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ALL-OPTICAL BACKBONE TECHNOLOGY

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1. Introduction^{Ref.1}

The electric power companies recognized the superior characteristics of optical fibre early, studied practical applications and have been laying their own optical networks since around 1980. Today, these companies anticipate a rapidly growing speed and capacity of Internet Protocol (IP)-based network traffic in the years ahead. It is also anticipated that the existing backbone networks composed of optical and electrical technologies might not be able to cope with the transmission needs, neither in capacity nor in speed. Also, as a result of the on-going deregulation in the electrical power industry and the telecommunications industry, the increase of broadband information on fibre to the home (FTTH) service will promote the use of optical cables in their access systems as well.

As electric power utilities are using a large number of optical communication systems, we think that it is important to foresee and understand the future backbone technologies capable of providing a large capacity and ultra-high speed from terabit per second to petabit per second in order to prepare for the ever-increasing needs of IP-based information and broadband services.

In order to realize economical backbone networks, telecommunication carriers and some of the electric power utilities are introducing wavelength division multiplexing (WDM) transmission systems that can expand the bandwidth without increasing the number of optical fibres. The electronic router is considered to be a bottleneck in raising the speed of optical backbone networks in the future. To solve this problem, it will be necessary to develop optical cross-connect switches and photonic routers. Such an ultra-high-speed network that is composed of all functions of multiplexing, demultiplexing, switching and routing at optical range is called "Photonic Network".

In connection with the rapidly growing needs for communications and the underlying Photonic Network, it is necessary for us to observe the future trends in the backbone network and the access network, and to identify the problems need to be solved.

This technical brochure outlines optical backbone technologies such as multiplexing methodology, amplifier technology, fibre technology, maintenance technology and measurement technology, to realize economical and efficient all-optical backbone network.

- **Regional Backbone Network**

The major offices/substations under the regional offices are interconnected in a loop topology, which helps in realizing an efficient and reliable network. The transmission speed is between 32Mbit/s and 600Mbit/s.

- **Local Network**

Distribution substations and field maintenance/construction offices under a regional office are also interconnected in a loop topology. The transmission speed is between 6Mbit/s and 150Mbit/s.

- **Access Network**

The access network is composed of point-to-multipoint communication systems that share the same optical fibre with multiple terminals so as to economically connect many circuit points installed on the customers' premises.

2.2 Optical Communication Networks for Electric Power Companies in the Future

Power system communication networks transmit information of system protection and system operation, monitoring and controlling information of power system equipment, as well as information to ensure efficient business operations. The volume of information related to load dispatching will increase with the increase of power system equipment. The volume of information related to information technologies (IT) is taking rapid strides along with the pursuit of business efficiency, meaning a higher efficiency for business operations and the progress of IT in order to cope with the deregulation of the electric power industry. It is planned to provide customers with a wide variety of information services that are designed to differentiate the services of competitors. Under these circumstances, the networks are now changing from a point-to-point system to a point-to-multipoint one.

In the future, therefore, the power system communication will rely more and more on the optical communication network that can flexibly fulfill needs of larger capacity and higher speed than other transmission media.

2.3 Entry into the Telecommunication Business of Electric Power Companies

As the use of personal computers (PCs) and the Internet expands, IT is making rapid inroads into work places and homes. Furthermore, it is anticipated that Ubiquitous Network Society will be realized soon, in which anyone can access any type of information at anytime, anywhere. The essential conditions in realizing this Ubiquitous Network Society include making computers

smaller, diversifying access terminals, developing attractive contents and using broadband networks.

Since the deregulation has been progressing in the telecommunication industry in many countries. As a result, major electric power utilities have joined the telecommunication business by establishing new communication companies. These new enterprises have now built their optical backbone networks and are offering private line services and IP-based services.

As well, the deregulation in the electric power industry has brought a lot of newcomers in this business. To win the strict competition, the existing electric power companies are taking measures, such as lowering their electricity price through cost reduction efforts. Now, under the principle of market after the removal of regulations, efforts are also being made to find new sources of revenue. Some of the electric power utilities have started the dark fibre rental service as one of their services.

Moreover, electric power companies in Japan have started FTTH business in order to put their own optical communication systems to profitable use. Of the ten major electric power companies in Japan, Chubu Electric Power Company started the field test of FTTH service in October 2000 and started FTTH service itself in November 2002. In March 2002, Tokyo Electric Power Company started FTTH service of a maximum speed of 100Mbit/s. Also, K-OPTI.COM, a subsidiary of Kansai Electric Power Company, joined FTTH business in April 2002. As of December 2002, five electric power companies are providing FTTH services themselves, through their subsidiaries or through affiliated companies. Since each electric power company is operating their business based on its own strategies, the type of organization offering service varies with the electric power company, namely the electric power company itself, or its subsidiaries/affiliated companies.

In view of needs for access systems with larger capacity and the increase of the number of subscribers, the arrival of Photonic Network with all-optical technologies that can realize backbone networks of ultra-large capacity and high speed is anticipated.

3. Roadmap of Research and Development of Photonic Networks

Internet traffic has been increased significantly since the appearance of World Wide Web (WWW) in the mid 1990's. The communication carriers had to increase network bandwidth to cope with this new situation and introduced wavelength division multiplexing (WDM) transmission systems, which enabled them to get more bandwidth without deploying additional optical fibre cable. WDM employs the multiplexing and demultiplexing operation in the wavelength domain in addition to optical pulse transmission technology. Compared with the case where only electronic multiplexing and demultiplexing is employed, data transmission at a significantly higher speed became possible by using the WDM technology. The noble optical network, which is called Photonic Networks, is expected to employ new optical communication technology, where data transmission technology used in the higher layers, such as switching and routing, is applied to the optical domain, as well as multiplexing and demultiplexing operation in wavelength domain in addition to optical pulse transmission. The roadmap of research and development of the Photonic Networks is described in the following sections.

3.1 The Efficacy of the Photonic Network as the Means for High Speed and Large Capacity Data Transmission

Expansion of transmission bandwidth of the backbone network is required due to the increase of the quantity of information of the data communications as the Internet grows. The installation of new optical fibre to cope with that bandwidth demand is high in cost, and the method to expand bandwidth by using already installed optical fibre is necessary. The method is used conventionally where the degree of multiplexing signals in electronic domain is increased and the multiplexed electronic pulse at a high data rate is converted into optical pulse to be transmitted in the optical fibre. By this method, however, the limitation of the speed of electronics devices restricts the maximum data transmission rate. In the electric domain, the maximum speed available at present is 40Gbit/s, and the speed limitation of the electronic devices is said to be around 100Gbit/s.

The multiplexing signals in the optical domain range is indispensable to overcome that limitation in the electric domain, and therefore, the Photonic Network is needed. Dense wavelength division multiplexing (DWDM) that uses multiple wavelengths as the multiplexing method in an optical domain has been rapidly developed and already put to practical use.

3.2 The Photonic Networks at Present and in the Future

Multiplexing about 100 wavelengths in DWDM is in practical use at present, and the prototypes

of DWDM system to multiplex several hundreds of wavelengths have been experimentally produced in the laboratory. To increase the number of multiplexed wavelength from hundreds to thousands of wavelengths in realization of super DWDM in the future, the progress of arrayed waveguide grating (AWG) in precision and stability, and the source laser technology to generate concurrently several wavelengths using supercontinuum (SC) light source is necessary. To realize super DWDM to multiplex thousands of wavelengths, a new optical fibre with wide band and an amplifier that enables operation in new bands have to be developed.

Once the link speed of tens of Tera bit/s is achieved with multiplexing wavelength technology, the performance bottleneck in the network moves from a link to a node, and then, the optical cross-connect which can switch optical paths has to be developed.

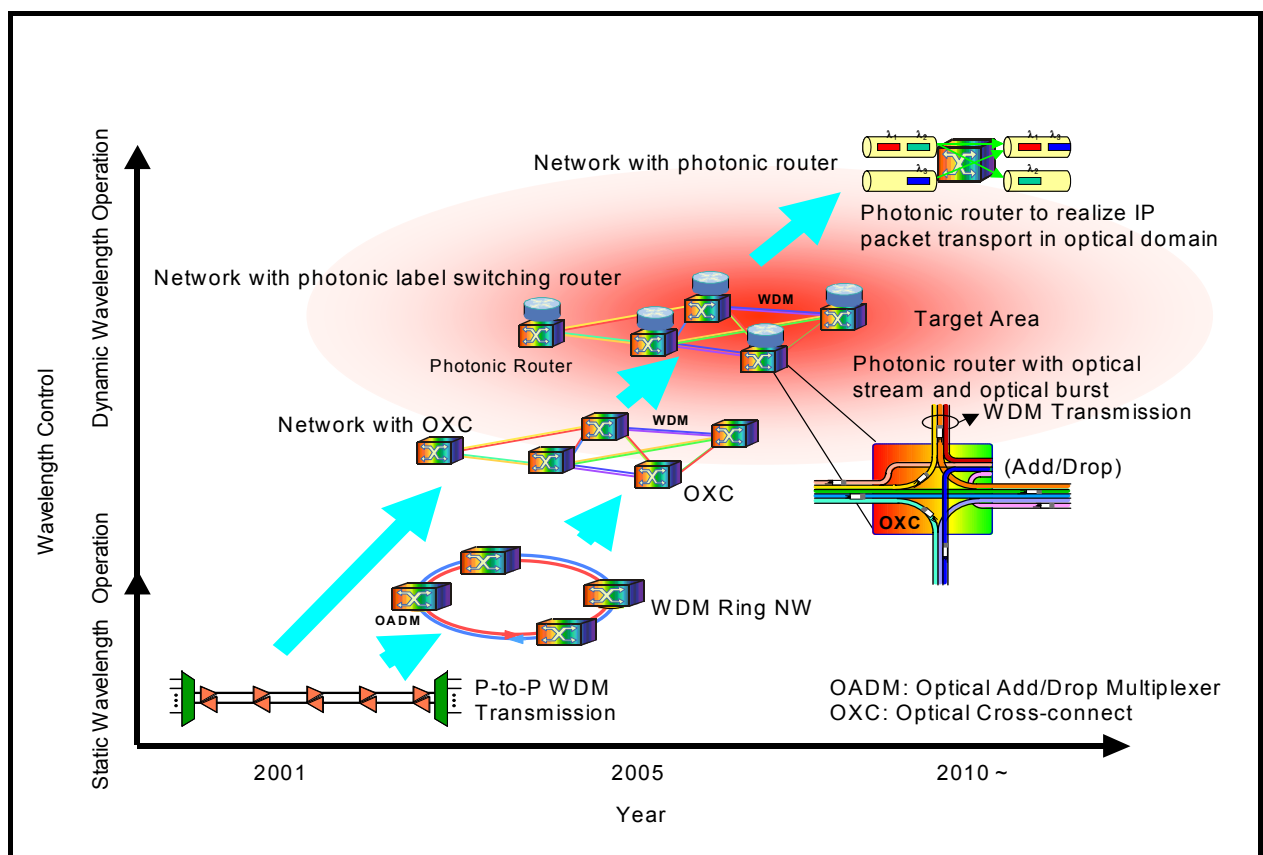


Fig. 3.2.1 Progress of the Photonic Network^{Ref.2}

3.3 Roadmap of the Development and Commercialization of Element Technology^{Ref. 2}

3.3.1 Development of Backbone Network

3.3.1.1 High Speed

The following technologies need to be developed to increase the data rate per wavelength,

considering reduction of equipment size and transmission cost.

- Optical transmission equipment with 80Gbit/s: Aiming at operating with a speed of 80Gbit/s or more by using the conventional electrical time division multiplexing (ETDM).
- Optical transmission equipment with 160Gbit/s: Aiming at operating with an ultra-high speed by using optical time division multiplexing (OTDM) because the speed exceeds the limitation of electronic devices.

Table 3.3.1 Roadmap for the development of ultra-high speed Photonic Network

	~ 2005	2005 ~ 2010	2010 ~
High speed	80-Gbit/s transmission equipment	160-Gbit/s transmission equipment	1-Tbit/s transmission equipment
Long distance	5,000km (@40Gbit/s)	10,000km (@40Gbit/s)	5,000km (@160Gbit/s)
High density	1.2bit/s/Hz	1.6bit/s/Hz	>2bit/s/Hz (multilevel modulation)
Wide band	150nm (5 bands)	200nm (seamless)	1.2 ~ 1.7 μ m (seamless)
Switch architecture	Wavelength pass switch	Optical burst switch	Optical packet switch
Optical device technology	Medium-scale optical switch	Large-scale optical switch	Ultra large-scale optical switch
	Ultra small size transponder array	Burst optical transponder	Optical 3R
	Semiconductor amplifier array	Optical wavelength conversion device	Optical buffer memory
Optical implementation technology	High density optical wiring	Optical waveguide platform	
	Small-size multi-core optical cable connector	Ultra small-size multi-core optical cable connector	
Optical monitoring technology	High speed optical SNR monitoring technology	High speed optical signal quality monitoring technology	
Control technology	Wavelength allocation control, optical burst routing control		Optical packet routing control

3.3.1.2 Large Capacity (Wide Band and High Density)

The following technologies about the improvement of the expansion of bands and the efficiency of wavelength usage to expand transmission capacity need to be developed.

- Development of an optical amplifier that is able to amplify the new wavelength bands such as the S band and U band.
- Development of an optical fibre which has the characteristics of low loss, low dispersion, and very low polarization mode dispersion in wide band, and flatness of polarization mode dispersion.
- Development of narrow band modulation technologies such as vestigial side band (VSB), single side band (SSB) and so on.

- Development of narrow bandwidth optical filters which have the characteristics of gain flatness for transparent channels and steep rejection characteristics of dropping channel to be suitable for the ultra-high density of wavelength
- Development of source laser technologies for the next generation in accordance with the ultra-high density of wavelength.

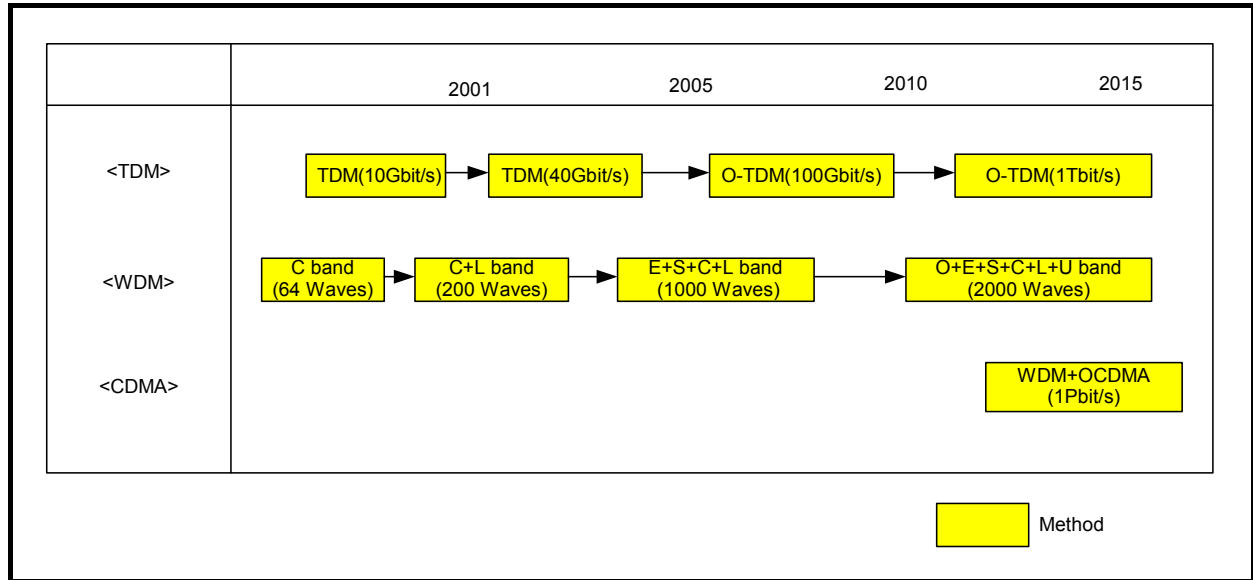


Fig. 3.3.1 Roadmap of the multiplexing method^{Ref.3}

3.3.2 Development of the Optical Switch in a Node

The signal processing such as IP packet routing in the present communication network is performed by routers and other network equipment based on the electronic circuits. However, the realization by using electronic devices has disadvantage of high cost and it is difficult to expand the capacity due to the limitation of electronic processing speed and O-E-O conversion is necessary in each relay station. The switching technology in the optical domain at the node that becomes bottleneck in the Photonic Network needs to be developed.

- Wavelength routing: to establish wavelength paths with optical cross-connect.
- Optical burst switching: to assign wavelength for the duration of data transport. It comprises optical switch and IP packet switching.
- Photonic packet routing: Wavelength is assigned to every optical packet. The network employs the photonic packet router.

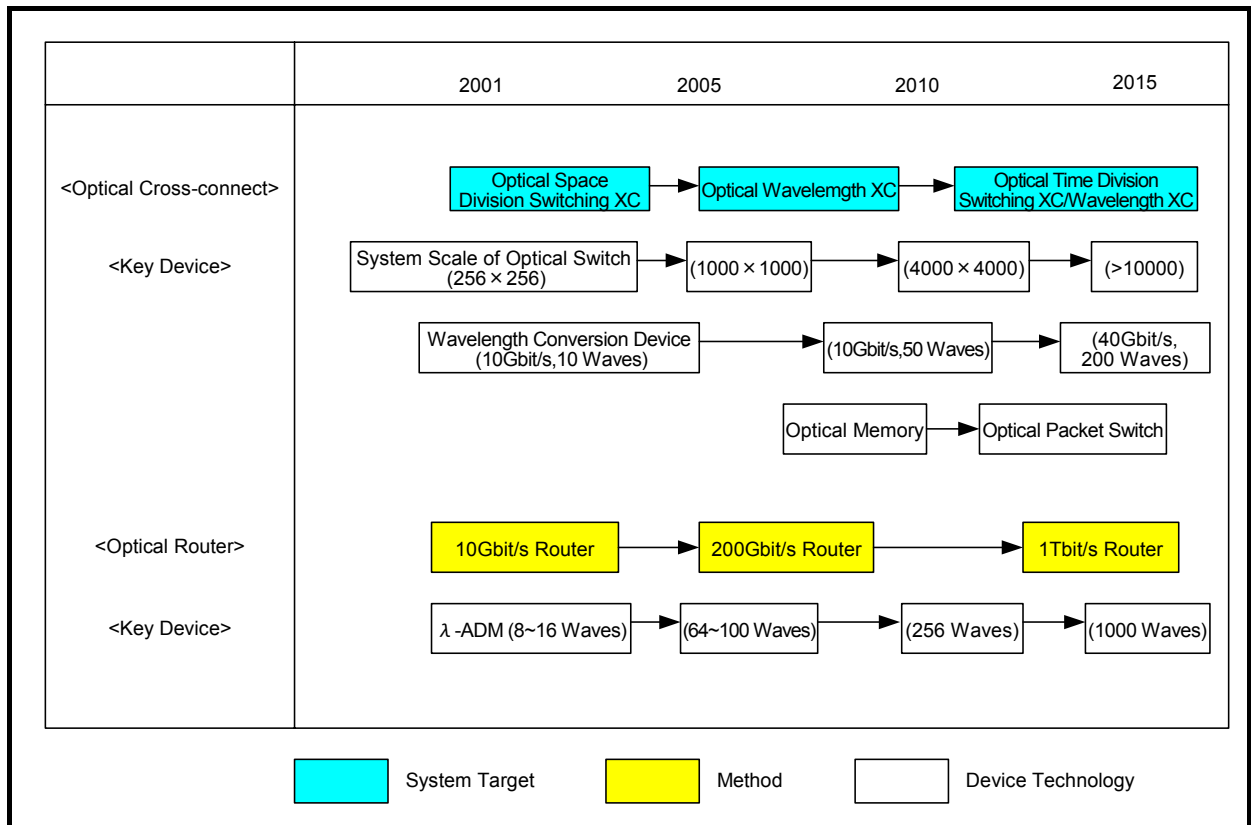


Fig. 3.3.2 Roadmap of branching & insertion, routing technology^{Ref.3}

4. Technology

The necessity of Photonic Networks is based on predictions that the information transmitted via networks increases at a rate higher than previously expected in the near future and that routing will become difficult if electrical processing continues to be employed. The transmission speed of access networks is expected to increase from the present level of kilobit or megabit per second to the gigabit class, together with a decrease in cost of terminal equipment. Accordingly, large transmission speeds of terabit per second (Tbit/s) or petabit per second (Pbit/s) will be required for backbone networks. The technologies necessary for realizing such networks are those capable of increasing the further link capacity of optical fibres and high speed routing at nodes. Innovation in network management should also be carried out.

Concerning point-to-point transmission using optical fibres, the wavelength division multiplexing over 100 wavelengths is commercially available with a transmission speed of 10Gbit/s. Increasing the number of the wavelengths and development of transmission systems with achieving higher bit rates per wavelength could make further enlargement of the total bit rate. Systems with a bit rate of 40Gbit/s using electrical multiplexing and demultiplexing (MUX/DMUX) will soon be commercially introduced, while optical MUX/DMUX technology might be employed for 160-Gbit/s systems. In the latter systems, the management of dispersion and nonlinear effects are indispensable. Although some ideas for that purpose are reported, but more precise and variable methods are needed. In order to increase the number of wavelengths, an exploitation of unused wavelength bands is desirable. The various optical amplifiers using rare-earth doped fibres, stimulated Raman scattering, and semiconductors are reported. However, these techniques are not established, with the exception of Erbium-doped fibre amplifiers that are useful in the C and L wavelength bands.

The signal processing at nodes is fully electrical at present. In other words, optical signals are converted to electrical signals in order to send them to an electronic router and then converted back to optical signals. This electrical procedure will become a bottleneck in the case of an explosion of traffic demand because the processor speed of the routers is at most 100 mega packets per second (Mpps). An optical routing where optical signals are routed without conversions between optical power and electrical power should be developed. It is known that the routing management that is one of the functions of a router is difficult to be performed optically at present. On the other hand, the packet switching and forwarding, another router functions could be possible without electric conversion.

It is considered that there are three main steps in establishing the optical routing technology. The first step is called wavelength routing, in which the direct wavelength path that carries stream data can be established by introducing optical cross-connect switches at each node. Each wavelength is selected according to whether it will be processed at the node or optically

bypassed the node. There are merits such as small delay time, reduction in router load and cost as well. The optical cross-connect is a kind of optical switch that has many input and output ports. As described below, the improvement on switching speed, number of ports, and reliability will be made. The wavelength-routed networks will soon be in practical use. However, for a system including wavelength conversion, further developments in hardware and software technologies are required.

