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Article

Development of a Broadband Self-recording Hydrophone

Bong-Chae Kim*

Marine Environment Research Department, KORDI
Ansan P.O. Box 29, Seoul 425-600, Korea

Abstract : A broadband self-recording hydrophone was developed to conveniently assemble a hydrophone array for use in receiving underwater sound waves. A trigger device with an electromagnetic induction coupler was also developed to control the hydrophone's operation. Main configurations and specifications of the self-recording hydrophone are introduced in this paper. We present experiment results conducted in a water tank to examine the operating behavior of the hydrophone. Some advantages are discussed when the self-recording hydrophones are used to make up a hydrophone array.

Key words : self-recording hydrophone, hydrophone array system, underwater acoustic measurement, electromagnetic induction trigger

1. Introduction

In the field of underwater acoustics, a hydrophone is a basic measurement instrument which generates electrical signals by receiving underwater sound waves (Burdic 1991; Caruthers 1977). A hydrophone is generally made up a hydrophone sensor, a pre-amplifier, cables, cable connectors, etc. In particular hydrophones used in the ocean must be capable of withstanding severe shipboard abuse and extreme hydrostatic pressure. Hydrophone sensors and hydrophone cables are generally shielded to be completely isolated from stray electrical noise fields.

When underwater acoustic experiments are conducted in the ocean, a hydrophone array is used to get spatial distribution in a sound field and to detect incoming direction of sound waves (Urick 1983; Waite 2002). A hydrophone array is also used to survey wide areas simultaneously by measuring spatial distribution of sound fields in the ocean.

Hydrophones in an array are vertically or horizontally installed in the ocean and receive underwater sound waves at their locations. Received acoustic signals are stored in a disc or a tape. A conventional hydrophone array has long cables as a medium for transmitting the signals. In the conventional array, the cables become more multiplex and complex as the hydrophone channel increases. It is not convenient to handle the conventional hydrophone array because of its extensive scale. And hydrophone intervals can not be adjustable even if necessary because the hydrophones are fixed in the cables. It is also difficult to repair the conventional hydrophone array if the cables to be in use are broken. These disadvantages will be more evident when the hydrophone array is used in the deep sea rather than in shallow water.

A solution to the problems of a conventional hydrophone array is to devise a wireless system for transmitting acoustic signals or to develop a self-recording hydrophone. In particular, when a hydrophone array consists of self-recording hydrophones, a trigger device is necessary to control all the hydrophones simultaneously.

In the past, if we tried to develop a wireless transmitting system or a self-recording hydrophone, it was difficult to realize these goals because they might become complicated by the makeup of low-density integrated circuits available at that time, and they needed an electrical source of fairly large size to supply sufficient electrical power. However, recently it becomes possible to develop a self-recording hydrophone owing to the availability of various memory devices of larger capacity and electronic components of high-density and low-power consumption.

We developed a portable hydrophone array system which

*Corresponding author. E-mail : bckim@kordi.re.kr

was compact, light, and easy to handle (Kim 2006). The hydrophone array system was superior in signal-to-noise ratio and directly provided acoustic data of digital type. However, there were restrictions in using the hydrophone array system in the real ocean because the hydrophones had low sampling frequency and insufficient memory capacity. So a broadband self-recording hydrophone was newly developed to overcome this shortcoming in the hydrophone array. In this paper, configurations of the self-recording hydrophone are described and experiment results measured by the hydrophone are presented.

2. System configurations

The block diagram of a broadband self-recording hydrophone is shown in Fig. 1 and the photograph of the hydrophone is shown in Fig. 2. Main specifications of the self-recording hydrophone are shown in Table 1. As shown in Fig. 1, the self-recording hydrophone is made up a hydrophone sensor, filters and amplifiers, a CPU(central processing unit) with an analogue to digital converter and a controller, a memory, a slave electromagnetic induction coupler, a transformer and amplifier, a clock, and a battery.

Model SQ06 (http://www.sensortech.ca) provided by the Sensor Technology Limited was used in the self-recording hydrophone as a hydrophone sensor. Receiving sensitivity

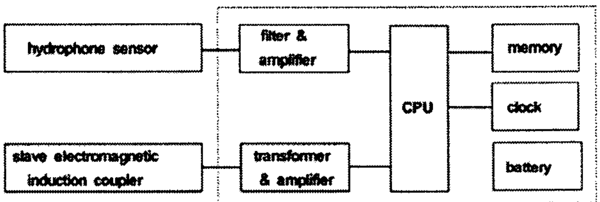


Fig. 1. Block diagram of a self-recording hydrophone.

