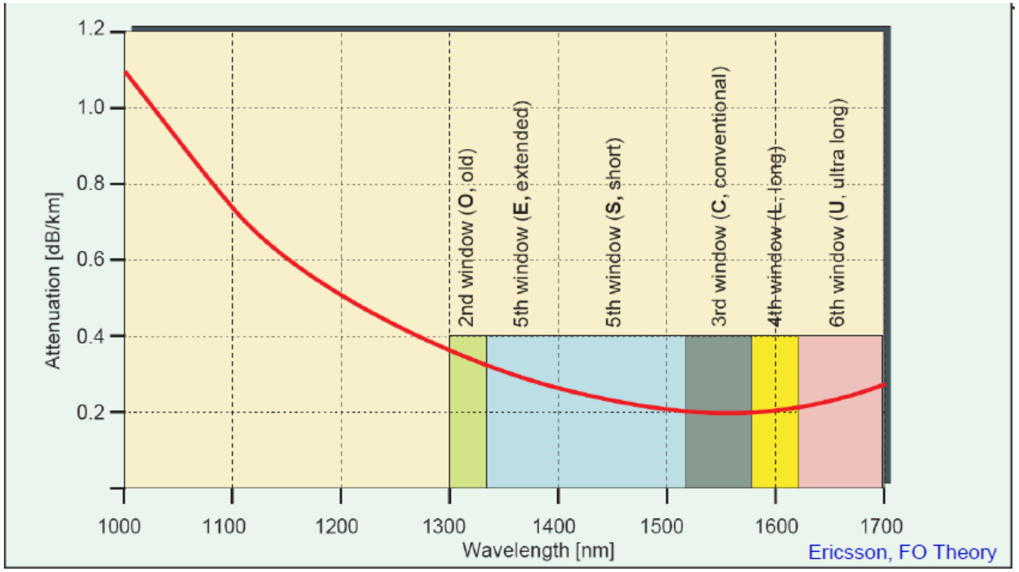
Lecture 8 SOT

Optoelectronic Systems in Telecom

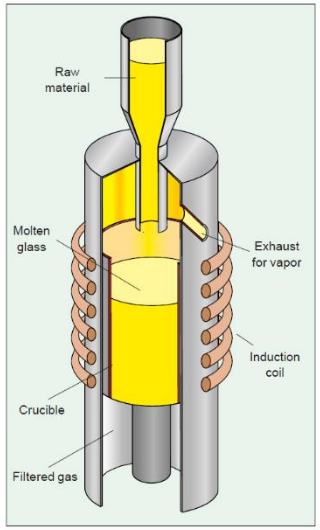
Assoc prof Ramona Galatus



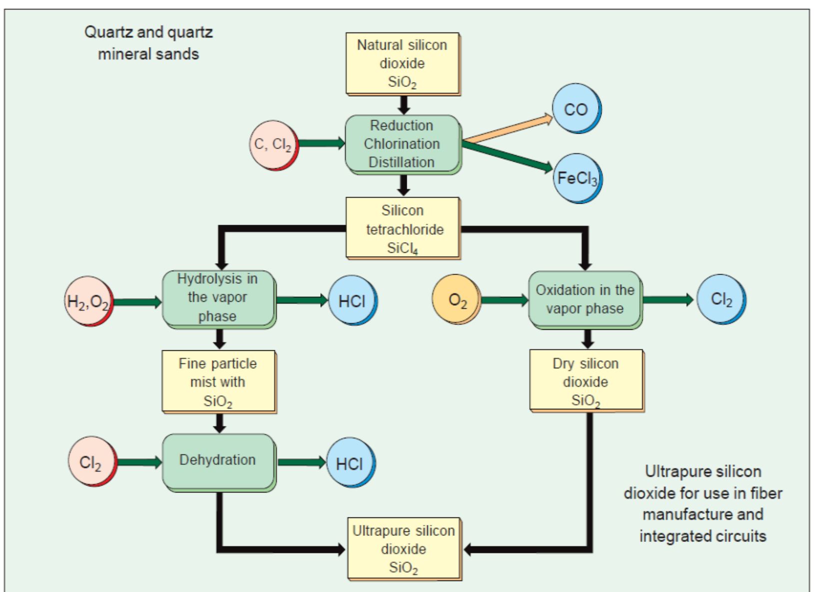
Pentru conformitate, putem raporta cifrele ITU la caracteristica atenuare/lung de unda

Original band (O-band): 1260 to 1360 nm
Extended band (E-band): 1360 to 1460 nm
Short band (S-band): 1460 to 1530 nm
Conventional band (C-band): 1530 to 1565 nm
Long band (L-band): 1565 to 1625 nm
Ultralong band (U-band): 1625 to 1675 nm

