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Double U-Shaped Slots Loaded Stacked Patch Antenna for Multiband Operation

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Abstract

The design of a seven-band stacked patch antenna for the C, X and Ku band is presented. The antenna consists of an H-slot loaded fed patch, stacked with dual U-slot loaded rectangular patch to generate the seven frequency bands. The total size of the antenna is 39.25 × 29.25 mm^2. The multiband stacked patch antenna is studied and designed using IE3D simulator. For verification of simulation results, the antenna is analyzed by circuit theory concept. The simulated return loss, radiation pattern and gain are presented. Simulated results show that the antenna can be designed to cover the frequency bands from (4.24 GHz to 4.50 GHz, 5.02 GHz to 5.25 GHz) in C-band application, (7.84 GHz to 8.23 GHz) in X-band and (12.16 GHz to 12.35 GHz, 14.25 GHz to 14.76 GHz, 15.25 GHz to 15.51 GHz, 17.52 GHz to 17.86 GHz) in Ku band applications. The bandwidths of each band of the proposed antenna are 5.9%, 4.5%, 4.83%, 2.36%, 3.53%, 1.68% and 1.91%. Similarly the gains of the proposed band are 2.80 dBi, 4.39 dBi, 4.54 dBi, 10.26 dBi, 8.36 dBi and 9.91 dBi, respectively.

Keywords

H-Shape Fed Patch, Microstrip Patch Antenna, Double U-Shape Slot Loaded Stacked Patch, Multiband Antenna

1. Introduction

Antenna is a very important component of communication system. The enormous growth of mobile and satellite communication systems along with wonderful use of radars opens a huge demand to new kind of antennas such as small antennas, multi frequency antennas, and broadband antennas [1]-[3]. Planar multi-resonators and stacked microstrip patch antenna techniques are combined to yield a wide bandwidth and higher gain. Several two-layered

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configurations have been discussed in [4]-[6], in which only a single patch on the bottom layer is fed by a coaxial probe and second patch on the top layer and both are electromagnetically coupled to each other. Multi-band or reconfigurable antennas are suitable candidates for providing multi-functionality. This will result in significant reductions in antenna size and cost. The primary advantage of the proposed multiband antenna lies in its ability to support two separate applications at two different frequency bands with distinctly different radiation patterns, gain and polarization characteristics using a single radiating aperture [7]. Although multi-band antennas have the capability of serving multiple frequency bands with one antenna, they are considered a weak choice in comparison to reconfigurable antennas because of crosstalk from the neighbor bands. In [8], we have to see that the multiband antenna can be obtained by using of slot couple technique in multiple patches. In 2012, M. A. Motin, *et al*. [9], presented the multiband microstrip patch antenna for X, K and Ku band application. In 2014, Jianxing Li *et al.* [10], represented the multiband probe-fed stacked patch antenna for GNSS application.

In the present paper, a multiband microstrip stacked patch antenna is introduced. The proposed structure is a planar structure having all the dimensions in mm. The proposed antenna is designed by using a substrate of FR4 having thickness 1.6 mm. This proposed antenna is having seven bands of operation. The entire investigation is based on equivalent circuit model. In [11], it represents the multi-band antenna by using stacked patch with multi-slot loaded patch, which can be compared to the proposed design. The co-axial feed technique is used for the analysis of this antenna because it occupies less space and has low spurious radiation by using Teflon connector. The proposed antenna design can be used in mobile communication, radar and satellite communication. Details of the antenna are given in the next stage.

2. Antenna Design and Theoretical Considerations

The design of the proposed multiband antenna is depicted in **Figure 1**. The upper patch is double U-shaped slot loaded stacked patch and the lower patch is the H-slot loaded fed patch. Due to the presence of the stacked patch antenna, there are two resonances associated with the two resonators [12].

Microstrip patch with a dielectric cover is considered as a single patch with a semi-infinite superstore with relative permittivity equal to unity and the single relative dielectric constant (ε_k) given as:

