INVITED PAPER *Special Section on Antenna and Propagation Technologies Contributing to Diversification of Wireless Technologies*

Design of a Microstrip Patch Antenna with Enhanced F/B for WBAN Applications

Uisheon KIM[†], *Nonmember and* **Jaehoon CHOI**[†a)], *Member*

SUMMARY This paper proposes a microstrip patch antenna for 2.45 GHz Industrial Scientific Medical (ISM) band Wireless Body Area Network (WBAN) applications. To enhance the front-to-back ratio (F/B) and specific absorption rate (SAR), an electrically coupled LC resonator is introduced. The overall dimensions of the proposed antenna are 54 mm × 45 mm × 2.4 mm and it has a gain of over 1 dBi for the entire 2.45 GHz ISM band. The proposed antenna has an enhanced F/B ratio and specific absorption rate, compared with those of a conventional patch antenna.

key words: *wireless body area network (WBAN), patch antenna, electrically coupled LC resonator (ELC)*

1. Introduction

With the recent development of wireless communication technology, many researchers pay great attention to the study of wireless body area networks (WBANs). WBANs link between various electronic devices in, on, and the human body. The application of WBANs has been expanding in medical services, national defense, wearable computing, and so forth. Several frequency bands have been assigned for WBAN systems, such as the medical implant communication system (MICS: 400 MHz) band, the industrial scientific medical (ISM: 2.4 GHz and 5.8 GHz) band, and the ultra-wideband (UWB: 3∼10 GHz) [1].

Since the human body has a high dielectric constant and conductivity at the microwave frequency band, not only can the input impedance and resonance frequency be changed, but the gain and radiation efficiency of an antenna can also be deteriorated when an antenna is operated on or in the body. These effects can be even more serious in compact and low profile antennas. Yuan et al. (1998) proposed a new type of internal PIFA for mobile phones to reduce the absorption of the human body [2]. Additionally, to protect the human body from radio wave exposure, the basic safety limits applicable for wireless devices are defined in terms of the SAR. Since various antennas operate simultaneously in/on the human body, the SAR becomes a critical issue in WBANs. Therefore, antennas for WBAN are required to have a compact size, flexibility, low human body effect, and low SAR [3].

A microstrip parch antenna is often used for on- or off-body communications because of its low profile, high gain, and ease of fabrication. However, the large back radiation of a microstrip patch antenna is a critical drawback that needs to be overcome for human body applications. Many studies have been performed to reduce the back radiation and SAR of antennas using various configurations, such as "metal cavity" [4], "reflector/director" [5], [6], and "Ferrite material" [7]. Recently, artificial structures (also called meta-materials), including Electromagnetic Band gap (EBG) structures [8], have been widely investigated. Those artificial periodic structures are composed of sub-wavelength constituent elements that make the structure behave as an effective medium with negative values of permittivity and/or permeability at the frequency of interest. Negative magnetic materials can typically be obtained by using the SRR. A thin wire structure is used to generate a broadband electrical response at a specific frequency band [9]. An electrically coupled LC resonator (ELC) structure, having a negative permittivity, was proposed in [10].

This paper proposes a microstrip patch antenna with enhanced front-to-back ratio (F/B) for WBAN applications. To reduce the back radiation of a patch, three-dimensional ELC resonators, with an inter-digital structure, are introduced. The characteristics of the ELC unit cell, with an inter-digital structure, and performance of the proposed patch antenna, with four ELCs, are analyzed. Finally, performances of the antenna on human body tissues are investigated.

2. Antenna Design

The proposed antenna has a two-layered substrate and consists of a rectangular microstrip patch antenna and four ELCs, as shown in Fig. 1. FR4 substrates with relative permittivity of 4.4 are used, and their thicknesses are 1.6 mm and 0.8 mm, respectively. The rectangular patch is located on the top of the upper substrate and is 2.4 mm above the ground plane, which is located on the bottom of lower substrate. The size of the microstrip patch is 27.8 mm × 27.8 mm, which has a resonance frequency of 2.45 GHz, and the feeding point is 6.2 mm from the center in the x-direction for better impedance matching.

