A Compact Internal Planar Antenna with a Capacitive Tuner for 3G and 4G Mobile Phone Application

Cheng-Hung Lin, Kwong-Kau Tiong, Jwo-Shiun Sun, YD Chen and Guan-Yu Chen

***Abstract*—**There have been many antenna designs studied and developed in 3G mobile phone application. Multiband operation has become a basic requirement for internal antennas to be used in the mobile phone for wireless communication system. These papers are evaluated the multiband antenna operation for the application in 3G wireless communication systems. In recent years, a 4G system is in development and expected to supply the better quality of data throughput operation.

In this paper, a high performance planar antenna [1, 2] with a capacitive tuner as the primary radiator for 4G operation is presented. A prototype of the proposed planar antenna with a compact area size of 60mmx13mmx8mm is implemented, and the antenna shows a wide operating bandwidth of about 350MHz and 550MHz for low band and high band respectively, making it easy to cover the LTE700, CDMA850/1900, GSM850/900/1800/1900, and UMTS2100 bands for wireless communication for the 3G/4G systems in a mobile phone application.

The multipath fading is a critical task in the wireless communication systems. In order to solve the problem; we consider the diversity technique in the system [3]. Therefore, a secondary antenna design with the receiver function used in the wireless communication systems is studied. The compact size of the secondary antenna is 60mmx7mmx8mm, and the antenna can generate three resonant modes to cover the CDMA850, CDMA1900, and UMTS2100 MHz for the system applications. The secondary antenna shows the bandwidth of about 210MHz and 360MHz for low band and high band bandwidth respectively.

The study mainly focuses on the current trends in development of compact and low profile multi-media PDA and Smartphone, and provides planar antennas design suitable for application in 3G/4G wireless communicating systems [4, 5]. The proposed antennas are easily fabricated by the flexible planar antenna at low cost and embedded into the mobile phone. A 50 ohms microstrip line is used to excite the planar antenna. The performed data including return loss, antenna gain, current distribution and radiation patterns are presented [6, 7]. The SAR results of the proposed antenna are also analyzed in phantom head and body modes. The antenna design can have the high efficiency and low SAR value. All of the performances tell that the proposed antenna is proper to applied in the wireless communication system.

***Keywords*—**capacitive coupling strip, diversity technique, internal mobile phone antenna, wireless communication system

I. Introduction

THE multiband antenna is demanded for operating in the wireless communication systems. The planar antennas are attractive to apply to mobile phone applications [8, 9]. The coupling between the traces of antenna radiator is helpful for extending the bandwidth. And the planar antenna can be easily integrated on the housing of the mobile phone. Some antenna structures [10, 11] satisfy specified bandwidth specifications for the wireless communication systems such as GSM850 (824-894MHz), GSM900 (880-960MHz), GSM1800 (1710-1880MHz), GSM1900 (1850-1990MHz), CDMA850 (824-894MHz) and CDMA1900 (1850-1990MHz) have been implemented and developed [3,4]. The communication systems have been proceeded very speedily and the UMTS2100 (1920-2170MHz) and LTE700 (746-787MHz) are in development. The mobile terminals are required to have small dimensions and compact size [12, 13], and to meet the miniaturization requirement for satisfying the quality concerns of antenna design [14, 15].

The fading of the multipath propagation is caused by the environments in the wireless communication system. The diversity technique is required to eliminate the fading of the signal to improve the quality and reliability of the data throughout performance [16, 17].

In this proposed design, the primary and secondary antennas are formed by copper and put on the surfaces of a plastic carrier of 60mm×13mm×8mm and 60mm×7mm×8mm separately. The location of primary antenna is on the top area of the mobile phone. The secondary antenna is on the bottom area. Further, the presence of the capacitive tuner of primary antenna leads to have a coupling trace to widen the bandwidth in the lower band. By using a coupling trace, the wide operating bands are achieved to cover LTE700, CDMA850/1900, GSM900/1800/1900 and UMTS2100 operations [18, 19]. The secondary antenna can be applied into the CDMA850/1900 and UMTS2100 MHz for mobile diversity technique applications.

The planar primary and secondary antennas analysis and design in practical smartphone handset size for experiment are implemented [20, 21]. The resonance frequency and input impedance optimized with various parameters are analyzed and evaluated. The designed internal planar antennas on the mobile phone are simulated and measured in far-field antenna anechoic chamber [22, 23]. A result of the bandwidth is referenced -6dB return loss and bandwidth of primary antenna covers 710-1060MHz and 1700-2250MHz, the secondary antenna covers 780-990MHz and 1850-2210MHz respectively. The applications of planar antennas provide 3G and 4G technology. The planar antenna for internal configuration can be designed in various structures shapes to meet mechanical requirements of mobile phone products. The proposed planar antenna has the better acceptable result for antenna applications [24].. The impact such as internal environments, complexity of design, narrow bandwidth and dimensional requirements can be easily solved and integration together. The proposed antenna, therefore, has advantages to meet wider bandwidth requirements [25], easy fabrication, matching tuning and considered the diversity technique to enhance the receiving sensitivity performance.

II. ANTENNA DESIGN

A. Application

In this design, we designed a novel compact internal primary antenna for multi-bands operation covering the LTE700, CDMA850/1900, GSM850/900/1800/1900 and UMTS2100 bands. We presented a planar antenna as Fig.1 suitable for application in a 3G and 4G mobile phone. The Fig.1 shows the geometry of the proposed planar primary antenna with the capacitive tuner and secondary antenna. The primary antenna is located on the top area of the PCB as Fig. 2. The area of the antenna is 60mmx13mm; height is 8mm..

