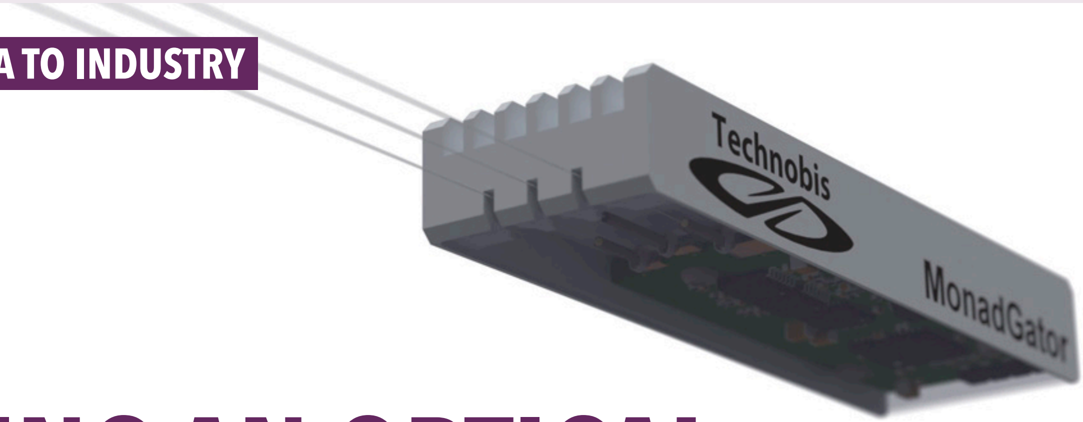

REDUCING AN OPTICAL SENSOR INTERROGATOR TO THE SIZE OF A MEMORY STICK

Fiber-optic sensing is gaining traction for accurate strain, shape and temperature measurement in aircraft, civil structures, high-tech machines and medical catheters and endoscopes. To support a higher market penetration, a cost and size reduction is needed. Technobis and Bruco Integrated Circuits have developed a memory stick-sized fiber-optic measurement system.

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Fiber-optic sensors have many appealing characteristics: they're small, lightweight, inert to chemical substances, able to withstand high temperatures and immune to electromagnetic interference. As a result, they're finding widespread use in a multitude of applications. For example, in structural health monitoring, the deformation and dynamic response behavior of objects are measured using optical fibers that are mounted on or even embedded in the structure being monitored.

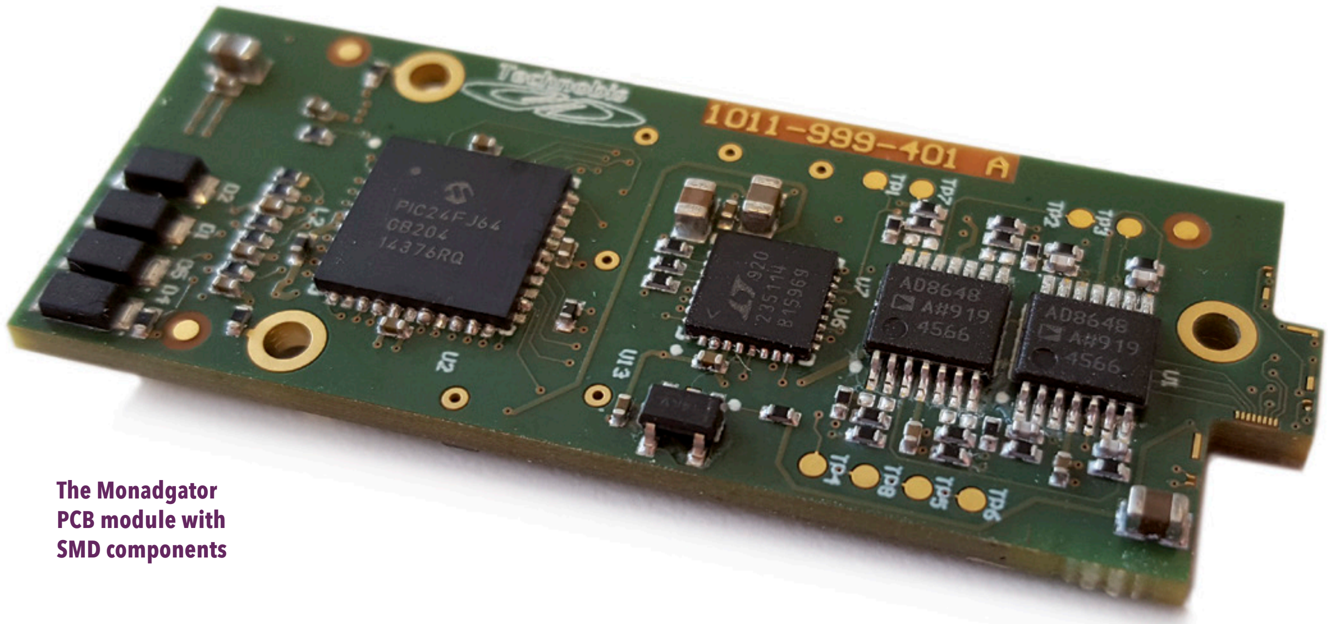
Successful applications have been shown and proven in the aerospace industry, performing standard strain and temperature measurement in the new generation of planes. In the medical domain, the technology is being applied in catheters, endoscopes and guide wires to gauge shape, temperature and pressure. There, the number of systems sold typically varies from 1,000 to 50,000 pieces per year. Further market adoption requires a more compact and lower-cost solution, including disposables in medical and fiber-optic battery monitoring systems.