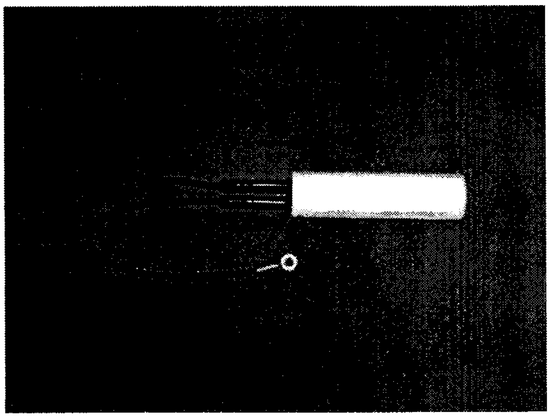


Fig. 2. Photograph of the self-recording hydrophone.

Table 1. Main specifications of the self-recording hydrophone.

Receiving sensitivity	–201.5 dB re 1 V/μPa
Frequency band	80 Hz~16 kHz
Digitizing frequency	65.536 kHz
Digitizing bit	16 bits
Dynamic range	81 dB
Tolerable maximum water depth	1,000 m
Data record time	2.8 hours
Data recording control method	external electromagnetic induction

of the hydrophone sensor is –201.5 dB re 1 V/μPa and capacitance of the sensor is 1,000 pF. Frequency response of the hydrophone sensor is flat in a range from 3 Hz to 20 kHz and the sensor can be used within 3,500 m depth.

Amplifiers and filters in the self-recording hydrophone were composed of two steps. A charge amplifier and a high-pass filter were used in the first step. The amplifier's gain was fixed at 20 dB and the filter's cutoff frequency was set at 80 Hz. An operational amplifier and a band-pass filter were used in the second step. Gain of the amplifier was fixed at 20 dB. Lower cutoff frequency and upper cutoff frequency of the band-pass filter were set at 67.5 Hz and 32 kHz, respectively. As a whole, acoustic signals in a frequency range from 80 Hz to 32 kHz were passed and magnified by 40 dB in the self-recording hydrophone.

A clock used in the self-recording hydrophone provides a precise timekeeper. Maximum error of the clock is about 2 minutes within one year and the oscillating frequency of the clock is 32,768 Hz. In the self-recording hydrophone, a sampling frequency to digitize acoustic signals was fixed at 65,536 Hz by using rising signal and falling signal of the clock. A flash memory of 1 GB was used to store acoustic data and a lithium battery of voltage amplitude 6 V and capacitance 1,300 mAh for a camera was used as an electrical source in the self-recording hydrophone.

If a beginning pulse for a trigger is applied at the slave electromagnetic induction coupler of the self-recording hydrophone, the pulse is magnified by a transformer and amplifier. The pulse is sent to a CPU and then the CPU immediately starts to operate the hydrophone. The hydrophone sensor converts underwater sound waves into electric signals. The signals are magnified and filtered by amplifiers and filters, respectively. The signals are digitized with 16 bits and 65.536 kHz by an analogue to digital converter in the CPU and are stored in a flash memory of the hydrophone. If signals are sampled with 65.536 kHz sampling frequency, data size for 1 second becomes about

0.128 MB. So the memory of 1 GB can store acoustic data for about 10,000 seconds. If cessation of acoustic measurement is desired, the CPU stops operating the hydrophone by applying a finishing pulse for a trigger at the slave electromagnetic coupler.

The self-recording hydrophone was manufactured to be as compact as possible. The hydrophone consisted of electronic components of low power consumption. That is, the hydrophone was operated by a single electrical source with 5 V. The hydrophone during operation only needed a current of 5 mA. So a lithium battery will be continuously used for about 260 hours as the electrical source of the hydrophone.

The block diagram of a trigger device is shown in Fig. 3. The trigger device is used to control operation of all the self-recording hydrophones in an array at the same time.

