A new interrogation system for a large number of strain sensors using Fiber Bragg Grating for application in residential buildings

R. García[a], S. Sales[a], J. Capmany[a], W. Warzanskyj[b], D. McDonald[c], M. Bastiani[d]
[a]IMCO2, Universidad Politécnica de Valencia, Camino de Vera s/n, 46020 Valencia, Spain,
ssales@dcom.upv.es
[b] Telefonica I+D, Emilio Vargas 6, 28043 Madrid, Spain
[c]Intune Technologies, 9C Beckett Way, Park West Business Park, Nangor Road, Dublin 12, Ireland
[d]Ecoazioni, Via Beniamino Ubaldi - Centro Direzionale Prato, 06024 Gubbio (PG) Italia

ABSTRACT

A new interrogation system for a large number of strain sensors is presented. In the residential building sensor market some facts have to be dealt with: low cost, networks with a large number of sensors, reliability, passive devices, amongst others. We have accomplished all of these with the new interrogation system we are going to present.

Topics : VI) Multiplexing and Sensor Networks
XI) System Applications and Field Trials
I) Physical and Mechanical Sensors

A new interrogation system for a large number of strain sensors using Fiber Bragg Grating for application in residential buildings

R. García[a], S. Sales[a], J. Capmany[a], W. Warzanskyj[b], D. McDonald[c], M. Bastiani[d]
[a]IMCO2, Universidad Politécnica de Valencia, Camino de Vera s/n, 46020 Valencia, Spain, ssales@dcom.upv.es
[b] Telefonica I+D, Emilio Vargas 6, 28043 Madrid, Spain
[c]Intune Technologies, 9C Beckett Way, Park West Business Park, Nangor Road, Dublin 12, Ireland
[d]Ecoazioni, Via Beniamino Ubaldi - Centro Direzionale Prato, 06024 Gubbio (PG) Italia

ABSTRACT

A new interrogation system for a large number of strain sensors is presented. In the residential building sensor market some facts have to be dealt with: low cost, networks with a large number of sensors, reliability, passive devices, amongst others. We have accomplished all of these with the new interrogation system we are going to present.

Keywords: Multiplexing and Sensor Network, System Applications and Field Trial, Mechanical Sensors

1. INTRODUCTION

In recent years, there has been growing interest in the area of smart structures which are designed to react to their environment by the use of integrated sensors and actuators in their body. Such structures are not only able to monitor the health of their body, but also forewarn about the onset of abnormalities in their states, and hence their impending failures. There are many advantages to such a system: less downtime, less frequent maintenance, better material usage and improved safety, reliability and economy [1, 2].

Fiber optic sensors based on Fiber Bragg Grating (FBG) technology is found to be suitable for strain sensing. In comparison with conventional electrical strain gauges, the FBG sensors are unsusceptible to EMI (Electro Magnetic Interference), are lightweight, small, and can be embedded and integrated into composite structures. They can give an absolute measurement and two important facts for the proposed application; they are passive and can be multiplexed using WDM (Wavelength Division Multiplexing) technique.

This work has been developed within the framework of the OFFSSOHO European Project. The main objective of this project is to propose an architecture which provides monitoring of the health of the residential buildings in a neighbourhood, using the deployed infrastructure of a telecom operator. The idea is to use the dark fibres installed up to the residential buildings. The system must be passive outside of the central office. The user must not provide electrical supply to the sensors. Thus, the main characteristics of the system must be: passive sensors, reliability, large distances and a large number of sensors, and a low price.

The main problem of the FBG sensors is the difficulty of discriminating between temperature and strain effects. Because of its inherent physical composition and structure, the FBG resonance frequency shifts with strain and temperature and sometimes even with humidity [3]. Therefore, it is necessary to subtract the temperature effect from the wavelength shift to measure the strain effect only. There have been many approaches to solve the above problem [4-6]. For a mass production scale we have to take into consideration that it is easy to install two uniform FBGs in the same place, one of them is going to be submitted only to the temperature variations ("*the reference FBG*") and the other is going to sense the strain and the temperature fluctuations ("*the strain FBG*") [7].

To reduce the cost of the system, the use of broadband light sources with tunable Fabry-Perot filters and some interrogation techniques have been proposed, previously. However, due to the long distances from the Central Office to the residential buildings, a source with more output optical power is required. We are going to use a tunable laser. Its price is going to be shared among the optical sensors. Furthermore, we are going to use a cheap tunable laser with a step size of 50 GHz. This not only provides a reduction in the price of the system, but also a change in the profile of the FBG that will be explained in the following sections.

