Microwave and Optical Technology Letters / Volume 56, Issue 12

Research Article | Full Access

Interrogation and multiplexing system for fiber loop mirror coupled intensity sensors using OTDR

Maria Thereza M. Rocco Giraldi, Cindy S. Fernandes, Marta S. Ferreira, Marco J. de Sousa, Pedro Jorge, João C. W. A. Costa, José L. Santos, Orlando Frazão

First published: 26 September 2014
https://doi.org/10.1002/mop.28720

ABSTRACT

In this article, it is proposed an interrogation and multiplexing system based on optical time domain reflectometer for fiber loop mirror coupled intensity sensors. Pulse width of approximately 100 ns enabled to attain a dynamic range of approximately 18 dB. Good linearity was achieved with a −13.3 dB/mm slope. The resolution of the sensing head was 0.027 mm. The proposed interrogation system showed to be an alternative technique for multiplexing and remote sensing. © 2014 Wiley Periodicals, Inc. Microwave Opt Technol Lett 56:2860–2864, 2014

1 INTRODUCTION

Optical Time Domain Reflectometer (OTDR) is the most utilized equipment to measure distributed losses in optical fibers. It uses Rayleigh scattered light to determine the attenuation of optical fiber links. OTDR is also useful to localize events, breaks and to evaluate splices and connectors 1. Due to these advantages and since OTDR is a simple, easy, and ready to be used tool, it has also been the starting point of distribution sensing techniques 1. As interrogation system, OTDR has been utilized in different configurations. One of the most common is to use fiber Bragg grating (FBG) and/or long period grating (LPG) with OTDR 2, 3. Recently, Gong et al 2 proposed a multipoint strain measurement system based on OTDR and FBG. Another approach uses OTDR to interrogate Fabry–Perot sensors 4, 5. Finally, a significant function of the OTDR is to enable multiplexing 6, 7 and remote sensing 7, 8 interrogation.

OTDR trace loss 7, 9-11 or reflection peak variation 6, 8 are the most attractive techniques for interrogation when this equipment is used. In the case of the OTDR trace loss and considering multiplexing and remote sensing, there is a compromise between the number of sensors to be multiplexed and the distance between sensors as the loss introduced by the sensors will be a serious limitation to the system. OTDR reflection peak variation does not present such limitation.

An optical fiber mirror is a device necessary in several applications. An important application is to use as sensing element. One of the solutions is to utilize a fiber loop mirror (FLM) which is straightforward developed using a 3 dB optical coupler. In this case, the output ports of the coupler are spliced together forming a loop. All light input to the loop is reflected back to the coupler input port due to constructive interference which occurs in the coupler after the counter waves propagate inside the loop 12.

The optical losses are merely a result of the 3 dB coupler insertion loss and the splice loss. FLM combined with LPG is an alternative solution to interrogate such gratings in reflection using an OTDR as the interrogation system 13.

In this article, it is presented an interrogation and multiplexing system based on OTDR to interrogate intensity sensors, in the case tapered based displacement sensors, coupled to FLMs. The proposed scheme used the information contained in the OTDR reflection peak variation to evaluate the sensors still allowing multiplexing and remote sensing.

2 EXPERIMENTAL SETUP

Figure 1 presents the experimental setup of the proposed interrogation system. A commercial OTDR from YOKOGAWA, model AQ 1200 OTDR—Multi Field Tester is used to interrogate intensity taper sensors. Remote sensing is obtained connecting 5.5 km of Corning SMF-28 fiber to the OTDR port. An optical coupler is connected at the fiber output. Ten percent of optical power is used to illuminate the sensor.

