Simulation Analysis and Electromagnetic Dosimetry of Patch Antenna on Hugo Voxel Model

B.S. Yew[1], F.H. Wee[2], S. Bahri, M. Muhamad[1]
[1]*Faculty of Innovative Design and Technology,*
Universiti Sultan Zainal Abidin, Kampus Gong Badak,
21300 Kuala Terengganu, Terengganu, Malaysia.
[2]*Embedded Computing Research Cluster,*
School of Computer and Communication Engineering,
Universiti Malaysia Perlis, Jalan Kangar-Alor Star,
Taman Pertiwi Indah Seriab, 01000 Kangar, Perlis, Malaysia.
bseokyew@unisza.edu.my

***Abstract*—The off-body, on-body simulation analysis and electromagnetic dosimetry of a simple structure patch antenna operating in 2.45 GHz ISM band is presented. The antenna design is based on conventional structure with flexible substrate features and copper as the conductive plane. The simulation analysis was performed in CST Microwave Studio. Anatomic simulation using HUGO voxel model was used for on-body simulation and electromagnetic dosimetry. For off-body analysis, the antenna resonates at 2.45 GHz with S11 parameter of -32.56 dB and radiates unidirectionally with efficiency of 91.96 %. It was found that the presence of human lossy tissues and organs caused frequency detuning of 50.4-51.5 MHz and radiation efficiency degradation of 7.93 % to 13.78 %. The electromagnetic dosimetry on specific absorption rate (SAR) exposure of the antenna when it is mounted over averaged 10 g of tissues for chest, back, abdomen, arm and thigh was well below the IEEE Std. C95.3 limit. The maximum and minimum SAR was found when the antenna was placed on the back (0.332 W/kg) and arm (0.121 W/kg) respectively on the human body. Varying the distance from 0-20 mm of the antenna from the human body reduces the SAR exposure to the human body.**

***Index Terms*—Patch antenna; Off-body; On-body; Specific absorption rate (SAR).**

I. INTRODUCTION

Body centric wireless communication refers to human-self and human-to-human networking with the implementation of wearable devices. It is useful in medical applications such as therapeutic and diagnostic as well as personal healthcare [1-5]. Wearable antennas are major component of body-centric wireless communications. There has been tremendous demand for the wearable antenna design to be light-weight, thin, bendable and at the same time exhibit desirable on- and off-body performances [6-8]. Electromagnetic (EM) dosimetry is the evaluation of the energy absorbed by a biological system resulting from the exposure to EM fields. In non-ionising EM dosimetry over ISM band at 2.45 GHz, the dose quantity is due to the absorbed power per unit mass known as the specific energy absorption rate (SAR). The SAR represents the power absorbed by a unit of mass, expressed in W/kg. In human body tissues, SAR is proportional to the square of the internal electric field generated by the source of the exposure, to the conductivity of the tissue and to the inverse of the density of the tissue [9, 10]. The limitations of SAR exposure based on the 10-g average SAR for the localized parts of the body, for example head and trunk and limbs are based on IEEE Std. C95.3 [11]. The limitations of SAR exposure for the frequency range from 100 kHz to 300 GHz are listed in Table 1.

For frequencies from 100 kHz to 300 GHz, exposure to non-ionising EM radiation at these frequencies can lead to significant absorption of energy and tissue heating [12].

Table 1
Limitation of SAR exposure

Frequency range	Limitation of SAR exposure (W/kg) Localized SAR (Head, trunk)	Localized SAR (Limbs)
100 kHz- 300 GHz	2	4

II. ELECTROMAGNETIC DOSIMETRY ON SPECIFIC ABSORPTION RATE (SAR) USING COMPLEX BODY MODEL WITH REALISTIC MATERIALS

The need for SAR measurements within models of exposed personnel is two-folds. First, over the frequency range where SAR is meaningful (approximately 100 kHz–6 GHz), it is the underlying basis for the maximum permissible exposure values found in many RF safety standards and guidelines such as IEEE Std 95.1, IEEE Std 95.3 and ICNIRP Guidelines [11, 13, 14]. The second need for determining SAR is that even under far-field plane-wave exposure conditions, the SAR varies widely with frequency, polarization, and spatial location within an object. The determination of the SAR provides a much-needed insight into the spatial distribution of absorbed energy, particularly with respect to different organs of the exposed subject.

In order to investigate the SAR in the human body that is exposed to the EM radiation under different types and conditions of radiation experimental, complex body model with realistic materials is preferred. In this simulation study, CST microwave studio Hugo Voxel model was used. Hugo voxel model is based on the Visible Human Project and represents a 38-year-old male (187-cm height and 113 kg-weight), offers a voxel resolution ranging from 8x8x8 mm^3 to 1x1x1 mm^3, and has a total of 32 different tissue types. This human model was discretized with 200 million grid cells, which corresponds to a resolution of 1.5mm [10].