2. SYSTEM ARCHITECTURE

The setup of the system is shown in figure 1. As can be seen, a tunable laser to multiplex the FBG sensors using the WDM technique is placed in the Operator premises. Several fibres are deployed from the Central Offices of the Operator to the different neighborhoods. The same laser can be used to illuminate different residential areas through the feeder fibres.

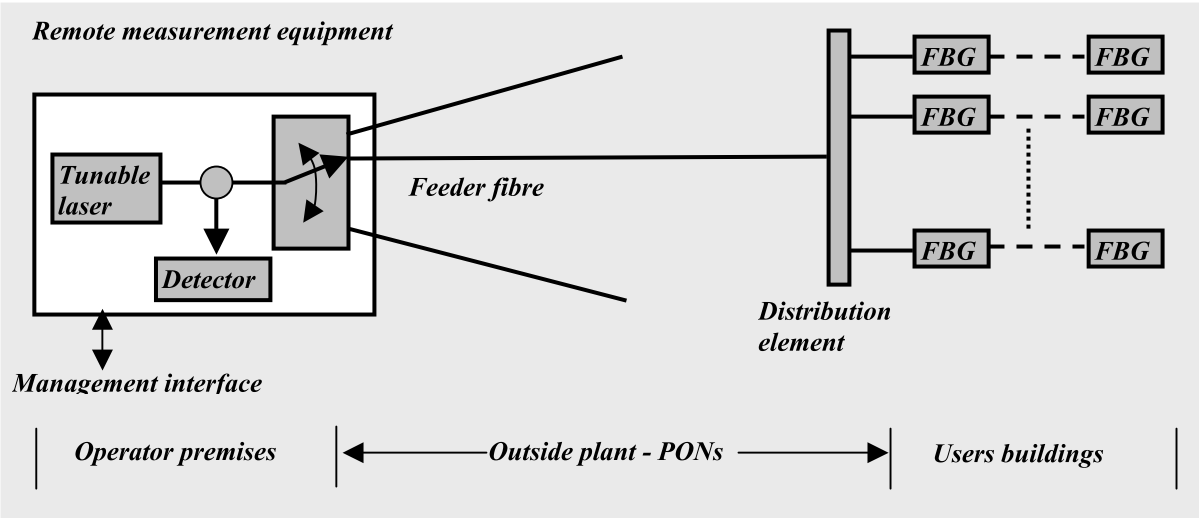


Figure 1: Layout of the system architecture of the OFFSSOHO project

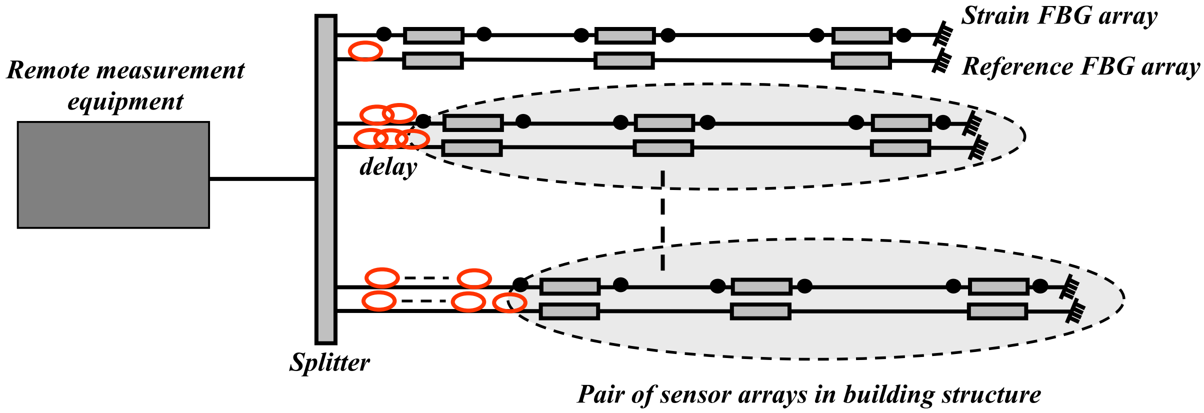
An important choice is to select the distribution element. One of the objectives of the OFFSSOHO project is the construction of the system with only optical passive devices outside of the operator premises to achieve lower maintenance costs and then also the operator does not have to provide electrical supply. Thus, the use of a switch is not allowed. Then, we can use two different kinds of devices: an element that takes into account the WDM (i.e. an Array Waveguide Grating, AWG) or an element that does not take into account WDM (i.e. a splitter). The use of an AWG limits the number of FBGs that can be installed in each output branch of the AWG, although the power efficiency is much higher than using a splitter. Bringing to mind some "easy" figures: 30 nanometres of tuning range of the laser and each sensor detecting strains of over 1000 microstrains in a temperature range of more than 60ºC shows that using an AWG, the number of sensors that can be multiplexed per feeder fibre are going to be about a dozen only. Thus, the alternative for the requirements of the OFFSSOHO project is to use a splitter. Using a commercial 32x32 port splitter with a total insertion losses of 17 dB we can allocate a dozen FBGs per branch with a distance feeder fibre of ten kilometres. For these features the optical plant losses are less than 35 dB and commercial OTDRs reach 40 dB, so the number of FBGs that can be interrogated are over 384.

