# FDTD analysis of capsule dipole antenna in the digestive system of a human body

## Yang Li[a)], Hiroyasu Sato, and Qiang Chen

*Graduate School of Engineering, Tohoku University,*

*6–6–05 Aramaki Aza Aoba, Aoba-ku, Sendai, Miyagi 980–8579, Japan*

a) *liyang@ecei.tohoku.ac.jp*

**Abstract:** The transmission factor from a capsule dipole antenna placed in a digestive system of a human body to the outside was investigated using the FDTD analysis. It was found that the local maximum of the transmission factor was observed in the frequency range of 400–600 MHz in the cases when a capsule dipole antenna passes through the different organs of a digestive system. Also it is confirmed that high value of the received power was obtained when the capsule dipole antenna and the receiving antenna have the same polarization.

**Keywords:** capsule endoscope, dipole antenna, digestive system, transmission factor, polarization

**Classification:** Antennas and Propagation

## References

[1] G. Iddan, G. Meron, A. Glukhovsky, and P. Swain, "Wireless capsule endoscopy," *Nature*, vol. 405, no. 6785, p. 417, May 2000. DOI:10.1038/35013140

[2] N. Ishii, T. Akagawa, K. Sato, L. Hamada, and S. Watanabe, "A method of measuring gain in liquids based on the Friis transmission formula in the near-field region," *IEICE Trans. Commun.*, vol. E90-B, no. 9, pp. 2401–2407, 2007. DOI:10.1093/ietcom/e90-b.9.2401

[3] D. Kurup, W. Joseph, G. Vermeeren, and L. Martens, "In-body path loss model for homogeneous human tissues," *IEEE Trans. Electromagn. Compat.*, vol. 54, no. 3, pp. 556–564, Jun. 2012. DOI:10.1109/TEMC.2011.2164803

[4] Z. N. Chen, G. C. Liu, and T. S. P. See, "Transmission of RF signals between MICS loop antennas in free space and implanted in the human head," *IEEE Trans. Antennas Propag.*, vol. 57, no. 6, pp. 1850–1854, Jun. 2009. DOI:10.1109/TAP.2009.2019933

[5] Q. Chen, K. Ozawa, Q. W. Yuan, and K. Sawaya, "Antenna characterization for wireless power-transmission system using near-field coupling," *IEEE Antennas Propag. Mag.*, vol. 54, no. 4, pp. 108–116, Aug. 2012. DOI:10.1109/MAP.2012.6309161

[6] www.itis.ethz.ch/database.

## 1 Introduction

The influx of ingestible capsule endoscope system is expected for healthcare applications [1]. In previous studies, homogenous human body models have been used in some studies [2, 3, 4]. When a capsule passes through various organs of the digestive system, the surrounding environment of the capsule such as the dielectric permittivity of each organs changes, and the absorption of EM waves will be changed. Furthermore, the electrical size of antenna changes as the effective wavelength in the organs changes. Thus, it is important to consider all the realistic human body digestive system. The digestive system is composed of the esophagus, the stomach, the small intestine and the large intestine. However, few researches focus on the received power from a capsule dipole antenna placed in different parts of the digestive system.

In this research, the transmission factor [5] was used as the path loss and was calculated. The transmission factor is the relative maximum received power under the condition that the complex conjugate matching conditions are satisfied at both the transmitting and the receiving ports.
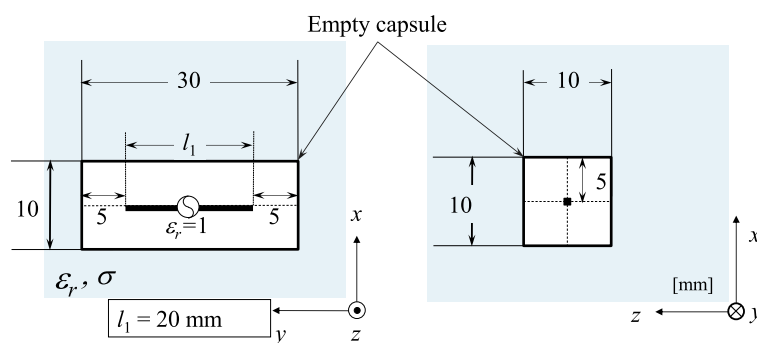
## 2 Analysis model

