Performances of an Implanted Cavity Slot Antenna Embedded in the Human Upper Arm

#Koichi ITO(1), Hiroki USUI (2), Masaharu TAKAHASHI (3)
(1) Faculty of Engineering, Chiba University
(2) Graduate School of Science and Technology, Chiba University
(3) Research Center for Frontier Medical Engineering, Chiba University
1-33 Yayoi-cho, Inage-ku, Chiba, 263-8522, Japan
E-mail: ito.koichi@faculty.chiba-u.jp

1. Introduction

Recently, implantable devices have drawn attention as near future communication tools [1], [2]. Such tools must be wireless when used to communicate with the exterior because they are embedded into the human bodies and pet bodies. So, the study on antennas for implantable devices (implanted antenna) is very important. In addition, the implanted antenna should be small and mechanically robust. In this paper, a cavity slot antenna with an H-shape slot is proposed as an implanted antenna. The model of this antenna operating in the ISM band (2.45 GHz) is analyzed by numerical simulations using the FDTD method. As a result, it is confirmed that the proposed antenna can be used as the implanted antenna.

2. Application for Implanted Antenna

The antenna can be implanted in various regions of the human body or in animals and has several applications. Some examples of the applications for animals are pets, farm animals control for safety and quality management, etc. Figure 1 shows one example of application for the implanted antenna for the human body. Potential applications are blood pressure and pulse of the patients continuous monitoring in sickrooms and intensive-care units, medical records and body information like allergy that can be saved to the implantable device which is useful for decision of diagnosis and treatment method, identity confirmation and attestation of a person, etc.

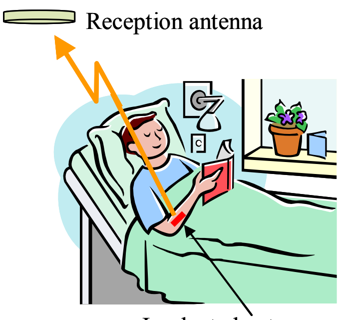


Fig. 1: Example of the application

3. Link Budget for Applications

When such applications are assumed, it is necessary to know for the proposed antenna its range of availability by use of a link budget that is shown in Table 1. When the operating frequency is fixed to 2.45 GHz and the distance between sender and receiver is 4 m etc, the needed implanted antenna gain can be deduced from the link budget [3].

Table 1: Link Budget

Frequency	2.45 GHz
Trans mission power	-71.25 dBW
EIRP	-96.25 dBW
Tx antenna gain	-24.0 dBi
Distance	4.0 m
Bit rate	7 kbps
Path loss	53.27 dB
Link C/N_0	50.79 dBHz
Require C/N_0	50.55 dBHz

4. Implanted Antenna Design and Method for Analysis

Figure 2 shows the configuration of a cavity slot antenna with an H-shape slot proposed as an implanted antenna [4]. A cavity slot antenna has a merit of high miniaturization and mechanically robustness [5]. The cavity slot antenna with an H-shape slot is made of a perfect parallelepiped electrical conductor where an H-type slot is inserted from the front face to the side. It is possible to miniaturize the antenna dimensions by setting up the H-type slot. In addition, as illustrated in Fig. 3, a dielectric ($\varepsilon_r = 2.17$) is filled into the implanted antenna, preventing the human tissues to come inside the antenna. The feeding point is located at the center of the slot on the antenna surface. Figure 4 shows the numerical simulation model when the antenna is embedded into the human body. The antenna is assumed to be implanted into the human model between the shoulder and the elbow. The dimension of the human model is 300×70×70 mm^3. Two configurations of the human model are analyzed: uniform model and 2-layer model (Fig. 4). The former is a 2/3 muscle-equivalent phantom ($\varepsilon_r = 34.87$, σ = 1.16 S/m), the latter is skin ($\varepsilon_r = 38.01$, σ = 1.46 S/m) and fat