The requirement of the sensors is that they have to work within a range from –20ºC to +60ºC and they have to sense ± 1200 microstrains according to the studies of the architects. The maximum strain and the temperature range allows the use of acrylate coating [8], reducing the overall cost of the system. The drawback is the fact that the FBGs are sensitive to changes in temperature and strain. To avoid this problem, we have installed two identical FBG sensors in the same place, as explained above.

Figure 2 shows the position of the FBGs. Two identical branches have been placed per position. This means that only half of the possible locations are used. However, this solution is easy and cheaper to produce than other solutions described in the preceding section. Figure 2 also shows the delays used to distinguish the responses from different sensors located in different branches. Thus, a combination of the WDM technique and the SDM (Spatial Division Multiplexed) technique are used to multiplex almost 400 FBGs.

Due to the restrictions of large numbers of sensors and large distances, we have chosen a high-power tunable laser. The drawback of the optical source is the price. To decrease the price we have used a laser with a course tuning step size. The Intune laser has a 50 GHz step size.

Figure 2: Layout of the deployment of the "strain sensors" and the "reference sensors"



The minimum detectable strain that has been planned to be measured is 20 microstrains so this implies that for a standard strain coefficient of a FBG, a shift of 1.5-2 GHz has to be detected. As the minimum step size of the laser is 50 GHz, the variations have to be detected using the amplitude variations of the power reflected by the FBG, instead of using the shifts from the central wavelength of the FBG. Also, this fact implies that the minimum FWHM (Full Width Half Maximum) of the FBG sensor must be more than 50 GHz. To avoid ambiguity in the data received from the FBG sensors, the ripple in the transfer function of the reflectivity of the FBG must be minimised. Also, it would be interesting that the transfer function was ramp-shaped. However, the ramp shape is almost impossible to fabricate with a low ripple, so we have decided to have a transfer function of the reflectivity which is symmetrical around the central wavelength in order to have a better resolution. If we have a transfer function which is not ramp-shaped, it is necessary that the FWHM has to be more than 100 GHz to avoid ambiguity in the interrogation system. The wider the FWHM, the more data we are going to obtain from a sensor and then it is easy to compensate the irregularities of the transfer function. But, the wider the FWHM, the poorer signal to noise ratio which is going to be obtained per wavelength and at the same time an overlap of the responses of different sensors will easily happen. As it is a trade-off, we have decided to have a FHWM of the FBGs at around 150 GHz.

3. MEASUREMENTS

We have installed four arrays of seven sensors in a mock-up to test the behaviour of the FBGs and the interrogation system. The performance of the system fulfils the requirements of the OFFSSOHO project. We have not only made measurements to test the accuracy, the maximum strain and compression or the maximum number of sensors to be deployed, we have also measured how the reference sensor compensates the variations in temperature and humidity adequately. Also, we have carried out experiments to verify the good behaviour of the FBGs in the long term. Furthermore, we have checked the good characteristics of the Polarization Dependece Losses and the ripple of the transfer function of the FBGs and we have checked the stability of the tunable laser in terms of amplitude and wavelength. Figure 3 plots the responses of two arrays of seven FBGs measured using the tunable source of 50 GHz step size. One of the arrays is that corresponding to the strain sensors which are prestrained at 1500 microstrains to detect compression and strain.

