Conference on Education and Training in Optics & Photonics
Marseille, 27th October 2005

An Optical Time Domain Reflectometry Set-Up for Laboratory Work at École Supérieure d'Optique

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Optical Time Domain Reflectometry

= very common technique to measure fibers attenuation
& localize defects in telecommunications lines

⇒ many industrial equipments with outstanding performances

BUT not adapted to lab works for students

Our set-up

Objectives :

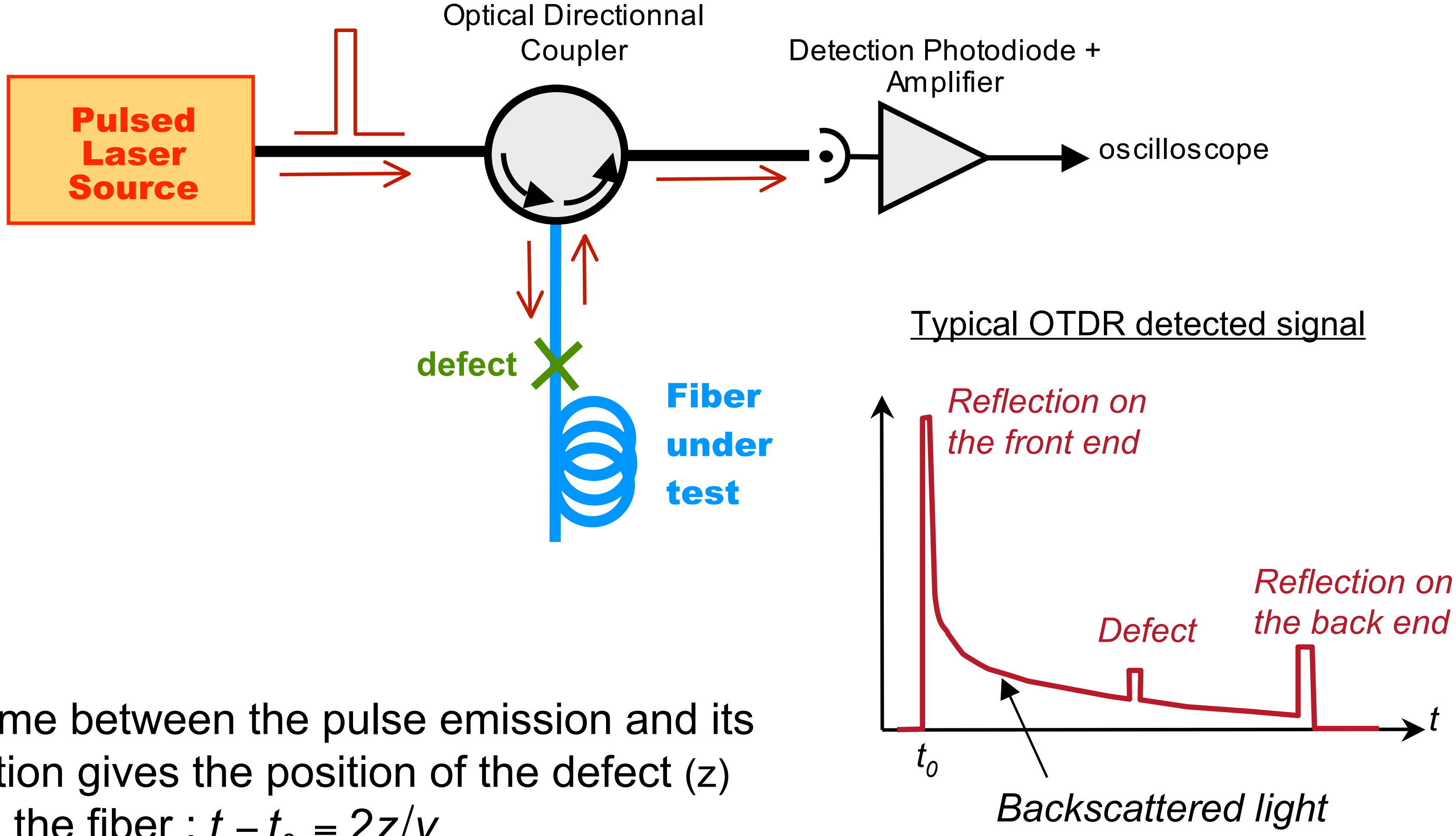
- demonstration of a performant technology with state-of-the art components
- access to all control parameters and optical signals
- simplicity of use and attractiveness for our students

