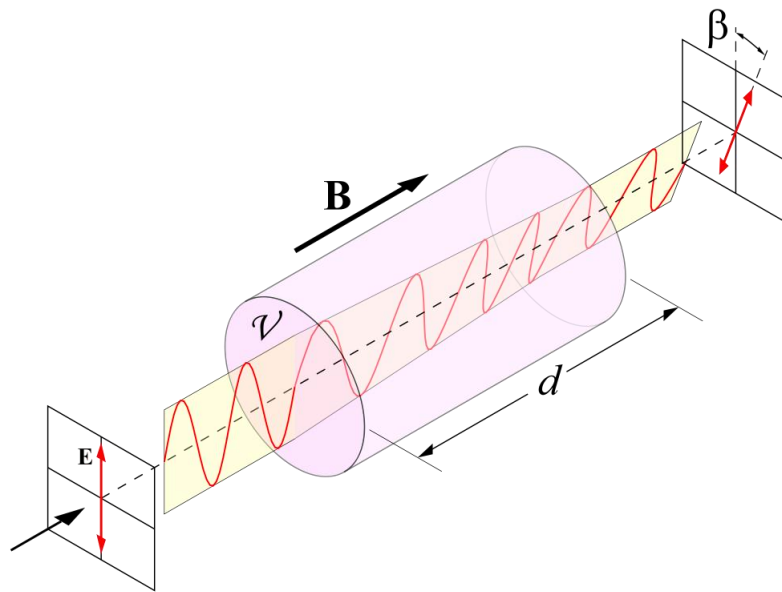


## Fiber Optic Current Sensors (FOCS) and Optical Current Transformers (OCT)

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The basic principle of FOCS and OCTs is to measure polarization rotation due to the Faraday effect. The Faraday effect is the rotation of the polarization state of light,  $\beta$ , when it passes through a magnetic field,  $B$ , induced by an electrical current. The larger the electric current, the greater the magnetic field and hence the larger the polarization rotation.

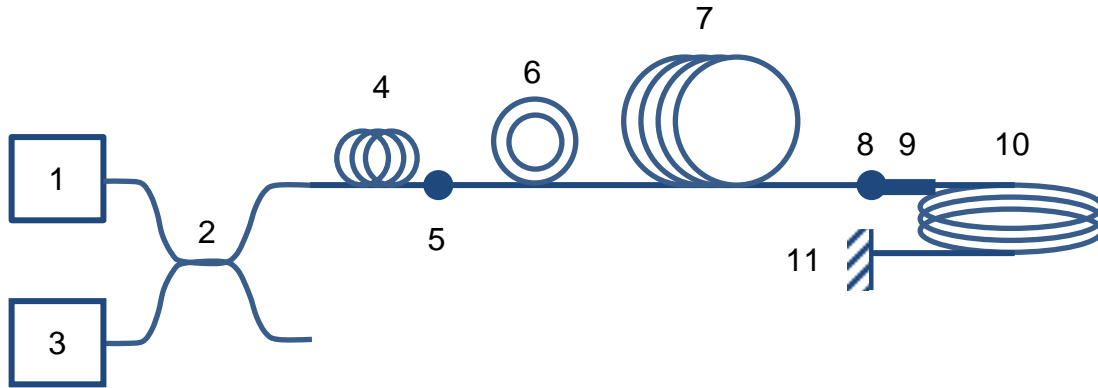


**Figure 1:** Polarization rotation as linearly polarized light passes through a material with a Verdet constant  $v$ , and a distance,  $d$ . The polarization rotation,  $\beta$ , is proportional to the magnetic field,  $B$ . [1]

FOCS/OCTs offer significant advantages over traditional current sensing technologies; the sensor element is naturally decoupled from the voltage line, there is minimal electrical interference on the signal line, they offer extremely fast response times with high measurement accuracy, the size and weight of the sensors is reduced in comparison with existing technologies and they do not explode during catastrophic failure, unlike oil-filled electrical insulation towers.

Fibercore Limited has developed a range of optical fibers designed specifically for use in FOCS. This includes the sensor element fibers **Spun HiBi SHB1250** and **Spun LoBi SLB1250** fibers, as well as supporting component fibers such as **HB-Z ZING™ polarizing fibers**, **HB**, **HB-T** and **HB-G fibers for delay coils** and **quarter wave plates**.

The fibers can be used in various deployments from simplistic low sensitivity, low accuracy, spun LoBi systems through to high sensitivity, high accuracy, circularly polarized, spun HiBi systems.



**Figure 2:** Optical schematic for a high sensitivity fiber optic current sensor, showing (1) broadband erbium doped light source, (2) coupler, (3) photo detector, (4) polarizer, (5) 45° splice, (6) fiber modulator, (7) 900m long delay coil, (8) 45° splice, (9) quarter wave plate, (10) 16m of spun HiBi fiber, (11) mirror.[2]

Historically, FOCS system manufacturers attempted to manufacture current sensors using standard telecoms fibers. However, the inherent random birefringence within these fibers caused significant limitations on the sensing accuracy. Techniques were developed to twist the fibers which ultimately created mechanical failure when the fibers were exposed to rapid thermal changes due to the torsional forces exerted on the fiber. Alternative methods of stripping the coating off the fiber and annealing the bare glass were developed, however due to the difficulty of stripping long lengths of coatings, poor yields and short lengths were fundamental limitations to this technique. Subsequently, spun fibers were invented where the fiber is spun during the fiber drawing stage, this creates a rotation along the length of the fiber which is locked into the fiber with no torsional force. The rotation causes the inherent birefringence effects to be axially rotated many times over the length of the sensor, averaging out the negative effects of the birefringence.

