JOURNAL OF THE KOREAN INSTITUTE OF ELECTROMAGNETIC ENGINEERING AND SCIENCE, VOL. 10, NO. 3, SEP. 2010 JKIEES 2010-10-3-02

Double-Layered Frequency Selective Surface Superstrate Using Ring Slot and Dipole-Shaped Unit Cell Structure

Hong-Min Lee[1] · Yong-Jin Kim[2]

Abstract

In this paper, a double-layered frequency selective surface(FSS) superstrate was built and tested. The unit cell of the proposed FSS consists of a ring slot and a dipole-shaped structure and shows a complementary frequency response. Each unit cell is printed on two sides of a substrate. By using these double-layered structures, the first resonant frequency of the pass-band can be lowered. As a result, the size of the unit cell is minimized and the spacing between the other cells is reduced. The proposed FSS-dipole composite antenna is designed for the gain enhancement of wide-band code division multiple access(WCDMA) frequency bands(1.92～2.17 GHz) with a low quality factor(Q=0.17). To verify the gain enhancement performance of the FSS, an FSS-dipole composite antenna was created. Although the FSS layer enhances the gain of the primary radiation source of the dipole antenna, the FSS-dipole complex antenna cannot show a uniform gain over the entire desired frequency band. The experimental results show a gain enhancement of 3 dBi with an FSS superstrate in the WCDMA frequency band.

Key words : Gain Enhancement, Frequency Selective Surface (FSS), Superstrate.

Ⅰ. Introduction

A frequency selective surface(FSS) over a radiation source is very useful for enhancing the gain of an antenna. Many approaches to achieving gain enhancement have been studied. There are various configurations possible for the design of FSS structures as superstrate layers. In [1] and [2], metallic strip elements have been used over a patch antenna. Dielectric rods[3], Fabry-Perot type cavities[4], and meta-material structures with zero refractive indexes[5] are also used as superstrates. In the microwave region, a defect mode with a high Q can be used as a superstrate to enhance gain[6]. As the element electrical spacing in an FSS increases, its bandwidth becomes narrower and the grating lobes are produced[7],[8]. Therefore, element spacing should be made small in terms of wavelength by introducing a smaller FSS unit cell structure. In [9], to reduce the overall dimensions of the unit cell, the constituting element actually consists of a parallel inductive and capacitive strips properly arranged so that they can be respectively coupled to the magnetic and electric fields of an incident wave.

To reduce the unit cell size, a passive element such as a ceramic chip capacitor can be used[10]. In the design process of an FSS that operates in a frequency range below 3 GHz, the size of an FSS unit cell increases. To reduce the unit cell size and to obtain a compact FSS composite antenna, an alternative design of the unit cell is necessary. In this paper, a double-layered FSS superstrate using the unit cell of a ring slot and a dipole-shaped structure is proposed and a broadband printed dipole antenna[11] is used as the primary radiating source. The proposed composite of an FSS superstrate and dipole antenna structure is simulated using a 3D field simulation tool, CST MWS(Micro Wave Studio)[12].

Ⅱ. Design of FSS the Unit Cell

The geometry of the proposed FSS unit cell structure is shown in Fig. 1. It is designed on a Rogers RO3210 dielectric substrate with a relative permittivity of 10.2 and a thickness of 1.27 mm. It consists of a ring slot and a dipole-shaped structure, which have different transmission characteristics.

The frequency characteristics of the unit cell structure are simulated using a periodic boundary condition(PBC) method, as shown in the right side of Fig. 1. A unit cell of the structure is placed inside a waveguide with PBC walls; a vertically polarized TEM wave impinges upon this structure.

The transmission coefficients of this structure are then simulated and the frequency response of the infinitely large structure is obtained. By simulating only the FSS

Manuscript received June 3, 2010 ; revised September 10, 2010. (ID No. 20100603-016J)

[1]Department of Electronic Engineering, Kyonggi University, Suwon, Korea.

[2]Gammanu INC Research Lab., Hwasung, Korea.