Four ELCs are formed in the upper substrate and the inter-digital structures of ELCs are placed on the top of the upper substrate. The ELC has a width of 3 mm, a length of 25.5 mm, and a height of 1.6 mm. The three-dimensional ELC resonator is illustrated in Fig. 2. A capacitor-like struc-

Manuscript received October 4, 2010.
Manuscript revised December 20, 2010.
[†]The authors are with the Department of Electronics and Computer Engineering, Hanyang University, 17 Haengdang-Dong, Seongdong-Gu, Seoul, 133-791, Korea.
a) E-mail: choijh@hanyang.ac.kr
DOI: 10.1587/transcom.E94.B.1135

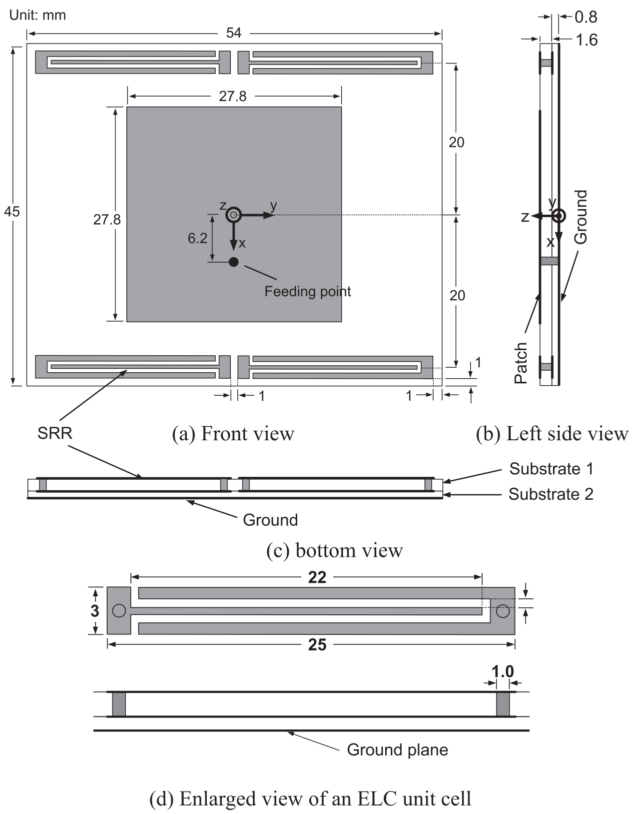


Fig. 1 Configuration of the proposed antenna.

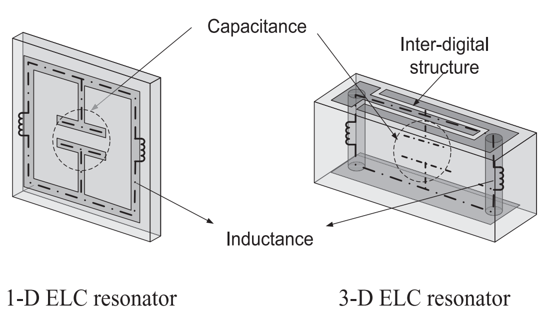


Fig. 2 The 3D ELC with inter-digital structure.

ture couples to the electric field and is connected in parallel to two vias that provide inductance to the circuits. To increase the inductance of the ELC, the inter-digital structure with one finger is added, as shown in Fig. 2. The inter-digital structure has a length of 22 mm and a gap of 0.5 mm. The ELCs are implanted 20 mm from the center of the patch antenna and are symmetric with respect to the x- and y- axes, as shown in Fig. 1.

Figure 3 shows the simulated structure used to calculate the S-parameter of the ELC. To generate TEM mode, the top and bottom planes of the rectangular waveguide are set to perfect electric conductor (PEC). Furthermore, the front and back planes of the rectangular waveguide are set to perfect Magnetic conductor (PMC). Figure 4 shows the simulated characteristics of the 3D ELC unit cell with inter-

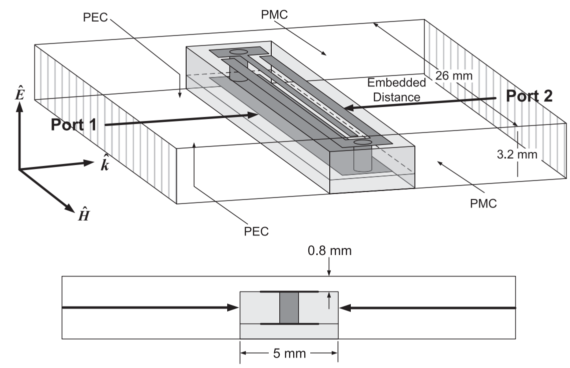


Fig. 3 Electric excitation of the ELC unit cell.