$$\varepsilon_k = \frac{2\varepsilon_{eff} - 1 + p}{1 + p}$$

where

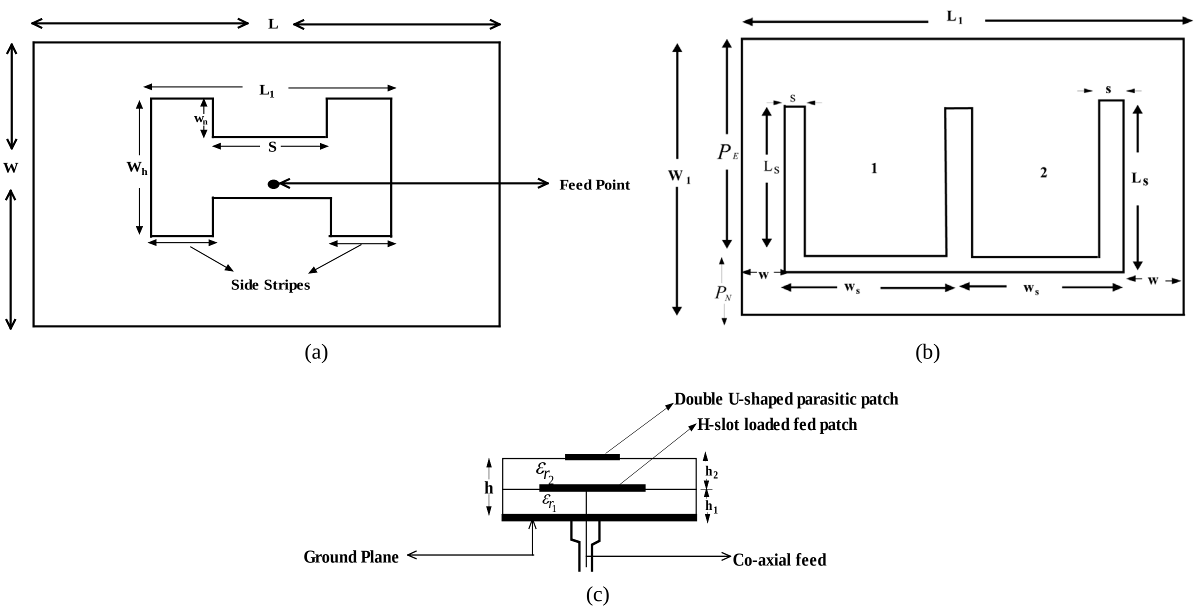

Figure 1. Configuration of stacked patch antenna. (a) H-slot loaded fed patch; (b) Double U-shaped slots loaded parasitic patch; (c) Side view of the proposed antenna.

$$p = 1 + \frac{10h_1}{W_e}$$

in which W_e is the effective width and ε_{eff} is the effective dielectric constant of the structure [13]. The effective dielectric constant of the lower patch is given as

$$\varepsilon_{e_1} = \frac{\varepsilon_k + 1}{2} + \frac{\varepsilon_k + 1}{2}\left(1 + \frac{12h_1}{W}\right) \quad (1)$$

where,

h_1 = height between ground plane and lower patch;

W = width of the patch.

The equivalent circuit of the simple patch antenna is parallel combination of resistance (R_1), inductance (L_1) and capacitance (C_1) (**Figure 2**), whose values are defined as [14]

$$C_1 = \frac{\varepsilon_0 \varepsilon_{e_1} L W}{2h_1}\cos^{-2}\left(\frac{\pi y_0}{L}\right) \quad (2)$$

$$L_1 = \frac{1}{\omega_1^2 C_1} \quad (3)$$

$$R_1 = \frac{Q_1}{\omega_1 C_1} \quad (4)$$

where

$$Q_1 = \frac{c\sqrt{\varepsilon_{e_1}}}{4 f_1 h_1}$$

L = length of the lower patch;

y_o = Y-coordinate of the feed point.

$$\omega_1 = 2\pi f_1$$

$$f_1 = \frac{c}{2\left(L + 2\Delta L\right)\sqrt{\varepsilon_{eff}}}$$

c = velocity of light.

ΔL = fringing length for the lower patch.

Considering the top patch as a simple stacked rectangular microstrip patch, the values of resistance (R_2), inductance (L_2) and capacitance (C_2) can be given as

$$C_2 = \frac{\varepsilon_0 \varepsilon_{r_2} L_2 W_2}{2h_2} \quad (5)$$

$$L_2 = \frac{1}{\omega_2^2 C_2} \quad (6)$$

$$R_2 = \frac{Q_2}{\omega_2 C_2} \quad (7)$$

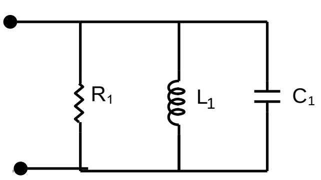

Figure 2. Equivalent circuit of patch antenna.

where

$$Q_2 = \frac{c\sqrt{\varepsilon_{e_2}}}{4 f_2 h_2}$$

where

L_2 = length of the stacked patch;

W_2 = width of the stacked patch;

$\omega_2 = 2\pi f_2$;

$f_2 = \dfrac{c}{2(L_2 + 2\Delta L_2)\sqrt{\varepsilon_{e_2}}}$;

ΔL_2 = fringing length for the top patch.

