Progress In Electromagnetics Research, PIER 83, 293–306, 2008

STUDIES ON DUAL-BAND MULTI-SLOT ANTENNAS

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Abstract—A new technique is proposed to increase the bandwidth (BW) of slot antenna operated at 2.4 GHz and 5 GHz, over the industrial-scientific-medical (ISM) bands and the Hiperlan2 bands. By splitting two side slots of the Z-like slot antenna into two or three fingers, several additional resonances can be created. By properly arranging the geometry of the feeding structure in the multi-slot region, the double-slot and triple-slot antennas have respectively 2.0 and 3.2 times wider bandwidth than the single Z-slot antenna. According to the results, the proposed triple-slot antenna can provide two separated impedance bandwidths of 672 Hz (about 28.3% centered at 2.4 GHz band) and 2752 MHz (about 53.5% centered at 5.2 GHz band), making it easily cover the required bandwidths for WLAN operation in the 2.4 GHz band and 5.2/5.8 GHz bands.

1. INTRODUCTION

With the rapid growth in wireless communication systems, antenna development has focus on small wide-band printed antennas which are easy to fabricate, and integrate with the RF front-end module. In particular, the ability to operate at multiple frequencies is highly desirable. As a result of its intrinsic wide bandwidth, good isolation characteristics due to its relatively low coupling through surface waves, and negligible radiation from feeding network, the printed slot antenna emerges as an excellent candidate for the newer generation of wireless antennas. Recently, a number of experimental investigations on the impedance bandwidth of printed slot antennas have been reported by various authors [1–16]. The proposed methodologies include modifying the feeding structure [1–7], the radiation aperture [8], introducing some tuning stubs into the radiating aperture [9–12], and feeding at slot edge with a microstrip line to create a second resonance [13–15]. Meanwhile, a study on frequency change has been shown in [16].

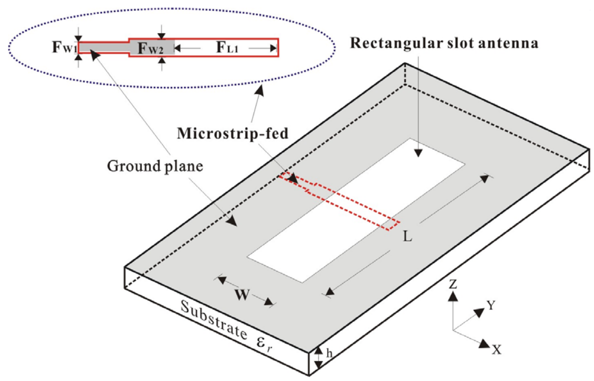
We have previously [17] introduced two novel techniques to enhance the bandwidth and to achieve the triple-band operation at the 2.4 GHz, 5.2 GHz, and 5.8 GHz by employing an Z-like slot to replace a traditional rectangular slot. In such a configuration, more radiation modes can be effectively excited due to additional current paths induced from the microstrip feed line and the slot edges. By adding a pair of symmetrically tuning stubs at each slot edge, the frequency at the upper band can be lowered. Figure 1 and 2 show the geometric figure and measured reflection coefficient (S_{11}) of the three antennas.

In this paper, we report further bandwidth enhancement by dividing the side apertures of the Z-like slot into two or three fingers. By arranging the geometry of the feeding structure in the multi-slot region, several resonant paths are created over the operating frequency bands. With a careful choice of the dimensions of the slots and fingers, these resonances can be merged together over the operating band and consequently the antenna can be used over a very wide bandwidth.

