

Design of On-body Antenna for Wireless Body Area Network

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Abstract— In this paper, a patch antenna for 2.45 GHz ISM (Industrial Scientific Medical) band Wireless Body Area Network (WBAN) applications is proposed. To enhance specific absorption rate (SAR), an electrically coupled LC resonator is introduced. The overall dimensions of the proposed antenna are $54 \times 45 \times 2.4$ mm³ 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.

Keywords— WBAN, ELC, patch antenna, SAR, On-body

I. 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].

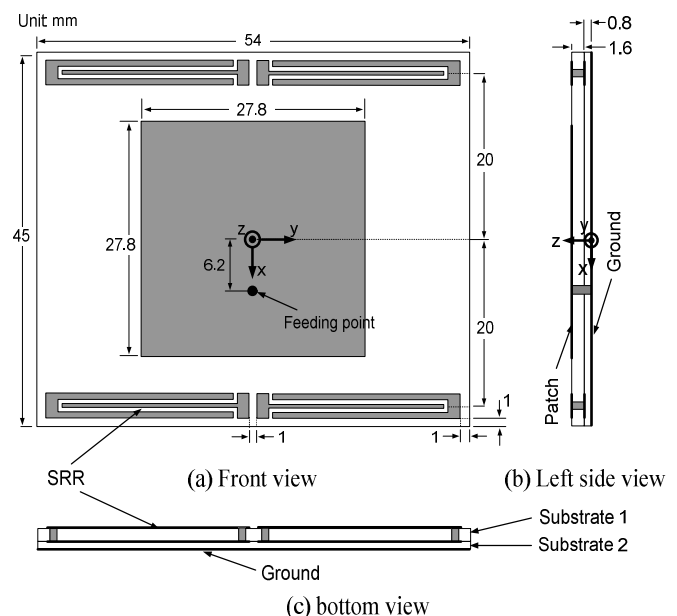
Since the human body has a high dielectric constant and conductivity at the microwave frequency band, the gain and radiation efficiency of an antenna can also be deteriorated as well as the input impedance and resonance frequency can be changed when an antenna is operated on or in the body. These effects can be even more serious in compact and low profile antennas. Moreover, 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 [2].

A patch 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 patch antenna is a critical drawback that needs to be overcome for human body applications.

This paper proposes a 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 analysed. Finally, performances of the antenna on human body tissues are investigated.

II. ON-BODY ANTENNA DESIGN

The proposed antenna has a two-layered substrate and consists of a rectangular patch antenna and four ELCs, as shown in figure 1. Two 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 patch is 27.8 mm $\times$ 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.



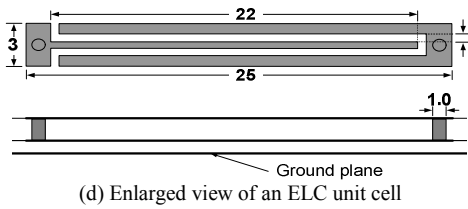


Figure 1. Configuration of the proposed antenna

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 3mm, a length of 25.5 mm, and a height of 1.6 mm. The three-dimensional ELC resonator is illustrated in figure 1(d).

The proposed antenna structure is designed and analyzed using SEMCAD X [3]. Figure 2 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 planes of the rectangular waveguide are set to perfect Magnetic conductor (PMC).

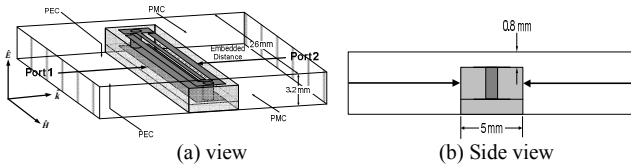
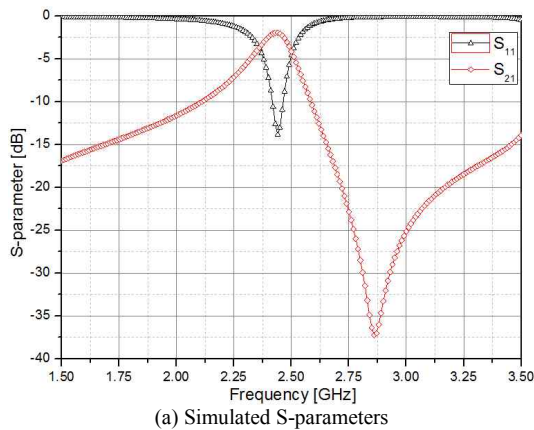
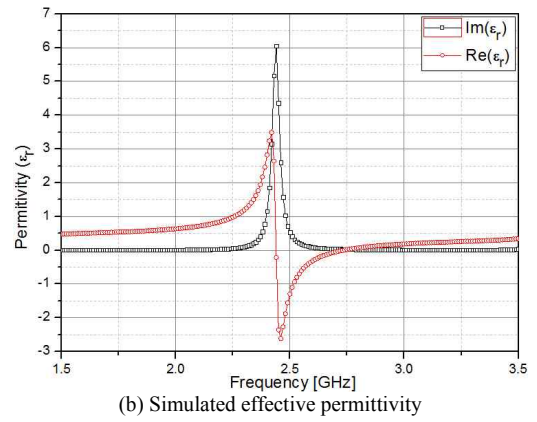


