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RECONFIGURABLE COPLANAR INVERTED-F ANTENNA WITH ELECTRONICALLY CONTROLLED GROUND SLOT

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Abstract—In this article, a coplanar inverted-F antenna with an electronically controlled ground slot enabling reconfigurability is proposed. Initially a quarter wavelength coplanar inverted-F radiator is designed to operate at 900 MHz. To minimize its size, the radiator is folded to occupy an area of about $10 \times 40\,\text{mm}^2$. Next, a ground slot is introduced to excite another resonance at around 1850 MHz without affecting the 900 MHz operation. The slot is loaded with three pairs of PIN diode switches with simple biasing circuits to vary its resonant frequency. The proposed reconfigurable antenna is fabricated and experimentally tested. A good agreement is achieved between the simulated and measured return loss of the antenna showing the experimental impedance bandwidth covering GSM900, PCS1900 and UMTS2100 services. In these frequency bands, the antenna offers nearly omni-directional radiation patterns with measured peak gain between 1.4 dBi to 3.45 dBi.

1. INTRODUCTION

Recent years have observed the demand for reconfigurable antennas. This trend has been driven by many newly emerging wireless services. With multiband capability, reconfigurable antennas can utilize more efficiently radio frequency spectrum, facilitating a better access to wireless services in modern radio transceivers. Various methods have been reported in the literature to achieve reconfigurable antennas. These are generally divided into two main categories: the frequency tunable and pattern diversity antennas. For frequency tunable antennas, much attention has been given to reconfigurable slot antenna

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designs [1–4] due to the flexibility of slots in integrating electronic switches. The frequency tuning characteristics of a slot antenna can be achieved by changing the slot effective length [1–3] or by switching the connection between the feed and the ground [4]. Apart from using ground slots, frequency reconfigurability can also be achieved by changing the induced current distribution [5] or varying the ground plane electrical length [6] supporting a patch antenna. For pattern diversity antennas, reconfigurability can be obtained by adjusting the physical configuration of the antenna radiator to produce tunable radiation patterns [7–13].

In designing a reconfigurable antenna, the selection of electronic switches is of paramount importance. Depending on the type of antennas, the switches such as RF MEMS [14–16], varactors and PIN diodes can be used. The choice is governed by electrical specifications, fabrication complexity, bias requirement, switching time, and price. For instance, RF MEMS switches are very low loss and their other advantages are that they do not require bias lines [14]. However, they are costly. PIN and varactor diodes are low cost and have a simple fabrication process. They require a proper bias network isolating the dc bias current from the RF signal, which usually leads to a complicated biasing network. The complicated dc bias network can sometimes be avoided, and one such solution has been reported in [3]. Furthermore, the limited operating frequency of some commercial low cost PIN diodes can be overcome using solutions proposed in [17].

Most of frequency reconfigurable slot antennas generate only single operating bands at a particular reconfigurable mode. Although many conventional multiband techniques exist such as multi-mode resonator or multi-resonator [18], they are difficult to implement in reconfigurable slot antennas. Recently, a coplanar inverted-F antenna (CIFA) with ground slots has been reported in [19]. It is capable to generate a new higher-band resonance from a ground slot without affecting its original resonance of the patch radiator.

This article provides a logical extension of the work reported in [19] and describes a new solution to achieve a reconfigurable antenna capable of generating multiband operation at each reconfigurable mode. By means of length-tunable ground slot, a new reconfigurable coplanar inverted-F antenna achieves dual-band operation at four different modes. The generated frequency bands cover several popular wireless services including GSM900, PCS1900 and UMTS2100.

The rest of the article is arranged as follows. In Section 2, the design of reconfigurable antenna including its passive and active components is described. Different modes of operation are revealed. Experimental results for return loss, radiation pattern and gain are described in Section 3. Section 4 concludes findings of the accomplished work.