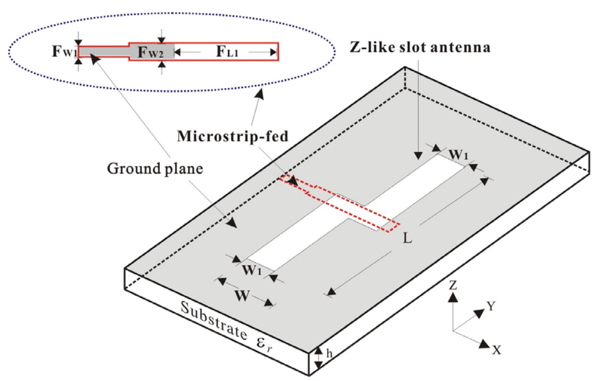
2. ANTENNA DESIGN

In this paper, these proposed antennas are fabricated on a 0.8-mm-thick FR-4 substrate with a dielectric constant of $\varepsilon_r = 4.4$ and $\tan\delta = 0.0245$. The slot is etched on the ground plane of the substrate as a radiating element. The length L of the slot is determined to be $\lambda_g/2$ (where λ_g is the guided wavelength at 2.4 GHz) in order to obtain a maximum power at the broadside direction. A microstrip-fed line on the bottom plane of the substrate is as a probe excitation of the slot antenna to excite the slot mode.

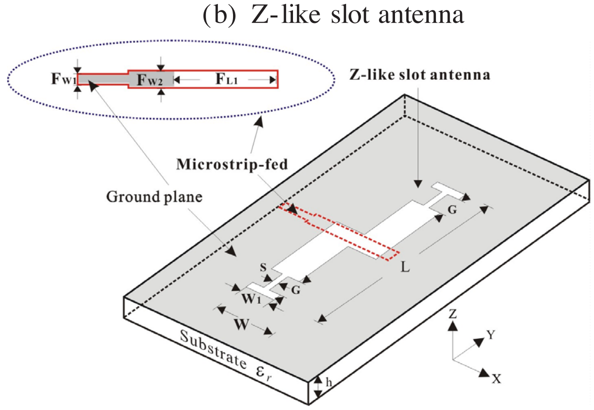
The proposed double-slot antenna is illustrated in Fig. 3(a). Each slot is split up into two fingers at each wing without enlarging the slot dimension. By employing the method, the capacitive coupling between the microstrip feed line and four slot edges results in the two excited modes. Moreover, four symmetrical tuning stubs are added at the slot edge. Matching is achieved by tuning the widths of the slots W_1 and W_2. Due to the higher impedance resulted from the stronger coupling between two neighboring edges, the width of the open



(a) Rectangular slot antenna



(b) Z-like slot antenna



(c) Z-like slot antenna with tuning stubs

Figure 1. Schematic configurations of the three slot antennas. (a) Rectangular slot antenna, (b) Z-like slot antenna, (c) Z-like slot antenna with tuning stubs.