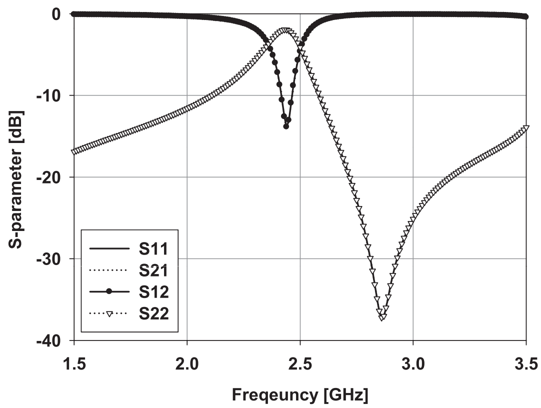
digital structure. When the electric field excites normally to the capacitor plate by the microstrip patch, the capacitive element couples strongly to the electric field and the inductive loops do not. Thus, it generates a strong electric resonance with negative permittivity, as shown in Fig. 4(b). Using the methods suggested in [10] and [11], it can be shown that the ELC has negative effective permittivity and low permeability values at 2.45 GHz. To verify the operating mechanism of the proposed ELC structure at 2.45 GHz, the electric and magnetic field distributions are analyzed and are illustrated in Fig. 4(d). Microwaves are unable to propagate in a medium with a negative electrical property ($\varepsilon < 0$ or $\mu < 0$), because that type of medium stores electromagnetic energy. We use this characteristic of ELC to reduce the back radiation and SAR by suppressing the surface waves around the ground plane of the patch antenna.

Figure 5 shows the radiated electric field distributions in the neighborhood of the proposed antenna. One can clearly observe that the E-field is weakened at the back of the ground plane. Figure 6 shows the radiation patterns of the proposed antenna. The back radiation is significantly reduced, but the peak gain is lowered due to the high dielectric loss caused by ELC structures, as shown in Fig. 4(b). The front-to-back ratios of the patch antenna with and without ELCs are 34.8 dB and 9.1 dB at 2.45 GHz, respectively.

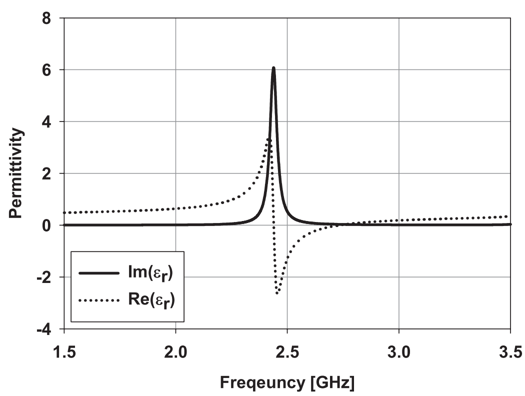
3. Antenna Performance on Body Tissue

In order to analyze the antenna performance in the human body, simulations were carried out after placing the proposed antenna on the human body models. Electrical properties of human body models used in this study are summarized in Table 1. Models 1 and 2 are simplified flat phantoms for fast simulation. Model 1 has one material layer, which has equivalent electrical properties to an entire human body [13]. Model 2 has four material layers: skin, fat, muscle, and bone [14].

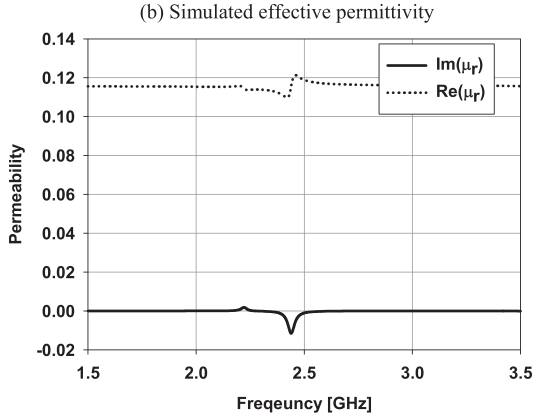
Figures 7(a) and (b) show the S_{11} characteristics of the proposed patch antenna with and without ELCs on the body models. The change in S_{11} characteristics of the patch antenna with ELCs is much smaller than that without ELCs. The front-to-back ratios of the patch antenna, with and with-



