Research Article

Compact Multiband Interdigital-Coupled-Fed Planar Antenna with Stepped-Impedance Structures for Mobile Handsets

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A new compact multiband planar antenna combining an interdigital-coupled feeding line and one stepped-impedance structure is presented here. This antenna is capable of generating five resonant modes to cover the ISM 915/2400/5800 MHz bands, GPS band, and IMT C-band, respectively. The five resonant frequencies covered by the proposed antenna can be adjusted individually by controlling the impedances and electrical lengths of the corresponding stepped-impedance sections. An additional advantage of the proposed stepped-impedance structure is its ability to suppress higher order resonance modes, thus filtering out unwanted interference. The proposed antenna utilizes a simple planar compact structure and occupies a small area of only $12 \times 30 \text{ mm}^2$. Details of the antenna design and experimental results are presented and discussed.

1. Introduction

Mobile wireless communication handsets typically use multiband antennas to transmit and receive wireless signals to cover all required wireless communication frequency bands [1–4]. Because of its compact size and multiband performance, the planar inverted F-antenna (PIFA) is preferred for multiband antenna for wireless communication devices [5–7]. However, the ability to cover multiple bands while minimizing the structure of slot antennas is still a challenge for antenna designers. Furthermore, the PIFA typically exhibits performance limitations related to the radiating branches, not only generating the lower resonant modes but also exciting several higher order modes. These unexpected higher modes will complicate frequency tuning of the multiband antenna. Additionally, these unexpected higher order modes will affect the power amplifier or low-noise amplifier's performances and in turn degrade multiband antenna's radiation properties.

Here we present a novel compact multiband planar antenna formed by the interdigital-coupled feeding line, one stepped-impedance line, and one shorted stripe line connected to the ground plane of the mobile handsets. The antenna feeding line comprises an interdigital structure for enhancing signal coupling and to allow more flexibility for wideband impedance matching [8]. The stepped-impedance

line forms folded stripe lines with different impedances and electrical lengths. This stepped-impedance structure is introduced to control five resonant modes to cover ISM 915/2400/5800 bands, GPS band, and IMT C-band operations, respectively. An additional advantage of using stepped-impedance structure includes the ability to suppress higher order resonant frequencies thus filtering out unwanted interference. Design consideration and experimental performances of the proposed antenna are studied and presented.

2. Antenna Design

Figure 1 shows the structure of the proposed interdigital-coupled-fed planar antenna. The proposed antenna mainly comprises the FR4 substrate, a ground plane under the substrate, and a radiating metal portion on the top of the substrate. Under the upside of the substrate, there is one ground-clear area under the radiating metal portion. The radiating metal portion comprises the interdigital-coupled feeding line, the stepped-impedance line, and one shorted line. The interdigital-coupled feeding line connecting a signal source forms a three-finger interdigital structure. One end of the interdigital-coupled-fed line is of the L-shape. The stepped-impedance line includes six bending stepped lines

FIGURE 1: Configuration of the proposed antenna on a 1.6 mm FR4 substrate. (a) Detailed dimensions of radiating element (front view). (b) Photo of the antenna prototype.

FIGURE 2: Measured and simulated return loss for the proposed antenna.

with different impedances and electrical lengths. The shorted line is connected to ground plane through one via hole.

Based on generalized transmission line theory, the multimode property of this stepped-impedance line can be characterized and determined by the impedances and electrical lengths of adjacent folded stripe lines [9–11]. In this proposed structure, the folded stripe lines control the excitations of the antenna bands centered at 915 MHz, 1575 MHz, 2400 MHz, 3200 MHz, and 5800 MHz to cover ISM 915/2400/5800 bands, GPS band, and IMT C-band operations, respectively. These five resonant modes generated by the corresponding respective stepped sections can be controlled individually. A ground plane with a length of 73 mm and a width of 54 mm is printed on the 1.6 mm thick FR4 substrate of relative permittivity of 4.4 and loss tangent of 0.02. The total size of FR4 corresponded to the width and length of 85 mm and 54 mm, respectively. The signal source feeds the interdigital-coupled lines and is subsequently coupled into the stepped-impedance lines. Both measurement and simulated results

including the peak gain, radiation efficiency, and radiation pattern are presented next to validate our proposed structure.

3. Experimental Results and Discussion

Figure 2 shows the measured and simulated return loss of the proposed antenna with the dimensions given in Figure 1. The measured data agrees very well with the simulated results obtained from the Ansoft simulation software HFSS [12]. The low band exhibits a measured 2.0:1 VSWR (−10 dB return loss) bandwidth covering ISM 915/2400/5800 bands (902–928 MHz, 2400–2500 MHz, and 5725–5875 MHz), GPS 1575 MHz band, and IMT C-band 3200–3400 MHz operation.

The measured gain radiation patterns of the constructed prototype are shown for the 915, 1575, 2450, 3200, and 5875 MHz frequency bands in Figure 3. At 915 MHz, the omnidirectional dipole-like radiation patterns can be seen,

FIGURE 3: Continued.

FIGURE 3: Measured gain radiation patterns at (a) 915 MHz; (b) 1575 MHz; (c) 2450 MHz; (d) 3200 MHz; and (e) 5875 MHz.

and the radiation patterns for higher frequencies show similar agreement with expected/simulated results. For the 1575, 2450, 3200, and 5875 MHz frequency bands, the measured gain radiation patterns are comparable to those observed in conventional internal mobile phone antennas.

