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A Study of Antenna Implanted in a Human Phantom

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1. Introduction

The implantable medical devices such as a cardiac pacemaker or an ICD (Implantable Cardioverter Defibrillator) with the transceiver function to transmit the medical data to the extracorporeal device have been recently investigated [1], [2]. It is expected that the equipment of the transceiver function brings the reduction of the treatment time and the alleviation of the patient burden. In order to realize this system, the antenna equipped in the implantable medical device must have the small structure and the high efficiency. We have so far investigated the loop antenna mounted on the metal chassis, which is modeled as the implantable medical device [3], and then the radiation property of the loop antenna implanted in the human phantom has been revealed.

In this paper, the miniaturization of above-mentioned loop antenna is investigated and the radiation property of the small loop antenna is shown. Its radiation property is compared with that of the monopole antenna whose area is the same as the small loop antenna. Additionally, the effect of the distance between the antenna element and the metal chassis on the radiation property is investigated. In these investigations, the test frequency is set to 400 MHz band, which is prepared for this system in Europe, the United State and Japan [4].

2. Antenna Configuration

In this section, the radiation property of the loop antenna and the monopole antenna is investigated when these antennas are miniaturized. Fig. 1 and 2 shows three configurations of the loop antenna and the monopole antenna, respectively. In Fig. 1, the loop antenna is designed on the glass epoxy board and is placed 12 mm above a metal chassis (50 mm×50 mm×15 mm), which is modeled as the implantable medical device. The aperture size of the loop antenna shown in Model 1, 2 and 3 is 15 mm×50 mm, 11 mm×38 mm and 7.5 mm×25 mm, respectively. In other words, the occupation area of each loop antenna is 27 mm×50 mm=1350 mm^2 in Model 1, 23 mm×38 mm=874 mm^2 in Model 2 and 19.5 mm×25 mm=487.5 mm^2 in Model 3. These values are very small compared with one wavelength (750 mm) at 400 MHz. In Fig. 2, the monopole antenna is wire of 1mm in diameter bended at a right angle and its occupation area is the same as that of the loop antenna shown in Fig. 1. The test frequency is fixed to be 403.5 MHz.

The human phantom as shown in Fig. 3 is used to evaluate the radiation property of the antenna implanted in a human body. This phantom has the circular cylinder structure made of the acrylic and is filled with the liquid medium of a relative permittivity ε_r = 61 and a conductivity σ = 0.8 S/m at 400 MHz [4]. The antenna is located at 10 mm from the inside wall of the human phantom, and this is modeled as the actual condition implanted in the human body.

Fig. 4 shows the VSWR characteristic of the loop antenna and the monopole antenna. Fig. 4 (i) shows the VSWR in free space and Fig. 4 (ii) shows the VSWR in the phantom. In both cases, the input impedance is matched to 50 Ω by a matching circuit. In free space, the bandwidth for a VSWR of 3 or less becomes narrow as the occupation area is decreased. The bandwidth in the phantom is more than 10 times wider than that in free space. This is because the antenna is surrounded by the lossy liquid medium. Fig. 5 shows the relationship between the average gain of *XY*-plane and the occupation area of the antenna. In both antennas, it is observed that the average gain is reduced by more than 15 dB by being implanted in the phantom. The average gain of the

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loop antenna becomes low as the occupation area is decreased. This is because the radiation resistance of the loop antenna becomes low due to the miniaturization. On the other hand, it is seen that the average gain of the monopole antenna is almost constant even if the occupation area is changed. This result shows that the large amounts of current are distributed on the metal chassis since the total length of the monopole antenna is about 0.1 wavelengths. From these results, the monopole antenna can be miniaturized compared with the loop antenna in the case of this antenna parameter including the size of this metal chassis.

