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# Experiment study of transmission characteristics through conducting human body equivalent liquid

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**Abstract:** In this paper, measurements of a dipole antenna in deionized water and human body equivalent liquid were performed, and the measured results are compared with the numerical analysis. The dispersive characteristics of relative permittivity and conductivity of human body equivalent liquid were considered in the FDTD analysis. To evaluate the antenna characteristics in the broadband frequency range, the S-parameter method was used. The input impedance and the transmission coefficient obtained in the numerical analysis and measurement were shown to be in good agreement. The reliability of both measurements and analysis were confirmed. These methods are useful to the design of capsule antennas.

**Keywords:** dipole, deionized water, human body equivalent liquid, S-parameter method, FDTD analysis

**Classification:** Antennas and Propagation

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## 1 Introduction

Ingestible capsule endoscope systems are expected to have wide healthcare applications [1]. Thus, several researchers have been studying high efficiency antennas for capsule endoscopes [2, 3, 4].

Generally, the maximum size of an ingestible capsule endoscope is a length of 20 mm and a diameter of 10 mm [1]. The efficiency of the antenna is extremely low due to the electrical size. Furthermore, the surrounding environment of the capsule changes as it passes through the various internal organs of a human body with different levels of dielectric permittivity.

To evaluate the characteristics of an antenna inside the human body, it is necessary to obtain accurate transmission characteristics through the human body. In previous studies, a chandelier meandered dipole antenna was studied numerically [3], however, the validity of analysis has not been presented. An experiment in which an antenna was placed in the meat [5] or the conducting liquid [6] was evaluated at 2.45 GHz. However, there are few researches which compared the results of EM analysis and measurements in a broadband frequency range with considering the dispersive characteristics of dielectric permittivity of human body tissue.

In [6], a pair of unbalanced offset-fed dipole antennas was used in the experiments. Recently, the S-parameter method has been widely applied with the use of a four-port vector network analyzer to obtain the input impedance of antennas over a broadband frequency range.

In this paper, a pair of dipole antennas was placed inside and outside a torso-shaped phantom, respectively, is measured by using the S-parameter method and the results are compared with FDTD analysis with considering dispersive effects of liquids. A human body equivalent liquid (HBEL) is used as equivalent body tissue, both the input impedance of dipole antenna placed in liquids and the transmission characteristics between the antennas were investigated.


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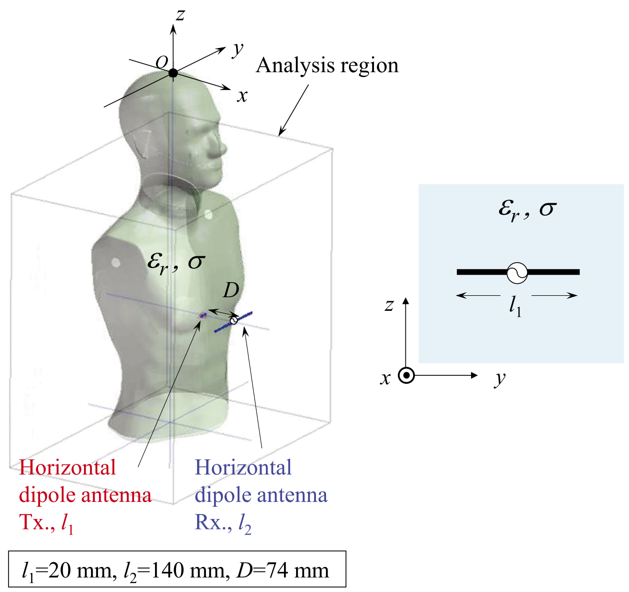
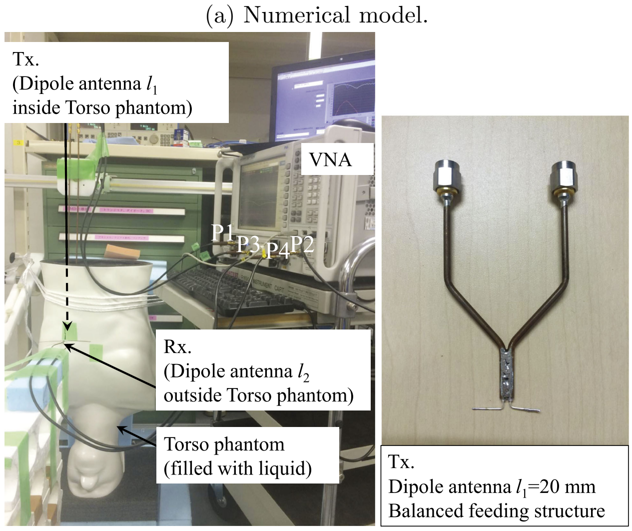
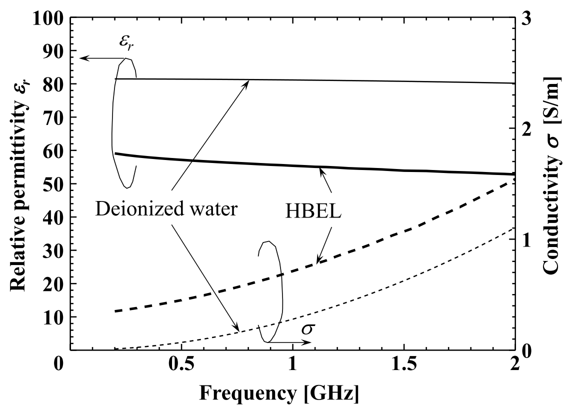
## 2 Model for experiment and analysis




(a) Numerical model.