The wavelength routing in the first step is suitable for streaming data like voice and video pictures. In the second step, optical burst data is switched in order to obtain higher efficiency of the network operation. The burst data has granularity between stream and packet data. In one of the architectures, the optical packets are sent prior to the burst data to reserve a wavelength. If there is no vacant wavelength, the burst data is discarded. The wavelengths are allotted during the real transmission of the burst data and then released after arrival at the next node. There seems to be no ultimate difficulty in this step although shortening the time for the wavelength assignment is a key issue.

The third step is the last one for photonic routing where the switching is done with every optical packet. For this purpose, the major breakthroughs in the optical buffer and optical switching by optical signals are required.

Essential technologies mentioned above are described in the following paragraphs: multiplexing, amplifier, add-drop routing, device, fibre, cable, maintenance, measurement, etc.

4.1 Multiplexing Technology

The recent quick spread of the Internet is causing a quick increase of network transmission traffic. This tendency will not stop but will gain further momentum as the access systems represented by FTTH become broadband.

According to some forecasts, a transmission capacity of the Pbit/s class will be necessary between major cities in the year around 2020. To support this transmission, the various multiplexing technologies are being studied for high-speed and large-capacity transmission.

This section introduces ①wavelength division multiplexing (WDM) that has realized the multiplexing of over a hundred wavelengths, ②optical time division multiplexing (OTDM) extended from the time division multiplexing (TDM) technology, and ③optical code division multiplexing now being studied as another new technology.

4.1.1 Wavelength Division Multiplexing (WDM) ^{Ref.4}

4.1.1.1 Outline

Dense wavelength division multiplex (DWDM) is a large-capacity optical transmission system attracting a great attention as a means of supporting the quickly growing communication and information with the spread of the Internet. DWDM is an important technology for future Photonic Networking.

While the conventional system inputs an intensity-modulated light into a single optical fibre for one signal, the DWDM system is able to transmit multiple optical signals using different optical wavelengths simultaneously.

Telecommunication carriers are actively implementing DWDM and now some systems in use multiplex 10-Gbit/s signals for more than 160 waves using the 1.55- μm band (C-band) and 1.58- μm band (L-band), with a transmission capacity of 1.6Tbit/s and more.

4.1.1.2 Features of Wavelength Multiplexing System

For multiplexing on the optical signal level, DWDM has the following features and allows the flexible and economical configuration of a large-capacity optical network.

- Since signals of different speeds and communication protocols can be accommodated, optical fibre can be used effectively.
- With 1552.52nm(193.1THz) as the standard, the wavelengths are arranged on the grids with 0.8-nm (100GHz) or 0.4-nm (50GHz) interval. (Under standardization by ITU-T G.692)
- Broadband optical amplifiers will enable an effective use of optical fibre.
- The transmission speed per wavelength can be reduced and the electronic circuit speed need not be increased. In addition, the allowable dispersion of the optical transmission line can be increased.
- Since the number of wavelengths can flexibly be set, facility investments can be made depending on the communication demand.
- Node processing (add and drop or routing) using wavelengths can be realized.

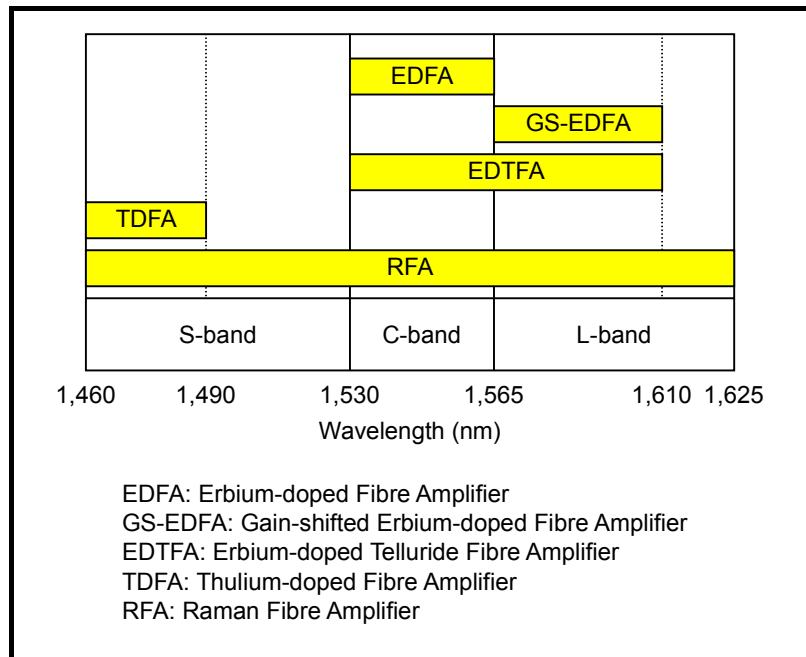


Fig. 4.1.1 DWDM waveband (optical amplifier band)

4.1.1.3 Wavelength Multiplex Transmission System

Fig. 4.1.2 shows an example of the DWDM system configuration. The DWDM system consists of wavelength converters that receive signals of the 1.31 or 1.55- μm band from existing optical terminal equipment, an optical multiplexer that multiplexes lights of different wavelengths, and a post-amplifier that amplifies the signals altogether. The light receiving section consists of a pre-amplifier that amplifies the multiplexed signals altogether, an optical demultiplexer that demultiplexes the wavelengths, and the optical receivers which receive the demultiplexed signals and send them to existing equipment. For repetition, an inline optical amplifier amplifies the wavelengths altogether.

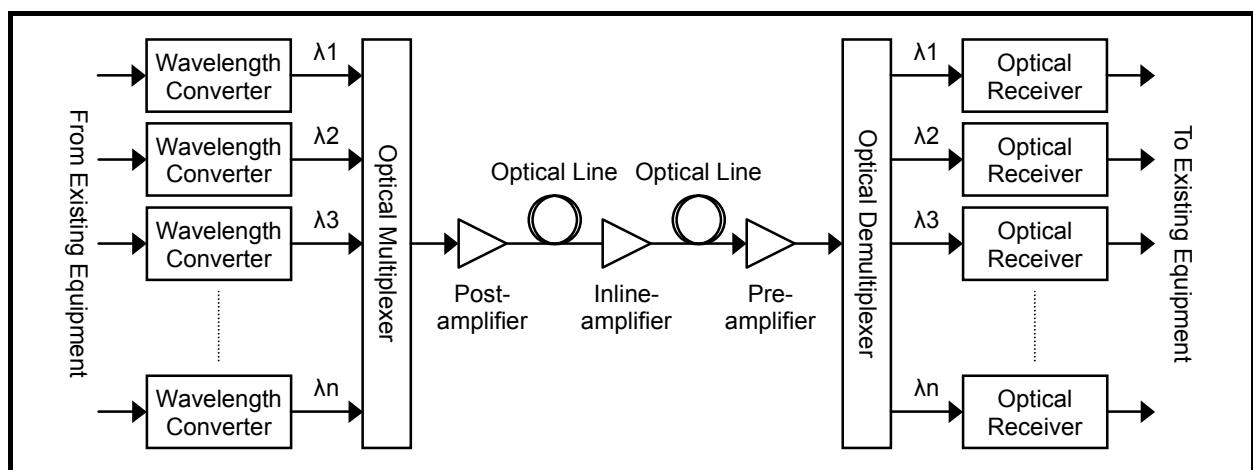


Fig. 4.1.2 Example of the DWDM transmission system configuration

Table 4.1.1 lists one example of the specifications of a 1.55- μm wavelength multiplex transmission system.

Table 4.1.1 Example of specifications of a wavelength multiplex transmission system

Item		Description
Fibre type		SMF, NZ-DSF, DSF (using L-band)
Wavelength multiplexes		72 channels max. (C-band: 32 waves, L-band: 40 waves)
Wavelength arrangement		1550-nm band (C-band): 1535.82 ~ 1561.01nm (0.8nm pitch) 1580-nm band (L-band): 1570.42 ~ 1603.17nm (0.8nm pitch)
Transmission speed		400Gbit/s max.
Transmittable signal type		150Mbit/s, 600Mbit/s, 2.4Gbit/s, 10Gbit/s
Allowable line loss		25dB $\times$ 4 ~ 6 spans (by system conditions) 30dB $\times$ 2 ~ 4 spans (by system conditions)
Unit	Size	W: 800mm, H: 2100mm, D: 600mm
	Mounting form	Self-standing rack
	Supply voltage	-48 VDC
	Cooling system	Fan cooling

4.1.1.4 1.31- μm Band Wavelength Multiplex System

In addition to the 1.55- μm band DWDM transmission system above, a system that transmits 1.31- μm optical signals by wavelength multiplexing is also in use. This system features strength against fibre bending. Losses are smaller when 1.31- μm optical signals are transmitted to SMF than when 1.55- μm signals are transmitted.

Now that the 1.55- μm band DWDM system is spreading globally on a massive scale, the 1.31- μm band WDM system is disadvantageous both in development speed and cost. Despite the excellent characteristics mentioned above, the 1.31- μm band WDM system is used only for transmission of about several tens of kilometers. Table 4.1.2 lists one example of the system specifications.

Table 4.1.2 Specifications of the 1.31- μm band four-channel multiplex transmission system

Item	Specification
Fibre type	SMF
Wavelength multiplicity	4 channels
Wavelength arrangement	$\lambda_1=1300\text{nm}$, $\lambda_2=1306\text{nm}$, $\lambda_3=1312\text{nm}$, $\lambda_4=1318\text{nm}$
Transmission capacity	10Gbit/s (2.4Gbit/s $\times$ 4 channels) max.

Item		Specification
Transmittable signal types		PDH: 32Mbit/s, 100Mbit/s, 400Mbit/s SDH: 50Mbit/s, 150Mbit/s, 600Mbit/s, 2.4Gbit/s
Allowable line loss		24dB (at 2.4Gbit/s)
Equipment	Size	W: 480mm, H: 400mm, D: 450mm
	Installation	On a JIS 19-inch rack or miscellaneous rack of 520mm wide
	Supply voltage	-48 VDC or +200 VAC
	Cooling type	Natural air cooling

4.1.1.5 Subjects

DWDM requires efficient, compact, and low-cost devices. To satisfy this requirement, the transmission light source should have stable and variable wavelengths and optical amplifiers should have broad wavelengths band.

Since one of the aims of multiplexed-transmission is a large-capacity transmission, many wavelengths are expected in a certain wave range. Reducing the frequency band occupied by one wavelength is effective for increasing the capacity. To satisfy this requirement, the current wireless communication systems modulate signals in various ways. Experimentally, non-return to zero (NRZ), return to zero (RZ), carrier suppressed return to zero (CS-RZ), optical duo-binary, single side band (SSB), vestigial side band (VSB), and quadrature phase shift keying (QPSK) modulations have been verified to be effective. The small frequency band per wavelength does not only have an advantage for high-density multiplexing but also features a great tolerance in dispersion compensation. The modulation type affects the nonlinear characteristics of an optical fibre because the optical power of a signal depends on the type of modulation. Consequently, this varies the launching optical power into an optical fibre and also the S/N ratio on the reception side. Of the modulations, NRZ, RZ, CS-RZ, and optical duo-binary have been studied by mutual comparison as reported here. Studies about SSB and VSB are not many but include a transmission experiment using a dedicated modulator with SSB and a transmission experiment by wavelength arrangement at unequal intervals with VSB. The coherent transmissions including QPSK are attractive but appropriate devices have not been developed yet.

4.1.1.5.1 NRZ Modulation

In digital signal transmission, the continuous mark signals with no breaks are called NRZ signals. NRZ optical signals can be obtained by a simple method that drives an optical modulator by NRZ electric signals and they are used for transmission at 10Gbit/s or less.

4.1.1.5.2 RZ Modulation

In digital signal transmission, the continuous mark signals with breaks are called RZ signals. Since the RZ signal amplitude changes faster than the NRZ signal amplitude, the frequency bandwidth is wider and the dispersion tolerance is smaller. When RZ optical signals propagate through an area of abnormal dispersion, the soliton effect increases the optical intensity. The soliton effect is produced by balance between the compression effect by self-phase modulation (SPM) and the pulse spread by dispersion.

4.1.1.5.3 CS-RZ Modulation

When light is modulated, its spectrum spreads symmetrically from the wavelength of the original light. The carrier has a certain optical power but the signal will not be lost even when the carrier is removed because it contains no signal. This kind of signal is called a carrier suppress signal. The spectral width becomes narrower than that of an RZ signal. When the carrier of constant optical power is removed, the optical power of a signal component can be increased for that amount. The easiest way of creating CS signals is using an optical modulator of the Mach-Zehnder type like a lithium niobate (LN) modulator. Driving the LN modulator by a large-amplitude signal voltage ($=V_{2\pi}$) with its bias as the optical null point will produce CS-RZ signals.

4.1.1.5.4 Optical Duo-binary Modulation

Duo-binary signals are tertiary signals that can reduce the frequency band when transmitting the same volume of information.

For conversion into tertiary signals, binary signals are pre-coded by a delay unit and a logic circuit and let through a low-pass filter having the quarter band of the bit rate. This is a band-limited tertiary signal of $+0-$. To obtain a tertiary value from an optical signal, the optical phase is used as well as 0 and 1 of the amplitude. In other words, a tertiary value is generated by the 0-phase of +1 and the π phase of -1. An LN modulator driven by two electrodes easily realizes this O/E conversion. For a signal reproduction, in this case no special decoder is necessary but a binary-signal receiver can be used as it is.

Among the four modulation types, the duo-binary modulation requires the narrowest frequency band and has the greatest tolerance against dispersion. Despite these excellent characteristics, the optical power into an optical fibre is the smallest. This is because the narrowest frequency band is susceptible to stimulated Brillouin scattering.

Table 4.1.3 lists the characteristics of the above modulations.

Table 4.1.3 Comparison of modulation types

	NRZ	RZ	CS-RZ	Optical duo-binary
Dispersion tolerance	Medium	Small	Small	Large
Receiver sensitivity	Medium	Slightly large	Slightly large	Slightly large
Allowable optical power	Medium	Large	Large	Small
Frequency bandwidth	Medium	Rather large	Large	Small

4.1.1.6 Outlook

As Table 4.1.4 shows, the DWDM technology is expected to further increase the transmission capacity with the optical amplifiers gaining broader bands and the evolution of other optical devices.

Meanwhile, the network configuration will grow from the current point-to-point communication network to a loop network of add/drop for each wavelength using add/drop multiplexer (ADM) technology and even to a mesh-type network of cross-connection (OXC) for each wavelength.

Table 4.1.4 Capacity increase of the wavelength multiplexing system

Item	Present	Future
Wavelength multiplicity	200 max.	1,000 max.
Optical amplification band	80nm max.	200nm max.
Wavelength interval	0.8nm / 0.4nm	0.8nm / 0.4nm / 0.2nm
Acceptable interface	10Gbit/s max. (40Gbit/s max.) (Gigabit Ethernet)	Not dependent on bit rate
Transmission capacity	Up to several Tbit/s	Up to tens Tbit/s

4.1.2 Optical Code Division Multiplexing

4.1.2.1 Outline

With the quick spread of Internet use, the demand for information communication services is even growing. As a general home service, 100Mbit/s-class FTTH is becoming a reality. To further propagate the service at a faster pace, increasing the backbone capacity is important.

As technologies for increasing the communication capacity, optical time division multiplexing (OTDM) and wavelength division multiplexing (WDM) have been studied.

The capacity increase by WDM is nearing saturation because the associated wavelength resources are anticipated to be lacking in future.

As a breakthrough technology, optical code division multiplexing (OCDM) is now under study. This technology has a feature where several channels can be multiplexed at the same time using the same wavelength. With the WDM technology combined, OCDM is expected to be a means of constructing an ultra-fast and large-capacity optical network that has a capacity of the petabit class.

4.1.2.2 Principle

Fig. 4.1.3 shows various multiplexing methods.^{Ref.5} Time division multiplexing (TDM) divides the time axis and assigns a segment to each channel for multiplexing. WDM assigns each channel to each band on the wavelength axis for multiplexing. Code division multiplexing (CDM) encodes channel data by using different optical orthogonal codes for each channel.

For encoding, each data bit is substituted with an optical orthogonal code. Whereas an optical orthogonal code has a characteristic that the correlation with its own code becomes 1 and that with a different code becomes 0. This characteristic allows code identification on the reception side by correlation operation using the same code but not the restoration of signals encoded using a different code.

Since each channel is formed in a specific band centered on the wavelength of the light source, many users can share a single band.

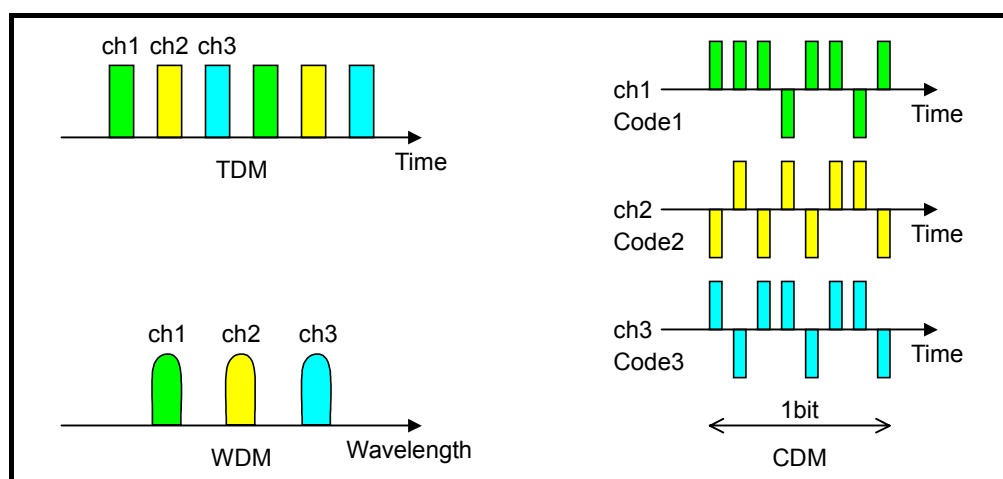


Fig. 4.1.3 Multiplexing methods

4.1.2.3 Outlook

The problems need to be solved for practical use are to reduce interference noises and to make optical transmitters and receivers stable and compact. Studies on technologies about an optical label switch router that maps IP addresses into OCDM optical codes are also progressing. Thus, OCDM is expected to be a means for laying Photonic Network.

4.1.3 Optical Time Division Multiplexing (OTDM)

4.1.3.1 Outline

TDM is a key technology for multiplexing in digital communication. The other major multiplexing methods are frequency division multiplexing (FDM) and CDM. TDM is being applied to a wide range of areas. European Telecommunications Standards Institute (ETSI) began to standardize the TDM-based dynamic synchronous transfer mode (DTM) to support personal digital cellular (PDC) and personal handyphone system (PHS) for mobile communications on one hand and the time compression multiplexing-time division multiple access/passive double star (TCM-TDMA/PDS) for access communications on the other hand.

The recent report on current technological trends introduces the prototype devices of electrical (E)-TDM (40 Gbit/s) and optical (O)-TDM (120Gbit/s) for terabit transmission equipment that will be used as trunk transmission equipment for digital communications.

4.1.3.2 E-TDM

The E-TDM multiplexing performance depends on the operating speed of the device. For multiplexing at 40Gbit/s, the operating frequency of a D-type flip-flop (D-F/F) should be 200GHz. For operation at this frequency, an indium-phosphorous (InP) heterostructure field-effect transistor (HFET) of 0.1- μm gate was proposed and 40Gbit/s E-TDM has already been realized in a prototype. According to some reports, even 100Gbit/s is feasible with field-effect transistor (FET) and super-dynamic D-F/F that are now available. In this speed area, however, the wiring delays cannot be ignored as the electromagnetic wave interferences, transistors and wirings should be refined without increasing parasitic resistances.

4.1.3.3 O-TDM

O-TDM processes optical signals using an ultra-fast phenomenon called a nonlinear optical

effect that is completely different from a signal processing by the conventional electric circuit. The basic circuit used for O-TDM consists of the optical Kerr effect and four-wave mixed switches and other components. Fig. 4.1.4 shows a four-wave mixed switch. At the switch, a signal of optical frequency ν_s parametrically interacts with a control light of optical frequency ν_{sa} ($\nu_{sa}=2\nu_p-\nu_s$) to produce a converted light. Since an optical pulse of optical frequency ν_{sa} is generated for a signal optical pulse overlapping with a control optical pulse, only a converted light can be obtained through an optical filter that allows only a light of a converted wavelength. This allows for the optical switching.

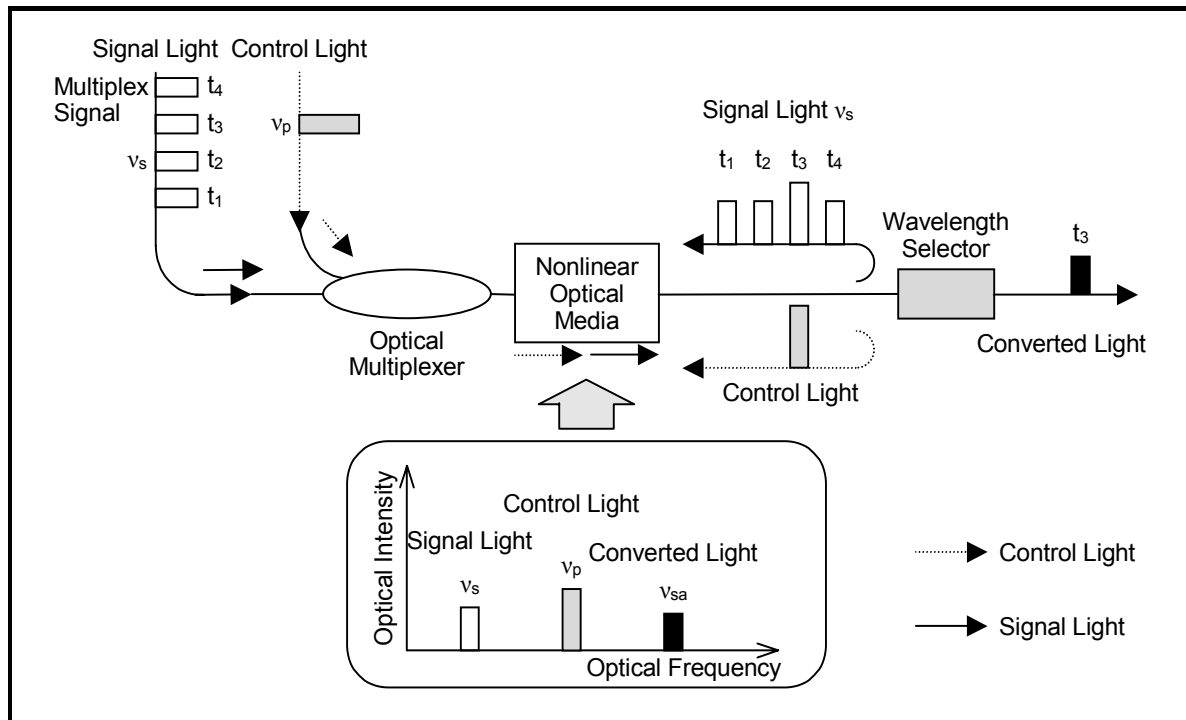


Fig. 4.1.4 Concept of four wave mixed switch operation

By using various high-speed laser technologies, O-TDM generates short optical pulses of several picoseconds to femtoseconds that are difficult to generate by electric circuits. Fig. 4.1.5 shows a schematic diagram for producing O-TDM signal using a single short pulse source. The picosecond-pulse train is divided into plural pulse trains by an optical coupler. After modulation and delay the pulse trains are again combined by an optical multiplexer.

