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Analysis of U-slot loaded Patch for Dualband Operation

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Abstract- **The analysis of U- slot loaded patch is carried out using equivalent circuit concept. The antenna exhibits dual resonance and the separation between two resonances is sensitive to the dimension of the slot. The theoretical results are compared with the simulated data using IE3D software which are in close agreement. Further radiation pattern is found to be invariant with the slot dimensions.**

***Index Terms*: Microstrip antenna, patch antenna, U- slot loaded patch and dual band antenna.**

I. INTRODUCTION

Microstrip antenna inherently has a low bandwidth that limits its application in practice. Several approaches have been made to improve the bandwidth of the single layer patch antenna, such as use of a thick or foam substrate [1-2]. Further a dual band antenna is a better option to accomplish the requirement of broadband microstrip antenna (MSA).

Various kind of microstrip antennas were proposed to provide dual band operation such as radial slot antenna [3], rectangular microstrip slot antenna with a π-shaped slot [4], and hybrid dielectric resonator antenna [5]. The reactively loaded antenna is one of the popular techniques to obtain the dual band operation. Dual resonance is obtained by introducing the slots parallel to the radiating edge of the patch [6], co-axial or microstrip stubs at the radiating edges [7-8], cutting the square slot in the patch [9-10]. These dual band microstrip antennas provide a tunable frequency ratio for various applications.

In this paper analysis of U slot loaded rectangular microstrip antenna [Fig. 1] using equivalent circuit concept is presented.

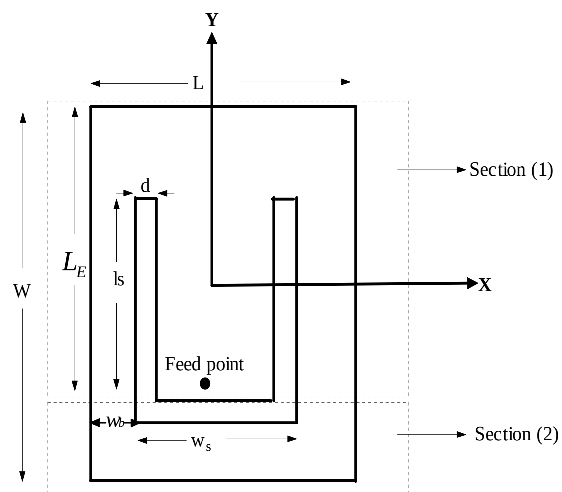


Fig. 1 U-slot loaded patch

A U-slot adds a capacitive component in the input impedance that compensates for the inductive component of coaxial probe. The aim of the paper is to study the effect of U-slot on the antenna parameters such as input impedance VSWR and return loss etc.

II.THEORETICAL CONSIDERATIONS

A simple microstrip antenna is considered as a parallel combination of resistance(R), inductance (L) and capacitance (C).The equivalent circuit of the patch can be given as shown in Fig 2 ,

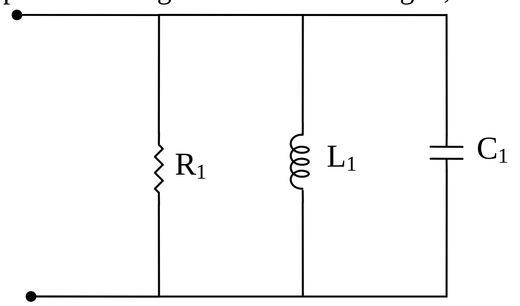


Fig. 2 Equivalent circuit of patch

where R_1, L_1, C_1 can be defined as [11]

$$C_1 = \frac{\varepsilon_0 \varepsilon_e LW}{2h} \cos^{-2}\left(\frac{\pi y_0}{L}\right) \quad \text{---(1)}$$

where L and W are length and width of the rectangular patch and 'h' is thickness of the substrate material. y_o is Y-coordinate of the feed point.

$$L_1 = \frac{1}{\omega^2 C_1} \quad \text{-- (2)}$$

$$R_1 = \frac{Q_r}{\omega C_1} \quad \text{-- (3)}$$

where

$$Q_r = \frac{c\sqrt{\varepsilon_e}}{4fh}$$

here, ε_e is effective permittivity of the medium which is given by [11].

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

where c is the velocity of light, f is the design frequency, ε_r is the relative permittivity of the substrate material.

