

# Design of Small Antennas for Multi Frequency Bands Operation

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Three single-feed microstrip patch antennas for multi-band operation are proposed in this paper. The first one is a planar inverted-F antenna (PIFA) with an L-shaped slit combined with a parasitic patch in co-planar geometry. It exhibits two operating frequency bands, which cover ISM bands (2.45 and 5.8 GHz) and U-NII bands (5.1, 5.2 and 5.8 GHz). There are four shorting pins inserted into the antenna. The second proposed antenna is a PIFA with a tilted slit and a shorting pin. It provides an impedance bandwidth which is wide enough to cover both IMT-2000 and 2.45 GHz ISM bands. The third antenna is a tri-band PIFA consisting of a U-shaped slot, one shorting pin and one shorting wall. It is able to generate three resonances (0.9, 1.8 and 2.45 GHz). Simulation and experimental results are given to verify the proposed antenna designs.

**Keywords:** Small Antennas, PIFA, Multi-bands, Shorting Pin, Shorting Wall

## Introduction

In recent years, there has been an explosion of wireless communication applications such as portable Wireless Local Area Network (WLAN) - 802.11a and 802.11b/HiperLAN2, etc. In addition, people would like to integrate the Bluetooth system in their handsets or personal digital assistants (PDAs) nowadays. Therefore, integrating different wireless communication systems into a single portable device would be much desirable and there is a great demand for compact antennas that can cover several frequency bands to address both space and cost issues. Planar inverted-F antennas (PIFAs) are good candidates due to their ease of design, compactness and low cost. PIFAs using L or U-shaped slots for dual-frequency operation have been reported in [1-4]. On the other hand, a recent design using a shorted patch to drive a parasitic patch yielding a dual-band operation has been demonstrated in [5].

In this paper, we propose three microstrip patch antennas making use of shorting pin and shorting wall for impedance matching and size reduction. The L-shaped slit antenna, which has four shorting pins, can cover the ISM bands (2.45 and 5.8 GHz) and U-NII bands (5.1, 5.2 and 5.8 GHz). It is a printed microstrip patch antenna with a parasitic patch in co-planar arrangement next to the main patch. An L-shaped slit is introduced in the main patch in order to obtain a dual-band operation. Three shorting pins are included within the main patch to reduce the size of the antenna. To cover all the frequency bands (5.1, 5.2 and 5.8 GHz), a parasitic patch is attached to one side of the antenna to generate one more resonance so that the upper band of the dual-band operation can be widened. Another shorting pin is also inserted in the parasitic patch for reducing its size. The proposed antenna is simulated using Ensemble [6]. A prototype is fabricated and tested, confirming that this compact antenna can cover all the aforementioned ISM and U-NII bands.

Higher speed and larger capacity are the advantages of the third generation (3G) mobile communication systems. Therefore, a foreseeable rapid growth for 3G systems is expected. To address this issue, our second proposed antenna is designed for IMT-2000 and 2.45 GHz ISM bands. The tilted slit provides a longer current path leading to a patch size reduction. Another commercial simulation software IE3D version 10.06 [7] is used to confirm the antenna design.

Originally, the third proposed antenna contains a U-shaped slot on the patch which is only able to perform dual-band operation. But in our design, one more slit is cut on the patch and an additional shorting wall is inserted near the feed point, making the antenna operate in three different

frequency bands (0.9, 1.8 and 2.45 GHz). Although further enhancement in the impedance bandwidth performance is required, it demonstrates the feasibility of obtaining the above three operating frequency bands by using a single-feed U-shaped slot PIFA. In addition, several parameters regarding to the third proposed antenna are being investigated. Both simulation and experiment are done to verify the antenna design, where the IE3D is used to perform the simulation and parametric studies.