3. Effect of Distance Between Antenna and Metal Chassis

This section describes the radiation property of the antenna element brought close to the metal chassis in order to miniaturize the implantable medical device including the antenna element. In this section, the loop antenna of Model 1 shown in Fig. 1 is used since the average gain is highest. In the monopole antenna, Model 3 shown in Fig. 1 is used since the average gain hardly changes by the size of the antenna element.

Fig. 6 shows the configuration of the loop antenna. In Fig. 6, the radiation property of the loop antenna is investigated when the distance d_L between the loop antenna and the metal chassis is varied from 4 mm to 12 mm. The aperture size of the loop antenna is the constant value of 15 mm ×50 mm. Fig. 7 shows the VSWR characteristic of the loop antenna whose input impedance at test frequency is matched to 50 Ω by a matching circuit. The bandwidth in free space is about 4 MHz, whereas that in the phantom is wider than 180 MHz. Fig. 8 shows the relation of the average gain and the distance d_L. The average gain in the phantom is more than 15 dB lower than that in free space, and the average gain is reduced by 0.5 dB/mm in both free space and the phantom as the antenna element comes close to the metal chassis. This is because the current with the opposite phase of the antenna current flows on the metal chassis by coming close to the metal chassis.

Next, the radiation property of the monopole antenna is investigated when the distance d_M between the loop antenna and the metal chassis is varied. Fig. 9 shows the configuration of the monopole antenna. The total length of the monopole antenna is fixed to be 44.5 mm, and the distance d_M is varied from 6.5 mm to 19.5 mm. Fig. 10 shows the VSWR characteristics of the monopole antenna. The bandwidths in free space and the phantom are wider than 12 MHz and 145 MHz, respectively. Compared with the loop antenna, the difference between the bandwidths in free space and the phantom is small. This is because the amount of the current that flows on the metal chassis in the monopole antenna is large as stated above. Fig. 11 shows the average gain as a function of distance d_M. As well as the loop antenna, it is seen that the average gain is reduced by 0.5 dB/mm in both free space and the phantom as the antenna element comes close to the metal chassis.

These results show that the variation of the average gain in the phantom along with the distance between the antenna element and the metal chassis is equivalent to that in free space. Moreover, it is also found that the variation of the average gain in the loop antenna is equal to that in the monopole antenna.

4. Conclusion

We have investigated the radiation property of the loop and the monopole antenna mounted on the metal chassis, which is modeled as the implantable medical device, when these antennas are miniaturized. From the result of the investigation, it is found that the gain reduction of the monopole antenna is smaller than that of the loop antenna in the investigation model when the antenna elements are miniaturized. Additionally, we have also revealed the effect of the distance between the antenna and the metal chassis on the radiation property. In the future, we will investigate the required actual gain to transmit between the implantable device and the extracorporeal device through the propagation experiment. Moreover, the further miniaturization of the antenna will be continuously investigated.

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[4] TELEC-T241. (In Japanese)

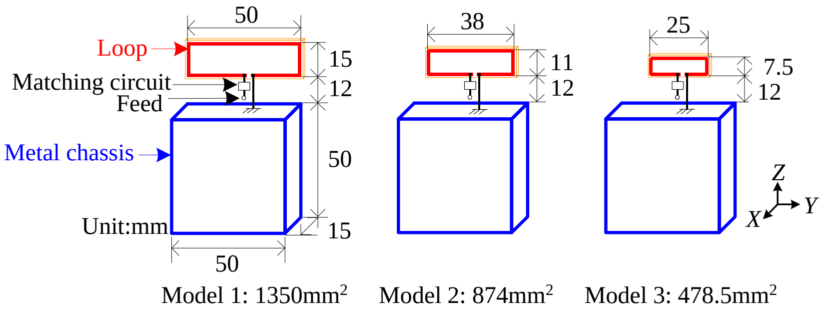


Fig. 1 Loop antenna configurations.