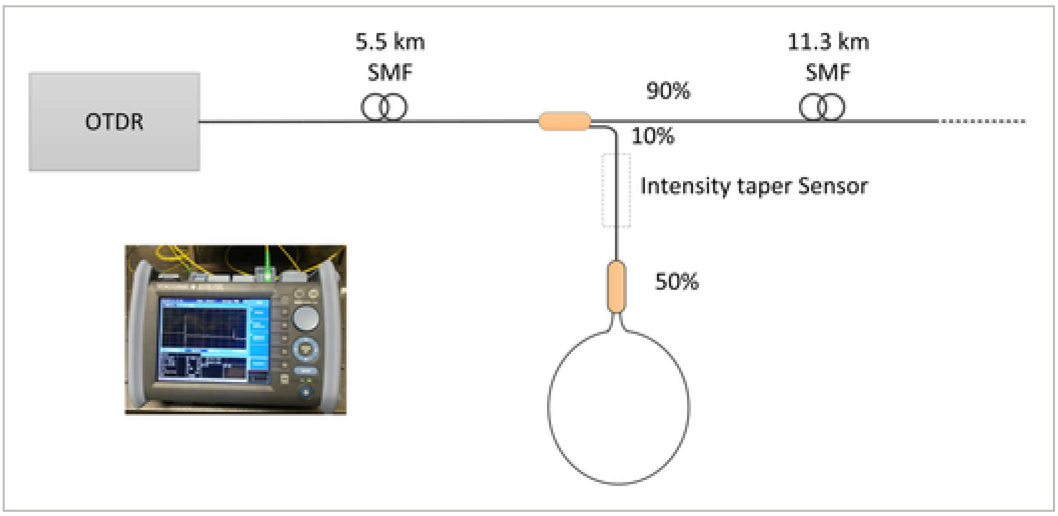

Figure 1

Open in figure viewer | PowerPoint

Experimental setup of the interrogation system for FLM coupled intensity sensor using OTDR. Inset: Photo of the OTDR. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

The 90% output port of the coupler enables multiplexing which is achieved connecting 11.3 km of Corning SMF-28 fiber to that coupler output port. To simulate intensity sensors, optical fiber tapers were used as displacement sensors.

The mode operation of the sensing head consists in applying curvature in the taper region with a value that depends on the displacement to be measured. Therefore, the displacement induced curvature variation originates a change in the insertion loss of the taper. A 3 dB optical coupler working as a FLM is connected to the output of the displacement sensor, generating a FLM coupled intensity sensor configuration. The inset in Figure 1 is a photo of the OTDR with the output signal presented in Figure 2(a).

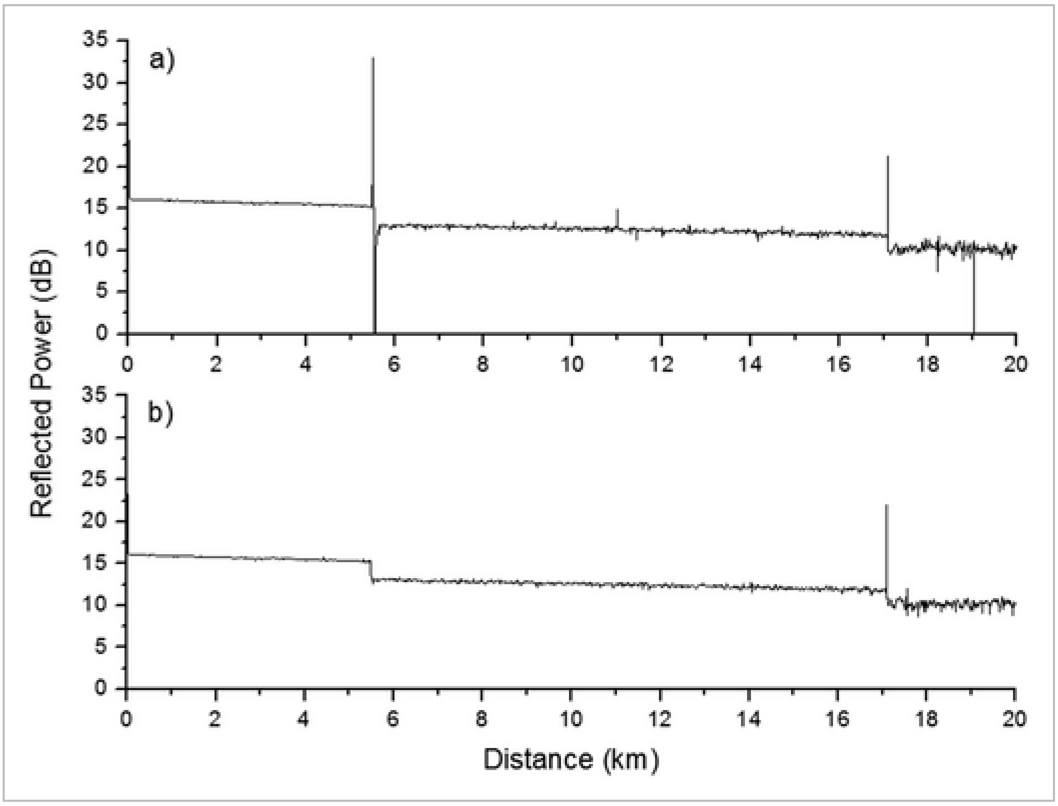

Figure 2

Open in figure viewer | PowerPoint

OTDR trace (a) in the presence of the FLM and (b) in the absence of the FLM

3 RESULTS AND DISCUSSION

3.1 Single Structure

In the single structure case, only one sensor is present and no multiplexing is performed. Figure 2 exhibits the OTDR trace in the presence (a) and absence (b) of the FLM after the single sensor. In Figure 2(a) it is clear the reflection peak due to the FLM and the Fresnel reflection after 11.3 km of fiber. It will be explored the reflection peak due to the FLM to interrogate the sensor. Note that in Figure 2(b) no reflection is present after the first coupler but the loss due to it is evidenced and around 2.5 dB. Using the proposed scheme, and despite such loss, it is possible to attain multiplexing of around 10 sensors (2.5 dB/sensor).