B. Diversity Technique

The internal secondary antenna is designed for multiband operation covering the CDMA850/1900 and UMTS2100 bands. We presented a planar secondary antenna as Fig. 2 suitable for application in a 3G wireless system. The Fig.2 shows the geometry of the proposed planar secondary antenna. The antenna is located on the bottom area of the PCB. The area of the antenna is 60mmx7mm; height is 8mm.

Both antennas are placed on the surface of the plastic carriers which are made of 1mm thick ABS (Acrylonitrile Butadiene Styrene, the relative permittivity 3.0 and conductivity 0.01S/m). The FR4 substrate of the mobile phone is 60mmx110 mm. For broaden the bandwidth to accommodate the multiband requirement, the ground portion under the antenna area is removed. (a 1mm thickness FR4 substrate of 60mmx110mm area). For the experiment, the dimension set for general smartphones phones design is reasonable [9, 10].

C. Antenna Structure

In the primary antenna structure, one end (point F) of the planar antenna is a feed point connected to the 50 ohms microstrip line for testing. Another end (point G) is a grounding point connected to the ground plane of the printed circuit board. The meandering structure of the trace is using for attaining an effective length on the desired resonance frequency. The total length from point F to points A of the planar antenna is about 110 mm which is corresponded to 0.25 wavelength of the 800 MHz; The total length from point F to points B of the planar antenna is about 40 mm which is corresponded to 0.25 wavelength of the 1800 MHz; The total length from point F to points C of the planar antenna is about 35 mm which is corresponded to 0.25 wavelength of the 2100 MHz.

In the secondary antenna structure, one end (point E) of the planar antenna is a feed point. Another end (point N) is a grounding point. The total length from point E to points K of the planar antenna is about 95 mm which is corresponded to 0.25 wavelength of the 800 MHz; The total length from point E to points D of the planar antenna is about 40 mm which is corresponded to 0.25 wavelength of the 1900 MHz.

Fig. 1 geometry of the proposed primary and secondary antennas

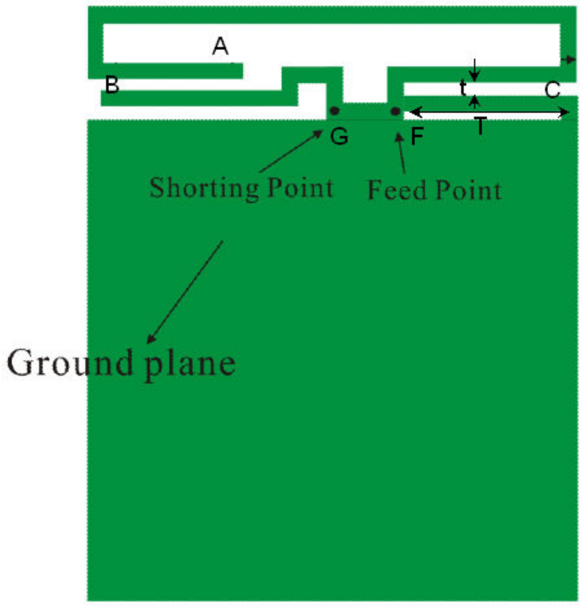


Fig. 2 geometry of the proposed primary antenna with the capacitive tuner

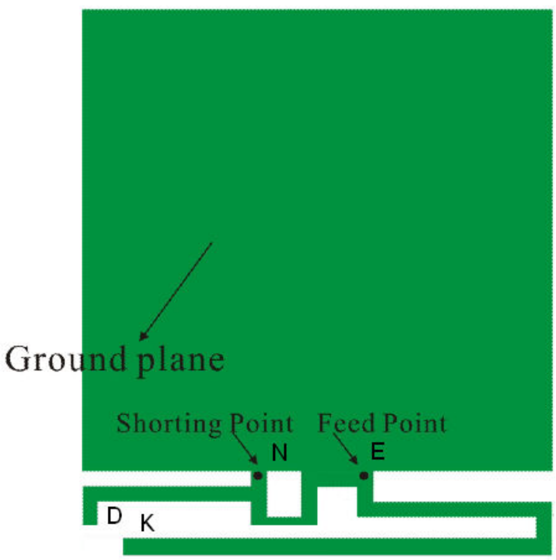


Fig. 3 geometry of the proposed secondary antenna

III. Evaluation

A. Return Loss

The proposed primary antenna was fabricated and measured. The Fig. 4 shows the measured and simulated return loss of the practical prototype. The primary antenna has a wide bandwidth of 350 MHz ranging from 710 to 1060 MHz (3:1 VSWR or 6-dB return loss). The bandwidth can be easily to cover LTE700, CDMA 850 and GSM850/900 operation. The high band bandwidth 550MHz from 1700 to 2250MHz, and it is easily covers CDMA1900, GSM1800/1900 and UMTS2100 operation.

The simulated results are evaluated by using Ansoft HFSS [26]. From the experiments, there is a good agreement between the measurement and simulation.

