Optical Add-Drop Multiplexers for Metro/Access Networks

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ABSTRACT As multi-media fields develop, metro/access networks are required to allow for flexible configuration changes as well as higher capacity and speed. An optical network configuration that integrates optical add/drop multiplexers (OADMs) with wavelength division multiplexing (WDM) system began to be introduced in these networks for its suitability. The authors have developed OADMs to be used in metro/access networks, which are capable of dealing with one to several channels arbitrarily selected.

1. INTRODUCTION

Presently, high-speed and wide-bandwidth broadband access systems such as ADSL, CATV and FTTH have become widespread. With respect to the data sent and received in such systems, those not only of text but also from multi-media fields --such as moving images and audio-- have grown in volume, and tend to increase hereafter. Thus, metro/access networks that connect subscribers with a trunk network are required to have scalability enabling rapid changes of communications capacity in response to the requirement of subscribers, in addition to transmission capacity enhancement and cost reduction, so that WDM systems have begun to be introduced.

Many metro/access networks adopt a ring configuration where the nodal bases are connected to form a ring, taking into consideration the reliability, transmission efficiency and ease of operation. At each nodal base, required signals are separated from a large amount of signals to carry out sending and receiving of information with the users. See Figure 1. Consequently, when conventional systems based on optical-electrical signal conversion are used, an enormous scale of equipment would be required, leading to an increase in system maintenance costs.

Recently, the coarse WDM (CWDM) communications technology is drawing attention since the technology allows a network configuration using devices with lower costs. However, because mutual entry between CWDM and the dense WDM (DWDM) for trunk networks is impossible, it is required to provide optical-electrical-optical conversion at switching nodes between the CWDM and DWDM systems.

To reduce the cost of large capacity transmission, whereas conventionally most signal processing has been done after optical-to-electrical conversion, it is required to process signals in optical form. Optical add/drop multiplex-

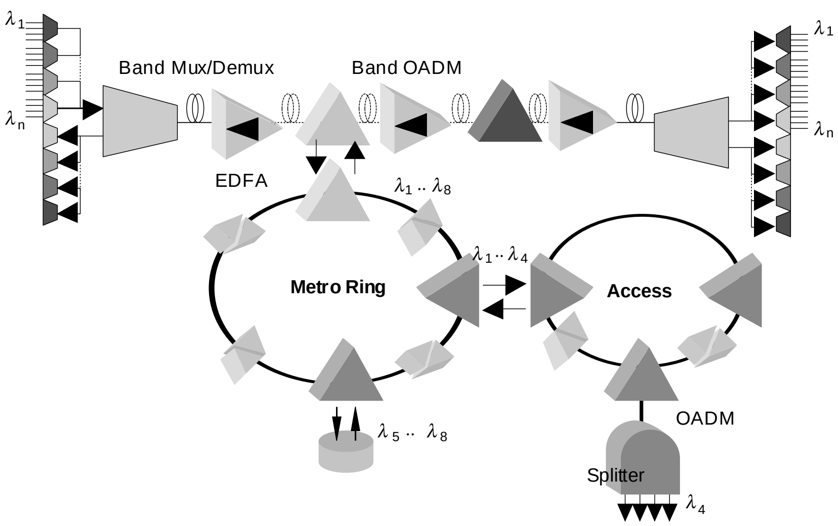

Figure 1 Typical system configuration of metro/access network.

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er (OADM) is one of the key devices to implement such optical signal processing where signals with arbitrary wavelengths are multiplexed to, or demultiplexed from, wavelength multiplexed signals. Use of this device makes it possible to freely add or drop signals with arbitrary wavelengths over multiplexed optical signals by assigning a wavelength to each destination. Moreover, it is possible to simplify the component configuration of optical amplifiers through reduction of the optical attenuation for the express channels --optical channels neither add nor drop at nodes-- in OADMs, thereby decreasing the total cost of networks.

2 CONFIGURATION OF OADM

2.1 Configurations Using TFF and FBG

The basic configuration of an OADM using dielectric thin-film filter (TFF) is shown in Figure 2.