To optimize the OTDR parameters (optical signal) it was evaluated the dynamic range of the FLM peak reflection by varying the input signal and its pulse width. The FLM reflection peak dynamic range as a function of the input signal attenuation for a pulse width of 500 ns is shown in Figure 3. It is observed that input signal attenuation between 10 and 15 dB allows obtaining a maximum dynamic range of around 15 dB.

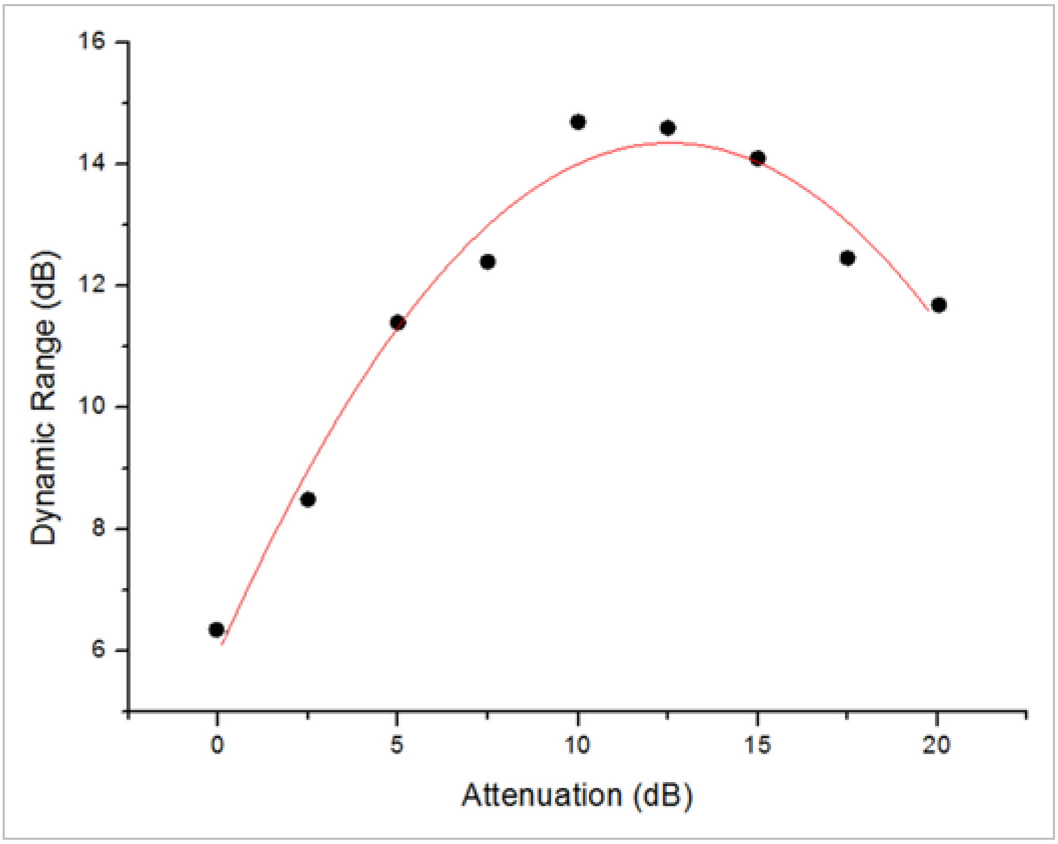

Figure 3

Open in figure viewer | PowerPoint

Dynamic range of the FLM reflection peak as a function of the input signal attenuation. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Figure 4 illustrates the FLM reflection peak dynamic range as a function of the OTDR input signal pulse width for an input signal attenuation of 10 dB since it has given the best dynamic range result. It is verified that smaller pulse width results in higher dynamic range.

As can be seen, a pulse width of approximately 100 ns enabled to attain an even better dynamic range of approximately 18 dB. In both curves, the dots represent the experimental results and the solid line is the fitting curve.