Manufacturing



- SiO_2-silica sau dioxid de siliciu (silicon dioxide) – mineral cuart -> sticla ultrapura
- Dopat:
  - Germanium – cresterea indice refractie miez
  - Florura (fluorine) – pentru descresterea indicelui de refractie a invelisului
- SiO2 in forma pura contine oxizi metalici-> eliminare
- Metode Corning:
  - Modified Chemical Vapor Deposition (MCVD)
  - Outside Vapor Deposition (OVD)
  - Vapor-Phase Axial Deposition (VAD)



Bibliografie - Cap 3 – Ericsson-> Eseu
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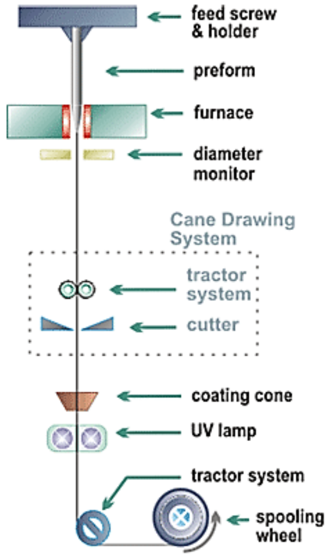

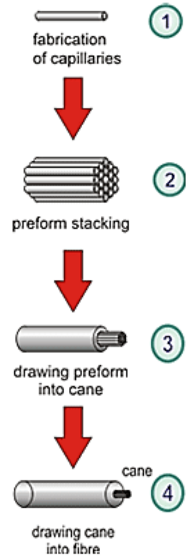

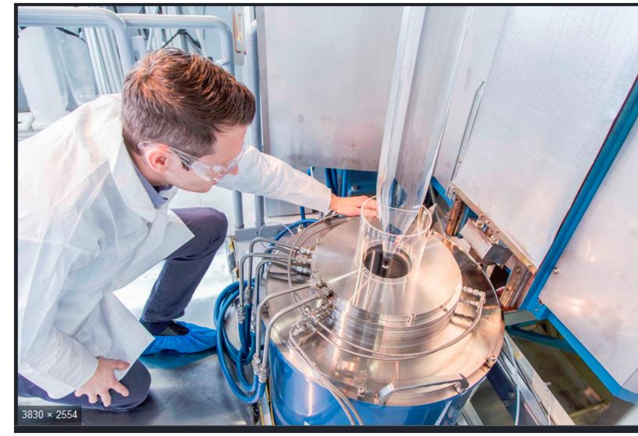