Fiber-optic sensing

Over the last years, fiber-optic strain sensors have been developed based on fiber Bragg grating (FBG). With this technique, light is sent through a fiber-optic cable and partially reflected by a microstructure inscribed into the fiber core. Strain on, or a temperature change of, the fiber causes a shift in wavelength of the reflected light, which can be measured very precisely and translated into strain or temperature values.

Current sensor detection devices, so-called interrogators, are mostly based on free-space spectrometry. An optical spectrometer (spectrophotometer, spectrograph or spectroscope) is an instrument used to measure properties of light over a specific portion of the electromagnetic spectrum, typically used in spectroscopic analysis to identify materials. Free space means that in measuring the reflection, the light will move through air. This approach has fundamental limits, regarding device dimensions, measurement resolution, accuracy and power consumption, for example.

For improving the resolution, interferometry seems to be a promising approach. An optical interferometer can precisely measure characteristics such as length, refraction index and surface irregularities. It divides a light beam into a number of beams that travel unequal paths and whose intensities, when reunited, add or subtract – interfere with each other. For high-resolution wavelength

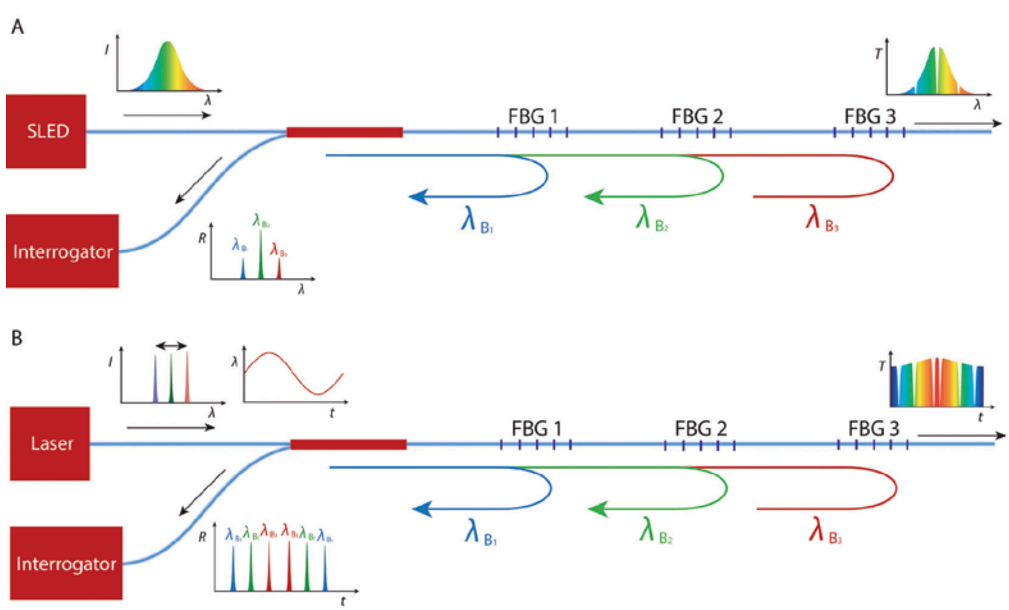


The Monadgator PCB module with SMD components

analysis, a fiber optics-based Mach-Zehnder interferometer was developed, which makes the reflected light of the FBG interfere with itself, resulting in a phase change proportional to a wavelength change. However, since the system still has a free-space design, it has limited practical use for integration in demanding environments due to its high sensitivity and associated erratic behavior.

As fiber sensing matures, device dimensions, power consumption and costs need to be optimized to serve the increasing application requirements. Over the last ten years, new interrogators – spectrometer and interferometer based – have been developed using photonic integrated circuits (PICs), which combine multiple photonic functions in a single device. This second generation is on the market now.

Technobis has been working on fiber-optic sensing solutions for many years, with module assembly as a vital core IP. Its current interrogators are based on spectrometry and interferometry on chip, capable of detecting wavelength shifts down to 10 attometers – corresponding to about 0.2 nano-strain. These second-generation systems, called Ladygator, are now in production or the design-in phase at OEMs. Main characteristics include a temperature resolution better than 0.001 degrees Celsius and 2,500 unique sensors per fiber. For a medical application, the tip position of a 2.2-meter-long catheter can be calculated with an accuracy of 1 mm. Responding to market demands for a smaller form factor, work is now underway on a third-generation measurement system the size of a memory stick.



