

Optical reflection can degrade performance of lasers or amplifiers unless blocked by isolators.

# Isolators protect fiberoptic systems and optical amplifiers

Barry Zhang and Liangju Lu

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In a modern optical transmission system many types of passive fiberoptic components are used to perform various functions. These components typically fall into four categories—connecting devices such as connectors and splices; branching devices such as couplers and splitters; filtering devices such as fiber Bragg gratings, add/drop filters, and wavelength division multiplexers (WDMs)/demultiplexers (WDDMs); and performance-improving devices such as attenuators, polarizers, dispersion compensators, and isolators.

Isolators are playing an increasingly important role in fiberoptic systems. Whereas most passive components are reciprocal, isolators are normally nonreciprocal—that is, they allow the passage of an optical beam in the forward direction with minimal losses (<0.5 dB) while blocking the transmission in the backward direction with 40–70-dB losses.

There have been numerous designs of different types of optical isolators such as all-fiber isolators,<sup>1,2</sup> fiber-embedded isolators, fiber Faraday rotator isolators,<sup>3</sup> and waveguide-based isolators.<sup>4</sup> The core of a typical commercially available isolator contains a Faraday rotator with 45° rotation and a pair of birefringent crystals or a pair of polarizers. A pair of microlenses such as gradient-index lenses usually couples the optical beam from one fiber to the other. The birefringent crystal-based structure makes a polarization-independent isolator, and the polarizer-based module makes a polarization-dependent isolator.

## How isolators work

Though most diode lasers emit linearly polarized beams with about a 20-dB extinction ratio, regular single-mode fibers do not maintain the input polarization status—which explains why most passive components, including isolators, are polarization-independent (see Fig. 1).<sup>5</sup> In the forward direction, the first wedged crystal splits the input beam into *e* and *o* beams.

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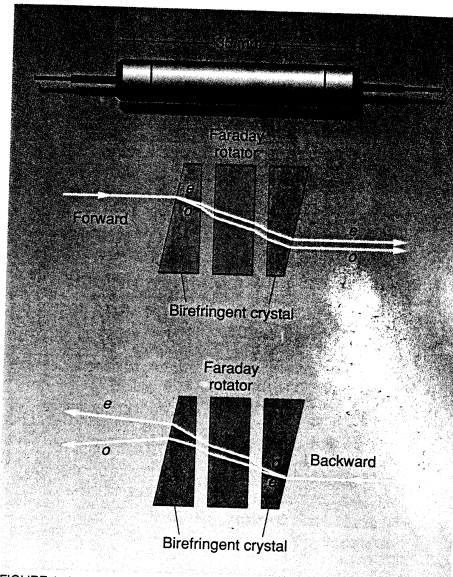


FIGURE 1. A polarization-independent isolator splits the input beam into two parallel beams that are then refocused by a lens into the optical fiber.

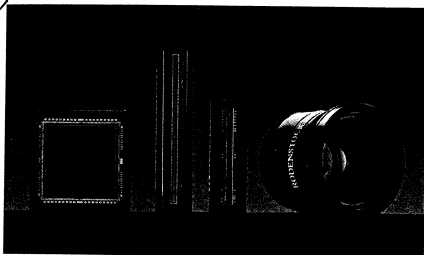
After passing through a 45° Faraday rotator the *e* and *o* beams enter the second wedge. Because the second crystal's axis is at 45° relative to the first crystal's axis, the *e* and *o* beams from the first crystal propagate through the second crystal as *e* and *o* beams, respectively. At the exit surface of the second crystal the two beams become parallel to each other. The lens focuses them both into the output fiber.

In the backward direction, the second wedge again splits the incoming beam into *e* and *o* beams. After passing through the 45° Faraday rotator, which rotates both beams by 45° in the same direction, the *e* becomes *o*, and *o* becomes *e* in the first wedge crystal. Therefore, the first wedge separates the two beams, further preventing this backward propagating beam from coupling into the input fiber.

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#### ► PASSIVE FIBEROPTIC COMPONENTS

the polarization status in an optical system such as a fiberoptic gyro and in systems in which some critical components are polarization-dependent (see Fig. 2). The two polarizers are aligned so that their optical axes are 45° apart.

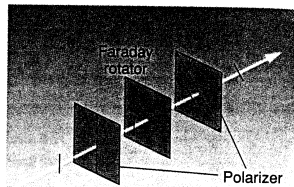


FIGURE 2. For systems such as a fiberoptic gyro, a polarization-dependent isolator maintains the polarization of the beam by aligning two polarizers so that their optical axes are 45° apart.

In the forward direction, the first polarizer transmits only one polarization. The Faraday rotator rotates the polarization of the transmitted beam by 45° so that it goes through the second polarizer without loss. If the beam comes from the backward direction, the remaining component of the beam (after the second polarizer) is rotated in the same direction by the Faraday rotation. Therefore, its polarization is perpendicular to the optical axis of the first polarizer and absorbed. Usually, polarization-maintaining (PM) fibers are used on both the input and the output ends. In some cases, regular single-mode fibers are used on the input ends or both ends. When PM fibers are combined correctly with a polarization-independent isolator, a single fiber can transmit two channels of signals with crossed polarization while obtaining isolation in both channels.

