Experiments of wideband color image transmission

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We have been studying about a high-speed underwater acoustic communication for color image transmission from underwater vehicle of deep water. The objective of our research is to transmit a JPEG compressed color image within once a second. Experiments were carried out at the depth of 1,000m area. The distance of transmission was 270 - 580 m. Two omni-directional hydrophones were used for receiving. QPSK and 8PSK were used as its modulation method. The two-channel decision feedback equalizer with phase compensator was applied for the demodulation algorithm. Because of this experiment was carried out at deep sea environment, the communication channel characteristics was relatively simple. In these experiments, when the SNR was higher than 12dB, error free communication was carried out in case of QPSK. And when the SNR was higher than 20dB, error free communication was carried out in case of 8PSK.

1 Introduction

Many types of underwater acoustic communication are investigated in these a few decades [1]-[6]. In JAMSTEC, we have been studying on acoustic communication in deep-ocean environment. In recent years, there are many needs for high speed acoustic data transmission, such as image transmission for a remotely operated vehicle (ROV). Generally, for transmitting control command signals to ROV, extremely low error rate transmission is necessary. And for transmitting image data from ROV, extremely high speed transmission is necessary. We have been studied about a high speed transmission mainly [7]-[11]. To operate an ROV, it is assumed that transmission rate of image from ROV is needed at least one image per second. And the image size is assumed 320×225 pixels. When JPEG is used for image compression method, the amount of image is estimated approximately 8 Kbytes. So, transmission rate is required over 64 kbps. From those condition, the objective of our investigation is to prove that it can be communicated at the rate of over 64 kbps with following requirements; carrier frequency of 80 kHz, band width of 40 kHz, communication range of up to 500 m, beam width of 30 degrees (60 – 90 degrees, omni-directional in horizontal). The authors are investigating short-range (up to 500 m) high speed (around 64 kbps) acoustic communication system for deep sea environment.

An acoustic image transmission experiment was carried out at Suruga Bay, Japan. The depth was approximately 1,000m. Propagated data of QPSK and 8PSK were obtained at near the sea bottom. The distance between the transmitter and the receiver was 270 - 580 m. The data of several transmission speeds were obtained. In this paper, experimental result of short range wideband acoustic colour image transmission is described.

2 Experimental equipments

2.1 Experimental setup

The experiment at sea was carried out at Suruga Bay, Japan. The depth of experiment area was approximately 1,000 m. The arrangement of the experiment is shown in Fig. 1. The transmitter was moored at the height of 8 m from the sea bottom. It consists of a transducer, a controller, a timer unit, battery packs, TD sensor (Alec ATD-HR) and a transponder (SGK NATS-7k). The transponder was used for main switch of the transmitter. It is controlled by acoustic command from the research vessel (R/V). And it is used for measurement of its position also. The receiver was suspended from R/V KAIYO by a coaxial armoured cable. It consists of two hydrophones (ITC-1042), a controller, a timer unit, a battery pack, CTD sensor (SBE-9Plus) and a transponder. Through this experiment, the angle between the transmitter and the receiver was carefully kept at the same angle by shifting ship position and by controlling cable length. It is considered for eliminating the influence of directivity pattern of the transducer.

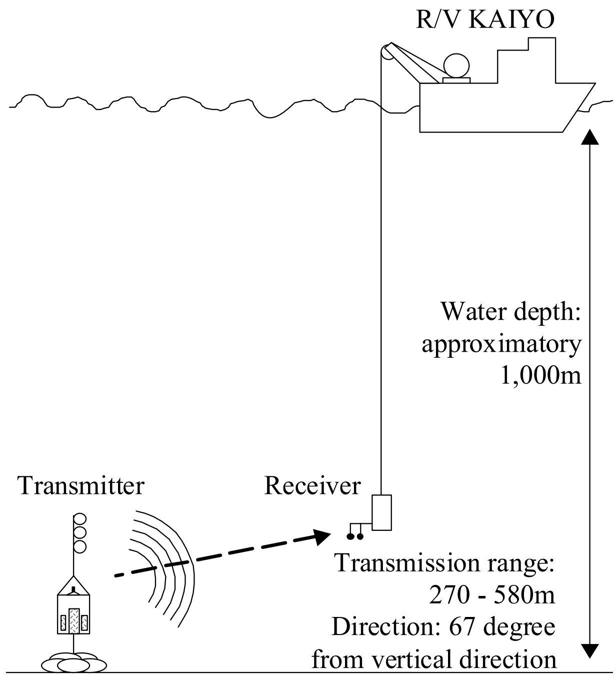


Fig.1 Arrangement of the sea trial.

