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To Study the Mathematical Analysis for Human area Networking using Finite Element Method

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Abstract

Human area network (HAN) makes use of human body as a medium for transmission of signal. This is also known as RED TACTON. Because of its unique characters, this technology can be said as a novel and promising technology many applications in the fields such as personal area network (PAN), computer network access, implant biomedical monitoring, human energy transmission, etc. In this paper, work has been carried out for analyzing the electrostatic coupling for the RED TACTON technology by performing computer simulation using the developed finite-element models, in which (1) we have the incidence and reflection of electronic signal in the upper arm model which were analyzed by using the theory of electromagnetic wave, (2) the finite-element models of electrostatic coupling were developed by using the electromagnetic analysis package of ANSYS software, (3) the signal attenuation of electrostatic coupling were simulated under the conditions of different signal frequency, electrodes direction, electrodes size & transmission distance. Finally, important conclusions are deduced on the basis of simulation results.

Keywords

Human area network (HAN), electrostatic coupling, finite-element, personal area network

1. Introduction

RED TACTON is a communication technology in which human body is used as a signal transmission medium. Compared with the current short distance wireless technology, including Bluetooth, Zigbee and so on, it has the characteristics of high transmission quality, high data rate, high security, easy network access and no communication bandwidth problem, etc. Due to its unique characters, this technology is proposed as a novel and promising technology for personal area network (PAN) [1], computer network access [2], implant biomedical monitoring[1,3], human energy transmission [1,3,4], etc.

Lot many discussion has been carried out about the interaction between the electrical signal and human body [5], but from research point of view little work has been done to describe the transmission mechanism of the electrical signal in human body by using the method of theoretical analysis. In this paper, the transmission process of electronic signal in the upper arm of human body is analyzed by using the relative theory of electromagnetic wave.

Compared with the waveguide type, the electrostatic coupling type HAN communication [6], which has the advantages of low attenuation, easy realization and low power consumption, is a promising approach for such data transmission. However, the investigation of the simulation primarily focuses on the type of waveguide required for this type of communication, little investigation has been done in the computer simulation of the electrostatic coupling RED TACTON communication. As a result, its relative problems remain unsolved. In this paper, simulation of electrostatic coupling has been done on the basis of finite-element models. The finite-element models of upper arm, electrostatic coupling electrodes, air medium and the ground are developed firstly by using the electromagnetic analysis package of ANSYS, then the attenuations were simulated under the conditions of different signal frequency, electrodes direction, electrodes size and transmission distance by using the developed model.

In this paper section 2 discusses the transmission mechanism of the electromagnetic wave in human body, Section 3 gives the signal attenuations under the conditions of different signal frequency, electrodes direction, & electrodes size. Finally, the conclusions are given in Section 4.

2. Theoretical analysis

The electromagnetic signal, which transmits in human body in an IBC system, can be equivalent to the time harmonic electromagnetic wave. In this paper, the transmission process of electromagnetic signal in an upper arm is divided into three processes, namely, incidence, reflection and effluence.

Meanwhile, it is assumed that: (1) Both the transmitter electrode and the receiver electrode of IBC system are considered as one point. (2) Only the first incidence and reflection are considered in every layer of the arm model. (3) Every tissue layer of arm model has infinite boundary, isotropic relative permittivity and isotropic conductivity.

In this case, it is also assumed that the upper arm model consists of skin layer, fat layer, muscle layer and bone layer, as shown in Fig. 1. The incident plane is *xoz*. *X*-axis is parallel to the medium plane and *z*-axis is vertical to the medium plane. The structure of upper arm is considered as *n* layers uniform medium. Meanwhile, let zero section represents air medium, section *n* represents muscle medium, section *n*+1 represents bone medium, and the position of $z=z_n$ represents the interface between section *n* and section *n*+1.

