Maximum Received Power From a Capsule Dipole Antenna in Digestive System of Human Body

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***Abstract*—The maximum received power from a transmitting capsule dipole antenna located in all the parts of digestive system of a human body are investigated using the FDTD analysis. It was found that the peak values of the maximum received power were in a frequency range around 500 MHz not only in the case of the stomach, but also in the cases of the esophagus, the small intestine and the large intestine. The maximum received power of -24.5 dBm at 472 MHz is obtained when the transmitting capsule dipole antenna is located in the stomach. Preferred positions of receiving antennas on the surface of human body are also discussed to obtain the high received power for each organ in the digestive system of a human body.**

***Keywords*—digestive system; maximum received power; capsule dipole antenna; antenna polarization**

I. Introduction

Ingestible capsule endoscope systems are expected for healthcare applications [1]. The capsule endoscope pass through the digestive system of a human body composed of the esophagus, the stomach, the small intestine and the large intestine, as shown in Fig. 1. In the previous work, the path loss through a human body has been studied by many researchers [2-6] and expressions of the path loss are different. In [2], $|S_{21}|$ was used as the path loss, it means that the transmitting antenna (Tx.) and the receiving antenna (Rx.) are terminated by 50 Ω and it is not enough to evaluate the optimum internal impedances for both the transmitting and the receiving antennas in order to obtain the maximum received power. In [4], the path loss which indicates the attenuation of the electric field as a function of the position of receiving point was used, however, it cannot be obtained the received power from the electric field when Tx. antenna has an in-negligible length compared with the effective wavelength in the digestive system. In [5], difference of values of $|S_{21}|$ between cases with and without a human body were used as the path loss, however, the mismatch losses of Tx. and Rx. antennas will be change and it is difficult to evaluate the attenuation through a human body as a function of the frequency.

The path loss in several organs, such as the stomach [4] or the small intestine [6] have been studied by some researchers. The surrounding dielectric permittivity and conductivity changes as the capsule pass through them and the characteristics of the path loss and the size of antenna compared with the wavelength of operating frequency also changes from moment to moment.

However, there is no researches study on the maximum received power from a capsule dipole antenna located in all the parts of digestive system, not only stomach or small intestine, but also esophagus, large intestine etc.

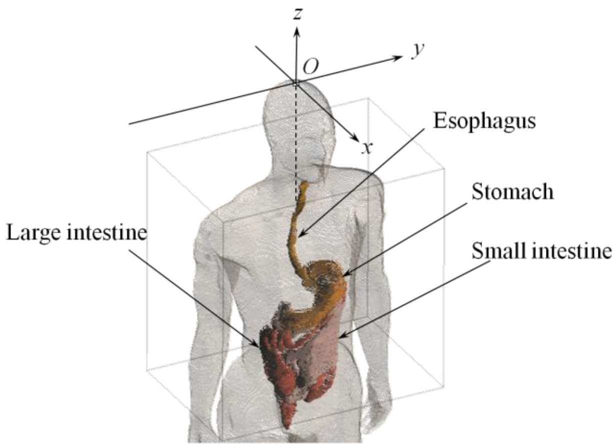

Fig. 1 Digestive system of human body

In this report, the maximum received power from a capsule dipole antenna located in all the parts of digestive system is obtained as the path loss through a human body. The effect of different organs of a human body on the maximum received power have been studied by comparing with the conductivity distribution of a human body. Effects of the position and the polarization of the transmitting and the receiving antennas were also presented. Furthermore, the preferred positions of the receiving antenna were discussed in order to obtain higher received power.