(ε_r = 5.28, σ = 0.10 S/m), muscle (ε_r = 52.73, σ = 1.74 S/m), respectively. Electrical constants use the 2.45 GHz (ISM band) value [6]. In the uniform human model, the antenna dimension is 3.2×5.2×2.8 mm^3, and in the 2-layer human model, the antenna dimension is 3.2×8.4×2.8 mm^3 as shown in Fig. 3 with the operating frequency being 2.45 GHz in both cases. The antenna dimension of the 2-layer human model is larger than that of the uniform human model because it is influenced by fat layer which has a low relative permittivity. In this paper, it is assumed that the implanted antenna is subcutaneously embedded into the human body. The upper surface of the antenna is directed towards the surface of the skin. And distance from the surface of the antenna to the surface of the skin is set to 4 mm. In addition, the antenna is placed in the center of the surface of the human model. The antenna is located along two kinds of direction: when the slot on the side of the antenna is paralleled to the *yz*-plane (Direction 1) or when it is parallel to the *xz*-plane (Direction 2) of the human model.

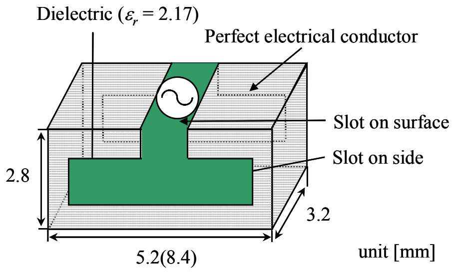


Fig. 2: Configuration of the cavity slot antenna with an H-shape slot

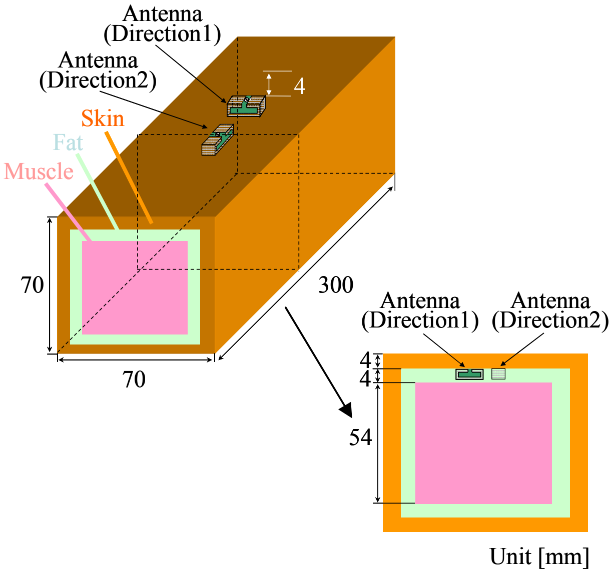


Fig. 3: Numerical simulation model of the 2-layer human arm

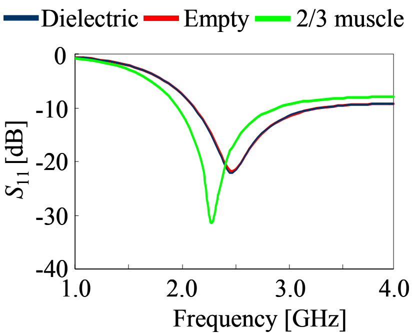
5. Performances of the Implanted Antenna