Figure 2. Electric excitation of the ELC unit cell

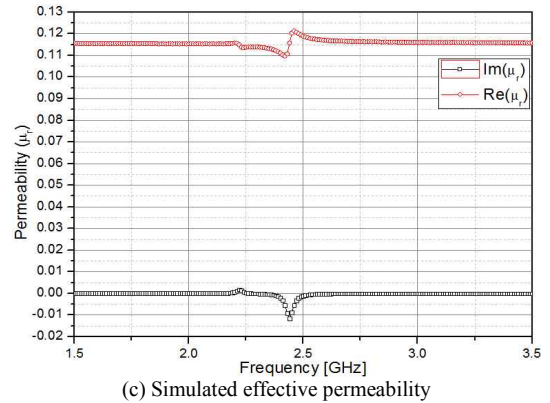
Figure 3 shows the simulated characteristics of the 3D ELC unit cell with inter-digital structure. When the electric field excites normally to the capacitor plate by the patch, the capacitive element couples strongly to the electric field and the inductive loops do not. Thus, it generates a strong electric resonance with negative permittivity, as shown in figure 3(b). Using the methods suggested in [4] and [5], it can be shown that the ELC has negative effective permittivity and low permeability values at 2.45 GHz. Microwaves are unable to propagate in a medium with a negative electrical property ($\epsilon < 0$ 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.



(a) Simulated S-parameters



(b) Simulated effective permittivity



(c) Simulated effective permeability

Figure 3. Characteristics of the ELC resonator

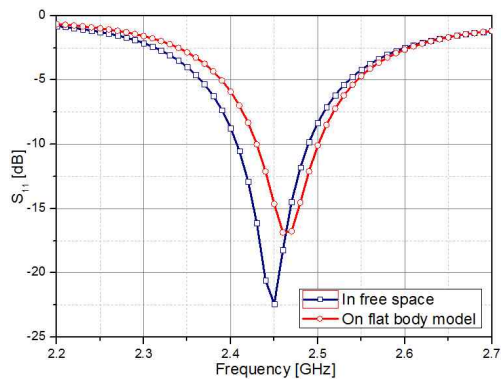
In order to analyze and measure the antenna performance on the human body, simulations and measurements were carried out after placing the proposed antenna on the flat human body models. Electrical properties of flat human body model used in this study are summarized in Table 1 [6].

TABLE 1. ELECTRICAL PROPERTIES OF FLAT HUMAN BODY MODEL

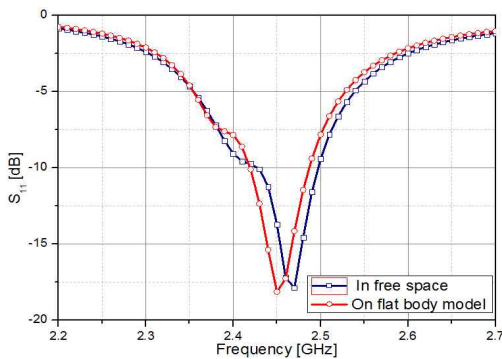
Shape	size [mm]	Material properties
Flat body model	200×200×50	$\epsilon_r=52.7$, $\sigma=1.95$ S/m, $\tan\delta=0.27$

Figure 4(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.

Figure 5 shows the simulated radiation patterns of the proposed antenna in free space and on flat body model. 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 figure 3(b). Figure 5(a) shows in free space, 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. The front-to-back ratios of the patch antenna with and without ELCs are 21.7 dB and 16.5 dB at 2.45 GHz, respectively, when the antenna is placed on flat body model as shown in figure 5(b).

