

## DUAL-FREQUENCY OPERATION OF A SINGLE-FEED RECTANGULAR MICROSTRIP ANTENNA WITH A $\pi$ -SHAPED SLOT

Hua-Ming CHEN\* and Yi-Fang LIN\*\*

\*Department of Physics

National Kaohsiung Institute of Technology, Kaohsiung 807, Taiwan

E-mail [hmchen@cc.nkit.edu.tw](mailto:hmchen@cc.nkit.edu.tw)

\*\*Department of Electronic Engineering

Cheng-Shiu Institute of Technology, Kaohsiung 833, Taiwan

### 1. Introduction

Recently, several dual-frequency designs of single-feed slotted rectangular microstrip antennas have been reported [1-3]. The two operating frequencies of such dual-frequency slot-loaded rectangular patches are of the same polarization planes and similar broadside radiation patterns. In such dual-frequency designs, different tunable frequency-ratio ranges for the two operation frequencies are also obtained. For the case, by etching a pair of narrow slots close to and parallel to the patch's radiating edges, the tunable frequency-ratio range is typical within 1.6-2.0 [1-3]. This frequency ratio confines the applications of such designs where a lower frequency ratio is required. As for obtaining a frequency ratio less than 1.6, the structure of such a slot-loaded microstrip antenna must be modified.

In this paper, we demonstrate that, by loading a  $\pi$ -shaped slot close to the radiating edge with a single probe feed located along the centerline of the rectangular patch (see Fig. 1), a new dual-frequency operation of the antenna can easily be obtained. The two operating frequencies of the proposed antenna are also found to have the same polarization planes and similar broadside radiation characteristics and the frequency ratio of the two frequencies is obtained ranging from 1.12 to 1.27, which is smaller range than that (1.6-2.0) of the conventional slotted designs [1-3]. This can make the present proposed antenna more suitable for dual-frequency applications where a lower frequency ratio is required. Details of the antenna design and experimental results are presented and discussed.

### 2. Antenna design and experimental results

The geometry of the  $\pi$ -shaped slotted microstrip antenna is shown in Fig. 1. The rectangular patch has a dimension of  $L \times W$ , and is printed on a substrate of thickness  $h$  and relative permittivity  $\epsilon_r$ . The  $\pi$ -shaped slot is etched on the rectangular patch close to and parallel to one of the radiating edges of the patch. The location of the embedded slot with respect to the radiating and non-radiating edge is denoted as  $l$  and  $w$ , respectively. The spacing between one arm of the  $\pi$ -shaped slot and x-axis is  $W_s$ . The lengths of the arms on the  $\pi$ -shaped slot are denoted as  $L_s$ . The widths of all the  $\pi$ -shaped slots are

the same, and denoted as  $d$  (1 mm in this study). Good impedance matching of the two operating frequencies can be obtained by using a single probe feed at a position  $x_p$  away from the patch center.

It is first noted that, by loading a pair of narrow slots close to the radiating edges of a rectangular microstrip patch [1-2], dual-frequency operation of the microstrip antenna can be obtained. The resonant frequencies associated with the modified  $TM_{10}$  mode is denoted as  $f_{10}$ . A simple-empirical formulas of modifying the well established formulas for rectangular unslotted patch have been found and written as [1-2]

$$f_{10} = \frac{c}{2(L + \Delta L + \Delta L')\sqrt{\epsilon_e}}, \quad (1)$$

where  $c$  is the speed of light in free-space,

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[ 1 + \frac{10h}{W} \right]^{-1/2}, \quad (2)$$

$$\Delta L = \frac{h}{\pi} \frac{W/h + 0.336}{W/h + 0.556} \left\{ 0.28 + \frac{\epsilon_r + 1}{\epsilon_r} [0.274 + \ln(W/h + 2.518)] \right\}, \quad (3)$$

$$\Delta L' = L \left( 1.5 \frac{l}{L} - 0.4 \frac{w}{W} \right). \quad (4)$$

It is worth noting that,  $\Delta L$  is the equivalent overlength for standard rectangular patch, and  $\Delta L'$  is a correction factor for the two slot-loading effect that depends on  $l$  and  $w$ . It is first found that, by embedding only one slot (without arms of the  $\pi$ -shaped slot) close to the radiating edge of the rectangular patch, the first mode ( $f_{10}$ ) has been excited at resonant 1746 MHz and shown in Fig.2. The first mode is good agreement with the calculated result of the equation (1), which is 1742 MHz.

