A Novel Compact CPW-fed Antenna with Multi-resonance Mode

Hyo-Sub Choi, Jae-Jin Ko and Chul-Dong Lee, *Member, KIMICS*

***Abstract*— A multi-resonance antenna for wireless communications is reported. By using double inverted-L strips, the antenna demonstrated compact size (15 mm × 14 mm) including the ground, multi-band operation for IEEE 802.11 a/b/g/p applications, and wide bandwidth of 1.7 GHz at 5 GHz band. Good radiation features of omni-directional patterns and 1.98 and 2.29 dBi peak antenna gains for the lower and upper bands, respectively, have been achieved.**

***Index Terms*— Compact Antenna, Multi-resonance Antenna, Wireless Communication, CPW-fed**

I. INTRODUCTION

Wireless communications have progressed very rapidly in recent years, and many mobile devices are becoming smaller and smaller. To meet the miniaturization requirement, the antennas employed in mobile terminals must have their dimensions reduced accordingly [1]. Also, antennas for wireless communication system need satisfy the requirements of multiple communication systems as growing consumer demand for multifunctional mobile handsets. In order to meet such requirement, multi-resonance antennas are attractive because they eliminate the need of separate antennas by allowing operations at multiple frequency bands [2].

Coplanar waveguide(CPW)-fed antennas have been investigated for wireless communication applications because of their advantages such as wide band characteristics, dual- or multi-band operation, simple structures with only one metal layer, and easy integration on the circuit board along with integrated circuit components. However, CPW-fed antennas reported in the literatures so far exhibited insufficient bandwidth at 5 GHz band [3-4] or suffered from large size although they satisfied bandwidth requirements of WLAN [5-6].

In this paper, CPW-fed monopole antenna with double inverted-L strips was designed for dual-band WLAN applications. The fabricated antenna has an ultra-compact size (15 mm × 14 mm) that includes the size of ground planes. The measured characteristics exhibited wide bandwidths in both 2 and 5 GHz bands. Especially in 5 GHz band, the antenna demonstrated ultra-wide bandwidth covering from 4.76 to 6.48 GHz. Details of antenna design are described, and the simulated and measured antenna characteristics are compared and discussed.

II. ANTENNA STRUCTURE

The structure of the designed multi-resonance antenna is shown in Fig. 1. A CPW feed and double inverted-L strips were fabricated on an 1.6-mm-thick FR4 substrate that has relative permittivity (ε_r) of 4.4. A 50-Ω CPW transmission line has a 4-mm-wide signal strip and 0.4-mm-wide gaps between the signal strip and the coplanar ground planes. Two identical ground planes have finite size of 5.1 mm × 5 mm. The main radiation elements are double inverted-L strips. The long meandered inverted-L strip was designed to resonate in 2 GHz band (the first resonance mode) and 5 GHz band (the second resonance mode). The short inverted-L strip was also designed to resonate in the upper part of 5 GHz band (the third resonance mode).

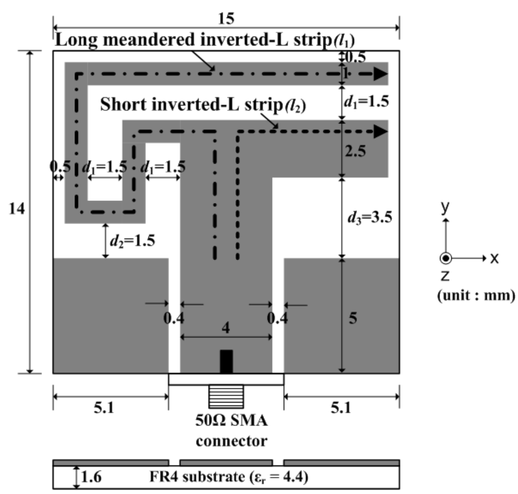

Fig. 1. Geometry of the designed antenna with multi-resonance mode.

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Hyo-Sub Choi is with the SoC platform R&D center, Korea Electronics Technology Institute, Seong-Nam, 463-816, Korea (Email: hschoi@keti.re.kr)

III. EFFECTS OF THE DESIGN PARAMETERS

The lengths of long meandered inverted-L strip and short stub (l_1 and l_2) and the spacing between the lines (d_2 and d_3) were used as design parameters to achieve wide band characteristics as well as dual-band resonance characteristics.

