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H-SHAPED STACKED PATCH ANTENNA FOR DUAL BAND OPERATION

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Abstract—Analysis of U-slot loaded patch stacked with H-shaped parasitic elements is given in this paper. It is found that the antenna exhibits dual resonance and both the resonance frequency (upper and lower) depends directly on slot width and inversely on slot length. Both upper and lower resonance frequency increase with increasing the value of h_2. Typically the bandwidth at lower and upper resonance is found 3.66% and 10.25% respectively. The radiated power at higher frequency (beamwidth 64°) is 0.73 dB as compared to lower resonance frequency (beamwidth 71°). The theoretical results are compared with the simulated data obtained from IE3D.

1. INTRODUCTION

In spite of having advantage like light weight, low profile, compact and cost effective, the conventional microstrip antenna has disadvantages of narrow bandwidth and low gain. A number of researchers have tried to minimize these drawbacks of the patch antenna by way of addition of parasitic elements either laterally or vertically [1], cutting slot including probe fed U-slot loaded patch antenna [2], double C-patch antennas [3] and E-shape patch [4]. Among various proposed methods stacked patch configuration seems to be very promising due to its capability of providing dual frequency characteristics [5–7] and wider bandwidth [8, 9].

In the present paper, an analysis of a U-slot loaded patch stacked with H-shaped patch is carried out. A U-slot loaded patch along with its initial dimensions provides other parameters such as slot length and slot width to improve the various antenna characteristics. In the present work variation of substrate thickness is also studied. The entire investigation is based on equivalent circuit model.

2. THEORETICAL CONSIDERATIONS

The configuration of the proposed antenna is shown in Fig. 1. The upper element is H-shaped parasitic patch and lower one is the U-slot loaded patch. Due to the presence of parasitic element in the stacked patch antenna, there are two resonance associated with the two resonators [10]. The first resonator is considered as a microstrip patch with dielectric cover which causes a change in resonance frequency as well as effective dielectric constant (ε_{ff}).

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

$$\varepsilon_s = \frac{2\varepsilon_{ff} - 1 + p}{1 + p}$$

where

$$p = 1 + \frac{10h_1}{W_{1e}}$$

in which W_{1e} is the effective width and ε_{ff} is the effective dielectric constant of the structure [11]. The effective dielectric constant of the lower substrate is given as

$$\varepsilon_{e_1} = \frac{\varepsilon_s + 1}{2} + \frac{\varepsilon_s + 1}{2}\left(1 + \frac{12h_1}{W_1}\right) \tag{1}$$

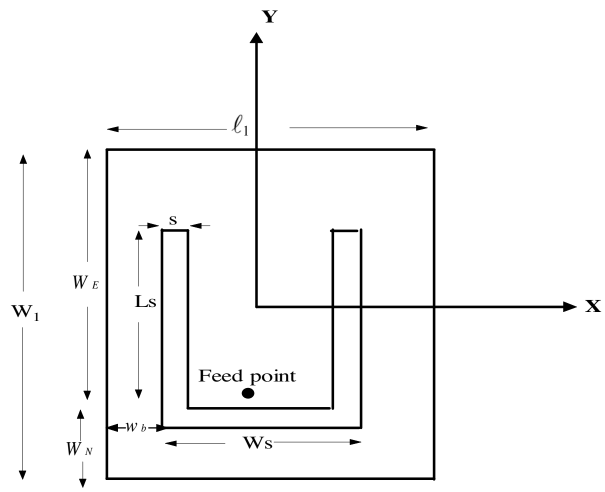
where

h_1 = height between ground plane and lower patch

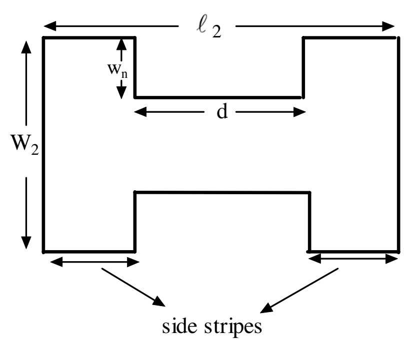
W_1 = width of the patch

The equivalent circuit of the simple patch antenna is parallel combination of resistance (R_p), inductance (L_p) and capacitance (C_p) (Fig. 2), whose values are defined as [12]