## Antenna Structures

### L-shaped Slit Antenna

The proposed L-shaped slit antenna geometry is shown in Fig 1 and Fig 2. The patch antenna is printed on an inexpensive FR4 substrate with a thickness of 0.5 mm and a dielectric constant of 4.6. There is an air layer of 4 mm separating the substrate and the ground plane. The main patch is divided into two sections by an L-shaped slit. On one of its side, the main patch is shorted to the ground plane via three shorting pins (diameter 1 mm) for size reduction, a typical property of the PIFA. It is noted that the use of three shorting pins provides a better impedance matching in the lower frequency band when compared with one or two shorting pins. In addition, shorting pins are easier to fabricate than a shorting wall. Since the proposed antenna is designed for integrating into a PCMCIA card, so the width of the ground plane is chosen to be

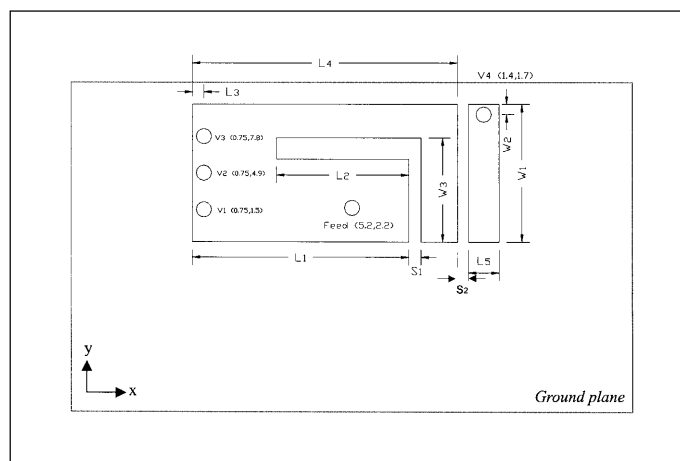


Figure 1 – Geometry of the Proposed L-shaped Slit Antenna (Top View)

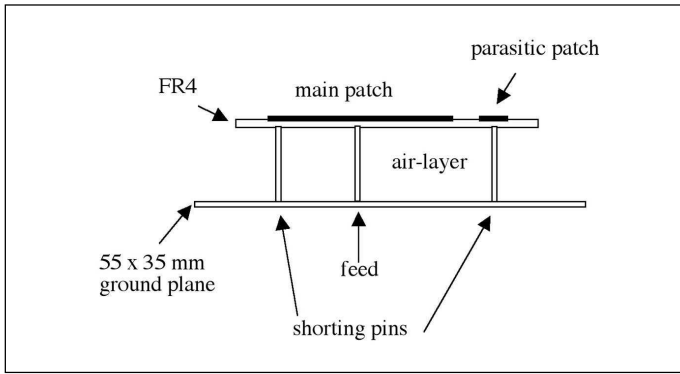


Figure 2 – Geometry of the Proposed L-shaped Slit Antenna (Side View)

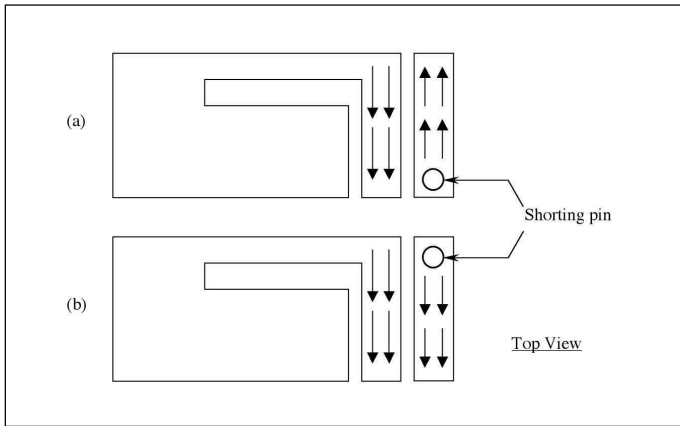


Figure 3 – Direction of Current Flow, (a) with Shorting Pin Located at the Bottom of the Parasitic Patch and (b) with Shorting Pin Located at the Top of the Parasitic Patch