Fig. 2 shows the results of return loss for the designed antenna in a different long inverted-L strip (l_1). We observed the variation of resonant frequency in different l_1 ranging from 29 mm to 35 mm. As shown in Fig. 2, as l_1 increases, both the first resonance mode and the second resonance mode decrease due to extending electrical length. The optimum value of long meandered inverted-L strip (l_1) is 35 mm long, which is a little bit longer than the quarter wavelength (30.49 mm) at the first resonant mode (2.46 GHz) because of current cancellation of meandering. Therefore, l_1 is a dominant parameter for determining the first and second resonance modes.

In succession the results of return loss for the designed antenna in a different short inverted-L strip (l_2) are indicated in Fig. 3. We observed the variation of resonant frequency in different l_2 ranging from 9.5 mm to 12.5 mm. As shown in Fig. 3, when l_2 was 12.5 mm long, the third resonance mode occurred at 5.99 GHz and the widest bandwidth was achieved at 5 GHz bands. Hence, l_2 is a dominant parameter for determining the third resonance mode.

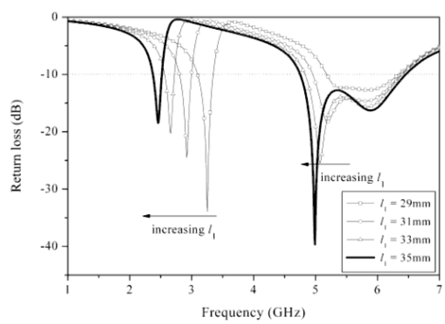


Fig. 2. Design parameter (l_1) sweep.

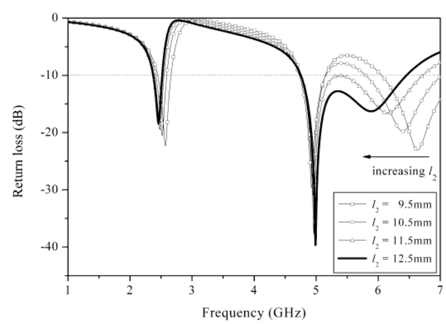


Fig. 3. Design parameter (l_2) sweep.

Fig. 4 shows the results of return loss for the designed antenna in different spacing between the long inverted-L strip and ground plane in left side ($d2$). We observed the variation of resonant frequency in different d_2 ranging from 0.5 mm to 2.0 mm. As shown in Fig. 4, as d_2 decreases, impedance is not matched at the second resonance mode (4.99GHz). When d_2 was 1.5 mm long, good impedance matching was obtained.

On the other hand, the results of return loss for the designed antenna in different spacing between the short inverted-L strip and ground plane in right side (d_3) are shown in Fig 5. We observed the variation of resonant frequency in different d3 ranging from 1.5 mm to 4.0 mm. As shown in Fig 5, as d_3 decreases, impedance is not matched at the third resonance mode (5.99 GHz). When d_3 was 3.5 mm long, good impedance matching was obtained.

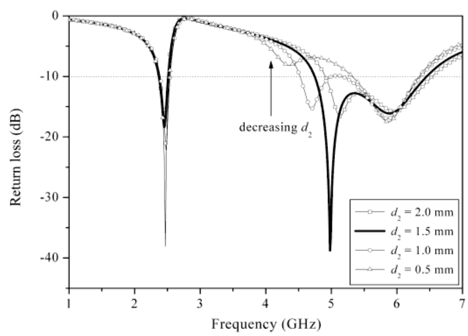


Fig. 4. Design parameter (d_2) sweep.

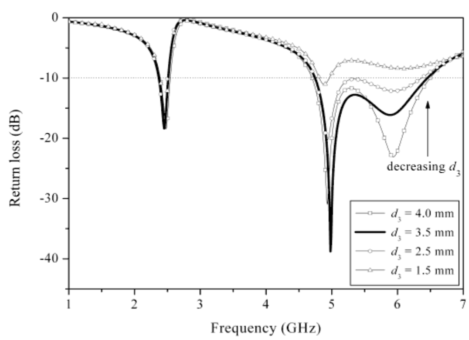


Fig. 5. Design parameter (d_3) sweep.

