A Novel Frequency and Radiation Pattern Reconfigurable Antenna for Portable Device Applications

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Abstract **─** In this paper, a dielectric embedded antenna with frequency and radiation pattern reconfigurable characteristic is proposed for portable terminal applications. The proposed reconfigurable antenna consists of one excitation element, two parasitic elements and eight radio frequency switches. The proposed reconfigurable functions are obtained by controlling the ON/OFF states of the radio frequency switches which are integrated into the excitation elements. As a result, the proposed reconfigurable antenna can operate at two frequencies, 1.9 GHz and 2.8 GHz for supporting DCS1800 (1.71-1.88 GHz) and UMTS (1.92-2.17 GHz), LTE2300 (2.305-2.4 GHz), LTE2500 (2.5-2.69 GHz), WIFI (2.4-2.484 GHz). The radiation pattern reconfigurable characteristic is achieved by controlling the state combination of six radio frequency switches installed on the parasitic elements, resulting in three modes in the radiation pattern at each frequency band. The experimental results demonstrated that the proposed antenna can achieve good frequency and radiation pattern reconfigurable characteristics.

Index Terms **─** Dielectric embedded antenna, frequency and radiation pattern reconfigurable antenna, switchable antenna.

I. INTRODUCTION

With the fast development of wireless communication technology, wireless communication is playing a more salient role in our daily life, and hence, the portable device has become one of popular mobile terminals. However, the electromagnetic radiation emitted from portable device is getting serious. It has been becoming an urgent issue that how to reduce the electromagnetic radiation of the portable device to improve the quality of life and how to reduce harm to health [1-3].

As for the antenna structure, most of the used antennas for portable device can be divided into internal antennas and external antennas, such as cell-phones and Wi-Fi routers. External antennas are mainly realized by using spiral antennas and monopole antennas etc. Internal antennas mainly adopt monopole antennas, including planar inverted F-antennas [4-6], etc. Furthermore, internal antennas have much lower electromagnetic radiation than that of the external antennas. However, they also suffer from the disadvantages of low efficiency and narrow bandwidth [7-9]. Recently, long term evolution (LTE) has been widely studied and investigated. It is desirable to develop a small antenna for portable devices, which can cover at least a few of existing service bands and LTE at the same time, especially before the wide spreading of LTE [10].

The reconfigurable antenna emerges one of the most important research topics and has been widely used in various communication devices. Reconfigurable properties are usually realized by insetting switches, capacitors or phase shifters into the antenna structures. In [11], Zhang et al. uses microstrip Yagi antenna and reconfigurable theory to design a pattern reconfigurable microstrip parasitic array, which can shift the main lobe radiation direction at +35, 0, and -35 in H-plane. In [12-16], wide slot antennas with reconfigurable characteristics for ultra wideband (UWB) wireless communication applications have been reported. The designed antenna can be used as UWB antenna, four band antenna, tri-band antenna, dual-band antenna and notch band UWB antenna by controlling the states of the switches. Recently, a Yagi patch antenna with dual-band and pattern reconfigurable characteristics is systematically discussed in [17]. The beam can scan over the E-plane by controlling the modes of the antenna. In [18], the reconfigurable technology has been applied to design a multi-band antenna for mobile phone. The designed folded loop-inverted F reconfigurable antenna can operate in Hepta-band including GSM850, GSM900, GPS, DCS, PCS, UMTS and WLAN for return loss lower than 6 dB. To expand the application of the reconfigurable antennas, a frequency-reconfigurable antenna for mobile phone with small size was proposed, which consists of a planar inverted F-antenna (PIFA) and a monopole antenna embedded in the same space. A switch was used in the PIFA for providing frequency-reconfigurable operation [10].

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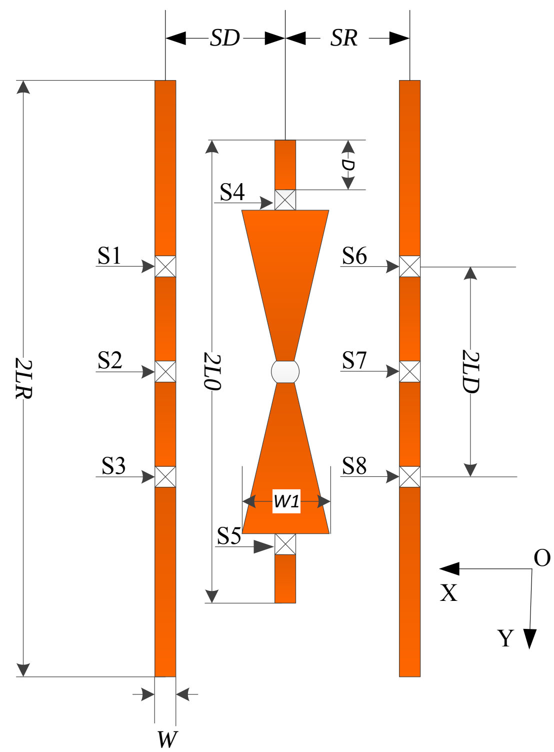
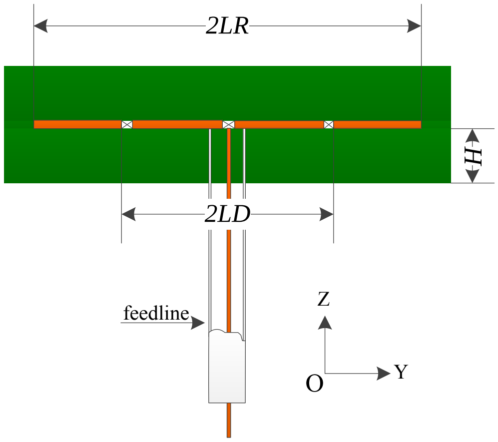
Although the previously designed antennas in [10, 18-21] can cover most existing service bands by altering the reconfigurable frequency bands, most of them cannot realize the frequency and radiation pattern reconfigurable characteristics at the same time to obtain the frequency reconfigurable functions and to reduce the electromagnetic radiation. For this reason, we propose a novel frequency and radiation pattern reconfigurable antenna for portable device applications. Eight radio frequency switches are integrated into the proposed antenna structure to alter the current paths for providing frequency and radiation pattern reconfigurable behaviors. The designed antenna can change the frequency bands to operate at two different frequencies and meanwhile maintains the stable radiation patterns. The radiation pattern reconfigurable characteristics are realized to reduce the electromagnetic radiation according to the position of the portable device toward users at each operating band. When the portable device such as cell phone is standby, the designed antenna can provide omni-directional radiation characteristic. When the portable device is used to communicate with other users, for instance calling other users for cell phone, the radiation pattern will be reconfigured as a directional radiation so that the electric field intensity toward the users can be weakened. Thus, the influence of the electromagnetic radiation for the users is reduced at this mode. By controlling the switches installed on the two parasitic elements, directive and reflective roles of the parasitic elements can be changed and the antenna's maximum radiation direction shifts between 90°and 270°in the H-plane.