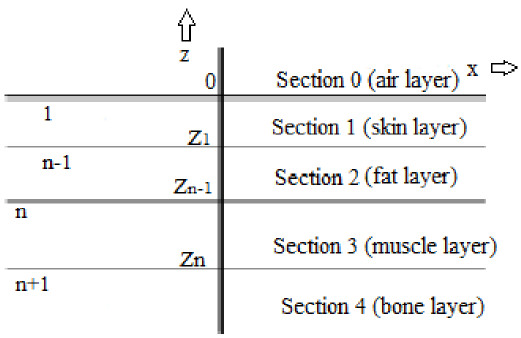

Figure 1: The structure of upper arm model

2.1 Incidence

The electrical field of section *n*, which represents the muscle layer of the upper arm model, is analyzed firstly. Both the incident angle and the reflection angle in interface z_n are θ_n and the refraction angle is θ_{n+1}. In this paper, the direction of the electrical field intensity in the every layer is divided into two kinds of polarization, one is vertical to the incident plane, and the other is parallel to the incident plane. When E ⊥xoz plane, then,

$$E_i^{'(n)} + E_r^{'(n)} = E_t^{'(n+1)} \quad (1)$$

$$H_i^{'(n)} \cos\theta_n - H_r^{'(n)} \cos\theta_n - H^{'(n+1)} \cos\theta_{n+1} \quad (2)$$

Similarly, when E // xoz plane, then,

$$H_i^{'(n)} + H_r^{'(n)} - H_i^{'(n+1)} \quad (3)$$

$$E_i^{'(n)} \cos\theta_n + E_r^{'(n)} \cos\theta_n = E_t^{'(n+1)} \cos\theta_{n+1} \quad (4)$$

In Eq. 1-4, subscript i, r and t represent incidence, reflection and transmission respectively. The superscripts represent the number of medium layers. Ei, Er, and Et can be expressed as:

$$E_i^{'(n)} = E_i^{'(n)} \exp(-j\gamma_n z_n) \quad (5)$$

$$E_r^{'(n)} = E_r^{'(n)} \exp(-j\gamma_n z_n) \quad (6)$$

$$E_i^{'(n+1)} = E_i^{'(n+1)} \exp(-j\gamma_n z_n) \quad (7)$$

Because the human arm is a dissipative medium, there are two kinds of attenuation, which are phase attenuation and amplitude attenuation, in the transmission of electromagnetic wave. To describe this attenuation, a propagation constant of γ is introduced in this paper. Then, the propagation constant of electromagnetic wave in the *n*th layer can be expressed as:

$\gamma_n = \beta_n - j\alpha_n$ i.e

$$\gamma_n = \omega\sqrt{\frac{\mu\varepsilon_n}{2}\sqrt{1+\left(\frac{\sigma_n}{\omega\varepsilon_n}\right)^2}-1} + \omega\sqrt{\frac{\mu\varepsilon_n}{2}\sqrt{1+\left(\frac{\sigma_n}{\omega\varepsilon_n}\right)^2}+1} \quad (8)$$

where α_n is the attenuation constant, β_n is the phase constant, which represents the phase delay of unit distance. ω_n, μ_n, ε_n and δ_n represent the frequency of electromagnetic, permeability, dielectric constant and conductivity respectively.

According to the relationship of H = ε / μ E , Fig. 1-4 can be expressed as:

$$E_i^{'(n)} + E_r^{'(n)} = E_t^{'(n+1)}$$

$$E_i^{'(n)} - E_r^{'(n)} = I_{n,n+1} E_t^{'(n+1)} \quad (9)$$

In Eq. 9, $I_{n,n+1}$ can be expressed as I⊥, which represents E⊥xoz plane, and I||, which represents E||xoz plane.

$$I^{\perp}_{n,n+1} = \frac{\sqrt{\delta^{(n,n+1)}\mu^{(n)}\cos\theta n+1}}{\sqrt{\delta^{(n,n+1)}\mu^{(n)}\cos\theta n}} \quad (10)$$

$$I^{\parallel}_{n,n+1} = \frac{\sqrt{\delta^{(n,n+1)}\mu^{(n)}\cos\theta n+1}}{\sqrt{\delta^{(n,n+1)}\mu^{(n)}\cos\theta n}} \quad (11)$$