IV. RESULTS OF THE PROPOSED ANTENNA

A compact antenna with multi-resonance shown in Fig. 6 was fabricated and its performance was measured. Two additional antennas were also fabricated and characterized to study operating mechanism of the dual-band antenna. They have either of the long meandered or the short inverted-L strip whose dimensions are the same as the corresponding inverted strips in the dual-band antenna. Fig. 6 illustrates the frequency responses of the three antennas. The frequency responses (i) and (ii) are simulated and measured return losses of the dual-band antenna, respectively. Simulations were carried out by utilizing an Ansoft's HFSS and measurements were conducted with an Agilent 8510C network analyzer Good agreement was observed between the simulated and measured frequency responses. The resonances at 2.44 and 5.06 GHz are from the long meandered inverted-L strip and the resonance at 6.04 GHz is from the short inverted-L strip. They could be verified from the measured frequency responses (iii) and (iv) in figure 6. In the 2 GHz band, -10 dB impedance bandwidth was measured to be 0.17 GHz (2.36~2.53 GHz) corresponding to 7.0 % of the center frequency of 2.44 GHz. It satisfies the bandwidth requirement of IEEE 802.11 b/g. In the 5 GHz band, -10 dB impedance bandwidth was measured to be 1.7 GHz (4.78~6.48 GHz) corresponding to 30.2 % of the center frequency of 5.63 GHz. It offers sufficient bandwidth for IEEE 802.11 a/p.

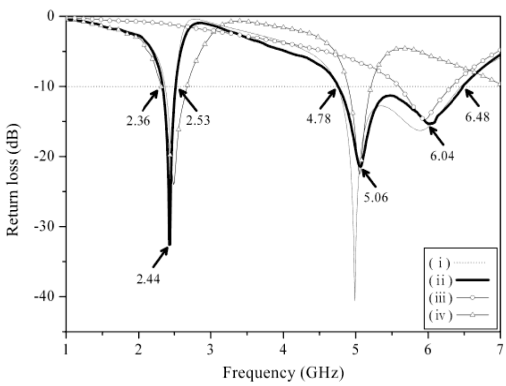
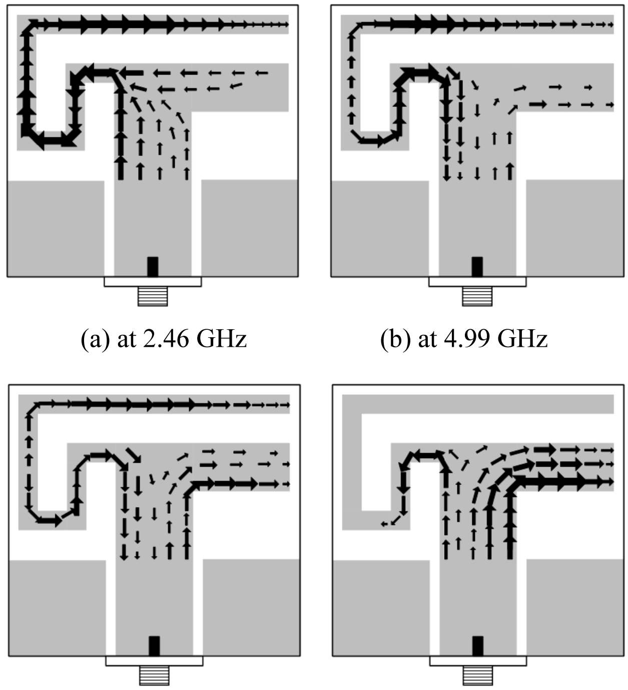


Fig. 6. Frequency responses for measured and simulated return losses : (i) simulated results for the dual-band antenna, (ii), measured results for the dual-band antenna, (iii) measured results for the antenna with long meandered inverted-L strip only, and (iv) measured results for the antenna with short inverted-L strip only.

High density of surface current was observed on the long inverted-L strip at 2 and 5 GHz. The surface current at 6 GHz was mostly concentrated on the short inverted-L strip. On the other hand, uniform current distribution was observed on both the long and short strips at 5.5 GHz, which verifies how radiation takes place from both the strips. The current distribution shows how the two strips are interacting to achieve double resonance and wide bandwidth at 5 GHz band.

