Wireless Power and Data Transfer System for Station-Based Autonomous Underwater Vehicles

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***Abstract*—Autonomous underwater vehicle (AUV) has widely been used for underwater explorations. However, AUV requires frequent launch and recovery processes for power feeding and data extraction. In order to solve these problems, we propose wireless power and data transfer system, which uses a pair of coils and transfer power and signal by using electromagnetic induction. We designed a system that can cover both power and communication signal transferring, and evaluated its performance by experiments. The obtained results suggest that the designed system can support high efficiency power transfer (>80%), high communication quality (with BER of 0.1%), and high data rate (>40kbps). It was confirmed that underwater wireless power and data transfer system can archived using single hardware.**

Keywords—autonomous underwater vehicle; wireless power transfer; wireless data transfer

1. INTRODUCTION

Autonomous underwater vehicle (AUV) has widely been used for underwater explorations, and its usage is still growing [1, 2]. For example, AUV has been used for collection of undersea resources such as methane hydrate, discovery of unknown organisms, and survey of the seabed environment [3]. Although AUV can explore the underwater autonomously, it requires frequent launch and recovery processes for power feeding and data extraction, which results in increase of operation cost. As an alternative, seafloor station has been proposed to achieve power feeding and data extraction without recovering process [4]. In the conventional method, wired power supply and acoustic communication have been used for power feeding and data extraction. However, we cannot ignore the risk of the event of a short circuit. Moreover, communication rate of underwater acoustic communication is sometimes limited (< 10kbps) [5]. As a method for solving them, we propose wireless power and data transfer system [6]. Wireless power and data transferring are very attractive as they free AUV from wire tethering at the station (Fig. 1). Wireless power and data transfer can be achieved by using a pair of coils using electromagnetic induction.

Wireless power transfer in seawater is has already been reported [7]. In previous research, wireless power transfer in seawater using electromagnetic induction method is discussed with low frequency (100 kHz) [8]. In order to suppress the increase of the radiation resistance which is inversely proportional to the quality factor and the transmission efficiency, it is important to drive the coil at low frequency (100 kHz). As a result of experiment, frequency characteristic of the coil, such as radiation resistance, inductance, and quality factor were clearly described [8]. However, transmission efficiency of the coil against frequency and transmission gap has not been discussed. Since the transmission efficiency is important in the wireless power transfer, we evaluate the transmission characteristics of the coil.

The scope of this study is to design a system that achieves wireless power and data transfer using a single hardware, that has not been designed and tested, to our knowledge, and to evaluate its performance in experiment. In the following sections, we design a system for wireless power and data transfer, perform experiments, and have some discussions.

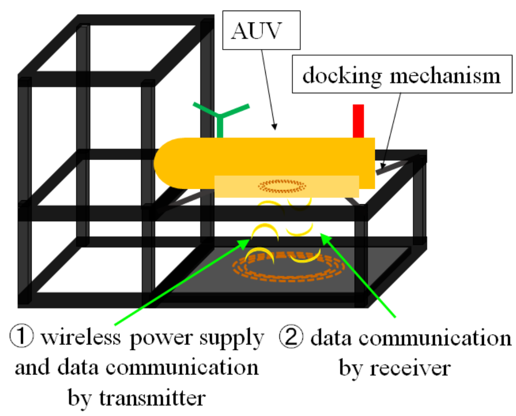

Fig. 1 wireless power supply and data communication system for AUV using seafloor platform

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2. System Design

2.1 Wireless Power Transfer

Wireless power transfer using coils has widely been studied in air. Especially, electromagnetic induction method and electromagnetic resonance method is used for wireless power transfer [9]. It is desirable to minimize the radiation resistance of coils for efficient power feeding. Radiation resistance depends on the radius of coils, operating frequency, the permeability of medium, and the conductivity of medium. In order to achieve wireless power supply in seawater, it is required to minimize the radius and frequency of the coil. In detail, the wireless power transfer with low frequency (100 kHz) in seawater using electromagnetic induction method has been reported [8].

