An Optical Combiner Module for DWDM Systems

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ABSTRACT An optical combiner module with two input ports has been developed which is aimed at applications in Raman amplifiers, high-power optical amplifiers for DWDM (dense-wavelength-division multiplexing) systems, and ADM (add-drop module). An averaged insertion loss of 0.2 dB has been achieved by optimizing the coupling system for the filtering element and fiber as well as by preparing a common optical platform for the module, thereby eliminating the excess loss of the filter. Moreover, the module permits easy integration of an optical isolator, so that responding to ever-diversifying system requirements will be made possible.

1. INTRODUCTION

At the beginning of the 1990s, erbium-doped fiber amplifiers (EDFA) came into practical application, bringing about a dramatic leap in optical communications technology. However the explosive growth in the Internet, which began in North America at about the same period, increased the volume of public telecommunications traffic to the point where even greater capacity was required. Fortunately the gain band of EDFAs is comparatively wide, so that wavelength-division multiplexing (WDM) using all the optical signals included in this wavelength band was identified as a method that could provide a better solution to the problem than increasing the transmission speed of optical signals, and was rapidly implemented.

The WDM technology using EDFAs started from the 1550-nm band, where transmission loss of optical fiber is low and gain flattening is easily accomplished, but soon spread to the 1530-nm band and has recently been employed even in the 1580-nm and 1500-nm bands, where gain coefficient is quite small. In addition, Raman amplification that can amplify optical signals outside the wavelength band of EDF (erbium-doped fiber) amplification is drawing attention, and is beginning to enter into practical application. At the same time, development of optical modules is also proceeding actively to cope with such requirements of next-generation optical communications systems as high density, wide bandwidth, wavelength multiplexing, high power, and ease of extension. Among these, the optical combiner module with two input ports is a multi-use module that can constitute a variety of optical devices, by changing the characteristics of the dielectric multi-layered filter (hereafter called "filter") used in the device, such as wavelength combiners for Raman amplifiers, wavelength multiplexers and demultiplexers for multiplexed optical signals as well as wavelength combiners for pumping and signal lights. Consequently, it is essential that the combiner module provide design freedom to change its structure flexibly depending on its specific application.

This contribution reports on the development of an optical combiner module with two input ports, in which the basic performance of the input portion has been improved to achieve high design flexibility, low insertion loss, and high power capacity [1)~7)].

2. OPTICAL COMBINER MODULE WITH TWO INPUT PORTS

Figure 1 shows the basic configuration of an optical combiner module with two input ports. The module consists of two single-mode fibers (SMF1 and SMF2), a two-core ferrule, the first lens, a filter, the second lens, a single-core ferrule, and a single-mode fiber (SMF3); and an isolator is inserted between the filter and lens in case of use for pumping modules. Each component is securely fixed either by laser welding or using adhesive, but the latter is not used in the optical paths to make the device capable of withstanding a high-power optical input of Watt-class.

An example of ray tracing will be described below, in which a λ_1-reflecting and λ_2-transmitting filter is used. A light with a wavelength λ_1 launched into the SMF1 on the

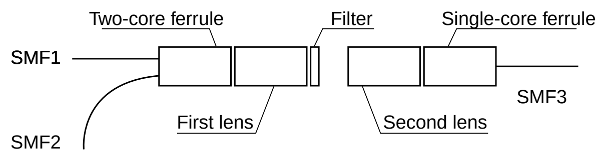

Figure 1 Basic configuration of optical combiner module with two input ports.

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two-core ferrule is collimated by the first lens and then is totally reflected by the filter. The reflected light is again collimated by the first lens before it is launched into the SMF2. Meanwhile, a light with a wavelength λ_2 that is launched into the SMF3 on the single-core ferrule is collimated by the second lens and is transmitted through the filter before being launched into the SMF2.

Figure 2 shows an appearance of this optical combiner module[8)~10)].

