SMALL-SIZE COUPLED-FED PRINTED PIFA FOR INTERNAL EIGHT-BAND LTE/GSM/UMTS MOBILE PHONE ANTENNA

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ABSTRACT: *A coupled-fed printed PIFA (planar inverted-F antenna) with a small footprint (about 415 mm^2) for eight-band operation covering the LTE700/2300/2500, GSM850/900/1800/1900, and UMTS bands in the mobile phone is presented. The proposed PIFA uses only a single radiating strip of length 45 mm which is short-circuited to the system ground plane of the mobile phone through a long inductive shorting strip and is capacitively excited by a long coupling strip. The capacitive excitation leads to the generation of the λ/8 resonant mode at about 850 MHz and the higher order resonant modes at about 1900 MHz for the printed PIFA. The inductive shorting strip contributes additional inductance to achieve enhanced impedance matching for the excited 850 MHz band to achieve a dual-resonant behavior, which results in a wide lower band to cover the LTE700/GSM850/900 operation. A higher order resonant mode at about 2650 MHz is also contributed by the long inductive shorting strip. This resonant mode incorporating the one at about 1900 MHz generated by using the coupling feed forms a wide upper band to cover the GSM1800/1900/UMTS/LTE2300/2500 operation. Compact integration of the proposed antenna with a nearby loudspeaker is also promising. Details of the results are presented.* Microwave Opt Technol Lett 52: 2123–2128, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25387

Key words: *antennas; mobile antennas; handset antennas; printed PIFA; small antennas*

1. INTRODUCTION

In the near future, it is expected that the LTE (long term evolution) service [1] which can provide better mobile broadband and multimedia services than the existing GSM and UMTS mobile networks [2] will become very attractive for the mobile users. The LTE can also support hand-over to the existing mobile networks. Hence, with the LTE incorporated to the mobile devices with the existing GSM/UMTS operation, ubiquitous mobile broadband coverage is promising to become a reality. For this application, the embedded antenna in the mobile device should cover all the LTE/GSM/UMTS bands, which include the LTE700 (698–787 MHz), GSM850 (824–894 MHz), GSM900 (880–960 MHz), GSM1800 (1710–1880 MHz), GSM1900 (1850–1990 MHz), UMTS (1920–2170 MHz), LTE2300 (2305–2400 MHz), and LTE2500 (2500–2690 MHz) bands. This is a big challenge for the internal antenna embedded in the mobile device, especially in the mobile phone which offers very limited space for the internal antenna.

In this article, we present a promising small-size coupled-fed printed PIFA (planar inverted-F antenna) to cover the eight-band LTE/GSM/UMTS operation. The proposed antenna is suitable to be directly printed on the system circuit board of the mobile phone [3–7], making it easy to fabricate at low cost and attractive for slim mobile phone applications [8–12]. The antenna requires a small footprint of about 415 mm^2, which is comparable with that of the recently reported printed PIFA for the GSM850/900/1800/1900/UMTS penta-band operation [3–5], yet it is capable of generating two wide operating bands to cover the LTE700/GSM850/900 (698–960 MHz) and GSM1800/1900/UMTS/LTE2300/2500 (1710–2690 MHz) operation, respectively. Details of the proposed antenna are studied in the article, and results of the fabricated prototype are presented. Compact integration of the loudspeaker with the proposed antenna is also studied.

2. PROPOSED ANTENNA

Figure 1(a) shows the geometry of the coupled-fed printed PIFA for the LTE/GSM/UMTS operation in the mobile phone, and dimensions of the metal pattern of the antenna are given in Figure 1(b). The antenna can be directly printed on the no-ground portion (size 15 × 45 mm^2 or 675 mm^2) at the top portion of the system circuit board of the mobile phone. In this study, an FR4 substrate of size 115 × 45 mm^2 is used as the system circuit board, on which the system ground plane of size 100 × 45 mm^2 is printed. The selected dimensions of the ground plane and circuit board are reasonable for practical mobile phones.