Wireless power transfer using electromagnetic induction method is carried out as shown in Fig. 2, by following processes. We applied power of P_{in} to the transmitting coil, which results in a production of magnetic field. A magnetic field propagates through transmission gap, and reaches to the receiving coil. Hence, it is able to receive output power of P_{out} at the receiving coil. Transmission efficiency is defined by ratio of P_{out}/P_{in}, that is proportional to a product of coupling coefficient k and quality factor Q [9].

In this study, the author designed a helical coil and measured transmission efficiency that have not been clarified yet. It has been found that the wireless power transfer can be achieved efficiently in saltwater when the operating frequency is low (on the order of 100 kHz) [8]. Based on this idea, we designed a pair of coils that consists of 20 turns of wire, radius of 57 mm, and pitch of 1.2 mm. Initially, the resonant frequency and the inductance of the fabricated coils, are approximately 2.94 MHz and 66.1 µH. To achieve the desired frequency of operation (around 100 kHz), a capacitor of C = 33nF was placed in series with the coils. Finally, the resonant frequency of the fabricated coils became 110 kHz.

2.2 Wireless Data Transfer

By using the coils for power transfer, wireless data transfer is also available. If the signal band for wireless data transfer and wireless power transfer are the same. Since the signal is distorted by the influence of frequency characteristic of channels, it is necessary to compensate the distortion at the receiver. Therefore, we adopted orthogonal frequency division multiplexing (OFDM) for signal modulation [10].

Wireless data transfer system is configured as shown in Fig. 3. Digital data signal is generated by using computer, and is modulated by quadrature phase shift keying (QPSK) [11]. That signal is modulated by OFDM using inverse discrete Fourier transform (IDFT), and sub-carriers that are orthogonal each other are generated. Frequency conversion at the carrier frequency f_c is performed to shift the center frequency of the signal to the frequency at which the wireless data transfer is achieved efficiently. The signal is input to the transmitting coil and received by the receiving coil across the transmission gap. By performing DFT calculation and equalization, it is possible to obtain the data at the receiver side [12].

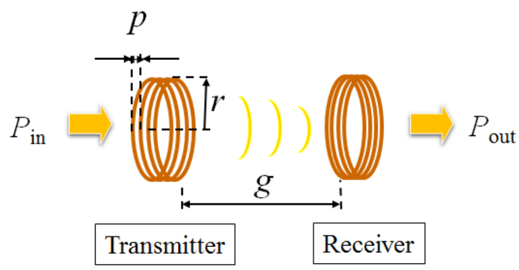

Fig. 2 Wireless Power Transfer system

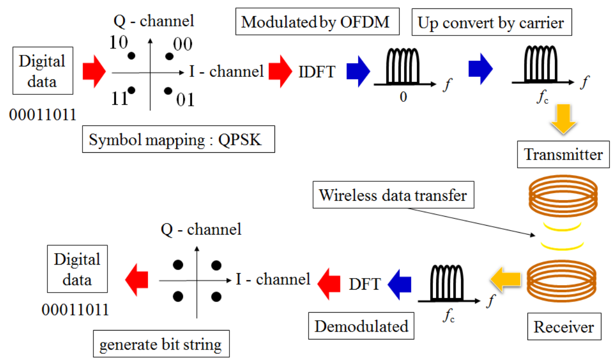

Fig. 3 Wireless Data Transfer system

3. EXPERIMENT

3.1 Wireless Power Transfer

We measured transmission efficiency in air, freshwater, and saltwater. To simulate the distance characteristics, transmission gap were changed from 10 to 50 (mm) and the measurements were performed with frequency from 50 to 200 (kHz) in step of 0.425 kHz.

The measurement system is shown in Fig. 4. Transmission characteristics against frequency and transmission gap were measured using vector network analyzer (VNA, Agilent E5061B). Since input impedance of coil is much lower than input/output impedance of VNA, the excitation coil (consists of 10 turns of wire, radius of 60 mm, and pitch of 1.2 mm) is placed between output coil and VNA, to match their impedance.