II. DESIGN OF THE PROPOSED FREQUENCY AND RADIATION PATTERN RECONFIGURABLE ANTENNA

The geometry of the proposed frequency and radiation pattern reconfigurable antenna is shown in Fig. 1, where S1-S8 are radio-frequency switches. The proposed antenna consists of a driven element, two parasitic elements and eight radio-frequency switches. In this design, the proposed antenna and these switches are embedded into the dielectric substrate whose dielectric constant is 4.4 and the loss tangent is 0.002. The driven element, which is realized by using a stepped dipole that is comprised of a triangle segment and rectangle segment, is approximately a quarter wave length at the resonance frequency of 1.9 GHz in free space. Moreover, the two parasitic elements are set along the driven element at each side. The driven element is fed via a 50 Ohm coaxial cable, which lies in the center of the proposed antenna. Thus, the proposed driven element can be regarded as a dipole antenna. On the basis of the theory of Yagi antennas [9-10], when the switches S1-S3 are turned OFF and the switches S6-S8 are turn ON, the length of the left parasitic element is shorter than the driven element and surface current phase on the left parasitic element is delayed referred to the excitation element. Therefore, the self-impedance of the left parasitic element is capacitive. Furthermore, the length of right parasitic element is longer than the driven element, and the surface current phase is ahead of the driven element. The self-impedance of the right parasitic element is inductive. In this case, the right parasitic element can be regarded as a reflector, while the left parasitic element acts as a director. When the left parasitic element works as a director and the right parasitic element works as a reflector, the H-plane radiation pattern tilts to the positive x axis. Conversely, when the switches S1-S3 are turned ON and the switches S6-S8 are turn OFF, the H-plane radiation pattern tilts to the negative x axis. In this case, the left parasitic element acts as a reflector while the right parasitic element acts as a director. When all the radio frequency switches integrated on the parasitic elements are turned ON, the proposed antenna can provide omni-directional radiation characteristic. In addition, when the two switches, namely S4 and S5, on the excitation element are turned ON, the proposed antenna operates at 1.9 GHz. In this case, the resonance length of the driven element is equal to (L0+D). When these two switches are turned OFF, the antenna works at 2.8 GHz. This is because the resonance length of the excitation element is related to the quarter wave-length which is equal to L0. Thus, switches S4 and S5 are used to alter the resonance length for providing reconfigurable frequency behaviour.



(a) Top view of the antenna



(b) Side view of the antenna

Fig. 1. Geometry of the proposed frequency and radiation pattern reconfigurable antenna.

III. RESULTS AND DISCUSSIONS

In this section, the performance of the proposed antenna is investigated by the use of the high-frequency structure simulator (HFSS). The parameters are optimized and listed as follows: H=2 mm, W=2 mm, W1=6 mm, 2L0=0.26 λ_0, 2LR=0.44 λ_0, 2LD=0.123 λ_0, SD=SR=0.06 λ_0, where λ_0 is the wavelength at the resonance frequency of 1.85 GHz in free space. The operating modes of the proposed antenna are realized by controlling the states of the eight radio-frequency switches shown in Fig. 1, while the operating modes are listed in Table 1. In the simulation, the proposed radio-frequency switches are realized by use of the ideal switch concepts [12-16]. In order to implement these radio frequency switches, the presence of a metal bridge represents the ON state, while its absence represents the OFF state [12-16]. In this paper, metal strips of size 2×2 mm are used for approximating the proposed radio-frequency switches. The VSWR of the proposed antenna at different modes are shown in Fig. 2. It can be seen that the proposed antenna can operate from 1.66 GHz - 2.17 GHz at Mode-1, Mode-2 and Mode-3 for VSWR<2.5. When the proposed antenna works at Modes 4-6, it can cover the bandwidth of 1.95 GHz - 2.97 GHz with VSWR less than 2.5. It can be seen from Fig. 2 that, the impedance bandwidths reach 36.4% and 26.3% at the two operating reconfigurable bands. In order to validate the simulation obtained by HFSS, two prototypes at Mode-4 and Mode-5 are fabricated and shown in Fig. 3. The measured and simulated VSWRs of Mode-4 and Mode-5 are shown in Fig. 4. It can be seen that the measured impedance band is 1.88-3.32 GHz for VSWR<2.5 at Mode-4, while it covers the bandwidth of 1.82-3.02 GHz at Mode-5 with VSWR<2.5. The measured results agree well with simulation ones, which helps to verify the effectiveness of the simulations.