Corresponding Author : Hong-min Lee (e-mail : hmlee@kyonggi.ac.kr)

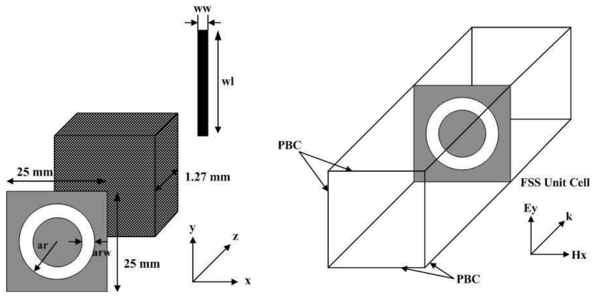


Fig. 1. The geometry of the proposed FSS unit cell structure.

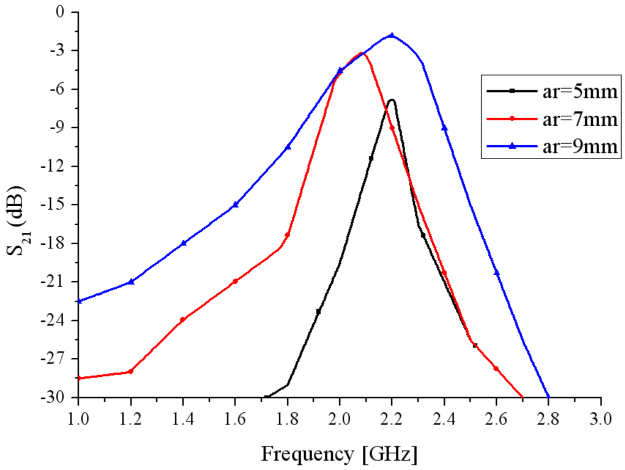


Fig. 2. Transmission characteristics of a ring slot cell as a function of ring slot width *arw*(*ar*=9 mm, *ww*=1 mm, *wl*=20 mm).

unit cell structure rather than the entire FSS structure, the overall simulation process time is reduced and its resonant frequency can be predicted. Fundamentally, a periodic array of ring slots with magnetic currents shows pass-band transmission characteristics, but a dipoles array with electric currents shows stop-band transmission characteristics. Figs. 2 and 3 show the transmission characteristics of a ring slot FSS unit cell for the different slot width arw and ring slot radius *ar*. The resonant frequency and bandwidth of the unit cell are controlled by the slot width *arw* and the slot radius *ar*, respectively. Figs. 4 and 5 show the transmission characteristics of a dipole FSS unit cell for the different dipole width *ww* and dipole length *wl*.

A hybrid of two closely coupled FSSs, whereby a layer of conducting elements(diploes) and a layer of aperture elements(ring slots) are etched on either side of a dielectric substrate may be defined as a complementary FSS(CFSS). The CFSS takes advantage of the interaction between the layers in order to produce strong fields separated by a distinct null; the lower pass-band reso-

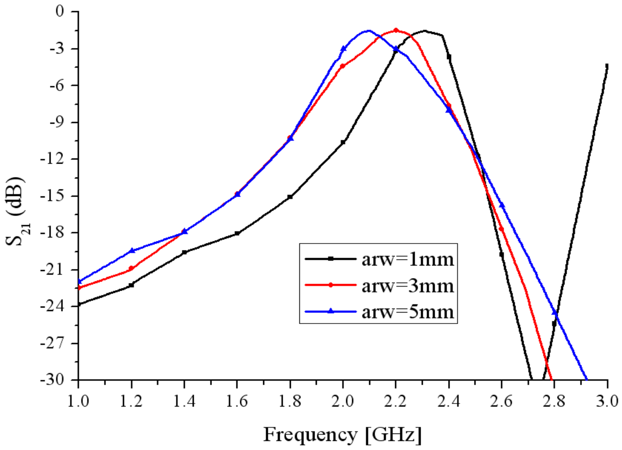


Fig. 3. Transmission characteristics of a ring slot cell as a function of ring slot radius *ar*(*arw*=2.5 mm, *ww*=1 mm, *wl*=20 mm).

