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Master's Degree Thesis

A Feasibility Study on Application of Power Transmission Using Magnetic Coupling to Body Area Network

Graduate School of Chosun University
Department of IT Fusion Technology
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자기공진방식의 전력전송에 대한 BAN 에서의 응용 가능성 연구

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Advisor: Prof. Youn Tae Kim

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This is to certify that the Master's Thesis of
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Graduate School of Chosun University

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Acronyms

PDA	Personal Digital Assistants
BAN	Body Area Network
RF	Radio Frequency
ADS	Advanced Design System
LCD	Liquid Crystal Display
LED	Light Emitting Diode
SHARP	Stationary High Altitude Relay Platform
WREL	Wireless Resonant Energy Link
AIC	Adaptive Inductive Coupling
NASA	National Aeronautics and Space Administration
MEMS	Micro Electro Mechanical Systems
MP3	MPEG Audio Layer-3

요 약

자기공진방식의 전력전송에 대한 BAN 에서의 응용 가능성 연구

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현재까지 BAN을 구성하는 장치간 전력전송에 적용한 대표적인 방법으로는 RF방식, 전도전류방식 등이 있다. 그러나 전송 거리가 증가할 때 효율이 급격히 감소하는 단점을 가지고 있다.

이 논문은 BAN에서 자기공진방식의 전력전송에 대한 응용 가능성을 제시한다. 고효율의 자기공진방식을 인체 표면에 위치한 장치간 전력전송에 응용하기 위해 인체의 자세, 전송거리, 코일의 감은수와 같은 다양한 조건들의 영향을 분석하였다.

전송효율은 인체의 자세에 따라 코일의 배열이 변화할수록, 송수신코일의 중심부 어긋남이 증가할수록 감소한다. 그러나 거리가 10㎝일 때 효율은 최대 46.2%로 높게 유지되며 전송경로가 90도의 큰 굴곡률을 가질 때도 5%이상을 유지한다. 지금까지 무선전력전송 기술들과 비교하여, 자기장 결합과 공진현상을 이용하는 전력전송기술은 비록 전송경로에 인체가 존재할지라도 높은 전송효율을 보여준다. 따라서 공진코일들을 이용한 전력전송은 BAN에서 사용되는 인체표면에 위치한 장치간 전력전송에서 높은 전송효율을 얻을 수 있다. 또한, 이것은 BAN에서의 자기공진방식을 이용한 전력전송의 효율성이 극대화 될 수 있도록 의복에 삽입되는 착용이 용이한 공진코일에 사용될 수

있다. 이 방식은 인체의 표면에 위치하는 하베스팅 장치들을 통해 무선으로 에너지를 얻을 수 있도록 인체활동을 기반으로 하는 에너지 하베스팅에 응용될 수 있다.

I. Introduction

A power transmission through the human body is a method for transmitting power through the human body by using electrodes attached to the human body. In this method, the signal containing power to transmit is inputted to the body through the electrode that is attached to the human body, and then, the inputted signal is transmitted to a device on or inside the human body using the body as a transmission medium. This method could be a key technology to supply power for mobile devices, such as cellular phones and PDAs, as well as implantable devices. Also, it could be applied to an energy harvesting, in which energy is collected based on human bodys' activities. The collected energy can be transmitted from harvesting devices to energy-requiring devices even without a wire. Currently, the biggest problem in transmitting power wirelessly such as an electromagnetic wave [1] or conduction current [2] is that transmission efficiency decreases rapidly as a transmission distance increases. So this thesis suggests power transmission method through the human body using magnetic coupling. Magnetic coupling method with a high efficiency and safety for the human body could be applied to solve a problem that power transmission through the human body had. So far, nobody has tried this research and a suitable basic layout is needed for power transmission through the human body first. As shown in Figure 1.1., using easily available coils, the various applications for the portable devices must be presented to use this method in real life.

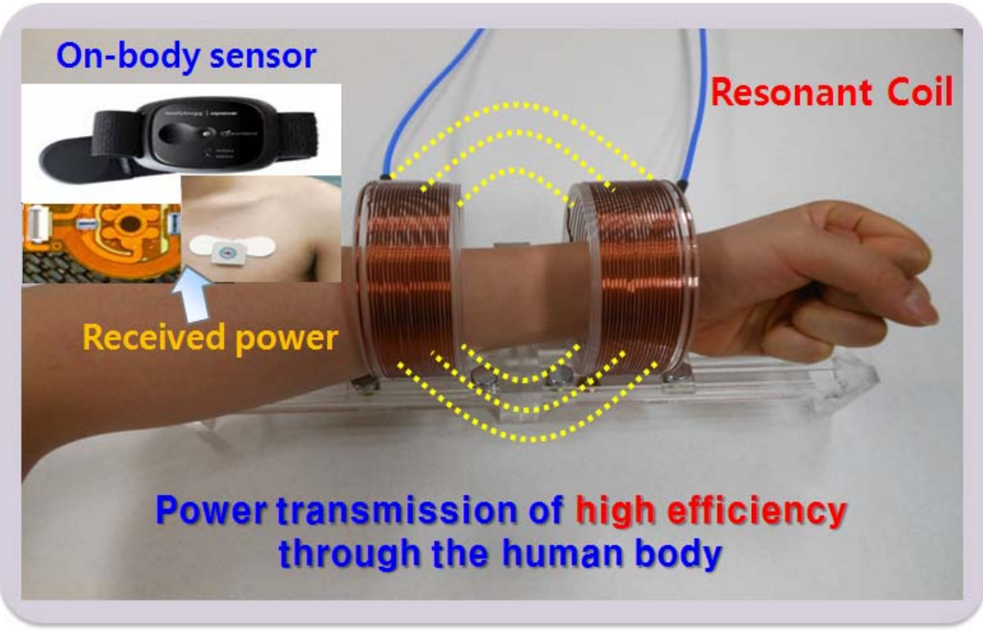


Figure 1.1. Power transmission through the human body using magnetic coupling.

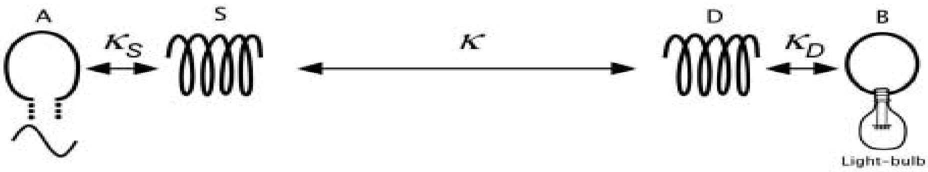
II. Previous methods

A. Purpose

Various methods transmitting a power wirelessly were reviewed to solve a problem that power transmission through the human body had.

B. Magnetic coupling method

Magnetic coupling method uses resonant coils to transmit power with relatively high transmission efficiency. It can transmit a power in a distance of a few meters and shows high transmission efficiency with a low frequency range. As shown in Figure 2.1. This method was first proposed by MIT. Using strongly coupled coils through a magnetic field, they transmitted power up to 60 watts through the air at a distance of 2 m with a high efficiency of 40% [3], they could turn on the lamp.



