Progress In Electromagnetics Research C, Vol. 15, 1–12, 2010

INTERDIGITAL CAPACITOR IFA FOR MULTIBAND OPERATION IN THE MOBILE PHONE

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Abstract—A compact and simple interdigital capacitor inverted-F antenna (IFA) operated at its quarter-wavelength ($\lambda/4$) mode as the fundamental resonant mode for achieving multiband operation in the mobile phone is designed. The proposed antenna consists of a monopole antenna and an IFA. The proposed interdigital capacitor IFA has a simple structure of comprising two meandered radiating strips of length about $\lambda/4$ and is fed using an interdigital capacitor coupling feed. The two meandered radiating strips also generate two $\lambda/4$ resonance modes at about 900 MHz and 2100 MHz to cover the GSM850/900/1800/1900/DCS/PCS/UMTS bands and the 2.4 GHz WLAN (IEEE 802.11b) band operations. Further, the proposed antenna has a simple planar structure and occupies only a small area of $10 \times 40\,\text{mm}^2$ on the system circuit board of the mobile phone. This proposed antenna with multiband, broadband matched impedance, stable radiation patterns, constant antenna gains, good radiation efficiency and compact size can be suitable for mobile phone applications.

Received 23 August 2010, Accepted 19 September 2010, Scheduled 24 September 2010
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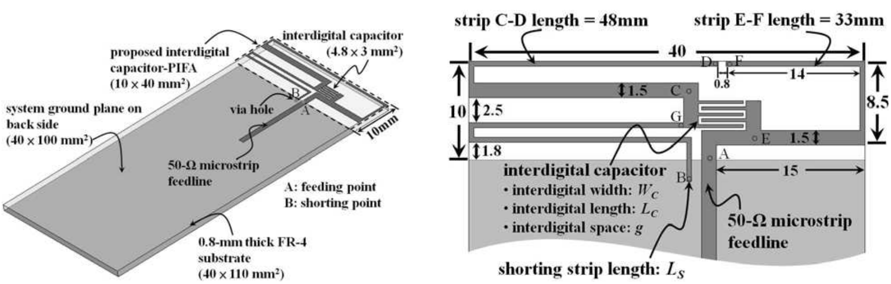
1. INTRODUCTION

Modern portable communication devices, such as a cellular phone, call for small size antennas operating over an increased operational bandwidth preferably in several frequency bands. Multiband antennas are required for these devices to support multiple standards. Due to the device convergence trend in the mobile handset, very limited space is available for the antenna structure. Conventional multiband antennas occupy significant space within the handset in order to support multiband performance. Therefore, small size and multiband internal antenna for mobile handset is an explosive issue. Much effort has been devoted to the multiband internal antenna in mobile phones during the past decade, such as microstrip antennas [1], loop antennas [2, 3], patch antennas [4–9], inverted-F shaped wire-form antennas (IFAs) [10, 11], and planar inverted-F antennas (PIFAs) [12–18]. Microstrip antennas are small in size and light in weight. However, the GSM 900 half-wavelength microstrip antennas are too large to be incorporated into a mobile handset. The planar inverted-F antenna (PIFA) has a desirable multiband feature with higher efficiency, low profile, conformal structure and lightweight internal antenna. This structure can be easily incorporated into personal communication equipment. Due to these advantages, PIFA become attractive candidates in wireless communications. But the narrow bandwidth characteristic of PIFA is one of the limitations for its commercial application for wireless mobile terminals. The typical PIFAs usually show a high profile of about 6 to 10 mm above the system ground plane or the grounded portion of the system circuit board in order to achieve wide bandwidths for GSM850/900/1800/1900/UMTS/WLAN operation. When the distance or thickness between the radiating strip and the ground plane is reduced, the operating bandwidth of the traditional PIFA is usually decreased quickly and the desired hexa-band operation is difficult to be covered. This causes a limitation for their applications in the modern thin-profile mobile phones that recently attract much attention on the market. For applications in thin-profile mobile phones, the IFAs with their radiating strips directly printed on the no-ground portion of the system circuit board of the mobile phone can be a promising candidate. In this case, the internal antenna generally shows no thickness above the system circuit board. Further, the fabrication cost of the two-dimensional (2-D) IFA can be reduced to be minimum, as compared to the typical 3-D PIFA. Based on the concept, a compact and simple IFA is proposed in this study. Another method by using the coupled-fed structure greatly decreases the very large input impedance seen at the operation mode to additional resonators and reduces the antenna size. The proposed IFA uses interdigital capacitor coupling feed, effects of the coupling feed in this study are different from the coupled-fed techniques that have been reported, in which the applied interdigital coupling feed results in two resonance modes excitation in the 900 MHz and 2100 MHz bands for bandwidth enhancement.