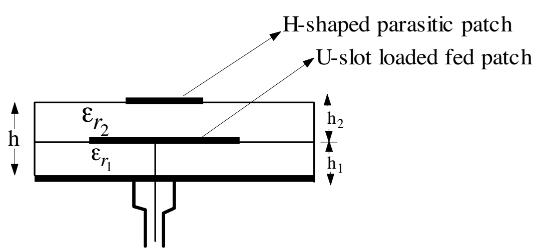
$$C_p = \frac{\varepsilon_0 \varepsilon_{e_1} \ell_1 W_1}{2h_1} \cos^{-2}\left(\frac{\pi y_0}{\ell_1}\right) \tag{2}$$



(a) U-slot loaded fed patch



(b) H-shaped parasitic patch



(c) Side view of the proposed antenna

Figure 1. Configuration of stacked patch antenna.

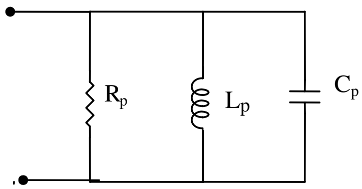


Figure 2. Equivalent circuit of patch antenna.

$$L_p = \frac{1}{\omega_1^2 C_p} \tag{3}$$

$$R_p = \frac{Q_1}{\omega_1 C_p} \tag{4}$$

where

$$\begin{aligned} Q_1 &= \frac{c\sqrt{\varepsilon_{e_1}}}{4 f_1 h_1} \\ \ell_1 &= \text{length of the lower patch} \\ y_o &= Y\text{-coordinate of the feed point} \\ \omega_1 &= 2\pi f_1 \\ f_1 &= \frac{c}{2\left(\ell_1 + 2\Delta\ell_1\right)\sqrt{\varepsilon_{eff}}} \\ c &= \text{velocity of light} \\ \Delta\ell_1 &= \text{fringing length for the lower patch} \end{aligned}$$

When a U-slot is etched into the patch, current distribution changes which ultimately changes the resonance behaviour of the patch. This change in the patch adds series inductance (ΔL_1) and series capacitance (ΔC_1) in the initial circuit of the patch. Therefore the equivalent circuit of U-slot loaded patch can be given as shown in Fig. 3, in which the resonance resistance R_1, ΔL_1 and ΔC_1 are given as [13–15]

$$R_1 = \frac{Q_1 h_1}{\pi f_r \varepsilon_{eff} \varepsilon_0 W_1 \ell_1} \cos^2\left(\frac{\pi y_0}{\ell_{eff_1}}\right) \tag{5}$$

where ℓ_{eff_1} is the effective length of the fed patch [16] and can be given as

$$\ell_{eff_1} = \ell + (\sin(\pi w_b/\ell))\,\frac{L_s}{2}$$

$$\Delta L_1 = \frac{Z_1 + Z_2}{16\pi f_1 \cos^{-2}\left(\frac{\pi y_0}{W_E}\right)} \tan\left(\frac{\pi f_1 L_s}{c}\right) \tag{6}$$

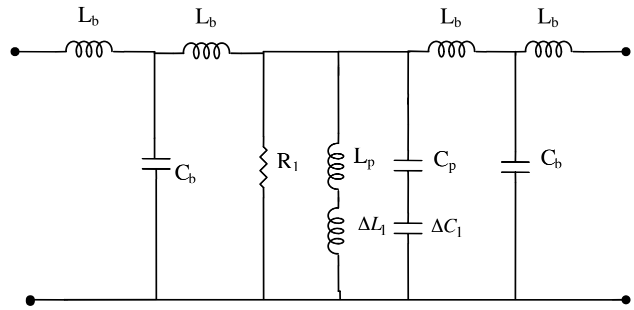


Figure 3. Equivalent circuit of U-slot loaded patch.

where

$$W_E = W_1 - W_N$$
$$Z_1 = \frac{120\pi}{\frac{W_s}{h_1} + 1.393 + 0.667\log\left(\frac{W_s}{h_1} + 1.44\right)}$$
$$Z_2 = \frac{120\pi}{\frac{W_s - 2s}{h_1} + 1.393 + 0.667\log\left(\frac{W_s - 2s}{h_1} + 1.44\right)}$$