II. Analysis Model

The human body model DUKE developed by SPEAG Co. Ltd was used in the FDTD analysis which is fabricated by using MRI images with 76 kinds of organs. The relative permittivity and conductivity of dispersive human body organs provided by ITIS (USA) [7] from 200 MHz to 3 GHz were used. Only the torso of a body (truncated body) was used in the simulation. Lumina of the digestive system were filled with the deonized water. The cross sections in *xz*-plane and *xy*-plane were shown in Fig. 2, respectively. Origin of the coordinates was set at the top of head. A dipole antenna with length of 20 mm was located in human body as Tx. antenna, the feed point was located at the planes of z=-470, -540, -610 and -700 mm in order to investigate the position of esophagus, stomach, small intestine and large intestine. A dipole antenna

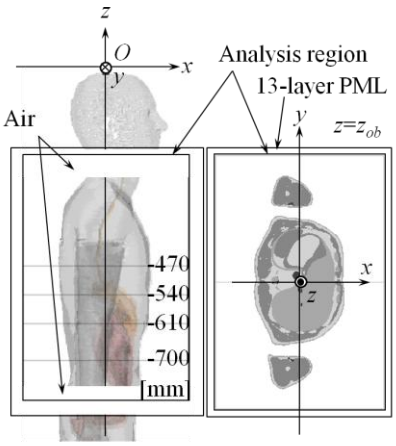

Fig. 2 Analysis model

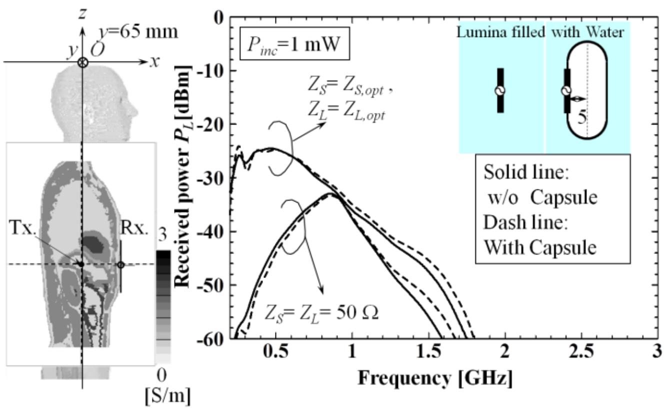

Fig. 3 Comparison of received power and the maximum received power between with and w/o capsule

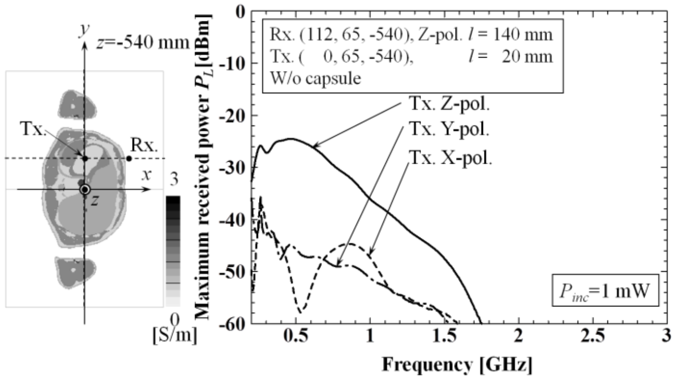

Fig. 4 The conductivity distribution (Left) and the maximum received power (Right) under the condition of dipole antenna was located at the stomach. z=-540 mm

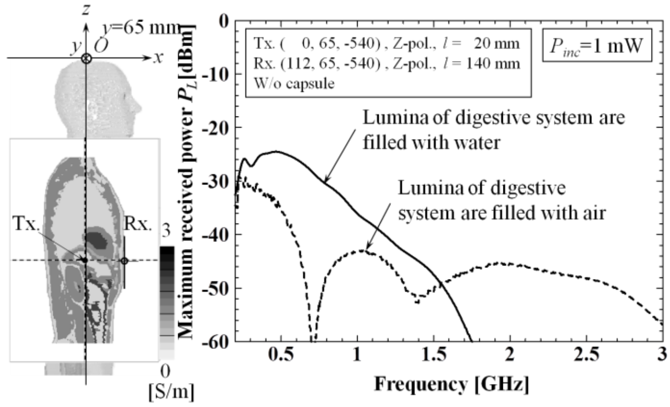

Fig. 5 The conductivity distribution (Left) and the maximum received power (Right) under the condition of dipole antenna was located at stomach (filled with water and air). z=-540 mm

with length of 140 mm was located on the surface of human body as Rx. antenna. The position and polarization of Tx. and Rx. antennas were discussed later. Ohmic loss was ignored to simplify the investigation. A capsule with the length of 30 mm and with the width of 10 mm was used. The capsule was filled by air (ε_r=1). For the reason that a capsule dipole antenna located at the interface of capsule has good transmission performance [8], transmitting dipole antenna was located at the interface of a capsule. The FDTD method with 13-layer PML was used.