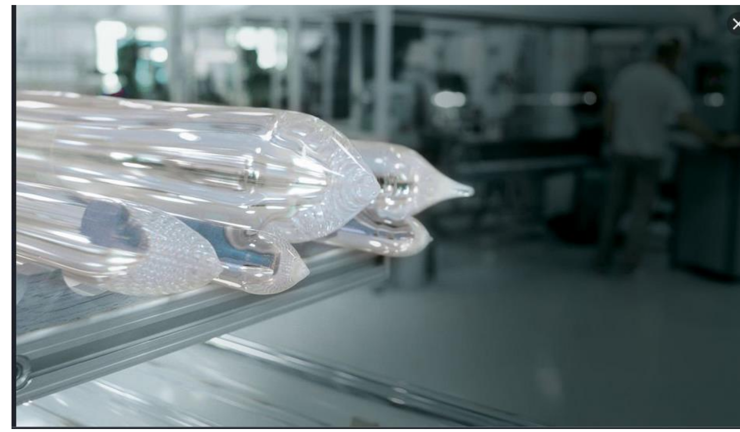

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Budget flux equation

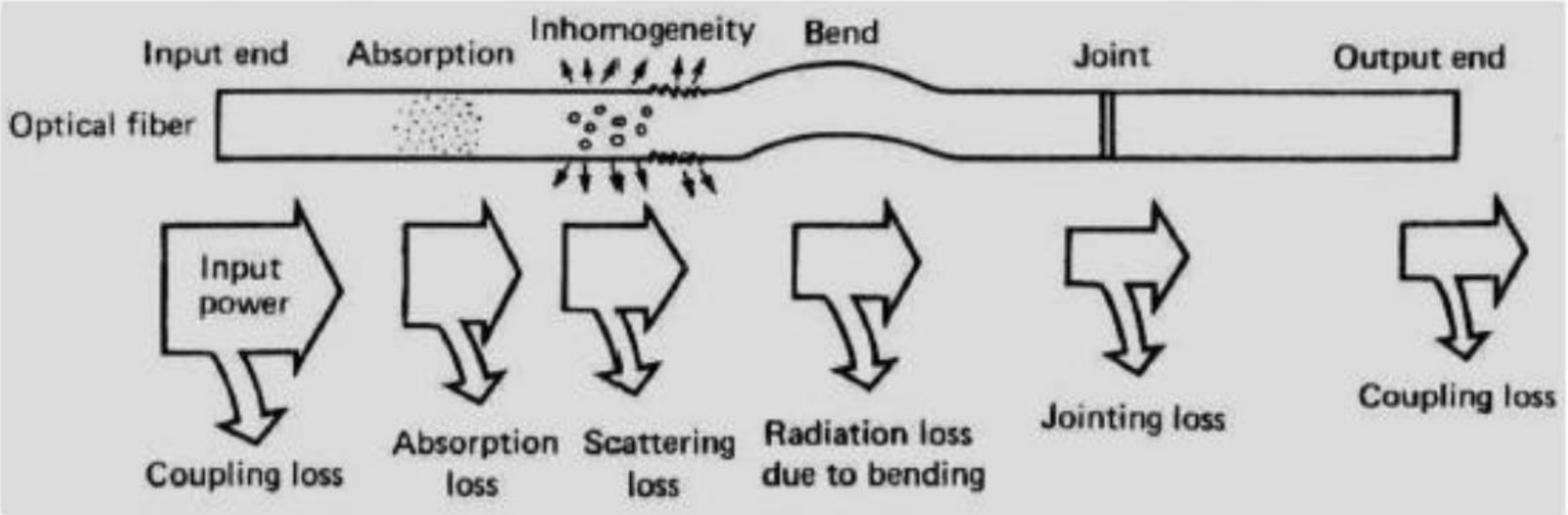
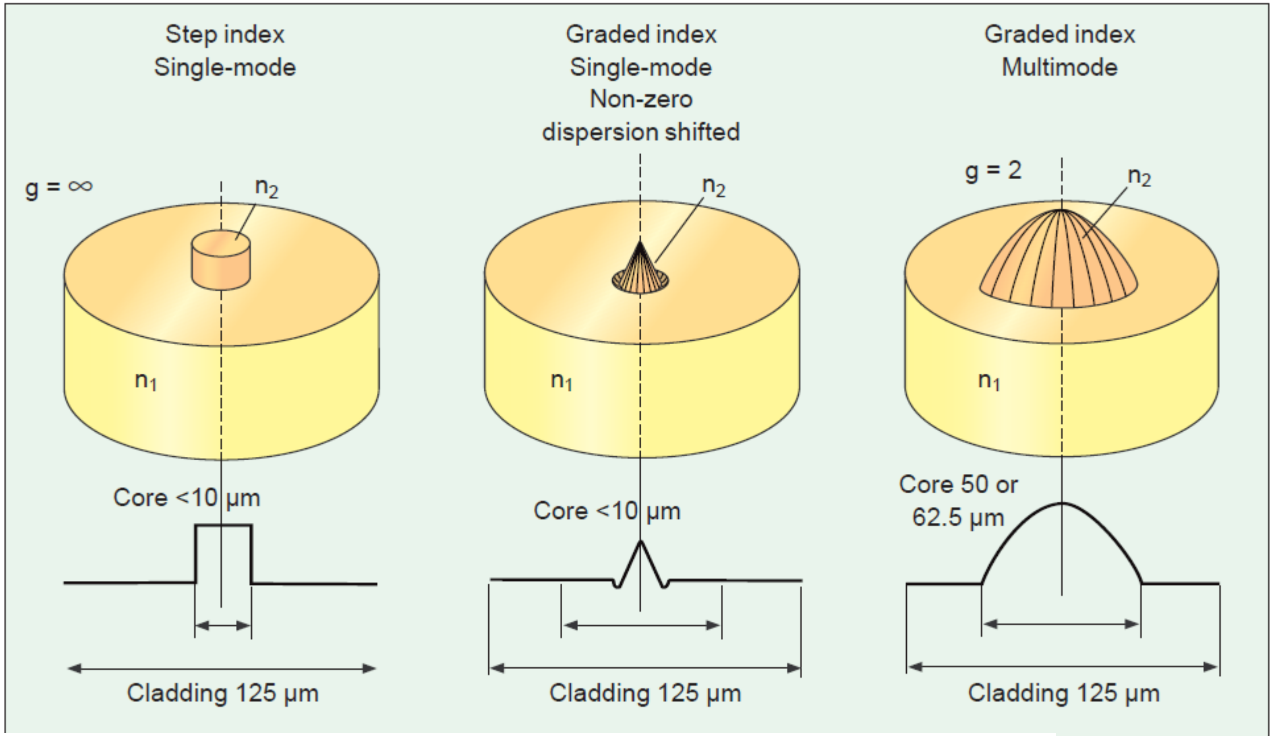


Figure 6.2 Causes of loss in an optical fiber.

$$P(z) = P_0 \cdot e^{-\alpha_T \cdot z}$$

$$\alpha_T = \alpha_{absorption} + \alpha_{scattering} + \alpha_{bending} + \textbf{waveguide loss}$$

Equations



$$n = n(r)$$

n_2 = the refractive index for the core (waveguide)
Δ = differential for the normalized refractive index
r = distance from the fiber's central axis in µm
a = the core's radius in µm
g = profile index
n_1 = the cladding's refractive index.

