



“KAIYO” Cruise Report

KY10-13

Research on Underwater Acoustic Technology,

Izu-Ogawsawara

04/Nov./2010 – 06/Dec./2010

Japan Agency for Marine-Earth Science and Technology
(JAMSTEC)

●Contents

1. Cruise Information

2. Researchers

3. Experiments

3.1. Experiments of long range acoustic propagation using phase conjugate waves

3.1.1. Overview

3.1.2. Experimental setup

3.1.3. Research results

3.1.3.1 Communication at the range of 1,000 km

3.1.3.2. Communication from the source near the seafloor

3.1.3.3. Communication from the two sources

3.2. Experiments of long range acoustic positioning

3.2.1. Overview

3.2.2. Experimental setup

3.2.3. Research results

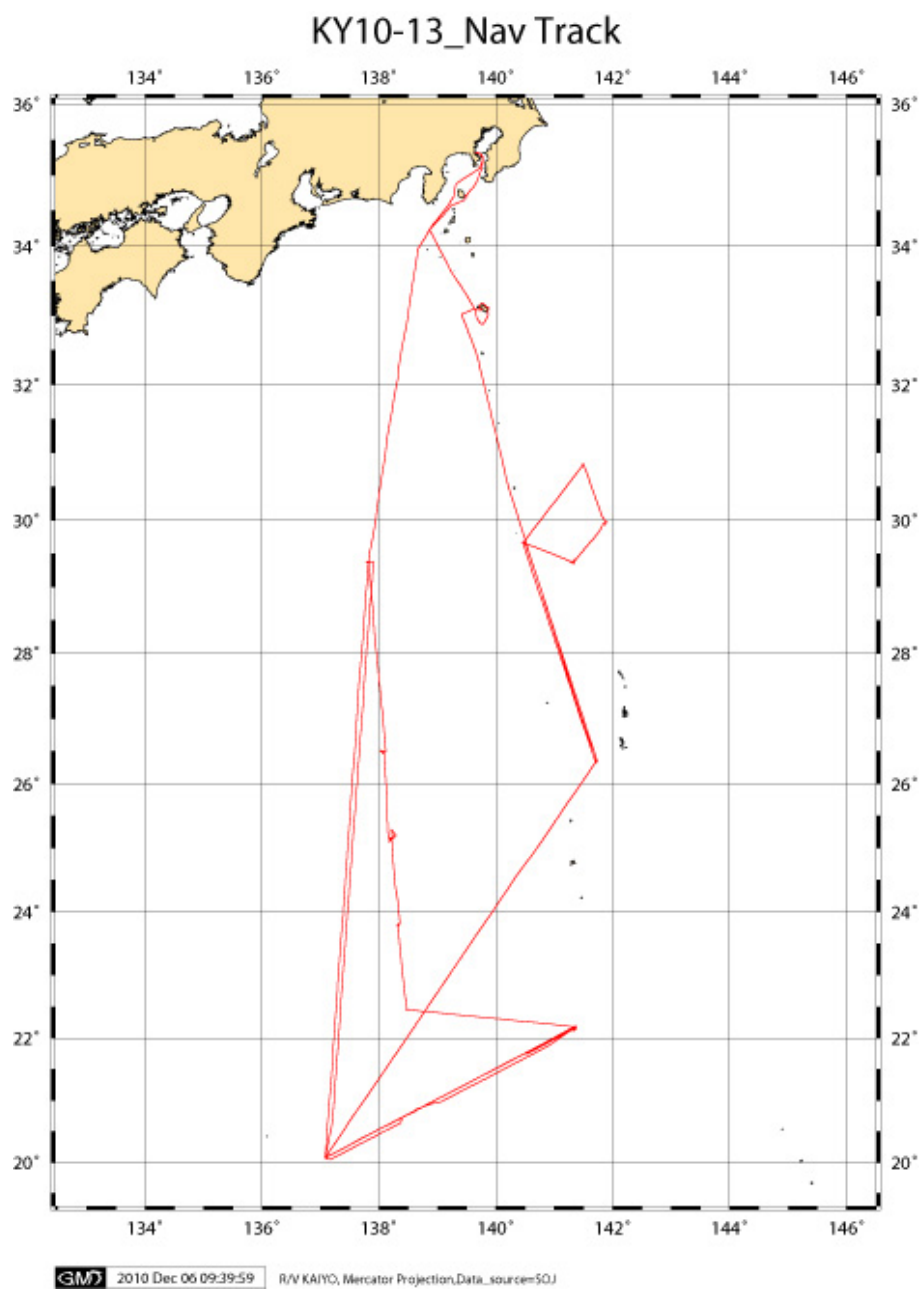
3.3. Research Information

- Deployment and recovery information

4. Notice on Using

1. Cruise Information

- Cruise ID: KY10-13
- Name of vessel KAIYO
- Title of the cruise Research on Underwater Acoustic Technology
- Title of proposal Research on Underwater Acoustic Technology
- Cruise period 04/Nov./2010 – 06/Dec./2010
- Ports of call Yokosuka
- Research area Izu-Ogasawara
- Research Map



2. Researchers

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- Science party [Affiliation, assignment etc.]
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3. Experiments

3.1. Experiments of long range acoustic propagation using phase conjugate waves

3.1.1. Overview

We have conducted the basic research on long horizontal communication, especially using time reversal in the deep ocean, which will be applied for communicating with an autonomous underwater vehicle (AUV). In our previous studies, a method of combining time reversal and adaptive equalization was proposed. In our latest trial, we executed experiments of passive time-reversal communication as follow. First, the experiment at the range of 1,000 km was performed. This is the first implementation of