

# 94.8 Km-Range Direct Detection Fiber Optic Distributed Acoustic Sensor

Faruk Uyar<sup>1</sup>, Talha Onat<sup>1</sup>, Canberk Unal<sup>1</sup>, Tolga Kartaloglu<sup>1</sup>, Ibrahim Ozdur<sup>1,2</sup> and Ekmel Ozbay<sup>1,3,4</sup>

<sup>1</sup>Nanotechnology Research Center, Bilkent University, Ankara, Turkey

<sup>2</sup>Department of Electrical and Electronics Engineering, Abdullah Gul University, Kayseri, Turkey

<sup>3</sup>Department of Electrical and Electronics Engineering, Bilkent University, Ankara, Turkey

<sup>4</sup>Department of Physics, Bilkent University, Ankara, Turkey

faruk.uyar@bilkent.edu.tr

**Abstract:** This work demonstrates an ultra-long range direct detection fiber optic distributed acoustic sensor which can detect vibrations at a distance of 94.8 km with 10 m resolution along the sensing fiber. © 2019 The Author(s)

**OCIS codes:** (060.2370) Fiber optics sensors; (280.4788) Optical sensing and sensors; (120.4825) Optical time domain reflectometry.

## 1. Introduction

Phase-sensitive optical time domain reflectometry ( $\phi$ -OTDR) based distributed acoustic sensors (DAS) have been utilized as a powerful tool for real-time monitoring of oil and gas pipelines, intrusion detection, critical facility security, various vibration measurements and so on [1]. For linear assets monitoring, such as pipeline and national borderline security, ultra-long range distributed sensors are desired. To achieve this, various DAS technologies have been reported including coherent detection scheme, Raman optical amplification assistance and distributed hybrid amplification [2-4]. However, all these approaches generally add a significant increase in the cost and complexity of the system.

In this paper, we present an ultra-long range direct detection  $\phi$ -OTDR sensor system with simple modifications to the structure. Vibration detection at the distance of 94.8 km with a spatial resolution of 10 m is achieved by using cascaded acousto-optic modulators and optimizing the system components. To the best our knowledge, it is the longest-range direct detection  $\phi$ -OTDR system reported up to date.

## 2. Experimental Set-up

The experimental set-up of the direct detection  $\phi$ -OTDR based DAS system is shown in Figure 1. A high-coherence (< 1 kHz linewidth) laser is used as the light source and a booster erbium doped fiber amplifier (EDFA) is used for amplification. Dual cascaded acousto-optic modulators (AOM) are adopted for generating ultra-high extinction ratio (ER) interrogation pulses. The first AOM generates slightly longer optical pulses than the second one in order to make synchronization easier. The optical pulse width is dictated by the second AOM. The interrogation pulses are launched into the fiber via a high isolation circulator. The Rayleigh backscattered light from the sensing fiber is guided into the second EDFA via the same circulator. The width of the optical pulses was set to 100 ns with 1 ms interrogation period. The second EDFA is a low noise and high gain pre-amplifier which operates at maximum gain. Following the EDFA, a relatively broader pass band and a very narrow pass band optical bandpass filters (OBPF) are employed in a cascaded arrangement to effectively filter out the amplified spontaneous emission (ASE) noise of the pre-amplifier EDFA. The filtered optical signal is converted to electrical signal by a photodetector (PD), amplified by a transimpedance amplifier (TIA) and acquired by a data acquisition (DAQ). The signal is then processed offline with a PC.

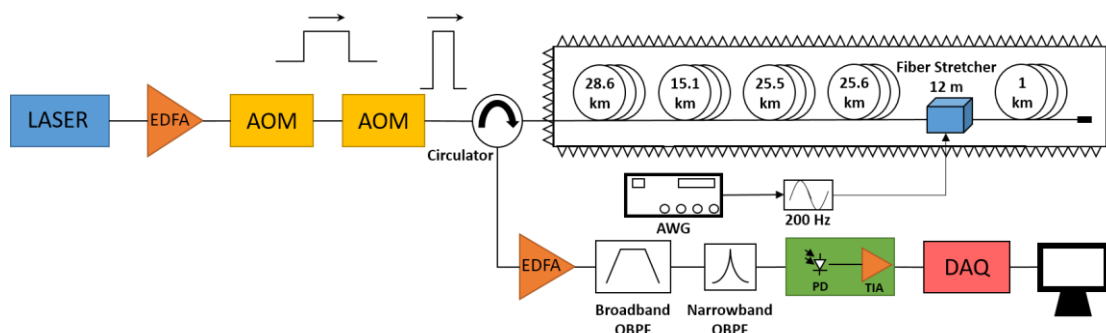


Fig. 1. Experimental set-up (Acronyms are explained in the text).

One of the limiting factors of signal to noise ratio in  $\phi$ -OTDR based DAS systems is the undesirable signal fluctuations caused by the leaked light due to the finite ER of the acousto-optic modulator (AOM). The AOMs employed in the experiment have ER values of 54 dB and 62 dB. These values may seem more than enough for many applications, however, because of the very large duty cycle of the interrogation pulses, these values are not high enough to suppress the extinct light. The CW leaked light gets scattered from the fiber and results in a time variable background DC noise level at the photodetector.