Constituents of optical fiber

Multimode fiber

Core	Cladding
GeO_2 - SiO_2	SiO_2 F - (P_2O_5) - SiO_2

Single-mode fiber

Core	Cladding
GeO_2 - SiO_2	F - (P_2O_5) - SiO_2 SiO_2 (P_2O_5) - SiO_2 F - SiO_2
SiO_2	F - (P_2O_5) - SiO_2 F - SiO_2

$$n(r) = n_2\left[1 - \Delta\left(\frac{r}{a}\right)^g\right]$$

g = 1 for triangular index profile
g = 2 for parabolic index profile
g = ∞ for rectangular step index profile

Equations

$$\Delta = \frac{NA^2}{2n_2^2} = \frac{n_2^2 - n_1^2}{2n_2^2} \approx \frac{n_2 - n_1}{n_2} \approx \frac{\Delta n}{n} \quad \text{for } \Delta << 1$$

a = core radius [µm]
NA = numerical aperture
λ = wavelength [µm]
k = number of light wavelengths per 2π units of length.

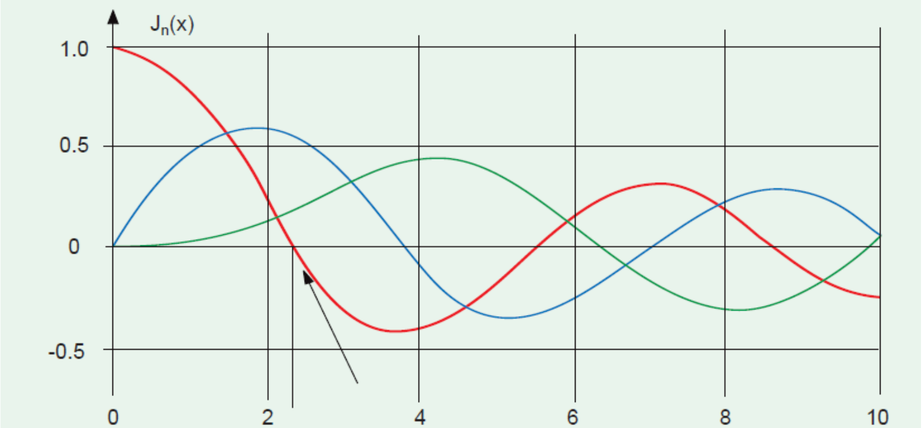
$$V = 2\pi \frac{a}{\lambda} NA = k \cdot a \cdot NA$$

$$N \approx \frac{V^2}{2} \cdot \frac{g}{g+2}$$

$$N \approx \frac{V^2}{2}$$

->fibra indice treapta

$$\lambda_c = \pi \frac{2a}{V_c} NA = \pi \frac{2a}{2.405} \cdot NA$$



First zero crossing of the fundamental function: $V_c = 2.405$

Conditie monomod

Nonlinear effects

Fiber nonlinearities fall into two categories

- stimulated scattering
- refractive index fluctuations

Stimulated Brillouin Scattering, SBC

Stimulated Brillouin scattering is an interaction between light and acoustic waves in an optical fiber. Some of the forward propagating light is redirected backwards thereby stealing power from the forward propagating light, thus reducing the power that can be delivered to the receiver. SBC arises at an input power level from 6–20 dBm.

Stimulated Raman Scattering, SRS

Stimulated Raman scattering is an interaction between light and the fiber's molecular vibrations. The SRS scatters light in both in the forward and backward direction, the backward propagating power can be eliminated by the use of an optical isolator. SRC arises at an input power level above 27 dBm, close to 1 W.

Self Phase Modulation, SPM

Self Phase modulation describes the effect an optical pulse has on its own phase. The edge of an optical pulse represents an intesity that is time-varying thus implicating a time-varying refractive index. The varying refractive index modulates the phase of the transmitted wavelength(s), this broadens the wavelength spectrum of the transmitted pulse. If sufficiently severe, this broadening may overlap into adjecent channels in DWDM systems. SPM arises at an input power level above 5 dBm.