#### Applications of optical isolators

The two main applications of optical isolators are optical transmission systems and fiberoptic amplifiers. Distributed-feedback lasers are used in many transmission systems. Distributed-feedback-laser frequency is very sensitive to reflection coupled back to the laser cavity because of the single-cavity mode. Because the laser gain profile is not flat, the frequency fluctuation also affects power stability (see Fig. 3). It is crucial, therefore, to have some kind of isolation from the optical circuitry.

In some cases, even Fabry-Perot lasers need isolation from the system to improve power stability. In general, the fewer the cavity modes the Fabry-Perot lasers have, the more important it is to have an isolator in the system.

Optical amplifiers such as erbium-doped fiber amplifiers (EDFAs) generate 10- to 40-dB gains. Amplified spontaneous emission or even lasing action is almost inevitable without isolators because of reflections from various joints and surfaces in the circuit. Sometimes more than one isolator is needed in a single amplifier.

Fiberoptic isolators have been used in many other applications, not only in telecommunications but also in biotechnology, sensing (such as fiberoptic gyros), and other fields.

#### Performance

The importance of each parameter of a single-stage isolator depends on the specific application (see table on p. 152). For example, if the system's power budget is low, insertion loss

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should be considered first. If power stability is critical, polarization-dependent loss is more important than other loss. In general, however, there are several factors that should be considered when purchasing isolators:

- Insertion loss can be attributed to three areas: surface loss, absorption loss, and coupling loss. Antireflection (AR) coating can generally reduce surface loss to less than 0.01 dB per surface. There are at least 12 optical surfaces in a single-stage fiberoptic isolator; therefore, the total

surface loss can add up to 0.1 dB.

Coupling loss between a pair of collimators is typically 0.15 to 0.25 dB. The total material absorption loss is usually less than 0.05 dB, which is mainly due to the Faraday rotator. Temperature variation affects coupling loss, whereas wavelength has an effect on both surface and coupling loss. The dependence on wavelength, however, is rather small over a small range (see Fig. 4).

- Isolation—maximum isolation of a single-stage isolator is limited by the

### How to buy fiberoptic isolators

Because of the complex requirements of each optical system, buying a fiberoptic isolator can be a daunting task. Following is a checklist of guidelines for potential buyers:

- **Polarization effect:** If the extinction ratio is important, a *p*-dependent isolator should be used with either polarization-maintaining fibers or even regular single-mode fibers. If the system has no polarization dependence, a *p*-independent isolator will be the obvious choice.

- **Single-stage or dual-stage:** A dual-stage fiberoptic isolator contains two isolator modules in a single package allowing >55 dB of isolation. In most applications, a single-stage isolator provides enough isolation. Dual-stage isolators add not only cost but also losses. Most manufacturers offer more than two grades in each category. If a lower grade is adequate for the system, it should be considered because of the significant cost savings.

- **Wavelength:** Standard telecommunications wavelengths of 1310 and 1550 nm are the obvious choices because they are much more available and less expensive. In fact, the only fiberoptic isolators available in the visible and near-infrared portions of the spectrum are those bulky packages that are much more expensive than a standard telecommunication type. If the peak wavelength of the system is more than 10 nm away from either 1310 or 1550 nm, it is wise to have isolators specially made at that wavelength for better isolation.

- **Reliability:** Unless the vendor can provide a test report on reliability, always perform a few tests after receiving the isolators. Temperature cycling is the easiest and the most important test to conduct. If an environmental chamber is not available, use a freezer and a laboratory oven or a hot plate to let the isolators go through a few temperature cycles. Measure all the important parameters at room temperature after temperature cycling. Any significant drift from the specified value indicates possible problems in the manufacturing process.

- **Physical information:** Dimensions, proper strain relief, and proper housing materials could affect either how isolators are used or their performance. The isolators should have the same fiber used in the rest of the system. It is also advisable to maintain the same jacket size throughout individual enclosures. Fiber-jacket material may also be important because some tight buffers are very hard to strip.

- **Termination:** Unless a frequent connection is necessary, always use fusion splice instead of connectors because the performance differences in insertion loss and return loss are significant.

- **Price:** Significant cost savings can be achieved by doing two things. First, stay with standard products, and, second, use hybrid components to combine two or three functions into one component.

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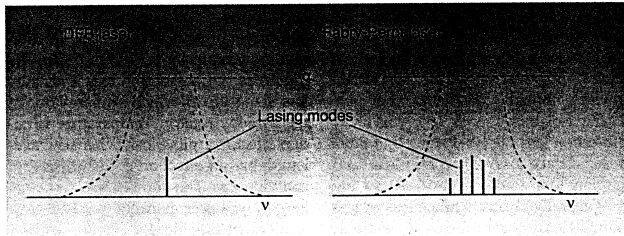


FIGURE 3. The effect of frequency fluctuations on power stability is shown by a laser cavity mode and gain profile ( $\alpha$  is cavity loss).

extinction ratios (ERs) of the components used. The ER is typically more than 40 dB. The dependence of isolation on temperature and wavelength are the direct effect of the temperature and wavelength dependence of the Faraday rotator material. One of the most popular materials is bismuth-substituted rare-earth iron garnet.

