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A Coupled-Fed Reconfigurable Antenna for Internal LTE Mobile Phone Applications

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Abstract—In this paper, a multi-frequency broadband planar reconfigurable antenna is designed for smart mobile phone applications. The antenna comprises two monopole strips and a parasitic shorting strip, and generates several independent resonant modes through this kind of stub loading. The miniaturization and broadbandization of the antenna is achieved by bending the strip line and using coupling feed. In addition, loading the matching circuit at the feeding point, the bandwidth can completely cover 824–960 and 1710–2690 MHz. In order to cover a lower band LTE band 20 (800 MHz), an RF switch at shorting point is used to switch low frequency to 791 MHz. So the proposed antenna can work at GSM850, 900; DCS1800; PCS1900; WCDMA bands 1, 2, 4, 5, 8; TD-SCDMA bands A, F; CDMA BC0, BC1 and LTE bands 1, 3, 5, 7, 8, 20, 38, 39, 40, 41. Also, the total size of the antenna is 15 mm × 30 mm × 0.8 mm, which is very suitable for 4G slim smart mobile phone applications.

1. INTRODUCTION

With the popularity of the 4G network, mobile antenna design is facing more and more challenges, such as multiband, wide bandwidth, small size, low cost and easy manufacture. In recent years, many planar monopole antennas [1–3], loop antennas [4, 5] and parasitic antennas [6–8] have been used in mobile phone to improve the disadvantages of PIFA antenna. A monopole antenna with three stubs was designed in [3]. The dimension of the antenna is only 15 mm × 42 mm that can cover CDMA800/GSM850/GSM900/DCS/PCS/UMTS/ISM/LTE2300/LTE2500, but the dimension is a little big. A parasitic antenna was proposed in [8], and the antenna consisted of a feed monopole and a short stub, with a coupling aperture for matching adjustment, so the antenna achieved a wide band. Furthermore, the space left for antenna design is getting smaller and smaller, several scholars proposed using impedance matching circuit at feeding port to obtain broadband coverage [9–12]. RF switch is also used to design a reconfigurable antenna to achieve a wide band by combing several different statuses. In [13–15], an RF switch was used to change the antenna's resonant length, so the antenna can work at different frequencies by changing the switch's status, but they load the switches on the antenna pattern that may bring bigger loss.

In this paper, we present a multi-frequency broadband recognizable antenna for LTE smart phone applications. The antenna is printed on an FR4 substrate with a dimension of 115 mm × 60 mm × 0.8 mm. The antenna is located on the top plane area, and the ground is on the back. The proposed antenna can completely cover 791–960 and 1710–2690 MHz by using a matching circuit at feeding point and an RF switch at shorting point. Details of the antenna design are presented. Return loss, bandwidth, and efficiency of the antenna are studied in this paper.

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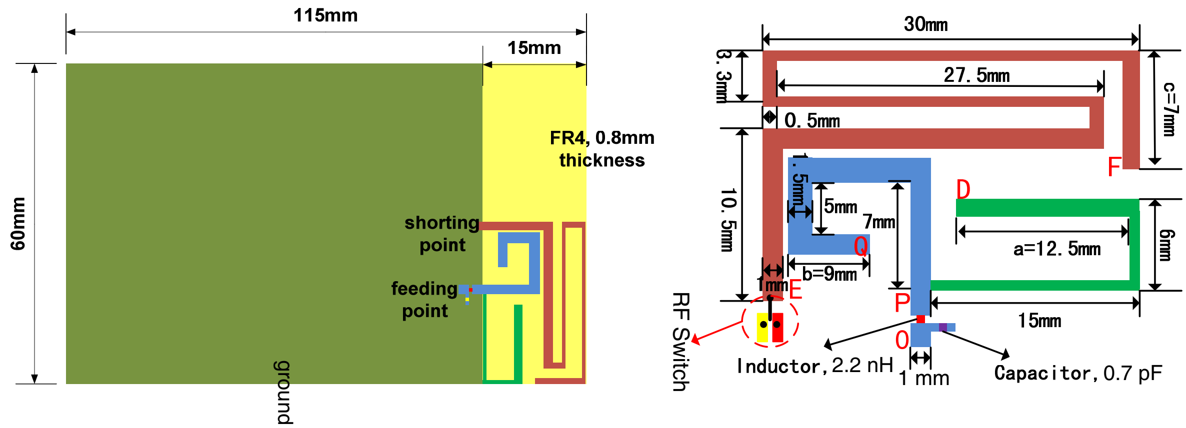
2. ANTENNA CONFIGURATION AND DESIGN