2.1 Application Examples

Figure 3 shows an application of the optical combiner module with two input ports as wavelength combiner for a Raman amplifier. The wavelength combiner No. 1 in the Figure incorporates a band-pass filter (BPF) that reflects a pumping light of 1420 nm and transmits that of 1440 nm radiated from the semiconductor laser modules (LDM), so that the combiner combines wavelength-wise the two pumping lights. Similarly, the wavelength combiner No. 2 combines wavelengthwise the pumping lights of 1460 nm and 1480 nm. Furthermore, the wavelength combiner No. 3 combines the pumping lights from the wavelength combiners No. 1 and No. 2, thereby outputs four pumping lights of 1420 nm, 1440 nm, 1460 nm, and 1480 nm. The combined pumping light ranging from 1420 nm to 1480 nm is then launched into the backward pumping module, which incorporates a long-wave pass filter (LWPF) that reflects pumping lights (from 1400 nm to 1500 nm) and transmits signal lights (from 1525 nm to 1570 nm). Thus, the pumping lights are reflected by the LWPF to be launched into an SMF to effect optical amplification, and the amplified signals emitted from the SMF are transmitted through the backward pumping module.

Figure 2 Appearance of optical combiner module.

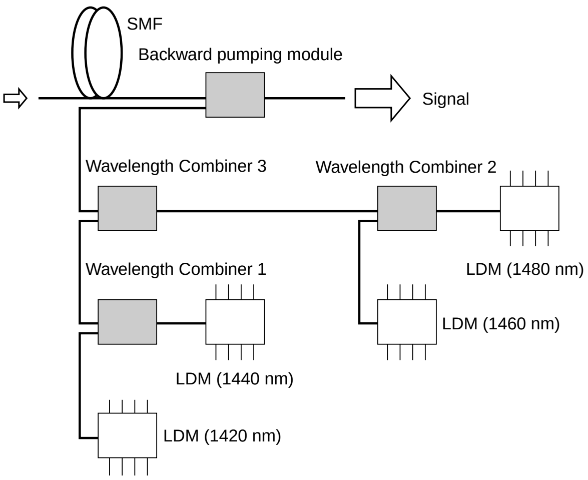

Figure 3 Configuration of Raman amplifier, an application of the optical combiner module.

Figure 4 shows another application of the optical combiner module in a Mux/Demux (multiplexer/demultiplexer) unit for ADM. The 100-GHz BPF incorporated in every optical combiner module comprises dielectric multi-layer filters of five-cavity structure, featuring a broad transmission bandwidth of 550 pm between the points 0.5 dB down from the peak wavelength, and the chromatic dispersion within the bandwidth is quite small. These filters are selected from those that are very precisely measured for their spectral characteristics using an incident beam with an accuracy of 0.001 degree or less with respect to the design incident angle, so that the peak wavelength achieves a good match with the signal wavelength. Figure 5 shows the measured results of transmission characteristics.

When a light containing eight signals of different wavelengths is incident upon the common port of the combiner module No. 1, the BPF No. 1 retrieves the signal light of 194.7 THz and reflects other seven signal lights to send them into the common port of the combiner module No. 2. Connecting such a stage in cascade, a Demux unit can be configured enabling to retrieve every signal light. Meanwhile, a Mux unit can be structured by injecting signal lights with different wavelengths from the reversed way.

2.2 Comparison with Other Module Configurations

When a high optical power of Watt-class is injected into an optical combiner module, the temperature of the module rises due a small fraction of optical power that is

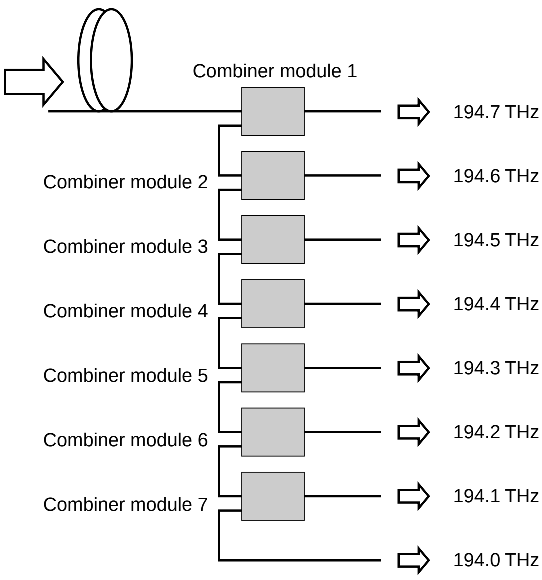

Figure 4 Configuration of Mux/Demux unit for ADM, an application of the optical combiner module.

