a narrow slit of 7 mm in height ($h$) and 1 mm in width. The slit is placed 3.2 mm away from the patch’s center line. On the other side of the substrate, the ground plane with a length of 15 mm covers the section of the microstrip feed line.

The use of a narrow slit allows additional surface-current paths [5] and the impedance bandwidth of the antenna can be controlled by the height of the slit. The height of the feed gap between the main patch and the ground is also an important parameter for controlling the impedance bandwidth. When the proper height of the narrow slit is chosen, a wideband characteristic can be achieved for the antenna.

3. EXPERIMENTAL RESULTS

The proposed antenna was constructed and experimentally studied. A theoretical analysis was performed using HFSS [6]. Figure 2 shows the calculated return losses for the proposed antenna with various slit heights. The change in slit height causes the change in the current path. In turn, additional resonances occur at the higher band. When this antenna has the optimal slit height ($h = 7 \text{ mm}$), the largest impedance bandwidth is obtained, as shown in Figure 2. Figure 3 shows the measured return losses with and without the slit. The measured 10-dB impedance bandwidth of the proposed monopole antenna with a narrow slit ranges from 3.1 GHz to more than 11 GHz. The measured radiation patterns of the proposed antenna in the $y-z$ and $x-z$ planes at three different frequencies are illustrated in Figure 4. Although the geometry of this antenna is asymmetric, it can be seen that the radiation patterns of the proposed antenna are almost symmetric, omnidirectional, and monopole-like over the entire operating band. The measured antenna gain for the frequency band of 3 to 10 GHz is presented in Figure 5. Good gain flatness with a maximum variation of 1.7 dB is observed over the entire frequency band.

4. CONCLUSION

A new compact wideband microstrip-fed monopole antenna has been investigated experimentally and numerically. By inserting a narrow slit at the lower right corner of the printed monopole, impedance-bandwidth enhancement has been achieved. The proposed antenna is promising for future UWB applications.

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INTERNAL CELLULAR/WLAN COMBO ANTENNA FOR LAPTOP-COMPUTER APPLICATIONS

Kin-Lu Wong and Liang-Che Chou
Department of Electrical Engineering
National Sun Yat-Sen University
Kaohsiung 804, Taiwan

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ABSTRACT: Two internal antennas for cellular (GSM/DCS) and WLAN dual-network operations are combined in an arrangement with optimized isolation for laptop-computer applications. The two antennas are formed into a combo antenna and can be mounted at the top edge of the supporting metal frame of the display of a laptop computer as internal antennas. The impedance and isolation characteristics of the proposed cellular/WLAN combo antenna with various possible arrangements are studied, and the optimized isolation for frequencies over the GSM (890–960 MHz), DCS (1710–1880 MHz), and WLAN (2400–2484/5150–5350/5725–5825 MHz) bands is analyzed. © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 47: 402–406, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21182

Key words: mobile antennas; GSM/DCS antennas; WLAN antennas; combo antennas; internal laptop antennas

1. INTRODUCTION

Due to the recent successful deployment of hot spots for wireless local area network (WLAN) communications, it has been widely recognized that the integration of WLAN and cellular networks can provide wireless users with seamless data services. For this kind of cellular/WLAN dual-network application, mobile devices usually need to be equipped with two separate antennas for global system for mobile communication/digital-communication system (GSM/DCS) and 2.4/5.2/5.8-GHz WLAN operations [1]. However, due to the limited space available in mobile devices, how to combine the two antennas in an arrangement with optimized isolation has become a challenging and important task.

In this paper, we present a study of combining two internal antennas into a combo antenna for GSM/DCS and WLAN operations for laptop-computer applications. The two antennas are modified from dual-band shorted T-shape monopoles [2–5], and both show low-profile and compact configurations, thus allowing them to be embedded within the narrow spacing (usually about 10 mm) between the display and the casing of a laptop computer. Possible arrangements of the proposed cellular/WLAN dual-network combo antenna are studied, and the impedance and isolation
characteristics of the combo antenna over the operating bands are analyzed.

2. ANTENNA DESIGN

Figure 1(a) shows the configuration of the proposed internal combo antenna for laptop-computer applications. The combo antenna comprises a GSM/DCS antenna for cellular operation and a WLAN antenna for operation in the 2.4-GHz (2400–2484 MHz) and 5.2/5.8-GHz (5150–5350/5725–5825 MHz) bands. The two antennas are mounted at the top edge of a ground plane (of size 260 × 200 mm² in this study), which is considered as the supporting metal frame of the display of a laptop computer. For the GSM/DCS antenna, a shorted T-shape monopole with two different radiating strips, both operated as quarter-wavelength resonant structures, is used. The shorter radiating strip controls a resonant mode for DCS operation at about 1800 MHz. The longer radiating strip can generate a resonant mode for GSM operation at about 900 MHz. Note that the longer radiating strip is folded to achieve a compact structure so that the GSM/DCS antenna can be easily embedded within the narrow space between the display and casing of the laptop computer; in this case, the total length of the antenna is only 76 mm.