Notice that the printed PIFA is configured to have a compact structure such that its footprint on the circuit board is only about 415 mm^2 [the no-ground portion (675 mm^2) less the shaded region (260 mm^2) shown in the figure]. The shaded region can be used to accommodate the nearby electronic components such as the loudspeaker [13–15] to allow compact integration of the proposed antenna inside the mobile phone; the results will be discussed in Figure 8 in Section 3.

The printed PIFA has a simple structure and mainly comprises a radiating strip, an inductive shorting strip and a coupling feed. The radiating strip is a long rectangular strip of length 45 mm and width 3 mm disposed on the top edge of the no-ground portion. By incorporating the planar printed coupling-feed technique [16–22] which in this study is simplified to directly use a coupling strip to capacitively excite the radiating strip through a small gap (g) of 0.5 mm, the impedance level of the antenna's λ/8 resonant mode at about 850 MHz is effectively decreased. By incorporating the long inductive shorting strip of width 0.5 mm and length (t) 36 mm which provides additional inductance to further improve the impedance matching for frequencies over this λ/8 resonant mode, a dual-resonant behavior is achieved to result in a wide lower band to cover the desired frequency range of 698–960 MHz. The coupling feed and the inductive shorting strip also contribute their higher order modes at about 1900 and 2650 MHz, respectively, which are formed into a wide upper band to cover the desired frequency range of 1710–2690 MHz. Detailed effects of the coupling feed and the inductive shorting strip on achieving the two desired lower and upper bands are studied with the aid of Figures 3 and 4 in the next section. The impedance matching over the lower and upper bands can also be controlled by adjusting the gap g in the coupling feed. The detailed effects are analyzed in Figure 5.

3. RESULTS AND DISCUSSION

The proposed antenna was fabricated and measured. Figure 2 shows the measured and simulated return loss for the fabricated prototype. The simulated results obtained using Ansoft HFSS version 11.2 [23] are similar to the measured data, which shows two wide operating bands centered at about 850 and 2200 MHz. With 3:1 VSWR definition which is widely used for practical internal mobile phone antenna design, the lower band has a wide bandwidth covering the desired 698–960 MHz band. The upper