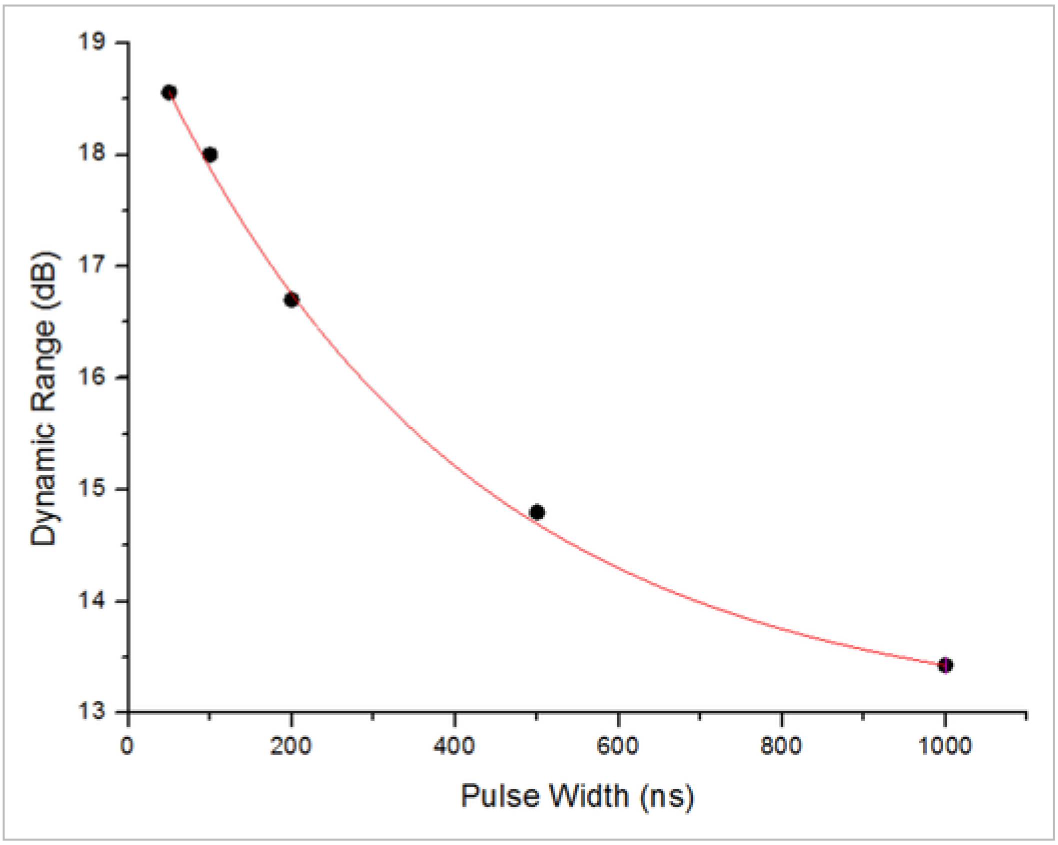

Figure 4

Open in figure viewer | PowerPoint

Dynamic range of the FLM reflection peak as a function of pulse width. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Figure 5 shows the trace of the OTDR as a function of the displacement sensor. It is clearly seen the decrease in the dynamic range of the FLM reflection peak as the displacement increases. The optical losses in the FLM reflection peak as a function of the displacement are presented in Figure 6. The results evidence a linear behavior with a slope of −13.3 dB/mm.

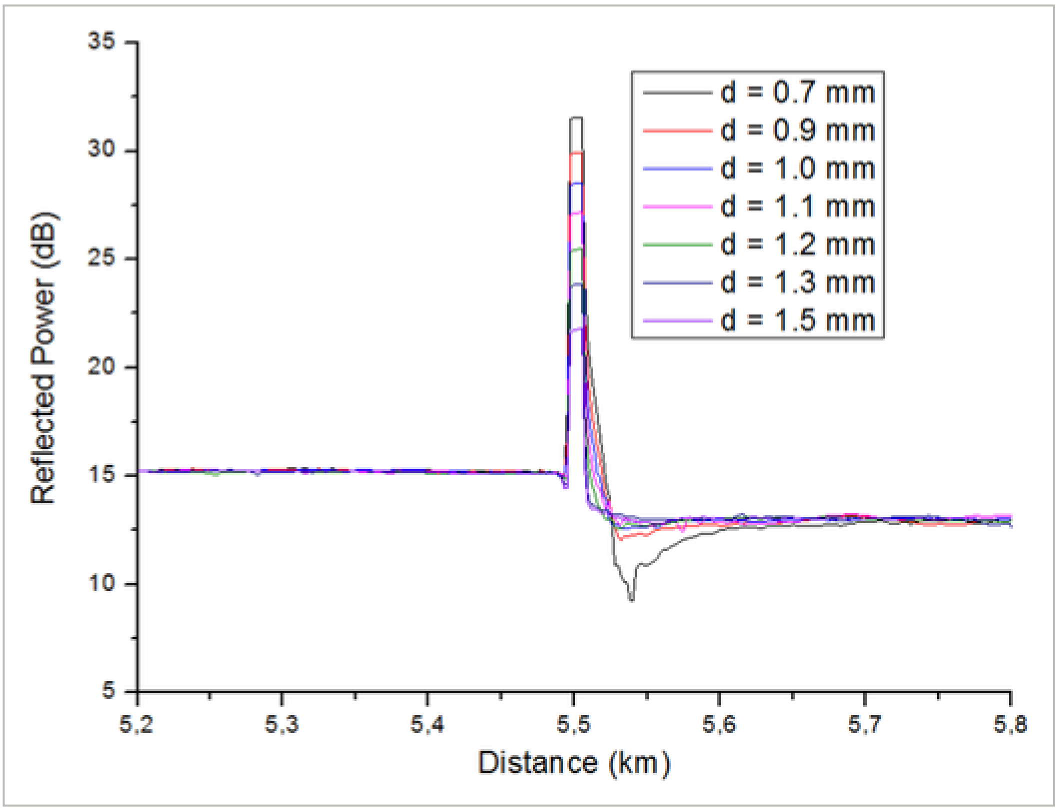

Figure 5

Open in figure viewer | PowerPoint

OTDR trace for different displacements. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

