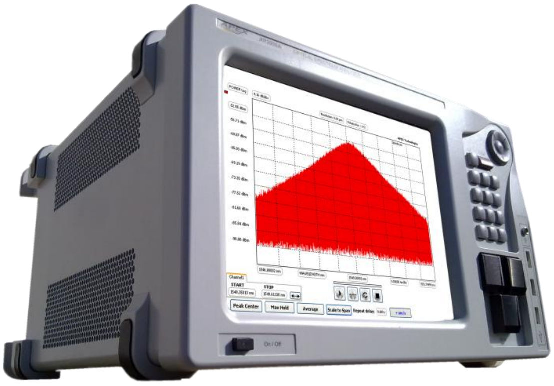
High Resolution Optical Spectrum Analyzer (OSA)

01/07/2013

Ultra High Resolution OSA for Characterizing and interrogating Fiber Bragg Grating Sensors



The APEX Technologies Ultra High Resolution Optical Spectrum Analyzer (OSA) can be used to measure the active/passive optical component insertion loss/gain thanks to the possibility to synchronize the internal Tunable Laser Source and the OSA sweepings. In this context, the APEX OSA remains a perfect tool to measure the Fiber Bragg Grating (FBG) Sensor reflection with 1 MHz of resolution, 63 dB dynamic and 0.3 pm wavelength relative accuracy.

Introduction to Fiber Optic Sensors

Optical fibers technology was first realized in the 1960s and has developed to be an integral part of modern telecommunications. Over the last few years, fiber optics and optoelectronics industry have seen tremendous amount of innovation and widespread use leading significantly reduced optical component cost with an improved quality. By taking advantage of these economies of scale, fiber-optic sensors were designed to measure the performance and status of optical networks. In addition to telecommunications applications, optical fibre sensors have moved from experimental research applications in the lab to broad usage and applicability in field applications such as oil and gas services, medical and biomedical engineering, electrical power industry, structural monitoring, defence and aerospace.

Optical fiber sensors are highly desirable solutions to sensing applications due to their small size, low loss transmission, immunity to electromagnetic interference, light weight and electrical isolation amongst other advantages. All the core of optical sensing technology is the optical fiber. As shown in figure 1, an optical fibre consists of a core surrounded by a lower refractive index cladding. For certain angles of incidence, light is launched into the allowable modes of propagation and guided along the fiber by the core-cladding boundary.

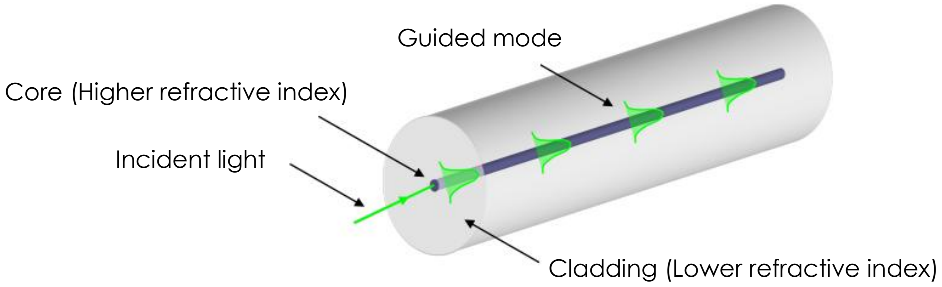


Figure 1 : Guidance of light in an optical fiber

Fundamentally, the fiber-optic sensor principle is based on the modulation of one or more properties of a propagating light wave, including intensity, phase, polarization, and frequency, in response to the environmental parameter being measured. In its simplest form, an optical fiber sensor is composed of a light source, optical fiber, sensing element, and detector. Optical fiber sensor operation and instrumentation have become well understood and developed. Many commercial discrete sensing systems have been proposed and developed which incorporate optical fiber according to many schemes such as Fabry-Perot (FP) cavities and fiber Bragg gratings (FBGs). Among all of these, FBG based sensors have received considerable attention in recent years and seen a rise in their utilization and commercial growth.

