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Master's Degree Thesis

Transmission System for Simultaneous Transfer of Conductive Power and Data for Implantable Devices

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Department of IT Fusion Technology
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임플란터블 디바이스용
전도형 전력 전송 및 데이터 통신 동시 시스템

February 25, 2016

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Acronyms

BAN	Body Area Network
BER	Bit Error Rate
DBS	Deep Brain Neuro Stimulator
EBPF	Elliptic Band Pass Filter
FSDT	Frequency Selective Digital Trasmission
ICD	Implantable Cardiac Defibrillator
IP	Insulin Pump
NIH	National Institutes of Health
RF	Radio Frequency
WPC	Wireless Power Consortium
WREL	Wireless Resonant Energy Link

요 약

임플란터블 디바이스를 위한 전도형 전력전송 및 데이터 통신 시스템

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기존 임플란터블 디바이스는 페이스메이커나 신경 자극기 같이 배터리로 구동하고 생체 데이터를 외부로 송수신 해야 한다. 이러한 디바이스는 측정된 생체 신호 및 치료를 위한 피드백 신호의 지속적인 송수신을 위해 무선 전력공급과 에러율이 매우 낮은 안정된 데이터 통신이 함께 요구된다. 본 연구에서는 동일한 전극을 사용하여 인체를 통해 임플란터블 디바이스로 전력과 데이터를 동시에 송수신 할 수 있는 전도형 전력전송방식을 제안하였다.

전도형 전력전송 기술은 커패시티브한 성질과 컨덕티브한 성질을 가지는 인체를 통해 직접적으로 전력을 전송하는 방식이다. 전도형 전력전송방식은 신호와 접지부분으로 이루어진 하나의 전극을 인체에 직접 접촉시켜 송신부와 수신부간 폐회로를 형성하여 전력 및 데이터를 전송 하는 방식이다. 이 방식은 전력과 데이터를 두 개 이상의 주파수로 나누어 하나의 전극을 통해 송수신이 가능하기 때문에 전력과 데이터 신호간의 간섭을 최소화할 수 있다.

또한, 전도형 전력전송방식은 자기 유도 및 공진형 방식과는 달리 코일 형태의 안테나가 필요하지 않다. 따라서, 전극의 모양에 구애 받지 않고, 다양한 소형 임플란터블 디바이스에 적용이 가능하다.

I. Introduction

Following groundbreaking developments of information, medical, and engineering technologies, research on implantable u-healthcare devices has been actively conducted [1]. Implantable devices, such as pacemakers (cardiac regulators) and implantable defibrillators, require a power supply for continuous transmission of feedback signals that are used in therapy [2][3][13]-[15]. Moreover, stable data communication with a very low error rate is required for accurate transmission of real-time measured body feedback signals [4]. Magnetic induction and resonance methods are being researched to supply power to implantable devices. These methods show high power transmission efficiency. Interference of each data and power signal must be minimized to simultaneously send the respective signals, whereby each signal must be transmitted in different frequency bands. To date, different antennas are used for data signal and power signal transmission, which results in the disadvantage of an increased implantable device size.

In this paper, we propose a conductive power transmission method that enables simultaneous transmission of power and data to an implantable device through the human body using the same electrode. The conductive power transmission technology directly transmits power through the human body, which has capacitive and conductive properties. The proposed conductive power transmission method directs one electrode composed of a signal and ground part to the human body to form a closed loop between the respective transmission and receiving parts for power and data transmission. This method enables transmission with one electrode by dividing power and data into two or more frequencies in which interference between the power and data signals can be minimized. Furthermore, the proposed conductive power transmission method does not require coil-form antennas, unlike magnetic induction and resonance type methods. Therefore, this method can be applied in various miniature implantable devices regardless of the electrode shape.

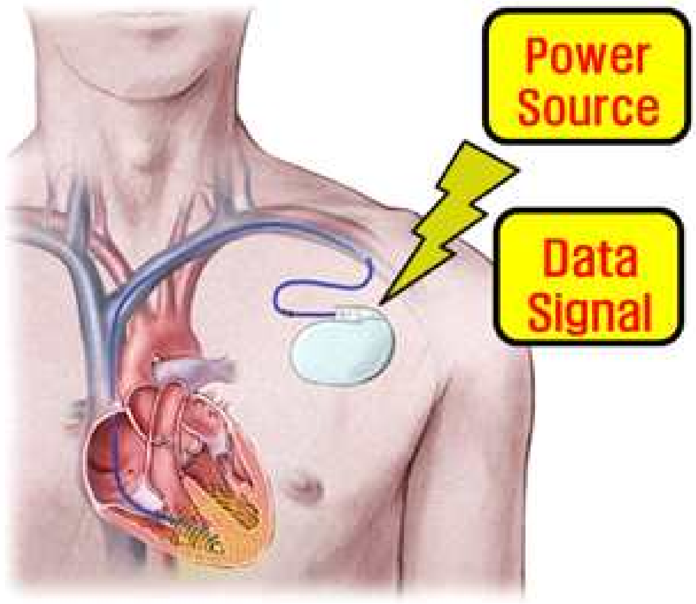


Figure 1.1. Data communication and power transmission for implantable devices.

II. Previous methods

A. Purpose

This study aims to examine general aspects of wireless power transmission-based wireless charging technologies and strengths and weaknesses of technical elements to consider for application to implantable devices.

B. Implantable medical devices and power module

The range of implantable medical devices applied for restoring or recovering physical functions damaged by population aging, diseases and unexpected accidents including a traffic accident is expanding by gradation. As shown in Figure 2.1, DBS(Deep Brain Neuro Stimulator), Cochlear Implants, Implantable Cardiac Defibrillator(Pacemaker and Insulin Pump are representative implantable medical devices.