The equivalent circuit of the fed patch is shown in **Figure 3(a)**, in which ΔL_1 and ΔC_1 are the additional inductance and capacitance respectively, which originate due to introducing the two notches and R_H is resonance resistance after cutting the notches into the patch. The value of R_H can be calculated using Equation (7) and the ΔL_1, ΔC_1 can be given as [15]

$$\Delta L_1 = \frac{h_1 \mu_0 \pi}{8}\left(\frac{W_h}{w_n}\right) \tag{8}$$

where

$$\mu_0 = 4\pi 10^{-7} \text{ H/m}$$

and

$$\Delta C_1 = \left(\frac{W_h}{w_n}\right) C_s \tag{9}$$

where C_s is the gap capacitance between two side strips [16]. Now the equivalent circuit of H-shaped patch is given as shown in **Figure 3(b)** in which "Z_N" is the impedance of the notch incorporated patch and is calculated from **Figure 3(a)**, Z_P is the impedance of the initial patch and C_m and L_m are the capacitive and inductive coupling between two resonant circuits.

When a dual U-slots is cut into the stacked patch, current distribution changes which ultimately changes the resonance behavior of the patch. Due to this changing in the patch adds series inductance (ΔL_2) and series capacitance (ΔC_2) in the initial circuit of the stacked patch, which is shown in **Figure 4**, in which the resonance resistance R_2, ΔL_2 and ΔC_2 are given as [17]-[19]

$$R_2 = \frac{Q_2 h_2}{\pi f_r \varepsilon_{eff} \varepsilon_0 W_2 L_2} \cos^2\left(\left(\left(\frac{\pi y_0}{L_{eff_2}}\right)\right)\right) \tag{10}$$

where $\ell_{eff\,2}$ is the effective length [15] and can be given as

$$L_{eff_2} = L_2 + \left(\sin\left(\pi w / L_2\right)\right)\frac{L_s}{2}$$

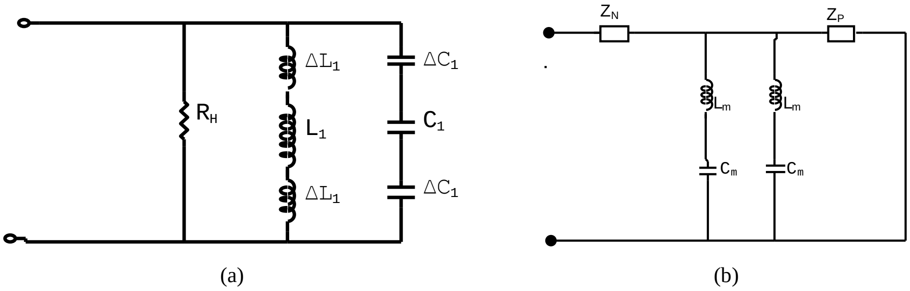

Figure 3. (a) Equivalent circuit of RMSA due to notch effect; (b) Equivalent circuit of H-shaped fed patch.

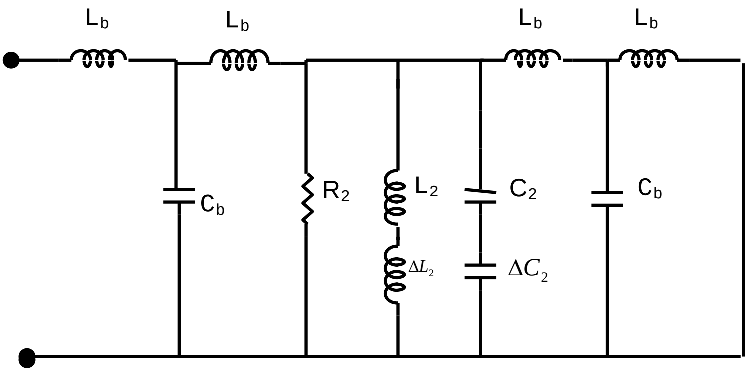

Figure 4. Equivalent circuit of U-slot loaded patch.

$$\Delta L_2 = \frac{Z_1 + Z_2}{16\pi f_1 \cos^{-2}\left(\frac{\pi y_0}{P_E}\right)} \tan\left(\frac{\pi f_1 L_s}{c}\right) \tag{11}$$

where

$P_E = W_1 - P_N$;

$$Z_1 = \frac{120\pi}{\frac{w_s}{h_2} + 1.393 + 0.667\log\left(\frac{w_s}{h_2} + 1.44\right)};$$

$$Z_2 = \frac{120\pi}{\frac{w_s - 2s}{h_2} + 1.393 + 0.667\log\left(\frac{W_s - 2s}{h_2} + 1.44\right)};$$

ΔC_2 is calculated as gap capacitance and given by [18].