2.2 Transducer

A wideband tilted toroidal transducer was used for this experiment. Directivity pattern of sound pressure level of the transducer is shown in Fig. 2. This pattern includes the characteristic of the power amplifier. Its main beam is directed from 90 degree (horizontal direction) to 60 degree. And its usable frequency range is between 60 kHz and 100 kHz. In Fig. 2, a dotted line is the directivity pattern of 60 kHz, a solid line is 80 kHz and a dot-and-dash line is 100 kHz.

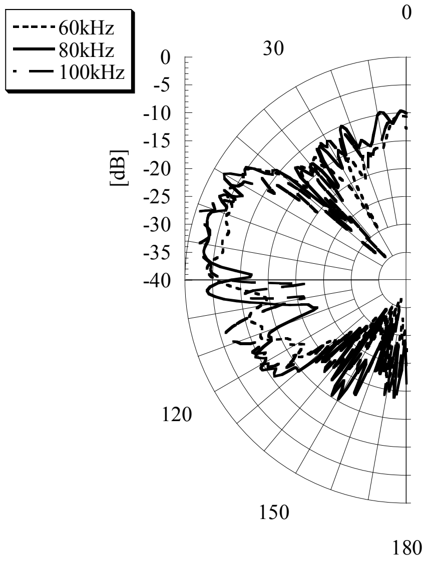


Fig.2 Directivity pattern of sound pressure level of the transducer.

2.3 Transmitter and receiver

A block diagram of a transmitter and a receiver is shown in Fig. 3. A top half is transmitter side, and a bottom half is receiver side. Modulated signals for transmit are pre-processed (blocks inside of a top dotted line box). In this experiment, two colour image data was used as source data (size of both image: 320 x 225 pixels). Those are compressed by JPEG to 7,510 and 8,460 Bytes, respectively. Carrier frequency is 80 kHz, sampling frequency is 800 kHz. Modulated signals of several patterns are stored in a hard disk drive (HDD), before going out to the sea. At the experiment, only a transmitter (inside of the top dot-and-dash line box) is moored in the sea. Acoustic signal, which is transmitted from the transducer, is received by two omni-directional hydrophones at the receiver. Hydrophones are separated in 10 λ of 80 kHz. Then, received signals are input to signal conditioning unit which includes two amplifiers and two band-pass-filters. After that, two-channel signals are digitized by analog-to-digital converter (ADC) and recorded in a HDD as binary files, respectively. After recovering the receiver, demodulation is processed by software (bottom dotted line box). As the demodulation method, two-channel DFE adaptive equalizer with phase compensation unit was applied [12]-[14]. Block diagram of that demodulation unit is shown in Fig.4. This block is programmed by MATLAB script.

3 Results

To measure a main beam signal and to eliminate influences of the beam pattern, transmission angle was kept at approximately 67º from vertical as shown in Fig. 5. The x-y origin (0, 0) means the transmitter position, which is determined by SSBL calibration using an acoustic navigation system and GPS. The x-axis is horizontal position of the receiver from the transmitter, and the y-axis is vertical position of it. Communication data were recorded at the slant range of approximately 260 m, 290 m, 350 m, 400 m, 460 m, 510 m, 550 m and 580 m. Horizontal range was measured by GPS. Vertical range was measured by TD sensors. The sea state was very calm during this experiment.

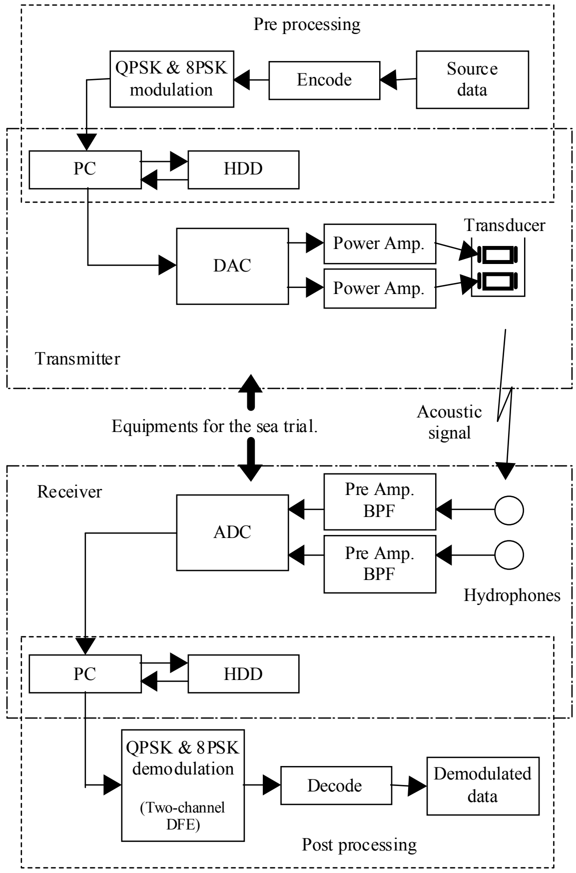


Fig.3 Block diagram of a transmitter and a receiver.

