Submarine Optical Communications System Providing Global Communications Network

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The capacity of the global communications network is being progressively increased to handle the rapid growth in telecommunication traffic generated by the Internet. Fujitsu supplies submarine optical cable systems that can provide the huge capacity and short transmission delay required by carriers. There are two ways to increase capacity: construct a new submarine cable system or upgrade the existing one. For the latter, in particular, coupler insertion technology has been established. This allows the existing submarine line terminal equipment (SLTE) and new SLTE to co-exist in one system. As the existing submarine portion will continue to be used unchanged, this technology can reduce the amount of work done at sea and contribute to cost and lead-time reductions. Fujitsu has chosen to use return-to-zero differential phase shift keying (RZ-DPSK) technology to improve the upgradeable capacity and has applied it to several transpacific projects.

1. Introduction

Efforts are now under way to expand the capacity of the global communications network in response to dramatic increases in communication traffic accompanying the rapid growth of the Internet. Fujitsu provides telecommunications carriers with submarine optical communications systems that can be used to construct communications infrastructures that provide a large capacity and short time delay. Fujitsu's delivery record for these systems, which continue to be deployed to keep up with the ongoing increase in traffic, is shown in **Figure 1**. Recently, however, there has been growing demand from telecommunications carriers to increase the number of wavelengths that can be handled by existing systems in order to increase communication capacity in a relatively short period of time as an alternative to the construction of new systems. An example of expanding capacity by increasing the number of wavelengths is given in **Table 1**.

In this paper, we describe Fujitsu's R&D activities toward increasing the number of wavelengths in submarine optical communications systems and briefly mention future developments.

2. Activities toward expanding communication capacity

2.1 Need for more wavelengths

The demand for communication capacity is increasing rapidly, and telecommunications carriers are finding that they must increase the capacity of their communications infrastructure to meet that demand. There are two main ways to increase the capacity of a submarine optical communications system: build a new system or increase the capacity (the number of wavelengths) of the existing system.

The former method involves deploying an entirely new system consisting of submarine optical cable, submarine repeaters, and transmit/receive submarine line terminal

equipment (SLTE). This method allows the use of technology that is state of the art at the time of deployment, so it provides a system with superior characteristics. Its drawback is that the lead time to service delivery is relatively long, which means that it cannot meet the demand from telecommunications carriers for a quick increase in capacity.

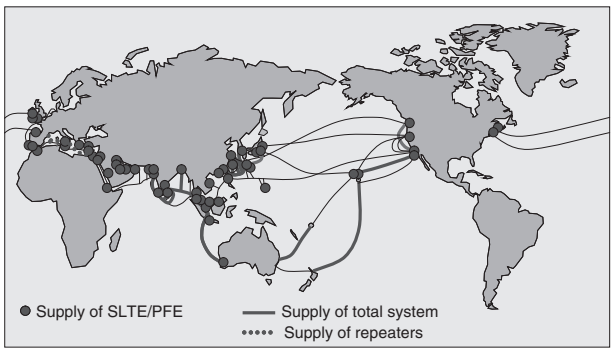
The latter method can increase the number of wavelengths as long as there is a margin in the transmission characteristics of the existing system, which is a feature of wavelength multiplexing systems. Compared with the deployment of a totally new system, this approach can upgrade a system quickly and inexpensively. Furthermore, as new technologies are being actively applied in this field, the existing platform can be combined with a new platform. Compared with simply upgrading the existing platform, this scheme is advantageous from the cost perspective while also achieving more capacity than the initial design of the existing platform. Moreover, the system provider of the new platform need not be the same as that of the existing platform; that is, a provider with superior technology can perform the upgrade.

2.2 Wavelength upgrading methods

Wavelength division multiplexing (WDM) equipment can be used to combine a new platform with the existing platform and increase the number of wavelengths in two ways: by adding new transponders (**Figure 2**) or by interconnecting existing and new platforms by using an optical coupler (**Figure 3**).

