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Master's Degree Thesis

A Parametric study on Conductive power transmission system for implantable medical devices with misalignment condition

Graduate School of Chosun University
Department of IT Fusion Technology
Jang Myoung Kim

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이식형 의료 기기의 이격에 대한 전도형 전력전송의 파라미터 연구

February 25, 2016

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This is to certify that the Master's Thesis of Jang Myoung Kim

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Acronyms

HBC	Human Body Communication
IMDs	Implantable Medical Devices
RF	Radio Frequency
SAR	Specific Absorption Rate

요 약

이식형 의료 기기의 이격에 대한 전도형 전력전송의 파라미터 연구

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현재 실시간으로 인체의 건강상태를 모니터링 하여 위급상황 시 적절한 치료를 수행하기 위해 다양한 이식형 의료장치들이 개발되고 있다. 이러한 이식형 의료장치들에 전력을 공급하기 위해 사용되는 배터리는 기기의 대부분의 면적을 차지할 정도로 매우 크며, 이를 해결하기 위해 이식형 기기의 소형화를 위해서는 소용량의 배터리를 사용하고 기기가 이식된 상태에서 배터리를 효율적으로 충전할 수 있어야 한다.

배터리 충전을 위해 인체 내부로 전력을 전송하는데 사용될 수 있는 방식으로는 자기유도방식과 Microwave방식이 있다. 자기유도방식은 magnetic coupling을 이용하여 송수신 코일로 전력을 전송하는 방식으로 수 Cm 이내에서는 전송효율이 높지만 송수신 코일의 이격과 전송거리의 증가에 따라 신호손실이 커지는 문제점이 있다. Microwave방식은 microwave를 통해 전력을 전송하는 방식으로 사용이 편리하지만 에너지가 사방으로 방사(radiate)되는 특징 때문에 전송효율이 낮은 단점이 있다.

이를 위해 본 연구에서는 송수신전극을 통해 인체를 매질로 전력을 전송하는 전도형 전력전송방식을 채택하였다. 인체는 전도성 성질을 지니기 때문에 저항을 갖는 전송채널로 사용가능하다. 전도형 전력전송 방식은 Microwave방식보다 전송효율이 높고 자기유도방식에 비해 효율은 낮지만 이격에 따른 신호손실이 적다. 이를 입증하기 위해 시뮬레이션과 실험을 진행하였고 인체매질과 유사한 소고기를 이용하여 네트웍 분석기로 측정하였다.

그 결과, 매질의 두께가 10mm 일 때 약 12%의 전송효율을 얻었으며 송신전극의 이격에도 신호손실이 매우 적었다. 본 방식을 인체내부에 위치하는 심박조율기나 혈류측정 센서와 같은 이식형 기기들에 적용할 경우, 인체 외부 굴곡에 따른 송수신부의 정렬이나 수신부의 이동에도 안정적인 전력전송의 채널확보가 가능하다. 위와 같은 이유로, 전도형 전력전송 방식은 인체 내부에 위치한 이식형 의료 기기로의 전력공급에 가장 적합한 방식으로 사용될 수 있다.

Ⅰ. Introduction

Recent years have witnessed the development of a wide range of implantable medical devices for monitoring the health condition of the human body on a real-time basis and for providing appropriate treatment options in emergency situations. Implantable medical devices which is to support or displace for function of organ in human body have been developed [18],[19],[17]. The use of implantable devices is desired since longterm operation or monitoring is possible, without need for replacement of embedded batteries. A battery is typically used to power an implantable device and occupies most of the available space within the device, and therefore any miniaturization of such devices requires small batteries. However, small batteries need to be charged more frequently than large ones because of their limited capacity. This can be a problem because surgical procedures cannot be performed when batteries need to be charged.

To solve these problems, many kinds of power transmission methods suggests a transmitting power inside the human body to charge the battery periodically. In general, there are two methods for transmitting power inside the human body: microwave radiation and inductive coupling using a couple of coil [5],[9],[20]. But bot methods occur signal loss and drop of efficiency by substitution of human body when it transmitted to IMDs into human body.

This paper adopted conductive power transmission method which transmits by utilizing human body actively in various location as least restriction and improved drawback when transmitting power into human body which is existing method. Due to this method used human body for transmission medium differ from other method, power can transmitted to receiver directly through the human body. It is suitable for power transmitting to device in human body, also it can possibly transmit power with one to one or one to many.

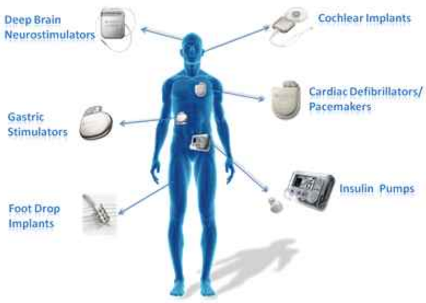

Figure 1. Various implantable devices for medical purposes

Conductive power transmission method assures higher efficiency than microwave method in identical transmitting distance, and is the system which transmits and receives power directly by using electrode through human body to troubleshoot alignment issue between transmitter and receiver of inductive method.

Ⅱ. Previous method

Ⅱ-1 Power transmission through the human body

Power transmission system using human body was proposed by Tesla for the first time [2], it has been developed as form of being able to implement data transmitting and receiving which is using human body. The transmitting system with power transmission and data communication using human body was proposed by T.G. Zimmerman [1]. Zimmerman proposed a PAN(Personal Area Network) which is able to transmit low power in transmission and low frequency bandwidth when using near-field communication with electrodes.