Fiber Bragg Grating sensors

Fibre Bragg gratings (FBG) are highly suited as sensor elements for measuring various static and dynamic fields such as temperature, strain and pressure. One of the main advantages of FBG sensors over other types of optical fiber sensors is that the measurand information is wavelength encoded, making the fiber grating sensor self-referencing and rendering it independent of light source fluctuations and system power or connector losses. In its most basic form, an FBG is wavelength-dependent optical filter/reflector formed by introducing a periodic refractive index structure along the optical fibre core that reflects light at wavelengths determined by the Bragg condition. In fact, When a broad-spectrum light beam is sent to an FBG, reflections from each segment of alternating refractive index interfere constructively only for a specific wavelength of light, called the Bragg wavelength as shown in figure 2.

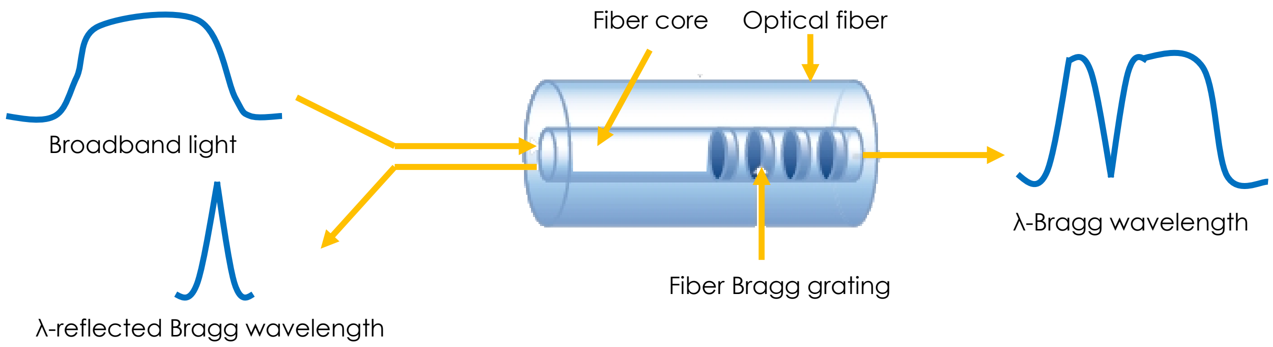


Figure 2: FBG sensor operating principle

Changes in strain and temperature affect both the effective refractive index n and grating period of an FBG, which results in a shift in the reflected wavelength. A great advantage in FBG sensors is that they can give very accurate measurement that isn't sensitive to any fluctuations to the fluence of illuminating sources. Although very attractive as sensors, FBGs suffer an inherent cross-sensitivity between temperature and strain. This creates a problem for sensor systems designed to monitor strain alone for example, as temperature variations along the fibre path can lead to unrepresentative, thermal-induced strain readings.

The ability to write FBGs with unique Bragg wavelengths lends itself well to wavelength division multiplexing (WDM) techniques. This provides the ability to daisy chain multiple sensors with different Bragg wavelengths along a single fiber over long distances. The number of sensors that you can incorporate within a single fiber depends on the wavelength range of operation of each sensor and the total available wavelength range of the optical interrogator.

APEX Ultra High Resolution OSA: perfect interrogation tool of FBG sensors

A key feature of the sensor system is the instrumentation required to measure the change in reflection wavelength from each FBG and hence deduce the local strain. One approach entails spectral analysis of the light reflected from the fiber. With typical FBG sensor wavelengths, optical interrogators must be capable of performing measurements with highest resolution and wavelength precision. Interferometric method used by APEX Technologies Ultra High Resolution Optical Spectrum Analyzer (UHR-OSA) is often used in laboratory settings and can provide high-resolution optical spectrum measurements. Recently, APEX Technolgies UHR-OSA has attracted a lot of attention of FBG sensors manufacturors and researchers due to its ability to measure the transmission/reflection (insertion loss/gain) of any actif/passif optical components.

Thanks to the tracking generator, the internal Tunable Laser Source (TLS) and the Optical Spectrum Analyzer sweepings can be synchronized. Therefore, the user measure the FBG sensor reflection spectrum. The APEX Technologies UHR-OSA uses a high performance sweeping Tunable Laser Source to illuminate the FBG sensor replacing the traditionally weak broadband light source. The internal TLS concentrates energy in a very narrow band providing a 500 KHz linewidth light source. The APEX Technologies UHR OSA based on this tunable-laser architecture operate by sweeping a very narrow band of light across a wavelength range while synchronously using the OSA to measure the reflections from the FBG(s). When the wavelength of the TLS matches the Bragg wavelength of the FBG, the OSA sees a corresponding response. The wavelength at which this response occurs corresponds to the temperature and/or strain of the FBG (Figure 3).