When embedding a pair of slots parallel to the non-radiating edges of the one slot loading patch, called  $\pi$ -shaped slot loading antenna, and a new resonant mode between the  $TM_{10}$  and  $TM_{20}$  modes of the one slotted rectangular patch antenna can be excited. Typical proposed antennas were implemented and experimented. Fig. 3 shows the measured return loss for the proposed antenna with various arm's positions ( $W_s$ ). Note that the frequency  $f_1$  is the resonant frequency of the perturbed  $TM_{10}$  mode and  $f_2$  is for the new resonant mode excited between the  $TM_{10}$  and  $TM_{20}$  modes. It is first found that the two excited resonant modes have good impedance matching for various arm's positions. The first resonant frequency ( $f_1$ ) decreases rapidly with increasing arm's position ( $W_s$ ), and the second resonant frequency ( $f_2$ ) is, however, very slightly affected by the variation of  $W_s$ , which results in an increase of the frequency ratio. The different effects of the slot loading on the first two resonant frequencies make a tunable frequency ratio ( $f_2 / f_1$ ) in the range of about 1.12 to 1.27.

By using the simulation software IE3D<sup>TM</sup>, the excited patch surface current densities for the two operating frequencies of the proposed antenna are also simulated and analyzed. For the case of  $f_1$ , the current distribution of the  $TM_{10}$  mode is strongly perturbed, since the arms of the  $\pi$ -shaped slot are existent. And owing to the arms of the  $\pi$ -shaped slot loading, the null of the current distribution is closed to the two edges of each arm-slot. The currents find a resonant condition by circulating around

the arm-slot, and the current-line path length with increasing the arm's position. An approximate equation is derived by fitting the experimental datas and written as

$$f_1 = \frac{c}{2(2L_s + d + W_s + \Delta W)\sqrt{\epsilon_e}}, \quad (5)$$

$$\Delta W = 2.003 \quad (6)$$

is a orrection fator for the  $\pi$ -shaped slot loading effect.  $\epsilon_e$  is effctive dielectric constant and can be determined by equation (2).

As for the case of  $f_2$ , the new resonant mode is slightly affected by changing the arm's position. It is seen that the excited current distribution is very similar to that of the  $TM_{10}$  mode of the case without the arm-slot. Thus, for the present dual-frequency design, the two operating frwquencies are expected to be of the same polarization planes and similar radiation characteristics. It is also obtained by a curved fitting method and approximate equation can be predicted according to

$$f_2 = \frac{c}{2(L/2 + L_s + \Delta L)\sqrt{\epsilon_e}}, \quad (7)$$

$$\Delta L = 1.616 \quad (8)$$

where  $\Delta L$  is also a orrect factor of the slot-loading efeect for the resonant mode  $f_2$ . And the equation (7) is independent of  $W_s$ , that is, the resonant mode  $f_2$  is slighedly affected with the various arm's position. The calculated results of equation (5) and (7) are shown in Fig. 4 for comparison. The experimental results of the radiation patterns are shown in Fig. 5. It is seen that both operating frequencies have the same radiation patterns and polarization planes, and good cross-polarization is also observed.

### 3. Conclusions

A novel rectangular microstrip antenna has been proposed to operate at dual frequencies. The microstrip antenna using a single probe feed and with a  $\pi$ -shaped slot embedded close to the patch radiating edge is proposed and experimentally studied. The two operating frequencies have the same polarization planes and similar broadside radiation characteristics. By varying the spacing of the two arms on the  $\pi$ -shaped slot, the proposed antenna can be provided a tunable frequency ratio from about 1.12 to 1.27. From physical models, simple semi-empirical formulas of the two frequencies have been obtained.

### 4. References

- [1] S. Maci, G. Gentili Biffi, P. Piazzesi and C. Salvador, "Dual-band slot-loaded patch antenna", *IEE Proc.-Microw. Antennas Propagat.*, vol. 142, no. 3, 1995, pp. 225-231.
- [2] S. Maci, G. Gentili Biffi, P. Piazzesi, "Dual-frequency patch antennas", *IEEE Antennas and Propagat. Magazine*, vol. 39, no. 6, 1997, pp. 13-20.
- [3] M. E. Yazidi, M. Himdi, and J. P. Daniel, "Aperture coupled microstrip antenna for dual frequency operation", *Electron. Lett.*, vol. 29, no. 17, 1993, pp. 1506-1508.

