Development of a Low-Loss Optical Circulator

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ABSTRACT The optical circulator is one of the key devices in the optical add-drop modules (OADMs) used in wavelength-division multiplexing (WDM) technology, which finds applications in large-capacity long-haul telecommunications systems. A low-loss optical circulator has been developed to significantly improve OADM performance. Insertion loss for these modules is extremely low--less than 0.44 dB at the operating temperature and wavelength range. High reliability and high power resistance are assured by fabrication techniques that use YAG welding for mechanical components, eliminating the use of adhesives in the optical path.

1. INTRODUCTION

The Internet, which in the 1990s spread primarily in North America, has undergone explosive growth in recent years. What were originally only local networks have expanded to a worldwide scale, and the data sent and received has gone from text only to still and moving images, requiring quantum jumps in capacity. In wide-area networks fiber-optics has become indispensable in the instantaneous transmission of large volumes of data.

Fiber-optic networks, which heretofore have been confined to universities, research institutes and a few large corporations have, with the spread of the Internet, advanced rapidly into ordinary homes. This has created a need for the more effective utilization of fiber-optic networks, and one way of accomplishing this has been with wavelength division multiplexing (WDM) technology, in which a number of signals of differing wavelength can be carried on a single fiber.

The optical circulator is one of the key devices used by WDM-type OADMs, which extracts and multiplexes the desired wavelengths. As networks have expanded in recent years and the distances that signals are transmitted have lengthened, the need to decrease the loss in each individual module as a means of sending the signals further has become more necessary than ever before. And since these modules can be used in bi-directional amplifiers and a wide range of other equipment, in addition to OADMs, reduction of loss has come to be an essential attribute.

This paper presents the fundamental principles of the optical circulator, and goes on to report on development of a marketable 3-port optical circulator that achieves low loss by optimizing losses between the various ports. It also reports on the development of a 4-port optical circulator that put into application the principles of the 3-port type.

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2. CONFIGURATION

Figure 1 is a schematic diagram of the newly developed low-loss 3-port optical circulator. It comprises three single-mode fibers (SMFs), single-fiber ferrules, lenses and a non-reciprocal section using a uniaxial birefringent crystal and garnet. The various components are held in place by laser welding and adhesive bonding, but to achieve high power resistance no adhesive is used in the optical path.

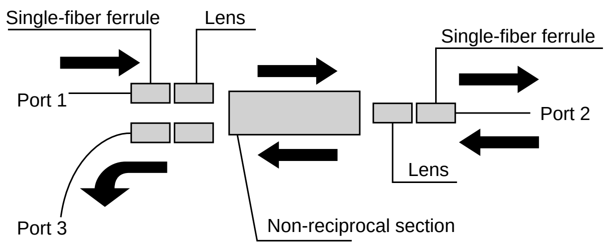

Figure 1 Schematic diagram of newly developed optical circulator.

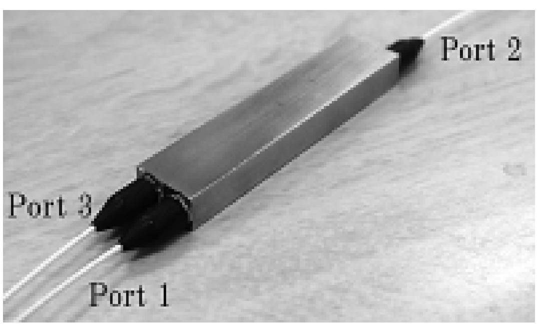

Figure 2 Appearance of newly developed optical circulator.

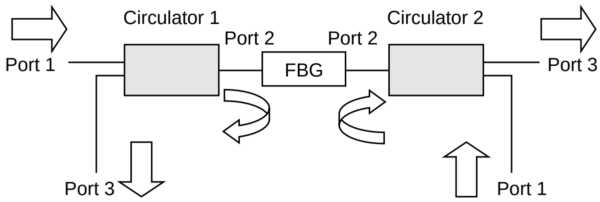

Figure 3 **Schematic diagram of use of optical circulators in an OADM.**

Table 1 **Specifications of newly developed optical circulator.**

Item	I/O ports	Rating
Insertion loss	1 to 2	≤0.5 dB
	2 to 3	
Isolation	2 to 1	≥30 dB
	3 to 2	
Directivity	1 to 3	≥55 dB
PDL	1 to 2	≤0.1 dB
	2 to 3	
Return loss	1, 2 & 3	≥55 dB
Rated wavelength range	1525~1570 nm	
Dimensions (L × W × T)	71.5 × 11 × 6 mm	

Following is a description of module function based on Figure 1. The light injected through port 1 is collimated at the lens, passes through the non-reciprocal section, and is focused at the lens of port 2 and output to port 2. Similarly the light injected through port 2 is collimated at the lens, passes through the non-reciprocal section, and is focused at the lens of port 3 and output to port 3. Figure 2 shows the appearance of the optical circulator.