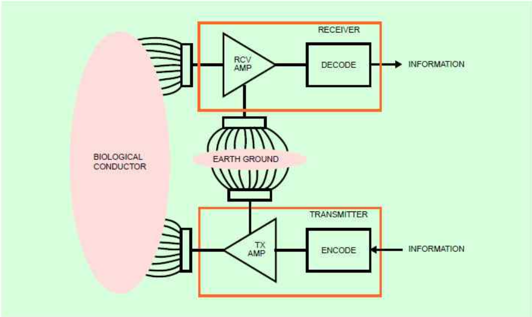

Figure 2-1. PAN schematic by Zimmerman

According to Zimmerman [1], near field communication can operate at very low frequency and low transmission power. The prototype of the PAN transmitter operates at 330 kHz, 30 V, with a transmission power consumption of 1.5 mW for charging the electrode capacitance. The PAN technology was proposed for integration into a custom Complementary Metal-Oxide-Semiconductor (CMOS) chip to decrease the size and cost. Also this purpose invented patent based on his study on data communication and power transmission using human body [3].

The human body has been used as the medium for transmitting data and power signal for Ubiquitous-Healthcare (U-Healthcare). Many groups have studied these methods by using various approaches with focus on data transmission and power transmission. However, only a few groups have investigated the need of power transmission system through human body by transmitting the reasonable power [4],[5],[6],[7],[8],[9].

MIT lab. was proposed a system that transmitted and received both data and power simultaneously [4]. In order to transmit power and data by using the human body, the new version of personal area network (PAN) and a "body modem" was built.

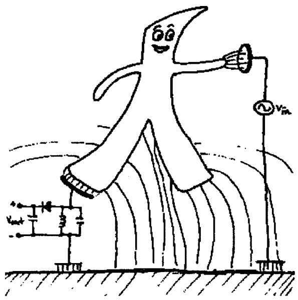

Figure 2-2. Intra-body electrostatic coupling(floated ground condition)

This method distributes electrical power as an alternating current at a voltage much higher than what ultimately appears at wall socket. Under this study conditions, an available power of 200 mW at 1.0 MHz applied at one hand leads to the recovery of about 20 mW of rectified, This system of 10% roughly reflects the proportion of the body's electrostatic coupling available at one foot in the presence of an electrode.

Ⅱ-2 Wireless Power Transmission on Implantable Medical Devices(IMDs)

Many kinds of methods for IMDs have been studied and purposed. Most of methods using coils utilize the pair of magnetic coupling coils. These methods classified inductive method or resonant method. Inductive method(magnetic inductive method) have most higher efficiency among the power transmission through the human body. But transmission distance have short distance other transmitting methods relatively. Another method using coils is resonant method. Resonant method(magnetic resonant method) have lower efficiency and longer transmitting distance than inductive method. Both methods also used primarily in the area of power transmission for implantable medical devices because of its largeness in utilizing.

Inductive method is generally used to power transmitting for implantable medical devices. Two groups studied inductive method with different condition respectively. One group studied inductive method with three types of coils as shown in Fig. 2-3 [5]. The transmission efficiency was 9% at distance of 8 mm and frequency of 1MHz in the open magnetic case. The transmission efficiency was 12% and 16% for the magnetic inductor and the aligned magnetic inductor, respectively.

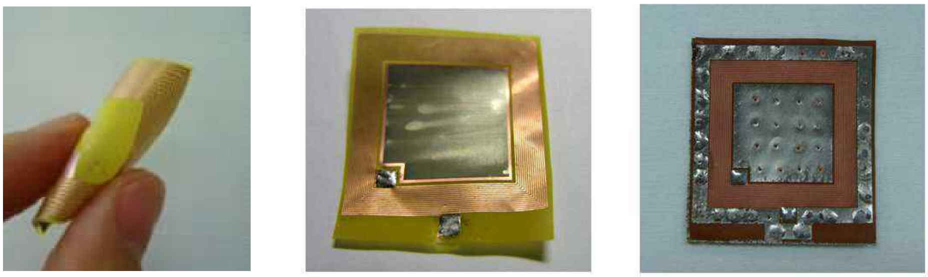

Figure 2-3. three conditions of induction coil

Another group studied inductive method with medium [6]. A medium consists of water bearing colloids is used as substitute for human body. And experiments emulated the effect of medium between the two coils and result is shown in Fig. 2-4. Measurement parameter is frequency of 4MHz, 10kbps of data transfer rate(up to 25 mm distance), 15~28 mm of transmission distance and 50 mm in diameter on chip. The chip fabricated in CMOS technology supplies 1.7 mA at 3.3 V, over a distance up to 25mm between coils.

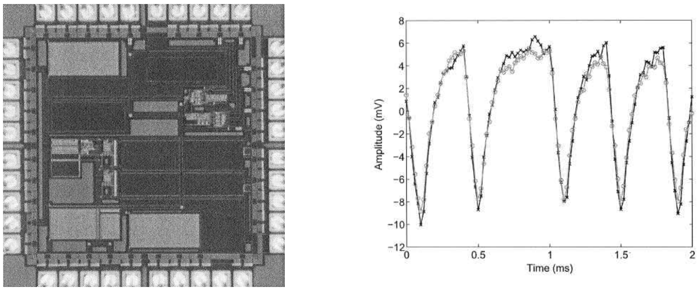

Figure 2-4. Photomicrograph of the fabricated chip and data envelope with gel between coils

Resonant inductive energy transfer is under studying for providing electric power in many commercially-available medical implantable devices [7],[8]. This study investigates wireless electricity (witricity) and its application to medical sensors and implantable devices [7]. In vitro experiments are conducted in open air and through a phantom of the human head. An in vivo animal experiment is also carried out. This study indicates that witricity(wireless electricity) is a suitable tool for providing wireless power to a variety of medical sensors and implanted devices.