The basic geometry of the proposed antenna is shown in Fig. 1, and Fig. 1(a) shows the integral structure. Detailed dimensions of the proposed antenna are shown in Fig. 1(b). In this paper, a 0.8 mm thick FR4 substrate of relative permittivity 4.4 and loss tangent 0.024 is used as the system circuit board. On the back side of the FR4 substrate, a ground plane of length 100 mm and width 60 mm is printed to serve as the system ground plane of the mobile phone. The whole clearance area with no ground is 15 mm × 60 mm. In order to achieve a small size, the antenna is disposed on the right corner and just occupies half of the clearance.



(a) (b)

Figure 1. Geometry of proposed Coupled-fed Reconfigurable Antenna for Internal LTE Mobile Phone Applications. (a) Integral structure of the proposed antenna. (b) Dimensions of the proposed antenna.

The antenna comprises two monopole strips (section PD and PQ) and a parasitic shorting strip (section EF). Point P is feeding point while E is shorting point. The two monopoles are directly fed by a 50 Ohm feed line after a matching circuit is put between points P and O. The parasitic shorting strip is excited by the monopoles coupling and connected to system ground at point E. The length of PQ is about 30.5 mm, which leads to the excitation of a 0.25-wavelength resonant mode at about 2.4 GHz. At the same time, the path PD is 37.5 mm, and a 0.25-wavelength resonant mode is also generated at about 1.76 GHz. A 0.25-wavelength resonant mode can be generated by the coupled-fed parasitic shorting strip EF, to form the antenna's lower band centered at about 850 MHz to cover the desired 824–960 MHz band. Also, a high-order resonant mode will be generated at 1.9 GHz, which is an octave of the low frequency.

Figure 2 shows the schematic diagram of the proposed antenna, which can achieve a very wide bandwidth larger than 1 GHz to cover the desired operating band of 1710–2690 MHz due to the matching circuit at the feeding point. Here, we connect a 2.2 nH inductor and shunt a 0.7 pF capacitor, which is a low pass circuit for high band impedance match and has little influence on low band.

As we can see, an SPDT is placed at the shorting point in Fig. 2, which is an active RF switch used to tune the low band to cover LTE band 20 (791 MHz). This kind of RF switches such as RFMD 1119A, Ethertronics EC 949 has been widely used in antenna design. We simulate the function of switch and achieves passive results in this paper. A 0 Ohm resistor and 3.9 nH inductor are in series at the shorting point respectively, which can be selected by the SPDT automatically. When connecting 0 Ohm resistor (state 1), the antenna can work at 824–960 MHz, while connecting 3.9 nH inductor, the low frequency can cover 791 MHz. According to the resonance theory $f = \frac{1}{2\pi\sqrt{LC}}$, the equivalent inductance L increases when a inductor is in series, so the resonant frequency f will be lower, which is equivalent to stretch the length of the antenna. All these demonstrate that the proposed antenna is reconfigurable at low frequency.

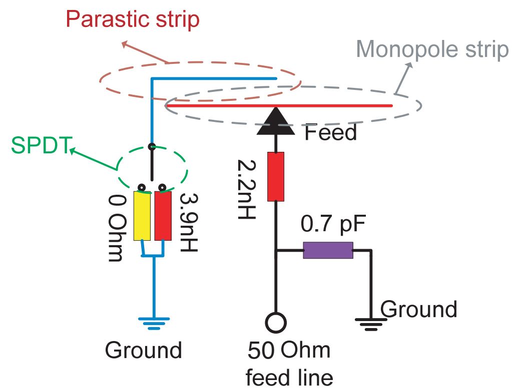


Figure 2. The schematic diagram of the proposed antenna.

3. RESULTS AND DISCUSSION

The simulated current distributions on the proposed antenna for different frequencies are displayed in Fig. 3. It is observed that the current is concentrated on the parasitic shorting strip (section EF) at 0.85 GHz, while the two monopoles are excited at 1.75 GHz and 2.4 GHz, respectively. Further, the parasitic shorting strip also generates a mode at 1.9 GHz. The current distributions demonstrate that the resonant modes are generated by that strip, which is in agreement with the analysis in Section 2.