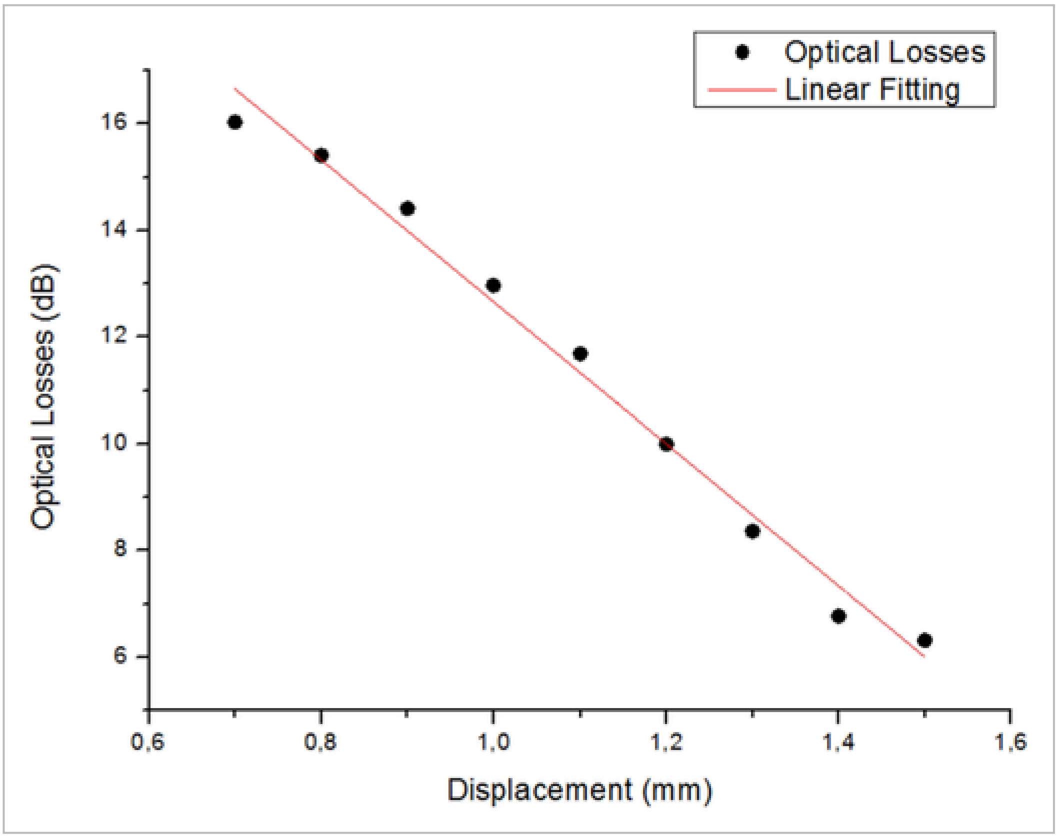

Figure 6

Open in figure viewer | PowerPoint

Optical losses in the FLM reflection peak as a function of the displacement. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

The sensing head resolution with the proposed interrogation system was obtained by performing a step of 0.4 mm in the displacement sensor which corresponds to a 3.91 dB signal intensity variation as shown in Figure 7. Considering this value and the average rms noise amplitude before and after the step change, it turns out a displacement resolution of 0.027 mm.

