Study of human body transmission characteristic as nonuniform medium

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Abstract

Human body transmission characteristic is investigated as nonuniform medium. The body is divided into multilayer and modeled with nonuniform transmission line. The analytical result is obtained with this simple and novel method. Numerical simulation is applied to validate this analytical method. The difference between them is within 0.01V/m.

1. Introduction

Human body transmission characteristic is a key problem need to be solved in many situations. For example, when you investigate the outside interference to implant device in human body, you have to calculate the attenuation of field in human body. There are mainly two methods to deal with this problem: one is using numerical simulation (FDTD, MOM, etc.) with complex human model [1-4], and the model is mainly from MRI. The other is analytic calculation with simple human model, considering the body as homogeneous medium [5]. In this paper, we take the nonuniform human body as multilayer structure. Then we analyze the transmission characteristics of multilayer structure using nonuniform transmission line method. Finally the field in the human body is obtained through analytical calculation. To validate our analytical method, we simulate field in human body by FEKO. The difference between theory and simulation is within 0.01V/m, which prove our analytical method is simple and proper.

2. Analytical Calculation

According to [6], the human body can be divided into four layers, which is shown in Fig.1.

Fig.1 Multilayer of human body

We analyze the electromagnetic wave transmission through the multilayer using nonuniform transmission line method, which is described in detail below. Firstly we get the characteristic impedance and transmission coefficient of every layer. If every layer is taken as a uniform transmission line, the characteristic impedance and transmission coefficient of every layer are displayed as formula 1 and 2.

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$$Z_i = \sqrt{\frac{j\omega\mu_i}{\sigma_i + j\omega\varepsilon_i}} \tag{1}$$

$$\gamma_i = \sqrt{j\omega\mu_i(\sigma_i + j\omega\varepsilon_i)} \tag{2}$$

Here the human body is considered as medium, which include conductivity and permittivity. The permeability is same as air.

Secondly several uniform transmission line is cascaded as a nonuniform transmission line, which is shown in Fig.2.

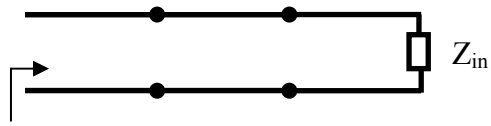

Fig.2 Nonuniform transmission line constructed by several uniform transmission line

Thirdly the parameter of ABCD network of nonuniform transmission line is acquired by (3).

$$[A] = \prod_{i=1}^{m} \begin{bmatrix} \cosh\gamma_i l_i & Z_i \sinh\gamma_i l_i \\ \frac{\sinh\gamma_i l_i}{Z_i} & \cosh\gamma_i l_i \end{bmatrix} = \begin{bmatrix} A_1' & A_2' \\ A_3' & A_4' \end{bmatrix} \tag{3}$$

Where m is the number of layers, Z_i and γ_i are characteristic impedance and transmission coefficient of every layer respectively.

Finally apply the coefficient obtained with (3) to formula (4), and get the field value through multilayer human body attenuation [7].

$$|V(H,\omega)| = \left| \frac{2Z_l}{A_3' Z_l Z_d + A_4' Z_d + A_1' Z_l + A_2'} U \right| \tag{4}$$

Where Z_l and Z_d are the medium impedance.

Now a plane wave transmits into the human body, and the attenuation is obtained with the method described above. The frequency of plane wave is 0.9GHz and electric field strength is 1V/m. We take the field calculation at the middle point of muscle as example. [6] displays the material parameter and thickness of every layer of human body. The thickness of bone is assumed to be infinite. It is reasonable for bone is much thicker than skin, fat and muscle. So according to the model in Fig.1, the muscle is terminated with a transmission line whose length is infinite. The characteristic impedance of bone is given as formula (5). Thus the input impedance from the middle of muscle to right can be calculated with (6).

$$Z_b = \sqrt{\frac{j\omega\mu_b}{\sigma_b + j\omega\varepsilon_b}} = \sqrt{\frac{j\times 9\times 10^8 \times 4\pi \times 10^{-7}}{0.14 + j\times 9\times 10^8 \times 12.45 \times \frac{1}{36\pi} \times 10^{-9}}} \tag{5}$$

$$Z_{in}^{l} = Z_m \frac{Z_b + Z_m \tanh\gamma_m l}{Z_m + Z_b \tanh\gamma_m l} = Z_m \frac{Z_b + Z_m \tanh(\gamma_m \times 4\times 10^{-2})}{Z_m + Z_b \tanh(\gamma_m \times 4\times 10^{-2})} \tag{6}$$

Where Z_m and γ_m are characteristic impedance and transmission constant of muscle layer. l is the distance between middle of muscle and bone.

