Design of Inner-Layer Capsule Dipole Antenna For Ingestible Endoscope

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Abstract - **To design antennas for ingestible wireless capsule endoscope systems, the effects of relative permittivity and conductivity of human body equivalent liquid (HBEL) on the effective electrical length of capsule antenna are investigated by numerical analysis. Three types of capsule dipole antennas, the isolated type, the surface type and the inner-layer type are discussed. The inner-layer capsule dipole antenna having characteristics of both large effective electrical length and small propagation loss is proposed. A design of internal impedance of capsule dipole antenna to obtain maximum received power at 500 MHz is also presented.**

Index Terms — **Antennas, propagation, EM wave theory, AP-related topics.**

1. Introduction

Wireless capsule endoscope system has gained popularity in health-care applications [1-2]. The system uses a wireless transceiver to obtain medical images of the inside of human body [1]. Generally, a capsule has a maximum length of 20 mm and a maximum diameter of 10 mm [1], and it is considered that the efficiency of antennas is extremely low caused by its physical size. Furthermore, the absorption of electromagnetic waves by the internal organs is quite large and the propagation loss through the human body is large.

In our previous research [3], a dipole antenna placed in a phantom filled with lossy liquid was studied. The experimental results are agree with the calculated results. However, the capsule antenna design was not investigated. In [4], the path loss has been studied in an in-homogeneous model and only the numerical results were presented, however, it is difficult to perform the experiment in an in-homogeneous real human body model. In [5], the transmission factor of capsule dipole antenna and capsule loop antenna are compared while only the simplest structure of capsule antenna was discussed.

In this report, three types of capsule dipole antennas were compared. The effect of relative permittivity and conductivity on the effective electrical length and the propagation loss were discussed. The inner-layer type capsule dipole antenna having characteristics of both large effective electrical length and small propagation loss and effectiveness is confirmed by the FDTD (Finite-Difference Time-Domain) analysis. The guideline in designing capsule antennas by using transmission factor is proposed.

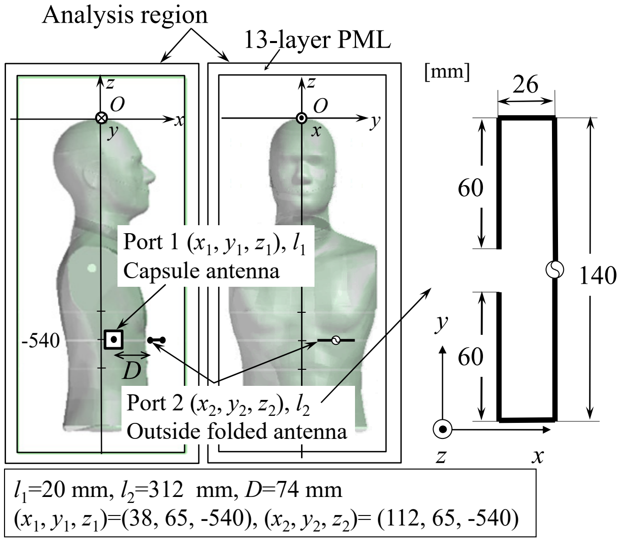

Fig. 1. Analysis model.

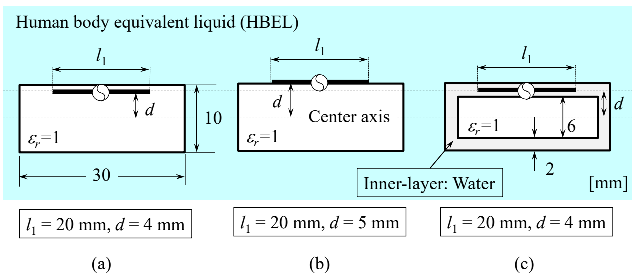

Fig. 2. Geometries of capsule antennas. (a) Isolated type capsule dipole antenna, (b) Surface type capsule dipole antenna, (c) Inner layer type capsule dipole antenna.

2. Analysis model

Fig. 1 shows the analysis model and Fig. 2 shows the geometries of three kinds capsule dipole antennas. A human torso-shaped phantom filled with the human body equivalent liquid (HBEL) developed by SPEAG was used as the phantom [5]. A capsule dipole antenna is placed inside the torso phantom at the position indicated as Port 1 (x_1, y_1, z_1) and an outside folded dipole antenna with length of l_2 =312 mm is placed at Port 2 (x_2, y_2, z_2). The distance between two antennas is set to D=74 mm. Dimensions of the rectangular column capsules are with length of 30 mm and width of 10 mm. Relative permittivity of capsule is set as the air (ε_r=1).

