Compact Heptaband Reconfigurable Loop Antenna for Mobile Handset

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***Abstract*—In this letter, an internal folded reconfigurable loop antenna for mobile handset applications is designed, built, and tested. Two operating states with different frequencies are obtained by switching the shorting pins of the loop. The bandwidth of the proposed antenna has been increased by adopting a matching bridge. In a compact volume of $60 \times 5 \times 5$ mm^3, the proposed antenna operates in heptaband, including GSM850, GSM900, GPS, DCS, PCS, UMTS, and WLAN, with the return loss lower than 6 dB. The efficiency and gain with the p-i-n diodes with their bias circuit are also measured and analyzed.**

***Index Terms*—Handset antennas, multiple-band antennas, reconfigurable antennas.**

I. INTRODUCTION

WITH the rapid development of internal multiband antennas, it is possible to achieve the miniaturization in mobile terminals, such as cell phones and personal digital assistants (PDAs). Different antenna patterns are adopted for the internal antenna design in the mobile handset applications, such as monopole antennas [1], [2], inverted-F antennas [3]–[5], and so on. Recently, the loop antennas have been widely discussed in publications due to their wide bandwidth, ease of controlling higher modes, and self-balance of the current [6]–[8]. The loop antenna can be designed as a folded inverted conformal antenna (FICA) in several commercial products [9]–[11]. Especially, the tuning pad proposed in [6] and [7] shows the ability to increase the impedance bandwidth by tuning the higher modes. However, the integration of more bands to an internal antenna in a space-limited mobile terminal continues to be a challenge.

A frequency reconfigurable antenna is one of the effective solutions in minimizing antenna design. It allows several operating states to be switched in the same antenna pattern without any extra structure. By combining these states, the bandwidth can be increased by multiple times. The reconfigurable concept is also adopted in the multiband antenna design [4], [5], and its performance has been validated. In this letter, a folded loop antenna is proposed for mobile handset applications. The proposed antenna is reconfigured by switching the shorting pins, controlled by two p-i-n diodes. Besides adopting the tuning pad studied in [6] and [7], a matching bridge is also used in both states to achieve wider bandwidth. Heptaband coverage is achieved in a volume of $60 \times 5 \times 5$ mm^3, including the Global System for Mobile Communications (GSM850: 824–894 MHz, GSM900: 880–960 MHz), the Global Positioning System (GPS: 1575 MHz), the Digital Cellular System (DCS: 1710–1880 MHz), the Personal Communication System (PCS: 1850–1990 MHz), the Universal Mobile Telecommunication System (UMTS: 1920–2170 MHz), and the wireless local area network (WLAN: 2400–2484 MHz). The proposed antenna is mounted on a typical mobile phone and measured. The results show good radiation efficiency and gain, even after considering the insertion loss of p-i-n diodes.

II. ANTENNA DESIGN

A. Antenna Geometry and Configurations

As shown in Fig. 1, the proposed antenna has an overall dimension of $60 \times 5 \times 5$ mm^3, and it is mounted on a $100 \times 60 \times 0.8$-mm^3 FR4 main board $(\varepsilon_\mathrm{r} = 4.4, \tan\delta = 0.01)$ with metal printed on the backside. The folded loop antenna with a uniform width of 1 mm is supported by foam with the permittivity close to that of air. A 50-Ω microstrip line is used on the front side of the main board and connected to the feeding pin of the loop. Two shorting pins, SP1 and SP2, are also on the front side. Two different operating frequencies are achieved by connecting SP1 or SP2 to the ground through vias. The part connecting the feeding pin and the shorting pin serves as a matching bridge with the width of 1 mm.

The loop antennas in the mobile handset are systematically studied by Wong [6], [7]. There are three resonant modes, including 0.5-wavelength mode, 1-wavelength mode, and 1.5-wavelength mode, that can be utilized. A tuning pad [6], [7] in a certain position of the loop is a good solution to achieve wide bandwidth because it has different effect to different modes. The 0.5-wavelength mode is tuned for lower bands, and the 1-wavelength and 1.5-wavelength modes are tuned together to cover the higher bands.

