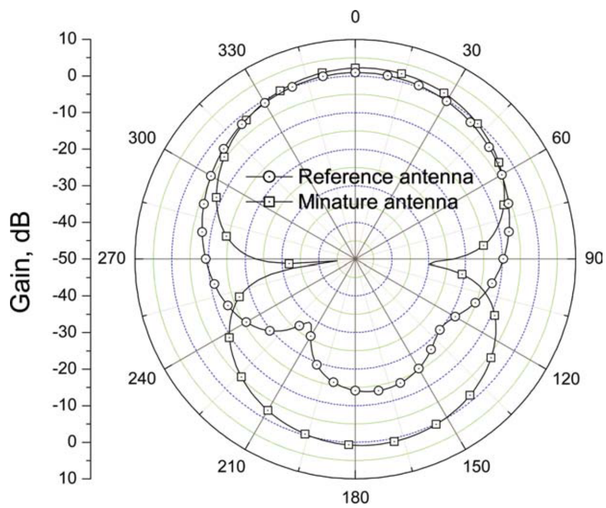

Figure 4 Radiation pattern in the azimutal plane. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

To know the effect of the miniaturization technique on the antenna's performances, a reference patch antenna has been designed on the same substrate with a conventional ground plane. Its size is 105 mm × 85 mm. The performances of the two antennas have been plotted together. Figure 3 shows the matching.

The gain of the two antennas has also been simulated.

Figure 4 shows that that the maximum gain has not been affected by the reduction technique. An explication is that the electrical length of the radiating element of the patch has not been reduced and it has not been slotted. The augmentation of the back side radiation can be caused by the radiation of the slot performed on the ground plane.

5. CONCLUSIONS

In this article, a miniaturization technique suitable for patch antennas has been presented. It is based on the use of FSSs. Simulations show a reduction of a 1.8 ratio of the geometrical dimensions. The final antenna measures 65 mm × 55 mm and has 2 dB gain in a 25 MHz frequency centered at 915 MHz.

REFERENCES

1. G. Marrocco, The art of UHF RFID antenna design impedance-matching and size-reduction technique, IEEE Antennas Propag Mag 50 (2008), 66–79.
2. K. Buell, H. Mosallaei, and K. Sarandi, A substrate for small patch antennas providing tuneable miniaturization factors, IEEE Trans Microwave Theory Tech 54 (2006), 135–146.
3. F.R. Yang, K.P. Ma, Y. Qian, and T. Itoh, A uniplanar compact photonic-bandgap (UC-PBG) structure and its applications for microwave circuits, IEEE Trans Microwave Theory Tech 47 (1999), 1509–1514.
4. C. Zhou and Y.D. Yang, The design of miniaturized printed wire antennas using double-layer periodic metallization, IEEE Antennas Wireless Propag Lett 6 (2007), 11–14.
5. C.C. Chang, Y. Qian, and T. Itoh, Analysis and applications of uniplanar compact photonic bandgap structures, Prog Electromag Res PIER 41 (2003), 211–235.

SMALL-SIZE PRINTED LOOP-TYPE ANTENNA INTEGRATED WITH TWO STACKED COUPLED-FED SHORTED STRIP MONOPOLES FOR EIGHT-BAND LTE/GSM/UMTS OPERATION IN THE MOBILE PHONE

Kin-Lu Wong and Wei-Yu Chen
Department of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan; Corresponding author: chenwy@ema.ee.nsysu.edu.tw

Received 24 September 2009

ABSTRACT: *A small-size internal printed antenna formed by a loop-type antenna integrated with two stacked coupled-fed shorted strip monopoles is presented. The proposed antenna has a small uniplanar structure of 40 × 15 mm^2 (600 mm^2) for eight-band LTE/GSM/UMTS operation in the mobile phone. The loop-type antenna comprises a driven monopole and a coupled portion short-circuited to the system ground plane of the mobile phone; the driven monopole alone contributes a resonant mode for the antenna's upper band, whereas the driven monopole and shorted coupled portion together provide a loop-type resonant path to generate a resonant mode for the antenna's lower band. Two stacked strips are then integrated with the loop-type antenna, with the two strips coupled-fed by the driven monopole and short-circuited to the ground plane through the shorted coupled portion. That is, two stacked coupled-fed shorted strip monopoles are formed and incorporated with the loop-type antenna in an integrated configuration. The two strip monopoles contribute two additional resonant modes to incorporate those generated by the loop-type antenna to achieve the desired wide lower band (698–960 MHz) and upper band (1710–2690 MHz) for eight-band LTE/GSM/UMTS operation. Details of the proposed antenna are presented.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 1471–1476, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25257