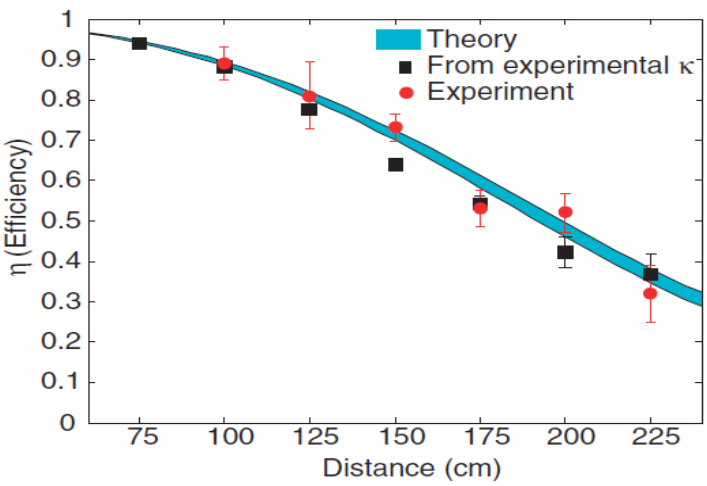


Figure 2.1. Magnetic coupling method in MIT.

As shown in Figure 2.2., Intel also presented Wireless Resonant Energy Link(WREL) in IDF(Intel Developer Forum) in 2008 [4]. It can transmit a power without so much of the loss of energy that afflicts other wireless power transmission technologies such as induction. It was used to transmit 60 watts of power to illuminate a light bulb with a high efficiency of 70~80%.

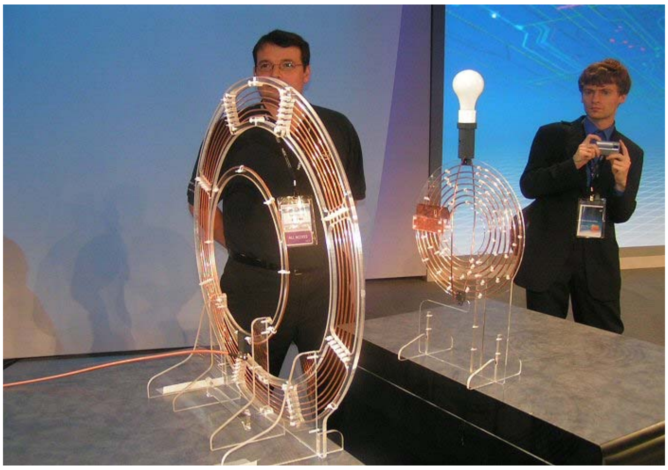


Figure 2.2. Wireless Resonant Energy Link(WREL) in Intel.

As shown in Figure 2.3., ETRI investigated a power transmission to turn on LED in 2010 [5].

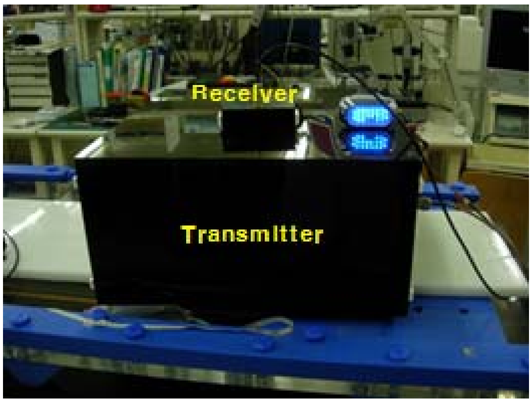


Figure 2.3. Turn on LED in ETRI.

Also, ETRI has developed the method for miniaturizing the sending and receiving coil. They simulated the method using ADS(Advanced Design System) in 2011, and used small coils that are 15 cm in diameter and 3 mm in thickness when the number of coil turns is 8, about 4 mm apart. As shown in Figure 2.4., power was transmitted at a distance of 15 cm with a high efficiency of 40% as shown in Figure 2.4. [6].

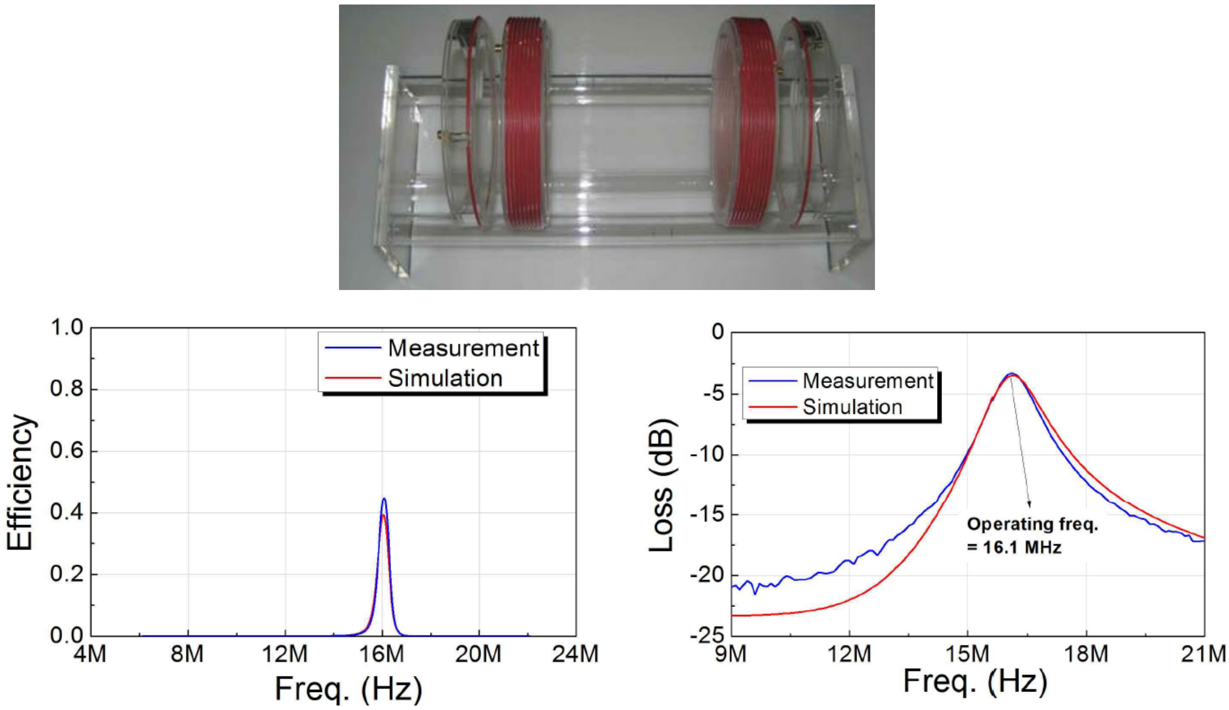


Figure 2.4. Experiment setup and ADS simulation in ETRI.

As shown in Figure 2.5., ETRI demonstrated a high-power transmission for LED, LCD computer in August 2011. The power level was 40 watts and its resonance frequency was 1.8 MHz [7]. Due to its small size and a slightly high resonance frequency, it could be applied to various area such as a portable mini supercomputer, personal robot maid, green car, and so on.

Figure 2.5. Magnetic coupling method for LED, LCD computer in ETRI.

C. Electromagnetic induction method

When a conductor moves through a magnetic field, an electric current flows on the conductor due to electromagnetic induction. This method is useful to transmit a power with a high transmission efficiency in a short distance of a few mm when multiple coils used for a pad, sheet, and portable devices, but its transmission efficiency decrease rapidly as a transmission distance increase and it is dependent on a relative location of coils. As shown in Figure 2.6.-2.8., this method has been applied to various devices, such as an electric toothbrush, shaver, and charge for cellular phone.

