

High-Performance Submarine Line Terminal Equipment for Next-Generation Optical Submarine Cable System: FLASHWAVE S650

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Global telecommunications traffic is rapidly growing in response to customer demand for broadband services and more reliable network performance. Thus, the demand for a submarine telecommunications system, which is a backbone infrastructure for international telecommunications, is also steadily increasing. This demand is not only for constructing a new cable system, but also for upgrading capacity by adding extra capacity to existing systems. To meet this demand, we have developed the FLASHWAVE S650, new Submarine Line Terminal Equipment (SLTE), by applying cutting-edge DWDM optical technologies. This equipment features excellent transmission performance, improved maintainability, and a flexible configuration suitable for a long-haul system, coupled with upgraded capacity. The FLASHWAVE S650 was successfully deployed in a SEA-ME-WE 4 cable system and certain upgraded systems. This paper describes the various functions, characteristics, and configuration of the FLASHWAVE S650.

1. Introduction

Due to the rapid worldwide expansion of communication networks to support broadband, there has been a growing need for using submarine optical communication systems as the main backbone infrastructure of international communications. This has prompted the demand for upgrade projects that can cope with the laying of cable for new systems, as well as expanding the transmission capacity of existing systems. The FLASHWAVE S650 was developed as cutting-edge Submarine Line Terminal Equipment (SLTE) in response to these needs.

The FLASHWAVE S650 can perform a maximum of 112-wave multiplex transmissions of 10-Gb/s signals through a single optical fiber.

The FLASHWAVE S650 has wavelength multiplexing and demultiplexing functions, as well as an optical amplification function through the use of an Erbium-Doped Fiber Amplifier (EDFA), a wavelength dispersion compensation

function necessary for long-distance optical transmission, an error correction function, and a surveillance control function that monitors such submersible equipment as submarine repeaters. Moreover, various redundant configurations, including an assortment of different options, offer the high reliability necessary to support the international communications backbone essential for a submarine communications system. In addition, the use of a Graphical User Interface (GUI) in combination with submarine communications System Surveillance Equipment (SSE) enables comprehensive control of the submarine communications system.

This product is employed in Southeast Asia-Middle East-Western Europe 4 (SEA-ME-WE4), a large submarine cable system connecting countries from Singapore to France, and designed for a capacity of 10Gb/s \times 68 waves. Moreover, it can be used to improve the existing system to be expanded through upgrade projects. This paper

first describes an example of the typical configuration of a submarine communications system, followed by the features and functions of the FLASHWAVE S650. Then it explains the configuration of the equipment in detail.

2. Configuration of submarine communications system

Figure 1 shows an example of the typical configuration of a submarine communications system. This system is composed of various kinds of equipment like SLTE and SSE, and the following equipment described below.

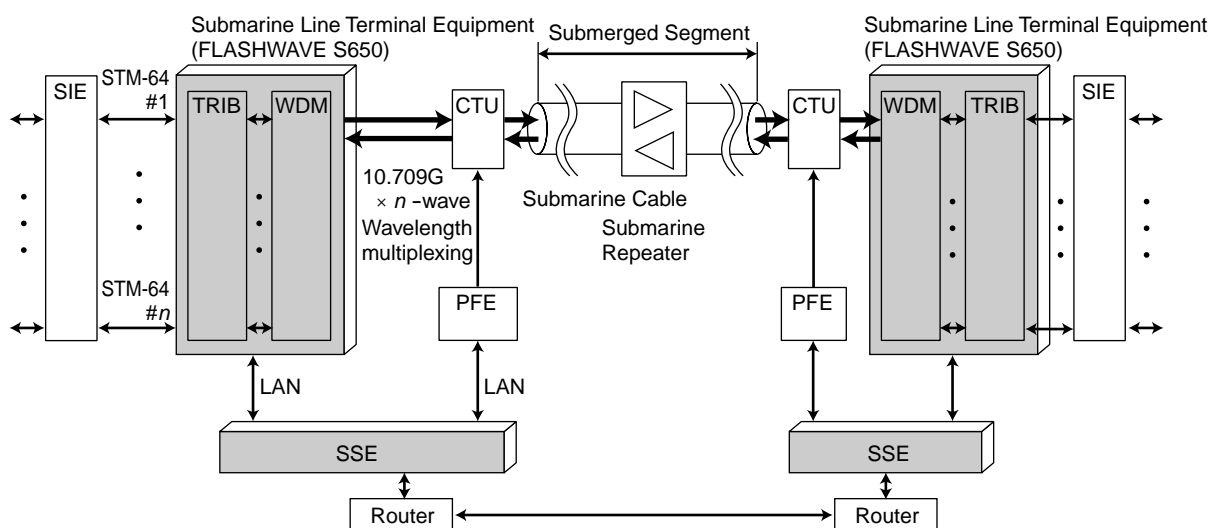
- 1) Power Feeding Equipment (PFE): Power supply equipment that supplies electric power to such submersible equipment as submarine repeaters.
- 2) Cable Termination Unit (CTU): Cable termination equipment that connects terrestrial cable to submarine cable.