2.1 Example Application

Figure 3 is a schematic diagram showing the use of optical circulators in an OADM.

When the multiplexed signal is input to port 1 of circulator 1 it flows through port 2 to a fiber Bragg grating (FBG) that reflect only certain wavelengths. The signal light reflected from the FBG is returned to port 2 of circulator 1 and output (or dropped) from port 3. The other signals pass though, being input to port 2 of circulator 2 and output to port 3. In the case of multiplexing, the added signal is input from port 1 of circulator 2. The signal output from port 1 to port 2 is reflected by the FBG, passing again through port 2 and being output to port 3. At this time it is multiplexed (added) to the signal passing through the FBG.

3. SPECIFICATIONS

In keeping with past designs aimed at lower loss, the targets set forth in Table 1 were set for all operating temperatures (-5 to 70°C) and a full range of wavelengths.

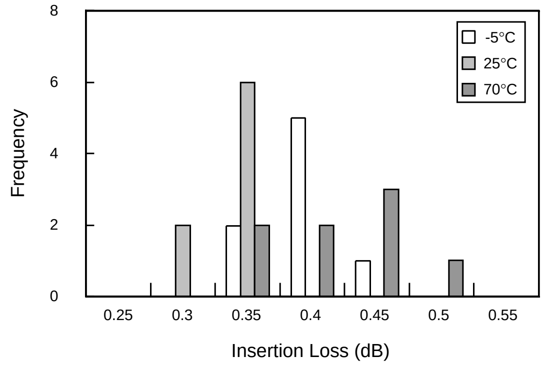

Figure 4 **Histogram of insertion loss from port 1 to port 2.**

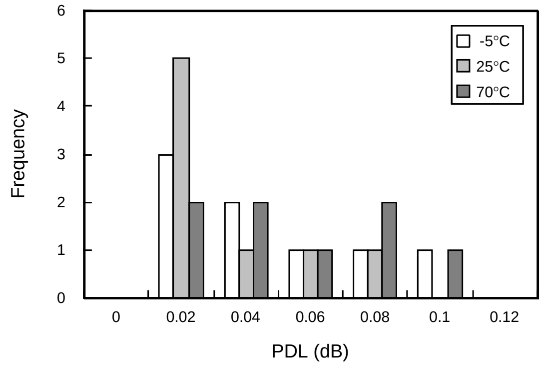

Figure 5 **Histogram of PDL from port 1 to port 2.**

4. OPTICAL CHARACTERISTICS

4.1 Insertion Loss, Temperature Characteristics and PDL

The port numbers correspond to those shown in Figure 2. Insertion loss and PDL are extremely important for this module, and indeed for any component used in fiber-optic communications. Figures 4 and 5 show histograms of insertion loss and PDL from port 1 to port 2, and Figures 6 and 7 give analogous histograms for port 2 to port 3.

Insertion losses were very low, averaging only 0.36 dB from port 1 to port 2, and 0.39 dB from port 2 to port 3. This was slightly higher than the value from port 1 to port 2 because of the use of an optical path converting element.

For PDL, the values averaged 0.04 dB for both port 1 to 2 and port 2 to 3, fully satisfying the specifications.

Figures 8 and 9 show typical wavelength dependence of insertion loss at selected temperatures for port 1 to 2 and port 2 to 3. The change in the characteristics due to temperature was very low--less than 0.05 dB. The wavelength change was also low--less than 0.1 dB from port 1 to port 2 and less than 0.08 dB from port 2 to 3.

4.2 Isolation

Figures 10 and 11 show histograms of isolation from port 2 to port 1 and from port 3 to port 2. When isolation is small the returned light influences the original signal, and

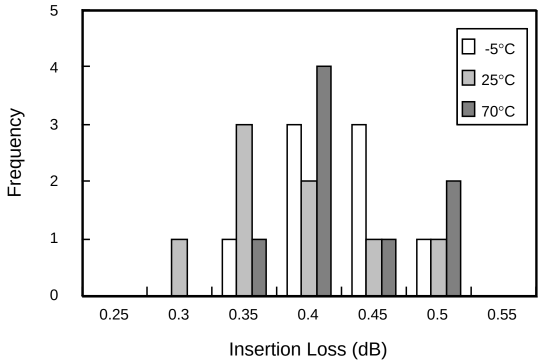

Figure 6 Histogram of insertion loss from port 2 to port 3.