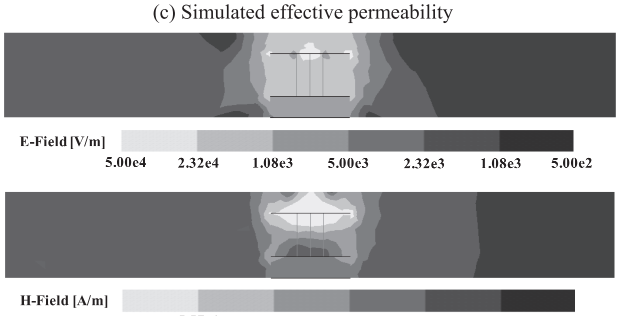
(a) Simulated S-parameters



(b) Simulated effective permittivity



(c) Simulated effective permeability



(d) Distributions of the electric and magnetic fields

Fig. 4 Characteristics of the ELC resonator.

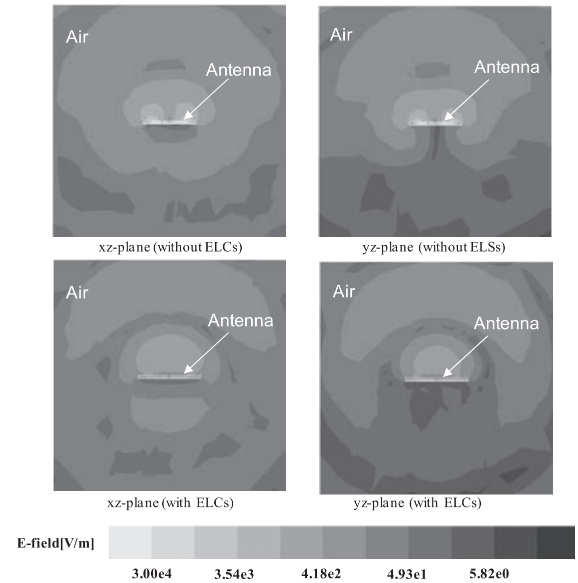


Fig. 5 Radiated E- fields of antenna with/without ELCs at 2.45 GHz.

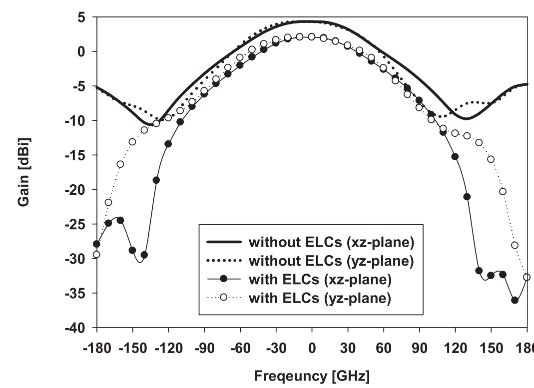
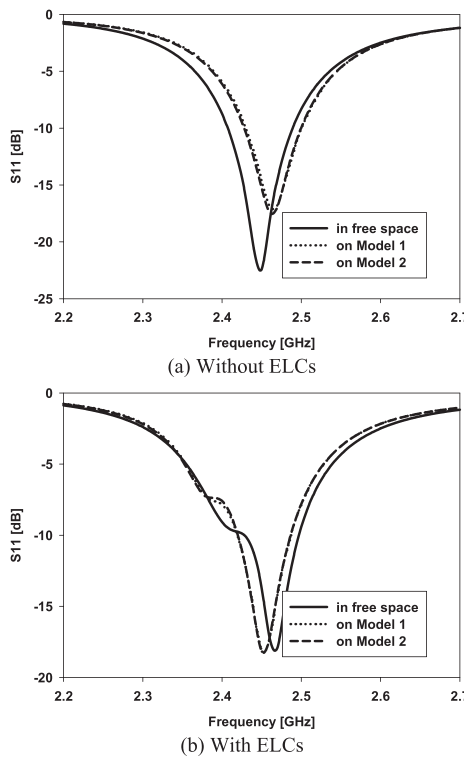


Fig. 6 Simulated radiation patterns of antenna with/without ELCs at 2.45 GHz.

Table 1 Human body models.