Table 1: Six modes of the proposed reconfigurable antenna

Modes	S1-S3	S4-S5	S6-S8
Mode-1	OFF	ON	OFF
Mode-2	ON	ON	OFF
Mode-3	OFF	ON	ON
Mode-4	OFF	OFF	OFF
Mode-5	ON	OFF	OFF
Mode-6	OFF	OFF	ON

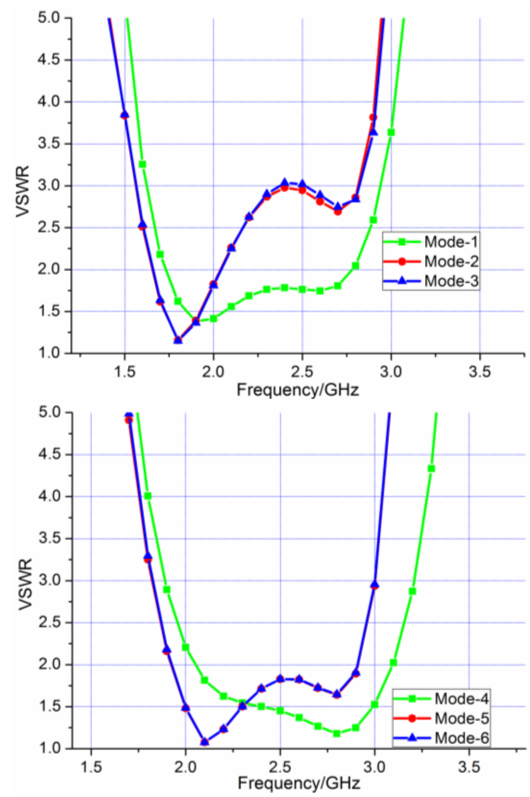
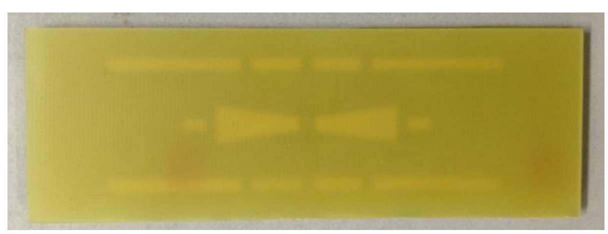
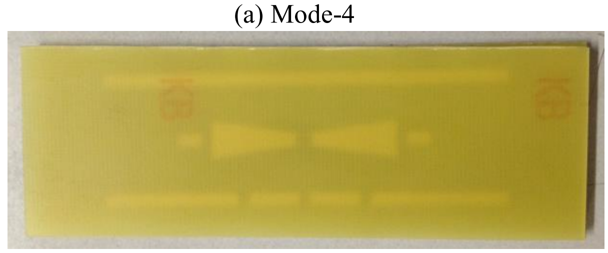


Fig. 2. VSWR of the proposed reconfigurable antenna.

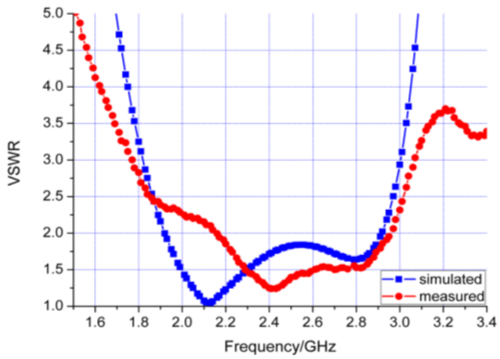


(a) Mode-4

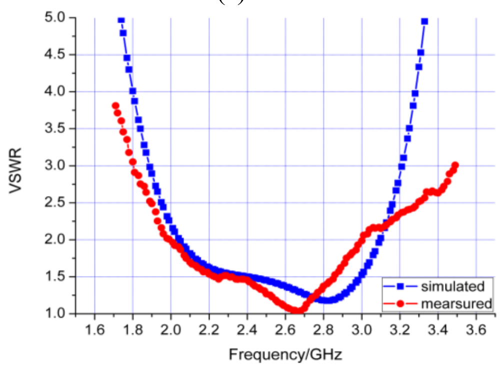


(b) Mode-5

Fig. 3. The prototype of the proposed antenna.



(a) Mode-4

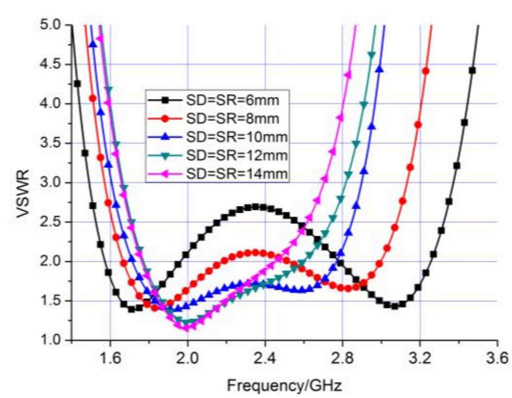


(b) Mode-5

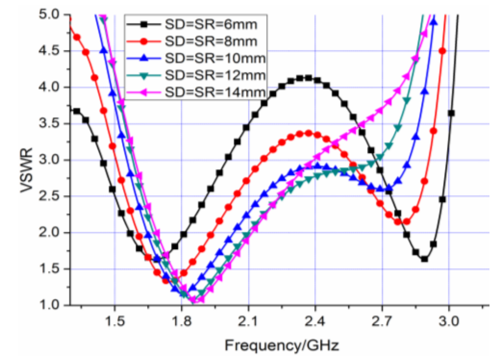
Fig. 4. The measured and simulated VSWR of Mode-4 and Mode-5.