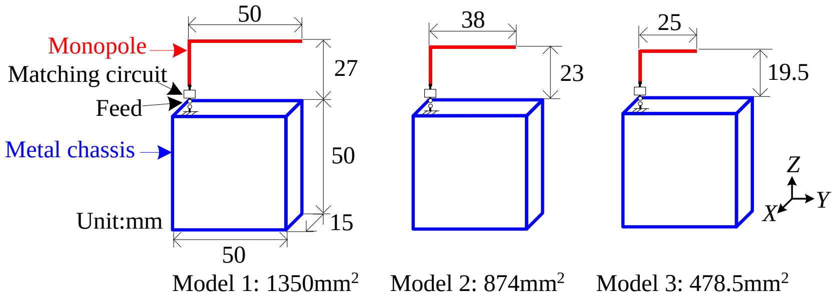


Fig. 2 Monopole antenna configurations.

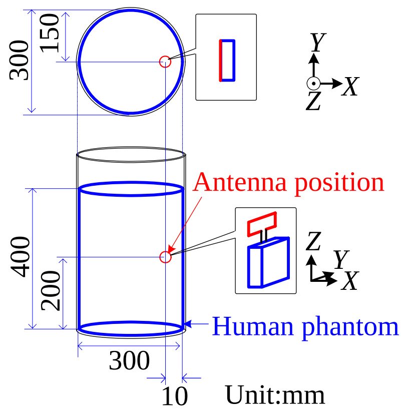


Fig. 3 Human phantom configuration and location of antenna.

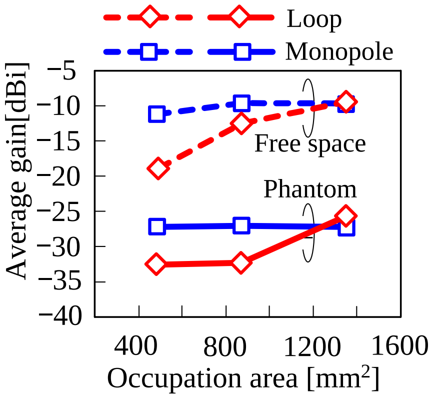


Fig. 5 Average gain of loop and monopole antenna.

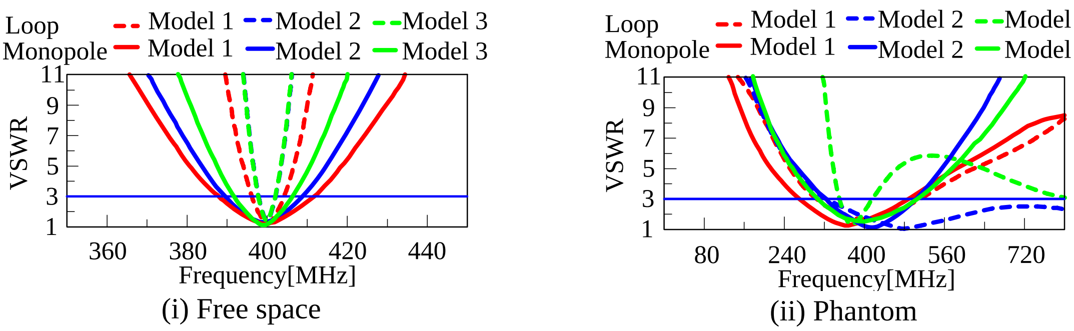


Fig. 4 VSWR of loop and monopole antenna.