III. Antenna Structure

The structure of the patch antenna used in the simulation analysis is based on the conventional microstrip antenna design operating at 2.45 GHz (single band resonance). Bendable foam material with measured dielectric constant (ε') of 2.331 and thickness of 2mm was used as the substrate whereas copper was used as the radiator and ground planes. Figure 1 shows the layout of the patch antenna. The dimension of the antenna is based on the reference [6].

IV. Result and Discussion

A. Off-body (Free Space)

Simulations were carried out in CST MWS. Firstly, the off-body (free space) performance of the antenna was investigated. The antenna resonates at 2.45 GHz with a S11 parameter of -32.56 dB and impedance bandwidth of 50 MHz. The VSWR is at 1.05. Figure 2 shows the performance of antenna in free space. The antenna radiates unidirectional with 7.23 dB gain and radiation efficiency of 91.96 %.

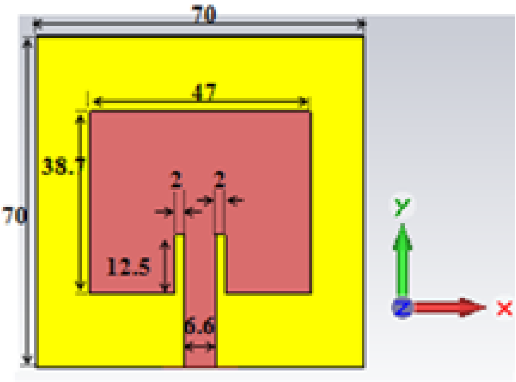
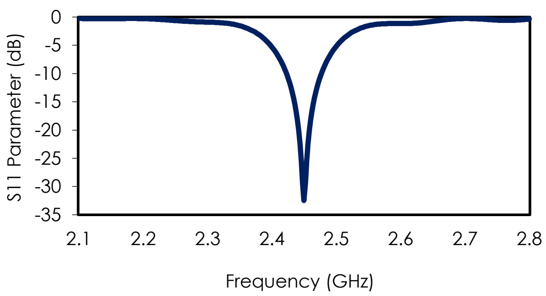


Figure 1: Conventional structure of patch antenna



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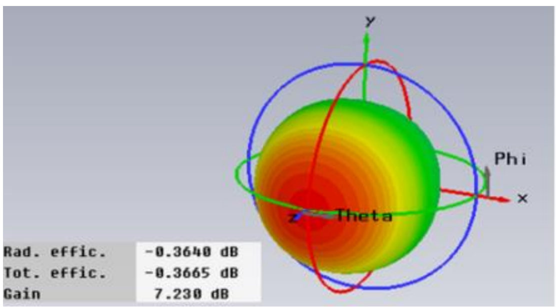

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Figure 2: Off body analysis of the patch antenna: (a) S11 parameter; (b) 3D radiation pattern

B. Effect of Antenna Placement on Antenna Performance

The prototype of the patch antenna was analysed in the vicinity of human body, particular on the chest, back, abdomen, arm and thigh, as illustrated in Figure 3. The summary of off- and on-body results is tabulated in Table 2.

Figure 3: Different antenna placement on Hugo voxel model (human body): (a) chest; (b) back; (c) abdomen; (d) arm; (e) thigh

Table 2
On- and off-body simulated results

Antenna Placement	Resonant Frequency, f_r (GHz)	Bandwidth (MHz)	S11 (dB)	Radiation Efficiency (%)
Off body	2.450	54.0	-32.46	91.96
Chest	2.466	51.2	-29.47	78.72
Back	2.466	50.4	-32.08	78.18
Abdomen	2.466	50.5	-29.16	78.45
Arm	2.466	51.5	-27.42	84.03
Thigh	2.466	50.6	-29.56	80.92

The S11 parameter of the antenna for off- and on-body simulation analyses is shown in Figure 4. It can be observed that there was frequency detuning when the antenna was mounted on the human body. The resonant frequency has been detuned (shifted) up from 50.4 to 51.5 MHz. It was found that the radiation efficiency of the antenna reduced by 7.93% to 13.78%, when it was mounted on human body (Figure 5). Presence of the lossy human tissues and organs with the variation in permittivity causes frequency detuning and degrades the performance of the antenna [8].

