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A Metamaterial-Based Handset Antenna with the SAR Reduction

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Abstract – A method to reduce the specific absorption rate(SAR) of the antenna for WiMAX mobile communication is proposed in this paper. The SAR reduction is achieved by miniaturizing the physical size of the antenna for the given resonance frequency by devising a metamaterial-composite right- and left-handed(CRLH) configuration-based radiator much smaller than the quarter-guided wavelength adopted a lot in the conventional planar inverted F antenna(PIFA) or modified monopole antenna. The proposed antenna is placed near the head-phantom and its SAR is evaluated by the full-wave simulations(SEMCAD X), where the metamaterial-inspired antenna is shown to have the lower value than a modified monopole as the reference in terms of the SAR.

Keywords: Handset antenna, CRLH configuration, SAR, SAR reduction, Size-reduction

1. Introduction

To link two parties or more who are distant from one another for communication, radio waves and wireless connections are needed. Antennas are essential to the devices for the wireless and mobile communication. As time and lifestyles change and moving range between the transmitter and the receiver expands, numerous functions are required and new services are demanded on handset antennas. Keeping up with these objectives, antenna design technologies along with RF components and digital circuits have evolved. Among the recent commercial communication services, WiMAX was introduced to mobile internet users and is subscribed to by them. With a sneak peak into the antennas of the WiMAX and other mobile gadgets, PIFAs and modified monopoles are commonly used [1, 2].

In the early R&D days of mobile devices, the antenna designer's main concern was attaining radiation efficiency and gain as high as possible. However, as time went on, the influence of handheld devices on the users and their interactions were aroused and there appeared the related topics. One of them is the specific absorption rate(SAR) [3-6]. This focus on the near-fields from the antenna radiator in a wireless device coupled to human body parts in terms of power per kg. The SAR was added to the requirements of handset antenna designs and a number of studies have been done for the SAR reduction. Z. Wang et al watched the variation of the SAR from the changing position of a rod antenna and found the length and point at the coordinator to give a lower SAR [3]. M. A. Mangoud et al adopted a hybridized numerical method to check the possibility of reducing the SAR of a handheld device by phasing the elements of an array [4]. H.-T. Chou et al used a shield that disturbs the EM fields from a monopole antenna to a human body as a technique to lower the SAR [5]. Instead of the shield, the ferrite is adopted to drop the level of the field interaction between a mobile phone and the human head [6]. With regard to the cost and effectiveness of the SAR reduction presented by the articles [3-6], it might be pointed out that their antennas are not very realistic for practical use and the ferrite and the shield will increase the total cost and degrade the antenna gain and efficiency.

In this paper, we suggest the approach to reduce the SAR of a mobile phone by coming up with a compact antenna. The antenna is a metamaterial [7-9]-inspired geometry which comprises a split-ring-resonator(SRR) and a meandered line. Its size is 0.09λg much smaller than the quarter-guided wavelength. It is a matter of course that the antenna should meet the gain and efficiency acceptable for the industrial standards. While possessing the desirable antenna performance, the proposed antenna will be shown to have the lower value of the SAR than a modified monopole as the common mobile antenna design through the SEMCAD X calculations where the two aforementioned antennas are placed in the vicinity of the head phantom [10]. So in the following sections, firstly, the design of the novel antenna will be mentioned, and secondly, the SAR values of the proposed antenna and a conventional one will be evaluated by the full-wave simulations with the head-phantom. Consequently, the compact antenna suggested by this work will be effective in the SAR reduction compared to the standard half- or quarter-guided wavelength handset antennas.

2. Design of the Conventional and Proposed Metamaterial-based Antennas for WiMAX-band

To begin with, a conventional type of antenna is designed for 2.4 GHz-band and is shown as the 3D