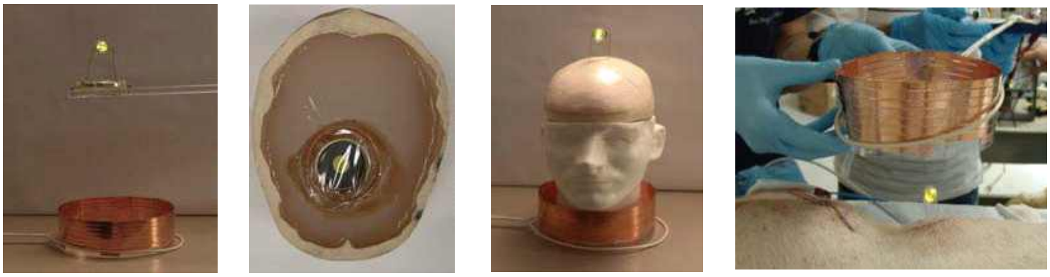

Figure 2-5. In vitro and in vivo experiment with animal experiment

Another resonant system is designed to deliver power efficiently from a stationary primary source to a moving implantable device (secondary circuit) via magnetic resonant coupling using small rodent (mouse) models [8]. A working prototype of the WPT system has been built, which employs a primary coil wrapped around an animal cage of 25 x 12 x 15 cm (length x width x high) in size as shown in Fig. 2-6. The resonant frequency of the Mouse Implant Device (MID) used in experiments is 2.135 MHz. The maximum received power is 60 mW. It is delivered by applying a sinusoidal current through the primary coil of 2.5 A (peak-to-peak).

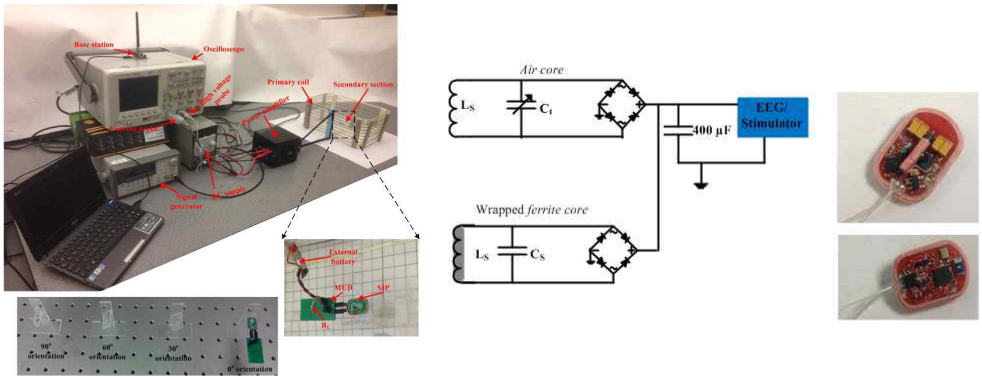

Figure 2-6. Experiment setup for wireless power transmission

Other method is microwave method without coils [9]. This method presents the wireless power transmission to a capsular endoscope using microwave. In previous studies, the electromagnetic (EM) induction method is used for power transmission. By such a method, both receiving power and transmitting information can be conducted by one antenna(without transceiving coil). This method proposed power receiving antennas inside the endoscope that operates at 433.92 MHz and 915 MHz, respectively. It calculate maximum received power in the intestines by using these antennas. This results show that adequate power can be well received with efficiency of around 4% at 433.92 MHz.

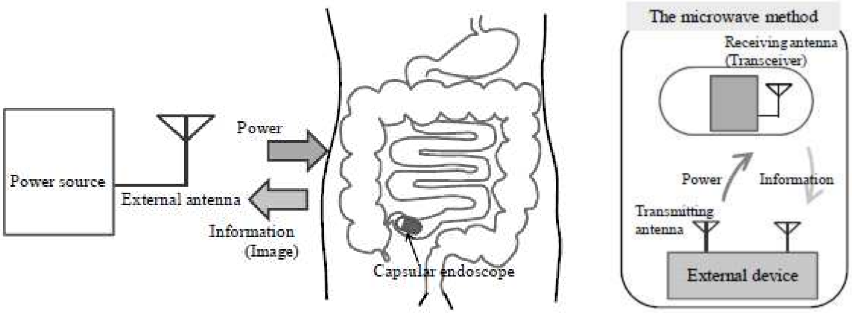

Figure2-7. Microwave power transmission method for IMDs

III. System architecture

In conductive power transmission, power is transmitted through the human body through the use of transmitting and receiving electrodes. As shown in Fig. 3-1, conductive paths are formed between the signal and ground electrodes because of the conductivity of the human body, and therefore power can be transmitted through a closed loop formed by the conductive paths between the power source and load. In the case of inductive coupling, signal loss can be induced by the misalignment of the center of coils that causes a coil to shift [10].

However, a conductive path is used in a conductive power transmission, and therefore any signal loss from the misalignment of electrodes and even from an increase in the transmission distance is minimal because there is little change in the resistance component on the conductive path. Therefore, the level of transmission efficiency remains almost constant regardless of any misalignment of electrodes or any increase in the transmission distance caused by movements in internal organs or the device itself.