the same as the width of the PCMCIA card. By adjusting  $L_1$  and  $L_4$  of the L-shaped slit, two operating frequency bands would be obtained. Furthermore, in order to achieve a wider impedance bandwidth for the upper operating frequency band, a parasitic patch with dimensions  $L_5 \times W_1$  is added with spacing  $S_2$  away from the main patch. This parasitic patch will resonate at a frequency close to the upper band of the main patch, so that the overall bandwidth of the upper operating frequency band can be greatly enhanced. It is also found that a shorting pin could be added to the parasitic patch for size reduction. However, caution is needed for selecting the location of this shorting pin. If the shorting pin is put in the opposite end of the parasitic patch, a good input impedance matching can be also achieved at the upper frequency bands but the antenna gain would be substantially reduced. Simulation results reveal that the current on the parasitic patch and the current along the nearby edge of the main patch are flowing in opposite directions and this leads to a cancellation effect. In contrast, when the shorting pin is placed at the proper location in the parasitic patch as shown in Fig 3, the two currents will flow in the same direction leading to a reasonable antenna gain. However, there is no significant current induced in the parasitic patch at the lower frequency band.

### Tilted Slit Antenna

In [8], a single-feed PIFA with a slit was reported to obtain two separate frequency bands operation. However, in our second proposed antenna design, one resonance is used to provide an impedance bandwidth of 27.3% ( $VSWR \leq 2.5$ ), that covers both IMT-2000 and 2.45 GHz ISM bands. The slit is etched on a FR4 PCB with a thickness of 0.5 mm and a dielectric constant of 4.6. In addition, the slit is modified as a tilted one, so that a longer current path is provided in order to reduce the overall size of the radiating patch. The PCB is separated by a 7 mm air layer above the ground plane, and the whole radiating element is located at 3 mm away from the left edge of the ground plane. The antenna geometry is

depicted in Fig 4. The size of the ground plane is 70 mm x 30 mm, which is sufficiently compact to be installed in most handsets available in the market. The ground plane here can be modeled as one of the layers in a multi-layered PCB. The shorting pin and probe feed have diameters of 2 mm and 1 mm respectively. The shorting pin is located at  $(x,y) = (3.5,19.5)$  mm of the Cartesian coordinate system with the origin  $(0,0)$  at the lower left-hand corner of the radiating patch. While the corresponding parameters for the probe feed are  $(5.0,14.5)$  mm.

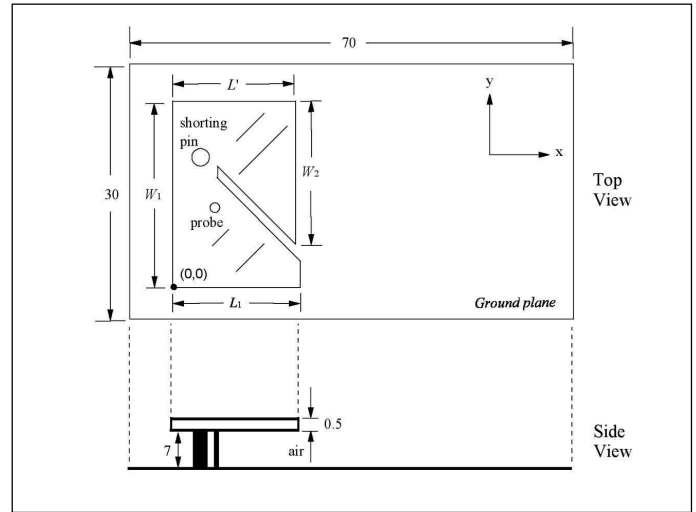


Figure 4 – Geometry of the Proposed Tilted Slit Antenna (Top View and Side View)

### U-shaped Slot Antenna

The proposed geometry of the U-shaped slot antenna is shown in Fig 5. The substrate of the antenna is FR4 with thickness of 1.6 mm and the dielectric constant of 4.6. There is a shorting wall (width 1 mm), a shorting pin (diameter 1 mm) and a ground plane presented in the antenna. In order to accommodate the shorting wall, a 1 mm slit is cut near the feed location. Although putting a shorting pin would be easier than a shorting wall, we found that only a small shorting wall is needed. The 1 mm shorting pin would be too thick for obtaining the required operating frequency bands. Therefore, a 1 mm shorting wall is finally chosen. The shorting wall is mainly used for matching the input impedance and tuning the first two resonances to desired frequency bands. In addition, without the shorting pin, the first two resonances of the antenna will shift to lower frequency bands. Therefore, by properly choosing the location