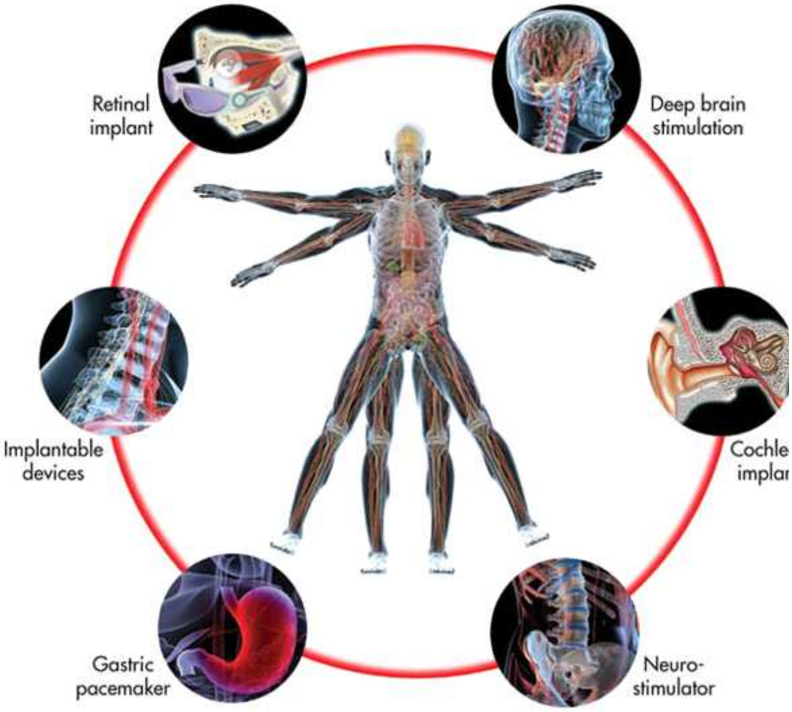


Figure 2.1. An application case of an implantable devices.

Figure 2.2 displays a module, which is one of implantable medical devices launched by Meditronic, U.S.A. and employes a primary battery as a power source. As shown in the figure, the life of device power lasts for 6 months to 6 years, which means it extensively varies depending on the conditions of patients. Energy used is calculated, based on the size of stimulus pulse signal applied to a patient, frequency, signal width and electrical impedance of a stimulator. As the graph displays, for a patient with a relatively slight symptom, it can be used for about 7.5 years, if the amount used is nearly 60 energy, but for a patient in a severe state, the battery must be replaced in a year, if stimulus pulse is frequently applied.

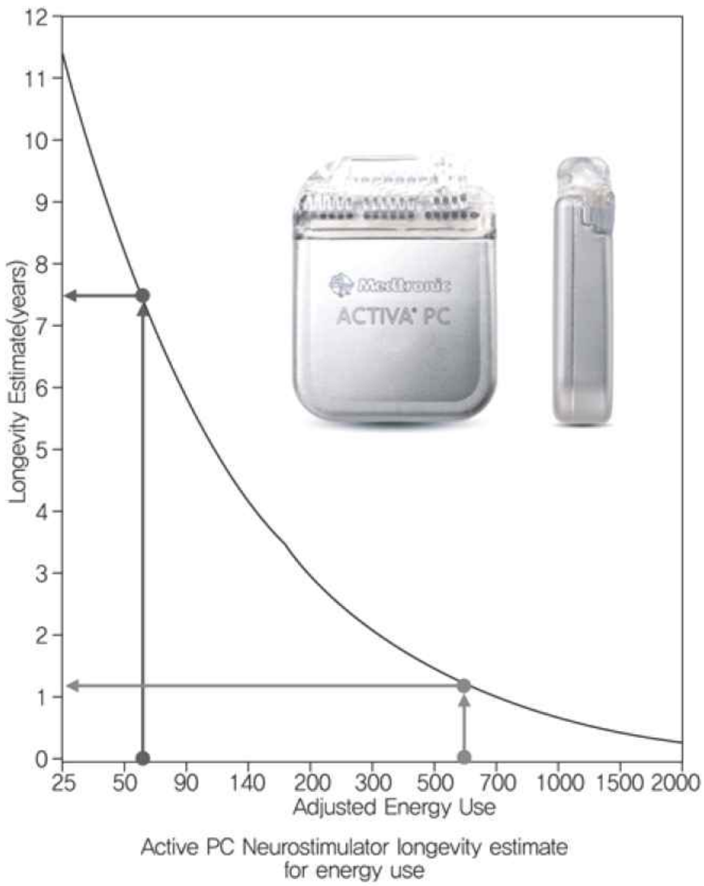


Figure 2.2. The service life of the Medtronics product depending on the amount used.

C. Implantable wireless power transmission technology

Thus far, a variety of implantable wireless power transmission technologies have been attempted. These technologies are classified into 1) Electromagnetic induction system using electromagnetic waves, 2) Electromagnetic resonance system, 3) Electromagnetic wave system, and 4) Ultrasonic wave system. First, magnetic induction system is to receive electricity induced between the transmitter coil and the receiver coil. Once the transmitter coil generates the magnetic field, the receiver coil receives the magnetic field and induces electricity again. This system has a very high transmitting efficiency of 90% or above, but the transmission distance is only several millimeters and the transmitting efficiency highly reduces, if the centers of the coils are not aligned with one another. Figure 2.3 shows a technology applied to Samsung Galaxy S5 Edge in 2015 from S4 in 2013[5], which have been commercialized as mobile devices for wireless power transmission in the air.

Figure 2.3. Magnetic induction system-based wireless charging in Samsung.

As shown in Fig 2.4, implantable devices such as CRT-P IPG of St Jude and RestoreULTRA of Medtronics use rechargeable power modules and they all adopt a magnetic induction system. The secondary battery capacity of these devices is about 50mAh and they are designed to charge every 20 days, averagely.

Figure 2.4. Pacemaker applying St Jude's early wireless power transmission technology.

Figure 2.5 indicates the contents announced by NIH(National Institutes of Health) in 2006. They revealed that when nearly 7.2W of power was transmitted to the receiver inserted below 5cm of a field mouse's heart, the receiver received approximately 26 to 73mW of power and the power transmitting efficiency was 1%. They added that since the coil didn't have a yoke, the efficiency fell at a frequency of 2MHz. Most magnetic induction system-based devices have reported a high efficiency during the experiments in the air, but NIH recommended to operate them for 60 minutes or less to increase the internal temperature of a mouse by less than 0.5℃[6].