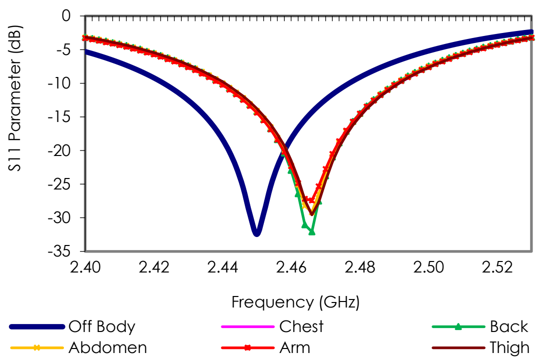


Figure 4: Off-body and on-body S11 parameters of the patch antenna

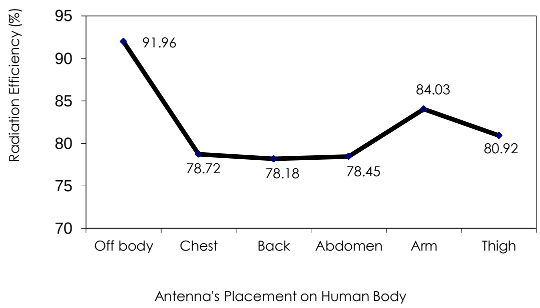
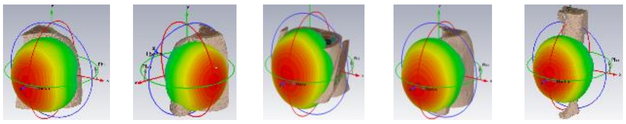


Figure 5: Radiation efficiency of antenna for off- and on-body simulation

The 3D radiation pattern with the presence of human body model is shown in Figure 6. The radiation pattern differs from one orientation to another with respect to the position of antenna placement on human body. The maximum radiation was observed in the direction that is away from the body most of the time.



(a) (b) (c) (d) (e)

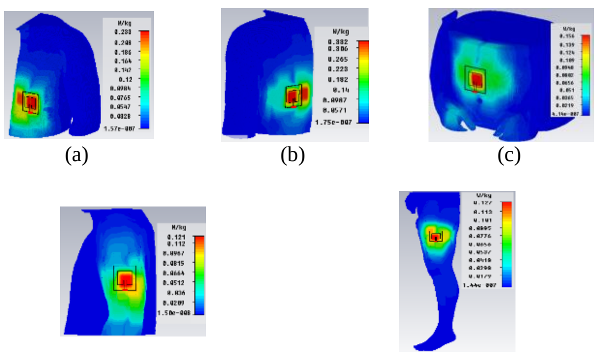
Figure 6: 3D radiation pattern of the antenna in the presence of human body: (a) chest; (b) back; (c) abdomen; (d) arm; (e) thigh

C. *Electromagnetic Dosimetry on SAR Exposure*

Table 3 and Figure 7 present the SAR with respect to the antenna placement on human body. The maximum SAR, 0.322 W/kg was found when the antenna was placed on the back of the human body. Whereas the minimum SAR, 0.121 W/kg was found on the arm. This is due to the larger equivalent permittivity and conductivity of tissues, organs and muscle in comparison with a multilayer anatomical human body model, which includes layers of fat and skin which have a smaller permittivity and conductivity [15].

Table 3
Specific Absorption Rate (SAR)

Antenna Placement	SAR (W/Kg)
Chest	0.233
Back	0.332
Abdomen	0.156
Arm	0.121
Thigh	0.127



(a) (b) (c)

(d) (e)

D. *Effect of Varying Antenna Placement Distance from Human Body*

Varying the distance from 0-20 mm of the antenna from the human body reduced the SAR exposure to the human body. This was expected as the antenna is mounted further away from the human body, there will be lesser SAR exposure towards the human body (Refer to Figure 8). On the other hand, the radiation efficiency increases as the distance of antenna placement on human body increase. This is due to the lesser human tissues and organs losses that are experienced. The radiation efficiency versus frequency is plotted in Figure 9. Varying the distance of the antenna from the human body barely change the S11 parameter of the antenna. This is because the ground plane of the antenna is large enough that it allows the antenna to be insensitive to the proximity of the human body [16]. Figure 10 shows the plot of S11 change versus frequency spectrum with respect to the antenna placement distance.

