High Spatial Resolution Optical Time Domain Reflectometer

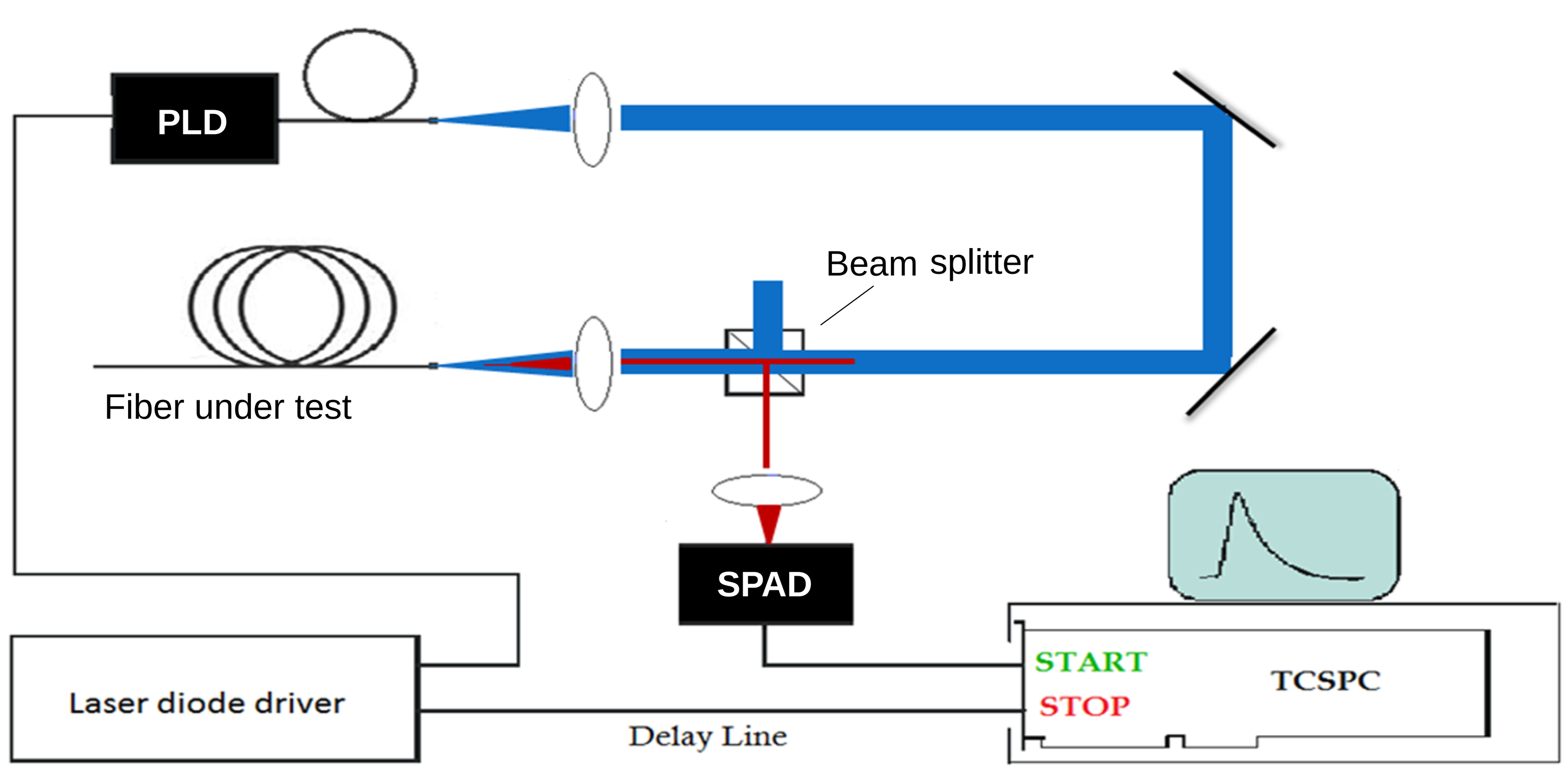
Ali El Sayed[1], Manuel Ryser[1], Valerio Romano[1,2]