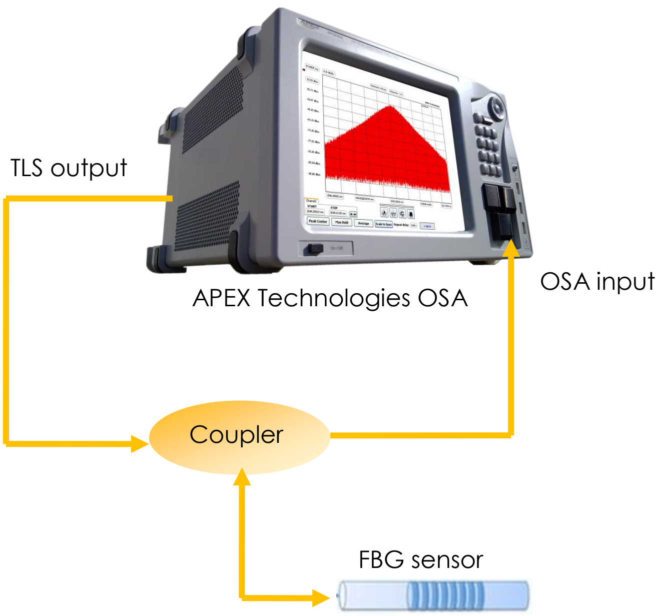


Figure 3: APEX Technologies interferometric method for measuring FBG sensor reflection/transmission

In this configuration the wavelength resolution is not related to the rectangular shape electrical filters (up to 5 MHz/40 fm) used for the OSA function but to the TLS linewidth making APEX UHR-OSA the only equipment in market measuring FBG sensors reflection with **1 MHz/8 fm resolution**. The APEX Technologies UHR-OSA method can deliver **a 0.3 pm wavelength relative accuracy and a +/- 3 pm absolute accuracy** thanks to its three different internal wavelength calibrators (2 relatives and 1 absolute), which translates to FBG sensor accuracies. On the other hand, the APEX UHR-OSA can measure the optical component transmission/reflection with **63 dB of dynamic range**.

If FBG sensor is starched, the wavelength at which we obtain maximum reflectance changes. The deformations of FBG are therefore determined of the basis of the spectral properties of the structure. With the APEX UHR-OSA, it is possible to study FBG deformations and to determine accurately at which wavelength do we obtain maximum reflectivity. Figure 4 depicts a zoom on the reflection,of an array of multiple FBG sensors. The two peaks correspond to two adjacent FBG sensors. Currently, APEX OSA guarantee a peak separation measurement accuracy of about 0.24 pm/30 MHz for a distance of 30 GHz.