ΔC_1 is calculated as gap capacitance and given by [14]. The value of C_b and L_b are calculated as [15]

$$\frac{C_b}{w_b} = (9.5\varepsilon_{r_1} + 1.25)\frac{w_b}{h_1} + 5.2\varepsilon_{r_1} + 7.0\,\text{pF/m} \tag{7}$$
$$\frac{2L_b}{h_1} = 100\left(4\frac{w_b}{h_1} - 4.21\right)\,\text{nH/m} \tag{8}$$

2.1. Analysis of Stacked Patch Antenna

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

$$C_2 = \frac{\varepsilon_0\,\varepsilon_{r_2}\ell_2 W_2}{2h_2} \tag{9}$$
$$L_2 = \frac{1}{\omega_2^2 C_2} \tag{10}$$
$$R_2 = \frac{Q_2}{\omega_2 C_2} \tag{11}$$

where

$$Q_2 = \frac{c\sqrt{\varepsilon_{e2}}}{4f_2h_2}$$

where

$$\begin{aligned}
\ell_2 &= \text{length of the parasitic patch} \\
W_2 &= \text{width of the parasitic patch} \\
\omega_2 &= 2\pi f_2 \\
f_2 &= \frac{c}{2\left(\ell_2 + 2\Delta\ell_2\right)\sqrt{\varepsilon_{e2}}} \\
\Delta\ell_2 &= \text{fringing length for the top patch}
\end{aligned}$$

When two symmetrical notches are incorporated into the parasitic patch an H-shaped patch is obtained and the equivalent circuit thus obtained is shown in Fig. 4(a), in whichΔL_2 and ΔC_2 are the additional inductance and capacitance respectively which originate due to introducing the two notches and R_H is resonance resistance after

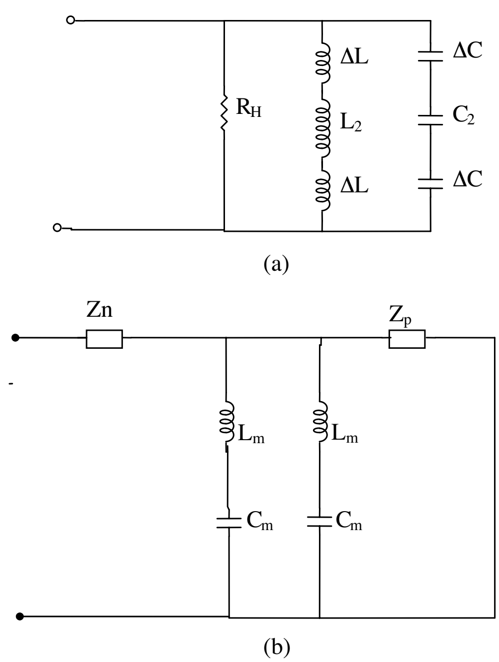


Figure 4. (a) Equivalent circuit of RMSA due to notch effect. (b) Equivalent circuit of H-shaped parasitic patch.

cutting the notches into the patch. The value of R_H can be calculated using Equation (5) and the additional inductance and capacitance can be given as [16]

$$\Delta L_2 = \frac{h_1 \mu_0 \pi}{8} \left(\frac{W_2}{w_n} \right) \tag{12}$$

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

And

$$\Delta C_2 = \left(\frac{W_2}{w_n} \right) C_s \tag{13}$$

where C_s is the gap capacitance between two side strips [17]. Now the equivalent circuit of H-shaped patch is given as shown in Fig. 4(b) in which 'Zn' is the impedance of the notch incorporated patch and is calculated from Fig. 4(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.

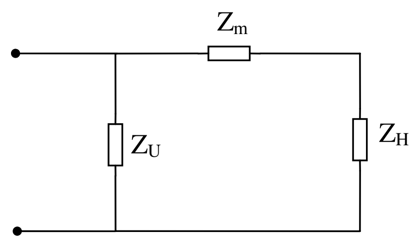


Figure 5. Equivalent circuit of proposed stacked patch antenna.

The equivalent circuit of the proposed stacked antenna can be given as shown in Fig. 5, in which only capacitive coupling is considered and is given by [18]

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

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 Fig. 5 as

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

In which Z_U and Z_H are the impedances of lower and parasitic patches calculated from Figs. 3 and 4(b) respectively and Z_m is the impedance due to mutual coupling between driven patch and parasitic patch.