- Return loss—a measure of reflection—is defined as the ratio of incident optical power to the reflected optical power in units of decibels (dB). A 50-dB return loss is equivalent to -50 dB reflection. Return loss is usually not a strong function of temperature or wavelength because the angle and the surface quality of the fiber facet are the two main factors affecting it.
- Polarization-dependent loss (PDL)—indicates the maximum insertion loss variation when the input polarization changes randomly. Low PDL is important for system optical-power stability.
- Polarization-mode dispersion (PMD)—is a measure of the time delay generated between the two orthogonal polarization states after passing through the isolator. High PMD not only limits system bandwidth but induces transmission errors.

- Optical power handling—is primarily determined by the surface treatment at the tip of the fiber. Normal AR coating can handle more than 300 mW fairly safely. Some manufacturers use index-matching material between the fiber tip and the lens. In this case, power handling is highly dependent on the type of material used. The symptom of optical damage to an isolator is a sudden increase of insertion loss and decrease of return loss on the input end.

Reliability and test standards  
Advancements in isolator technologies have been driven mainly by the increasing needs of the telecommunications industry worldwide. Reliability has been a critical issue for passive components in telecommunications because, in a long-haul transmission system, repair or replacement of those components is not practical. Several industry standards

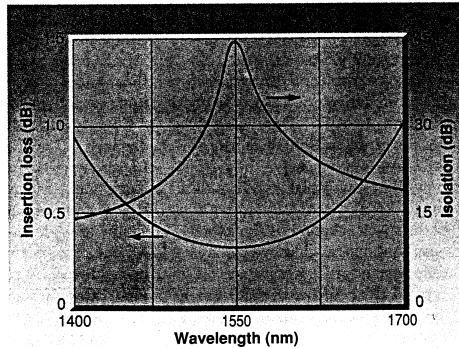


FIGURE 4. Insertion loss and isolation are dependent on the transmission wavelength (single-state 1550-nm isolator shown).

on optical components, including isolators, have been issued. Among them, the Bellcore GR-1221 standards have realized greater acceptance by the industry.

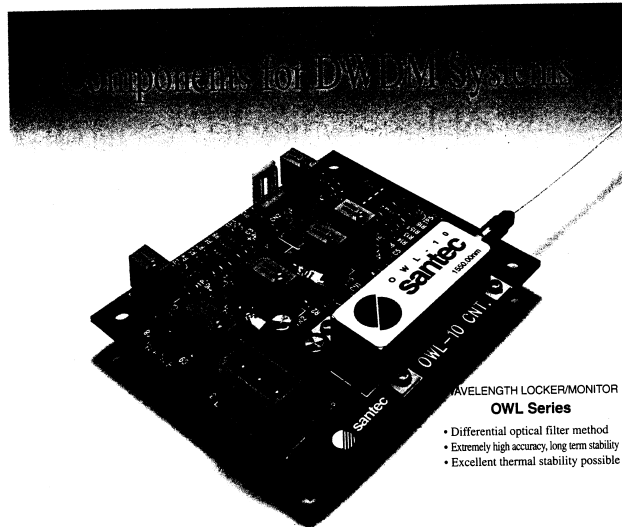
Special requirements from other industries such as low out-gassing for the aerospace industry and high or low tem-

perature capability for sensing also have been addressed. A common standard has not yet been established.

#### Future development

Standard fiberoptic isolators have become almost commodity items. Their performance, size, and even package

styles are increasingly similar. Isolator prices also have stabilized after a continuous decline for several years. Some manufacturers have moved more toward hybrid components such as the isolator/WDMs, isolator/WDDMs, isolator/tap couplers, and isolator/filters. By using these hybrid components, customers can not only cut cost but also save space.

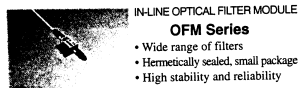


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#### Typical specifications of single-stage isolators

Isolation (peak)	<40 dB
Isolation (min. at $\pm 20$ nm, 23°C)	32 dB
Insertion loss	<0.5 dB
Return loss	<60 dB
Bandwidth	$\pm 20$ nm
Polarization-dependent loss	<0.05 dB
Polarization mode dispersion	<0.2 ps
Power handling	<300 mW at specified wavelength
Operating temperature	-5°C to 60°C
Storage temperature	-40°C to 85°C

The availability of specialty isolator products will increase in the future because of the growing complexity of modern optical systems. These products may include waveguide-based integrated isolators and densely packed multiport isolators for multichannel applications.

There will be continued efforts in new Faraday rotator materials for the visible and near-IR part of the spectrum. New isolator materials for 980 nm will likely be the driving force in this category because of the growing need for an EDFA pump source at 980 nm.

The future for passive fiberoptic components will continue to bring advancement. Growing demand from telecommunications and other industries is likely to nurture technical breakthroughs never before seen. □

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