Key words: *mobile antennas; handset antennas; printed antennas; small antennas; LTE/GSM/UMTS antennas*

1. INTRODUCTION

Printed antennas with a uniplanar and compact structure are very attractive for slim mobile phone applications, mainly because they can be directly printed on the system circuit board of the mobile phone at low cost and their antenna height above the circuit board can generally be ignored. A variety of small-size all-printed mobile phone antennas (printed area about 600 mm^2 or less) for covering pentaband WWAN (wireless wide-area network) of the GSM850 (824–894 MHz), GSM900 (880–960 MHz), GSM1800 (1710–1880 MHz), GSM1900 (1850–1990 MHz), and UMTS (1920–2170 MHz) have been reported in the published articles [1–7]. Recently, owing to the promising system of the LTE (long-term evolution) that can provide better mobile broadband and multimedia services than the GSM and UMTS systems [8–10], it is expected that in the very near future the LTE will be incorporated with the existing GSM/UMTS operation in the mobile phone. For this expectation, the internal mobile phone antenna should cover the additional three operating bands of the LTE, which include the LTE700 (698–787 MHz), LTE2300 (2305–2400 MHz), and LTE2500 (2500–2690 MHz). That is, eight-band LTE/GSM/UMTS operation will be required for the internal mobile phone antennas.

In this article, we present a novel internal uniplanar printed antenna with a small size of 40 × 15 mm^2 (600 mm^2) and capable of generating two wide operating bands to cover the

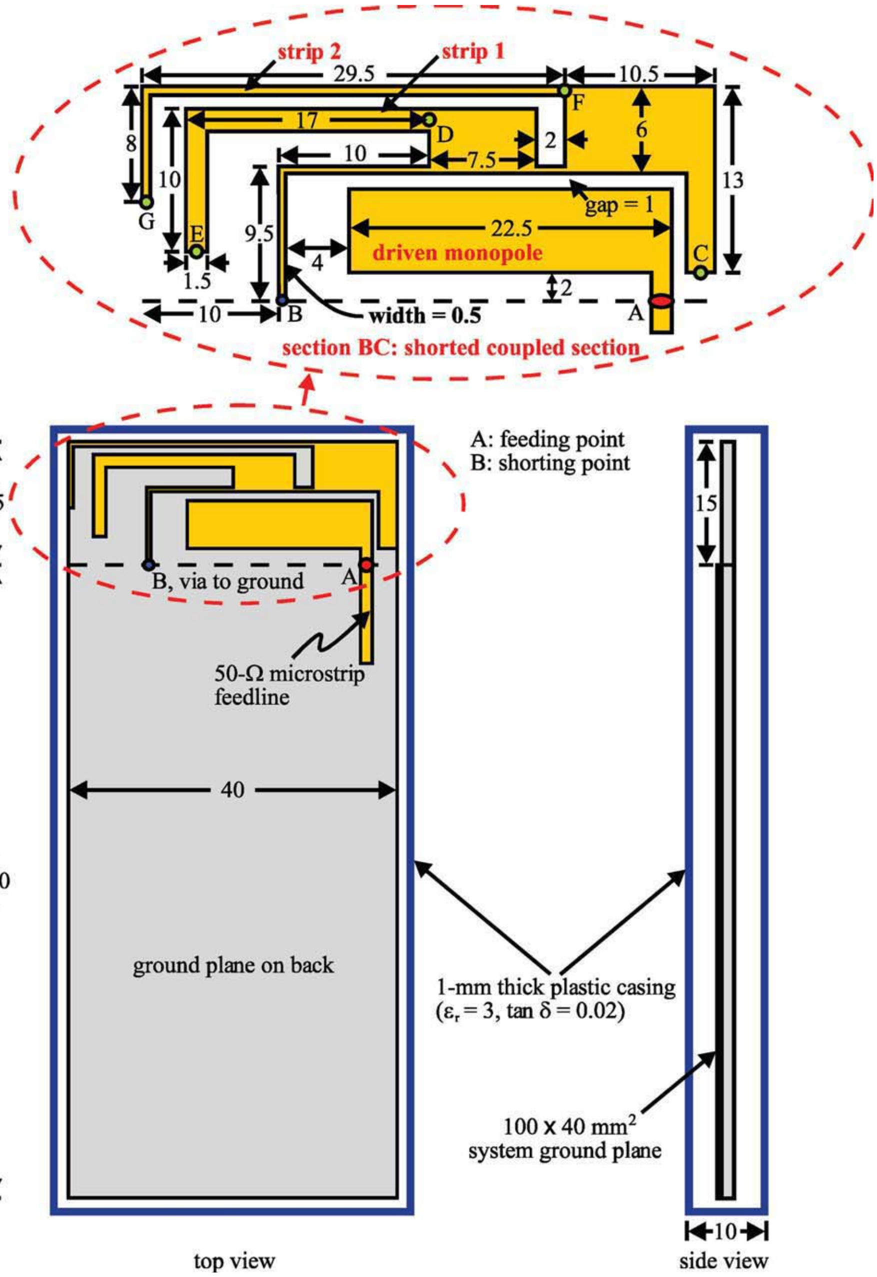

Figure 1 Geometry of the printed loop-type antenna integrated with two stacked coupled-fed shorted strip monopoles for eight-band LTE/GSM/UMTS operation in the mobile phone. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