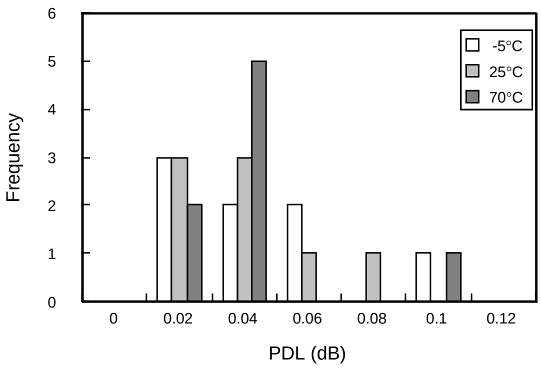

Figure 7 Histogram of PDL from port 2 to port 3.

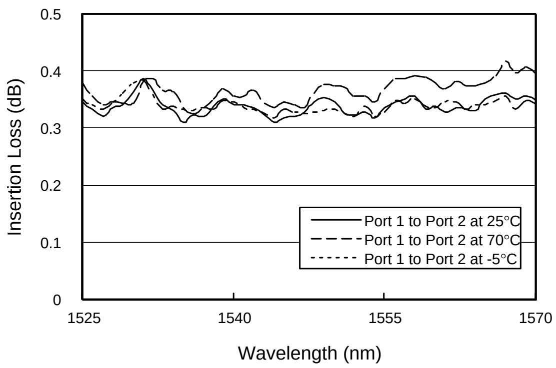

Figure 8 Wavelength dependence of insertion loss at selected temperatures from port 1 to port 2.

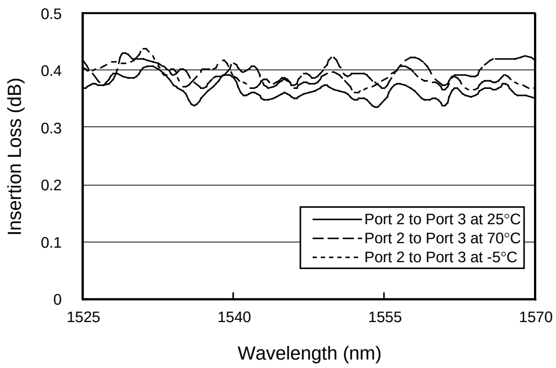

Figure 9 Wavelength dependence of insertion loss at selected temperatures from port 2 to port 3.

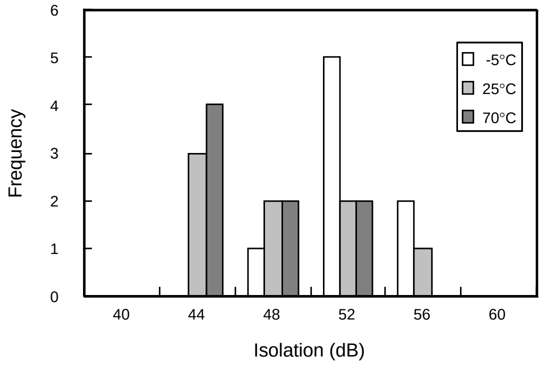

Figure 10 Histograms of isolation from port 2 to port 1.

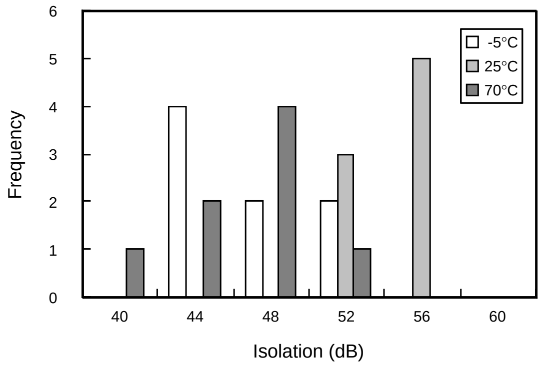

Figure 11 Histograms of isolation from port 3 to port 2.

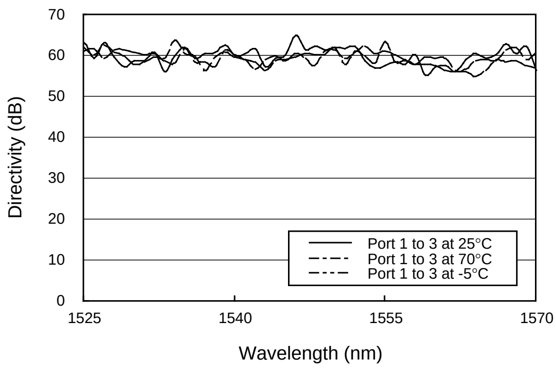

Figure 12 Wavelength dependence of directivity at selected temperatures from port 1 to port 3.

from the principle of the optical circulator is temperature dependent, but by optimizing the design of this module it was possible to fully satisfy the specifications with an average of 47 dB.

