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Frequency Dependence of Radiation Efficiency of Antennas Inside Human Body

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Abstract: In recent years, body-centric wireless communications (BCWCs) has become an active area of research because it has various applications such as health-care, personal communications and so on. In this study, the radiation efficiency of antennas inside human body is calculated from 10MHz to 1GHz to evaluate the transmission characteristics through human body, and the performance of the radiation efficiency is studied. Simulation is completed mainly by the finite-different time domain (FDTD) method.

Keyword: body-centric communication, FDTD, dipole antenna, radiation efficiency.

1. Introduction

Body-centric wireless communications (BCWCs) is becoming more and more important in medical applications [1]. The BCWCs mainly includes three manners in terms of propagation channel: on-body communication, in-body communication and off-body communication [2]. In-body communication means communications using implantable devices. The design of antennas and the characterization of radio-wave propagation on BCWCs are being researched by many researchers around the world [2]. Most of the researches focused on on-body communications now, but few on in-body communications. Human body tissues are poor transmission medium. Because the frequencies for BCWCs widely range from 10MHz to 60GHz bands, how to choose an appropriate frequency band for individual applications is required in terms of transmission loss. The electric properties of the human body tissues, relative dimensions of the human body to wavelength, and the propagation channels around the body extremely are depend on frequencies [3], it is necessary to study the radiation performance of antennas inside human body with different frequency band in order to design and optimize the wireless communication system for BCWCs applications.

In this study, the radiation efficiency of antennas inside human body is calculated from 10MHz to 1GHz to evaluate the transmission characteristics through human body. A cylindrical model was used as a human body phantom as a first step, and a dipole antenna was embedded in the center of the model. The ground under the phantom is assumed to be PEC and have infinite dimensions. Software SEMCAD X and FEKO were used in the simulation.

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2. Simulation method

2.1 Formula

According to the view of conservation of energy [4], we can get

$$P_{in} = P_r + P_l \tag{1}$$

Here, P_{in} is the power delivered by the sources;
P_r is the power radiated to the space;
P_l is the power lost to heat in the volume whose definition is :

$$P_l = \frac{1}{2}\int_V \sigma \left|\vec{E}\right|^2 dv \tag{2}$$

The definition of the radiation efficiency is:

$$\eta_{rad} = \frac{P_r}{P_{in}} \tag{3}$$

2.2 Simulation software and hardware

FDTD method is widely used on BCWCs. There are many kinds of software based on the FDTD, such as CST's Microwave Studio (Germany), XFDTD packages by REMCOM (USA) and so on. In this study, software SEMCAD X is used which is a 3D full wave simulation environment provided by SPE AG.

In this study, the computing use GPU in order to improve the computing speed and reduce the calculation time. The hardware is shown in Tab.1.

Table.1 Simulation hardware

Hardware	Details	Numbers
CPU	Intel(R) Core(TM)i7-4820K @ 3.70GHz 3.70GHz	1
GPU	NVIDIA GeForce GTX780 3GB	3
Memory	8GB DDR3-1600 (Total:32GB)	

2.3 Simulation Model

A circularity cylindrical dielectric with uniform dielectric constant was used as the phantom of human body. This kind of phantom is called theoretical phantom. The height of the cylindrical represents the human's height, and the perimeter represents the mean numerical circumference of the chest, waist and hip of the human body. The ground under the phantom is represented by PEC and has infinite dimensions.

Some researchers also use dipole antenna inserted into the subcutaneous fat layer of the body[5]. In this study a small dipole antenna was embedded into the middle of the phantom vertically as shown in Fig. 1.

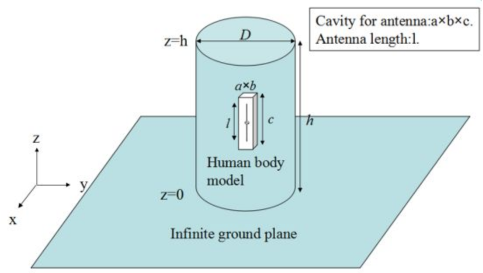

Fig. 1 Simulation Model

The cavity is： $a \times b \times c = 40 \times 40 \times 160mm$;
Dipole antenna size： $l = 137mm$.

2.4 The electrical parameters of human body

We can assume that the human body model has homogeneous dielectric properties [6].We set the relative permittivity to 42, and set the electric conductivity to 0.6 as a first step.

2.5 Time step and Grid

In order to satisfy the Courant stability condition, the time step and the grid should be according to the following formula:

$$v\Delta t \le \frac{1}{\sqrt{\left(\frac{1}{\Delta x}\right)^2 + \left(\frac{1}{\Delta y}\right)^2 + \left(\frac{1}{\Delta z}\right)^2}} \quad (4)$$

When the grids are set to $\Delta x = \Delta y = \Delta z = \Delta$,

The above formula can be rewritten as:

$$v\Delta t \le \frac{\Delta}{\sqrt{d}} = \frac{\Delta}{\sqrt{3}} \quad (5)$$

In the condition of $D = 280mm, h = 170cm$, the grid settings as shown in Tab.2 ,and the time step factor is set to 1 in this simulation.