The impedance bandwidths with varying dimensions of SD and SR are shown in Fig. 5. It can be seen from Fig. 5 that the impedance bandwidth of the proposed antenna is decreased with the increment of SD and SR at Mode-2, Mode-3 and Mode-4. The impedance bandwidth is widest when the value of the SD and SR are 8 mm at Mode-1, Mode-5 and Mode-6.

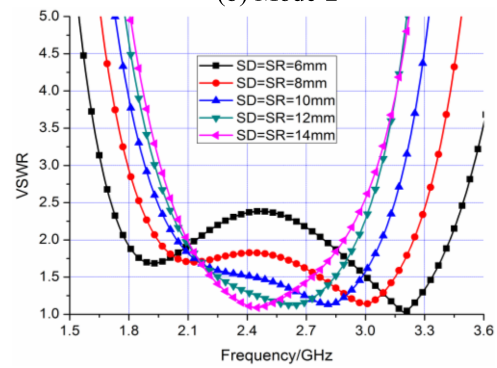
Figure 6 shows the maximal gain of the proposed antenna at the center frequencies and edges of the desired service bands. The maximal gain for the Mode-2 and Mode-3 at 1.9 GHz is about 3.83 dBi. The maximal gain for Mode-5 and Mode-6 at 2.8 GHz is 6.2 dBi.



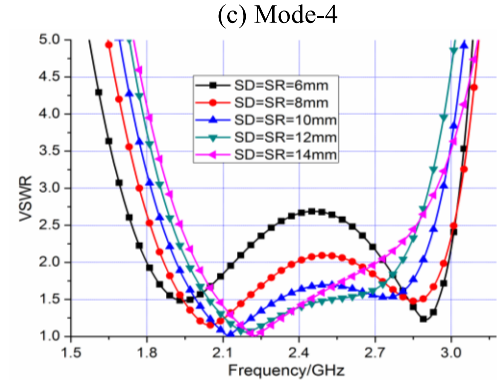
(a) Mode-1



(b) Mode-2



(c) Mode-4



(d) Mode-5

Fig. 5. VSWR of the proposed reconfigurable antenna with different values of SD.

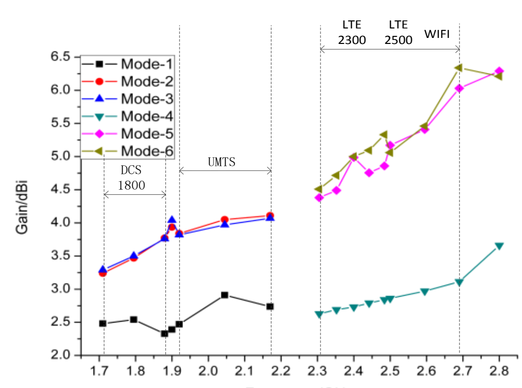
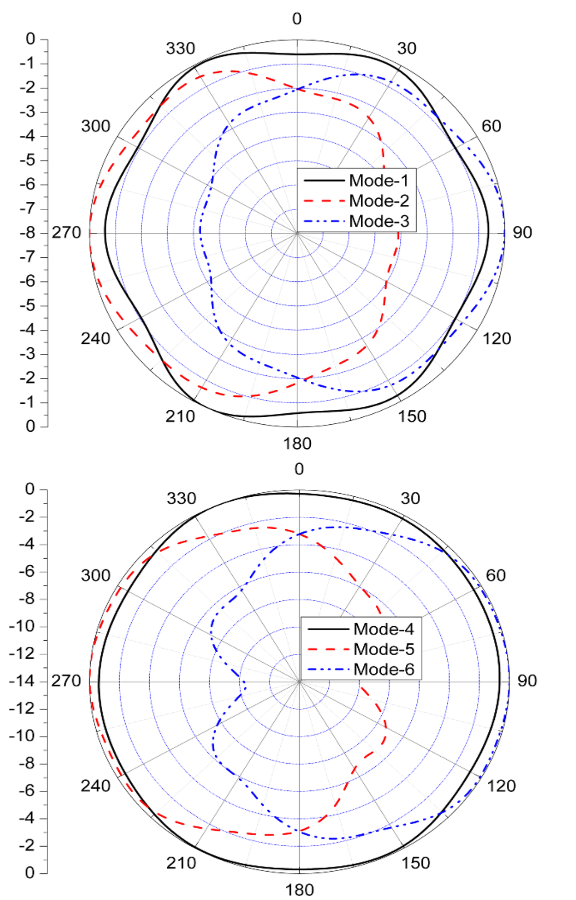
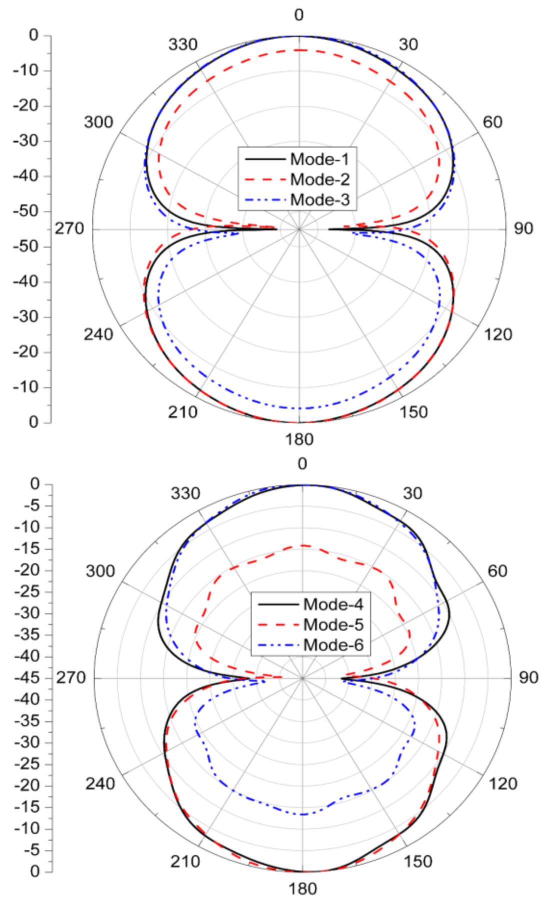