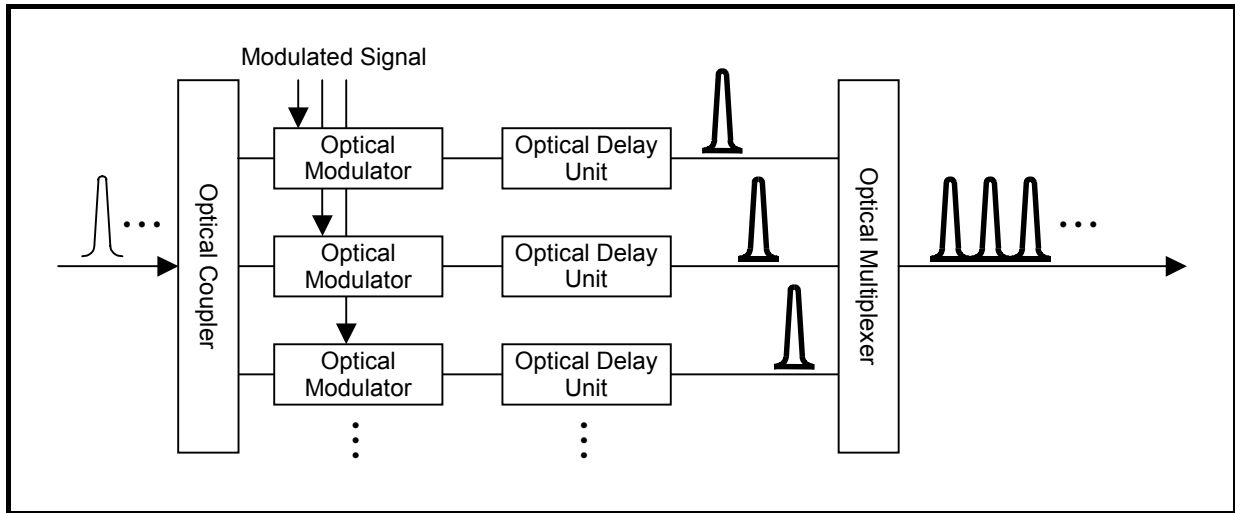


Fig. 4.1.5 Concept of O-TDM operation

The TDM circuit basically consists of optical switches.

Fig. 4.1.6 shows the configuration of a 120-Gbit/s O-TDM prototype.

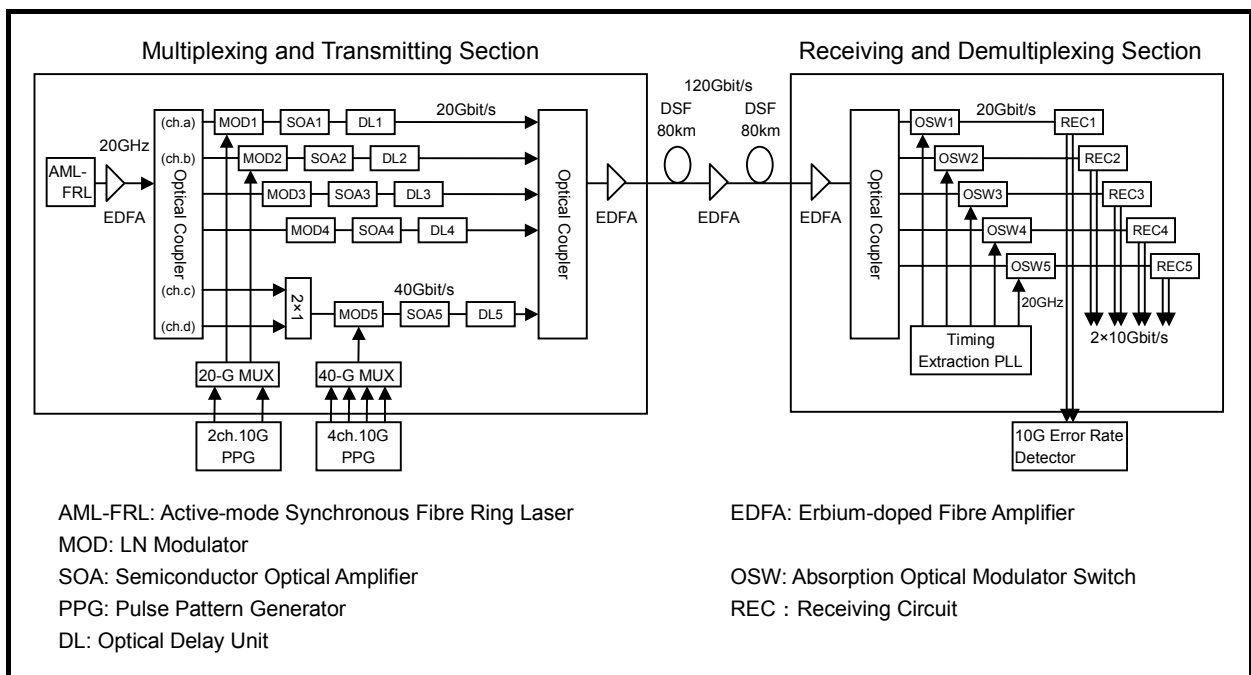


Fig. 4.1.6 Configuration of 120-Gbit/s prototype

4.1.3.4 Outlook

DWDM and O-TDM are effective means for realizing terabit transmission. On the laboratory level, the maximum transmission speed by TDM is 1.28Tbit/s and the total transmission speed by DWDM is more than 10Tbit/s.

4.2 Amplifier Technology

As a breakthrough technology regarding transmission limitations determined by the speed, distance, and capacity, expectations of all optical processing are growing. In the technique transparent signal processing is performed using ultra-high frequency characteristics of light. The implementation of such optical processing places a greater importance on the optical amplification technology in which the optical signal is directly amplified.

Already available optical amplifiers for communication purposes are optical fibre amplifiers with rare earth, semiconductor optical amplifiers, and Raman amplifiers.

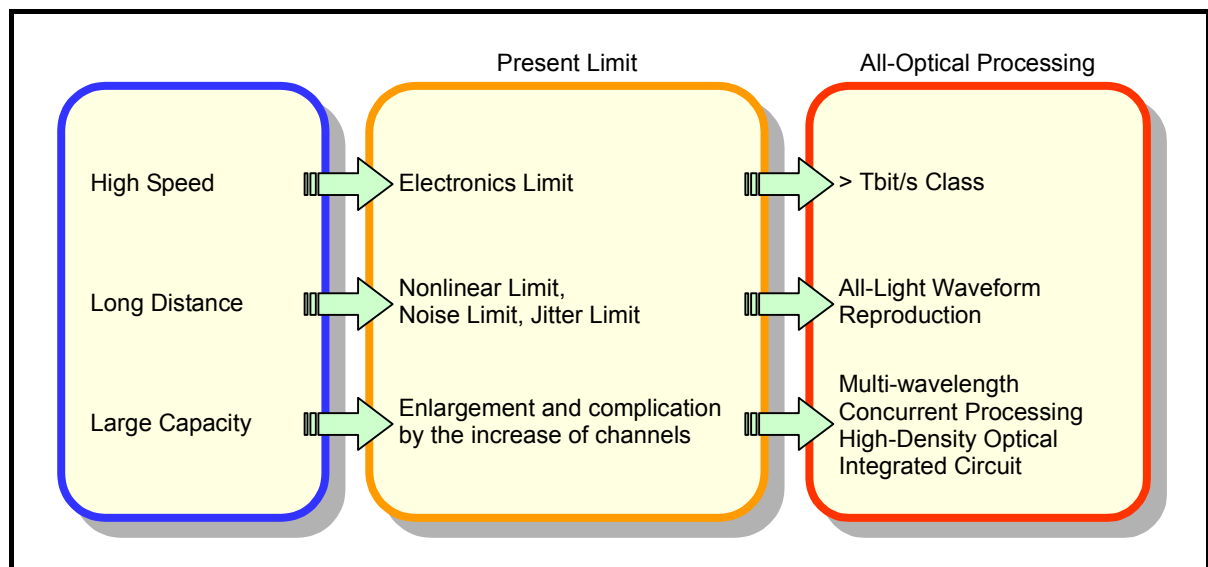


Fig. 4.2.1 Expectation for all-optical processing

4.2.1 Optical Fibre Amplifier with Rare Earth

4.2.1.1 Outline

The first experiment on a 1.55- μm band optical fibre amplifier using erbium-doped optical fibre was reported in 1987 by Southampton University in the United Kingdom. This optical fibre amplifier resulted in a higher output power, lower loss, and higher sensitivity of optical properties, opening the door to high-speed and large-capacity optical communications.

The key features of an optical fibre amplifier are the increased transmission distance regardless of the signal transmission speed and modulation format, and high-speed transmission with a simple device configuration. In addition, the optical amplification properties make a wider bandwidth, higher output power, higher gain, and lower noise possible.

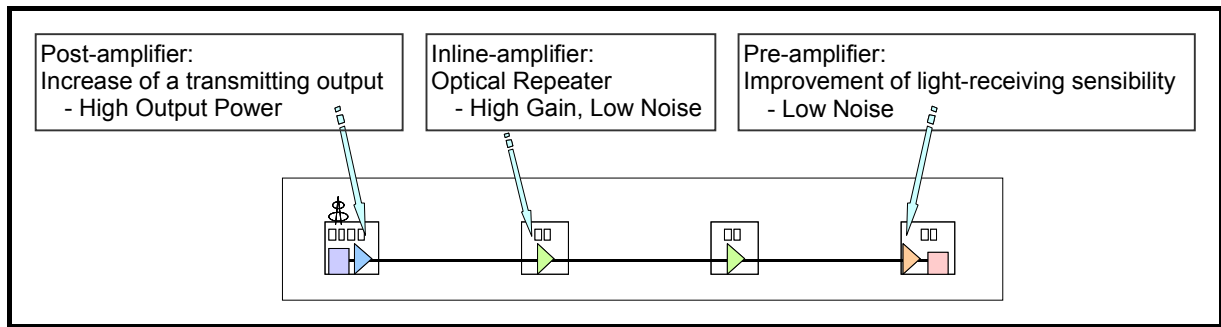


Fig. 4.2.2 Features and uses of an optical fibre amplifier

4.2.1.2 Configuration

An optical fibre amplifier consists of a rare earth ion-doped optical fibre, a pump light source that supplies the amplification energy, and an optical multiplexer that multiplexes the pump light onto the optical signal path.

Rare earth erbium ions for the 1.55- μm band amplification and praseodymium ions for the 1.31- μm band amplification are added to the optical fibre. The pump light wavelengths are 1.48 μm or 0.98 μm for erbium-doped fibre amplifiers, and 1.01 μm for praseodymium-doped fibre amplifiers.

Because the laser diode (LD) for 1.48- μm band provided comparatively large output more than 200mW from the beginning, it is widely used as a post-amplifier pump light source.

On the other hand, the use of a 0.98- μm pump light source has been delayed because of the reliability problems such as the end deterioration phenomenon. However, in view of its positive features like a low noise factor (3 ~ 4.5dB) and high pump efficiency ($\sim 10\text{dB/mW}$), the 0.98- μm pump light source has recently been used in optical fibre amplifiers for long-distance transmission systems.

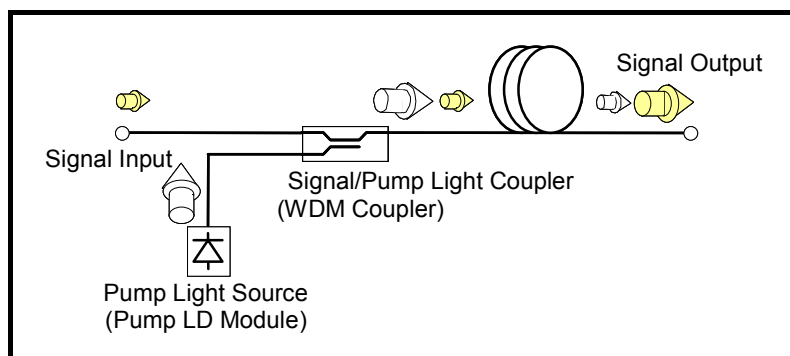


Fig. 4.2.3 Example of an optical fibre amplifier configuration

4.2.1.3 Broadband Optical Fibre Amplifier

The use of the optical fibre amplifier as a key device in DWDM requires still lower noise, higher output power, wide bandwidth characteristics and gain flattening in the future.

Table 4.2.1 Wide bandwidth characteristics of the optical fibre amplifier

Requirement	Amplifier	Key device
Low noise	Pre-amplifier: Carry out high-sensitivity reception of the high-speed signal	980-nm band pump LD module for noise figure (NF) reduction
High output power	Post-amplifier: Keep the output power at the time of wavelength multiplex	1470nm: 200~250-mW class LD module 980nm: 150 (DCH structure:300)-mW class LD module
Broad band / Gain flatness	Post-amplifier Inline-amplifier Pre-amplifier	- Al co-doped EDFA - Er-doped fluoride optical fiber amplifier - Er-doped tellurite optical fiber amplifier - Compounded type/Parallel type EDFA

4.2.1.3.1 Al Co-doped Erbium-doped Fibre Amplifier (EDFA)

One example of implementing the wide bandwidth characteristics to obtain broadband properties is the common practice of co-doping optical amplification fibre with aluminum (Al) ions and erbium (Er) so that gain peaks are flattened.

Adding Er to the pure silica core of silica-based optical fibre obtains gain peaks at 1536nm and 1552nm.

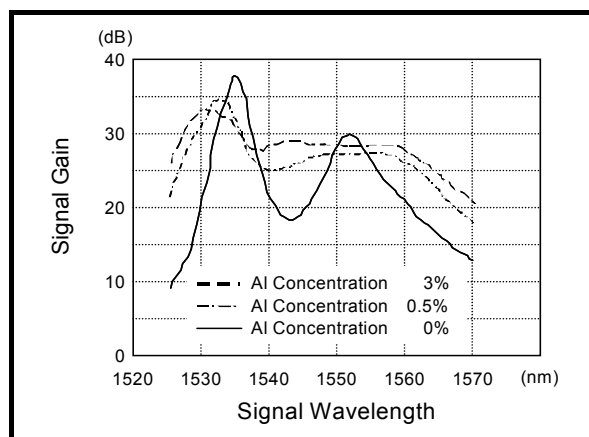


Fig. 4.2.4 Amplification properties of Al co-doped optical fibre

4.2.1.3.2 L-band Erbium-doped Fibre Amplifier (EDFA)

Normally, the amplification band of EDFA, which is called the C-band, is about 35nm at around 1530 ~ 1565nm. Recently, using a longer EDF, this is about 10 times longer, in a low population inversion led to the development of L-band EDFA that amplifies the 1570 ~ 1600nm wavelength area, and commercialization and installation of L-band EDFA have already begun.

If a 1.55- μ m band DWDM transmission is performed in DSF marked effects due to the nonlinear effect four-wave mixing (FWM) occur, since the wavelength dispersion is zero, causing problems for DWDM transmission. Since the wavelength band, from 1570 to 1610nm, whose dispersion is not zero, can be used for L-band EDFA; it is appropriate for the DWDM transmission.

An example of implementing a broadband EDFA by configuring C-band EDFA and L-band EDFA in parallel through a WDM coupler has also been reported as shown Fig. 4.2.5.

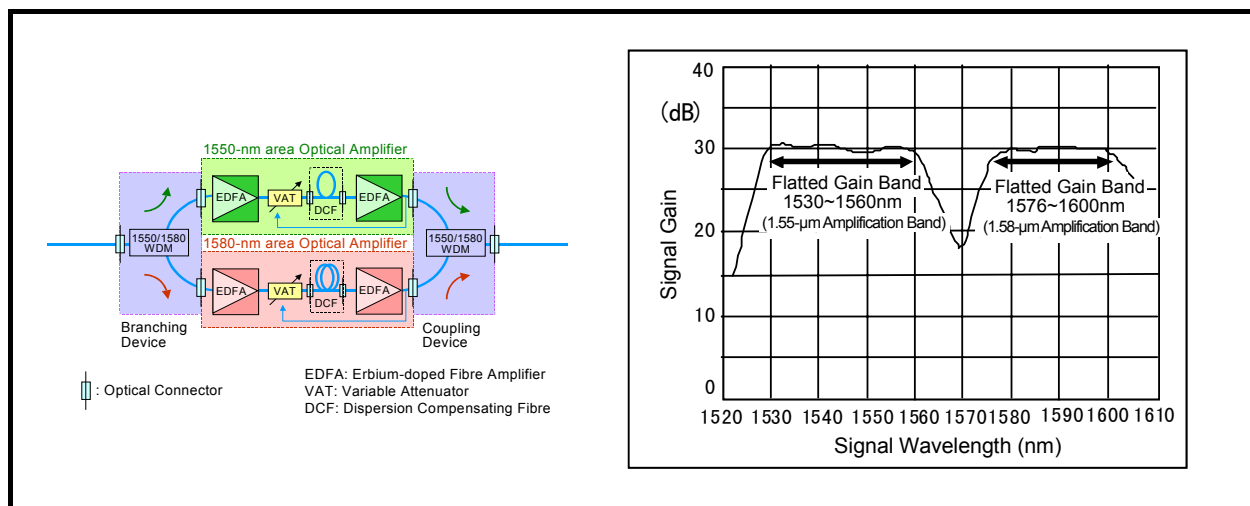


Fig. 4.2.5 Amplification properties of parallel EDFA

4.2.1.3.3 Er-doped Telluride Fibre Amplifier (EDTFA)

Using telluride glass instead of the general silica-based glass optical fibre, the entire wavelength band of 1530 ~ 1610nm can be amplified at a time. Since the gain depends in a great measure on the wavelength for this EDTFA, it needs to be flattened with the help of a gain equalization filter.

4.2.1.3.4 Er-doped Fluoride Fibre Amplifier (EDFFA)

If fluoride glass is used as the glass component in the optical fibre, the properties of flattened and broader gain peaks can be obtained in comparison with silica-based glass, one example is shown in Fig 4.2.6, in which the gain is from 1525 to 1565nm.

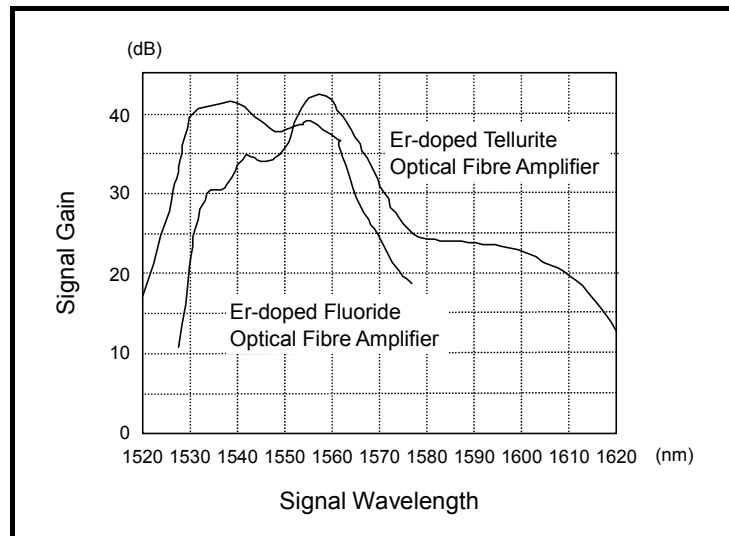


Fig. 4.2.6 Amplification properties of EDTFA and EDFFA

4.2.1.3.5 Thulium-doped Fibre Amplifier (TDFA)

If the rare earth element to be added is changed to thulium, the short wavelength of 1.45- μm band and the long wavelength of 1.65- μm band can be amplified.

4.2.1.4 Outlook

Fig. 4.2.7 shows the optical fibre amplifiers of various wavelength bands that have been developed. Attempts to obtain still broader amplification features by combining these optical fibre amplifiers have already begun, and the results of the effort will have an effect on the future optical communications.

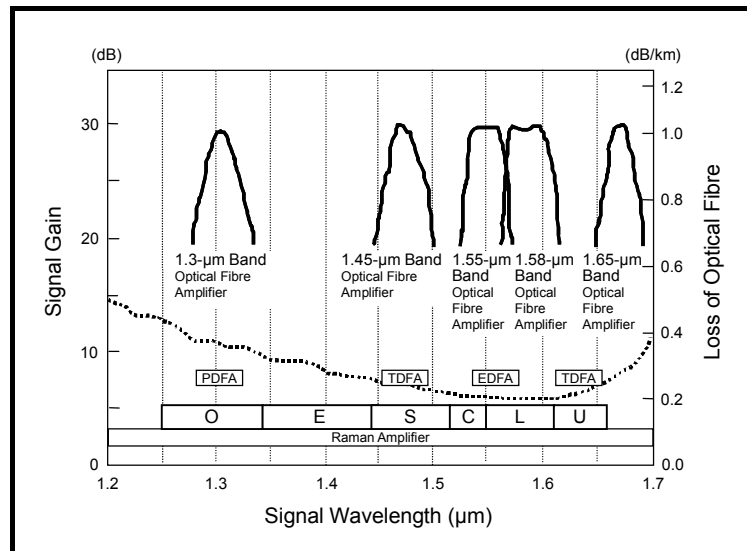


Fig. 4.2.7 Future prospects of the optical fibre amplifier

4.2.2 Optical Fibre Raman Amplifier

4.2.2.1 Outline

Although the research on Raman amplifiers that use the stimulated scattering phenomenon produced by nonlinear scattering in the optical fibre began in the 1980s, but in view of its low amplification efficiency and requirement of a pump light source with high output power, the high-efficiency rare earth doped optical fibre amplifier has gained prominence in recent years. Lately, however, with still higher output power of the semiconductor laser available for the pump, the demand for an optical amplification in the broadband wavelengths has been increasing, causing a sudden upsurge in research and development activities of Raman amplifiers.