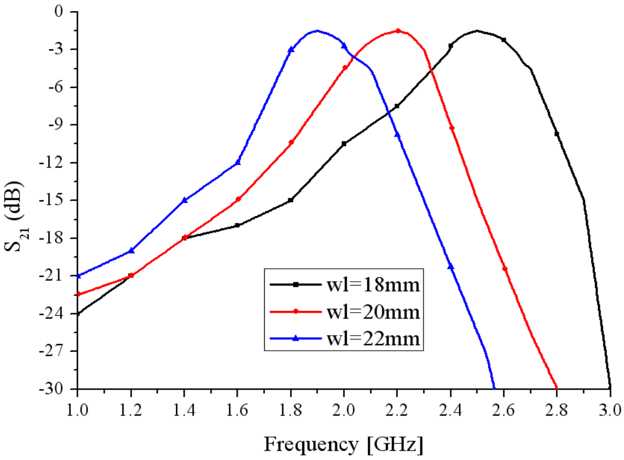


Fig. 4. Transmission characteristics of an dipole cell as a function of dipole width *ww*(*ar*=9 mm, *arw*=2.5 mm, *wl*=20 mm).

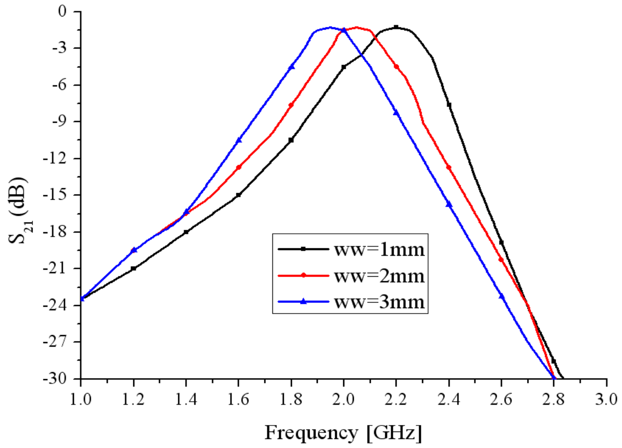


Fig. 5. Transmission characteristics of a dipole cell as a function of dipole length *wl*(*ar*=9 mm, *arw*=2.5 mm, *ww*=1 mm).

nance appears at a frequency that is much lower than that of a single layer ring slot array[13]. However, the CFSS is not limited by unit element and a double-layered FSS consisting of a rectangular slot and a ring-shaped element can be used[14]. In this case, a periodic array of annular rings shows stop-band transmission characteristics and a periodic array of rectangular slots shows pass-band transmission characteristics.

In the design of the FSS unit cell, we use a double-layered structure with a ring slot and a dipole which are put on top of each other so that the resonant frequency of the cell is near a 2 GHz frequency band. A comparison of the simulated frequency responses of the conventional single element and the proposed double-layered FSS unit cell structure is shown in Fig. 6. Compared to the ring slot FSS(pass band center frequency ≈ 3 GHz), the double-layered FSS with a ring slot and a dipole shows two narrow pass bands resonant frequencies(at ≈2 GHz and ≈4 GHz) separated by a distinct null at the frequency of 2.7 GHz. These changes are directly deduced from the figure since the interlayer coupling accounts for the position of the null as well as its bandwidth[13]. As a result, the size of the double-layered FSS unit cell structure can be reduced.

The design specification of the FSS-dipole composite antenna for the wideband code division multiple access (WCDMA) system is shown in Table 1. The FSS superstrate layer is used to operate at a frequency band of 1,920~2,170 MHz. Therefore, the −3 dB pass-band bandwidth of the proposed FSS should be more than 250 MHz. By optimizing the parameters of the unit cell and the distance between the FSS superstrate and ground plane, the bandwidth is increased to 360 MHz and the quality factor Q is lowered to 0.17. The optimized parameters of the proposed unit cell structure are: ar=11 mm, arw=4 mm, ww=1.2 mm and wl=21.5 mm, and total size of one unit cell is 25×25×1.27 mm.

Table 1. Design specification of an FSS-dipole composite antenna.

