Peer-Reviewed Technical Communication

New Scientific Underwater Cable System Tokai-SCANNER for Underwater Geophysical Monitoring Utilizing a Decommissioned Optical Underwater Telecommunication Cable

Kenichi Asakawa, *Senior Member, IEEE*, Takashi Yokobiki, Tada-nori Goto, Eiichiro Araki, Takafumi Kasaya, Masataka Kinoshita, and Junichi Kojima, *Member, IEEE*

***Abstract*—We have developed a new cost-effective scientific underwater cable system named Tokai Submarine Cabled Network Observatory for Nowcast of Earthquake Recurrences (Tokai-SCANNER) using a decommissioned optical underwater telecommunication cable. We have used this cable in two ways simultaneously: 1) to construct an ocean-bottom observatory at the end of the cable, and 2) to use the cable as a long emitting antenna to sense electromagnetic properties of the Earth's crust. We have also developed a new time-synchronization system that sends a one-pulse-per-second (1PPS) signal and NMEA data to underwater sensors. To vary the supply voltage and current to the observatory and to emit a low-frequency electromagnetic field around the underwater cable, we have also developed an underwater power unit that has a wide input voltage and current range. Tokai-SCANNER has been functioning since April 2007.**

***Index Terms*—Ocean-bottom observatory, scientific underwater cable, time synchronization.**

I. Introduction

JAPAN is located near plate boundaries where massive earthquakes occur periodically, causing considerable damage and casualties. Because most plate boundaries are located under the seafloor, seismic observation of the seafloor is important to elucidate the nature of the earthquakes and to mitigate such damage. Scientific underwater cable systems play an important role in seismic observation of the seafloor because they enable real-time, continuous, and long-term monitoring of earthquakes and tsunamis.

In Japan, eight scientific underwater cable systems have been constructed since the late 1970s [1]. Although these cables cover only a limited area, they have produced fruitful results. For example, the off-Muroto system showed that cabled ocean-bottom seismometers can increase the estimation accuracy of the earthquake hypocenters [2]. In 2004, the same system showed that the tsunami sensors detected a small tsunami about 20 min before the tsunami hit the Muroto coast [3]. This finding showed that the system is useful for issuing early tsunami warnings.

Scientific underwater cable systems also provide long-term, real-time data in many other scientific fields including oceanography, marine biology, and marine chemistry. Such long-term and real-time data are necessary to advance these fields of science. Several ambitious new projects to construct scientific underwater cable systems have been promoted worldwide. Near North America, a ca. 800-km-long scientific underwater cable system, NEPTUNE Canada, is currently being constructed at the University of Victoria [4], over the northern part of the Juan de Fuca tectonic plate and VENUS [4] in waters near Victoria and Vancouver. Actually, NEPTUNE USA is expected to be constructed soon in the southern part of the Juan de Fuca tectonic plate.[1] In Europe, the European Seafloor Observatory Network (ESONET) consortium [5] proposed ten scientific underwater cable systems from the Arctic Ocean to the Black Sea. The NEMO-SN1 [6], which is a part of ESONET, has been operating in the central Mediterranean Basin since 2005. In Taiwan, the Marine Cable Hosted Observatory (MACHO) [7] has been planned. In Japan, the Dense Ocean-Floor Network System for Earthquakes and Tsunamis (DONET) [8], [9] is now being constructed off the Kii Peninsula. It will eventually comprise 20 observatories in a region where mega-thrust earthquakes are expected to occur.

We have developed a new scientific underwater cable system named Tokai Submarine Cabled Network Observatory for Nowcast of Earthquake Recurrences (Tokai-SCANNER). Tokai-SCANNER is located off Toyohashi in central Japan (Fig. 1), where huge earthquakes are expected to occur, and where the Headquarters of Earthquake Research Promotion in Japan advocates promotion of real-time observation. We

Manuscript received May 02, 2008; revised October 14, 2008; accepted May 13, 2009. First published October 20, 2009; current version published November 25, 2009.

Associate Editor: R. C. Spindel.

K. Asakawa is with Marine Technology Center, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka 237-0061, Japan (e-mail: asakawa@jamstec.go.jp).

T. Yokobiki and E. Araki are with the Earthquake and Tsunami Research Project for Disaster Prevention, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka 237-0061, Japan.

T.-N. Goto was with the Institute for Research on Earth Evolution (IFREE), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka 237-0061, Japan. He is now with the Department of Civil and Earth Resources Engineering, Graduate School of Engineering, Kyoto University, Kyoto 615-8540, Japan.

T. Kasaya and M. Kinoshita are with the Institute for Research on Earth Evolution (IFREE), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka 237-0061, Japan.

J. Kojima is with the KDDI R&D Laboratories, Inc., Saitama 356-8502, Japan.

Color versions of one or more of the figures in this communication are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/JOE.2009.2026987

[1]http://www.ooi.washington.edu

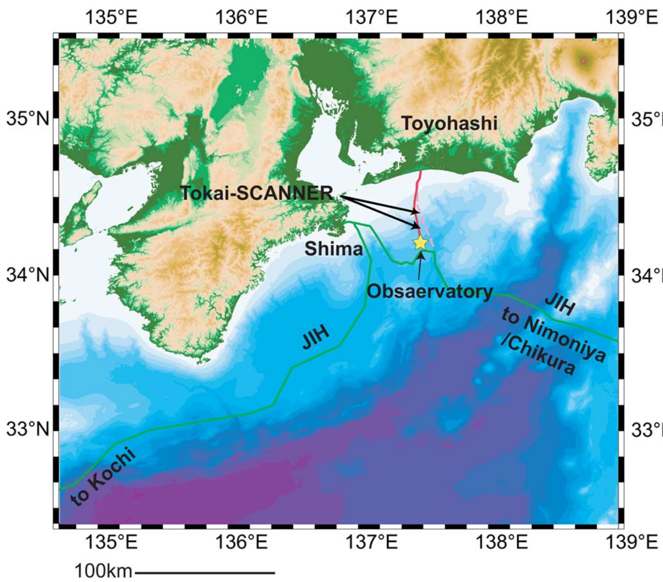

Fig. 1. Location of Tokai-SCANNER.

Fig. 2. Landing station.

have reused a pair of ca. 60-km-long decommissioned optical underwater telecommunication cables. The cables had been a segment of the domestic telecommunication cable network called Japan Information Highway (JIH) developed by KDDI Corporation in 1999. It uses up-to-date technologies of dense wavelength division multiplex (DWDM) and optical amplification, which have enabled development of a flexible wideband communication system. KDDI Corporation abandoned a pair of landing cables off Toyohashi and the landing station (Fig. 2), donating them to JAMSTEC in 2006. We have used the west-side cable for ocean bottom observations. A shunt fault exists in the east-side cable at about 5 km from the landing point. We will use the east-side cable as a passive electric antenna to observe the electromagnetic properties of the Earth's crust.