Features of Raman amplifiers include optical amplification that is possible with the normal optical fibre and the capability of obtaining any amplified wavelength by setting the pump wavelength. The wide bandwidth characteristics of amplifiers for a large-capacity transmission are extremely desirable for DWDM, but the amplification bands become incomplete with the rare earth doped optical fibre amplifiers because of their dependence on the rare earth elements. For this reason, an attention has been focused on the Raman amplifier as a means of amplifying the wavelength bands that cannot be amplified by the rare earth doped optical fibre amplifier.

4.2.2.2 Configuration

For an optical amplification, the Raman amplifier uses the nonlinear phenomenon of stimulated Raman scattering that causes emission in the wavelength area to be shifted from the pump light

wavelength by the specific optical frequency when strong pump light is transmitted in the optical fibre. Thus, by achieving the variable wavelength of the pump light with high output power, it becomes possible to amplify any wavelength band and to perform an optical amplification of the wide bandwidth characteristics by multiplexing the pump light with different wavelengths.

The following section discusses some typical distributed Raman amplifiers.

4.2.2.2.1 Distributed Raman Amplifier

Since the optical fibre itself is involved in the amplification process in a distributed Raman amplifier, the amplifier acts in such a way that the transmission path losses are compensated, thereby improving the optical S/N ratio.

As an example of this application, the remote pump light is launched at the receiving side of a submarine cable system for Raman amplification to increase the distance between relay points.

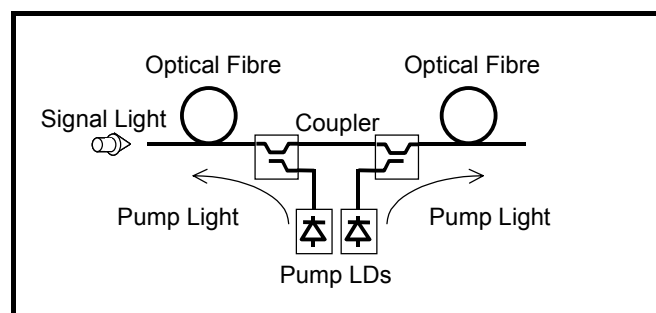


Fig. 4.2.8 Configuration example of a distributed Raman amplifier

4.2.2.2.2 Hybrid Raman Amplifier

Since the optical fibre can be used as an amplification medium to lower the input level so that nonlinear effects can be suppressed, the hybrid amplifier combined with EDFA is used as a technology to reduce the wavelength interval of DWDM. Also, the DWDM transmission using DSF can be implemented because FWM can be suppressed even in the zero dispersion wavelength band. At the same time, the improved optical S/N ratio can increase the relay distance from 80km to 120 ~ 140km.

4.2.2.3 Subjects

In case of Raman amplifiers, the first issue is about the multiplexing method for the pump light

source. Another one is the countermeasure for characteristic variations when the optical fibre for the transmission path is itself used as an amplification medium. The third one is the countermeasure for level variations caused by multiple relays. Since the amplifier cannot be used in a saturated area, the signal level is not restored if the signal level falls below a certain point. The fourth one is the increase in power consumption involved in the higher output power of the pump light source.

4.2.3 Semiconductor Optical Amplifier (SOA)

In contrast to the semiconductor laser, the semiconductor optical amplifier is a device that performs optical amplification of the incident signal light through stimulated emissions. The amplification is accomplished by setting the reflection factor of both ends extremely low so that the resonance can be suppressed as much as possible and by using the population inversion caused by carrier injections into the laser active layers.

Although the amplification is possible in various wavelength bands, but there are still many problems to be solved before its commercial use is possible. Examples are the high noise factors, low gain/saturation power, and low stability/reliability compared with the optical fibre amplifier.

Integration can already be achieved, and now applications such as to optical gate switches or matrix switches are in use, for example, to optical cross-connects, and receive a widespread attention; the same is true for wavelength conversion and waveform regeneration using nonlinear effects.

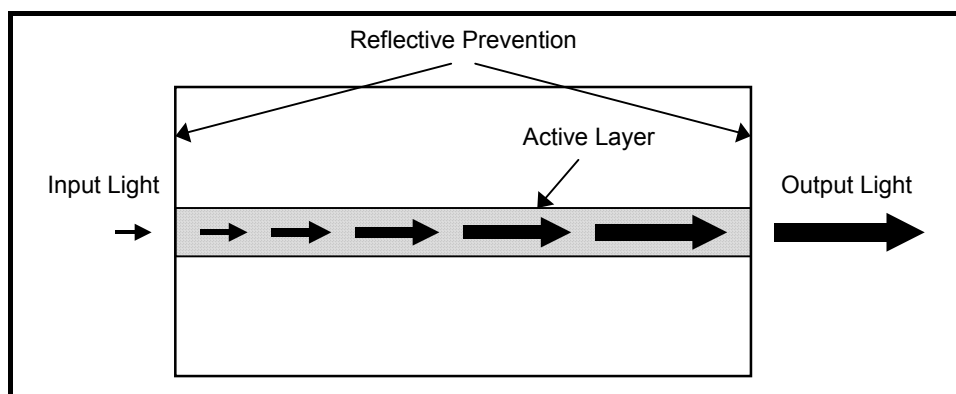


Fig. 4.2.9 Concept of the semiconductor optical amplifier

4.3 Add-drop and Routing Technology

The growing demand for a large transmission capacity to meet the quick increase of Internet

traffic and the advance of wavelength multiplexing technology are making Photonic Networking a reality. For Photonic Networking, the add-drop and routing technologies are very important to control wavelengths and exchange data between any arbitrary points.

This section introduces the optical cross-connect, optical ADM, and optical router technologies.

4.3.1 Optical Cross-connect

4.3.1.1 Outline

The optical communication started from a point-to-point transmission and changed to ring networking using the ADM function. Then the development of the optical ADM function has put the WDM function into practice and is now promoting its diffusion.

For future optical communications, a mesh-like configuration of optical transmission lines is expected to change the entire network into a flexible and very efficient one that can detour faults and partial traffic congestions. For laying such type of a mesh network, the optical cross-connect technology is necessary.

If further technological advance allows the independent management of wavelengths according to traffic fluctuations, the high-grade Photonic Networking can be realized on optical routers.

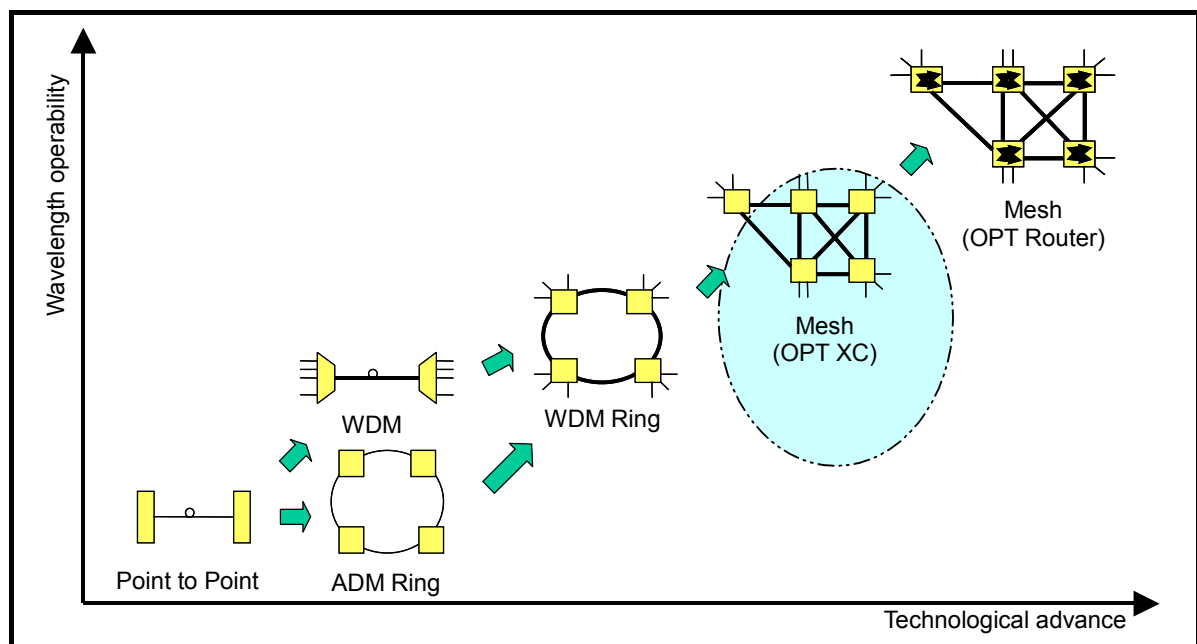
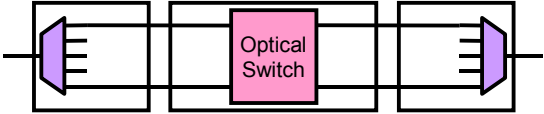
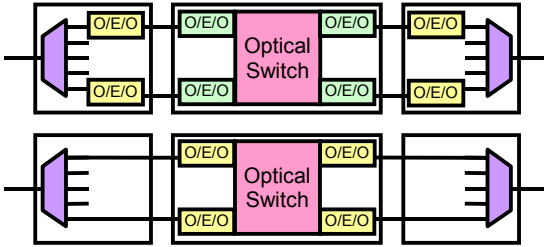
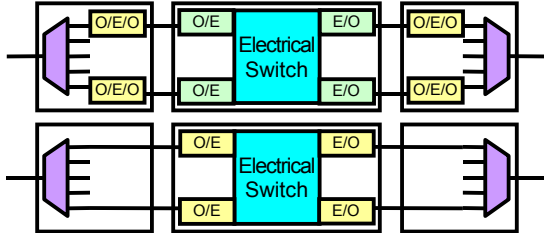


Fig. 4.3.1 Advance of network technology

4.3.1.2 Optical Cross-connect Functions and Types

The switch elements used for the optical cross-connect are electronic and optical switches. The optical switches either convert optical signals from WDM once into electronic signals and again into optical signals, or directly enter optical signals from WDM. By function, the switch elements are classified into the transparent type and opaque type.

Table 4.3.1 Classification of optical cross-connect switch elements

Function	Switch Element	Combined with WDM
Transparent	Optical Switch	
Opaque	Optical Switch	
	Electronic Switch	

The transparent-type of the optical cross-connect (OXC) may be advantageous in terms of equipment cost, scale, and power consumption but it is disadvantageous in terms of fault identification, noise accumulation, and connection to the WDM of another manufacturer. This is the opposite in case of the opaque-type of OXC. Table 4.3.2 lists these characteristics.

In view of their characteristics, both types of OXC need to be implemented together to make the effective use of their advantages.

Table 4.3.2 Characteristics of OXC functions

Function	Switch Element	Feature
Transparent	Optical Switch	(: Not dependent on the signal speed or protocol (: Curtailing electronic processing →(: Possibly reducing cost, power consumption, and space (: Quality monitor system not established yet (: Difficult to locate a fault (: Shared protection difficult →(: Necessary to reserve spare band by 1+1 protection (: Optical interface not conforming to standards O/E and E/O necessary to make the interface open (: Limitation of applicable range due to loss of switch element
Opaque	Optical Switch	(: Dependent on the signal speed and protocol (: Electronic processing (E/O, O/E) →(: Wavelength conversion possible →(: Very free network configuration (: Quality monitoring by LOS/LOF/BER possible →(: Very consistent with the conventional management techniques (: Abundant management functions (SDH, G.709) available (: Shared protection possible →(: Possibly curtailing resources necessary for protection
	Electronic Switch	

(: Advantage

(: Disadvantage

4.3.1.3 Outlook

At present, the electronic switches of about 100×100 in scale and 10Gbit/s in speed per channel are about to become practical, and the optical switches of 10s×10s in scale and 10Gbit/s in speed per channel have already been commercialized.

In the future, the speed per channel will be improved, the switch will be increased to 1000s×1000s in scale, and the cost and size are likely to be reduced.

4.3.2 Optical ADM

The supply of optical ADM products has started to help not only to increase the capacity of a backbone network (point-to-point DWDM), but also to lay a network for each optical wavelength path.

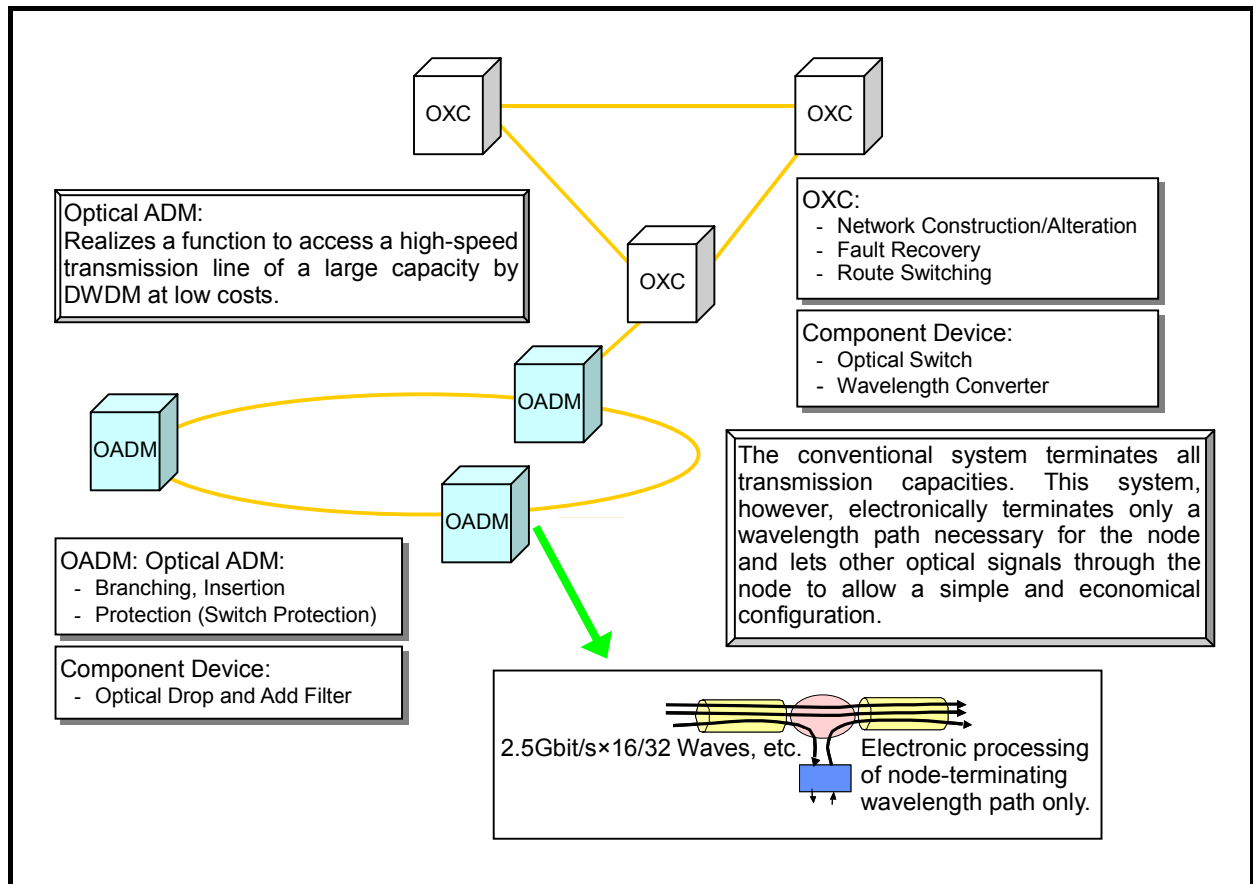


Fig. 4.3.2 Roles of optical ADM in Photonic Network

4.3.2.1 Outline

Optical ADM devices can be classified into the fixed wavelength type with an optical filter and the dynamic wavelength type with a tunable filter or a tunable laser.

4.3.2.1.1 Fixed Wavelength Type

Fig. 4.3.3 shows a typical example of the fixed wavelength type of optical ADM. This is a system that branches and inserts a signal by using an optical circulator and fibre grating. As its configuration is simple and inexpensive, this is now the most popular and is applicable to the branching and insertion of up to units of 8 waves.

Inserting a gain equalizer or variable optical attenuator is needed as a countermeasure. The details for the optical circulator are given in chapter 4.4.6, and the details for the fibre grating are given in chapter 4.4.7.

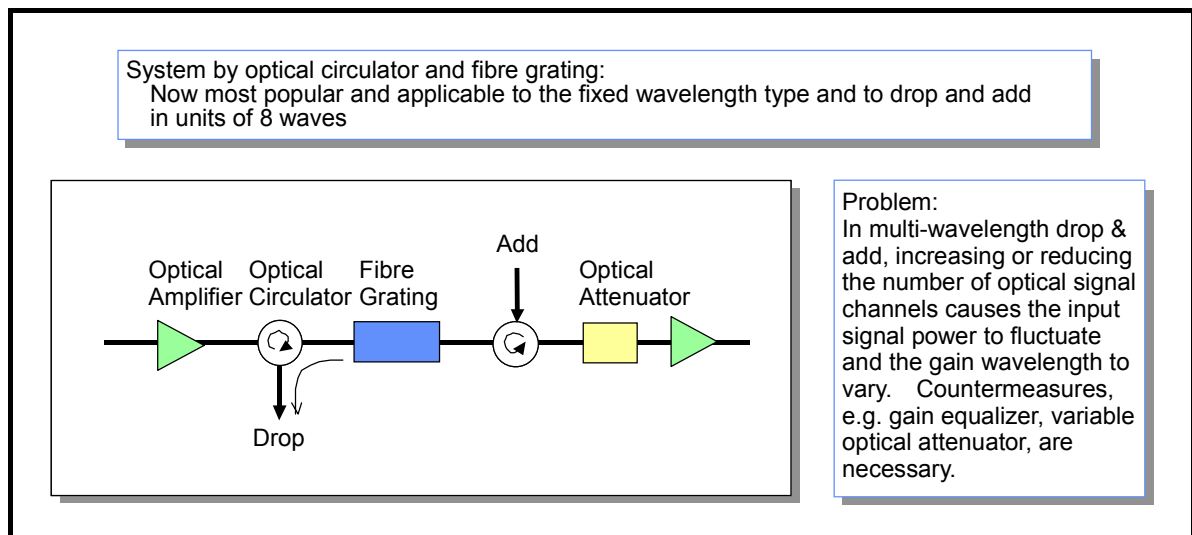


Fig. 4.3.3 Example of the fixed wavelength type

4.3.2.1.2 Dynamic Wavelength Type

There is a system with an acousto-optic tunable filter (AOTF) as the dynamic wavelength type of optical ADM.

When ultrasonic waves travel through a substance, periodic strains cause the refractive index to change periodically. This produces diffraction grating that interacts with optical waves to cause such phenomena as reflection and diffraction. This is called acousto-optic effects.

An AOTF changes the surface refractive index with surface acoustic waves (SAW) traveling through the surface of a substance, and it uses an ultrasonic frequency modulation for the optical wavelength separation. It used to be difficult to create a better filter with a high quenching ratio by reducing the multi-wavelength intervals, but this difficulty is recently being resolved. An AOTF is used as an optical device for optical ADM because a single device has the drop/add function for several arbitrary optical wavelengths. The AOTF can drop and add wavelength multiplex signals at 0.8-nm intervals to realize 32-wave ADM equipment.

The details of the optical circulator are given in chapter 4.4.7.

4.3.2.2 Subjects

The problems need to be solved for future optical ADM equipment are as follows:

- Management of optical path wavelengths

It is necessary to monitor the optical signal quality such as optical power level and wavelength deviation and to monitor and control network operations such as wavelength management and path route management.

International Telecommunication Union-Telecommunication sector (ITU-T) is proceeding with standardization.

- Protection of wavelength paths
- Development and commercialization of optical devices for compact and low-cost equipment

4.3.3 Optical Router

4.3.3.1 Outline

The advances in the Internet use are increasing the demand for the band assurance and quality of service (QoS) that have been a best-effort for the Internet service. As a means of satisfying this demand, the multi-protocol label switching (MPLS) is being developed, which transfers IP packets with labels. Under the current traffic scale, this processing can be executed electronically. If the traffic continues to increase, the electronic processing will not be able to cope with high-speed IP packet processing.

To overcome this limitation, an optical technology is applied to IP packet processing as an optical router.

4.3.3.2 Configuration

Fig. 4.3.4 shows the concept of IP packet transfer by optical routers. MPLS transfers IP packets with labels, but an optical router assigns a wavelength instead of a label for routing. Therefore, the optical routing may also be called MP λ S.

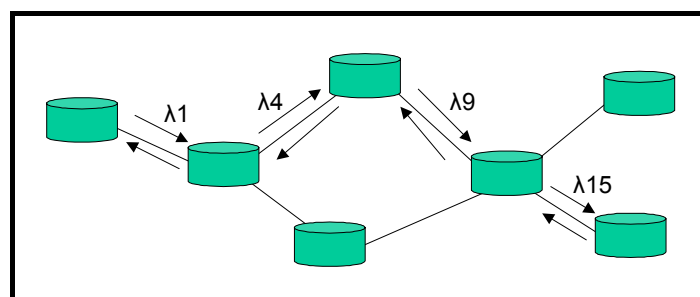


Fig. 4.3.4 Concept of wavelength routing

Fig. 4.3.5 shows a typical example of wavelength routing configuration. ^{Ref.6} Wavelength

multiplex signals from input ports are demultiplexed to each wavelength. Each wavelength is sent to an optical switch via a wavelength converter. Each wavelength is switched in the optical switch and output to a destination port. Each wavelength is multiplexed again at every destination. An optical switch at the center of wavelength routing processes optical signals after conversion into electronic signals or without this conversion.

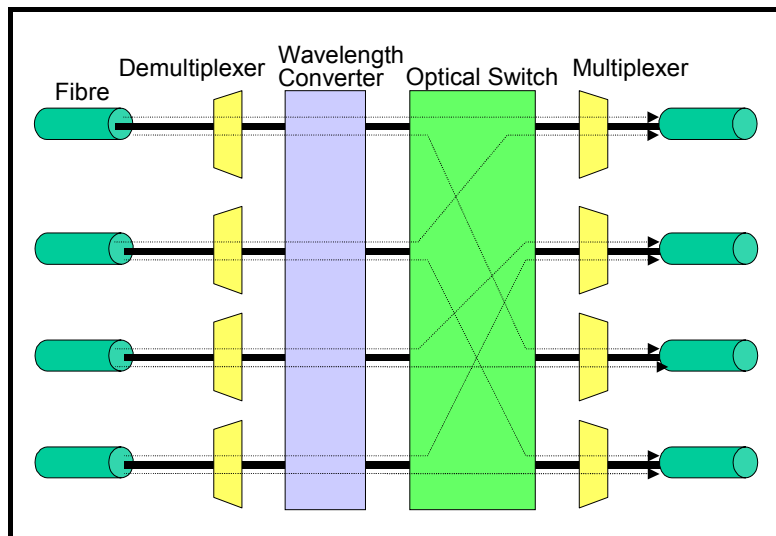


Fig. 4.3.5 Example of wavelength routing configuration

4.3.3.3 Subjects

The optical router is still being researched. To make the optical router popular for practical use, the protocols should be unified for cost reduction and multi-vendor configuration.