Model No.	Shape / size [mm]	Material properties	
1	Flat body tissue 200×200×50	ε_r=52.7, σ=1.95 S/m, tanδ=0.27	
2	Flat body tissue 200×200×45	Skin (2 mm)	ε_r=38.01, σ=1.464 S/m, tanδ=0.283
		Fat (3 mm)	ε_r=5.28, σ=0.1 S/m, tanδ=0.145
		Muscle (30 mm)	ε_r=52.93, σ=1.739 S/m, tanδ=0.242
		Bone (10 mm)	ε_r=18.55, σ=0.81 S/m, tanδ=0.32

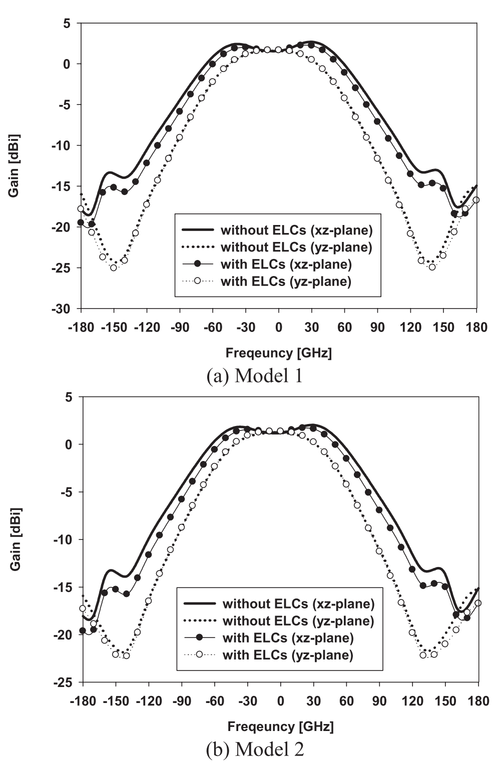
out ELCs, are 21.7 dB and 16.5 dB at 2.45 GHz, respectively, when the antenna is placed on human body models as shown in Fig. 8. Figure 9 shows the SAR distributions of the proposed antenna located on body models. In the simu-



(a) Without ELCs

(b) With ELCs

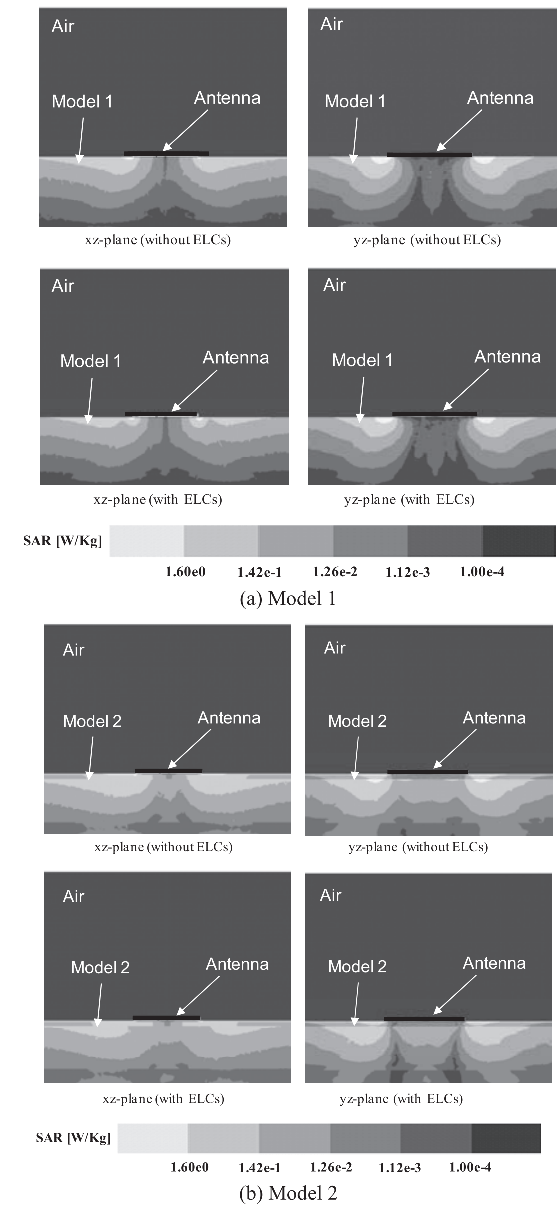
Fig. 7 S_{11} characteristics of antenna on body models.



(a) Model 1

(b) Model 2

Fig. 8 Simulated radiation patterns on body models at 2.45 GHz.



(a) Model 1

(b) Model 2

Fig. 9 Simulated SAR distributions on body models at 2.45 GHz.

lation, the input power is normalized as 1 W. Owing to the decrease of the E- and H-fields at the back of ground plane by ELCs, the local SAR value in Model 2 is decreased from 1.67 W/kg to 1.26 W/kg.