For the WLAN antenna, a shorted T-shape monopole with two folded radiating strips is used, and the total antenna length is only 18 mm. The two folded radiating strips are also operated as quarter-wavelength resonant structures, with the longer and shorter ones controlling the 2.4- and 5.2/5.8-GHz bands, respectively. Details of the dimensions of the GSM/DCS and WLAN antennas are given in Figure 1(b); these design dimensions are obtained by following the design considerations presented in [2–5].
Also note that the GSM/DCS antenna is short-circuited to the top edge of the ground plane using an inverted-L shorting strip, as is the WLAN antenna. In addition, this shorting strip is arranged to be in-between the antenna’s longer radiating strip and the ground plane. This arrangement makes the shorter radiating arm retain an effectively large distance to the ground plane, thereby making possible a wider impedance bandwidth in the DCS band for the GSM/DCS antenna and in the 5.2/5.8 GHz band for the WLAN antenna.

Based on the configurations of the GSM/DCS and WLAN antennas shown in Figure 1(b), there are four possible arrangements (see case 1 to case 4 in Fig. 2) by which to combine the two antennas into a combo antenna, and the distance between the two antennas is denoted as \( d \). It is expected that the isolation between the two antennas will be dependent on the different arrangements of the two antennas and the distance \( d \) between the two antennas as well [6, 7]. The related results are analyzed in the next section.

3. RESULTS AND DISCUSSION

The two antennas with the four possible arrangements shown in Figure 2 are studied. Since it is noted that the shorting strips of the two antennas in the case-4 arrangement face each other back-to-back (that is, their shorting points face each other), the isolation between the two antennas is expected to be optimized [6, 7]. Based on this expectation, the proposed combo antenna with the case-4 arrangement is firstly constructed and tested. The measured and simulated S-parameters for this arrangement with \( d = 6 \) mm are shown in Figure 3. Note that the simulated results in this study are all obtained using the Ansoft simulation software High-Frequency Structure Simulator (HFSS) and good agreement between the measurement and simulation is obtained.

As seen in Figure 3(a) for the GSM/DCS antenna excited with port 2 (the WLAN antenna) terminated to a 50Ω load, two separate resonant modes covering the GSM and DCS bands are obtained. The operating frequencies over the GSM and DCS bands all have good impedance matching (\( S_{11} \) less than –10 dB). For the isolation (\( S_{21} \)) between the two antennas, it is seen that the maximum measured \( S_{21} \) is as low as –27 dB over the GSM band and –24 dB over the DCS band; these results are well suited for practical applications. For the results shown in Figure 3(b) for the WLAN antenna excited with port 1 (the GSM/DCS antenna) terminated to a 50Ω load, two wide operating bandwidths with \( S_{11} \) less than –10 dB covering the 2.4- and 5.2/5.8-GHz bands are seen. For the operating frequencies over the bands, the measured maximum \( S_{21} \) is about –19 and –24 dB over the 2.4 GHz and 5.2/5.8 GHz bands, respectively, which is also acceptable for practical applications.

Figure 4 Simulated (a) \( S_{11} \) and (b) \( S_{22} \) for the proposed combo antenna with different arrangements (cases 1 to 4) with \( d = 6 \) mm

Figure 5 Simulated (a) \( S_{21} \) and (b) \( S_{12} \) for the proposed combo antenna with different arrangements (cases 1 to 4) with \( d = 6 \) mm
For comparing the performances of the proposed combo antenna with various arrangements, a simulation study is conducted. Figure 4 shows the simulated $S_{11}$ and $S_{22}$ for different arrangements of cases 1 to 4 with the same spacing of $d = 6$ mm. From the results in Figure 4(a), it is seen that the obtained bandwidths for the lower band at about 900 MHz are about the same. On the other hand, the obtained bandwidths for the upper band at about 1800 MHz are varied. The bandwidths for cases 3 and 4 are seen to be larger than those for cases 1 and 2. This behavior is largely because the shorter radiating strips of the GSM/DCS antenna are extended away from the WLAN antenna; thus, smaller coupling effects are expected, which leads to almost no variations in the bandwidths obtained. For the impedance matching of the WLAN antenna [see Fig. 4(b)], the variations in the 5.2/5.8-GHz band are seen to be relatively large, compared to those in the 2.4-GHz band. However, except for case 3, the obtained bandwidths generally cover the 5.2/5.8-GHz band.

