Distributed temperature sensing system using a commercial OTDR and a standard EDFA with controlled gain

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ABSTRACT

The distributed temperature sensor system based in the spontaneous Raman backscattering is demonstrated for the first time to our knowledge, using a commercial OTDR (Optical Time Domain Reflectometer) and a standard erbium doped fiber amplifier (EDFA) with controlled gain. We evaluated this approach in a 30 km of single mode fiber using an OTDR pulse width of 100 ns and an EDFA with 17 dBm of output power.

Keywords: DTS, OTDR, Raman, EDFA, Gain Controlled EDFA, AGC

1. INTRODUCTION

Distributed temperature sensor based in fiber optic Raman Effect (R-DTS) has been proposed for applications in many different areas, such as, power cable temperature monitoring, fire detection and pipeline leakage detection systems. The optical fiber passivity allows using DTS systems in explosive atmospheres, nuclear power plants and environments with high electromagnetic interference (EMI) [1 - 3].

R-DTS techniques are mainly based on optical time domain reflectometry (OTDR) and the distributed temperature is obtained by measuring the Stokes and anti-Stokes (AS) backscattering signals generated by Raman Effect [3].

The main limitation of R-DTS is the very low power and consequently poor signal-to-noise ratio (SNR) of Raman anti-Stokes backscattering signal. In order to overcome these drawbacks the OTDR requires high power transmitter, high sensitivity receiver and coded signal techniques to improve the R-DTS performance. In particular, for the last one many efforts have been devoted to improve the use of coding techniques providing significant Raman anti-Stokes SNR enhancement.

EDFAs modules have been widely used to improve the range in optical telecommunications and they present low size, low cost and low power consumption when compared with other amplification techniques, such as, lumped Raman amplifier. The use of EDFAs to improve the dynamical range of DTS system is very important but unfortunately ordinary EDFAs present transient effects that are prejudicial for R-DTS based in OTDR transmission [4].

Recently we demonstrated the use of an EDFA in a DTS with proper gain control scheme that allows the system operates with simplex coding avoiding the generation of transient effects in the EDFA [5].

A commercial OTDR is an instrument used to characterize optical fibers in telecommunication systems. In 30 years old it evolved cost in aspects and it has delivered its full potential as a test & measurement tool. Nowadays a handheld OTDR operating at 1310/1550 nm, 30 dB dynamical range, 1 m resolution is available for a few thousand dollars. According [6] even based on a well-established principle, OTDRs continuously evolves to meet customers' increasing needs and the constant evolution of technology. As a standalone product or as part of a fiber monitoring system, OTDR will not only maintain its leadership but even extend its coverage [6].

In this work, we propose a R-DTS which is implemented using a commercial OTDR and a standard erbium doped fiber amplifier (EDFA) with controlled gain. The main idea is to use the OTDR transmitter and receiver features (short pulse width and high gain/bandwidth, respectively) with an EDFA with no slow transient effects which is used to send a high intensity pulse to the fiber sensing generating a improved anti-Stokes backscattering signal to the OTDR receiver. We evaluated this approach using three models of OTDR in a 30 km of single mode fiber using a pulse width of 100 ns and an EDFA with 17 dBm of output power.

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2. THE PROPOSED OTDR-EDFA-DTS SYSTEM

Figure 1 shows the experimental setup used to evaluate the R-DTS using commercial OTDRs and an optical gain-controlled EDFA [7]. We tested the system using three commercial OTDRs available in our laboratory. The OTDRs models used were A (PK model 7600/865E), B (NetTest model CMA 4000i) and C (Exfo model AXS-110). The optical characteristics at 1550 nm of these OTDRs are shown in the Table 1. The OTDR light pulses were injected in a gain controlled EDFA. A return optical circuit composed by optical circulators (Cir1 and Cir2) was used in order to send the Raman anti-Stokes backscattered signal generated in the output fibers to the OTDR. This circuit we call OTDR-DTS converter that was based in a previous development [7]. The backscattered signals were filtered by a band-pass filter (1445 – 1475 nm), that was used to avoid the backscattering interferences of the amplified stimulated emission (ASE), Rayleigh and Raman Stokes in the Raman anti-Stokes backscattering detected signal. The traces acquired were stored in each OTDR. Five spools (F1, F2, F3, F4 and F5) of single mode fiber composed the optical sensing fiber link. Their characteristics are: F1 and F2 (G.657A1 type, lengths 24.975 km and 0.01 km respectively, attenuation in 1550 nm = 0. 19 dB/km), F3, F4 and F5 (G.652 type, 5.83 km, 0.01 km and 0.175 km, respectively, attenuation in 1550 nm = 0.21 dB/km). To evaluate the experiments each 10-m fiber spool (F2 and F4) was warm up in different temperature values. The other spools were left at room temperature.