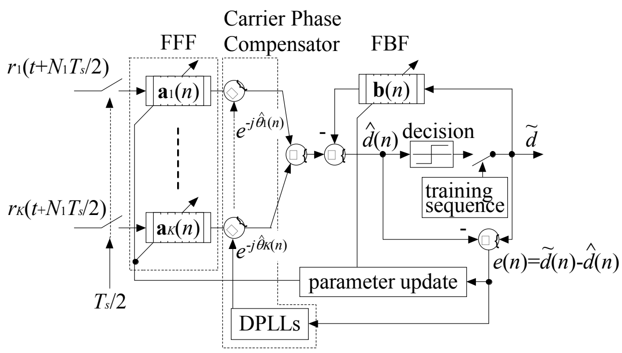


Fig.4 Block diagram of a multi-channel DFE receiver with phase compensator.

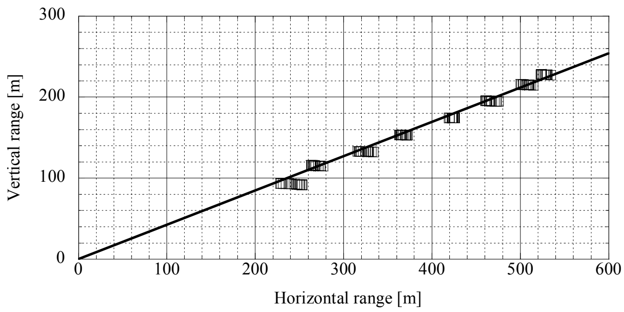
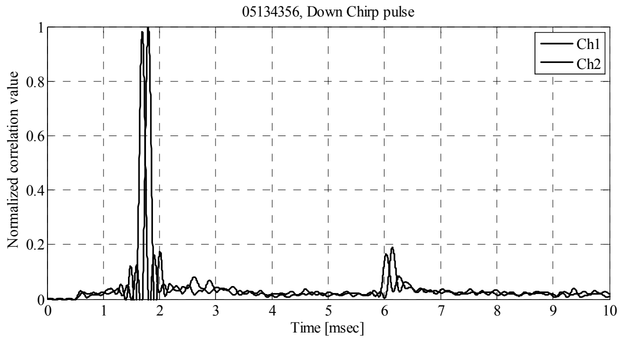


Fig.5 Relative slant range between the transmitter and the receiver. The origin point (0, 0) is the position of the transmitter. Solid line is the angle of 67 º from vertical.

So, these relative ranges are thought to be very accurate. Typical channel response of 510 m is shown in Fig. 6. Solid line shows a response of channel 1, and dot-and-dash line shows a response of channel 2. This is the correlation results of Chirp pulse (100 k – 60 kHz). It is shown that remarkable multi-path is the reflected wave from the sea bottom which is delayed between 4.5 ms and 5 ms from direct wave.

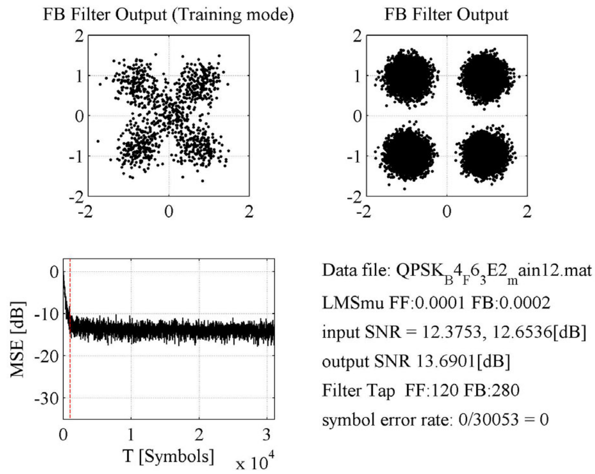


.Fig.6 Typical channel response.