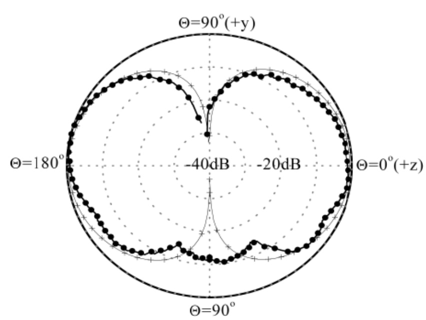


(a) at 2.46 GHz (b) at 4.99 GHz

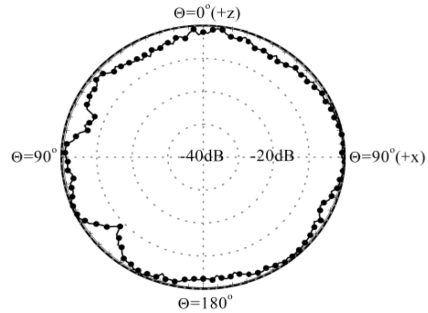
(c) at 5.50 GHz (d) at 6.00 GHz

Fig. 7. Surface current distributions at 2.45 (a), 5.00 (b), 5.50 (c), and 6.00 GHz (d).

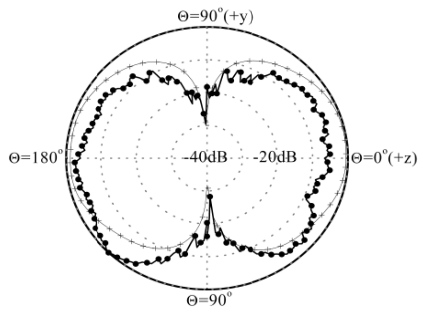
The measured and simulated radiation patterns of the dual-band antenna at 2.44 GHz and 5.63 GHz are plotted in Fig. 8. The omni-directional radiation characteristics are similar to those of the y-directed dipole antenna as expected by the simulation study. The gain of dual-band antenna was measured and plotted as a function of frequency in Fig. 9. The peak antenna gains are 1.98 and 2.29 dBi for the lower and upper bands, respectively. The gain variations throughout the -10 dB impedance bandwidth are 0.78 and 0.87 dBi for the lower and upper bands, respectively.



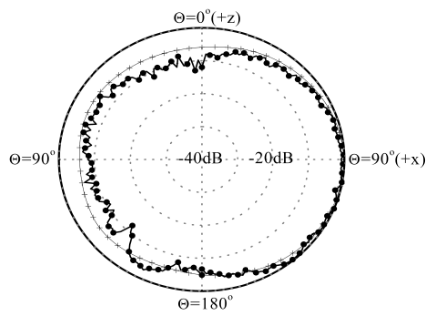
<a : y-z plane>



<a : x-z plane>

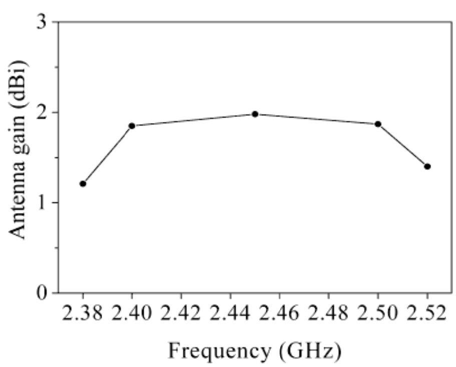


<b : y-z plane>

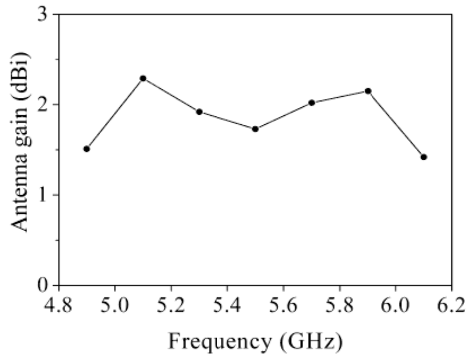


<b : x-z plane>

Fig. 8. Measured (─●─) and simulated (─+─) radiation patterns at 2.44 (a) and 5.63 GHz (b).



(a)



(b)

Fig. 9. Measured antenna gain at lower band (a) and upper band (b).