time-reversal communication at such a range. As results, demodulation could be achieved well by the proposed method. The second was the experiment of the communication from the source near the seafloor to the receiver at the axis of the SOFAR channel at ranges up to 180 km. The results show that it is possible to realize communication in transmitting from outside the SOFAR channel. The third is the experiment in which the two sources transmit signals simultaneously, that is, a kind of experiment of multi-user communication. By the simple frequency division multiplexing, it was demonstrated that communication from the two sources were accomplished. In this paper, the results in these experiments are described.

3.1.2. Experimental setup

The experiments were performed using two kinds of sources and twenty channels receiver array. One of the sources, indicated as No. 1 source, is the projector manufactured with IXSEA, whose maximum source level is 200 dB. The other, indicated as No. 2 source, is PS-500 D manufactured by EAI, whose source level is 186 dB. The bandwidth of both projectors is 500 +/- 50 Hz approximately. The receiver array was composed of twenty receiver systems, which were spaced approximately 6.0 m apart. The total length of the array was approximately 114 m. HTI-90-U hydrophones were used as the receivers.

Fig. 1 (a) shows the bathymetry of the experiment site, whose depth is from 4,000 to 5,000 m approximately. The measurement of communication at the range of 1,000 km was executed on the line between the points A and B as shown in Fig. 1 (a). Other measurements were executed on the line between B, C, and D. In Fig. 1 (b) and (c), the sound speed profiles (SSP) are shown in these measurements.

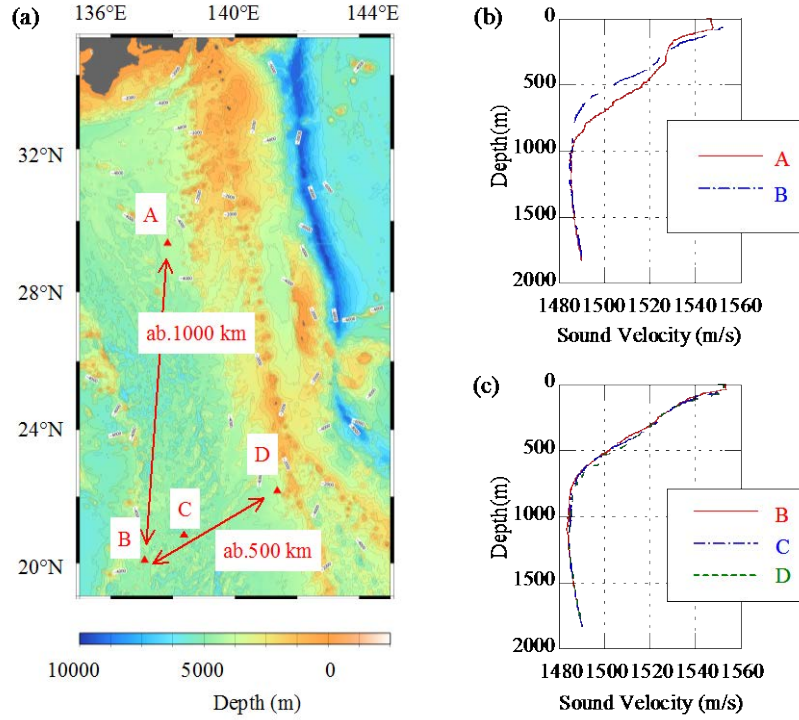


Fig.1: (a) Bathymetry of experiment site, (b) sound speed profiles (SSPs) at points A and B, (c) SSPs at points B, C, and D.