For the lower band at ISM 915 MHz, the measured gain varied from about 0.4 to 0.7 dBi, and the antenna radiation efficiency is better than 50% over 902~928 MHz. For the upper bands including GPS 1575 MHz, ISM 2450/5800 MHz, and IMT C-band 3200 MHz, the antenna gain varies from 1.0 to 3.0 dBi, with the radiation efficiency better than 60%. The measured peak gain and radiation efficiency results of the proposed antenna are acceptable for practical application.

In order to show the resonant modes of the proposed antenna, the simulated surface current distributions on the radiating metal portion and the ground plane at 915, 1575, 2450, 3200, and 5875 MHz are shown in Figure 4. As shown

in Figure 4(a), the strong excited surface currents at 915 MHz are flowing along the folded stripe line 6 as defined in Figure 1. As shown in Figure 4(b), the strong excited surface currents at 1575 MHz are flowing along the folded stripe line 4. As shown in Figure 4(c), the strong excited surface currents at 2450 MHz are flowing along the folded stripe lines 2, 3, and 6. As shown in Figure 4(d), the strong excited surface currents at 3300 MHz are flowing along the folded stripe lines 2, 4, and 5. As shown in Figure 4(e), the strong excited surface currents at 5875 MHz are flowing along the folded stripe lines 1 and 2. These current distribution characteristics indicate that these five resonant modes can be tuned and controlled by the corresponding impedances and electrical lengths of folded stripe lines 1–6.

Furthermore, Figure 5 depicts the simulated return loss variations with the different widths W_2 , W_3 , W_4 , W_5 , and W_6 of folded stripe lines 2, 3, 4, 5, and 6, respectively. The obtained

FIGURE 4: Continued.

(d)

(e)

FIGURE 4: Simulated current distributions on the radiating metal portion and the ground plane at (a) 915 MHz; (b) 1575 MHz; (c) 2450 MHz; (d) 3300 MHz; and (e) 5875 MHz.

result indicates that these five resonant frequencies can be adjusted effectively by the corresponding folded stripe lines. It agrees with the current distributions as shown in Figure 4.

4. Conclusion

In this letter we report the design and fabrication of a novel multiband printed antenna formed by interdigital-coupled feeding line, one stepped-impedance line, and one shorted stripe line connected to the ground plane of the mobile handsets. A prototype of the proposed antenna has been

successfully realized and experimental validation matches expected results. The proposed antenna utilizes a simple planar structure with a small area of only $12 \times 30 \text{ mm}^2$. This antenna is able to generate five resonant modes to cover the ISM 915/2400/5800 frequency bands, GPS band, and IMT C-band operation. These five resonant modes can be controlled individually by the corresponding stepped-impedance lines. This merit would be attractive for antenna designers since it enables optimization and tuning of the antenna by adjusting the geometrical parameters of each individual corresponding stepped-impedance lines without disturbing adjacent sections.

FIGURE 5: Simulated return loss of the proposed antenna with variations of widths W_2 (a), W_3 (b), W_4 (c), W_5 (d), and W_6 (e).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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References

- [1] B. Yuan, Y. Cao, G. Wang, and B. Cui, "Slot antenna for metal-rimmed mobile handsets," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 1334–1337, 2012.
- [2] L. Hu and W. Hua, "Wide dual-band CPW-fed slot antenna," *Electronics Letters*, vol. 47, no. 14, pp. 789–790, 2011.
- [3] B. Yuan, Y. Cao, and G. Wang, "A miniaturized printed slot antenna for six-band operation of mobile handsets," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 854–857, 2011.
- [4] S.-W. Chen, D.-Y. Wang, and W.-H. Tu, "Dual-band/tri-band/broadband CPW-Fed stepped-impedance slot dipole antennas," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 1, pp. 485–490, 2014.
- [5] Y. Cao, B. Yuan, and G. Wang, "A compact multiband open-ended slot antenna for mobile handsets," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 911–914, 2011.
- [6] Y.-L. Ban, Y.-F. Qiang, Z. Chen, K. Kang, and J.-H. Guo, "A dual-loop antenna design for hepta-band WWAN/LTE metal-rimmed smartphone applications," *Institute of Electrical and Electronics Engineers. Transactions on Antennas and Propagation*, vol. 63, no. 1, pp. 48–58, 2015.
- [7] D. Wu, S. W. Cheung, and T. I. Yuk, "A compact and low-profile loop antenna with multiband operation for ultra-thin smartphones," *Institute of Electrical and Electronics Engineers. Transactions on Antennas and Propagation*, vol. 63, no. 6, pp. 2745–2750, 2015.
- [8] J.-X. Liu and W.-Y. Yin, "A compact interdigital capacitor-inserted multiband antenna for wireless communication applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 922–925, 2010.
- [9] B. Yu, B. Jia, and Z. Zhu, "Compact tri-band bandpass filter with stub-loaded stepped-impedance resonator," *Electronics Letters*, vol. 51, no. 9, pp. 701–703, 2015.
- [10] C.-J. Wang and L.-T. Chen, "Modeling of stepped-impedance slot antenna," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 2, pp. 955–959, 2014.
- [11] Y. Sung, "UWB monopole antenna with two notched bands based on the folded stepped impedance resonator," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 500–502, 2012.
- [12] *HFSS Version 17*, ANSYS, Canonsburg, Pa, USA, 2016.