Characteristics of three types of capsule dipole antennas are as follows:

(a) Isolated type: A dipole antenna with length of l_1 is placed inside the air capsule with a distance of d=4 mm from the center axis. The antenna conductor is isolated from the lossy surrounding HBEL.
(b) Surface type: The antenna conductor is placed on the surface of the capsule with a distance of d=5 mm from the center axis. The antenna conductor is touched to the lossy surrounding HBEL.
(c) Inner-layer type: The antenna conductor is placed in an inner-layer deionized water provided inside the capsule with thickness of 2 mm.

The relative permittivity and conductivity of the human body equivalent liquid (HBEL) used for the phantom and the deionized water used for inner-layer of capsule [6]. The relative permittivity of HBEL is smaller and the conductivity is larger than the case of deionized water.

In the FDTD analysis, the rectangular shaped capsule was used. The number of cells is 202×304×462. The Gaussian differential pulse was used as an excitation. 13-layer PML was used as an absorbing boundary condition.

3. Results and observations

To compare the propagation loss among the three types of capsule antennas without considering the effect of antenna mismatching, the transmission factor τ [4] which is the relative maximum received power under the conjugate matching condition, defined by

$$\tau = \left.\frac{P_L}{P_{inc}}\right|_{Z_S=Z_{in}^*, Z_L=Z_{out}^*} = \frac{P_L}{P_{in}} = \frac{1}{1-|\Gamma_S|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \quad (1)$$

was evaluated. P_L is the received power delivered to the load Z_L, P_{inc} is the incident power, Γ_S and Γ_L are the optimum reflection coefficients toward the source Z_s and toward the load Z_L.

Fig. 3 shows the transmission factor τ from capsule antennas to the outside folded dipole antenna through torso-shaped phantom. A local maximum of transmission factor τ were observed for each cases of (a) Isolated type, (b) Surface type and (c) Inner-layer type, respectively. The reason why there is a local maximum can be considered that the lower radiation efficiency in low frequency range and the higher conductivities in high frequency range. The maximum values τ of -26.9 dB at 495MHz, -31.3 dB at 500MHz and -24.6 dB at 478MHz were obtained for case (a), case (b) and case (c), respectively. From the above results, observations are listed below.

(a) Isolated type: It is the electrically small antenna having difficulty of impedance matching. High Q-factor with high received power possible.
(b) Surface type: It is the half-wavelength antenna and easy to match the input impedance to 50Ω. However, Q-factor is low and received power is relatively low.

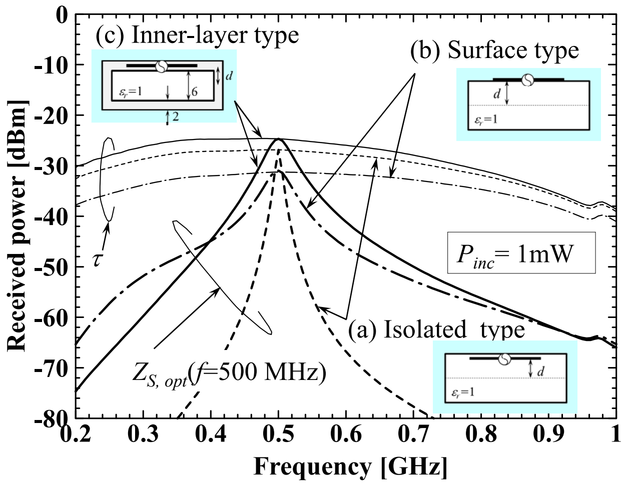

Fig. 3. Transmission factor of three types capsule dipole antennas.

(c) Inner-layer type: It is the half-wavelength antenna and easy to match the input impedance to 50Ω. Q-factor is lowest, however, received power is relatively large which will be caused by the lower conductive current around the feeding point compared with the surface type touched to the lossy HBEL.

4. Conclusion

In this research, the inner-layer capsule dipole antenna was proposed and the effects of relative permittivity and conductivity of HBEL on the capsule dipole antenna were investigated by the FDTD analysis. It is found that the inner-layer of deionized water provided in the air capsule was contributed to enlarge the effective electrical size of dipole antenna and contributed to decrease the conductive current loss at the feeding point, resulting in high received power through the human body phantom.

Acknowledgment

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