Frequency band	1,920~2,170 MHz
TX band	1,920~1,980 MHz
RX band	2,110~2,170 MHz
Min. gain	8 dBi
Size of ground plane	280×280 mm

Ⅲ. Experimental Results

In this paper, a double-layered FSS superstrate consisting of a ring slot and a dipole etched on a dielectric substrate is designed. A cavity resonant antenna in which a broadband printed dipole antenna is embedded in a multilayer structure consisting of a grounded dielectric slab and FSS superstrate is considered. The effect of the air-gap length on the gain of this antenna is shown in Fig. 7. It is clear that the resonant length necessary for the antenna to produce the wider bandwidth(1.9~2.2 GHz) is h=73 mm. In the design of the FSS superstrate 9×9 unit cells are used. A broadband(1.91~2.27 GHz) printed dipole antenna is used as the primary radiating source. The geometry of the proposed FSS-dipole composite antenna structure is shown in Fig. 8. Where N is the total number of FSS arrays and h is the optimum resonant air-gap distance from the ground plane to the FSS. The geometry of printed dipole antenna with an integrated balun is shown in Fig. 9. It is fed by a 50 Ω

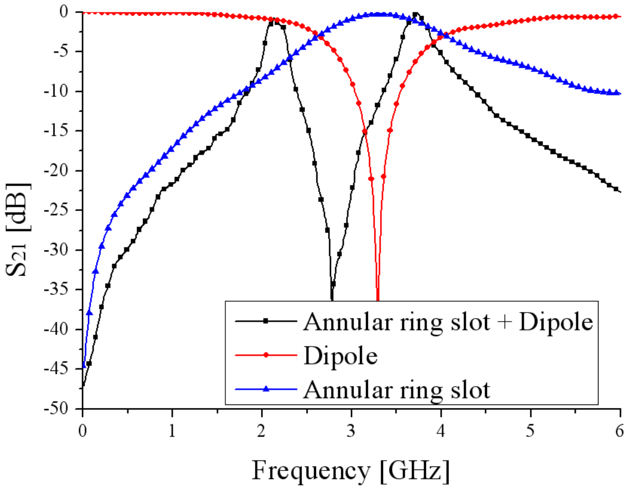


Fig. 6. Transmission characteristics of the different FSS unit cell structure.

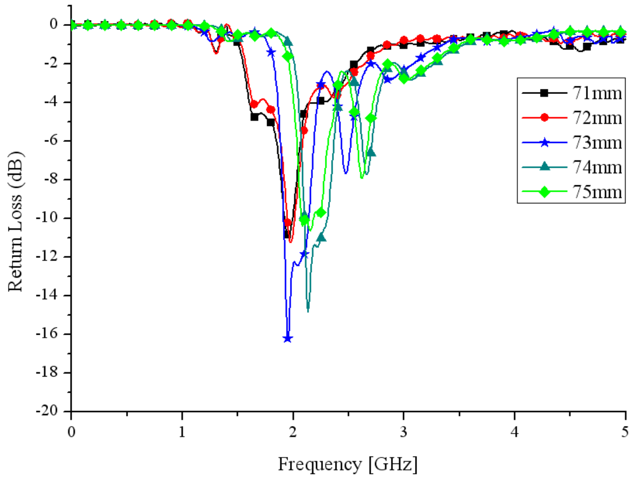


Fig. 7. Simulated return loss of the FSS-dipole composite antenna for different air-gap length h.

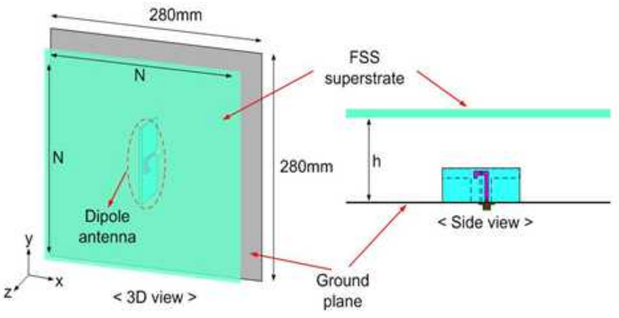


Fig. 8. Geometry of the proposed FSS-dipole composite antenna structure.