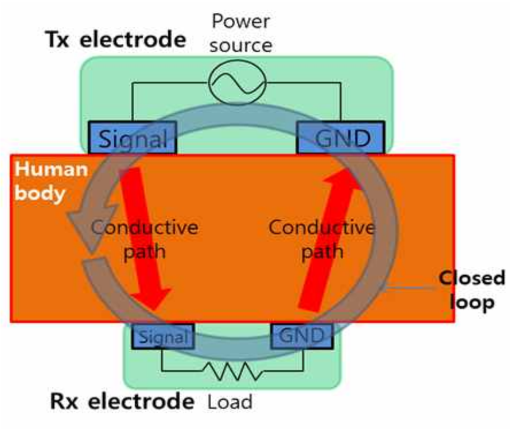

Figure 3-1. Architecture of conductive power transmission method

Each transmitting or receiving electrode in conductive method is composed of signal and ground electrodes and is attached to the human body. When it transmits power through the human body, the power leakage can occurs between signal and ground electrodes and also to increase of a power loss. To solve this issue, an electrode which is increased a distance between signal and ground electrode(gap) used for minimization on effect of leakage.

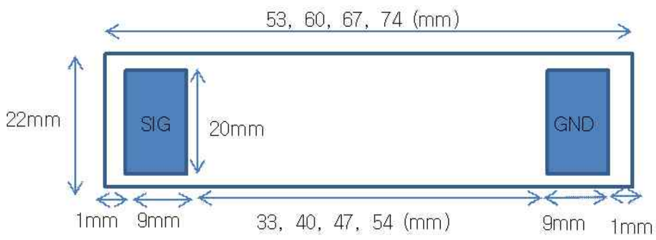

Figure 3-2. Architecture of electrode in conductive method

Ⅳ. Experiment setup

Ⅳ-1. Substitution as human body and measurement environment

Consider characteristics of human body, various conditions and electrodes were used in experiment. The Phantom which is used in experiment instead of human body has problem to process the experiment appropriately. Sliced beefs are used to model the human body, because a power signal in a conductive power transmission passes through the muscle tissue of the human body mainly. And electrical properties of this tissue are similar to those of a beef tissue [16]. Also, results of channel model on this paper were compared with other groups which try to power transmission using similar medium [5],[9]. Because model of human body was also in unstable condition, we measured it repetitively in identical condition. And experiment progressed with manufacturing a measurement cage as below to cover error occurrence. This error means the signal loss caused by being in touch with resistance component as well as our body or some conductive material around substitution model when measuring.

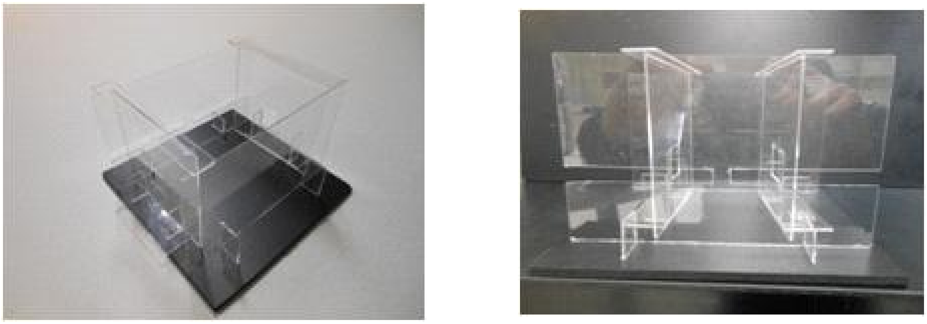

Figure 4-1. Measurement cage in order to prevent the error occurrence or signal loss when it measured

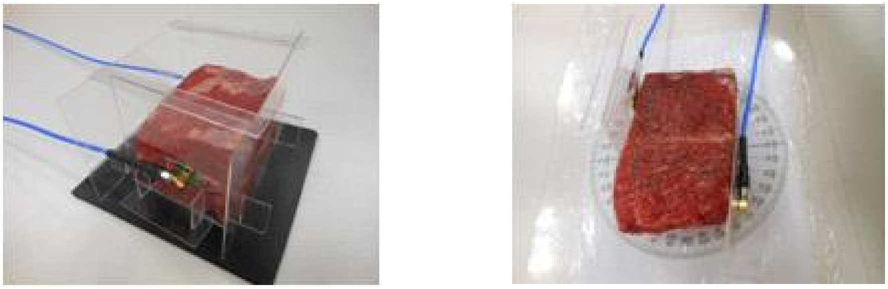

Figure 4-2. Measurement under the change of medium's condition

Power transmission generally requires a carrier frequency no higher than tens of MHz for effective penetration of electronic power to the subcutaneous tissue [11]. Also it have shown that RF energy between 1 and 10 MHz penetrates the body with minimum energy loss [12]. And frequency bandwidth and power for this method set 5MHz of frequency and 1mW of power considering SAR and amount of maximum power that is harmless to human body [13]. Also the Radio-Frequency Protection Guidelines (RFPG) in many countries such as Japan and the US Are recommend the limits of current for contact hazard due to an ungrounded metallic object under the electromagnetic field in the frequency range from 10 kHz to 15 MHz [14]. Signal loss is measured using a network analyzer at 5 MHz after fixing the beef slice with a plastic case. For secure the safety of human body as well as minimization on effect of leakage and maximization of transportable power, low frequency is used in this method.

Ⅳ-2. Configuration and type of electrode

As shown in Fig. 4-3, electrodes are used to measure the signal loss and transmission efficiency of conductive power transmission.