Cross Phase Modulation, CPM

Cross Phase modulation originates the same way as SPM. Whereas SPM relates to the effect that a pulse has on itself, CPM describes the effect that a pulse has on the phases of pulses in other channels. SPM may occur both in single- and multi-channel system and CPM will only occur in multi-channel systems. CPM arises at an input power level above 5 dBm.

Four-Wave Mixing, FWM

One of the most troubling of the nonlinear effects is the four-wave mixing. It occurs when multiple signals co-propagate, they mix to produce additional channels that can steal power from and overlap with the original signals.

- SBS – interactiune lumina- unde acustice
- SRS – interactiune lumina cu vibratiile moleculare ale materialului
- SPM – se datoreaza efectului de polarizare KERR - > variatia indicelui de refractie cu intensitatea -> efect: induce defazaj in faza (phase shift)

$$\Delta n = n_2 I$$

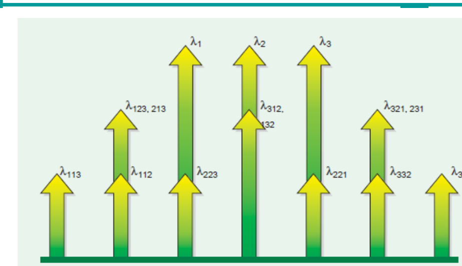
http://www.rp-photonics.com/self_phase_modulation.html

- CPM – se datoreaza efectului de polarizare KERR -> efect: o lungime de unda poate afecta faza unei alte unde cu o alta lungime de unda

$$\Delta n^{(2)} = 2 n_2 I^{(1)}$$

- FWM – mixaj 4 unde care se propaga-> zgomot

http://www.rp-photonics.com/kerr_effect.html



Rayleight scattering

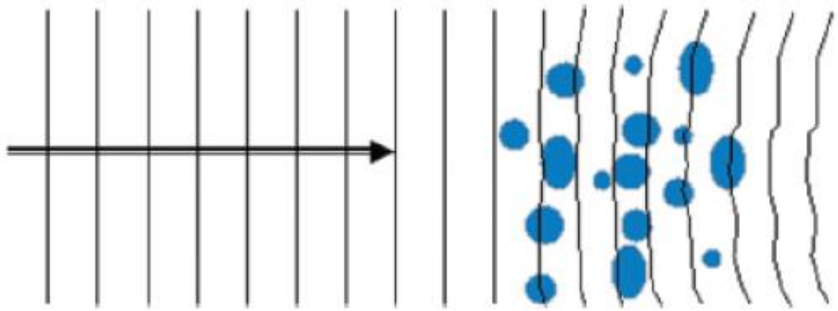


Figure 6.13 Inhomogeneities in a glass fiber produce refractive index variations that act as scattering centers for Rayleigh scattering.

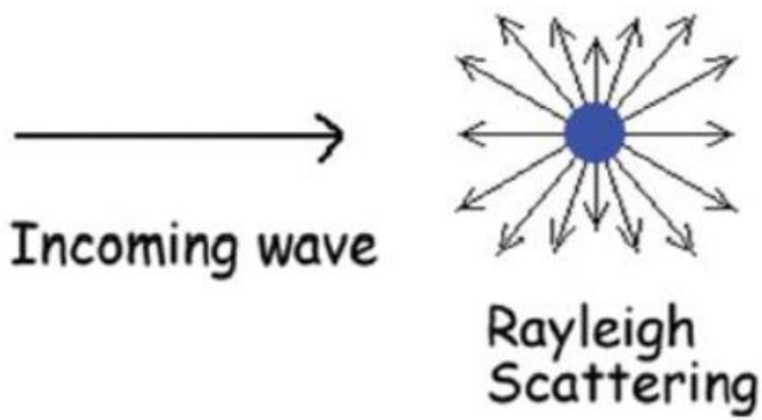


Figure 6.14 Dispersal of light produced by Rayleigh scattering.