## Spun LoBi Fiber

A spun LoBi fiber is single-mode (SM) fiber which is spun during the fiber drawing stage, averaging out the inherent birefringence induced during the fiber manufacturing processes.

When the spun LoBi fiber is coiled, bend-induced birefringence is created within the fiber which reduces the maximum sensitivity of the FOCS. As the coil diameter is reduced or as the number of coils is increased, the stress on the fiber cumulatively increases, creating higher total birefringence and making the measurements less sensitive [3]. Subsequently spun LoBi fibers are typically used in low sensitivity FOCS or OCTs which have a large coil diameter and a relatively low number of coils.

**For more information, see the Fibercore Factnote: [SLB1250](#)  
And the Fibercore Technote: [Spun Fiber For Current Sensors](#)**

## Spun HiBi Fiber

For high sensitivity FOCS and OCTs, it is advisable to use spun HiBi fiber. This fiber differs from the spun LoBi fiber by having a polarization maintaining (PM) axis which is formed by Fibercore's Bow-Tie structure. By carefully balancing the spin pitch of the fiber with an accurately controlled level of birefringence, a fiber can be designed that can overcome the effect of bend-induced stress by the coiling process yet still be sensitive to the Faraday effect. Subsequently longer lengths of spun HiBi fiber can be used than spun LoBi fiber, this allows more coils of fiber with smaller coil diameters to be used, giving a higher sensitivity [3]. The HiBi nature of the fiber also helps to reduce the effects of temperature and vibration.

**For more information, see the Fibercore Factnote: SHB1250  
And the Fibercore Technote: Spun Fiber For Current Sensors**

## Polarizing Fiber

It is common to use light with a single polarization state in a current sensor system. Fibercore have developed an all-fiber polarizing ZING™ fiber which is capable of stripping energy from the fast axis, leaving only light in the slow axis. By having an all-fiber device, low insertion loss, small form factor and high reliability polarizers can be achieved. This is particularly important for any current sensor that experiences vibrations, such as any designs incorporated into switchgear and circuit breakers.

**For more information, see the Fibercore Factnote: HB-Z Zing™ Fiber**

## Depolarizer

FOCS commonly use depolarizers as well as polarizers. If a light source has an uncontrolled polarization state, for example a super luminescent diode coupled into non-PM SM fiber, then it is necessary to depolarize the light before polarizing. Otherwise the polarization state in the SM fiber can rotate, causing power fluctuations on the output of the polarizer. By splicing two PM fibers together with the stress axis offset by 45°, a Lyot depolarizer can be created. To maximize the performance of a Lyot depolarizer, it is important to choose the correct lengths of the two pieces of PM fiber. This is non-arbitrary and depends on many factors including the birefringence of the fiber, wavelength, bandwidth, and spectral shape of the light source. Fibercore HB series, HB-G and HB-T series of PM fibers are ideal for use as Lyot depolarizers.

**For more information, see the Fibercore Factnotes: HB, HB-G and HB-T  
And Fibercore Presentation: Depolarizers Using Fibercore's PM Fibers**

## Delay Coil Fiber

Depending on the optical configuration, a delay coil can help improve the sensor signal by creating a suitable phase shift between the orthogonal linear polarization states, typically a few hundred meters of fiber is used to create the delay [2]. To maintain the polarization state, a PM fiber can be used. Fibercore offer three suitable ranges of fibers, HB, HB-T and HB-G series. The HB fibers have a 125µm cladding diameter and the HB-G fibers have 80µm claddings. The 80µm fiber offers the advantages of higher sensitivity, reduced packing size and improved reliability when coiled into small diameters.

For more information, see the Fibercore Factnotes: **HB, HB-T and HB-G**

## Quarter Wave Plate Fiber

A quarter wave plate is used to convert linearly polarized light into circularly polarized light. This can be achieved by splicing a short piece of HB or HB-G spliced with the birefringent axis rotated by 45°. The exact length depends on the light source and birefringence of the fiber.

For more information, see the Fibercore Factnotes: **HB, HB-T and HB-G**

## Erbium Doped Fiber

Erbium doped fibers can be used to make ASE light sources capable of emitting broadband incoherent light. Using a broadband light source can considerably improve the current sensing stability over temperature in comparison with using a narrowband light source [3]. Fibercore manufacture two ranges of erbium doped fibers, IsoGain and MetroGain offering a wide range of absorption rates, cladding diameters and pump wavelengths. For high conversion efficiencies IsoGain fibers, such as I-4(980/125) offer the best option or for short fiber lengths and smaller packing sizes, the M-12(980/125) is ideal.

For more information, see the Fibercore Factnotes: **IsoGain and MetroGain**

## References

[1] <http://upload.wikimedia.org/wikipedia/commons/thumb/c/cb/Faraday-effect.svg/2000px-Faraday-effect.svg.png> - Published under GNU Free Documentation License, Version 1.2

[2] V.P. Gubin et Al, "Use of Spun optical fibers in current sensors", Quantum Electronics, vol. 36, no. 3, pp. 287-291, 2006

[3] R.I. Laming and D.N. Payne, "Electric Current Sensors Employing Spun Highly Birefringent Optical Fibers", Journal of Lightwave Technology, vol. 7, no. 12, pp. 2084-2094, 1989