The strip of the capacitive tuner is easily controlled by adjusting the dimensions of two parameters, T and t. The width of the strip is preferred 2 mm. By varying T and t, the coupling between the strip sections will be varied and capable of tuning resonant frequencies of the excited resonant modes. To perform the effects of the capacitive coupled strip, a comparison of the return loss for the proposed antenna is shown in Fig. 5. When adding the tuning strip, the impedance matching at adjacent frequencies between the two resonant modes is improved. It can cover the LTE700, CDMA850 and GSM850/900 bands. The improvement of the width T and gap t of the coupling strip are studied. The return loss of tuning the length T from 8 to 12 mm is shown in Fig. 7; the gap t from 0.5 to 1.5 mm is in Fig.8. The results present that the length T= 10mm and t=0.5mm can have a good match for the antenna performance.

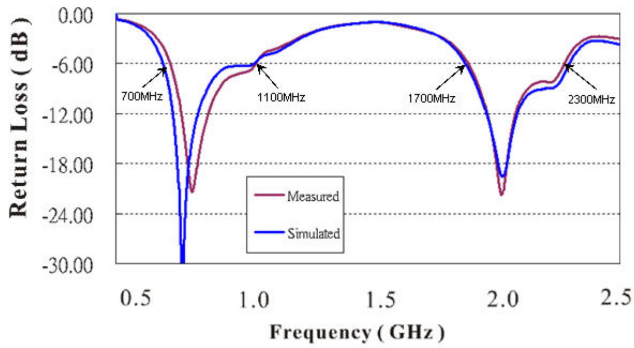


Fig. 4 measured and simulated return loss of the proposed primary antenna.

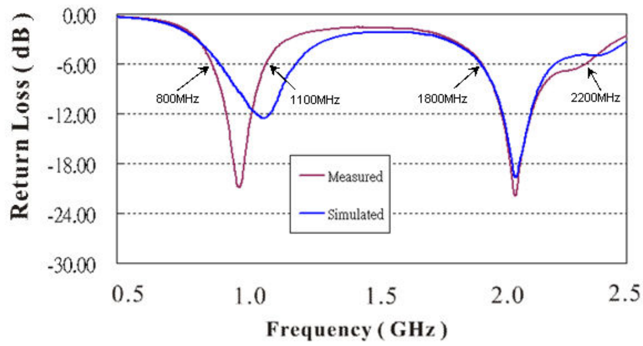


Fig. 5 measured and simulated return loss of the secondary antenna.

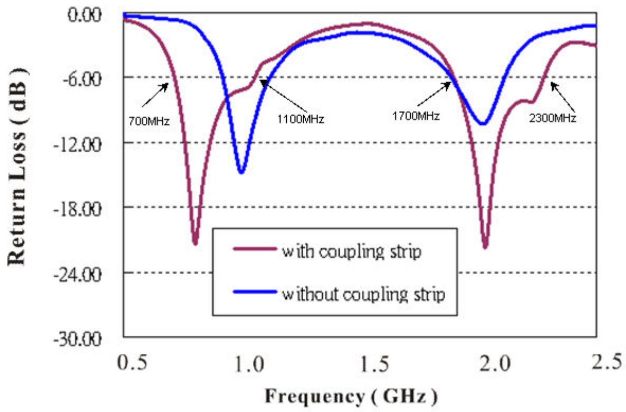


Fig. 6 measured return loss of the primary antenna with the coupling strip.

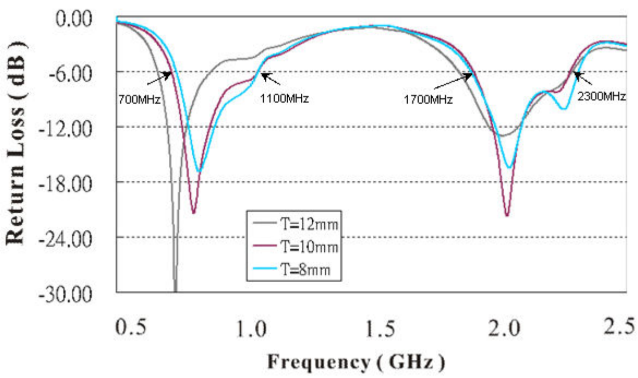


Fig. 7 measured return loss of the primary antenna by tuning T

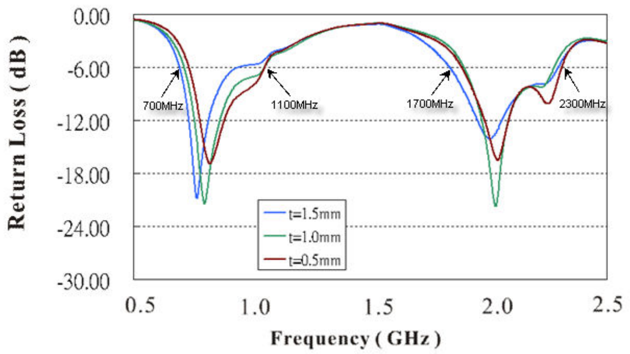


Fig. 7 measured return loss of the primary antenna by tuning t

B. Gain and Efficiency

The measured antenna gain and radiation efficiency are shown in Table 1. The antenna gain in the low band for LTE, CDMA850 and GSM850/900 is about 2.1dBi, and the efficiency is about 60%; in the high band for CDMA1900, GSM1800/1900 and UMTS2100 is about 1.8dBi and the efficiency is about 45%. The Fig. 5 shows the measured and simulated return loss of the secondary antenna prototype. The secondary antenna has a bandwidth of 210 MHz (780 to 990 MHz). The bandwidth can be easily to cover CDMA850 operation. The high band bandwidth of 360 MHz(1850 to 2210MHz), and is easily covers CDMA1900 and UMTS2100 operation.