[1]Institue of Applied Physics, University of Bern,Sidlerstrase 5, CH-3012 Bern, Swtizerland
[2]Bern University of Applied Science, ALPS, Pestalozzistrasse 20, CH-3400 Burgdorf, Switzerland
Email: ali.elsayed@iap.unibe.ch

Abstract

To measure fiber losses, the methods of choice are the cut-back method and the optical time domain reflectometer OTDR. Conventional OTDRs are optimized for telecommunication fibers of tens of kilometers length, with time resolution in the ns range. Here we present an adapted version that allows to measure the losses of special fibers, e.g. of short active fibers of few meters length. Our high resolution optical time domain reflectormeter HROTDR allows to measure the overall attenuation in short optical fiber pieces, to locate big scattering centers, defects and faults, and to estimate the fiber length. Various types of high resolution photon-counting OTDR's at telecommunication wavelengths have already been developed, using InGaAs avalanche photodiode. However their time resolution is limited because of the temporal jitter (400 ps) of this kind of detector. Our purpose in this experiment is to characterize short optical fibers with very high spatial resolution. Therefore, we have built a HROTDR using a silicon based avalanche photodiode with temporal jitter down to 40 ps, based on time-correlated single-photon-counting technique (TCSPC) which measures the arrival time of a photon with very high precision.

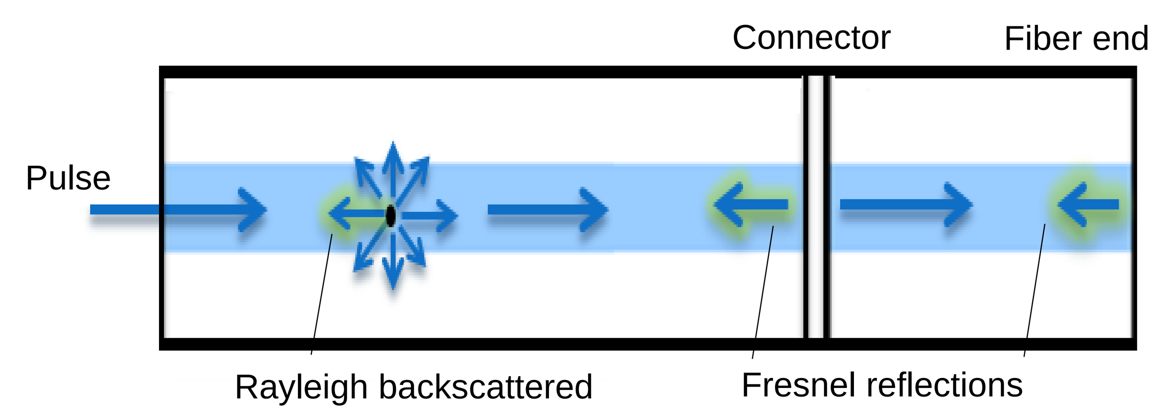
Experimental Setup



60 Picosecond optical pulses (**blue path**) from a pulsed laser diode (PLD) operating at 468 nm are launched into the fiber under test through 50:50 beam splitter. As the laser pulse propagates along the fiber, some photons will be Rayleigh-scattered and others Fresnel reflected. Part of them are recaptured by the fiber and guided back (**red path**) toward the launching end, where they are focused into single photon avalanche photodiode (SPAD) via the 50:50 beam splitter. A time correlated single photon counting module (TCSPC) is connected to the SPAD and to the laser driver, measures the time between each detected photon and reference pulse that generated it.

OTDR & Rayleigh Scattering

- The OTDR measures temporally resolved the Rayleigh backscattered light which is caused by small-scale (small compared to the wavelength) inhomogeneities of the refractive index that are produced in the fiber fabrication process, to measure the characteristics of the fiber.



- A series of optical pulses is injected into the fiber under test. From the same end, backscattered or reflected light from points along the fiber is extracted. The strength of the returning pulses is measured and integrated as a function of time.
- Rayleigh scattering results in an attenuation inversely proportional to the fourth power of the wavelength.