2. ANTENNA CONFIGURATIONS

2.1. Folded Coplanar Inverted-F Antenna Design

Initially, a $\lambda/4$ 900 MHz microstrip radiator of width $L_2 = 2$ mm is designed in CST Microwave Studio v2010. The radiator is fed by a

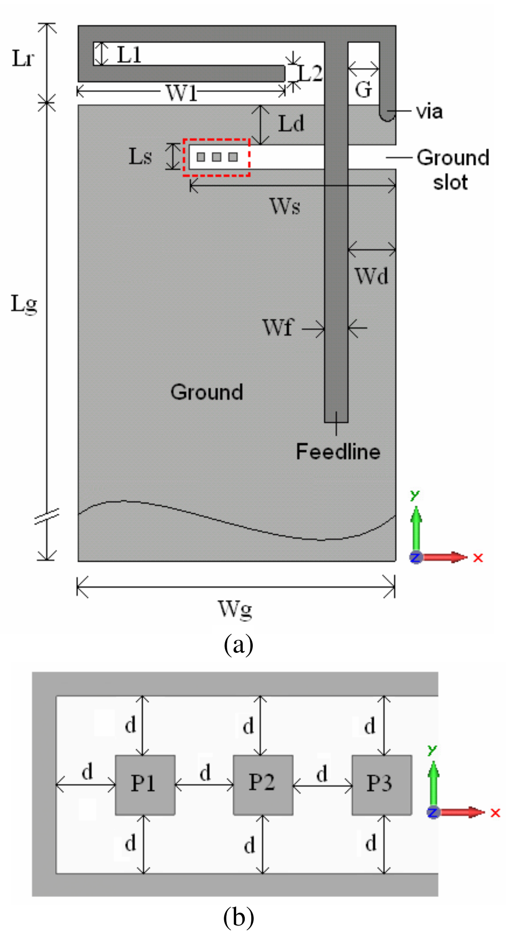


Figure 1. Proposed reconfigurable antenna. (a) Passive antenna configuration. (b) Close view of short-end section of ground slot (marked as red box in (a)).

$50\,\Omega$ microstrip feedline of width $W_f = 3\,\text{mm}$ and placed $W_d = 6\,\text{mm}$ from the antenna edge. To occupy a small area of $L_r = 10\,\text{mm} \times W_g = 40\,\text{mm}$, one end of the radiator is folded twice with $L_1 = 3\,\text{mm}$ and $W_1 = 26\,\text{mm}$ to form the configuration shown in Figure 1. To realize an inverted-F antenna, other end of the radiator is grounded through a via. This is to compensate the large capacitance introduced from the coupling of the folded arm to the ground. The other parameters are the gap between the feedline to the shorting strip $G = 4\,\text{mm}$ and the $L_g = 90\,\text{mm} \times W_g = 40\,\text{mm}$ ground plane supporting the antenna. The chosen ground plane size is typical for many wireless transceivers such as a mobile phone.

2.2. Reconfigurable Ground Slot Design

Following the technique in [19], a slot is introduced in the ground plane to excite the higher frequency band centered about 1850 MHz. The ground slot is placed $L_d = 5\,\text{mm}$ from the ground top edge and has a dimension of $L_s = 3\,\text{mm} \times W_s = 26\,\text{mm}$ as shown in Figure 1(a). In order to achieve an electronically variable (reconfigurable) slot length, three identical $1\,\text{mm} \times 1\,\text{mm}$ conducting pads (P1, P2 and P3) and three pairs of PIN diode switches are introduced in the ground slot as presented in Figure 1(b) and Figure 2 respectively. The gap $d = 1\,\text{mm}$ in Figure 1(b) is chosen to allow uniform decrease of the slot effective length, thus allowing uniform increase in the excited resonant frequency. All final dimensions are achieved through optimization using parametric study in CST Microwave Studio.

