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A NEW DUAL-BAND MICROSTRIP ANTENNA WITH U-SHAPED SLOT

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Abstract—In this paper, we present a new dual band planar antenna. The proposed antenna consists of a microstrip patch with a U-shaped slot that is fed by a broadband electromagnetic coupling probe, known as L-probe. Radiation characteristics of the antenna and different methods for control of the resonant frequencies are investigated.

1. INTRODUCTION

Microstrip antennas are widely used in many applications due to their low profile, low cost and ease of fabrication. In some applications it is desired to have a dual band or multiband characteristics. These characteristics can be obtained by coupling multiple radiating elements or by using tuning devices such as varactor diodes [1, 2]. However, these methods make antenna more complicated. A simple method to achieve the dual band characteristic in a microstrip antenna is embedding a slot in the patch as the structure proposed in [3] in which the radiating patch includes a pair of step-slots. In microstrip antennas, embedded slots can also be used to enhance the impedance bandwidth of a single band antenna. A circular arc slot [4] and a U-shaped slot [5] have

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been investigated in order to broaden the bandwidth of a single band antenna.

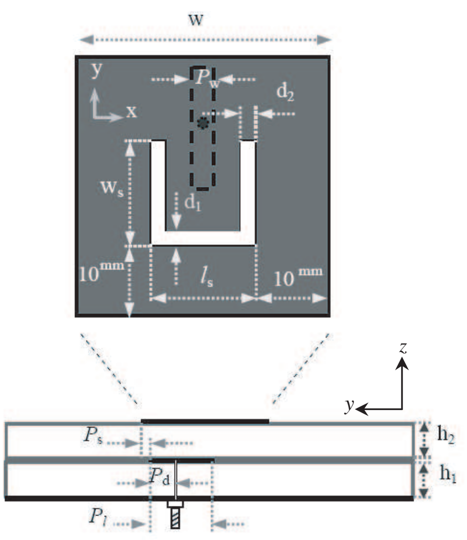
To realize a broadband characteristic in feeding a microstrip antenna, an L-probe can be used. This feeding structure is also known as broadband electromagnetic coupling probe [6].

In this paper, dual band characteristics are achieved by embedding a U-shaped slot in a rectangular patch. Also, an L-probe is used to realize matching between the feed system and radiating system in a wide frequency range. Radiation performance of the designed antenna is simulated using the HFSS software and the simulated results are validated by experimental results.

2. ANTENNA CONFIGURATION

The configuration of the proposed antenna is shown in Fig. 1(a). The substrate used for this design is RF-35 with relative permittivity of 3.5, loss tangent of 0.0018 and thickness of $h_1 = h_2 = 1.524\,\text{mm}$. Dimensions of the ground plane are also $100\,\text{mm} \times 100\,\text{mm}$.

As shown in Fig. 1, the radiating element is a square patch



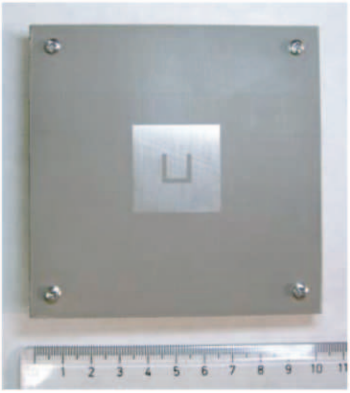


Figure 1. Configuration of the proposed antenna, (a) top view of the radiating patch and side view of the whole antenna structure, (b) photograph of the fabricated antenna.

with a U-shaped slot. The radiating patch is fed by a broadband electromagnetic coupling probe, known as L-probe. By using the slot, the dual band operation of the antenna can be achieved. In general, the first resonant frequency is associated with the size of the square patch and the second resonant frequency is associated with the U-slot parameters. The other parameters in Fig. 1 (P_d, P_w, P_l, P_s) are optimized to achieve good impedance matching at both resonant frequencies. For obtaining two resonant frequencies at 2.28 GHz and 3.80 GHz, optimum values of the structural parameters of the antenna are as follows.