We have used the west-side cable simultaneously in two ways. One is to provide electric power and communication lines to an observatory connected at the end of the cable [10], [11]. The other is to use the cable as a long emitting antenna generating low-frequency electromagnetic waves to monitor electromagnetic properties of the Earth's crust [12]. Because the optical underwater telecommunication cables have only one conductor, and because the return currents flow in seawater, we can use the cables as electric antennas. Furthermore, because the water content of the Earth's crust influences both electromagnetic and mechanical properties, we can estimate the mechanical properties of the crust by monitoring its electromagnetic properties. We can generate a low-frequency electromagnetic field by controlling the supply voltage and current flowing in the cable. Nearby electromagnetic fields that can be monitored with ocean-bottom electromagnetometers will reveal the electromagnetic properties of the crust. We have developed a new underwater power unit [13] that has a wide input voltage and current range; using it, we can widely vary the supply current.

We have also developed a new time-synchronization system and evaluated its performance [14]. It provides a one-pulse-per-second (1PPS) signal, clock, and modified NMEA[2] data to underwater sensors. The NMEA data format, specified by the National Marine Electronics Association, defines the interface between various marine electronic devices including global positioning system (GPS) receivers. The 1PPS signal is a set of pulses per second synchronized with GPS time. These signals will be used to give precise GPS time to underwater sensors.

Transmission delay has been monitored at the landing station using the 1PPS signal that returns from the junction unit attached at the cable end. We have confirmed that the fluctuation of the transmission delay is less than ± 2 ns over four months [10], which is far better than the scientific requirements.

Since its construction in March 2007 [15], Tokai-SCANNER has functioned well. In April 2007, two sensor units were connected to the junction unit: DOMES[3] and S-SMAD.[4] DOMES includes an Overhauser absolute magnetometer, electrometers, a thermometer, and a tiltmeter. S-SMAD comprises an ocean-bottom seismometer, a pressure gauge, and a differential pressure gauge. An acoustic reference station developed by Asada *et al.* [16] was connected to the junction unit in September 2008. This acoustic reference station will be used to measure the Earth's crust movement.

In this communication, we will describe Tokai-SCANNER's configuration, power feeding system, optical data transmission system, time-synchronization system, and construction work. Contents of this communication are largely based on papers presented at prior conferences [10]–[15].

II. System Configuration

Fig. 3 depicts the basic configuration of Tokai-SCANNER. A repeater is inserted in the cable. A junction unit is connected at the end of the cable. Two sensor units, DOMES and S-SMAD, and the acoustic reference station have been connected to the junction unit. Two underwater mateable connectors remain available for future expansion. An electrode is connected to the

[2]NMEA is a data specification for communication between marine electronic devices defined by the National Marine Electronics Association.

[3]Deep-sea Overhauser Magnetometer, Eletrometers, and Standalone heat flow meter (SAHF).

[4]Seismic Sensor-Management-and-Acquisition Device.

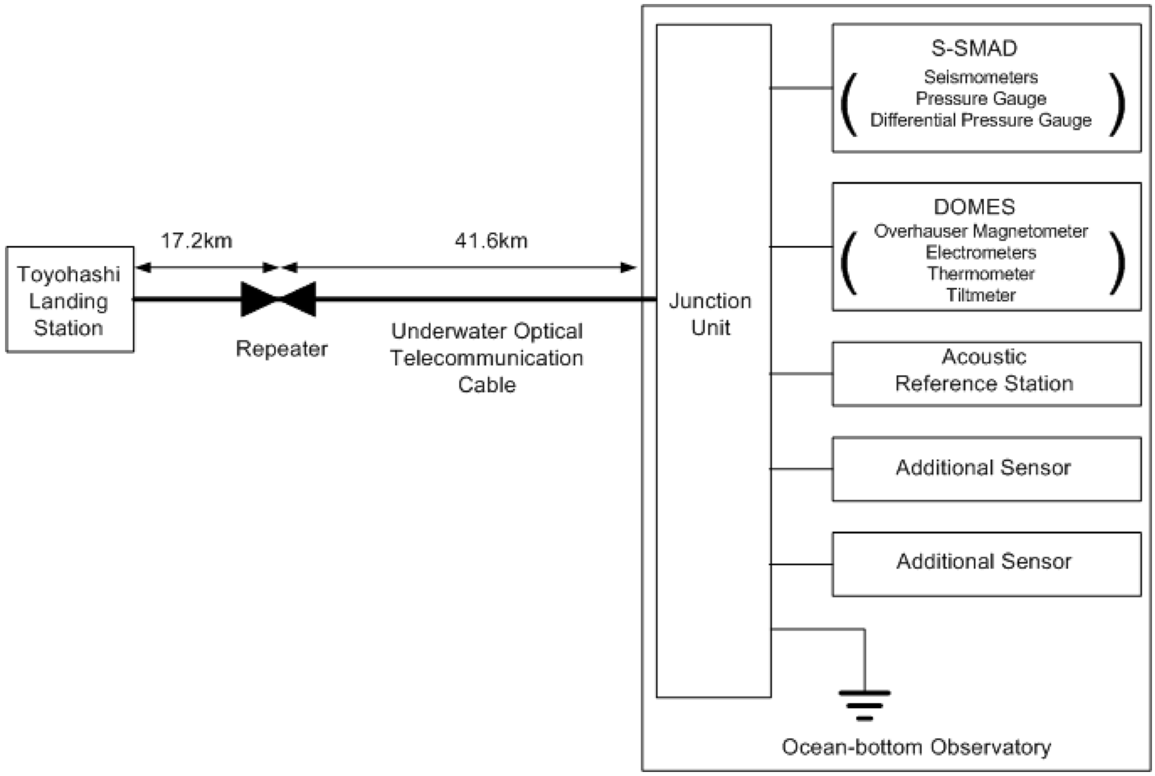

Fig. 3. Basic configuration of Tokai-SCANNER.