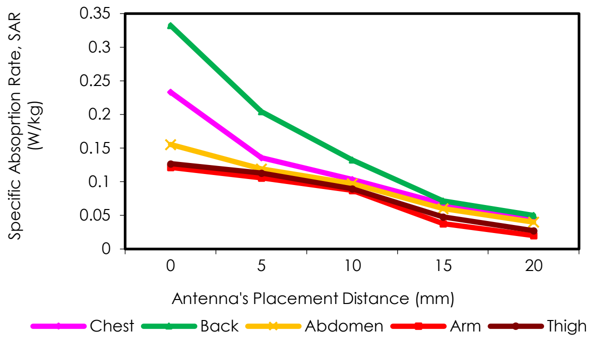


Figure 8: SAR versus antenna placement distance from human body

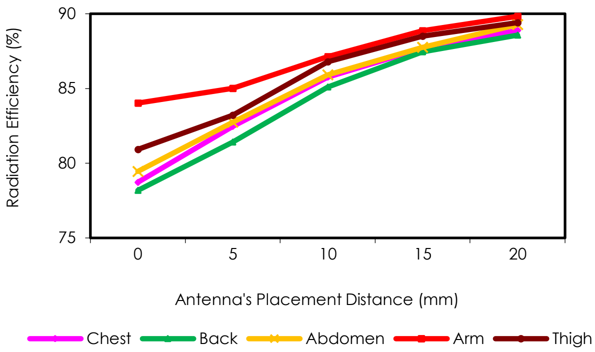
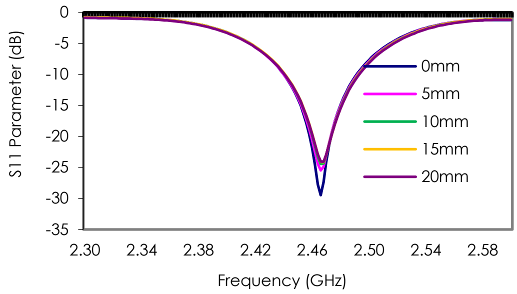


Figure 9: Radiation efficiency versus antenna placement distance from human body



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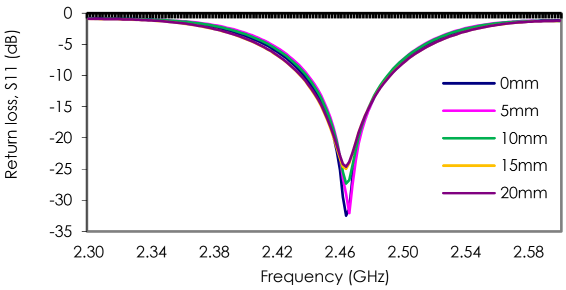

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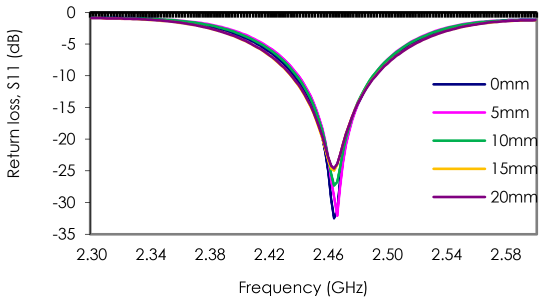

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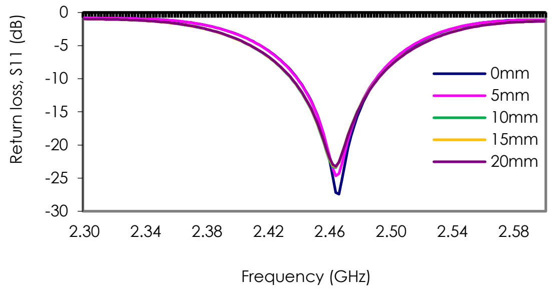

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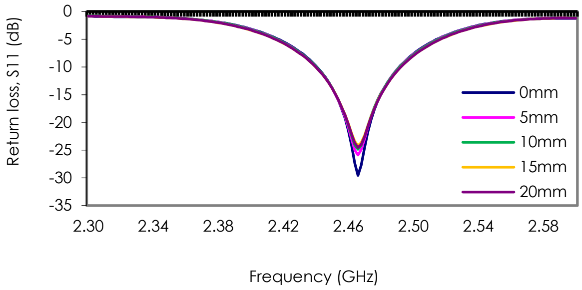

(e)

Figure 10: S11 versus frequency: (a) chest; (b) back; (c) abdomen; (d) arm; (e) thigh

V. Conclusion

The presence of the human tissue and organs results in frequency detuning and degradation of the radiation efficiency. In this simulation analysis, it was found that electromagnetic dosimetry on SAR exposure of the antenna over averaged 10 g of tissues on the human body (chest, back, abdomen, arm and thigh) was well below the IEEE Std. C95.3 limit of 2 W/kg. It was also found that the effect of varying the distance of the antenna from the human body causes a decrease in SAR. However, the S11 of the antenna barely changed when the antenna was placed further away from the human body.

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