4.4 Device Technology

The developments in optical fibre communication, such as the latest development of wavelength multiplexing technology, have contributed significantly to the development of Photonic Networks. In actuality, the developments of technologies for the optical devices that form the main components of a network are responsible for its realization. This section provides an overview of the latest trends in the optical device technology.

4.4.1 Semiconductor Lasers

The continuous wave oscillation of a laser diode (LD) at room temperature was achieved in 1970, and the double hetero-structure was experimentally used to effectively confine carriers on the

Gallium-Arsenic (GaAs) substrate. The oscillation wavelength was in the 0.8- μm wavelength region, but in view of the optical fibre loss area at that time, it was an appropriate wavelength region. Next, after the loss area of the optical fibre moved to the 1- μm wavelength region, the LD also moved from the GaAs substrate to the InP substrate. The use of InP materials improves reliability dramatically in comparison with GaAs materials, and the embedded LD once thought to be difficult to achieve, could be easily implemented. The benefits were the reduction of the LD threshold, lateral mode stability, and longer life. Fig. 4.4.1 shows the advance of the LD technologies.

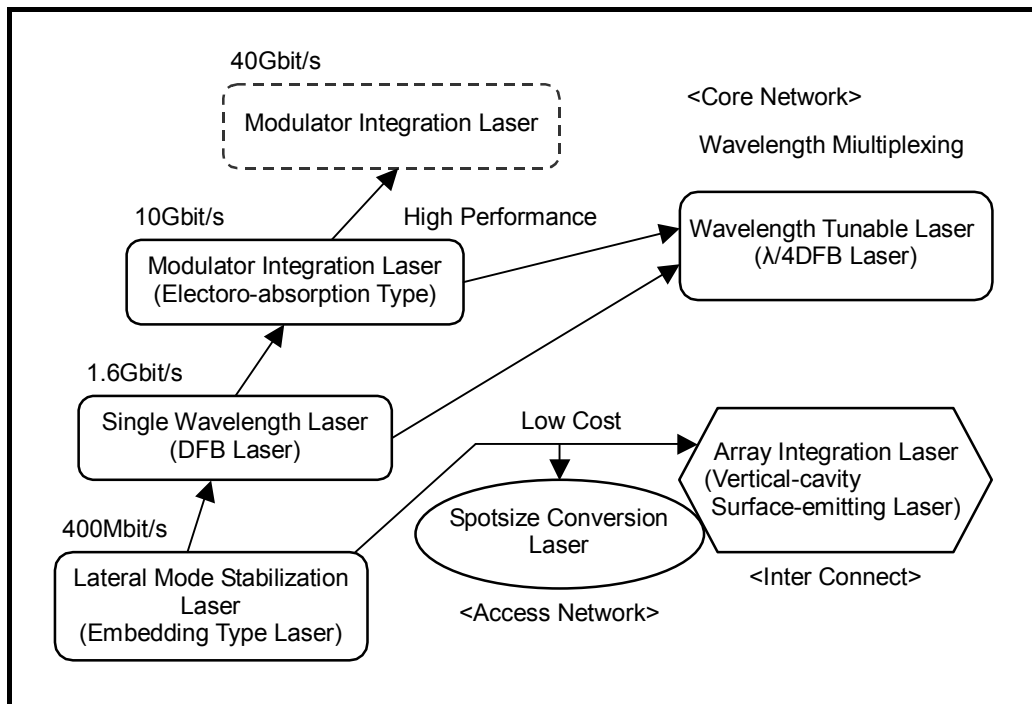


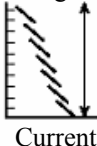
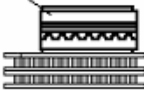
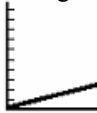
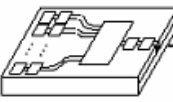
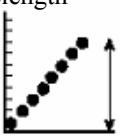
Fig. 4.4.1 Advance of LD technologies^{Ref.7}

Better performance led to the development of the distributed feedback (DFB) laser that could oscillate single wavelength and the electro-absorption (EA) modulator integrated DFB laser. These types of lasers were developed to avoid the transmission distance limitations caused by wavelength dispersion of the optical fibre. If the DFB laser is modulated by the direct current drive mode, the carrier variations involved in relaxation oscillation when the oscillation starts are caused and the refractive index is changed, resulting in wavelength chirping that causes the change in the oscillation wavelength. Thus, the external modulator that in principle did not cause any wavelength chirping was adopted. The Mach-Zehnder (MZ) interferometer type modulator is already in commercial use. The EA-DFB laser is not suitable for a long-distance transmission because of wavelength shifts resulting from changes in the refractive index caused by changes in the electric field.

As the WDM technology was developed, the wavelength tunable laser, whose oscillation wavelength could be set, appeared. The advantages of the wavelength tunable laser include the

reduction of the number of laser parts when the system handles more wavelengths, the ease of repair if the laser fails, and the convenience with which any wavelength can be inserted or removed for wavelength routing or at nodes during system operation. Table 4.4.1 shows the classification of variable wavelength lasers.

Table 4.4.1 Classification of variable wavelength lasers^{Ref.7}

Type	Structure of Laser /Mechanism of Wavelength Variation	Feature
Current control type	 The refractive index is dependent on carrier	 The wavelength variable range becomes wider, but the change in wavelength has the form of a jump ~ 32nm (~ 40ch)
Temperature control type	DFB Laser  The refractive index is dependent on temperature Two-tier Peltier Cooler	 The wavelength can be changed continuously, but the variable range is narrow 5 ~ 7nm (7ch)
Array integration type	 Component Switching	 The wavelength variable range is wide, but the number of components increases 6 ~ 32nm (8 ~ 40ch)

The wavelength variation is implemented by changing the refractive index, and two methods are provided to change the reflection factor, either by changing the temperature or carriers by injection. The method that changes the reflection factor by carrier injection can further be divided into a method that changes the injection current distribution by dividing the electrode of the DFB laser and a method that changes the current of the distributed reflector of the distributed bragg reflector (DBR) laser.

Each of these methods has advantages and disadvantages. If the method that changes the temperature is used, the wavelength can be changed continuously, but the variable range is narrow. If the method that changes the current is used, the variable range of wavelength becomes wider, but the change in wavelength has the form of a jump, rather than being continuous. Moreover, the jump location cannot be controlled. As a way to compensate for these weaknesses, a method that uses a laser array was proposed. Fig. 4.4.2 shows an example of implementing this method.

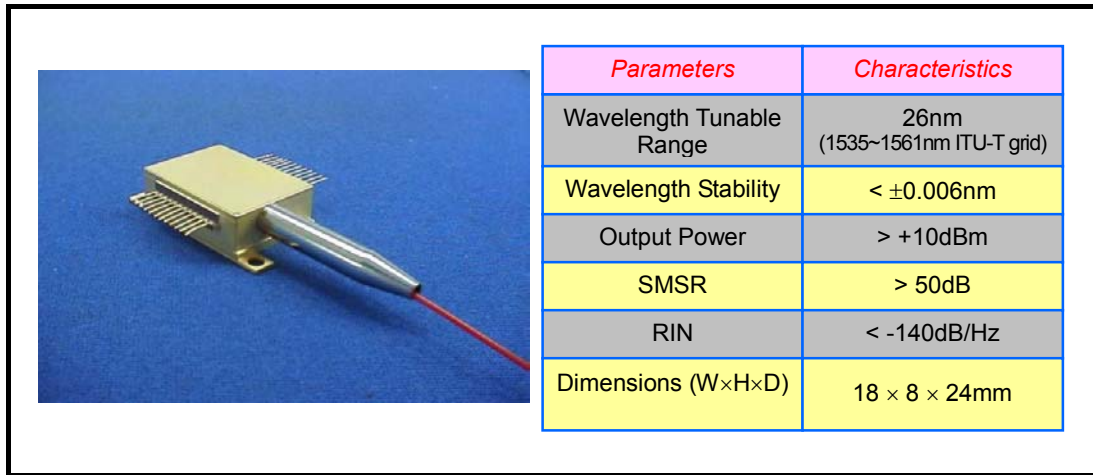


Fig. 4.4.2 32-wave tuneable LD module

4.4.2 Light-receiving Component

A light-receiving component is used in optical communications to convert weak optical signals attenuated by optical fibre into electric signals. After being converted into electric signals, the signals are amplified by an electric amplifier. The performance required from the light-receiving components such as the pin photodiode and avalanche photodiode (APD) includes high sensitivity, high-speed response, low noise, high quantum efficiency, and matching with the wavelength bands used.

The basic properties for 40Gbit/s were implemented at an earlier stage in the 1990s, and the focus of recent research and development has shifted to the high optical input resistance and various integration structures with respect to the EDFA light and the development of a detector with a better wide bandwidth characteristics. Table 4.4.2 presents a technical overview of 40-Gbit/s high-speed light-receiving components.

Table 4.4.2 Technical overviews of the 40-Gbit/s high-speed light-receiving components

Light-receiving component	Technical overview
Waveguide type light-receiving component	Light-receiving components that receive light from a direction perpendicular to the semiconductor substrate are called the surface-incident light-receiving components, while those that receive light from a direction parallel to the substrate are called the waveguide light-receiving component. Because the waveguide light-receiving component can support both high-speed response and high quantum efficiency, its structure is suitable for light-receiving components of 40Gbit/s or greater. Implementation examples of high-speed response with 40Gbit/s and high quantum efficiency of about 70% have already been reported.

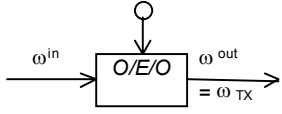
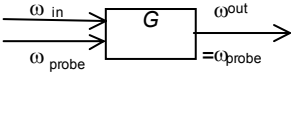
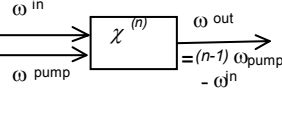
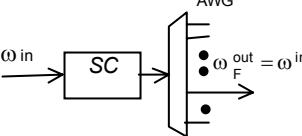
Light-receiving component	Technical overview
Single traveling carrier photodiode (UTC-PD)	In contrast to the normal pin photodiode basic structure, the single traveling carrier photodiode consists of a p-type doped light absorption layer, a wide gap, and a low-density carrier traveling layer. Very fast response can be obtained if the thickness of the light absorption layer is designed appropriately. A pulse response corresponding to 220GHz in the 3dB-down band has already been reported.
Passive waveguide integration light-receiving component	Component created by integrating passive waveguides on a waveguide type light-receiving component. This component has been developed for monolithic integration with other semiconductor waveguide devices such as filters and spot-sized amplifiers, for protection of the incident surface of strong light such as EDFA light, and for making the surface more reliable.
Optoelectronic integrated component (OEIC)	Integration of light-receiving components and pre-amplifier ICs on the semiconductor substrate. When an OEIC is created by monolithic integration of waveguide light-receiving components and distributed amplifiers consisting of HEMTs on an InP substrate, a 3dB-down band of 43 ~ 52GHz and an O/E conversion efficiency of 12V/W have been reported.
Avalanche photodiode (APD)	To implement APD exceeding 40Gbit/s, in addition to the basic issues of increased speed by the reduction of the CR time constant and by the reduction of the carrier traveling time, a high gain band product (GB product) is required. An external quantum efficiency of 43 ~ 58%, a maximum band of 30 ~ 34GHz, and a GB product 130 ~ 180GHz, by using thin-film InAlAs as the multiplication layer to increase the GB product, have been reported achieved.

4.4.3 Wavelength Conversion

In order for Photonic Networks to be built, the total optical wavelength converter that converts wavelengths without converting light into electricity is essential for signal processing technology at the light level to overcome the limitations of electronics.

The optical-electronic-optical (OE-EO) type wavelength converters convert the optical signal into an electric signal and then back to an optical signal after processing at the electric stage is completed, while the total optical type performs all processing at the optical level. The total optical type consists of an optical gate type, lightwave mixing type, and spectral diffusion type. These are implemented using secondary and tertiary nonlinear effects, especially phase shifts due to self-phase modulation (SPM) and cross-phase modulation (XPM), and optical parametric interactions called four-wave mixing (FWM) and difference frequency generation (DFG). The optical gate type converter mainly uses cross-gain modulation (XGM) and XPM resulting from the above nonlinear effects and the lightwave mixing type converter mainly uses FWM and DFG. SPM is used for the spectral diffusion type converter. Table 4.4.3 presents the configuration, features, and tasks of each converter type.

Table 4.4.3 Classification of the wavelength converter

Type	Feature	Principal	Optical device	Feature	Subject
OE-EO conversion type		OE-EO Conversion +Electric Processing	PD/LD + Optical Modulator	-Already developed -Ultra-broad band -Electric signal is reproducible	-Restriction of transparency -Restriction of signal speed (~10Gbit/s)
Optical gate type		Gain Saturation Absorption Saturation XAM, XGM XAM (SOA-MI, MZI; MOLM)	LD EA Modulator SOA Fibre	-Ultra-high speed (<40Gbit/s) -The capability of improved waveform shaping and improved extinction ratio	-Restriction of transparency -Restriction of dynamic range
Lightwave mixing type		TWM, DFG (n=2) FEM (n=3)	LiNbO ₃ AlGaAs SOA DFB-LD Fibre	-Nearly complete transparent property -Ultra-high speed (<100Gbit/s) -Multi-wavelength batch conversion	-Improvement in conversion efficiency is required -Structure and composition are complicated -Tunability
Spectral diffusion type		SPM	DSF Filter	-The capability of simplifying monitoring and control	-The need to make pulses shorter -Large pump power

4.4.3.1 OE-EO Conversion Type

The OE-EO type converter has the advantage that it has already been developed. However, because its range of use is severely limited due to the need for the development of separate electronic circuits for each signal speed, it seems unlikely that this type will develop into an ultra-high speed and ultra-large capacity optical communication system in the future. An OE-EO type converter whose signal speed is 10Gbit/s has already been developed.

4.4.3.2 Optical Gate Type

The optical gate type converter mainly uses gain saturation, cross-absorption modulation (XAM), and XGM of optical semiconductor devices, and also XPM provided by, for example, a nonlinear loop mirror (NOLM) with an interferometer configuration consisting of a semiconductor optical amplifier (SOA) and optical fibre. A signal speed exceeding 40Gbit/s can be supported. Also, a compact configuration using a semiconductor amplifier can be implemented. In particular, the converters using XPM have excellent features such as an improved waveform shaping and improved extinction ratio.

4.4.3.3 Lightwave Mixing Type

The lightwave mixing type converter mainly uses parametric effects, such as difference frequency generation (DFG) and FWM in LiNbO₃ and AlGaAs. This type of converter has nearly complete transparent properties and can support a high-speed signal exceeding 100Gbit/s. Also, this type can be applied to coherent multi-wavelength batch conversion and optical phase conjugation that cannot be implemented by other methods.

4.4.3.4 Spectral Diffusion Type

The spectral diffusion type converter uses SPM in the optical fibre and group velocity dispersion interaction. This type of converter can operate even at a speed exceeding 40Gbit/s and may have the capability of simplifying monitoring and control because the optical filter can set the conversion wavelength. Recently, an active research has been going on in spectral diffusion caused by the interactions of tertiary nonlinear effects in the optical fibre in the 1.55- μ m band. The purpose is to simplify the multi-wavelength light source of WDM.

Fig. 4.4.3 shows the configuration of a wavelength converter that uses supercontinuum generation (SCG). The spectra of incoming signal light are diffused and then only the elements of the wavelength to be converted by the optical filter are demultiplexed. Because passive devices do demultiplexing, the significant simplification of wavelength control can be expected. For the spectral diffusion, the soliton adiabatic compression effect and the SPM effect in the normal dispersion area are used. This technique can generate ultra-wide band spectra extending over 200nm. These spectra are demultiplexed by an arrayed waveguide grating (AWG) to create a multi-wavelength light source. The problems remain to be solved are the need to make pulses shorter and to deal with power of pump light that is too strong.

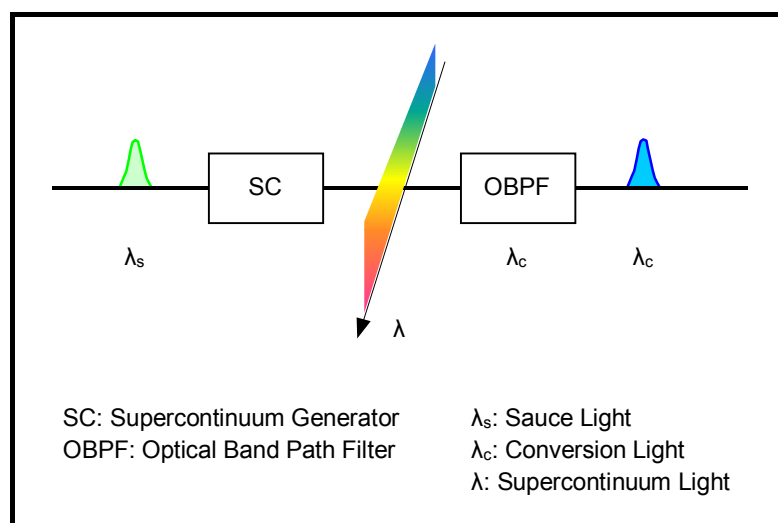


Fig. 4.4.3 Configuration of the wavelength converter using SCG

4.4.4 Optical Switching

Because the optical switch changes the destination of the signal that passes through the optical fibre without converting it to an electric signal, the frame processing of the transmission standards such as synchronous optical network (SONET) and synchronous digital hierarchy (SDH) is not needed. Thus, the optical switch is a key device that is indispensable for the OXC devices and optical ADM (OADM) devices set up at relay points or branching points in a high-speed, large-capacity WDM network.

Fig. 4.4.4 shows the main types of optical switch. These include the mechanical type that is currently the most widely used, the mirror type that performs switching operation electrically by forming a small variable mirror on the silicon substrate, the plane waveguide type formed by plane lightwave circuit technology, and the bubble type.

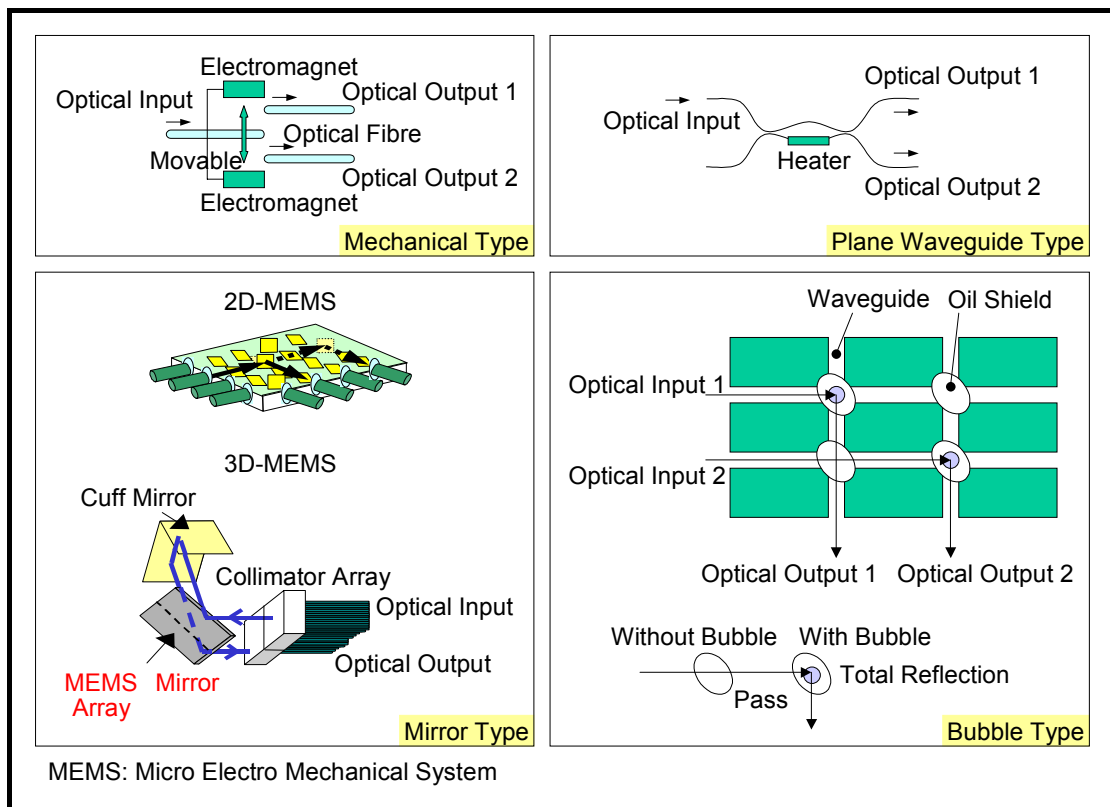


Fig. 4.4.4 Types of optical switch

4.4.5 Dispersion Compensation

4.4.5.1 Wavelength Dispersion Compensation

The wavelength dispersion is a phenomenon in which the propagation speed of the light in an

optical fibre changes with a wavelength. The cause is the light of differently different wavelength contained in a pulse is spreading with a different refractive index during the propagation in the fibre.

Since almost all optical fibres have the positive dispersion value from which the light with shorter wavelength is transmitted faster, as the method of fixed dispersion compensation, there is the method of inserting in some places the element or an optical fibre in which wavelength has the negative dispersion value from which a longer light is transmitted faster. There are two kinds of these methods, dispersion compensating fibre (DCF) and fibre Bragg grating (FBG) with the chirping characteristics, and DCF is used overwhelmingly.

Since the wavelength dispersion tolerance is severe in the 40-Gbit/s system, in correspondence of only DCF, it is difficult to compensate the dispersion. In order to follow the change of the wavelength dispersion value accompanying the amount of dispersion compensation for every relay section at the time of a system operation start-up, and temperature change of the transmission line under system operation, the automatic dispersion compensation system which always makes the amount of dispersion compensation optimal is needed. There is virtually imaged phased array (VIPA) as an example of an automatic dispersion compensation system. VIPA, which is a space transmission type, has the feature that the amount of dispersion is different for every wavelength. The structure and outside view of VIPA are shown in Fig. 4.4.5. This bulk optical device consists of a VIPA plate which is a wavelength diffractive grating, consisting of reflective coatings on both sides of a thin glass plate, and a three-dimensional mirror. The wavelength dependence of the transmittance and the group delay has periodical characteristics with 200-GHz spacing. Moving the three-dimensional mirror horizontally results in variable dispersion compensation with a range of -800 to $+800$ ps/nm over the entire C-band ($1530 \sim 1560$ nm) for a 40-Gbit/s NRZ signal.