Fig. 6. Gain of the proposed reconfigurable antenna.

The radiation patterns of the proposed antenna at 1.9 GHz and 2.8 GHz are given in Fig. 7. The H-plane is designated as XOZ plane and E-plane is designated as XOY plane. It is shown that the maximum beams are 90° and 270°in the H-plane at 1.9 GHz and 2.8 GHz for Modes 2-3 and 5-6, respectively. Moreover, the half-power beam widths are 179°and 160°degree at Mode-2 and Mode-5, respectively. As for Mode-1 and Mode-4, the proposed antenna can provide a near omni-directional characteristic. According to the design theory of Yagi antenna, the amplitude and phase of surface current on the director and reflector elements can be adjusted to change the space between adjacent elements. The LD effects on the radiation pattern of the proposed antenna are shown in Fig. 8. It is found that the antenna can provide omni-directional radiation patterns for Modes 1 and 4, while it has a directional radiation patterns for other modes with varying LD. The smaller the LD is, the better directional radiation patterns can be achieved.

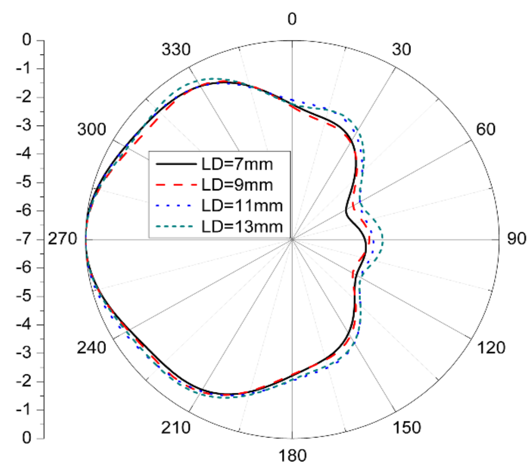


(a) H-plane

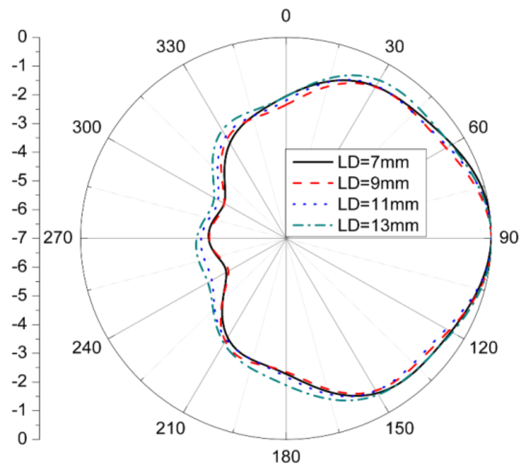


(b) E-plane

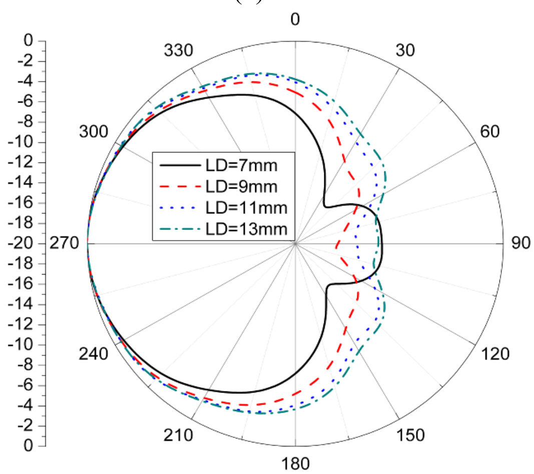
Fig. 7. Radiation pattern of the proposed reconfigurable antenna.



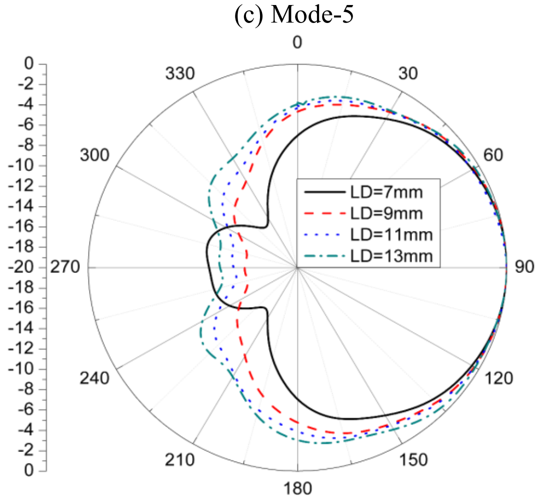
(a) Mode-2



(b) Mode-3



(c) Mode-5



(d) Mode-6

Fig. 8. Radiation pattern of the proposed reconfigurable antenna in the H-plane with different values of LD.