LTE700/GSM850/900 bands (698–960 MHz) and the GSM1800/1900/UMTS/LTE2300/2500 (1710–2690 MHz) bands, respectively. Note that with eight-band operation obtained, the printed area of the proposed antenna is comparable to those of the reported pentaband GSM850/900/1800/1900/UMTS operation in the 824–960 MHz and 1710–2170 MHz bands [1–7]. The proposed antenna uses a driven monopole as its feed; the driven monopole alone can generate a resonant mode in the desired antenna's upper band. The driven monopole also serves as a coupling feed [11–17] to couple the electromagnetic energy to a shorted coupled section to form a loop-type antenna [18–21] to generate a resonant mode in the antenna's lower band. Two stacked strips are then added to the shorted coupled section and configured such that the two stacked strips are short-circuited to the ground plane using the shorted coupled section as their common shorting strips and are excited capacitively by the driven monopole as their common coupling feed. That is, two stacked coupled-fed shorted strip monopoles are formed, which generates two additional resonant modes for the proposed antenna, with one in the lower band and one in the upper band. There are hence four effective radiators in the proposed antenna, including one driven monopole, one loop-type antenna, and two coupled-fed strip monopoles in an integrated configuration. The four radiators generate four resonant modes, with two in the lower band to cover the desired frequency range of 698–960 MHz and two in the upper band to cover the frequency range of 1710–2170 MHz. That is, eight-band LTE/GSM/UMTS operation is obtained for the proposed antenna. Details of the operating principle of the proposed antenna are studied. The antenna performances are presented and discussed.

of the shorted coupled section, the bandwidth of the proposed antenna can be greatly enhanced. Notice that at where the two strips connected to the shorted coupled section, the strip width is widened to obtain sufficient capacitive coupling between the two shorted strips and the driven monopole, which functions as the coupling feed for the two shorted strips. In this case, two additional coupled-fed shorted strip monopoles are obtained, which generate two additional resonant modes at about 1300 and 1900 MHz. The one at about 1300 MHz also leads to improved impedance matching of the original resonant mode at about 850 MHz contributed by the loop-type resonant path; the two modes together form a wide lower band for the proposed antenna to cover the desired frequency range of 698–960 MHz. The other one at about 1900 MHz incorporates the resonant mode contributed by the driven monopole to result in a wide upper band for the proposed antenna to cover the desired frequency range of 1710–2690 MHz. More detailed results will be discussed with the aid of Figures 4 and 5 in Section 3.

Figure 2 Photograph of the fabricated prototype of the proposed antenna (casing not included in the photograph). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

2. PROPOSED ANTENNA

Figure 1 shows the geometry of the proposed antenna, which is a printed loop-type antenna integrated with two stacked coupled-fed shorted strip monopoles for eight-band LTE/GSM/UMTS operation in the mobile phone. The proposed antenna is directly printed on the no-ground portion (size 15×40 mm^2) of the system circuit board of the mobile phone. In this study, an FR4 substrate of 115×40 mm^2 is used as the system circuit board; on its back side, a system ground plane of size 100×40 mm^2 is printed. A plastic casing made of a 1-mm-thick plastic plate whose relative permittivity is 3.0 and loss tangent is 0.02 encloses the system circuit board to simulate the practical mobile phone casing.

The proposed antenna is an all-printed structure; it comprises a driven monopole, a shorted coupled section (section BC), and two stacked strips (Strips 1 and 2) connected to the shorted coupled section. The driven monopole itself can function as an efficient quarter-wavelength radiator to generate a resonant mode at about 2300 MHz for the antenna's upper band. Further, the driven monopole and the shorted coupled section of length about 46.5 mm together provide a loop-type resonant path [18–21] to generate a resonant mode at about 850 MHz for the antenna's lower band. These two resonant modes, however, cannot cover the desired eight-band LTE/GSM/UMTS operation.