$$w = 30\,\mathrm{mm},\ w_s = 10\,\mathrm{mm},\ l_s = 10\,\mathrm{mm},\ d_1 = 1.5\,\mathrm{mm},\ d_2 = 1.5\,\mathrm{mm}$$
$$P_l = 15\,\mathrm{mm},\ P_w = 2.5\,\mathrm{mm},\ P_s = 1.75\,\mathrm{mm},\ P_d = 7.05\,\mathrm{mm}$$

The proposed antenna with optimum dimensions has been fabricated. Fig. 1(b) demonstrates the photograph of the fabricated antenna.

3. RETURN LOSS

Figure 2(a) illustrates both the simulated and experimental results of the antenna return loss. Here, return loss is defined as $R = 20 \times \log_{10} |\Gamma|$, where Γ is the reflection coefficient. As shown in this figure, experimental values of the first and second resonant frequencies are 2.31 GHz and 3.78 GHz, respectively. Current paths of the 1st and 2nd modes are shown in Fig. 2(b). Dash-dot lines show the average length of current paths for each mode.

In accordance with results shown in Fig. 2(b) the resonant frequencies can be calculated approximately as follows:

$$f_1 = \frac{c}{2\sqrt{\varepsilon_{\mathit{eff}}}L_1} \tag{1}$$

$$f_2 = \frac{c}{2\sqrt{\varepsilon_{\mathit{eff}}}L_2} \tag{2}$$

where L_1 and L_2 are the average lengths for current paths of the 1st and 2nd resonant modes and c is the free space velocity of light.

The effective permittivity ($\varepsilon_{\mathit{eff}}$) is also given by [7]:

$$\varepsilon_{\mathit{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10h}{w}\right)^{-0.555} \tag{3}$$

where h and w are height of the substrate and width of the patch, respectively. The above equation, which is given in [7], is valid for single layer substrates. However, while the effect of L-shaped feed system is negligible, this equation can be used for two-layered substrates

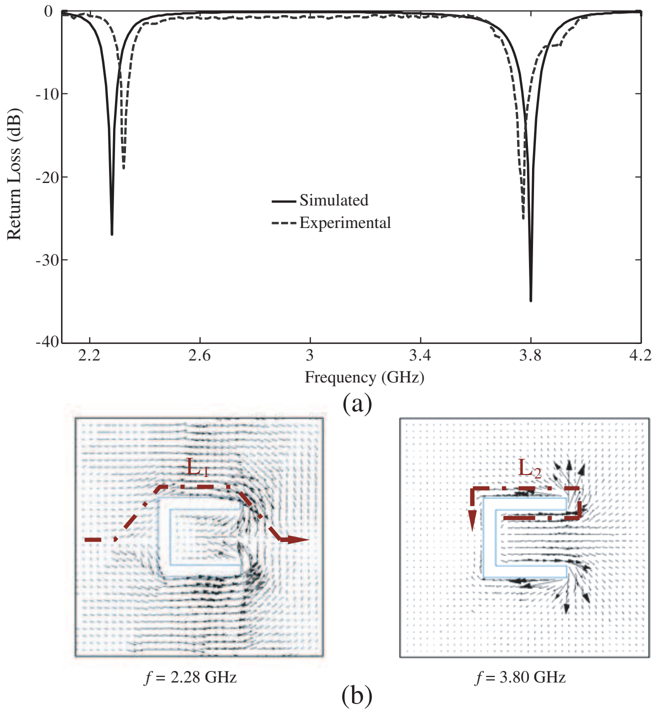


Figure 2. (a) Return loss of the antenna, (b) current paths of the 1st and 2nd modes.

provided that the parameter h is substituted by the total height of $h_1 + h_2$.