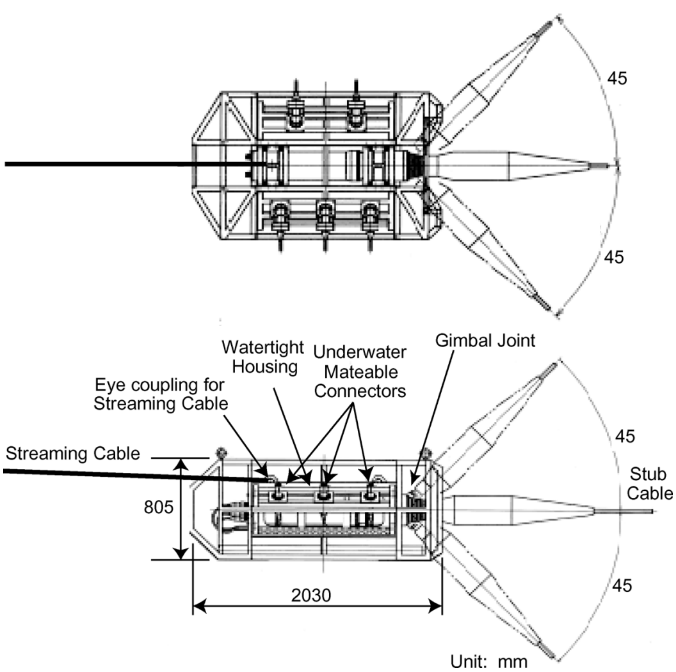

Fig. 4. Schematic view of the junction unit.

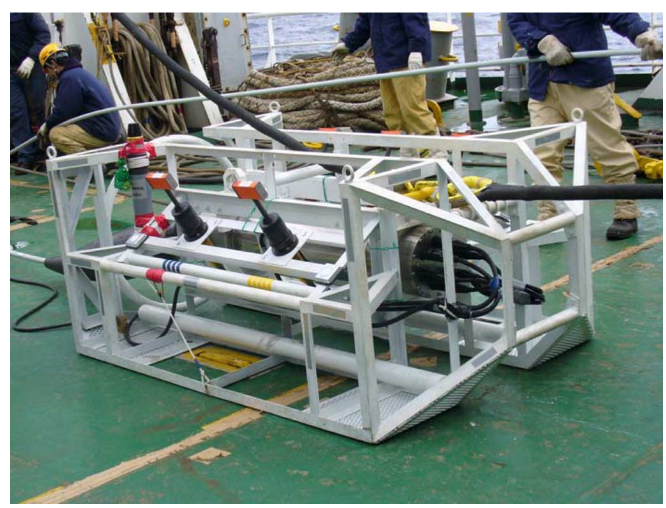

Fig. 5. The junction unit.

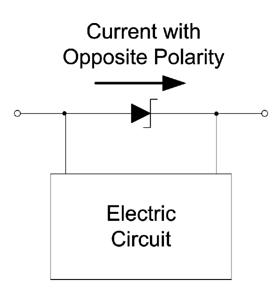

Fig. 6. Basic equivalent circuit of the power supply system in repeaters.

junction unit. This electrode is used to make a path to seawater for the electric current that is supplied from the landing station. Because the polarity of the supplied current is negative, no electric corrosion occurs.

Figs. 4 and 5, respectively, present a schematic view and a photograph of the junction unit. A watertight housing is connected directly to the end of a ca. 50-m-long stub cable through a gimbal joint. A streaming cable can be connected directly to the watertight housing through an eye coupling. All tension on the

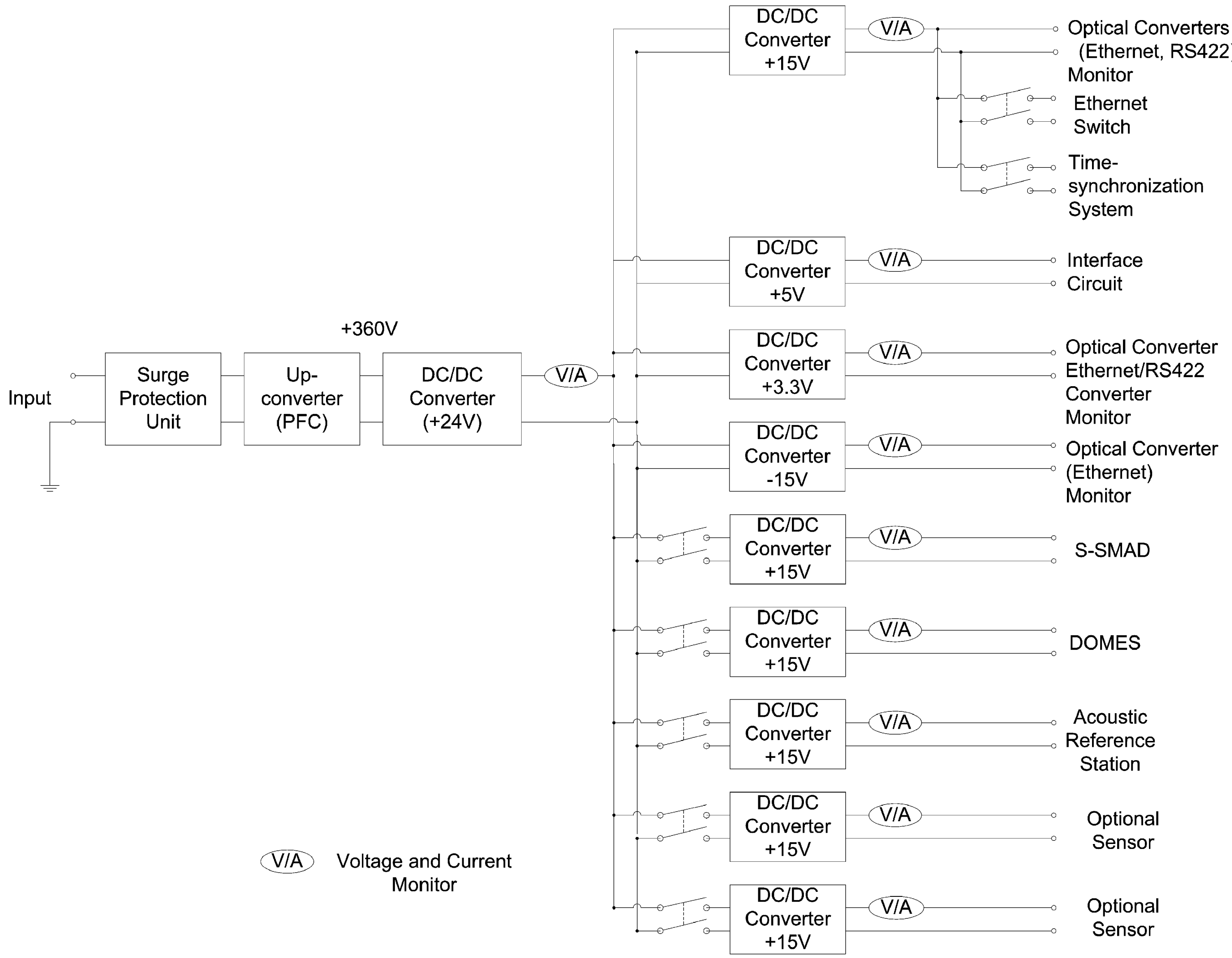

Fig. 7. Configuration of the underwater power unit.

streaming cable is directly transferred to the stub cable through the watertight housing when installing or recovering the junction unit. That configuration makes the frame of the junction unit simple and light.