4.3 Directivity

Figure 12 shows the wavelength dependence of directivity at selected temperatures from port 1 to port 3. The change due to both temperature and wavelength was 55 dB or more, satisfying the specifications.

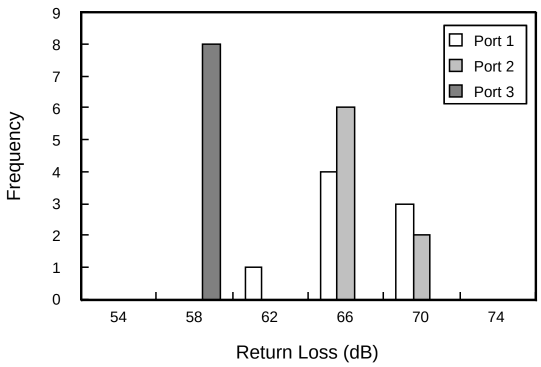

Figure 13 Histogram of return losses.

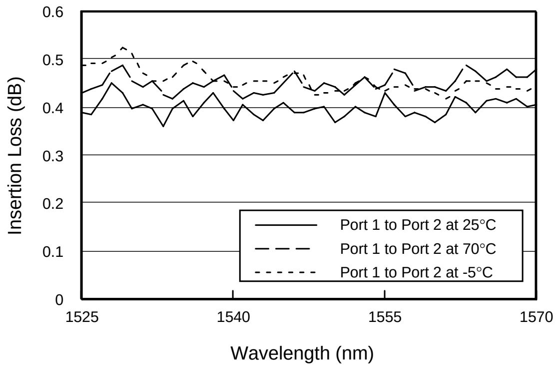

Figure 14 Wavelength dependence of insertion loss at selected temperatures for 4-port circulator from port 1 to port 2.

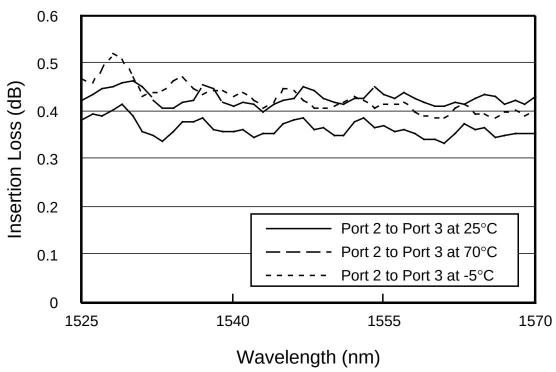

Figure 15 Wavelength dependence of insertion loss at selected temperatures for 4-port circulator from port 2 to port 3.

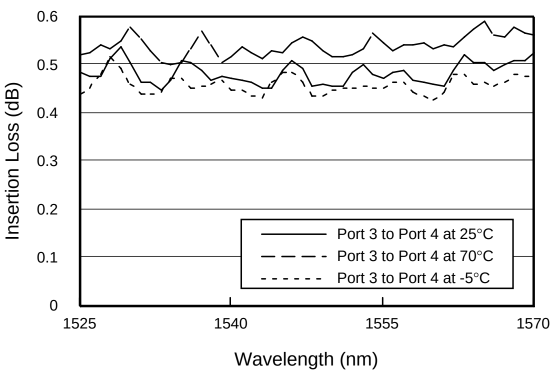

Figure 16 Wavelength dependence of insertion loss at selected temperatures for 4-port circulator from port 3 to port 4.

4.4 Return Loss

Figure 13 shows a histogram of return losses at each of the ports. The average for all ports was 63 dB, fully satisfying the specifications.

5. 4-PORT CIRCULATOR

In the present work a 4-port circulator was also developed by applying the technology used in the 3-port design. Figures 14 through 16 show the wavelength dependence of insertion loss at selected temperatures for a 4-port circulator. It was possible to realize a module having an insertion loss of less than 0.53 dB from port 1 to 2 and port 2 to 3, and less than 0.6 dB from port 3 to 4. The specifications shown in Table 1 were also fully satisfied for characteristics other than insertion loss.

6. CONCLUSION

Based on the fundamental principle of the optical circulator, it was possible, by optimizing losses between the various ports, to develop a low-loss 3-port circulator with an insertion loss of less than 0.44 dB within the range of the operating temperatures and wavelengths. The realization of these low-loss characteristics promises to improve the performance both of OADMs and of a wide range of other equipment such as bi-directional amplifiers.

It was also possible, applying the technology used in the 3-port circulator, to develop a 4-port circulator with an insertion loss of less than 0.6 dB. This will make it possible to meet rising expectations with respect to 4-port circulators.

ACKNOWLEDGMENT

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