As a result, the reflection electromagnetic field and the incidence electromagnetic field of $z=z_n$ can be expressed as:

$$E_r^{(n)} = R^{(n)} E_i^{(n)} = (1-I_{n,n+1}) E_i^{'(n)} / (1+I_{n,n+1}) \quad (12)$$

$$E_t^{(n+1)} = T^{(n)} E_i^{'(n)} \quad (13)$$

In Eq. 12 and Eq. 13, *R* and *T* represent the reflection coefficient and transmission coefficient respectively. On the other hand, the relationship between E_i and E_t can also be expressed as:

$$E_i^{'(n)} = E_t^{'(n)} \exp[-j\gamma_n(z_n - z_{n-1})] \quad (14)$$

According to Eq. 14, the following equations can be obtained.

$$E_i^{'(n-1)} + E_{R\backslash r}^{'(n-1} {}^{+E_t^{'(n)}} \quad (15)$$

$$\Phi_n = 2\gamma_n(z_n - z_{n-1}) \quad (16)$$

The solution of Eq. 15 be expressed as:

$$\begin{cases} E_r^{\prime(n-1)} = R^{(n+1)} E_i^{\prime(n-1)} \\ E_t^{\prime(n)} = T^{(n-1)} E_t^{\prime(n-1)} / [1 + R^{(n)} \exp(-j\phi^{(n)}] \end{cases} \quad (17)$$

Then, according to Eq. 12, 13, 14, 17, the electrical field of interface z_{n-1} in the nth layer can be obtained.

$$E_t^{\prime(n)} = \left\{ \frac{T^{(1)} E_t^{(1)} / exp\ j(Y_n Z_n - Y_n Z_n)}{exp(jY_{n\Delta} Z_n) + R^{(n)} exp(-jY_{n\Delta} Z_n)} \right\} \times \left\{ \prod_{p=2}^{n-1} \frac{T^p}{exp(jY_{p\Delta} Z_p) + R^{(p)} exp(-jY_{p\Delta} Z_p)} \right\} \quad (18)$$

Where $E_i^{(1)}$ represents the electrical field generated by the transmitter of the system, $\Delta Z_P = Z_P - Z_{P-1}$. In the case of n=1, 2 and 3, the expressions of electrical field $E_t^{'(2)}$ and $E_t^{'(3)}$ can be expressed as:

$$\begin{cases} E_i^{\prime(1)} = E_i^{(1)} \\ E_t^{\prime(2)} = \dfrac{T^{(1)} E_i^{(1)} / \exp[j(Y_2 Z_2 - Y_1 Z_1)]}{\exp(jY_2 \Delta Z_2) + R^{(2)} \exp(-jY_2 \Delta Z_2)} \\ E_t^{\prime(3)} = \dfrac{T^{(1)} E_i^{(1)} / \exp j(Y_3 Z_3 - Y_1 Z_1)}{\exp(jY_3 \Delta Z_3) + R^{(3)} \exp(-jY_3 \Delta Z_3)} \dfrac{T^2}{\exp(jY_2 \Delta Z_2) + R^{(2)} \exp(-jY_2 \Delta Z_2)} \end{cases}$$

(19)

2.2 Reflection

At the interface of z_n, in the case of some electromagnetic signal transmits into the (n+1)th layer, some electromagnetic signal reflects into the nth layer simultaneously. The reflection coefficient of z_n can be expressed as:

$$\begin{cases} R^{(n)} = (1 - I'_{n-1,n})/(1 + I'_{n-1,n}) \\ I'_{n-1,n} = [1 - R^{(n)} \exp(-j\phi^{(n)})]/[1 + R^{(n)} \exp(-j\phi^{(n)})] \\ \phi^{(n)} = 2Y_n (Z_n - Z_{n-1}) \end{cases}$$

(20)

Therefore, the reflection electrical field of $E_r^{(n-1)}$, which is reflected by the interface of z_n, can be expressed as:

$$E_r^{\prime(n)} = R^n E_t^{\prime(n)} = (1 - I'_{n-1,n}) E_t^{\prime(n)} / (1 + I'_{n-1,n}) \quad (21)$$