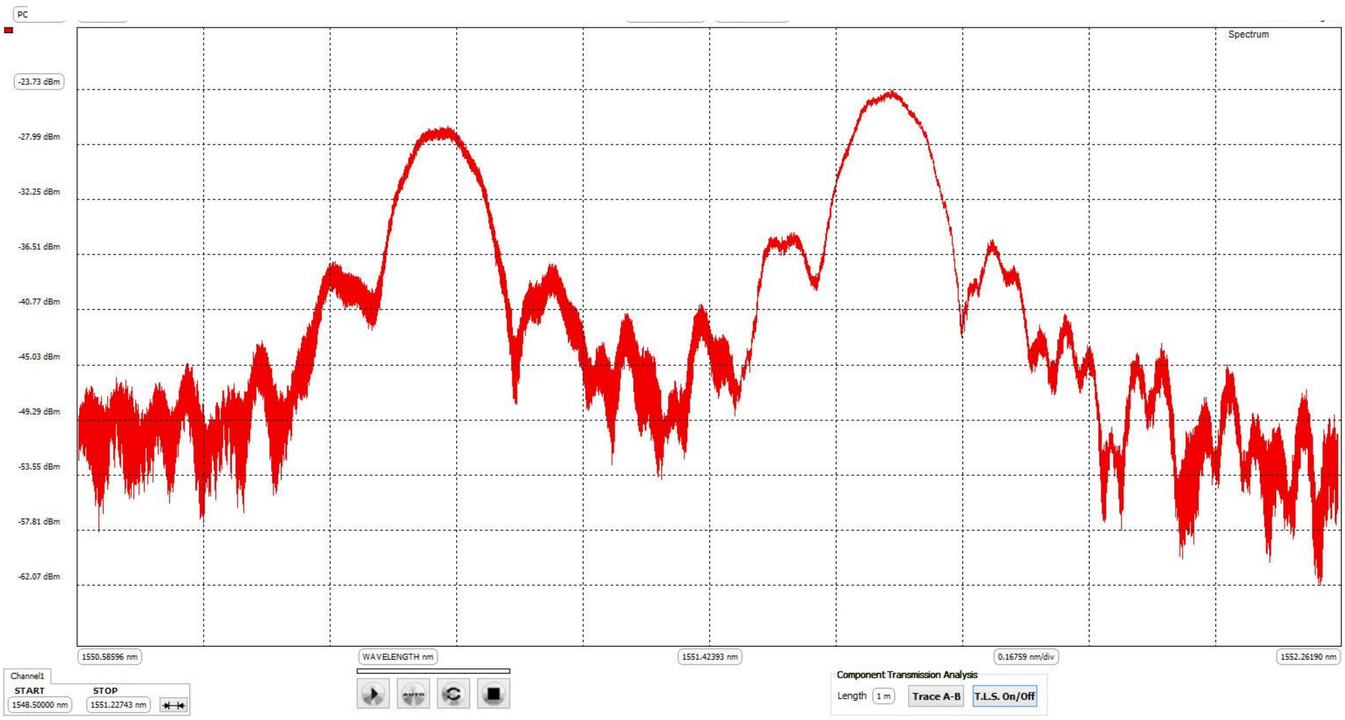


Figure 4: FBG sensors reflection spectra measured by APEX Technologies OSA

Polarization-dependence loss (PDL) of transmission-type optical devices, such as long-period fiber grating (LPFG) sensor and wavelength-tunable filters, is an inherent problem that limits information Sensors capacity in optical sensor applications. The FBG sensor, which is a partially transmission/reflection-type fiber device, also suffers from PDL. External perturbation such as transverse force can increase the birefringence of most FBGs. As a result, the interrogation accuracy of an FBG-based sensor may be significantly deteriorated due to an uncertain wavelength shift caused by the variation of polarization state of the input light.

In this context, APEX UHR OSA remains a perfect tool to study the sensitivity of FBG sensors to the polarization states. The availability of two internal independent channels for each polarization is one of the most specific features of the APEX UHR OSA. In fact, the APEX APEX UHR OSA splits the input signal into two orthogonal polarization axes in order to measure them simultaneously. The main advantage is to provide users the possibility to display separately and/or simultaneously the two polarization channels. It can also recombine them and display a polarization-independent measurement as shown in figure 4.

Figure 5 shows the polarization-dependent reflection spectra of a FBG sensor under different transverse forces measured by the APEX UHR OSA. By applying external forces on the FBG sensor (by just moving the FBG sensor), the APEX UHR OSA shows clearly the amplitude variation of the reflection peak in each polarization channel. In some cases (figure 5(a)), the reflection peak amplitude can be same for both polarization states.

