A Contactless Power and Signal Transmission Device for Implanted Functional Electrical Stimulation (FES)

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Abstract

This paper proposed a contactless power and signal transmission device using electro-magnetic coupling for a Functional Electrical Stimulation (FES) system, which consists of two coils. The two coils are the primary coil outside and the secondary inside the body, and the in vivo coil is composed of a coupling of two parts, the one to receive stimulate power and the other to receive signal one, each at a different radio frequency. In this study, we aim at the simultaneous power-signal transmission system, which enables power and signal for muscle stimulation to be concurrently transferred from outside the body, while allowing for the separation inside. Besides, the induced voltage of the magnetic flux on signal transmission, suppressed to 0.15 V, the output signal voltage of 2 V or more was established at a signal frequency of 7.7 MHz, thus leading to stable operation. The study also aimed to reach for higher power output of the secondary coil leading to stable operation.

1. INTRODUCTION

The FES system are using transdermal electrode and surface electrode of the main electrodes of the present FES treatments. The transdermal electrode can transmit the accurate stimulation waveform because of using a cable. But it may cause wire breaking or infectious diseases on the surface of the skin penetrated. Although the surface electrode can develop a transdermal system, it has a drawback of not being able to give an impulse to the muscles correctly. As the further developed FES system than these systems, an implantable electrode has already been reported[2]. In this system, however, cables are still used to connect the electrodes with the controller implanted in the body. Thus we consider this implantable FES system as insufficient because the danger of the disconnection isn't solved completely.

To overcome these problems, we have proposed a fully implantable electrode as the next-generation electrode, aiming at the establishment of a technology that simul-taneously transmits both electrical control signals from outside the body and power to stimulate muscles, by non-contact.

1.1. Outline of the implanted FES system

The implanted FES system we designed is made up of two sets of coils; the one located outside and the other located inside the body. This system uses an electromagnetic coupling to transmit not only signals to muscles but also driving power simultaneously by non-contact. Fig. 1 shows an external view of the FES system. For power transmission, it utilizes the magnetic field with a frequency of 100 kHz, as is considered to have a relatively minor effect on the body. For signal transmission, it is assumed to use a time division multiplex system based on ASK modulation, with a frequency bandwidth between 5 MHz and 7 MHz. Fig. 2 represents an equivalent circuit for the FES system.

1.2. Implanted device design

To transmit a time division signal via ASK modulation, a frequency of at least 5 MHz was used. A magnetic field of 100 kHz frequency for power produces noise in signal transmission due to simultaneous transmission. It is usually used a low-pass filter to reduce the noise. But, our solution to this problem is to take advantage of the magnetic characteristics of the devices.

In this study, we use two types of ferrite coils having different relative permeabilities, with the signal coil integrally wound around each of the ferrites. The number of coil turns is controlled so that the induced voltages are equal in the magnetic field for power generation, while the two coils are connected in series on opposite directions of polarity. As a result, the generated noise in signal transmission is cancelled. However, the different selfresonance frequencies enable to obtain the induced voltage in the high-frequency bandwidth for signal transmission because the characteristic of each ferrite changes in the high frequency. Fig. 3 shows the relationship between frequency and relative permeability of two kinds of ferrites (N-35 and N-21) used for the core. It is found that the relative permeability of N-35 ferrite decreases at 1 MHz or more while that of N-21 ferrite is constant. Accordingly, it is expected to enlarge the difference of each coil voltage induced in the high frequency if using these ferrites. We used two kinds of ferrites with different characteristic for such reason. Additionally, the power coil to generate stimulation waveforms is wound on the signal coil due to receive both power and signal simultaneously.

Subsequently, an experiment was performed to apply the magnetic fields for power and signal simultaneously. The number of coil turns is 20 for N-35 and 50 for N-21. The results are shown in Fig. 4. The experiment proved that the induced noise voltage was suppressed to 0.15 V in 103 KHz band for power and that the signal transfer allowed an output of at least 2 V at 7.7 MHz. Based on the results obtained, we were able to confirm the usefulness of this system.

2. METHODS

We have seen in the previous section that it is possible to transfer both power and signals simultaneously from outside and to separate them within the body. This method focuses on improvement for higher power output in the secondary coil in the body. From the experiments conducted in the past, it is found that the maximum output of the coil receiving signal is obtained when the size ratio of N-35 and N-21 in the longitudinal direction is 7:3.

We tried to examine in this section and to achieve the higher power output of the coil receiving power. Fig. 5 represents an external view of the primary coil used in the experiment, as well as the equivalent circuit. A capacitor is inserted in parallel on the secondary side, resulting in an improvement of transmission efficiency. We inserted an capacitor which was named C_2 and measured load characteristic in case of changing the value of capacitor.

3. RESULTS

The result is presented in Fig. 6. It is observed that before capacitor insertion, the highest power was 52 mW at a load resistance of 1 kΩ, while the output of 202 mW was measured at 3.3 kΩ after a capacitor of 3300 pF was inserted. The value of this 3300 pF almost agrees with the computed value.

4. DISCUSSION AND CONCLUSIONS

In this experiment we found that there is the realization of a fully implantable device that allows power and signals simultaneously transmitted from outside the body to be separated and to stimulate muscles within the body. The secondary coil received power was able to produce a higher power output by inserting a capacitor. This system, however, has a drawback that shortening the winding position length causes an increase in the cross-sectional area of the secondary coil, which needs to be investigated. This system not only uses magnetic material and electromagnetic characteristics, but also allows the establishment of the optimum system when in consideration of surrounding noise and biological effects. It is therefore highly desirable to achieve its early realization.