A. 2/3 Muscle-equivalent Phantom Model

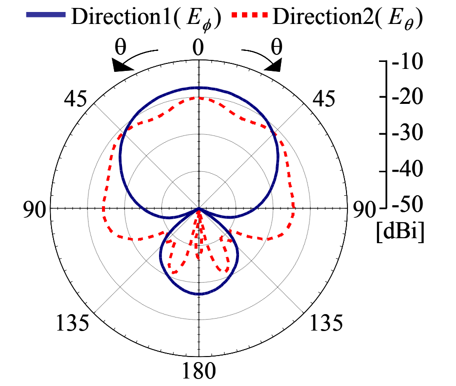
Figure 5(a), (b) shows the frequency characteristics of the *S*-parameter and the radiation characteristics (Direction 1) in the *xz*-plane by numerical simulations using the uniform human model. In addition, in order to confirm the influence when the inner material of the antenna is changed, the inner material of the antenna was set as air, dielectric or 2/3 muscle-equivalent phantom. In this figure, the S_{11} are lower than -20 dB whichever the inner material into the antenna is. When the inner material is either air or dielectric, the frequency characteristics of *S*-parameter is the same. However, when the inner material is a 2/3 muscle-equivalent phantom, the resonant frequency is shifted of 200 MHz compared to the air and the dielectric cases. Even if the inner material is different, the radiation directivity is almost the same, with a maximum gain about -17.5 dBi. From these results, it is confirmed that the antenna even if filled with dielectric is not adversely changed. Figure 5(c) shows the radiation characteristics with different antenna directions (Direction 1 and Direction 2) in the *xz*-plane. The radiation characteristics are shown in the main polarization direction. The studied inner material of the antenna is dielectric. The S_{11} are lower than -20 dB and the characteristics are the same in each antenna directions, but in the radiation characteristics, the maximum gain and the radiation directivity are different. When Direction 1 is compared to Direction 2, the radiation directivity of the Direction 2 has a more elliptical shape than Direction 1. The maximum gain of Direction 1 is -17.5 dBi and the one in Direction 2 is -20.2 dBi. From the link budget and Fig. 5(c), in Direction 1, the range of -24 dBi or more, where a wireless communication is possible, is about 104°, and for Direction 2 it is 140°, both centred on 0°. Direction 2 has a wider range of wireless communication than Direction 1. Table 2 shows the radiation efficiencies that the antenna is embedded into the uniform human model. The radiation efficiency is 0.39 %. This value is very low because the antenna is embedded into the human model that is medium of loss.

B. 2- layer (skin-fat-muscle) Model

Figure 6 shows the frequency characteristics of the *S*-parameter and the radiation characteristics (Direction 1 and Direction2) in the *xz*-plane using the 2-layer human model. The inner material of the antenna is the dielectric. The S_{11} is about -20dB and the characteristics are same in each antenna directions. In Fig. 6(b), the maximum gain of Direction 1 is -18.2 dBi, and for Direction 2 it is -19.2 dBi, the maximum gain is approximately the same, but the radiation directivity is not same. The radiation directivity of the Direction 2 is more elliptical than Direction 1 like in the uniform human model. From link budget and Fig. 6(b), the range that is more than -24 dBi is about 104° symmetrical in the Direction 1, and in Direction 2 is about 160°, both centred on 0°. Direction 2 has wider range of communication than Direction 1. The radiation efficiency is 0.33 % as shown in table 2. This value is lower than the value of uniform human model.

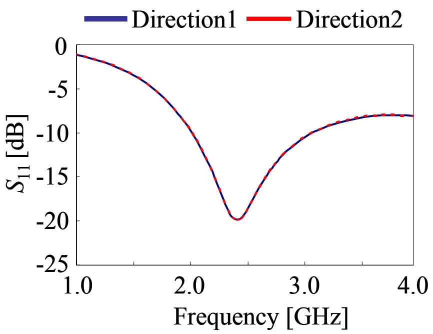


(a) S-parameter with each inner material.

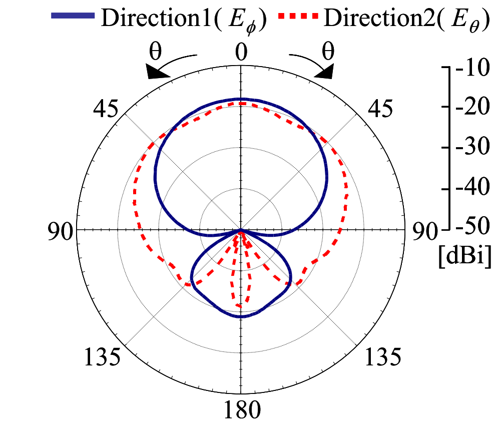


(b) Radiation characteristics in two kinds of direction.