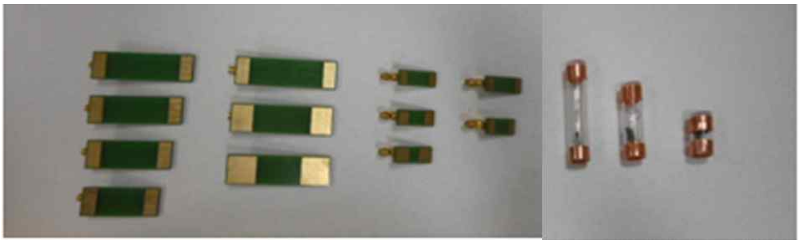

Figure 4-3. Electrode for analyzing human body channel

1) Directional electrode

Directional electrode which is shape of rectangle is used in experiment for signal transmitting and receiving with steady direction. Configuration of directional electrode designed that signal and ground electrode located both ends on electrode. And signal induced coupling to each signal electrodes to ground electrodes.

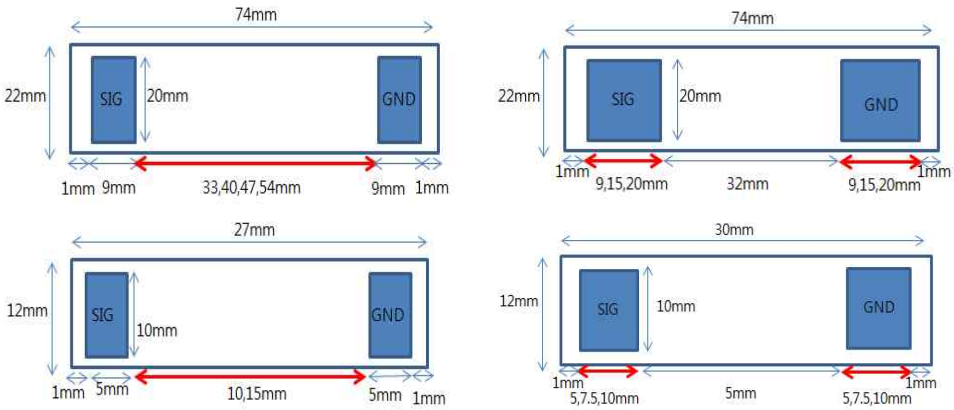

Figure 4-4. Various condition of directional electrode

Directional electrode decreases leakage between signal electrode and ground electrode, and size of transmitter-receiver was manufactured larger than size of receiver electrode to increase directivity of power transmission. Considering the biggest size of electrode which is applicable to human body material power transmission as IMDs(87.5mm diameter Synchromed), we manufactured transmitter as $12 \times 74 mm^2$ and $12 \times 30 mm^2$ for receiver with assumption. Measurement using directional electrode was progressed as measurement of signal loss measurement by size of signal and ground electrode and signal loss measurement by gap of signal and ground electrode in parts.

2) Capsular electrode

Capsular electrode which is similar with directional electrode is able to insert in medium. It assumed that directional electrode applied a plane-type receiving electrode to a cylinder-type receiving electrode for electrode to be appropriate in receiving from inner side of human body. A plane-type of transmitting electrode is attached to the medium surface, and a cylinder-type of receiving electrode(capsular electrode) is inserted between the beef slices as condition of IMDs located in human body.

Figure 4-5. Architecture of capsular electrode which located on IMDs

Architecture of capsular electrode has signal electrode and ground electrode at end of both pole of electrode identical to directional electrode, and only receiving electrode was manufactured as cylinder capsular shape. Transmitting electrode configured with plane-type of electrode(rectangle) and 54 mm of gap. The receiving electrode has a 7.5 mm, 33 mm and 54 mm of gap between signal and ground electrodes for the measurement of any changes in signal loss caused by a power leakage. Measurement of conductive method configured with substitution of human body, network analyzer for transmitting and receiving and electrodes and located as shown in Fig. 4-6.

Directional electrodes measured with attached on substitution of human body both of electrodes. In case of capsular electrode, after locating receiving electrode to inner side of copy model, we measured with contacting transmitting electrode to outside of copy model. Major parameter on this paper is b_2/a_1 of input versus output(S21) as shown in Fig. 4-7.

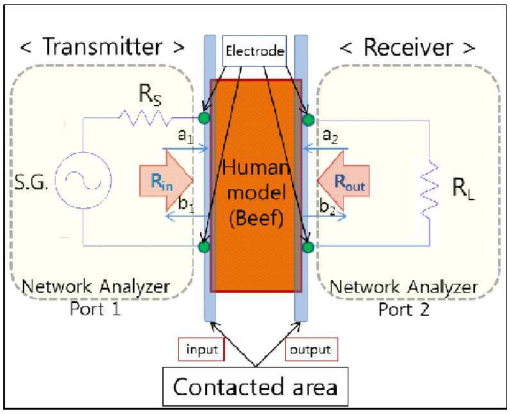

Figure 4-6. Schematic of conductive power transmission method

V. Measurement result

Prior to Measured results, various name of specific parts in electrode and experiment parameter were determined as shown in Table 1.

Table 1. Name of specific parts in electrode and experiment parameter

Substitution of human body (beef)	Medium	Signal electrode	SIG_T
Transmitting electrode	Tx	Ground electrode	GND_T
Receiving electrode	Rx	Distance between signal and ground electrode	Gap

V-1. Simulation

Through the EM(Electro-magnetic) simulation, simulation model for electrode and human body are configured as shown in Fig. 5-1. By using this simulation result, data for comparison group with experiment result secured and analyzed mechanism of conductive method. Simulation model are comprised of directional electrode and dielectric substance of single layer as medium. Size of electrode in simulation set as shown in Table 2., thickness of medium is 10mm, frequency is 5MHz.