B. Reconfigurable Shorting Design

As mentioned above, two working states with different operating frequencies of the loop antenna can be achieved by

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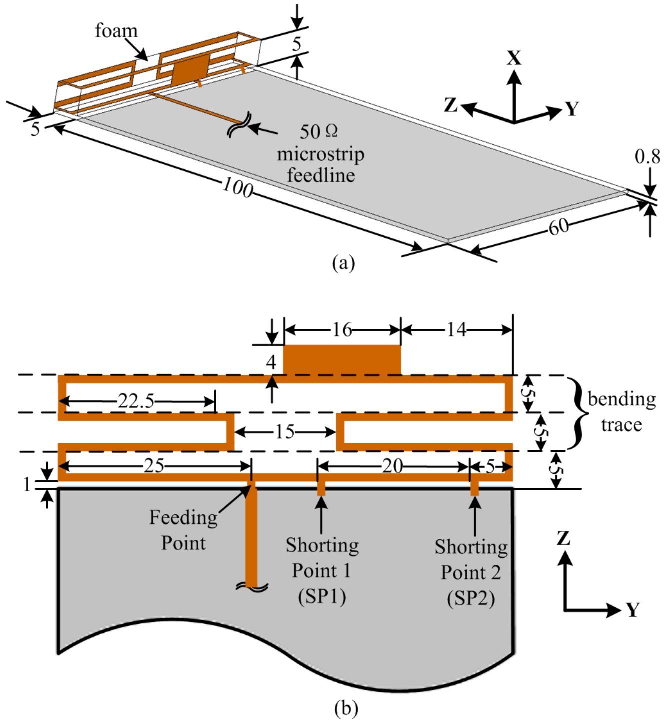

Fig. 1. Geometry and dimensions of the proposed antenna. (a) 3-D view. (b) Detailed dimensions in the planar view.

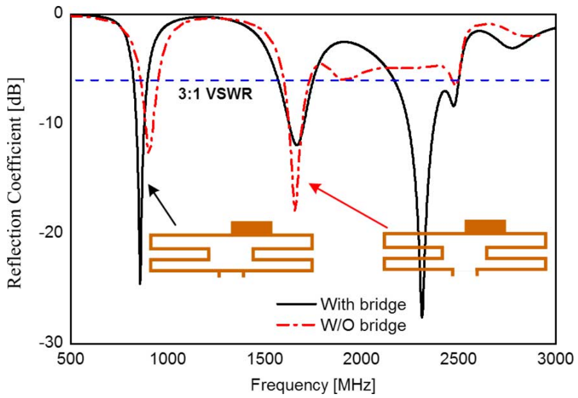

Fig. 2. Simulated return loss of SP1 state of the proposed antenna with or without the matching bridge.

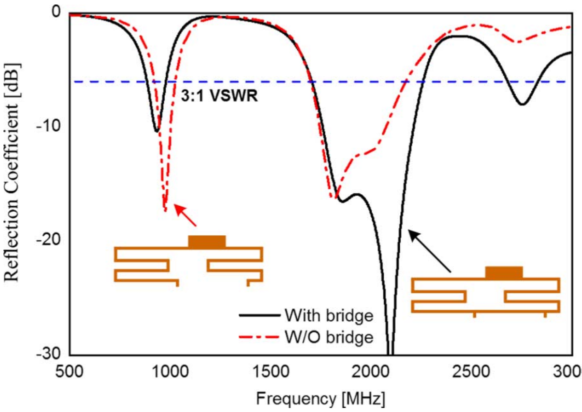

Fig. 3. Simulated return loss of SP2 state of the proposed antenna with or without the matching bridge.