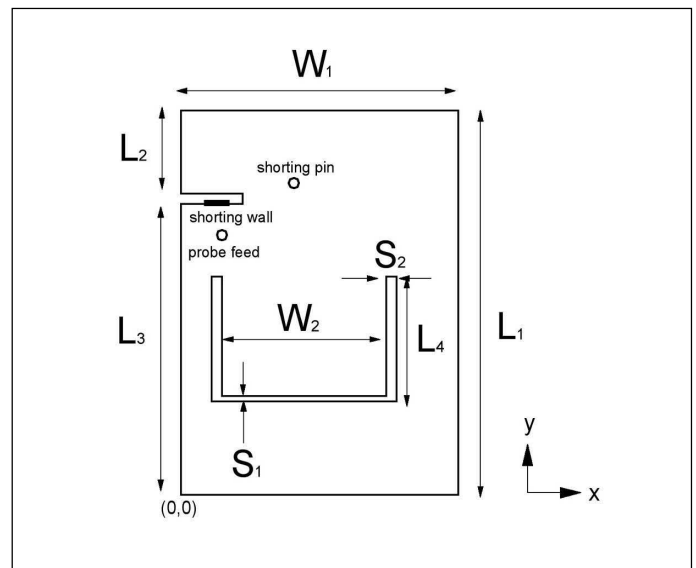


Figure 5 – Geometry of the Proposed U-shaped Slot Antenna (Top View)

of the shorting wall and pin, three operating frequency bands (0.9, 1.8 and 2.45 GHz) could be obtained within a single-feed microstrip patch antenna. The shorting pin and shorting wall are located at (11, 30) mm and (4, 28) mm, respectively. While the corresponding parameters for the probe feed are (4, 25) mm.

### Simulation and Measurement Results

#### L-shaped Slit Antenna

The proposed antenna is fabricated with the following dimensions:  $L_1 = 14.7$ ,  $L_2 = 8$ ,  $L_3 = 0.75$ ,  $L_4 = 18.2$ ,  $L_5 = 2.8$ ,  $W_1 = 10$ ,  $W_2 = 1.2$ ,  $W_3 = 7.3$ ,  $S_1 = 0.9$  and  $S_2 = 1.1$  mm. Fig 6 shows the comparison of the simulated and measured S11. The slightly shift in the resonant frequency may due to the fabrication tolerances. In addition, an infinite FR4 layer has been assumed in the simulation which is different from

