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# COMPACT SHORTED MICROSTRIP PATCH ANTENNA FOR DUAL BAND OPERATION

**A. Mishra, P. Singh, N. P. Yadav, and J. A. Ansari**

Department of Electronics & Communication
University of Allahabad
Allahabad 211002, India

**B. R. Vishvakarma**

Department of Electronics Engineering
I. T. BHU
Varanasi 221005, India

**Abstract**—In the present paper notch loaded shorted microstrip patch antenna has been analysed using cavity model. The proposed antenna shows dual band operation which depends on notch dimensions as well as shorting wall. The frequency ratio is found to be 1.5278 for the notch loaded rectangular patch, while in notch loaded shorted patch, the frequency ratio varies from 2.9764 to 2.725 for increasing value of notch width and it is almost invariant with notch depth. Further a slot loaded shorted patch antenna shows the dual frequency nature with the frequency ratio 1.7. The theoretical results are compared with IE3D simulation as well as reported experimental results.

## 1. INTRODUCTION

Compact microstrip antennas have received much attention due to increasing application of small antennas for personal communication equipments [1–5]. Shorted patch antennas have been reported to overcome the size constraints for a variety of communication link. Recently it has been demonstrated that loading the microstrip antenna with shorting pin and shorted wall can reduce the patch size for a fixed operating frequency [6–9].

Various kind of microstrip antennas have been proposed to achieve dual band operation such as redial slot [10], microstrip patch antenna

Corresponding author: A. Mishra (mishraanurag31@gmail.com).

with $\pi$ shaped slot [11]. One of the most popular techniques to obtain the dual band frequency is reactive loading by introducing the slots parallel to radiating edge of the patch [12] and cutting square slot in the patch [13, 14]. Another type of reactive loading can be introduced to get higher frequency by cutting a notch parallel to the rediating edge of the patch [15].

In this paper, two antenna geometries are analysed for dual band operation using the circuit theory concept. In first geometry, a notch with dimension $(L_n \times W_n)$ is introduced along one of the radiating edge and another radiating edge is shorted with shorting wall, while in second geometry, a slot with dimension $(L_s \times W_s)$ is loaded in rectangular microstrip patch antenna with shorted wall. Various antenna parameters are calculated as a function of frequency for different values of notch and slot dimensions.

### 2.1. Analysis of Notch Loaded Shorted Patch Antenna

The geometry of proposed antenna is shown in Fig. 1.

A simple rectangular microstrip patch antenna can be analysed as a parallel combination of $R_1$, $L_1$ and $C_1$ as shown in Fig. 2, where $R_1$, $L_1$ and $C_1$ can be defined as [16].

$$C_1 = \frac{\varepsilon_e \varepsilon_o L W}{2h} \cos^{-2}(\pi x_o / L) \tag{1}$$