The proposed interdigital capacitor coupling feed IFA has a simple structure of comprising two meandered radiating strips of length about $\lambda/4$ at 900 MHz and 2100 MHz to cover GSM 850/900 (824 $\sim$ 894 MHz/890 $\sim$ 960 MHz), GSM1800/1900/UMTS (1710 $\sim$ 1880 MHz/1850 $\sim$ 1990 MHz/1920 $\sim$ 2170 MHz) and IEEE 802.11b (2400 $\sim$ 2484 MHz) operations; that is, hexa-band operation for WWAN (wireless wide area network) communication is obtained. Design considerations of the proposed antenna are described in the paper, and results for the fabricated prototype are presented and discussed. Effects of the major parameters of the antenna's interdigital capacitor coupling feed are also analyzed.

2. ANTENNA STRUCTURE AND DESIGN

Figure 1 illustrates the geometry and configuration of the proposed IFA with an interdigital capacitor coupling feed for GSM850/900/1800/1900/UMTS bands and the 2.4 GHz WLAN band operation in the mobile phone. The commercial program high frequency structure simulator (HFSS) based on the finite-element method (FEM) is used for analyzing the behavior of proposed model and determining suitable values of parameters. As seen in this figure, the pro-



(a) (b)

Figure 1. (a) Geometry of the proposed interdigital capacitor IFA for multiband operation in the mobile phone. (b) Dimensions of the metal pattern of the proposed antenna.

posed IFA has a simple single metallic layer structure and is printed on a miniature area of $10 \times 40\,\mathrm{mm}^2$ on the no-ground portion of the system circuit board of the mobile phone. Detailed dimensions of the metal pattern of the proposed IFA are given in Figures 1(a) and 1(b). In this study, a 0.8 mm thickness FR4 substrate of relative permittivity (ε_r) 4.4 and size $110 \times 40\,\mathrm{mm}^2$ is used to simulate the system circuit board; on its back side, a system ground plane of size $100 \times 40\,\mathrm{mm}^2$ is printed. These dimensions are reasonable for practical mobile phones on the market. The proposed IFA has a simple structure and mainly comprises two meandered radiating strips and using interdigital capacitor coupling-feed portion. The widths of two meandered radiating strips (strips C-D and E-F in the Figure 1(b)) are composed of 1.5 mm and 0.5 mm, except that of the $4.8 \times 3\,\mathrm{mm}^2$ interdigital capacitor section in the feed part with the shorting strip to the top edge of the system ground plane at point B (a via-hole and the shorting point) through a meandered shorting strip of length 20 mm (section-BG).