Realization by 3 students during a summer traineeship (A. CADIC) and a scientific lab project (A. HULEUX & F. REYNALDO) from 2002 to 2003

Now a labwork for 2nd-year students

Optical Time Domain Reflectometry

Principle



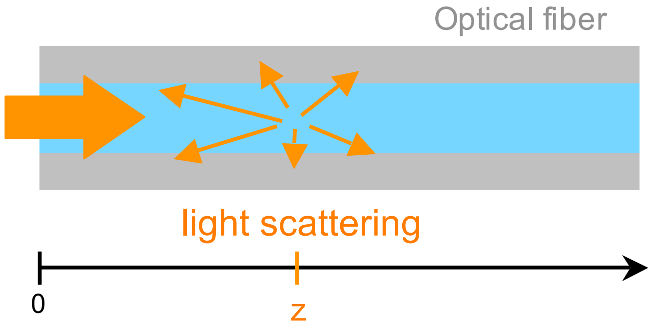
The time between the pulse emission and its detection gives the position of the defect (z) inside the fiber : $t - t_0 = 2z/v_g$

v_g = group velocity in the fiber

OTDR signals

Backscattered signal

Main contribution to the attenuation in fibers at λ = 1.55 µm : **Rayleigh scattering**



At $t = 2z/v_g$, we measure :

Pulse duration

$$P_{bs}(z) = S \frac{\alpha_d}{2} v_g \tau \cdot P_{in}(z=0) \cdot e^{-2\alpha z}$$

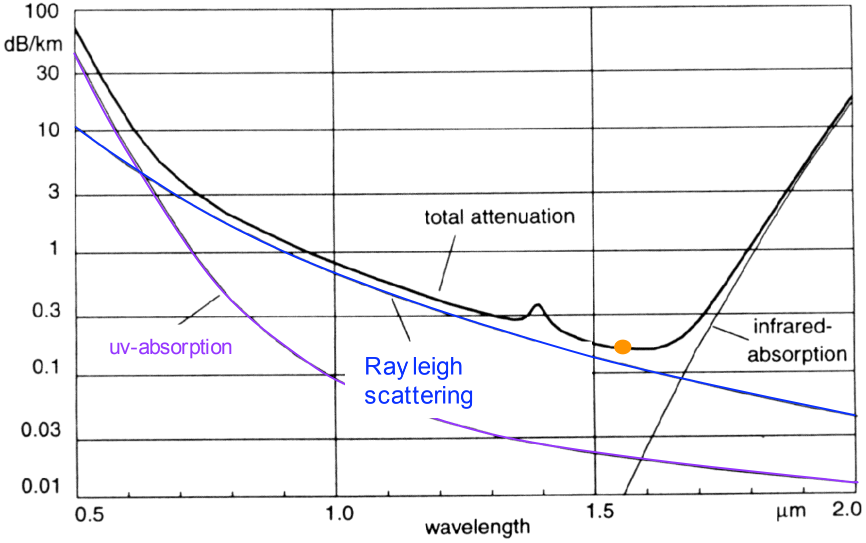
Capture coefficient

$$S \propto \left(\frac{NA}{n}\right)^2$$

Diffusion coefficient

$$\alpha_d \propto 1/\lambda^4$$

Attenuation of the signal (2 paths)



⇒ Single-mode fibers at λ = 1.55 µm :

$P_{in}(z=0)$ = 10 mW, τ = 100 ns

$$S \frac{\alpha_d}{2} v_g \tau \cong 5 \times 10^{-7}$$

$S \cong 1.5 \times 10^{-3}$
$v_g \cong 2 \times 10^8$ m.s^{-1}
$\alpha_d \cong$ 0.14 dB/km