3.1.3. Research results

3.1.3.1 Communication at the range of 1,000 km

In the experiment at the range of 1,000 km, the receiver array was moored at the point A and the No. 1 source was moored at the Point B. Both the source and the receiver array were set at the depth around the axis of SOFAR channel.

In this experiment, binary phase shift keying (BPSK) was used as the modulation method, and the symbol rate was 100 bps. In the proposed method, the adaptive equalizer, one-channel decision feedback equalizer (DFE) is used after time reversal focusing. In this case, the initial 200 symbols were used as the training signal for the adaptive equalizer. In the previous experiments, the probe signal for passive time reversal was transmitted before the data signal. However, by sending probe signals, the effective data rate is decreased. Then, in this experiment, the initial 200 symbols were used also as a probe signal for passive time reversal.

In Fig. 2 (a), an example of the signals after chirp correlation received at the array is shown. This figure shows that many multi-path signals were received. In Fig. 2 (b), one of the demodulation results is shown. In these figures and hereafter, “TR” indicates the case when only time reversal is used, and “TR+AE” indicates the method in which time reversal and adaptive equalization were combined. From these results, it is proved that the proposed method, TR+AE, makes communication at the range of 1,000 km possible.

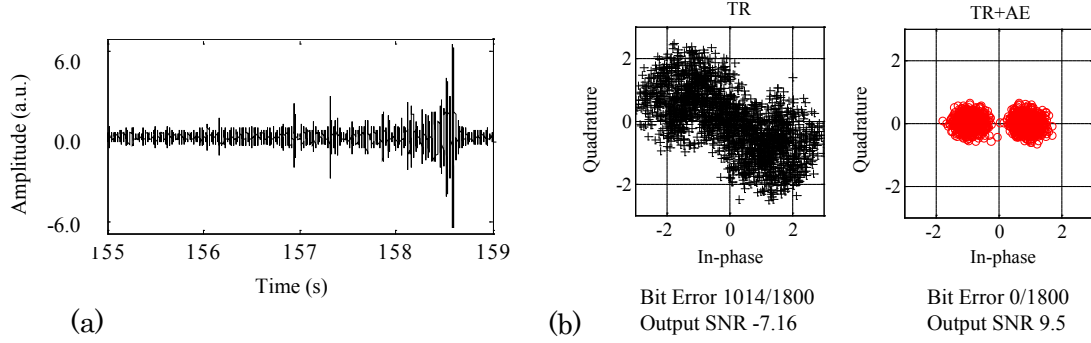


Fig. 2: (a) Channel response, (b) demodulation results at the range of 1,000 km.

3.1.3.2. Communication from the source near the seafloor

As known well, there exists acoustic channel duct named SOFAR channel in the deep ocean, in which many multi-path waves are received to the long range by refraction in the typical sound speed profiles as shown in Fig. 1. The previous experiments were conducted inside this duct, so that multi-path waves are utilized effectively by time reversal. It is planned that AUV will cruise inside this duct and execute communication.

In the meantime, it is also preferred that it is possible to communicate with AUV near the seafloor. Thus, the experiment of communication from the source under the SOFAR channel was carried out. In this experiment, the receiver array was moored at the point B and the No. 1 source was suspended from the R/V KAIYO to the depth of 4,000 m and 3,500 m at the ranges of 150 and 180 km, respectively, around the point C.

Fig. 3 (a) shows the signals after the chirp correlation received by the array at the range of 150 km. This shows that signals could be observed at the axis of the SOFAR channel although they were transmitted from the depth of 4,000m. Fig. 3 (b) shows one of the demodulation results, which demonstrate that it is possible to achieve communication from outside the SOFAR channel.