The first method adds a new transponder section to the system by using transponders that incorporate new technology. The hardware scale in this upgrade is small, but the interface between the optical and control systems depends on the individual circumstances and the hardware and firmware must be redesigned. As a result, it tends to be difficult to reduce costs and shorten the lead time with this method.

The second method involves the use of new SLTE. On the output side, the output of existing



SLTE: Submarine line terminal equipment
PFE: Power feeding equipment

Figure 1
Submarine communication systems delivered by Fujitsu.

Table 1
Effect of increasing number of wavelengths.

	Initial design	After upgrade
No. of wavelengths	16	41 (maximum)
Total capacity	160 Gb/s	410 Gb/s

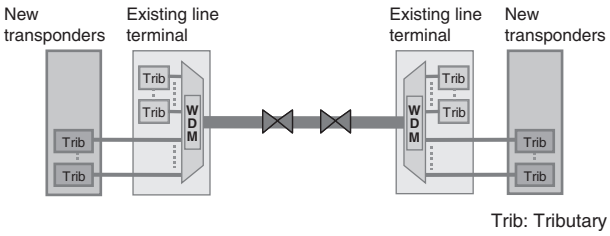


Figure 2
Increasing number of transponder slots.

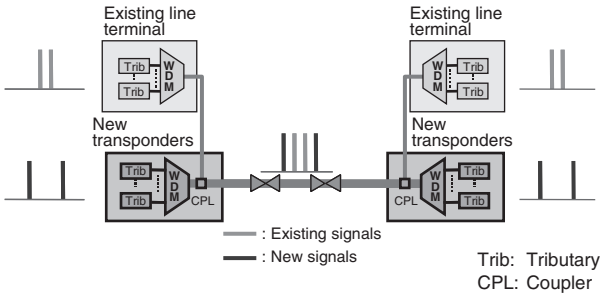


Figure 3
Coupler insertion method.

equipment is multiplexed with signals from the new equipment through an optical coupler, and the multiplexed signal is transmitted over the submarine cable. On the receive side, the transmitted signal is demultiplexed by an optical coupler and input to existing and new equipment. This approach to deploying new SLTE by inserting a coupler is called the "coupler insertion method". Although this method cannot achieve as large a maximum capacity as a completely new system, it can provide increased capacity quickly in response to customer needs. The following section describes this method in more detail.

3. Coupler insertion method

In the coupler insertion method, the optical output of the existing SLTE connected to the submarine cable is temporarily disconnected and then reconnected to the optical coupler incorporated in the new SLTE. As a result, wavelengths from both existing and new equipment are multiplexed and transmitted over the submarine cable, and the resulting multiplexed signal is demultiplexed by an optical coupler on the receive side and received by both existing and new SLTE. Here, the optical transmit power ratio of existing and new signals is adjusted by a variable optical attenuator connected to the transmit-side coupler. On the receive side, interface-level adjustment is performed by a variable optical attenuator connected to the receive-side coupler. These optical couplers and variable optical attenuators are installed in Fujitsu's FLASHWAVE S650[1] optical SLTE.

3.1 Transmission quality design

To maintain a specified level of signal quality after the addition of more wavelengths by coupler insertion, the optical signal-to-noise ratio (OSNR) of existing signals and newly added signals must be ascertained and transmission degradation estimated. This requires a survey of design information such as the gain-wavelength characteristics and OSNR of the system to be upgraded, signal quality (Q value) of existing signals, transmission quality margin of existing signals, and transmission path information (wavelength dispersion and nonlinearity degradation). Once this information has been considered, the number of wavelengths that can be added to the system can be designed.

3.2 Upgrade procedure

As described above, the insertion of couplers requires temporary disconnection of existing signals, so meetings with customers should be held, and if necessary, data signals on the existing channel should be rerouted.

First, existing equipment is disconnected from the submarine cable and connected to the new SLTE. Next, the levels of existing signals are adjusted on their side and communication with the new SLTE is checked. Signals on the new SLTE are then activated and their power levels and the wavelength dispersion compensation are adjusted. Finally, after a characteristics check, the system is restored to the signal transmitting state.