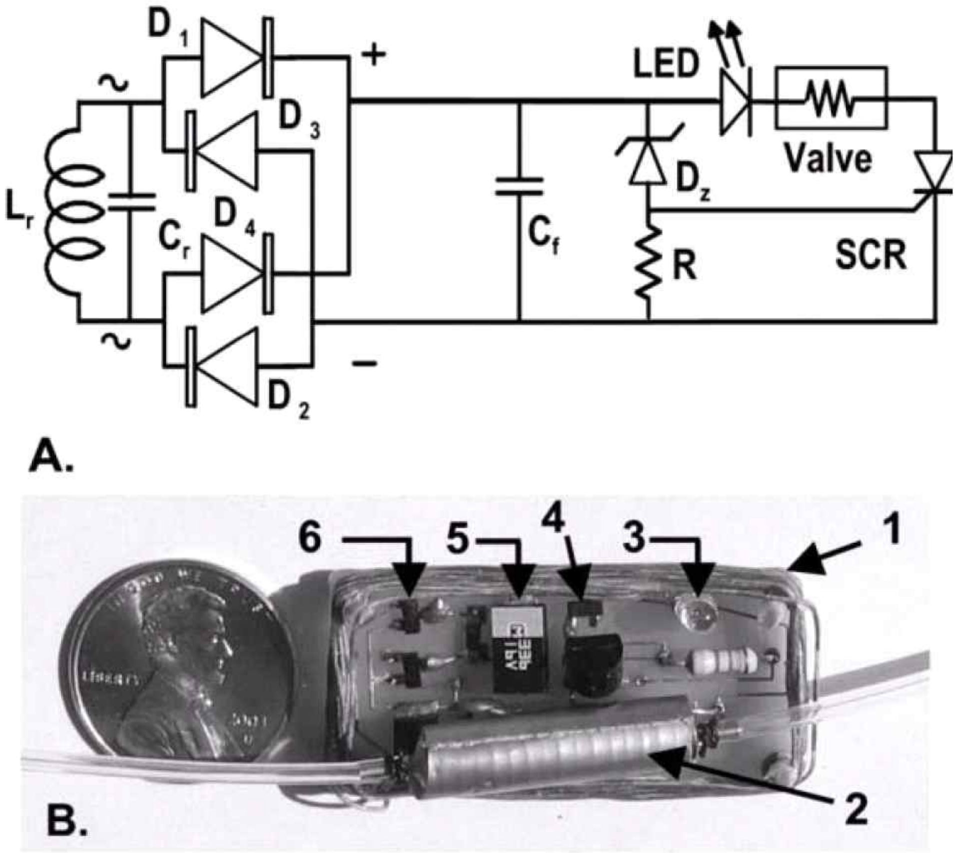


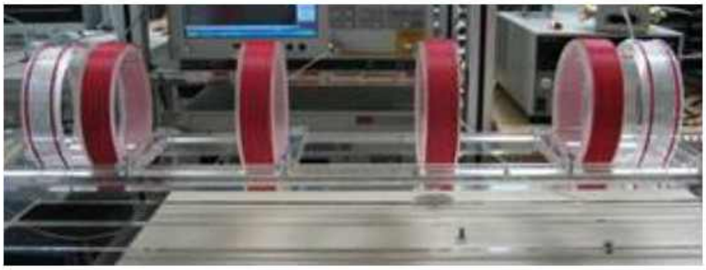
Figure 2.5. Electromagnetic induction system-based power transmission module inserted 5cm of a mouse heart: 1% transmitting efficiency.

Magnetic resonance system is to transmit the magnetic field oscillating at a resonant frequency, which is created in the transmitter, to the receiver coil designed to have the same resonant frequency. Unlike the magnetic induction system, this has a transmitting efficiency of about 90% at a distance of 1m and this makes it possible to transmit at a long distance, in proportion to the diameter size of a device. Currently, there is a continuing study on this technology and Intel announced in IDF that they were developing the same technology named "Wireless Resonant Link(WREL)", as displayed in Figure 2.6[7]. This technology is characterized by big-sized transmitter and receiver and it is hard to extract electricity from the output terminal, freely. Besides, there are a lot of problems regarding where and how to place the power supply coil, how to distribute power when there are a lot of devices to receive power, and how to set a control function in the power supply unit depending on the amount of power used or the charge amount. In order to solve these problems, so far, there have been active researches to develop small-sized receiver coils and improve the transmission efficiency using a feeding coil by conducting experiments in various coil structures.

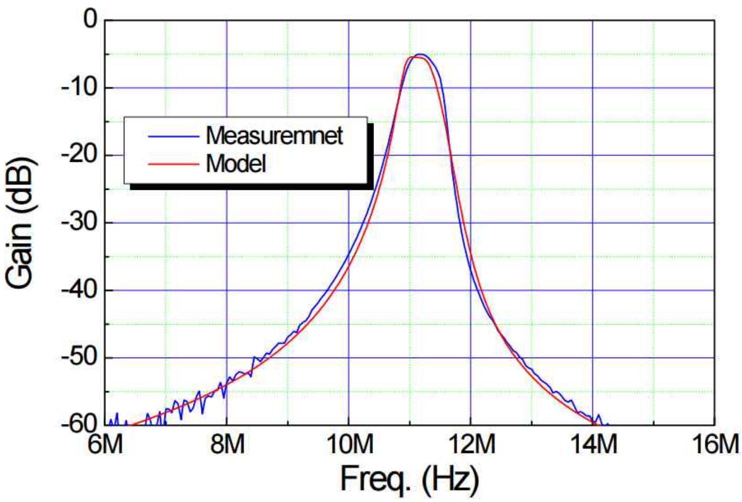
Figure 2.6. Intel's Wireless Resonant Energy Link(WREL) technology announced in IDF 2008.

Figure 2.7 shows a multiple coil transmission system, which is an advanced type of the magnetic resonance system[8]. Figure (a) indicates a system with a transmission distance of 50cm and a low transmission efficiency of 0.65%. By placing two feeding coils for a bridge role in a proper way, as shown in Figure(b), it is possible to improve the transmission efficiency. After placing the two bridge coils, the transmission efficiency increased to 32%.

(a)



(b)



(c)

Figure 2.7. Experiment setup and ADS simulation in ETRI, (a) miniaturizing the sending and receiving coil (b) additional feeding coils (c) signal loss according to frequency

Ultrasonic wireless power transmission system in Figure 2.8 employes the piezoelectric effect of ferroelectric materials. In other words, electricity is created, when compressive force or tensile force is applied to both ends of the piezoelectric body. On the contrary to this, contraction or relaxation occurs, when an electric field is applied. It is possible to get ultrasonic waves by using the latter and generate electricity from ultrasonic pressure by using the former[9]. In conclusion, using this piezoelectric phenomenon, ultrasonic wireless power transmission system transmits ultrasonic waves created outside to the human body. Then, the piezoelectric ultrasonic receiver inside converts acoustic energy into electric energy and transmits power[10].