In order to investigate the proposed antenna in detail, the proposed antenna has been compared with standard Yagi antenna at 1.9 GHz. The dimensions of the proposed antenna and standard Yagi antenna are given in Table 2. From Table 2, we can see that the proposed antenna is small in size.

Since all the antenna elements are embedded in the dielectric substrate, the wavelength of the proposed antenna at operation frequency is shorter than the wavelength in free space. In this paper, the effective wavelength in the dielectric substrate is defined in equation (1):

$$\lambda_r = \frac{\lambda_0}{\sqrt{\varepsilon_r}}, \tag{1}$$

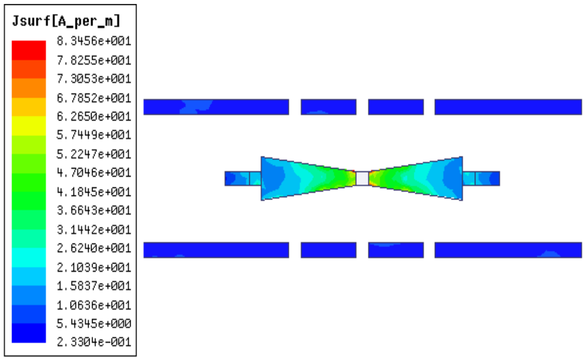
where λ_r is the wavelength in the substrate at 1.9 GHz. Therefore, we should consider the dielectric substrate effects when we design our proposed antenna.

Table 2: Dimensions of standard Yagi antenna and the proposed antenna

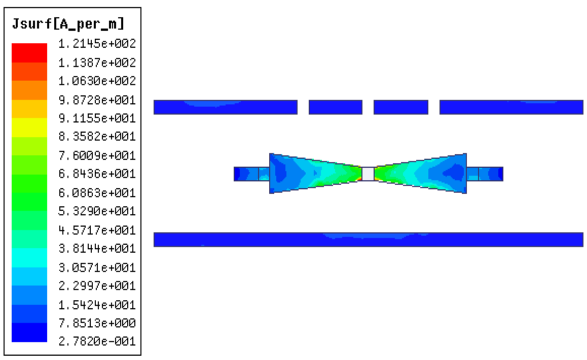
	Standard Yagi Antenna	The Proposed Antenna
Length of driven element	$0.462\,\lambda_0$	$0.26\,\lambda_0$
Length of reflector	$0.499\,\lambda_0$	$0.44\,\lambda_0$
Length of director	$0.375\,\lambda_0$	$0.123\,\lambda_0$
Spacing between driven element and reflector	$0.25\,\lambda_0$	$0.06\,\lambda_0$
Spacing between driven element and director	$0.3\,\lambda_0$	$0.06\,\lambda_0$

To further understand the principle of the proposed antenna, the distribution of the electric current at each mode has been shown in Fig. 9. As shown in Fig. 9 (a)-(c), the currents on the directors at Mode-2 and Mode-3 are larger than that of Mode-1. The distribution of the electric currents at Mode-4, Mode-5 and Mode-6 are similar to those of Mode-1, Mode-2 and Mode-3. The electric current on the reflectors at Mode-5 and Mode-6 are smaller than that of Mode-4.

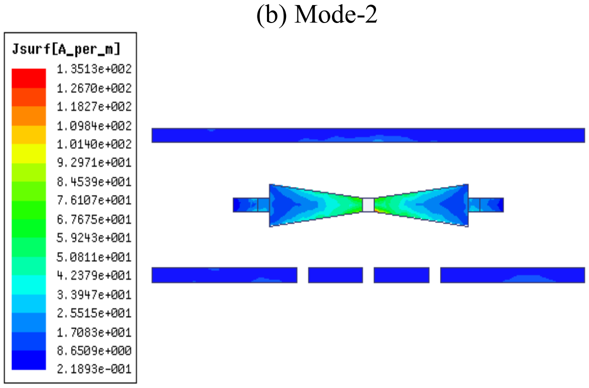
The electric field distribution in XOY plane of the proposed antenna is given in Fig. 10. Compared Fig. 10 (a) with Fig. 10 (b), it can be seen that the electric field intensity around the reflector at Mode-2 is lower than the electric field intensity at Mode-1 because of the electric current distribution. Obviously, the electric field distribution at Mode-2 is almost symmetric to the electric field distribution at Mode-3. When the proposed antenna works at 2.8 GHz, the electric field distribution is similarly shown in Fig. 10 (d)-(f). As shown in Fig. 10 and Fig. 11, the electric field intensity around director at Mode-2, Mode-3, Mode-5 and Mode-6 becomes higher because of the energy conservation law. If the proposed antenna is applied on portable device, the electromagnetic radiation towards the users will be reduced by controlling the modes.