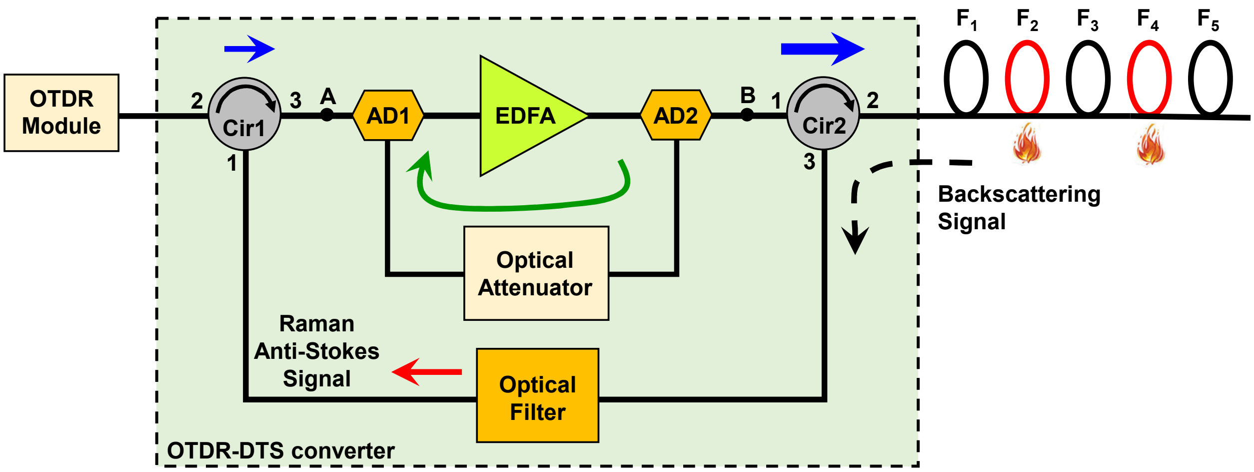

Figure 1. Experimental setup used to evaluate the R-DTS using commercial OTDRs and an optical gain-controlled EDFA.

Table 1. Resume of optical characteristic of the three commercial OTDRs used in the experimental setup.

OTDR model	Dynamic range	Linearity	Loss resolution	Distance resolution
A	50 dB	0.05 dB/dB	0.001 dB	0.8 m
B	36 dB	0.04 dB/dB	0.001 dB	0.1 m
C	35 dB	0.03 dB/dB	0.01 dB	0.08 m

The influence of transient effects of EDFAs in telecommunication applications and their mitigation have been extensively studied [8 -11]. The EDFA transients arise due to the operation in deep saturation and due to the long upper state lifetime of Erbium ions (~ 10 ms). This long time implies that there are too many inverted carriers to be shared to the input bit stream of EDFA [8]. Due to the intrinsic requirements of the repetition frequency of OTDR, the pulsed signal occupies a short time in the OTDR temporal frame and there are idle periods in the transmission period. The repetition frequency depends on the fiber length to be sensing. The idle periods cause abrupt power changes (transients) in the EDFA output signal. Several approaches have been proposed to mitigate EDFA transients. Some common methods use optical gain clamping by optical feedback [8-10] or/and electrical automatic gain control [11].

The Figure 1 shows also the all-optical EDFA with automatic gain control that was mounted using two identical add/drops centered at 1546,80 nm. The technique is based on a feedback loop where part of the amplified spontaneous emission (ASE), is dropped by the add/drop 2 (AD2), passes through an optical attenuator and is coupled back into its input by add/drop 1 (AD1). The dropped channel is amplified by the EDFA and once again dropped by the AD2 for a new feedback cycle. After several cycles, this control channel acquires enough power becoming a laser in the loop and competes with the Fabry-Perot (FP) laser for the EDFA gain. As a result, assuming an appropriate loop attenuation level, the control channel power responds in accordance to the power fluctuations of OTDR, maintaining the EDFA gain practically constant and removing the EDFA oscillations.