Electric power, communication lines, and the time-synchronization signal are provided to sensors through underwater mateable connectors. The maximum available electric power to each sensor is +15 V/1 A. The communication protocol between the landing station and the junction unit is Ethernet, so that the system can be connected easily to the terrestrial IP network. In fact, 10-Mb/s Ethernet or RS422 can be selected on command for communication interface between the junction unit and the sensors.

III. Power Feeding System

As described in the Introduction, we seek to vary the supply current flowing in the cable to use the cable as a long emitting antenna. The supply current for optical underwater telecommunication cable systems is usually restricted by repeaters; little allowance exists. For JIH, the current applied to repeaters is specified as 0.92 A. To avoid this restriction, we decided to supply a current with an opposite polarity to that of normal operation. Because the power supply system in repeaters basically consists of zener diodes, as depicted in Fig. 6, by supplying a current with opposite polarity, we can inactivate the repeater and thereby vary the value of the supply current. However, the current is limited to 1.5 A because of the allowable current of the electric wires in the repeater.

To improve the quality of the electromagnetic monitoring, we developed an underwater power unit [13] that has a wide input voltage and current range. Because of the limited development period and the limited budget, we decided to develop a simple underwater power unit to minimize the development risk. The total power consumption was estimated as about 108 W at the initial design stage.

Fig. 7 presents the configuration of the underwater power unit in the junction unit. At the input stage, after passing through the surge protection circuit, the input voltage is up-converted to +360 V. Then, after being down-converted to +24 V, the voltage is reconverted to several output voltages. Electric power provided to each sensor is isolated electrically from others by isolated converters to prevent unforeseen stray current corrosion.

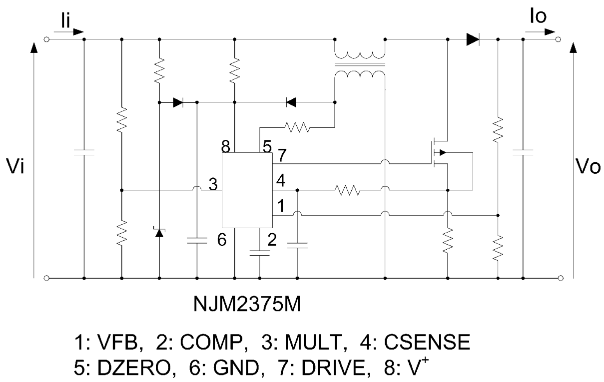

Fig. 8. Basic circuit of the up-converter at the input stage.

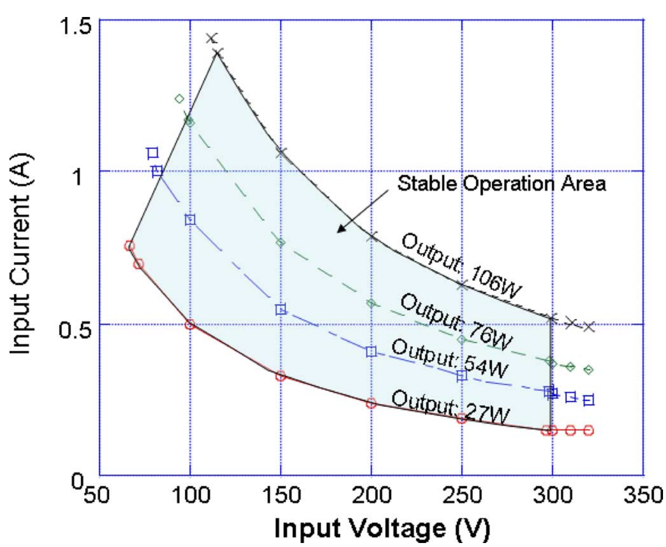

Fig. 9. Input range of the underwater power unit.

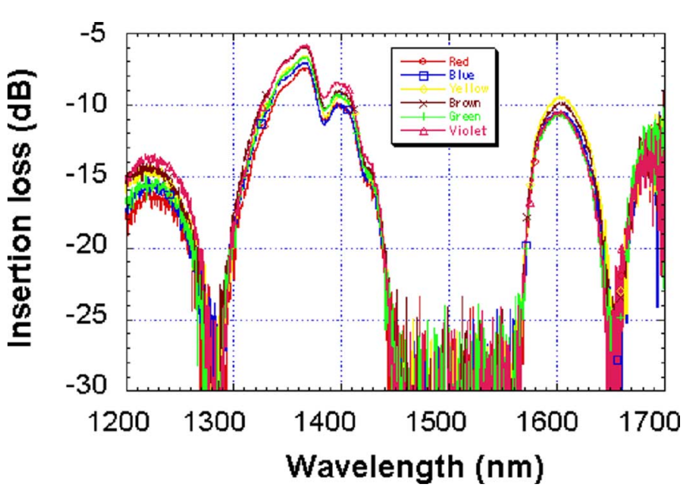

Fig. 10. Loss spectrum of the spare repeater.

For the up-converter at the input stage, a power factor controller (PFC) is used. Fig. 8 portrays the basic circuit of the up-converter. The PFC is usually used to improve the conversion efficiencies of alternating current/direct current (ac/dc) converters. We used the PFC to support a wider input