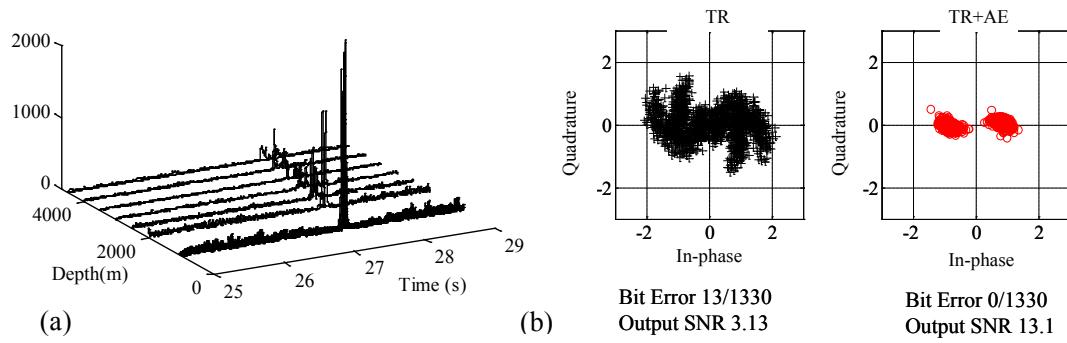


Fig.3: (a) Channel response, (b) demodulation results at the range of 150 km.

Fig. 4 similarly show the results at the range of 180 km, in which signals were transmitted from the depth of 3,500 m. Fig. 4 (a) show that signals are not received considerably at the axis of the duct, differently from the previous case. However, Fig. 4 (b) shows that communication can be realized.

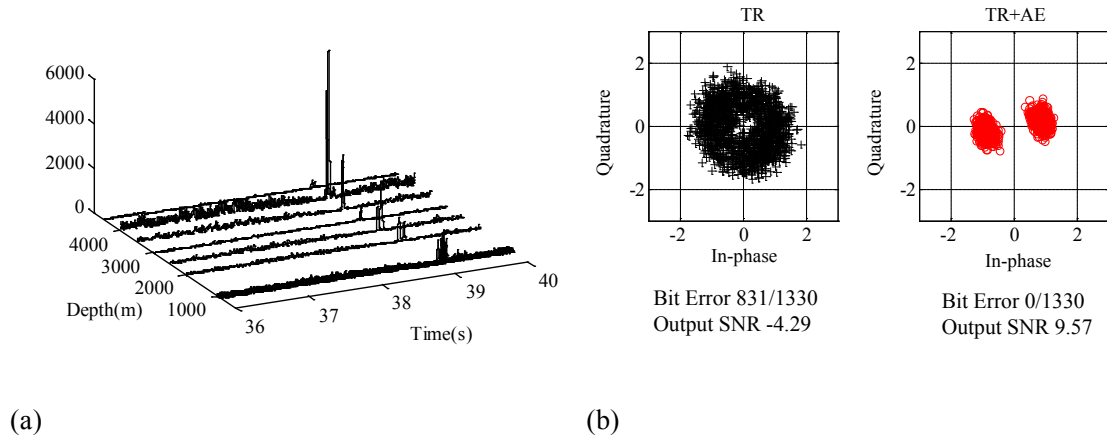


Fig.4: (a) Channel response, (b) demodulation results at the range of 180 km.

3.1.3.3. Communication from the two sources

As mentioned above, there is a plan to develop multiple AUVs in JAMSTEC. Then, basic experiments of multi-user communication in the deep ocean were conducted.

Active time reversal can focus waves to multiple targets simultaneously in space, as known well. Passive time reversal has also been applied to communication from multiple sources. Different probe signals from different sources bring anti-cross talk communication. However, these probe signals are not always orthogonal and then cross talk mitigation is not adequate in practice. First, in this experiment, passive time-reversal communication from two sources was tried. However, it was not possible to achieve demodulation.

The experiment adopting the simple frequency division multiplexing method was executed. The receiver array was moored at the point B. The No. 1 source was suspended from the research vessel and the No. 2 source was moored, around the point D to the depth of 1,000 m approximately.

Thus the experiments were executed at the range of 500 km. The bandwidth of signals transmitted from the No.1 and No. 2 sources are 475 ± 24 Hz and 525 ± 24 Hz, respectively, so that the data rates are 48 bps. These signals are divided with sharp band path filters. They were transmitted almost simultaneously.