An arbitrary signal wavelength is branched (i.e., dropped) from wavelength-multiplexed signals via a narrow band-pass filter (BPF), whereby only the desired signal wavelength being transmitted while others reflected. Meanwhile, an arbitrary signal wavelength can be inserted (i.e., added) into wavelength-multiplexed signals via a narrow BPF, whereby the desired signal wavelength being transmitted is combined with the reflected signal wavelengths.

Figure 3 shows the basic configuration of an OADM using a fiber Bragg grating (FBG).

The wavelength-multiplexed signals enter an FBG through a circulator, where only one arbitrary signal wavelength is reflected while others are transmitted. The reflected signal wavelength is branched (i.e., dropped) into a port other than that where the wavelength-multiplexed signals enter. In the case of wavelength multiplexing an arbitrary signal wavelength, the signal wavelength incident on the circulator is reflected by the FBG, and is inserted (i.e., added) into the wavelength-multiplexed signals that are transmitted via the circulator.

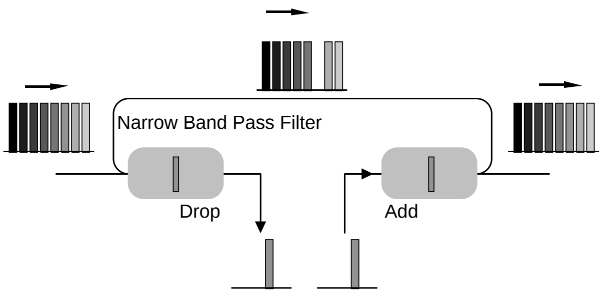

Figure 2 Configuration of OADM using TFF.

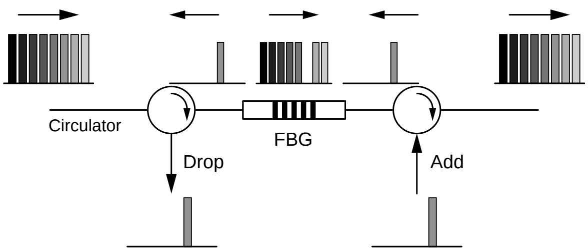

Figure 3 Configuration of OADM using FBG.

Features of these configurations are as follows. The configuration using the TFF is simple in construction and low in cost since it comprises only a TFF module. On the other hand, the configuration using the FBG can reduce the level of the signal wavelength contained in the wavelength-multiplexed signals down to 0.1 % or less --whereas it is about 0.3 % for the one using the TFF, so that it advantageously reduces the interference with the signal wavelength to be added after dropping, thereby decreasing signal noises.

In actual applications of OADMs for metro/access networks, it is typically required to add/drop four channels. In this report, accordingly, configurations for four consecutive channels using TFF-based OADMs will be described in detail.

2.2 TFF Module

Figure 4 shows the basic configuration of a TFF module for OADM. It consists of two single-mode optical fibers, dual-core ferrule, first lens, TFF, second lens, single-core ferrule and single-mode optical fiber. Whereas each of these components is fixed using laser welding or adhesive, the latter is not used in the optical paths to make this device resistant against an optical input of the watt-class power. The optical path is such that, in the case of a λ_1-reflecting and λ_2-transmitting filter, the light with wavelength λ_1 incident on the dual-core ferrule side is collimated by the first lens to be totally reflected by the filter; the reflected light with wavelength λ_2 is again incident on and collimated by the first lens to enter another fiber on the dual-core ferrule; the transmitted light with wavelength λ_2 is coupled into the fiber on the single-core ferrule via the second lens. Figure 5 shows the appearance of a TFF-based optical combiner module.

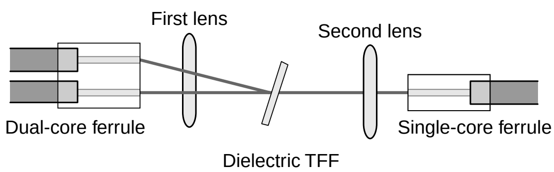

Figure 4 Basic configuration of TFF-based optical combiner module for OADM.

Figure 5 Appearance of TFF-based optical combiner module.

