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ELECTRICAL CHARACTERISTICS OF HUMAN TISSUE IN THE INTRA-BODY COMMUNICATION WITHIN A LIMITED FREQUENCY DOMAIN (1MHZ - 10MHZ)

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ABSTRACT

With development of the current coupling intra-body communication research, it is necessary to increase carrier frequency of communication in the future research to obtain high-speed and stable communication mode. The feature of tissue in human limbs is intensively analyzed with the carrier frequency of 1MHz to 10MHz when the condition of quasi static approximation is tenable. In combination with relevant theories and experimental data, it is concluded that quasi-static coupling of human body is not tenable, which may be used as the theoretical basis for further research of modeling theory.

Keywords: *Intra-Body Communication(IBC); Current Coupling; Carrier Frequency; Quasi-Static Approximation*

1. INTRODUCTION

The intra-body communication is a new communication method, which is used to achieve wireless communication between personal electronic devices with body as communication medium [1]. In the communication, the electric field is coupled to the body to implement data communication with human tissue as the communication channel. If an electrical conductor is placed in the electric field, the induced electrostatic charge will be generated on the surface of the conductor; when the electric field varies, quantity of electric charge will change as well. At the moment, physical quantity variation of the electric field is detected to obtain relevant information, which is widely adopted in the electrostatic detection technology [2]. If the information to be sent is modulated to the quasi electrostatic field and coupled to human body, a weak electric field will be produced around the human body [3], a receiver is used to detect variation of the weak electric field, modulate and extract relevant information, then the wireless body area communication will be achieved, which may be applied to medical monitoring, patient nursing and other medical fields.

In 1995, Zimmerman [4] developed the first body area communication system based on the quasi electrostatic field; Partridge [5] discussed effects produced from different earthing conditions and different polar-plate areas. However, transmission rate of the communication system is low, within dozens of Kbps [6][11-15]. On the basis, NTT increased load voltage to 25V to make the communication rate up to 10M. Nonetheless, all above is achieved with human body considered to be a capacitor. The capacitive coupling intra-body communication has a great impact on signal transmission by reason of distance between receiving & sending electrodes and the human body [7], with strong interference from environment. Therefore, it is necessary to pursue a more stable coupling communication means to make up for the shortcoming. In the current coupling intra-body communication, human body is regarded as a communication transmission line, and signal is transmitted in the human body in the form of current.

Most achievements relevant to the current coupling intra-body communication remain experiments, simulation and prototype design, even if part of mechanism analysis and mathematic models [6] [8-15]are accomplished, the communication is still carried out with a carrier

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frequency of less than 1MHz. This greatly hinders market application and further research of the current coupling intra-body commutation. Comparison of Wegmuller's research results and Hachisuka's shows that increase of frequency is helpful to improvement of communication rate.

It is the carrier frequency that determines communication rate, so it is necessary to study the channel model of human body under high frequency and low voltage. Under frequencies of 1MHz, S.H.PUN[16,17] etc. abstracted the human forearm as a standard cylinder by means of the Maxwell equation and all boundary conditions to establish the channel model of the human forearm. It is proven from experiments that experimental results on the surface of the human forearm are almost consistent with those model calculation results, which shows that the model is somewhat feasible. As the frequency of the inputted current is raised, effect on dielectric property of human tissue is continuously amplified, and the capacitance effect is gradually obvious, which makes the signal transmission process more complicated; for this reason, the conditions omitted in the previous modeling process have to be taken into account, even the quasi-static environment required for PUN's model will be reconsidered.

Therefore, the electric mechanism of human tissue within the scope of 1MHz to 10MHz will be focused in this paper. Emphasis is laid on the tenable quasi static approximation conditions. Furthermore, in the process of modeling, it is proposed what conditions may be omitted and what conditions must be taken into consideration.

2. QUASI STATIC APPROXIMATION

When some space-time conditions are satisfied, effect of "displacement current" can be left out; this will produce instantaneous relation between the source and the field. At each moment, relation of its source and its field is similar to that of the source of the field of the static field, so the field is also called "approximately stable field". In general, the following conditions must be met to obtain the approximately stable field.