III. Maximum received power in digestive system

A) Stomach

The maximum received power P_L represent the power delivered to the internal impedance of Rx. antenna when the internal impedance of Tx. and Rx. are selected to satisfy the complex conjugate matching condition [9]. The color of human organs depends on the conductivity at 1 GHz. Fig. 3 shows the received power (Z_S= Z_L= 50Ω) and the maximum received power (Z_S= $Z_{S,opt}$, Z_L= $Z_{L,opt}$) between with and without capsule when the capsule was move in the stomach. The center of Tx. antenna was located at (0, 65, -540) in *z* direction polarization and the center of the Rx. was located at (112, 65, -540) in *z* direction polarization. The results are almost same, and it is enough to evaluate the maximum received power without considering the capsule in the numerical analysis. The received power and the maximum received power are almost same at 900 MHz for the reason that the input impedance was almost 50 Ω at 900 MHz nearby. Because the structure of the stomach is wide, capsules with antenna will rotate in the stomach, then it is necessary to consider the *x*, *y* and *z* direction polarization of Tx. antenna. Rx. antenna was set to *z* direction polarization and the polarization of the Tx. antenna changed to *x* and *y* direction. Fig. 5 shows a relatively higher received power was obtained when Rx. antenna was set in the same polarization with Tx. antenna For the stomach, Rx. antennas with different polarization were preferred in order to obtain a relative high received power. Fig. 6 shows resonance happened at 700 MHz and 1.4 GHz when the stomach was filled with air. This phenomenon caused by the geometry of stomach. The length of the stomach is almost 11 cm, and the 1/4 and 1/2 wavelength resonant happened at 700 MHz and 1.4 GHz, separately.

B) Esophagus

Fig. 4 (Left) shows an example of the conductivity distribution in *xz*-plane in the position of esophagus. It is found

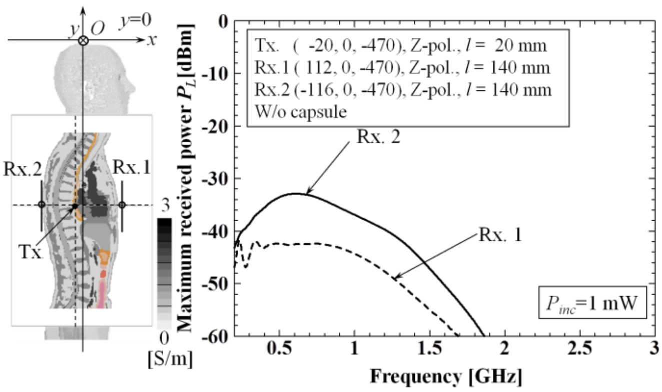

Fig. 6 The conductivity distribution (Left) and the maximum received power (Right) under the condition of dipole antenna was located at the esophagus (*z*-polarization) *z*=-470 mm

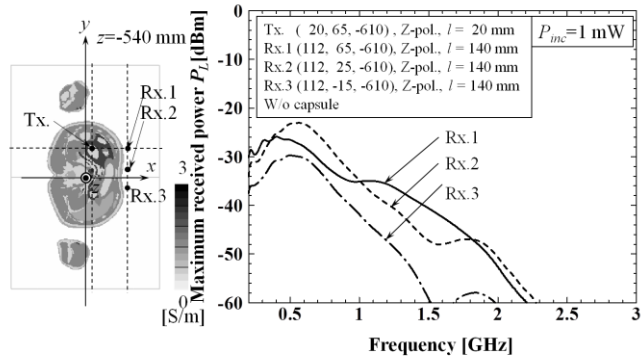

Fig. 7 The conductivity distribution (Left) and the maximum received power (Right) under the condition of dipole antenna was located at small intestine (*z*-polarization). *z*=-610 mm