2.3 Effluence

The effluence process of the electromagnetic signal is opposite to the incidence process of it. The electromagnetic signal reflected by the interface of z_n, transmits into the (n-1)th layer. Similarly, it transmits through the other layers of the arm model and reaches the position of receiver electrode, which connects to the skin of the model. Consequently, the electrical effluence field of the nth layer can be expressed as:

$$E_0^{\prime(n)} = \left\{ \frac{T^{(n-1)} E_t^{(n)} exp\ [j(Y_1 Z_1 - Y_{n-1} Z_{n-1})]}{exp(jY_{n-1} \Delta Z_{n-1}) + R^{(n-1)} exp(-jY_{n-1} \Delta Z_{n-1})} \right\} \times \left\{ \prod_{p=1}^{n-2} \frac{T^p}{\exp(jY_p \Delta Z_p) + R^{(p)} \exp(-jY_{p\Delta} Z_p)} \right\}$$

(22)

According to Eq. 26, the electrical field in skin layer, fat layer and muscle layer can be expressed as in equation 23.

$$\begin{cases} E_0^{\prime(1)} = E_r^{(1)} \\ E_0^{\prime(2)} = \dfrac{T^{(1)} E_r^{(2)} / \exp(Y_1 Z_1 - Y_2 Z_2)}{\exp(jY_2 \Delta Z_2) + R^{(2)} \exp(-jY_2 \Delta Z_2)} \\ E_t^{\prime(3)} = \left\{ \dfrac{\dfrac{T^{(2)} E_i^{(3)}}{\exp j(Y_1 Z_1 - Y_3 Z_3)}}{\exp(jY_3 \Delta Z_3) + R^{(3)} \exp(-jY_3 \Delta Z_3)} \right\} \times \left\{ \dfrac{T^1}{\exp(jY_1 \Delta Z_1) + R^{(1)} \exp(-jY_1 \Delta Z_1)} \right\} \end{cases}$$

(23)

Finally, the electrical field of receiver electrode is the synthesis of the electrical fields in section 1, 2, and 3. According to Eq. 21-23, the electrical field of receiver electrode, which represents as E_o, can be expressed as:

$$E_0 = E_0^1 + E_0^2 + E_0^3 \quad (24)$$

? (°)	F(khz)						
	10	50	100	500	1000	5000	10000
0	1.9997	1.9992	1.9983	1.9947	1.9331	1.9657	1.9125
90	1.9998	1.9986	1.9985	1.9953	1.9939	1.9047	1.7538

3. Simulation and analysis

The parameters involved in this simulation include the incidence signal amplitude of A_i, the received signal amplitude of A_o, the incidence signal frequency of f, the transmitter electrode radius of r_i, the receiver electrode radius of r_o. In this paper, the axis of the upper arm model is defined as axis x. The long axis of the ground electrode is defined as axis y. The angle between axis y and axis x is defined as θ. The distance between the circle center of transmitter electrode and that of receiver electrode is defined as d.

3.1 Influence of electrode direction

In this simulation, two kinds of cases are considered: (a) the long axis of the ground electrodes is vertical to the axis x and (b) the long axis of ground electrodes is parallel to the axis x. Let r_i=r_o=10mm, d=150mm firstly, the signal, which has the amplitude A_i of 2mV and the frequency of f, is applied to the transmitter electrode. Meanwhile, let θ=0º and then θ=90º. The amplitudes of the received signal, which are presented as A_o, are shown in table 1. It can be seen from Table. 1 that with the rising of signal frequency, the amplitudes of the receiver electrode under all conditions decrease except it under the condition of θ=0, f=5MHz. In the case of θ=90º and f=10MHz, it reaches the minimum of 1.7538mV. In the case of f =1MHz, the variation of the amplitudes is less than 0.7mV, indicating that the influence of the electrode direction is limited. In the case of f >1MHz, the variation of the amplitudes increases with the rising of signal frequency. It reaches the maximum of 158.7μV in the case of f =10MHz, indicating that the influence of the electrode direction is considerably increased. Table 1 also shows that compared with the case of *y//x*, the signal attenuation is relatively low in the case of *y*⊥*x*, which represents that the long axis the ground electrodes is parallel to the axis of the arm model.