The PIN diode used in the antenna is MAP4274-1279T (MACOM). It is a single-diode series with dimension of $1\,\text{mm} \times 0.7\,\text{mm}$ and height of 0.6 mm. It is forward biased with the voltage of $0.7\,\text{V}_{\text{DC}}$

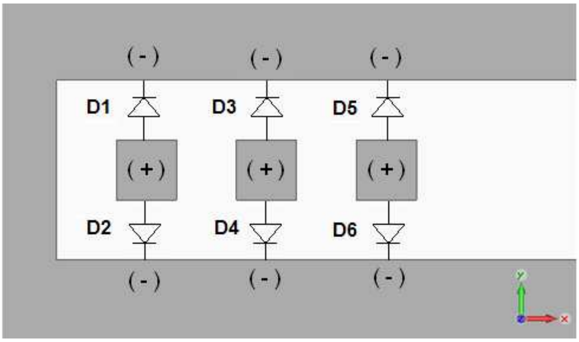


Figure 2. Configuration of the PIN diode switches bias network.

Table 1. Reconfigurable antenna modes of operation.

Diode Combination	Diode States			
	Mode 1	Mode 2	Mode 3	Mode 4
D1 & D2	OFF	ON	OFF	OFF
D3 & D4	OFF	OFF	ON	OFF
D5 & D6	OFF	OFF	OFF	ON

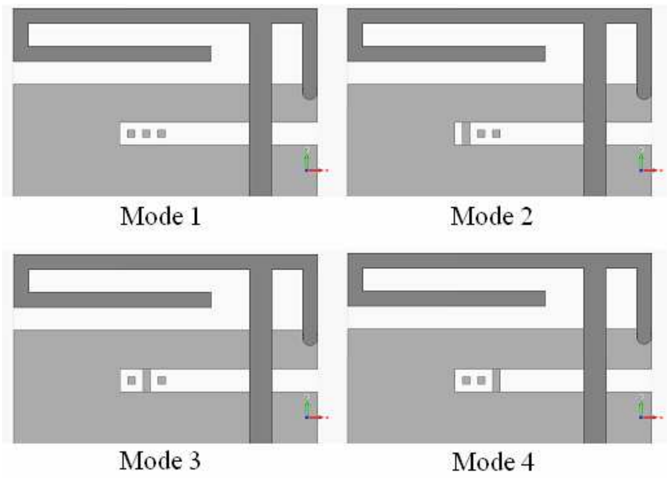


Figure 3. Antenna configurations used in simulation when the diodes are turned on or turned off.

and current of 10 mA. During forward bias, it exhibits an intrinsic capacitance of 0.1 pF with forward bias resistance of 3 Ω.

The switches are designed to operate in three diode pairs. The switch states at each mode are given in Table 1. From the table, the ON-state indicates the diode is forward biased while the OFF-state indicates it is reverse biased. Figure 3 shows the simulation model of the ground slot in each mode. For simulation simplicity, the ON-state diode is represented by a 1 mm × 1 mm PEC. In this case, the effect of the PIN diode forward biased resistance is neglected. The PEC is removed to represent the OFF-state diode.

Figure 4 shows the return loss from the simulation model.

It is observed that equal spacing of the diodes, as described by parameter d, results in a nearly uniform increase in resonant frequency at each ascending mode. The total bandwidth coverage (at 6 dB return loss or VSWR 3:1) of the upper frequency is about 280 MHz.

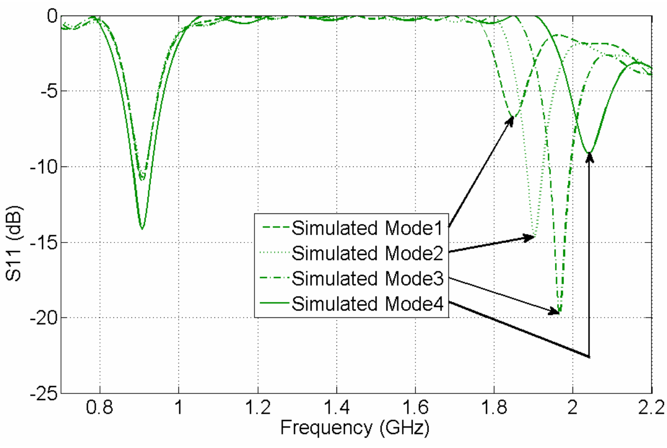


Figure 4. Simulated S_{11} of different diode modes.