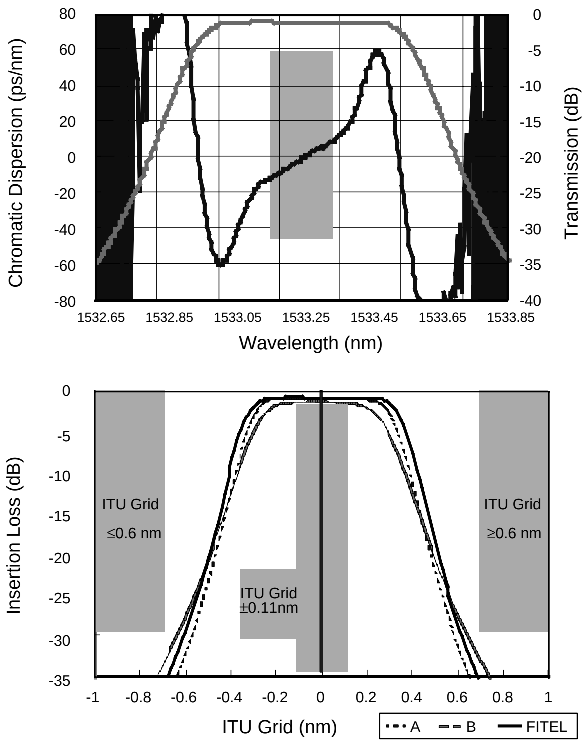

Figure 5 Typical transmission and dispersion characteristics of 100-GHz BPF based on optical combiner module.

absorbed. In an experiment where a pumping light of 6 W was injected into a module with a coupling loss of 0.2 dB, the temperature rise of the module package recorded more than 10°C suggesting a higher temperature rise inside.

Because of their simple structures and ease of design, optical collimators are often used, in which a lens having a distributed refractive index profile is adhesively bonded with a fiber end. However, these types of collimators are obviously less reliable in terms of optical-power resistance than the air-gap type based on welding or solder bonding, because minute foreign particles contaminating the organic adhesive may absorb optical power thus resulting in possible burning of the adhesive. Meanwhile, solder bonding is likely to lead to loss increase caused by the accelerated creep phenomenon of solder due to temperature rise. In contrast, the developed optical combiner module is stabilized in performance because it entirely employs laser welding reducing sources of insertion loss change against heat. Furthermore, the module is very reliable against high-power operation because it uses no adhesive in its optical paths thus eliminating possibilities of burning.

It is known that an ultra-narrow band BPF can not achieve desired transmission characteristics unless the thickness of every filter layer is controlled with a precision of 0.01 %. We have established a measuring method that enables precise measurement of filter chips used in the combiner module, making it possible to manufacture ultra-narrow band BPF modules rather easily.

Table 1 Specifications of wavelength combiner for WDM systems.

Operating Temp.	0 - 70°C	Notes
λ_{op}	1400 - 1620 nm	R-, S-, C-, L-band
Insertion loss	< 0.25 dB	@R.T., ASOP, λ_c
	< 0.45 dB	@T_{op}, ASOP, λ_{op}
PDL	< 0.05 dB	@T_{op}, ASOP, λ_{op}
Directivity	> 60 dB	@T_{op}, ASOP, λ_{op}
Optical power	< 3 W	@T_{op}, ASOP, λ_{op}
Return loss	> 50 dB	@T_{op}, ASOP, λ_{op}

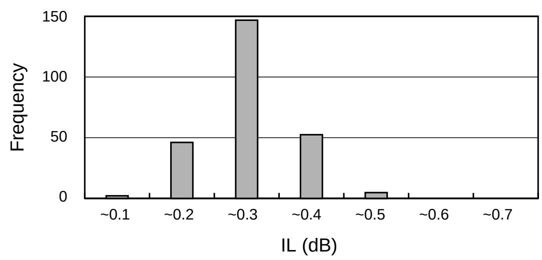

Figure 6 Histogram of insertion loss of pumping modules for Raman amplifiers. (Ports SMF1 to SMF2)