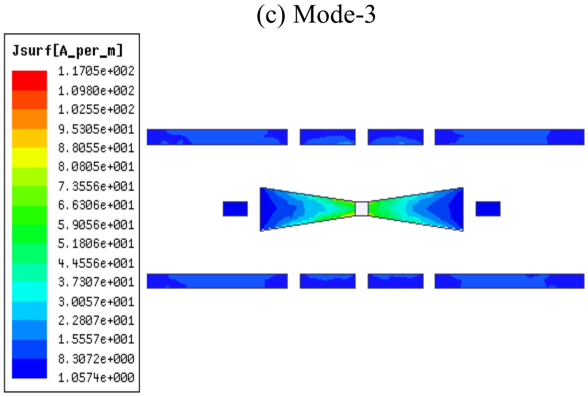
(a) Mode-1



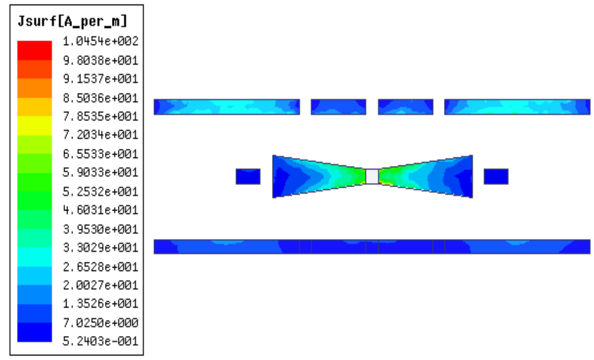
(b) Mode-2



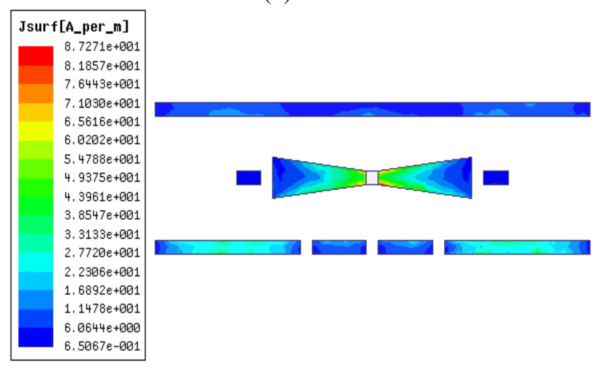
(c) Mode-3



(d) Mode-4

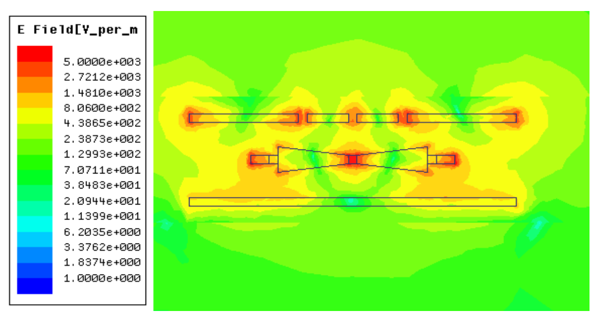


(e) Mode-5

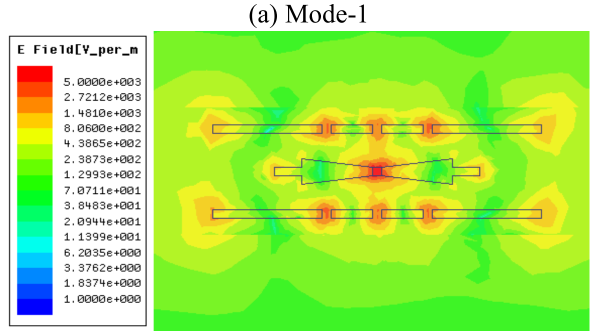


(f) Mode-6

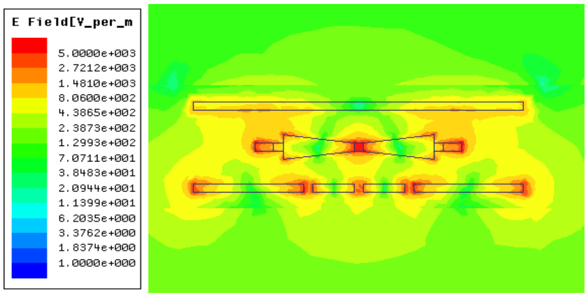
Fig. 9. The distribution of the electric current of the proposed reconfigurable antenna.