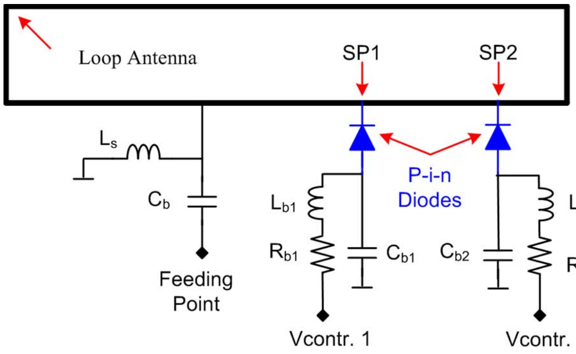

Fig. 4. Diagram of bias circuit of p-i-n diodes.

selecting the shorting pins, SP1 or SP2, and are named as SP1 state and SP2 state.

When SP1 connects to the ground and SP2 is open, the loop works in the SP1 state. The simulated return loss of SP1 state is illustrated in Fig. 2. The antenna covers the bands of GSM850, GPS, and WLAN with 6-dB return loss, operating at the modes of 0.5-wavelength, 1-wavelength, and 1.5-wavelength. The three modes are determined by the length of loop. The higher modes are not tuned together by the tuning pad. The matching bridge connecting the feeding pin and SP1 works as a shunt inductor for the impedance matching for the all three modes. Comparing between the solid and dashed lines in Fig. 2, the bandwidth has been improved by adopting the matching bridge.

When SP2 connects to the ground and SP1 is open, the loop works in the SP2 state. The simulated return loss of SP2 mode is illustrated in Fig. 3. The antenna covers the bands of GSM900, DCS, PCS, and UMTS with 6-dB return loss. The length of the loop is shorter than that of SP1 state. As a result, the 0.5-wavelength mode works at a higher frequency than the SP1 state. The 1-wavelength and 1.5-wavelength modes are tuned together by the tuning pad [6], [7] for wider bandwidth coverage. The matching bridge connecting the feeding pin and SP2 also works as a shunt inductor with a different length from that of SP1 state. From the comparison between the solid line and dashed line in Fig. 3, the lower frequency shift down and the higher band has been broadened by adding the matching bridge. For both the effect of tuning pad and matching bridge, the higher band is able to cover the bands of DCS, PCS, and UMTS.

III. EXPERIMENT RESULTS

The SP1 and SP2 states of the proposed antenna are controlled by two p-i-n diodes. The position of the p-i-n diode is illustrated in Fig. 4. When the left p-i-n diode is "ON" and the right p-i-n diode is "OFF," the antenna works in the SP1 state. When the left p-i-n diode is "OFF" and the right p-i-n diode is "ON," the antenna works in the SP2 state. The detailed diagram of the bias circuit of p-i-n diodes is shown in Fig. 4. The selected p-i-n diodes are Philips BAP64–03 silicon PIN diodes, with good performance up to 3 GHz [12]. When the p-i-n diode is forward-biased, it works as a series resistor. In the frequency band of 0.5–2.5 GHz, the insertion loss introduced by the p-i-n diode is 0.1–0.2 dB at its typical bias current of 10–100 mA. When the p-i-n diode is reverse-biased, it is equivalent to a series capacitor of approximately 0.45 pF, and the isolation in the

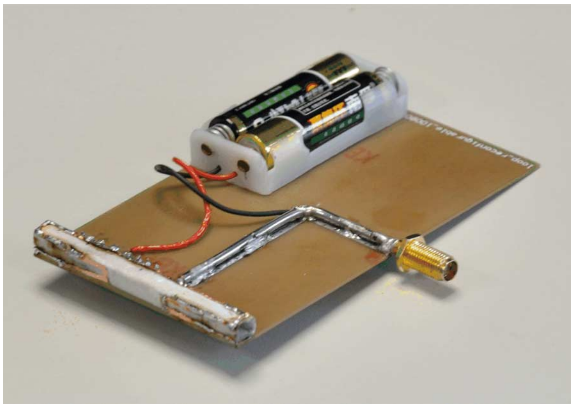

Fig. 5. Photograph of the proposed antenna.