3.2 Influence of electrode Size

Let r_i=10mm, r_o=10mm, d=10mm, A =2mV, and the transmission signals with f=10,100,500kHz, and 1MHz are applied to the transmitter electrode respectively. To investigate the relationship between the electrode size and the attenuation of received signal, r_i is changed from 6mm to 14mm firstly, The amplitudes of the received signals are shown in Fig. 2. It can be seen from Fig. 2 that the amplitudes of the received signals under all conditions increase with the rising of the transmitter radius. Also,the increasing of the transmitter electrode area can lead to the increasing of signal attenuation. In the case of f =10 kHz, the variation of the amplitudes of received signals is less than 1 μV, indicating that the influence of the electrode direction is limited at this frequency. In the case of f =100 kHz, the variation of the amplitudes of received signals increase with the rising of r_i, indicating that the influence of the electrode area is considerably increased. The simulation results shown in Fig. 3 indicate the influence of r_o on the attenuation of revering signal is similar to that of r_i. amplitudes of the received signals is only 54.8 μV (f =10 kHz), indicating that the influence of this receiver electrode area is considerably low on this condition.

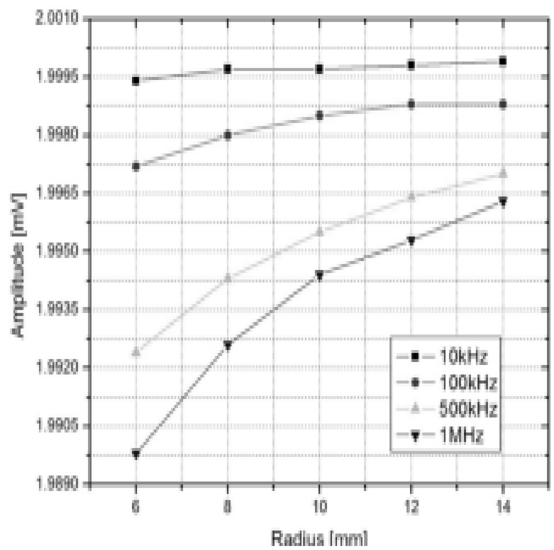

Fig 2: Results of A_o influenced by r_i

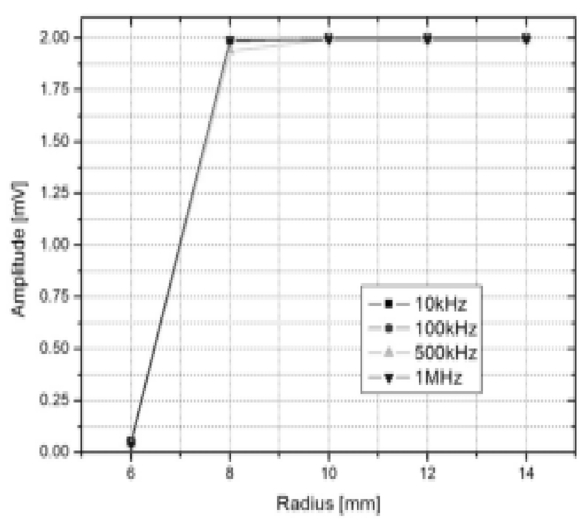

Fig 3: Results of A_o influenced by r_o

4. Conclusions

Some important conclusions are therefore deduced as follows: (1) The transmission of electronic signal in the upper arm model can be analyzed by using the reflection and incidence theory of EM wave, indicating that the EM wave theory is an import tool to clarify the mechanism of data transmission using human body; (2) In the case of the air medium model and the ground model are developed, the electrostatic coupling HAN communication can also be simulated by using the finite-element method; (3) In the electrostatic coupling, the influence of the electrode direction, electrode size is considerably low in the case of the signal frequency is less than 10 kHz. The influence of the factors mentioned above increases with the rising of signal frequency.

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