The Optical Submarine Repeater and Its Associated Technologies

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Abstract

The key to meeting the increasing needs of submarine cable systems (increase in capacity, increase in distance, multipoint connections, etc.) is how to incorporate and implement designs for optical submarine repeaters, gain equalizers and the branching units installed in the submarine sections. This paper introduces the functions of different types of equipment and the technologies applied to them.

Keywords

optical submarine repeater, gain equalization, branching unit, EDFA, Remote control, OADM

1. Introduction

Following the introduction of new services such as data communication and video distribution via the Internet, the demand for international communications has been expanding rapidly. In order to meet these market demands, technologies for increasing the capacity of long-distance optical signal transmission systems are being further researched and developed, and optical submarine cable systems for applying the latest technologies are being planned and laid one after another.

This paper describes the performances and technologies of the submarine equipment, such as the optical submarine repeaters, gain equalizers and branching units.

2. Optical Submarine Repeater

As it is laid on the sea bed, the optical submarine repeater should be a maintenance-free. It is designed therefore to achieve high reliability by applying the following technologies.

Photo and **Table** show an external view and the main specifications, respectively.

1) Direct optical amplification: This repeater employs optical amplifiers using erbium-doped fibers (EDF) and 980 nm pump laser diodes (LDs). The pump LDs are provided in a redundant configuration in order to realize high reliability.

2) High reliability: The optical submarine repeater achieves high reliability by applying advanced LSI technology and high-reliability components.

3) High resistance to water pressure and high performance sealing: The housing of the submarine repeater is designed to withstand the pressure of 8,000m water depth. The high-performance sealing technology is based on our long years of experience in the field of submarine repeaters for coaxial systems.

4) All-optical monitoring: In order to implement a high

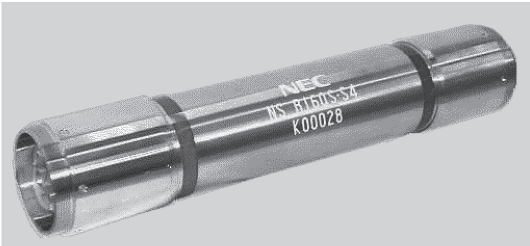

Photo External view of an optical submarine repeater.

Table Specifications of the optical submarine repeater.

Item	Specifications
Wavelength range	1538.48 to 1567.13 nm
Accommodated systems	Max. 8 systems (8-fiber pairs)
Noise Figure	4.7 dB (typical)
Optical output power	≥ +15 dBm
Polarization dependence loss	≤ 0.3 dB
Pump LD	980 nm × 2/system
DC voltage drop	≤ 34 V (4 systems), ≤ 68 V (8 systems)
Power feeding current	1.10 A ±2%
Dielectric strength	12 kV DC
Supervisory Function	All-optical monitoring/COTDR
Operating temperatures	0 to 35°C
Maximum applicable depth	8,000 meters
Shock/vibration resistance	100 G, 5 to 55 Hz/amplitude 1.5 mm
Material of Housing	Beryllium-copper alloy

reliability monitoring system, an all-optical monitoring system is adopted because this does not require electrical circuitry inside the submarine repeater.

Fig. 1 shows the function block diagram of the system unit, which is composed of two optical amplifiers for amplifying signals in both directions.

Optical amplifiers with high power outputs of more than +15 dBm and low noise figures of less than 4.7 dB are implemented by the forward pumping scheme with high-power 980 nm pump LDs. The transmission bandwidth is realized as large as up to 40 nm thanks to optimization of the EDF lengths and the use of individual gain flattening filters (GFF). Two pump LDs are provided in redundancy and their outputs are multiplexed/divided using an optical coupler and are injected into the EDFs of both directions. Each pump LD is controlled so that the LD output is constant. In addition, the system is designed so that the transmission path characteristics can be maintained even if one of the two pump LDs fails.

The operating status of the optical submarine repeater is monitored using the supervisory signal with the dedicated wavelength of all the wavelengths transmitted from the terminal equipment only the supervisory signal wavelength (λsv) is looped back to the opposite direction fiber by the wavelength selective reflector (WSR) in the optical supervisory circuit of the repeater, as shown in Fig. 1. The looped-back supervisory signal wavelength is received by the terminal equipment, which then analyzes the gain of each repeater section from the level of the supervisory signal wavelength and detects faults such as any loss increases in the submarine cable or a failure of an optical submarine repeater.