⇒ $P_{bs}(z=0) \cong$ 5 nW

Distance resolution = $v_g\tau/2 \cong$ 10 m

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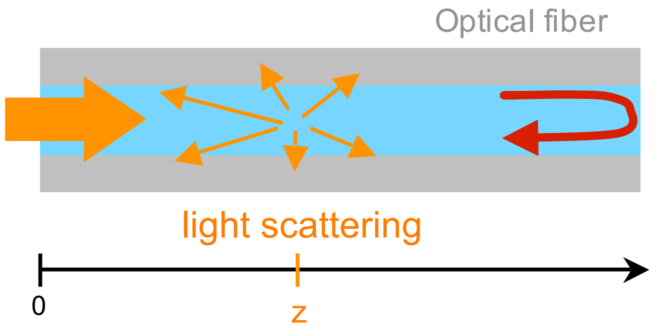


Reflected signals

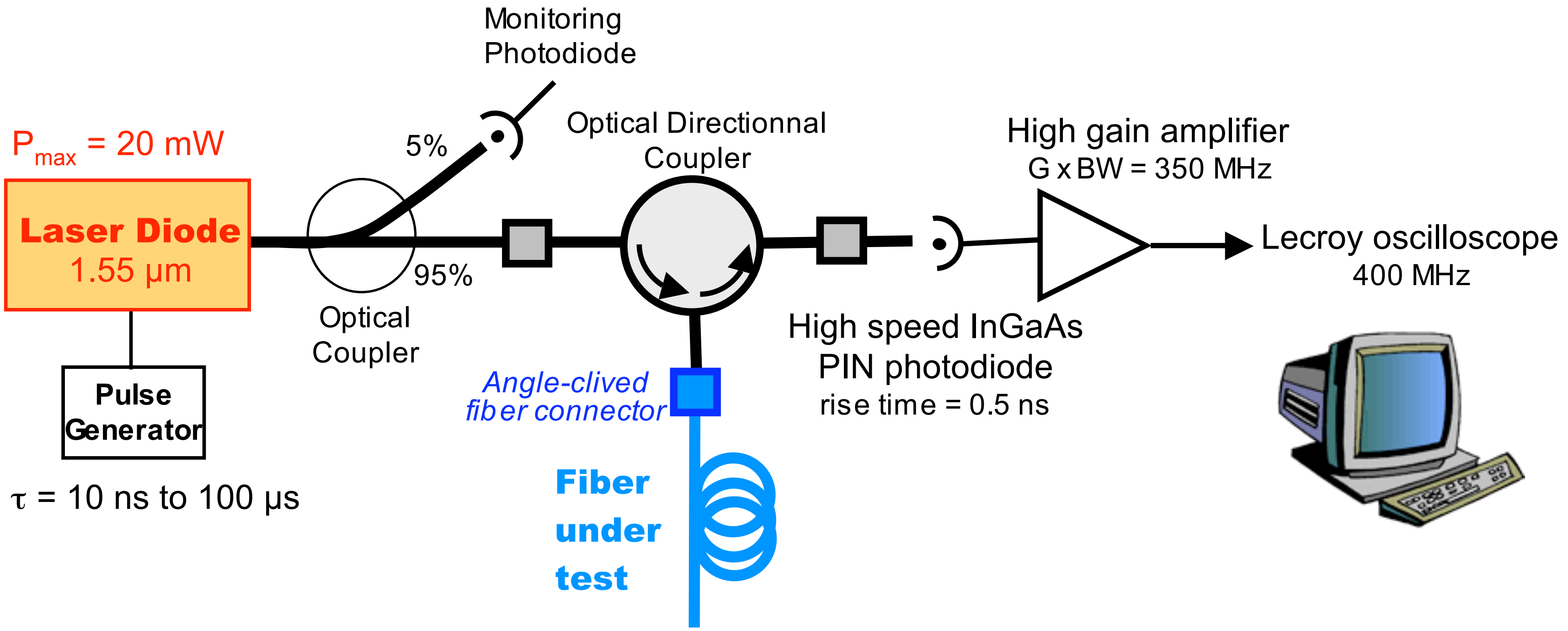
$$P_r(z) = R\cdot P_{in}(z=0)\cdot e^{-2\alpha z}$$

$P_{in}(z=0) = 10$ mW, $R(z=10\ \mathrm{km}) = 4\%$

⇒ $P_r(z=L) \cong 200$ µW

High dynamic desired !