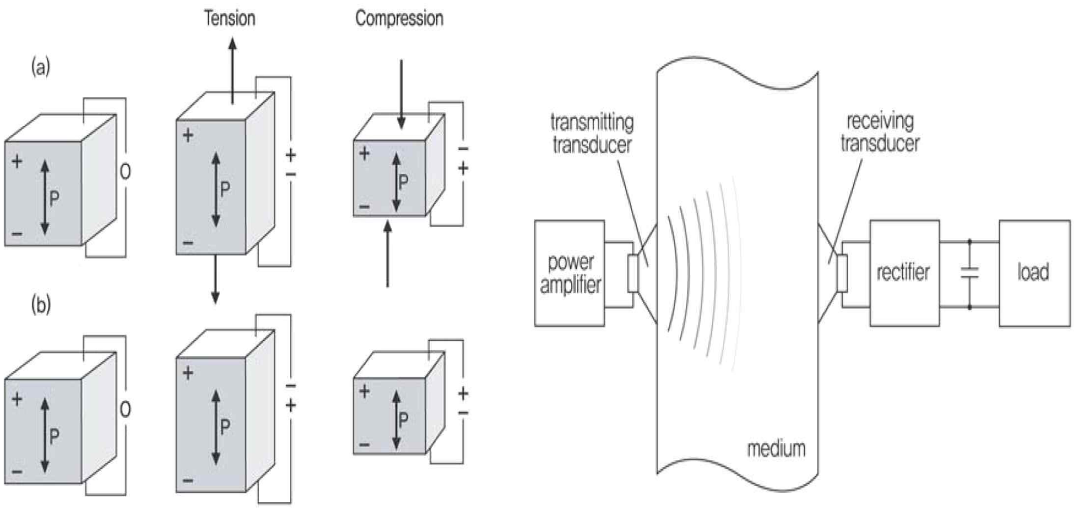


Figure 2.8 Characteristics of the piezoelectric body
: (a) Electricity generated by mechanical compression/expansion,
(b) Displacement by the magnetic field.

In relation to power transmission in the water or human body, ETRI reported a result using an ultrasonic device. Figure 2.9 shows a diagram of ultrasonic wireless power transmission system in the water developed by ETRI and its experiment result. By using the frequency optimal control technique, which adjusts the frequency applied to the transmitting device to the impedance of the receiving device, the maximum transmission efficiency at a close distance of 10mm was 50% to 60% and even at a long distance of 200mm, the maximum transmission efficiency approached 30%. Also, the transmission capacity was 500mW at a distance of 200mm.

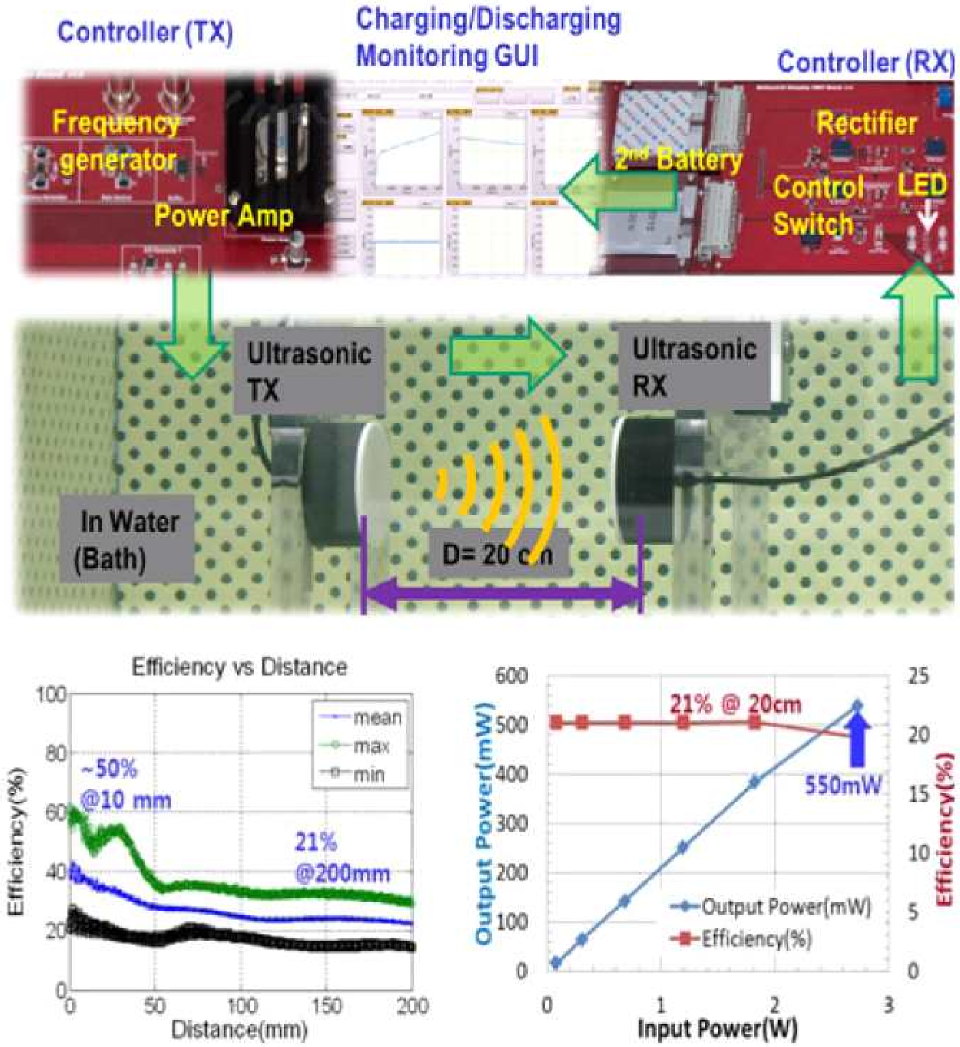


Figure 2.9. Ultrasonic wireless power transmission system developed by ETRI and power transmission efficiency and transmission experiment result.

ETRI also announced that in the experiment of ultrasonic power transmission by the medium of a pig skin tissue at a distance of nearly 20mm[11], the transmission efficiency approached 20%, which was lower than the transmission efficiency by the medium of water. They reported this resulted from the difference in absorption rate between the skin tissue and water. In addition, as shown in Figure 2.10, Purdue University announced an implantable power transmission module using sound waves, as a technology that requires more studies, since the transmission efficiency or capacity is yet low[12].