Table 2. Size of electrode used in simulation

	Size of electrode	Size of signal and ground electrode	Gap of signal and ground electrode

Transmitter electrode	74 x 22 mm^2	20 x 9 mm^2	54 mm
Receiver electrode	27 x 12 mm^2	10 x 5 mm^2	15 mm

Real human body is composed of many tissues and transmission line of medium is composed of muscle mainly so, medium modeled with permittivity and conductivity of muscle [15],[16].

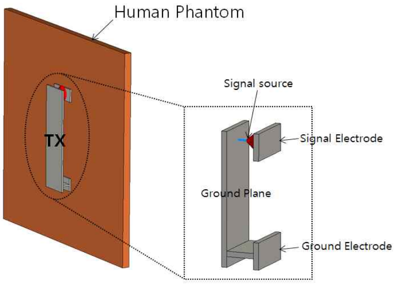

Figure 5-1. Electrode and medium modeling in simulation

By simulation for current flow, architecture of electrode designed for decreasing signal loss. For decreasing leakage signal to ground, electrode contained extra ground electrode as shown in Fig. 5-1. Thus, ground electrode induct a transmitting signal to direction of ground electrode on attached surface of medium as shown in Fig. 5-2.

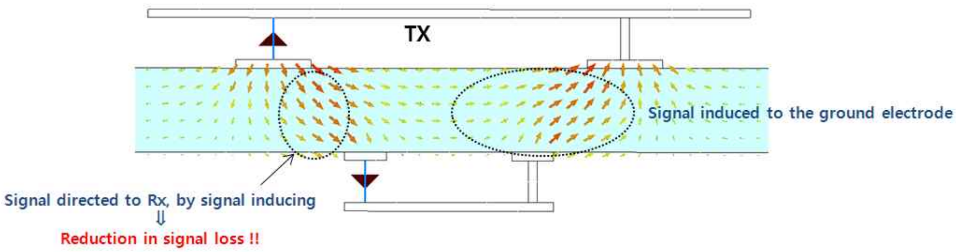

Figure 5-2. Simulation result of current distribution

V-2. Directional electrode

Directional electrode was measured that size of electrode parts controlled separately as shown in Table 3. These conditions used in attempt to

Table 3. Electrode and gap of Tx and Rx

	Electrode thickness in transmitter (mm) (Gap : 54mm)	Electrode thickness in receiver (mm) (Gap : 15mm)
Changes in transmitter electrode	9	5
	20	5
Changes in receiver electrode	9	5
	9	10

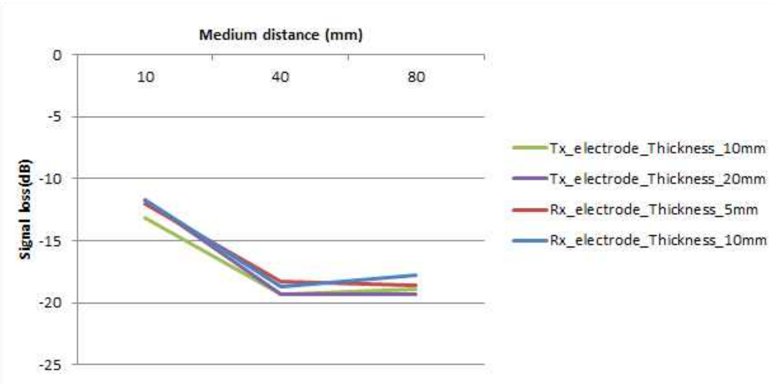

Figure 5-3. Signal loss by size of signal and ground electrode

This results show that signal loss of changes in signal and ground electrode similar with each electrodes. Most biggest difference in signal loss is around -2dB. Next experiment is gap between signal and ground electrode in directional electrode.

Table 4. Change of gap in Tx and Rx

	Transmitter Gap(mm) (SIG_T, GND_T : 9mm)	Receiver Gap(mm) (SIG_T, GND_T : 5mm)
Changes in Tx_Gap	54	15
	33	15
Changes in Rx_Gap	54	15
	54	13

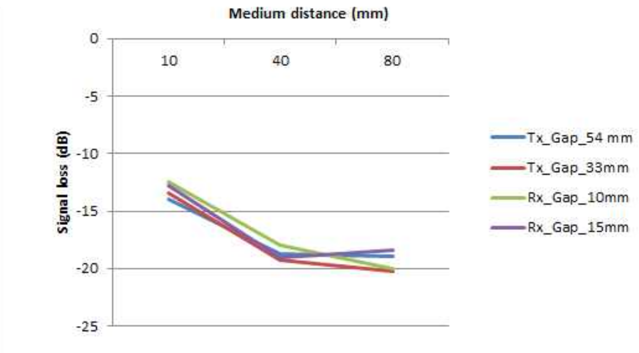

Figure 5-4. Signal loss by gap of signal and ground electrode and architecture of Tx and Rx

Measurement results in signal loss by gap show signal loss by gap is similar with result in Fig. 5-3.

V-3. Capsular electrode

Applied directional electrode, capsular electrode measured signal loss when Rx located in human body. Tx set which is size of 9×20 mm^2 and 54 mm of gap. And Rx on the inside of medium is capsular electrode which is size of $10\times20mm^2$ and gap of 54mm and hat result shows in Fig. 5-5.