Experimental set-up



P_{max} = 20 mW

Laser Diode
1.55 μm

Pulse Generator

τ = 10 ns to 100 μs

5%

95%

Optical Coupler

Monitoring Photodiode

Optical Directionnal Coupler

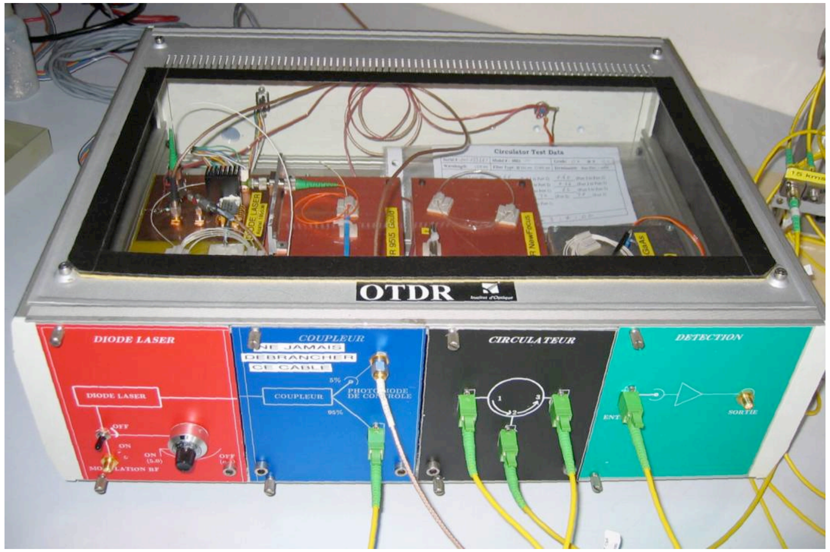
Angle-clived fiber connector

Fiber under test

High speed InGaAs PIN photodiode
rise time = 0.5 ns

High gain amplifier
G x BW = 350 MHz