Light scattering along the fiber

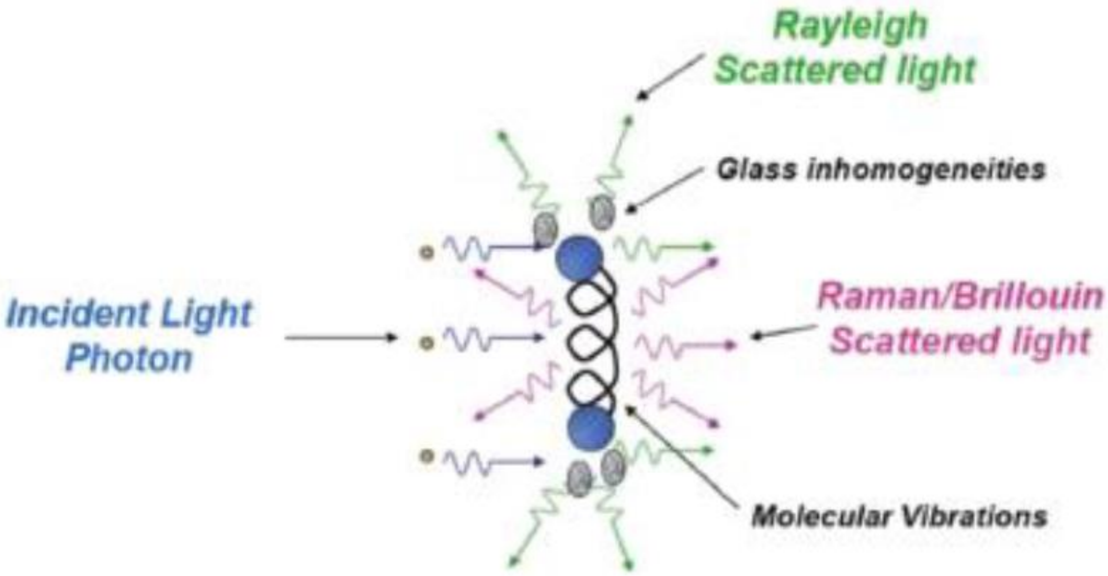


Figure 6.10 Pictorial representation of scattering mechanisms (elastic and inelastic). Rayleigh scattering is caused by index variations. There is no energy transfer, which defines an elastic collision. Raman/Brillouin scattering is caused by molecular vibrations. There is an exchange of energy which defines an inelastic collision.

Elastic versus Inelastic

- Elastic
  $\lambda_{scattered} = \lambda_{incident}$
  - Rayleigh
    - voids
    - density variations
    - Impurities
    - composition fluctuations
    - structural variations
    - any micro nanoscopic variations

- Inelastic
  $\lambda_{scattered} \neq \lambda_{incident}$
  - Raman
    - thermally excited molecular vibrations
  - Brillouin
    - bulk molecular vibrations induced by pressure/acoustic wave set off by thermally induced molecular vibrations

Stokes and Anti-Stokes

D. Krohn et al, Fiber Optic Sensors, SPIE, 2014

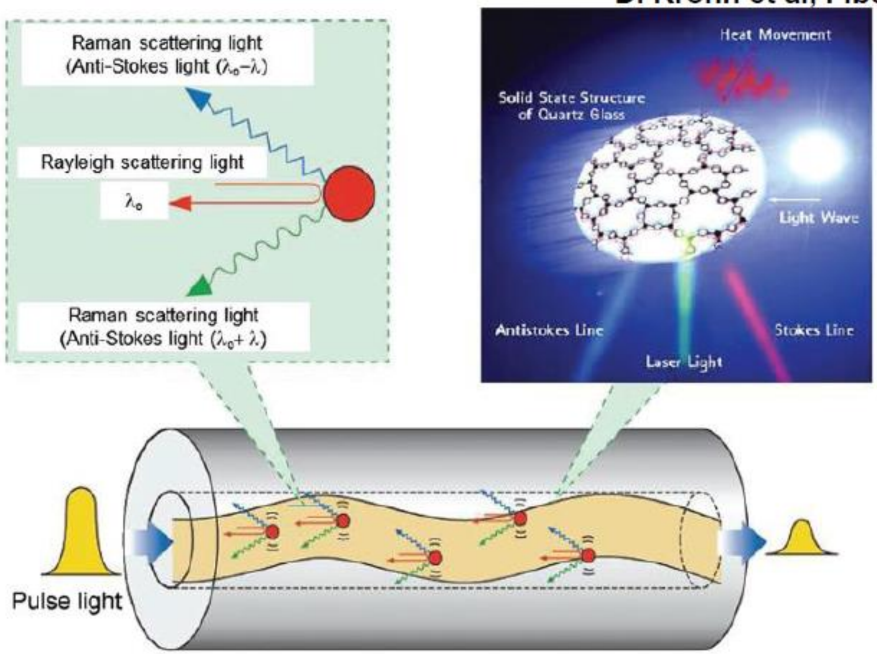
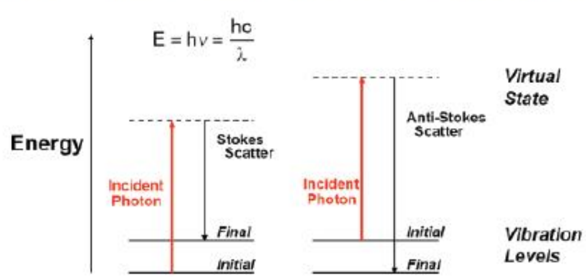


Figure 6.17 Raman scattering process in a silica glass fiber (source: LIOS).