$$L_1 = \frac{1}{\omega^2 C_1} \tag{2}$$

$$R_1 = \frac{Q_r}{\omega C_1} \tag{3}$$

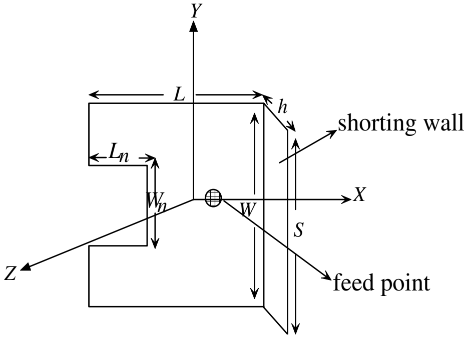



**Figure 1.** Geometry of notch loaded shorted patch antenna.

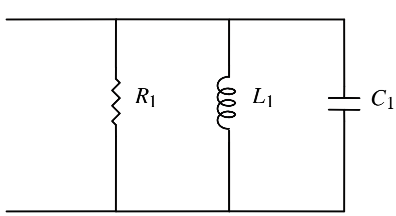



**Figure 2.** Equivalent circuit of rectangular patch.

in which

$L$ = length of the rectangular patch

$W$ = width of the rectangular patch

$x_o$ = feed point location along length of the patch

$h$ = thickness of the substrate material

and

$$Q_r = \frac{c\sqrt{\varepsilon_e}}{fh}$$

where

$c$ = velocity of light

$f$ = design frequency

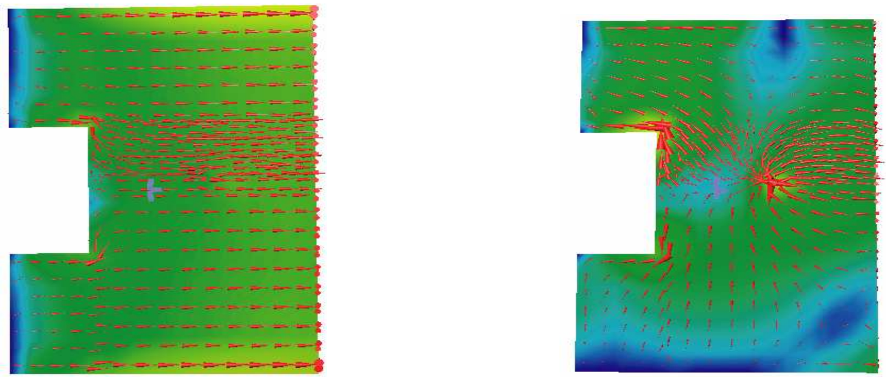
$\varepsilon_e$ = effective permittivity of the medium which is given by [16]

$\varepsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{10h}{W}\right)^{-1/2}$

where, $\varepsilon_r$ = relative permittivity of the substrate material.

The notch is introduced along one of the radiating side and other side is shorted by the shorting wall. Due to the effect of notch, the two current flows in the patch, one is the normal patch current and resonates at the design frequency of the initial patch; however, the other current flows around the notch consequently alters the resonance frequency, as shown in Fig. 3.

Due to this discontinuity an additional series inductance ($\Delta L$) and series capacitance ($\Delta C$) appear that modify the equivalent circuit of



(a) (b)

**Figure 3.** Current distributions of notch loaded shorted patch antenna: (a) $fr_1 = 2.731\,\text{GHz}$, (b) $fr_2 = 8.01\,\text{GHz}$.

RMSA as shown in Fig. 4, in which series inductance ($\Delta L$) and series capacitance ($\Delta C$) can be calculated as [17, 18].

$$\Delta L = \frac{h\mu_0\pi}{8}(L_n/L)^2$$

and $$\Delta C = (\tfrac{L_n}{L}) \cdot C_S$$

where

$\mu_0 = 4\pi \times 10^{-7}\,\mathrm{H/m}$

$L_n$ = depth of the notch

$C_s$ = gap capacitance and is given by [19].

It may be noted that the two resonant circuits, one is the initial $R\ L\ C$ of the shorted patch shown in Fig. 5 and another one is after cutting the notch, are coupled through mutual inductance ($L_m$) and mutual conductance ($C_m$). Now the equivalent circuit of the proposed antenna can be given as shown in Fig. 6.

The input impedance of the notch loaded microstrip patch can be calculated as

$$Z_T = Z_{notch} + \frac{Z_{short} Z_m}{Z_{short} + Z_m} \tag{4}$$

where $Z_{short}$ = input impedance of the shorted patch and can be given as

$$Z_{short} = \frac{R_1 j\omega}{j\omega + L_T R_1 - R_1 C_1 \omega^2} \tag{5}$$

in which

$$L_T = \frac{L_S + L_1}{L_1 L_S}$$

where $L_S$ = Inductance due to shorting wall and defined as [16]

$$L_S = 0.2h\left[\log\frac{2h}{(S+t)} + 0.2235\frac{(S+t)}{h} + 0.5\right]$$

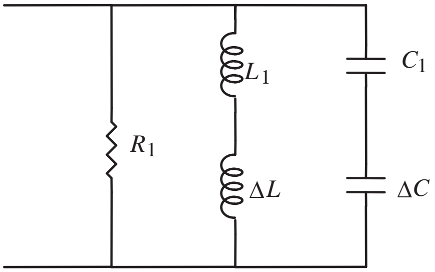



**Figure 4.** Equivalent circuit of patch due to effect of notch.

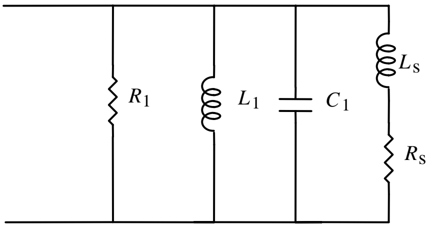



**Figure 5.** Equivalent circuit of shorted patch antenna.

where

$S$ = length of the shorting wall
$h$ = height of the substrate i.e., width of the shorting wall
$t$ = thickness of the shorting wall

$$Z_{notch} = \frac{j\omega R_1 L_2}{j\omega L_2 + R_1 - R_1 L_2 C_2 \omega^2} \tag{6}$$

where

$$L_2 = L_1 + \Delta L$$
$$C_2 = \frac{C_1 \Delta C}{C_1 + \Delta C}$$

and

$$Z_m = \left(j\omega L_m + \frac{1}{j\omega C_m}\right)$$

where $L_m$ and $C_m$ are the mutual inductance and mutual capacitance between two resonant circuits and given as [20].