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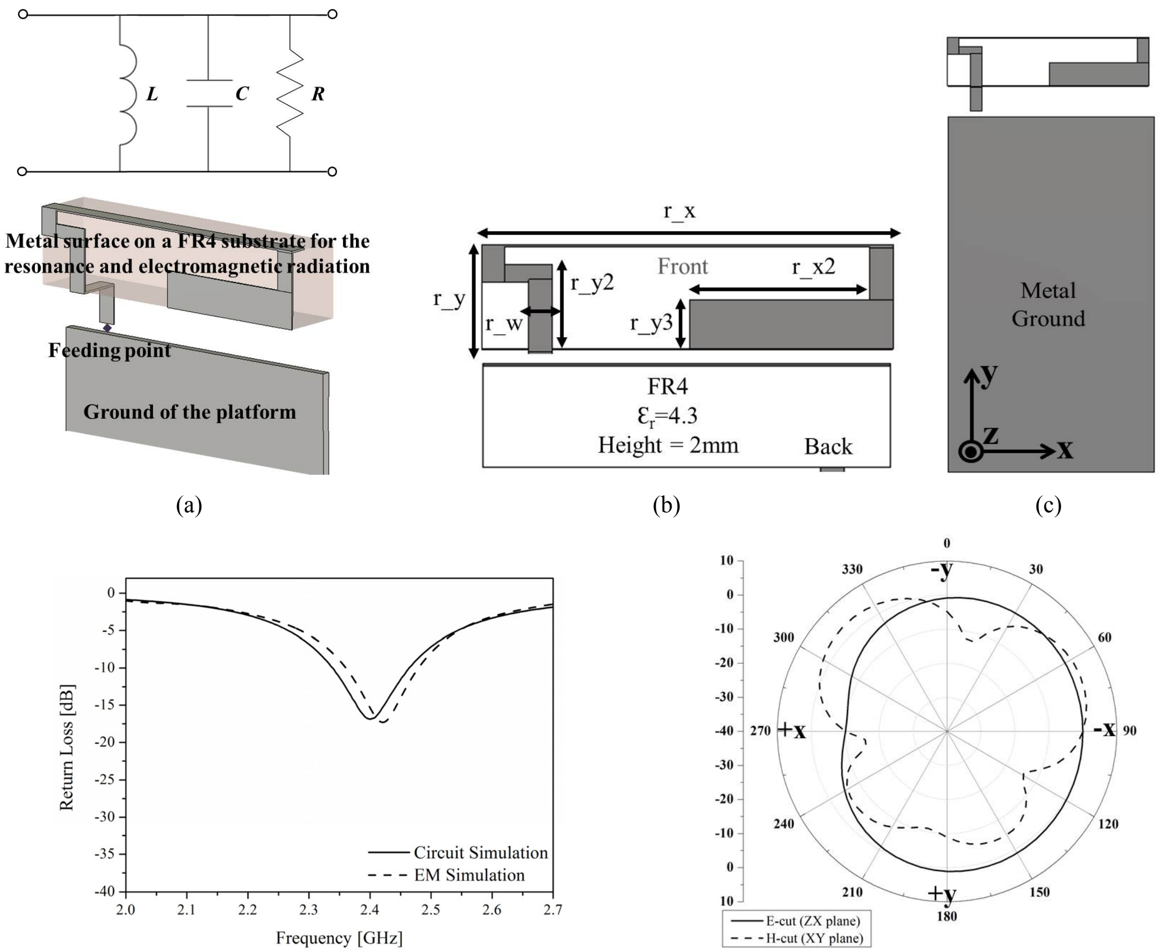


(a) (b) (c)