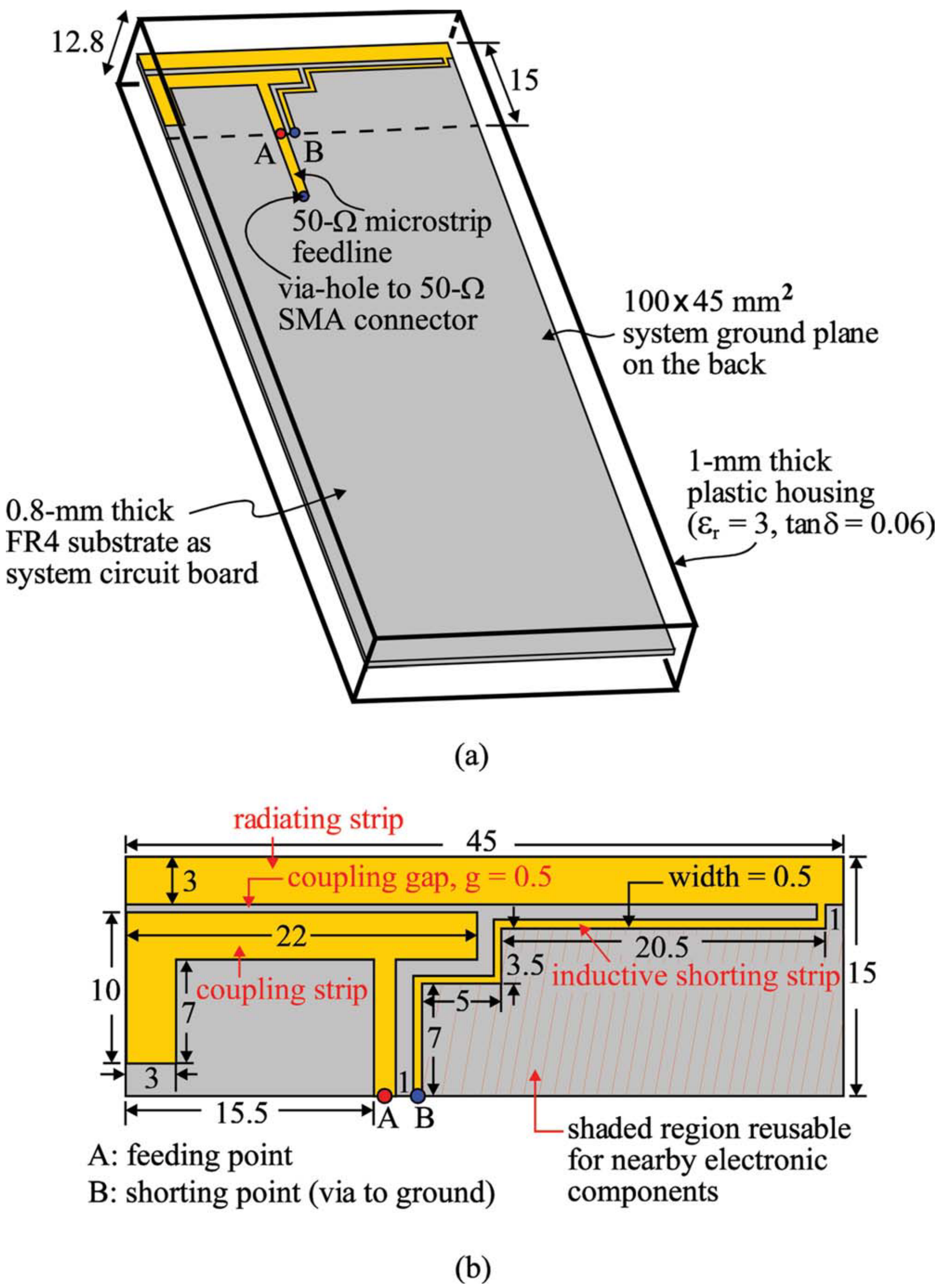


Figure 1 (a) Geometry of the coupled-fed printed PIFA for the LTE/GSM/UMTS operation in the mobile phone. (b) Dimensions of the metal pattern of the antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

band has an even wider bandwidth of larger than 1.2 GHz covering the desired 1710–2690 MHz band. That is, the proposed antenna can cover the eight-band LTE/GSM/UMTS operation.

Figure 3 shows the simulated return loss and input impedance for the proposed antenna, Ref1 (the printed PIFA with a direct feed and a simple shorting strip) and Ref2 (the printed PIFA with a coupling feed and a simple shorting strip). It is clearly seen that the high-impedance level of the resonant mode at about 850 MHz is effectively decreased owing to the use of the coupling feed [see Fig. 3(b)]. This leads to the excitation of a resonant mode in the desired lower band around 850 MHz [see Ref2 in Fig. 3(a)], although the radiating strip has a short length of 45 mm only (about 1/8 wavelength at 850 MHz). In addition to the $\lambda/8$ mode excitation, a higher order mode at about 1900 MHz is also excited. However, the two excited modes for Ref2 cannot cover the desired eight-band LTE/GSM/UMTS operation.

Figure 4 shows the simulated return loss for the proposed antenna, Ref3 and Ref4; the three antennas have the same coupling-feed dimensions but different lengths of the inductive shorting strip. Ref3 has the shortest length of the shorting strip among the three antennas. By increasing the length of the shorting strip [see Ref4 compared to Ref3], the impedance matching for frequencies over the lower band is improved, and a higher order mode occurred at about 2650 MHz is also seen. When the length of the shorting strip is further increased [see the proposed antenna compared with Ref4], the obtained bandwidth of the lower band is greatly widened to cover the desired 698–