A photo of the fabricated antenna is shown in Fig. 4. To test the antenna, a short 50 Ohm cable with an SMA connector is connected to the feeding point, and 0402 lumped elements are used for

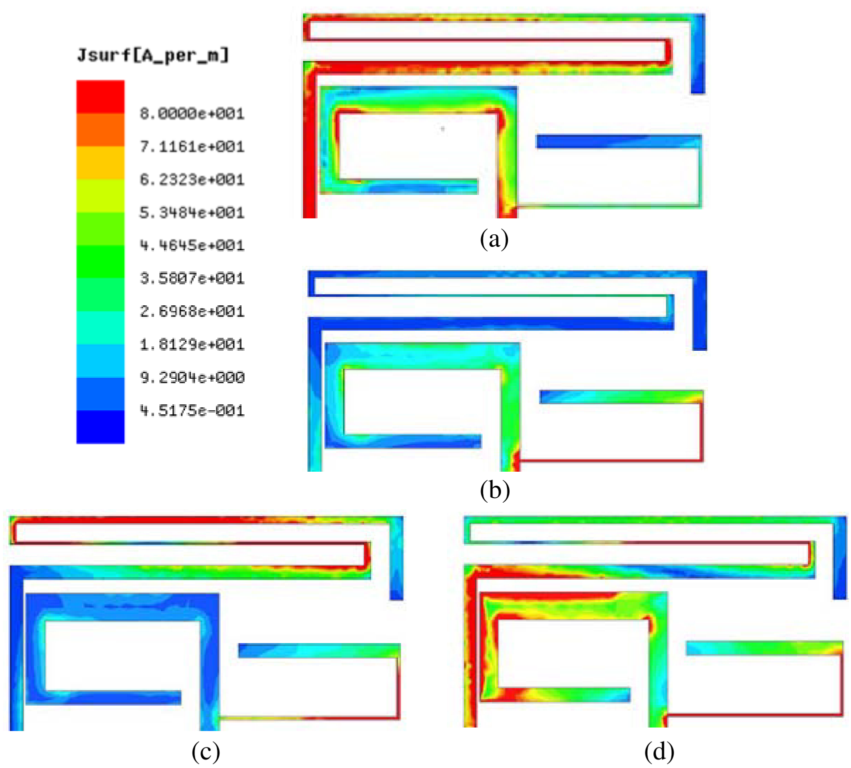


Figure 3. The Current distributions on the proposed antenna at (a) 0.85, (b) 1.75, (c) 1.9, and (d) 2.4 GHz.

Figure 4. Fabricated prototype of the proposed antenna.

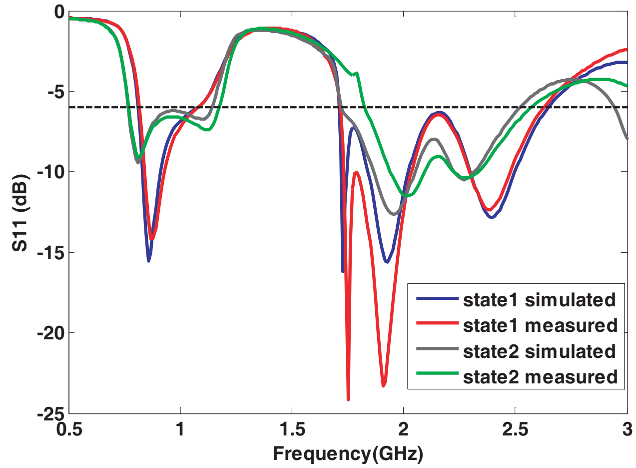


Figure 5. Simulated and measured S_{11} of the proposed antenna.

Name	Freq(GHz)
m1	0.791
m2	0.824
m3	0.96
m4	1.71
m5	2.17
m6	2.3
m7	2.4
m8	2.496
m9	2.69