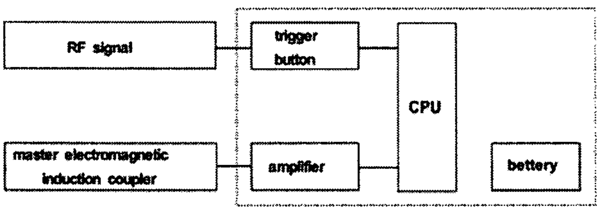


Fig. 3. Block diagram of a trigger device for control of the self-recording hydrophone.

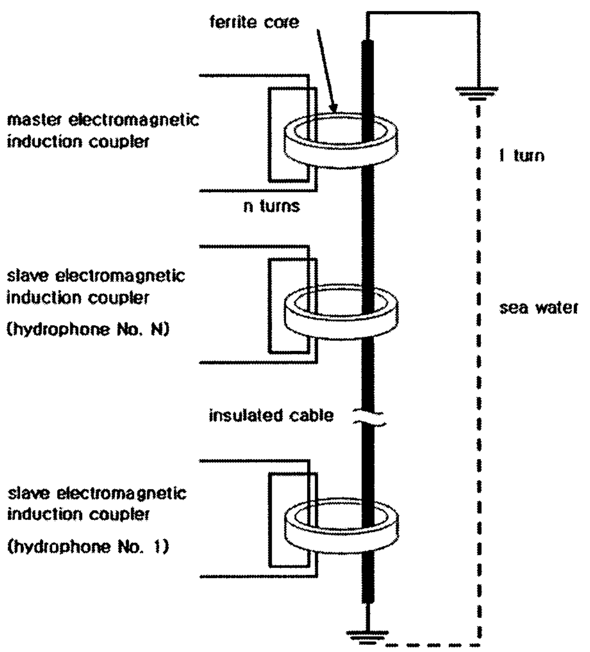


Fig. 4. Diagrammatic view of the electromagnetic induction couplers for control of the self-recording hydrophones.

Fig. 4 shows diagrammatic view of the electromagnetic induction couplers for control of the self-recording hydrophone. Schematic view of the hydrophone array system to use in the sea is shown in Fig. 5.

As shown in Fig. 3, the trigger device consisted of a trigger button, a CPU, a battery, an amplifier, etc. And the hydrophone array system is made up a buoy inserted into an RF transceiver and a trigger device, a trigger cable, a master electromagnetic induction coupler, an insulated cable, several self-recording hydrophones; all with a weight as shown in Fig. 5.

A beginning pulse and a finishing pulse for triggers are generated by a trigger device. A CPU in the device generates the beginning pulse or the finishing pulse when a trigger button is pressed or operated by an RF signal as necessary. The pulses are magnified by an amplifier and applied at a master electromagnetic induction coupler through a trigger cable. An electromagnetic induction coupler is a kind of transformer which consists of two wire coils wound on a ferrite core. In the case of the master

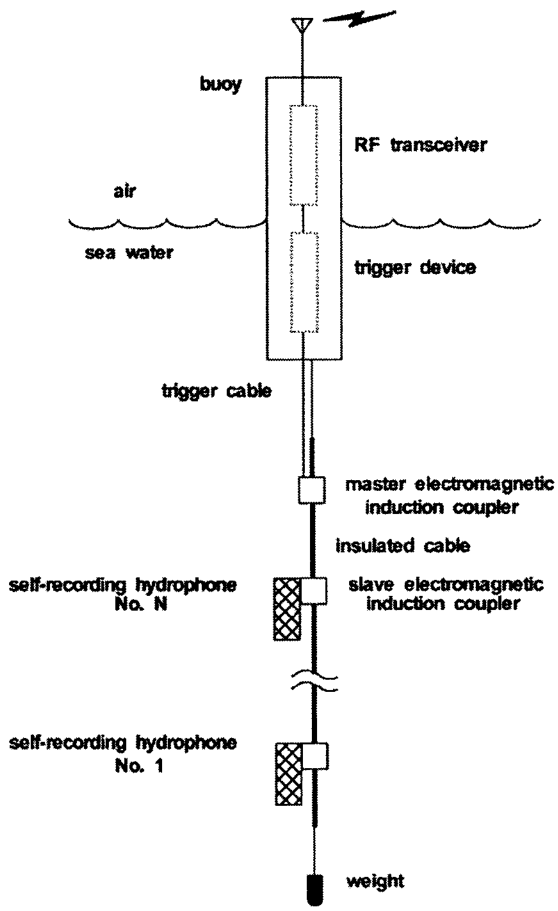


Fig. 5. Schematic view of the hydrophone array system.

electromagnetic induction coupler, the primary is made of n-turns coil and the secondary forms a loop composed of an insulated cable and conductive sea water as shown in Fig. 4. When the beginning pulse for a trigger is applied at the primary of the master electromagnetic induction coupler, a $1/n$ amplitude of the primary voltage is induced at the secondary of the master electromagnetic induction coupler.

