Fiberoptics For Practical Sensing Applications (II)

The Boundaries Of The Fiber-Sensing Universe Expand Vigorously

by Scott D. Wohlstein

Fiberoptic sensing systems (FOSS) offer an extremely dynamic picture of technology today. Less than a year ago, I wrote an article[1] on the basics of using fiberoptic sensing techniques, primarily for measuring temperature and pressure. That article generated a great deal of response from readers. Indeed, even before the issue had been printed, I was approached by several people who, having learned that the article was forthcoming, asked me specifically how FOSS could help in their particular application – a graphic demonstration of how dynamic the field can be. This sequel explains what types of applications are currently being sought most vigorously.

"Catch-All?" – Not Really

The earlier article made several generalizations in applications areas and inviting aspects of the technology. To wit, "Sensing systems have been used in such applications as temperature, pressure, strain, acceleration, acoustic wave, fluid depth and volume, electric field, magnetic field, and displacement sensing (in the last case, fiberoptic ring gyroscopes have been used for years). Advantages of fiberoptic sensors over traditional sensing methods include fiber's immunity to electromagnetic and radiofrequency interference, its potential for high data rates, and its electrical passivity in explosive environments....Applications of the system (FOSS) include vacuum, radioactive, hazardous chemical and other hostile environments."[1] Figure 1 depicts the general structure of a fiber sensing system configured for pressure or temperature measurement.

At the time, that wide-ranging list of possible applications seemed to cover most, if not all, the likely potential applications of fiberoptic sensing systems. Now, in retrospect, that description looks like just the tip of the iceberg. Many new applications use a mixture of sensing methods to produce hybrid devices. Some project examples highlight the hybrid approach.

Medical Applications

Medical applications of recent interest lie in the area of nonreactive, single-point sensing. Specific examples include monitoring temperature and pressure of critical organs, analysis of blood constituents *in vivo*, and the delivery and analysis of light emission therapy at specific remote areas of the body.

Critical-Organ Analysis. The monitoring of temperature and pressure of critical organs applies to any body component (*e.g.*, the brain) where it is not desirable to use standard electrically conductive sensing mechanisms because of eddy current activities. Such a system can relay the location and amount of pressure and/or temperature in any part of the organ. The integration of two-phase optical time domain reflectometry could result in a triangulated, three-dimensional model of pressure and/or

Scott Wohlstein is president of SD Laboratories, Convent Station, N.J. This article is a sequel to one published in July of 1989.

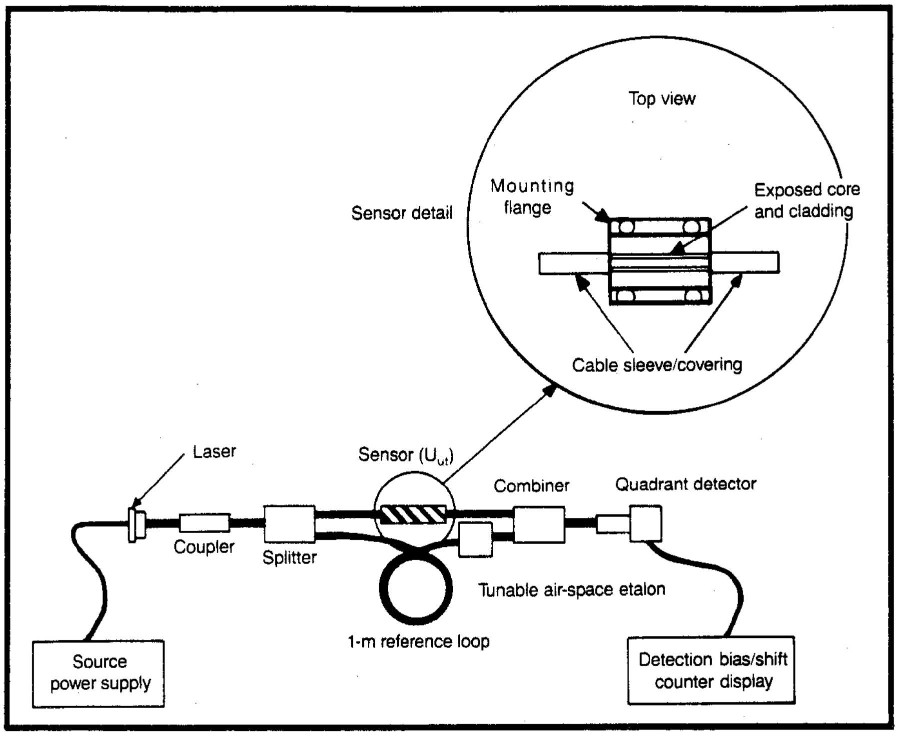

Figure 1. Complete system layout for a fiberoptic temperature or pressure transducer system.

temperature versus dimension.