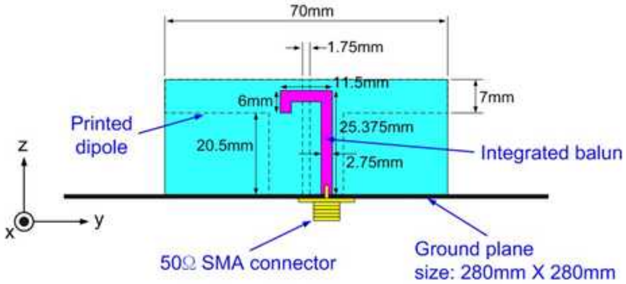


Fig. 9. Geometry of the printed dipole antenna with an integrated balun.

coaxial connector and is designed with a Teflon substrate(thickness=1.27 mm, relative permittivity=2.2); the size of the ground plane is 280×280 mm. The measured return loss of the fabricated dipole antenna is shown in Fig. 10. The measured resonant frequency and impedance bandwidth of the fabricated dipole antenna are 2.23 GHz and 320 MHz(2.08~2.4 GHz), respectively. The measured radiation patterns of the fabricated dipole antenna are shown in Fig. 11. The fabricated dipole antenna has maximum gain of 7.4 dBi at 2.2 GHz. The photographs of the fabricated FSS-dipole composite antenna structure are shown in Fig. 12.

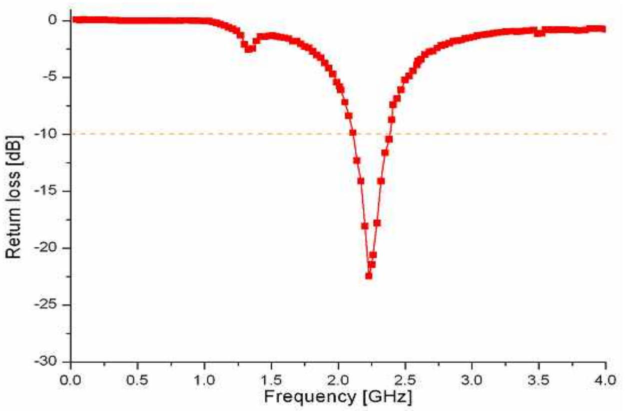


Fig. 10. Measured return loss of the fabricated dipole antenna.

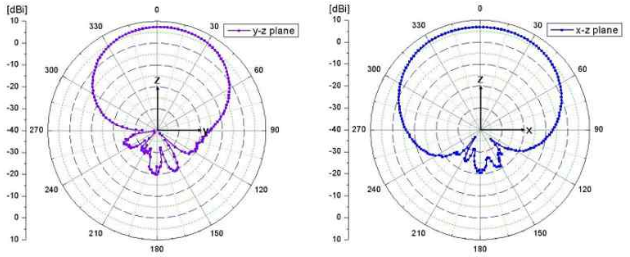
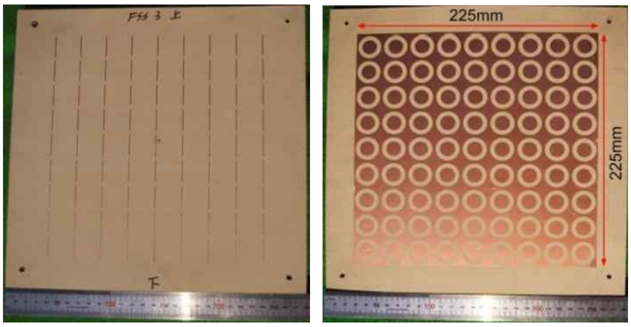
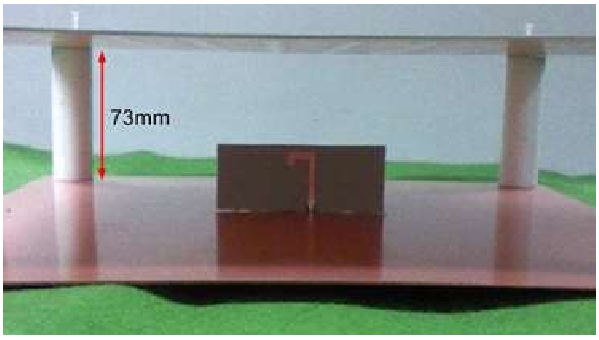


Fig. 11. Measured radiation patterns of the fabricated dipole antenna.

The measured return loss for the FSS-dipole composite antenna structure is shown in Fig. 13. Although the FSS superstrate enhances the gain of the primary radiation source of the dipole antenna, it acts as a resonant load. Therefore the input impedance of the dipole antenna is changed. When the dipole antenna is combined with the FSS superstrate, the resonant frequency of the composite antenna is lowered. In order to achieve the best performance frequency tuning of the dipole antenna is needed. The measured radiation patterns and variation of gain of the proposed antenna are shown in Fig. 14 and Fig. 15, respectively. As shown in Fig. 7, the reflection coefficient magnitudes of the antenna depend on the air-gap length *h*. However, the reflection



(a) Dipole array layer (b) Ring slot array layer



(c) FSS-dipole composite antenna

Fig. 12. Photographs of the fabricated FSS and dipole antenna.