2.2. Design Specifications of Proposed Antenna

Substrate material used	Foam
Dielectric constant (ε_{r_1}, ε_{r_2})	1.1
Thickness between ground and lower patch (h_1)	6.0 mm
Thickness between lower and parasitic patch (h_2)	5.5 mm
Length of the fed patch (ℓ_1)	39.40 mm
Width of the fed patch (W_1)	29.40 mm
Length of the slot (L_s)	15 mm
Width of the slot (s)	1.2 mm
Feed location (x_0, y_0)	(0, −5.27 mm)
Length of the parasitic patch (ℓ_2)	26 mm
Width of the parasitic patch (W_2)	18 mm
Depth of the notch (w_n)	4 mm
Width of the notch (d)	15 mm

3. DISCUSSION OF RESULTS

The variation of return loss with frequency for different slot width (s) is shown in Fig. 6, for a given value of slot length $L_s = 12$ mm, $h_1 = 6$ mm, $h_2 = 5.5$ mm. It is observed that the antenna shows dual resonance in which both lower and upper resonance frequency increases with increasing value of slot width and the bandwidth at upper resonance (10.25%) is higher than the bandwidth at the lower resonance (3.26%). The bandwidth of the antenna also increases with slot width whereas at lower resonance it is almost the constant. All theoretical results are found to be approximately in good agreement with the simulated results using MOM based IE3D [21].

The variation of return loss with frequency for different value of slot length (L_s) is shown in Fig. 7 for a given value of $s = 1.2$ mm, $h_1 = 6$ mm, $h_2 = 5.5$ mm. It is found that both lower and upper resonance frequency decreases with increasing slot length and the band width at the upper resonance (10.25%) is higher as compared to the

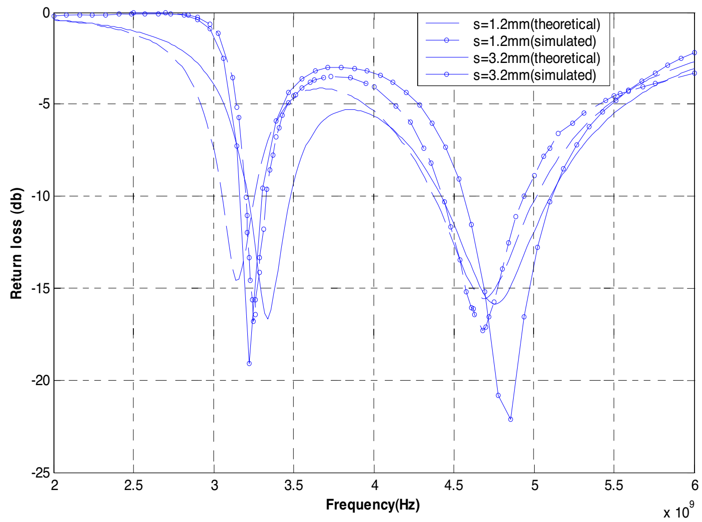


Figure 6. Variation of return loss with frequency for different slot width ($L_s = 12\,\mathrm{mm}$, $h_1 = 6\,\mathrm{mm}$, $h_2 = 5.5\,\mathrm{mm}$).

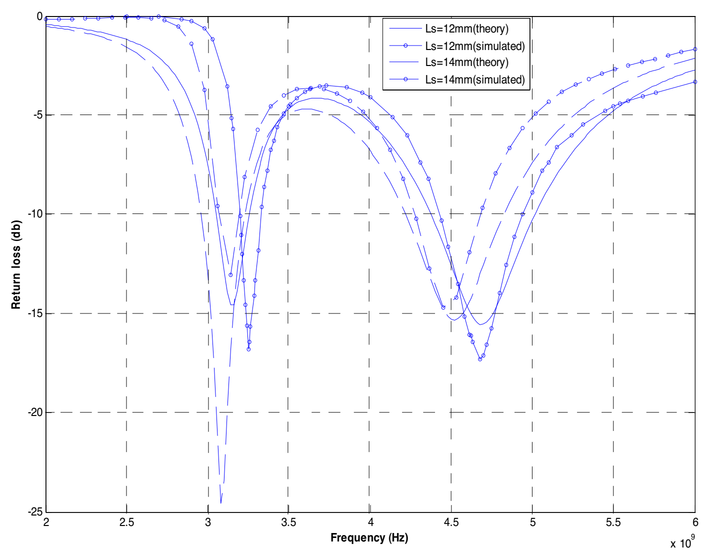


Figure 7. Variation of return loss with frequency for different slot length ($s = 1.2\,\mathrm{mm}$, $h_1 = 6\,\mathrm{mm}$, $h_2 = 5.5\,\mathrm{mm}$).