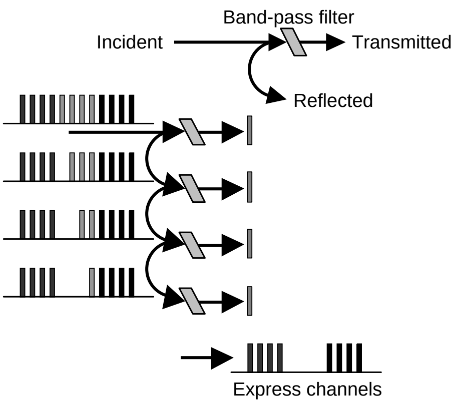

Figure 6 Basic configuration of TFF-based four-channel OADM, where four BPFs are connected in series.

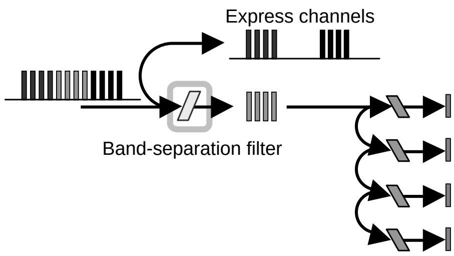

Figure 7 Configuration of TFF-based four-channel OADM using band-separation filter.

Table 1 Target specifications for four-channel OADM with 100-GHz spacing.

Item	Min.	Max.
Operating temp.	0°C	70°C
Pass band	±0.11	NA
Pass band loss	NA	3.5 dB
Express channels loss	NA	0.6 dB
Ripple (Drop channel)	NA	0.5 dB
Adjacent channel isolation	25 dB	NA
Polarization dependent loss	NA	0.3 dB
Chromatic dispersion@pass band	NA	±70 ps/nm

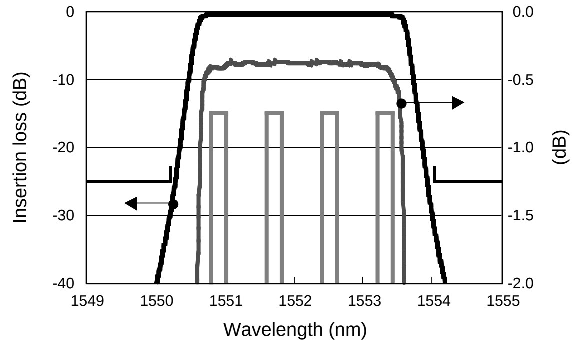

Figure 8 Transmission spectrum of 4-skip-0 filter module.

2.3 Four-Channel OADM

Figure 6 shows the basic configuration of a TFF-based four-channel OADM for branching (i.e., dropping). A signal wavelength for one channel is transmitted through a BPF and the rest signal wavelengths are reflected to enter the next BPF. By repeating these steps four times, four channels are branched from the multiplexed signal wavelengths, whereby four TFF modules are connected in series to constitute an OADM. But this configuration is at a disadvantage in terms of the high insertion loss imposed on the express channels due to the repeated reflections by the four filters. Higher insertion loss for the express channels has an adverse influence on the cost such that the system requires optical amplifiers of higher gain in the later stage of signal transmission.

2.4 Use of Band-Separation Filter

In order to improve the insertion loss on the express channels, an alternative configuration shown in Figure 7 is suggested, where a band-separation filter (i.e., 4-skip-0 filter) is used to separate four channels in block from multiplexed signal wavelengths. With this configuration, the express channels undergo only one reflection, so that the insertion loss is greatly improved leading to a reduction in total system cost.

When BPFs are used to configure a WDM system, the insertion loss difference of each channel depends on the number of reflection at the BPFs. Accordingly, the use of four-channel band-separation filter reduces the passing times through the reflection filters, thus improving the insertion loss characteristics. The insertion loss differences between the signal wavelengths added or dropped are also improved by a factor of four.

3. TARGET SPECIFICATIONS

Target specifications for a four-channel OADM with 100-GHz spacing using 4-skip-0 band-separation filters have been specified as shown in Table 1.