In the case of the slave electromagnetic induction coupler inserted in a self-recording hydrophone, the primary forms a loop composed of an insulated cable and conductive sea water and the secondary is made of n-turns coil. The secondary of the master electromagnetic induction coupler is the same as the primary of the slave electromagnetic induction coupler. So when a beginning pulse with a $1/n$ amplitude of the original voltage is applied at the secondary of the master electromagnetic induction coupler, the original beginning pulse for a trigger is induced at the secondary of the slave electromagnetic induction coupler. Then the self-recording hydrophone immediately starts to operate.

The CPU in the trigger device generates a finishing pulse if a trigger button is pressed or operated by an RF signal in order to stop operating the self-recording hydrophone. The pulse is magnified by an amplifier and applied at a master electromagnetic induction coupler through a trigger cable. So the original finishing pulse for a trigger is induced at the secondary of the slave electromagnetic induction coupler inserted in the hydrophone. Then the self-recording hydrophone immediately stops the operation.

As shown in Fig. 5, the self-recording hydrophones are attached to an insulated cable at an appropriate interval. The hydrophones receive and store underwater sound waves at their locations. At this time all the hydrophones attached to the cable simultaneously start to store the acoustic signals by a wireless beginning pulse and simultaneously stop storing the acoustic signals by a wireless finishing pulse. The acoustic data in the flash memories of the hydrophones are dumped in a computer by connecting the hydrophones to the computer. And the self-recording hydrophones can be repeatedly used after the flash memories are emptied.

3. Measurement results and discussions

An experiment was carried out in a water tank (3 m × 4 m × 4 m) to investigate operating conditions of a self-recording hydrophone and a trigger device and to examine quality of acoustic data received by the hydrophone. Underwater sound sources were installed at the middle of a side of the water tank. A self-recording hydrophone and a reference hydrophone were set up at the center of the tank. At this experiment an underwater speaker (Lee 2006) and a projector of model USRD F33 were used as the sound sources to generate pulsed continuous waves. A hydrophone of Bruel & Kjaer model 8103 was used as a reference receiver. Center frequency of the waves generated in the water was about 580 Hz, 780 Hz, 1.7 kHz, 3.0 kHz, 6.4 kHz, and 12.7 kHz, respectively. Pulse length of the waves was in a range from 2 ms to 60 ms and was narrowed as the frequency increased. Here, the underwater speaker was used to generate sound waves of 580 Hz, 780 Hz, and 1.7 kHz, respectively. The projector was used to generate sound waves of 3.0 kHz, 6.4 kHz, and 12.7 kHz, respectively.

The waveforms received by the self-recording hydrophone are shown in Fig. 6 to Fig. 11. In these figures x-axis