U-slot loaded patch is analyzed by considering two sections in the patch. First section is an E-shaped patch [12] and second (lower one) as microstrip bend line. The dimension of both sections is shown in Fig-1. Section 1 is analyzed as a patch in which two parallel notches are incorporated. This perturbation in the patch changes the current length which is accounted for by an additional series inductance ΔL and a series capacitance ΔC (Fig 3). So the equivalent circuit of section (1) is modified as Fig 4.

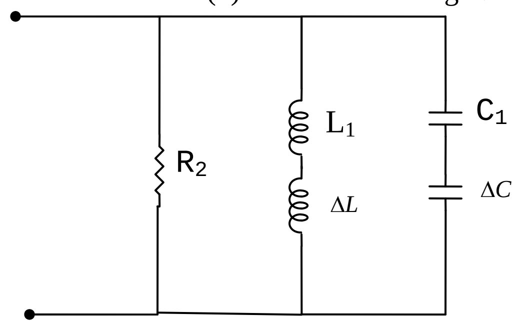


Fig. 3 Equivalent circuit of section (1)

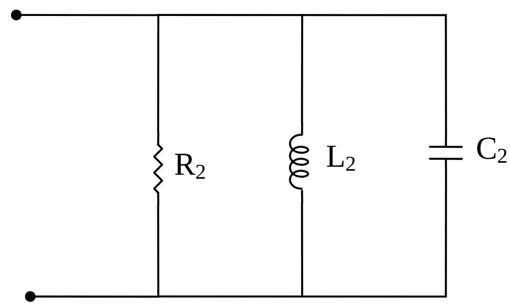


Fig. 4 Modified circuit of section (1)

in which

$$L_2 = L_1 + \Delta L$$

and

$$C_2 = \frac{C_1 \Delta C}{C_1 + \Delta C}$$

The additional inductance is given as [13]

$$\Delta L = \frac{Z_1 + Z_2}{16\pi f \cos^{-2}\left(\frac{\pi y_0}{L_E}\right)} \tan\left(\frac{\pi f l s}{c}\right) \quad \text{---(4)}$$

where

$$Z_1 = \frac{120\pi}{\frac{w_s}{h} + 1.393 + 0.667 \ln\left(\frac{w_s}{h} + 1.444\right)}$$

$$Z_2 = \frac{120\pi}{\frac{(w_s - 2d)}{h} + 1.393 + 0.667 \ln\left(\frac{w_s - 2d}{h} + 1.444\right)}$$

The capacitance ΔC is calculated as gap capacitance given by [14].

$$\Delta C = 2 l s \frac{\varepsilon_0}{\pi}\left[\ln\left(2\frac{(1+\sqrt{k'})}{1+\sqrt{k'}}\right) + \ln\coth\left(\frac{\pi d}{4h}\right) + 0.013 C_f \frac{h}{d}\right] \times \cos^{-2}\left(\frac{\pi y_0}{L_E}\right) \quad \text{--(5)}$$

where $k' = \sqrt{1-k^2}$

$$k^2 = \frac{\left(\frac{2w_s}{d} - 1\right)}{\left(1+\frac{w_s}{d}\right)\left(\frac{w_s - d}{d}\right)}$$

The second section is considered as two microstrip bend line and the equivalent impedance of this shape is given as [15].

$$Z_b = j\omega L_b + \frac{1}{\frac{1}{j\omega L_b} + j\omega C_b}$$

where

$$\frac{C_b}{w_b} = (9.5\varepsilon_r + 1.25)\frac{w_b}{h} + 5.2\varepsilon_r + 7.0 \quad \text{pF/m} \quad \text{-- (6)}$$

and

$$\frac{2L_b}{h} = 100\left(4\sqrt{\frac{w_b}{h}} - 4.21\right) \text{nH/m} \quad \text{--(7)}$$

Combining the above two sections we consider U-slot loaded patch and its equivalent circuit is given as shown in Fig. 5.