The two meandered radiating strips are slightly different in lengths; the lengths of strip C-D like the IFA structure and strip E-F like the monopole antenna are 48 mm and 33 mm, respectively, which both are close to $\lambda/4$ at about 900 MHz and 2100 MHz. By exciting the two meandered strips use the interdigital capacitor coupling feed in the proposed antenna, the IFA $\lambda/4$ (strips C-D and L_S in the Figure 1(b)) modes and monopole antenna $\lambda/4$ modes can be easily generated at about 900 MHz and 2100 MHz, respectively. The two modes form a wide lower band for the proposed IFA to cover GSM 850/900 operation. While the two modes form the desired upper band to cover GSM1800/1900/UMTS/WLAN operation, the resulted is shown in Figure 2. The successful excitation of the two modes of the two

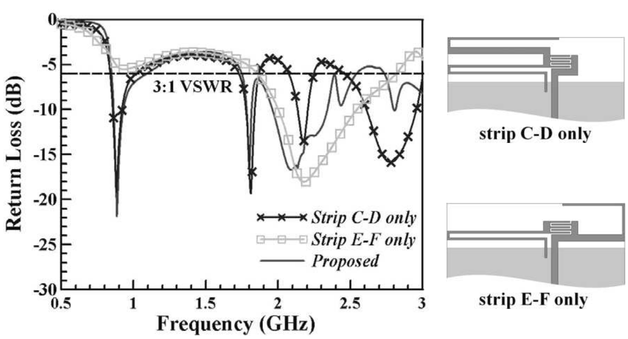


Figure 2. Simulated return loss S_{11} for the proposed antenna and the two cases with strip C-D only and strip E-F only.

meandered radiating strips is mainly owing to the interdigital capacitor coupling feed used in the proposed IFA, which greatly decreases the very large input impedance observed at the mode for the traditional PIFA with a direct feed. Further, the coupling feed also results in small input impedance (less than $100\,\Omega$) for the excited modes or higher-order modes of the proposed IFA. Detailed results will be discussed in the next section with the aid of Figures 3 and 4.

The interdigital capacitor coupling ($4.8 \times 3\,\text{mm}^2$) feed is located in-between the two meandered radiating strips and consists of a feeding interdigital coupling strip and a shorting interdigital coupling strip (interdigital coupling structure are $W_C \times L_C$, $0.3 \times 4.5\,\text{mm}^2$), both separated by a coupling gap of $g = 0.3\,\text{mm}$. The feeding strip is fixed to have a width 1.5 mm and a length 6 mm and is connected to the printed $50\,\Omega$ microstrip feed line on the front side of the system circuit board. For easy tuning in the proposed design, the dimensions of the feeding strip are fixed in the study, while the length of the coupling strip and the width g of the coupling gap are adjusted to fine-tune the effect of the coupling feed on improving the impedance matching of the desired lower band at about 900 MHz and the upper band at about 2100 MHz. The preferred interdigital coupling strip length L_C and width W_C in

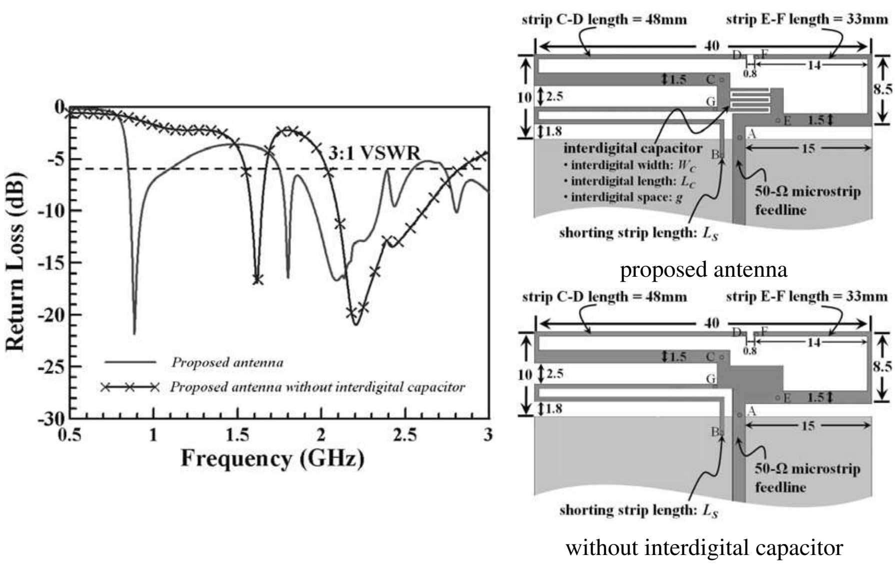


Figure 3. Comparison of the simulated return loss S_{11} of the proposed antenna and the proposed antenna without interdigital capacitor coupling feed.