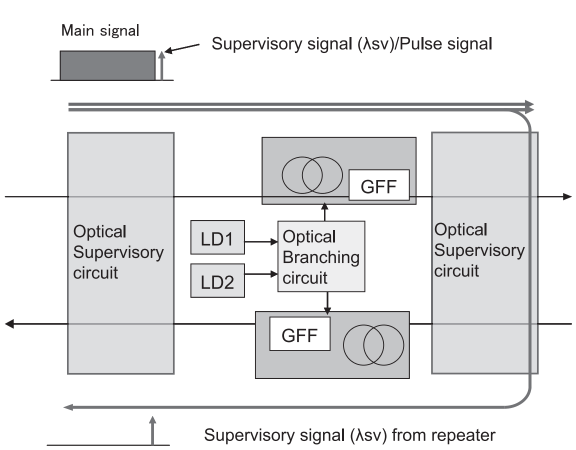

Fig. 1 Function block diagram of system unit.

3. Gain Equalizer Unit

The gain equalizer units are laid at intervals of several repeater sections in order to realize the wide transmission bandwidth of the submarine cable system's many cascaded repeaters. There are two equalization types. One is the gain shape equalizer (SEQ) that compensates for the gain wavelength characteristics of optical submarine repeaters and cables. The other one is the tilt equalizer (TEQ) that compensates for the gain tilt due to variance in repeater output levels and cable loss. The details of the gain equalization technology are described in section 4.1 of “Construction Technology for Use in Repeatered Transoceanic Optical Submarine Cable Systems.”

Fig. 2 shows the block diagram of a gain equalizer unit.

The TEQ has several kinds of modules in order to compensate the gain tilt errors that are anticipated for the system due to the performances of the optical submarine repeaters and cables.

4. Branching Unit

Branching units realize the systems that connect three or

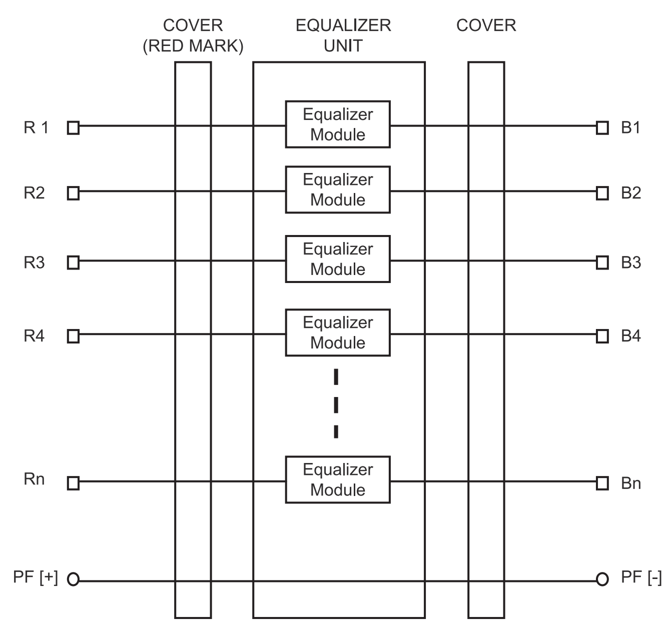

Fig. 2 Block diagram of gain equalizer unit.

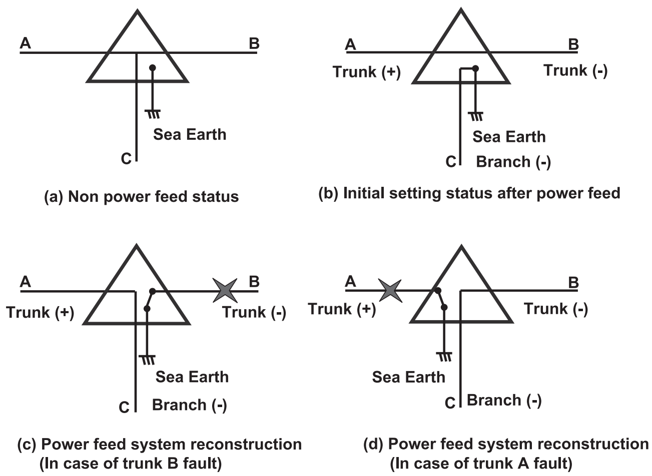

Fig. 3 Power feed path switching.

more landing stations.