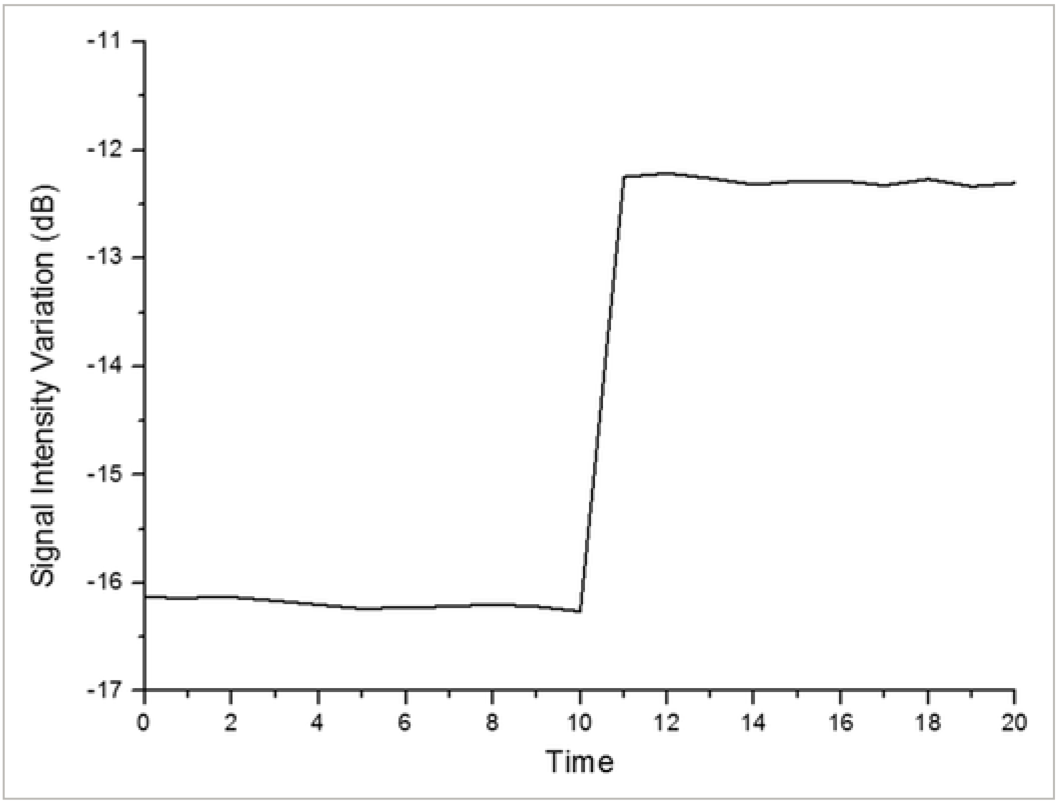

Figure 7

Open in figure viewer | PowerPoint

Step procedure to obtain the resolution of the interrogation system

3.2 Multiplexing Sensor

One important feature of this proposed interrogation technique based on OTDR is also enabling to multiplex several intensity sensors in parallel along the fiber. This feature is illustrated in Figure 8, which shows a system with two FLM coupled intensity sensors. Note that at the last sensor, the 90 × 10 optical coupler is not necessary and the sensor can be connected directly to the optical fiber. Considering the 2.5 dB loss originated by the 90 × 10 optical coupler insertion loss, it is possible to attain multiplexing of around 10 sensors.