Figure 5 shows the corresponding simulated $S_{21}$ and $S_{12}$ for the case-4 arrangement studied in Figure 4. For frequencies over the GSM and DCS bands in Figure 5(a), very slight variations in $S_{21}$ are seen, and it can be concluded that $S_{21}$ is almost unaffected by the spacing $d$ between the two antennas. On the other hand, over the 2.4-GHz band in Figure 5(b), $S_{21}$ can be decreased by about 3 dB by increasing $d$ from 0 to 10 mm. As for the 5.2/5.8-GHz band, although there are also some variations, the maximum $S_{21}$ is less than $-20$ dB for $d$ varied from 0 to 10 mm.

The performances of the proposed combo antenna as a function of the spacing $d$ are also studied. Figure 6 shows the simulated $S_{11}$ and $S_{22}$ for the proposed combo antenna with the case-4 arrangement as a function of $d$. As seen in Figure 6(a) for the GSM/DCS antenna, almost no variations in the impedance matching are seen for $d$ varied from 0 to 10 mm. On the other hand, for the results of the WLAN antenna shown in Figure 6(b), some variations are seen. There are some slight shifting by about 2.4 GHz. However, the obtained impedance bandwidths are about the same. For the upper band at about 5.5 GHz, the obtained impedance bandwidths are generally increased with an increase in $d$. However, even with $d = 0$, the obtained bandwidth can still cover the 5.2/5.8-GHz band.

Figure 7 shows the corresponding simulated $S_{21}$ and $S_{12}$ for the case-4 arrangement studied in Figure 6. For frequencies over the GSM and DCS bands in Figure 7(a), very slight variations in $S_{21}$ are seen, and it can be concluded that $S_{21}$ is almost unaffected by the spacing $d$ between the two antennas. On the other hand, over the 2.4-GHz band in Figure 7(b), $S_{21}$ can be decreased by about 3 dB by increasing $d$ from 0 to 10 mm. As for the 5.2/5.8-GHz band, although there are also some variations, the maximum $S_{21}$ is less than $-20$ dB for $d$ varied from 0 to 10 mm.
4. CONCLUSION

A combo antenna comprising one GSM/DCS antenna and one WLAN antenna for cellular/WLAN dual-network operation for a laptop computer has been proposed and studied. With the use of the shorted T-shape monopole for both the GSM/DCS and WLAN antennas, the proposed combo antenna shows a low profile and is thus very promising to be embedded inside the casing of the laptop computer as an internal antenna. The impedance and isolation characteristics of various possible arrangements of the GSM and WLAN antennas in the proposed combo antenna have also been analyzed. The results indicate that optimized isolation for frequencies over the operating bands can be obtained when the shorting strips of the GSM/DCS and WLAN antennas are arranged to face each other back-to-back (the case-4 arrangement in this study). On the other hand, relatively small variations in the impedance matching of the GSM/DCS and WLAN antennas have been observed for various arrangements of the combo antenna. The effects of the spacing between the two antennas have also been analyzed. However, the results indicate that the effects on the performances of the combo antenna due to the variations in the spacing are relatively small, as compared to the effects due to the various arrangements of the GSM/DCS and WLAN antennas in the proposed combo antenna.

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ERRATUM: PLANAR WAVES WITH NEGATIVE PHASE VELOCITY IN ISOTROPIC CHIRAL MEDIUMS

Tom G. Mackay
School of Mathematics
University of Edinburgh
James Clerk Maxwell Building, King’s Buildings
Edinburgh EH9 3JZ, United Kingdom

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Some typographical errors appeared in my original paper [1]. Eqs. (13) and (14) should correctly read as follows:

\[ k \hat{k} \cdot \mathbf{P} = \begin{cases} \omega |E_0|^2 \exp(-2k \hat{k} \cdot \mathbf{r}) \text{Re} \left\{ \sqrt{\varepsilon \mu + \xi} \times \text{Re} \left\{ \sqrt{\varepsilon \mu} \right\} \right\} & \text{for } k = k^{(i),(iv)} \varepsilon \\
\omega |E_0|^2 \exp(-2k \hat{k} \cdot \mathbf{r}) \text{Re} \left\{ \sqrt{\varepsilon \mu - \xi} \times \text{Re} \left\{ \sqrt{\varepsilon \mu} \right\} \right\} & \text{for } k = k^{(ii),(iia)} \varepsilon 
\end{cases} \]

(13)

and

\[ \text{Re} \left\{ \sqrt{\varepsilon \mu + \xi} \right\} \times \text{Re} \left\{ \sqrt{\varepsilon \mu} \right\} < 0 \quad \text{for } k = k^{(i),(iv)} \varepsilon \\
\text{Re} \left\{ \sqrt{\varepsilon \mu - \xi} \right\} \times \text{Re} \left\{ \sqrt{\varepsilon \mu} \right\} < 0 \quad \text{for } k = k^{(ii),(iia)} \varepsilon \]

(14)

These errors do not affect the conclusions reached in [1].

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