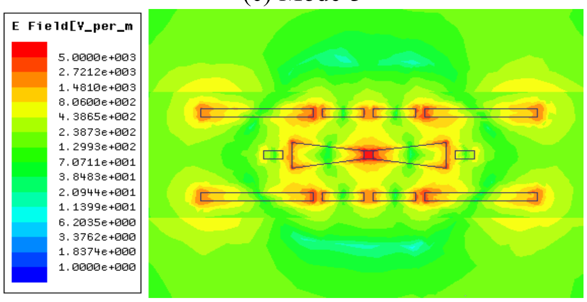
(a) Mode-1



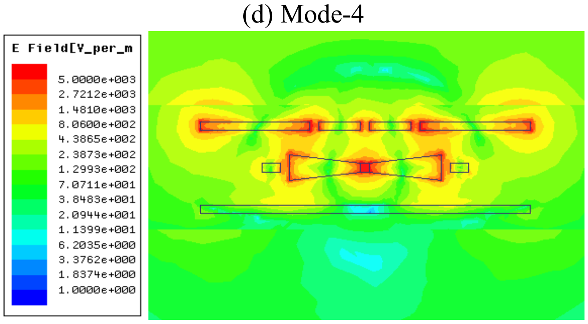
(b) Mode-2



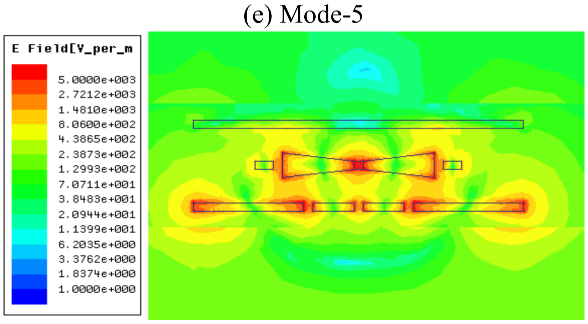
(c) Mode-3



(d) Mode-4

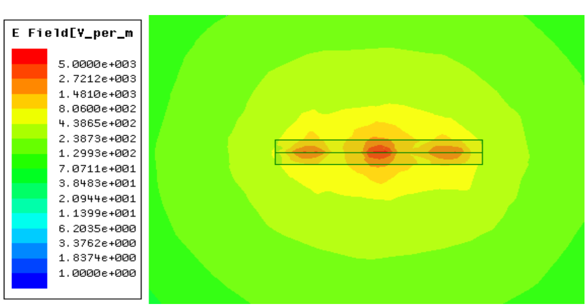


(e) Mode-5

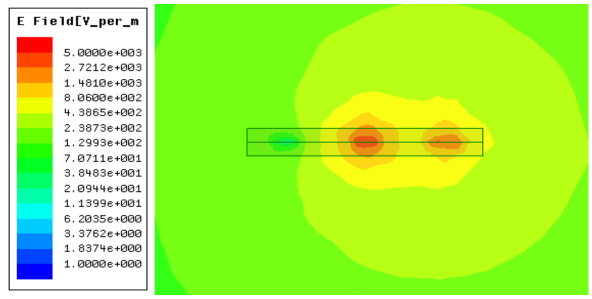


(f) Mode-6

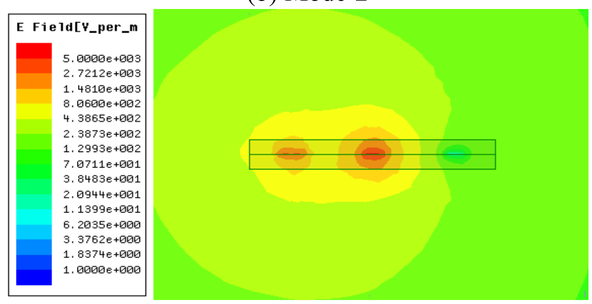
Fig. 10. Electric field distribution in XOY plane of the proposed reconfigurable antenna.



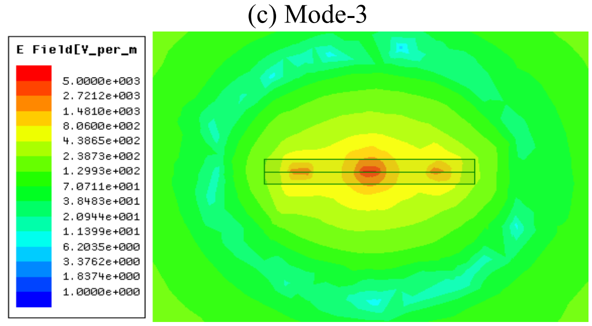
(a) Mode-1



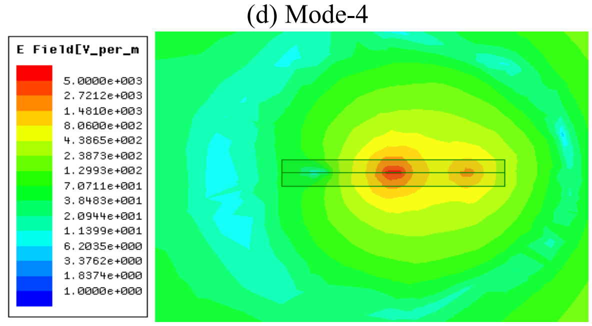
(b) Mode-2



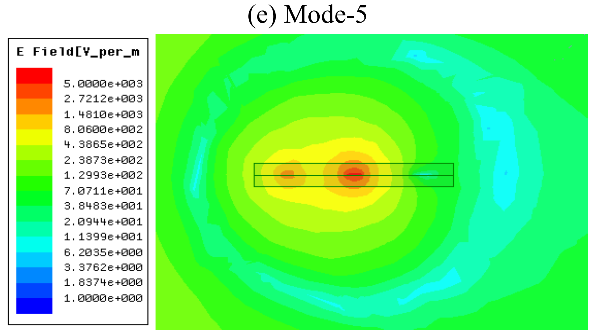
(c) Mode-3



(d) Mode-4



(e) Mode-5



(f) Mode-6

Fig. 11. Electric field distribution in XOZ plane of the proposed reconfigurable antenna.

IV. CONCLUSION

Based on the dielectric embedded technology and the theory of the Yagi antenna, a frequency and radiation pattern reconfigurable antenna has been presented and investigated in detail. The experimental results demonstrated that the proposed antenna can operate at 1.9 GHz and 2.8 GHz, and can provide directional or omni-directional radiation patterns. By controlling the states of the switches, the electric field intensity towards users becomes weak, and hence, the electromagnetic radiation from the portable device can be reduced. The proposed antenna can cover DCS1800 and UMTS at the lower band and can provide support for LTE2300, LTE2500 and WLAN at the upper band. In comparison with the conventional microstrip Yagi reconfigurable antennas, the proposed antenna is relatively small for the given frequency because all the components are buried in the substrate. In the future, we will investigate the proposed antenna by using the PIN diodes switches.

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