Design of temperature optical fiber sensor system

Irene González-Alamillo, Ana P. González-Marcos
Dpto. Fotónica e Ingeniería Biomédica. ETS Ingenieros de Telecomunicación.
Universidad Politécnica de Madrid, 28040 Madrid. Spain
POLITÉCNICA
ETSIT UPM
Neurophotonic & Nonlinear Dynamics Group

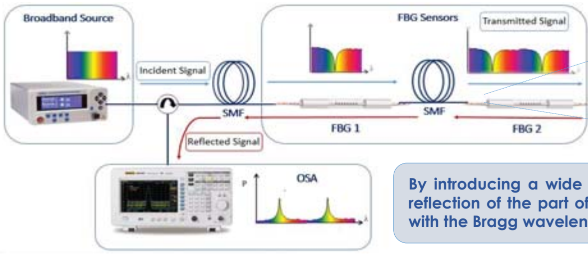
Background

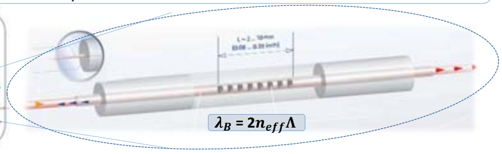
The rapid growth of the telecommunications industry over the last decade has boosted the development of photonics and optoelectronics technology, enabling dramatic improvements in the quality, sensitivity and dynamic range of fiber optic sensors, making them ideal substitutes for traditional sensors used in rotation, acceleration, electric fields, magnetic fields, temperature, pressure, deformation, humidity, chemicals, etc.

Therefore, **sensing methods are transcending from the electrical domain to the optical domain** as they present multiple advantages that solve a great number of electrical sensing problems, such as: *immunity to electromagnetic interference, low weight and volume , long life and multiplexing capacity, among others.*

One of the most optical sensors used and deployed are based on the Bragg-grating

- **A Bragg network is a periodic perturbation of the refractive index of the core of an optical fiber induced by interaction of a laser via the phenomenon of photosensitivity.**





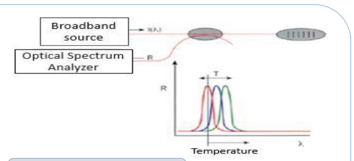
By introducing a wide spectrum light beam into the fiber containing the FBG, a reflection of the part of the spectrum of the source whose wavelength coincides with the Bragg wavelength λ_B

Target of the project

In this project, the principal aim is based on the design of two systems with optical temperature sensors "Fiber Bragg Grating" (FBG) that operate in **the dynamic range of 0-60ºC**. To be able **to measure these changes of temperature in multiple points**, a temperature sensors array of 5 FBGs is designed using the technology of Multiplexing by wavelength division (WDM), and his performance and precision is compared to a system formed by the only sensor FBG to measure the temperature in a point [1]. This analysis and design will carry out **by the CAD software VPIphotonics ™**. Simulation is required to reduce prototyping costs. To realize this design, it is necessary to take into account two factors:

1. Changes in the Bragg wavelength

- **Refection spectrum besides depending on the resonance condition, depends on temperature disturbances in the fiber. Therefore, the reflected wavelength of the Bragg network changes in a magnitude $\Delta\lambda_B$ with the temperature.**

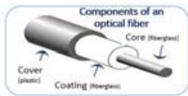


$$\Delta\lambda_B = 2\left(\Lambda\frac{n_{eff}}{\partial T} + n_{eff}\frac{\partial\Lambda}{\partial T}\right)\Delta T$$

$$\Delta\lambda_B = \lambda_B(\alpha_n + \alpha_\Lambda)\Delta T$$

2. Photosensitivity

- **The optical fiber photosensitivity refers to a permanent change in the refractive index of the fiber core when it is exposed to light with a characteristic wavelength and intensity depending on the core material**



The thermo-optical constant, ξ, depends on the material of the fiber core

Methodology

In order to carry out the design of each System, two parts are distinguished: design and characterization of the sensor; interrogator design

Sensor characterization

Thermo-optical design

- The wavelength reflected by the Bragg network changes by a magnitude $\Delta\lambda_B$ with the temperature. These changes are **induced by variations of the effective refractive index of the fiber and the period of the Bragg grating as a function of temperature.** Therefore, the objective is based on determining expressions of these parameters that depend on thermo-optical coefficients and the temperature [5].

$$\Delta n_{eff} = \frac{dn}{dT}\Delta T \qquad \frac{\Delta\Lambda}{\Lambda} = \alpha\Delta T$$

$$\lambda_{B2} = 2\left(n_{eff1} + \frac{dn}{dT}\Delta T\right)(\Lambda_1 + \Lambda_1\alpha\Delta T)$$

1º term; 2º term

Variation in n_{eff1} (1º term)

$$N_{core} = n_{effcore}(1 + \xi_{core}\Delta T)$$

$$N_{reves} = n_{effreves}(1 + \xi_{reves}\Delta T)$$

Variation in Λ (2º term)

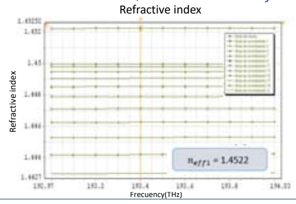
$$\Lambda_{period} = \Lambda_1(1 + \alpha\Delta T)$$

$$\Lambda_{length} = L_1(1 + \alpha\Delta T)$$

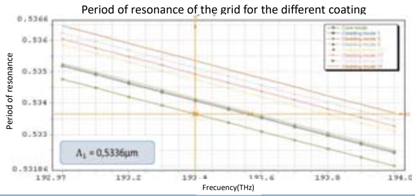
Coupled mode theory analysis

- In **short-period (FBG) networks** the power coupling, known as contradirectional coupling, occurs between fundamental modes traveling in opposite directions. Therefore, the objective is to **determine the expressions of the effective refractive index of the fiber and the grating period of the network** based on the coupling of the fundamental mode of the core with itself, denominated hybrid mode HE11 [3].