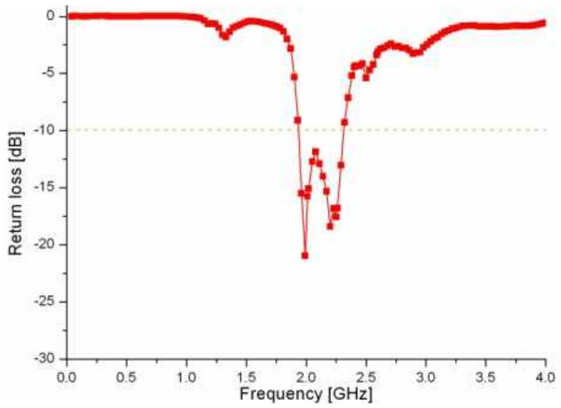
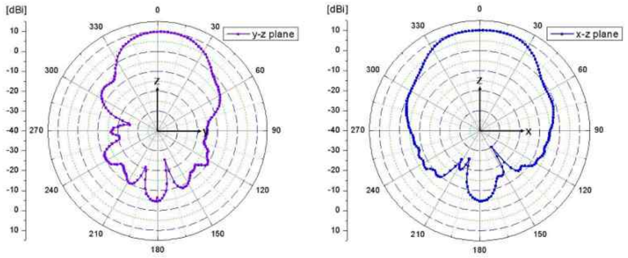
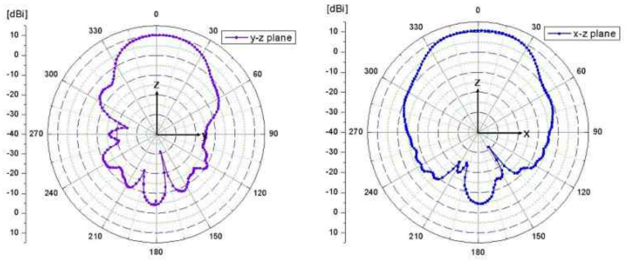


Fig. 13. Measured return loss of the FSS-dipole composite antenna.



(a) 1.95 GHz



(b) 2.14 GHz

Fig. 14. Measured radiation patterns of the fabricated FSS-dipole composite antenna.

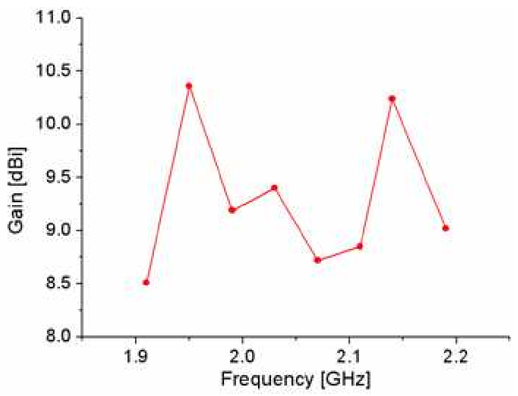


Fig. 15. Measured gain of the proposed antenna versus frequency.

phases of the FSS and ground plane are also changed according to air-gap length h. When the resonant air-gap distance h is 71 mm, the proposed composite antenna can be resonant and shows higher gain compared to a primary radiating source antenna.

In this design, the resonant air-gap distance h is chosen as 73 mm. Therefore, two peaks of antenna gain appear at two different frequencies($f \approx 1.95$ and 2.45 GHz), as shown in Fig. 15. A maximum gain of 10.4 and 10.3 dBi is achieved in the Tx/Rx frequency-band, respectively. As a result, an increased gain of about 3 dBi is obtained.

Ⅳ. Conclusion

In this paper, a double-layered frequency selective surface structure was built and tested. The size reduction of the proposed FSS unit cell structure is obtained by combining a ring slot with a dipole structure, which shows a complementary frequency response. As a result, the size of a unit cell is miniaturized to 0.14 λ_0(λ_0 refer to the wavelength of 2.14 GHz) and a gain enhancement of 3 dBi is achieved.