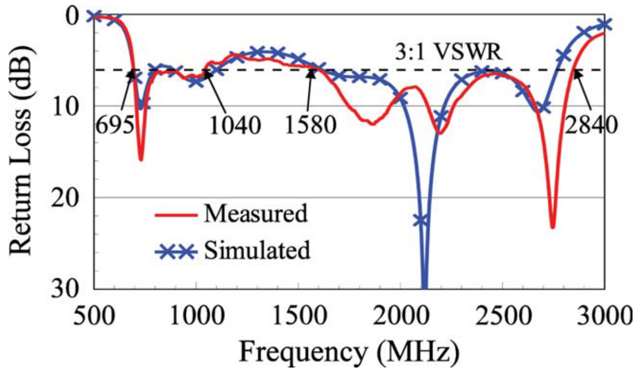


Figure 2 Measured and simulated return loss for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

960 MHz band, and the two higher order modes owing to the use of the coupling feed and the inductive shorting strip, respectively, are formed into a very wide band to cover the desired 1710–2690 MHz band.

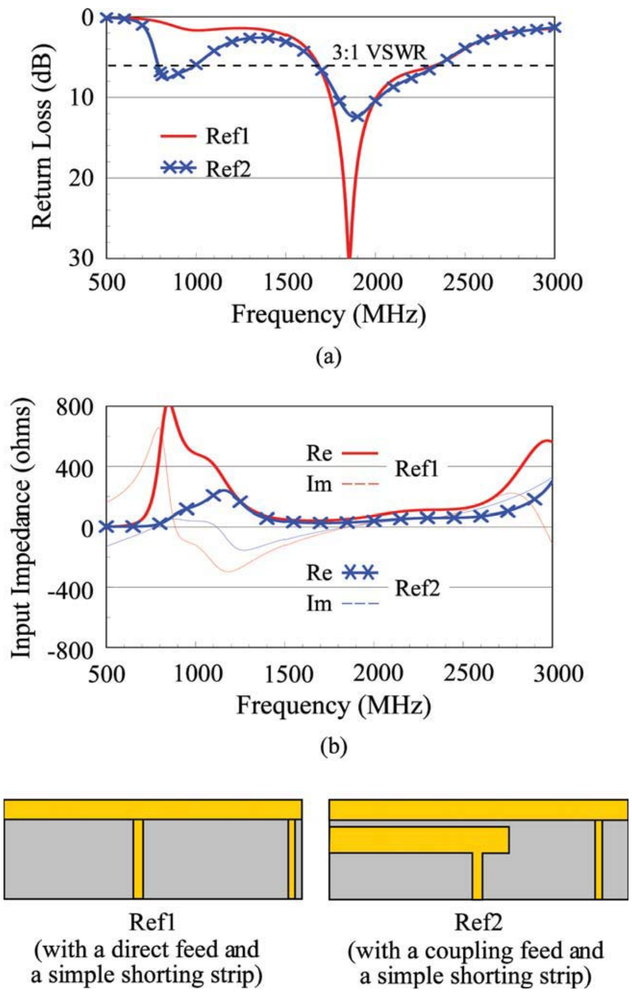


Figure 3 Simulated (a) return loss and (b) input impedance for the proposed antenna, Ref1 (the printed PIFA with a direct feed and a simple shorting strip) and Ref2 (the printed PIFA with a coupling feed and a simple shorting strip). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