Using the electromagnetic induction method, Splash Power developed the Splash Power Pad [8]. Multiple coils are implemented inside the pad, so power is transmitted to a portable device on the pad. This method can transmit power to various devices at the same time, due to the multiple coils.

Figure 2.6. Power pad in Splash Power company.

Fulton Innovation developed eCouple [9]-[10]. It can transmit power up to 1400 watts with a efficiency of 98% using AIC(Adaptive Inductive Coupling) that can find out optimum condition for a operating point and resonant frequency and can transmit a information with a data rate of 1.1Mbps. It has various application areas in an office as shown in Figure 2.7.(a). Also, it has been proposed to a car to charge the iPhone and iPad as shown in Figure 2.7.(b).

(a) (b)

Figure 2.7. eCoupled in Foulton Innovation : (a) Layout, (b) Toyota Avalon to Offer iPhone/iPod Dock.

Tokyo University developed Large area power transmission sheet by combining an organic semiconductor transistor with a MEMS device as shown in Figure 2.8. [11]. The position of a device over a power transmitting pad is detected by sensors, and a coil below the device transmits power. It can be easily applied to a wallpaper or floor due to flexibility of a power transmitting pad.

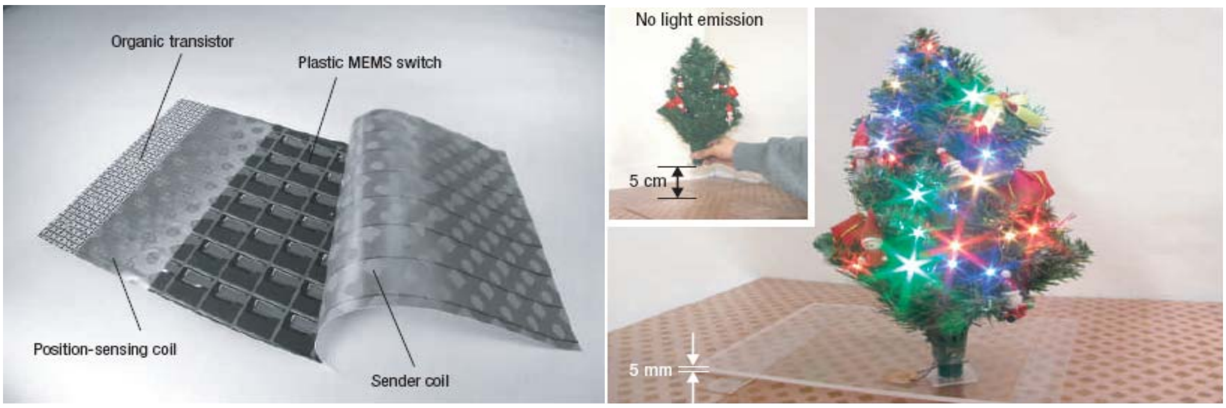


Figure 2.8. Large area power transmission sheet in Tokyo University.

D. Microwave radiation method

Microwave radiation method transforms power into a radio wave whose wavelength is on the order of a few centimeters, and then transmits the radio wave to a device. This method was proposed at first by Tesla at the beginning of 20th century. It is useful for long distance but is harmful to the human body because of energy radiation in a high frequency range. It is also bulky, expensive and difficult to make a circuit design compared with other methods. Using the Microwave radiation method, Powercast developed the Power Caster chip set that can transmit power up to 3 watts at the frequency of 915 MHz [12]. The developed chip set can be applied for wireless keyboard, mouse, medical wireless power transmission device, intelligent sensor network for defense industrial, and so on.

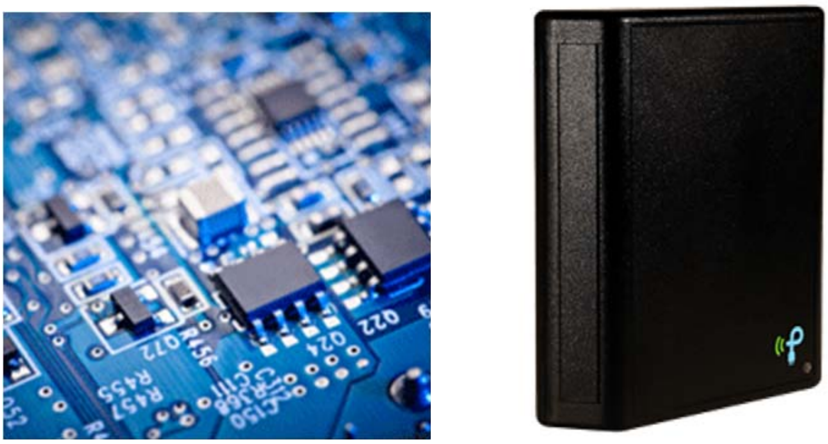


Figure 2.9. Transmitter and receiving chip in Powercast.

In addition to the small power transmission, a large transmission has been tried as shown in Figure 2.10. NASA planed a project named Sun Power Satellite(SPS) to transmit power from a satellite to the ground [13]-[14]. The aim of the project was to provide electrical power to Earth by converting the Sun's energy and beaming it to the surface.

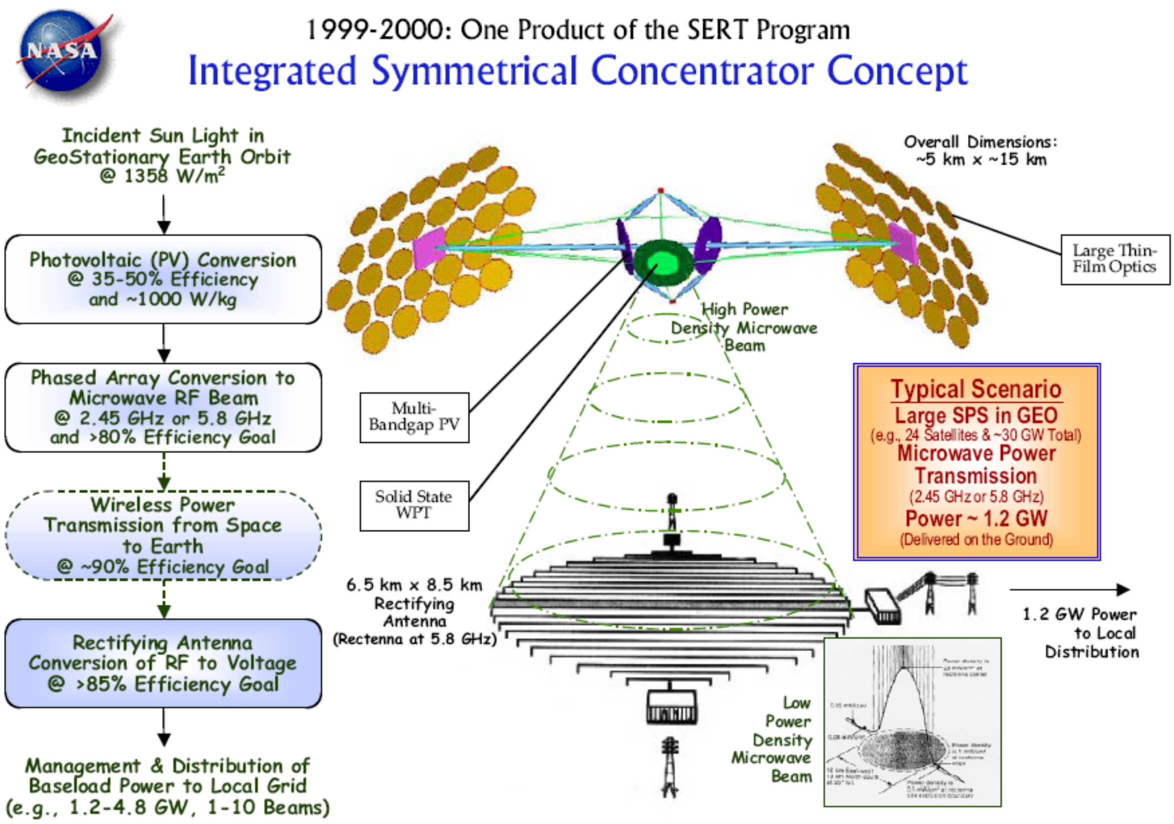


Figure 2.10. Power transmission through Sun Power Satellite.