In order to demonstrate the improving of use of an EDFA in the OTDR output to detect Raman anti-Stokes the Figure 2(a) shows a typical Raman anti-Stokes trace of OTDR module models A, B and C without optical amplification (average time = 7 minutes, pulse width = 100 ns) and a trace of model A with optical amplification. In this case the points A (EDFA input) and B (EDFA output) in Figure 1 where joined by a fusion splice.

We can observe that the traces for models B and C are very noised and impractical to use. The model A presents a better performance without optical amplification probably due to its high dynamical range, but when the optical amplification is introduced (blue trace), its performance is improved in around 7 dB that is very important in Raman anti-Stokes signal analyzing. On the other hand, the Figure 2(b) shows the necessity of use of an EDFA with gain control in the OTDR output in order to measure the Raman anti-Stokes traces properly. The traces of OTDR model A are shown with some levels of gain control. The gain control is adjusted in the optical attenuator. We can observe that the traces are very distorted and impractical to use, unless to the trace where the attenuation is optimum (blue trace).

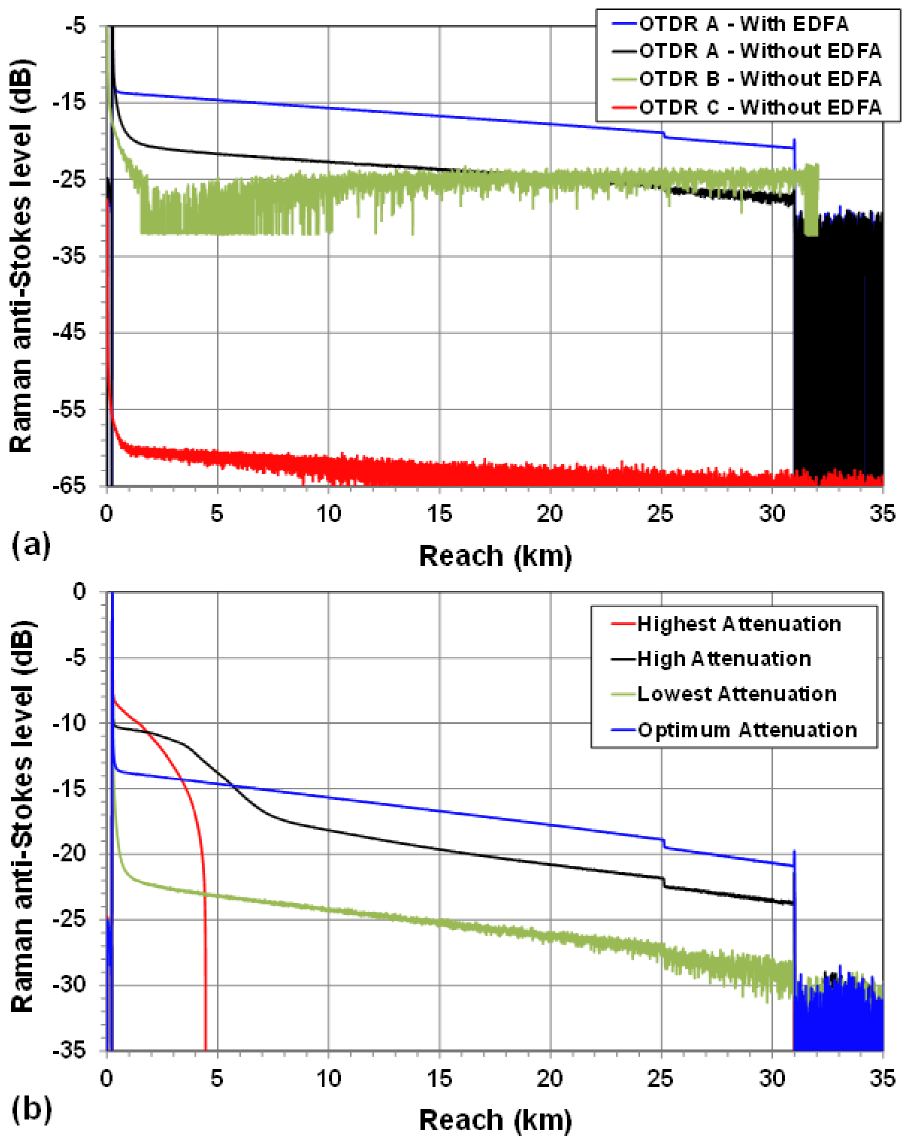

Figure 2. (a) Typical Raman anti-Stokes traces of three OTDR models without optical amplification and (b) typical Raman anti-Stokes traces of OTDR model A with some levels of gain control.