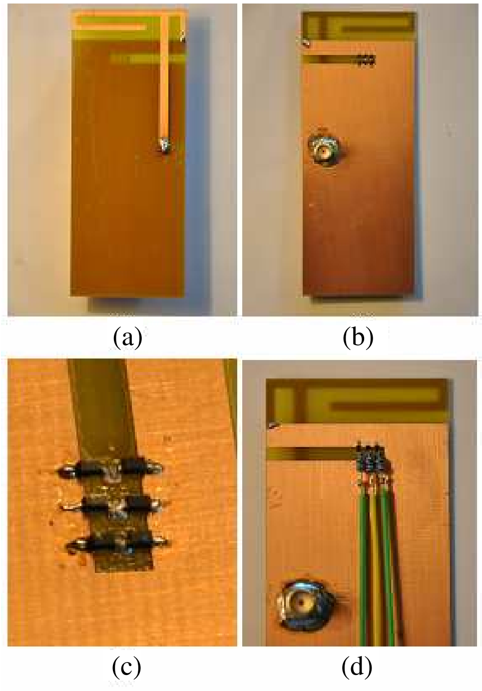


Figure 5. Fabricated antenna. (a) Front view. (b) Back view. (c) Integrated PIN diode configuration. (d) Bias line connection to PIN diode switches.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The photograph of the manufactured reconfigurable antenna is shown in Figure 5. The antenna is fabricated on a 1.6 mm FR4 substrate with relative permittivity of $\varepsilon_r = 4.4$. During measurements, the PIN diode switches are biased with a simple dc bias network as proposed in [3]. Each conducting pad (P1, P2 and P3) is initially soldered to a 1.2 kΩ resistor to protect the diodes and the VNA, as shown in Figure 5(d). A GW GPC-3030D dc power supply unit is used to bias the diodes. The S-parameter measurements are carried out using R&S ZVA24 VNA. Figure 6 shows both the simulated and measured S_{11} of the proposed antenna. Close agreement between the measured and simulated results is observed in each mode. Discrepancies are due to the idealized switches used in CST simulations.

The measured results show that the proposed reconfigurable antenna covers two frequency bands: between 850 MHz to 960 MHz at lower band and between 1800 MHz to 2140 MHz at upper band (at 6 dB return loss or VSWR 3:1). As a result, the proposed antenna can be considered as a good candidate for wireless services application such as GSM900, PCS1900 and UMTS2100. In fact, the proposed antenna