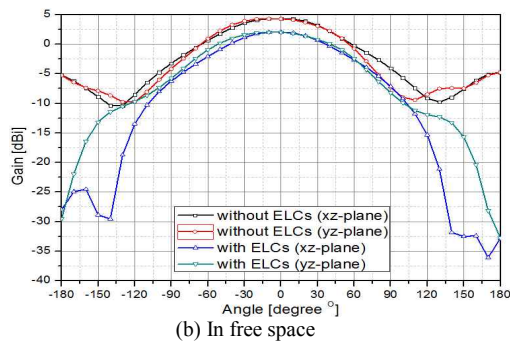


(a) Without ELCs

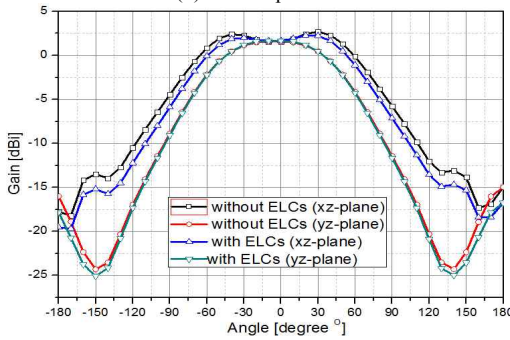


(b) With ELCs

Figure 4. Simulated S_{11} characteristics of antenna on flat body model.



(b) In free space



(b) On flat body model

Figure 5. Simulated radiation patterns of antenna with/without ELCs at 2.45 GHz.

For the SAR simulation, 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 is decreased from 1.67 W/kg to 1.26 W/kg.

III. EXPERIMENTAL RESULTS

Figure 6 is a photograph of the fabricated antenna. A flat body model 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.

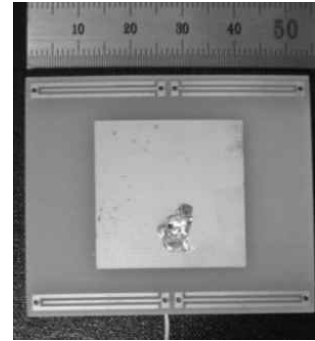


Figure 6. Photography of the fabricated antenna.

The measured S_{11} characteristics are illustrated in figure 7. When the antenna is placed on the flat body model, the S_{11} values of the patch antenna with and without ELCs are -19.06 dB and -6.74 dB at 2.45 GHz, respectively. 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).

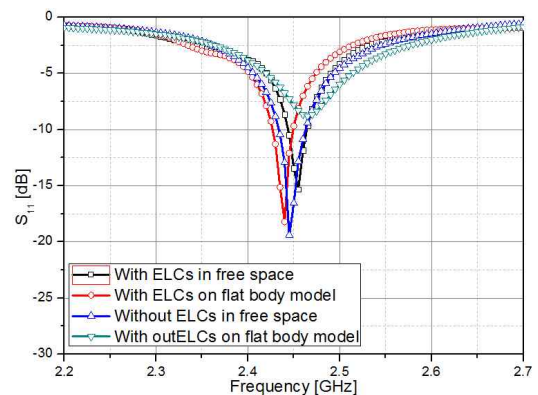


Figure 7. Measured S_{11} characteristics of the antenna on a flat phantom.

The simulated and measured results of radiation for 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 body model, 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.

TABLE 2. SIMULATED AND MEASURED RESULTS OF GAIN AND F/B

		In free space		On flat body model	
		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

The SAR is an essential factor when the antenna is operated on or inside the human body. Figure 8 shows the measured SAR distributions of the proposed antenna located on the flat body model. 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 requires that the SAR values should be below 1.6 watts per kilogram (W/kg) over a volume of 1 gram of tissue to evaluate SAR [6]. When the proposed antenna is placed on flat body model, 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.

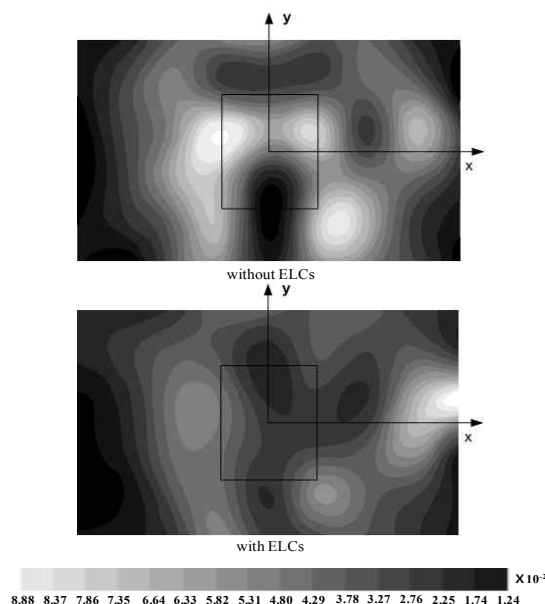


Figure 8. Measured SAR distributions at 2.45 GHz..

IV. CONCLUSIONS

In this paper, a patch antenna for wireless body area network applications is proposed. To enhance the front-to-back ratio, an electrically LC resonator structure is installed. 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.

ACKNOWLEDGMENT

Thanks to SPEAG for providing free license of SEMCAD X used in this study.

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