The result of the experiment are shown in Figs. 5 and 6. Figure 5 shows a relationship between frequency and transmission efficiency. As shown in Fig. 5, it was found that the transmission efficiency mainly depends on a gap between coils, and it does not depend on the transmission medium (air, fresh water, and saltwater). When g = 10 mm, we found that the designed coil can transfer the power efficiency reaches to 80%, and the transmission efficiency curve has two peaks. This phenomenon can be observed when the coupling coefficient k is sufficiently large, due to small transmission gap between coils. When g = 30 and 50 (mm), we found that the peak of transmission efficiency locates at the resonance frequency of coils (f_0 = 110 kHz), and the transmission efficiency becomes 78 % and 55%, at g = 30 and 50 (mm), respectively.

Figure 6 shows a relationship between transmission gap and the transmission efficiency. We found that maximum efficiency is approximately 81% at g = 10 mm, and transmission efficiency is inversely proportional to transmission gap. This results confirm that the transmission efficiency depends on parameters of coils, k and Q.

These results indicate that the wireless power transfer using coils can be archived even in saltwater if we minimize radius of coils r and their operating frequency f.

3.2 Wireless Data Transfer

We also made up wireless communication system using LabVIEW (National Instruments). The data transfer system is shown in Fig. 7. OFDM modem was designed whose center frequency f_c was 110 kHz, with signal bandwidth of 50 kHz. The number of sub-carrier is 64 with uniform 16 pilot carriers. The effective data rate of fabricated system was approximately 42 kbps. Data transfer was performed in saltwater using the fabricated coil with excitation coil, and bit-error rate (BER) was measured with changing signal levels.

The experimental results are shown in Figs. 8 and 9. Figure 8 shows that relationship between transmission gap and signal to noise ratio (SNR). As a condition, change the signal from -3 to -20 (dB) and the amplification factor of the amplifier was constant. Although, transmission efficiency was inversely proportional to the transmission gap definitely, SNR was inversely proportional to transmission gap slightly.

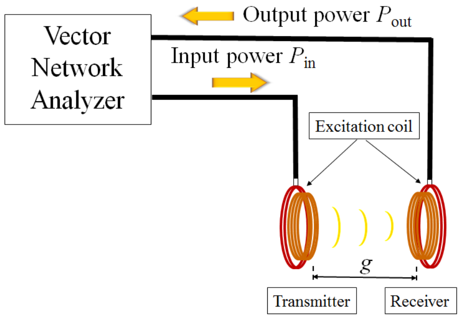

Fig. 4 The measurement system of VNA

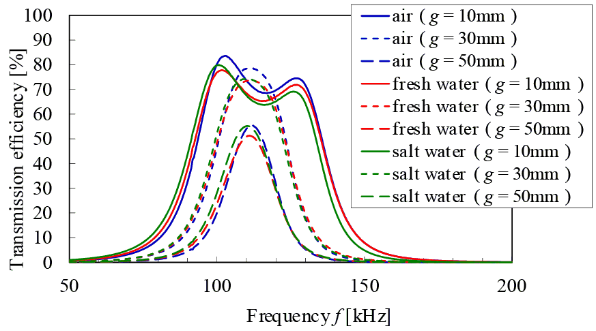

Fig. 5 Relationship between frequency and power transmission efficiency obtained in experiment

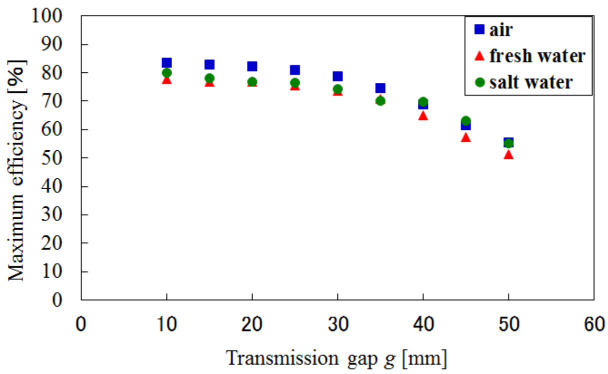

Fig. 6 Relationship between transmission gap and power transmission efficiency obtained in experiment