The measured peak gain data as shown in Table 2. The antenna gain in the CDMA850 band is about 1.5dBi, and the efficiency is about 52%; In the CDMA1900 and WCDMA2100 band is about 1.6 dBi and the efficiency is about 45%.

Table 1 measured antenna gain of the primary antenna

Frequency (MHz)	700	750	850	950	1000
Gain (dBi)	1.9	2.1	2.3	2.1	2.2
Efficiency (%)	55	58	62	57	57
Frequency (MHz)	1700	1800	1950	2100	2200
Gain (dBi)	1.3	2.2	2.3	1.8	1.5
Efficiency (%)	43	47	49	45	44

Table 2 measured antenna gain of the secondary antenna

Frequency (MHz)	800	850	900	1850	2200
Gain (dBi)	1.9	2.1	2.1	2.3	2.2
Efficiency (%)	53	57	56	58	57

The efficiency difference between primary antenna and secondary antenna is an important parameter for diversity technique applications as (1).

$$\Delta G = 10 \cdot \left[\log(G_1) - \log(G_2)\right] \qquad (1)$$

Blanch, S., Romeu, J., Corbella, I. [27] describe a formula to calculate the envelope correlation of the primary and secondary antennas from its S-parameter description as (2).

$$\rho_e = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{\left(1 - (|S_{11}|^2 + |S_{21}|^2)\right)\left(1 - (|S_{22}|^2 + |S_{12}|^2)\right)} \qquad (2)$$

The calculated parameter of the primary and secondary antennas is listed in Table3.

Table 3 calculated parameters of primary and secondary antennas

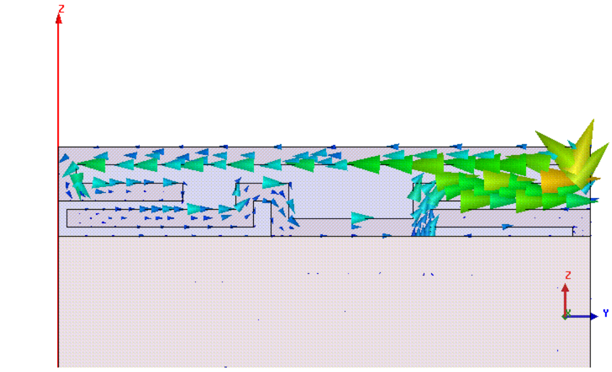
Frequency (MHz)	850	1900	2100
Envelope Correlation Coeficiency -Measured	0.32	0.29	0.24
Envelope Correlation Coeficiency -Simulated	0.21	0.15	0.13

C. Current Distribution

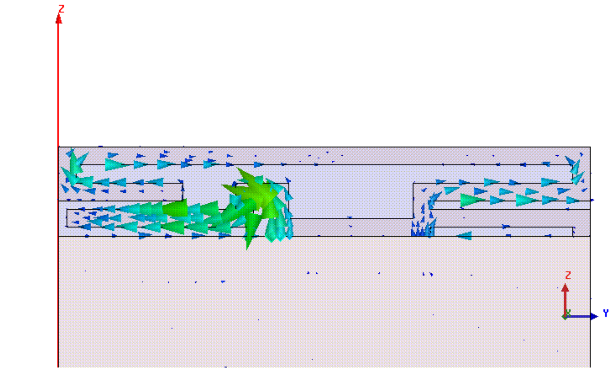
The vector current distributions excited on the surface of the primary antennas in the 850, 1900, and 2100 MHz are presented in Fig. 8(a), (b) and (c). The vector current distributions of the secondary antennas in the 850, 1900 and 2100 MHz are presented in Fig. 9(a), (b) and (c).

In the primary antenna, the current from point F to points A is corresponded to 800 MHz; the current from point F to points B of the planar antenna is corresponded to the 1800 MHz; the current from point F to points C is corresponded the 2100 MHz.

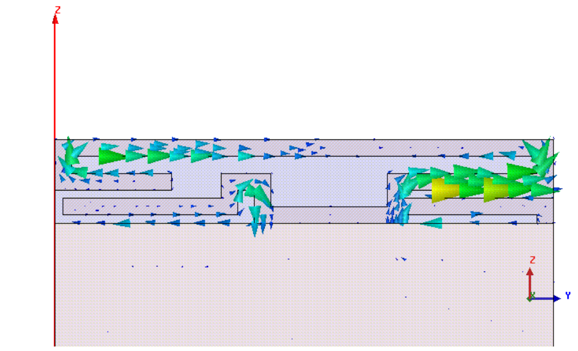
In the secondary antenna, the current from point E to points D is corresponded to 850 MHz; the current from point E to points P of the planar antenna is corresponded to the 1800 MHz; the current from point E to points R is corresponded the 2100 MHz.



