MODULE 5: Optical Circulators

Aims:

- To understand the operation of optical circulators
- To explore the applications of optical circulators

Keywords: Optical circulator, add-drop multiplexer, bi-directional

Description:

Optical circulators are couplers that have specific couplings depending on the propagation direction of light signals. There are two variants: 3-port circulator and 4-port circulator.

In a 3-port circulator, as shown in Figure 5.1, light signal enters via port-1 and exits via port-3, while port-2 is a bi-directional port. On the other hand, in a 4-port circulator, light signal enters via port-1 and exits via port-4, while port-2 and port-3 permit bi-directional propagation, as shown in Figure 5.2.

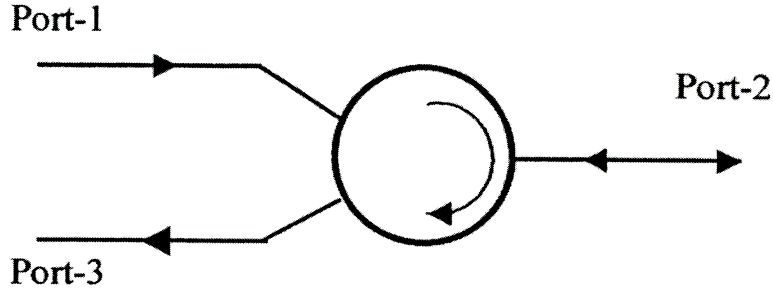

Figure 5.1 3-port Optical Circulator

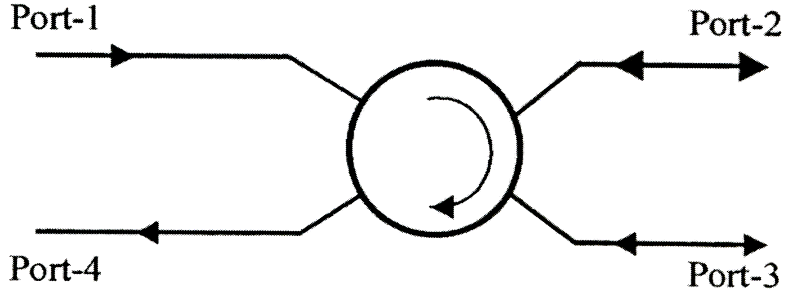

Figure 5.2 4-port Optical Circulator

These are versatile devices for optical network applications. Both types of circulators can be used to construct Add-Drop muitiplexers, and for coupling different sections of a network together. When two optical circulators are employed at either end of an optical fiber link, a single fiber can be made to carry bi-directional signals, and thus double the capacity of the link. They can replace the standard fiber coupler in OTDR application for measuring optical fiber length and fiber loss characteristics, with much improved performance. They can also be used in conjunction with a fiber Bragg grating (FBG) for sensing application.

By connecting an EDFA to port-1 and port-3, and a FBG to port-2 of a 3-port optical circulator, we have, in effect, a fiber ring laser with wavelength determined by the FBG, and laser emission from the unconnected end of the FBG.

Characteristics:

Optical circulators are built with the same polarizing optics, such as polarisers, Faraday rotators, wave plates, prisms and beam splitters, as in optical isolators. These optics separate and rotate the state of polarization of light as it traverses the device. With the appropriate design, a reflected beam can be annulled (as in an optical isolator) or channelled into a different port instead of the entry port (as in an optical circulator). Therefore, optical circulators have similar optical isolation capability to an isolator. For example, in a 3-port circulator, there is strong optical isolation between port-1 and port-2, and also between port-2 and port-3. The internal configuration of a particular commercial 3-port polarization insensitive optical circulator is shown schematically in Figure 5.3 (Ref.3).

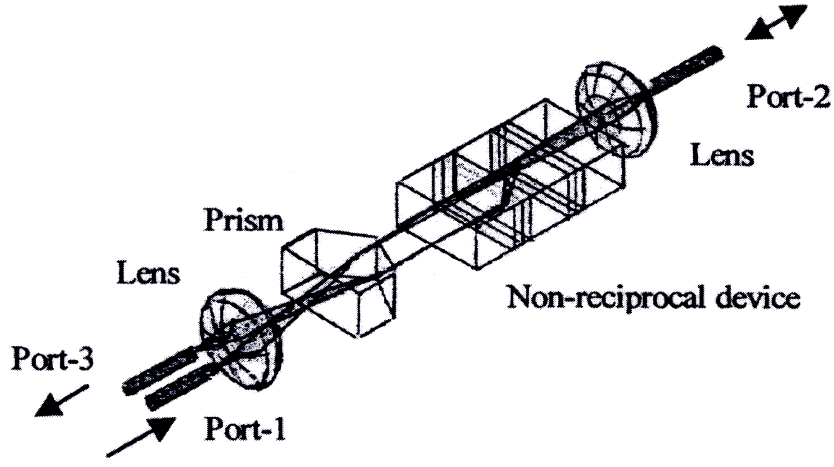

Figure 5.3 Configuration of Optical Circulator

Light coming from the optical fiber at port-1 is focused and redirected via the combination of a lens and a prism to enter a non-reciprocal device, which consists of a seven-element stack of bi-refringent plates and Faraday rotators. The forward transmitted light is then focused by a second lens into the optical fiber at port-2. The backward travelling light from port-2 is diverted by the non-reciprocal device into a direction that can be focused into the optical fiber at port-3, thus achieving the optical circulator function.

Due to the presence of bulk optical components in the design, optical circulators typically have slightly higher insertion loss compared to other types of fiber couplers. Their operation is also wavelength dependent, such that a 1550 nm optical circulator will not work in a 1310 nm network. This is because of the strong wavelength dependence of bi-refringent plates and Faraday rotators.

Preview questions:

1. Why is an optical circulator called a "circulator"?
2. What percentage of a signal entering port-1 of an "ideal", i.e. lossless, 3-port optical circulator will be detected at port-3, when there is only a bare fiber connected to port-2?
3. Can we send a signal directly from port-1 to port-3 in a 4-port optical circulator? Why?
4. Compare and contrast a 3-port 3 dB fiber coupler with a 3-port optical circulator.

Experiments:

These experiments are designed to illustrate the special properties of a 3-port optical circulator.

Equipment required:

3-port optical circulator, 1550 nm laser, power meter, patch cords

5.1 3-Port Optical Circulator:

Procedures:

1. Connect the 1550 nm source to port-1 and measure the output power at port-2 and port-3. What do you observe? Why?
2. Connect the 1550 nm source to port-2 and measure the output power at port-3 and port-1. What do you observe? Why?
3. Connect the 1550 nm source to port-3 and measure the output power at port-i and port-2. Is there any reading at all? Why?

References:

1. See e.g. "Development of a low-loss Optical Circulator", by Y. Makiuchi and H. Matsuura, http://www.furukawa.co.jp/review/fr0022/fr22_09.pdf
2. For an add/drop multiplexer, see e.g. "Fiber Bragg Gratings Filter WDM Signals" by B. Hitz, in Photonics Spectra, March 2003, pg.74~78.
3. See e.g. "The development of Ultra Small Size Polarization Insensitive Optical Circulator", H. Matsuua, M. Konishi and T. Hatano, http://www.socnb.com/report/default_e/1988a11_e.pdf