Lecroy oscilloscope
400 MHz

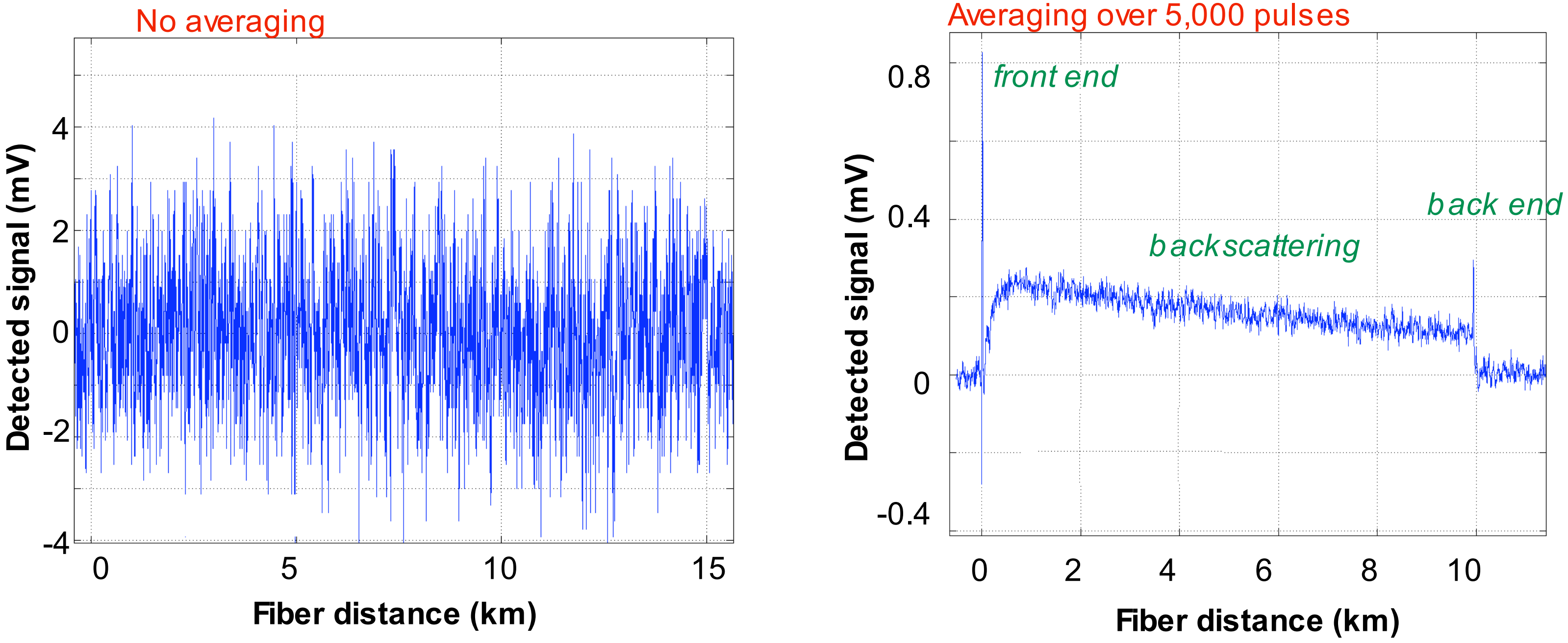


Front panel with all the electrical & optical connections

5 optical inputs/outputs
+ LD control
+ Monitoring PD
+ Amplified photodetected signal

Averaging the backscattered signal

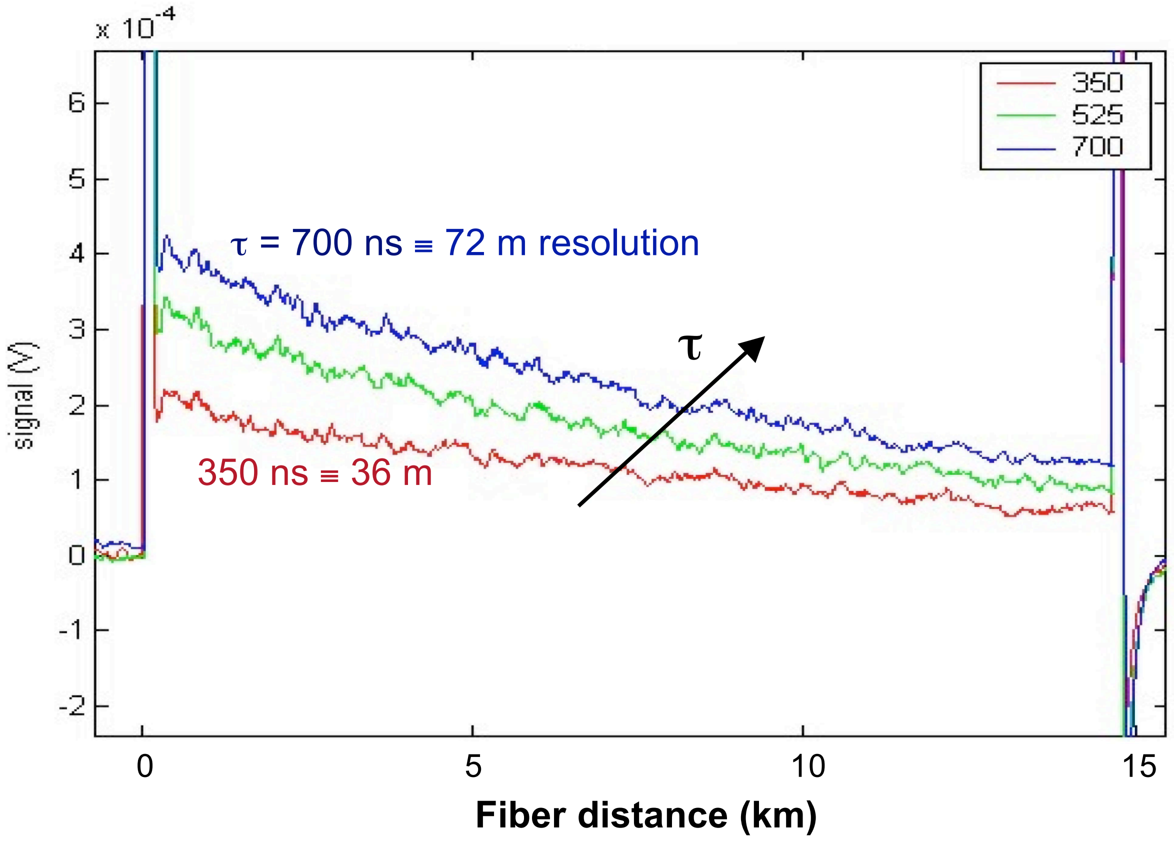
Signal obtained with τ = 100 ns, P_{in} = 13 mW, fiber length = 10 km