that the conductivity of the heart is larger than the other organs from the conductivity distribution. When the capsule passes through the esophagus, because the structure of the esophagus is narrow, it is only necessary to consider the *z*-direction polarization of Tx. antenna. Tx. antenna was located at (-20, 0, -470) vertically and a dipole antenna with length of 140 mm was located as Rx. antenna in *z* direction polarization. Rx. antenna was set in front of body (112, 0, -470) and back of body (-116, 0, -470) separately. Fig. 4 (Right) shows the maximum received power increases from 200 MHz to 600 MHz for the reason of the geometry of human body, while decreases from 600 MHz because conductivity of organs increases significantly from 500-600 MHz. Fig. 4 also shows the maximum received power when the Rx. antenna located at the back is higher than it located in the front of body, because the high conductivity heart causes high EM-wave attenuation in the front direction.

C) Small intestine and large intestine

When the capsule passes through the small intestine, because the small intestine is coiled in a large area in the middle of the abdomen, several Rx. antennas should be

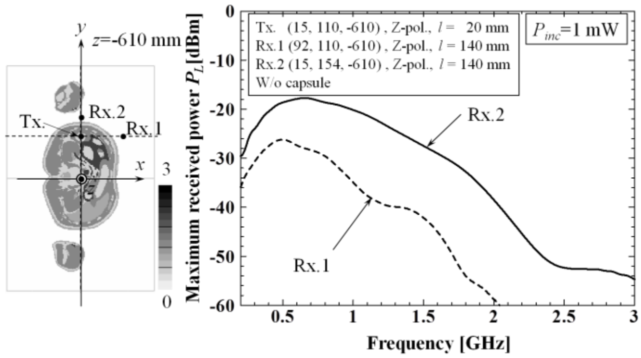

Fig. 8 The conductivity distribution (Left) and the maximum received power (Right) under the condition of dipole antenna was located at the large intestine (*z*-polarization) *z*=-610 mm

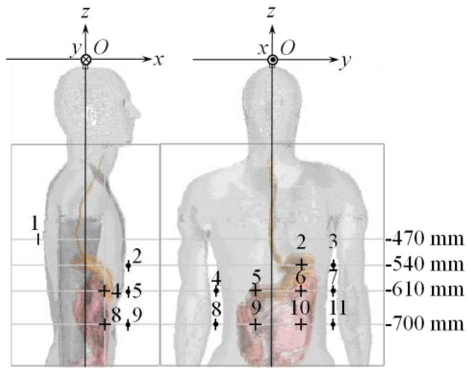

Fig. 9 The preferred positions of receiving dipole antenna

considered. Considering Tx. antenna was located at (20, 65, -610) in *z* polarization, three Rx. were located in front of body with the same height and with a distance of 40 mm in *y* direction. Fig. 7 shows that P_L decreases less than -10 dB within the distance of less than 80 mm. The numbers of Rx. antenna which were used for small intestine could be determined, four Rx. antennas with different polarization in front of body could be used for small intestine. The large intestine is surrounding the small intestine, most part of the large intestine is located in the sides of the human body, so it is certainly to considered that both sides of human body are important in order to obtain high maximum received power. For example, Fig. 8 shows that Tx. antenna was located at (15, 110, -610), and Rx. was located in the side of human body P_L was almost 10-15 dB higher than in case of Rx. antenna located in other place, such as in the front. Four Rx. antennas with different polarization in side of body could be used for the large intestine.