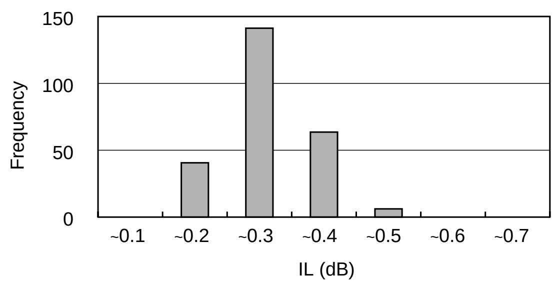

Figure 7 Histogram of insertion loss of pumping modules for Raman amplifiers. (Ports SMF2 to SMF3)

3. SPECIFICATIONS

Wide bandwidth, low insertion loss, and sufficient power resistance that are expected to be strongly required hereafter have been taken into consideration in determining the specifications of the optical combiner module for wavelength combining as shown in Table 1.

4. PRODUCT CHARACTERISTICS

Optical characteristics of optical combiner products such as pumping module, wavelength combiner, pumping module with an isolator, and polarization-maintaining pumping module will be described below based on the results of measurements.

4.1 Insertion Loss Distribution

Figures 6 and 7 show histograms of insertion loss of selected pumping modules that combine signal light and pumping light under conditions of full temperature range, full wavelength band, and unpolarized state of polariza-

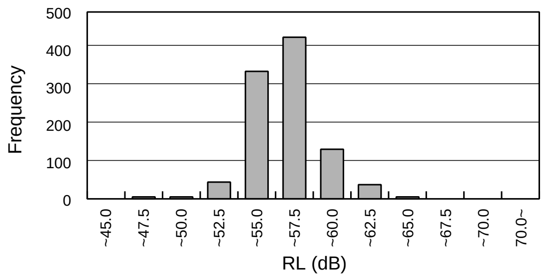

Figure 8 Histogram of return loss of pumping modules for Raman amplifiers. (Ports SMF1, SMF2, and SMF3)

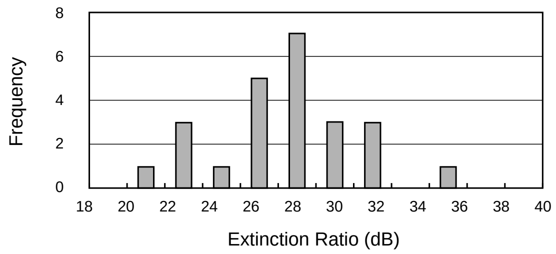

Figure 9 Histogram of extinction ratio of polarization-maintaining pumping modules.

tion. Figure 6 relates to the loss between ports SMF1 and SMF2, and Figure 7 between ports SMF3 and SMF2, respectively. Because the module uses aspherical lenses, both the reflection port and transmission port have an averaged insertion loss of 0.2 dB with a dispersion of 0.03 dB --excellent performance.

4.2 Return Loss Distribution

Figure 8 shows a histogram of return loss of selected pumping modules that combine signal light and pumping light, including the measured results of port SMF1 through SMF3. The return loss satisfactorily meets the specifications and its wavelength dependence is small.

4.3 Extinction Ratio

Figure 9 shows a histogram of extinction ratios of signal lights in polarization-maintaining pumping modules that are used in polarization-maintaining optical amplifiers having polarization-maintaining fibers (PMF) on input- and output-optical ports. The extinction ratio should be as high as possible, because it substantially affects the amplification efficiency and the insertion loss of optical amplifiers. The two-core ferrule used in the developed combiner module is designed to be less susceptible to degradation in extinction ratio even when PMF is used on all ports[8].