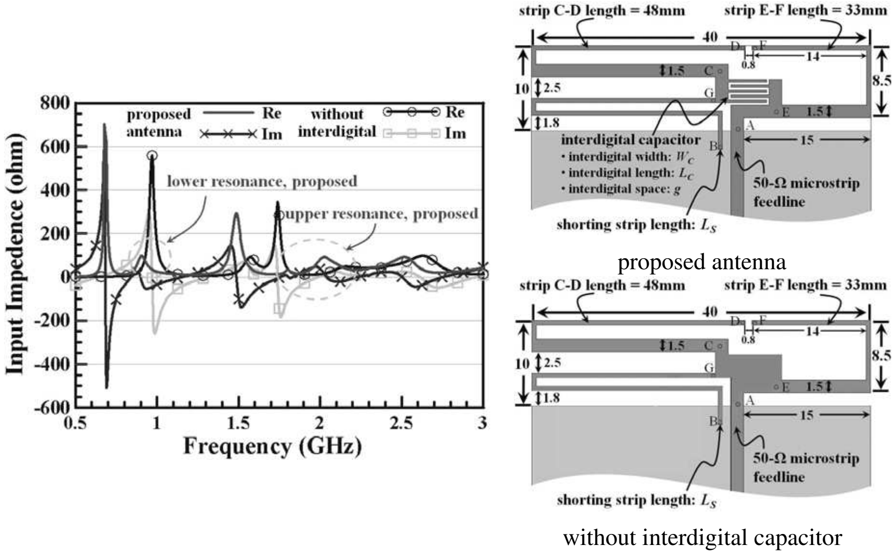


Figure 4. Simulated input impedance versus frequency for the proposed antenna and the proposed antenna without interdigital capacitor coupling feed.

this study are adjusted to be 4.5 mm and 0.3 mm, respectively. Detailed effects of varying the two parameters of N (interdigital finger number) and g are analyzed in Figure 5 in the next section. Furthermore, effects of the meandered shorting-strip length are also studied in Figure 6.

3. RESULTS AND DISCUSSIONS

In Figure 2, a comparison of the simulated return loss S_{11} for the proposed IFA and the two cases with strip C-D only and strip E-F only is presented. For the case of strip C-D only, there are four resonant modes excited at about 0.9, 1.8, 2.2 and 2.8 GHz; while for the case of strip E-F only, two resonant modes at about 1.0 and 2.2 GHz are generated. It is then observed that the two modes at about 900 MHz are formed into the desired wide lower band for GSM 850/900 operation, and the three modes at about 1.8, 2.2 and 2.8 GHz are formed into the wide upper band for GSM1800/1900/UMTS/WLAN operation.

A comparison of the simulated return loss S_{11} of the proposed IFA and the proposed IFA without interdigital capacitor coupling-feed portion (the corresponding antenna with a direct contact feed) is presented in Figure 3. Quite different from the obtained two wide bands at about 900 MHz and 2100 MHz for the proposed IFA, there are two resonant modes excited at about 1600 MHz and 2200 MHz for the proposed antenna without interdigital capacitor coupling-feed. This behavior is reasonable because the two meandered radiating strips in the antenna without interdigital capacitor coupling-feed are of incomparable lengths (about 48 and 33 mm, starting from point A to each one of the two open ends), which is close to about $\lambda/4$ at 1600 MHz and 2200 MHz and hence results in the excitation of the $\lambda/4$ mode as the general PIFA. This behavior can be seen more clearly from the simulated input impedance versus frequency for the proposed IFA and the proposed antenna without interdigital capacitor coupling-feed studied in Figure 4. It is seen that owing to the presence of the coupling feed, the very large input impedance seen at about 900 MHz is greatly decreased. This explains the successful excitation of the desired lower band at about 900 MHz seen in Figure 3 for the proposed IFA. Also, it is seen that two higher-order resonant modes or $\lambda/4$ modes with good input impedance levels are generated at about 2100 MHz. This explains the successful excitation of the two resonant modes which form the desired upper band as seen in Figure 3.