So the nonuniform transmission line is composed by three uniform transmission lines. The first one is equipment uniform transmission line of skin, with the length of 2mm. The second one is equipment uniform

transmission line of fat, with the length of 2mm. The last one is the equipment uniform transmission line of muscle, with the length of 4mm, and terminated with input impedance Z^{l}_{in}. The material parameter at different frequency is shown in table 1, according to [6].

Table 1 Material parameters at different Frequency

Frequency	parameter	Skin	Fat	muscle	bone
900MHz	ε_r	41.4	5.46	55.03	12.45
	σ	0.86	0.05	0.94	0.14
1.8GHz	ε_r	38.87	5.35	53.55	11.78
	σ	1.18	0.08	1.34	0.27
thickness		2mm	3	8mm	Infinite

Then use formula (3) and (4), the electric field at the middle of muscle is 0.1991V/m. If the thickness of muscle is changed to 3mm, the electric field at the middle of muscle is 0.2984V/m.

When the frequency of incident wave is changed to 1.8GHz, the material parameter is changed as well. In this situation, the electric field at the middle of muscle is 0.2073V/m when the thickness of muscle is 8mm.

3. Simulation

To validate the analytical result, we complete the simulation using Feko software. The simulation model is four layer slabs, which is shown in Fig.3. The material parameter of every layer is as table 1.

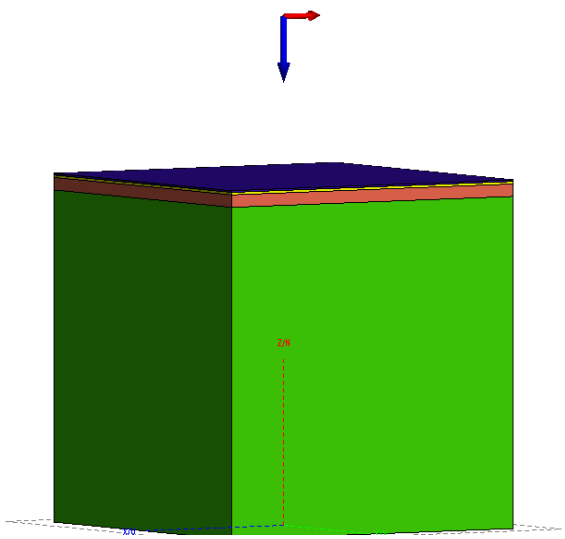

Fig.3 model of simulation

The red arrow is direction of electric field, with 1V/m strength. The blue arrow is direction of wave transmission. Through body attenuation, the electric field at middle of muscle is 0.2068837V/m when frequency of incident wave is 0.9GHz. The difference between analytical result and simulation is within 0.01V/m.

4. Conclusion

The human body transmission characteristic is investigated in this paper. The body is considered as nonuniform medium, which is more reasonable than uniform medium assumption. For wave transmission in nonuniform medium, we propose a new method to solve it. It can be modeled with nonuniform transmission line.

Then analytical result is easy to get. Simulation validates the analytical method, and difference between them is within 0.01V/m. It confirms our analytical method is feasible and correct.

5. References

1. Y. Lu Z. Xiang, “Electromagnetic dyadic green’s function in cylindrically multilayered media,” IEEE Trans. on Microwave Theory and Techniques, vol. 44, no. 4, pp. 614－621, 1996.

2. N.K. Uzunoglu P.G. Cottis, G.E. Chatzarakis, “Electromagnetic energy deposition inside a three-layer cylindrical human body model caused by near-field radiators,” IEEE Trans. on Microwave Theory and Techniques, vol. 38, no. 8, pp. 415－436, 1990.

3. C. M. Weil, “Absorption characteristics of multilayered sphere models exposed to UHF/Microwave radiation,” IEEE Trans. Biomed. Eng., vol. BME-22, no. 6, pp. 468－476, Nov. 1975.

4. A. Christ, T. Samaras, A. Klingenb ock, and N. Kuster, “Characterization of the electromagnetic near-field absorption in layered biological tissue in the frequency range from 30 MHz to 6000 MHz,” Phys. Med. Biol., vol. 51, pp. 4951－4965, 2006.

5. IFAC web site (http://niremf.ifac.cnr.it/tissprop/)

6. Neus Vidal and Jos´e Mar´ a L´opez-Villegas, “Changes in Electromagnetic Field Absorption in the Presence of Subcutaneous Implanted Devices: Minimizing Increases in Absorption”, IEEE Trans. on Electromagnetic Compatibility, vol. 52, no.3, pp. 545-555

7. Dan Shi, Yuanmao Shen, Yougang Gao, “Determination of Shielding Effectiveness of Multilayer Shield by Making Use of Transmission Line Theory”. The VII International symposium EMC'2007, St. Petersburg, Russia