The average lengths for current paths of the 1st and 2nd resonant modes can be obtained by using the following approximate relations:

$$L_1 = \alpha_1 l_s + \alpha_2 w_s + \alpha_3 w. \tag{4}$$

$$L_2 = \beta_1 d_1 + \beta_2 d_2 + \beta_3 l_s + \beta_4 w_s. \tag{5}$$

Based on results of several simulations, optimum values of α_i and β_i in the above equations are obtained as follows.

$$\alpha_1 = 0.385,\ \alpha_2 = 0.445,\ \alpha_3 = 1.000$$

$$\beta_1 = -1.097,\ \beta_2 = 0.630,\ \beta_3 = 0.876,\ \beta_4 = 1.412$$

For the values of parameters given in Section 2, the average lengths of current paths for the 1st and 2nd resonant modes are obtained as $L_1 = 38.3\,\text{mm}$ and $L_2 = 22.2\,\text{mm}$. Also, the effective permittivity is obtained as 3.097. Thus, Equations (1) and (2) give the resonant frequencies of 2.23 GHz and 3.84 GHz, respectively.

4. RADIOTIAN PATTERN

Figure 3 shows the measured co-polarization and cross-polarization radiation patterns for both resonant modes. As shown in this figure, radiation pattern of the antenna is broadside at both resonant frequencies. Also the cross-polarization of the 1st mode is 17 dB less than the co-polarization values in the angular region of $\theta < 50°$. For the 2nd mode, the cross-polarization level is considerably low in the E-plane, and its values in the H-plane are acceptable in the region of $\theta < 20°$. We have previously shown current paths of the 1st and 2nd modes in Fig. 2(b). Increasing the cross-polarization level of the 2nd mode in the H-plane is due to the large x-component of the current density in the vicinity of the right and left edges of the slot.

Figure 4 shows simulated radiation efficiency. As shown in this figure, the efficiency of designed antenna is better than 80% in both of 1st and 2nd modes.

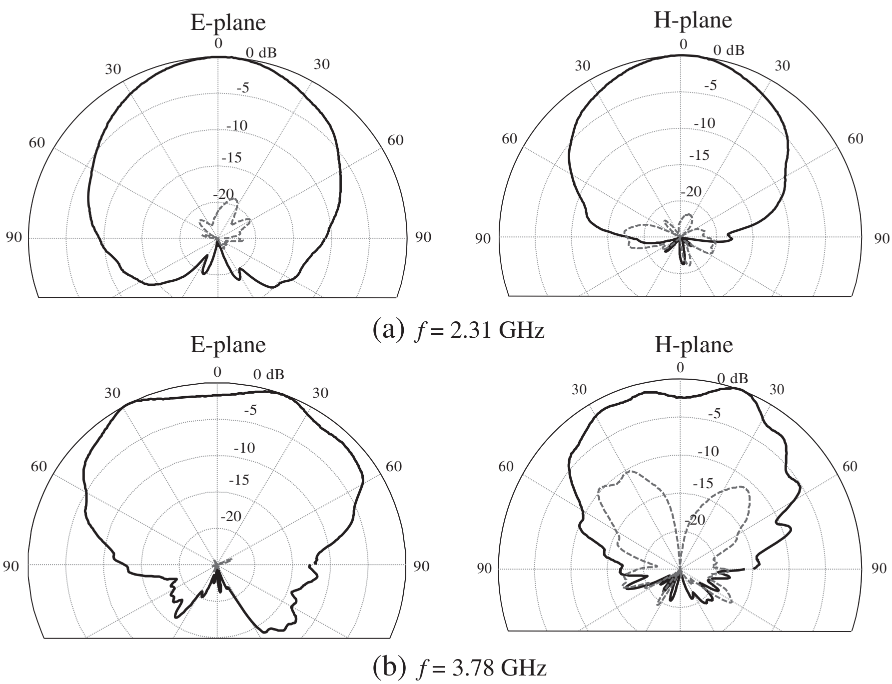


Figure 3. Measured radiation patterns of (a) the 1st mode, and (b) the 2nd mode. Co-pol: —, X-pol: - - -.