(a)

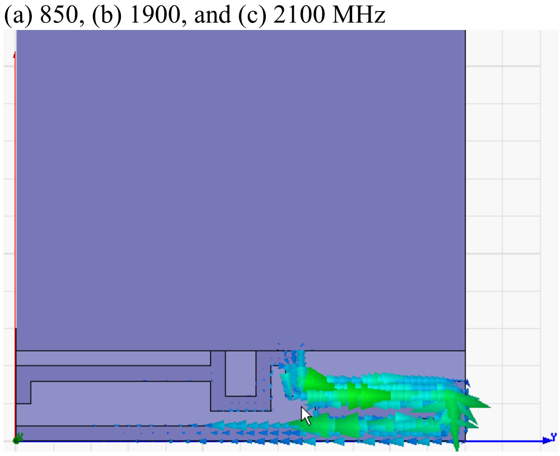


(b)

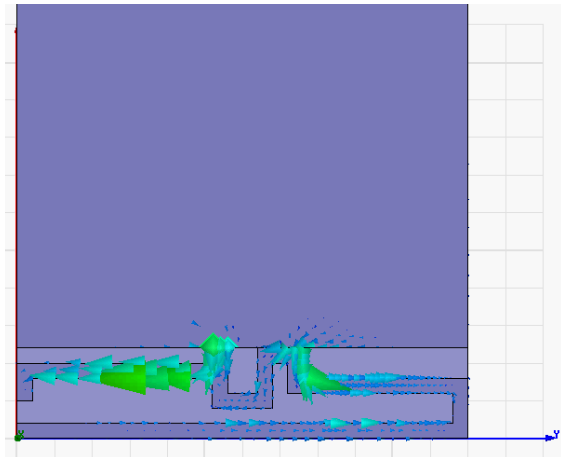


(c)

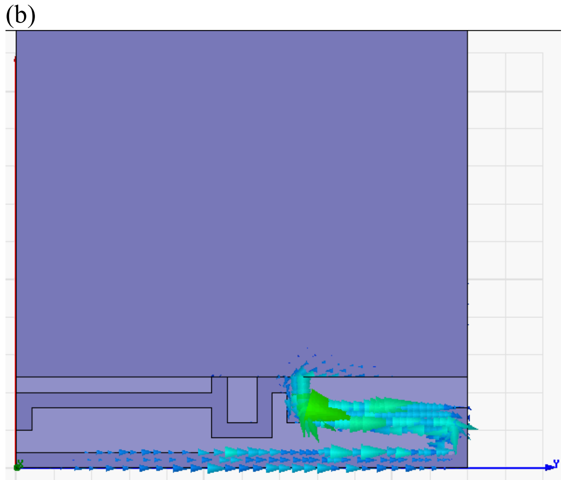
Fig. 8 the vector current distributions of the primary antenna in (a) 850, (b) 1900, and (c) 2100 MHz



(a)



(b)



(c)

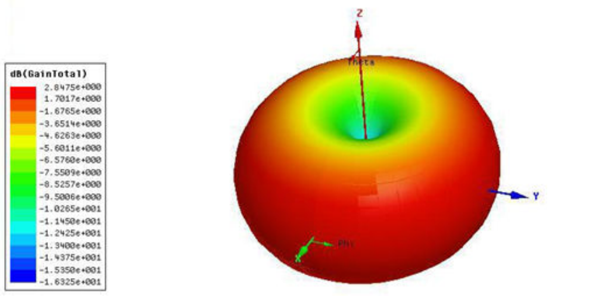
Fig.9 the vector current distributions of the secondary antenna in (a) 850, (b) 1900, and (c) 2100 MHz

D. Radiation Pattern

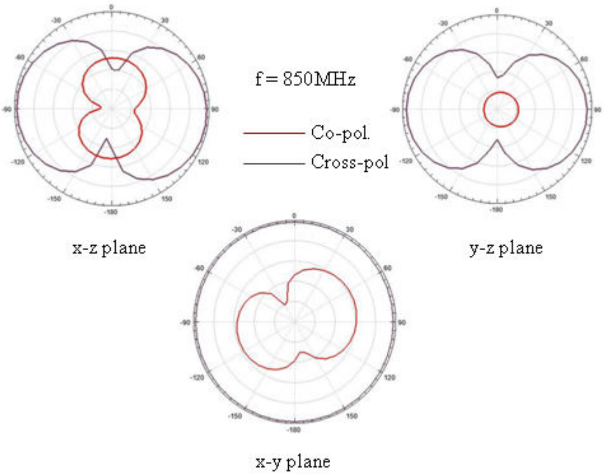
The radiation patterns of primary and secondary antennas are also studied [13, 14]. The measured three dimensions radiation pattern of primary antenna in 850 MHz is shown in Fig. 10(a). The two dimensions radiation pattern is in Fig. 10(b). The measured three dimensions radiation pattern of primary antenna in 1900 MHz is shown in Fig. 11(a). The two dimensions radiation pattern is in Fig. 11(b). The measured three dimensions radiation pattern of primary antenna in 2100MHz is shown in Fig. 12 (a). The two dimensions radiation pattern is in Fig. 12 (b).

The measured three dimensions radiation pattern of secondary antenna in 850 MHz is shown in Fig. 13(a). The two dimensions radiation pattern is in Fig. 13(b). The measured three dimensions radiation pattern of secondary antenna in 1900 MHz is shown in Fig. 14(a). The two dimensions radiation pattern is in Fig. 14(b). The measured three dimensions radiation pattern of secondary antenna in 2100 MHz is shown in Fig. 15(a). The two dimensions radiation pattern is in Fig. 15(b).

The monopole-like radiation pattern in 850 MHz are shown omni-directional radiation in the azimuthal plane (x–y plane) in Fig. 10(b) and 13(b) which indicates that stable radiation performances are obtained in the lower band. The radiation patterns are observed more variations and nulls in the azimuthal plane (x–y plane) in Fig. 11(b), Fig. 12(b), Fig. 14(b) and 15(b), due to the antenna is not symmetric to the center of the system grounding plane.