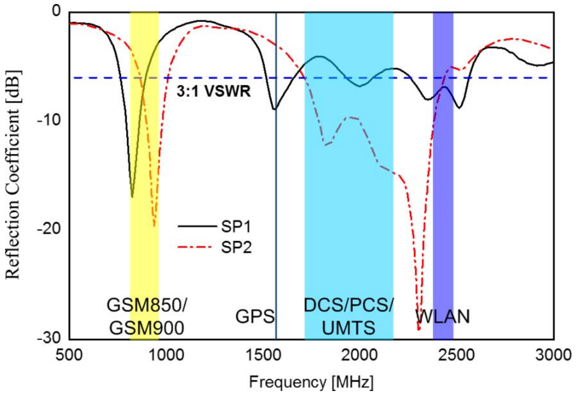

Fig. 6. Measured return loss of SP1 and SP2 states of the proposed antenna.

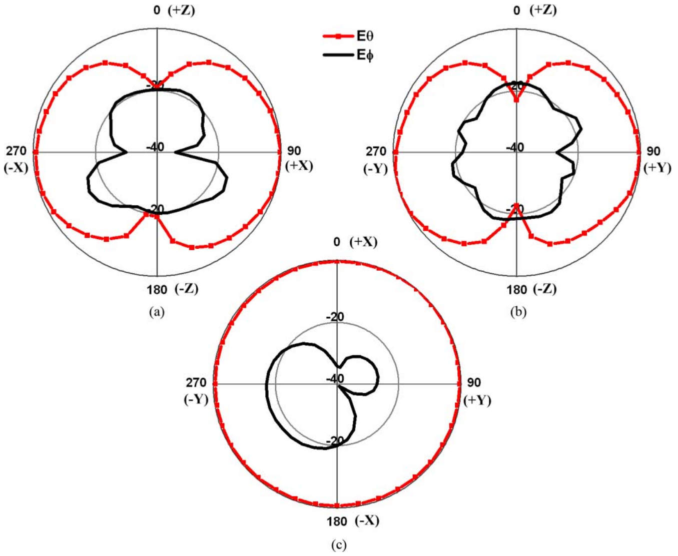

Fig. 7. Measured radiation pattern of SP1 state of the proposed antenna at 848 MHz: (a) xz-plane; (b) yz-plane; (c) xy-plane.

required band is better than -15 dB. In the bias circuit, the dc blocking capacitances (C_{b}, C_{b1}, and C_{b2}) are 120 pF; the RF choking inductors (L_{b1} and L_{b2}) are 120 nH; the RF shorting inductor (L_{s}) is 100 nH; and bias resistors (R_{b1} and R_{b2}) are Ω. The designed prototype of the proposed antenna with switching mechanism (diodes and bias circuit) is shown in Fig. 5. The bias voltage is 3 V, supplied by two AAA batteries, the bias current is 65 mA.