3. RESULTS OF TEMPERATURE MEASUREMENTS AND DISCUSSION

To perform temperature calibration and experiments the two spools of 10 m were put on two distinct hot plates. The hot plates were used to warm up the 10-m fiber spools in different temperature values. Thermistors were placed on the top of each hot plate to measure the temperature.

Using the same OTDR configuration previously described (approximately 7 minutes of average time and a pulse width equal to 100 ns) several measurement data were captured by the three models of the OTDRs with different values of temperatures adjusted in the hot plates. The temperature peaks detected for each OTDR are presented in Figure 3.

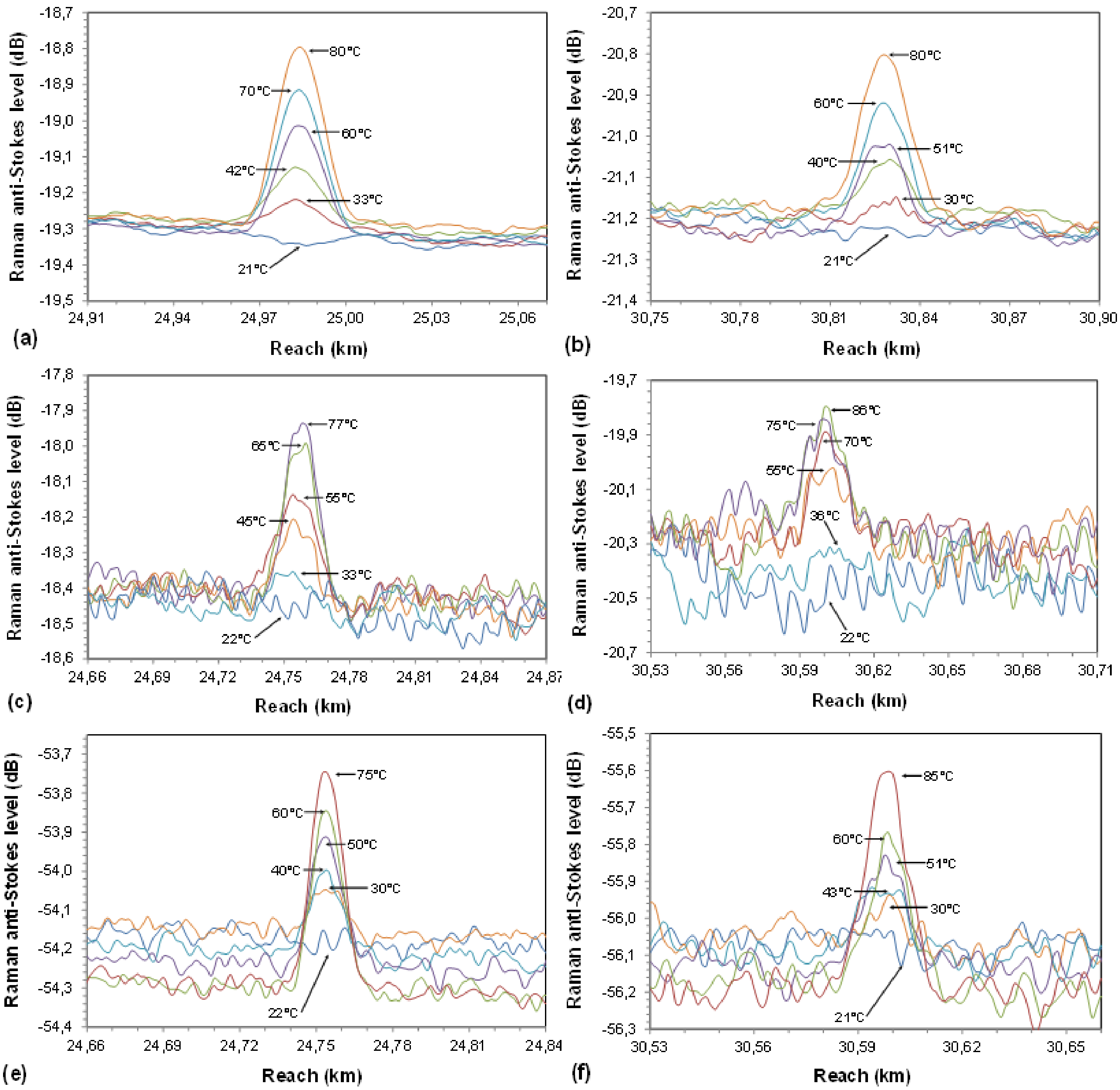

Figure 3. OTDR curves of each heating point: (a) first heating point for OTDR A, (b) second heating point for OTDR A, (c) first heating point of OTDR B, (d) second heating point for OTDR B, (e) first heating point for OTDR C and second heating point for OTDR C.