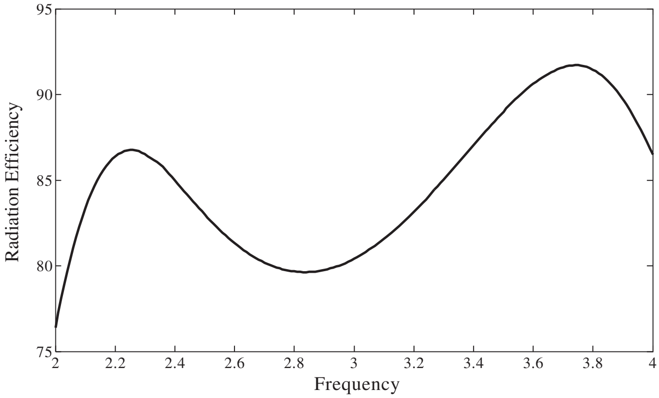


Figure 4. Radiation efficiency of the antenna.

5. FREQUENCY CONTROL

From current distribution shown in Fig. 2, it is found that the first resonant frequency can be easily controlled by adjusting the width of the square patch that was represented by parameter w. Fig. 5(a) illustrates variation of the first resonant frequency versus variation of the parameter w. Now it is desired to introduce a method for control of the resonant frequency of the second mode with minimum effect on the first mode.

In accordance to Equation (5), when the parameter w_s and l_s are varied, the 2nd current path is changed and so the 2nd resonant frequency is altered. For example, as shown in Fig. 5(b), when w_s is varied from 7 mm to 12 mm, the resonant frequency of the 2nd mode moves from 4.35 GHz to 3.44 GHz. In this case the resonant frequency of the 1st mode varies from 2.34 GHz to 2.22 GHz.

The other parameter that can be used to control the resonant frequency of the 2nd mode is d_1. In accordance to Equations (4) and (5), increasing d_1 results in an increase of the 2nd resonant frequency, while the 1st resonant frequency remains fixed. Fig. 5(c) illustrates variation of the second resonant frequency versus variation of the parameter d_1.

Figure 6 presents the resonant frequencies of the first and second modes and ratio of the two frequencies against d_1 and w_s. As shown in this figure, the ratio of the two resonant frequencies varies from 1.55 to 1.86 in Fig. 6(a), and from 1.49 to 2.02 in Fig. 6(b). It should be noted that for all cases presented in Figs. 5 and 6, feed position and its parameters (P_d, P_w, P_l, P_s) are fixed and equal to the values given in