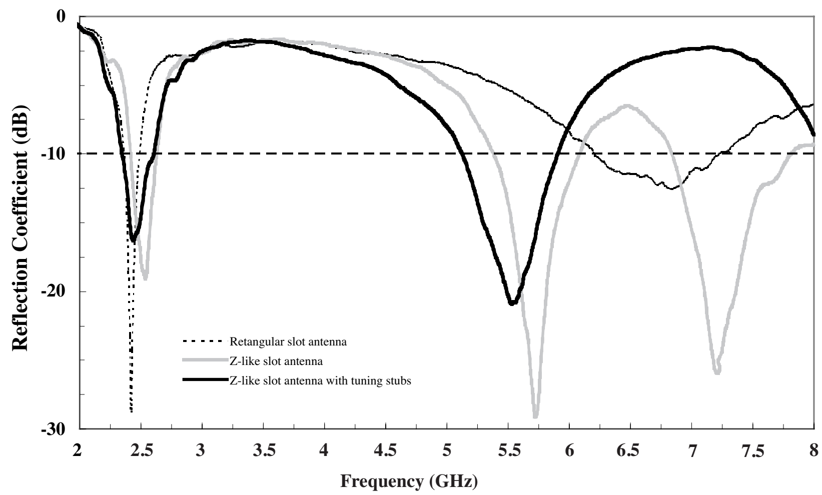


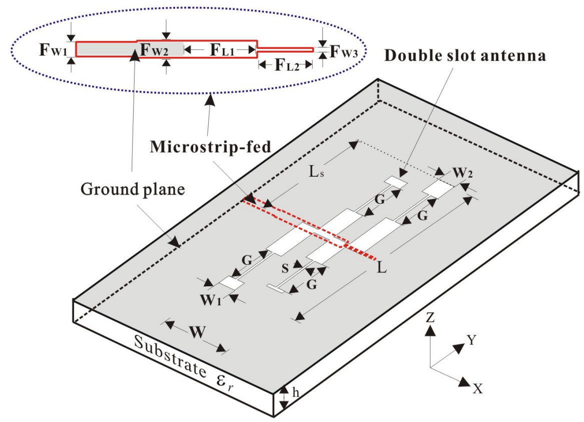
Figure 2. Comparison of the measured reflection coefficients of the three slot antennas.

circuited microstrip line inside the front slot (W_2) should be narrowed for small reflection.

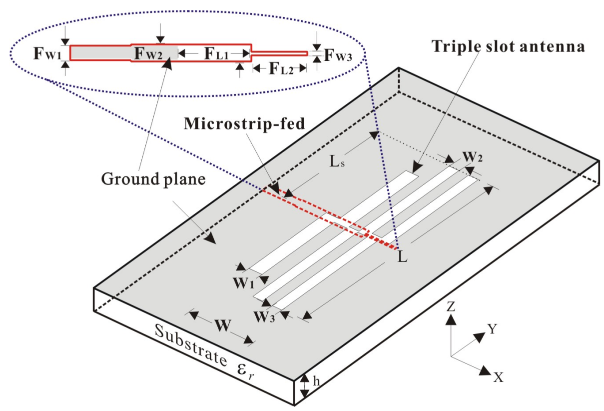
In order to obtain more excited modes, we employ the same design concept and divided the Z-like slot into three fingers at each wing without changing the size. The proposed triple-slot antenna is shown in Fig. 3(b). Due to the higher impedance of the narrow slot, the width of the open circuited feed line is tuned and decreased more as before. The geometrical parameters of the three slot antennas are described in Table 1. In our experiment, the dimensional parameters of the feed line are changed and compared in order to obverse the variation of the impedance bandwidth and the initial resonant frequency of the proposed slot antennas.

3. RESULTS AND PARAMETRIC STUDY

The antennas were simulated using Ansoft High-frequency structure simulator (HFSS) software and the reflection coefficients (S_{11}) of the antenna are measured using a calibrated vector network analyzer. Fig. 4 show the simulated reflection coefficients of the three slot antennas at lower band (simple Z-like slot, double-Z-slot, and triple-Z-slot). As can be observed from the figure, the number of resonances of the slot antenna and its initial resonant frequency increase as the number of finger-slot increases. When appropriately designed, these



(a) Double-Z-slot antenna



(b) Triple-Z-slot antenna

Figure 3. Schematic configuration of the three slot antennas. (a) Double-slot antenna, (b) Triple-slot antenna.

resonances can be moved together closer and merged into a wide operating band. Thus, the available bandwidth, as defined by $S_{11} = -10\,\text{dB}$, is increased. This phenomenon is particularly important at the lower resonant band of these proposed slot antennas. Fig. 5 plots the measured impedance locus of the double-slot and triple-slot antennas on the Smith chart in the 2.4-GHz band. While the double-slot antenna shows a single resonant loop, the triple-slot antenna has 3 loops. This demonstrates that more excitation modes of the proposed slot antennas have appeared.