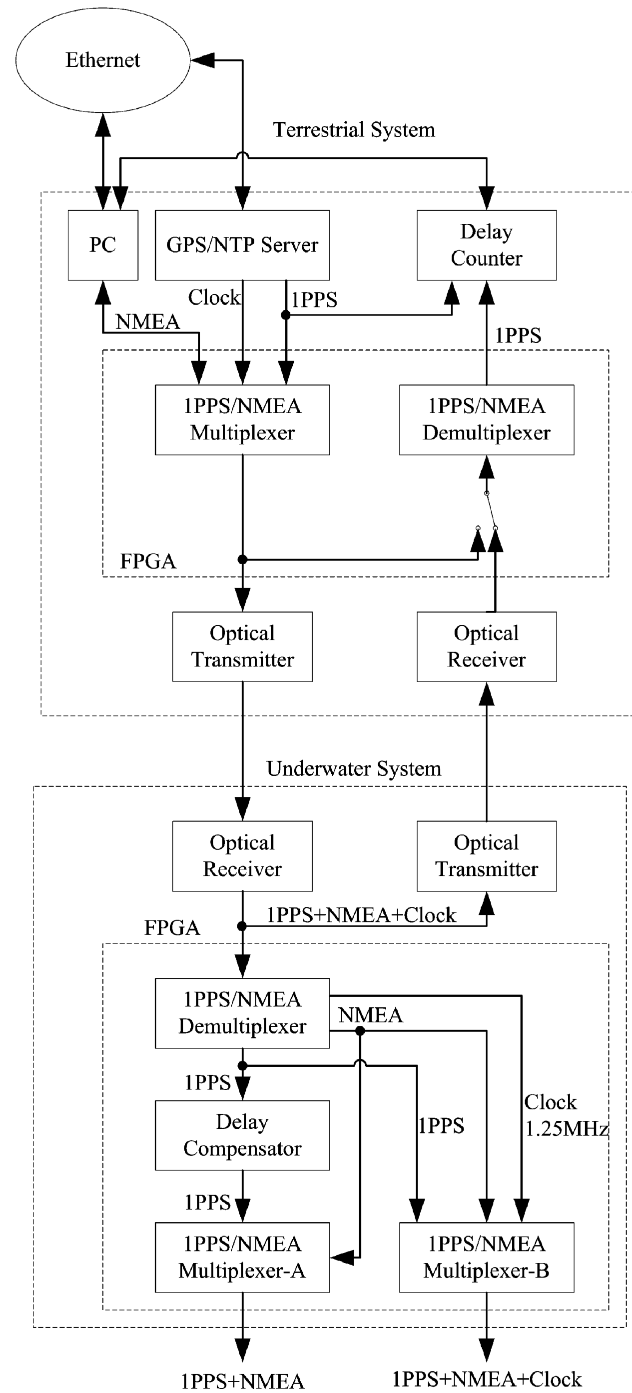

Fig. 11. Block diagram of the time-synchronization system.

voltage and current range. The PFC controls the switching frequency and switching duty simultaneously. As input signals for control, it uses the input voltage, the current flowing through the transformer, and the output voltage. The up-converter is activated when the input voltage V_i becomes greater than about 64 V, although the control circuit for startup and shutdown is not presented in Fig. 8.

Fig. 9 depicts the input voltage and current range of the underwater power unit. The shaded area shows where the stable operation was confirmed. The input voltage and current range depends on the output power. When the output power is 27 W,

TABLE I

MEASURED LOSS MARGINS. UPLINK IS A LINK FROM THE JUNCTION UNIT TO THE LANDING STATION. DOWNLINK IS THE OPPOSITE. THE DEFINITIONS OF THE THRESHOLD LOSSES WHICH ARE EQUIVALENT TO THE TRANSMISSION LOSS MARGINS ARE AS FOLLOWS. ETHERNET: LOSS AT WHICH THE LINK ALARM ON THE CONVERTER AT THE LANDING STATION IS TURNED ON. SERIAL DATA: LOSS AT WHICH THE 1PPS SIGNAL THAT TURNED BACK FROM THE JUNCTION UNIT CANNOT BE RECEIVED AT THE LANDING STATION. RS422 (DOWNLINK): LOSS AT WHICH COMMANDS FROM THE LANDING STATION CANNOT BE RECEIVED AT THE JUNCTION UNIT. RS422 (UPLINK): LOSS AT WHICH THE LINK ALARM ON THE RECEIVER AT THE LANDING STATION IS TURNED ON

Transmission signal	Estimated loss	Measured loss (uplink /downlink)	Estimated loss margin	Measured loss margin (uplink /downlink)
Ethernet	25.8	25.0/23.8	10.2	13.8/12.8
Serial data		23.9/22.9		12.8/15.3
RS422		23.3/22.6		12.8/12.8

for example, the input voltage and current can be changed from 67 V/0.76 A to 300 V/0.15 A.

IV. Optical Data Transmission System

Because the cable has three fiber pairs, we have made three optical data transmission channels [10], [11]: 1) Ethernet, 2) serial data for the time-synchronization system, and 3) RS422 for control and monitor of the power feeding system. Commercially available optical transmitter/receivers are used (ETH-100 for Ethernet, OS0155STR for serial data, and D422 for RS422).

The optical amplifiers in the repeater are inactivated, as described in the previous section, to widen the range of the supply current. In this case, the optical amplifiers in the repeater attenuate optical signals.

We measured the loss spectrum of the repeater using a spare repeater at an early stage of the design. Fig. 10 depicts the measured loss spectrum of the spare repeater. A white light source was used for the measurement. The spectrum of the white light source was measured beforehand and was used as a reference. Although the loss spectrum shows the minimum value at about 1370 nm, we decided to use 1611 nm for optical data transmission because JIH uses several wavelengths within 1545±10 nm; moreover, 1611 nm is a commercially available wavelength for coarse wavelength division multiplex (CWDM) systems.

Table I shows the transmission loss margins that were measured using a variable optical attenuator inserted between the optical fibers of the cable and the optical transmitters/receivers in the landing station. The measured transmission loss margins were larger than 12.8 dB: they are sufficient to assure stable operation.

V. Time-Synchronization System

Fig. 11 depicts a block diagram of the time-synchronization system [14]. This system provides the 1PPS signal, the modified NMEA data, and clock to underwater sensors. The 1PPS signal, the NMEA data, and clock are provided using a network time protocol (NTP)/GPS server in the landing station. A rubidium oscillator in the NTP/GPS server provides a precise 10-MHz clock. The 10-MHz clock is used as a carrier to transmit the 1PPS signal and the NMEA data. It is synchronized with the 1PPS signal to suppress jitter resulting from multiplexing and demultiplexing. The NMEA data are sent every second.

To measure and to compensate the transmission delay over the cable, we embedded a loopback circuit in the underwater

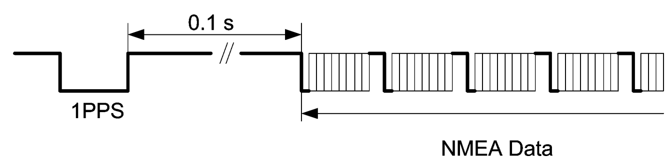

Fig. 12. Data format.

system. The terrestrial system demultiplexes the loopbacked signal, and the delay counter measures the delay time. Information related to the measured delay time is added to the NMEA data and is sent to the underwater system. It is used to compensate the delay time of the 1PPS signal.