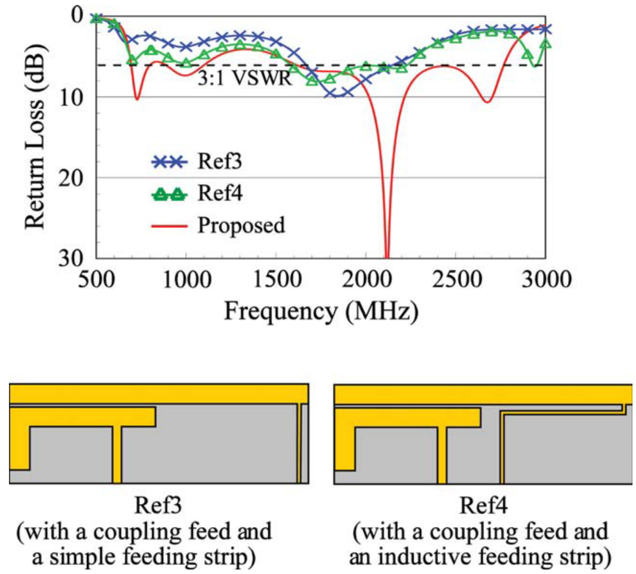


Figure 4 Simulated return loss for the proposed antenna, Ref3 and Ref4. The three antennas have the same coupling-feed dimensions but different lengths of the inductive shorting strip. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Effects of varying the coupling gap g in the coupling feed are studied in Figure 5. Results of the simulated return loss for g varied from 0.3 to 0.8 mm are shown in the figure. Large effects on the impedance matching of the antenna's lower band are seen, and there are almost no variations in the impedance matching of the upper band. This behavior confirms that the lower band is mainly affected by the coupling feed, and good impedance matching of the lower band can be effectively adjusted by the gap g.

The measured radiation patterns at 830 and 2200 MHz (about central frequencies in the desired lower and upper bands) for the proposed antenna are shown in Figure 6. Dipole-like radiation pattern with omnidirectional radiation in the azimuthal plane (x–y plane) at 830 MHz in the lower band is seen. This is similar to many internal WWAN (wireless wide area network) mobile phone antenna operated in the 900 MHz band [2], mainly owing to the system ground plane dominating the radiation in the antenna's lower band. At 2200 MHz in the upper band, the

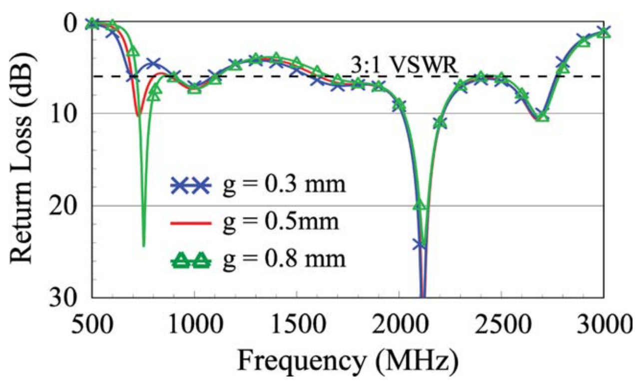
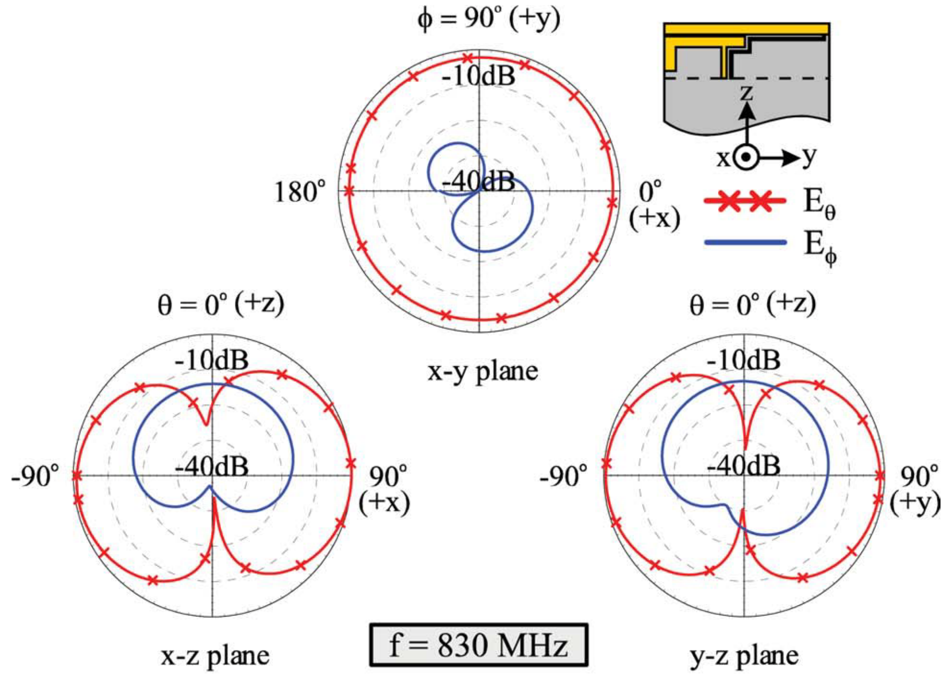
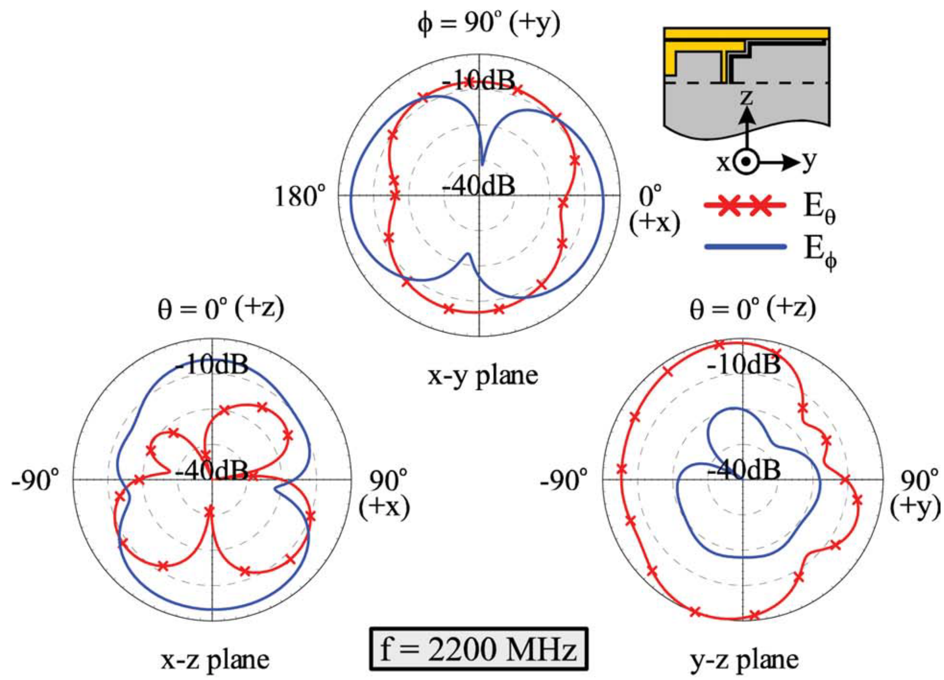