A. Propagation effect

Within the range of biomedium scale R_h , the time required to transmit electromagnetic wave from the transmitting electrode to the receiving electrode is expressed with the phase delay e^{-ikR_h} [18]. Because

$$e^{-ikR_h} = 1 - ikR_h - \frac{(kR_h)^2}{2!} - i\frac{(kR_h)^3}{3!} \cdots \quad (1)$$

If $kR_h \ll 1$, e^{-ikR_h} approximates to the constant 1, amplitude variation and phase delay of the wave in the organism are very small, and the propagation effect may be left out.

Because

$$kR_{\max} = (1-i)\sqrt{2\pi f \varepsilon} \qquad (2)$$

Where f is the carrier frequency, $\varepsilon = \varepsilon_r \varepsilon_0$, ε_r is the relative dielectric constant of the conductor, and ε_0 is the dielectric constant in free space.

Propagation characteristics of human tissue may be acquired through importing of experimental data, which is illustrated in Figure 1.

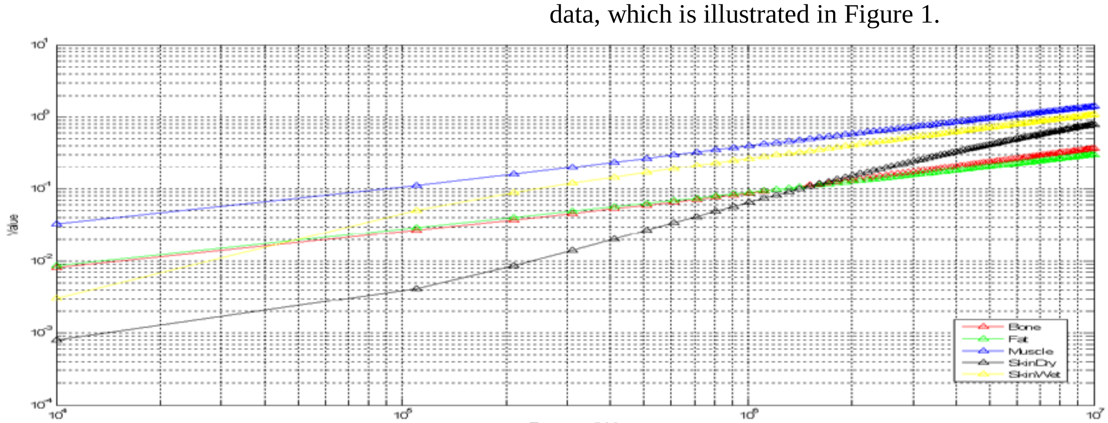

Fig. 1 Propagation Characteristics Of Human Tissue

On the basis of the above data, it is not difficult to find that $kR_h \ll 1$ (it is considered to meet relevant conditions when the frequency is less than a quantification level.) is always tenable when the

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carrier frequency is lower than 1MHz. Therefore propagation characteristics of tissue may be ignored. When the carrier frequency rises from 1MHz to 10MHz, the value of kR_h demonstrates a linear growth trend; when the carrier frequency is 10MHz, the calculated kR_h value of tissue may no longer meet the condition of kR_h □ 1, even the condition of kR_h □ 1 may emerge, so propagation effect at the moment can not be ignored.

B. Capacitance effect

There is the conduction current besides the displacement current inside the conductor:

$$\vec{j}_w = \varepsilon \frac{\partial \vec{E}}{\partial t} \qquad (3)$$

$$\vec{j}_c = \sigma \vec{E} \qquad (4)$$

where $\varepsilon = \varepsilon_r \varepsilon_0$, ε_r is the relative dielectric constant of the conductor, ε_0 is the dielectric constant of free space, $\vec{j}_w$ and $\vec{j}_c$ indicate the displacement current and the conduction current respectively, and σ is the electric conductivity.

If the induced electric field is a harmonic electric field, then $\vec{E} = \vec{E}_0 e^{-i\omega t}$, so the following expression may be derived:

$$\frac{\vec{j}_w}{\vec{j}_c} = \frac{\varepsilon(-i\omega \vec{E})}{\sigma_c \vec{E}} \qquad (5)$$

Equation (6) may be obtained through modular arithmetic of Equation (3):

$$\left| \frac{\vec{j}_w}{\vec{j}_c} \right| = \frac{\varepsilon\omega}{\sigma_c} \qquad (6)$$

Therefore, the condition, which allows the displacement current to be ignored, is $\left| \vec{j}_w / \vec{j}_c \right|$ □ 1, namely

$$\frac{\varepsilon\omega}{\sigma_c} \text{ □ } 1 \qquad (7)$$

From this, the internal condition which allows the approximately stable field to be tenable may be derived, that is to say, the variation frequency of the electromagnetic field is much less than its own characteristic frequency of the conductor. It is named the capacitance effect inside the conductor.