3.3 Replacement of existing system

A system upgrade may also consist of replacing signals produced by old transponders by those produced by new transponders. For example, 2.5-Gb/s signals may be replaced by 10-Gb/s signals. However, optical repeaters in the system keep output levels fixed, which means that removing signals on the existing side has the effect of raising the optical power level of remaining signals and increasing the possibility of transmission degradation. For this reason, existing signals should be dropped and new signals added with the level of the new signals adjusted to minimize the effects on other channels.

4. RZ-DPSK

4.1 Capacity increase by RZ-DPSK

In terms of modulation formats, non-return-to-zero on-off keying (NRZ-OOK) has been used for terrestrial 10-Gb/s systems, while return-to-zero differential quadrature phase shift keying (RZ-DQPSK) and NRZ differential phase shift keying (NRZ-DPSK) have been used for terrestrial 40-Gb/s systems. In submarine 10-Gb/s systems, the RZ-OOK modulation format has been used, but use of RZ-DPSK is progressing because of the enhanced sensitivity it provides even in submarine optical communications systems.

RZ-DPSK is more sensitive than RZ-OOK by about 3 dB, which means that the required OSNR can be lower for the same signal quality. This characteristic can be utilized to increase the interval between optical repeaters in new cable systems: the number of optical repeaters can be reduced by 30%, which enables a significant drop in system cost. RZ-DPSK also features greater robustness to self-phase modulation group velocity delay (SPM-GVD), which is one type of fiber-nonlinearity degradation, than RZ-OOK. These two features can also be applied effectively to an upgraded submarine optical communications system.

The gain band of optical repeaters connected in a multistage format to achieve long-distance transmission is limited, and WDM signals must be arranged within this range. In general, gain is small on the short- and long-wavelength sides of the gain band, which prevents signals from being sufficiently amplified there and prevents sufficient OSNR from being achieved. In the case of RZ-DPSK, however, the required OSNR is small, so WDM signals can be placed in such locations as well. In addition, wavelength dispersion that has accumulated over the transmission path is large on the short- and long-wavelength sides as a result of the fiber dispersion slope (which reflects the dependence of wavelength dispersion on wavelength). Thus, while the degradation due to SPM-GVD would be expected to be large, that for RZ-DPSK is small, so its applicable domain is broader than that of RZ-OOK. The RZ-DPSK format is therefore suitable for creating large-capacity optical communications systems.

4.2 RZ-DPSK transmission on NZ-DSF

Submarine optical communications systems use non-zero dispersion shifted fiber (NZ-DSF) or dispersion-managed fiber (DMF). In phase modulation formats like RZ-DPSK, it is known that noise generated by optical repeaters becomes phase noise that can degrade the signal.[2] This noise can be large in the zero-dispersion region of NZ-DSF where wavelength dispersion is small, especially for a relatively long transmission distance. One countermeasure to this problem is to use RZ-OOK, which has little degradation of this type in the vicinity of zero dispersion and to use RZ-DPSK elsewhere, thereby ensuring sufficient signal quality. However, when RZ-OOK wavelengths are placed near RZ-DPSK wavelengths, RZ-OOK power-modulated signals will be converted to phase-modulated signals that will be added to the RZ-DPSK phase-modulated signals as noise, which will degrade the signal quality. This degradation is related to the difference in RZ-DPSK and RZ-OOK signal propagation speeds (which are proportional to the product of accumulated dispersion and wavelength spacing). An example of transmission degradation over 8000 km of NZ-DSF is shown in **Figure 4**. For a large accumulated dispersion, practically no penalty arises, but for a small accumulated dispersion, a large penalty occurs if the wavelength spacing of those two signals is small. Degradation can therefore be reduced by setting this spacing to a large value.[3]

4.3 RZ-DPSK transmission on DMF

DMF is a combination of "plus D fiber" deployed immediately after an optical amplifier in the repeater interval and "minus D fiber" placed after that fiber. Plus D fiber has positive wavelength dispersion and a large effective