With the adding of the two stacked strips, which are short-circuited to the system ground plane through section BD and BF

3. RESULTS AND DISCUSSION

Figure 2 shows the photograph of the fabricated prototype of the proposed antenna; the plastic mobile phone casing is not included in the photograph. Results of the measured and simulated return loss of the proposed antenna are shown in Figure 3. The simulated results obtained using Ansoft simulation software HFSS version 11.2 [22] agree with the measured data. Two wide operating bands are generated for the proposed antenna. The lower band shows a measured 3:1 VSWR (6-dB return loss) bandwidth of 660 MHz (685–1345 MHz), whereas the upper band has a bandwidth of 1300 MHz (1685–2985 MHz). The wide lower and upper bands cover the desired eight-band LTE/GSM/UMTS operation.

The operating principle is analyzed in Figure 4 in which results of the simulated return loss of the proposed antenna, the case with the driven monopole only (Ref1), the case with the loop-type antenna only (Ref2), and the case with the loop-type antenna and Strip 1 only (Ref3) are presented. The corresponding dimensions of Ref1, Ref2, and Ref3 are the same as those of the proposed antenna given in Figure 1. For Ref1, a wide resonant mode is seen to occur at about 2300 MHz, although the impedance matching of this resonant mode still needs to be improved. For Ref2, a second resonant mode at about 850 MHz is generated, and the impedance matching of the original or first one at about 2300 MHz is also improved. For Ref3, a third

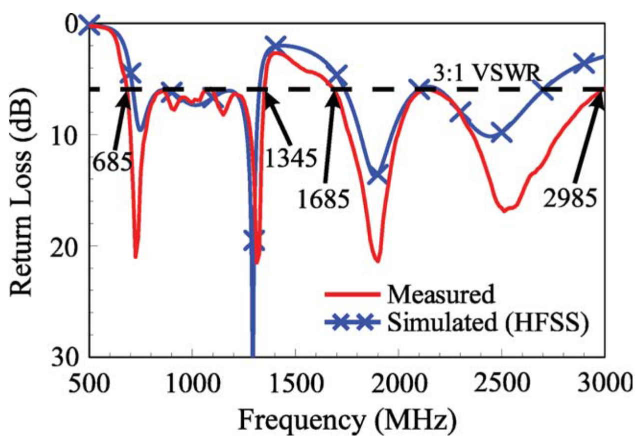

Figure 3 Measured and simulated return loss of the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

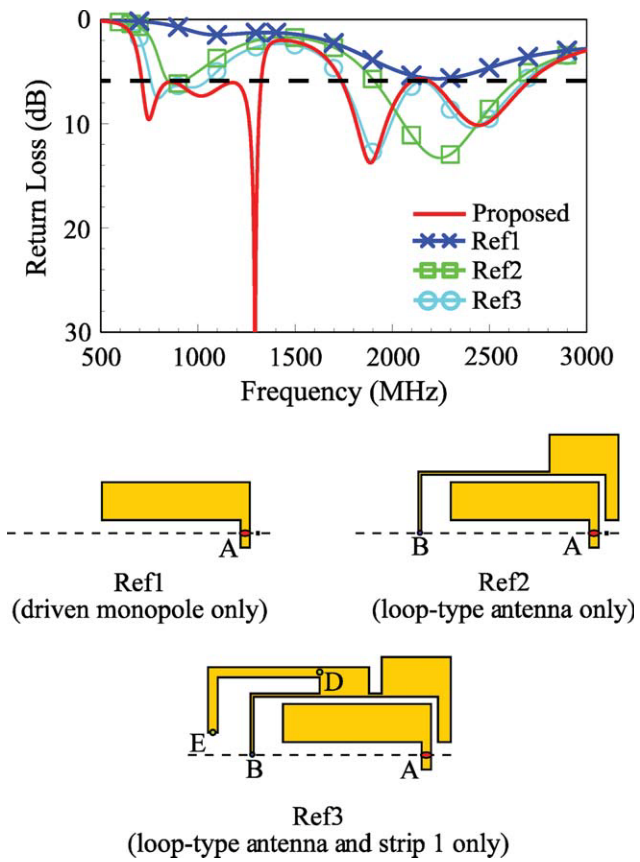

Figure 4 Simulated return loss of the proposed antenna, the case with the driven monopole only (Ref1), the case with the loop-type antenna only (Ref2), and the case with the loop-type antenna and Strip 1 only (Ref3). Corresponding dimensions of the four antennas studied in the figure are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