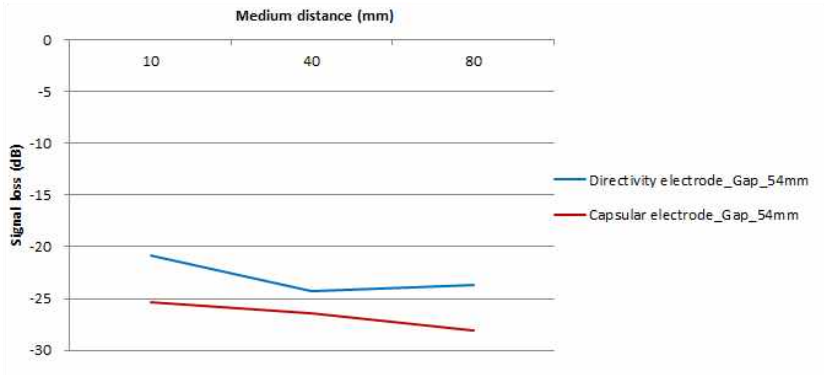

Figure 5-5. Signal loss of capsular electrode's gap and architecture of capsular electrode

< Figure 5-6. Measurement with capsular electrode into medium >

Signal loss was decreased by coupling between electrodes with less leakage between signal and ground electrode and rise of gap. Compare with directional electrode, capsular electrode shown that both electrode have same architecture but measuring condition is different as shown in Fig. 5-6. Size of medium is 180×180×80mm and when electrode attached a fat not a muscle, signal loss increased sharply.

Common characteristics of electrodes assured the fact that signal loss didn't increase constantly depending on thickness of material but increment of signal loss slowed down from certain thickness(4Cm). Capsular electrode which is 7mm and 54mm of gap located in medium. That results show in Fig. 5-7.

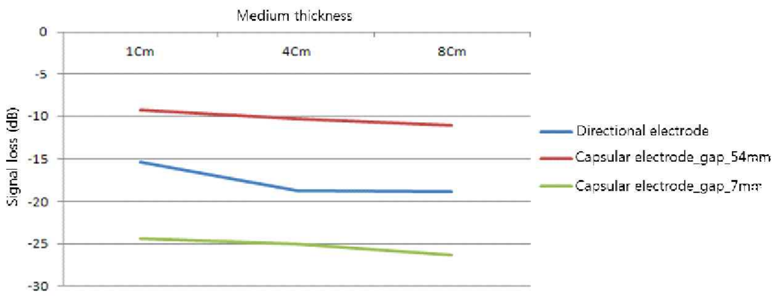

Figure 5-7. Signal loss by capsular electrode with changes of gap

Measurement result shows that signal loss by gap bigger than directional electrode. When gap is smaller, signal loss increased by affect on leakage between signal and ground electrode and less affect of coupling between Tx and Rx.

V-4. Condition of medium and misalignment of electrode

Next measurement result is misalignment of Tx and Rx. In this experiment shows characteristics of conductive method with less effect on alignment and channel model for conductive method. Condition of alignment is classified as degree of Tx and misalignment between Tx and Rx.

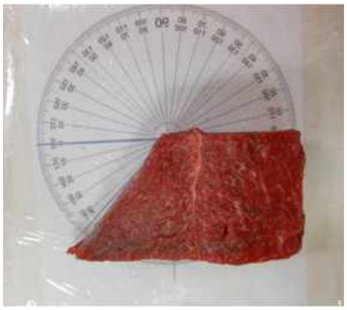

Figure 5-8. Change of medium's condition: an degree of transmitting

Using directional electrode, signal loss by degree between Tx and Rx is less difference considering cut out some mediums. This condition of medium assumed as on the human body.

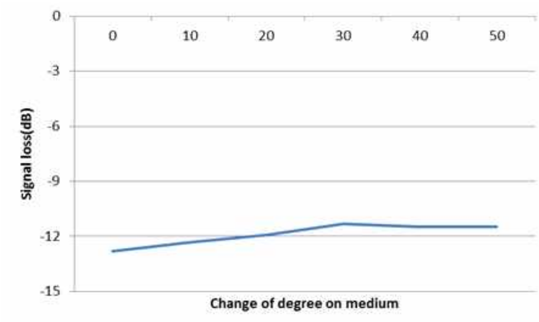

Figure 5-9. signal loss with change of degree

Measurement results show that changes in degree between Tx and Rx are uniformed as shown in Fig. 5-9. Tx and Rx in Conductive method show that Tx has less signal loss by closed loop even though Tx attached on curved shape of human body.

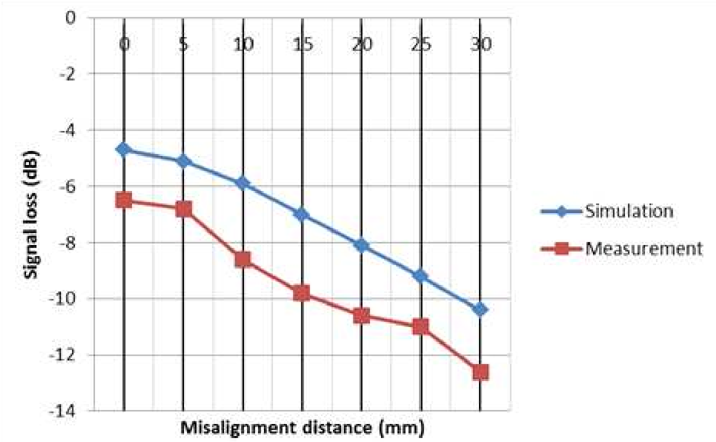

Figure 5-10. Misalignment result with measurement and simulation

Constant value was denoted without any change of efficiency despite gap of transmitting-receiving electrode regardless of capsular as well as directional electrode form. IMDs in human body can vary location to a certain degree in accordance with movement of inner side organ as well as activity of human body. And, when setting power-applying device to external human body, also considering the difficulty realistically in arranging accurately with inserted device, power transmission of conduction method is considered as optimal method of power-transmission into inner human body.