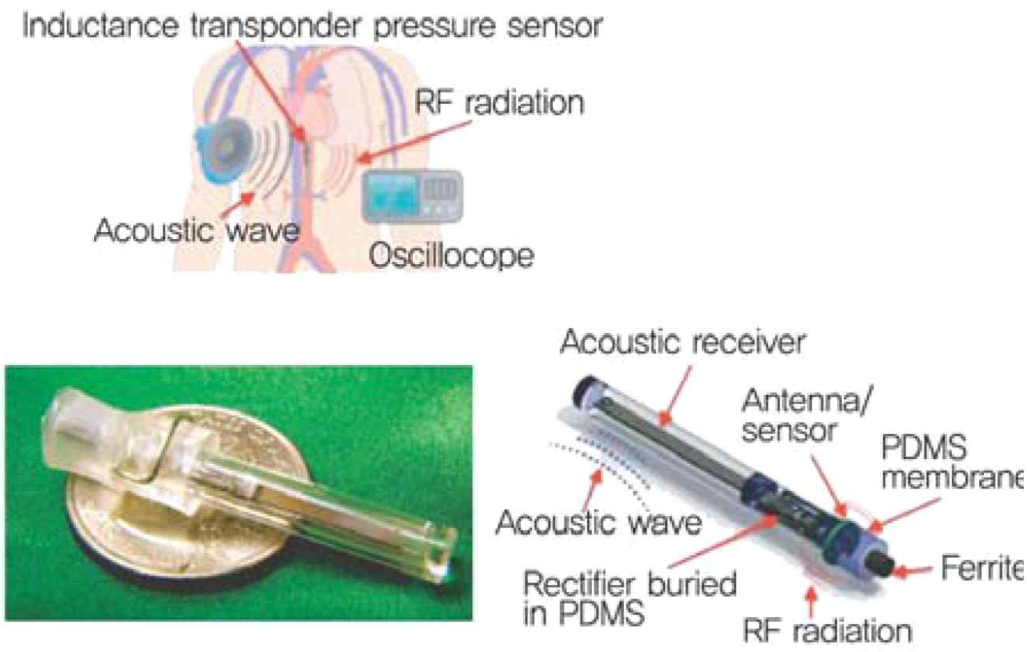


Figure 2.10. A sound wave resonant cantilever-based power transmission system suggested by Purdue University.

III. Experiment and result

A. System architecture

Existing implantable devices, such as pacemakers and nerve stimulators, are powered by batteries and must transmit biological data outside the body. These devices require a wireless power supply and stable data communication with a very low error rate for continuous transmission of the feedback signals used in therapy. In this study, the proposed conductive power transmission method, which requires a continuous power supply and stable data communication, was used. Experiments were performed to evaluate the simultaneous transmission of power and data with one electrode.

B. Conductive power transmission

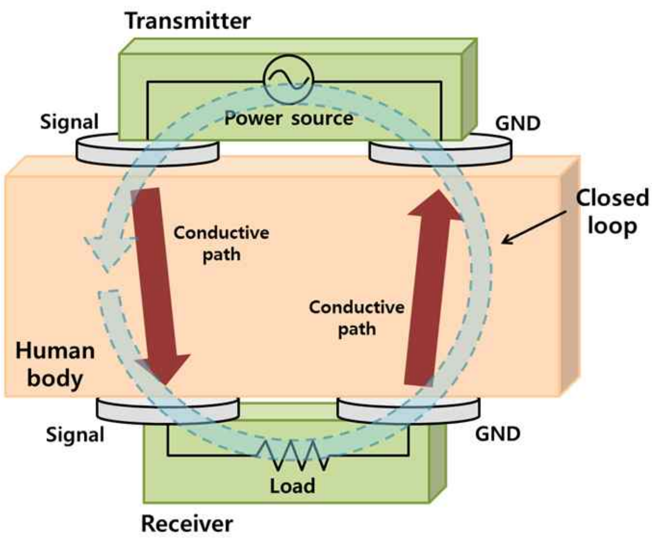


Figure.3.1. Structure of the conductive power transmission system.

As shown in Figure 3.1, the conductive power transmission system transmits and receives power through both a transmitting electrode on the surface of the human body and a receiving electrode inside the body. The transmitting and receiving electrodes respectively consist of signal and ground electrodes. Each electrode comes into contact with the body. The human body is conductive; therefore, a conductive path is formed between the signal electrode and ground electrode through the body. Accordingly, a closed loop is formed between the power signal source and load resistance in which power can be transmitted, as shown in Figure 3.1. The human body has finite conductivity thus, power loss occurs on the closed loop on account of the resistance component on the conductive path. Conductive loss likewise occurs. Therefore, additional signal loss due to power leakage between the signal and ground electrode, as well as signal loss between the conductive path occur. Resonant-type power transmission uses transmitting and receiving coils at a specific frequency. Despite its high transmission efficiency, it has the disadvantage of increased signal loss due to misalignment in the core part of the transmitting and receiving coils [16]. In conductive power transmission, the change of signal loss is small because the resistance components are consistently maintained in the coupling path, even in misalignments of transmitting and receiving coils or changes of transmission distance. Therefore, stable transmission efficiency can be maintained, even in misalignment and transmission-distance change cases, such as in the movement of devices or internal organs when power is transmitted to an implantable device.

Existing power transmission technology for simultaneous data and power transmission requires an additional antenna for data transmission. Moreover, the frequency must be sufficiently isolated to minimize the frequency interference between the data and power, and the antenna size increases accordingly.

In contrast, the conductive power transmission system facilitates power and data transmission using one electrode without additional antennas because it uses the same electrode that is employed for human body communication (HBC). This consequently helps reduce the antenna size.

C. Human Body Communication

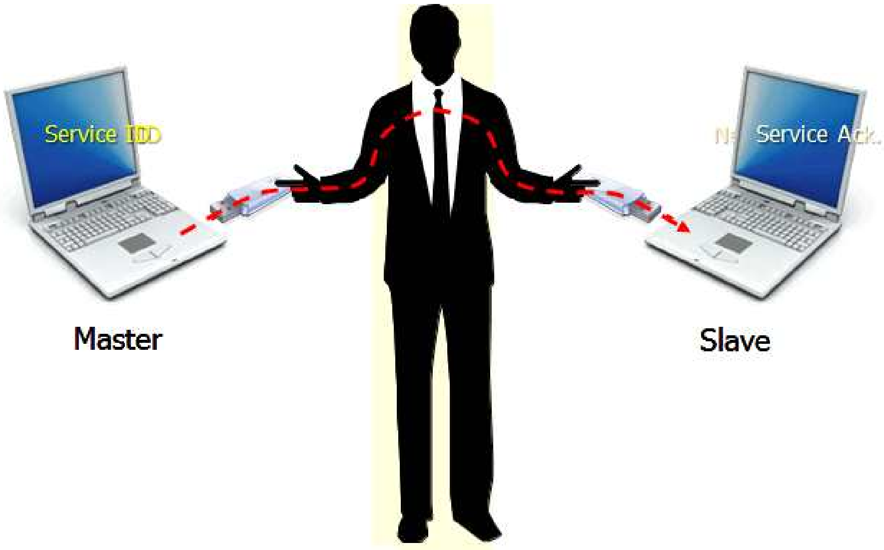


Figure.3.2. Structure of the Human Body Communication.