Fig. 4: Radiation patterns with the uniform human model



(a) S-parameter with two kinds of direction.



(b) Radiation characteristics with two kinds of direction.

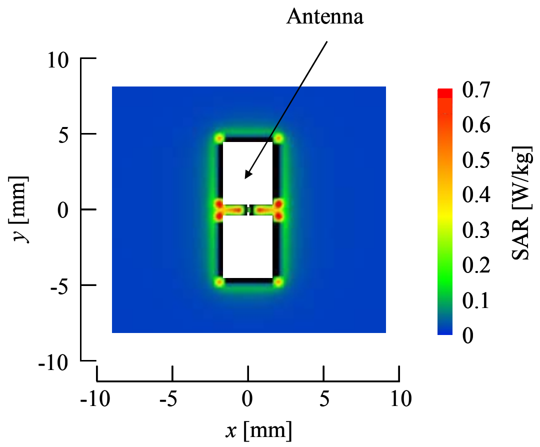
Fig. 5: Characteristics of the 2-layer human model

TABLE 2: RADIATION EFFICIENCIES WITH EACH HUMAN MODEL

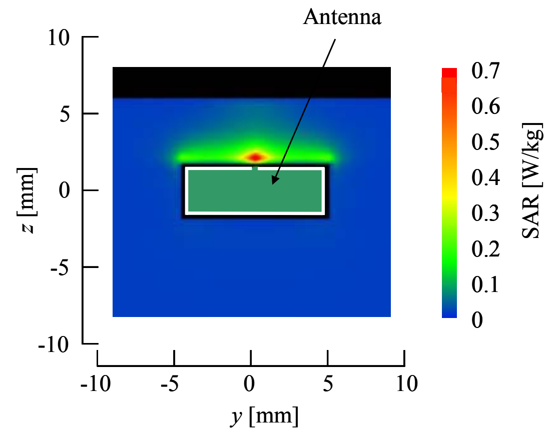
Human model	Radiation efficiency [%]
Uniform	0.39
2-layer	0.33

C. SAR Evaluation of the Antenna

Because the antenna is embedded into the human body, it is necessary to evaluate the SAR (Specific Absorption Rate [W/kg]) to examine whether there is an influence on the human body. Figure 7 shows the SAR distributions over the xy-plane and yz-plane for the antenna implanted into the 2-layer human model. High SAR values were observed at each corner in the xy-plane and around the feeding point in the yz-plane of the antenna. But in this report, when the input power for the antenna is assumed to be 25 µW, the peak SAR value is 0.63 W/kg. This value is lower than the peak 1-g averaged SAR standard value of ANSI (1.6 W/kg) and the peak 10-g averaged SAR standard value of ARIB (2 W/kg) [7], [8]. Therefore, the peak SAR values of the antenna meet the ANSI and ARIB standards.



(a) xz-plane.



(b) yz-plane.

Fig. 6: SAR distributions

6. Trial Manufacture of an Implanted Antenna

Figure 7 shows the configuration of the trial manufacture antenna. To conduct experimentation, the feeding to an antenna is employed method that the coaxial cable is inserted from side of the antenna to the other side. In addition, the location of slot on side of the antenna is changed for impedance matching and simplifying fabrication of the antenna. Dimensions of the trial manufacture is 4.0×10.0×10.0 mm^3, Therefore, input impedance is lower than the realistic antenna as shown in Fig. 9 Moreover, input characteristic of the fabricated antenna was measured as shown in Fig. 8. Table 3 shows the composition of the 2/3-muscle equivalent phantom. This composition is simulated well with the target value of electrical constants.