Because the delay compensator, which is embedded in a field-programmable gate array (FPGA), is running with a 100-Mb/s clock, we can compensate the delay time with 10-ns resolution. For that reason, the system can provide the 1PPS signal with an accuracy of 10 ns. Because we use the same 1PPS/NMEA demultiplexer in the terrestrial system as that in the underwater system, the terrestrial and the underwater system have equal transmission delay because of demultiplexing.

The underwater system can provide output signals of two kinds to sensors: one is 1PPS + NMEA data. The interface is RS422; the data format is presented in Fig. 12. The other is 1PPS + NMEA data + clock. For the latter signal, the 1PPS signal and the NMEA data are encoded using the 1.25-MHz clock as a carrier signal. Using this coding, the 1PPS signal, the NMEA data, and the clock can be sent to sensors through one electric line.

The 1PPS/NMEA demultiplexer in the underwater system extracts the 1PPS signal and the NMEA data from the transmitted signal. After the delay compensator compensates the delay time, 1PPS/NMEA multiplexer-A multiplexes the 1PPS signal and the NMEA data; 1PPS/NMEA multiplexer-B multiplexes the 1PPS signal and the NMEA data using the 1.25-MHz clock as a carrier signal.

Before embedding the underwater system into the junction unit, we evaluated the fluctuation of transmission delay. A pair of 10-km optical fibers was used for evaluation. Room temperature was measured for comparison. The fluctuation of transmission delay attributable to the temperature fluctuation can be described as

$$\Delta t = \frac{L}{c}\frac{dn}{dT}\Delta T + \frac{nL}{c}\left(\frac{1}{L}\frac{dL}{dT}\right)\Delta T \tag{1}$$

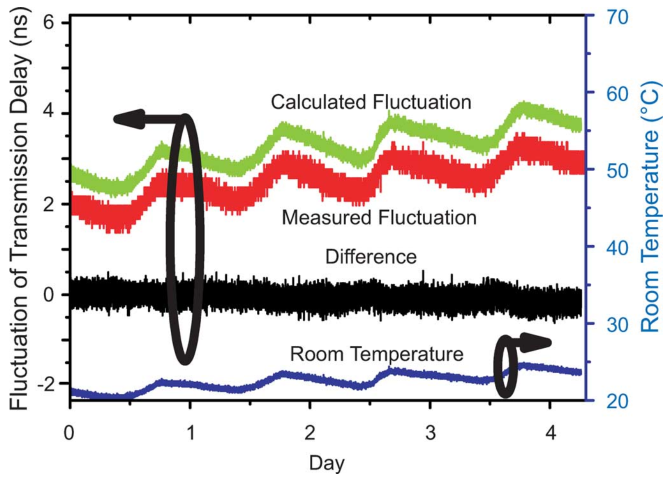

Fig. 13. Comparison between the transmission delay fluctuation and the room temperature fluctuation.

where

c	speed of light;
L	fiber length (10,018 m in this test);
n	refractive index of the optical fiber (1.468);
ΔT	room temperature fluctuation in Celsius;
Δt	fluctuation of transmission delay;
$\frac{dn}{dT}$	temperature coefficient of the refractive index (1.19 $\times$ 10 $^{-5}$/°);
$\frac{1}{L}\frac{dL}{dT}$	thermal expansion coefficient of optical fibers (5.5 $\times$ 10 $^{-7}$/°).

Fig. 13 shows the measured transmission delay fluctuation, the room temperature fluctuation, the calculated fluctuation of the transmission delay attributable to the room temperature fluctuation, and the difference between the measured transmission delay and the calculated transmission delay over four days. The long-term fluctuation of the transmission delay occurs mainly because of the room temperature fluctuation. The difference between the measured transmission delay and the calculated transmission delay is less than $\pm$0.5 ns.

After installing the junction unit on the seafloor, we monitored the long-term fluctuation of the transmission delay. Fig. 14 shows that the fluctuation of the transmission delay was less than $\pm$2 ns over four months. This fluctuation level is far better than the scientific requirement. Using (1), a temperature change of 1 °C corresponds to a delay fluctuation of 2.5 ns.

VI. Installation

The installation was conducted in March 2007 [15] using the 109-m-long cable ship KDD Pacific Link, which is a specialized ship for laying and repairing optical underwater telecommunication cables.

The procedure of that installation was as follows:

1) picking up the streaming cable attached at the end of the cable with a grapnel;
2) recovering the streaming cable and the end of the optical underwater telecommunication cable onto the ship;

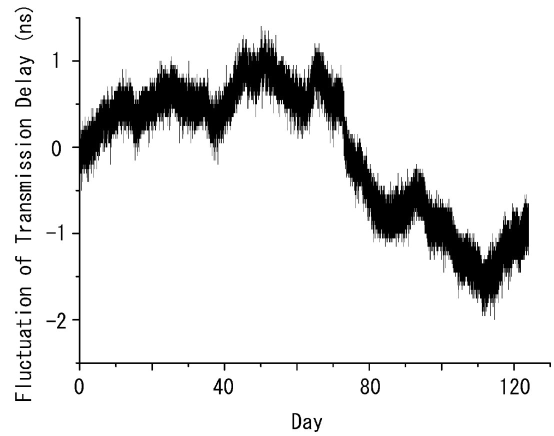

Fig. 14. Fluctuation of the loopbacked 1PPS's transmission delay. Converted to one-way transmission delay.

Fig. 15. Junction unit just before being paid out.

3) connecting the junction unit to the cable and another streaming cable to the junction unit;
4) installing the junction unit and the streaming cable onto the seabed.

Fig. 15 presents a photograph of the junction unit immediately before being paid out over the stern sheave. The junction unit was hoisted with an A-frame. The entire weight of the junction unit and the cable attached to the junction unit was supported by a streaming cable.

After this installation work, S-SMAD and DOMES were connected to the junction unit in April 2007. The acoustic reference station was connected to the junction unit in September 2008. Fig. 16 portrays a photograph of the junction unit and sensors on the seafloor. Since deployed, they have been functioning and transmitting data continuously. Fig. 17 is an example of the recorded seismic wave. Clear seismic waves were recorded.