Tab.2 Grid settings

Frequency	Δ
10MHz-20MHz	0.007λ
20MHz-100MHz	0.015λ
100MHz-300MHz	0.03λ
300MHz-500MHz	0.05λ
500MHz-1000MHz	0.07λ

2.6 Boundary conditions

The ABC (absorption boundary condition) is chosen in this simulation, and filled padding is set between the model and the ABC.

3. Result and analysis

The radiation efficiency from 10MHz to 1GHz is shown is Fig.2, the material of the dipole antenna is PEC.

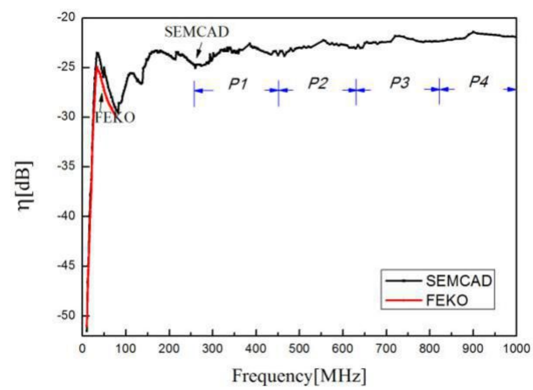

Fig. 2 Radiation Efficiency from 10MHz to 1GHz

The following results could be obtained through Fig. 2.

(1) The radiation efficiency is rather low.
(2) The radiation efficiency is extremely dropped in the range of 10MHz to 30MHz.
(3) With the frequency increased, the range of variation is become small and the radiation efficiency shows the periodical characteristics.

A detailed analysis of this phenomenon below:

(1) Because of the absorption of the human body's sake, overall radiation efficiency is low, because the radiation efficiency is rather low. Radiation efficiency is generally in the range of -25 to -30dB.

(2) In the range of 10MHz to 100MHz, software FEKO which based on the MoM method was also used to verify the results from SEMCAD.

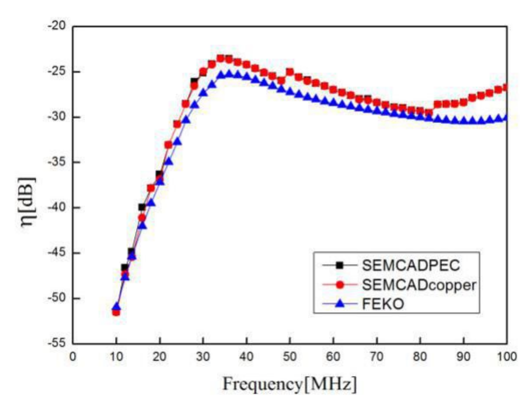

Fig. 3 Radiation Efficiency from 10MHz to 100MHz

SEMCAD software simulation results are shown in Fig. 3. Whether the material of the antenna is selected as PEC or copper, the results are almost the same. The simulation results using software FEKO is very similar with the results using SEMCAD, in some frequencies the results are nearly 1-2dB lower than that use SEMCAD. It is probably because the computational electromagnetic s algorithm of these two software are different and the value of the results are too small to avoid the errors come out.

The radiation efficiency is extremely dropped in the range of 10MHz to 30MHz.The first peak appears at 30-40MHz.In this study, it is dispensable to evaluate interactions between the human body and the electromagnetic(EM) waves radiated from the antennas. Here, there are two kinds of interactions: an influence of the human body phantom on the performance of antennas and an influence of EM waves on the human body phantom. The reason why the radiation efficiency is extremely dropped below 30MHz is related to the performance of the embedded dipole antenna. The dipole antenna below 30MHz where most of the energy is concentrated in the very near distance of the antenna. The lower the frequency, the more energy was concentrated, which was consumed by the phantom. In order to study it we Observed the electric field strength along the Y axis(z =850mm) direction observation in 10MHz and 35MHz in two cases of electric field strength, as shown in Fig. 4.

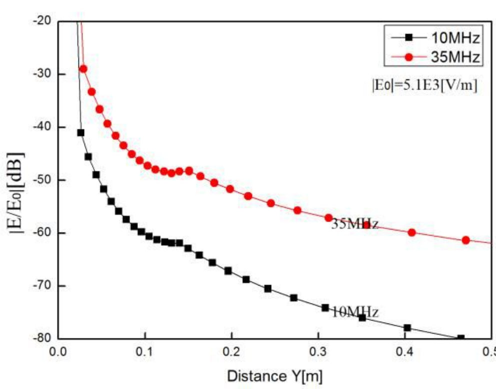

Fig. 4 Electric field value along the Y axis

As shown in Fig.4, the electrical field distribution are different in 10MHz and 35MHz.X =0 is the central axis of the phantom and the inflection point of the curves is the junction between the body and the space. The value of the electric field inside the phantom is relatively larger at 10MHz, and the value of the electric field in the space is larger at 35MHz.The more energy radiated from the phantom leads to the radiation efficiency larger.