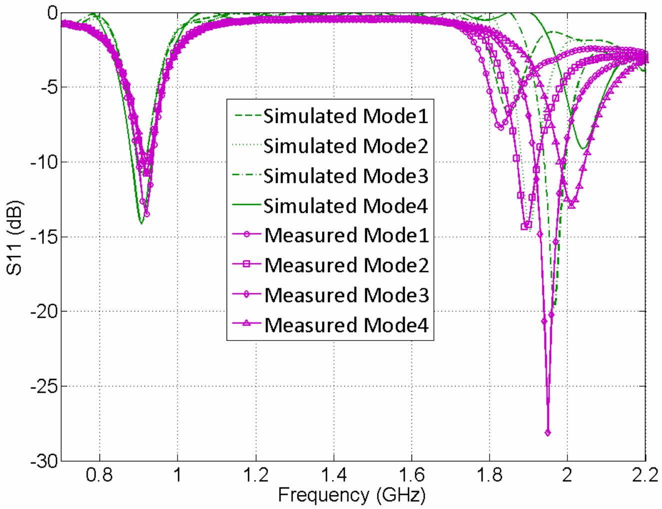
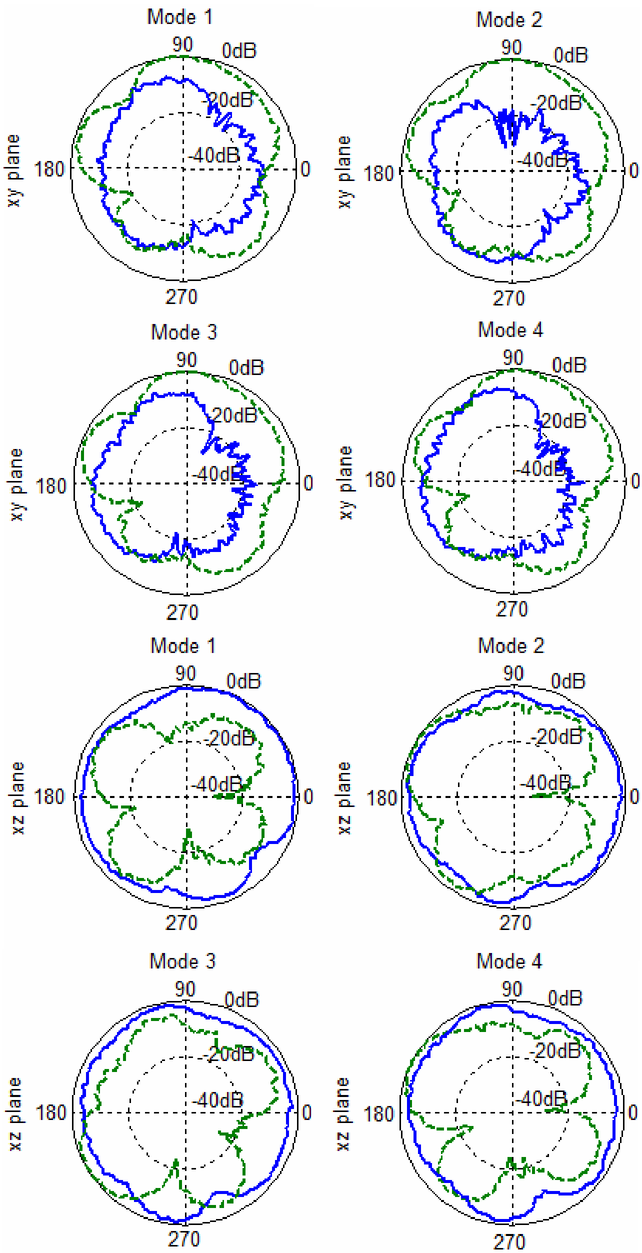
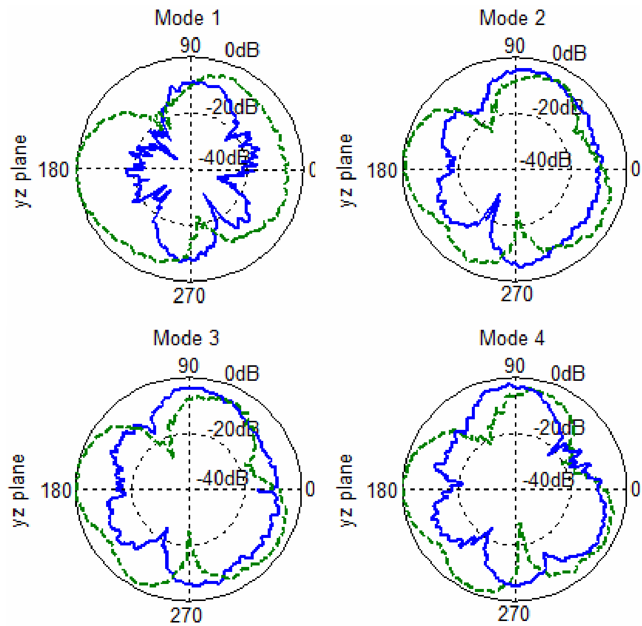
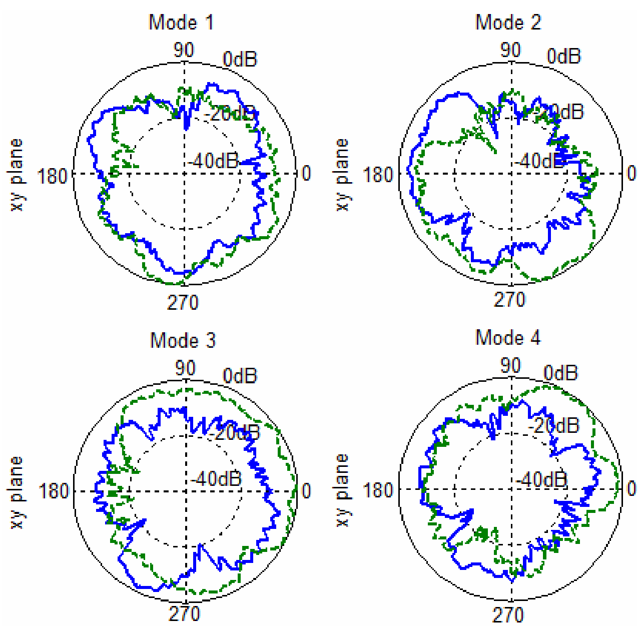