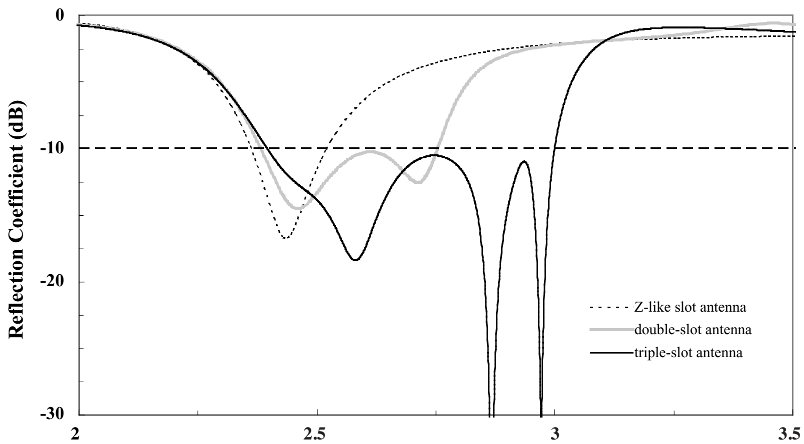
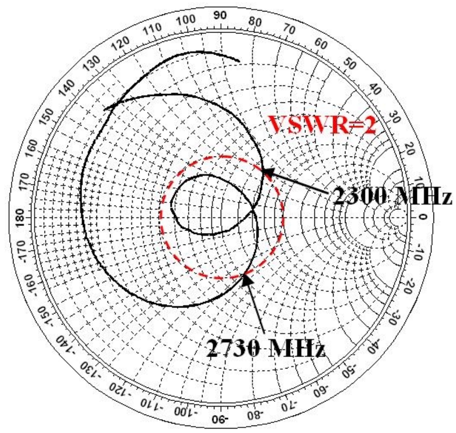


Figure 4. Comparison of the simulated reflection coefficients of the three proposed slot antennas without tuning stubs.

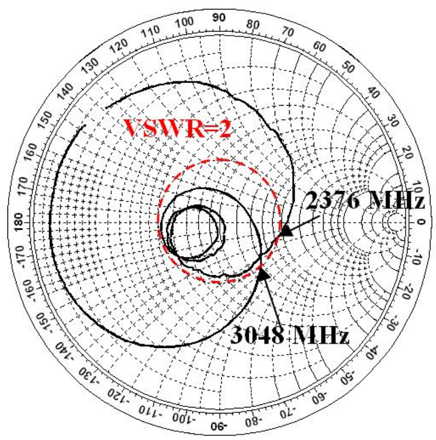
Table 1. Dimensions of three proposed slot antennas (Unit: mm).

Parameter / Type	Z–like slot	Double–slot	Triple–slot
$L \times W$	32.75×10	32.9×10	34.3×10
W_1	5	2.5	2
W_2	–	2.5	1.5
W_3	–	–	1.5
G	1.75	7	–
S	1	0.3	–
F_{W1}	1.2	1.2	1.2
F_{W2}	1.4	1.4	0.6
F_{W3}	–	0.4	0.3
F_{L1}	10	3.9	4.9
F_{L2}	–	6.7	4.6
L_S	–	17.2	15.65
Ground Plane	54×30		

In order to achieve wide-band operation, the tuning parameters of the matching network have been studied carefully. By adjusting the width of the $50\,\Omega$ microstrip line, we have a trade-off between impedance bandwidth and initial frequency as shown as following. Fig. 6 shows the comparison of the impedance bandwidth and the



(a) Double - slot antenna



(b) Triple - slot antenna

Figure 5. Measured impedance loci on the Smith chart at the 2.4 GHz-band. (a) Double-slot antenna, (b) Triple-slot antenna.

initial resonant frequency of the double-slot antenna as a function of the width F_{W2}. From this figure, as F_{W2} increases the initial resonant frequency reduces as well; on the contrary, the bandwidth decreases. The maximum impedance bandwidth is 501 MHz when the width is 0.8 mm. Figs. 7 and 8 show the variations of the impedance bandwidth and initial resonant frequency of the triple-slot antenna at the 2.4- and 5-GHz bands by changing the value of the width F_{W2}. It is approximately observed that the initial resonant frequency at the 2.4-