$$L_m = \frac{C_p^2(L_1 + L_2) + \sqrt{C_p^2(L_1 + L_2)^2 + 4C_p^2(1 - C_p^2)L_1 L_2}}{2(1 - C_p^2)} \tag{7}$$

$$C_m = -\frac{(C_1 + C_2) + \sqrt{(C_1 + C_2)^2 - 4C_1 C_2(1 - C_p^{-2})}}{2} \tag{8}$$

where $C_p = \frac{1}{\sqrt{Q_1 Q_2}}$ and $Q_1$ and $Q_2$ are quality factors of the two resonant circuits.

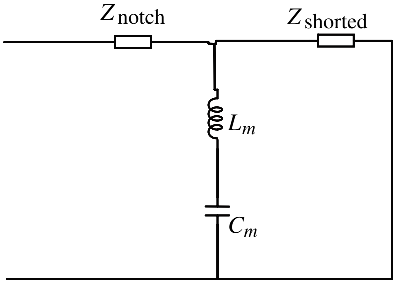



**Figure 6.** Equivalent circuit of coupled notch loaded shorted patch antenna.

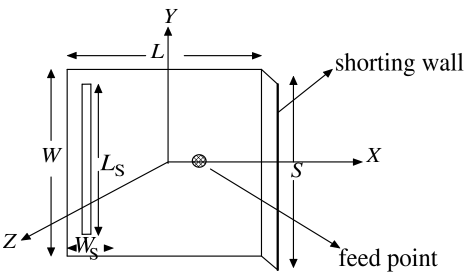



**Figure 7.** Geometry of slot loaded shorted patch antenna.

## 2.2. Analysis of Slot Loaded Shorted Patch Antenna

The geometry of slot loaded shorted patch antenna is shown in Fig. 7.

The slot on the patch can be analysed by using the duality relationship between the dipole and slot [21]. The corresponding current distribution for the slot loaded shorted patch is shown in Fig. 8.

The input impedance of a single slot parallel to the radiating edge can be given as [22].

$$Z_S = j30 \int \left( \frac{e^{-jkr_1}}{r_1} + \frac{e^{-jkr_1}}{r_2} - 2\cos kh \frac{e^{-jkr_0}}{r_0} \right) \sin k(h - |z|) dz \quad (9)$$

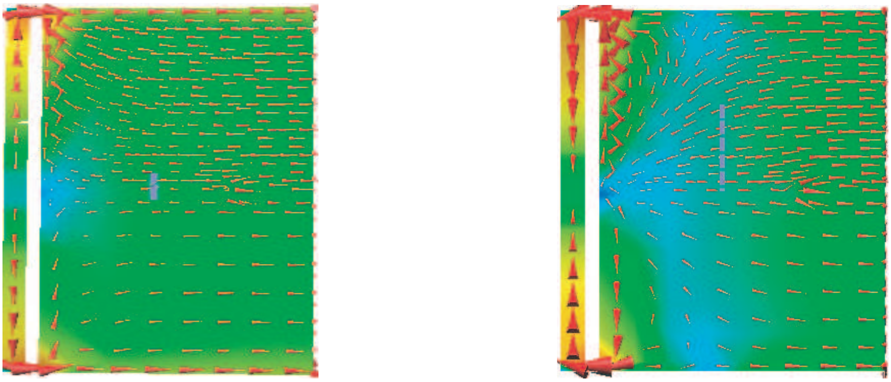
where $k = 2\pi/\lambda$, $\lambda =$ wavelength in the medium, $h =$ thickness of the substrate

$$r_1 = \left[y^2 + (h+z)^2\right]^{1/2}$$
$$r_2 = \left[y^2 + (h-z)^2\right]^{1/2}$$
$$r_0 = \left[y^2 + z^2\right]^{1/2}$$

Equation (9) can be given as

$$Z_S = R_{slot} + jX_S \quad (10)$$

where $R_S$ is the real part of the Eq. (10) and equivalent to radiation resistance of the slot and imaginary parts $X_S$ is input reactance of the



(a) (b)

**Figure 8.** Current distributions of slot loaded shorted patch antenna: (a) $fr_1 = 2.4$ GHz, (b) $fr_2 = 4.1$ GHz.

slot and can be given as [22]

$$X_S = 30\left\{[2S_i(kL_{slot}) + \cos(kL_{slot})][2S_i(kL_{slot}) - S_i(2kL_{slot}) - \sin(kL_{slot})]\left[2C_i(kL_{slot}) - C_i(2kL_{slot}) - C_i\left(\frac{2kW_S^2}{L_{slot}}\right)\right]\right\} \quad (11)$$

where $S_i$ and $C_i$ are sin and cosine integrals and $k = \frac{2\pi}{\lambda}$.

