remains bellows this level beyond the upper simulated limit. Several resonances have been found.

Reference model (Vivaldi antenna) show better behavior at low frequencies but seems to have a lower high cut frequency in terms of S_{11}. It means that resonances are not as deep as they are at "palm tree" and are shifted from those as well. As a matter of fact, not important differences are observed except form frequency cuts.

Figures 4–9 present radiation pattern measurements of both models. These figures present both co-polarization (Co-pol) and cross-polarization (X-pol) patterns at different frequencies for both antennas at E-plane.

It can be seen that X-pol levels at main direction are always lower at the suggested antenna, up to 6 dB at 4 GHz. Main lobes at "palm tree" are wider in the Vivaldi reference model.

Gain values are almost the same for both antennas at the main radiation direction within 0.5 dB margin. Gain values goes from 5.5 to 8.5 dB from 6 to 12 GHz where radiation pattern is conserved.

It can be seen that no higher frequency has been obtained attending to -10 dB S_{11} threshold but other limitations, mainly radiation pattern deformation, set a high cut at 13 GHz.

Currents have been considered as well. A Figures 10 and 11 show electric current at one of the metallic leaves of the reference model and at one of the suggested antenna arm, respectively, at 8 GHz. It may be observed how the electrical current on the Vivaldi model is broken into several parts attending to the leaves on the suggested modification. Results show good agreement with simulations on FDTD.

4. CONCLUSIONS AND FUTURE WORK

A novel profile for tapered slot line antennas has been proposed. This model has at least as good frequency response as the proposed reference model (Vivaldi antenna). Better cross-polarization levels have been achieved from 3 to 10 GHz. Some frequencies reported multilobe radiation patterns. Gain levels are slightly increased but so are some main lobes what may lead to higher gains by narrowing the main lobe.

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INTERNAL PRINTED LOOP-TYPE MOBILE PHONE ANTENNA FOR PENTA-BAND OPERATION

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ABSTRACT: *An internal printed loop-type antenna comprising a driven monopole and a coupled strip for application in GSM850/GSM900/DCS/PCS/UMTS penta-band operation is presented. The antenna is suitable to be printed on the system circuit board of the mobile phone and short-circuited to the system ground plane to form as a loop-type structure. The antenna provides two wide bands at about 900 and 1900 MHz to cover the GSM850/900 and DCS/PCS/UMTS bands, respectively. The lower band is generated by the driven monopole and coupled strip operated together as a half-wavelength loop resonant structure. The upper band is formed by two resonant modes: the first one is the driven monopole operated alone as a quarter-wavelength monopole and the second one is contributed from the driven monopole and coupled strip operated together as a one-wavelength loop resonant structure. Details of the proposed antenna are presented and discussed.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 2595–2599, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22791

Key words: *mobile phone antennas; printed antennas; internal mobile phone antennas; loop antennas; penta-band operation*

1. INTRODUCTION

The internal mobile phone antenna with a loop structure is attractive for practical application owing to its balanced one-wavelength resonant mode that can result in small excited surface currents on the ground plane of the mobile phone [1, 2]. With this characteristic, when the mobile phone is held by the user's hand, small effects on the performances of the antenna can be obtained [3]. To utilize this advantageous property, promising loop antennas capable of dual-band or multiband operation in the mobile phone have been reported in the literature [3–6]. However, among the available designs, the penta-band loop antennas that can cover the major existing mobile communication bands including the global communication system (GSM850, 824–894 MHz and GSM900, 890–960 MHz), the digital communication system (DCS, 1710–1880 MHz), the personal communication system (PCS, 1850–1990 MHz), and the universal mobile telecommunication system (UMTS, 1920–2170 MHz) are still very few.

In this article, we present a printed loop-type antenna capable of penta-band operation in the mobile phone. The antenna is suitable to be printed on the system circuit board of the mobile phone and short-circuited to the system ground plane to form as a loop-type structure. In addition, the antenna can be bent by 90° to occupy a small space inside the casing of the mobile phone, and penta-band operation can still be obtained. Design considerations of the proposed antenna are described in the article. Results of the constructed prototype are presented and discussed.