Figures 5(a) and 5(b) show the simulated return loss S_{11} as a function of the interdigital coupling finger number N and the interdigital coupling-gap width g in the coupling feed. In Figure 5(a), the results for the interdigital finger number N varied from 2 to 8 are shown; other dimensions of the antenna are the same as given in Figure 1. Strong effects on the excited resonant modes in both the lower and upper bands are seen, indicating that proper selection of the interdigital finger number N is important in the interdigital coupling feed of the proposed IFA. In this design, the preferred interdigital finger number N is determined to be 5 from the obtained results. Figure 5(b) shows the results for the coupling-gap width g varied from 0.3 mm to 0.6 mm. Although the effect on the excited resonant modes is seen to be smaller than that in Figure 5(a), the impedance matching for frequencies in the lower and upper bands can be adjusted by varying the gap width g, and the preferred gap width g is chosen to be 0.3 mm in this study.

Effects of the lengths of the meandered shorting strip L_S (section BG) on the antenna performances are also studied. The simulated results of three different lengths of $L_S = 25$, 35 and 45 mm are presented in Figure 6, and other dimensions of the antenna are the same as given in Figure 1. For the three cases, the obtained bandwidth of the antenna's lower band is slightly varied and can all cover the desired GSM 850/900 MHz operation. While for the upper band, it is seen to

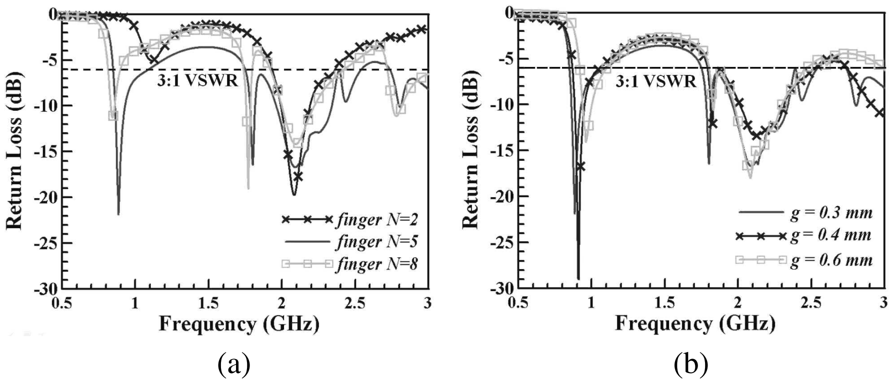


Figure 5. Simulated return loss S_{11} as a function of (a) the interdigital finger number N and (b) the interdigital gap g in the coupling feed. Other dimensions are the same as given in Fig. 1.

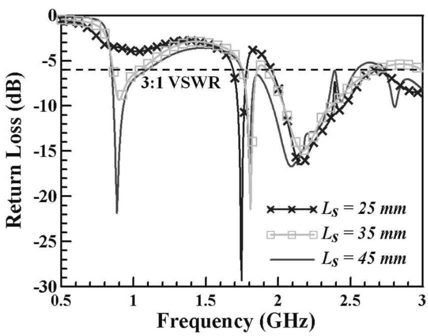


Figure 6. Simulated return loss S_{11} as a function of the shorting-strip length L_S. Other dimensions are the same as given in Fig. 1.