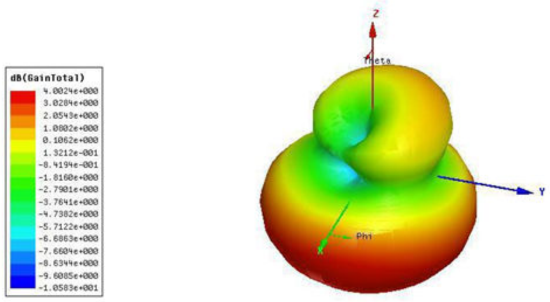


(a)

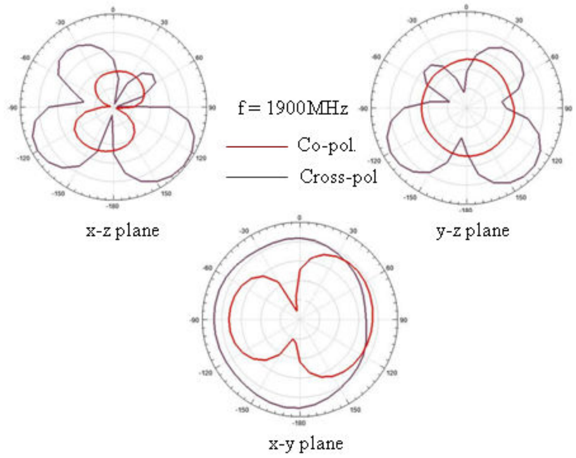


(b)

Fig. 10(a) measured radiation pattern of primary antenna in 850MHz in three dimensions. (b) two dimensions

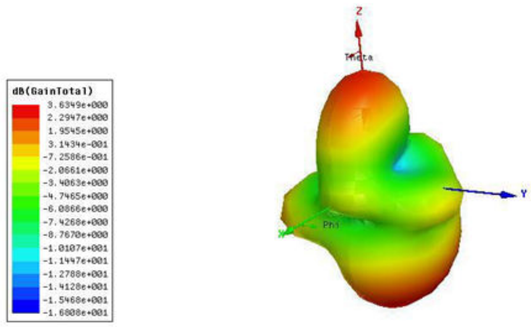


(a)

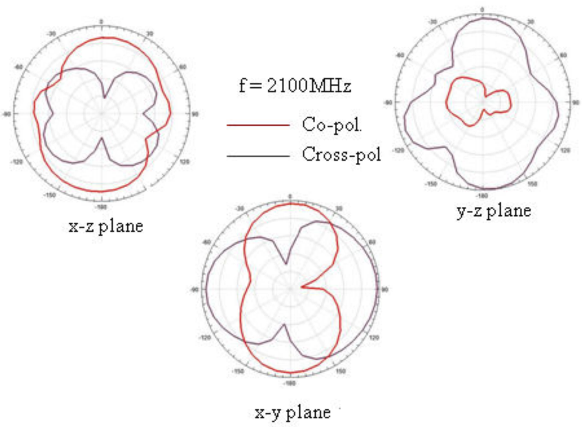


(b)

Fig. 11(a) measured radiation pattern of primary antenna in 1900MHz in three dimensions. (b) two dimensions

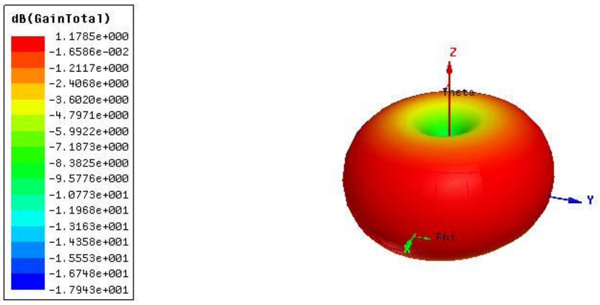


(a)

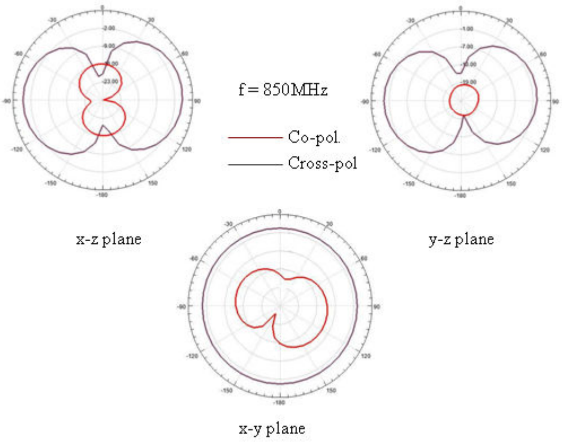


(b)

Fig. 12(a) measured radiation pattern of primary antenna in 2100MHz in three dimensions. (b) two dimensions

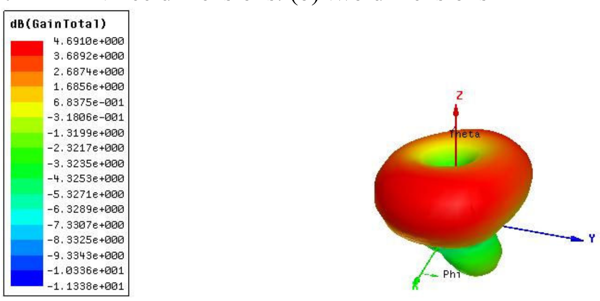


(a)