References

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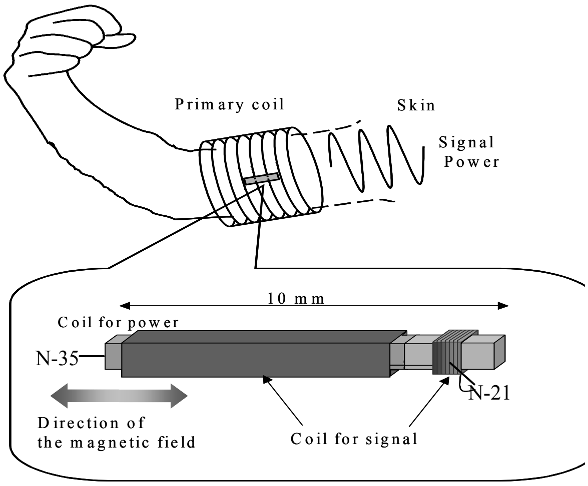

Fig.1 External view of the implanted FES module.

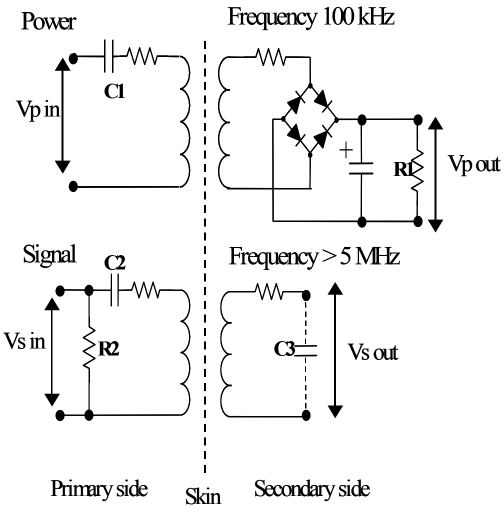

Fig.2 Equivalent circuit for the FES system.

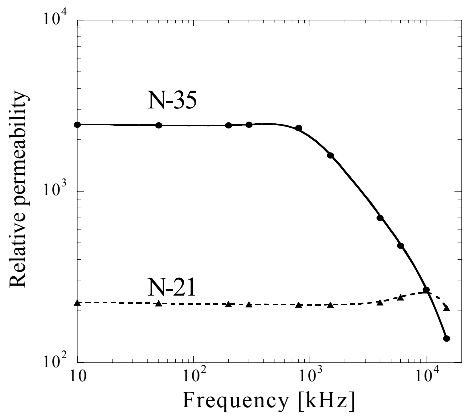

Fig.3 Relationship between frequency and relative permeability of two kinds of ferrites.

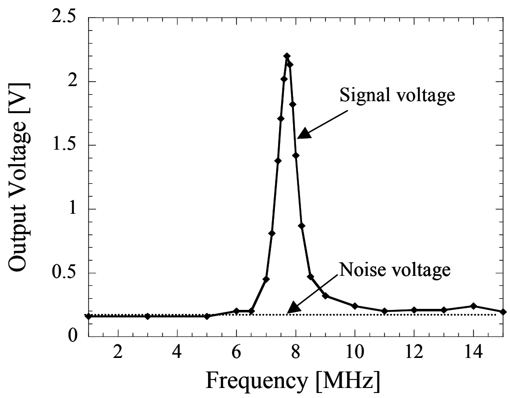

Fig.4 Signal transmission in electric power magnetic

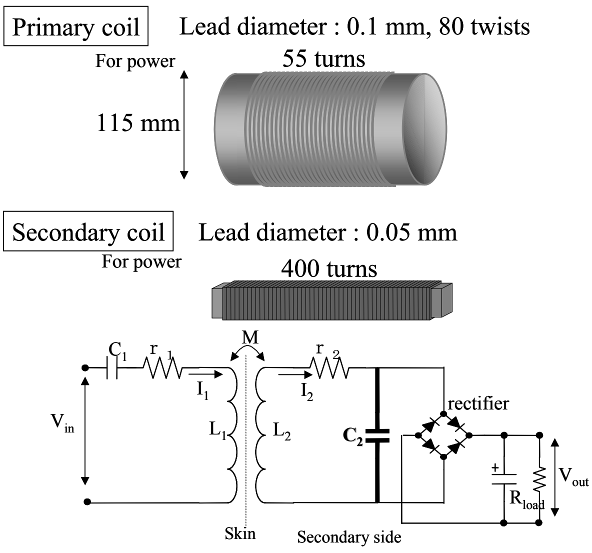

Fig.5 Coils and equivalent circuit used in the experiment.

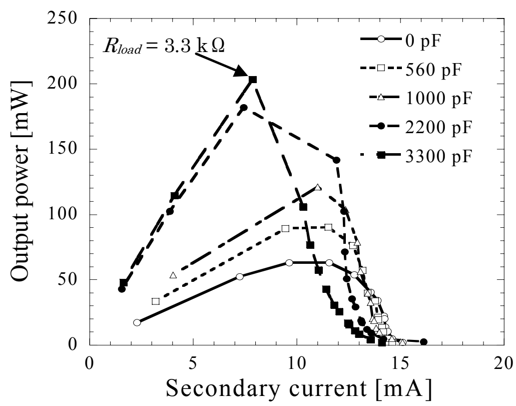

Fig.6 Output change by improvement of transmission efficiency gained through capacitor insertion.