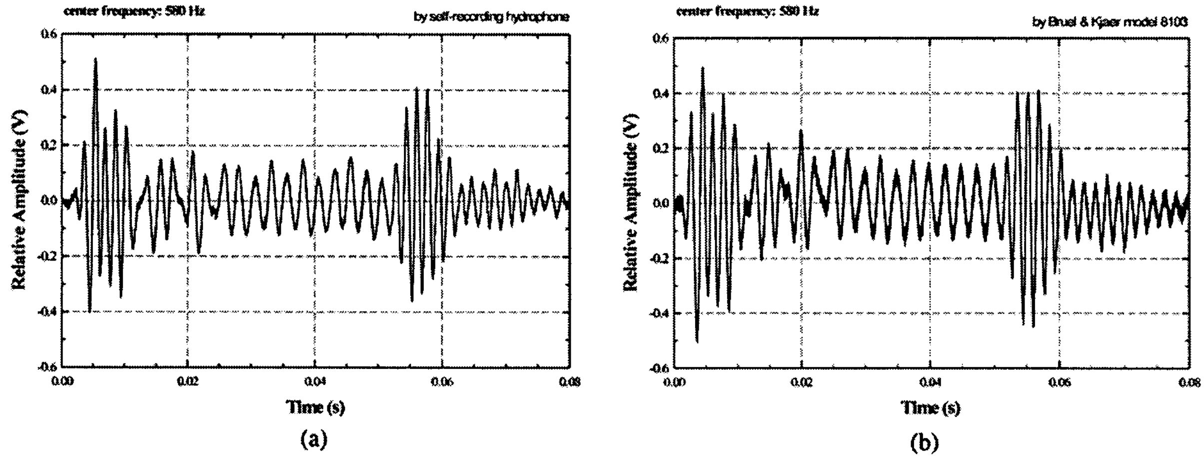
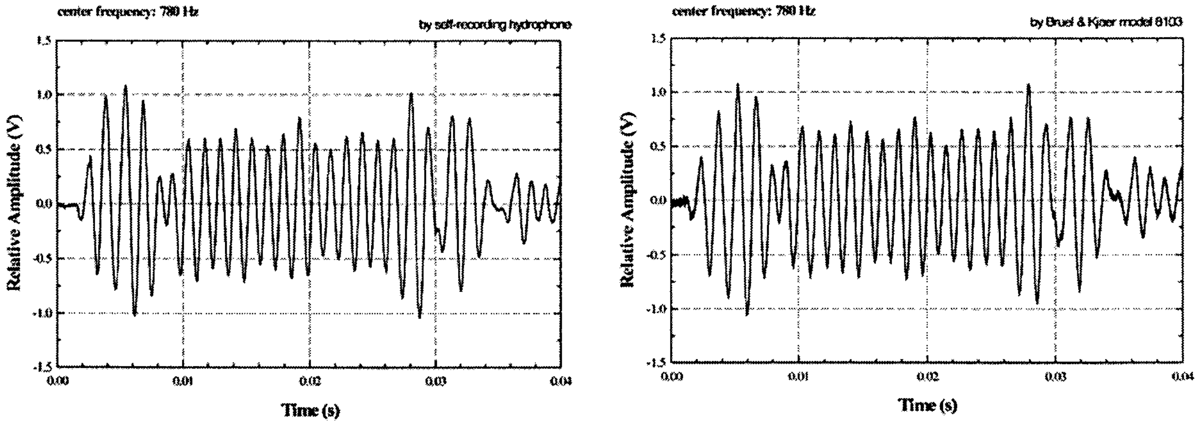
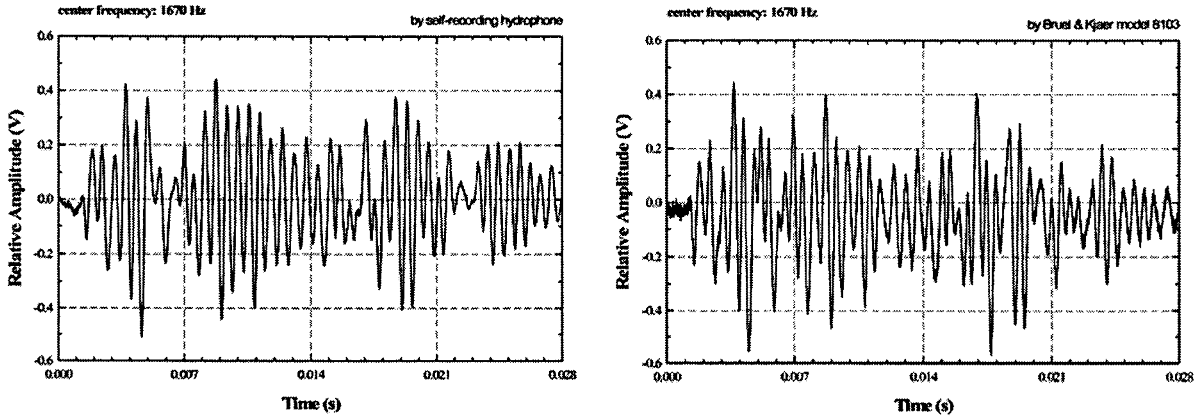


Fig. 6. Waveform of center frequency 580 Hz sound received by the self-recording hydrophone (a) and the reference hydrophone (b).