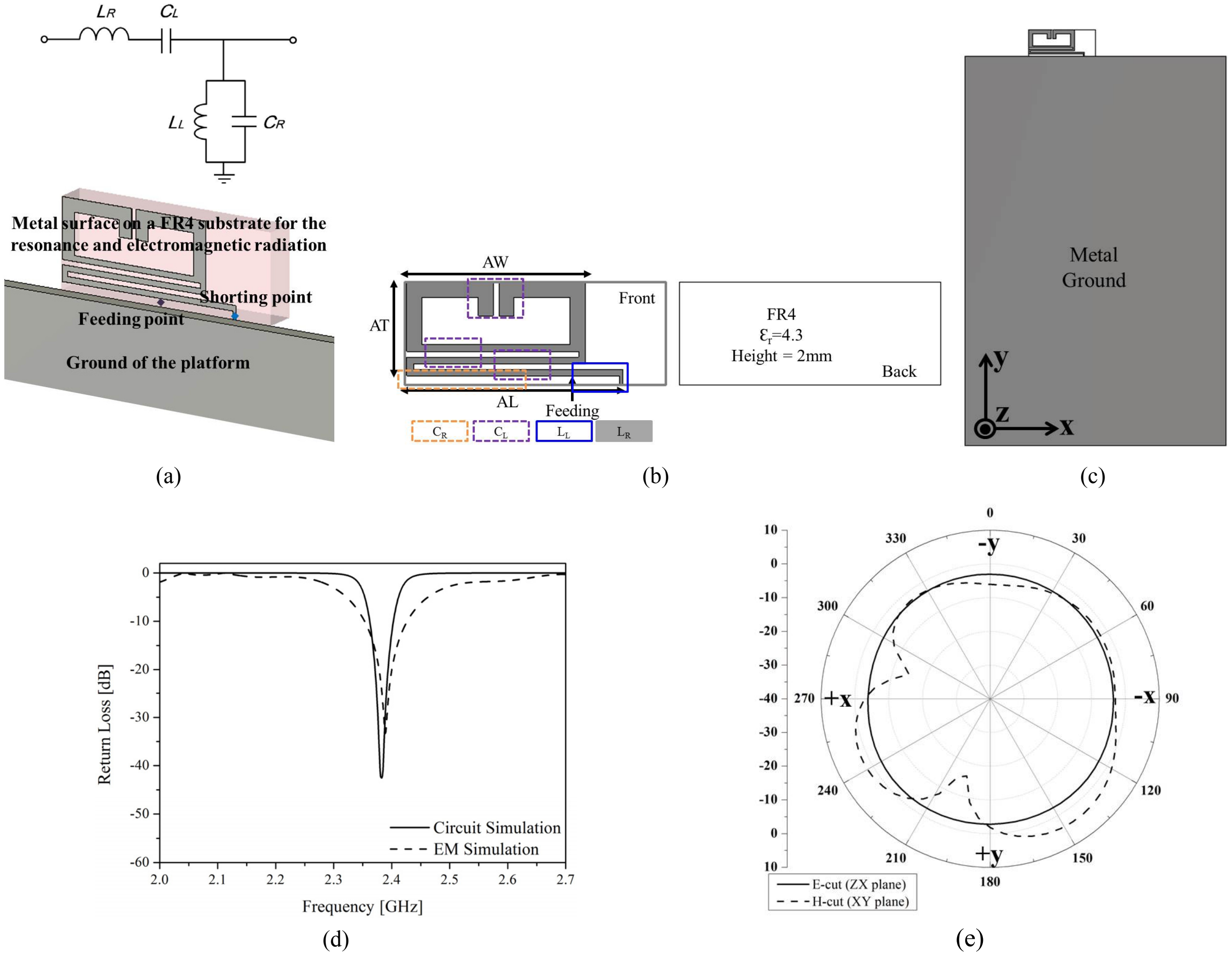
(d) (e)

Fig. 1. Geometry of the conventional antenna: (a) Equivalent circuit and 3D geometry; (b)Top-view; (c) placed on the top-edge of the ground; (d) S_{11} as the return loss; (e) 2D radiation pattern at 2.4GHz

structure put in the electromagnetic simulator as below.

Fig. 1 shows the overall view of the 3D geometry of a modified monopole as a conventional antenna where the gray part is a metal line on the white part as FR4 substrate for the resonant current path leading to electromagnetic radiation. This commonly adopted antenna can be modelled by an ordinary parallel R-L-C resonator which merely has the same resonance frequency, and is not suitable for figuring out the physical shape. And the geometry is determined by not the parallel resonator, but a transmission-line monopole. (R=150ohm, C=17.6pF, L= 0.25nH) The geometrical parameters r_x, r_x2, r_y, r_y2, r_y3, and r_w are obtained as 35 mm, 15.3 mm, 8.7 mm, 7.2 mm, 4.2 mm, and 2mm for the resonance at 2.4 GHz for the modified monopole above. This $0.25\lambda_g$ -sized antenna has the omni-diredtional radiated field pattern as in Fig. 1(c) appropriate for the mobile communication. Also, the conventional antenna comes to have the peak gain over 4 dBi and efficiency over 60%, acceptable to the industrial standard. However, sicne this antenna takes almost all the top-edge of the platform ground, it is highly likely to make its near-field spread and strong over the human head and other body parts contacting or near the handset. Then, this will result in the SAR exceeding the regulation on it. This likelihood necessitates the schmess to devise a smaller antenna which takes a portion of the top-edge of the ground. Therefore, the design method of a small resonator-based antenna is sought and the area of metamaterials is chosen. Next, a CRLH metamaterial configuration antenna, smaller than $0.25\lambda_g$, is designed with the same metal ground plane, but to have the similar radiation performance to the modified monopole antenna.