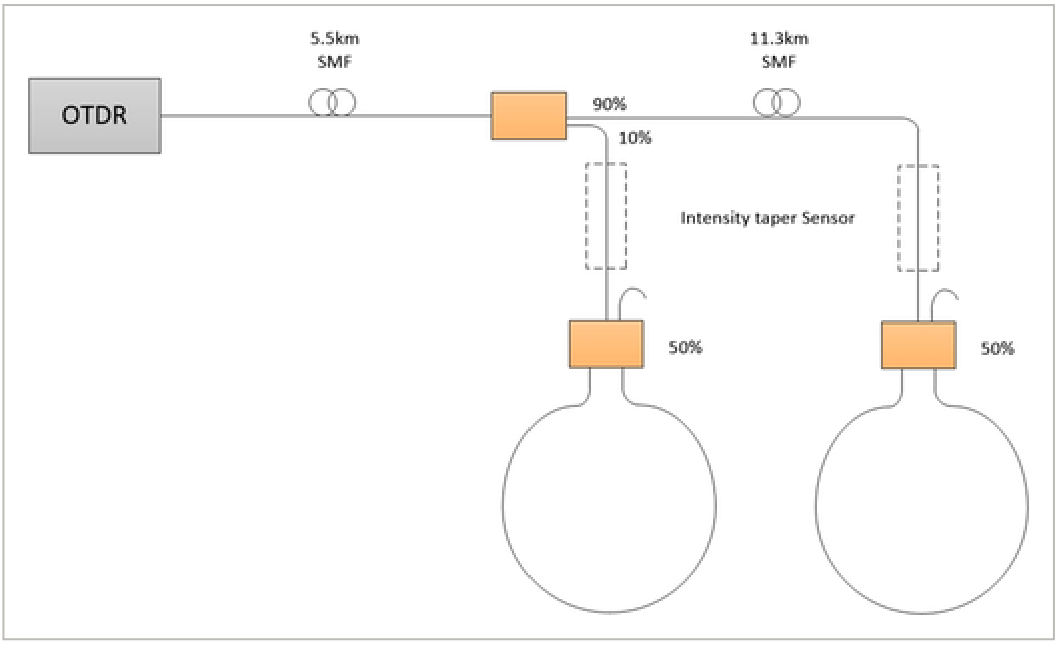

Figure 8

Open in figure viewer | PowerPoint

Experimental setup of the interrogation and multiplexing system for FLM coupled intensity sensors using OTDR. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Figure 9(a) presents the OTDR trace of the two multiplexed sensors. Note that the FLM reflection peak of the second sensor presents a dynamic range of around 21.3 dB which is much greater than the 10 dB Fresnel reflection presented in Figure 2(b). It is also important to analyze the crosstalk between the two sensors. Figure 9(b) shows the OTDR trace when the first sensor (5.5 km) followed by a FLM is absent. The dynamic range of the second FLM reflection peak is still around 21.3 dB. Finally, Figure 9(c) illustrates the OTDR trace when the second sensor (~17 km) followed by a FLM is not present. The dynamic range of the first reflection peak is around 18.1 dB which is the same as shown in Figures 9(a) and 2(a). The signal observed between 5.5 km and approximately 17 km is maintained constant along the fiber. Using this type of OTDR, the sample interval is 16 m that corresponds to the minimum distance between the two FLMs.

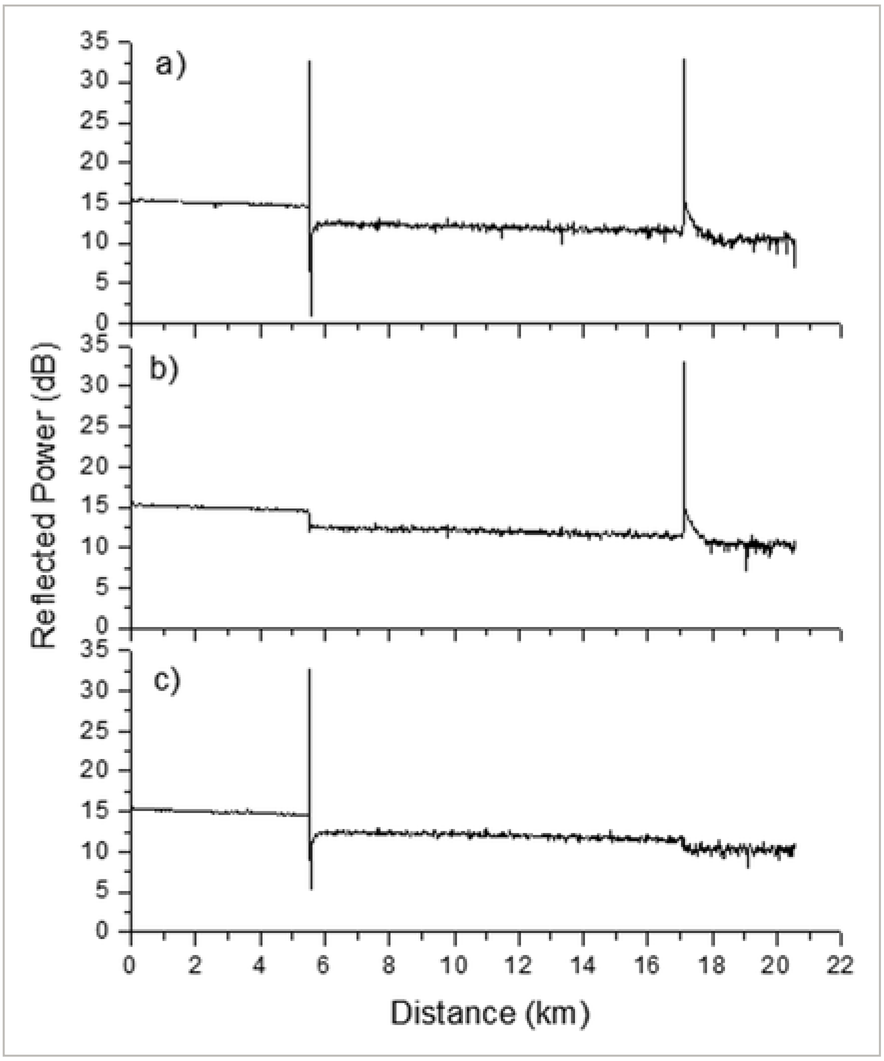

Figure 9

Open in figure viewer | PowerPoint

OTDR trace of (a) two multiplexed sensors, (b) in the absence of the first sensor and FLM, and (c) in the absence of the second sensor and FLM

4 CONCLUSION

In this article, it was proposed an interrogation and multiplexing system based on OTDR for FLM coupled intensity sensors. The scheme was characterized to obtain its maximum dynamic range. It was achieved a maximum value of 15 dB when input signal attenuation of around 10 dB is used. Pulse width of approximately 100 ns enabled to attain an even better dynamic range of approximately 18 dB for the first FLM and approximately 21 dB for the second. Despite the coupler losses, 2.5 dB, the proposed scheme permits multiplexing of around 10 sensors. The technique demonstrated good linearity with a −13.3 dB/mm slope. A 0.027 mm resolution was achieved. The proposed interrogation system showed to be a feasible alternative technique for sensor multiplexing and remote sensing.