Fig. 5 (a) and (b) show the demodulation results from the No. 1 and No. 2 sources, respectively. Comparing the results of single user communication, the demodulation results are deteriorated because data signals from the two sources were received concurrently. However, demodulations with two users were demonstrated well.

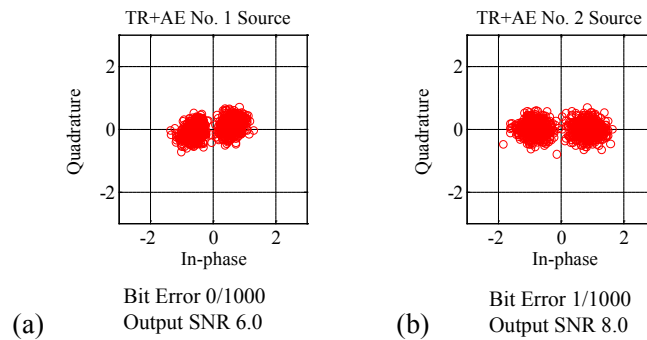


Fig.5: Demodulation result from two sources at the range of 500 km.

3.2. Experiments of long range acoustic positioning

3.2.1. Overview

In this cruise, experiments has been executed of long range acoustic positioning to measure cruising AUV that cruises a distance of over few hundred km. The positioning method is based on estimation of direction of arrival (DOA) of acoustic signal from some reference transmitter devices. Then the AUV is equipped with receiver array on the body that is horizontally long, to estimate DOA with received acoustic signal. In the experiments, two transmitter devices were moored at about 1000 m depth. And receiver array was configured on experimental flame with an inertial navigation system (INS) that outputs motion of the array. The receiver array was hung from R/V "KAIYO" at about 1000 m depth, and was towed during the experiments.

3.2.2. Experimental setup

Fig.6 shows experimental configuration. Two transmitters were moored at about 1,000 - 1,100m depth which is near the axis of sound fixing and ranging (SOFAR) channel, and the distance between two transmitters was few hundred km. The receiver array was hung from R/V "KAIYO" during experiments, and it was also about at SOFAR channel depth. Therefore, the receiver array was towed by "KAIYO" in order to simulate movement of AUV. Then the towing speed was 0.5 - 1 kt. Experimental devices are shown in Fig.7. Pictures of (a) transmitter-A, (b) transmitter-B, and (c) receiver array are shown. Eight receivers, which were allocated as a

planer array, were set on the array frame and the array was horizontally long. The size of the receiver array is H 0.7 m and L 4.9 m. Furthermore, an INS was equipped on the frame to measure the motion of the array frame. Acoustic signals transmitted by two transmitter devices were received by the receiver array and recorded as digital signal data for post-processing and consideration. The data of INS, depth, and sound velocity were acquired simultaneously. The data of INS, which includes information of attitude of the receiver array, is used to compute absolute DOA.

Table 1 shows general information of the experiments. The propagation range was 300 - 700 km. Two set of experiments, Ex.1 and Ex.2, were implemented. In each set of experiment, two transmitters were moored and a receiver array was suspended. The points of moored transmitters and suspended receiver array are shown in Fig.8. In Fig.8, the distances between two transmitters were about 500 km. During each experiment, multiple receive points were set at different days.

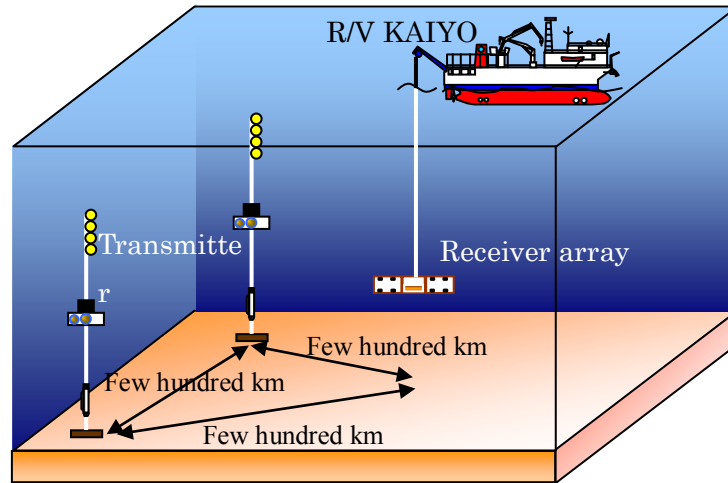
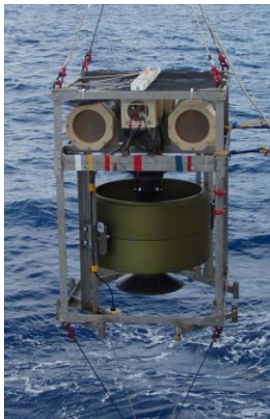
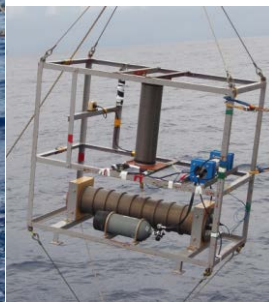