Figure 5 Simulated return loss as a function of the coupling gap g; other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]



(a)



(b)

Figure 6 Measured radiation patterns at (a) 830 MHz and (b) 2200 MHz for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

measured radiation pattern shows more variations compared with that at 830 MHz. This behavior is because the wavelength of the frequencies in the antenna's upper band is comparable with the length of the system ground plane and surface current nulls are usually excited in the system ground plane which is also part of the radiator in the upper band. Measured radiation patterns for other frequencies over the antenna's lower and upper bands are also observed to be similar to those plotted in the figure and are not shown for brevity.

Figure 7 shows the measured antenna gain and simulated radiation efficiency for the proposed antenna. For the lower band shown in Figure 7(a), the radiation efficiency is about

46–76% and the antenna gain is about −1.2 to 1.0 dBi. For the upper band in Figure 7(b), the radiation efficiency varies from about 57–86%, whereas the antenna gain is about 2.2–4.3 dBi. The obtained radiation performances are acceptable for practical mobile phone applications.

The proposed antenna integrated with a nearby loudspeaker is studied in Figure 8. The photo of the antenna integrated with a practical loudspeaker is shown in the figure, and the measured return loss for the two cases with and without the loudspeaker shows some variations. However, the impedance matching for frequencies in the desired lower and upper bands is still better than 3:1 VSWR (6-dB return loss), except for the frequencies in the GSM900 band which are better than 5 dB return loss. This small impedance matching degradation can be improved by fine adjusting the dimensions of the proposed antenna. However, the presence of the loudspeaker which contains lossy materials, can cause some decrease in the radiation efficiency of the antenna, which is expected to be within 10% for frequencies in the lower and upper bands [24].