Results

Instrument Response Function IRF

Repetition Frequency = 5 MHz **FWHM = 95 ps**

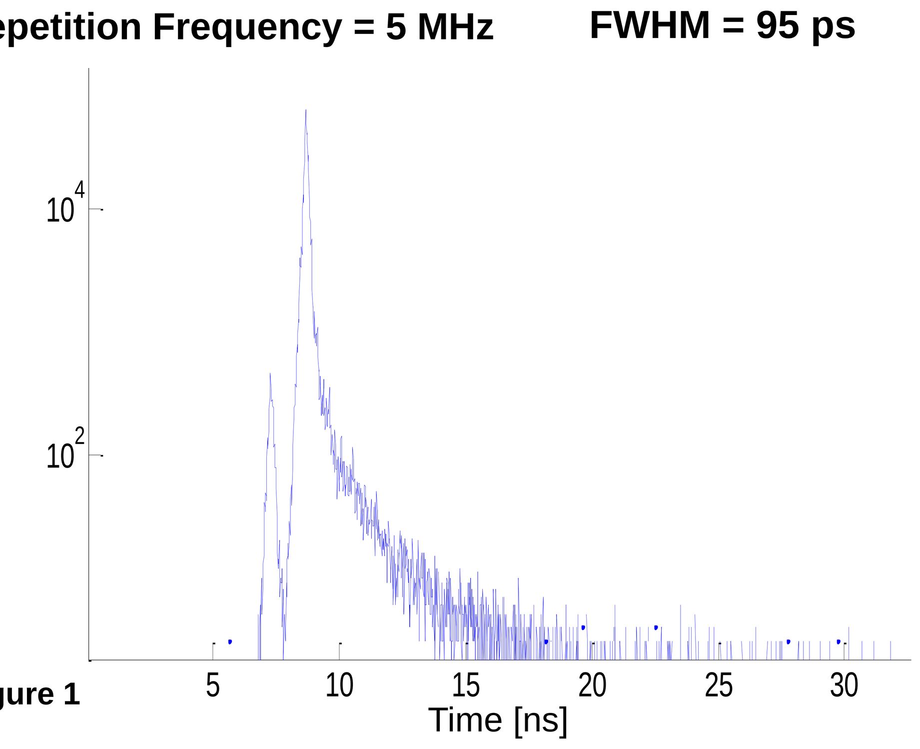


Figure 1

The characteristic of a complete TCSPC system that summarizes its overall timing precision is its Instrument Response Function (IRF).

In Figure 1, We measured the IRF of our system at a wavelength of 468 nm, obtaining time resolution of 95 ps, equivalents to 1 cm spatial resolution.