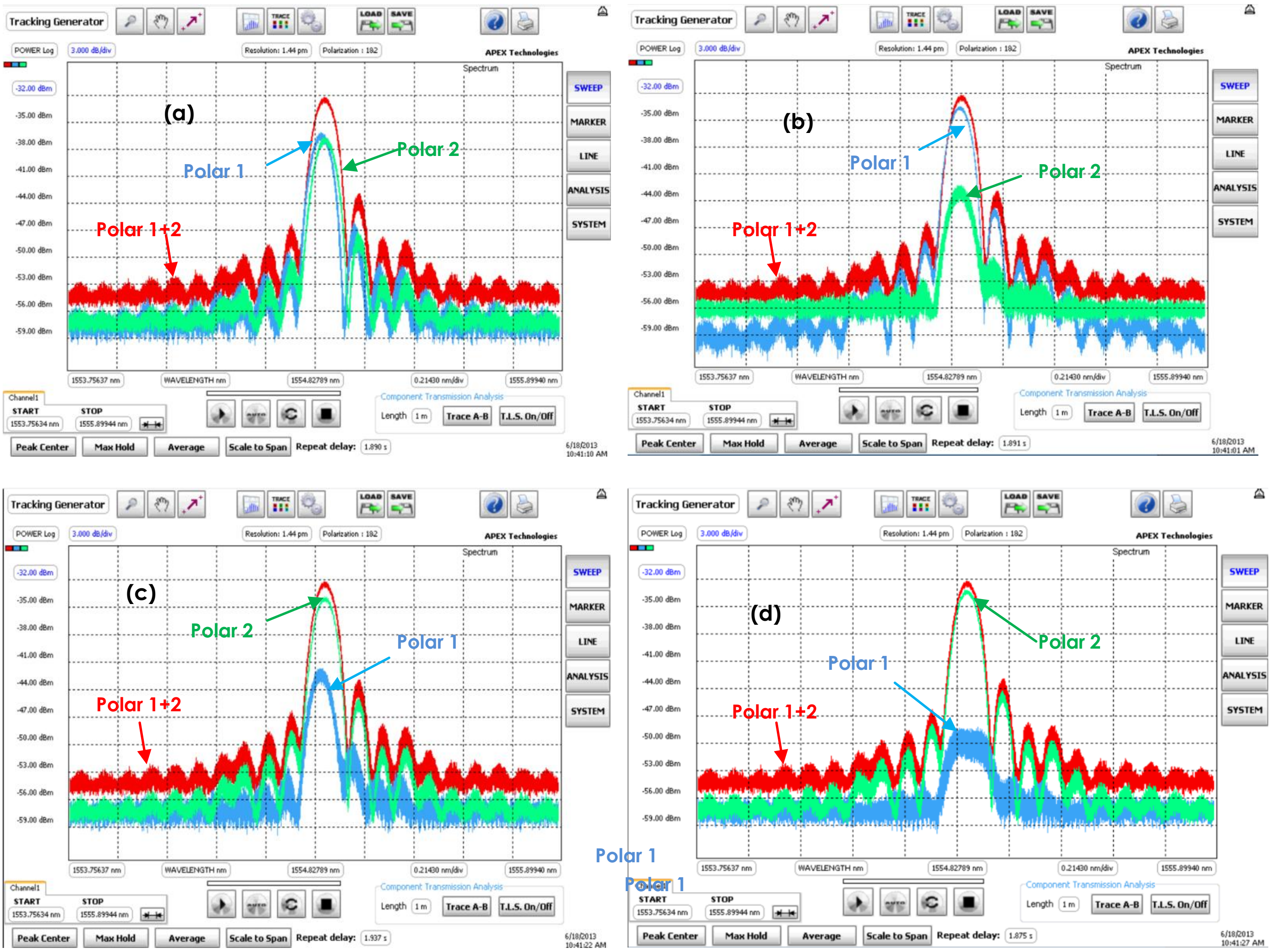


Figure 5: FBG sensors polarization-dependent reflection measured by APEX Technologies OSA

Although the amplitude of the reflection was seen to fluctuate significantly, the wavelength position remained constant. The polarization dependence of the radiation direction is negligible at wavelengths close to the Bragg wavelength of the grating. Since the system operates by taking a snapshot of the reflected spectral information, the polarization induced amplitude fluctuations only affect the SNR (Signal to Noise Ratio) of the system.

Conclusion

The APEX Technologies High Resolution OSA used in laboratory settings remains a perfect tool for measuring FBG sensors reflection/transmission spectrum. Thanks to its interferometric method and tracking generator option, the APEX OSA can flexibly measure the FBG sensor reflection spectrum deformation with:

- 1 MHz/8 fm of wavelength resolution
- 63 dB of dynamic range
- 0.3 pm wavelength relative accuracy for a 30 GHz peak separation

The availability of two internal independent channels for each polarization axis inside the APEX OSA gives the possibility to study the FBG sensor sensitivity to the polarization states.

Acknowledgments

The authors are grateful to *Dr. Johan Vlekken and Dr. Jan Van Roosbroeck* from FBGS Technologies for providing FBG sensors as well as for their technical support.

Contact

Apex Technologies
9bis, rue Angiboust
91460 MARCOUSSIS
FRANCE
Tel : +33 1 69 63 26 30
Fax : +33 1 69 63 26 37
Email : info@apex-t.com
Web site: www.apex-t.com