Recently, body communication technology for transmitting signals between body-connected devices has been developed using the direct transmission of digital signals and the body as a communication channel. HBC for data communication in implantable devices is a short-range communication technology that transmits data through the medium of the human body [17].

This technology, which implements the body area network (BAN), transmits signals between the devices connected to the body using the frequency-selective digital transmission (FSDT) method instead of general modulation methods without frequency modulation [17][18]. Miniature devices can be manufactured because the human body is used as a medium. Moreover, diversely shaped cables for connections between these devices are not required for providing convenient services. Furthermore, the HBC module size is 30 mm X 70 mm with a 1.6-mm thickness, 23-mW power consumption, and a 2-Mbps data rate. Therefore, it is possible to simultaneously transmit data and power using HBC and conductive power transmission regardless of the electrode material or shape.

D. Mesurement Setup for Transmission Efficiency Using Human-flesh-like Material

To measure the power of conductive power transmission and data transmission efficiency, distilled water and a beef medium were used for the experiment. The beef medium is characteristically very similar to human flesh [19]. Distilled water has the lowest conductivity among human body phantoms [20]. These substances were therefore used to compare the power transmission efficiencies according to medium characteristics. Figure 3.3 shows the experimental setup and a schematic diagram of the conductive transmission. Figure 3.3 (a) depicts the measurement of power transmission efficiency using the distilled water medium, while Figure 3.3 (b) presents the measurement of efficiency using the beef medium. The size of the transmission electrode used in the experiment was 40 x 20; the receiving electrode was 25 x 10. The thickness of the medium was 2~50 mm. The insertion locations of an embedded-type pacemaker that is transplanted just beneath the skin, and a nerve stimulator that is transplanted in the musculoskeletal layer, were considered for the thickness measurement. To verify the power transmission efficiency, power was generated using a crystal oscillator, which outputs signals of a 3.3-V amplitude at 1 MHz. An elliptic low-pass filter was used to remove surrounding noise. Load resistance, which varied from 10 to 1000 Ω, was used in the receiving part to measure the received power. Signal loss was measured using a network analyzer with the ratio of the peak voltage of an electrocardiography electrode of the transmitting part and the peak voltage of the receiving part.

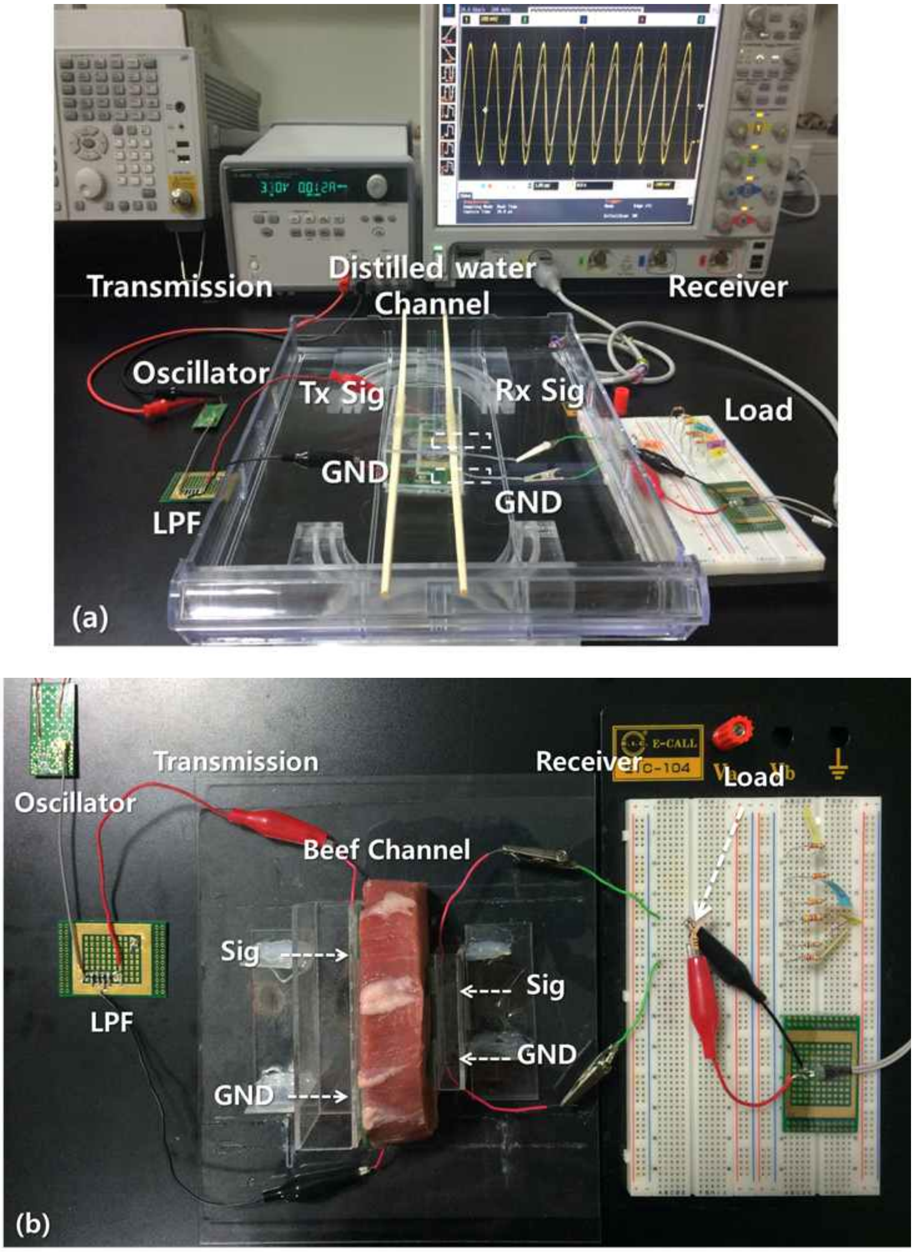


Figure.3.3 Experimental setup of Conductive transfer vs. material : (a) distilled water, (b) beef.