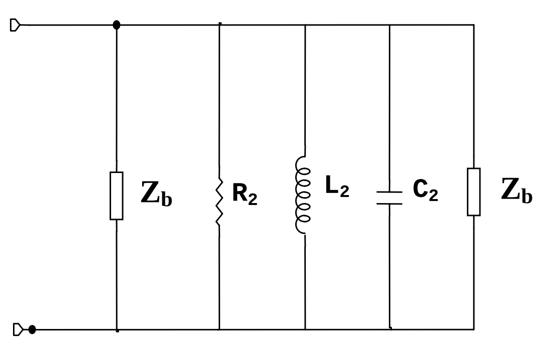


Fig. 5 Equivalent circuit of U-slot loaded patch

Now the total impedance of U-slot loaded patch is given as

$$Z_T = \frac{Z_b Z_P + Z_b Z_P + Z_b Z_b}{Z_b + Z_P + Z_b} \quad \text{--(8)}$$

$$Z_P = \frac{1}{\frac{1}{R_2} + \frac{1}{j\omega L_2} + j\omega C_2}$$

The microstrip antenna was designed for frequency 3 GHz. The design specifications of the U slot loaded patch are given below

Table 1: Design specifications of U-slot loaded patch

Length of the patch (L)	5 cm
Width of the patch (W)	7 cm
Dielectric substrate (ε_r)	Air, (ε_r =1)
Thickness of the patch (h)	15 mm
Length of the slot (ℓ_s)	3.2 cm
Width of the slot (d)	0.4 cm
Feed location (x_0, y_0)	(0,-1.495 cm)

IV. DISCUSSION OF RESULTS

Variation of return loss as a function of frequency for a given slot dimensions (w_s= 4 mm, ls= 3.2 cm) is shown in Fig. 6, alongwith the simulated results using IE3D software[16].

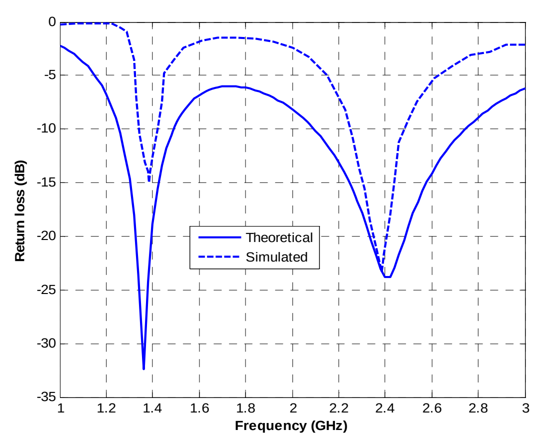
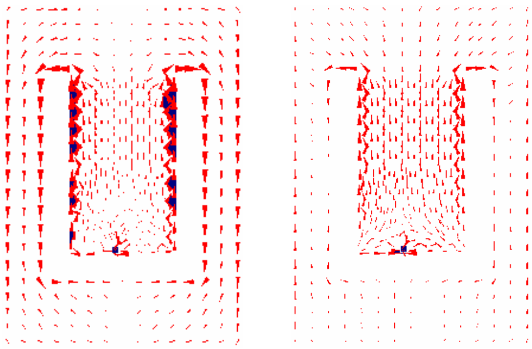


Fig.6 Variation of return loss with frequency (d=4 mm, ls=3.2cm, w_s= 4 mm)

It is found that the antenna resonates at two frequencies f_1=1.385 GHz and f_2=2.385 GHz which is attributed to the current distributions shown in Fig. 7 for lower and upper resonances respectively.



(i) Lower resonance (ii) Upper resonance

Fig. 7 Current distributions

It may be mentioned that both theoretical and simulated data are found to be approximately in close agreement so far as resonance is concerned.

The variation of return loss as a function of frequency for different value of slot width ‘d’ is shown in Fig. 8 for a given value of slot length ls = 3.2 cm (w_s=3 cm). It is observed that both lower and upper resonance frequency shift to higher frequency side with increasing value of slot width (d) this is because of the fact that increasing slot width decreases the current length.

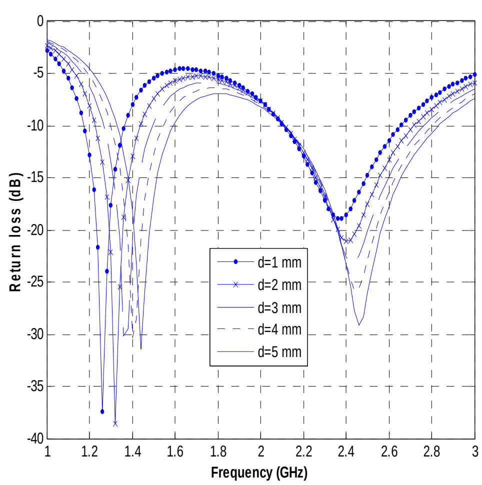


Fig. 8 Variation of return loss with frequency for different value of slot width (d) (ls=3.0 cm, w_s= 4 mm)

It is further observed that matching and bandwidth improve with increasing value of ‘d’ at upper resonance whereas matching degrades with increasing value of d at lower resonance.