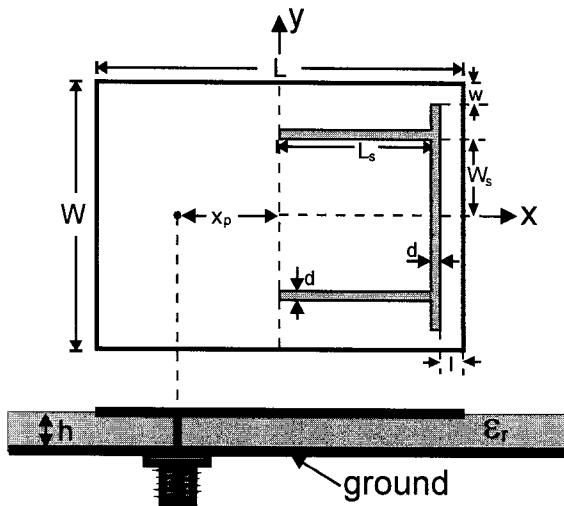


Fig. 1 Geometry of rectangular microstrip antenna with a  $\pi$ -shaped slot

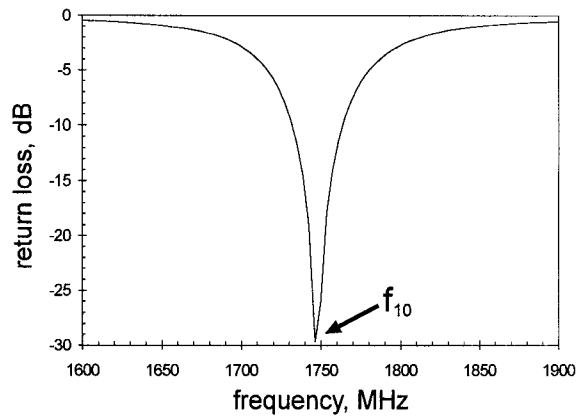


Fig. 2 Measured return loss against frequency for the one slotted rectangular microstrip antenna

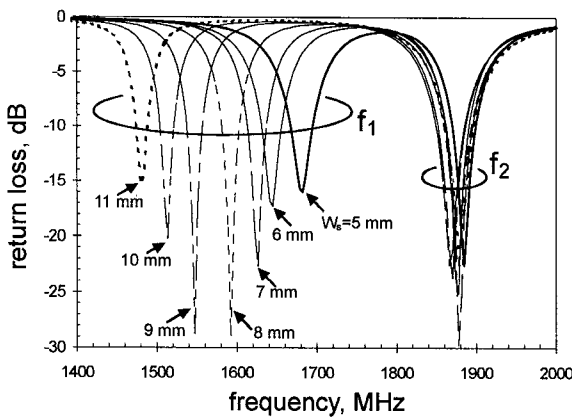


Fig. 3 Measured return loss for the proposed antenna with various arm's position ( $W_s$ )

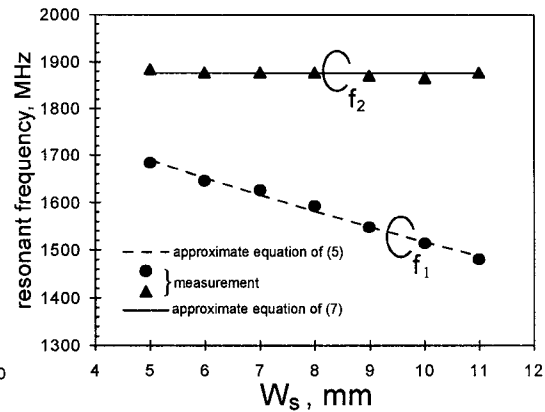


Fig. 4 Calculated and experimental resonant frequencies against various arm's position ( $W_s$ )

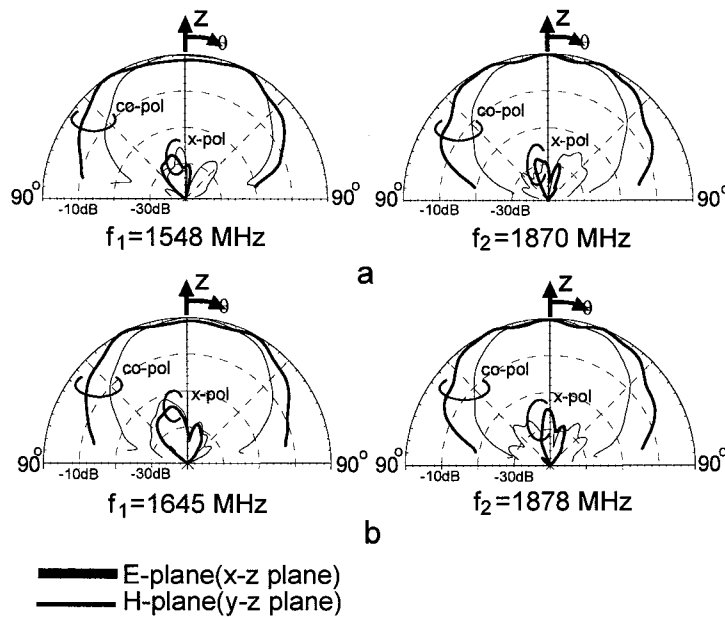


Fig. 5 Measured radiation patterns for the proposed antenna  
 (a)  $W_s = 9$  mm  
 (b)  $W_s = 6$  mm