The FDTD analysis model of a human body developed by SPEAG Co., which was constructed by using MRI images. It includes 76 kinds of organs and the relative permittivity and conductivity of each organ provided by ITIS [6] were used. The torso part of a human body was used in the FDTD analysis. The lumina of digestive system were filled with deionized water. The cross-sections of an analysis model in $xz$-plane and $xy$-plane are shown in Fig. 1(a). The geometry of the rectangular column capsule is shown in Fig. 1(b): it has a length of 30 mm and a diameter of 10 mm. The origin of coordinates was placed at the top of the head. The capsule dipole antenna (Tx.) with a length of $l_1 = 20$ mm was placed at $(x_1, y_1, z_1)$ in the digestive system of a human body and a receiving dipole antenna (Rx.) with a length of $l_2 = 140$ mm was placed at $(x_2, y_2, z_2)$ outside of a human body. The position of capsule antenna changes along the digestive system at $z = -470, -540$ and $-610$ mm which corresponds to the cases when the capsule antenna was placed in the esophagus, the stomach, the small intestine and the large intestine. The FDTD method considering the dispersive effect of complex dielectric permittivity was used for numerical analysis.

## 3 Comparison between measurement and analysis

An example of the conductivity distribution in the xz-plane is shown in Fig. 2. The color indicates the magnitude of conductivity at 1 GHz. It was observed that the conductivity of the heart is larger than the other organs. When the capsule passes through the esophagus, the polarization of the dipole antenna is vertically placed because the structure of the esophagus is narrow. Both capsule dipole antenna and receiving antenna were selected as z-direction. The position of capsule dipole antenna is $(x_1, y_1, z_1) = (20, 0, -470)$ in the esophagus and two cases of the position of receiving antenna placed in front of body $(x_2, y_2, z_2) = (112, 0, -470)$ and at the back of body $(x_2, y_2, z_2) = (-116, 0, -470)$, were calculated respectively.
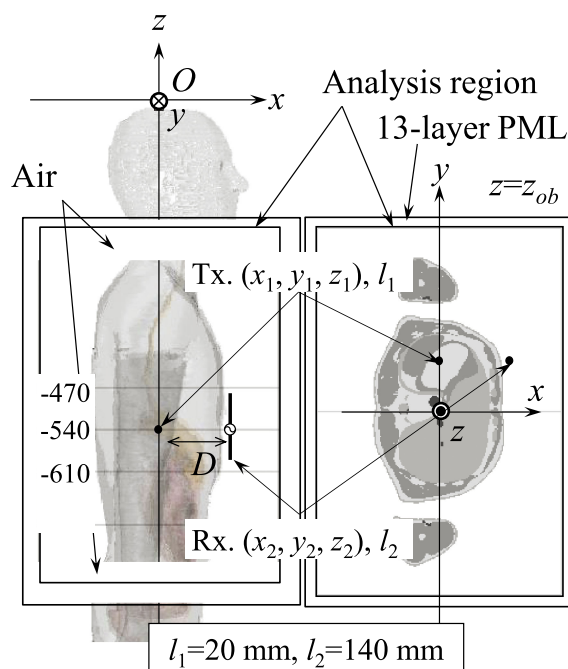
(a) Inhomogenous human body model.



(b) Structure of capsule dipole antenna.