Refractive index



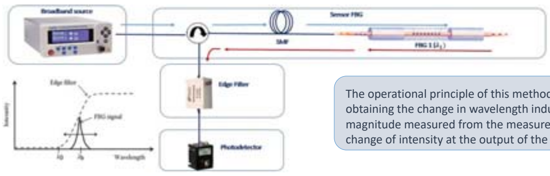
Period of resonance of the grid for the different coating



Interrogator design

Edge filter interrogation technique design

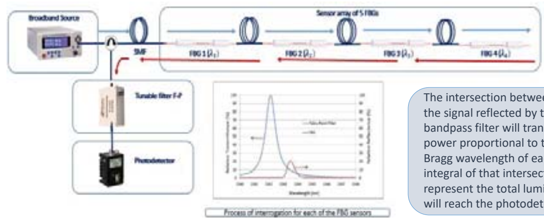
- The principle of interrogation of any FBG interrogation technique is **to convert the Bragg wavelength shift to a variation of an electrical signal.** Filtering based on the edge filter technique offers a linear relationship between the Bragg wavelength and the optical intensity change at the output of the photodetector [2].



The operational principle of this method is based on obtaining the change in wavelength induced by the magnitude measured from the measurement of the change of intensity at the output of the filter.

Tunable filter Fabry-Perot interrogation technique design

- A narrowband tunable filter scans across the entire range of the wavelength spectrum of the grating, and the spectrum is given by the reflected signal strength of the FBGs scanned against the tunable filter control signal [4].



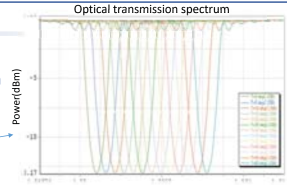
The intersection between the spectrum of the signal reflected by the array and the F-P bandpass filter will transmit a variable power proportional to the variation of the Bragg wavelength of each sensor. The integral of that intersection area will represent the total luminous power that will reach the photodetector

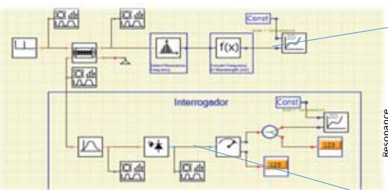
Simulation results

System temperature sensor FBG + Edge filter

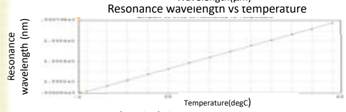
- Analyzing the results obtained after the simulation, it can be affirmed that there is indeed a linear relationship between the movement λ_B and temperature, and the design of a sensor with **a sensitivity of 11.2pm / ºC was achieved**, whose value is very close to a real FBG

Optical transmission spectrum

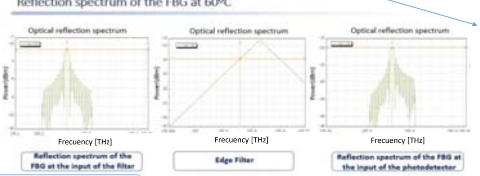




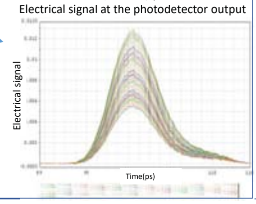
Resonance wavelength vs temperature



Reflection spectrum of the FBG at 60ºC



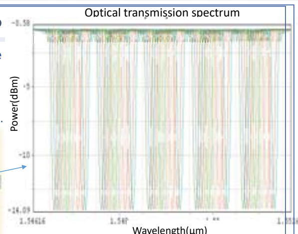
Electrical signal at the photodetector output

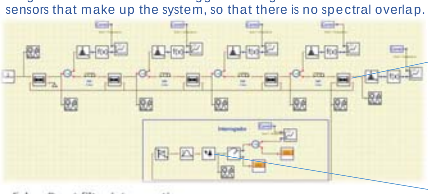


System array of temperature sensors FBGs + F-P

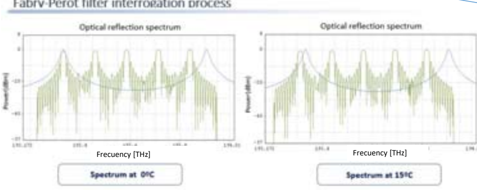
- Analyzing the results obtained after the simulation, the design of the array sensor with a **sensitivity of 11.2pm / ºC was achieved.**
- The temperature sensors FBGs array have been designed with a range of 1nm between the Bragg wavelengths of each of the sensors that make up the system, so that there is no spectral overlap.

Optical transmission spectrum

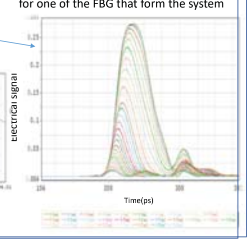




Fabry-Perot filter interrogation process



Electrical signal at the photodetector output for one of the FBG that form the system



References

[1]M. Y. G. N.F. Öztürk, «"Design of a Fiber Bragg Grating Multiple Temperature Sensor",» IEEE Xplore, 2016.
[2]G.Rajan, Optical Fiber Sensors :Advanced Techniques and Applications, CRC Press, 2015.
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[5]B. H. a. K. J. K. Avram Bar-Cohen, "Thermo-Optic Effects in Polymer Bragg Gratings", University of Maryland, College Park, Marylan, USA