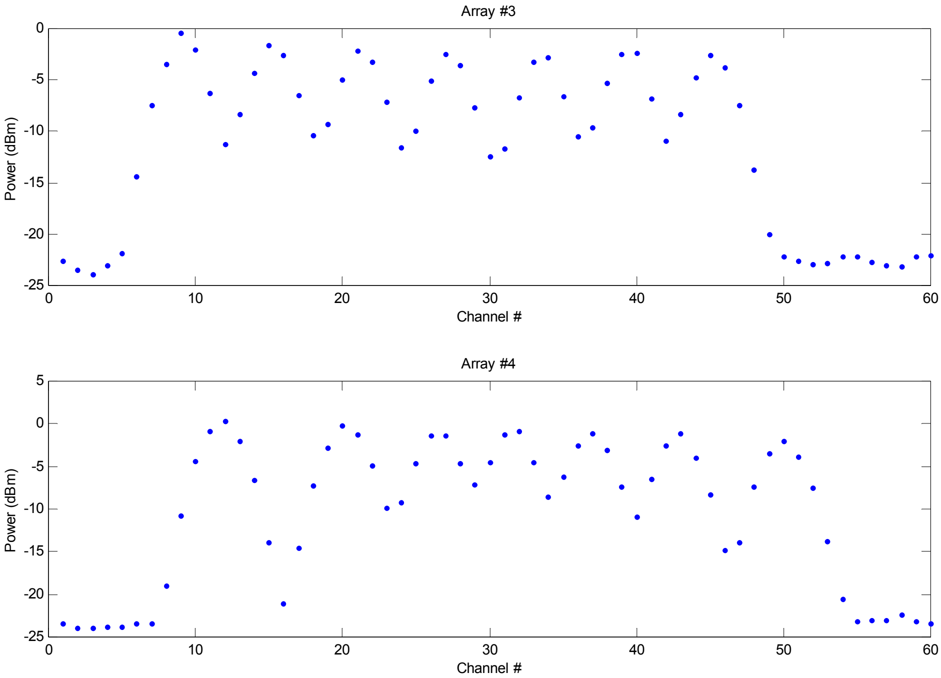


Figure 3: Plot of two arrays of sensors designed, fabricated and measured

4. CONCLUSIONS

We have presented a new interrogation system for strain sensors using FBGs for application in residential buildings. The design and implementation of the system has fulfilled the initial requirements. The novelty of the interrogation system is the use of a cheap tunable laser which provides high power to interrogate a large number of sensors over a short period of time. The switching time of the tunable laser is 200 nanoseconds. Also, we have developed a new FBG with a triangular shape to be used with the course step size of the tunable laser. Another important fact is that outside the central office all the devices are passive, as this was a requirement of the telecom operator. The system has been tested and verified over the entire range of temperatures and the range from the maximum compression to the maximum elongation, fulfilling the required accuracy. Furthermore, a cost analysis has been done and for different scenarios of high/low demand and high/low density of users. The results of the economic study show that is economically feasible to install the system in some circumstances.

The authors acknowledge financial support from the Valencia Government CTIDIB 2002/70 project, Spanish McyT TIC2001-2969-c03-01 and the European Union IST-2001-37052 OFFSSOHO project.

REFERENCES

1. J. Dakin and B. Culshaw, *Optical Fiber Sensors,* Artech House, 1996.
2. K.T.V. Grattan and B.T. Meggit, *Optical Fiber Sensor Technology. Advanced Applications – Bragg Grating and Distributed Sensors*, Kluwer Academic Publishers, Dordrecht, 2000.
3 P. Kronenberg, P. K. Rastogi, P. Giaccari and H. G. Limberger, *Relative humidity sensor with optical fiber Bragg gratings*, Opt. Lett., vol. 15, pp. 1385-1387, 2002.
4. P.M. Cavaleiro, F. M. Araújo, L. A. Ferreira, J. L. Santos and F. Farahi, *Simultaneous Measurement of Strain and Temperature Using Bragg Gratings Griten in Germanosilicate and Boron-Codoped Germanosilicate Fibers*, IEEE Photon. Technol. Lett., vol. 11, pp. 1635-1637, 1999
5. X. Shu, Y. Liu, B. Gwandu, F. Floreani, L. Zhang and I. Bennion, *Fiber grating type dependence of temperature and strain coefficients and application to simultaneous temperature ans strain measurement*, pp. 83-86.
6. B-O. Guan, H-Y Tam, X-M Tao, X-Y Dong, *Simultaneous Srain and Temperature Measurement Using a Superstructure Fiber Bragg Grating*, IEEE Photon. Technol. Lett., vol. 12, pp. 675-677, 2000
7. A.D. Kersey, T.A. Berkoff, W.W. Morey, *Fiber-optic Bragg grating strain sensor with drift-compensated high-resolution interferometric wavelength-shift detetction.* OSA Optics Letters, vol. 18, nº 1, Januuary, 1993
8. D. Inaudi, S. Vurpillot, N. Casanova, A.O. Wyser, *Development and field test of deformation sensors for concrete embedding,* SPIE Conference on Smart Structures and Materials, 5-6.03.1997, San Diego, USA