Spectrometry measurement using optical fiber grating

Monadgator

Last year, Technobis already took first steps to bring down the cost of the system by reducing the cost of the light source, package and PIC. This only left the electronics to be optimized. Together with Bruco Integrated Circuits, Technobis has developed the Monadgator system – "monad" means "single" and "gator" is an abbreviation of "interrogator". Following overall specs that have been jointly drawn up by the system architects of both companies, the device integrates a PIC with discrete off-the-shelf electronics. It can have a readout of 1-200 FBG sensors and it spits out raw serial sen-

The memory stick-sized Monadgator housing combines a PCB containing the electronics, and a photonic submodule with the fiber-optic interconnections.

sor data to be processed in the main processing unit.

The Monadgator combines a photonic submodule, developed by Technobis, and a printed circuit board containing the electronics, developed by Bruco. Everything is assembled by Technobis in a small box, measuring 60 by 12 by 5 mm. The photonic submodule holds two light sources and a spectrometer section including photodiodes, integrated on a PIC. To measure the temperature of these three parts, three thermistors have been added. The electronics submodule consists of circuitry to transfer the photodiode current measurements to a host. It also controls the light sources, one at a time, and gauges the local temperatures on both submodules. The temperature data is part of the output stream.

The memory stick-sized box detects the reflected light that's coming in on the fiber. The light originates from one of the two light sources inside the module, which inject it into the fiber. The photodiodes register the reflections and the electronics amplifies, filters and digitizes their output current by sampling a current-related voltage with a rate of 4 ksample/s. The result is sent via a serial interface to a host that's attached to the box's output connector, in frames containing sixteen data samples and four temperature measurement channels.

The photonics interface connects the optics to the electronics. To drive the two light sources, two current outputs are used. The light sources each have a thermistor connected to an input circuit on the electronics core. The photodiodes are connected to the inputs of a transimpedance amplifier (TIA), with a thermistor connected to a core input circuit. The physical interface is implemented by means of direct wire bonding instead of a connector interface.

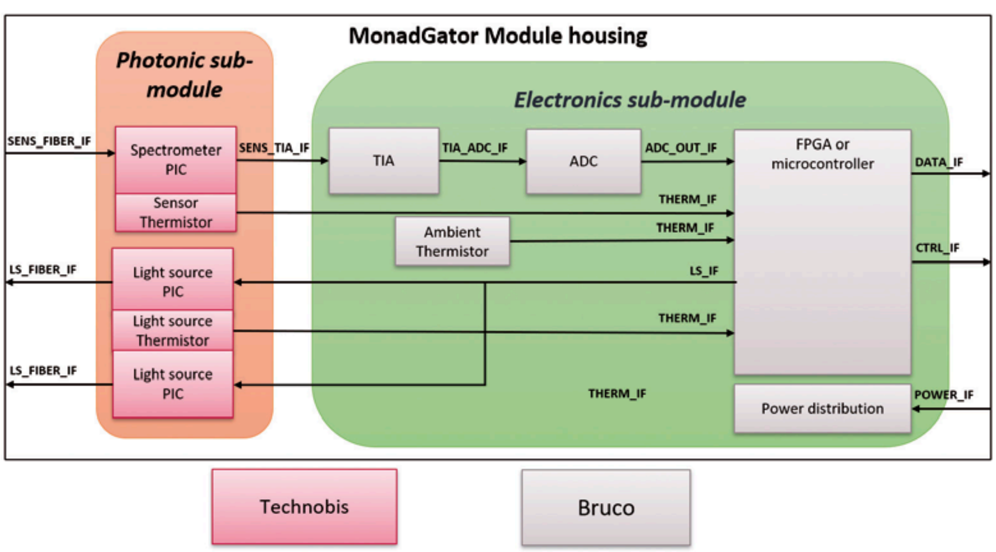
The host interface is used to control the Monadgator module, to power the complete device and to transfer sensor data and device information. This RS-485 interface also serves as a device control interface. To be able to load new firmware, a programming interface is included as well.

ASIC

The current Monadgator module is an intermediate step, generation 3A, aimed at delivering demonstrators and low-volume production samples to develop the market and customer base. Still, the bill of materials for the electronics is already five times lower. The final goal for the third-generation system, generation 3B, is to go to an ASIC for high-volume application, which will reduce the BOM by a factor of 50. Developing an ASIC from scratch is very risky because of the large investments and long development time, but by working closely together at an early stage, Technobis and Bruco pave the way for a seamless effort that mitigates the risks involved.

From idea to working prototype took four months, with intensive communication. The complete working measurement system will be delivered within three months. The first industrial customer, from the oil and gas industry, has already shown interest.

The Monadgator block diagram



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Edited by Nieke Roos