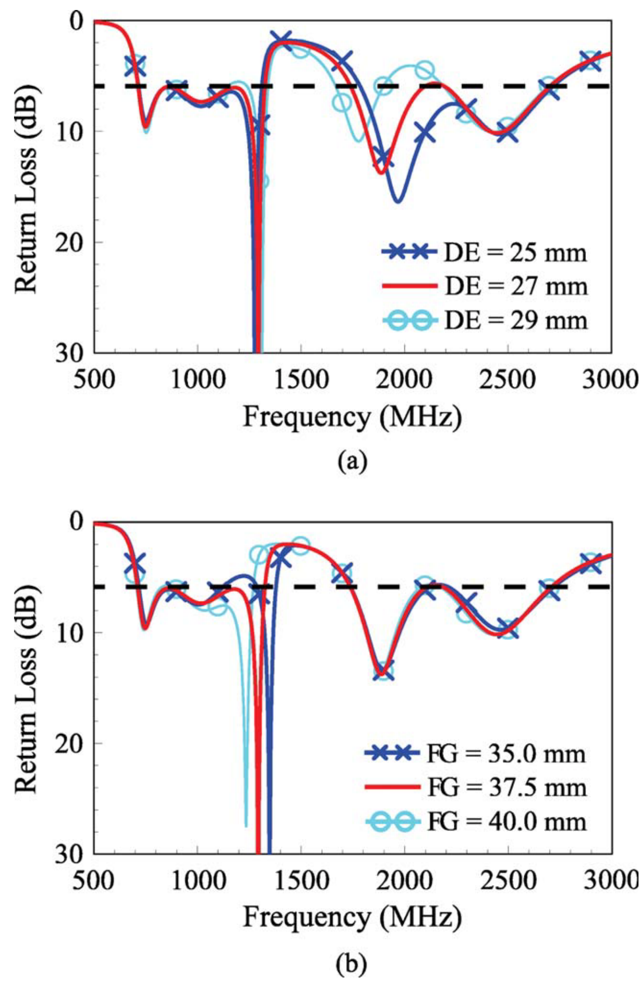

Figure 5 Simulated return loss for the proposed antenna as a function of (a) the length of Strip 1 (section DE) and (b) the length of Strip 2 (section FG). Other dimensions are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

resonant mode at about 1900 MHz is excited, and the first one is shifted to about 2500 MHz. These two modes form a very wide upper band for the proposed antenna. Also, the adding of Strip 1 also leads to a dual-resonant behavior for the second mode at about 850 MHz, hence widening the bandwidth of the antenna's lower band. For the proposed antenna (Strip 2 added to Ref3), a fourth resonant mode at about 1300 MHz is generated, which incorporates the one at about 850 MHz to form a very wide lower band for the proposed antenna. Notice that with the very wide lower and upper bands obtained, the proposed antenna can be printed on the small no-ground portion of 40 × 15 mm^2 or 600 mm^2 only.

Effects of the lengths of Strips 1 and 2 are studied in Figure 5. The simulated return loss for the length of Strip 1 (section DE) varied from 25 to 29 mm is shown in Figure 5(a). By varying the length of Strip 1, only the third resonant mode is effectively varied, with the other three modes very slightly affected. This indicates that the third resonant mode at about 1900 MHz for the proposed antenna is indeed contributed by Strip 1. Figure 5(b) shows the simulated return loss for the length of Strip 2 (section FG) varied from 35 to 40 mm. Only the resonant mode at around 1300 MHz is varied; the other three modes are almost not affected. This also confirms that the resonant mode at about 1300 MHz is controlled by Strip 2.

Figure 6 plots the measured radiation patterns at 830 and 2200 MHz (central frequencies of the desired lower and upper bands) for the proposed antenna. Dipole-like radiation pattern with omnidirectional radiation in the azimuthal plane (*x-y* plane) is seen at 830 MHz, while the radiation pattern at 2200 MHz shows some dips in the azimuthal plane. The obtained patterns in general show no special distinctions to those of the printed internal mobile phone antennas [1–7]. Figure 7 shows the measured antenna gain and radiation efficiency of the proposed antenna. Over the LTE700/GSM850/900 bands shown in Figure 7(a), the antenna gain is about −0.3–0.8 dBi, and the radiation efficiency

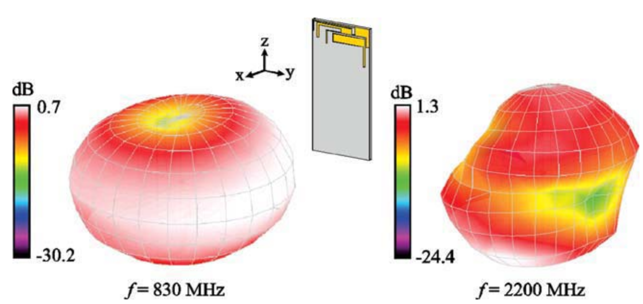

Figure 6 Measured radiation patterns at 830 and 2200 MHz for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