2. ANTENNA DESIGN

Figure 1 shows the proposed loop-type antenna in its planar structure for penta-band operation in the mobile phone. The antenna is printed on the top no-ground portion (45×20 mm^2) of a 0.8-mm thick FR4 substrate of relative permittivity 4.4, which is treated as the system circuit board of the mobile phone. A ground

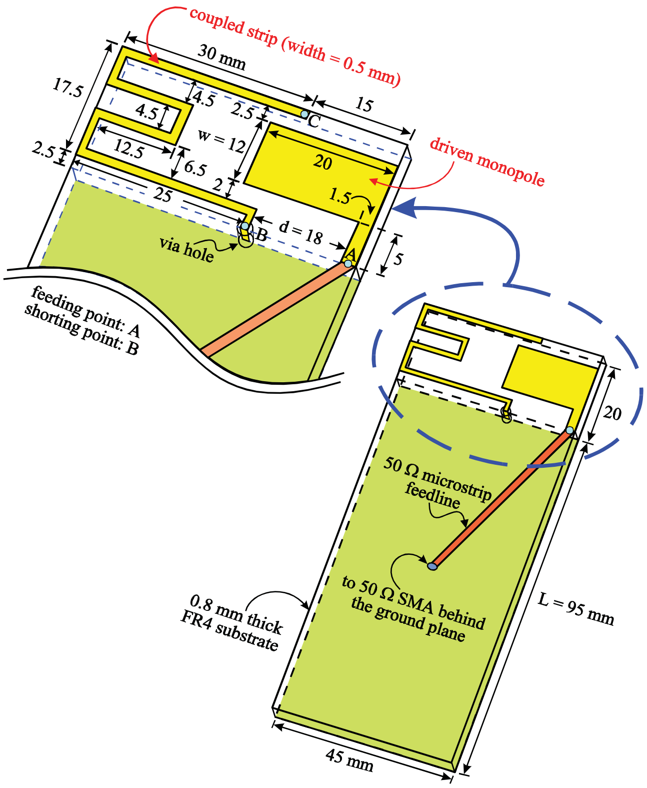


Figure 1 Geometry of the printed loop-type mobile phone antenna for penta-band operation. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

plane of size 45 × 95 mm^2 as the system ground plane of the mobile phone, which does not cover the top no-ground portion of the substrate, is printed on the back surface of the FR4 substrate.

The antenna is mainly composed of a driven monopole and a coupled strip. The driven monopole is of an inverted-L shape, and its feeding point (point A) is connected to a 50-Ω microstrip line printed on the FR4 substrate. The driven monopole alone (that is, the coupled strip is not present) can support a resonant path of about 35 mm, thus providing a quarter-wavelength resonant mode at about 1800 MHz. With the end portion of the driven monopole widened to be 12 mm (w), the excited resonant mode can have a wide bandwidth to cover the DCS/PCS bands. Effects of the width w on the performance of the antenna are also studied, and the results are shown in Figure 4 for detailed discussion in the next section.

The coupled strip has a narrow width of 0.5 mm and is meandered in its middle section to achieve a longer resonant length inside the limited region of the top no-ground portion of the substrate. From point B, which is short-circuited to the ground plane, to point C (the open end), the length of the coupled strip is about 100 mm in this design. In addition, the open end of the coupled strip is extended toward the driven monopole, and there is a small gap of 2.5 mm in between the two end portions of the driven monopole and coupled strip. Through the small gap, the coupled strip is electromagnetically coupled to the driven monopole, thus a loop-type structure is formed. In this case, the total length of the loop-type structure starting from point A to point C then to point B is about 135 mm, which is close to about a half-wavelength of the frequency at 900 MHz. This loop-type structure leads to the excitation of a half-wavelength loop resonant mode at about 900 MHz and a one-wavelength loop resonant mode at about 1900 MHz.