Using a reference trace at room temperature, a calibration trace at a controlled temperature and allied with post-processing analysis becomes possible to recover the temperature of others captured traces by the Raman distributed sensing system at different temperatures values of the hot plates. Table 2 presents the reference and the controlled temperature values of Raman anti-Stokes levels of each OTDR model used to perform the post-processing study.

Besides the reference and calibration temperatures, others values of temperatures were set on each hot plate and measured by thermistor. Anti-Stokes OTDR traces were captured for each new temperature value. The obtained trace data was post-processed to obtain the corresponding hot plate temperature value. A comparison between the values obtained by the R-DTS system of temperature and the thermistors measured data is shown at Figure 4.

Table 2. Reference, calibration temperatures and Raman anti-Stokes levels for each heating position.

OTDR model	Heat position	Reference temperature	Reference Raman anti-Stokes level	Controlled temperature	Calibration Raman anti-Stokes level
A	24.98 km	21 ºC	-19.34 dBm	80 ºC	-18.79 dBm
	30.83 km	21 ºC	-21.17 dBm	80 ºC	-20.75 dBm
B	24.76 km	22 ºC	-18.47 dBm	77 ºC	-17.94 dBm
	30.60 km	22 ºC	-20.51 dBm	86 ºC	-19.84 dBm
C	24.75 km	22 ºC	-54.10 dBm	75 ºC	-53.70 dBm
	30.60 km	21 ºC	-56.04 dBm	85 ºC	-55.60 dBm