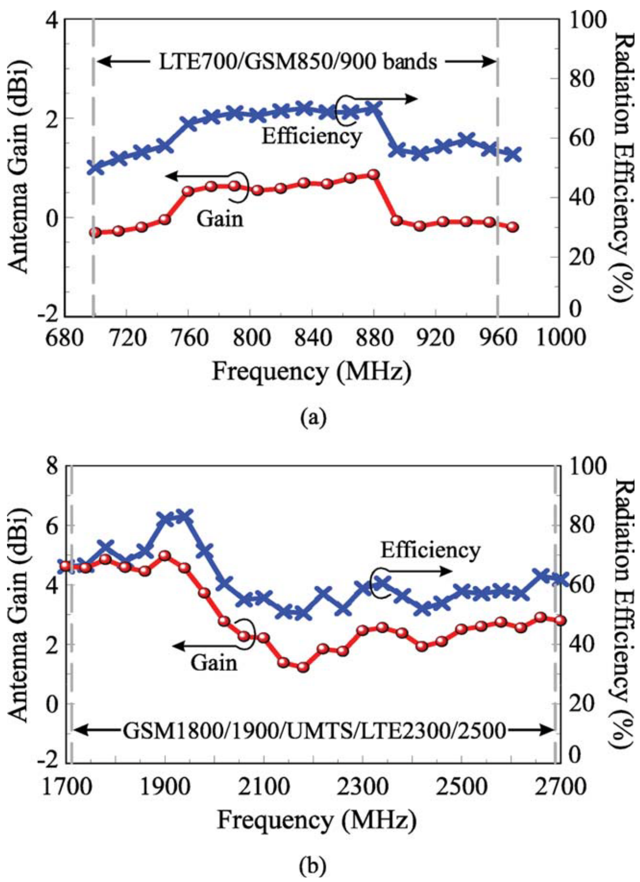

Figure 7 Measured antenna gain and radiation efficiency of the proposed antenna. (a) The LTE700/GSM850/900 bands and (b) the GSM1800/1900/UMTS/LTE2300/2500 bands. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

is ranged from about 50 to 70%. Over the GSM1800/1900/UMTS/LTE2300/2500 bands shown in Figure 7(b), the antenna gain is about 1.2–4.9 dBi, and the radiation efficiency is varied from about 50 to 82%.

4. CONCLUSIONS

A uniplanar printed antenna with small size and wide band for eight-band LTE/GSM/UMTS operation has been proposed, fabricated, and tested. The proposed antenna comprises four effective radiators, including one loop-type antenna, one driven monopole therein for the antenna feed, and two stacked coupled-fed shorted strip monopoles, incorporated into a compact structure. The four radiators contribute four resonant modes to form two wide operating bands to cover the desired frequency ranges of 698–960 MHz and 1710–2690 MHz. Good radiation characteristics for frequencies over the operating bands have also been observed. Also, with the all-printed structure for the proposed antenna, it can be easily fabricated at low cost and the antenna height above the system circuit board can be ignored, hence making it very attractive for slim mobile phone applications [23–27].