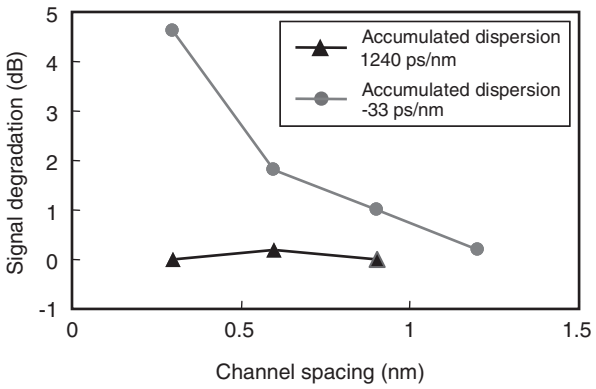


Figure 4
Channel spacing dependence of signal degradation.

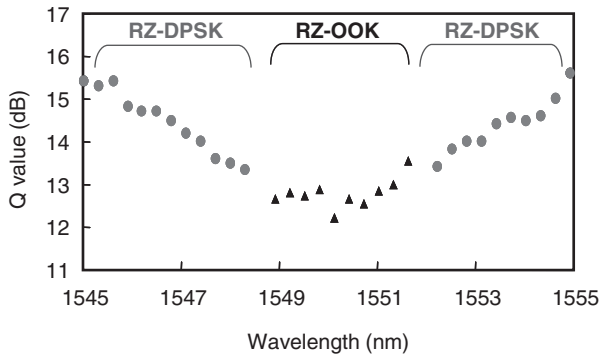


Figure 5
Channel dependency of Q value.

core area, which provides a small loss and good resistance to nonlinear effects. Minus D fiber has a small effective core area, so it compensates for the wavelength dependency of wavelength dispersion (dispersion slope) in plus D fiber. A signal that passes through plus D fiber, in which nonlinear effects cannot easily occur, will suffer some optical power loss but will then be input into minus D fiber that can also minimize nonlinear effects. This is why DMF is considered to have exceptional transmission characteristics. A good transmission path can be achieved on DMF with RZ-OOK and good transmission characteristics can be achieved with RZ-DPSK. Moreover, since DMF transmits signals over positive and negative dispersion fibers, there is no need to transmit signals only in the vicinity of zero dispersion as is necessary with NZ-DSF. As a result, signal degradation due to phase noise near zero dispersion is also small.

4.4 Increase in number of wavelengths by RZ-DPSK

When one sets out to perform an upgrade, the existing transmission path and existing modulation format are often NZ-DSF and RZ-OOK, respectively, which means that the system will be affected by the same two problems that occur in NZ-DSF transmission as described above (i.e., transformation of repeater-generated noise into phase noise that degrades the signal and conversion of RZ-OOK power-modulated signals into phase-modulated signals that become noise, which degrades the signal quality). However, when RZ-DPSK and RZ-OOK signals are configured adjacent to each other, these problems can be solved by broadening the channel spacing so that the difference between their propagation speeds is larger and by using RZ-OOK for long-distance transmission in the zero-dispersion region. Q-value characteristics for NZ-DSF transmission using RZ-DPSK and RZ-OOK are shown in **Figure 5**. Good characteristics were obtained by using RZ-OOK in the vicinity of zero dispersion (near 1550 nm) and RZ-DPSK in all the other regions.

5. Future developments

The huge cost of laying new cable for submarine optical communications systems has prompted studies on ways of increasing capacity within a limited signal bandwidth. For example, a high-density system can be achieved by reducing the wavelength spacing from the present 37.5 GHz (0.3 nm) to 25 GHz (0.2 nm).

Fujitsu researchers are also investigating the application of 40-Gb/s transmission (used in terrestrial systems) and digital coherent technology (now under study) to long-distance submarine systems.

6. Conclusion

Since they serve as a global telecommunications infrastructure, submarine optical communications systems must be able to respond quickly to changes in traffic demand, and the coupler insertion method has been established as a way to upgrade systems and increase capacity. To further expand the capacity of upgraded systems, RZ-DPSK transponders have been developed and applied to transpacific systems. Looking forward, Fujitsu plans to develop systems with even greater capacity to provide submarine optical communications systems with superior reliability and contribute to the expansion of broadband services.

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