4. CONCLUSIONS

A small-size coupled-fed printed PIFA to cover all the eight operating bands of the LTE/GSM/UMTS (698–960/1710–2690 MHz) in the mobile phone has been proposed. The footprint of the proposed antenna is only about 415 mm^2 on the system circuit board of the mobile phone, and the antenna is allowed to be integrated with a nearby loudspeaker to achieve a compact integration in the mobile phone. Good radiation characteristics over the operating bands have also been observed. Owing to its all printing structure and uniplanar configuration, the proposed antenna is especially suitable for application in the slim mobile phone.

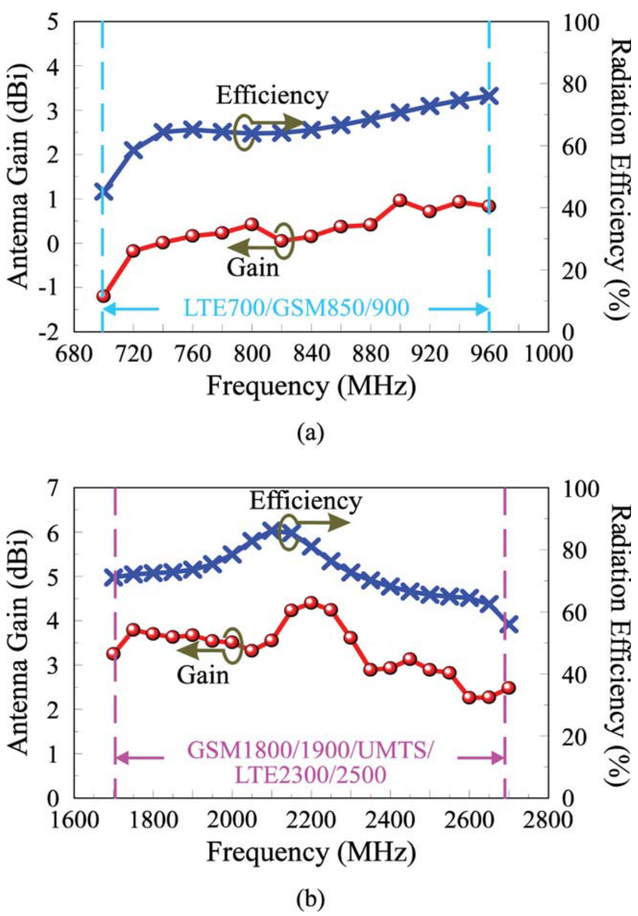


Figure 7 Measured antenna gain and simulated radiation efficiency for the proposed antenna. (a) The lower band (698–960 MHz). (b) The upper band (1710–2690 MHz). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

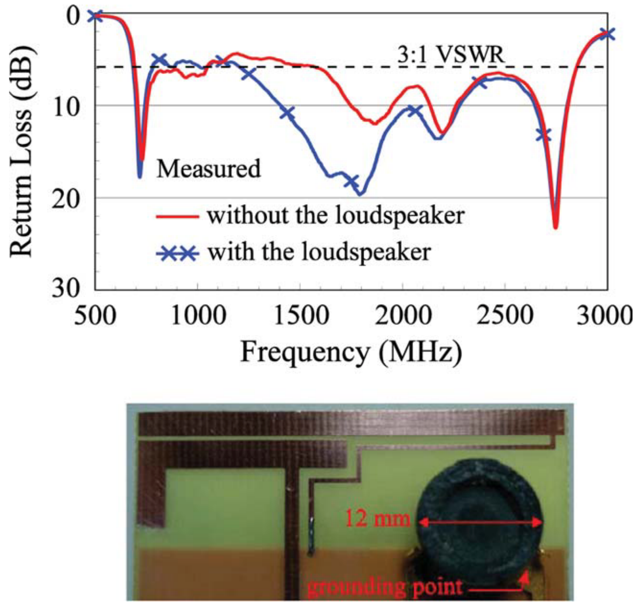


Figure 8 Measured return loss for the proposed antenna with and without a practical loudspeaker grounded to the system ground plane and occupied a certain portion in the no-ground portion (see the photograph in the figure). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