As shown in Figure 2.11., communications Research Centre experimented SHARP(Stationary High Altitude Relay Platform) to operate a pilotless aircraft in 1987 [15]. Using a microwave radiation method, it could transmit power to a pilotless aircraft flying at 21 km and the aircraft made a flight over 2 km for an hour.

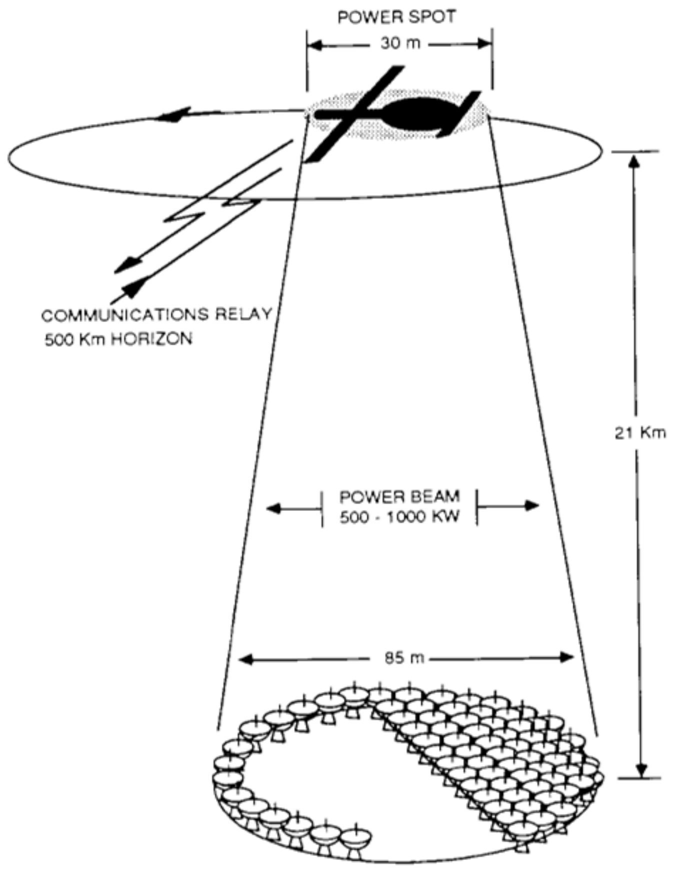


Figure 2.11. Stationary High Altitude Relay Platform(SHARP).

III. Experiment and result

A. Measurement setup

Figure 3.1. shows the sending and receiving coil of power transmission, and the measurement setup of a signal loss between the coils. The power coil is used for impedance matching between a signal source and the sending coil and the load coil between a load and the receiving coil. The coils of copper wire are 10 cm in diameter and 3 cm in width when the number of coil turns is 20. A distance between the sending coil and power coil, or that between the receiving coil and load coils, is controlled to minimize return losses at the inputs of the power coil and load coil, and it is 0.2 cm in this study. An arm was inserted inside the coils as shown in Figure 3.1., and signal losses were measured using a network analyzer.

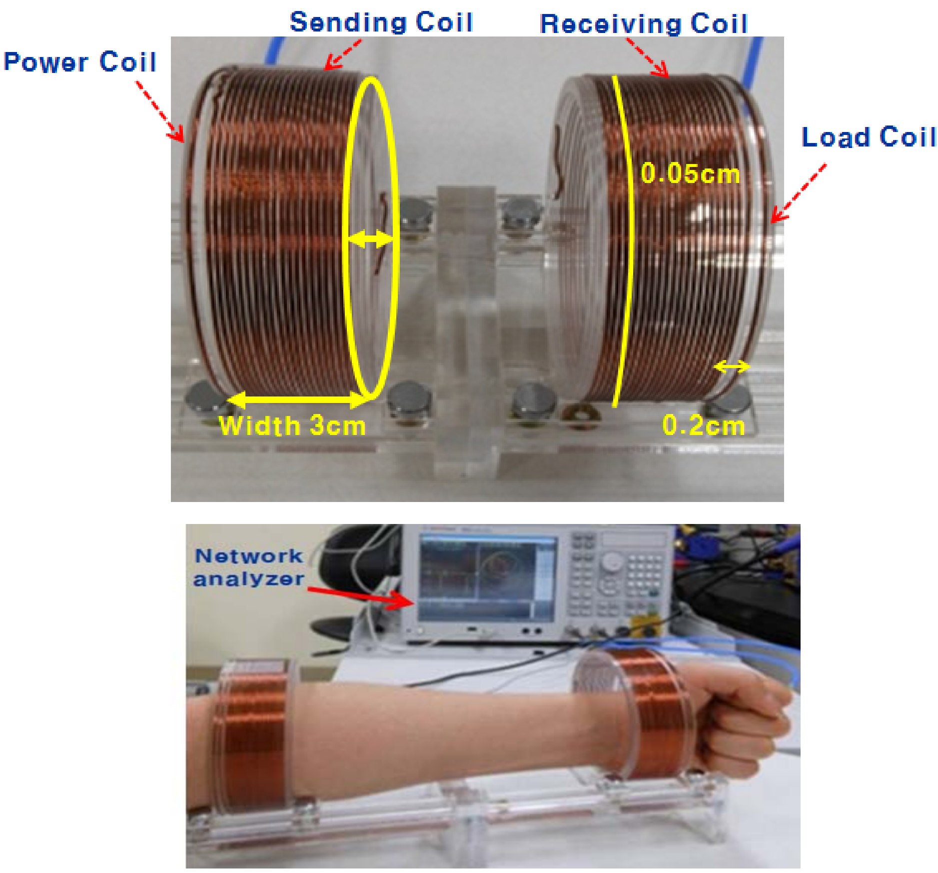


Figure 3.1. Measurement Setup.

B. The effects of the human body and the number of coil turns on a resonant frequency

Figure 3.2. shows the effects of the human body and the number of coil turns on a resonant frequency. The resonant frequency decreases as the human body exists on the transmission path. Because a dielectric polarization phenomenon occurs due to increase of magnetic coupling through the human body between the coils. Thus, a capacitor element through the human body is added to an existing capacitor element that the coils had and the resonant frequency decreases. Also, as the number of coil turns increases, the resonant frequency decreases but has a constant value gradually. Because the electric current offset between coils increase, even if a inductance element that reduces the resonant frequency increases when the number of coil turns increases. In other words, the resonant frequency has a constant value gradually due to decreases of effective length of the coils and variation in a inductance element when the electric current offset, which flew in the opposite direction.