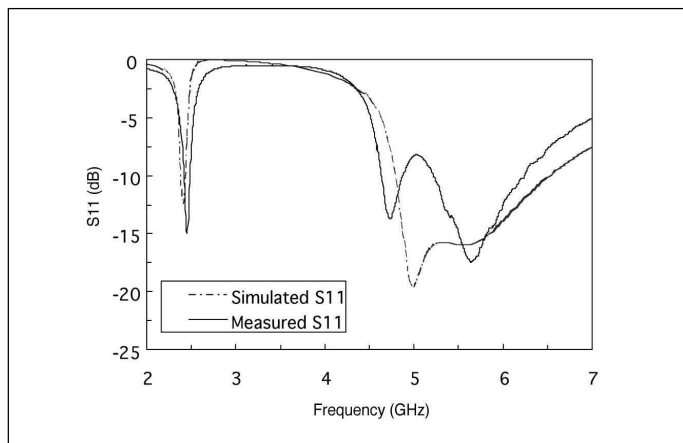


Figure 6 – Simulated and Measured S11 of the Proposed L-shaped Slit Antenna

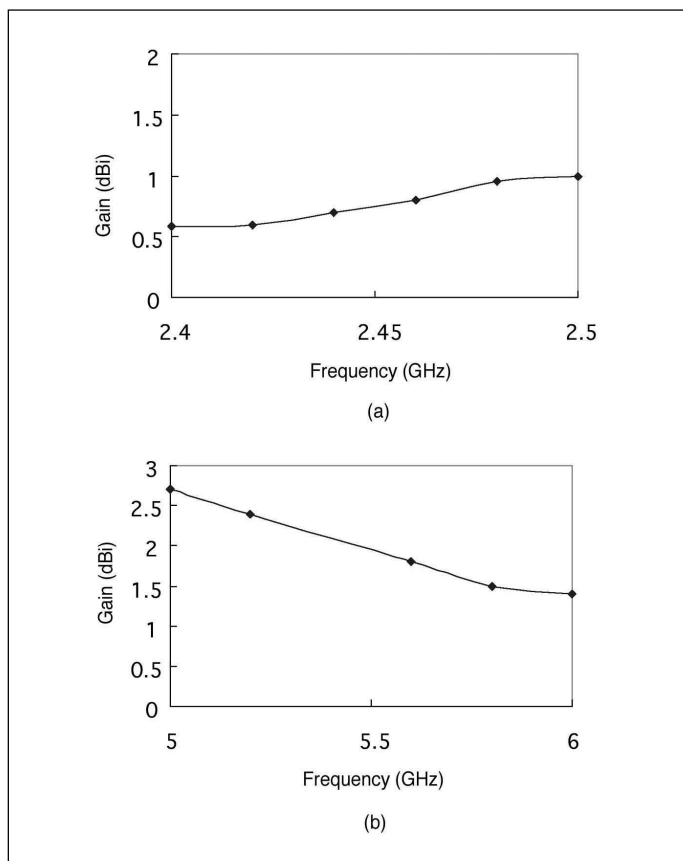


Figure 7 – Measured Antenna Gain of the Proposed L-shaped Slit Antenna, (a) Lower Frequency Band and (b) Upper Frequency Band

the fabricated antenna. According to the result, the impedance bandwidth of the first resonant frequency at 2.45 GHz is 114 MHz for  $VSWR \leq 2.5$  (or  $-7.3$  dB in S11). While for the upper resonant frequency at 5.6 GHz, a much wider impedance bandwidth is obtained (4.6 - 6.6 GHz) for  $VSWR \leq 2.5$ . This is because the main patch and the shorted parasitic patch generate two resonating modes at two close frequencies. The corresponding measured antenna gains for the first and second resonant frequencies are shown in Fig 7 (a) and 7 (b), respectively. They are measured at the maximum gain direction across the frequency bands. Fig 8 shows the radiation patterns measured at 2.45 GHz and 5.6 GHz.

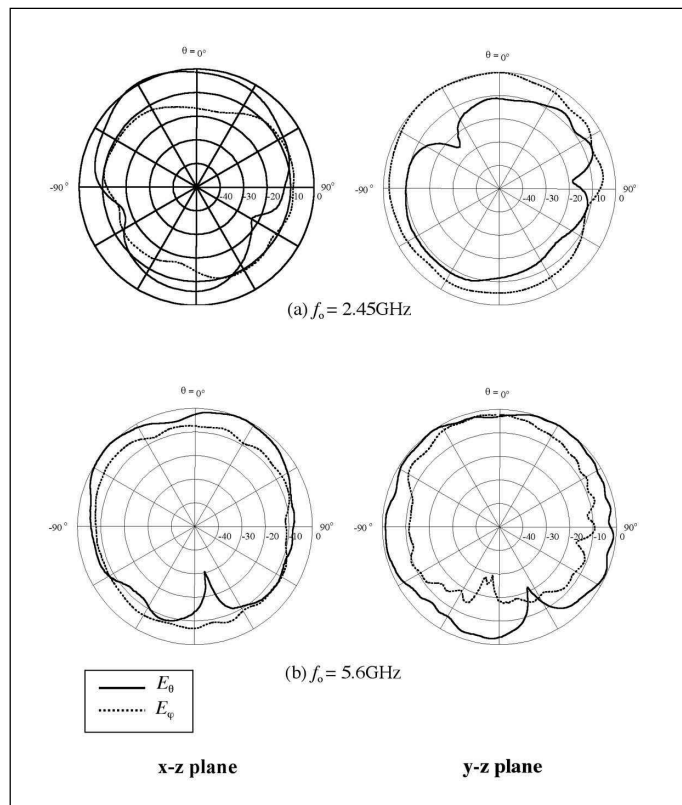


Figure 8 – Measured Radiation Patterns for the Proposed L-shaped Slit Antenna at (a) 2.45 GHz and (b) 5.6 GHz