REFERENCES

1. C.H. Chang and K.L. Wong, Printed λ/8-PIFA for penta-band WWAN operation in the mobile phone, IEEE Trans Antennas Propag 57 (2009), 1373–1381.
2. C.I. Lin and K.L. Wong, Printed monopole slot antenna for internal multiband mobile phone antenna, IEEE Trans Antennas Propag 55 (2007), 3690–3697.
3. K.L. Wong and C.H. Huang, Printed PIFA with a coplanar coupling feed for penta-band operation in the mobile phone, Microwave Opt Technol Lett 50 (2008), 3181–3186.
4. C.T. Lee and K.L. Wong, Uniplanar coupled-fed printed PIFA for WWAN/WLAN operation in the mobile phone, Microwave Opt Technol Lett 51 (2009), 1250–1257.
5. K.L. Wong and W.Y. Chen, Small-size printed loop antenna for penta-band thin-profile mobile phone application, Microwave Opt Technol Lett 51 (2009), 1512–1517.
6. T.W. Kang and K.L. Wong, Chip-inductor-embedded small-size printed strip monopole for WWAN operation in the mobile phone, Microwave Opt Technol Lett 51 (2009), 966–971.
7. C.H. Chang and K.L. Wong, Small-size printed monopole with a printed distributed inductor for penta-band WWAN mobile phone application, Microwave Opt Technol Lett 51 (2009), 2903–2908.
8. S. Sesia, I. Toufik, and M. Baker (Eds.), LTE, The UMTS long term evolution, from theory to practice, Wiley, New York, 2009.
9. G. Park, M. Kim, T. Yang, J. Byun, and A.S. Kim, The compact quad-band mobile handset antenna for the LTE700 MIMO application, In: Proceedings of the IEEE Antennas Propagation Society International Symposium, Charleston, SC, 2009, Session 307.
10. J. Cho and K. Kim, A frequency-reconfigurable multi-port antenna operating over LTE, GSM, DCS, and PCS bands, In: Proceedings of the IEEE Antennas Propagation Society International Symposium, Charleston, SC, 2009, Session 317.
11. L. Lu and J.C. Coetzee, A modified dual-band microstrip monopole antenna, Microwave Opt Technol Lett 48 (2006), 1401–1403.
12. W.J. Tseng, Coupled-fed antenna device, U.S. Patent Application Publication No.: 2007/0257842 A1, 2007.
13. K.L. Wong and C.H. Huang, Compact multiband PIFA with a coupling feed for internal mobile phone antenna, Microwave Opt Technol Lett 50 (2008), 2487–2491.
14. K.L. Wong and C.H. Huang, Bandwidth-enhanced internal PIFA with a coupling feed for quad-band operation in the mobile phone, Microwave Opt Technol Lett 50 (2008), 683–687.
15. C.H. Chang, K.L. Wong, and J.S. Row, Coupled-fed small-size PIFA for penta-band folder-type mobile phone application, Microwave Opt Technol Lett 51 (2009), 18–23.
16. K.L. Wong and S.J. Liao, Uniplanar coupled-fed printed PIFA for WWAN operation in the laptop computer, Microwave Opt Technol Lett 51 (2009), 549–554.
17. C.H. Wu and K.L. Wong, Ultra-wideband PIFA with a capacitive feed for penta-band folder-type mobile phone antenna, IEEE Trans Antennas Propag 57 (2009), 2461–2464.
18. W.Y. Li and K.L. Wong, Internal printed loop-type mobile phone antenna for penta-band operation, Microwave Opt Technol Lett 49 (2007), 2595–2599.
19. Y.W. Chi and K.L. Wong, Internal compact dual-band printed loop antenna for mobile phone application, IEEE Trans Antennas Propag 55 (2007), 1457–1462.
20. Y.W. Chi and K.L. Wong, Compact multiband folded loop chip antenna for small-size mobile phone, IEEE Trans Antennas Propag 56 (2008), 3797–3803.
21. Y.W. Chi and K.L. Wong, Quarter-wavelength printed loop antenna with an internal printed matching circuit for GSM/DCS/PCS/UMTS operation in the mobile phone, IEEE Trans Antennas Propag 57 (2009), 2541–2547.
22. Ansoft Corporation HFSS, Available at: http://www.ansoft.com/products/hf/hfss/.
23. K.L. Wong and Y.C. Lin, Thin internal planar antenna for GSM/DCS/PCS/UMTS operation in a PDA phone, Microwave Opt Technol Lett 47 (2005), 429–432.
24. K.L. Wong, Y.C. Lin, and T.C. Tseng, Thin internal GSM/DCS patch antenna for a portable mobile terminal, IEEE Trans Antennas Propag 54 (2006), 238–242.

25. K.L. Wong, Y.C. Lin, and B. Chen, Internal patch antenna with a thin air-layer substrate for GSM/DCS operation in a PDA phone, IEEE Trans Antennas Propag 55 (2007), 1165–1172.
26. R.A. Bhatti, Y.T. Im, J.H. Choi, T.D. Manh, and S.O. Park, Ultrathin planar inverted-F antenna for multistandard handsets, Microwave Opt Technol Lett 50 (2008), 2894–2897.
27. R.A. Bhatti and S.O. Park, Octa-band internal monopole antenna for mobile phone applications, Electron Lett 44 (2008), 1447–1448.

A COMPACT DUAL BAND BRANCH LINE COUPLER WITH ARBITRARY POWER DIVISION RATIO

Kwisoo Kim,[1] Jongsik Lim,[1] Kwangsoo Kim,[2] and Dal Ahn[1]
[1] Department of Electrical Communication Engineering, SoonChunHyang University, Asan, Chungnam, Republic of Korea; Corresponding author: dahnkr@sch.ac.kr
[2] Electrical Engineering Department, Sogang Institute of Advanced Technology, Sogang University, Seoul, Republic of Korea

Received 25 September 2009

ABSTRACT: *This article presents a compact dual-band (DB) branch line coupler (BLC) with different power division ratio at arbitrary two frequency bands. In this article, we add a technique to satisfy transmission lines of conventional BLC with different impedance at two bands, while they are transformed to π-type equivalent circuits. The design equations for DB BLC with different coupling coefficients at two bands are given. Furthermore, folded shape of shunt lines make about 77% circuit dimension comparing to conventional single-band BLC. A DB BLC operating different power division ratio at 0.9 and 2.0 GHz is demonstrated in excellent agreement with both circuit simulation and experimental results.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 1476–1480, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25258

Key words: *branch line coupler (BLC); dual band coupler; π-type equivalent circuit*

1. INTRODUCTION

A dual-band (DB) circuit can be constructed by circuit components which are adjusted to obtain the required behavior of the circuit at two frequency bands. This approach reduces the number of components and the circuit size, which leads to cost reduction of the circuit [1, 2].