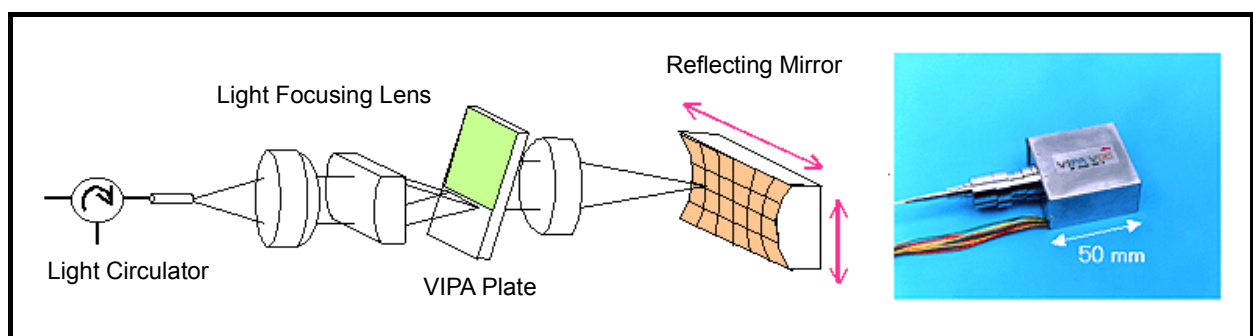


Fig. 4.4.5 The structure and outside view of VIPA

4.4.5.2 Polarization-mode Dispersion Compensation

When performing high-speed transmission exceeding 10Gbit/s, the consideration of polarization

mode dispersion (PMD) is required. Because the fibre-core contains slight asymmetries, a delay will arise between two orthogonal axes in the fibre, resulting in waveform degradation. It becomes impossible to disregard the influence of transmission waveform degradation by the PMD effect as the transmission speed accelerates. In order to overcome this, a method of inserting the optical component which has a transmission time delay difference between polarization orthogonal axes in the optical part of a receiving end as PMD compensation technology, a method of adjusting a waveform in the electric part of a receiving end in a delay circuit, etc., and a method of adjusting incidence polarization to the peculiar axis of the transmission line in a transmitting end, etc. can be considered.

4.4.6 Optical Circulator and Optical Isolator

In nonreciprocal optical circuit elements such as optical circulators and optical isolators, the Faraday effect, which is one of the magneto-optical effects, is used. The Faraday effect is a magneto-optical effect with respect to transmitted light. If a magnetic field parallel to the travel direction of light is applied to media and linearly polarized light is shone, the electric field vector of the transmitted light generally draws the locus of an ellipse and the direction of the major axis of the ellipse is rotated from the oscillation direction of the electric field of the original linearly polarized light. This rotation angle is called the Faraday rotation angle and the ratio of minor axis to major axis of elliptically polarized light is called the Faraday ellipticity. The Faraday effect is a nonreciprocal effect. If light travels through a medium and then back through the medium, both the Faraday rotation and Faraday ellipticity are doubled. The magnetic garnet is mainly used for long wavelength isolators, such as 1300 ~ 1500nm, and dimly magnetized semiconductor (DMS) elements are used for short wavelength isolators.

4.4.6.1 Optical Isolator

Isolators consist of a type whose forward direction characteristics depend on the polarized light and a type whose forward direction characteristics do not depend on the polarized light. The former type is used when the polarized light state is constant, as with LD output light, and the latter type is used when the polarized light state is not constant, as with optical fibre output light. For commercial use of the optical isolator, the following are some of the requirements that must be met:

- the backward direction losses with respect to the feedback light must be sufficiently large
- the forward direction losses must be sufficiently small
- the isolator should be small enough
- the temperature coefficient must be small
- the saturation magnetic field must be small enough, about 0.1T

- the price must be relatively cheap compared with overall system cost

To meet the above requirements, it is necessary not only to use high-quality material for the Faraday optical rotator, but also to solve various technical problems such as the selection of polarizer, an anti-reflection coating, and a method of coupling to the fibre.

4.4.6.2 Principle and Configuration of the Optical Circulator

Fig. 4.4.6 shows the configuration of the polarized-light independent type of optical circulator. The incoming light from port 1(3) is separated into the P and S elements, which are made perpendicular to each other by the prism A. Each beam is passed through the Faraday rotator and half-wave plate via the reflecting prism, and then led to polarizing prism B. Since the beam receives an optical rotatory power of 45° in the Faraday rotator and an optical rotatory power of -45° in the half-wave plate, the polarization is brought back to the original polarization, and the light after composition by polarizing prism B exits from port 2(4). If, on the other hand, the light enters from port 2(4), it receives an optical rotatory power of -45° in the half-wave plate and an optical rotatory power of -45° in the Faraday rotator, then is composed by polarizing prism A for output from port 3(1). Thus, the cycle $1 \rightarrow 2$, $2 \rightarrow 3$, $3 \rightarrow 4$, and $4 \rightarrow 1$ are implemented. Some other proposals have also been made for configuring the optical circulator.

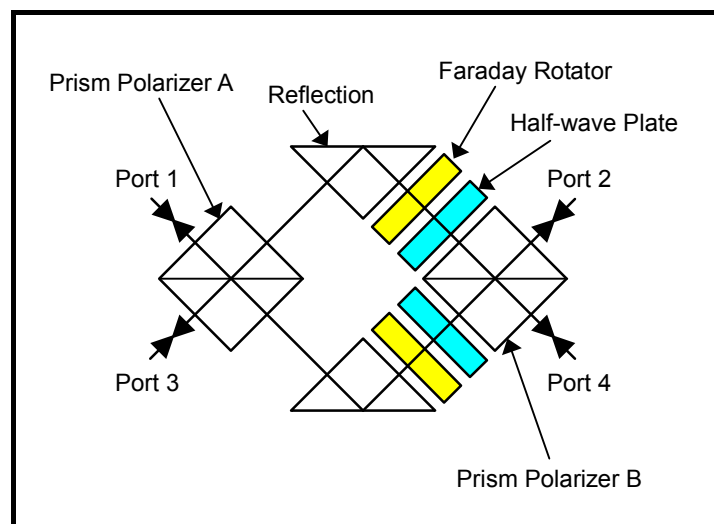


Fig.4.4.6 Layout of an optical circulator

4.4.6.3 Trends in the Development of the next Generation of Magneto-optical Devices

Before optical fibre communication can find widespread use in ordinary homes, the optical isolator must become cheaper. This will only be possible by the development of a low-cost

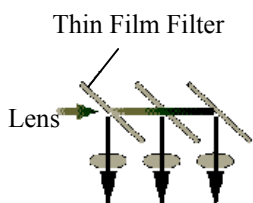
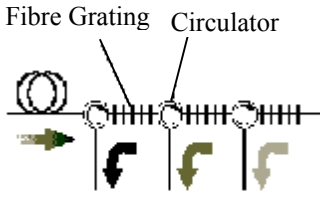
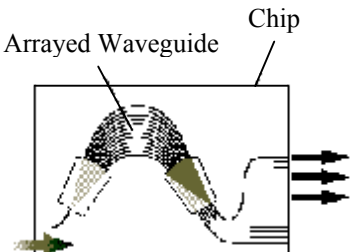
optical rotator with a high Faraday performance index and of a small, light, and LD integrated device. Also attempts are being made to create an isolator or circulator on the optical waveguide for the purpose of integration with semiconductor lasers. Our future task will be the integration of optoelectronic integrated circuits using semiconductors and optical isolators.

4.4.7 Optical Filters and Variable Wavelength Filters

Optical multiplexing/demultiplexing technology is a key element technology for WDM systems. The WDM transmission system consists basically of an optical multiplexer/demultiplexer and a broadband optical amplifier.

Table 4.4.4 lists the types and features of optical multiplexer/demultiplexer on the market.

Table 4.4.4 Types and features of optical multiplexer/demultiplexer^{Ref.8}

Type	Thin Film Filter Type	Fibre Grating Type	Arrayed Waveguide Grating Type
Structure			
Number of CH	~ 16ch	~ 40ch	~ 40ch (~ 128ch)
Loss	Low Loss, Large Loss Disuniformity	Low Loss, Large Loss Disuniformity	Small Loss Disuniformity
Dependence on Temperature	Small Dependence on Temperature	Small Dependence on Temperature (Compensation Package)	Temperature is controlled by the heater
Cost	High Assembling Cost	Need Additional Parts Cost	Low Assembling Cost
Use	Metro-System	Long Haul (Submarine) (Add/Drop)	Long Haul and Metro-System (Add/Drop)

The fibre grating type is a refraction index change type of grating that uses the property that the refraction index changes when ultraviolet rays are directed at Ge-doped silica glass and forms periodic refraction index changes in the optical waveguide. The device reflects only specific wavelengths corresponding to the periodic refraction index and is used in the optical ADM that branches/inserts only desired signal light on the transmission path, dispersion compensation unit (DCU), and gain equalization filter (GEF). Because the optical fibre grating can be manufactured cheaply due to direct processing of the fibre, connectivity with the line is good, and optical

properties such as the central wavelength, bandwidth, and reflection factor can be changed easily, it has a wide range of applications. In particular, the uniform grating has steep wavelength characteristics with sharp peaks and is used in the optical ADM. Multiple peaks called side lobes are generated on both sides of the main peak of the reflection spectra in the optical ADM and can be controlled by using a technique called apodization technique that controls the reflection factor modulation on both sides of the grating. Some examples have been reported.

The arrayed waveguide grating (AWG) type is manufactured using an optical integrated circuit technology called the plane lightwave circuit (PLC). From the point of view of manufacture, its features are low cost, high reliability, and amenability to mass production, since it consists of integrated circuits. Because the same materials as those used for optical fibre are used in manufacture, AWG provides such excellent features as low transmission loss and low connection loss. Also, losses and loss variations virtually do not increase as the number of wavelengths increases because of batch demultiplexing, thus resulting in spectra with uniform properties and in the possibility of multiple channels. In addition to integration, there are no restrictions on the design of the wavelength resolution and the length of the optical waveguide can be adjusted. Although wavelength shifts occur due to double refraction of the waveguide, but a solution by which a half-wave plate is inserted is already commercially available. AWG with the maximum channels of 1,000 was reported by Nippon Telegraph and Telephone Corporation (NTT) in November 2000.

For the variable wavelength filter, acousto-optic effect tunable filter (AOTF) has been developed as a key device for building OADM. Fig. 4.4.7 shows its structure. If a tandem electrode is placed on the surface of a piezoelectric material and a high frequency electric field is applied, surface acoustic waves (SAW), which propagates in a form with energy concentration on the surface via the piezoelectric effect, are excited. In a linear optical waveguide in which SAW is propagated, the polarization mode of specific wavelengths rotates due to the acousto-optic (AO) effect, creating wavelength selectivity. By applying multiple frequencies, f_1 and f_3 , to the tandem electrode simultaneously with the input light as λ_1 , λ_2 , λ_3 , λ_4 , and λ_5 in the state shown in the Fig. 4.4.7, the polarized light, λ_1 and λ_3 , can be output from the output port as selected lights, λ_1 and λ_3 , with the branching function. By modulating the frequency of the control signal, tuning in a wide range exceeding 80 nm can be done. If a control signal of multiple frequencies is applied at the same time, the multiple wavelengths can be selected at the same time.

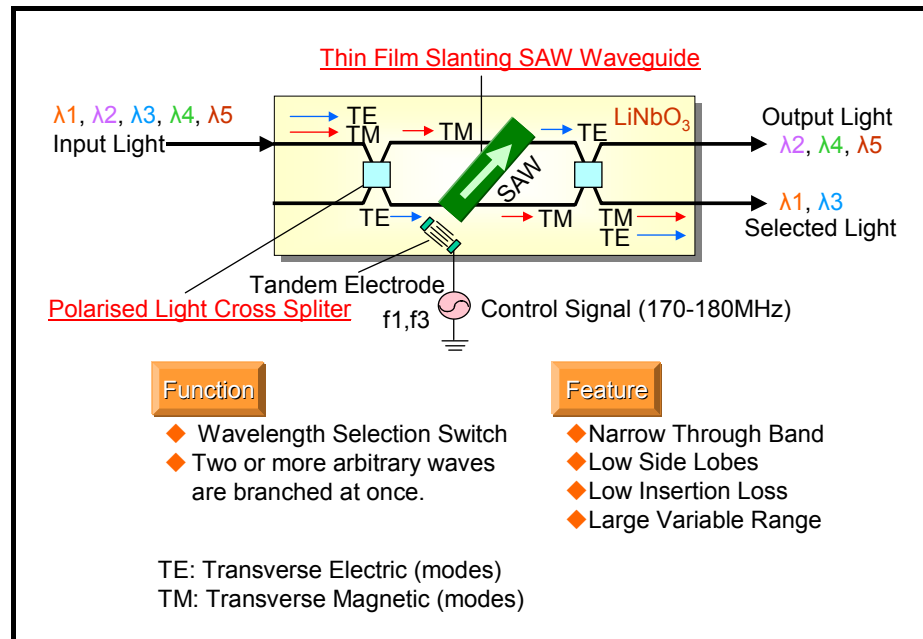


Fig.4.4.7 Acousto-optic tunable filter (AOTF)

4.4.8 Connectors

An optical connector generally consists of a ferrule that secures the optical fibre and a sleeve that aligns and maintains the ferrule. The structure is such that the ends of the optical fibres can be aligned precisely.

Initially, the optical connector was developed as a transmission device for connecting the office cable and the light source, light-receiving components, and optical devices, and for rack connection with an inter-frame cable. A typical optical connector is the FC connector.

As the installation of optical fibre for branch lines has continued to grow, the importance of the isolation function increased. As a result, the push-on type with superior operability, such as the SC connector, became widely available. Recently, more compact optical connectors such as the MT-RJ connector, LC connector, and MU connector, which have superior implementation density, have been developed.

As a means to reducing and simplifying labor, the direct connector connection on the transmission path has been on the rise recently. One typical type of connector is the MT connector.

Table 4.4.5 lists the features of the typical optical connectors described above.

Table 4.4.5 Optical connectors

Kind of Connector	Feature
FC Connector 	The screw bundle type connector which used $\phi 2.5$-mm ferrule. Ferrule is aligned precisely within a precision sleeve and it is connected . It is used for large uses, such as transmission device and a measuring instrument.
SC Connector 	The push-on type connector which used $\phi 2.5$-mm ferrule. Ferrule is aligned precisely and it is connected within a precision sleeve. Attachment and detachment are easy, are excellent in workability, and have spread most with transmission equipment, LAN, the measuring instrument, etc.
MT-R Connector 	2 package connection connector to which mini-MT ferrule is used and the same latch mechanism as a modular plug is attached. Ferrule is aligned precisely and it is connected by the precision guide pin. Since 2 heart combination is possible in the size equivalent to SC connector, it is suitable for high-density connection.
LC Connector 	The connector to which $\phi 1.25$-mm ferrule is used and the same latch structure as a modular plug is attached. Ferrule is aligned precisely and it is connected within a precision sleeve. It is the small connector which used thin ferrule, and is suitable for high-density connection.
MU Connector 	The push-pull combination type connector which used $\phi 1.25$-mm ferrule. Ferrule is aligned precisely and it is connected within a precision sleeve. It is the small connector which used thin ferrule, and is suitable for high-density connection.
MT Connector 	The multi-fiber package type connector fabricated precisely. Ferrule is aligned precisely by the precise guide pin, and it is connected using the clip for combination. It is suitable for high-density connection of a multi-fiber cable , and is used by the public communication circuit .

4.4.9 Optical Couplers

An optical coupler or optical branching/coupling device is an optical component whose function is to branch optical power passing through one optical fibre into two or more optical fibres, or to couple optical power passing through two or more optical fibres to one optical fibre. The optical branching device can be used as an optical coupling device if the input terminal and output terminal are interchanged. Because the same can be said of the optical coupling device, the two are generally not distinguished. Fig. 4.4.8 shows the basic structure of the optical coupler.

The optical fibre melting type and optical waveguide type are the most common optical coupler structures

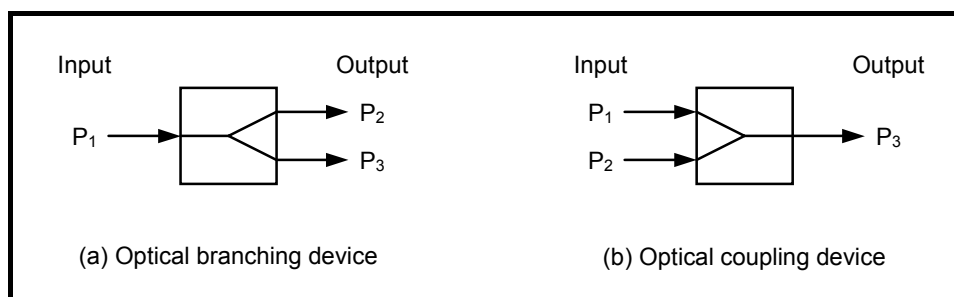


Fig. 4.4.8 Basic configuration of optical

4.4.9.1 Optical Fibre Melting Type

A 2×2 type optical fibre can be formed by melting and drawing, after heating, two parallel optical fibres. Fig. 4.4.9 shows a coupler of the optical fibre melting type. Since the optical fibre itself is handled, this type features a small number of components, compactness, low loss, and low cost. It is also possible to branch optical power by a specified ratio.

Generally, this type is more frequently used as a 1×2 type. It is used as a 1×2 type after treatment, non-reflective end treatment, so that no reflection occurs in one port.

If several optical couplers are combined, the desired number for distribution can be achieved. When the number for distribution is relatively small, a small space is sufficient for accommodation. However, as the number increases, a larger accommodation space is needed and the number of processes for fusion connection increases.

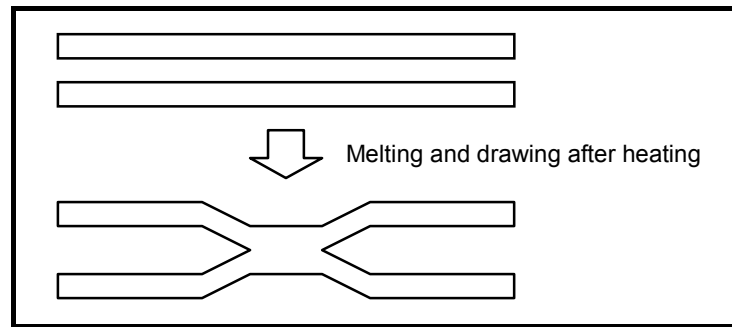


Fig. 4.4.9 Optical coupler of the fibre melting type

4.4.9.2 Optical Waveguide Type (Star Coupler Type)

An optical waveguide coupler uses a chip, such as silicon and silica, created by forming silica waveguides on the substrate. Since the basis of the coupler is the branching into two parts called the Y branching due to the shape of the branching, the number for distribution is generally 2 raised to the n-th power (2, 4, 8, 16, ...). Fig. 4.4.10 shows the structure of the optical waveguide coupler.

As with the optical fibre melting type, the desired number for distribution can be achieved by combining several optical couplers. As the number increases, this type is more advantageous in terms of accommodation space and number of processes for fusion connection in comparison to the optical fibre melting type.

In terms of shape, available types are the optical fibre core wire exposure type, which provides an optical fibre core wire; the adapter receiving type, which receives the connector provided externally using a coupler adapter; and the cord core wire exposure type, which provides a coupler cord core wire. Since the cord core wire exposure type provides a cord core wire from the coupler, the coupler can be made more compact. In particular, its thickness can be reduced. This is advantageous in reducing the accommodation space when the number for distribution is large.

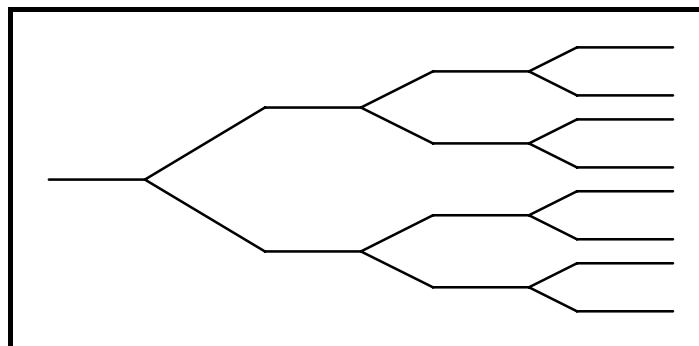


Fig. 4.4.10 Optical coupler of the optical waveguide type

4.4.9.3 Optical Coupler Applications

In addition to its use for branching and coupling of light in a variety of optical lines, the optical coupler is used in many optical components. For example, it is used as a branching device between lines and measuring instruments for continuous data monitoring. As a coupling device, it is used to multiplex signal light and light from the pump light source in an optical amplifier. In the former case, because the amount of the data signal used for monitoring is small, an optical coupler with a branching ratio of 90 ~ 99: 10 ~ 1 is used.

Recently, the number of applications in which one piece of information is provided to many terminals has increased, for example, from a parent station to subscribers. A method for branching to tens to hundreds of destinations has been used by combining optical couplers in several stages. When this method is used, the number of branching combinations that can be selected increases because additional branching can occur at each branching point or a branching point can be skipped. More specifically, it becomes possible to select branching in child stations under the parent station as well as in the stations at levels below the child stations.

4.5 Fibre Technology

The rapid expansion of the transmission capacity for an access network is expected in the near future, and it is socially required to expand the capacity for backbone network in order to cope with the expansion of access networks. In order to increase the capacity of backbone network, an installation of the new transmission line or an upgrade of the installed transmission line are required. For those requirements, two approaches have been developed such as increasing the channel bit rate and multiplexing channels based on wavelength division. In order to achieve two approaches, new fibres having various chromatic dispersion characteristics and various properties for suppressing nonlinear phenomena are developed. When upgrading an ordinary single-mode fibre (SMF) to high bit-rate or long-haul transmission line in 1.55- μm band applicable to EDFA operation, the decreasing of the accumulated dispersion is required. Dispersion-compensating fibre (DCF) was developed for such purpose. Moreover, dispersion-slope compensating fibre (DSCF) is also being developed to increase bit rate of non zero-dispersion fibre (NZ-DSF) transmission line developed in order to control chromatic dispersion and to suppress nonlinear phenomena in the WDM transmission.

4.5.1 Technology for Fibre as DWDM Transmission Medium

4.5.1.1 SMF

Because the zero-dispersion wavelength of SMF is in the 1.31- μm band, the signal distortion by FWM is negligible as long as operating at the 1.55- μm band. However, because the chromatic dispersion at the 1.55- μm band is as large as 18ps/nm/km or so, the dispersion compensation technique is required for long-haul or high bit-rate transmission.