VII. Conclusion

We developed a new, cost-effective scientific underwater cable system using a pair of decommissioned optical underwater telecommunication cables. Scientific underwater cable systems enable long-term continuous real-time observation,

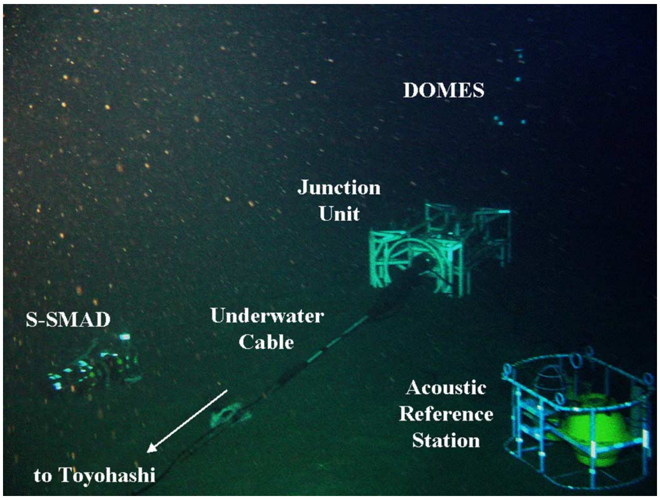

Fig. 16. Photograph of the ocean bottom observatory.

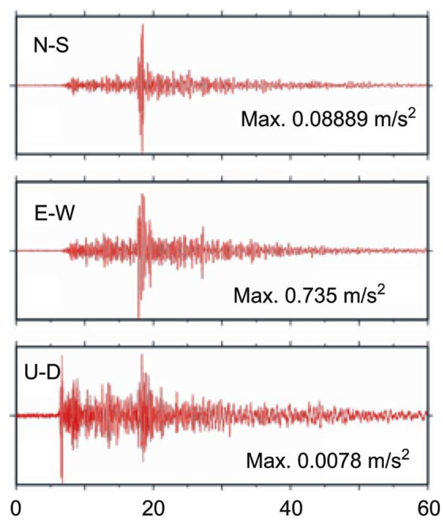

Fig. 17. Example of recorded seismic wave.

which is necessary to advance ocean science. A salient issue related to these systems is their initial construction cost. Today, some optical underwater telecommunication cable systems that use up-to-date technology of optical amplification and WDM technology are anticipated to retire in several years. These cables will provide valuable opportunities to construct cost-effective scientific underwater cable systems if these cables are laid where scientific observation is needed. Tokai-SCANNER is the first attempt to reuse a decommissioned optical underwater telecommunication cable.

Tokai-SCANNER has the following new features.

A. *Using the Cable as a Long Emitting Antenna*

We use the cables in two ways. One is to construct a new ocean-bottom observatory at the end of the cable. The other is to use the same cable simultaneously as a long emitting antenna for low-frequency electromagnetic waves. The latter function can monitor electromagnetic properties of the Earth's crust that are relevant to its mechanical properties.

We have developed a new underwater power unit that has a wide input voltage and current range. We also showed that the current restriction by the repeater can be avoided by applying a current with an opposite polarity. In this case, the repeater attenuates optical signals. However, by selecting a proper wavelength, we can realize an optical transmission system using off-the-shelf optical transmitter/receivers. The system has sufficient loss margins to secure stable operation.

B. *Time-Synchronization System*

We have developed the new time-synchronization system. It provides the 1PPS signal, the NMEA data, and clock to underwater sensors. Transmission delay was measured using a 1PPS signal returned from the junction unit. The fluctuation of the delay time was less than ± 2 ns over four months, which was far better than the scientific requirement.

After this installation work, S-SMAD and DOMES were connected to the junction unit in April 2007. In September 2008, an acoustic reference station was added. Since then, they have been functioning and transmitting data continuously. Two underwater mateable connectors remain for future connection.

Acknowledgment

The authors would like to thank Prof. N. Fujii, Prof. J. Kasahara, Prof. M. Kumazawa, Prof. H. Nagao, and Prof. K. Sayanagi for their contributions to the startup of this project.

References

[1] K. Suyehiro, H. Mikada, and K. Asakawa, "Japanese seafloor observing systems: Present and future," *J. Mar. Technol. Soc.*, vol. 37, no. 3, pp. 102–114, 2003.
[2] S. Kimura, "Seismicity at the Nankai trough off Muroto," Rep. Contract Res. JAMSTEC, Jpn. Mar. Sci. Tech. Ctr., Yokosuka, Japan, 1999.
[3] H. Matsumoto, H. Mikada, and K. Asakawa, "Can the offshore cabled observatory contribute to Tsunami warning systems," in *Proc. 4th Int. Workshop Sci. Use Submar. Cables Relat. Technol.*, 2006, pp. 107–110.
[4] C. R. Barnes and V. Tunnicliffe, "Building the world's first multi-node cabled ocean observatories (NEPTUNE Canada and VENUS, Canada): Science, realities, challenges and opportunities," in *Proc. OCEANS Conf./MTS/IEEE TECHNO-OCEAN Conf.*, Kobe, Japan, Apr. 2008, DOI: 10.1109/OCEANSKOBE.2008.4531076.
[5] R. Person, L. Beranzoli, C. Berndt, J. J. Dañobitia, M. Diepenbroecke, P. Favali, M. Gillooly, V. Lykousis, J. M. Miranda, J. Mienert, I. E. Priede, R. S. Santos, L. Thomsen, T. Van Weering, and C. Waldman, "ESONET: An European sea observatory initiative," in *Proc. OCEANS Conf./MTS/IEEE TECHNO-OCEAN Conf.*, Kobe, Japan, 2008, DOI: 10.1109/OCEANSKOBE.2008.4531109.
[6] P. Favali, L. Beranzoli, and F. Italiano, "NEMO-SN1 real-time cabled seafloor observatory (southern Italy): Operation assessment after two years from the deployment and next perspectives," in *Proc. Int. Symp. Underwater Technol./Int. Workshop Sci. Use Submar. Cables Relat. Technol.*, 2007, pp. 476–481.
[7] S.-K. Hsu, C.-S. Lee, T.-C. Shin, C.-S. Liu, B.-S. Huang, B.-Y. Kuo, C.-H. Lin, and D. Tang, "Marine cable hosted observatory (MACHO) project in Taiwan," in *Proc. Int. Symp. Underwater Technol./Int. Workshop Sci. Use Submar. Cables Relat. Technol.*, 2007, pp. 305–307.
[8] E. Araki, K. Kawaguchi, S. Kaneko, and Y. Kaneda, "Design of deep ocean submarine cable observation network for earthquakes and tsunamis," in *Proc. OCEANS Conf./MTS/IEEE TECHNO-OCEAN Conf.*, Kobe, Japan, 2008, DOI: 10.1109/OCEANSKOBE.2008.4531071.
[9] K. Kawaguchi, Y. Kaneda, and E. Araki, "The DONET: A real-time seafloor research infrastructure for the precise earthquake and tsunami monitoring," in *Proc. OCEANS Conf./MTS/IEEE TECHNO-OCEAN Conf.*, Kobe, Japan, 2008, DOI: 10.1109/OCEANSKOBE.2008.4530918.