Variation of return loss as a function of frequency is shown in Fig. 9 for different value of slot length for a constant value of slot width (d= 4mm).

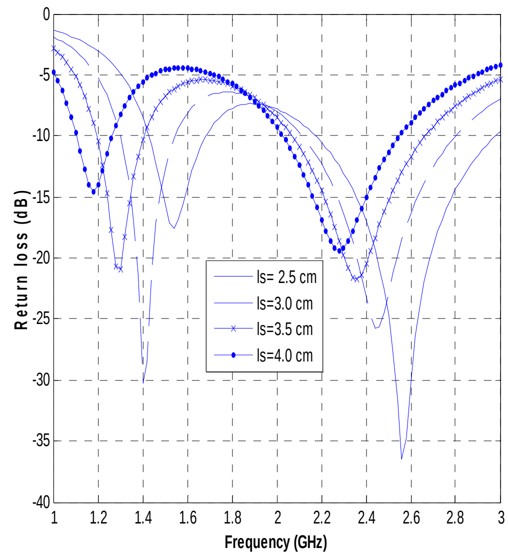


Fig. 9 Variation of return loss with frequency for different value of slot length (ls) (d= 4 mm)

It is observed that both lower and upper resonance frequency shift to lower frequency side with increasing value of slot length it is attributed to the fact that increase in slot lengths increases the current lengths and hence the resonance frequencies decrease.

It is interesting to note that ratio of the two resonances depend on the dimensions of the slot. It is found that ratio of two resonances (upper/lower i.e. f_2/f_1) decreases with increasing slot width for a given slot length of ls= 3.0 cm (Fig. 10 a), whereas the ratio of two resonances increases with increasing value of slot length for a given slot width of d=4 mm (Fig. 10 b). The dependence of ratio of two frequencies allows flexibility in the design of the dual band antenna.

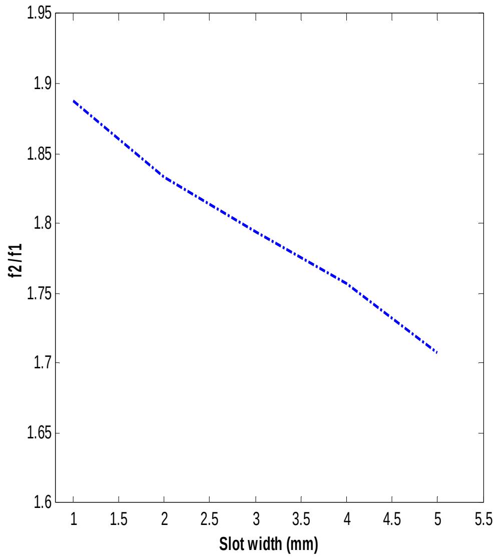


Fig. 10 (a) Variation of frequency ratio (f_2/f_1) with slot width (ls= 3 cm, w_s= 4 mm)

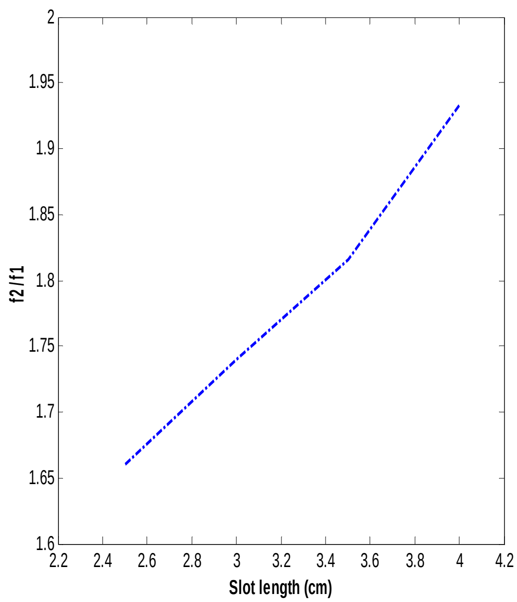


Fig.10 (b) Variation of frequency ratio (f_2/f_1) with slot length (d=4 mm, w_s= 4 mm)

V. CONCLUSIONS

From the analysis it is found that a dual band antenna with specific frequency ratio can be designed by cutting an U-slot with suitable dimensions. Both upper and lower resonance frequencies are controllable by the U-slot parameters.

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