4.5.1.2 Low Water Peak Fibre (All Wave)

The chromatic dispersion characteristics of low water peak fibre are equivalent to that of SMF. However, OH-loss peak at 1.383 μm is less than 0.31dB/km and stable even after hydrogen aging. This high reliability around the 1.39- μm region enables the expansion of operating window. In addition, the low water peak fibre is also suitable for the DWDM transmission at the 1.5- μm window in combination with DCF. Furthermore, for the coarse wavelength division multiplexing (CWDM) transmission system with a moderate construction cost, this fibre is superior to a conventional SMF because low water peak fibre can exploit the transmission band near 1.383 μm .

4.5.1.3 Dispersion Compensating Fibre (DCF)

There are various techniques to compensate the chromatic dispersion of SMF and low water peak fibre. One technique is the repeated insertion of the DCF module with high negative dispersion into the transmission line, thereby making the accumulated positive dispersion of transmission line down to zero.

4.5.1.4 Reverse-dispersion Fibre (RDF)

Similarly to DCF, RDF with the negative dispersion and negative dispersion slope is developed in order to cancel the chromatic dispersion of transmission line in combination with SMF. However, RDF was designed such that its negative dispersion per unit is relatively small in comparison to that of DCF ($-80 \sim -100\text{ps/nm/km}$ for DCF while $-17 \sim -45\text{ps/nm/km}$ for RDF) in order to provide the characteristics required for an optical fibre cable. In case a new transmission line is installed, RDF is superior to NZ-DSF in terms of low dispersion slope and low accumulated dispersion. For the next generation transmission, RDF and SMF with the expanded effective area (A_{eff}) and reduced attenuation are under development.

4.5.1.5 Non Zero-dispersion Compensating Fibre (NZ-DSF)

NZ-DSF has been developed as an optical fibre for DWDM systems to solve such problems as FWM occurrence and residual chromatic dispersion. The fibre was designed to have no zero chromatic dispersion and a little residual positive chromatic dispersion at the 1.55- μm window to suppress FWM occurrence, while SMF and DSF were designed to obtain zero-dispersion in operation.

4.5.1.6 Dispersion-slope Compensating Fibre (DSCF)

In order to upgrade the 1.55- μm transmission line using NZ-DSF or DSF with zero chromatic dispersion at the 1.55- μm window, DSCF was developed. While DCF compensates chromatic dispersion of SMF, DSCF compensates chromatic dispersion and dispersion slope at the 1.55- μm window of NZ-DSF and DSF. DSCF has a high negative dispersion slope, and inserting DSCF modules periodically into the installed transmission line upgrades the transmission system.

Table 4.5.1 Combinations of transmission line fibres and compensating fibres

Transmission fibre	Compensating fibre
SMF All Wave	DCF
NZ-DSF	DSCF
SMF + RDF	

4.5.2 Nonlinear Effects in Optical Fibres

For the future DWDM transmission system, performance improvements of subsystem such as wavelength stabilization and tunability of light sources, and bandwidth expansion of optical amplifiers, downsizing and cost reduction are required. In addition, a thoughtful consideration is required to reduce signal distortion by nonlinear effects as shown in Table 4.5.2, because high optical power is launched into the fibre in the WDM system.

Table 4.5.2 shows the type and features of nonlinear effects.

Table 4.5.2 Nonlinear effects

Item	Phenomenon	Optical threshold level
Self-phase modulation (SPM)	Refractive index change due to intensity change of signal light	10mW or more

Item	Phenomenon	Optical threshold level
Cross-phase modulation (XPM)	Refractive index change due to intensity change of other signal lights	10mW or more
Four-wave mixing (FWM)	Third intermodulation distortion among signal lights and between signal light and amplified spontaneous emission (ASE) of optical amplifier (Optical third-order beat interference)	1mW or more
Stimulated Raman scattering (SRS)	Interaction between thermal vibration of glass molecule and incident light results in an occurrence of light with a wavelength difference of several tens nanometer from incident light, reducing output light power	100mW or more
Stimulated Brillouin scattering (SBS)	Interaction between acoustic wave and incident light results in reflection of incident light, reducing output light power	Several mW or more

In the DWDM system, XPM and FWM have to be considered in addition to SPM which occurs in a single channel transmission. Both SPM and XPM broaden the signal spectrum. Once signal broadening occurs, the transmission signal shape broadens to a larger extent due to chromatic dispersion

FWM is a phenomenon that generates a new frequency interference light due to nonlinear interaction among signal lights, and FWM results in a cross talk among channels degrading the transmission quality. Because the FWM generating efficiency decreases with increasing the residual chromatic dispersion of transmission fibre, the influence of FWM is negligible in case of using SMF for the 1.55- μm band operation. On the other hand, in case of using DSF for the 1.55- μm band WDM operation, it is necessary to adopt such methods as unequal interval allocation of signals to avoid superposition of signal lights with FWM interference lights. Alternatively, the employment of the 1.58- μm window is considered and proposed. In addition, a new NZ-DSF which has moderate low chromatic dispersion and small FWM generating efficiency for the DWDM transmission has also been developed.

4.6 Cable Technology ^{Ref.9}

4.6.1 Background

The expansion of optical fibre networks from the 1970s has been coupled with the annual demand for a greater maximum number of fibres per cable. With the expansion of networks, the demands to increase the number of fibres per cable as much as possible in order to fulfill the need for more lines led to the production of higher fibre-count fibre-optical multicore cables. On the other hand, the number of optical fibre cables increased with the number of carriers such as new common carriers (NCCs) and cable television companies. This was followed by the

demand for cables themselves to become narrower, and the producers proceeded with the development deliberations that centered on the optical fibre development key words “higher density”, which brings us to the optical fibre cables of today.

4.6.2 Optical Fibre Cable Multicore Technology

4.6.2.1 The Progression towards Higher Density

In the early stages of optical fibre development, it was common for cables to contain between a few and ten fibres. In such cables the optical fibre is covered in silicon and polyamide resin and then sheathed in 0.9mm of nylon.

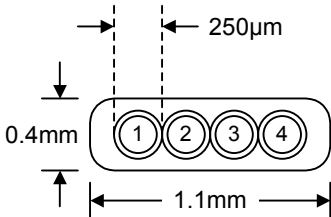
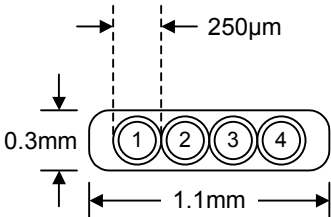
Later, as the demand for a higher density grew, the resin covering was replaced with ultra violet (UV) cured resin with an outer diameter of 0.25mm (250µm). Further advances then lead to the development of fibre ribbon whose fibres are placed in parallel and collectively clad. This is the present standard and is used in the majority of cables with a small number or more strands.

When the fibre ribbon was initially introduced it was 0.4-mm thick, but at present 0.3-mm thin fibre ribbon, as it is called, is frequently applied. In this way, higher-density cables have been achieved.

At the same time as the appearance of fibre ribbon, mass fusion splicing techniques were also developed using fusion splicers, called multi-core bonding machines, and MT connectors, etc. that allowed collective bonding. This made construction work faster and simpler.

There have been many changes in the area of cable structures, in addition to the changes leading to increased fibre density.

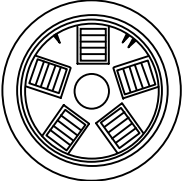
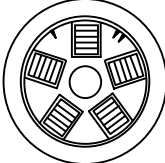
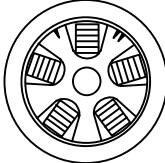
Table 4.6.1 Technology trend for optical fibre ribbon

Item		Previous 4-fibre ribbon	Thin 4-fibre ribbon
Optical fibres	Sheath	Ultra violet cured resin	
	Outer diameter	250 ± 15µm	
Fibre ribbon dimensions		Width: 1.1mm, Thickness: 0.4mm	Width: 1.1mm, Thickness: 0.3mm
View of structure			

4.6.2.2 Technologies to make Thin Cables

The increase in the number of fibres in cables has been coupled with a greater demand for cables with thin outer diameter. Thin fibre ribbon has been used to decrease the volume of cables and the work has been done to reduce the diameter of slots. The size of tension member in the center of cable has been reduced following a relaxing of thinking concerning stretch and distortion of cables, while optical fibre strength tests became more rigorous. The cables are specified with a narrower tension member and suppressed slot diameter. In addition, stronger sheath material (LLDPE: linear-low density polyethylene) has been adopted to reduce sheath thickness.

Table 4.6.2 Comparison chart with previous standard (example of 100 fibre type)

Item	Previous specification	WB (Water Block) type one direction twist	WB (Water Block) type SZ twist
Optical fibre ribbon	4-fibre ribbon	Thin 4-fibre ribbon	Thin 4-fibre ribbon
Tension member nominal diameter	2.6mm	1.8mm	2.0mm
Sheath classification	Aluminum laminated sheets Black polyethylene	Black polyethylene Black or LLDPE	Black polyethylene Black or LLDPE
Overall outer diameter	Nom. 15mm	Nom. 13.5mm	Nom. 14.5mm
Approx. weight	200kg/km	135kg/km	175kg/km
View of structure			

4.6.2.3 Future Trend

The high fibre-count ribbon (from 4 to up to 24) loose tube type structure cables are becoming generally popular. As one example, a uni-tube unit structure high fibre-count cable is shown in Fig. 4.6.1 that has several layered 12-fibre ribbons (tape) in each unit.

The future trend of optical fibre cables is for increased demand. It is thought that there will be more discussion about how to decrease the diameter of higher fibre-count cables, and for access networks, discussion about how to structure ribbon so that fibres may be easily split.

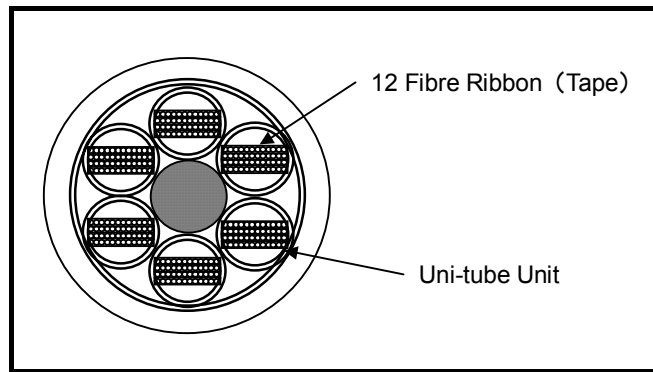


Fig. 4.6.1 High fibre-count cable with uni-tube structure

4.6.2.4 Outline of All-dielectric Self-supporting (ADSS) Cable

The cables usually contain optical fibres in loose tube construction as shown below or as ribbons that are protected from moisture and vibrational effects by the use of gel filling compounds. The cables then contain non-metallic strength elements, usually aramid yarns or glass reinforced plastic (GRP), with a thermoplastic sheath overall. The required strength of the cable will be determined by the maximum span length and the specified wind and ice load measures set. Some designs can, to a certain extent, be tailored to match the specific requirements of a particular application by modification of the amount of aramid surrounding the core although this has implications for the design and proving of fittings.

The fibres in tubes or ribbons are longer than the physical cable length, the overfeed or excess fibre being introduced to provide a strain margin. As loading and, therefore, strain on the cable increases, there should be zero fibre strain, at least under the worst case.

The choice of sheathing material is, in many cases, fundamental to the ability of an ADSS cable to perform. As an ADSS cable, by definition, must support its own weight across possibly large spans, in a wide variety of climatic conditions and environments, the importance of the right cable/clamp arrangement is paramount. The choice of sheath material and its ability to bond with internal elements and be steadfast under compressive and tensile loads must be assessed and proven. In addition, the cable is subject to electrical induction which can cause inadequate materials to become rapidly decayed, allowing subsequent attack of the strength elements themselves and will likely culminate in cable failure. The choice of suitable sheath materials, or the use of proven accessories which remove the electrical gradient that may cause the material damage, is again imperative.

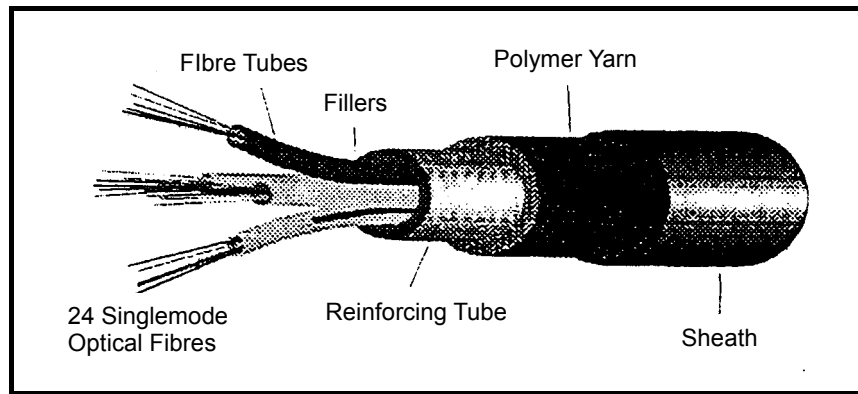


Fig. 4.6.2 Example of structure of ADSS cable

4.6.3 High Fibre-count OPGW

4.6.3.1 Outline of Progress towards Higher Fibre-count Built-in OPGW

The built-in OPGW is an overhead ground wire with optical fibre housed inside, and comes in two types: the fixed type and non-fixed type. Typical examples of the structure of each are given in Fig. 4.6.3.

The fixed type OPGW has a grooved aluminum spacer inside an aluminum tube. The ones containing the optical fibres in the grooved parts are differentiated from those that twist the optical fibres together into a spongy thread. However, in recent years spacers have been adopted that allow for higher-fibre count structures.

The non-fixed type OPGW does not fix the fibres to the twisted thread part, and therefore is less susceptible to expansion and contraction in installation, but is more susceptible to crushing pressure than the spacer type OPGW since they have no spacer. In order to increase its resistance to crushing pressure, aluminum clad steel wires are arranged in a fan shape around the perimeter of the aluminum tube.

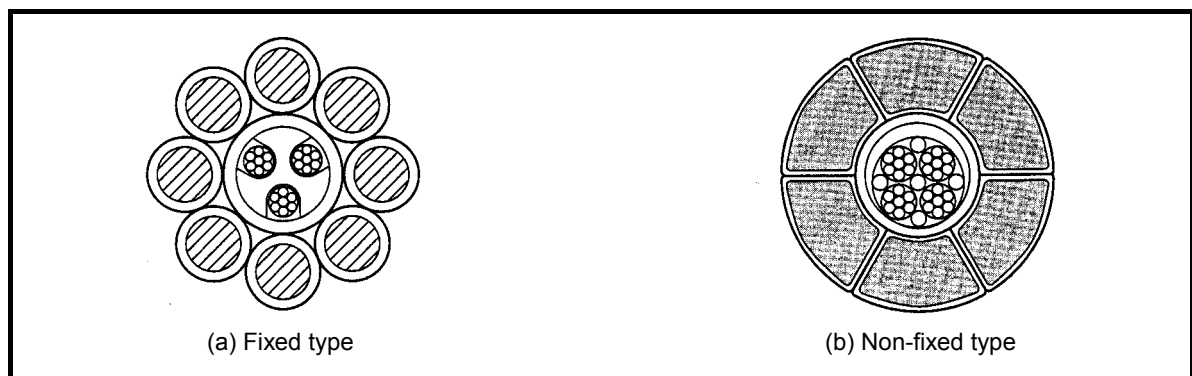


Fig. 4.6.3 Examples of built-in OPGW structure

4.6.3.2 The Trend towards High Fibre-count

The response to the demand for high fibre-count has been achieved for the spacer type OPGW by housing a large number of fibres inside the grooved area of the spacer. At the time of development stage, there was only a single fibre; however the number has been generally increasing, first with cables housing 3 fibres at once, and then with cables housing 6 fibres at once. The number of grooves determines the number of fibres. A 5-mm aluminum tube diameter allows 18 fibres, a 6-mm tube 24 fibres and a 6.5-mm tube 30 fibres. Fig. 4.6.4 shows the structure of the optical fibre cable and Fig. 4.6.5 shows an example of the structure of an optical unit.

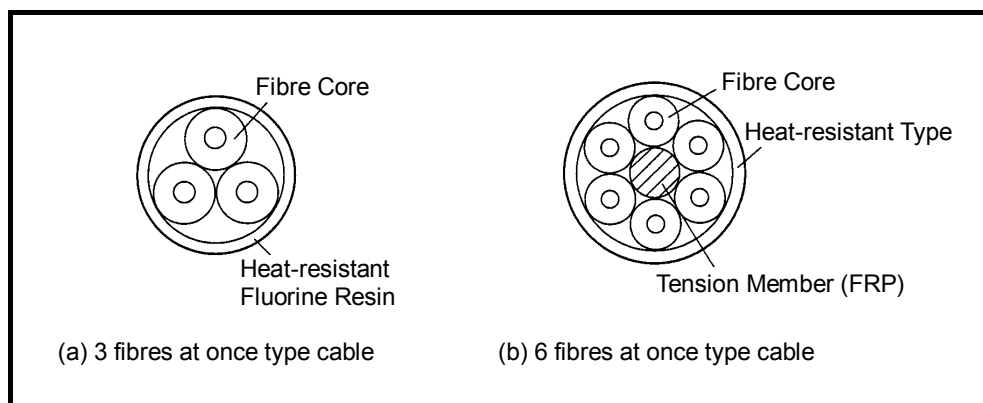


Fig. 4.6.4 Optical fibre cable structure

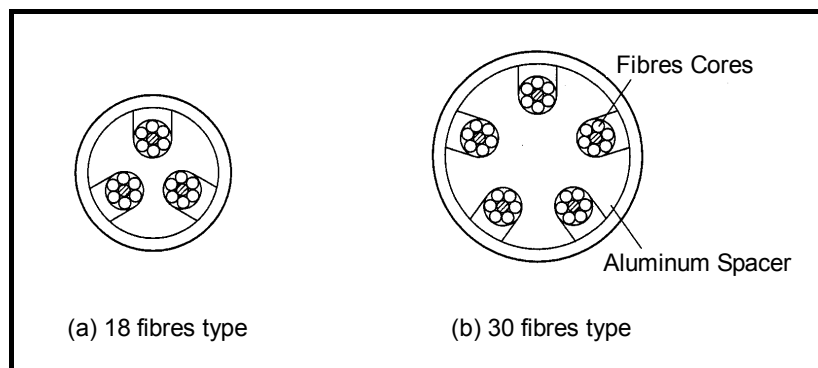


Fig. 4.6.5 Examples of structure of spacer type optical unit

The response for non-fixed type OPGW has been to house a large number of fibres inside the optical fibre cable. The initial design wrapped the optical fibres around the perimeter of the tension member located in the center; however, this was later replaced by a structure with 6 fibres wrapped around the central tension member. Now, the cables with 5 tension members each surrounded by 12 optical fibres are beginning to be applied in practice.

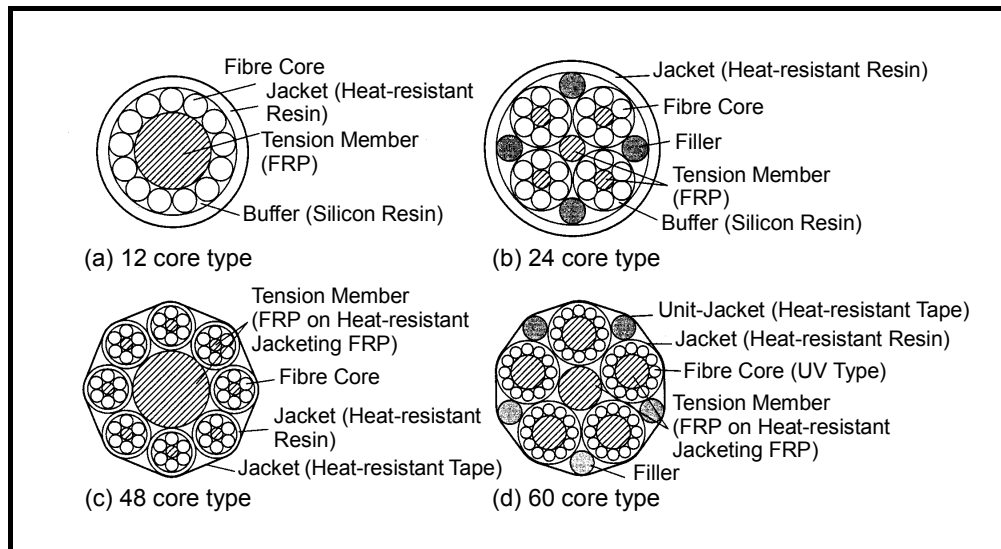


Fig. 4.6.6 Examples of structure of non-fixed type optical fibre cable

4.6.4 Outline of Optical Attached Cable-Wrapped Type OPGW

An optical attached cable-wrapped (OPAC-W) type OPGW is a type of optical fibre cable that is rolled out and attached to the existing overhead ground wire. As opposed to built-in OPGW, whereby the overhead ground wire must be re-laid, the most notable characteristic of OPAC-W type is that an existing overhead ground wire does not need to be re-laid. Nevertheless, as the optical cable is rolled onto existing overhead ground wire, the diameter of the existing cable increases, and the greater wind pressure must be taken into account. Therefore, it is necessary when increasing the number of fibres in the cable, to devise ways, as far as possible, to limit an increase in the diameter of the optical cable.

4.6.4.1 The Trend towards High Fibre-count

Together with an increased transmission capacity, the trend for OPAC-W type OPGW, like built-in type OPGW, has been for a higher fibre-count. In addition, since it is possible to increase the fibre-count by running OPAC-W type OPGW on existing built-in type OPGW cables, this kind of usage seems likely to continue to grow in the future.

The increase in fibre-count for OPAC-W type OPGW has been from 6 fibres to 12, and then to 24 fibres by using 6 fibre self-contained units. Furthermore, there are examples in practice where 48 fibres have been used in sections of cable line. Fig. 4.6.7 shows examples of the structure of 6, 12, 24 and 48-fibre OPAC-W type OPGW.