4. Experimental Results

Figure 10 is a photograph of the fabricated antenna. The antenna structure is designed and analyzed using a high frequency structure simulator (HFSS Ver.12) [14]. A flat phantom, with dimensions of 300 mm × 200 mm × 200 mm, is used to measure the radiation performances of the fabricated antenna. It is filled with an equivalent liquid-to-body tissue at 2.45 GHz.

The measured S_{11} characteristics are illustrated in Fig. 11. When the antenna is placed on the flat phantom, the S_{11} values of the patch antenna, with and without ELCs, are −19.06 dB and −6.74 dB at 2.45 GHz, re-

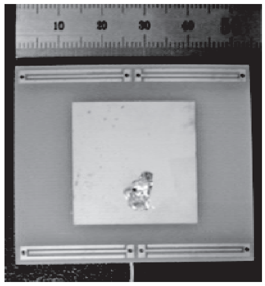


Fig. 10 Photography of the fabricated antenna.

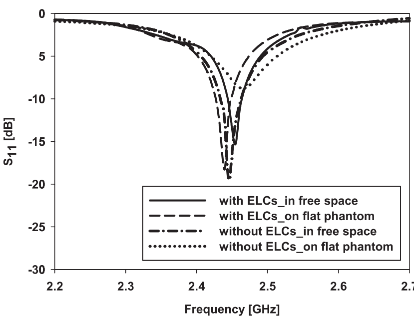
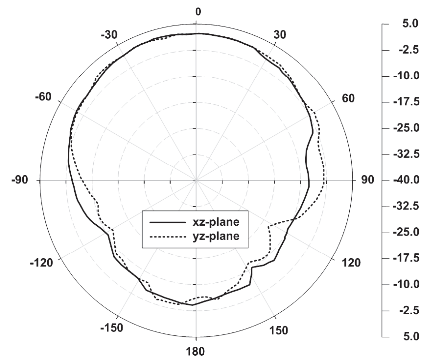


Fig. 11 Measured S_{11} characteristics of the antenna on a flat phantom.

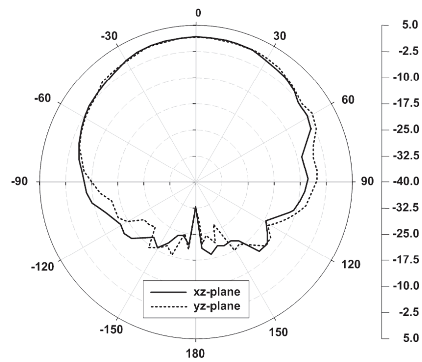
spectively. The −6 dB impedance bandwidth of the antenna without ELCs is 65 MHz (2.435 GHz~2.5 GHz) and that of the antenna with ELCs is 105 MHz (2.385 GHz~2.49 GHz), which is sufficient to cover the 2.45 GHz ISM band (2.4 GHz~2.485 GHz).

Figure 12 shows radiation patterns measured in an anechoic chamber. The simulated and measured results of the proposed antenna are summarized in Table 2. The back radiation in free space is certainly reduced by adding the ELC resonators. However, the reduction of the back radiation, by using the ELC resonators on flat phantom, becomes small, because the resonant characteristic of ELC is changed by the electrical properties of the flat phantom. It is recommended that one should consider the effect of the human body carefully when a resonator structure, such as ELC, is designed. The patch antenna with ELCs on the flat phantom has a peak gain of 1.7 dBi, while the patch antenna with ELCs in free space has a peak gain of 2.0 dBi at 2.45 GHz. The front-to-back ratios, with and without ELCs, are 23.7 dB and 19.2 dB at 2.45 GHz, respectively.