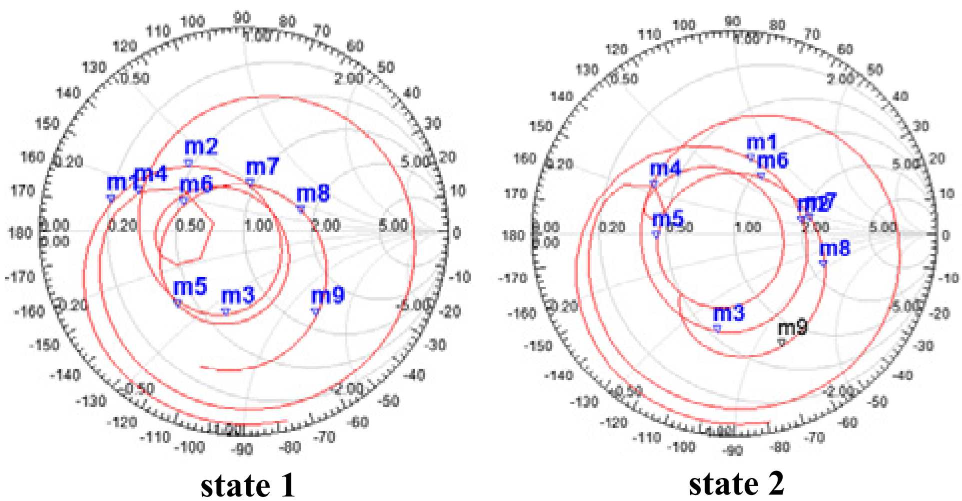


Figure 6. Simulated state 1 and state 2 Smith chart of the proposed antenna.

impedance matching and analog function of the RF switch. Results of the measured and simulated S_{11} for the fabricated antenna are presented in Fig. 5. The simulated results are obtained using Ansoft simulation software high frequency structure simulator (HFSS), and the measured results are obtained using Agilent 5071C. Very good agreement between the simulated and measured results can be seen in the figure. For state 1, a 0 Ohm resistor is connected to the shorting point by the SPDT RF switch, and the obtained input impedance is better than $3:1$ VSWR or S_{11} less than -6 dB, which can cover 824–960 and 1710–2690 MHz. On the other hand, when the RF switch is changed to another state (state 2), where a 3.9 nH inductor is connected to the shorting point. In this state, a lower frequency (791 MHz) can be achieved. Due to the two states, the proposed antenna can work at GSM850, 900; DCS1800; PCS1900; WCDMA bands 1, 2, 4, 5, 8; TD-SCDMA bands A, F; CDMA BC0, BC1 and LTE bands 1, 3, 5, 7, 8, 20, 38, 39, 40, 41, which is very suitable for LTE smart phone applications. Fig. 6 shows the simulated Smith charts of state 1 and state 2. It is clear that the entire bands are in good impedance in state 1. However, the points rotate along the impedance circle diagram clockwise when a 3.9 nH inductance (state 2) is in series, which demonstrate the inductance increase, so the resonant may move to lower band.

To optimize the proposed antenna, the dimensions are swept. Effects of length a of the monopole PD are studied in Fig. 7. Simulated results of the S_{11} for length a varied from 11.5 to 13.5 mm with step 1 mm are shown. Again, some effects on 1.76 GHz are seen. The resonant frequency of 1.76 GHz decreases significantly when a increases, and there is almost no influence on other bands, which demonstrates that the resonant mode of 1.76 GHz is generated by the monopole PD. Further, the value of $|S_{11}|$ decreases significantly when a increases due to the coupling distance between monopoles PQ and PD, which causes the impedance match to change.

The same effects can also be seen in Fig. 8 and Fig. 9 that the length of the monopole PD and the length of parasitic shorting strip EF are swept. Length b just affects 2.4 GHz obviously while length c influences both 850 MHz and 1.9 GHz which can prove that the coupled-fed parasitic shorting strip EF generates a lower band centered at about 850 MHz as well a high-order resonant mode at 1.9 GHz, which is an octave of the low frequency.

The efficiency for the fabricated antenna is measured in an ETS chamber, and the measured results are presented in Fig. 10. The measured radiation efficiencies are about 33–52% and 40–67% for frequencies over the lower and upper bands, respectively.

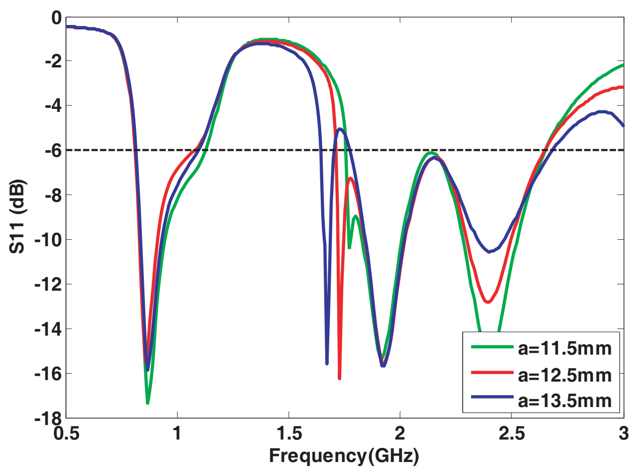


Figure 7. Simulated S_{11} as a function of the length a.