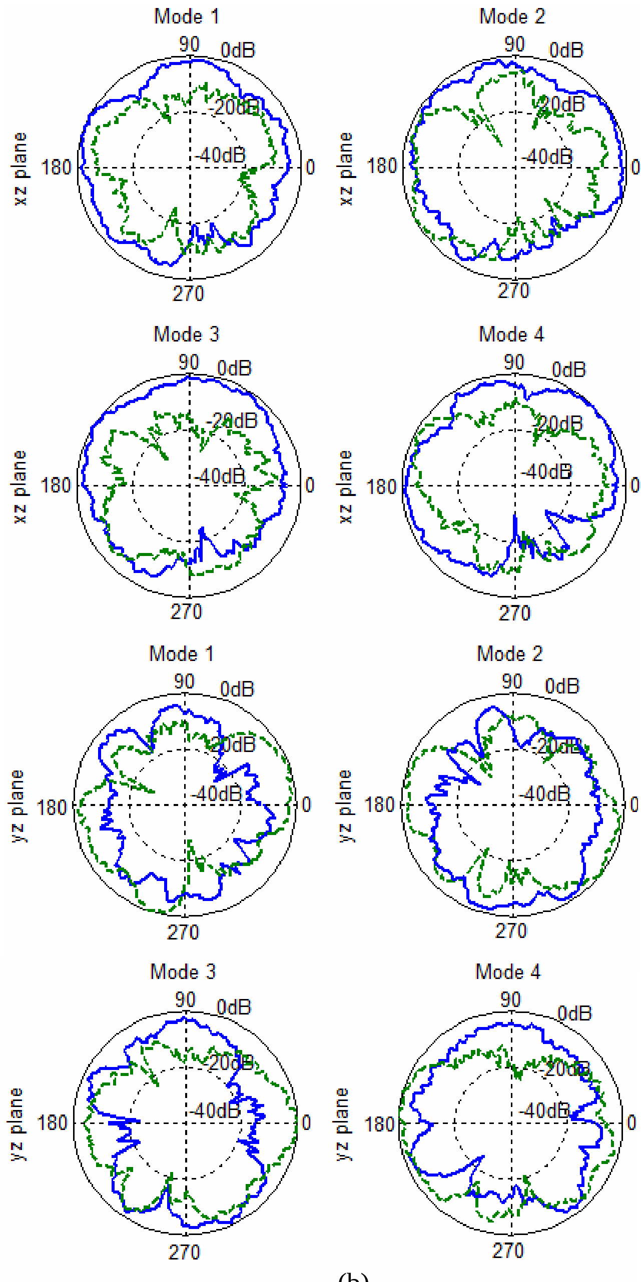
Figure 6. Measured and simulated results for the antenna input refection coefficient S_{11} for the four modes when the individual diodes are turned on or turned off.