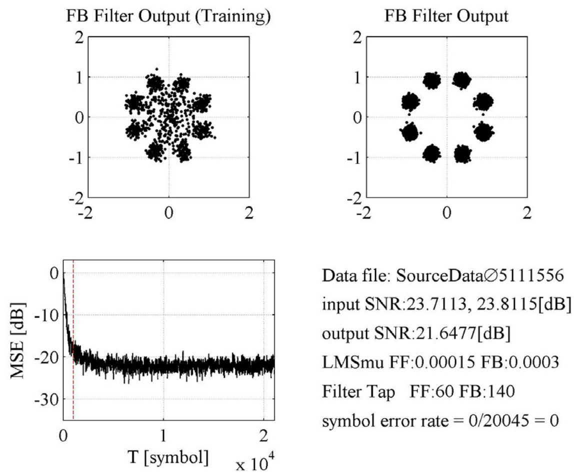
(Slant range: 512 m, direction: 22.4 deg)

Fig. 7 shows examples of demodulation. (a) is a result of QPSK, slant range is 510 m, transmission rate is 80 kbps. (b) and (c) are results of 8PSK, and those transmission rate is 120 kbps. (b) is the case of 290 m of slant range. (c) is the case of 510 m of slant range. Top left of each figure is scatter plot during training mode. Top right of each figure is scatter plot during decision oriented mode which means colour image data part. Bottom left of each figure is mean-square-error (MSE) in each iteration. A dotted line shows the point of changing from the training mode to the decision oriented mode. In Fig. 7 (a), each point of scatter in decision oriented mode (top right) is converged well to 4 constellation. By using QPSK, the error free communication was achieved in 510 m of slant range and 80 kbps of transmission rate. In this case, a colour image can be transmitted in approximately 0.8 s. In Fig. 7 (b), each point of scatter in decision oriented mode (top right) is converged well. The error free communication was achieved in 290 m of slant range by using 8PSK. In this case, a color image can transmit in approximately 0.6 s. And in Fig. 7 (c), each point of scatter in decision oriented mode (top right) was not converged well to 8 constellation. The number of error symbols in this packet was 520 symbols in 510 m of slant range. In this case, a colour image cannot rebuild.

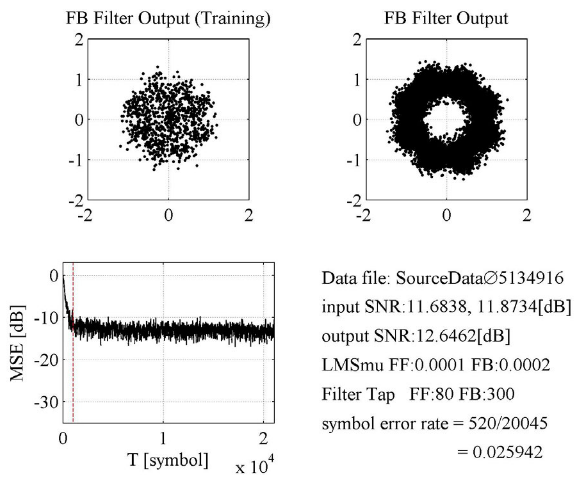
All results are shown in Fig. 8 as the plot of symbol error rate vs. average input SNR characteristic. Square, diamond, cross and circle are cases of 16 ksps (32 kbps), 20 ksps (40 kbps), 25 ksps (50 kbps) and 40 ksps (80 kbps) respectively by using QPSK. Black triangle, black diamond, black square and black circle are cases of 16 ksps (48 kbps), 20 ksps (60 kbps), 25 ksps (75 kbps) and 40 ksps (120 kbps) respectively by using 8PSK. Solid line is the calculated value in case of QPSK, when the noise is assumed additive white Gaussian noise (AWGN). And dotted line is the calculated value in case of 8PSK in AWGN channel. When using two-channel DFE adaptive filter, the communication performance is fitted well to theoretical value in AWGN channel. From this figure, when SNR was higher than 12 dB, error free communication was carried out in case of QPSK. And also when the SNR was higher than 20 dB, error free communication was carried out in case of 8PSK.



(a) QPSK (80kbps, Slant range: 510m)



(b) 8PSK (120kbps, Slant range: 290m)