Very weak signals to be detected (P < 10 nW)

⇒ need for averaging over N successive pulses to increase the SNR as $\sqrt{N}$

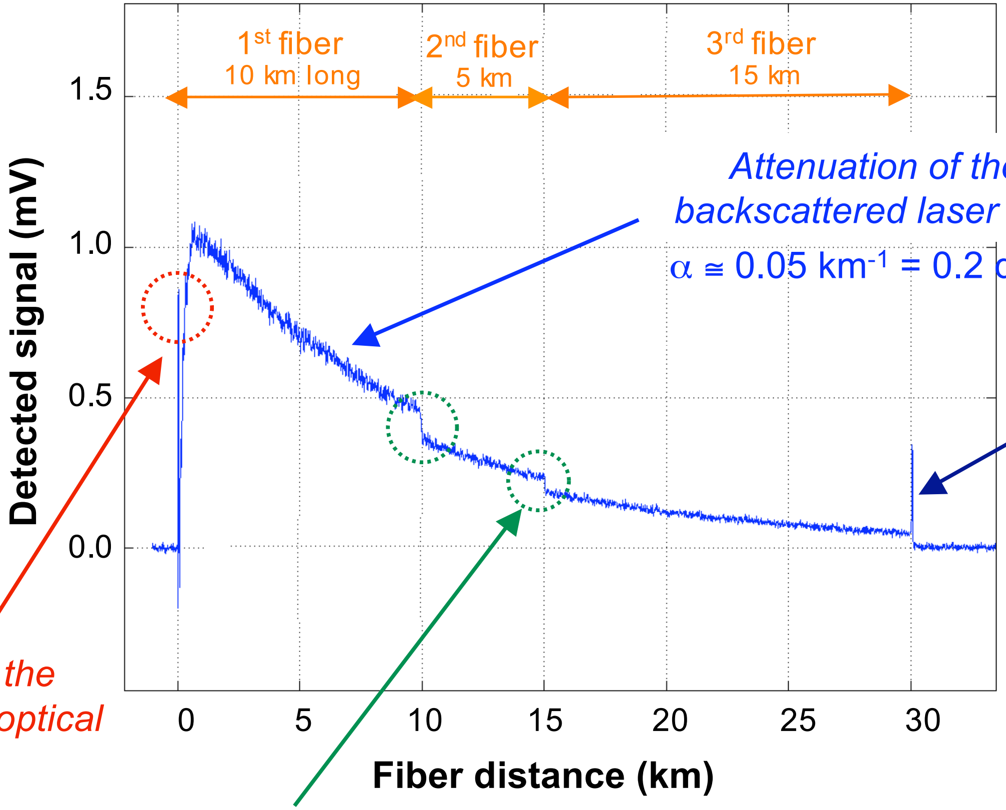
Influence of the pulse duration



Improvement of the backscattered detected signal with an increase of pulse duration at the expense of a reduction of the spatial resolution

OTDR signal & analysis

Signal obtained with τ = 500 ns, P_{in} = 13 mW
Averaging over 50,000 pulses



Attenuation of the backscattered laser light

$\alpha \cong 0.05$ km^{-1} = 0.2 dB/km

Reflexion at the fiber end

(glass/air reflexion)

Low reflection at the fiber front end + optical components

Angle-cleaved connectors between fibers

(no parasitic reflexions)

~ -1 dB attenuation

Distance resolution = $v_g\tau/2 \cong 50$ m

Conclusion

- Realization of a simple OTDR set-up at 1.55 µm for the characterization of single-mode fibers

Non-destructive technique to control long fibers in transmission lines
Measurements of losses and reflections of in-line components at the useful λ
Home-made experiment, however very good sensitivity and resolution
Standard telecoms components (laser diode, directional coupler, high speed photodiode)

- Great pedagogic interest for undergraduate students

A 4.5 hours lab work
Use of very common photonics components + full characterization
Familiarization to signal measurements (noise, SNR) & gain/bandwidth
Characterization of standard single-mode fibers
Easy handling of the set-up, impressive results