[10] T. Yokobiki, T. Goto, E. Araki, K. Asakawa, T. Kasaya, M. Kinoshita, K. Kawaguchi, M. Harada, T. Nakajima, H. Nagao, and K. Sayanagi, "Development of a new cabled observatory "Tokai SCANNER"," in *Proc. OCEANS Conf./IEEE/MTS TECHNO-OCEAN Conf.*, Kobe, Japan, 2008, DOI: 10.1109/OCEANSKOBE.2008.4531002.

[11] K. Asakawa, T. Yokobiki, T. Goto, E. Araki, M. Kinoshita, and K. Mitsuzawa, "Outline of new cabled observation system off Toyohashi," in *Proc. Int. Symp. Underwater Technol./Int. Workshop Sci. Use Submar. Cables Relat. Technol.*, 2007, pp. 185–190.

[12] T. Goto, T. Kasaya, M. Kinoshita, E. Araki, K. Kawaguchi, K. Asakawa, T. Yokobiki, M. Harada, T. Nakajima, H. Nagao, and K. Sayanagi, "Scientific survey and monitoring of the off-shore seismogenic zone with Tokai SCANNER: Submarine cabled network observatory for nowcast of earthquake recurrence in the Tokai region, Japan," in *Proc. Int. Symp. Underwater Technol./Int. Workshop Sci. Use Submar. Cables Relat. Technol.*, 2007, pp. 670–673.

[13] K. Asakawa, T. Yokobiki, T. Goto, K. Furukawa, A. Yamaguchi, and K. Tazaki, "Power supply system for Toyohashi cabled observatory with wide input-range," in *Proc. MTS/IEEE OCEANS Conf.*, Boston, MA, 2006, DOI: 10.1109/OCEANS.2006.306968.

[14] T. Yokobiki, E. Araki, T. Goto, and K. Asakawa, "Time-synchronization system for cabled observation system," in *Proc. 17th Int. Offshore (OCEAN) Polar Eng. Conf.*, 2007, pp. 1121–1125.

[15] K. Asakawa, T. Goto, T. Yokobiki, E. Araki, R. Iwase, M. Kinoshita, J. Kojima, Y. Fujii, Y. Okatake, and Y. Taguchi, "Deployment of the junction unit for off-Toyohashi cabled observatory," in *Proc. MTS/IEEE OCEANS Conf.*, Vancouver, BC, Canada, 2007, DOI: 10.1109/OCEANS.2007.4449179.

[16] M. Mochizuki, A. Asada, T. Ura, M. Fujita, M. Sato, Y. Matsumoto, O. L. Colombo, T. Tanaka, H. Zheng, and K. Nagahashi, "Fundamental developments of new generation seafloor geodetic observation system based on AUV technology," in *Proc. OCEANS Conf./IEEE/MTS TECHNO OCEAN Conf.*, 2008, DOI: 10.1109/OCEANSKOBE.2008.4530936.

Kenichi Asakawa (M'96–SM'08) received the B.E., M.S., and Dr. Eng. degrees in engineering from Tokyo Institute of Technology, Tokyo, Japan, in 1974, 1976, and 1979, respectively.

He joined KDD Research and Development Laboratories in 1979 where he had been engaged in developments of ROVs, AUVs, and other technologies related to construction and maintenance of underwater telecommunication cables. In 2002, he moved to the Japan Agency for Marine-Earth Science and Technology (JAMSTEC, formerly, Japan Marine Science and Technology Center), Yokosuka, Japan. Since then he has been involved in the development of ocean observing instruments and systems.

Takashi Yokobiki received the Ph.D. degree in engineering from Kyushu University, Fukuoka, Japan, in 2001.

From 2001 to 2004, he was with the Department of R&D, KDDI Submarine Cable Systems, Inc., where he developed submarine cables and cable terminations for the submarine optical telecommunication systems. Since 2004, he has been a Research Scientist at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan. His research interests include long-term real-time monitoring using cabled observation system.

Tada-nori Goto received the M.S. degree in earth science from Kobe University, Kobe, Japan, in 1993 and the Ph.D. degree in science from Kyoto University, Kyoto, Japan, in 1997.

In 1997, he was as a Postdoctoral Fellow at the Earthquake Research Institute, University of Tokyo, Tokyo, Japan. From 1998 to 2000, he was an Assistant Professor at the Aichi University of Education, Japan. From 2000 to 2008, he was a Researcher at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan. Since 2008, he has been an Associate Professor at the Graduate School of Engineering, Kyoto University. His research interests are electromagnetic sounding method to illuminate underground structures below the seafloor, especially around earthquake zones, and seafloor long-term monitoring.

Eiichiro Araki received the M.S. and Ph.D. degrees in geophysics from the University of Tokyo, Tokyo, Japan, in 1997 and 2000, respectively.

In 2000, he was as a Contract Researcher at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan, where he has been a Research Scientist since 2001. He was a Visiting Researcher at the Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC, from 2002 to 2003. His research interests are seismology and instrumentation technique in seafloor, such as seafloor long-term monitoring using borehole to observe the dynamics of seismogenic plate boundary.

Takafumi Kasaya received the Ph.D. degree in science from Kyoto University, Kyoto, Japan, in 2001.

In 2001, he was a COE Postdoctoral Researcher at the Disaster Prevention Research Institute, Kyoto University. From 2002 to 2005, he was a Postdoctoral Researcher at Deep Sea Research Division, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan. Since 2006, he has been a Research Scientist at the Institute for Research on Earth Evolution (IFREE), JAMSTEC. His research interests are electromagnetism and geophysical exploration.

Masataka Kinoshita received the Ph.D. degree in science from the Graduate School, University of Tokyo, Tokyo, Japan, in 1990.

From 1990 to 2001, he worked at the School of Marine Science and Technology, Tokai University, as an Assistant Professor (1990–1997) and an Associate Professor (1997–2001). Since 2001, he has been working at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan, currently as a Principal Investigator. His current research interests include subseafloor geothermal state, especially in seismogenic fault zone and hydrothermal areas.

Junichi Kojima (M'XX) received the B.E. and M.E. degrees in electrical engineering from Tokyo Institute of Technology, Tokyo, Japan, in 1979 and 1981, respectively.

He joined KDDI (formerly KDD), Saitama, Japan, in 1981, and since then he has been engaged in research and development in the construction and maintenance of underwater telecommunication cables. His research interests include AUVs, acoustic telemetry system for AUVs, and cable fault location systems.