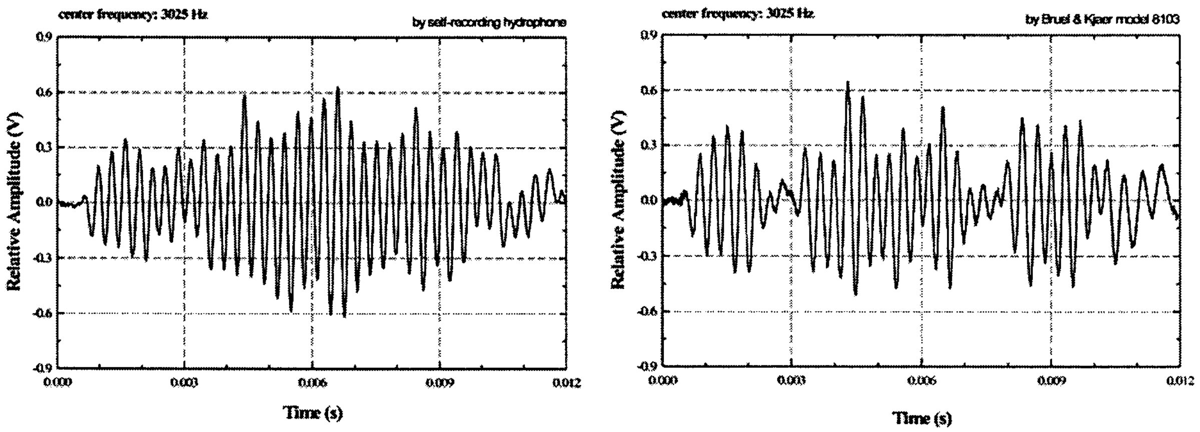
(a) (b)

Fig. 7. Waveform of center frequency 780 Hz sound received by the self-recording hydrophone (a) and the reference hydrophone (b).



(a) (b)

Fig. 8. Waveform of center frequency 1.7 kHz sound received by the self-recording hydrophone (a) and the reference hydrophone (b).



(a) (b)

Fig. 9. Waveform of center frequency 3.0 kHz sound received by the self-recording hydrophone (a) and the reference hydrophone (b).

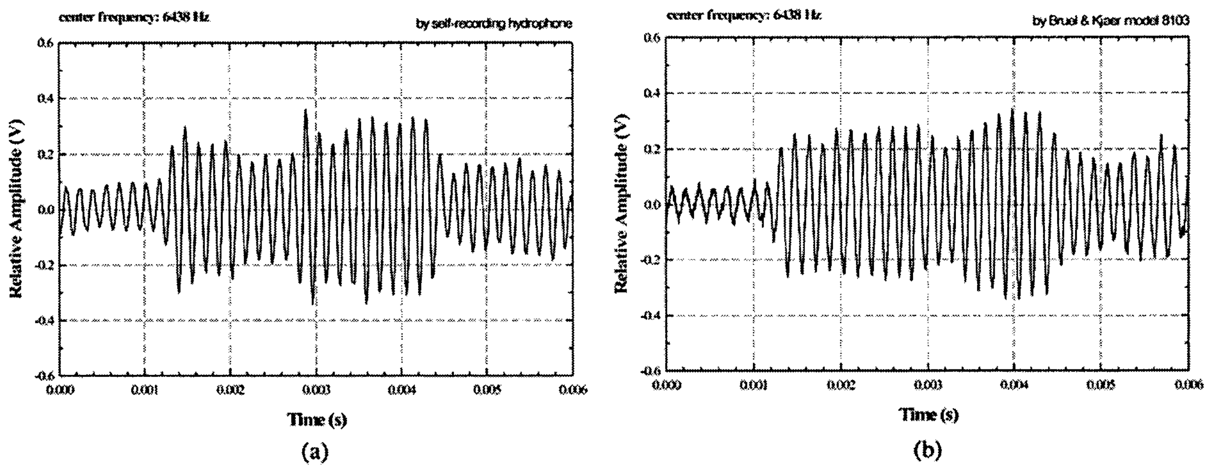


Fig. 10. Waveform of center frequency 6.4 kHz sound received by the self-recording hydrophone (a) and the reference hydrophone (b).