Blood-Constituent Analysis. The analysis of blood constituents can now be performed in real time, without use of reactive chemistry techniques, and can generate reports for instant analysis and treatment. This application uses a blend of velocimetric, scattering and spectroscopic methods to detect items such as fats, cholesterol and glucose, as well as counts for both red and white blood cells.

Light Emission Therapy. In light emission therapy, fibers are used to deliver light to specific organs or remote areas of the body, use that light to activate specific chemicals, and analyze the resulting light emission via real-time spectroscopic analysis.

Transportation Applications

The transportation industries have use for FOSS in such areas as distributive pressure and stress measurements on military and commercial aircraft and naval vessels and for navigational/control systems on aircraft, ships and ground vehicles.

Pressure/Strain Measurements. The detection and analysis of pressure-stress-strain components on aircraft (commercial or military) and naval vessels (*e.g.*, oil tankers, submarines) use the concept of distributed sensing. The output of such a sensing system can be used to generate reports, in real time, on the location and severity of stress at strategic structural points. By comparing current conditions with prerecorded readings, such an analysis system can report significant deviations from the prerecorded "safe" data and thereby direct repair efforts.

Navigation and Control. Navigation/control systems on land, sea and air vehicles use several fiberoptic sensing technologies. These include Sagnac-interferometric and intensity-modulation techniques to produce high-speed, high-accuracy performance. Navigational systems report position (both relative and stationary-satellite referenced), bearing, altitude, and so on. Control systems involve internal communications, engine diagnostics, vessel structure, vessel environment, and so on.

Commercial-Industrial Applications

The commercial and industrial sectors use FOSS in an ever-widening scope of applications. These include, but are hardly limited to, measurements and control of temperature, pressure, fields and acceleration. Separate measurement and analysis applications in traditional fields of spectroscopy, radiometry and photometry also abound. Several specific examples follow; these represent only a small fraction of present-day activity in FOSS.

Measuring Temperature In A Hostile Environment. The monitoring of temperature of a piece of prototype hardware in a hazardous environment is readily done with fiberoptic sensors. In one example, a system reports the temperature at several points on the body of a prototype during "burn-in" testing in a caustic environment over the temperature range of $-5°$ and $+100°$ C with 0.1-percent accuracy.

Measuring Temperature in a High-Field Environment. Another temperature-in-a-hostile-world application embraces the monitoring of temperature in a vessel being bombarded by microwaves. This application eliminates the unwanted antenna system setup required for standard thermocouple sensors; a more pedestrian example would be to monitor and control the temperature of food as it is cooked in a microwave oven.

Testing Ultramicro-Miniature Motors. As the development of what has been referred to as "nanotechnology" (*i.e.*, structures smaller than "micro-miniature") evolves, the testing of very tiny components becomes more complex. In the case of ultramicro-miniature motors, a fiber sensing system can eliminate the use of an optical encoder disk, which can create too much drag on the motor shaft.

Detecting Deposited Chemicals. Often, experimenters must detect and analyze deposited chemicals in small, remote locations. One key form of this application uses near-infrared (1 to 3 μm) spectroscopy and zirconium-fluoride fibers to qualify and quantify chemicals (often, polymers or organics) and reactions (*e.g.*, oxidation, reduction, surface-destructive beta growth, and so on). Not only is this application a high-speed one, but it is also nondestructive.

Trends

The current research thrust in fiber-based sensing is total system performance regardless of configuration. Since there are only four basic types of interferometric FOSS (Michelson, Sagnac, Mach-Zehnder and Fabry-Perot), many

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practitioners consider everything else as variations on one of these themes. If the community's main interest is diverted to "intrinsic" sensing systems, greater advances will be made in the highly birefringent, polarization-maintaining nonlinear materials. This would ultimately produce more advanced systems that do utilize "extrinsic" components.

Work on interferometric sensors will advance sharply with the development of more accurate, higher-speed gyroscopes. In addition, amplitude-type sensors will become more application-specific and less generically structured.[2]

The next generation of FOSS will not use end-effect components with passive chemicals or special mountings. Instead, improvements in systems performance will come primarily from advanced signal processing and the use of acousto- or electro-optic materials to aid in nonlinear light manipulation. Vast networking, up to at least the level of "smart-skinned" structures with built-in fibers, and long-distance systems (possibly even up to telecommunications-like distances) will evolve.

Although there are more experts in the "classical" fiberoptics field, the innovative "hybrid" fiberoptic sensing field is growing rapidly as application-specific devices become more the rule than the exception.

References

1. Scott D. Wohlstein, "Using Fiberoptics For Practical Sensing," *Lasers & Optronics*, **8** (7):73-76 (July 1989).
2. J.W. Berthold, "Fiber Optic Intensity Sensors: Commercial Hardware for Industrial Applications," *Photonics Spectra* **22** (12):125-138 (Dec 1988).
3. The bulk of the November 1989 issue of *Optics News* covered the topic of fiber-optic sensors. Five feature articles in that issue [*Optics News*, **15** (11) (Nov 1989)] provide far more detail than is possible here.