Stokes photons

$$\nu_s = \nu_i - \nu$$



anti-Stokes photons

$$\nu_a = \nu_i + \nu$$

Figure 6.11 Energy-level representations for the emission of Stokes and anti-Stokes scattering components.

Silica fiber

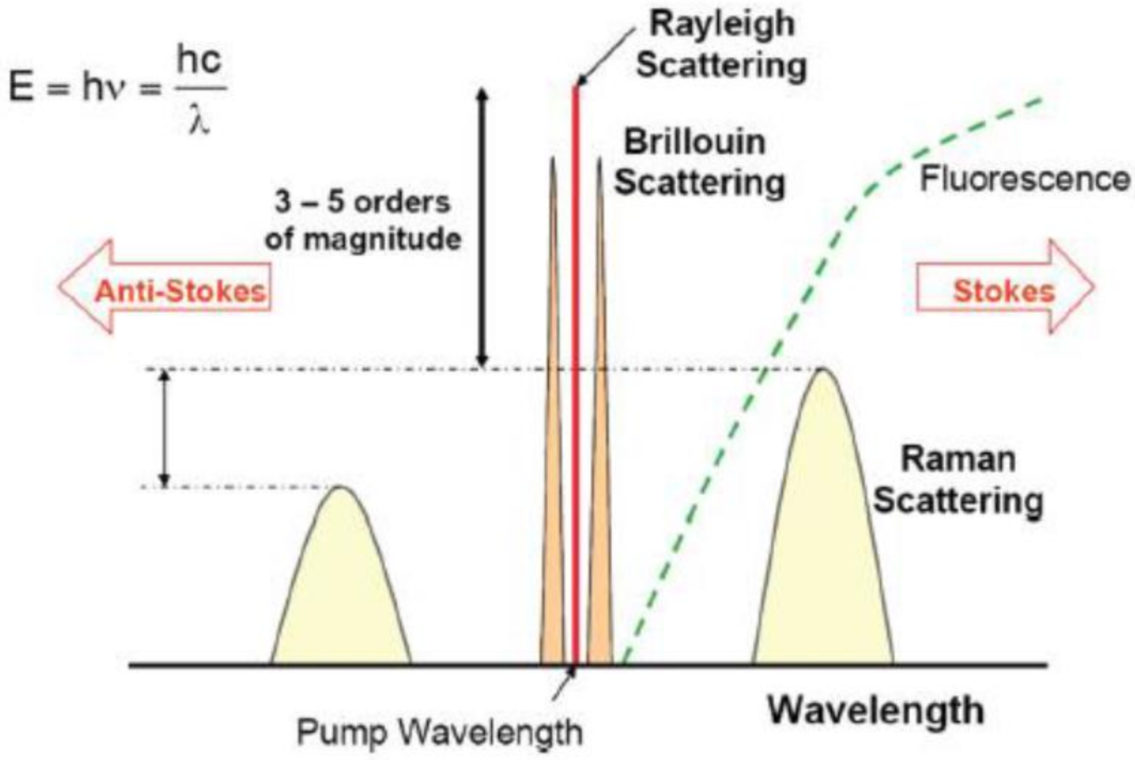
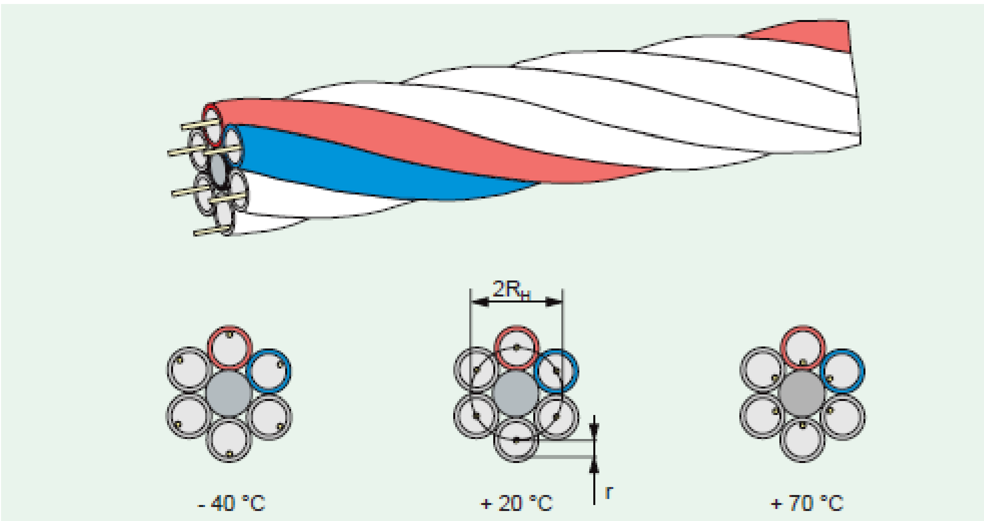


Figure 6.12 Pictorial representation of the scattering emission spectrum in a silica fiber.