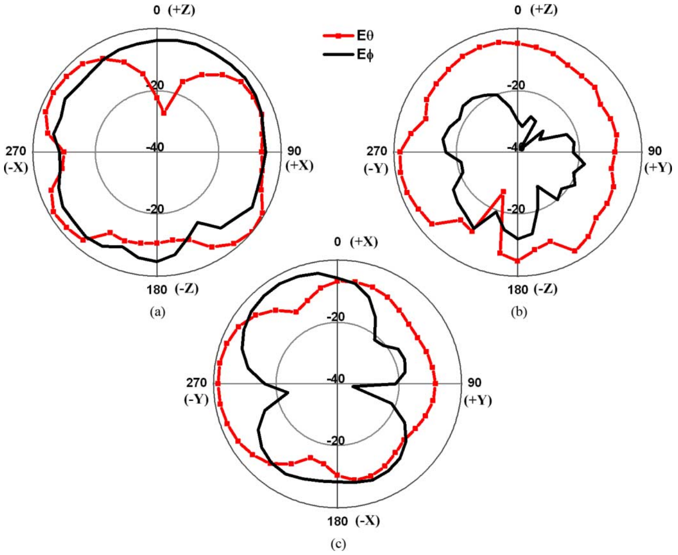

Fig. 8. Measured radiation pattern of SP1 state of the proposed antenna at 2435 MHz: (a) xz-plane; (b) yz-plane; (c) xy-plane.

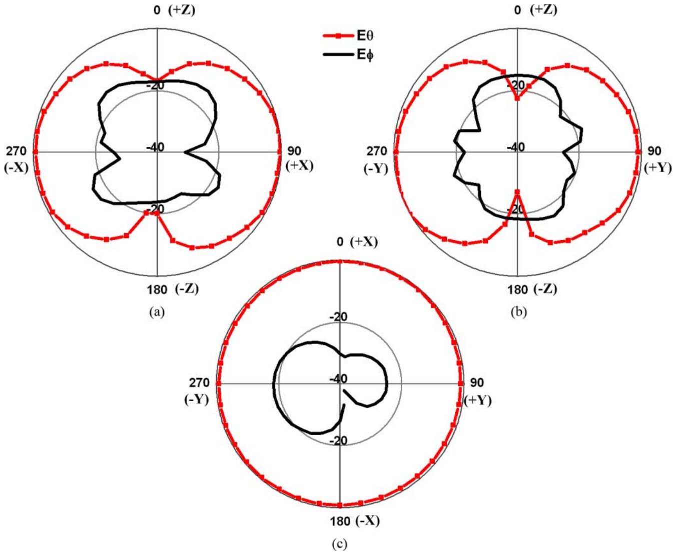

Fig. 9. Measured radiation pattern of SP2 state of the proposed antenna at 908 MHz: (a) xz-plane; (b) yz-plane; (c) xy-plane.

The measured return losses of both working states are shown in Fig. 6. These results match the simulation model. The heptaband is covered with 6-dB return loss by combining the bandwidths of SP1state and SP2 state. For the SP1 state (solid line), the achieved bands are 770–885, 1520–1660, and 2260–2560 MHz, covering GSM850, GPS, and WLAN bands. For the SP2 state (dashed-dotted line), the achieved bands are 875–1010 and 1705–2410 MHz, covering GSM900, DCS, PCS, and UMTS bands. Once again, the heptaband is covered in the volume of $60 \times 5 \times 5$ mm^3.

The radiation patterns are measured and illustrated in Figs. 7–10. For SP1 state, 848 and 2435 MHz are chosen, and 908 and 1910 MHz are chosen for SP2 state. In the bands lower than 1 GHz, the ground plane is the main radiator, and

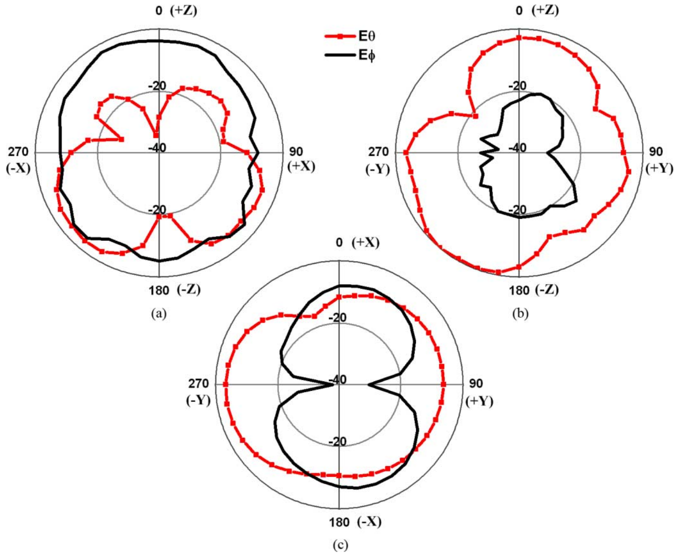

Fig. 10. Measured radiation pattern of SP2 state of the proposed antenna at 1910 MHz: (a) xz-plane; (b) yz-plane; (c) xy-plane.