Fig.6 Experimental configuration.



(a) Transmitter-A.



(b) Transmitter-B.



(c) Receiver array.

Fig.7 Experimental devices.

Frequency band of the transmitted signal was $500\text{Hz} \pm 50\text{Hz}$, and was coded by a pseudo noise (PN) code. The 8-th, 9-th, and 10-th M-sequence codes were used as PN codes. The acoustic signal was modulated by binary phase shift keying (BPSK) according to the PN codes, which is spread spectrum technique. Wave number allocated to each chip of PN code was five. The acoustic pulses were not single but with multiple pulses transmitted at regular intervals. The received pulses are synthesized at post-processing.

Table 1 General information of experimental operations.

Ex.	Date	Device	Operation	Point	Propagation range
Ex.1	8/Nov.	Transmitter-A	Mooring	Ex1,Tx-A 20°05.1624'N, 137°05.3389'E	-
	9/Nov.	Transmitter-B	Mooring	Ex1, Tx-B 22°10.5725'N, 141°21.3659'E	-
	10/Nov.	Receiver array	Towing	Ex1, Rx-A 22°27.3926'N, 138°27.5855'E~ 22°27.6567'N, 138°28.6273'E	300 km
	11/Nov.	Receiver array	Towing	Ex1, Rx-B 23°47.2317'N, 138°20.1373'E~ 23°48.5475'N, 138°21.0995'E	430 km
	13/Nov.	Receiver array	Towing	Ex1, Rx-C 25°09.0484'N, 138°12.0209'E~ 25°09.1064'N, 138°13.8375'E	570 km
	14/Nov.	Receiver array	Towing	Ex1, Rx-D 26°29.7536'N, 138°05.4199'E~ 26°29.6351'N, 138°06.4533'E	720 km
Ex.2	25/Nov.	Transmitter-A	Mooring	Ex2,Tx-A 26°20.0508'N, 141°42.0601'E	-
	26/Nov.	Transmitter-B	Mooring	Ex2, Tx-B 29°39.9016'N, 140°27.9932'E	-
	27/Nov.	Receiver array	Towing	Ex2, Rx-A 30°50.0112'N, 141°29.9924'E~ 30°50.7693'N, 141°28.9603'E	500 km
	28/Nov.	Receiver array	Towing	Ex2, Rx-B 29°56.0456'N, 141°51.9658'E~ 29°57.1093'N, 141°50.7134'E	400 km
	29/Nov.	Receiver array	Towing	Ex2, Rx-C 29°21.8833'N, 141°20.5641'E~ 29°21.6006'N, 141°18.7219'E	340 km