4.4 Wavelength Characteristics

Figure 10 shows the wavelength dependent insertion loss of selected pumping modules that incorporate an isolator. If the insertion loss changes by 0.1 dB per module within the signal wavelength band, an optical amplifier for next-generation communications systems that are provided with four or more stages of EDFAs may have a wavelength dependent insertion loss of 0.4 dB or more, thereby becoming unable to meet the performance requirements.

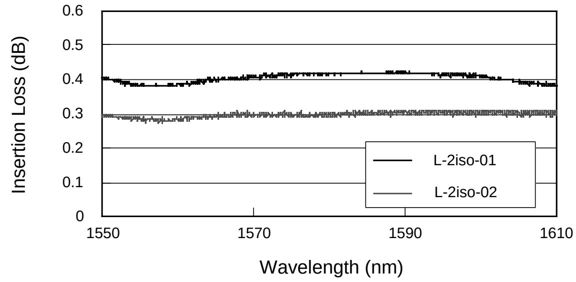

Figure 10 Wavelength dependent insertion loss of L-band pumping modules.

Accordingly, the insertion loss must be as flat as possible in the signal wavelength band, and the developed pumping module is designed to provide an insertion loss flatness of 0.05 dB or less within the band[9), 10)].

4.5 High-power Performance

A pumping light of 1 W or more is sometimes injected into a wavelength combiner for Raman amplifiers. In view of this, the developed combiner module was tested for its high-power performance, in which 12 modules were tested with a pumping light of 3 W at 1480 nm for 1000 hours in a high-temperature, high-humidity tank. The insertion loss degradation of each combiner module before and after the test was 0.1 dB or less.

Next, the temperature rise in a wavelength combiner module under pumping light injection was checked using a Thermo-viewer. Figures 11 and 12 show the results. From Figure 11, because the module is provided with low insertion loss and countermeasures against high-power optical input, only a small temperature rise of 2 to 3°C evenly distributed is seen even at an optical input of 3 W. Figure 12 shows the result of an optical power injection test of 6 W into a wavelength combiner module having an insertion loss of 0.29 dB. Although the temperature at the two-core ferrule rose by 10°C, no change in insertion loss was seen.

5. RELIABILITY

Reliability tests were carried out in accordance with Telcordia standards GR-1209 and GR-1221 to confirm the reliability of the optical combiner module with two input ports. In each test, loss and its changes were seen to satisfy the specified values, thereby confirming sufficient reliability.

6. SUMMARY

An optical combiner module with two input ports has been developed, which features high reliability, compactness, and ultra-low insertion loss. The product is expected to be used in wide areas of application such as pumping light combiners for Raman amplifiers, optical amplifiers for DWDM systems, and Mux/Demux units.

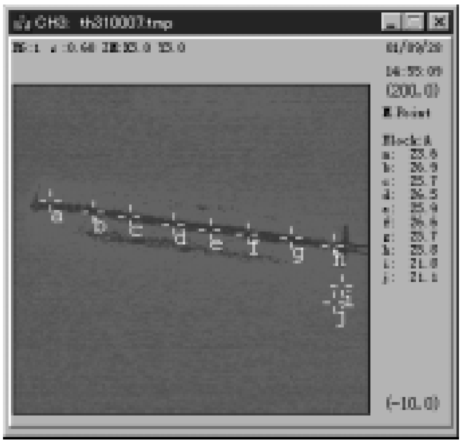

Figure 11 Temperature rise of a combiner module when an optical power of 3 W is injected.

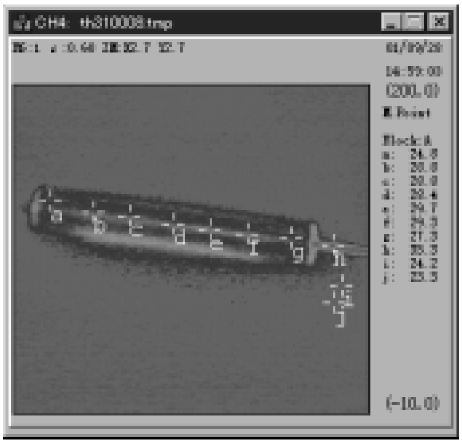

Figure 12 Temperature rise of a combiner module when an optical power of 6 W is injected.

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