- 3) SDH Interface Equipment (SIE): Equipment that interfaces with a terrestrial SDH network.
- 4) Submarine cable and submersible equipment: Submarine repeaters that use a high reliability optical amplifier and gain equalization equipment to rectify the wavelength dependability of gain via a multi-stage connection of optical fibers and repeaters.

3. Features and functions of FLASHWAVE S650

The FLASHWAVE S650 enables significantly improved maintainability compared with conventional equipment, while attaining a globally high level of transmission capability using the technology shown below.

Table 1 lists the main specifications of this product. Moreover, the following describes the functions of this equipment in detail.



SSE: System Surveillance Equipment
 SIE: Synchronous Digital Hierarchy (SDH) Interface Equipment
 CTU: Cable Termination Unit
 PFE: Power Feeding Equipment
 WDM: Wavelength Division Multiplexer
 TRIB: Tributary
 LAN: Local Area Network
 STM: Synchronous Transfer Module

Figure 1
 Typical Configuration of submarine communications system.

Table 1
Main Specifications of FLASHWAVE S650.

Item	Specs
Dimensions	600(W) × 300(D) × 2200(H) mm
Wavelength multiplex	Max 112 waves
Wavelength interval	37.5 GHz (approx. 0.3 nm)
Error correcting gain	8.2 dB
Operational environment requirements	Temperature: +5°C to +40°C Humidity: 5 to 85%
Power supply requirement	DC -48V
Submersible-side interface	
Optical receiving level	-5.0 to +12.5 dBm
Optical transmitting level	+7.0 to +15.5 dBm
Wavelength bandwidth	1533.47 to 1566.83 nm
Transmission speed	10.709 Gb/s (U-FEC)
Encoding	RZ
Terrestrial-side interface	
Optical receiving level	-14.0 to -1.0 dBm (ITU-T G.957 S64.2b)
Optical transmitting level	-1.0 to +2.0 dBm (ITU-T G.957 S64.2b)
Wavelength bandwidth	1530.0 to 1565.0 nm
Transmission speed	9.953 Gb/s (ITU-T G.707)
Encoding	Scrambled binary NRZ (ITU-T G.707)

3.1 High-density wavelength multiplexing

The use of 37.5-GHz (about 0.3-nm) wavelength multiplex intervals, coupled with world-class, dense wavelength division multiplexing and demultiplexing technology, enables the long-distance optical transmission of 10-Gb/s signals through a maximum of 112 waves. In addition, by using a colorless Arrayed Waveguide Grating (AWG) that can combine waves at a ratio of 8:1 with a thin-film-wave multiplexing/demultiplexing unit that can combine and separate waves at a ratio of 14:1, the system becomes applicable to multiple wavelength ranges and number of wavelengths systems by simply changing the colorless AWG setting.

At initial setup, for example, sending multiple DL (Dummy Light) signals on the transmission side to compensate for an inadequate number of 10-Gb/s signals can stabilize the transmission of even a single signal.

3.2 Improved level of error correction

Higher transmission performance can be achieved through the use of an error correction function called Ultra-Forward Error Correction (U-FEC). By using the STM-64 signal coupled with error correcting compression through the SIE at a rate of 9.95 Gb/s, the signal is transmitted as a 10.71-Gb/s signal. On the reception side, any errors in the signal are detected and corrected, and then reconverted back into a 9.95-Gb/s signal. This in turn reduces the error rate in the transmission channel from 3.0×10^{-3} to 1.0×10^{-13} , thus allowing for a high correction gain of 8.2 dB.