In combination with the data in [19], the value of k may be computed by means of Equation (7), where $k = \frac{\varepsilon\omega}{\sigma_c}$, so current characteristics of partial human tissue are obtained as shown in Figure 2.

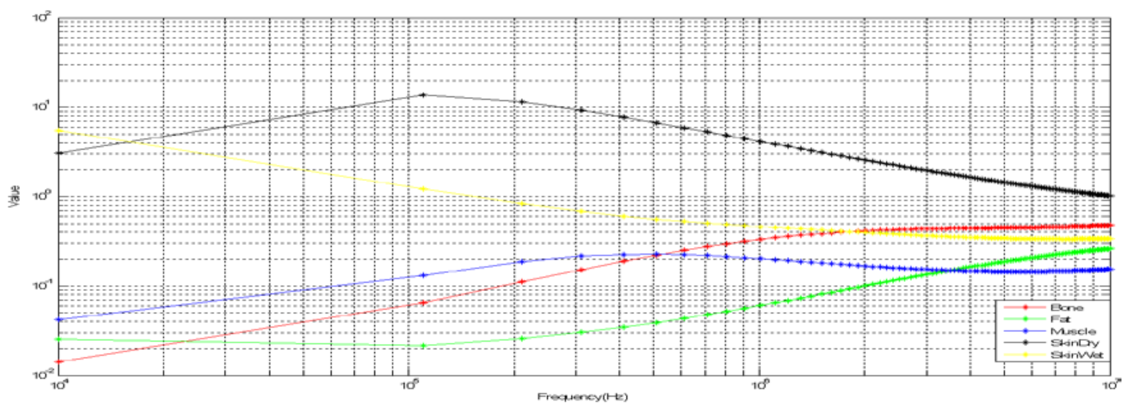

Fig. 2 Conduction Effect Of Human Tissue

It is not difficult to find that capacitance effect of most human tissue meets the condition of quasi static approximation (when $k \leq 0.1$, namely less than a quantification level, it is considered to meet relevant conditions.) when the carrier frequency is lower than 1MHz, at the moment, the displacement current inside human body may be ignored except the conduction current. However, when the communication frequency is gradually raised, the value of k demonstrates a linear growth pattern with rise of the frequency. Especially when the frequency goes up to 10MHz, other tissue no longer

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meets the condition of quasi static approximation in addition to skeleton and fat. For this reason, in later research, the effect of the displacement current upon the entire communication system will have to be taken into account in increasing the carrier frequency.

With increase of the carrier frequency, the capacitance effect becomes more and more obvious, and when the communication frequency rises to a certain value, the capacitance characteristic is dominant over the current characteristic in the whole system. At the moment, the current coupling type will not be suitable for the system any more. Therefore, it is also vital to find out the critical carrier frequency of current coupling.

C. Magnetic induction effect

According to faraday's law, the varying electric field and the varying magnetic field may be excited each other. If the displacement current is ignored (namely the capacitance effect), then the effect of the varying electric field upon the magnetic field is ignored. Obviously, after the two conditions are satisfied, interaction of the electric field and the magnetic field will disappear, which means that they are related to their own corresponding sources, feature of the steady field will be shown and the description method is similar to that of the static field.

As a result, once the capacitance effect is present, the magnetic induction effect will be generated with it.

3. CONCLUSION

On the basis of the existing theory, the quasi-static characteristics of human tissue within the range of 1MHz to 10MHz are analyzed in combination with the existing experimental data, it is concluded that coexistence of the propagation effect, the capacitance effect and the magnetic induction effect must be considered in establishing the theoretical model in the case of the carrier frequency of more than 1MHz. This makes the model more difficult to be established, but it heightens general applicability of the model and provides theoretical basis for theoretical generalization of the current coupling model.

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