4. CHARACTERISTICS OF PRODUCTS

4.1 Characteristics of 4-skip-0 Band-Separation Filter Module

Figure 8 shows the transmission spectrum of a 4-skip-0 filter module. Over the four channels with a 100-GHz spacing (327.5 GHz) in the transmission band from 193.0 THz to 193.3 THz, the insertion loss is 0.49 dB --a low value. The flatness of insertion loss over the transmission band is 0.13 dB --excellent performance, and the isolation between adjacent channels is 25 dB or more.

Figure 9 shows the reflection spectrum. The insertion loss is 0.3 dB or less --a low value. The isolation over the transmission band is 18 dB or more, ensuring a drop-channel isolation of 36 dB or more --large crosstalk-- when used as an OADM for add/drop.

Figure 10 shows the transmission chromatic dispersion, giving a low value of dispersion of ±25 ps/nm or less over

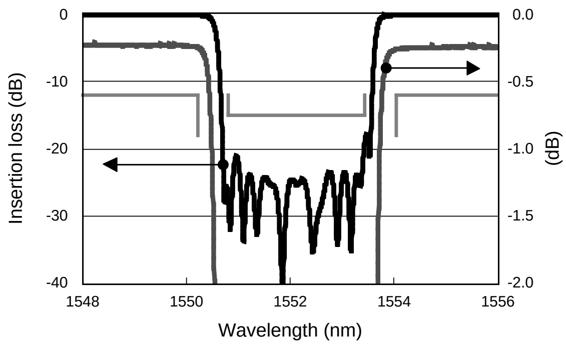

Figure 9 Reflection spectrum of 4-skip-0 filter module.

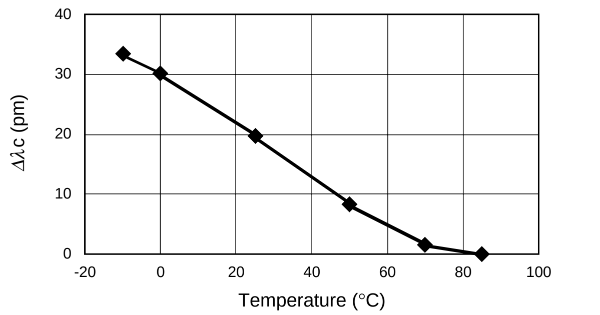

Figure 12 Temperature dependence of transmission spectrum of 4-skip-0 filter module.

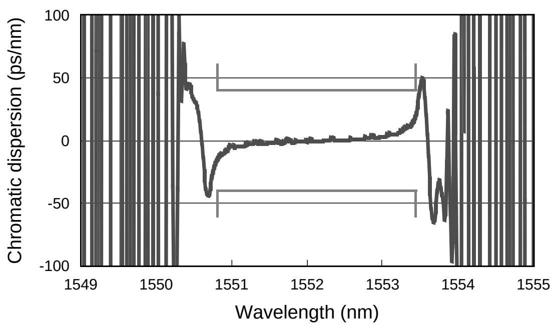

Figure 10 Transmission chromatic dispersion of 4-skip-0 filter module.

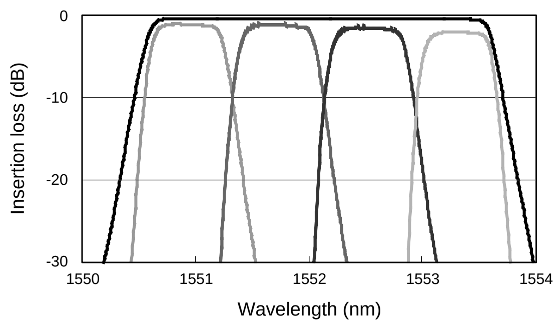

Figure 13-1 Transmission spectrum of four-channel OADM module.

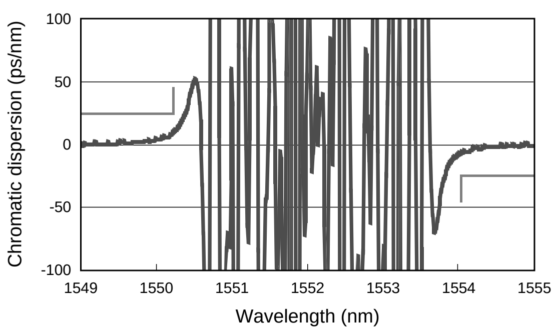

Figure 11 Reflection chromatic dispersion of 4-skip-0 filter module.