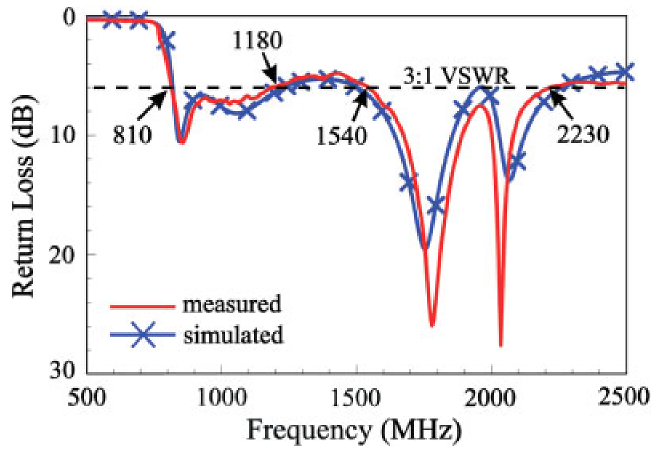


Figure 2 Measured and simulated return loss for the antenna with dimensions given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

The antenna's lower band is formed by the excited half-wavelength loop resonant mode, which shows a wide bandwidth to cover the GSM850/900 bands. That is, the lower band is generated by the driven monopole and coupled strip operated together as a half-wavelength loop resonant structure. For the antenna's upper band, it is formed by two resonant modes: the first one is the quarter-wavelength resonant mode generated by the driven monopole alone, and the second one is the one-wavelength loop resonant mode [7–10] contributed from the driven monopole and coupled strip operated together as a loop-type structure. This upper band has a wide bandwidth to easily cover the DCS/PCS/UMTS bands. Thus, with the wide lower and upper bands obtained for the proposed antenna, penta-band operation is achieved.

3. RESULTS AND DISCUSSION

The proposed antenna in its planar structure shown in Figure 1 was first fabricated and tested. Figure 2 shows the measured and simulated return loss for the constructed prototype. The simulated results are obtained using Ansoft HFSS (High Frequency Structure Simulator) [11], and good agreement between the simulation and measurement is obtained. A wide lower band having an impedance bandwidth (3:1 VSWR or 6-dB return loss) of 370 MHz (810–

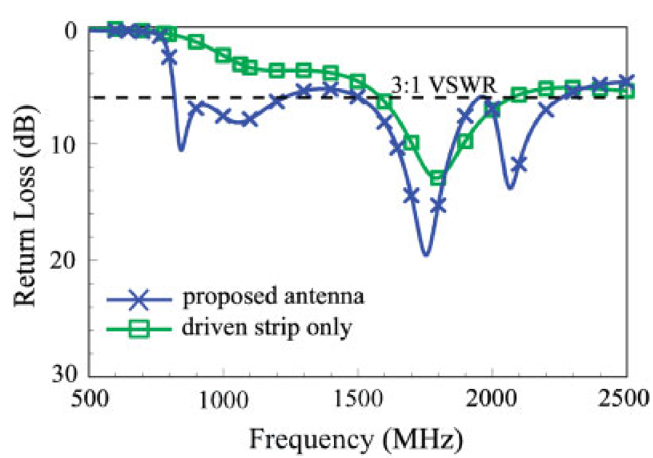


Figure 3 Simulated return loss for the proposed antenna and the case with the driven monopole only. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

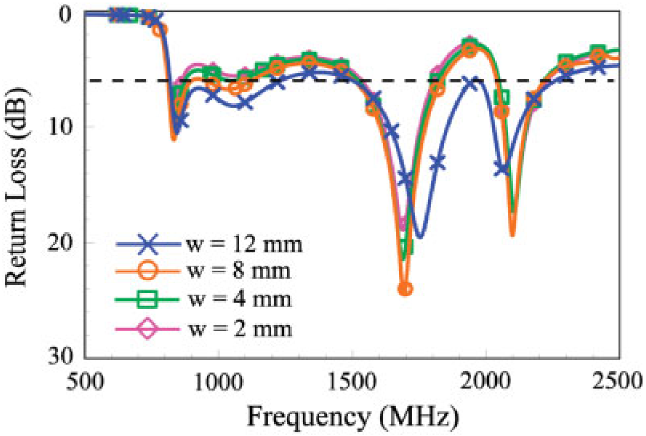


Figure 4 Simulated return loss as a function of the width *w* of the driven monopole; other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

1180 MHz) is excited, which easily covers the GSM850/900 bands and is mainly contributed from the driven monopole and coupled strip operated together as a half-wavelength loop resonant mode as discussed in Section 2. This behavior can be explained more clearly from the results of the proposed antenna and the case with the driven strip only (the coupled strip not present) shown in Figure 3. When the coupled strip is not present, the lower band cannot be excited.