Figure 3 shows the experimental setup for the conductive power transmission and data communication using HBC. Using the same electrode as in a human body phantom, data transmission through the conductive power transmission, as well as HBC transference of power and data occurred. The FSDT method was used in the HBC module for data communication through the human body. In this study, an HBC transmission module with a 2-Mbps transfer speed was used to measure the data transmission efficiency. A 16-Mhz center frequency with a size of 11.79 dBm was used for communication between these modules. Each HBC transmitting and receiving module was connected by two laptops and beef channel electrodes to compose transmitting and receiving parts for data transmission. An additional elliptic band-pass filter with a 2~16-MHz pass band was used to remove the conductive power transmission signals inserted in the HBC transmitting and receiving modules.

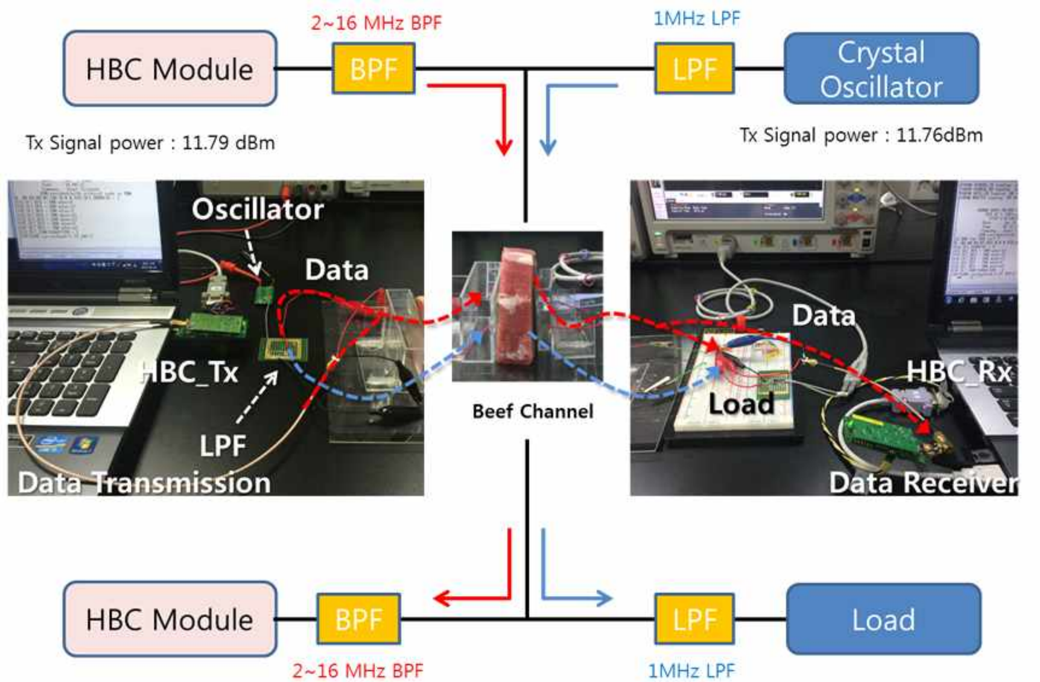


Fig.3.4. Experimental setup of Conductive and Data transmission.

E. Measurement Results

Figure 3.5 shows signal loss according to load impedance of distilled water and beef thickness. The optimum load impedance was found to maximize power transmission efficiency.

As shown in the figure 3.5, maximum transmission efficiency was obtained when load impedance was 200 Ω regardless of the thickness. It is therefore evident that the optimum input impedance is 200 Ω and that impedance matching occurs at 200 Ω in accordance with the maximum power transmission condition. The power transmission efficiency, which depends on the medium thickness (transmission distance), was measured according to the ratio of received power to transmitted power. During power transmission, the power transmission efficiency of distilled water varied from 2% to 10%, while the efficiency of the beef medium varied from 5% to 95% depending on the change of medium thickness.

The above result shows that transmission efficiency can be greater than 10% in any part of the human body, and that a maximum of 95% transmission efficiency can be obtained in thin areas, such as skin layers. In addition, the data transmission BER showed a value under 10^{-6} when simultaneously sending data and power, as well as when sending only data. Based on this result, it is evident that power and data can be simultaneously transmitted when no mutual interference exists between power transmission and data communication.

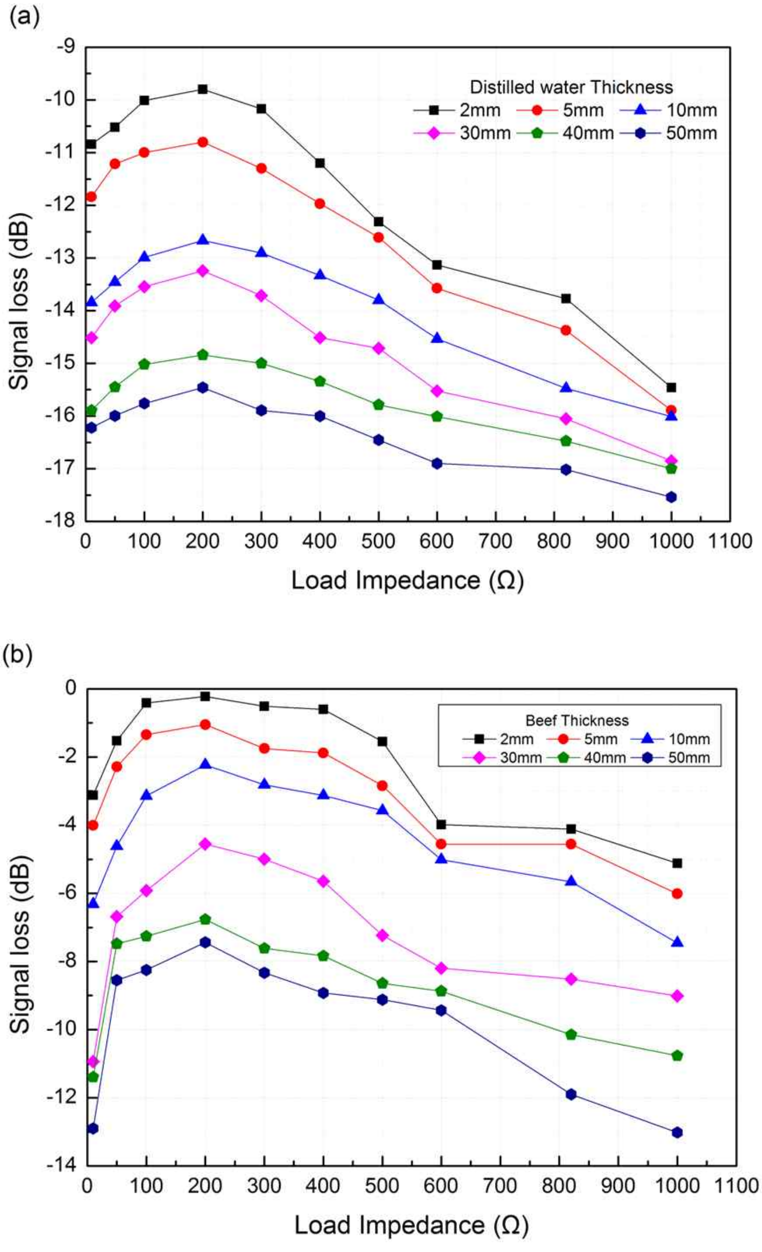


Figure.3.5 Signal loss according to Load Impedance vs. material for (a) distilled water (b) beef

