As our antenna is radiating for both the frequencies bands so can be used for uplink as well as for downlink in Ku band. Ku band has main applications in satellite communications, terrestrial microwave communications, and radar, especially police traffic-speed detectors. Ku band also used for consumer direct -to- home access and for distance learning applications. This multiband antenna can also be used for K –band, the radar applications for this band provides short range and very high resolution. In air traffic management (ATM) these radar sets are called surface movement radar (SMR) or air surface detection equipment (ASDE).

Table 4. Overall Characteristics of the Modified antenna

Compact Patch Antenna	Operating Frequency (GHz)	Simulated Return Loss (dB)
For X Band	8.25	-15.604
	9.73	-16.514
For Ku band	11.93	-36.738
	14.19	-25.036
	16.52	-33.755
For K band	18.7	-16.282
	20.75	-15.557

V. CONCLUSIONS AND FUTURE WORK

The presented design demostrates the use of U-slot and L-slot to get the multiband operation of rectangular patch antenna.The position of the slots and dimension are choosen to get the desired results. The inset feed which is place closer to the center has served the purpose of reducing input impedance. This modified rectangular patch antenna can be used for X, Ku and K band applications. It fulfills the demands of applications such as radar, satellite communications systems, high performance aircrafts, synthetic aperture radar (SAR), air surface detection equipment (ASDE) and some modern communications systems which require the antennas with multi-frequency operation modes. This modified rectangular patch antenna has seven resonant frequencies as 8.25 GHz, 9.7 GHz, 11.93 GHz, 14.19 GHz, 16.52 GHz, 18.7 GHz and 20.75 GHz, which falls in X, Ku and K bands. In future by using metamaterials which have negative electric permittivity can improve the antenna performance significantly. Metamaterial based antennas can demonstrate improved efficiency-bandwidth performance. Metamaterials employed in the ground plane surrounding antennas offers improved isolation between radio frequency or microwave channels of MIMO (multiple-input multiple-output) antenna arrays.

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