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COMPACT INTERDIGITAL MICROSTRIP BAND PASS FILTER

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ABSTRACT: *A compact microstrip band pass filter using interdigital coupled line and meandered electromagnetic band gap (EBG) slots is proposed in this article. The interdigital capacitor in the signal strip with meander EBG slots etched in the ground plane contributes to the series capacitance. In addition, the finger of the interdigital is shorted to ground through via holes, which results in the shunt inductance. The combination of series capacitor and shunt inductor is useful to realize the left-handed metamaterial and improve the frequency selectivity. The filter, which is composed by cascading two units, has a resonant frequency of 2.8 GHz and a fractional 3 dB band width of 28.6% (2.4–3.2 GHz). A return loss of 18 dB and a maximum of 1.6 dB insertion loss in the pass-band are achieved. The filter size is 11.2 × 4.00 mm*^{2}*, which is 0. 172* $\lambda_g \times 0.06\ \lambda_g$*, and the length of resonator is 5.6 mm, which is 0.086* λ_g*, where* $\lambda_g = 65$ *mm is the guided wavelength at center frequency.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 2128–2132, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25403

Key words: *metamaterial; EBG; compact; interdigital; BPF; microstrip*

1. INTRODUCTION

In the development of the communication and electronic systems, small size and high performance filters are needed to reduce the cost and improve the system performance, which brings increased opportunities for designing a compact band pass filter (BPF) for many modern microwave applications, such as automotive radar and broadband wireless communication. A number of compact BPFs have been developed before, such as, Using Meander Spurline and Capacitively Loaded Stubs [1], sierpinski-based resonator [2] using defected ground structure combined with lumped capacitor [3], using Multilayered Transmission Line [4], MCMD technology [5], and superconductor [6]. Unfortunately, these kinds of compact BPFs have few disadvantages: the size of filters in [7, 2] are 23 mm length resonating at 5.6 GHz and 40 mm length resonating at 2.2 GHz, respectively, the filters in [3–5] are difficult to fabricate because they are based on MCM-D technology or lumped capacitor, and the superconductor [6] filter can only work at low temperature. What's more, it is too expensive for these filters to be widely used.

Since microstrip resonators are the basic components of a planar filter design, it is necessary to select proper resonator types used in filter design. Conventional half-wavelength open-line microstrip resonator is too large to be used in designing filters. A novel type of simplified composite right/left handed transmission line (CRLH TL) has been investigated based on improved interdigital capacitor combined with meander EBG structure and this new CRLH TL presents a potentially convenient approach in designing a compact BPF with high-quality selectivity characteristic. The novel designed filter is constituted of two cascaded resonator units along with the transmission line. Each unit is composed by improved interdigital capacitor with sloped fingers and the meander EBG etched in the ground plane as the same shape as the interdigital. And via holes are used to short the finger of the interdigital to ground. By appropriately selecting the dimensions of the resonator units, compact filters can be achieved. In this article, this structure is fully analyzed, designed, and fabricated. To obtain a high performance BPF, multiple compact resonators have to be cascaded. However, this increases the geometrical dimensions of the filter. We use two cells to be cascaded and the overall length is 10.8 mm. However, this compact resonator presents the potential to reduce the dimensions by vertically stacking these left-handed transmission lines.

2. COMPACT RESONATOR APPROACH BASED ON CRLH TL THEORY

A improved resonator (as shown in Fig. 1) implemented on microstrip with interdigital capacitors and stub inductors connected to the ground plane has been proposed. Based on the previous theory and structure [8] and a series microwave applications, such as dual-band branch-line coupler [9], asymmetric backward-wave directional coupler [10], zeroth order resonator [11], the novel hybrid ring and four-cell ZOR antenna [12] have been proposed.

Interpretation of dispersion curve is a well-examined approach in electromagnetism [13]. A periodic structure with capacitance and inductance periodically loaded in the transmission line can be considered as an effective medium provided that the dimensions of the unit cell are small comparing with the excitation wavelength. The general CRLH TL model shown in [14] consists of a transmission line in series with a capacitance C and in parallel with an inductance L represents the most general