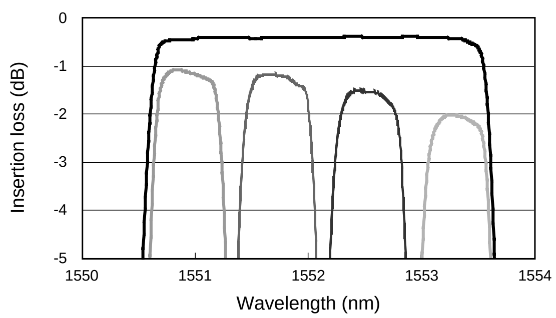

Figure 13-2 Transmission spectrum of four-channel OADM module. (Magnification)

the transmission band.

Figure 11 shows the reflection chromatic dispersion, giving a low value of dispersion of ±10 ps/nm or less over the reflection band.

Figure 12 shows the temperature dependence of transmission spectrum. The conventional dependence of 1 pm/°C has been improved to 0.5 pm/°C.

4.2 Characteristics of 4-skip-0 OADM

Figures 13-1 and 13-2 show the transmission spectrum of a four-channel OADM module.

The insertion loss for each channel is as low as 1.24~2.21 dB and its ripple is 0.20 dB or less for the wavelength band of ITU grid ±0.11 nm. Other optical characteristics are shown in Table 2, and the appearance in Figure 14.

Table 2 Optical characteristics of four-channel OADM with 100-GHz spacing.

Drop channel (THz)	193.3	193.2	193.1	193.0
Pass band loss (dB)	1.24	1.33	1.66	2.21
Pass band ripple (dB)	0.17	0.16	0.14	0.19
Band width@-0.5 dB (nm)	0.50	0.52	0.49	0.45
Band width@-25 dB (nm)	1.03	1.05	1.03	0.88
Chromatic dispersion (Min)(ps/nm)	-27.36	-31.44	-33.12	-46.90
Chromatic dispersion (Max)(ps/nm)	39.60	15.56	12.46	11.07

Pass band: λ_{ITU} ±0.11 nm
Express channels loss: 0.28 dB

Figure 14 Appearance of four-channel OADM module.

5. APPLICATION EXAMPLES IN METRO/ACCESS NETWORKS

In conventional long-haul transmission systems, emphasis has been placed on how much capacity and how far the system can transmit. In metro/access networks, however, low cost and system flexibility are strongly required.

In the metro-ring system, certain signal wavelengths are added to or dropped from wavelength-multiplexed signals at several nodes. Figure 15 shows the configuration of a DWDM metro system using the C-band that comprises four channels by eight nodes --32 channels in total-- with a signal spacing of 100 GHz. This configuration assigns four consecutive signal wavelengths to one node, wavelength multiplexes by four channels, amplifies the signal light using low-cost optical amplifiers, and combines the signals using eight 4-skip-1 band-separation filter modules based on TFF to carry out transmission. The 4-skip-1 module transmits four consecutive channels to do add/drop, while reflecting all the other channels except the four consecutive channels and one adjacent channel. When required, optical amplifiers may be used according to the transmission distance.

Advantages of this system configuration are: 1) Low-cost optical amplifiers without gain flattening filters (GFFs) to equalize the amplifier gain within the signal bandwidth can be used; 2) Optical components used for wavelength multiplexing and those used for add/drop multiplexing at each node --such as 4-skip-1 filter module, optical amplifier, 100-GHz combiner module, etc.-- can be standardized for use.

However, this configuration using 4-skip-1 filters has the disadvantage that the number of available signal wavelengths in the C-band decreases by about seven channels. When the 4-skip-0 band-pass filter described in Section 2.4 is used as shown in Figure 16, the number of signal wavelengths increases from 32 to 40 --the number of node increases from eight to ten-- thereby implementing an advantageous and efficient system configuration.