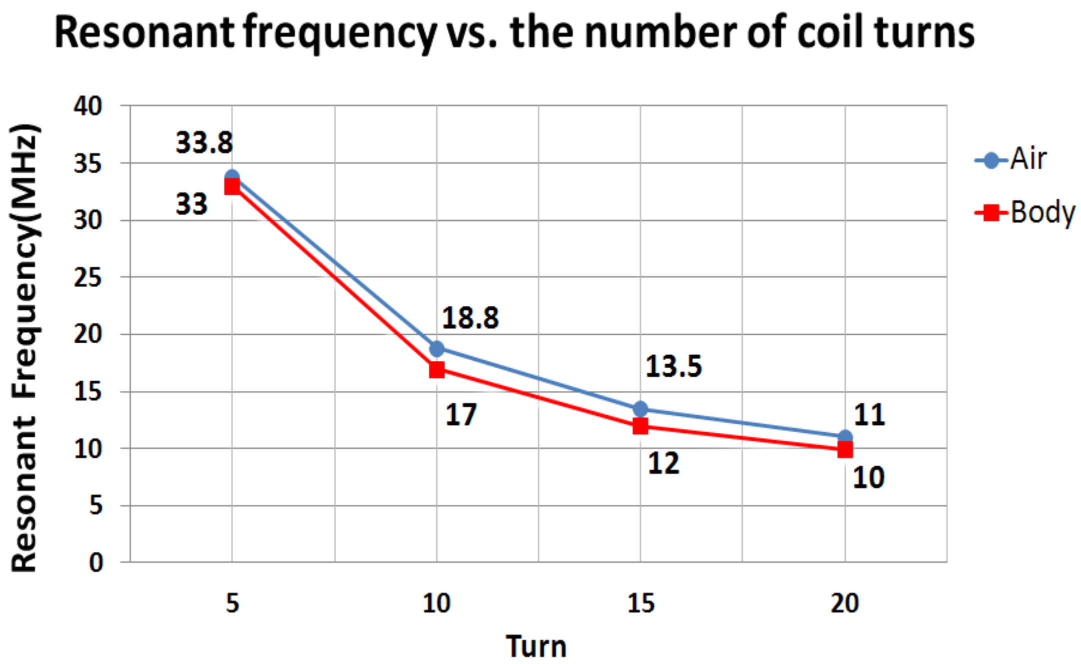


Figure 3.2. Measurement results on resonant frequency.

C. The variation in signal loss according to the number of coil turns and transmission distance

Figure 3.3. shows the variation in signal loss according to the number of coil turns and transmission distance, where the signal loss was measured at the resonant frequency of corresponding coil turns and the arm was inserted inside the coils. The signal loss decreases as the number of coil turns increases because magnetic coupling between the coils increases accordingly. But the variation in magnetic coupling of an additional coils decreases because magnetic coupling between the coils is strong enough when the distance is less than 5 cm.

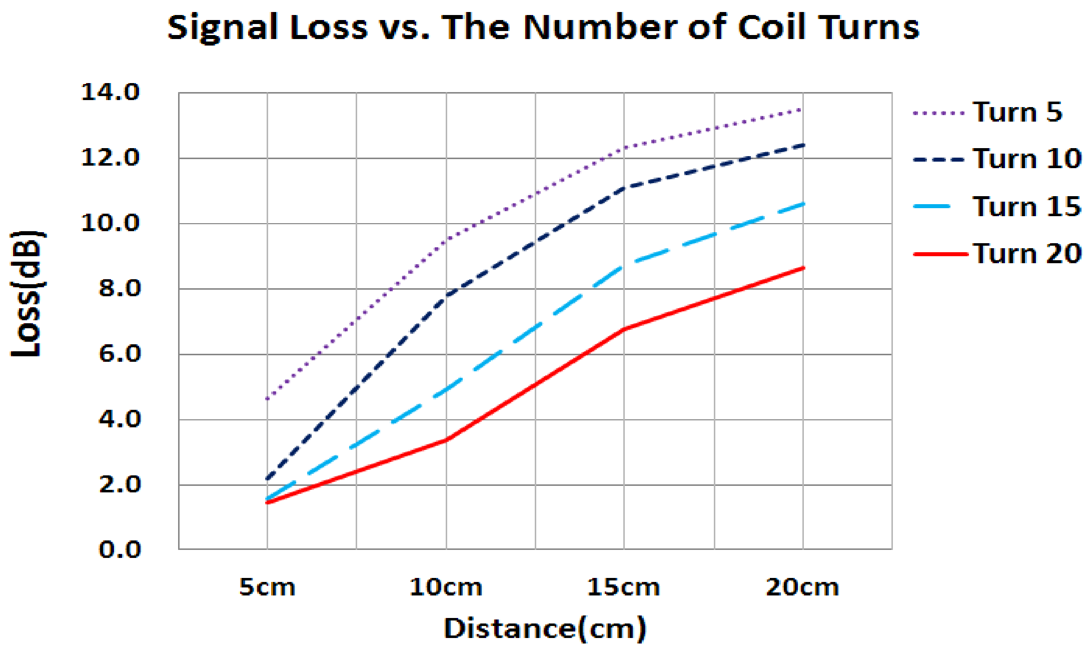


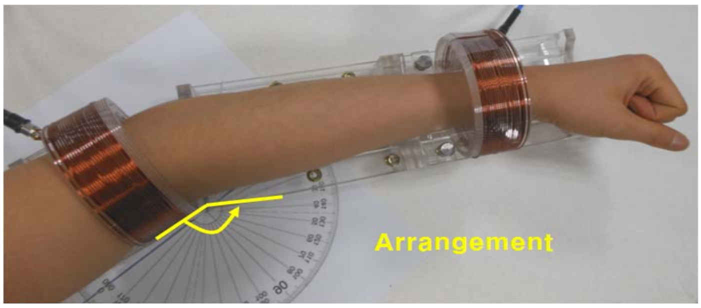
Figure 3.3 Measurement results on signal loss.

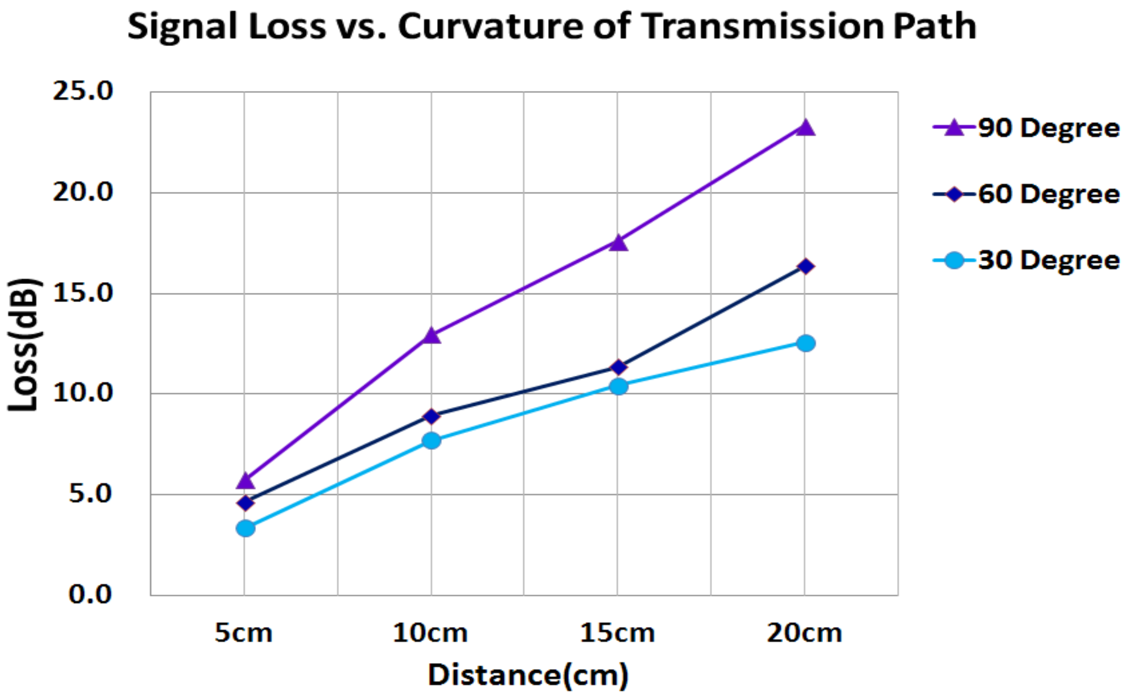
D. The effects of movement on signal loss