V. VERIFICATIONS OF THE PROPOSED ANTENNA

The designed antenna can be applied for WLAN applications specified in IEEE standards 802.11 b/g (2.400~2.484 GHz) and 802.11a (5.150~5.850 GHz). To verify operation of the antenna, working distances were measured in terms of current signal strength, current signal quality, and signal to noise ratio. Fig. 10 shows a setup for working distance measurement. Basically, the wireless communication distance was measured between WLAN router made in ALTech company and laptop computer with a WLAN card used in IEEE standards 802.11 b/g (2.4000~2.484 GHz). The antenna initially used for the measurements was a 4.5 dBi dipole antenna (reference antenna). For comparison between antennas, we converted the reference antenna into the designed antenna. Various performances, such as current signal strength, current signal quality, and signal to noise ratio, in terms of working distance are quantitatively plotted in Fig. 11. From the results, it is noted that although performances of the designed antenna are slightly lower than those of the reference antenna, the designed antenna satisfies specifications of 802.11 b/g standards. Therefore, the designed antenna is compatible with commercial WLAN router.

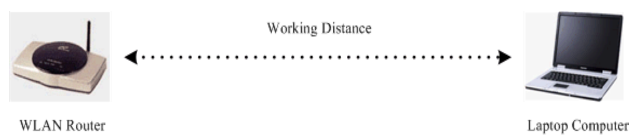


Fig. 10. Setup for working distance measurement.

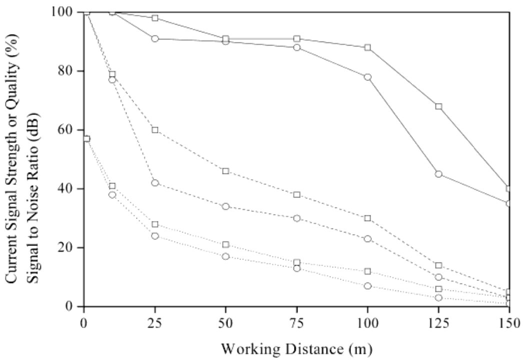


Fig. 11. Measurement of working distance.
(i) —□— Current Signal Strength in terms of the reference antenna [%]
(ii) —○— Current Signal Strength in terms of the designed antenna [%]
(iii) ---□--- Current Signal Quality in terms of the reference antenna [%]
(iv) ---○--- Current Signal Quality in terms of the designed antenna [%]
(v) ·····□····· Signal to Noise Ratio in terms of the reference antenna [dB]
(vi) ·····○····· Signal to Noise Ratio in terms of the designed antenna [dB]

VI. CONCLUSIONS

A multi-band compact antenna was designed and characterized. By incorporating double inverted-L strips, compact size (15 mm × 14 mm) dual-band operation for WLAN operation, and very wide bandwidth of 1.7 GHz at 5 GHz band were achieved. The parametric studies of the designed antenna have been investigated. It was observed that the lengths of long meandered inverted-L strip and short stub (l_1 and l_2) and the spacing between the lines (d_2 and d_3) were used as design parameters to affect wide band characteristics and dual-band resonance characteristics. The antenna exhibited omni-directional radiation patterns and small gain deviation less than 0.9 dBi. In addition, the operation of the designed antenna for WLAN applications was verified through the measurement of communication distance. The antenna is compatible with all of IEEE 802.11 a/b/g/p standards.

ACKNOWLEDGMENT

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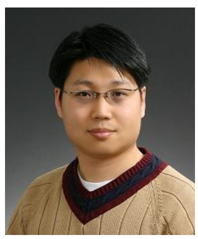
Hyo-Sub Choi received the B.S. degree in the Dept. of Electronics Engineering from Kwangwoon University, Seoul, Korea, in 2004, and the M.S degree in the Dept. of Information Communications Engineering from Gwangju Institute Science and Technology (GIST), Gwangju, Korea, in 2006. From 2006 to 2009, he was a Researcher with the Samsung Electronics R&D Institute. He is currently working in Korea Electronics Technology Institute (KETI). His research interests include antenna design and in-vehicle network system.



Jae-Jin Ko received the B.S. and M.S degrees in the Dept. of Computer Engineering from Kwangwoon University, Seoul, Korea, in 1997 and 2000, respectively. From 2000 to present, he is working in Korea Electronics Technology Institute (KETI). His research interests include embedded system and in-vehicle network system.

Chul-Dong Lee received the M.S. degree in the Dept. of Electrical and Electronic Engineering from Hanyang University, Seoul, Korea, and the Ph.D. degree from Chung Pook National University, Chungju, Korea. From 1977 to 2008, he was a Senior Researcher with Electronic Technology Research Institute (KETI). He is currently the director of Jeonbuk embedded system research centerin Jeollabukdo.