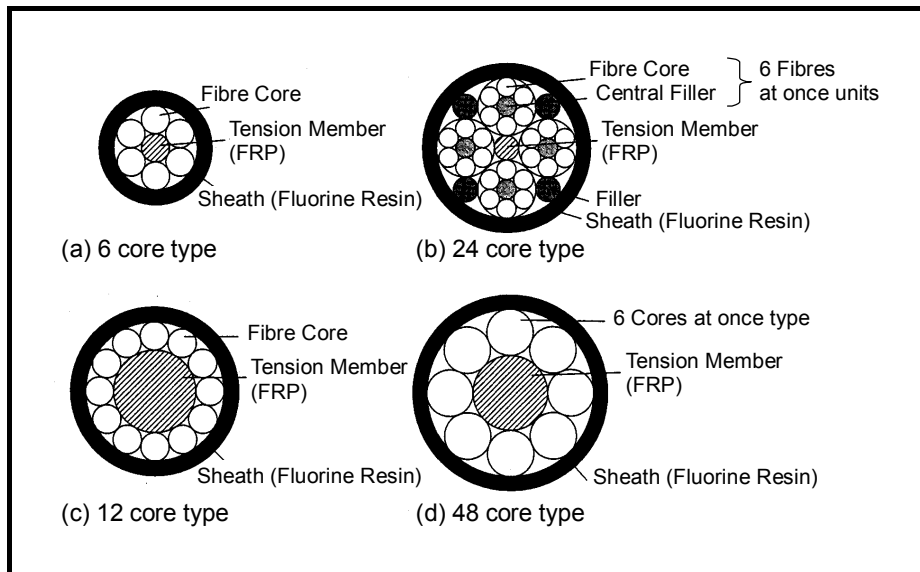


Fig. 4.6.7 Examples of structure of OPAC-W type OPGW

4.7 Maintenance Technology & Measuring Technology

4.7.1 Outline

In recent years our progression towards an advanced information society has led to the establishment of an advanced telecommunication network made up mainly of optical fibre. The volume of transmitted information by optical communications has jumped dramatically, and highly reliable optical cable networks are being called for. Maintenance is becoming more important. The demand is rising for cable line monitoring apparatus with the aim of improving reliability of optical cable networks, improving the efficiency of servicing, and enabling quick recovery from defective optical cables damaged in a natural disaster or otherwise.

4.7.2 Cable Line Monitoring Technology

4.7.2.1 Monitoring Methods

Cable line monitoring is performed through the combination of a signal light at 1.31- μm wavelength, a monitoring light at 1.55- μm wavelength, a coupler and a filter. A well-known method of cable line monitoring is the water detection module. In this system, the cable is pre-equipped with monitoring optical fibres in addition to the normal signal light optical fibres, and a water detection module is installed at the point of connection inside the closure. A cable line may be monitored by continually monitoring those optical fibres.

The water detection module is made of the combination of a material that expands when water

seeps in and a curved part that is lifted up with the expansion of the material when water seeps in. This movement bends the optical fibre causing a macro-bending loss that may be detected by the optical time domain reflectometer (OTDR) and other devices, and the fact of water seepage into the cable is detected.

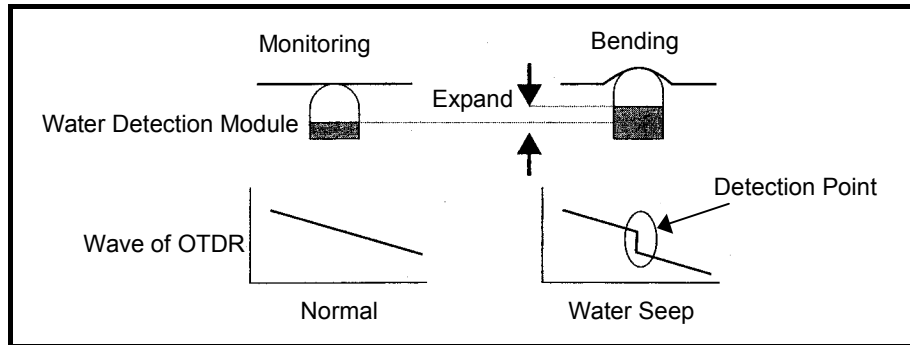


Fig. 4.7.1 Water detection module

4.7.2.2 Cable Line Monitoring Devices

Some generally well-known monitoring devices for telecommunication carriers are those for relay networks and subscriber networks.

4.7.2.2.1 Relay Network Monitoring Device

In addition to the function of monitoring from both directions, the relay network monitoring device has the function of ultra-fast shunting over a specific segment through the concurrent use of optical cable transfer splicing system (CATS), and shunting inside an exchange.

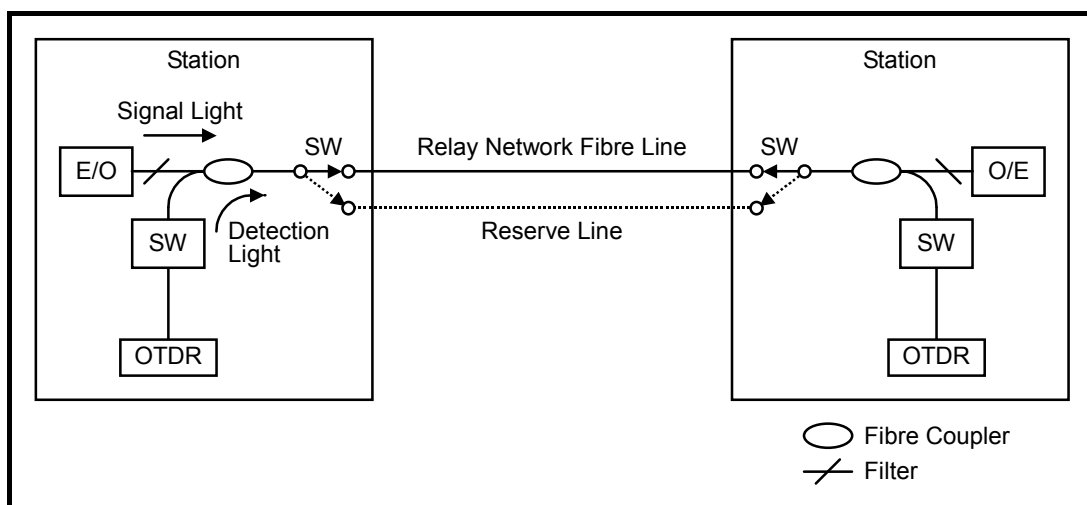


Fig. 4.7.2 Relay network monitoring device

4.7.2.2.2 Subscriber Network Monitoring Device

The subscriber network monitoring device has the functions of remote and automatic verification testing during periods of maintenance work; optical fibre targeted testing, and remote and automatic searching for optical fibre fault positions, etc.

For other examples, the system that monitors not only optical fibres but also whole cable lines continuously and the cable line monitoring system that conducts centralized management and control via general subscriber telephone line networks have been developed and commercialized.

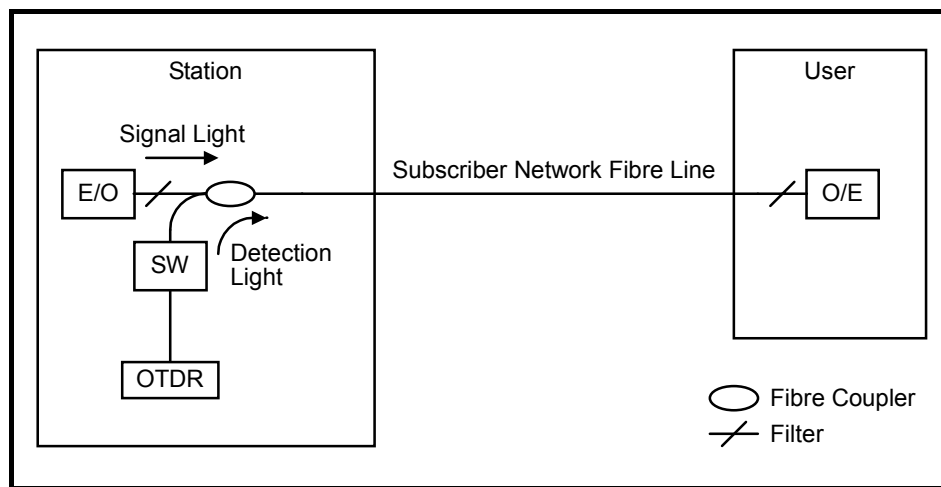


Fig. 4.7.3 Subscriber network monitoring device

4.7.3 Outline of Fibre Deterioration Diagnosis Technology

A certain percentage of optical fibres develops minute scratches on the glass surface. With time strains in the fibre by the external environment cause these to grow larger, and upon reaching a certain size the fibre fractures.

Nevertheless, it is not easy to eliminate the strain that optical fibres experience by altering the environmental conditions of facilities during and after the cable production. A method using OTDR is established in order to detect the location of cable line losses caused by radical bending or strain that dramatically reduced the life expectancy of fibres, and has been used for cable line monitoring systems, etc.

The demand for preventive fibre maintenance that measures the longitudinal strain in fibres undetectable through losses in cable line increases. The methods of strain distribution measurement in optical cables using Brillouin scattered light have been developed and commercialized.

4.7.3.1 Brillouin Scattering

Brillouin scattering is a phenomenon whereby a medium-specific frequency deviates and is scattered when high coherency incident light interacts with acoustic waves that occur in a medium.

This frequency is called the Brillouin frequency shift (ν_B). It is given by the following formula:

$$\nu_B = 2n_A V / \lambda$$

n_A : optical fibre refractive index

V : speed of sound

λ : wavelength of incident light

The Brillouin frequency shift is $\pm 13\text{GHz}$ at the $1.31\text{-}\mu\text{m}$ band and $\pm 11\text{GHz}$ at the $1.55\text{-}\mu\text{m}$ band. The change in Brillouin frequency shift is proportional to the distortion, and the rate of change ($d\nu_B/d\epsilon$) in the case of UV-cured resin coated fibres is $581\text{MHz}/\%$ at the $1.31\text{-}\mu\text{m}$ band, and $493\text{MHz}/\%$ at the $1.55\text{-}\mu\text{m}$ band. Furthermore, as Brillouin scattering is dependent on temperature, approximately $1\text{-MHz}/^\circ\text{C}$ frequency shift at the $1.55\text{-}\mu\text{m}$ band, it is necessary to either conduct measurements in the exactly same environment as the reference fibre, or perform temperature conversions.

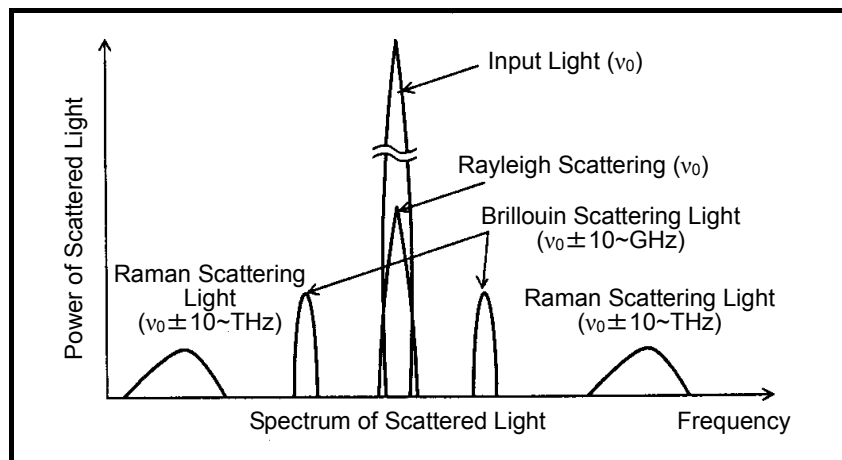


Fig. 4.7.4 Spectrum of scattered light inside optical fibre

4.7.3.2 Method of Strain Distribution Measurement in Optical Fibres using Brillouin Scattered Light

By seeking the amount of Brillouin frequency shift in the optical fibre it is possible to measure the strain being placed on the optical fibre. The two methods of measurement, Brillouin optical time domain analysis (BOTDA) and Brillouin optical time domain reflectometer (BOTDR), are available.

4.7.3.3 BOTDA

The principle of BOTDA is shown in Fig. 4.7.5. Placed at one end of the test fibre is a pulsed light source pump, and at the other end is a continuous wave (CW) light source probe. Each light source couples light through the optical fibre in the opposite direction.

The light frequency difference between the pulsed light source and the CW light source is adjusted to the Brillouin frequency shift. The CW light is amplified by the stimulated Brillouin scattering when it encounters the pulsed light. After passing through an optical frequency filter it is converted to electrical signals by a photo-detector.

The strain being applied on the optical fibre is assessed from the Brillouin frequency shift between the pulsed light and CW light that the Brillouin amplification produces efficiently when the wavelength of the CW light is changed. Also the location of the strain is measured from the time taken for the amplified CW light to arrive at the photo-detector.

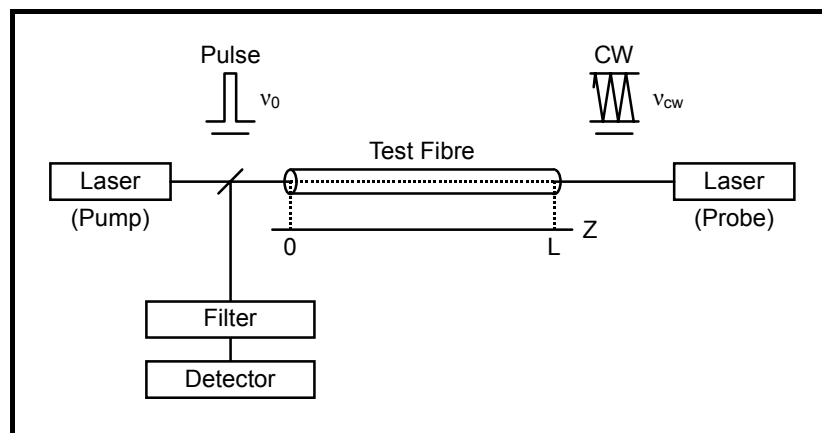


Fig. 4.7.5 Principle of BOTDA

4.7.3.4 BOTDR

In BOTDR pulsed light is coupled from each end and the returned Brillouin scattered light is measured using coherent detection. The principle of BOTDR is shown in Fig. 4.7.6.

In contrast to the coupled pulsed light, since the only frequency shift in Brillouin scattered light is the Brillouin frequency shift, it is possible to detect only the Brillouin scattered light by matching frequency difference (ν_S) between the pulsed light ($\nu_0 + \nu_S$) and local light (ν_0) to the Brillouin frequency shift (ν_B).

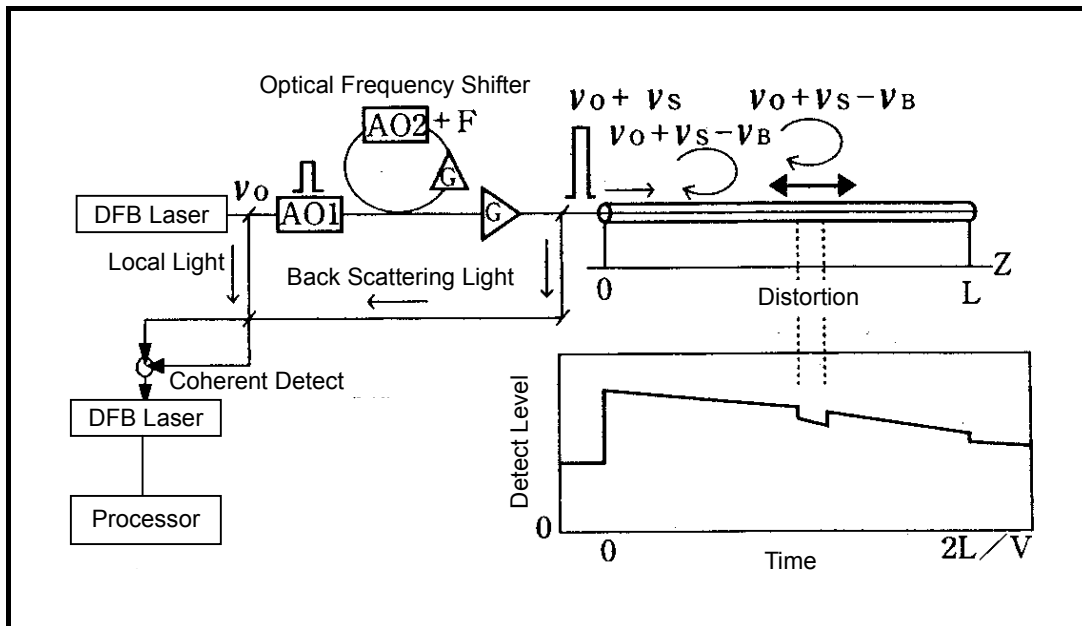


Fig. 4.7.6 Principle of BOTDR and signal waveform

5. Subjects for Practical and Commercial Use

The communications network for electric power utilities is required to have stable and high reliability as it is primarily designed to transmit such important information as power system protection, system operation, facilities monitoring and controlling information, all for securing stable operation of the power grid, and administrative information aimed to improve the efficiency of business operations.

In building up this communications network, the part for transmitting power system protection information, system operation information, and facilities monitoring and controlling information is constructed mainly with microwave multiplex radio systems, while the part for transmitting administrative information is built mainly with optical communications systems.

The topology of optical communications networks for electric power utilities consists of trunk networks, including those between the head office and branch offices and extra-high-voltage power stations, etc. In addition, it comprises local networks, such as those between branch offices and sales offices and distributing substations.

5.1 Future Prospects of Photonic Networks for Electric Power Utilities

The basic principle on standby systems and redundancy configurations differs between electricity service information and administrative information, of which the former includes system protection and operation information and facilities monitoring and controlling information. Since electricity service information in particular is required to have high reliability, the communications network for electric power utilities is built with standby systems and redundancy configurations for each category of information. However, transmission equipment and media are often used commonly both for electricity service information and administrative information, which differ from each other in required performance, and accordingly the communications network is usually built to meet the performance requirements for electricity service information. An increasing volume of administrative information may lead to projects to install dedicated transmission lines for this category of information. It is predicted that interested parties will have to discuss the joint use of transmission lines for electricity service information and administrative information in the years ahead.

At present, the maximum speed in the trunk networks of electric power utilities is 2.4Gbit/s though dense wavelength division multiplexing (DWDM) has not yet been introduced into these networks to increase the transmission capacity. However, WDM has been introduced into several sections in an effort to solve a shortage of core fibres, or conductors, in optical fibre cable networks.

Concerning the volume of information to be transmitted in electric power utilities in the years ahead, a forecast shows that power system operation information will increase with further expansion of electricity service facilities and that administrative information will sharply increase through wider use of ITs to improve the efficiency of business operations.

It is also expected that such techniques as DWDM, optical add/drop multiplexer (OADM) and optical cross-connect will be used to realize high-capacity communications networks.

The following paragraphs predict how the configuration of communications network will change in each category of information.

5.1.1 Power System Protection

The volume of information for power system protection is expected to increase in the years ahead through further expansion of power systems and the upgrading of relevant information. In terms of configuration, the networks used for this category of information will continue to consist of dedicated lines as they do at present, in view of fluctuations and restrictions on transmission delay time.

Apparently it is difficult to apply the Photonic Network of the general-purpose technology to the transmission of information for power system protection, which is required to have high reliability specific to electric power utilities, because such technology can hardly meet the transmission conditions for this category of information. In applying the Photonic Network technology to the transmission of power system protection information in the years ahead, it is expected that a new version of the technology capable of meeting fluctuations and restrictions on transmission delay time will be developed for maintaining the safety of electricity service and will be introduced in transmission systems for this purpose.

5.1.2 Power System Operation, Monitoring and Controlling

Similarly to power system protection, the volume of information on power system operation, monitoring and controlling is expected to increase with further expansion of the power grid. It is also probable that the volume of information in this category will increase through the upgrading of information on the operation of power plants and substations.

In terms of configuration, the networks for this type of information will continue to be composed of dedicated lines as they are. Further progress in the IP technology will give them such advantages as the capability to flexibly meet changes in the volume of information and to cut

back costs through effective use of general-purpose technologies.

In the area of information that is packetized now like power system operation information, it is expected that future progress in IP will lead to the creation of a high-speed IP network capable of flexibly meeting changes in the volume of information and further to the development of an advanced version of the network that will effectively utilize general-purpose technologies involved in Photonic Network.

5.1.3 Load-dispatching Telephone and Safety Instructions Telephone

Load-dispatching telephone and safety instructions telephone are essential as a means of communication about load dispatching and some other affairs between instructing stations, specifically load-dispatching offices or power system offices, and work sites or customers. These telephone systems also provide an essential means of communication concerning the restoration of damaged facilities in emergency or disaster. Accordingly the telephone systems are expected to remain in service in the years ahead.

It is predicted that, with further progress in VoIP, voice information will shift from switched-transport networks to IP networks or will be integrated into the latter while the general-purpose technologies in Photonic Networks will come into wide use for this category of information.

5.1.4 Administrative Information

Improvement of efficiency in various sectors of business operations will probably lead to a dramatic increase in the volume of administrative information to be transmitted. IP networks using general-purpose technologies will be diffused widely, resulting in the need to build optical networks that can flexibly meet ever-diversifying user requirements.

Administrative information is also expected to progress from the present packet system to the IP network and further to the Photonic Network in the years ahead. Since administrative information differs in quality from information on the safety of electricity service, however, it is likely that Photonic Networks for administrative information will be built separately from those for electricity service safety information in view of possible traffic congestion.

5.2 Prospects of Photonic Networks for FTTH Service

In recent years, some electric utilities began to offer FTTH service with their own organizations, their subsidiaries or affiliates.

The FTTH service provides high-speed telecommunications with an access speed of somewhere between 10Mbit/s and 100Mbit/s per subscriber.

Since the number of subscribers still remains small at present, WDM has not yet been introduced into trunk networks for FTTH service. But a forecast shows that an expansion of the service area and increasing the number of subscribers will lead to a steep rise in the volume of information to be transmitted over these networks in the years ahead.

It is also expected that such techniques as DWDM and OADM will be applied to future high-capacity networks for FTTH service.

6. Conclusions

The today's trend of telecommunication technologies is toward the ever-expanding IP networks and along with the advance of the IP technology and the expansion of its applications, the backbone network has been required of more broadness ever since to handle a wide variety of information. Around 2005, it is expected that a new society in which networks called Ubiquitous Network interconnect all information equipment and people can communicate with each other at anytime, anywhere. In order to realize the Ubiquitous Network, the backbone networks will be required of much higher speed and larger capacity, through which a very large amount of information will be transmitted, and the Photonic Network will be essential for these backbone networks.

The power utilities recognized the excellent characteristics of optical fibre early and began constructing optical fibre networks around 1980, and now have a very vast length of optical fibre cables already installed. As mentioned in chapter 1 and 2, those optical cables have been used not only for the power system communication but also for telecommunication business.

Electric power companies in some countries have been started providing their customers with information services using optical fibres. The information services cover, at the moment, automatic meter-reading, where the transmission speed is not high but this will evolve into a comprehensive service that includes remote household equipment control and home security as well as medical and health care services. For such services, image information will be transmitted only using the optical fibre technology because of the volume of information. In this technical brochure, we introduce the key technologies to realize the all-optical backbone network.

In realizing an all-optical backbone network, further technological developments are necessary to meet such requirements as the higher speed, larger capacity and higher reliability. It is our mission as ones engaged in the electric power industry and telecommunication business to contribute to the advance of the optical backbone technology toward the realization of the Ubiquitous Network Society in future.

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