(3) As the frequency increased, the range of variation is become small. From 260MHz nearby, the variation of the radiation efficiency shows the periodical characteristics. Efficiency changes become flat with the increase of the frequency. In Fig.2 the frequency range of P1, P2, P3 and P4 shows the periodic characteristics and the range is about 180MHz. In order to find the reason of the periodic characteristics, we designed the following two groups of simulations. In this phantom, there are two most important parameters: diameter D and height h. The numerical simulation was performed by changing the diameter of the phantom while fixing the height of the phantom, and by changing the height while fixing the diameter. The results are shown in Fig. 5 and Fig. 6.

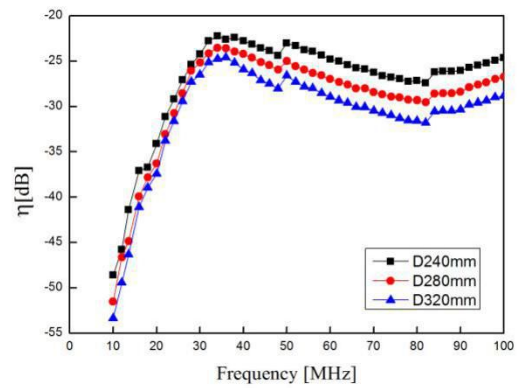

Fig. 5 Radiation Efficiency with the diameter of phantom.

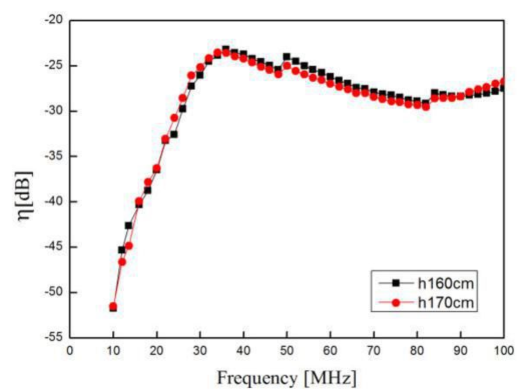

Fig. 6 Radiation Efficiency with the height of phantom.

Fig.5 shows that the diameter of the phantom has great effect on the radiation efficiency of the antenna, when the diameter increase 40mm, the efficiency dropped about 2-3dB. Fig. 6 shows that the height of the phantom also has effect on the radiation efficiency, but not as obviously as the diameter. Thus, it can be inferred that the radius of the cylindrical phantom may be a important reason of the periodic variation of the radiation efficiency.

4. Future research

In this study a relatively simple uniform dielectric constant phantom was used. However, in fact the relative permittivity and electrical conductivity of human body tissues varying with the frequency. According to the Debye equation: $\varepsilon_r = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau} + \frac{\sigma}{j\omega\varepsilon_0}$ (6).

The parameters in the equation could be found in[8]. Permittivity and electrical conductivity of the muscle could be calculated approximately [8]. In this study we do not take into account these factors for the reason that these factors would make the results much more complicated. For example, an approximate solution which dielectric properties of human body depend on frequency was presented in Fig.7. This approximate solution could be used in the future simulation in order to obtain more accurate results.

5. Conclusions

In this study, frequency characteristics of body-centric wireless communications was numerically calculated in a wide range of 10MHz to 1GHz.The radiation efficiency was rather low through the body and was extremely dropped in the range of 10MHz to 30MHz.As the frequency increased, the range of the variation is become smaller and the variation of the radiation efficiency shows the periodical characteristics.

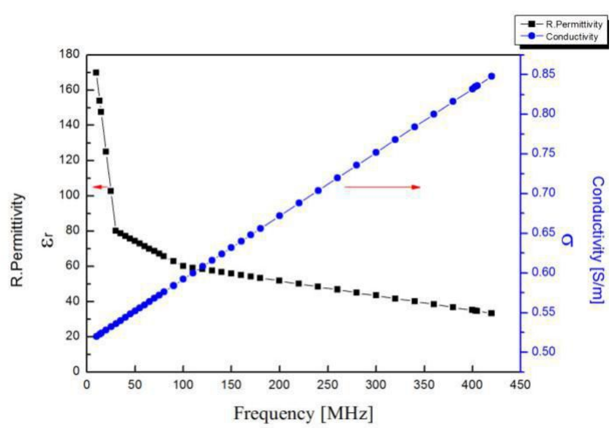

Fig. 7 Relative permittivity and electrical conductivity of human body tissues varying with the frequency.

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