The value of C_b and L_b are calculated as [19]

$$\frac{C_b}{w} = \left(9.5\varepsilon_{r_2} + 1.25\right)\frac{w}{h_2} + 5.2\varepsilon_{r_2} + 7.0\ \text{PF/m} \tag{12}$$

$$\frac{2L_b}{h_2} = 100\left(4\frac{w}{h_2} - 4.21\right)\ \text{NH/m} \tag{13}$$

Similarly we can analyze circuit concept of second U-slot which is parallel and compact to first U-slot on the upper patch.

The equivalent circuit of the proposed multiband antenna can be given as shown in **Figure 5**, in which only capacitive coupling is considered and given as [20]

$$C'_m = \frac{\left(C_{eq} + C'_{eq}\right) + \sqrt{\left(C_{eq} + C'_{eq}\right)^2 - 4C_{eq}C'_{eq}\left(1 - k_c^{-2}\right)}}{2} \tag{14}$$

where

$$C_{eq} = \frac{\Delta C_1 C_p}{2C_p + \Delta C_1}$$

$$C'_{eq} = \frac{\Delta C_2 C_2}{2C_2 + \Delta C_2}$$

and k_c is the coupling coefficient between two resonators.

Thus the total input impedance can be calculated from **Figure 5** as

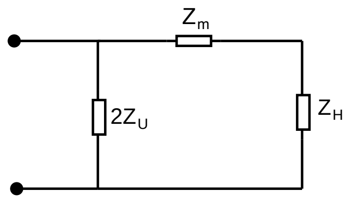

Figure 5. Equivalent circuit of proposed stacked patch antenna.

$$Z_{in} = \frac{2Z_U(Z_m + Z_H)}{2Z_U + Z_H + Z_m} \tag{15}$$

In which Z_H and Z_U are the impedances of initial and parasitic patches calculated from **Figure 3(b)** and **Figure 4** respectively and Z_m is the impedance due to mutual coupling between fed patch and stacked patch.

3. Design Specifications for the Proposed Antenna

Substrate material used	FR4
Dielectric constant ($\varepsilon_{r_1}, \varepsilon_{r_2}$)	4.4
Thickness between ground and lower patch (h_1)	1.6 mm
Thickness between lower and parasitic patch (h_2)	1.6 mm
Length of the fed patch (L)	39.25 mm
Width of the fed patch (W)	29.25 mm
Depth of the notch (w_n)	4 mm
Width of the notch (S)	15 mm
Length of the first U slot (L_s)	15.7 mm
Width of the first U slot (s)	1.0 mm
Base width of first U-slot (w_s)	10.3 mm
Length of the second U slot (L_s)	15.7 mm
Width of the second U slot (s)	1.0 mm
Base width of second U-slot (w_s)	10.3 mm
Feed location (x_0, y_0)	(−0.275, −4.37 mm)
Length of the parasitic patch (L_2)	39.25 mm
Width of the parasitic patch (W_2)	29.25 mm

4. Discussion of Results

All the simulation results of the proposed antenna are given as **Figures 6-8**. Discussion of results have been explain in terms of S_{11} parameters, resonance frequencies, gains and radiation patterns.

The variation of reflection coefficient with frequency for the proposed multiband antenna is depicted in **Figure 6**; it is found that the antenna can be operated for seven band applications. In which both lower and upper resonance frequencies of each bands are (4.24 GHz and 4.50 GHz), (5.02 GHz and 5.25 GHz), (7.84 GHz and 8.23 GHz), (12.16 GHz and 12.35 GHz), (14.25 GHz and 14.76 GHz), (15.25 GHz and 15.51 GHz), (17.52 GHz and 17.86 GHz) with return loss −13.81 dB, −17.02 dB, −26.07 dB, −12.79 dB, −20.42 dB, −31.32 dB and −18.41 dB respectively. The bandwidth of each bands are 6%, 4.5%, 4.83%, 2.36%, 3.53%, 1.68% and 1.91%. From **Figure 7**, it is observed that proposed antenna gains are 2.80 dBi, 4.39 dBi, 4.54 dBi, 6.25 dBi, 10.26 dBi, 8.36 dBi and 9.91 dBi respectively. From both the figure it is clear that the antenna gain is high as a higher frequency of the proposed antenna so that it is very useful in radar application. In [4], Ansari *et al*. has already presented the similar work for dual band application. But in the proposed antenna we have replace and changed the radiating patch in place of U-slot loaded patch and H-slot loaded parasitic patch. We have to see that, if changed