#### Tilted Slit Antenna

Fig 9 shows a comparison of the simulated and measured S11 with  $L'$  equals to 18 mm and other dimensions are  $L_1 = 20$ ,  $W_1 = 23$  and  $W_2 = 16.5$  mm. There are two resonances generated by the tilted slit antenna and a better impedance matching is found for the first resonance. An impedance bandwidth of ( $VSWR \leq 2.5$ ) 605 MHz (1.913 - 2.518 GHz) is obtained experimentally, which covers both the IMT-2000 band (1.92 -

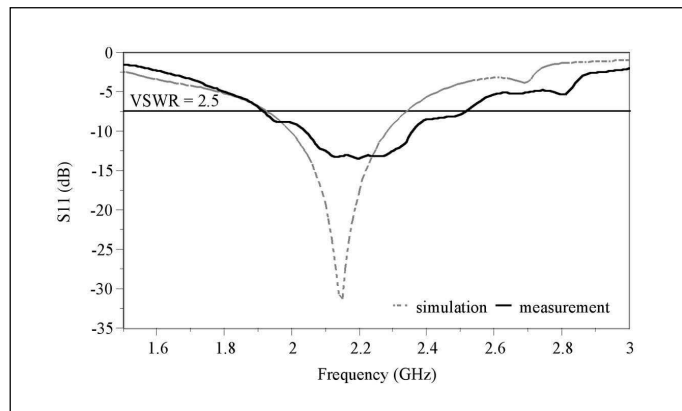


Figure 9 – Simulated and Measured S11 of the Proposed Tilted Antenna with  $L'$  Equals to 18 mm

2.17 GHz) and the 2.45 GHz ISM band (2.4 - 2.5 GHz). If  $L'$  (shown in Fig 3) is increased from 16 mm to 24 mm, a longer current path is provided resulting in lowering the two resonances as depicted in Fig 10. In addition, it is noted that  $L'$  is a critical parameter for the input impedance matching of the first resonance. Although a deeper null is obtained when  $L'$  is equal to 16 mm, the percentage of impedance bandwidth is narrower compared to the one with  $L'$  which is using 18 mm. The measured radiation patterns of the antenna at 2.045 GHz and 2.45 GHz are given in Fig 11 (a) and 11 (b) respectively, while the peak gain is 2.1 dBi. We also found that reducing the size of the finite ground plane will decrease the antenna gain as larger backlobe is obtained.

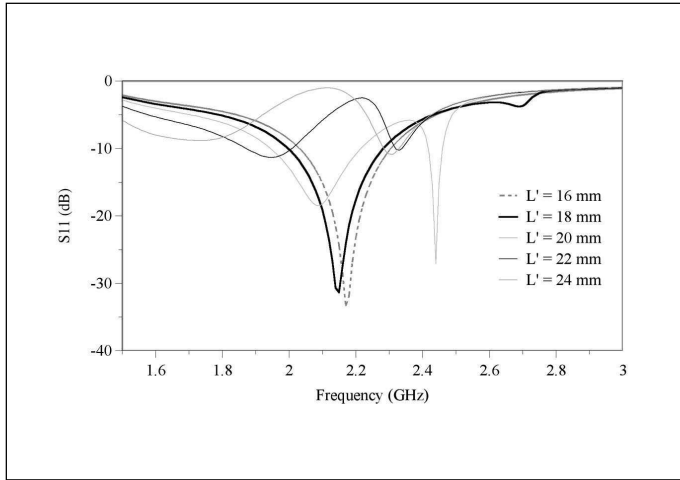


Figure 10 – Simulated S11 of the Proposed Tilted Antenna with Different Length of  $L'$