This work was supported by the Korea Science and Engineering Foundation(KOSEF) grant funded by the Korea government(MOST) (No. R01-2007-000-10315-0).

References

[1] Y. J. Lee, J. Yeo, R. Mittra, and W. S. Park, "Design of a high-directivity electromagnetic band gap (EBG) resonator antenna using a frequency selective surface(FSS) superstrate", *Microw. Opt. Tech. Lett.*, vol. 43, no. 6, pp. 462-467, Dec. 2004.

[2] Y. J. Lee, J. Yeo, R. Mittra, Y. J. Lee, and W. S. Park, "Design of frequency selective surface(FSS) type superstrate for dual-band directivity enhancement of microstrip patch antennas", *IEEE Int. Symp. Antennas & Propagat.*, vol. 3A, pp. 2-5, Jul. 2005.

[3] C. Cheype, C. Serier, M. Thevenot, T. Monediere, A. Reineix, and B. Jecko, "An electromagnetic bandgap resonator antenna", *IEEE Trans. Antennas & Propagat.*, vol. 50, no. 9, pp. 1285-1290, Sep. 2002.

[4] T. Akalin, J. Danglot, O. Vanbesien, and D. Lippens, "A highly directive dipole antenna embedded in a Fabry-Perot type cavity", *IEEE Microwave & Wireless Component Lett.*, vol. 12, no. 2, pp. 48-50, Feb. 2002.

[5] Z. Weng, N. B. Wong, Y. C. Jiao, and F. S. Zhang,

"A directive patch antenna with metamaterial structure", *Microwave Opt. Technol. Lett.*, vol. 49, no. 2, pp. 456-459, Feb. 2007.

[6] Y. J. Lee, J. Yeo, R. Mittra, and W. S. Park, "Application of electromagnetic bandgap(EBG) superstrates with controllable defects for a class of patch antennas as spatial angular filters", *IEEE Trans. Antennas & Propagat.*, vol. 53, no. 1, pp. 224-235, Jan. 2005.

[7] B. A. Munk, *Frequency Selective Surface: Theory and Design*, Wiley Inter-Science, 2000.

[8] J. L. Volakis, *Antenna Engineering Handbook*, *4th edition*, McGraw Hill, 2007.

[9] K. Sarabandi, N. Behdad, "A frequency selective surface with miniaturized elements", *IEEE Trans. Antennas & Propagat.*, vol. 55, no. 5, pp. 1239-1245, May 2007.

[10] F. Bayatpur, K. Sarabandi, "Single-layer high order miniaturized-element frequency selective surfaces", *IEEE Trans. Microw. Theory Tech.*, vol. 56, no. 4, pp. 774-781, Apr. 2008.

[11] B. Edward, D. Rees, "A broadband printed dipole with integrated balun", *Microwave Journal*, vol. 30, no. 5, pp. 339-344, May 1987.

[12] CST STUDIO SUITETM 2006B MWS manual, CST Corporation.

[13] D. S. Locker, J. C. Vardaxoglou, and R. A. Simpkin, "Complementary frequency selective surfaces", *IEE Proceeding of Microwave, Antennas and Propagation*, vol. 147, pp. 501-507, 2000.

[14] Yongjin Kim, Sungsoo Nam, and Hongmin Lee, "Frequency selective surface superstrate for wideband code division multiple access system", *Wireless Technology Conference 2009 EuWIT*, pp. 33-36, 2009.

Hong-Min Lee

received the B.S. degree in electrical engineering from Yonsei University, Korea, in 1972 and M.S. and Ph.D. is electronic engineering from Yonsei University in 1974, and 1990, respectively. Since 1991, he is a professor of electronic engineering of Kyonggi University and his research areas are antenna, microwave circuit design. Currently his research is mainly focused on the design for metamaterial structures and EBG. He is accredited to be Marquis Who's Who in the world, IBC and ABI.

Yong-Jin Kim

received the B.S. degree and M.S. in electronic engineering from Kyonggi University, Suwon, Korea, in 2007 and 2009. He currently an assistant engineer at Gammanu INC Research Lab. His research interests are antennas, RF communication systems, and base-station antennas.