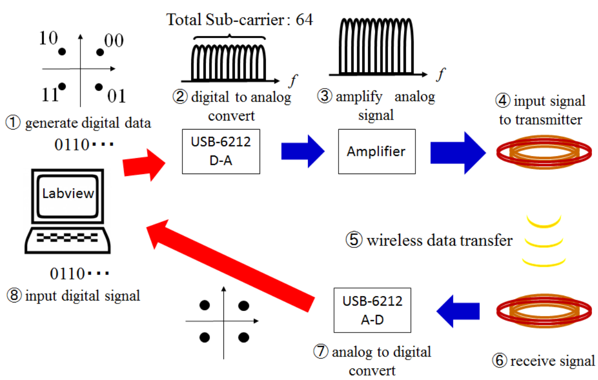

Fig. 7 The data transfer system

This result indicates that if the original signal level is upper -20 dB at least, the influence of the noise is not much.

Figure 9 shows a relationship between SNR and BER when we increase g from 10 to 50 (mm). We found that BER becomes smaller as SNR increases, and BER of 10^{-4} is achieved with SNR of 26, 33, and 38 (dB) when g = 10, 20, and 30 (mm), respectively. As a result, transmission efficiency and efficient bandwidth for data transfer (Fig. 5) are inversely proportional to transmission gap, BER is improved as transmission gap is small in the case of the same SNR.

These results indicates that single hardware which used for wireless power transfer can achieve high data rate and high quality data communication.

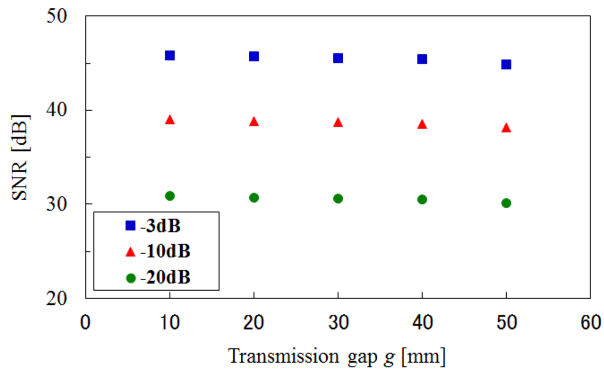

Fig. 8 Relationship between transmission gap and SNR obtained in experiment

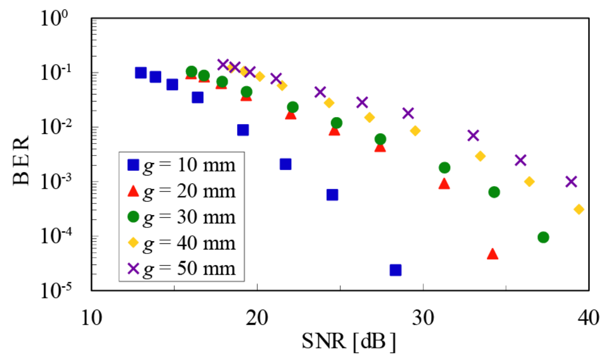

Fig. 9 Relationship between SNR and BER obtained in experiment

4. CONCLUSION

In this study, we proposed a system which achieves wireless power supply and data communication using single hardware. As a basic study, the author designed a system for power and data transfer, and evaluated its performance in experiments. First, the author designed two helical coils which resonate at about 100 kHz and measured their transmission characteristics. Second, the author demonstrated wireless data communication modulated by OFDM using same hardware and indicated a relationship between SNR and BER. From these results, it was found that the wireless power transfer can be archived with efficiency of 81% in salt water (similar in air, and fresh water). Moreover, high quality data communication with BER of 0.1% can also be archived within 30 mm using the same hardware.

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