The arrangement of coils changes according to body movement, so the effects of movement on signal loss were measured as shown in Figure 3.4., where the number of coil turns was 20. As the curvature of transmission path increases, the signal loss increases as shown in Figure 3.4.(a), but its value remains low when the transmission distance is less than 10 cm, because the coupling between the resonant coils is very strong.

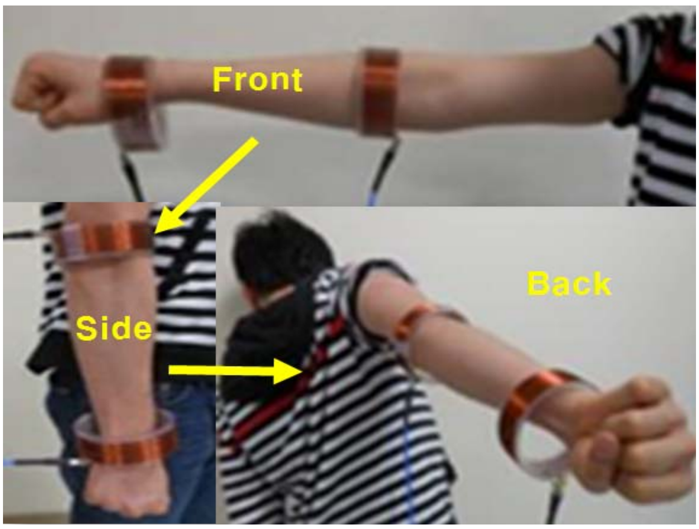
Figure 3.4.(b) shows variation in signal loss according to the body posture. The signal loss up to 6 dB increases compared with fixed the coils under the condition of different posture. The variation in signal loss was measured at a distance of 20 cm as shown in

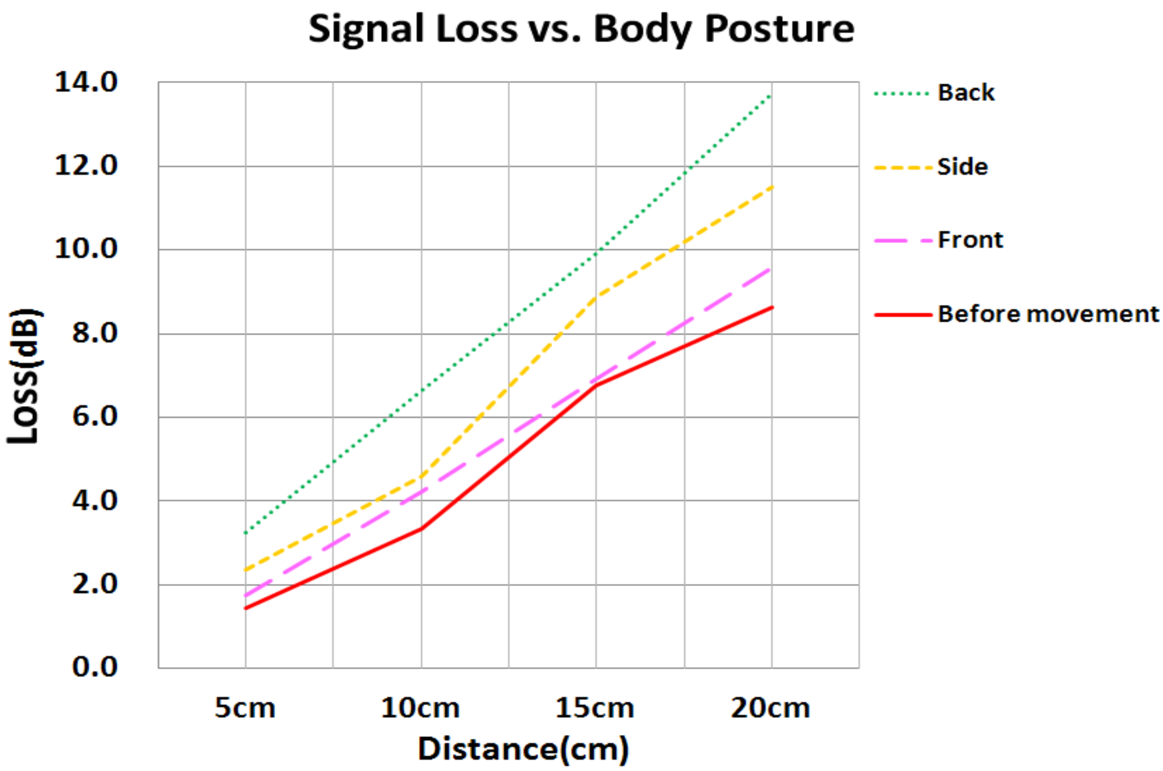
Figure 3.5. when the misalignment of the center of coils that causes a coil to shift horizontally is between 0 and 4 cm.





(a)





(b)

Figure 3.4. Measurement results on the effects of human body movement: (a) Variation in signal loss according to the curvature of transmission path, (b) Variation in signal loss according to the body posture.

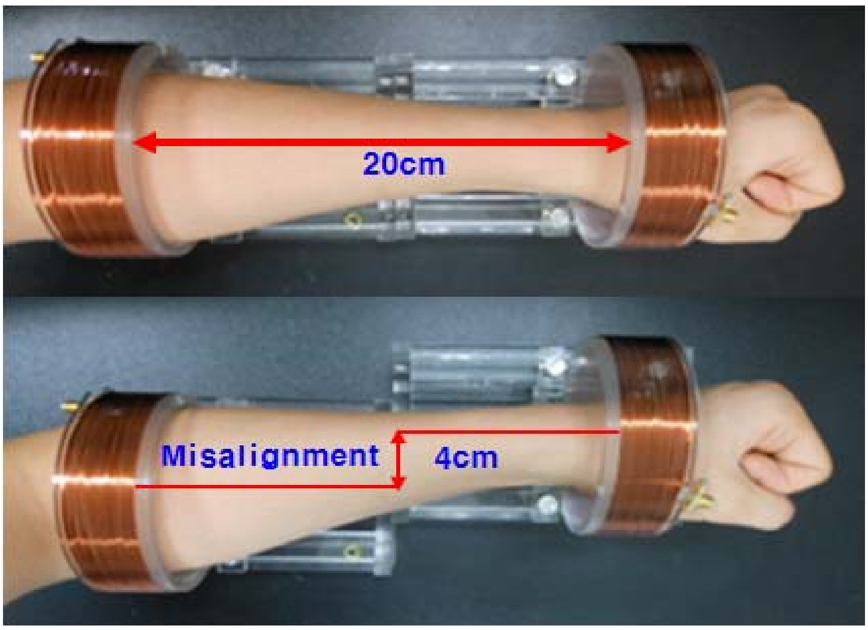


Figure 3.5. Signal loss measurement according to the misalignment of the center of coils.