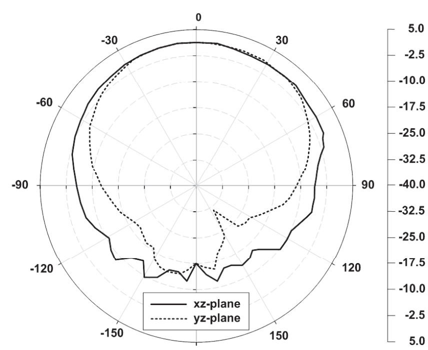
The SAR is an essential factor when the antenna is operated on, or inside, the human body. The SAR was measured at the Radio Research Agency, using the ESSAY system [16]. The proposed antenna is excited by the spectrum analyzer. Figure 13 shows the measured SAR distributions of the proposed antenna located on the flat phantom. When we measured the SAR distribution, the coaxial feeding cable was placed under the substrate along the positive x-axis. It caused the unsymmetrical property in the SAR distribution, shown in Fig. 13. Since the input power required to measure the SAR of handset antennas, at the 1800 MHz frequency band, is generally 250 mW, the same input power is used to measure the SAR of the proposed antenna. The SAR distribution was scanned in the tissue simulating liquid at 5 mm above the inner surface of the phantom shell. The Federal Communications Commission (FCC) of the United States



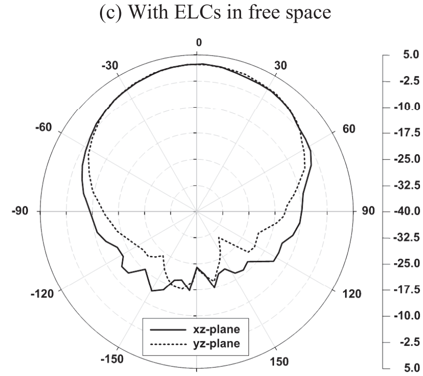
(a) Without ELCs in free space



(b) Without ELCs on the phantom



(c) With ELCs in free space



(d) With ELCs on phantom

Fig. 12 Measured radiation patterns at 2.45 GHz.

Table 2 Simulated and measured results.

		In free space		On flat phantom (Model 1)	
		Peak gain [dBi]	F/B [dB]	Peak gain [dBi]	F/B [dB]
Simulated	Without ELCs	4.2	9.1	2.5	16.5
	With ELCs	2.6	34.8	2	21.7
Measured	Without ELCs	3.0	19.2	1.5	9
	With ELCs	2.0	34.6	1.7	19.2

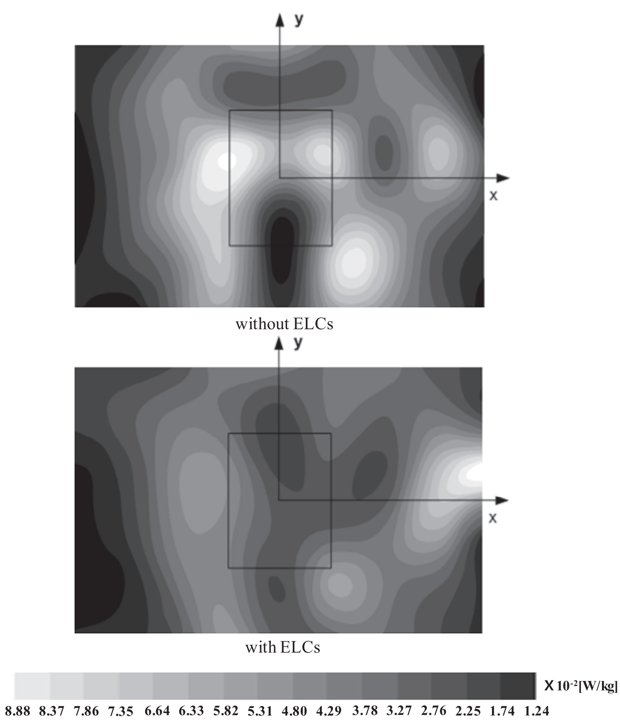


Fig. 13 Measured SAR distributions at 2.45 GHz.

requires that the input power should be below 1.6 watts per kilogram (W/kg) over a volume of 1 gram of tissue to evaluate SAR [13]. When the proposed antenna is placed on Model 1, the SAR value of the proposed antenna is reduced from 0.073 W/kg (1 g tissue) to 0.05 W/kg (1 g tissue) by adding the ELC structure.

5. Conclusions

In this paper, a microstrip patch antenna for wireless body area network applications is proposed. To enhance the front-to-back ratio, an electrically LC resonator structure is introduced. The overall dimension of the proposed antenna is 53 mm × 45 mm × 2.4 mm and it has a gain of over 1 dBi over the entire 2.45 GHz ISM band. The proposed antenna has enhanced F/B and SAR performances compared to those of conventional patch antenna.

Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST) (no. 2010-0017934).