Mode 1
Mode 2
Mode 3
Mode 4
Mode 1
Mode 2
Mode 3
Mode 4
xy plane
xz plane
90
180
270
0
0dB
-20dB
-40dB


Mode 1
Mode 2
Mode 3
Mode 4
yz plane
90
180
270
0
0dB
-20dB
-40dB

(a)


Mode 1
Mode 2
Mode 3
Mode 4
xy plane
90
180
270
0
0dB
-20dB
-40dB


Mode 1
Mode 2
Mode 3
Mode 4
xz plane
yz plane
90
180
270
0
0dB
-20dB
-40dB

(b)

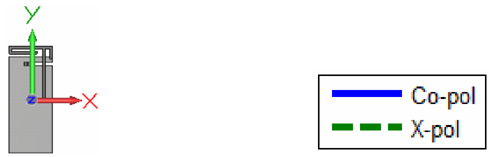


Figure 7. Measured radiation patterns. (a) Lower band 900 MHz at all modes. (b) Upper band; Mode 1: 1820 MHz, Mode 2: 1880 MHz, Mode 3: 1930 MHz, Mode 4: 2010 MHz.

Table 2. Measured antenna gain and simulated total efficiency at different modes.

Operational Modes	All Modes	Mode 1	Mode 2	Mode 3	Mode 4
Frequency, f (MHz)	900	1820	1880	1930	2000
Peak Gain, G (dBi)	1.4	2.65	3.13	3.22	3.45
Total Efficiency, η (%)	69	63	76	80	74

can cover more bands surpassing mode 4, with extra pair of switches in the tunable ground slot. In addition, parameter d can be easily adjusted to obtain desired band separation between adjacent modes.

Figure 7 shows the measured radiation patterns of the antenna. The figures present all three planes of the radiation patterns in Cartesian coordinates; the xy plane, the xz-plane and the yz plane. At each plane, the co-polarization and cross-polarization patterns are measured. For lower band 900 MHz, the radiation patterns are nearly omni-directional and show good consistency between modes except at yz-plane of mode 1 and xy-plane of mode 2. At upper band, the radiation patterns are on average close to omni-directional. Discrepancies are due to the measurement set-up limitations such as the positioning of bias and coaxial feeder line. These limitations are due to general challenges met in an accurate experimental characterization of antennas with small ground planes [20]. The measured gain and the simulated efficiency of the proposed antenna are shown in Table 2. From the presented table, the gain ranges from 1.4 dBi to 3.45 dBi, while the efficiency is between 63% and 80%. The gains are expectedly low due to the small electrical size of the antenna.

The obtained efficiencies are due conduction losses partially incurred in the PIN diodes switches. Anyhow, these values are of acceptable for portable wireless applications [18].

4. CONCLUSION

In this article, a new frequency reconfigurable coplanar inverted-F antenna employing a tunable ground slot has been presented. Using three pairs of PIN diode switches in the ground slot, it has been demonstrated that the antenna can excite new resonant frequencies at each of its four switching modes. The obtained experimental results show that the proposed antenna can cover several popular wireless services including GSM900, PCS1900 and UMTS2100. It produces nearly omni-directional radiation patterns and features gain between 1.4 to 3.45 dBi with good efficiency between 63% and 80%. The proposed slot tunable antenna concept should be of interest to the designers of reconfigurable antennas for multiband wireless transceivers.

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