ACKNOWLEDGMENTS

The authors would like to thank CAPES (Project BEX 4463/13-7**)** and CNPq for their partial support to this work. This work is also financed by the ERDF (European Regional Development Fund) through the COMPETE Programme (operational programme for competitiveness) and by National Funds through the FCT - Fundação para a Ciência e Tecnologia (Portuguese Foundation for Science and Technology) within Project FCOMP-01–0124-FEDER-037281.

REFERENCES

1 Glisic, B. and Inaudi, D., *Fibre optic methods for structural health monitoring*, Wiley, West Sussex, 2007.
Wiley Online Library | Google Scholar

2 Gong, X., Hua, D., Zhang, P., Hu, L., and Wang, Y., Alternate dual pulses technique for fiber Bragg grating Ultra-multi- point strain measurement, In: Eighth International Symposium on Precision Engineering Measurement and Instrumentation, Chengdu, China, August 8–11, 2013.
Google Scholar

3 Frazão, O., Falate, R., Baptista, J. M., Fabris, J. L., and Santos, J. L., Optical bend sensor based on a long-period fiber grating monitored by an optical time-domain reflectometer, *Opt Eng* **44** (2005), 110502-1– 110502-3.
Google Scholar

4 Cibula, E. and Donlagic, D., In-line short cavity Fabry-Perot strain sensor for quasi distributed measurement utilizing standard OTDR, *Opt Express* **14** (2007), 8719– 8730.
Crossref | Web of Science® | Google Scholar

5 Xu, P., Pang, F., Chen, N., Chen, Z., and Wang, T., Fabry-Perot temperature sensor for quasi-distributed measurement utilizing OTDR, In: 1ST Asia-Pacific Optical Fiber Sensors Conference (APOS 2008), Chengdu, 2008.
Google Scholar

6 Kwon, I.-B., Kim, C.-Y., Seo, D.-C., and Hwang, H.-C., Multiplexed fiber optic OTDR sensors for monitoring of soil sliding, In: XVIII IMEKO World Congress, Rio de Janeiro, Brazil, September 17–22, 2006.
Google Scholar

7 Bravo, M., Vallejo, M. F., and López-Amo, M., Hybrid OTDR-Fiber laser system for remote sensor multiplexing, *IEEE Sens J* **12** (2012), 174– 178.
Crossref | Web of Science® | Google Scholar

8 Yuan, J., Zhao, C., Ye, M., Kang, J., Zhang, Z., and Jin, S., A Fresnel reflection-based optical fiber sensor system for remote refractive index measurement using an OTDR, *Photonic Sens* **4** (2014), 48– 52.

Crossref | CAS | Google Scholar

9 Satar, N.J.M., Rahim, N.S.A., and AbdRahman, M.K., Displacement sensor for structural monitoring using optical time domain reflectometer, In: AIP 1150, Kuala Lumpur, Malaysia, January 12–16, 2009.
Google Scholar

10 Hatta, A.M., Permana, H.E., Setijono, H., Kusumawardhani, A., and Sekartedjo, , Strain measurement based on SMS fiber structure sensor and OTDR, *Microwave Opt Technol Lett* **55** (2013), 2576– 2578.
Wiley Online Library | Web of Science® | Google Scholar

11 Hatta, A.M., Indriawati, K., Bestariyan, T., Humada, T., and Sekartedjo, , SMS fiber structure for temperature measurement using an OTDR, *Photonic Sens* **3** (2013), 262– 266.
Crossref | CAS | Google Scholar

12 Agrawal, G.P., *Fiber-optic communication systems*, Wiley, West Sussex, 2002.
Wiley Online Library | Google Scholar

13 Bravo, M., Baptista, J.M., Santos, J.L., López-Amo, M., and Frazão, O., Ultralong 250 km remote sensor system based on a FLM interrogated by an optical time-domain reflectometer, *Opt Lett* **36** (2011), 4059– 4061.
Crossref | CAS | PubMed | Web of Science® | Google Scholar

Citing Literature

Maria Thereza M. Rocco Giraldi, Cindy S. Fernandes, Marta S. Ferreira, Marco J. de Sousa, Pedro Jorge, João C. W. A. Costa, José L. Santos and Orlando Frazão, Fiber optic displacement sensor based on a double-reflecting OTDR technique, *Microwave and Optical Technology Letters*, **57**, 6, (1312-1315), (2015).
Wiley Online Library

Maria Thereza Miranda Rocco Giraldi, Cindy Stella Fernandes, Marta S. Ferreira, Marco Jose de Sousa, Pedro A. S. Jorge, Joao Crisostomo Weyl Albuquerque Costa, Jose Luis Campos Oliveira Santos and Orlando Frazao, Fiber Loop Mirror Sensors Interrogated and Multiplexed by OTDR, *Journal of Lightwave Technology*, **33**, 12, (2580), (2015).
Crossref