In recent year, numerous studies for DB couplers/dividers [2–11] that are operating at arbitrary frequencies with only one circuit have been reported. Nguyen and Caloz proposed DB composite right/left-handed (CRLH) BLC in metal-insulator-metal technology [2]. Cheng and Wong proposed DB BLC with shunt stub lines [3]. You and Zhu implemented DB BLC with patterned ground plane that is referred to as defected ground structure [4]. Kim et al. suggested DB BLC using two center-tapped branches [5]. Throughout these studies runs a common theme, that of the same power division ratios at two bands [2–11].

In contrast to earlier approaches, this article presents a compact DB BLC with arbitrary power division ratios at two arbitrary frequencies. We apply a new technique that produces a transmission line (TL) having a different impedance at two bands, while the TLs of a conventional single-band (SB) BLC are transformed into a π-type equivalent circuit. The findings concerning a range of arbitrary two frequencies and power division ratios are included in this article. The design equations for DB BLC are presented and through measured results validated the proposed design method.

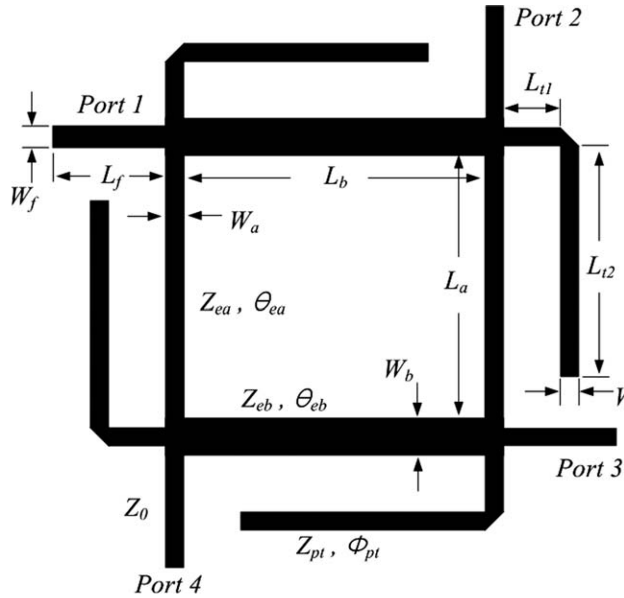

Figure 1 Configuration of the proposed DB BLC

2. THEORY AND DESIGN EQUATIONS

Figure 1 shows the schematic representation of the proposed compact DB BLC with arbitrary power division ratio. The TLs of the coupler are transformed to π-type equivalent circuit which has different impedance value at two bands.

The DB BLC consists of four external feeding TLs whose characteristic impedance is Z_0. The transformed TLs from a conventional SB BLC have impedances of Z_{ea} and Z_{eb} and electrical lengths of θ_{ea} and θ_{eb} length, respectively. The shunt stubs have an impedance and electrical length of Z_{pt} and Φ_{pt}, respectively.

Figure 2(a) shows a TL with line impedance Z_0 and electrical length θ. The line in Figure 2(a) can be transformed to the

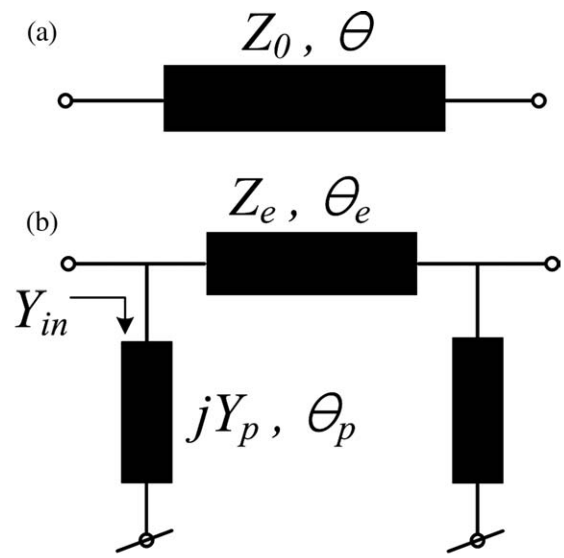

Figure 2 Schematic of (a) a transmission line (TL) and (b) π-type equivalent circuit of the TL