**Fig. 1.** Analysis model.

The transmission factor $\tau$ of each case were shown in Fig. 2(a). The local maximum of $\tau$ was observed at 600 MHz corresponding to the half-wavelength resonant frequency of capsule antenna, while $\tau$ decreases as the frequency increases as the conductivity of surrounding organs increases. It was also observed that higher $\tau$ is obtained in the case when the receiving antenna is placed at the back of a human body compared to the case when the receiving antenna is placed in front of a human body. The reasons noted were the absorption, reflection and refraction caused by high conductivity of the heart.
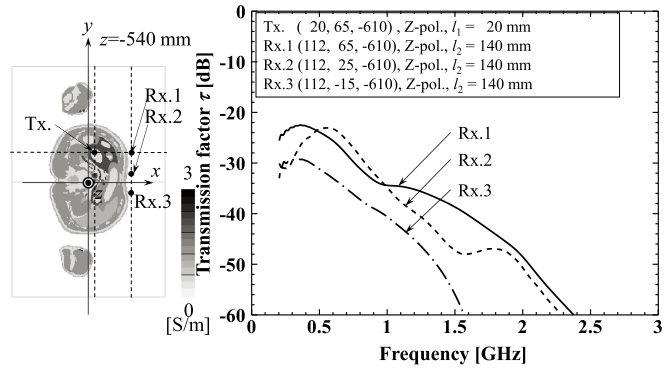
When the capsule moves in the stomach, the capsule antenna will rotate and it is necessary to consider the $x$, $y$ and $z$ direction polarization of the transmitting antenna. An example of $\tau$ when the capsule dipole antenna is placed in the stomach is shown in Fig. 2(b). The polarization values of the transmitting antenna in $x$, $y$ and $z$ directions were calculated at $(x_1, y_1, z_1) = (0, 65, -540)$, while the polarization values of the receiving antenna were settled in the $z$ direction at $(x_2, y_2, z_2) = (112, 65, -540)$. It was observed that a relatively higher $\tau$ was obtained when the capsule dipole and receiving antennas have the same polarization.
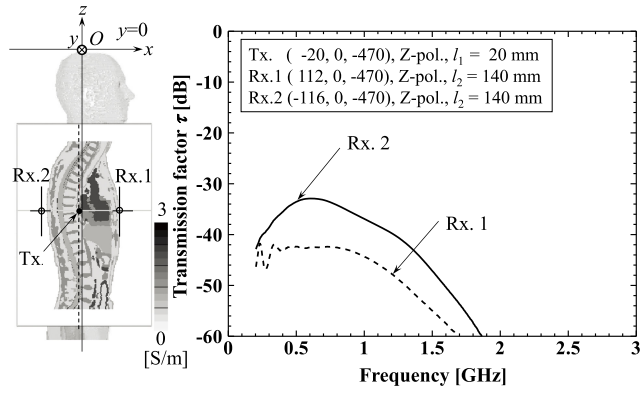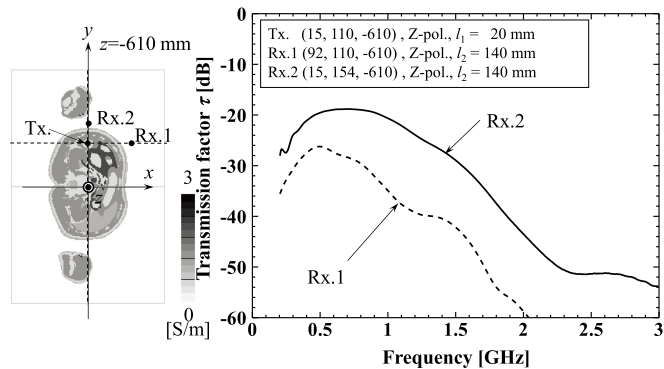
(a) Transmitting antenna is placed in the esophagus.
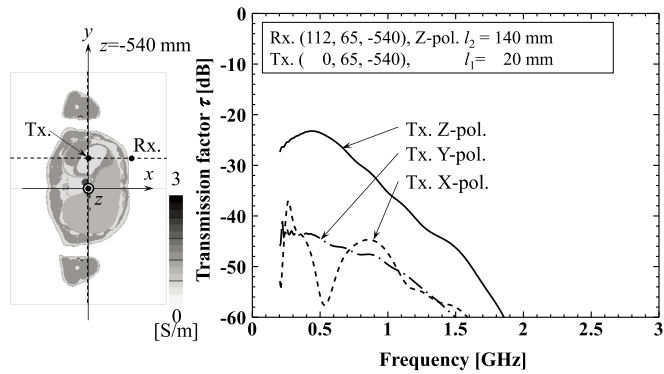


(b) Transmitting antenna is placed in the stomach.



(c) Transmitting antenna is placed in the small intestine.



(d) Transmitting antenna is placed in the large intestine.

**Fig. 2.** Transmission factor in the digestive system.

When the capsule moves into the small intestine, because the small intestine is very long and coiled in a large area in the middle of the abdomen irregularly, a set of receiving antennas using diversity technology should be considered. For example, under the condition that the capsule dipole antenna is placed at $(20, 65, -610)$ in $z$ direction polarization, three receiving antennas are placed in front of the body with the same coordinate in $z$ direction and a distance of 40 mm in $y$ direction. Fig. 2(c) shows the results: compared to the case of minimum distance Rx.1, there is no obvious decrease in the case of Rx. 2 (at a distance of 40 mm from Rx.1): in the case of Rx. 2 the value is a little larger than the value of Rx.1 in a frequency range of 500 MHz to 1 GHz, which is caused by the spiral and complex structure of the small intestine. However, with a distance of 80 mm, the difference is larger than 10 dB, so another receiving antenna is necessary to ensure a high value of the transmission factor. The numbers and positions of the receiving antennas used for the small intestine can be determined.

The large intestine surrounds the small intestine. Most of the large intestine is located at the sides of the human body, so it is considered that placing the receiving antenna at the sides can obtain a high transmission factor. For example, under the condition that the capsule dipole antenna is placed at $(15, 110, -610)$, as shown in Fig. 2(d), when the receiving antenna is placed in the left or right side of the human body, the $\tau$ is 10–15 dB higher than that when the receiving antenna is placed at the front of the body.

## 4  Conclusion

The transmission factor from a capsule dipole antenna placed in the digestive system of a human body was investigated. It was found that the peak values of the transmission factor were observed in the frequency range of 400–600 MHz for different organs of the digestive system when the capsule dipole and receiving antennas have the same polarization.

## Acknowledgments