The Pulse Shape Effect on Signal-to-Noise Ratio for φ-OTDR Systems

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Abstract: We experimentally investigate the effect of the probe pulse shape on the performance of φ-OTDR based distributed vibration sensors by comparing the SNR values for rectangular, Gaussian and triangular pulses. © 2021 The Author(s)

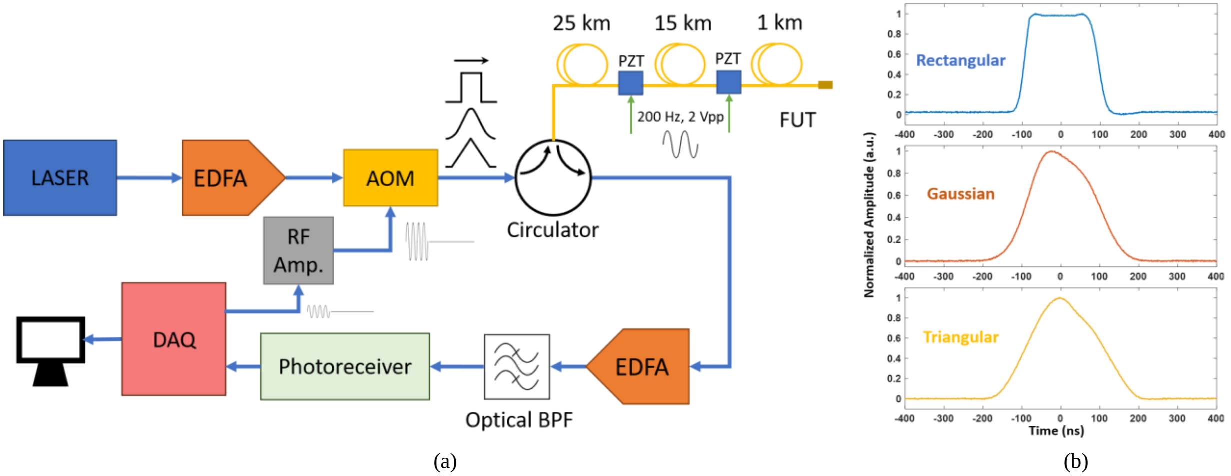
1. Introduction

In phase-sensitive optical time domain reflectometer (φ-OTDR) based distributed vibration sensor (DVS) systems, the probe pulse is one of the most important parameters determining both the spatial resolution and detection performance. In order to get higher back reflection light signal and thereby better signal-to-noise-ratio (SNR), the energy of the probe pulse launched into the fiber should be increased. However, the modulation instability (MI) phenomena resulting from self-phase modulation (SPM) and four-wave mixing (FWM) limit the peak power that can be launched into the fiber and thus the operational range of the system [1, 2]. Another performance limiting factor is visibility fading due to Fermi-Pasta-Ulam (FPU) recurrence that comes into play depending on the probe pulse shape [3].

The effect of the probe pulse shape on the trace visibility has been investigated previously [3], however, its effect on the detection performance has not been quantified. In this work, we experimentally investigate the effect of three probe pulse shapes, i.e. rectangular, Gaussian and triangular, on the detection performance of the DVS system by comparing the mean SNR results of external vibrations.

2. Experimental set-up and the generation of different-shaped probe pulses

The experimental set-up is shown in Fig. 1a. A continuous wave (CW) light at 1550.12 nm is generated by a narrow linewidth (~100 Hz) laser and amplified by a high-power erbium doped fiber amplifier (EDFA). The amplified CW light signal is, then, modulated by a high extinction ratio (~72 dB) and low insertion loss (~2 dB) acousto-optic modulator (AOM) to generate the different-shaped interrogation pulses. Light pulses are sent to the fiber under test (FUT) via a circulator and the backscattered signal from the FUT is amplified by a high-gain EDFA. The amplified backscattered signal including the amplified spontaneous emission (ASE) noise is filtered by cascaded optical band pass filters (BPF) preceded by photoreceiver. The optical signal is converted to electrical signal and amplified at photoreceiver, then acquired by a data acquisition (DAQ) card with a sampling rate of 256 MS/s. The sampling rate is reduced by an integer factor 25 at the DAQ card, resulting in 10 MS/s, and the downsampled data is sent to PC for offline processing.