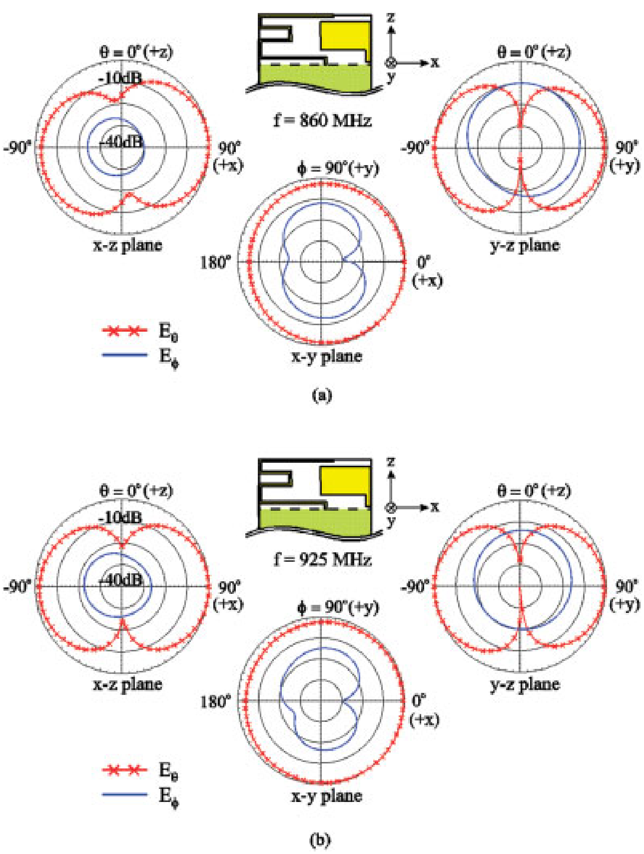


Figure 5 Measured radiation patterns at (a) 860 MHz and (b) 925 MHz for the antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