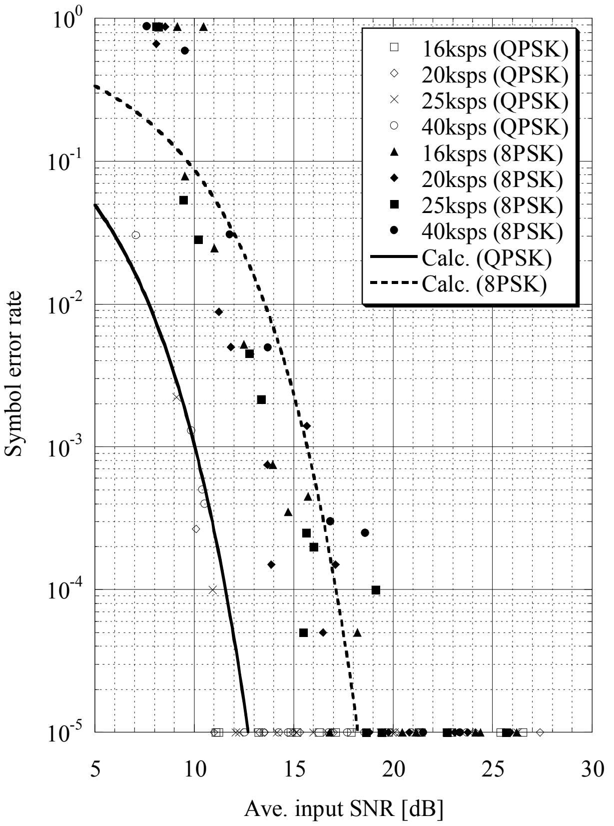


(c) 8PSK (120kbps, Slant range: 510m

.Fig.7 Examples of demodulation.

Fig. 9 shows final product of demodulation. Fig. 9(a) shows the result in case of 80 kbps and 510 m of slant range. Fig. 9(b) shows the result in case of the same condition with Fig. 9(a), but another packet. In this experiment, error correcting code was not applied for transmitting data. Therefore, demodulated image sometimes collapsed in spite of only a few symbol errors occurred. But, the rapid update is thought to be better, while it is keeping a low symbol error rate.

As another point of view of experimental result, Fig. 10 shows the symbol error rate vs. slant range characteristic. Fig. 10(a) shows the results of QPSK, and Fig. 10(b) shows the results of 8PSK. Fig. 10 shows that how far it can be communicated using this method, when both of its acoustic radiation power and its transmission direction are fixed. In this experiment, when using QPSK, it can be communicated with no error up to 510 m at 80 kbps of transmission rate, and when using 8PSK, it can be communicated without errors up to 300 m at 120 kbps of transmission rate.



.Fig. 8 Symbol error rate vs. average input SNR.

5 Conclusion

The wideband acoustic colour image transmission experiment was carried out at the 1,000 m depth area. This experimental equipment is not a real time system, but real acoustic propagation data were obtained. Range characteristics of transmission were measured in very calm condition. As a result, 80 kbps of transmission rate was achieved at 510 m of slant range. Furthermore, 120 kbps of transmission rate was achieved at 300 m of slant range. This system is for a short range communication, but high-speed colour image transmission will be useful in the deep ocean application such as an acoustic remote controlled ROV system.

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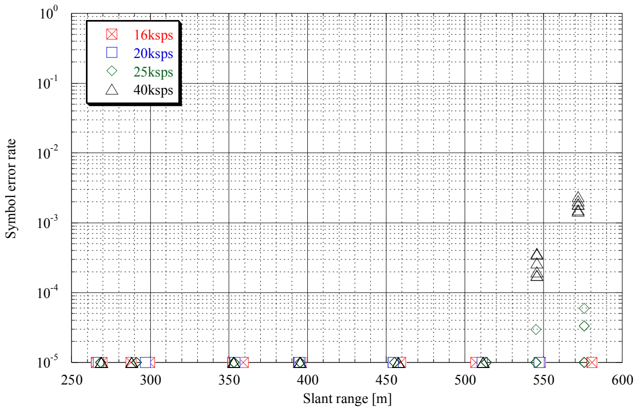
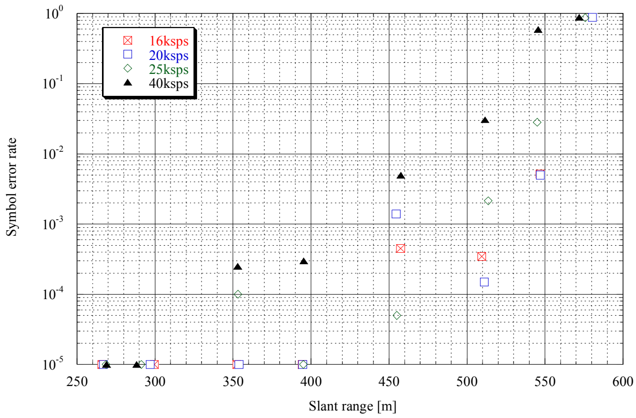
(a) Manipulator (320×225pixels, 7,510Bytes)

(b) Shrimp (320×225pixels, 8,460Bytes)

.Fig. 9 Examples of demodulation results.



(a) QPSK



(b) 8PSK

.Fig. 10 Symbol error rate vs. slant range.