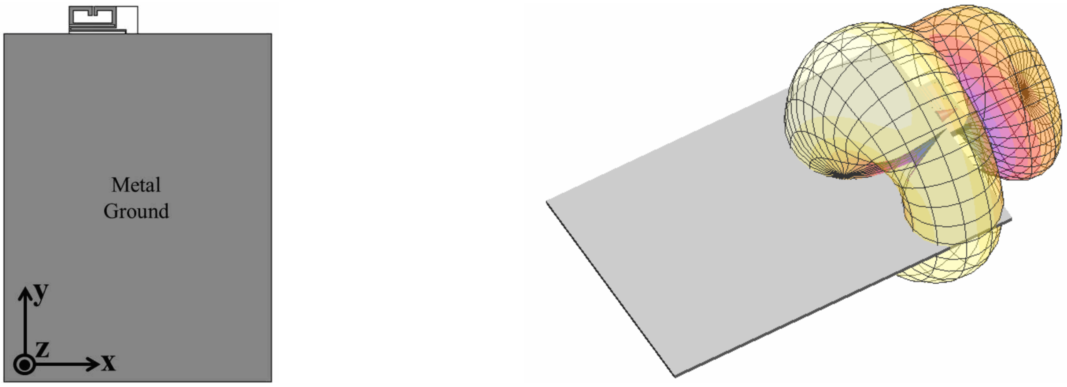
The novel compact antenna is suggested as Fig. 2 which comprises a loop split by a gap and an RF signal-fed meandered line short-circuited to the ground. This is interepreted by a CRLH equivalent circuit, and its elements can be mapped to the corresponding geometrical shapes for implementation, while the conventional parallel R-L-C equivalent circuit is an electrical model of the resonance frequency. Between the CRLH circuit and the proposed antennam, we take the series capacitance(C_L) and line inductance(L_R) mainly from the gap and the path of the open loop, and the series inductance(part of L_R) and inter-line capacitance(part of C_L) of the meandered line for



(a) (b) (c)

(d) (e)

Fig. 2. Geometry of the proposed antenna and return loss: (a) Equivalent circuit of the CRLH configuration [7-9] and 3D geometry; (b)Magnified view of the radiating element; (c) placed on the top-edge of the ground; (d) S_{11} as the return loss; (e) 2D radiation pattern at 2.4GHz



(a) (b)

Fig. 3. Geometry of the proposed antenna and its 3D far-field pattern: (a) Geometry; (b) 3D far-field pattern

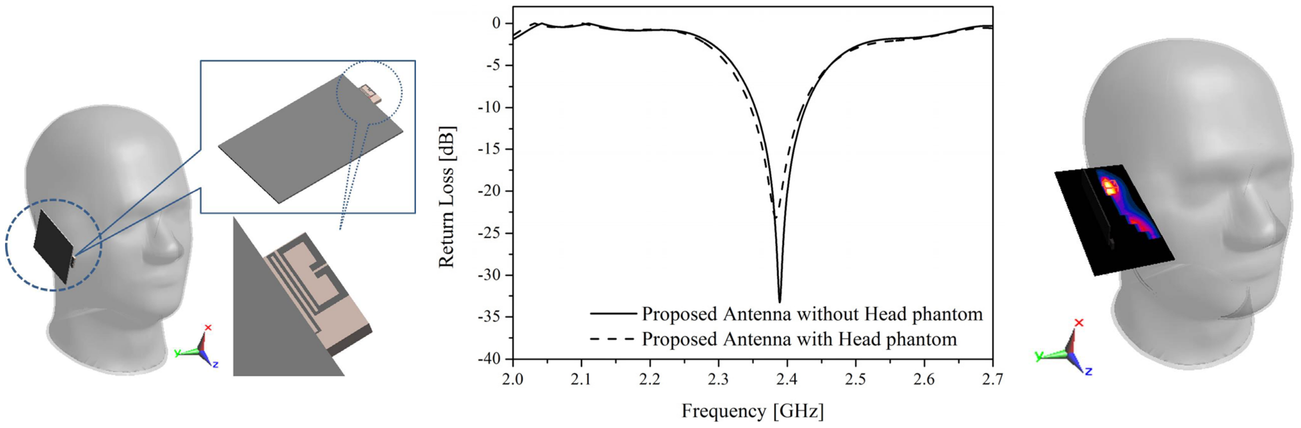
impedance matching and resonance-frequency adjustment within a limited space as shown in Figs. 2(a) and (b). Besides, the shunt capacitance(C_R) between the bottom of the meandered line and the ground can be used as the extra tuning element along with the shorting pin at the end of the meandered line as L_L. The analogy of the parts of the physical shape to the circuit elements is pictorially described as the brown broken-line box for C_R, the purple dashed-line box for C_L, the blue solid-line L_L, and the gray box for L_R in Fig. 2. The overall size of the radiating element amounts to $0.09\lambda_g$ which takes only a small portion of the ground edge as clearly seen in Fig. 2(c). The return loss has the resonance at 2.4 GHz in Fig. 2(d) with the following physical dimensions: AW=9.5mm, AT= 5.5mm and AL=11.5mm with the area of the ground = 54mm*81mm and 2mm-thick FR4 as the substrate. With these input parameters, the 3D radiated field pattern of this proposed radiating element is achieved.