In the present analysis only the capacitive reactance $X_S$ is considered and the value of $R_S$ is very small and can be neglected. Another side of the radiating edge of the patch is shorted with shorting wall which adds an inductance parallel to the patch. The equivalent circuit of the slot loaded shorted patch microstrip patch antenna is shown in Fig. 9.

The total input impedance of the circuit can be calculated using Fig. 9 as

$$Z_T = \frac{j\omega L_S Z_P Z_{slot}}{Z_P + Z_{slot} + j\omega L_S} \quad (12)$$

where $Z_P$ = Input impedance of the RMSA and can be defined as

$$Z_P = \frac{1}{1/R_1 + 1/j\omega L_1 + j\omega C_1} \quad (13)$$

Now using Equations (4) and (12) one can calculate the various antenna parameters for both the proposed antennas, such as reflection coefficient, VSWR and return loss.

## 3. DESIGN AND SPECIFICATIONS

**Table 1.** Design specifications for the notch loaded shorted patch antenna.

| | |
|---|---|
| Substrate material used | Foam |
| Relative permittivity of the substrate ($\varepsilon_r$) | 1.07 |
| Thickness of the dielectric substrate ($h$) | 3 mm |
| Length of the patch ($L$) | 25 mm |
| Width of the patch ($W$) | 38 mm |
| Depth of the notch ($L_n$) | 6.5 mm |
| Width of the notch ($W_n$) | 13 mm |
| Length of the shorting wall ($S$) | 38 mm |
| Feed location ($x_0, y_o$) | (4.32 mm, 0) |

**Table 2.** Design specifications for the slot loaded shorted patch antenna.

| | |
|---|---|
| Substrate material used | Foam |
| Relative permittivity of the substrate ($\varepsilon_r$) | 1.07 |
| Thickness of the dielectric substrate ($h$) | 3 mm |
| Length of the patch ($L$) | 25 mm |
| Width of the patch ($W$) | 38 mm |
| Length of the slot ($L_s$) | 36 mm |
| Width of the slot ($W_s$) | 1 mm |
| Length of the shorting wall ($S$) | 38 mm |
| Feed location ($x_0, y_o$) | (6 mm, 0) |

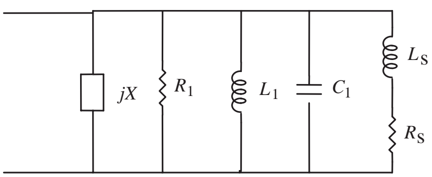



**Figure 9.** Equivalent circuit of slot loaded shorted patch.

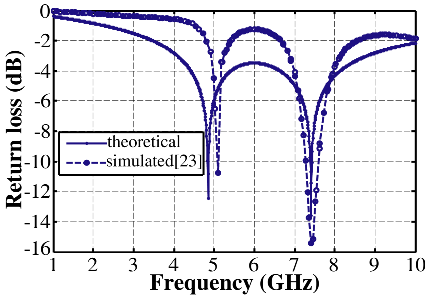



**Figure 10.** Comparative plot of return loss with frequency for notch loaded patch.

## 4. RESULT AND DISCUSSION

Figure 10 shows the variation of return loss with frequency for notch loaded patch antenna along with simulated results using IE3D [23].

From the figure it is observed that the antenna shows dual frequency behaviour with frequency ratio 1.5278 (simulated, 1.4544). However, when the patch is shorted with shorting wall, the frequency ratio increases up to 2.9764 as shown in Fig. 11.

From Fig. 12, it is observed that the lower resonance frequency remains almost constant while the upper resonant frequency increases with increasing value of notch depth ($L_n$) for a given value of notch width ($W_n = 13$ mm).