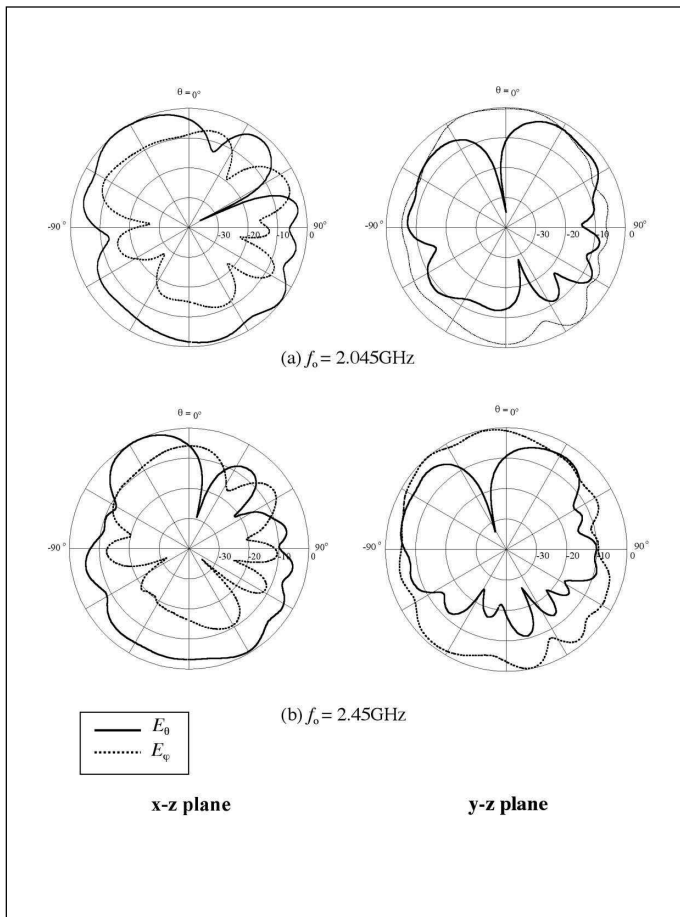


Figure 11 – Measured Radiation Patterns for the Proposed Tilted Antenna at (a) 2.045 GHz and (b) 2.45 GHz

### U-shaped Slot Antenna

The proposed U-shaped slot antenna is constructed with the following dimensions:  $L_1 = 37$ ,  $L_2 = 8$ ,  $L_3 = 28$ ,  $L_4 = 12$ ,  $W_1 = 27$ ,  $W_2 = 16$ ,  $S_1 = 0.5$  and  $S_2 = 1$  mm. The simulated and measured S11 are shown in Fig 12. It is found that the experimental result agrees with the simulation result well. The antenna operates at 0.895 GHz, 1.825 GHz and 2.48 GHz in measurement and the slight frequency shift may come from the fabrication errors. The impedance bandwidths of the antenna are 25 MHz,