4.1 Power Feed Path Design

With regard to the power feed path design, there are two types of the branching unit (BU), the fixed power feed path type (hereafter, Fixed type) and the power feed path switching type (hereafter, SW type). The SW type electrical circuitry uses a vacuum relay with a high withstanding voltage for the path switching. The vacuum relay is switched either by controlling the feed current of the submarine cable system or by remote control using a command signal from the terminal equipment.

The SW type BU has the function of re-making the system power configuration if a submarine cable fault should occur. **Fig. 3** shows the settings of the SW type BU. This unit is capable of the following four connection status settings.

(a) Non power feed status.

(b) Initial status: (+) feed for trunk A — (-) feed for trunk B and (-) feed for branch C — Sea earth (GND).

(c) Trunk B fault status: (+) feed for trunk A — (-) feed for branch C.

(d) Trunk A fault status: (+9 feed for trunk B — (-) feed for branch C.

After the submarine cable has been laid, the non power feed status can be used to confirm absence of faults such as grounding in the cable by interconnecting A, B and C in the submarine branching unit while isolating them from the sea earth (GND). In the initial operation status, the power feed path is configured with a both-ends power feed between trunks A-B and connecting the branch C to the sea earth (GND). If a fault occurs in trunk A or B, the BU reconfigures the power feed path to ensure trunk power feed by enabling power feed between trunk B and branch C or between trunk A and branch C.

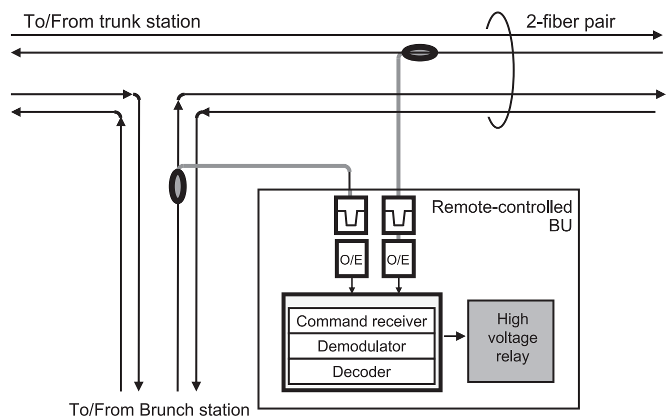

Fig. 4 Configuration of remote-controlled BU. (one example)

At the outset, the vacuum relay used for power feed path switching was controlled with the feed current. However, with a system connecting four or more stations, control is very difficult and power feed switching may become impossible depending on the mode of the fault. Therefore, a remote control method for setting the vacuum relay using a signal from the terminal station is being developed. While the vacuum relay switched by the feed current control is a non-holding relay as described above, that relayed by remote control also uses a holding relay. This arrangement holds the power feed circuit status even in the case of a fault, thus maintaining communications if a fault occurs and enabling repair after the fault is located.

Fig. 4 shows an example of the configuration of a remotely controlled type BU. The control signal used to transmit information from the terminal station is obtained by superimposing the control signal carrier onto the optical signal by means of ASK or FSK modulation. The vacuum relay of the BU specified in the control signal can be switched as desired. In the example of Fig. 4, the optical signal in which the control signal is superimposed is a signal with a dedicated wavelength. In consideration of a case of cable fault, it is required to provide one or more control paths from both the trunk and branch stations.

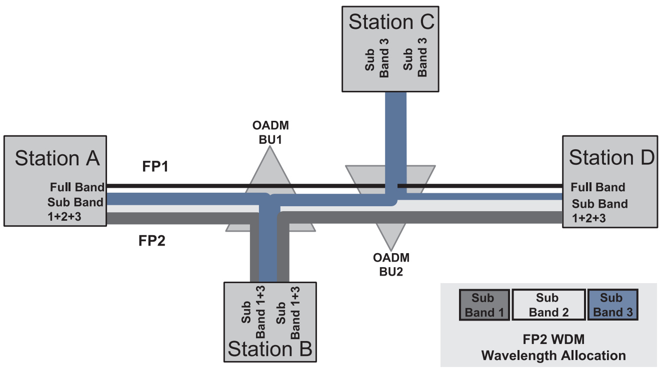

Fig. 5 Configuration of OADM BU system (one example).