Figure 3.6 shows power transmission loss results according to the misalignment distance when a misalignment occurred between transmitting and receiving electrodes due to body movement. According to the measured results, approximately 20% of transmission efficiency was gained. This was the case even in a 50-mm alignment when the pacemaker was fixed to a 2-mm-thick skin layer. These results show that operating time can be expanded over a specific number of hours through conductive power transmission if the battery capacity of the implantable device is more than approximately 1000mAh. Moreover, the battery duration can be increased by more than 25% when aligning the transmitting and receiving electrodes, which is a highly appropriate method for implantable devices.

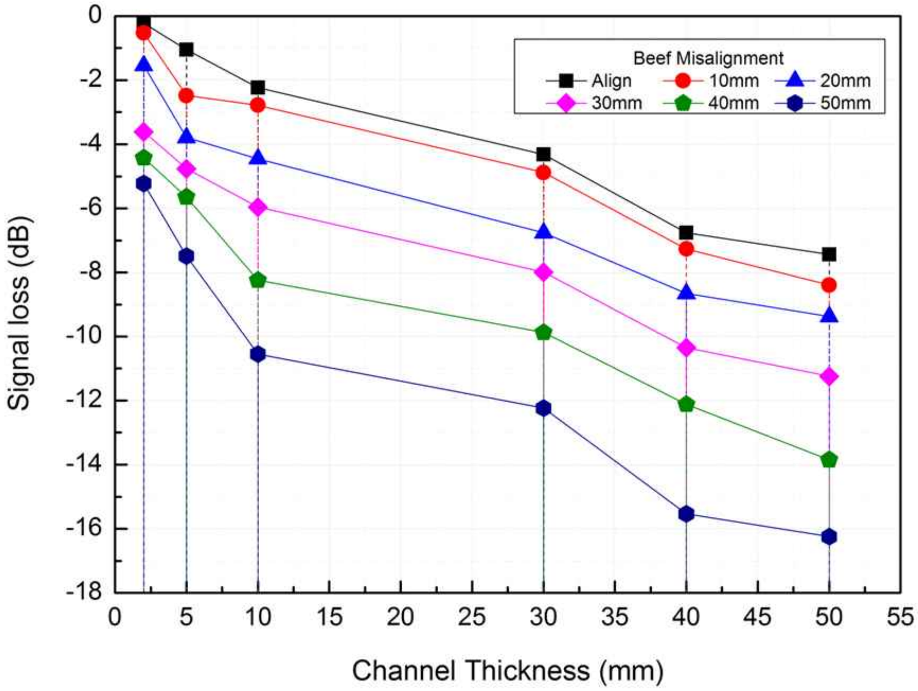


Figure.3.6. Signal loss according to misalignment.

Ⅳ. Conclusion

The simultaneous transmission of power and data is possible through one electrode in the conductive power transmission system proposed in this paper. Furthermore, a continuous power supply and stable data transmission are possible. The proposed method is therefore suitable for application to medical devices inserted in the human body. We conducted a comparison of the proposed method with an existing resonance method for implantable devices. The proposed conductive power transmission method showed a rapid increase in transmission efficiency by more than 95% when the thickness of the medium was below 2 mm. A low BER of the order 10^{-6} is therefore achievable using HBC in which data can be accurately transmitted without the receiving influence of frequency interference. The proposed method can be applied to inserted data-recording devices, such as embedded-type pacemakers that are implanted under the skin. High-speed data transmission is possible using a 2-Mbps-level HBC, in which the method can be used for miniaturization and improving the multifunction capabilities of implantable devices. In addition, the method can be used in power supply technology, thereby securing a stable power transmission channel despite movements of body organs or receiving parts.

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List of Publications

Paper

"Conductive Power Transmission and Data Communication system for implantable devices", **Jong Jin Baek**, Y. T. Kim, submitted to Microwave and Optical Technology letters, Oct. 2015.

"Wireless power transmission using resonant coil consisting of conductive yarn for wearable devices", M. J. Jeong, T. I. Yun, **Jong Jin Baek**, Y. T. Kim, Textile Research Journal, Apr. 2015.

List of Publications

Conference

"Conductive power transmission for implantable devices", **Jong Jin Baek**, J. H. LEE, Y. T. Kim, IEEE International Symposium ISCE 2014, Jun. 2014.

"AC-DC converter for wireless power transmission of energy harvesting system", Tae-il Yun, J. H. Lee, **Jong Jin Baek**, Y. T. Kim, IEEE International Symposium ISCE 2014, Jun. 2014.

"Conductive Power Transmission with Human Body Communication for Implantable Devices", K. H. Park, **Jong Jin Baek**, J. H. Lee, Y. T. Kim, International biomedical engineering conference, Nov. 2014.

"Touch Based Multi-band Service using Human Body Communications", K. H. Park, **Jong Jin Baek,** C. H. Hyoung, J. H. Hwang, Y. T. Kim, IEEE International symposium on antennas and propagation and USNC-URSI, Jul. 2013.

Abstract

Conductive Power Transmission and Data Communication System for Implantable Devices

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In this paper, we propose a conductive power transmission method that enables simultaneous power transmission and data communication through the human body. The conductive power transmission system enables simultaneous power transmission and data communication using one electrode. The electrode size is not relevant to the frequencies of the signals used. Therefore, it is possible to use the same electrode, even though the frequency is isolated to minimize the interference between two signals. In an experiment, a beef channel with an impedance similar to that of the human body was used to minimize the interference of the two signals. These signals were used in communication with the human body as a medium. Power efficiency according to the thickness of the medium was measured through the respective transmitting and

receiving electrodes. In addition, a frequency selective digital transmission method was used for communication with implantable devices in the human body. The data communication speed and bit error rate (BER) were measured to evaluate communication quality. Experimental results show that the maximum efficiency of power transmission according to the beef channel thickness is 95%, and the data communication BER is 10-6.

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