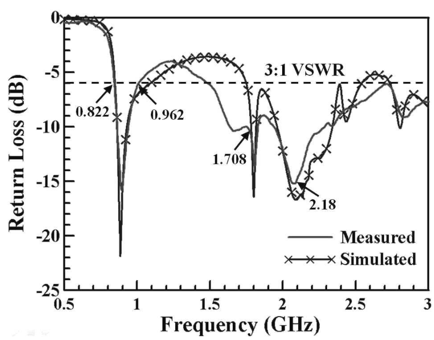


Figure 7. Measured and simulated return loss S_{11} for the proposed antenna.

be shifted to lower frequencies when a larger length is selected. The obtained bandwidth of the lower band is also varied. For the length selected to be 25 mm, however, the obtained bandwidth cannot cover the desired GSM 850/900 MHz operation. For this reason, the length is selected to be 45 mm for the prototype studied in Figure 6.

The measurement of return loss S_{11} is carried out with an HP8720C network analyzer. Figure 7 shows the measured and simulated return loss S_{11} of the proposed antenna. A good agreement between the simulation and the measurement is obtained. For return loss characteristic S_{11} less than -6 dB (VSWR $\leq$ 3), as observed in Figure 7. The lower band shows a wide bandwidth of 180 MHz (822 $\sim$ 1002 MHz), which covers the desired GSM 850/900 operation. A wide bandwidth of 1500 MHz (1508 $\sim$ 3008 MHz) is also obtained for the upper centred band at about 2.08 GHz, which covers the GSM1800/1900/UMTS/WLAN operation.

The radiation patterns are measured in a far-field anechoic chamber. Figure 8(a) plots the measured 3-D and 2-D radiation patterns at 900 MHz for the proposed IFA, the radiation characteristics of the constructed prototype studied in Figure 7. This pattern characteristic is similar to those observed for the conventional planar inverted-F antennas for GSM operation, dipole-like radiation patterns for the frequency is seen, the radiation patterns with good omnidirectional radiation in the azimuthal plane (x-y plane). The measured radiation patterns at 1800 MHz and 2100 MHz are plotted in Figures 8(b) and 8(c). More variations in the radiation patterns are seen, as compared to those in Figure 8. This is mainly owing

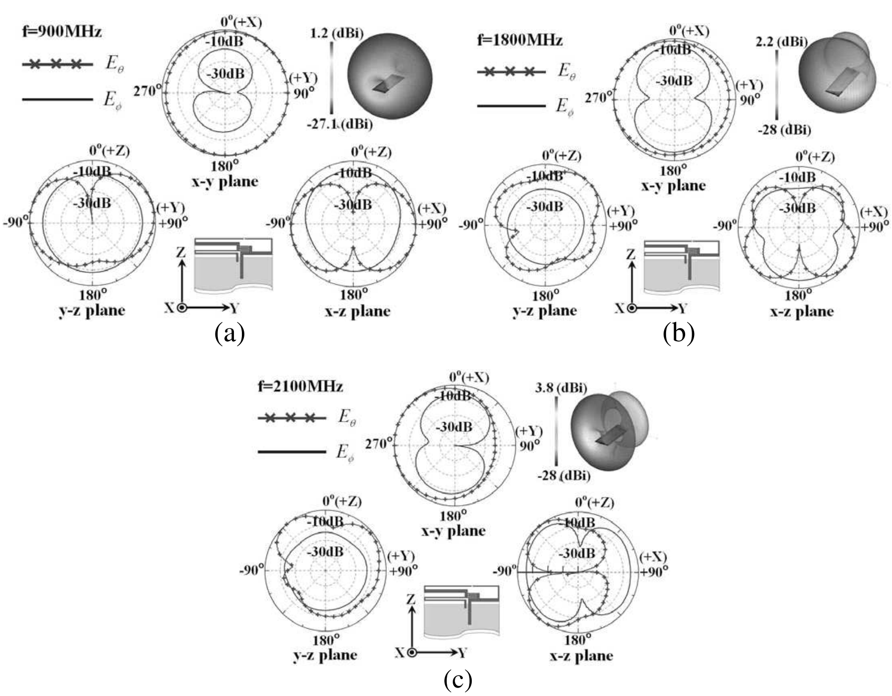


Figure 8. Measured 3-D and 2-D radiation patterns at (a) 900 MHz, (b) 1800 MHz, (c) 2100 MHz for the proposed antenna.