The test fiber is placed in an isolated box for acoustic isolation. The test fiber is a 96 km long single-mode fiber (SMF-28), comprising fiber coils of 28.6 km, 15.1 km, 25.5 km, 25.6 km and 1 km connected together to obtain a  $\sim$ 96 km test fiber. A fiber stretcher is placed at the location of 94.8 km which generates vibration and induces phase shift at the specific section of the fiber. The stretcher is driven by an arbitrary waveform generator (AWG) which is set to generate 200 Hz sinusoidal wave with an amplitude of 4 V<sub>pp</sub>.

### 3. Results

Coherent beating of the Rayleigh backscattered suppressed light results in a time varying noise. The effect of the AOM extinction ratio on the noise is analyzed by comparing the noise levels when the AOMs are completely turned off. Figure 2a shows the fluctuation noise for three different extinction ratio cases, 54 dB (AOM 1), 62 dB (AOM 2) and  $>$  110 dB (AOM 1 and AOM 2 cascaded). It can be seen that the 54 dB ER modulator gives the largest noise as the leaked light power is the biggest, and the dual AOM case suppresses the noise below the noise floor.

The vibration detection performance of the system is measured at 94.8 km (corresponds to channel 9479) using the test fiber. The power spectral density of channel 9479 is shown in Figure 2b. The 200 Hz tone can be seen with an SNR value of 12.2 dB.

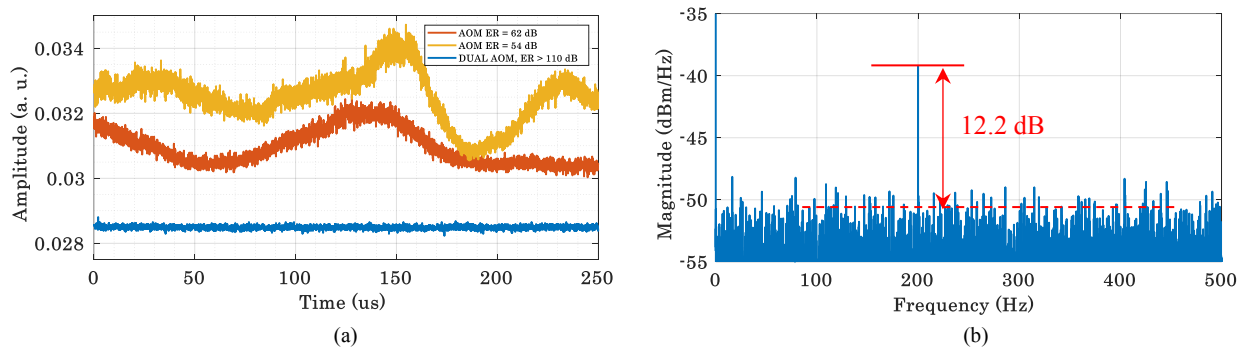


Fig. 2. a) Time domain channel data, b) Power spectral density of channel data.

The key design features to achieve these results are the usage of dual AOM in order to reduce the coherent noise caused by the finite ER and suppression of the ASE noise by the ultra-narrow pass bands optical filters. Also, the ultra-high sensitivity linear-gain photodetector and TIA units is another key component that contributes to range improvement.

### 4. Conclusion

In this work, a direct detection  $\phi$ -OTDR based DAS system is presented which has 12.2 dB signal to noise ratio at the distance of 94.8 km with dual acousto-optic modulator architecture. To the best our knowledge, it is the longest-range reported direct detection  $\phi$ -OTDR system. The use of dual AOM increases the extinction ratio of interrogation pulses to  $>$  110 dB. Due to the long range, the system has the potential to decrease the number of optical interrogators needed for long haul linear assets monitoring.

### References

1. X. Liu, B. Jin, Q. Bai, Y. Wang, D. Wang, and Y. Wang, "Distributed fiber-optic sensors for vibration detection," *Sensors* **16**, 1164 (2016).
2. L. Lv, F. Pang, H. Liu, X. Mei, J. Chen, Y. Li, T. Wang, Y. Song, "50-km-long distributed vibration fiber sensor based on phase-sensitive otdr using coherent detection," in *Lasers and Electro-Optics Pacific Rim (CLEO-PR), 2017 Conference on*, (IEEE, 2017), pp. 1–2.
3. F. Peng et al., H. Wu, X.-H. Jia, Y.-J. Rao, Z.-N. Wang, and Z.-P. Peng, "Ultra-long high-sensitivity  $\phi$ -otdr for high spatial resolution intrusion detection of pipelines," *Optics express* **22**, 13804–13810 (2014).
4. Z. Wang, J. Zeng, J. Li, M. Fan, H. Wu, F. Peng, L. Zhang, Y. Zhou, and Y. Rao, "Ultra-long phase-sensitive otdr with hybrid distributed amplification," *Optics letters* **39**, 5866–5869 (2014).