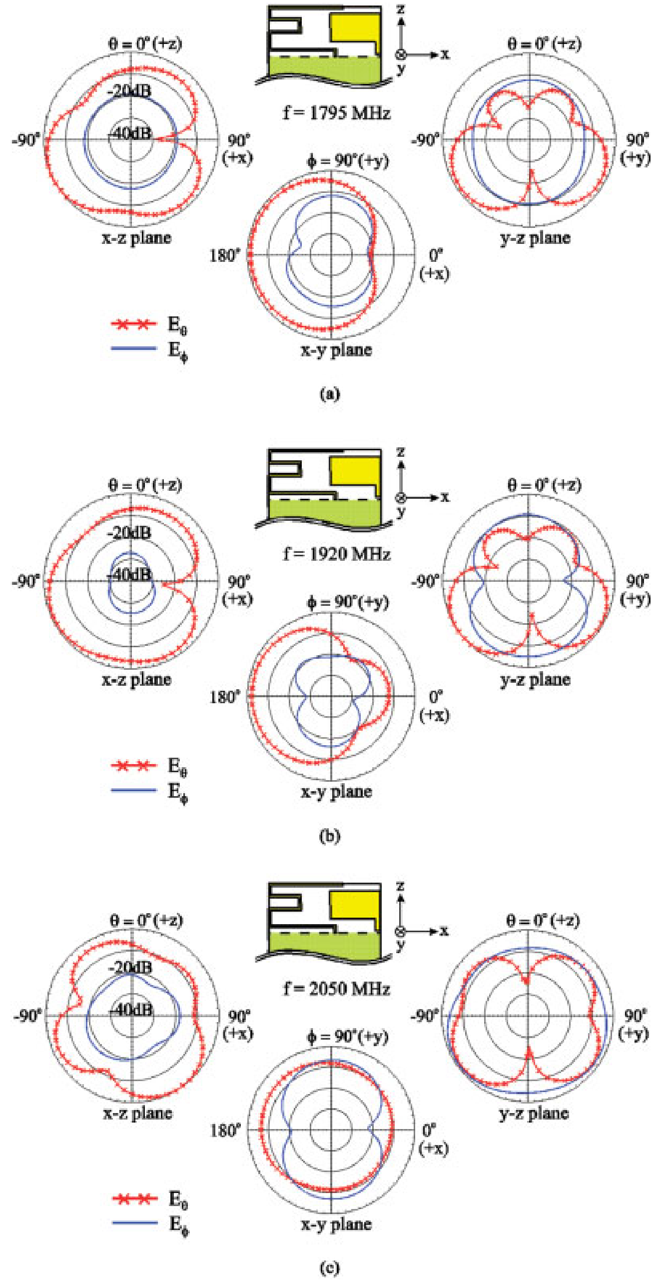
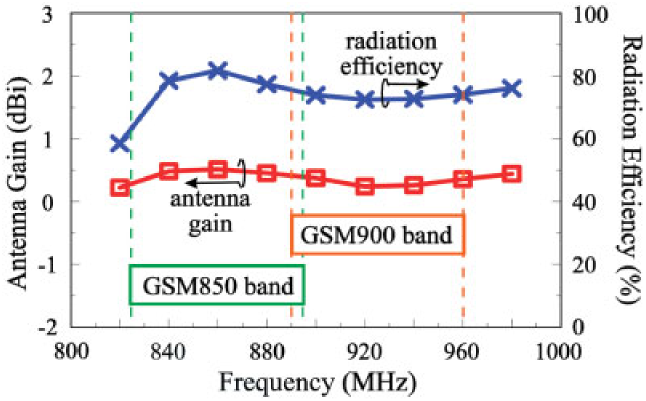


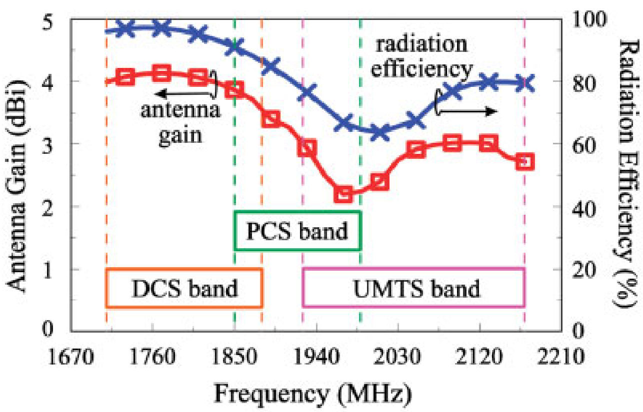
Figure 6 Measured radiation patterns at (a) 1795 MHz, (b) 1920 MHz, and (c) 2050 MHz for the antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

For the upper band, it has a bandwidth of 690 MHz (1540–2230 MHz) and also easily covers the DCS/PCS/UMTS bands. The upper band is formed by two resonant modes. The first one is contributed from the driven strip alone operated as an inverted-L monopole. This behavior can also be explained clearly in Figure 3, in which there is only one resonant mode excited at about 1800 MHz when the coupled strip is not present. For the second mode in the upper band, it is generated by the driven monopole and coupled strip operated together as a one-wavelength loop resonant mode as discussed in Section 2.

Figure 4 shows the simulated return loss as a function of the width *w* of the driven monopole, and other dimensions are the same as in Figure 1. Results show that only when the width *w* is large enough (12 mm here), the obtained bandwidth of the first



(a)