Fig. 9 shows the positions of Rx. antennas with different polarizations. No. 1 is *z*-polarization for esophagus. No. 2 is *yz*-polarization and No. 3 is *xz*-polarization for stomach. Four Rx. antennas in front of body (*yz*-plane, No. 5, 6, 9, 10) could be used for the small intestine, the largest distance is 65 mm in *y* direction and 45 mm in *z* direction. Four Rx. antennas with different polarizations in side of body (*xz*-plane, No. 4, 7, 8, 11) could be used for the large intestine. It can be seen that the maximum received power P_L was relative high in the small intestine and the large intestine (-20~-30 dB), P_L was relative low in the esophagus (-30~-40 dB) under the condition of Tx. and Rx. antennas are in the same polarization. The maximum received power was different in different human body organs. The peak value of maximum received power appeared in a range around 500 MHz. Table 1 shows all the results in this report.

IV. CONCLUSION

In this report, the maximum received power from capsule dipole antenna located in all parts of digestive system of a human body was investigated. In case of with and without capsule, the maximum received powers are almost same. The results also show that the maximum received power decreases by the presence of the organs with high conductivity such as the heart. A relative high received power was obtained under the condition of the receiving antenna and the transmitting antenna are in the same polarization. Finally, preferred positions of the receiving antenna have been discussed in order to obtain a high received power.

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REFERENCES

[1] G. Iddan, G. Meron, A. Glukhovsky, P. Swain, “Wireless capsule endoscopy,” *Nature*, pp. 405-417, 2000.

[2] 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.

[3] K. Kim, S. Lee, E. Cho, J. Choi, and S. Nam, “Design of OOK system for wireless capsule endoscopy,” in *Proc. ISCAS*, May 2010, pp. 1205–1208.

[4] A. Alomainy, and Y. Hao, “Modeling and characterization of biotelemetric radio channel from ingested implants considering organ contents,” *IEEE Trans. Antennas and Propag.*, vol. 57, no. 4, pp. 999–1005, April 2009.

[5] 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 and Propag.*, vol. 57, no. 6, pp. 1850–1854, Jun. 2009.

[6] P. Ara, S. Cheng, M. Heimlich and E. Dutkiewicz “Sensitivity analysis of human phantom models for accurate in-body path-loss model development,” *Personal, Indoor, and Mobile Radio Communications (PIMRC), 2015 IEEE 26th Annual International Symposium on*, pp. 1328–1332 Dec. 2015.

[7] Hasgall PA, Di Gennaro F, Baumgartner C, Neufeld E, Gosselin MC, Payne D, Klingenböck A, Kuster N, “IT’IS Database for thermal and electromagnetic parameters of biological tissues,” Version 3.0, September 01st, 2015. www.itis.ethz.ch/database

[8] H. Sato, Y. Li, and Q. Chen “Measurement of dipole antenna in deionized water,” *2015 International Symposium on Antennas and Propagation (ISAP)*, Nov. 2015.

[9] Q. Chen, Ozawa, K., Q. W. Yuan, and Sawaya, K., “Antenna Characterization for Wireless Power-Transmission System Using Near-Field Coupling,” *IEEE Trans. Antennas and Propag. Magazine*, vol. 54, pp.108-116, Aug. 2012.

Table 1 Position and polarization results

Fig.	Z [mm]	Tx.X [mm]	Tx.Y [mm]	Tx. Pol.	Rx.X [mm]	Rx.Y [mm]	Rx. Pol.	Distance [mm]	P_L _peak [dB]	Freq (P_L _peak) [MHz]	Add
4	-540	0	65	Z	112	65	Z	112	-24.5	472	Filled with water
4	-540	0	65	Y	112	65	Z	112	-44.4	254	
4	-540	0	65	X	112	65	Z	112	-41.1	254	
5	-540	0	65	Z	112	65	Z	104	-30.9	250	Filled with air
6	-470	-20	0	Z	112	0	Z	132	-41.9	337	
6	-470	-20	0	Z	-116	0	Z	96	-32.9	606	
7	-610	20	65	Z	112	65	Z	92	-25.9	402	
7	-610	20	65	Z	112	25	Z	100	-23.0	560	
7	-610	20	65	Z	112	-15	Z	122	-29.7	502	
8	-610	15	110	Z	92	110	Z	77	-26.2	489	
8	-610	15	110	Z	52	110	Z	51	-18.8	676	