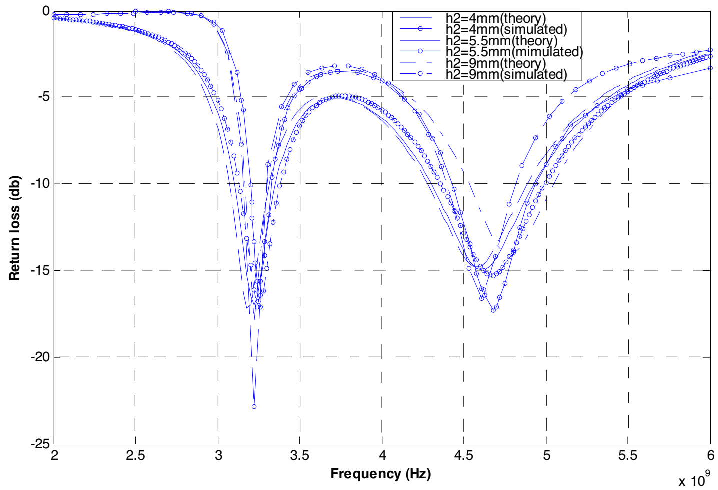


Figure 8. Variation of return loss with frequency for different value of h_2 ($L_s = 12\,\text{mm}$, $s = 1.2\,\text{mm}$, $h_1 = 6\,\text{mm}$).

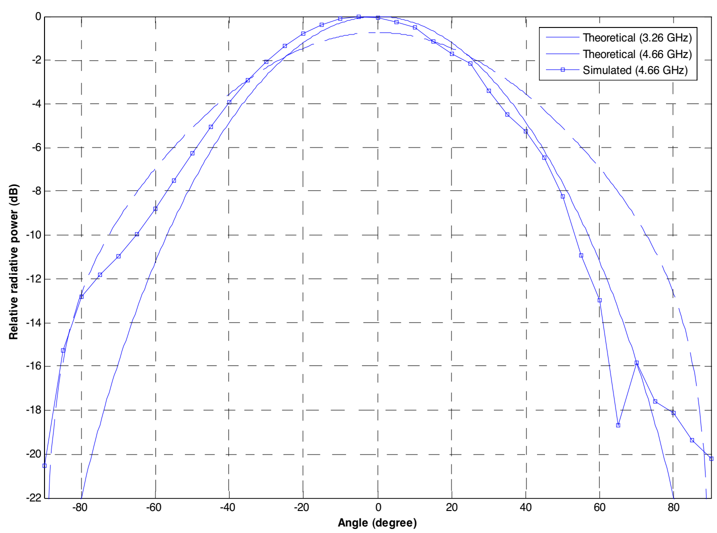


Figure 9. Radiation pattern.

lower resonance (3.66%). It is further observed that the bandwidth at upper resonance increases with increasing slot length where as it is almost invariant at lower resonance. The theoretical results are found to be in good agreement with simulated results using IE3D.

Figure 8 shows variation of return loss with frequency for different upper substrate thickness (h_2) for given value of $L_s = 12\,\text{mm}$, $s = 1.2\,\text{mm}$, $h_1 = 6\,\text{mm}$. It is found that both lower and upper resonance frequency increases with increasing upper substrate thickness (h_2) and bandwidth at upper resonance is shown to be higher than that at lower resonance. In this case also the bandwidth at upper resonance increases with increasing substrate thickness h_2. The theoretical results compare well with simulated results.

Radiation pattern of the antenna is shown in Fig. 9 for both upper and lower resonance. It is found that radiated power at upper resonance frequency is higher by 0.73 dB and beam width is lower (64°) as compared to lower resonance frequency (71°). This shows that the directivity improves by stacking H-shaped patch. The theoretical results are in almost good agreement with simulated result.

4. CONCLUSIONS

From the analysis it is found that U-slot loaded patch when stacked with H-shaped patch exhibits dual resonance and the radiated power and directivity improves.

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