Anatomy of An Transparent Optical Circulator

PDV Workshop

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Discussion on Optical Circulators

- Outline
  - General Description
    - Common uses and specifications
    - Use in a PDV System
    - Birefringence
  - Specific Details
    - Internal Components
      - Reflective vs. Transparent
    - Port to port paths
    - Cross-section photo

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Common uses and specifications

•An optical circulator is a multi-port, nonreciprocal device that routes light from one specific port to another.

•Optical circulators have at least 3 or 4 ports, up to 6 port possible (JDS Uniphase, Huihong Fiber)

•Circulators do not disregard backward propagating light, but direct it to another port.

	C-Band (1530-1570 nm)	C+L-Band (1525-1610 nm)
Insertion Loss	0.6 dB	0.7 dB
Channel Isolation	36-40 dB / chan	30 dB / chan
Polarization Dependent Loss (PDL)	< 0.1 dB	< 0.15 dB
Polarization Mode Dispersion	< 0.1 psec	< 0.1 psec

Optical circulators are commonly found in bi-directional transmission systems, WDM networks, fiber amplifiers, and optical time domain reflectometers (OTDRs).

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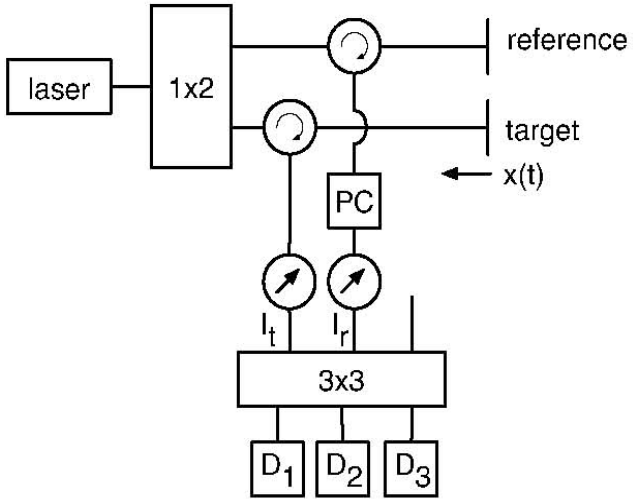
Use in a PDV System

•3-Port optical circulators are commonly used in PDV systems.

•1550 nm laser light is launched into Port 1 and will exit out of Port 2 to the target.

•Doppler-shifted light off the moving surface is reflected back into Port 2 and exits out of Port 3.



Dolan and Jones, Rev. Sci. Instrum. **78, 76102 (2007).**

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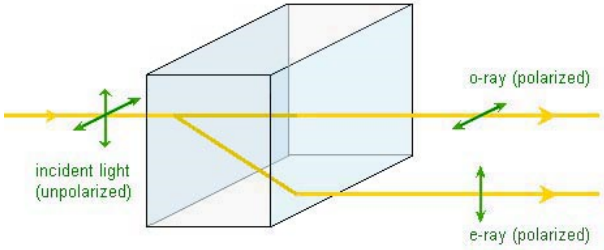
A Note on Birefringence

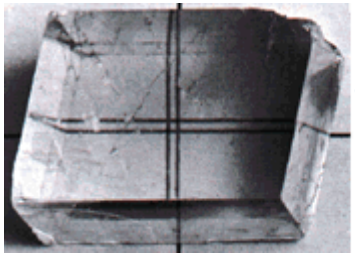
•Birefringence is the decomposition of a ray of light into two rays (the ordinary ray and the extraordinary ray) when it passes through certain types of materials.

•This effect only occurs if the material is anisotropic (directionally dependent).

•Birefringence can be formalized by assigning two different refractive indices to the material for different polarizations.



Birefringence in anisotropic material



Birefringence witnessed in calcite

Birefringence magnitude is defined by

$$\Delta n = n_e - n_o$$

where n_e and n_o are the refractive indicies for polarizations parallel (extraordinary) and perpendicular (ordinary) to the axis of anisotropy respectively

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A Note on Birefringence (YVO_4)

•Yttrium orthovanadate (YVO_4) is a very desirable birefringent material used in optical circulators:

- •Wide transparency range (0.4 to 4.5 um)
- •Large birefringence (n_o = 1.9447, n_e = 2.1486 @ 1.55 um (more than three times more birefringent than $LiNbO_3$.)
- •High birefringence leads to a more compact design.