The max. variation in signal loss according to the misalignment was 7 dB and this result was similar to variation in signal loss according to the body posture in the distance like Figure 3.4.. Thus, the variation in signal loss according to the body posture shows that magnetic coupling decrease due to the misalignment of the center of coils.

E. Measurement result

Figure 3.6. shows a summary of the measurement results, in which signal losses were transformed into transmission efficiency. The power transmission using magnetic coupling to body area network shows very high efficiency over 70% when the distance is 5 cm. And also, it maintains high efficiency between 5.1 and 46.2% when the distance is lee than 10cm even under the conditions such as the body posture, curvature of transmission path and human body on the transmission path.

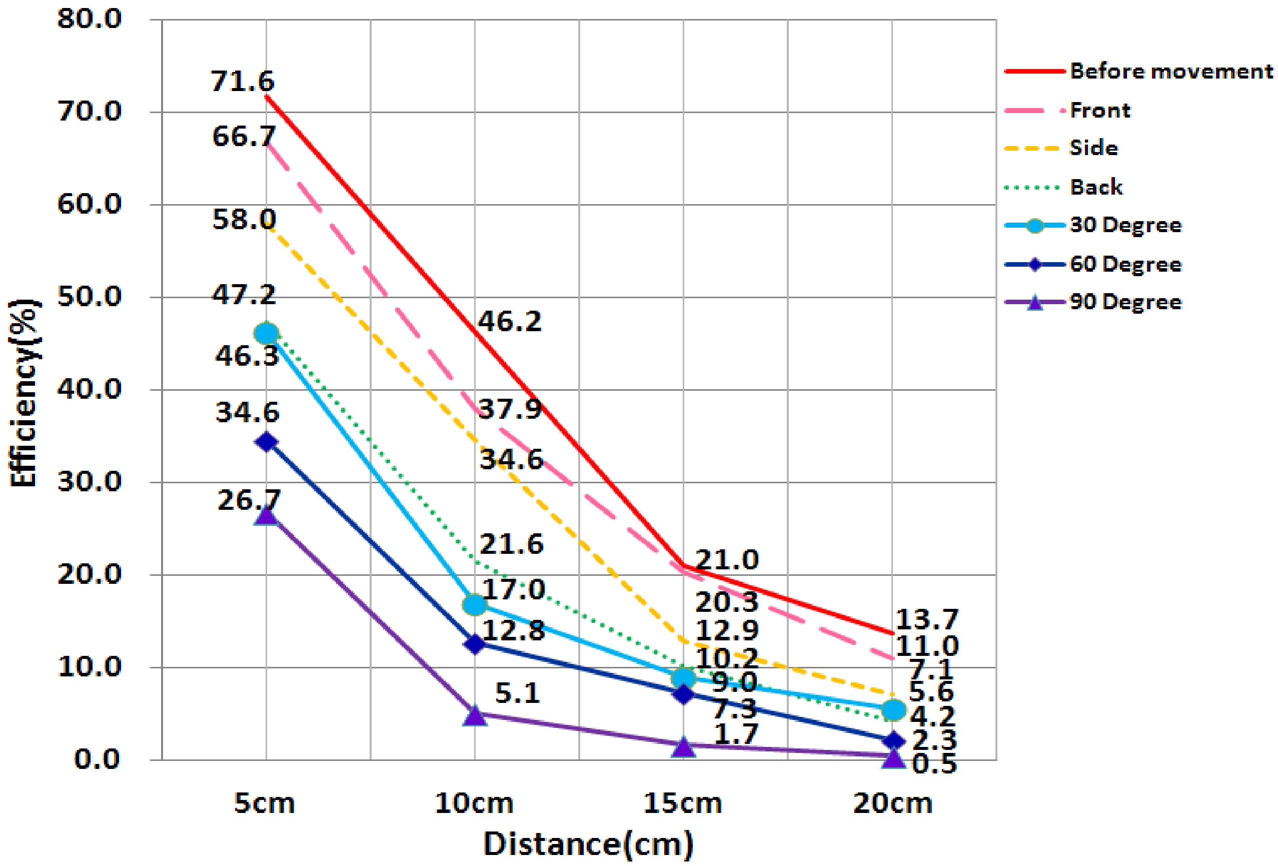


Figure 3.6. Transmission efficiency under various conditions.

IV. Conclusion

The effects of various conditions such as the body posture, transmission distance, number of coils were analyzed to apply magnetic coupling method with a high efficiency to power transmission between devices located on the human body. The transmission efficiency decreases as the arrangement of the coils changes according to body movement and the misalignment of the center of coils that causes a coil to shift horizontally. However, efficiency is maintained highly with a maximum of 46.2% at a distance of 10 cm, and over 5% at least even when the transmission path has a large curvature of 90 degree. In comparison with wireless power transmission, power transmission using the resonant coils that are coupled strongly through the magnetic field shows high transmission efficiency, even when the human body exists on the transmission path. Therefore, using resonant coils, it is possible to achieve high transmission efficiency in power transmission between devices located on the human body for body area networks. And also, it can be used for easily attachable resonant coils inserted clothes in order that the efficiency of power transmission using magnetic coupling to body area network can be maximized. This method will be applied to energy harvesting based on human body activity to collect energy without wires via harvesting devices located on the human body.

In recent years, interest in a power transmission using magnetic coupling has increased, due to of its high transmission efficiency [3]-[7]. However, little research has been done on the application of power transmission using magnetic coupling to a body area network [16]-[17]. In a body area network, sensor devices for health monitoring or data devices such as wearable computers and cellular phones are located on the surface of the human body. Using a power transmission technology, battery could be removed from devices to minimize the device's size. Instead, the power needed by battery-less devices is stored in a large-capacity battery located for instance in a backpack, and it is transmitted to the devices upon request using resonance of the coils that are installed respectively in each device and the battery.

This thesis presents a feasibility study on application of power transmission using magnetic coupling to a body area network [18], in which resonant coils are arranged along the human body. The effects of various parameters, such as transmission distance and body movement, on transmission efficiency are investigated. As shown in Figure 3.7., this research presents how to apply power transmission through the human body using easily attachable resonant coil to body area network. If we use this easily attachable resonant coils inserted clothes, it will collect a power from energy harvesting based on human body activity and the power could be transmitted to wearable devices, such as smart-glasses, clock type MP3, Smart phone, and so on.