3.3 Wavelength dispersion compensation

When using cables that may extend over several thousands of kilometers, as in submarine communications systems, it is essential to reduce the degradation of wavelength dispersion compensation for the optical fibers. Especially in the Dense Wavelength Division Multiplexing (DWDM) system that uses wide-ranging wavelengths, any difference in wavelength dispersion quantity between signals on the short wavelength side and long wavelength side cannot be ignored.

Therefore, by adopting Dispersion Compensation Fiber (DCF), this equipment can compensate the wavelength dispersion of a wide array of signal wavelengths in the wavelength multiplex part of each transmission and reception, and permit the use of Virtually Imaged Phased Array (VIPA)¹⁾ — variable dispersion compensation technology originally developed by Fujitsu — that enables optimal dispersion compensation to each wavelength by performing dispersion compensation individually for each wavelength.

Furthermore, individual dispersion compensation by using VIPA makes automatic optimization possible. It controls the dispersion compensation value to comply with the lowest error correction value set by FEC through dispersion compensation on the reception-side VIPA.

Moreover, by adopting VIPA as an individual method of dispersion compensation, the

footprint of the device can also be dramatically reduced when compared to devices using the conventional DCF and optical amplifier combination setup, thus allowing a reduction in installation area to less than half of that of equivalent competitive systems.

3.4 Pre-emphasis setting

The loss and gain of optical fiber in a transmission route, as in the case of submarine optical fiber cable and the optical amplifier of submarine repeaters, have a respective dependency on wavelength. Moreover, when each wavelength is output at the same level from the transmission side, the input level on the reception side is not uniform, thus causing a difference in transmission level between transmission and reception, even if wavelengths are sent at the same level. Therefore, without adjustment, transmission quality would be different for every wavelength.

This product utilizes pre-emphasis technology to enable the output level of each wavelength to be adjusted with regard to the wavelength dependency of a transmission frequency. Moreover, Fujitsu managed to achieve this pre-emphasis control automatically. In other words, adjusting the output level for each wave from the transmission side to comply with the margin of transmission quality calculated by FEC from the monitor value of the error correction level on the reception side, and allowing for automatic adjustment of output level on the transmission side ensures the uniform transmission quality of each wavelength.

3.5 Surveillance and control of submarine equipment

A command signal can be modulated and transmitted to such submersible equipment as submarine repeaters and gain equalizers through the conversion of a multiplexed output signal and in a range that will not affect the transmission characteristics.

Moreover, response signals can be received

from submersible equipment through transmission using a similar method.

3.6 System surveillance and control

Surveillance and control of this product are possible in a private network in combination with SSE. The SSE enables management of the cable-laying route by displaying a map (a clickable map) that visualizes via GUI where each unit has been installed, thus providing the ability to control not only the SLTE at the same location, but also the submersible equipment and power feeding equipment of the submarine transmission system. In this way, the entire submarine communications system can be controlled.

Moreover, connecting a PC to the connector from the COMmon Management (COM) sub-rack and running the surveillance control terminal (Craft Terminal) allows isolated use of the SLTE to enable access of most security and control items through a simple interface.

3.7 Safety measures

In order to even out a maximum signal level of 100 or more waves, the wavelength multiplexer for the output level of this product's optical amplifier is set to more than +20 dBm (100 mW). Moreover, the excitation light supplied to the optical amplifier is also at a high output level of +18 to +23 dBm, which can be dangerous to the human body when output directly. Therefore, this equipment is compliant with international safety standard IEC60825, provides Automatic Power Reduction (APR) capability should the output exceed +10 dBm, and also includes safety features that automatically decrease output to less than +10 dBm, such in cases where the optical fiber becomes detached.

3.8 Redundant configuration

As for the tributary section that consists of individual units separated by wavelength, up to 20 waves along with a single spare wave to the system wave can be allocated and switched by

using an optical switch employing the $\langle N+1 \rangle / \langle N:1 \rangle$ setup, or can allow the switching of individual units that use a single spare wave with the same wavelength for a redundant $\langle 1+1 \rangle$ setup. With a $\langle N+1 \rangle$ setup, the wavelength of the reserve system that is not usually used can be utilized to carry extra traffic.

In the wavelength multiplexing section that collectively processes the main signals, the unit containing the optical parts is separated from the control function component that is directly related to the transmission characteristics. This redundant configuration enables a higher reliability to be realized. Moreover, all transmission characteristics can be maintained individually, even when a redundant light source fails in a broadband amplifier.