4.2 Transmission System Design

Regarding the transmission path design, there are two types of BU, the fiber branching type that branches signals on a per-fiber basis and the OADM (Optical Add Drop Multiplexer) type that branches signals on a per-wavelength basis.

The OADM type BU is capable of flexible wavelength multiplexing/demultiplexing by using optical filters in accordance with the system requirements.

Fig. 5 shows an example of system configuration applying OADM type BU. Here, the transmission wavelengths are divided into some sub-bands and each sub-band is allocated for the communication between each station. In Fig. 5, Fiber pair 1 (FP1) provides full-band connection between stations A and D while fiber pair 2 (FP2) applies the OADM function for connections between the branch and trunk stations and those between the branch stations. This configuration makes it possible to implement a submarine cable system as a mesh network instead of the current ring network.

5. Mechanical Design of Submarine Equipment

The submarine equipment is composed of the pressure resistant housing and the internal unit mounted inside the housing.

(1) Internal Unit

The most important consideration in the submarine equipment mechanical design is the heat dissipation characteristics.

The thermal contact resistance between the electrical circuitry and the pressure housing is minimized in order to obtain optimum heat dissipation. Therefore, the high power parts such as the pumping LDs in the optical submarine repeater are mounted directly in the metallic cases of the sub-unit. In consideration of the thermal resistance and the alleviation of external impacts, the internal unit is fixed using rubber cushions and metallic springs inside the pressure resistant housing.

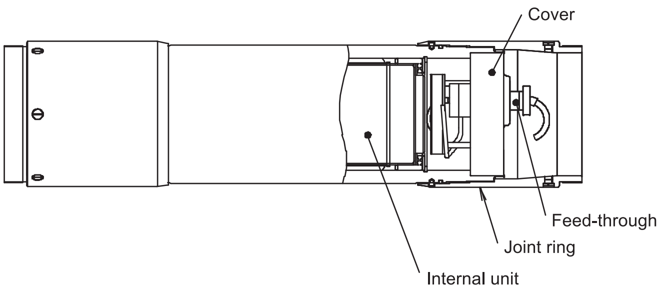

Fig. 6 Structure of pressure housing.

(2) Pressure-Resistant Housing

Fig. 6 shows a pressure-resistant housing design based on the coaxial submarine repeater technology. The housing is composed of the following main parts;

1) The cylinder and the two cover assemblies;
2) The two joint rings connecting the cylinder to the cable.

The main material of the pressure-resistant housing is the beryllium-copper alloy that features a high tensile strength and excellent corrosion resistance characteristics. The pressure resistant housing is sealed in order to effectively protect the submarine repeater unit against penetration of water and gases from the seawater. This sealing design is achieved using the following technologies;

1) Sealing of cylinder and covers by means of electron beam welding;
2) Sealing of optical fibers (feed-through) by soldering.

The solder used to seal the fibers remains stable for a long period and is capable of maintaining the relative humidity inside the pressure-resistant housing at below 20% for 25 years. The feed-through sealing can prevent penetration of water and gases effectively, even if a cable near to the submarine equipment is cut. In order to ensure airtightness and water pressure resistance, the pressure resistant housing is tested using helium gas at an equivalent pressure to the maximum depth of the submarine system. Impacts and vibrations during the transportation and placing of the equipment on the seabed are buffered by the rubber cushions and metallic springs placed between the optical submarine repeater housing and the submarine repeater unit.

The optical submarine repeater and cable couplings are connected using a clamping ring at the end of the joint ring.

The pressure-resistant structure of the submarine branching unit is designed based on the basic design of the repeater as described above. However, the pressure resistant housing of the branching unit is in general larger than that used with the optical submarine repeater. This is because, in order to perform power feed switching, a higher withstanding voltage than the optical submarine repeater is required inside the housing and two couplings need to be attached on the branching side.

6. Conclusion

NEC has provided more than 3,000 sets of equipment for the market and up to the present time none of these has failed. We intend to continue to offer our high-reliability, high-performance designs in the future, and as the acknowledged leading company in the industry, we will continue to provide an unrivalled performance in the construction of international and domestic submarine networks.

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