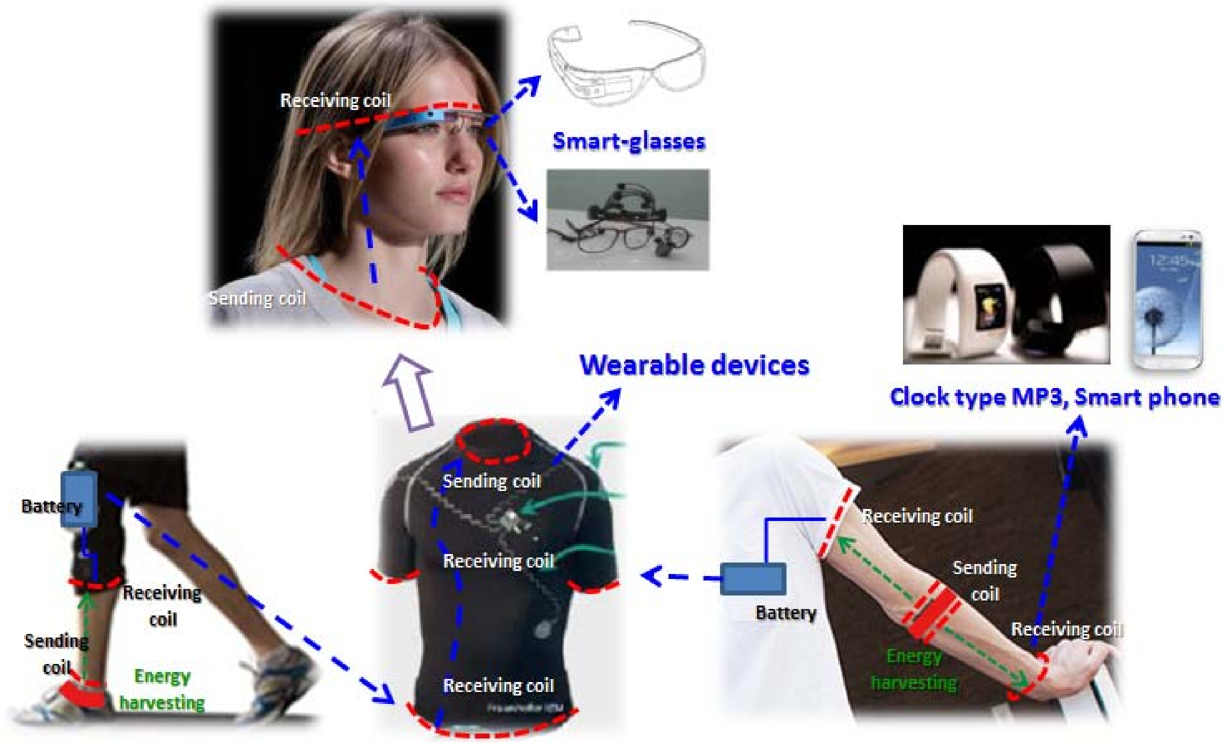


Figure 3.7. Application for various portable devices.

References

[1] A. S. Y. Poon, S. O'Driscoll, and T. H. Meng, “Optimal operating frequency in wireless power transmission for implantable devices”, in Proc. IEEE EMBS, 2007.
[2] E. R. Post et. al., “Intrabody Buses for Data and Power”, in Proc. ISWC, pp. 52-55 1997.
[3] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljacic, “Wireless power transfer via strongly coupled magnetic resonances”, Science, vol. 317, no. 5834, pp. 83-86, July 2007.
[4] Intel Developer Forum (IDF) 2008, www.intel.com/idf/
[5] Y. H. Kim, S. Y. Kang, S. Cheon, M. L. Lee, T. Zyung, “Optimization of wireless power transmission through resonant coupling”, Proceedings of International Symposium of Power Electrics, Electrical Drives, 2010.
[6] S. Cheon, Y.-H. Kim, S.-Y. Kang, M. L. Lee, J.-M. Lee, and T. Zyung, “Circuit-model-based analysis of a wireless energy-transfer system via coupled magnetic resonances”, IEEE Transactions on Industrial Electronics, vol. 58, no. 7, pp. 2906–2914, July. 2011.
[7] In-Kui Cho, Seong-Min Kim, Jeong-Ik Moon, Jae-Hun Yoon, Woo-Jin Byun, Jae-Ick Choi, “Wireless power transfer system for LED display board by using 1.8 MHz magnetic resonant coils”, Radio & Broadcasting Res. Div., ETRI, Daejeon, South Korea, Electromagnetic Compatibility Symposium - Perth (EMCSA), pp. 1-4, 9-11 November. 2011.
[8] www.splashpower.com
[9] www.ecoupled.com
[10] www.visteon.com
[11] T. Sekitani, et. al., “A large-area wireless power transmission sheet using printed organic transistors and plastic MEMS switches”, Nature Materials, vol.6, pp. 413-417, 2007.
[12] www.powercastco.com
[13] Dudenhoefer, James E. and George, Patrick J., “Space Solar Power Satellite Technology Development at the Glenn Research Center: An Overview”, NASA/TM—2000-210210, July 2000.
[14] W. Keith Belvin, John T. Dorsey and Judith J. Watson, “Solar Power Satellite Development: Advances in Modularity and Mechanical Systems”, NASA Langley Research Center, Hampton, VA 23681, 2010.
[15] J. Schlesak, A. Alden and T. Ohno, “A microwave powered high altitude platform”, IEEE MTT-S Int. Microwave Symp. Dig., pp. 283-286, 1988.

[16] W. Fu, B. Zhang, D. Qiu, and W. Wang, “Analysis of transmission mechanism and efficiency of resonance coupling wireless energy transfer system”, in Proc. Int. Conf. Elect. Mach. Syst.,Wuhan, China, pp. 2163-2168, 17-20 October, 2008.

[17] C. Zhu, C. Yu, K. Liu, and R. Ma, “Research on the topology of wireless energy transfer device”, in Proc. Vehicle Power Propulsion Conf., Harbin, China, pp. 1–5, 3-5 September 2008.

[18] Min Joo Jeong, Jung Hwan Hwang, Chang Hee Hyoung, Sung Weon Kang, and Youn Tae Kim, “Feasibility study on application of power transmission using magnetic coupling to body area network”, Electronics Letters, Vol. 48, No. 16, pp. 1013-1015, 2 August 2012.

List of Publications

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Min Joo Jeong, Jung Hwan Hwang, Chang Hee Hyoung, Sung Weon Kang, and Youn Tae Kim, "Feasibility study on application of power transmission using magnetic coupling to body area network", *Electronics Letters, Vol. 48, No. 16, P. 1013 ~ 1015, 2 August 2012.*

Abstract

A Feasibility Study on Application of Power Transmission Using Magnetic Coupling to Body Area Network

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Several studies have proposed the application of wireless power transmission in body area networks, in which power is transferred in a form of an electromagnetic wave or conduction current. However, its transmission efficiency decreases rapidly as a transmission distance increases.

This thesis presents a feasibility on power transmission using magnetic coupling to body area network. The effects of various conditions such as the body posture, transmission distance, number of coils were analyzed to apply magnetic coupling method with a high efficiency to power transmission between devices located on the human body.

The transmission efficiency decreases as the arrangement of the coils

changes according to body movement and the misalignment of the center of coils that causes a coil to shift horizontally. However, efficiency is maintained highly with a maximum of 46.2% at a distance of 10 cm, and over 5% at least even when the transmission path has a large curvature of 90 degree. In comparison with wireless power transmission, power transmission using the resonant coils that are coupled strongly through the magnetic field shows high transmission efficiency, even when the human body exists on the transmission path. Therefore, using resonant coils, it is possible to achieve high transmission efficiency in power transmission between devices located on the human body for body area networks. And also, it can be used for easily attachable resonant coils inserted clothes in order that the efficiency of power transmission using magnetic coupling to body area network can be maximized. This method can be applied to energy harvesting based on human body activity to collect energy without wires via harvesting devices located on the human body.

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