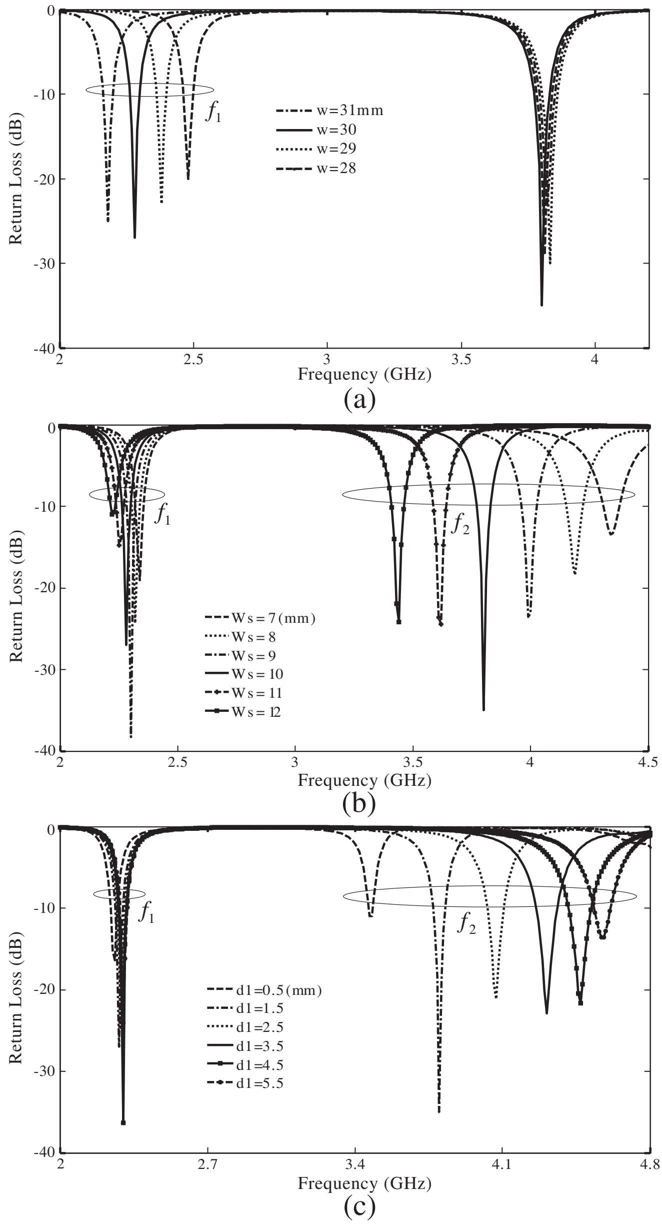


Figure 5. Variation of the resonant frequencies versus (a) w, (b) d_1 and (c) w_s. $P_l = 15\,\text{mm}$, $P_w = 2.5\,\text{mm}$, $P_s = 1.75\,\text{mm}$, $P_d = 7.05\,\text{mm}$.

Section 2. This is due to the broadband characteristic of the L-probe feeding structure. This can be compared with the structures presented in [3, 8] in which the feed position should be varied according to the resonant frequencies of the antenna.

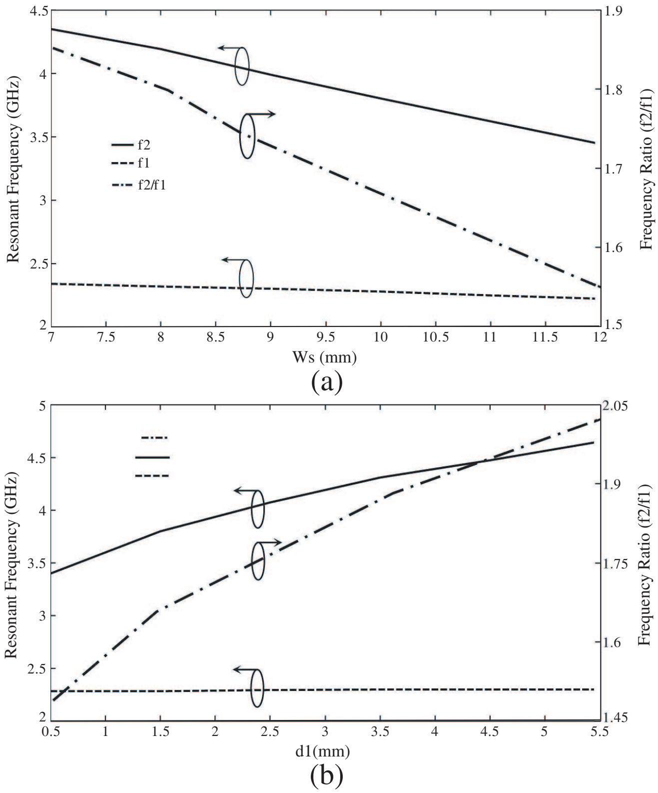


Figure 6. Variation of the resonant frequencies and frequency ratio versus (a) w_s, and (b) d_1.

6. CONCLUSION

In this paper, a new dual band microstrip antenna with U-shaped slot is studied. To provide a wideband matching in feeding system, a broadband electromagnetic coupling probe is used. Radiation characteristics of the antenna are investigated experimentally and by numerical simulations. It is shown that the antenna radiation pattern is broadside and cross-polarization level is low at both resonant frequencies. Frequency control method of the proposed antenna is discussed. It is shown that the frequency ratio (f_2/f_1) can be easily adjusted by appropriate selection of the structural parameters.

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