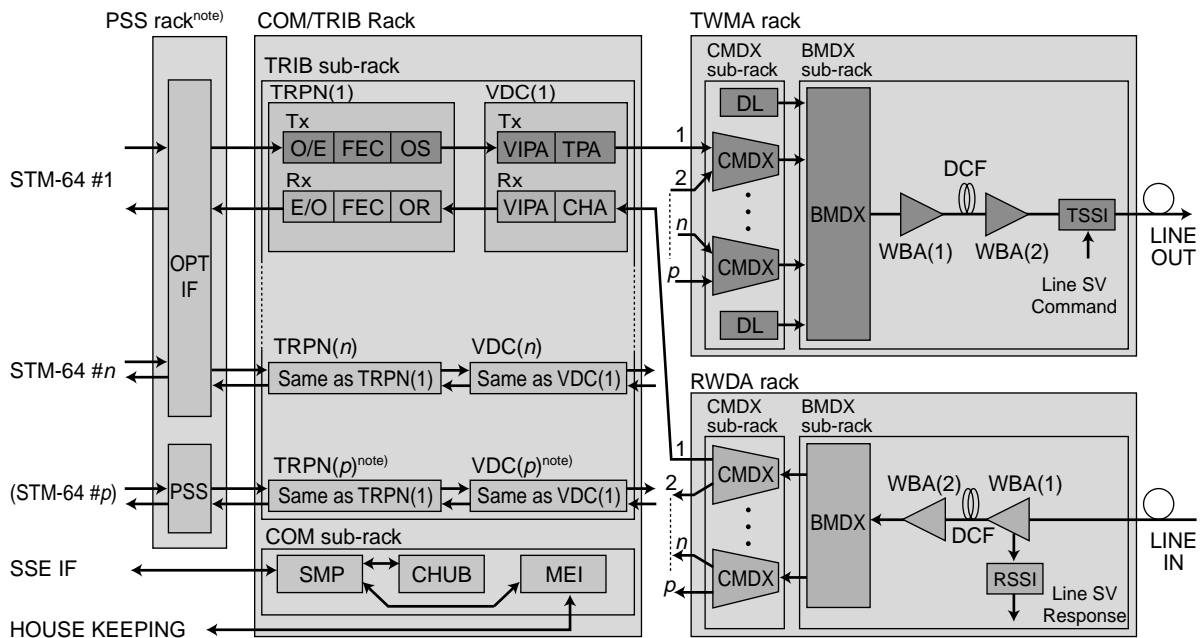
ity to be realized. Moreover, all transmission characteristics can be maintained individually, even when a redundant light source fails in a broadband amplifier.

4. Installation setting for FLASHWAVE S650

4.1 Sub-rack configuration

Figure 2 shows a block diagram of the basic configuration for the $\langle N+1 \rangle / \langle N:1 \rangle$ setup of the FLASHWAVE S650. **Figure 3** shows the front view of this basic configuration.

The main functions of this equipment are



note) PSS is optional.

BMDX: Band Multiplexer and Demultiplexer
 CHA: Channel Amplifier
 CHUB: Common HUB
 CMDX: Channel Multiplexer and Demultiplexer
 COM: Common Management
 DCF: Dispersion Compensation Fiber
 DL: Dummy Light
 E/O: Electrical to Optical signal converter
 FEC: Forward Error Correction
 IF: Interface
 MEI: Maintenance and External Interface
 O/E: Optical to Electrical signal converter
 OPT IF: Optical Interface
 OR: Optical Receiver
 OS: Optical Sender

PSS: Protection Switching System
 RSSI: Receive Submersible Supervisory Interface
 RWDA: Receive Wavelength Demultiplexer and Amplifier
 SMP: System Management Processor
 SSE: System Surveillance Equipment
 SV: Supervisory
 TPA: Transmit Pre-emphasis Amplifier
 TRIB: Tributary
 TRPN: Transponder
 TSSI: Transmit Submersible Supervisory Interface
 TWMA: Transmit Wavelength Multiplexer and Amplifier
 VDC: Variable Dispersion Compensator
 VIPA: Virtually Imaged Phased Array
 WBA: Wide Band Amplifier

Figure 2
 Functional block diagram.