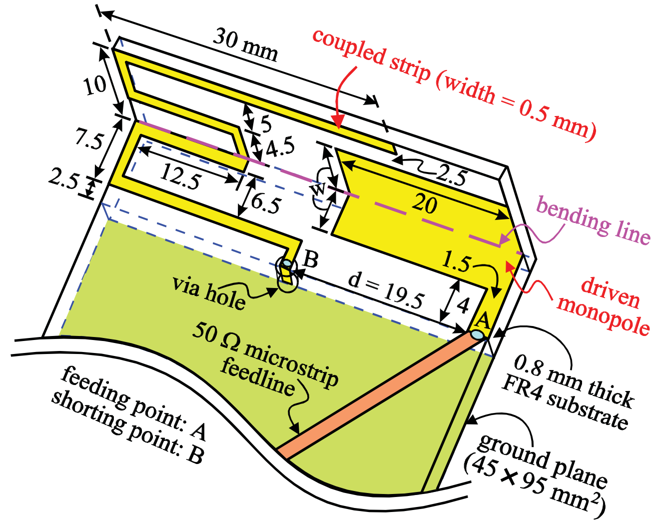
(b)

Figure 7 Measured maximum antenna gain and simulated radiation efficiency over (a) GSM850/900 bands and (b) DCS/PCS/UMTS bands. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

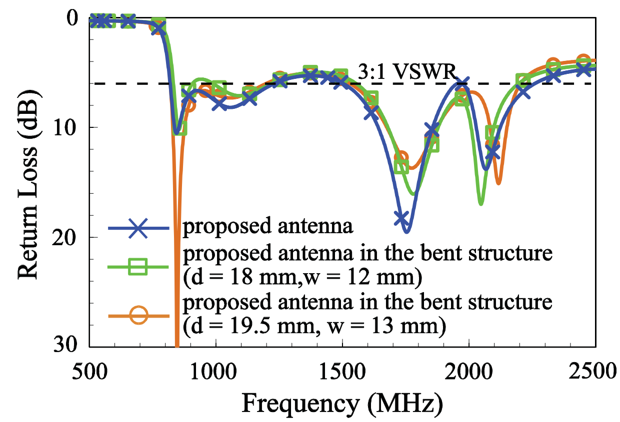
mode of the upper band contributed by the driven monopole alone can be enhanced to be wide enough to cover the DCS/PCS bands. That is, wider bandwidth with increasing widths of the driven monopole is obtained; this behavior is similar to that observed for the monopole with a wider radiating strip [12]. The second mode of the upper band is also found to have a wider bandwidth, which covers the UMTS band. The larger width w can also result in improved impedance matching of the antenna's lower band, thus providing a wide bandwidth to cover the GSM/DCS bands.

The radiation characteristics of the constructed prototype are also studied, and the measured radiation patterns at 860 and 925 MHz (center frequencies of the GSM850 and GSM900 bands) are plotted in Figure 5. Similar radiation patterns at 860 and 925 MHz are observed, which suggests that stable radiation characteristics are obtained over the antenna's lower band. The radiation patterns are also seen to be similar to that of the general internal mobile phone antenna [13]. This behavior is mainly because the half-wavelength loop resonant mode excited for the lower band is an unbalanced mode. In this case, the excited surface currents on the system ground plane are large and thus dominate the radiation performance in the 900 MHz band.

Figure 6 plots the measured radiation patterns at 1795, 1920, and 2050 MHz (center frequencies of the DCS, PCS, and UMTS bands).



(a)



(b)

Figure 8 (a) Geometry of the proposed antenna in the bent structure. (b) Simulated return loss for the proposed antenna in Figure 1 and in the bent structure. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