(a) (b)

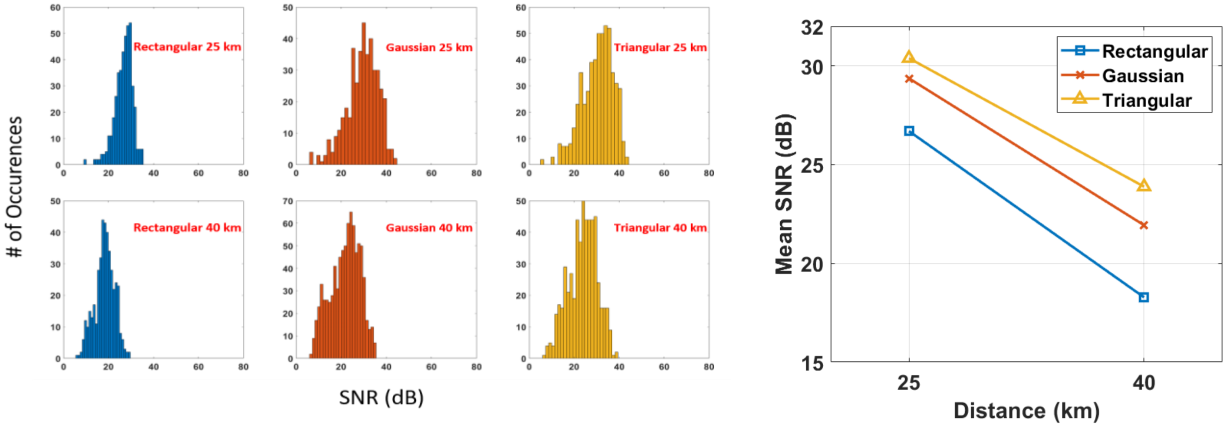
Fig. 1. a) Experimental set-up (acronyms are explained in the text), b) rectangular, Gaussian, triangular optical pulses obtained at the AOM output

In this study, three different pulse shapes, namely rectangular, Gaussian and triangular, are investigated in terms of their effects on DVS system performance. All three electronic pulses are synthesized in the DAQ card with a full width half maximum (FWHM) of 100 ns and a carrier frequency of 110 MHz. Peak amplitudes of pulses are calibrated to have the same energy. The synthesized electronic pulses from the DAQ card are amplified by an RF amplifier before being an input to AOM. The obtained optical pulses at the output of AOM are shown in Fig. 1b. The realized rectangular pulse departs from the shape of ideal rectangular due to the rise/fall time of AOM which is ~18 ns.

3. Experimental results

To experimentally investigate the effect of probe pulse shape on the SNR of the DVS system, a test set-up (FUT, shown in Fig. 1a) consisting of 25-km, 15-km and 1-km single mode fibers, with 2 piezoelectric transducers (PZT) in between, is used. The repetition rate of the DVS system is set to 2 kHz, in order to cover 41 km-length FUT, and interrogated with each pulse, i.e. rectangular, Gaussian and triangular, one by one. The PZTs over the FUT are driven by a continuous sinusoidal signal of 2 Vpp, 200 Hz generated by an arbitrary waveform generator.

Each interrogation data is collected over a duration of ~12 hours in order to include all the randomness effects such as temperature variation, polarization change, laser frequency drift, component noises and so on, into the performance characterization. In this manner, we quantify the performance of the DVS system in a statistical manner based on the mean SNR parameter, which we previously reported in [4, 5]. The mean SNRs are calculated at two PZT positions, i.e. at 25 km and 40 km, over the histograms of time varying SNR values (Fig. 2a).



(a) (b)

Fig. 2. a) SNR histograms, and b) Mean SNRs at 25 km and 40 km for rectangular, Gaussian, triangular pulses.

The resulting SNR values for rectangular, Gaussian and triangular pulses are compared in Fig. 2b. The results show that the system probed by triangular pulse provides the highest mean SNR with an approximate difference of 3.8 dB with rectangular pulse at 25 km. The mean SNR difference increases as the distance goes up, resulting in ~1.9 dB with Gaussian pulse and ~5.6 dB with rectangular pulse at 40 km. Complying with the trace visibility results reported in [3], the system probed by rectangular pulse is impaired by non-linear phenomena more than triangular and Gaussian pulses, yielding degraded detection performance and range.

4. Conclusion

The effect of the probe pulse shape, particularly rectangular, Gaussian and triangular shapes, on the performance of φ-OTDR based distributed vibration sensors has been experimentally investigated and the detection performance has been quantified by providing the mean SNR results at 25 km and 40 km. The results suggest that SNR and the detection range can be increased by optimizing the probe pulse shape.

5. References

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