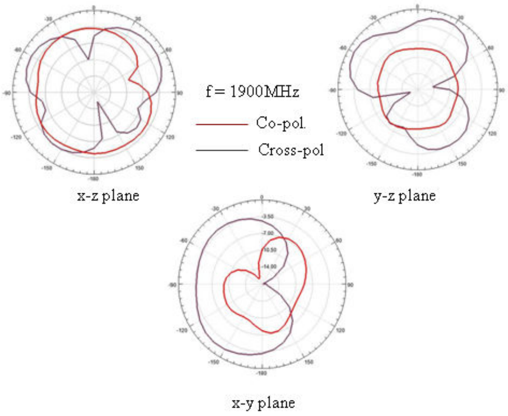


(b)

Fig. 13(a) measured radiation pattern of secondary antenna in 850MHz in three dimensions. (b) two dimensions

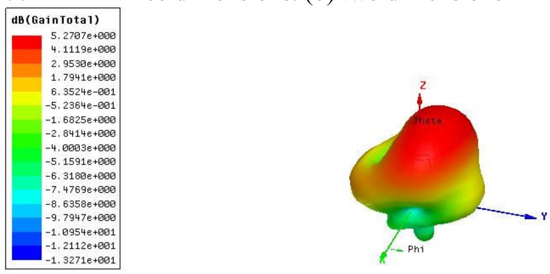


(a)

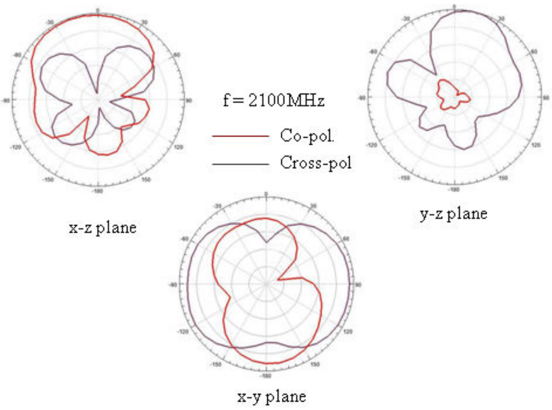


(b)

Fig. 14(a) measured radiation pattern of secondary antenna in 1900MHz in three dimensions. (b) two dimensions



(a)



(b)

Fig. 15(a) measured radiation pattern of secondary antenna in 850MHz in three dimensions. (b) two dimensions

E. Radiation Pattern

The SAR results of the proposed antenna are also analyzed. The measured SAR of 800, 900, 1800, 1900 and 2100 MHz in 1-g in phantom head and body modes are listed in Table 4. The SAR results are tested using 23 dBm (2W continuous power) . The circuit board is spaced 3 mm far away to the phantom ear for considering the thickness of the mobile phone housing in phantom head mode and added 15mm more for considering the thickness of the case in phantom body mode. The SAR results can meet the limit of 1.6 W/kg for the 1-g [26].

The RSS value of the field components gives the total field strength (Hermitian magnitude) as (3).

$$E_{tot} = \sqrt{E_x^2 + E_y^2 + E_z^2} \quad (3)$$

The SAR measurement is the local specific absorption rate in mW/g. E_{tot} is the total field strength in V/m. σ is the conductivity in mho/m. ρ is the equivalent tissue density in g/cm3.

$$SAR = E_{tot}^2 \cdot \frac{\sigma}{\rho \cdot 1'000} \quad (4)$$

Table 4 measured SAR values of primary antenna

Frequency (MHz)	800	900	1800	1900	2100
Transmit Power (dBm)	23	23	23	23	23
SAR (mW/g) -Phantom Head	0.43	0.62	1.07	1.15	1.24
SAR (mW/g) -Phantom Body	0.27	0.31	0.65	0.74	0.78

IV. CONCLUSION

A novel multiband planar antenna with a capacitive tuner has been proposed for mobile phone applications. These resonant modes are formed into two wide operating bands for the low and high bands to cover LTE700, CDMA850/1900, GSM850/900/1800/1900 and UMTS2100 operations. The large bandwidth of the proposed antenna makes it very suitable for 3G and 4G mobile phone applications. The primary antenna is placed on the top area of the mobile phone and the dimension is 60mmx13mmx8mm; the secondary antenna is on the bottom area and the dimension is 60mmx7mmx8mm. The evaluation of the antennas shows the high efficiency and low SAR value. The small dimension and good performance make the proposed antenna very suitable for 3G/4G mobile phone applications.

ACKNOWLEDGMENT

The authors acknowledge the Antenna and EMC Department of HTC, Taiwan, for sport the wireless technique and measurement environment.