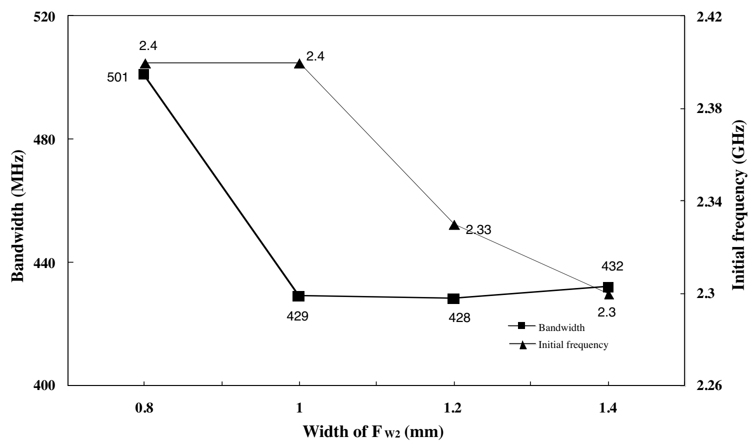


Figure 6. Comparison of the width F_{W2} of the double-slot antenna on measured bandwidth and initial resonant frequency.

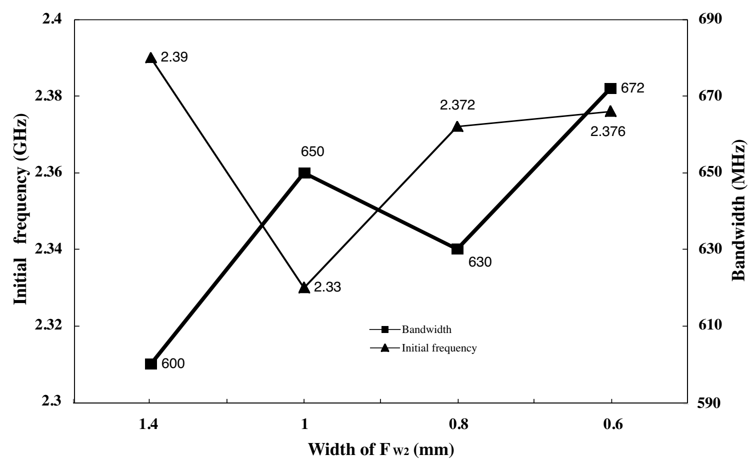


Figure 7. Comparison of the width F_{W2} of the triple-slot antenna on measured bandwidth and initial resonant frequency at the 2.4-GHz band.

GHz and 5-GHz bands increases and the impedance width decreases as the width of the F_{W2} increases. After properly optimized the parameters, the triple-band operation has been achieved. As shown in Fig. 9, the bandwidths of the three proposed slot antennas cover the bandwidth specification of the wireless communication systems, including the Bluetooth, WLAN, WiMAX and Hiper-LAN systems. The impedance bandwidth performances of the three types of antennas

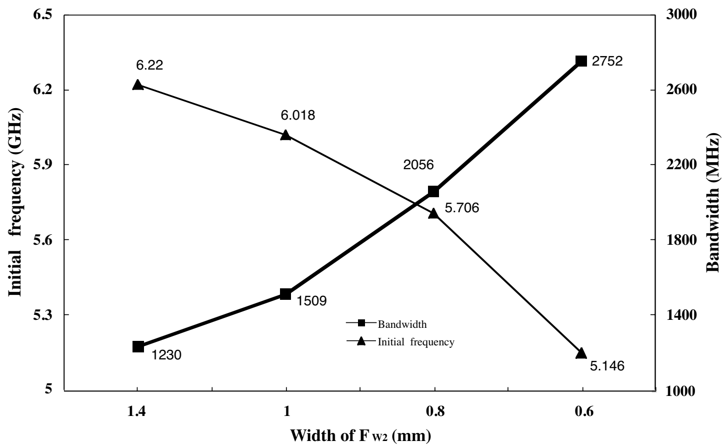


Figure 8. Comparison of the width F_{W2} of the triple-slot antenna on measured bandwidth and initial resonant frequency at the 5-GHz band.