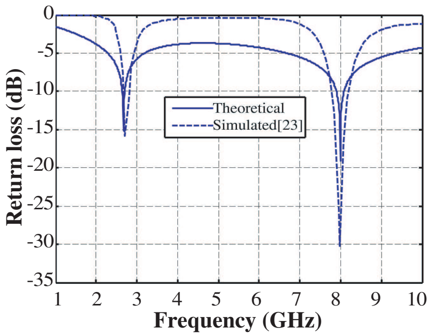



**Figure 11.** Variation of return loss with frequency for notch loaded shorted patch along with simulated results ($L_n = 6.5$ mm, $W_n = 13$ mm).

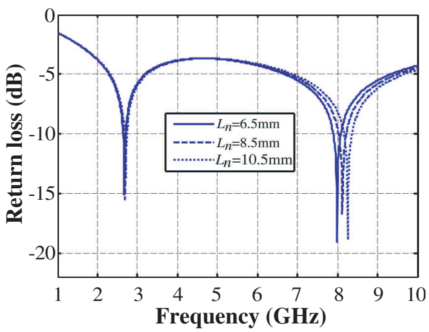



**Figure 12.** Variation of return loss with frequency for different value of notch depth $L_n$ ($W_n = 13$ mm).

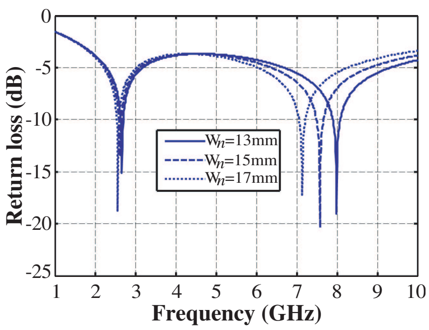



**Figure 13.** Variation of return loss with frequency for different value of notch width $W_n$ ($L_n = 6.5$ mm).

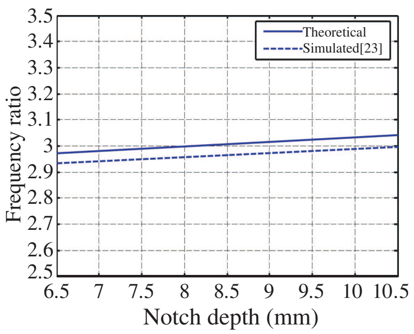



**Figure 14.** Variation of frequency ratio with different notch depth ($W_n = 13$ mm).

Figure 13 shows the variation of return loss with frequency for different value of notch width for a given value of notch depth ($L_n = 6.5$ mm) and shorting wall length ($S = 38$ mm). It is observed that both the upper and lower resonance frequencies depend inversely on notch width for a given value of notch depth but a large shift in upper resonance frequency is observed as compared to the variation of lower resonance frequency.

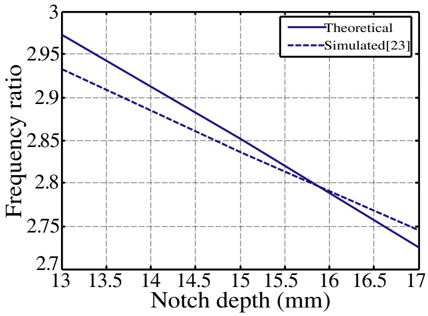



**Figure 15.** Variation of frequency ratio with different notch width ($L_n = 6.5\,\text{mm}$).

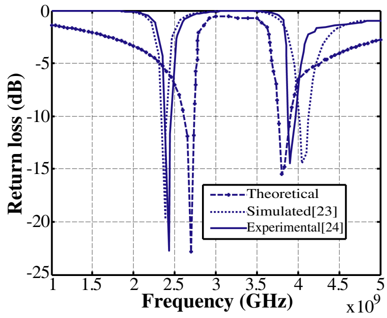



**Figure 16.** Comparative graph of return loss with frequency for slot loaded shorted patch ($L_{slot} = 36\,\text{mm}$, $W_s = 1\,\text{mm}$).

The variation of frequency ratio ($f_2/f_1$) with notch depth is given in Fig. 14 along with simulated results. It is found that there is a small increase in the frequency ratio ($f_2/f_1$) for a given value of notch width ($W_n$), while the variation of frequency ratio decrease sharply with the notch width of the antenna as shown in Fig. 15.

Figure 16 shows the theoretical return loss along with simulated and experimental results [24] for the slot loaded shorted patch. The theoretical results are found to be in good agreement with the simulated and experimental results. Slight deviation in resonance frequency is due to some approximations in the proposed theory.

## 5. CONCLUSION

From the analysis, it is concluded that the frequency ratio of the antenna is very sensitive with notch and slot dimensions. The frequency ratio depends inversely on the notch width while it is almost invariant with notch depth. Thus one can optimize both the resonance frequencies for various scientific and industrial applications.

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