Attenuation of Commercial Passive Fiber

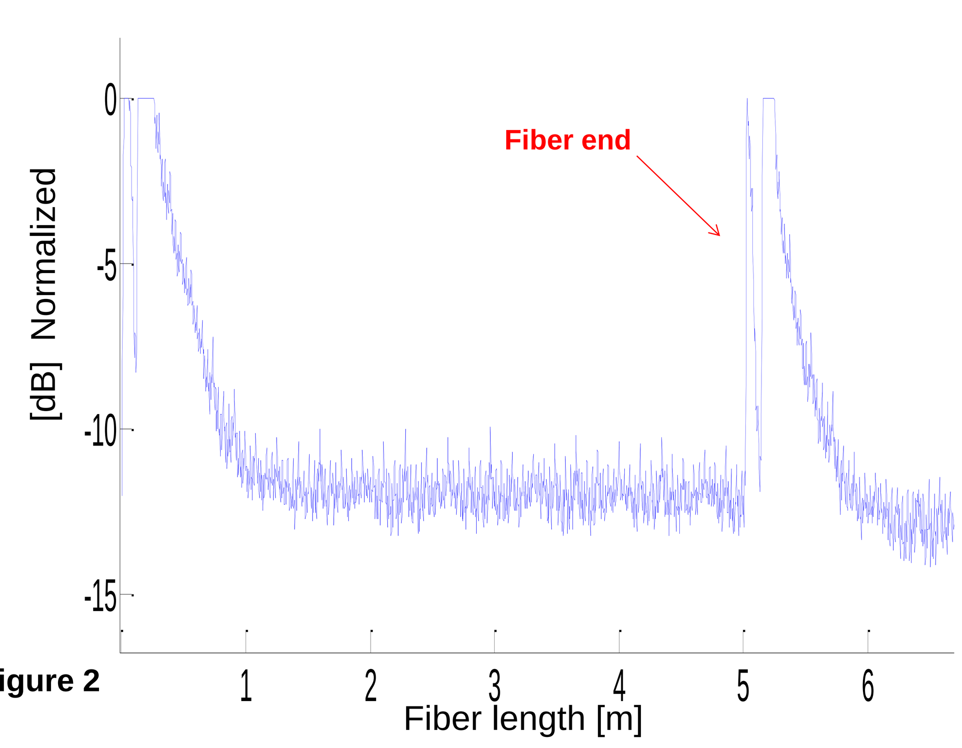


Figure 2

Figure 2, represents the measurement of commercial passive fiber of 5 meters length. All the measurements were taken at a wavelength of 468 nm.

We obtained attenuation coefficient of 42 dB/km in agreement with the fiber datasheet value. The attenuation coefficient is obtained by calculating the slope of the linear fitted trace.

Attenuation of Homemade Doped Fiber

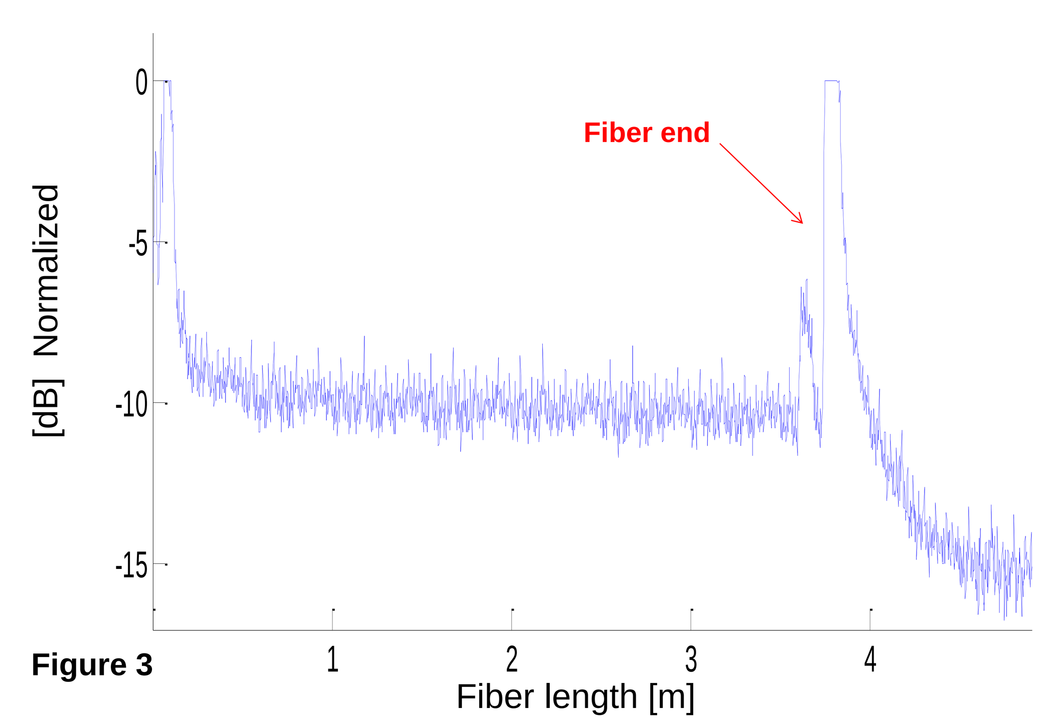


Figure 3

Figure 3, represents the measurement of a 3.7 meters length Ytterbium-doped homemade fiber with an attenuation coefficient of 180 dB/km at 468 nm

The fiber was drawn by the Optical Fibers and Fiber Lasers group at the Institute of Applied Physics, University of Bern.

Conclusion

All OTDRs share the same technical bottleneck to counter the tradeoff between: Signal-to-noise ratio (dynamic range) and the spatial resolution limit / dictated by the peak power and pulse width of the probe pulse. Now we are able to overcome this problem by using the advantage of time-correlated single-photon-counting technique, that the dynamic range can be increased without decreasing the pulse width, just by longer measurement times, as the signal to noise ratio SNR depends only on the total acquisition time. TCSPC has very high time-resolution as well, which allows us with the given setup, to characterize a fiber of several meters length with a spatial resolution of 1 cm.