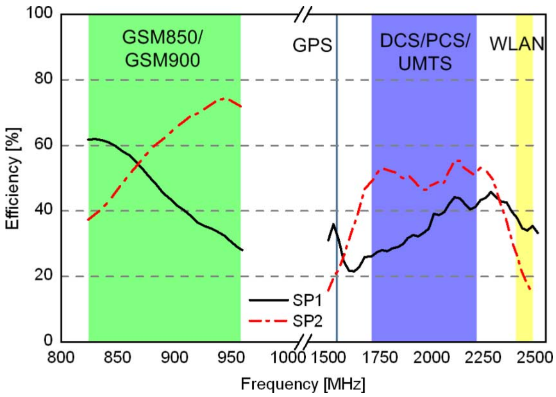

Fig. 11. Measured radiation efficiency of SP1 and SP2 states of the proposed antenna.

donut-shaped patterns appear in both states of SP1 and SP2 with low cross-polarization level. In the higher bands, the radiation patterns vary due to the radiation from both antenna elements and ground planes.

The measured radiation efficiencies and gains of SP1 and SP2 states are shown in Figs. 11 and 12, respectively. The efficiency of the proposed antenna is enhanced by combing the curves of two states. For the GSM band, the efficiency is greater than 53.6%; for the GPS band, the efficiency is greater than 26.4%; for the DCS, PCS, and UMTS bands, the efficiency is greater than 46.4%; and for the WLAN band, the efficiency is greater than 34.1%. For the GSM band, the gain is greater than -0.44 dBi; for the GPS band, the gain is greater than -1.41 dBi; for the DCS, PCS, and UMTS bands, the gain is greater than 0.45 dBi; and for the WLAN band, the gain is greater than -0.19 dBi. All the results are including the insertion loss of p-i-n diodes. Higher efficiency about 0.1–0.2 dB can be achieved by adopting high-quality diodes in the practical applications [12].

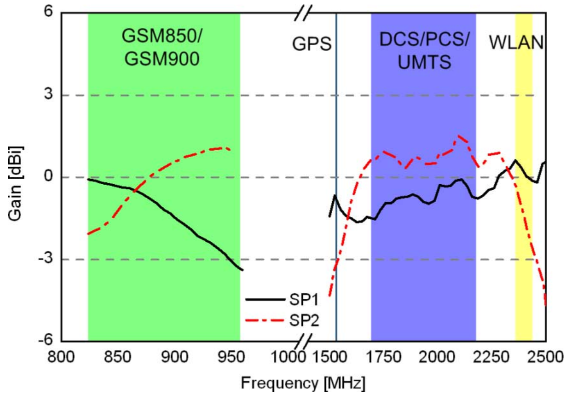

Fig. 12. Measured gain of SP1 and SP2 states of the proposed antenna.

IV. CONCLUSION

In this letter, we proposed a compact reconfigurable loop antenna for mobile handset applications. By combining two loop states with different frequencies, heptaband including GSM850, GSM900, GPS, DCS, PCS, UMTS, and WLAN can be covered in a volume of $60 \times 5 \times 5$ mm^3, much smaller than previous internal antenna designs. The bandwidth has been enhanced by adopting the tuning pad and the matching bridge. A prototype of the proposed antenna is being designed and tested. Good results of efficiency and gain illustrate the potential use of the proposed antenna for mobile applications.

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