YVO_4 Crystal

NOTE: Rutile or Titanium Dioxide (TiO_2) has higher birefringence values (no = 2,453, ne = 2.694 @ 1.55 um), and has a wider transparency (0.4 to 6 um), but it is also harder, which increases the production cost.

TiO_2 Crystal

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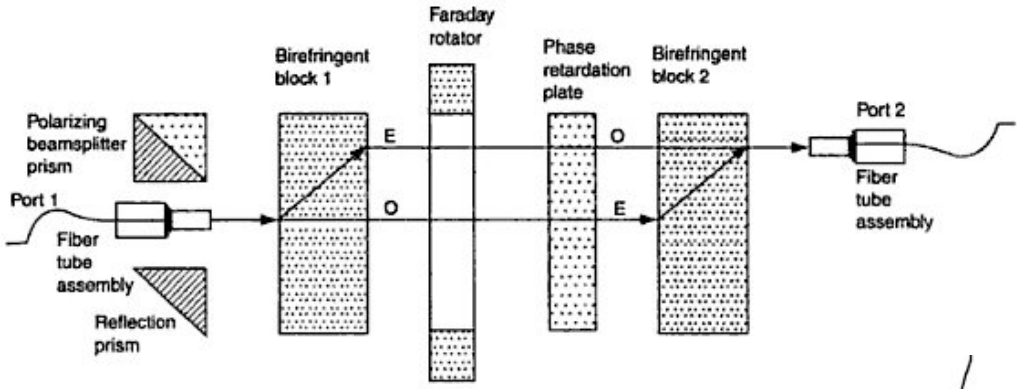
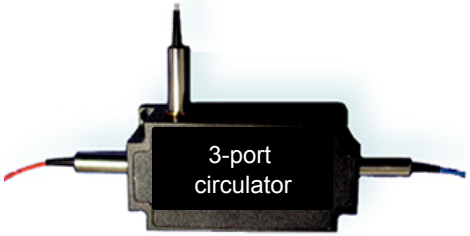
Reflective (Cube-style) Optical Circulators

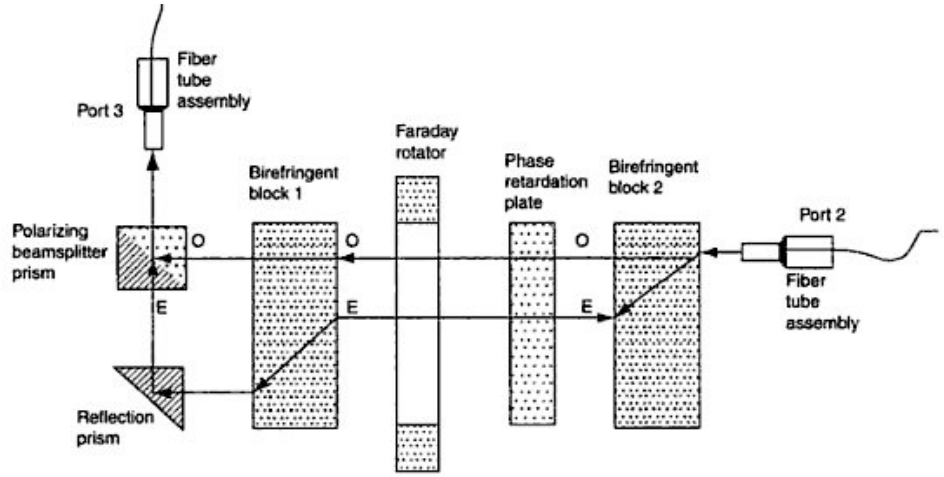
Typically polarization maintaining



Port 1 to Port 2



- Bulky; uses PBSs to re-combine and each port needs its own collimating assembly
- 30dB isolation at most
- Reflective components make unit more difficult to align



Port 2 to Port 3

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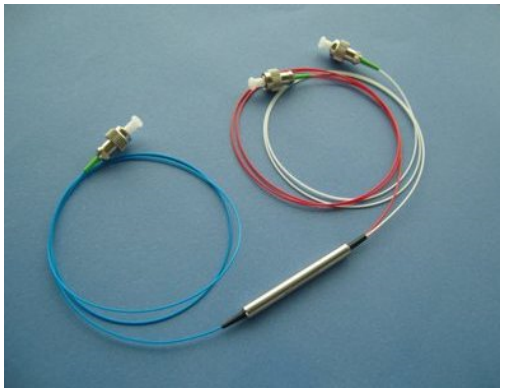
Transparent (Inline) Optical Circulators