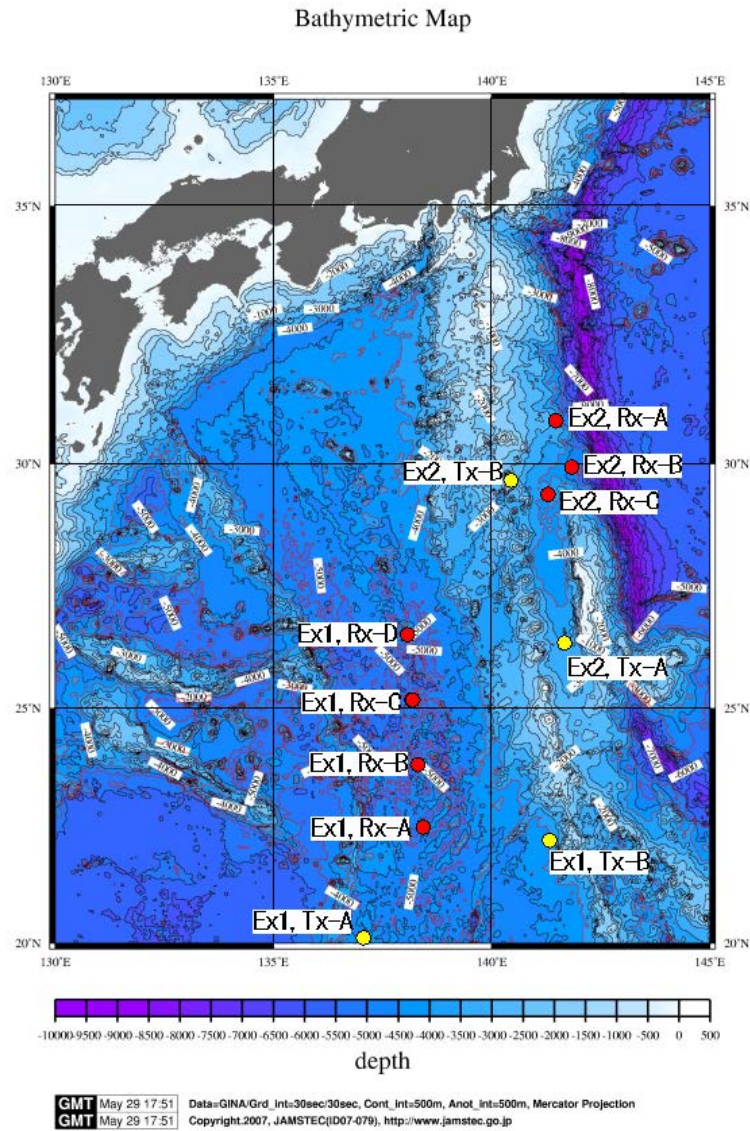


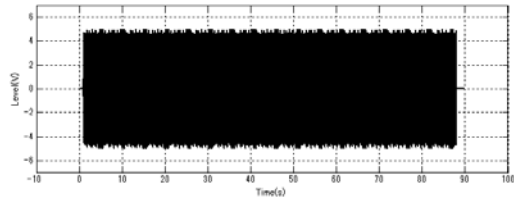
Fig.8 Points of operation of experimental devices.

3.2.3. Research results

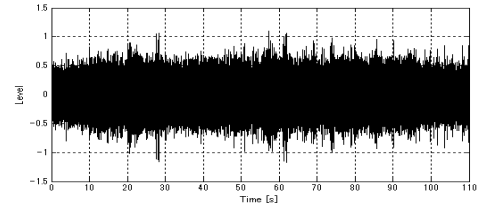
Figs.9 shows the transmitted signal and an example of received signal. The left figures show the transmitted signal, and the lower one is extended figure, which shows wave shape of the modulated signal. The right figure shows received signal. The received signal is buried in noise.

As an example, result of Ex.2, Rx-C is shown in Figs.10 - Figs.12. In the Ex-2 and Rx-C, the vessel cruised toward west direction at about 0.5 – 1 knots during the experiment. Figs.10 shows absolute value of correlation functions of complex base-band signals between the received signals from two transmitters and coded signals with 9-th M-seq. as PN codes. The PN codes for two transmitters are different each other. Peaks of each symbol are found and be able

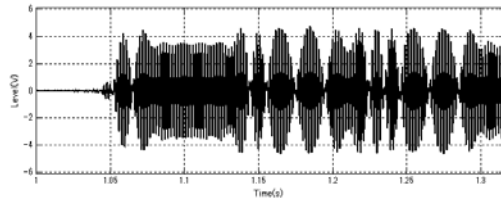
to be detected the symbol points. The detected peak points are used to estimate the DOA of the acoustic signals. Fig.11 shows estimation results of Doppler shift of received signal. The top points of the lines in Fig.11 represent frequency shift rate of received signal. These results indicate the relationship between the movement of the vessel and positional relation of transmitters and receiver. At last, results of estimation of DOA from respective transmitters to receiver array are shown in Fig.12. Fig.12 shows absolute DASs of each peak detected in Fig.10. More accurate estimations are able to be given by synthesizing the peaks.



(a) Transmitted signal.