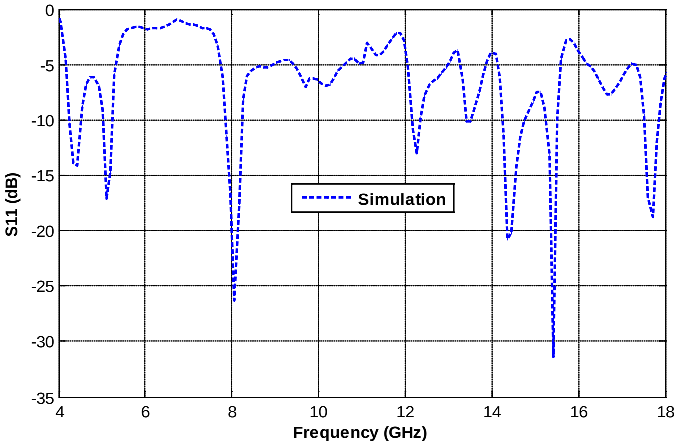

Figure 6. Variation of return loss with frequency for the proposed antenna.

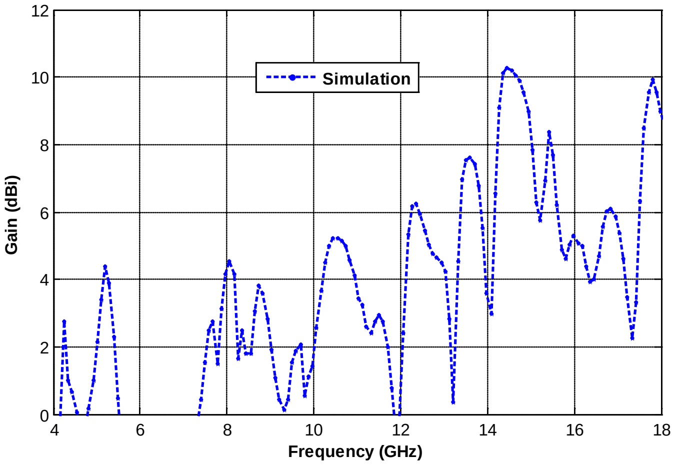

Figure 7. Variation of gain with frequency for the proposed antenna.

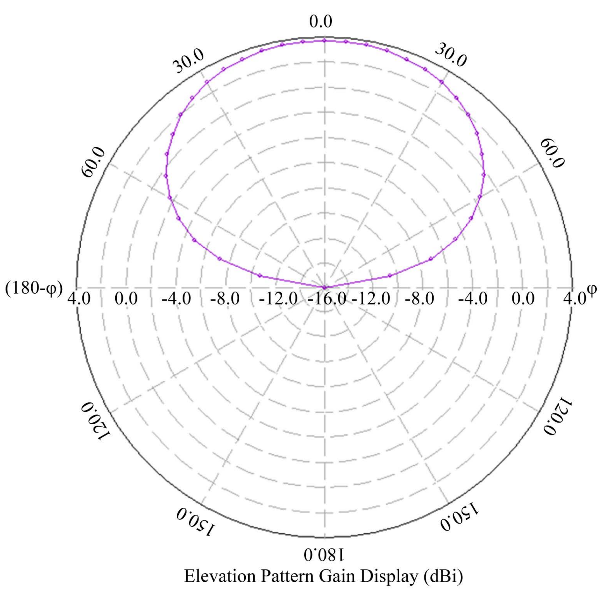

Figure 8. Radiation pattern of the proposed antenna at frequency 8.08 GHz.

the patch, the results are obtained as a multiband antenna with good gain, which is more useful as compared to dual band application presented in 2008. Radiation pattern of the proposed antenna is shown in **Figure 8**. It is found that radiated power is good. This shows that the directivity improves by stacking dual U-shaped patch.

5. Conclusion

A stacked multiband proximity coupled microstrip patch antenna is presented. This antenna has a very simple structure printed on FR4 substrate. Multiband has achieved by using dual U-slot loaded stacked patch. The total volume of the antenna is $39.25 \times 29.25 \times 1.6\ mm^2$. The proposed antenna shows satisfactory multiband performance and good radiation pattern. Proposed antenna finds the application in C, X and Ku band which can be used for radar, VSAT, mobile and satellite communication.

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