(b) Experiment setup.




(c) Relative permittivity and conductivity of the deionized water and HBEL.

**Fig. 1.** Numerical model and experiment setup.

Fig. 1(a) and (b) show the torso-shaped phantom as the container of liquids. The torso-shaped phantom was filled with two kinds of liquid separately: the deionized water and the human body equivalent liquid (HBEL) developed by SPEAG Co.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with a temperature of 18°C. To obtain the S-parameters of differential mode antennas in a broadband frequency range, the mixed-mode S-parameter method [7] was applied with the use of the N5224A four-port VNA. A dipole antenna with length $l_1$ was placed inside the torso phantom at the position of the stomach as transmitting antenna (Tx., VNA: P1, P3). Also, a dipole antenna with length $l_2$ was placed outside of the torso phantom as receiving antenna (Rx., VNA: P2, P4). $S_{dd11}$ and $S_{dd21}$ were calculated as the differential mode S-parameters [7]. The distance between the antennas was set at 74 mm. The input impedance of transmitting antenna and the transmission characteristics were compared between the deionized water (low conductivity) and the HBEL (high conductivity).

The FDTD method was used in the simulation. The relative permittivity and conductivity of the deionized water and the HBEL were measured by using the coaxial probe method separately, and the measured results were used in the analysis as fitting curves with a general dispersive material, as shown in Fig. 1(c) [8, 9]. The number of cells in the FDTD analysis was 202 × 304 × 306, and the cell sizes were taken as $\Delta x = \Delta y = \Delta z = 2$ mm. 13-layer PML was used as an absorbing boundary condition. The ohmic loss of the antenna was ignored and the material of the antenna was considered as perfect electric conductors (PEC).

## 3 Comparison between measurement and analysis

Fig. 2(a) and (b) show the input impedance of the dipole antenna with $l_1 = 20$ mm (Tx.) placed in deionized water and in the HBEL. An agreement between the calculated and the measured values was observed from 200 MHz to 2 GHz. In air, the half-wavelength resonant frequency of the dipole antenna with $l_1 = 20$ mm was almost 7.5 GHz. In deionized water, the half-wavelength ($0.5\,\lambda_g$) resonance at 687 MHz with resistance of 8.7 Ω, and the wavelength ($\lambda_g$) anti-resonance at 1.2 GHz with resistance of 50.7 Ω were observed, respectively. In the HBEL, the half-wavelength ($0.5\,\lambda_g$) resonance at 850 MHz with resistance of 16.7 Ω, and the wavelength ($\lambda_g$) anti-resonance at 1.5 GHz with resistance of 51.2 Ω were observed, respectively. It is worth noting that in the low frequency band (200 MHz–400 MHz), because the conductivity of the HBEL was larger than that of the deionized water, led to the input resistance of antenna placed in the HBEL larger than that of antenna placed in deionized water.

Consider the approximation of plane wave in lossy medium: Fig. 2(c) shows the theoretical effective wavelength in liquids $\lambda_g$ and $l_1/\lambda_g$. The theoretical effective wavelength was calculated from the phase constant $\beta$:

$$\beta = \omega\sqrt{\mu\varepsilon}\sqrt{\frac{1}{2}\left[\sqrt{1+\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right]} \quad [\text{rad/m}] \tag{1}$$

$$\lambda_g = \frac{2\pi}{\beta} \tag{2}$$

When a dipole antenna with a length of 20 mm was placed inside a torso-shaped phantom, the theoretical half-wavelength ($0.5\,\lambda_g$) resonant frequency was 690 MHz in deionized water, and was 850 MHz in the HBEL. There was an agreement between the measured values and the theoretical plane wave approximation.