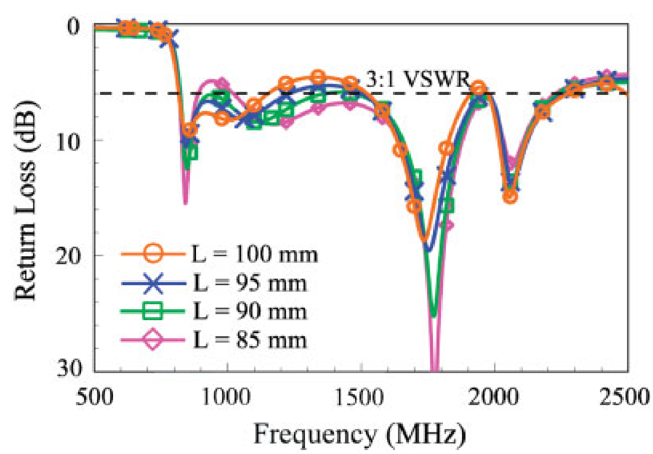


Figure 9 Simulated return loss as a function of the groundplane length L; other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Similar radiation patterns at 1795 and 1920 MHz are seen, which indicates that stable radiation performance is obtained over the band. This behavior is mainly because the operating bands of DCS and PCS are covered by the resonant mode contributed from the driven strip alone operated as an inverted-L monopole. In addition, owing to the driven strip asymmetrically located at the top no-ground portion, asymmetric radiation patterns at 1795 and 1920 MHz are also seen. At 2050 MHz, more symmetric radiation patterns are seen, different from those at 1795 and 1920 MHz. This behavior is because the resonant mode covering the UMTS band is generated by the driven monopole and coupled strip operated together as a one-wavelength loop resonant mode as discussed earlier.

Figure 7 shows the measured maximum antenna gain and simulated radiation efficiency. As shown in Figure 7(a), stable antenna gain of about 0.4 dBi over the GSM850/900 bands is seen. Small variations in the radiation efficiency are also obtained. The efficiency over the GSM850 band is about 62–81%, while that over the GSM900 band is about 72–76%. Results for the DCS/PCS/UMTS bands are shown in Figure 7(b). More variations in the antenna gain and radiation efficiency are seen. Over the DCS and PCS bands, the antenna gain is about 3.6–4.1 dBi and 2.2–3.8 dBi, respectively. Over the UMTS band, it is about 2.2–3.0 dBi. For the efficiency, it is larger than 85% over the DCS band and about 64–90% over the PCS bands. Over the UMTS band, the efficiency is about 62–80%.

Characteristics of the proposed antenna in the bent structure are also studied. The configuration of the antenna bent by 90° is shown in Figure 8(a). With the bending, the antenna can occupy a smaller space inside the mobile phone, and the parameters d and w are adjusted to compensate for the small effects of the bending on the impedance matching of the antenna. Figure 8(b) shows the simulated return loss for the proposed antenna in Figure 1 and in the bent structure. By slightly adjusting d and w to be 19.5 and 13 mm, the proposed antenna in the bent structure can still achieve good impedance matching to cover the penta-band operation.

Finally, effects of the groundplane length on the performance of the antenna are studied. Figure 9 shows the simulated return loss as a function of the groundplane length L. When the length L is increased to 100 mm, enhanced matching for frequencies over the lower band is seen. Conversely, when the length L is decreased to 85 mm, the impedance matching is slightly degraded for the lower band. As for the upper band, smaller effects of the length L on the impedance matching of the antenna are seen. Generally speaking, effects of the groundplane length are smaller for the proposed antenna than for the conventional internal mobile phone antennas [13, 14].

4. CONCLUSION

A printed loop-type antenna suitable for application in the mobile phone has been proposed and studied. The antenna can be operated in the planar structure with an area of 20×40 mm^2 to cover the penta-band operation. The antenna is easy to fabricate at lost cost and integrate with the system circuit board of the mobile phone to operate as an internal antenna. Good radiation characteristics over the operating bands have also been obtained. The antenna can also be bent by 90° to allow it to occupy a smaller space inside the mobile phone as an internal antenna, and good performance of the antenna can still be obtained.

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LEFT-HANDED CHARACTERISTIC ANALYSIS OF A SPLIT-RING RESONATOR DEFECTED GROUND STRUCTURE TRANSMISSON LINE

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ABSTRACT: *The left-handed properties of a split-ring resonator defected ground structure transmission line (TL) is investigated in this article. Then the transmission zero location, dispersion relation, impedance characteristic as well as refraction index are derived in detail. The numerical and measurement results validate that, this type of TL unit has the left-handed properties with transmission zero.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 2599–2602, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22752

Key words: *split-ring resonator (SRR), defected ground structure (DGS), composite right/left-handed (CRLH), transmission zero*

1. INTRODUCTION

As early as the year 1968, Veselago has theoretically indicated the abnormal phenomenon of the left-handed metamaterial when