References

[1] P.S. Hall and Y. Hao, eds., Antennas and Propagation for Body-Centric Wireless Communications, Artech House, 2006.
[2] Q. Yuan, C.H. Liang, Q. Chen, and K. Sawaya, "A new type of PIFA built in portable telephone to alleviate the absorption of human body," Chinese Journal of Electronics, vol.7, no.1, pp.18–23, 1998.
[3] N. Haga, K. Saito, M. Takahashi, and K. Ito, "Characteristics of cavity slot antenna for body-area networks," IEEE Trans. Antennas Propag., vol.57, no.4, pp.837–843, April 2009.
[4] F.J. Wang and J.S. Zhang, "Wide band cavity-backed patch antenna for PCS/IMI2000/2.4 GHz WLAN," Progress in Electromagnetics Research, PIER, vol.74, pp.39–46, 2007.
[5] Y. Rikuta, H. Arai, and Y. Ebine, "Reflector shape optimization for FB ratio of dipole antenna," Asia-Pacific Microwave Conference, Taipei, Taiwan, June 2001.
[6] R.Y.-S. Tay, Q. Balzano, and N. Kuster, "Dipole configuration with strongly improved radiation efficiency for hand-held transceivers," IEEE Trans. Antennas Propag., vo1.46, no.6, pp.798–806, June 1998.
[7] J. Wang and O. Fujiwara, "Reduction of electromagnetic absorption in the human head for portable telephones by a ferrite sheet attachment," IEICE Trans. Commun., vol.E80-B, no.12, pp.1810–1815, Dec. 1997.
[8] S. Zhu and R. Langley, "Dual-band wearable textile antenna on an EBG substrate," IEEE Trans. Antennas Propag., vol.57, no.4, pp.926–935, April 2009.
[9] J.B. Pendry, A.J. Holden, D.J. Robbins, and W.J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," IEEE Trans. Microw. Theory Tech., vol.47, no.11, pp.2075–2084, 1999.
[10] D. Schurig, J.J. Mock, and D.R. Smith, "Electric-field-coupled resonators for negative permittivity metamaterials," Appl. Phys. Lett., vol.88, 041109, 2006.
[11] J.D. Baena, J. Bonache, F. Martin, R. Marques Sillero, F. Falcone, T. Lopetegi, M.A.G. Laso, J. García–García, I. Gil, M.F. Portillo, and M. Sorolla, "Equivalent-circuit models for split-ring resonators and complementary split-ring resonators coupled to planar transmission lines," IEEE Trans. Microw. Theory Tech., vol.53, no.4, pp.1451–1461, April 2005.
[12] P. Gay-Balmaz and O.J.F. Martin, "Electromagnetic resonances in individual and coupled split-ring resonators," J. Appl. Phys., vol.92, no.5, pp.2929–2936, Sept. 2002.
[13] D.L. Means and W. Kwok, Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields, Federal Communications Commission Office of Engineering & Technology, Supplement C (Edition 01-01) to OET Bulletin 65 (Edition 97-01), June 2001.
[14] K.Y. Yazdandoost and R. Kohno, Medical Implant Communication System (MICS), IEEE 802.15-06-0342-00-0ban, July 2006.
[15] Ansoft High Frequency Structure Simulator (HFSS), Ver. 12.0, ANSYS Inc.
[16] http://emfsafety.koreasme.com/

Uisheon Kim received the B.S. and M.S. degrees in Electronic Engineering from Dankook University, Korea, in 2002 and 2004, respectively. She had worked for the EMW Antenna co., Ltd. as an associate Research Engineer of the R&D Center from 2004 to 2006. And She is currently working toward the Ph.D. degree at Hanyang University, Seoul, Korea. Her research interests include antenna and microwave circuit design.

Jaehoon Choi received the B.S. degree from Hanyang University, Korea, the M.S. degree and the Ph.D. degree from Ohio State University, Ohio, in 1980, 1986, and 1989, respectively. From 1989–1991, he was a research analyst with the Telecommunication Research Center at Arizona State University, Tempe, Arizona. He had worked for the Korea Telecom as a team leader of the Satellite Communication Division from 1991 to 1995. Since 1995, he has been a professor in the Department of Electronics and Computer Engineering at Hanyang University, Korea. He has published more than 100 refereed journal articles and numerous conference proceedings. He also holds over 20 patents. His research interests include antenna, microwave circuit design, and EMC. Currently, his research is mainly focused on the design of compact, multi-band antenna for mobile wireless communication, software defined radio (SDR) systems, and ultra-wideband (UWB) systems.