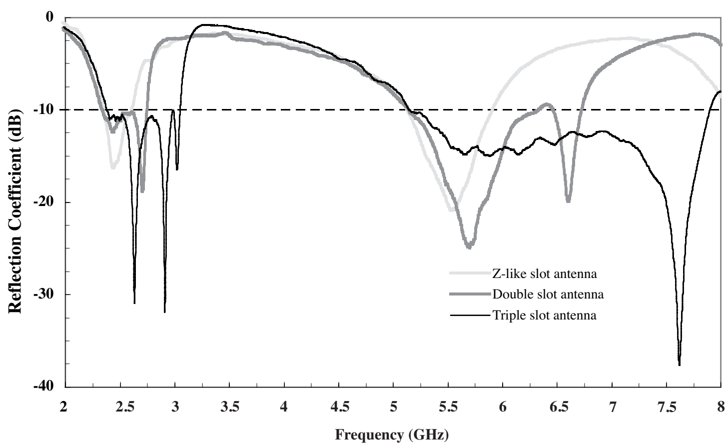


Figure 9. Measured reflection coefficient of the three proposed antennas.

are summarized in Table 2. All three types of antenna exhibit higher impedance bandwidth over conventional slot antennas, and the double-slot and triple-slot antennas have 2.0 and 3.2 times wider bandwidth than the single Z-slot antenna.

The radiation patterns of the proposed antennas are measured in the anechoic chamber. Figs. 10 and 11 present the simulated and measured radiation patterns of the E-and H-planes of the double-slot