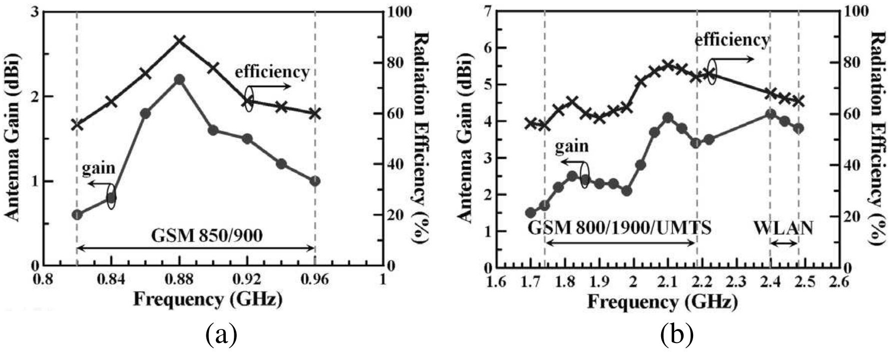


Figure 9. Measured antenna gain and radiation efficiency for the proposed antenna (a) Lower band for GSM 850/900 operation; (b) Upper band for GSM 1800/1900/UMTS/WLAN operation.

to the excited surface current nulls in the system ground plane for the operating frequencies in the upper band. The observed radiation patterns also show no special distinctions as compared to those of the conventional internal mobile phone antennas in the 1800 MHz and 2100 MHz bands.

Figures 9(a) and 9(b) present the measured antenna gain and radiation efficiency. The lower band for GSM850/900 MHz operation shown in Figure 9(a), the antenna gain is varied from about 0.6 to 2.2 dBi, while the radiation efficiency is ranged from about 57% to 89%.The upper band for GSM1800/1900/UMTS/WLAN operation shown in Figure 9(b), the antenna gain is in the range of 1.5 to 4 dBi, and the radiation efficiency is about 58% to 79%. Acceptable radiation characteristics for practical applications are obtained for the proposed IFA.

4. CONCLUSION

A compact and simple IFA using intergidital capacitor coupling feed for internal mobile phone antenna application has been proposed and studied. The proposed IFA is easily printed on the no-ground portion of the system circuit board of the mobile phone at low cost and occupies a very small area of 400 mm^2 ($10 \times 40\,\text{mm}^2$) only, owing to the successful excitation of the mode as the fundamental resonant mode. Compared to the traditional PIFA using a direct feed, the interdigital capacitor coupling feed greatly decreases the very large input impedance seen at the $\lambda/4$ mode for the traditional PIFA and results in successful excitation of the $\lambda/4$ mode for the proposed IFA. The IFA generates two wide operating bands at about 900 MHz and 2100 MHz to cover GSM850/900 and GSM1800/1900/DCS/PCS/UMTS/WLAN operations, respectively. Good impedance matching of the two wide operating bands is achieved by using the interdigital capacitor coupling feed in the proposed IFA. In addition, this proposed antenna with stable radiation patterns, good antenna gains, high radiation efficiency and compact size can be suitable for mobile phone products of GSM850/900/1800/1900/DCS/PCS/UMTS/WLAN applications.

ACKNOWLEDGMENT

This research work was supported by the both National Science Council of the Republic of China under the grant number NSC 98-2220-E-027-006 and NSC 98-2221-E-024-016.

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