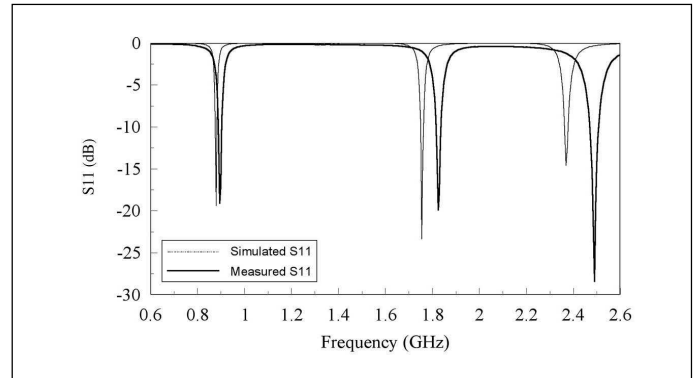


Figure 12 – Simulated and Measured S11 of the Proposed U-shaped Slot Antenna

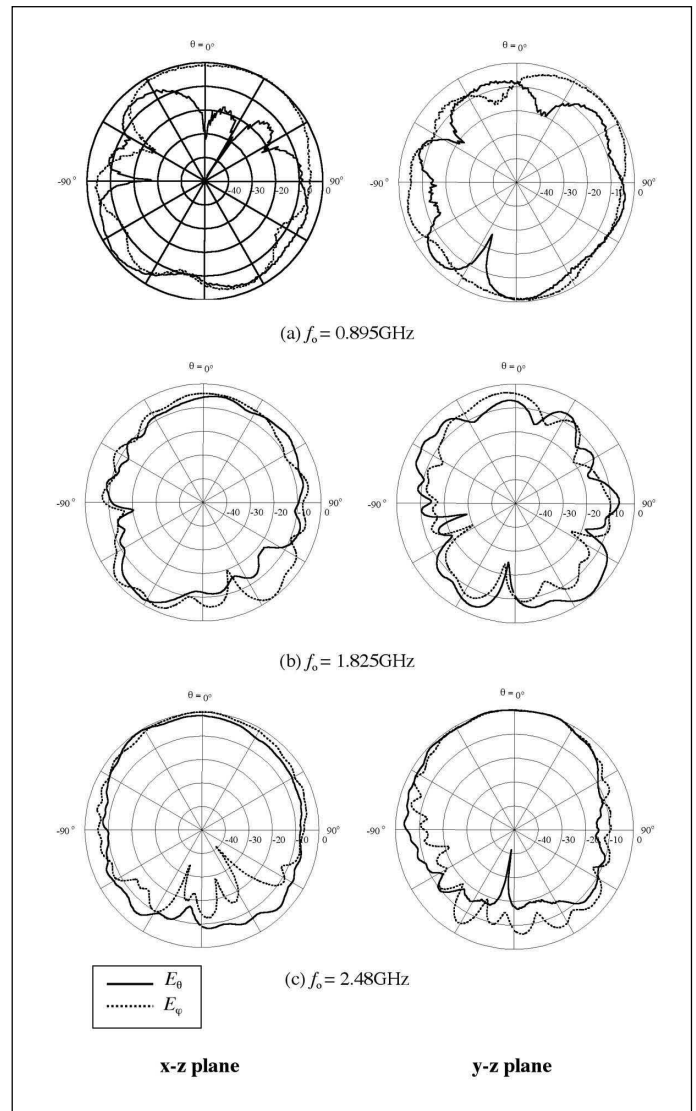


Figure 13 – Measured Radiation Patterns for the Proposed U-shaped Slot Antenna in (a) 0.895 GHz, (b) 1.825 GHz, and (c) 2.48 GHz

37 MHz, and 66 MHz respectively ( $VSWR \leq 3$ ). The measured radiation patterns of the antenna are depicted in Fig 13. On the other hand, several parameters of the antenna are being investigated with the aid of IE3D. They include the width of the U-slot, length and width of the outer rectangular patch, and width of the shorting wall. The parametric studies give a valuable insight for designing a single-feed tri-band PIFA. For this study, only one parameter is changed each time and the corresponding frequency responses are summarised in Table 1 (eg when  $S_2$  is increased, the first and second operating frequencies will shift downward and the magnitude of the first operating frequency's return loss will also become smaller). Obviously, more work could be done on impedance bandwidth enhancement for this antenna to satisfy the applications later on.

	Freq 1	Freq 2	Freq 3	RL <sub>1</sub>	RL <sub>2</sub>	RL <sub>3</sub>
Width of $S_2$ ↑	↓	↓	—	↓	—	—
Length of $L_1$ ↑	↓	↓	—	↓	—	—
Width of $W_1$ ↑	—	—	↓	—	↓	—
Width of shorting wall ↑	↑	↑	—	—	↓	↓

Table 1 – Parametric Studies of the Proposed U-shaped Slot Antenna

## Conclusions

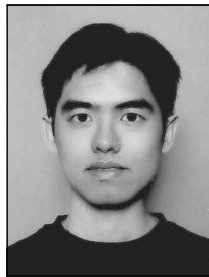
In this paper, three different PIFAs for multi-band operation are proposed and demonstrated. The first two (L-shaped slit and tilted slit) antennas with proper ground plane size are successfully designed for practical applications. They entail the use of shorting pins for impedance matching and size reduction. While for the third proposed antenna, it is noted that a single-feed U-shaped slot patch antenna is able to generate three resonances with the use of one shorting pin and one shorting wall. Detailed research is carrying out to improve the impedance bandwidth in order to satisfy engineering applications. The results will be presented in the later articles.

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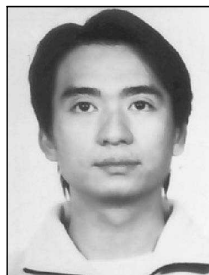
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Prof Chan provided consulting and contract services to international companies such as Lockheed, Boeing, Tektronix, PCCW, Yokohama Rubber, etc. He also assisted a wide range of small and medium-sized enterprises in Hong Kong for enhancing the performance and competitiveness of their products. He is also a founding member of 2 spin-off companies associated with CityU's Wireless Communications Research Center.