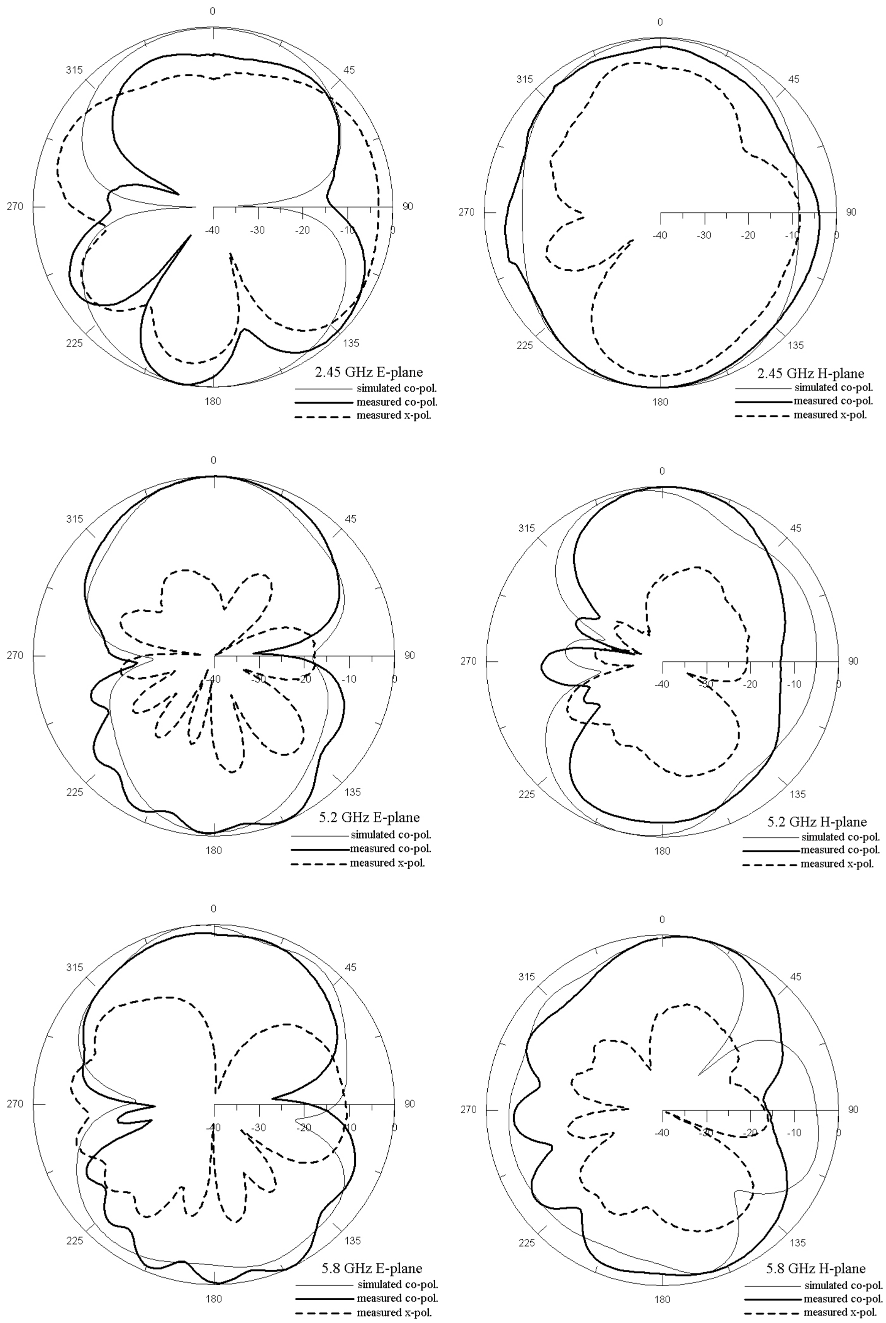


Figure 10. *E*- and *H*-plane radiation patterns of the double-slot antenna at the 2.45, 5.20 and 5.80 GHz.