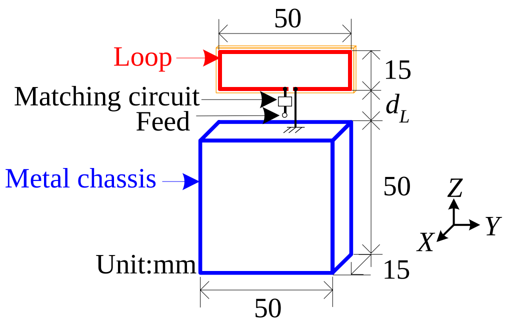
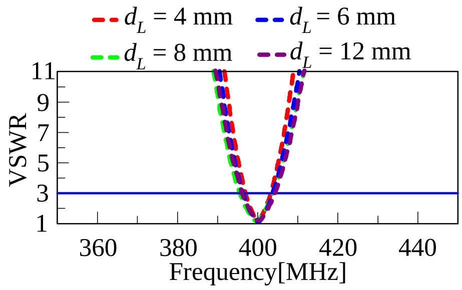
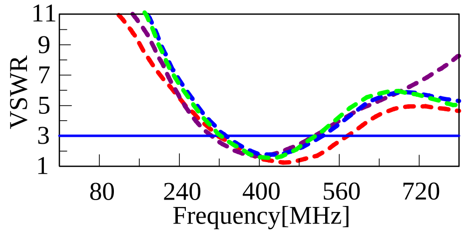


Fig. 6 Loop antenna configuration.



(i) Free space



(ii) Phantom

Fig. 7 VSWR of loop with distance d_L varying from 4 mm to 12 mm.

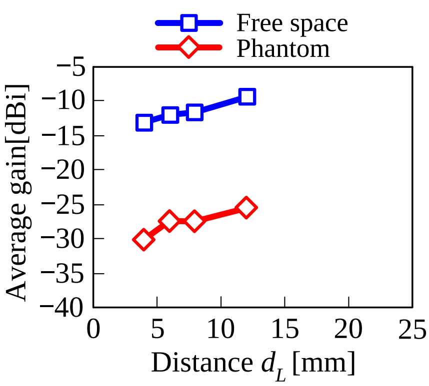


Fig. 8 Average gain of loop vs. distance d_L.

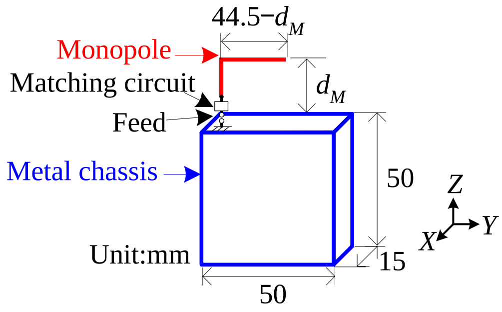
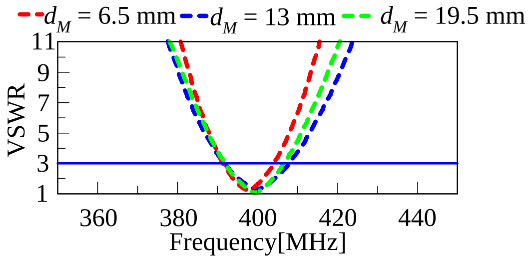
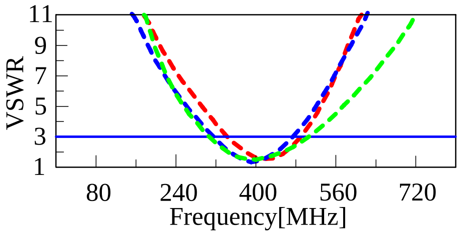


Fig. 9 Monopole antenna configuration.



(i) Free space



(ii) Phantom

Fig. 10 VSWR of monopole with distance d_M varying from 6.5 mm to 19.5 mm.

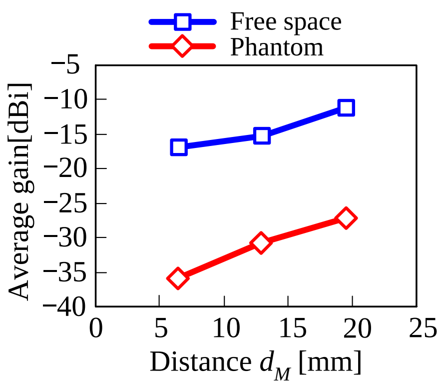


Fig. 11 Average gain of monopole vs. distance d_M.