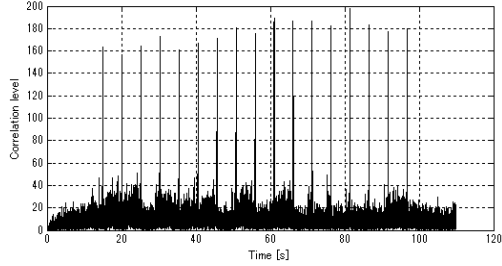


(c) Received signal.

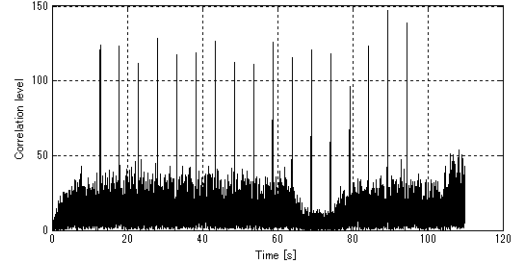


(b) Extended figure of top of the transmitted signal.

Fig.9 Transmitted and received signals during the experiments.

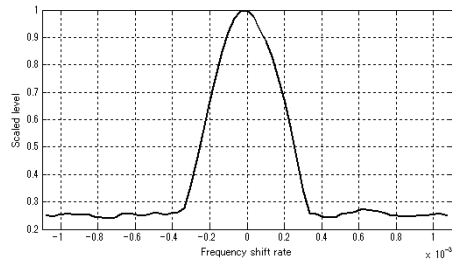


(a) Case of transmitter-A.

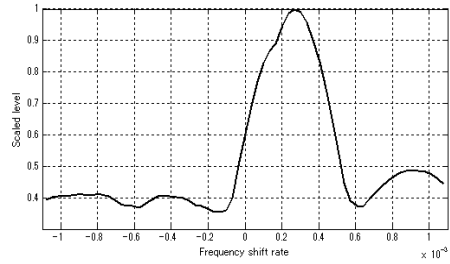


(b) Case of transmitter-B.

Fig.10 Correlation functions between the received signal and coded signal in base-band.

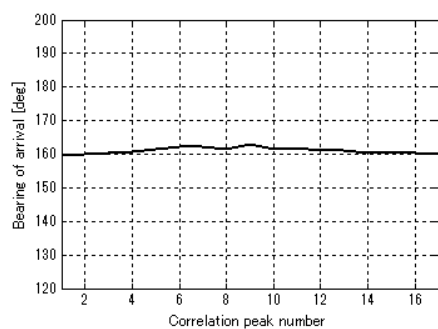


(a) Case of transmitter-A.

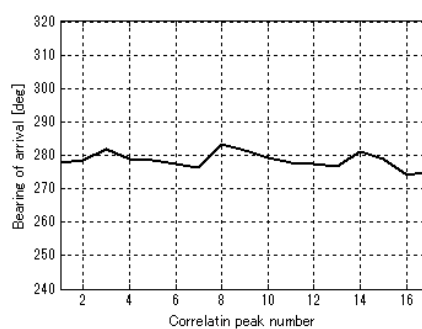


(b) Case of transmitter-B

Fig.11 Estimation of Doppler shift of received signal.



(a) Case of transmitter-A.



(b) Case of transmitter B.

Fig12 Estimation of absolute DOA of the acoustic signal.

3.3. Research Information

- Deployment and recovery information

Name of moored point	Moored date	Recovery date	Depth [m]	Latitude	Longitude
COM1	2010/06/30	2010/07/01	1,662	34° 48.9881N	138° 37.2955E
COM2	2010/07/01	2010/07/02	1,635	34° 48.9541N	138° 37.3240E
NAV1	2010/07/02	2010/07/02	1,635	34° 48.9788N	138° 37.3012E
COM3	2010/07/03	2010/07/03	1,635	34° 49.0289N	138° 37.2821E
COM4	2010/07/04	2010/07/04	1,662	34° 49.0465N	138° 37.3009E
NAV2	2010/07/05	2010/07/05	1,635	34° 49.0061N	138° 37.3337E
COM5	2010/07/06	2010/07/07	1,635	34° 49.0433N	138° 37.2917E
NAV3	2010/07/08	2010/07/08	1,635	34° 48.9129N	138° 37.3464E

4. Notice on Using

This cruise report is a preliminary documentation as of the end of the cruise.

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