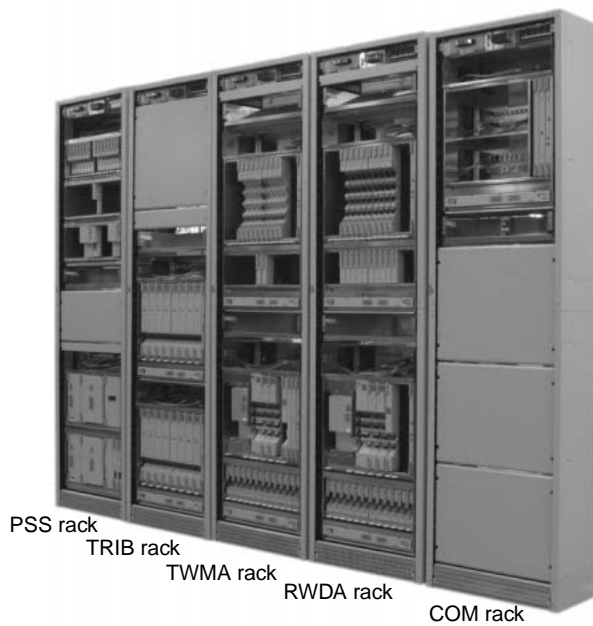


Figure 3
Front view of FLASHWAVE S650.

comprised of four sub-racks:

- 1) COM sub-rack
Provides surveillance control capability for the entire system.
- 2) Tributary (TRIB) sub-rack
Provides U-FEC error correction capability for the terrestrial STM-64 interface, an individual dispersion compensation function for every wavelength as provided by VIPA, and a pre-emphasis setting function. A single sub-rack can accommodate up to eight waves at 10 Gb/s.
- 3) Channel Multiplexer and Demultiplexer (CMDX) sub-rack
Allows each wavelength block to be multiplexed or demultiplexed through the use of AWG, and enables the production of DL on the transmitting side.
- 4) Band Multiplexer and Demultiplexer (BMDX) sub-rack
Provides the capability of optical amplification through a broadband amplifier and block multiplexer/demultiplexer, the package wavelength dispersion compensation function by DCF, the function to set the optical level of the output

signal to a transmission line, and the ability to send and receive monitoring signals from submersible equipment.

In addition, there are three types of sub-racks that can be used optionally to provide redundancy for the tributary section.

- 1) Optical Interface (OPT IF) for $\langle N+1 \rangle / \langle N:1 \rangle$ configuration sub-rack

Enables branching to the spare wave for each wavelength when using the $\langle N+1 \rangle / \langle N:1 \rangle$ configuration, and switching between each wavelength to and from the spare wave.

- 2) Redundant system switching (PSS: Protection Switching System) sub-rack

Provides the ability to control switching using the $\langle N+1 \rangle / \langle N:1 \rangle$ configuration, and select the spare wave.

- 3) Optical interface for $\langle 1+1 \rangle$ composition (OPT INT: OPTical INTerface) sub-rack

Provides the ability to compose the main signal with the reserve system using the $\langle 1+1 \rangle$ configuration.

4.2 Rack configuration

This system can be mounted in a standard ETSI rack (600 mm [width] \times 300 mm [depth] \times 2200 mm [height]) through a minimal setup of the COM rack, RWDA rack, and TWMA rack, and can support up to 16 multiplexed waves in a system. To increase number of wavelengths, all that is needed is adding a TRIB rack. Each TRIB rack supports a maximum of twenty-four 10-Gb/s signals. Moreover, it is possible to add a redundant $\langle N+1 \rangle / \langle N:1 \rangle$ configuration to the tributary section by adding a PSS rack. Each PSS rack can support a maximum $\langle 20+1 \rangle / \langle 20:1 \rangle$ redundant configuration.

5. Conclusion

The SEA-ME-WE 4 system that connects countries from Singapore to France was made possible through the development of the latest submarine line terminal equipment — the FLASHWAVE S650.

This equipment utilizes the latest optical-communications technology, including Fujitsu's original technology, to realize transmission characteristics that are of the highest level in the world. By employing a flexible setup, this equipment can be used in upgrade projects, as well as to construct new submarine communication systems. Further miniaturization and more func-

tions by using the Full Band Tunable laser are planned for implementation in the future.

Reference

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