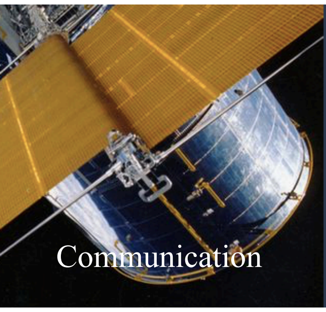
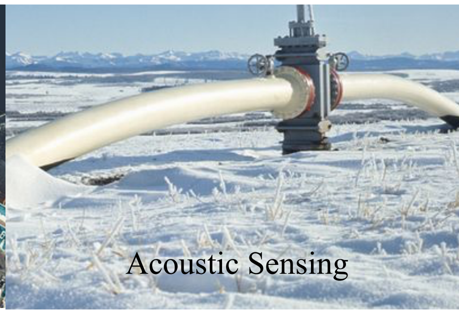




EXTREMELY STABLE SINGLE FREQUENCY LASER FOR OPTICAL SENSING

Optical sensing is critically important in oil and gas, homeland security, and industrial markets where the measurement of distance, temperature, and/or pressure is required for a broad range of applications. These applications include finding and monitoring of oil fields in order to increase their productivity, opto-acoustic sensing in submarine-towed arrays, monitoring and securing pipelines and power lines, and border and perimeter protection. Common to these applications is the need for high sensitivity and resolution, with real-time monitoring over long distances.

Optical sensors tend to be smaller and weigh less than electronic devices, and they deliver higher speed, sensitivity, and bandwidth. At the root of these and other advantages is the fact that the sensing and signal-propagation functions rely on photons rather than electrons. This enables a single segmented fiber to form distributed or arrayed sensors that cover extensive locations while conveying the sensed information to a remote station. With small modifications, fiber elements can form many signal-processing devices (such as splitters, combiners, multiplexers, filters, and delay lines), enabling all-fiber measuring systems.

Furthermore, the dielectric glass or plastic materials from which fibers are made makes fiber sensors passive and immune to electromagnetic interference (EMI) so they can perform reliably in close proximity to large electrical equipment such as generators or motors and invite less potential for damage to the sensing element (or remote electronics) if lightning strikes nearby (see Laser Focus World, October 2003, p. 89). Also, because fiberoptic sensors generate neither heat nor sparks, they are safe for operation in hazardous environments such as oil refineries, grain bins, mines, and chemical processing plants. Standard glass fiber loses none of its performance in many corrosive environments or at temperatures reaching 450°F. Special fibers can extend sensor operation beyond 450°F to as high as 1200°F.

Sensor types

Optical fiber is a physical medium so changes in its environment can alter its geometrical (size, shape) and optical (refractive index, mode conversion) profiles. Unlike communication applications, however, which minimize such external influences, fiberoptic sensors deliberately enhance and measure them. The way in which sensors detect such perturbations classifies them as either extrinsic or intrinsic.

In extrinsic devices, the fiber serves as a conduit for transmitting and receiving light at the sensing region. Signal variation occurs outside the fiber, usually within a controlled space. An external environmental change in this space will alter the known parameters of incoming photons.

Intrinsic sensors are all-fiber devices in which external perturbations interact directly with the fiber itself causing some sort of measurable change in the transmitted photonic signal. These sensors are generally more sensitive than external devices and so they are more susceptible to unwanted external perturbations. The all-fiber configuration is more geometrically versatile and simplifies the connection of sensing and transmitting elements. But intrinsic sensors are generally more expensive and less easily multiplexed. They also require more-complex signal-demodulation schemes.

Typical extrinsic sensor applications include linear and angular positioning for aircraft fly-by-light systems or for process control, where they monitor temperature, pressure, liquid level, or flow rate. Intrinsic sensors are used more often to measure rotation, strain, acoustic emissions, and vibration.

Most current fiberoptic sensors are "point sensors" in which the sensing gauge length is localized to discrete regions, typically requiring a large number of sensors to cover an extended area of interest. Cost, complexity, and fragility of point sensors currently limit the widespread application of these systems. The development of "distributed sensors," capable of sensing continuously over an entire length of fiber, remains a challenge.

Distributed sensors

Most distributed sensors are based on optical time-domain reflectometry (OTDR). The system is probed by a short pulse of optical radiation returned back by reflection. But this technique generally poses a tradeoff between dynamic range and spatial resolution. Shortening the pulses coupled into the fiber and broadening the measurement bandwidth helps improve spatial resolution, but it increases noise level and decreases the dynamic range.

An alternative approach applies coherent frequency-modulated continuous-wave (FMCW) techniques that are well established in radar applications using longer-wavelength radiation. However, optical FMCW techniques modulate the frequency of a laser around its center frequency by coupling part of the light into a reference arm, which plays the role of the local oscillator in a heterodyne coherent detection scheme. A second, longer optical fiber acts as the sensing element.

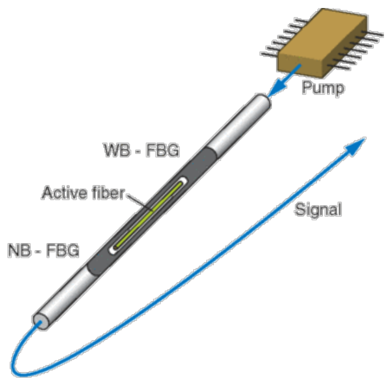
Reflected light from the sensing region mixes with the light from the local oscillator to generate a beat frequency. The distance information of the sensing fiber derives from measurement of the photocurrent beat frequency using an electrical spectrum analyzer. The distributed reflection of the sensing fiber can simply be Rayleigh backscattering of the optical fiber. Such coherent detection schemes can easily achieve sensitivities down to -100 dB. Also, large dynamic measurement ranges are possible because the photocurrent beat signal is proportional to the square root of the returned laser power and light from the local oscillator helps amplify the backscattered signal.

The principal advantage of FMCW techniques over alternatives like OTDR is its ability to provide spatial resolution on the order of millimeters over a distance of several kilometers. This, however, assumes that the laser source has a long coherence length and a frequency that can be modulated linearly and at high speed. These attributes allow sensing at high spatial resolution with a large measurement range. But they have been largely absent from conventional semiconductor lasers used in fiber sensor applications. Such lasers include both distributed-Bragg-reflector (DBR) and distributed-feedback (DFB) sources in master oscillator-power-amplifier configurations. The DBR lasers, for example, have demonstrated output powers up to 160 mW in a MOPA configuration—but at a cost to the linewidth, which can reach 200 to 500 kHz. Conversely, DFB lasers have delivered narrower linewidths but at outputs limited to 5 mW.

Laser driven

One solution that has elicited interest is fiber lasers that incorporate ytterbium/erbium (Yb/Er) co-doped fiber. This fiber exhibits extremely high optical gain per unit length of up to 5 dB/cm with negligible ion clustering. Its emergence has enabled linear diode-pumped DBR fiber lasers delivering linewidths of 2 kHz, allowing distributed fiber sensors over distances longer than 50 km (as opposed to hundreds of meters demonstrated with conventional DFB sources).

NP Photonics have developed one such laser that fuses two spectrally narrow fiber Bragg gratings to a very short piece of Yb/Er co-doped fiber (see Fig.). This forms a laser cavity with total length of less than 5 cm and frequency stability better than 10 MHz over hours, thermal tuning ranges of 20 GHz, continuous and linear piezo tuning ranges of 100 MHz, and output powers of 150 mW—all of which contribute to reliable and robust sensor systems.



NP Photonics Offer extremely stable, single-frequency fiber laser which are insensitivity to vibrations.