- More compact
- Uses one collimating lens per two or more fibers
- Easier to align, thus cheaper
- More efficient due to the reduction in component count
- The use of birefringent crystals exclusively over PBSs offers higher isolation between channels, and lower polarization mode dispersion



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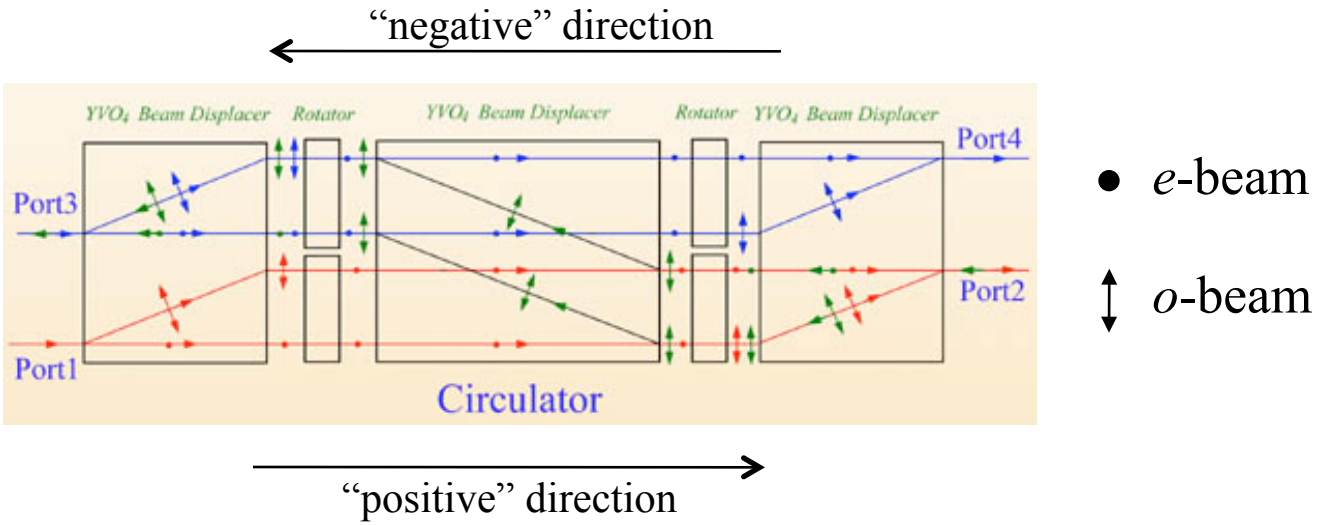
Transparent (Inline) Optical Circulators

Basic Operation



Fiber 1 to Fiber 2 (positive direction):

•The first birefringent crystal separates the fiber 1 beam into it's ordinary and extra-ordinary (*o* and *e*) components, both having mutually orthogonal polarizations.

•The *o* component sees the first rotator and picks up a 90°rotation.

•Both *o* and *e* components (now the same orientation) traverse the beam displacer un-deviated.

•Now the *e* component now sees the second rotator, and picks up a 90°rotation while the *o* component sees no rotation.

•Both *o* and *e* are recombined into fiber 2 by way of the second birefringent crystal.