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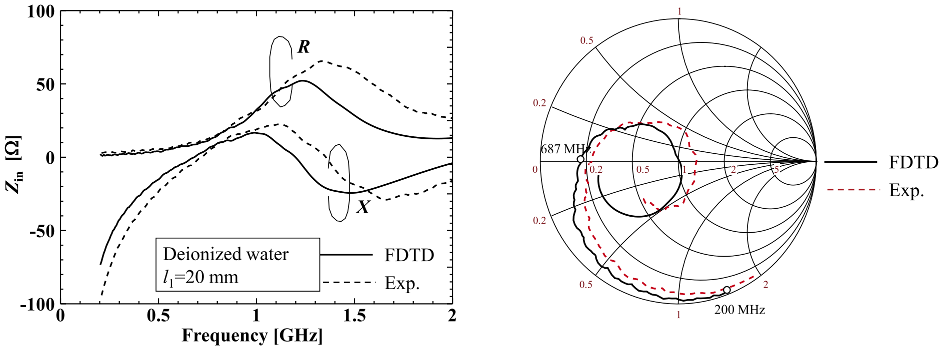
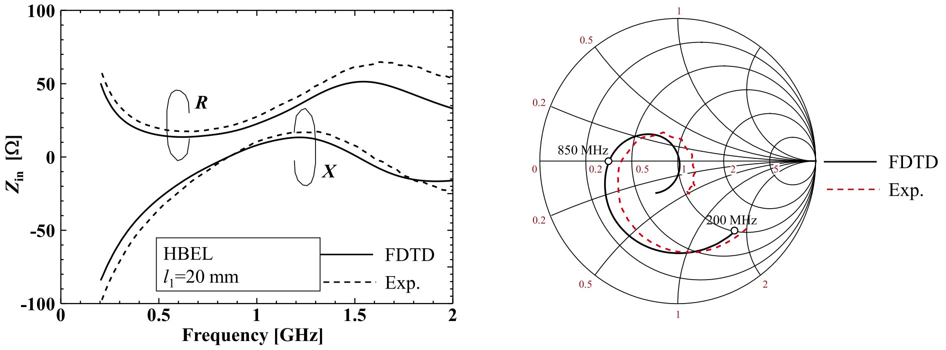
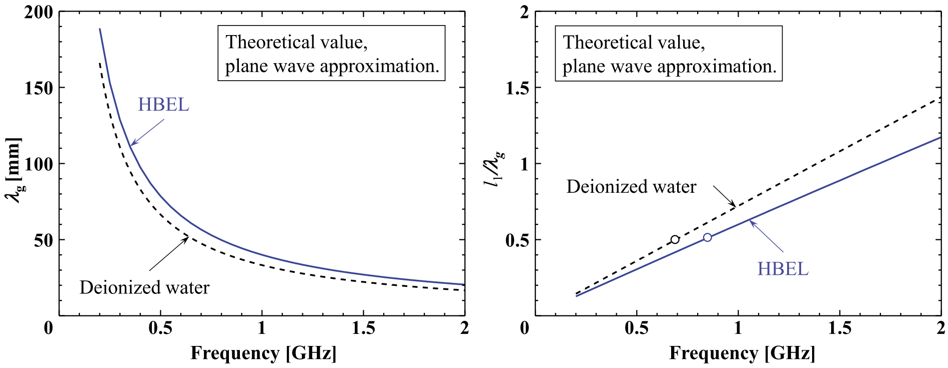



(a) In deionized water.




(b) In the HBEL.




(c) Theoretical effective wavelength $\lambda_g$ and $l_1/\lambda_g$.

**Fig. 2.** Input impedance of the dipole antenna placed in liquids and theoretical effective wavelength.

Fig. 3 shows the transmission coefficients from the dipole antenna placed inside a torso-shaped phantom to the outside. Good agreement between the calculated and the measured values was observed. In deionized water, a relatively high transmission level of around −23 dB through the torso-shaped phantom with wide band characteristics below 1 GHz was observed. In the HBEL, because the conductivity of the HBEL was larger than that of the deionized water, a high transmission level of around −30 dB through the torso-shaped phantom with wide band characteristics at 920 MHz was observed. The transmission coefficients in both the deionized water and the HBEL decreased in the frequency range above 1 GHz because the conductivity of liquid increases with the frequency, as shown in Fig. 1(c).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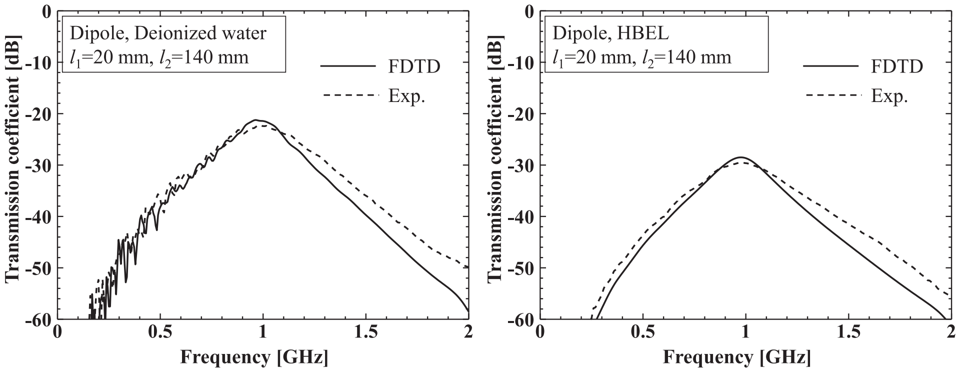


**Fig. 3.** Transmission coefficients through the torso-shaped phantom.

## 4 Conclusion

In this research, measurements of a dipole antenna placed in deionized water and HBEL were carried out, and the measured results were compared with FDTD analysis and theoretical plane wave approximation. The mixed-mode S-parameter method was used to obtain the transmission coefficient under balanced feeding. Good agreement between the measured and the calculated results was obtained in a broadband frequency range, and the validity of both the measurement method and the dispersive FDTD analysis were confirmed. Those methods will be usable for the design of antennas for a capsule endoscope.

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