V-5. Efficiency Comparison with other methods

In this study, we investigated the need of Power Transmission System (PTS) through the human body by transmitting reasonable power. Maximum efficiency with conductive method and other methods compared as shown in Fig. 5-11. Inductive method shows 20% of efficiency at 10 mm of transmission distance and 433.92MHz [5], microwave method shows 4% of efficiency at 15 mm of transmission distance and 1MHz [9].

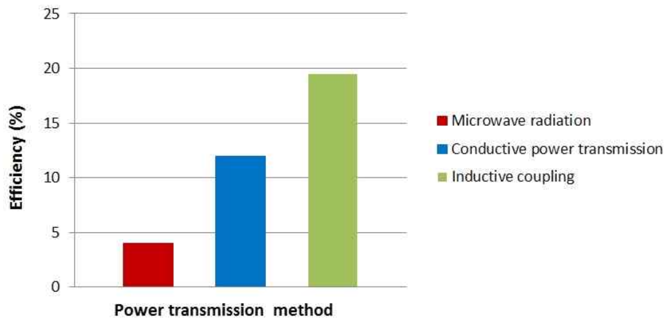

Figure 5-11. Comparison of maximum efficiency with 3 methods

In contrast, proposed method shows 12% of efficiency (0.53 of standard deviation) at 10~15mm transmission distance. The efficiency of conductive power transmission method is 3 times higher than method of microwave in identical transmission distance. Although transmission efficiency is lower than inductive method, variation of signal-loss is intensely small. Closed loop formed between transmitter and receiver, conductive method shows more stable efficiency than inductive method using couple of coils especially aspects of misalignment condition.

VI. Conclusion

Inductive method shows maximum efficiency when a pair of coil aligned exactly and need of additional space in device moreover, under the condition of exactly aligned with transmitter and receiver is very difficult on ununiformed human body. Microwave method have easy to use but has shown low efficiency because of radiated power transmission.

The proposed method uses the finite conductivity of the human tissue. Transmitting and receiving electrodes are attached to the human body, and conductive paths are formed through the human body between signal and ground electrodes. Therefore, power is transmitted through a closed loop formed by these paths. The paths are less effected by misalignment condition.

Proposed method have more higher transmission efficiency than microwave method because of power transmission through the human body as conductive medium. Also, it has lower transmission efficiency than inductive method but has less effect on alteration of transmission efficiency by misalignment of transmitter to receiver and transmission distance. In addition, usage is more conveniently. Considering these aspects, it can be used as power supply method, which can secure stable channel in serial transmission regardless of movement of human organ and of receiver in case of applying main method to implantable devices located inner side of human body.

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List of Publications

Paper

M. J. Jeong, K. H. Park, **Jang Myoung Kim**, J. H. Hwang, C. H. Hyoung, Y. T. Kim, "Feasibility study on application of power transmission using magnetic coupling to body area network", Electronics Letters, August 2012.

Conference

J. M. Kim, M. J. Jeong, D. H. Kim, J. H. Hwang, C. H. Hyoung and Y. T. Kim, "Comparative Study of Conductive and Inductive Power Transmission Method on Misalignment for Application to Implantable Device", 2013 IEEE AP-S/USNC-URSI, Jul. 2013.

M. J. Jeong, K. H. Park, **J. M. Kim**, J. H. Hwang, C. H. Hyoung and Y. T. Kim, "Wireless power transmission on surface of the human body using resonant coil of thin-film type", 2013 IEEE AP-S/USNC-URSI, Jul. 2013.

J. M. Kim, J. H. Hwang, S. W. Kang and Y. T. Kim, "A Study on Power Transmission through the Human Body for Implantable Device", 2012 IEEE AP-S/USNC-URSI, Jul. 2012.

Li Meina, **Jang Myoung Kim**, Y. T. Kim, "A combined heart rate and movement index sensor for estimating the energy expenditure", Sensors, 2010 IEEE, Nov. 2010.

Abstract

A study of conductive power transmission using the human body as a transmission medium

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A battery is typically used to power an implantable device and occupies most of the available space within the device, and therefore any miniaturization of such devices requires small batteries. However, small batteries need to be charged more frequently than large ones because of their limited capacity. This can be a problem because surgical procedures cannot be performed when batteries need to be charged.

In general, there are two methods for transmitting power inside the human body: inductive magnetic coupling and microwave radiation. The former uses inductive coils to transmit power with a high level of transmission efficiency but a signal loss increases from the misalignment of the coils and transmission distance. The latter shows constant signal loss regardless of the alignment but shows also a low level of transmission efficiency because of energy radiation.

This paper proposes a method for power transmission: conductive power transmission using the human body as a transmission medium. A human body be able to transmission channel because of characteristics of conductivity. Conductive power transmission shows a higher level of efficiency than microwave radiation and is less likely to increase signal loss from the misalignment of resonant coils than inductive coupling.

To prove this, experiment was proceeded with simulation. It was measured by network analyzer with using beef which is similar to medium of human body. The results indicate that the maximum transmission efficiency of conductive power transmission is 13% when its transmission distance is 10 mm. Also signal loss have little impact on misalignment condition.

In case of adopting this method to implantable medical devices located in outside flexion of human body, it can secure channel for stable power transmission during move of receiver or alignment of transmitter-receiver in accordance with outside flexion of human body. For these reasons, conductive power transmission can be used most suitable power transmission method for implantable medical devices.

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