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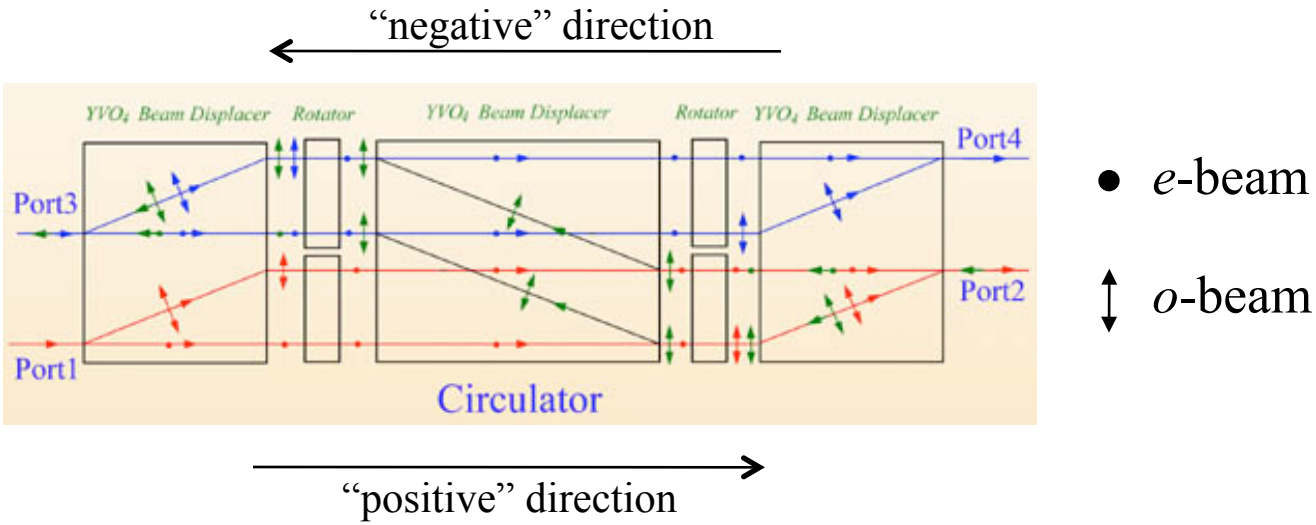
Transparent (Inline) Optical Circulators

Basic Operation



Fiber 2 to Fiber 3 (negative direction):

•Birefringent crystal separates the fiber 2 beam back into it's ordinary and extra-ordinary (*o* and *e*) components.

•The *e* component sees the first rotator and picks up a 90°rotation.

•Both *o* and *e* components (again the same orientation, **but opposite polarization**) get displaced .

•Now the *o* component now sees the second rotator, and picks up a 90°.

•Both *o* and *e* are recombined into fiber 3 by way of the birefringent crystal.

Port 3 to Port 4 (repeats port 1 to port 2 path)

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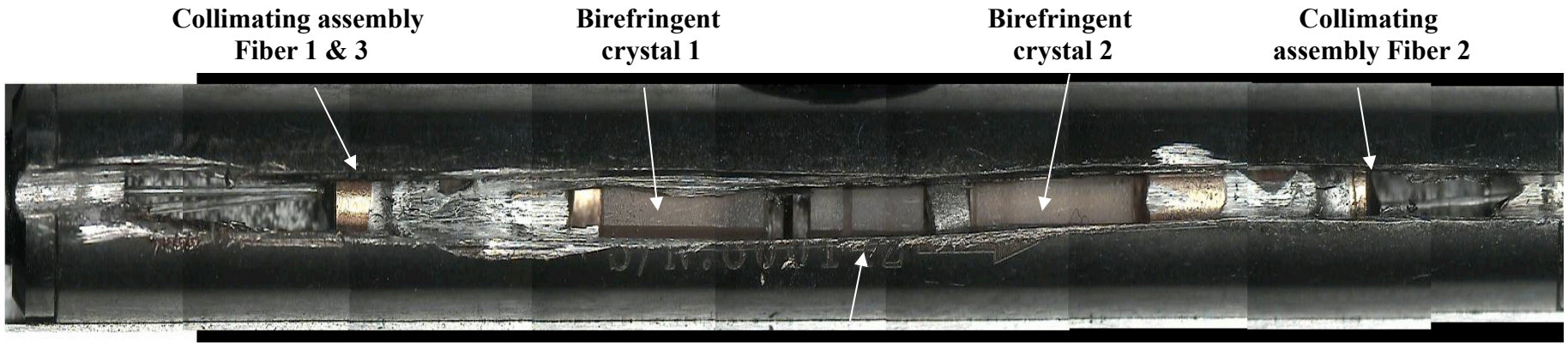
Commercially available inline circulator

Cross-Section Photo



- Couldn't get specific component data from vendor

- Best guess at components in this design are:
  - Collimating assemblies,
  - birefringent crystals,
  - walk-off crystal combined with rotating components possibly applied by liquid-phase epitaxy (LPE)

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Summary

- Surprisingly, a circulator requires a large number of parts to operate efficiently.
- Transparent circulators offer higher isolation than those of the reflective style using PBSs.
- A lower PMD is obtained using birefringent crystals rather than PBSs due to the similar path lengths between *e* and *o* rays.
- Many various circulator designs exist, but all achieve the same non-reciprocal results.

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