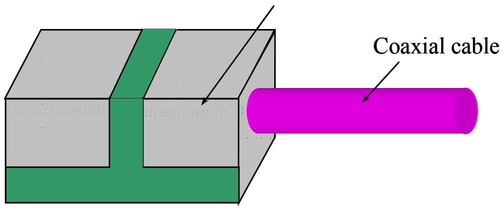


Fig. 7: Configuration of the trial manufacture antenna

(a) Side of the antenna (b) Surface of the antenna

Fig. 8: Fabrication of the antenna of scale model

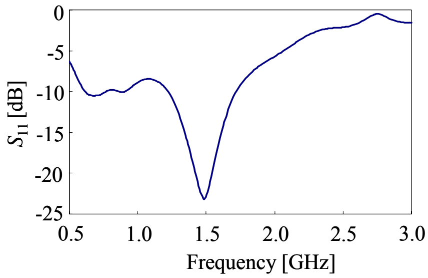


Fig. 9: *S*-parameter of trial manufacture of the antenna

Table 3: Composition of the 2/3-Muscle Equivalent Phantom (A Batch is Approximately 700 g)

Material	Amount [g]
Deionized water	520.4
Ager	16.1
Polyethylene powder	156.1
Sodium chloride	2.4
TX - 151	4.7
Dehydroacetic acid sodium salt	0.3

7. Conclusion

In this paper, a cavity slot antenna with a H-shape slot is proposed for use as an implanted antenna. At first, the link budget of such an antenna aiming at short range communication is conducted. When the distance between sender and receiver is 4 m, the needed implanted antenna gain should be more than -24 dBi. With a uniform (2/3 muscle-equivalent phantom) and 2-layer (skin, fat, muscle) human model is used for embedding the antenna, this antenna is compact and thin. However, the antenna dimension in the 2-layer human model is larger than that of the uniform model because the antenna is embedded into the fat-layer which has a lower permittivity than the 2/3 muscle-equivalent phantom. This antenna resonates at 2.45 GHz, and a radiation in the human front face is confirmed. From the link budget, in the uniform human model, the range where a wireless communication is possible is 104° in the Direction 1, and Direction 2 is 140°. In the 2-layer human model, for Direction 1 it is 104°, and for Direction 2 it is 160°. In addition, the SAR was evaluated to check whether the proposed antenna influences the human body. The peak SAR value is 0.63 W/kg. This value satisfies the standard values of ANSI and ARIB. According to the results, the proposed antenna can be used as an implanted antenna.

References

[1] J. Kim and Y. Rahmat-Samii, “Implanted Antennas Inside a Human Body: Simulations, Designs, and Characterizations,” *IEEE Trans. Microwave Theory Tech*., vol. 52, no.8, pp. 1934-1943, Aug.2004.

[2] P. Soontornpipit, C. Y. Furse and Y. C. Chung, “Design of Implantable Microstrip Antenna for Communication With Medical implants,” *IEEE Trans. Microwave Theory Tech*., vol. 52, no.8, pp. 1944-1951, Aug.2004.

[3] H. Usui, M, Takahashi, and K, Ito, “A fundamental study for implantable slot antenna,” Technical Report of IEICE., AP2005-90, pp. 41-44, Oct. 2005 (in Japanese).

[4] S.changyong, M, Takahashi, and K, Ito, “Implanted PIFA for 2.4 GHz ISM-band applications,” Technical Report of IEICE., AP2005-152, pp. 93-96, Jan. 2006 (in Japanese).

[5] T. Hatsuda, S. Kozono, H. Suzuki, “Radio transmission, satellite, mobile communication,” pp.243-253, Maruzen. Tokyo, 2001 (in Japanese).

[6] T. Hikage, N. Ohno, M. Omiya, and K. Itoh, “Cavity-Backed Slot Antennas for the Microwave Energy Transmission,” Technical Report of IEICE., AP97-67, pp. 57-64, July. 1997 (in Japanese).

[7] C. Gabriel and S. Gabriel. Compilation of the dielectric properties of body tissues at RF and microwave frequencies. Armstrong Lab., [Online]. Available: http://www.brooks.af.mil/AFRL/HED/hedr/reports/dielectric/home.html

[8] *IEEE Standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz*, IEEE standard C95.1-1999, 1999.

[9] “Radio-radiation protection guidelines for human exposure to electromagnetic fields,” Telecommun. Technol. Coucil Ministry of Internal Affairs and Communications (in Japanese).