This 3D plot of the far-filed pattern presents the peak gain of 4.4 dBi and efficiency of 70% at the resonance frequency. Moreover, the beam pattern has an omni-directional distribution in the azimuth plane as desired. This indicates that the proposed antenna has the radiation performance meeting the handset device standards while its size is $0.09\lambda g$, much smaller than the quarter-guided wavelength of the conventional handset antenna.

3. The SAR of the Proposed Antenna Compared to the Conventional Radiator

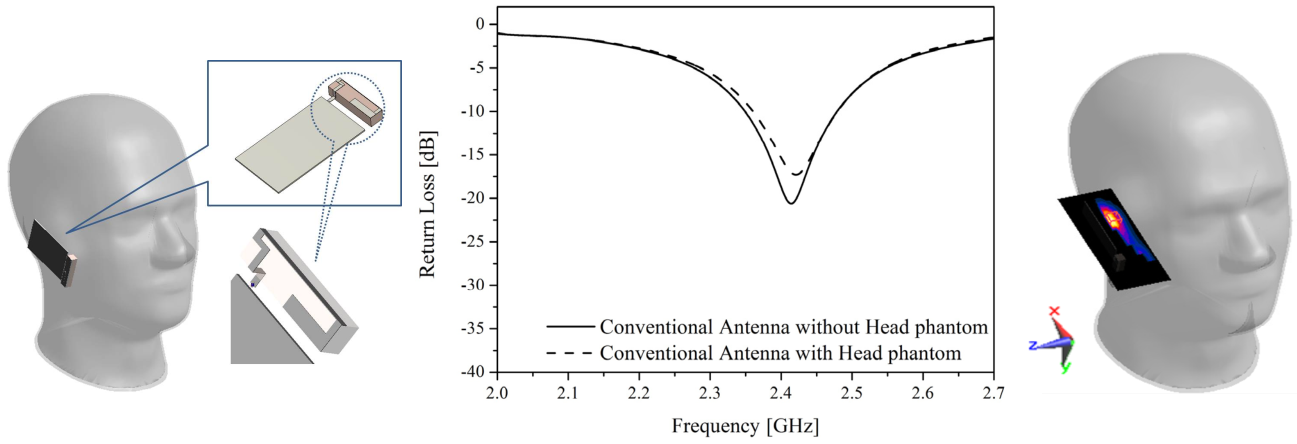
In this section, the SAR of the proposed CRLH-based antenna with regard to a human head is investigated.

Fig. 4(a) has the novel compact antenna positioned in the vicinity of the human head phantom provided by the SEMCAD X, which is known for its accuracy and commonly used in the handset-antenna developers' community. The return loss in Fig. 4(b) is not very different from Fig. 2(c) except the fluctuation in the magnitude of S_{11} before and after the resonance frequency, mainly caused by the changed environment and boundary conditions. The SAR has been evaluated as 1.21W/kg with Minimum SAR= 0.00035 and Maximum SAR=2.124 which is lower than 1.6W/kg as the Korean standard and 2W/kg as the EU standard of the SAR from the standpoint of 1g. So the proposed antenna passes the SAR test. Also, this SAR entails the near-field from the antenna distributed on the investigation plane of the head phantom as shown in



(a) (b) (c)

Fig. 4. Set-up and characteristics of the SAR of the proposed antenna: (a) Human head phantom; (b) S_{11}; (c) Field distribution on the test area of the head



(a) (b) (c)

Fig. 5. Characteristics of the conventional antenna: (a) Geometry; (b) S_{11}; (c) Field distribution in the head phantom for the SAR evaluation

Fig. 4(c). As the SAR is less than the cut-off level, the proposed antenna has 61% of the antenna efficiency and 6 dBi of the peak gain, which is applicable to mobile phones for the WiMAX communication. For a note, the reflected field by the head phantom with a higher permittivity could increase the gain of the antenna.