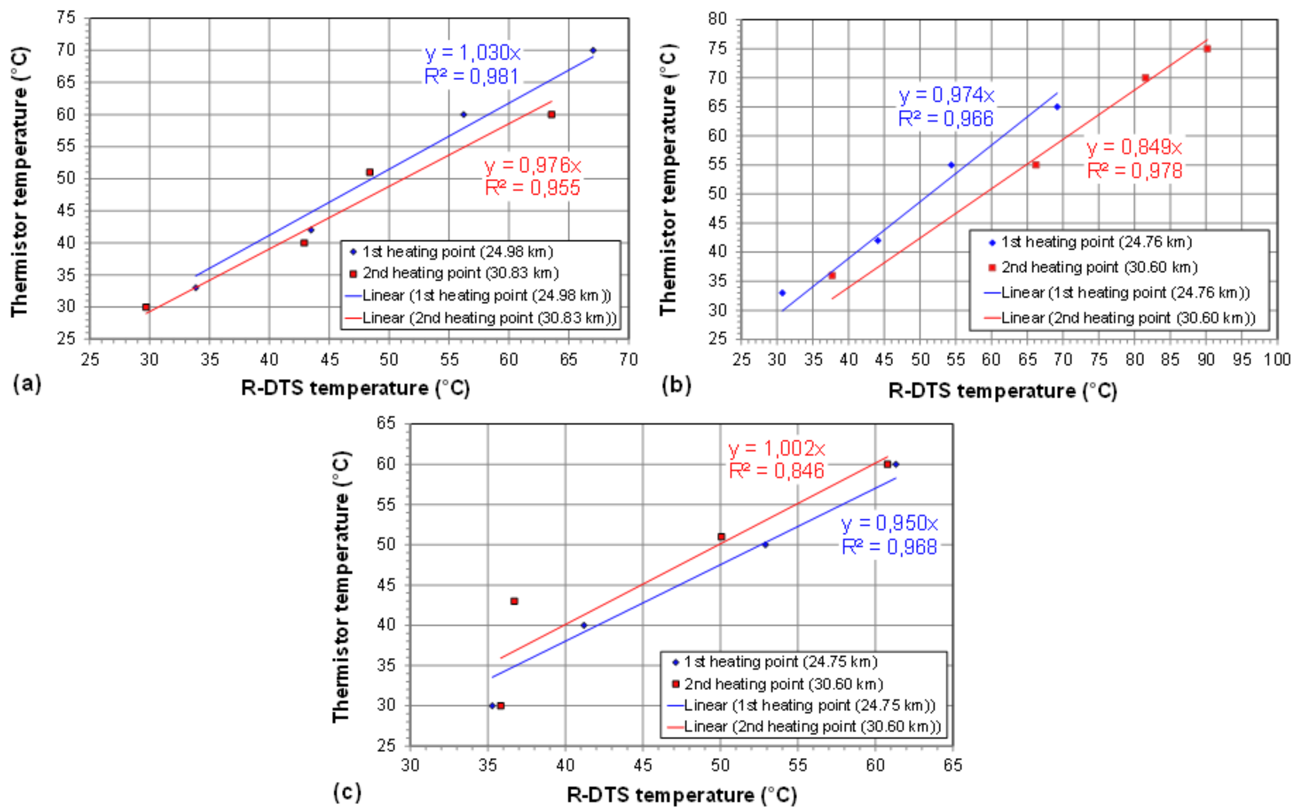

Figure 4.Comparison between R-DTS processed temperatures and thermistor measurements: (a) OTDR A; (b) OTDR B; (c) OTDR C.

From Figure 4 it is possible to observe the differences between the linearity of the data measured by the R-DTS system and the thermistor. OTDR types A and C are newer models than the OTDR B and have presented more accurate results, in other words, the error between the processed R-DTS data and the thermistor temperature for both models A and C are less than 5 % against an error of approximately 16 % of OTDR B.

4. CONCLUSION

In this paper we have demonstrate for the first time of our knowledge a distributed temperature sensor based in the spontaneous Raman backscattering using a commercial OTDR module and a gain controlled EDFA. We evaluated this approach using three models of OTDR modules in a 30 km of single mode fiber using a pulse width of 100 ns. Using this technique, we achieved 10 m spatial resolution, 16.5dB dynamic range and less than 5 % of temperature linearity comparing the R-DTS with a reference thermistor.

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REFERENCES

[1] Ukil, H. Braendle and P. Krippner, "Distributed Temperature Sensing: Review of Technology and Applications," In Sensors Journal, IEEE 12(5), 885-892 (2012).
[2] X. Bao, L. Chen, "Recent Progress in Distributed Fiber Optic Sensors", Sensors 12(7), 8601-8639 (2012).
[3] Gabriele Bolognini and Arthur Hartog, "Raman-based fibre sensors: Trends and applications," Optical Fiber Technology, 19, 678-688 (2013).
[4] G. Bolognini, J. Park, M. A. Soto, N. Park, F. Di Pasquale, "Analysis of distributed temperature sensing based on Raman scattering using OTDR coding and discrete Raman amplification", Measurement Science and Technology, 18 (10), (2007).
[5] F. R. Bassan, R. S. Penze, A. A. Leonardi, J. P. V. Fracarolli, C. Floridia, J. B. Rosolem, F. Fruett, "Raman-based distributed temperature sensor using simplex code and gain controlled EDFA", Proc. SPIE 9634, (2015).
[6] A. Champavere, "New OTDR Measurement and Monitoring Techniques," in Optical Fiber Communication Conference, OSA Technical Digest (online) (Optical Society of America, 2014), paper W3D.1.
[7] Rosolem, J. B., Dini, D. C., Urso, J. E., "Active wavelength converter for use with an optical time-domain reflectometer (OTDR) and method for increasing OTDR supervision distance range", Patent US7369219 (B2) , USA, Priority date: 2005-04-21.
[8] Y. Awaji, H. Furukawa, N. Wada, P. Chan; R. Man, "Mitigation of Transient Response of Erbium-Doped Fiber Amplifier for Burst Traffic of High Speed Optical Packets", in Conference on Lasers and Electro-Optics, CLEO 2007, pp.1-2 (2007).
[9] Y. Awaji, H. Furukawa, N. Wada, E. Kong, P. Chan, R. Man, "Guidelines for amplification of optical packets in WDM environment regarding impact of transient response of erbium-doped fiber amplifier", In Computer Networks, 52(10), 2087-2093 (2008).
[10] M. Shiraiwa, Y. Awaji, H. Furukawa, S. Shinada, B. J. Puttnam, N. Wada, "Performance evaluation of a burst-mode EDFA in an optical packet and circuit integrated network," In Opt. Express, 21, pp. 32589-32598, (2013).
[11] L. Rapp, "Feedforward control techniques for Erbium–doped fiber amplifiers - challenges and solutions", In Journal of Optics, 1-22 (2015).