REFERENCES

[1] Wong, K.L, Planar antennas for wireless communication, John Wiley & Sons, Inc, 2003
[2] D. Kraus and R.J. Marhefka, Antennas for all applications, McGraw-Hill, 2002
[3] G.Y. Chen, J.S. Sun, and YD Chen, "The 3D Far-Field Antenna Measurement Technology for Radiation Efficiency, Mean Effective Gain and Diversity Antenna Operation," *2006 The 7th International Symposium on Antennas, Propagation, and EM Theory (2006 ISAPE)*, Guilin, China, Oct. 2006, pp.42-45
[4] S.Y. Huang, J.S. Sun, "Multi-band antenna applications in mobile phone," *Microwave & Optical Technology Letters*, Vol. 49, Oct. 2007, pp.2498-2501
[5] H.W. Hsieh, Y.C. Lee, K.K. Tiong, and J.S. Sun, "Design of a multi-band antenna for mobile handset operations," *IEEE Antennas and Wireless Propagation Letters*, Vol. 8, 2009, pp.200-203.
[6] Hala Elsadek and Dalia. M. Nashaat, "Novel broadband Antenna Configuration for Wireless Communications Applications," *Proceedings of the 11th WSEAS International Conference on COMMUNICATIONS*, Heraklion, Agios Nikolaos, Crete Island, Greece, July 26-28, 2007
[7] S.Y. Huang, J.S. Sun, "Small antennas application in portable phones," *Microwave & Optical Technology Letters*, Vol. 50, No 12, October 13, 2008, pp. 3020-3023
[8] Yashar Zehforoosh, Changiz Ghobadi, and Javad Nourinia, "A Novel Multilayer Microstrip Antenna for Ultra Wideband Applications," *Proceedings of the 5th WSEAS International Conference on Telecommunications and Informatics*, Istanbul, Turkey, May 27-29, 2006 (pp239-242)
[9] I-T Tang, D.-B. Lin, W.-L. Chen, and J.-H. Horng, "Miniaturized hexaband meandered PIFA antenna using three meandered-shaped slits," *Microwave and Optical Technology Letter*, Vol. 50, No. 4, pp. 1022-1025, Apr. 2008.
[10] S.Y. Sun, S.Y. Hung, and J.S. Sun, "A Printed Multi-Band Antenna for Cell-Phones Applications", *Microwave and Optical Technology Letters*, Vol. 51, Issue 3, March 2009, pp. 742-744.
[11] C.A. Balanis, Antenna Theory, John Wiley & Sons, Inc., 2005
[12] J.D. Kraus, Antennas, McGraw-Hill Book Co., New York, 1965
[13] K.L. Wong and C.H. Huang, "Bandwidth-enhanced PIFA with a coupling feed for quad-band operation in the mobile phone," *Microwave Opt Technol Lett* 50 (2008), 683–687.
[14] W.Y. Li and K.L. Wong, "Surface-mount loop antenna for AMPS/GSM/DCS/ PCS operation in the PDA phone," *Microwave Opt TechnolLett* 49 (2007), 2250–2254.
[15] K.L. Wong and C.I. Lin, "Internal GSM/DCS antenna backed by a step-shaped ground plane for a PDA phone," *IEEE Trans Antennas Propagation* 54 (2006), 2408–2410.
[16] Y.S. Liu, J.S. Sun, R.H. Lu, Y.J. Lee, "New Multiband Printed Meander Antenna for Applications," *Microwave & Optical Technology Letters*, Vol. 47, No.6, Dec. 2005, pp.539-543.
[17] 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.
[18] J.-S. Chen, W.-C. Chiang, N.-C. Wang and Yung-Fa Huang, 2008, "Adaptive Load Balance and Handoff Management Strategy for Adaptive Antenna Array Wireless Networks," *Proc. of the 12th WSEAS International Conference on Communications*, pp. 213-218, July 23-25, 2008.
[19] J.-S. Chen, K.-Y. Li, and N.-C. Wang, "A Minimal Standard Deviation Overlapped Area Allocation Strategy For Adaptive Antenna Array Wireless Networks," *Proceedings of the 12th WSEAS International Conference on Systems (ICS 2008)*, Heraklion, Crete Island, Greece, pp. 310-137, July 22-24, 2008.
[20] C.R. Rowell and R.D. Murch, "A compact PIFA suitable for dual frequency 900/1800-MHz operation," *IEEE Trans Antennas Propagation* 46 (1998), 596–598.
[21] D.-B. Lin, I.-T. Tang, and Y.-Y. Chang, "Flower-Like Cpw-Fed Monopole Antenna For Quad-Band Operation of Mobile Handsets," *Journal of Electromagnetic Waves and Applications*, volume 23, no. 17/18, page 2271-2278, 2009.
[22] S.Y. Huang, S.Y. Chen, and J.S. Sun, "Study on Antenna Radiation Characteristics Affected by Specific Anthropomorphic Mannequin," *WSEAS Transactions on Communications*, Issue 11, Vol. 4, November 2005, pp. 1203-1214. (ISSN 1109-2742)-----EI
[23] G.Y. Chen, J.S. Sun, S.Y. Huang, YD Chen, C.H. Lin, and J.Y. Yang, "Mobile Handset Measurement for Wireless System Networking," 2006 *China-Japan Joint Microwave Conference* (2006 CJMW), Chengdu, China, Aug. 2006, pp. 698-701
[24] R. Borowiec and P.M. Slobodzian, "A miniaturized antenna for 2G/3G frequency-band application," *Microwave Opt Technol Lett* 48 (2006), 399–402.
[25] J.D. Kraus, Electromagnetics, McGraw-Hill Book Co., New York, 1965
[26] http://www.ansoft.com/products/hf/hfss/, Ansoft Corporation HFSS.
[27] Blanch, S., Romeu, J., Corbella, I. "Exact representation of antenna system diversity performance from input parameter description," *Electronics Letters*. 39(9) 705-707, 2003.

Cheng-Hung Lin was born in Taipei, Taiwan. He received his M.S. degree in Electrical Engineering Department of National Taiwan Ocean University in 2002. He is currently pursuing his Ph.D. at the National Taiwan Ocean

University.He has joined the antenna and system integration department in HTC company since 2002 and designed the HTC internal CDMA and multiband antennas with low SAR and high efficiency in 2004. His research interests include antenna effect on the human body (SAR and HAC), Performance evaluation methods and novel designs of antennas for mobile handsets applications.