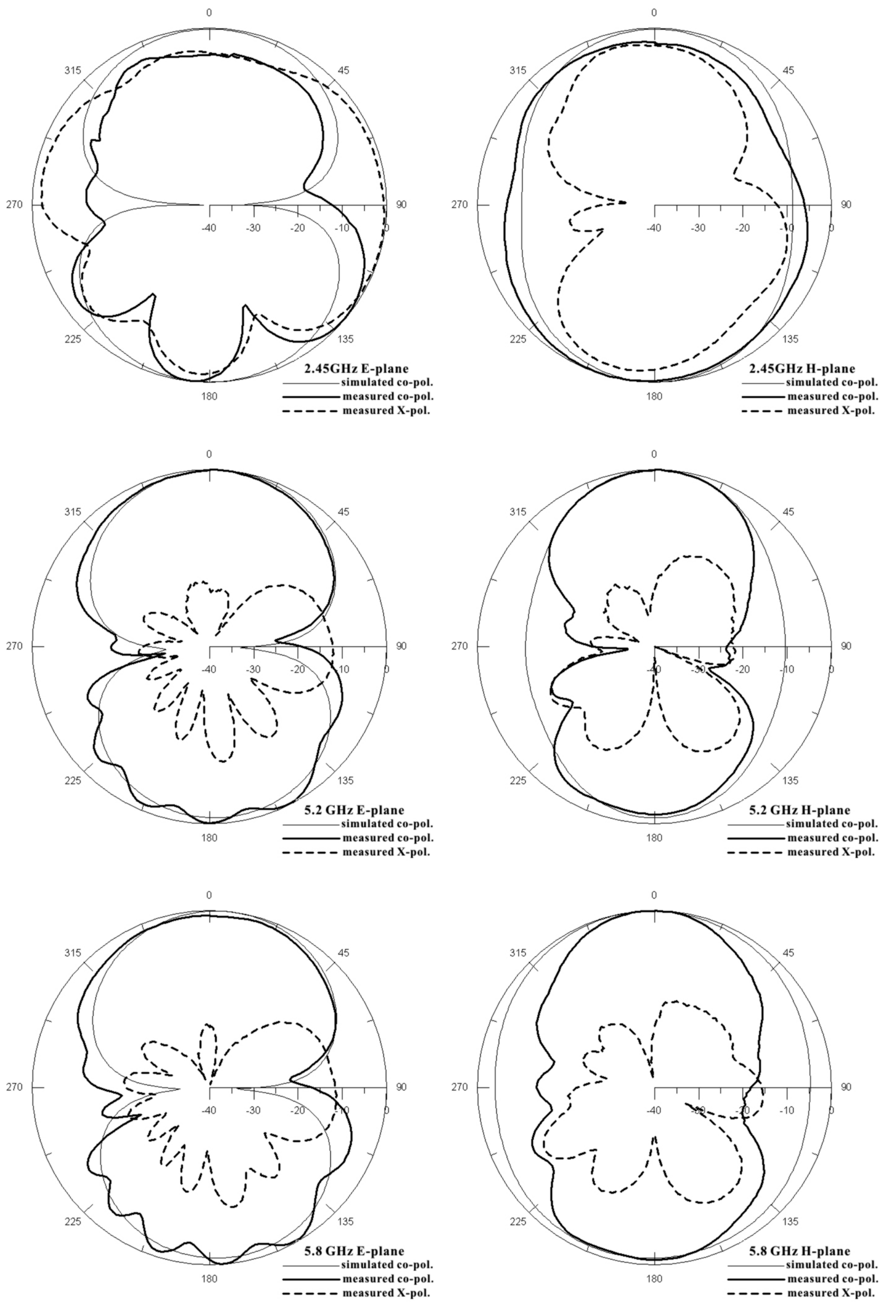


Figure 11. E- and H-plane radiation patterns of the triple-slot antenna at the 2.45, 5.20 and 5.80 GHz.

Table 2. Impedance performances of these three proposed antennas.

	Center frequency of lower band (MHz)	Impedance BW of lower band (MHz)	Center frequency of higher band (MHz)	Impedance BW of higher band (MHz)
Z-like slot	2505	210	5513	778
Double-slot	2556	430	5921	1623
Triple-slot	2715	672	6517	2792

and triple-slot antennas at 2.45, 5.2 and 5.8 GHz. At 2.4 GHz, the higher cross polarization level due to a higher orthogonal component of the surface current at 2.4 GHz for the two antennas, leads to a depression of antenna gain, which is restored at 5.2 and 5.8 GHz. However, the maximum intensity of the radiation power is directed towards the broadside. The measured gains of the double-Z-slot and triple-Z-slot antennas are about 1.4 and −1.4 dBi at 2.4 GHz, 5.5 and 4.8 dBi at 5.2 GHz, 5.3 and 8.9 dBi at 5.8 GHz respectively. The differences in gain between the two antennas can be explained by the difference in current paths and field distributions at different frequencies. The radiation efficiency of the double-slot and triple-slot antennas are measured about 83% and 80% at 2.45 GHz, 77% and 69% at 5.20 GHz, respectively. The reason of the lower radiation efficiency at the 5.20 GHz may be attributed to the higher loss tangent factor of the substrate.

4. CONCLUSION

In this paper, we successfully show a new technique to demonstrate the wider bandwidth than the conventional slot antenna. The technique is based on creating more resonances by introducing additional finger slots, without any significant increase in the occupied slot area. The parameters of the feed line for wide bandwidth and the initial resonant frequency have been investigated in order to study the effect of the parameters. These antennas show the dual-band impedance operation, good reflection coefficient and similar radiation patterns over the WLAN and ISM frequency bands.

ACKNOWLEDGMENT

The research described here was carried out at the RF Circuit and Antenna Laboratory, National University of Tainan, under the Grants: NSC 96-2221-E-024-001 of the National Science Council, Taiwan. Support of the simulation tools from the National Center for High Performance Computing, Hsinchu, Taiwan is also acknowledged.

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