To verify the lower SAR as one of the benefits of the proposed antenna, we need to observe the SAR of the conventional modified monopole of the quarter-guided wavelength resonant radiator as shown in Fig. 1(a) as a comparative study.

The modified monopole radiator is fed from the ground whose size is the same as the proposed antenna case as appearing in Fig. 5(a). Also, the radiator is the metallic pattern on FR4 like the compared case. The shape and physical dimensions are obtained to have the resonance at 2.4 GHz which is confirmed by Fig. 5(b). The resultant SAR is 2.03W/kg with Minimum SAR=3.69 and Maximum SAR=3.69 and this exceeds the SAR standards which results in failure. With 61% and 6.3 dBi as the antenna efficiency and peak-gain, respectively, the conventional antenna cannot pass the test. Fig. 5(c) plots the near-interactive field from the antenna distributed on the observation cut of the head phantom. Therefore, throughout the comparative study, it is found that the design of a compact antenna can help the SAR reduction effectively rather than the half- or quarter-guided wavelength radiators, where the head phantom is exposed to the field from the smaller area for the resonant current on the proposed compact antenna.

3. Conclusion

In this paper, a method was suggested to reduce the specific absorption rate(SAR) of the antenna for WiMAX mobile communication. The SAR reduction was made possible by miniaturizing the physical size of the antenna for the resonance frequency of 2.4GHz by devising a metamaterial CRLH-based radiator much smaller than the quarter-guided wavelength with the conventional planar inverted F antenna(PIFA) or modified monopole antenna. The proposed antenna was positioned near the head-phantom and its SAR was evaluated by the full-wave simulations(SEMCAD X), where the metamaterial-based antenna was shown to have the lower value than a modified monopole as the reference in terms of the SAR.

Acknowledgement

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References

[1] K. L. Wong, Planar Antennas for Wireless Communicators, John Wiley & Sons, Inc., New Jersey, 2003.

[2] S. Hong, S. Kahng, and J. Choi, “Design of an Internal Multi-resonant Monopole Antenna for GSM900/DCS1800/US-PCS/S-DMB Operation,” IEEE Transactions on Antennas and Propagation, vol.56, no.5, pp.1437-1443, May 2008.

[3] Z. Wang, and X. Chen, “A low SAR whip type mobile handset antenna,” IEE 11th International Conference on Antennas and Propagation, vol. 1, no. 480, pp. 352-355, 2001.

[4] M. A. Mangoud, R. A. Abd-Alhameed, and N. J. McEwan, “SAR reduction for Handset with Two-element Phased Array Antenna computed using Hybrid MOM/FDTD technique,” Electronic Letters, vol. 35, no. 20, Sep. 1999.

[5] H.-T. Chou, and D. Wu, “Radiation of a handset monopole antenna in the presence of a finite shielding sheet for the purpose of SAR reduction,” IEEE APS, vol. 1, pp. 452-455, 2002.

[6] Wang, O. Fujiwara and T. Takagi, “Effects of ferrite sheet attachment to portable telephone in reducing electromagnetic absorption in human head,” IEEE International Symposium on Electromagnetic Compatibility, vol. 2, pp. 822-825, 1999.

[7] S. Yoo, and S. Kahng, “CRLH ZOR Antenna of a Circular Microstrip Patch Capacitively Coupled to a Circular Shorted Ring,” Progress In Electromagnetics Research C, vol. 25, 15-26, 2012.

[8] G. Jang, and S. Kahng, “Compact metamaterial zeroth-order resonator bandpass filter for a UHF band and its stopband improvement by transmission zeros”, *IET Microwaves, Antennas & Propagation IET,* vol.5, no.10, pp.1175-1181, July 2011.

[9] Boram Lee, and Sungtek Kahng, “Compact UWB Bandpass Filter as Cascaded Center-Tapped CRLH Transmission-Line ZORs for Improved Stopband,” *Journal of Electrical Engineering & Technology*, vol.8, no.2, pp. 371-375, February 2013.

[10] SEMCAD X by SPEAG, www.speag.com.

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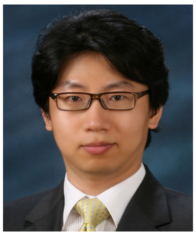

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