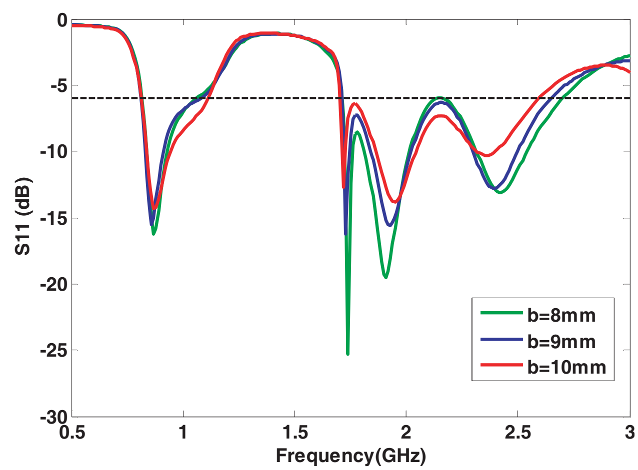


Figure 8. Simulated S_{11} as a function of the length b.

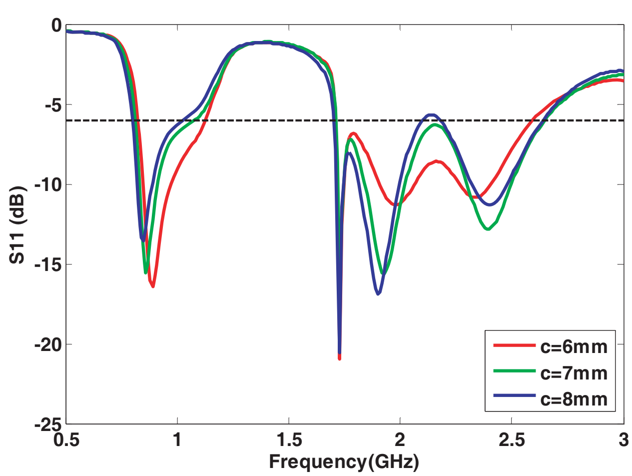


Figure 9. Simulated S_{11} as a function of the length c.

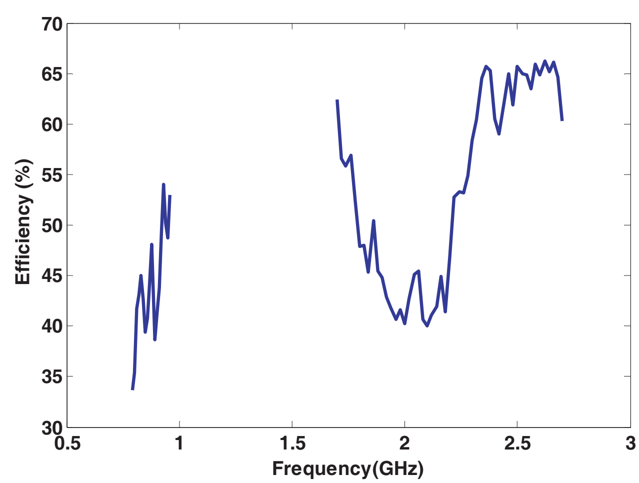


Figure 10. Measured radiation efficiency for the fabricated antenna.

4. CONCLUSION

In this paper, we present a multi-frequency reconfigurable planar antenna for smart mobile phone applications. The antenna achieves miniaturization and broadbandization by bending the strip line and using coupling feed. In addition, after loading the matching circuit at the feeding point and RF switch at the shorting point, the bandwidth can completely cover 791–960 and 1710–2690 MHz. So the proposed antenna can work at GSM850, 900; DCS1800; PCS1900; WCDMA bands 1, 2, 4, 5, 8; TD-SCDMA bands A, F; CDMA BC0, BC1 and LTE bands 1, 3, 5, 7, 8, 20, 38, 39, 40, 41. Also, the total size of the antenna is $15\,\mathrm{mm} \times 30\,\mathrm{mm} \times 0.8\,\mathrm{mm}$, which is very suitable for 4G slim smart mobile phone applications.

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