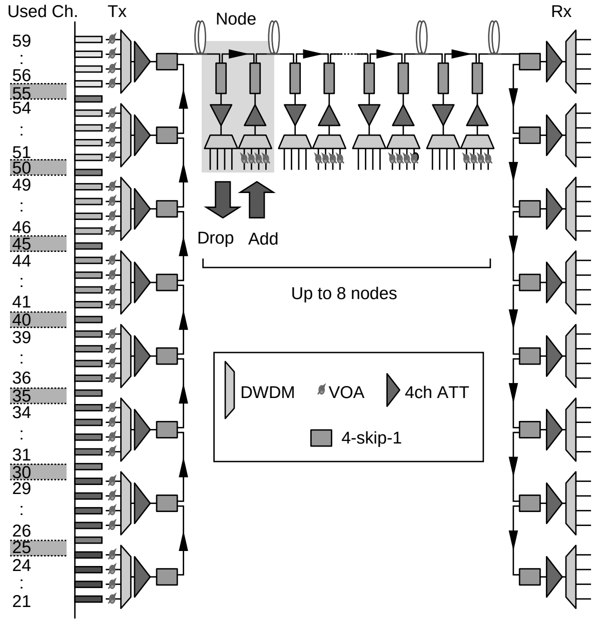

Figure 15 Schematic diagram of DWDM metro network system using TFF-based OADM with 4-skip-1 filter.

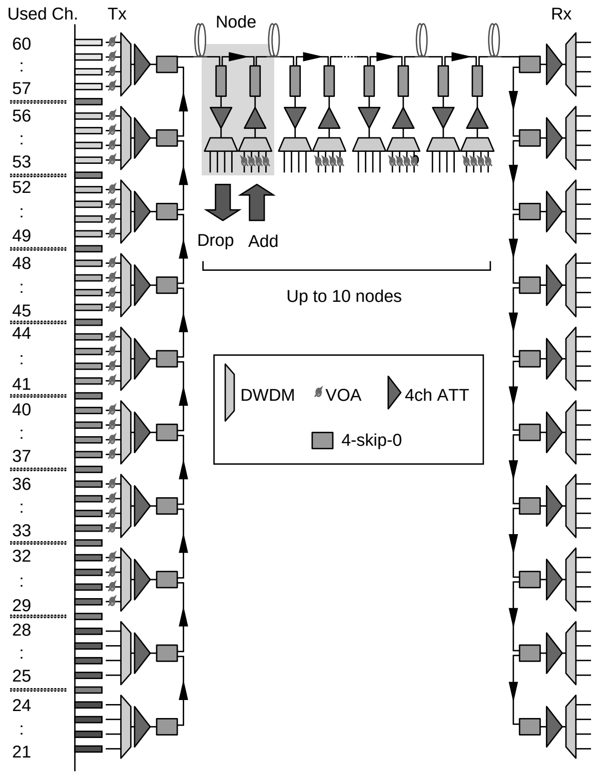

Figure 16 Schematic diagram of DWDM metro network system using TFF-based OADM with 4-skip-0 filter.

6. CONCLUSION

We have developed the OADM that substantially improves the insertion loss for express channels by using, unlike conventional OADM systems comprising series connection of 100-GHz optical combiner modules, 4-skip-0 band-separation filter modules. We have also established flexi-

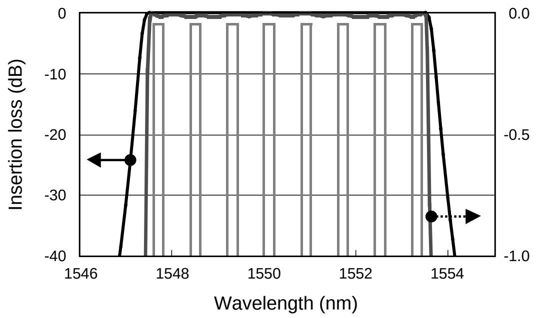

Figure 17 Transmittance spectrum of 8-skip-0 filter module designed.

ble system configurations taking advantage of the characteristics of this module.

Hereafter, we plan to develop an 8-skip-0 filter module that enables the add/drop of consecutive eight signal wavelengths with 100-GHz spacing in block, as shown in Figure 17.

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