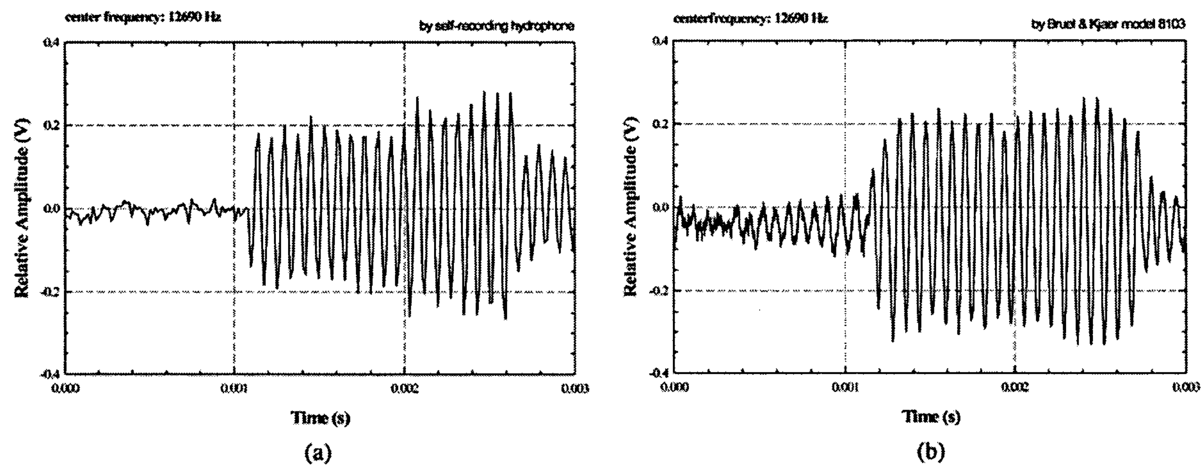


Fig. 11. Waveform of center frequency 12.7 kHz sound received by the self-recording hydrophone (a) and the reference hydrophone (b).

represents time in seconds and y-axis represents relative voltage amplitude in volts to be proportional to sound pressure amplitude. The waveforms received by the reference hydrophone are also shown in the figures. The waveforms by the self-recording hydrophone can be compared with the waveforms by the reference hydrophone.

As a result, it was verified that the self-recording hydrophone and the trigger device operated very well. The self-recording hydrophone excellently received underwater sound waves and was very strong against electrical noises. In particular, in case of center frequency of 580 Hz and 780 Hz, respectively, the waveforms received by the self-recording hydrophone were completely same with the waveforms received by the reference hydrophone.

In the case of higher center frequency than 1.7 kHz, it was confirmed that characteristic against noise of the self-recording hydrophone was superior to that of the reference hydrophone. It is thought that this happened because the self-recoding hydrophone, by using a battery, was better isolated from drifting electrical noises than the reference hydrophone. The waveforms received by the self-recording hydrophone were not completely identical with the waveforms received by the reference hydrophone as frequency increased. The self-recording hydrophone and the reference hydrophone were installed closely together in a water tank during the experiment; however, they were not set up at the exactly same position in the water. When a hydrophone receives underwater sound waves radiated by a sound source, reflected waves will interfere with direct waves at the hydrophone's position. It was thought that this phenomenon happened because the interference was variable with the hydrophone's location. Remarkably, the effect of non-coincidence of the hydrophone's position appeared as the frequency increased. As shown in Fig. 10 and Fig. 11, the self-recording hydrophone satisfactorily received high frequency sound waves used for active sonars. And the hydrophone directly provided digital acoustic data.

If a hydrophone array consists of the self-recording hydrophones, it is easy to adjust hydrophone intervals with measuring conditions. It is convenient to handle the array because only a cable is necessary regardless of the number of hydrophone channels. The hydrophone array is easily separated hydrophones and a cable, so it is more convenient to carry or to repair the array than with a conventional hydrophone array.

4. Conclusions

A broadband self-recording hydrophone was developed to construct a hydrophone array and to use for receiving underwater sound waves. A trigger device was developed to control operation of all the hydrophones used in the hydrophone array at the same time. An experiment was conducted in a water tank to examine operating condition of the self-recording hydrophone and the trigger device. As a result, the self-recording hydrophone and the trigger device operated very well. The hydrophone directly provided digital acoustic data and was very strong against electrical noises. A hydrophone array consisting of self-recording hydrophones can be used to conveniently receive underwater sound waves during ocean acoustic experiments.

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