Cables-Temperature influence



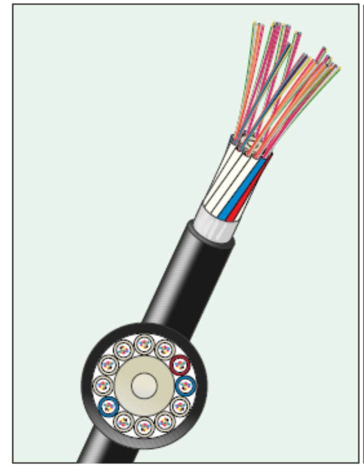


Fig. 5-21 Optical fiber cable, concentric construction, with loose tubes around the central strength member.
Cable illustrated is the GRHLDV

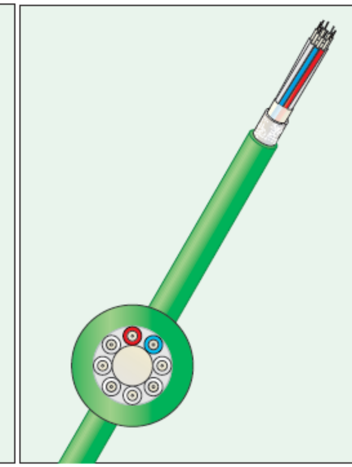
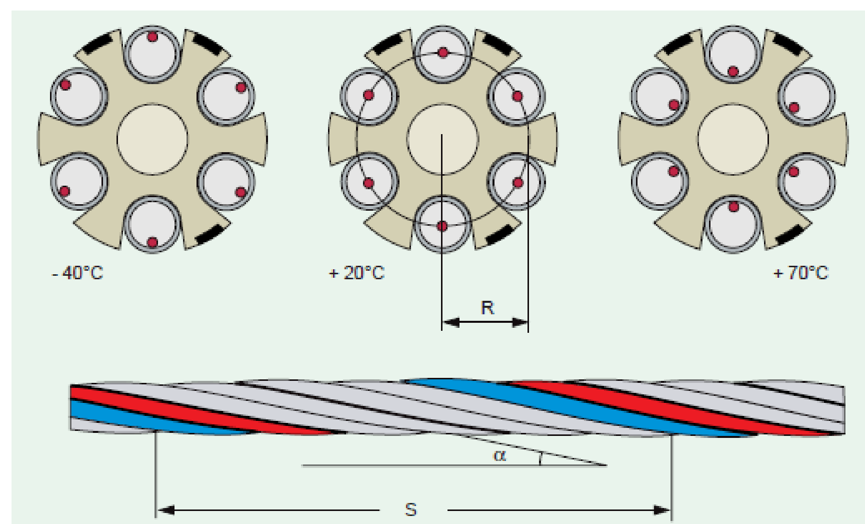


Fig. 5-22 Optical fiber cable; concentric construction with tight buffered fibers around the central strength member.
Cable illustrated is the GNHLBDUV

- Plasticul – coeficient mare de expansiune la temperatura
- Sticla- coeficient de expansiune mic
- Aliniere-> reducerea stresului
- Codul culorilor
- Sloturi fibre optice
- Bending

$$L = S\sqrt{1+\left(\frac{2\pi R}{S}\right)^2}$$



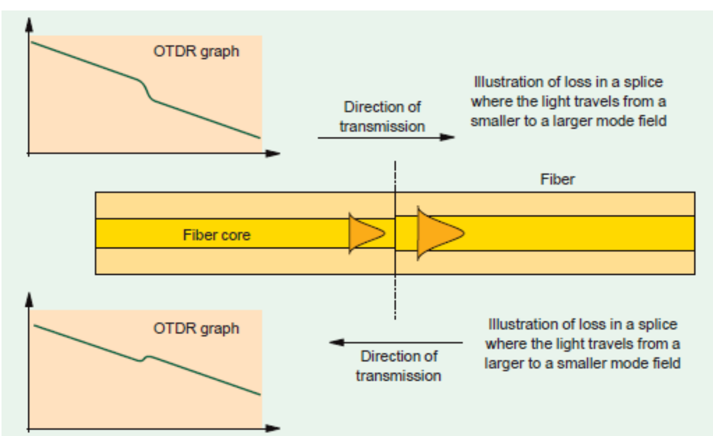
Budget flux equation

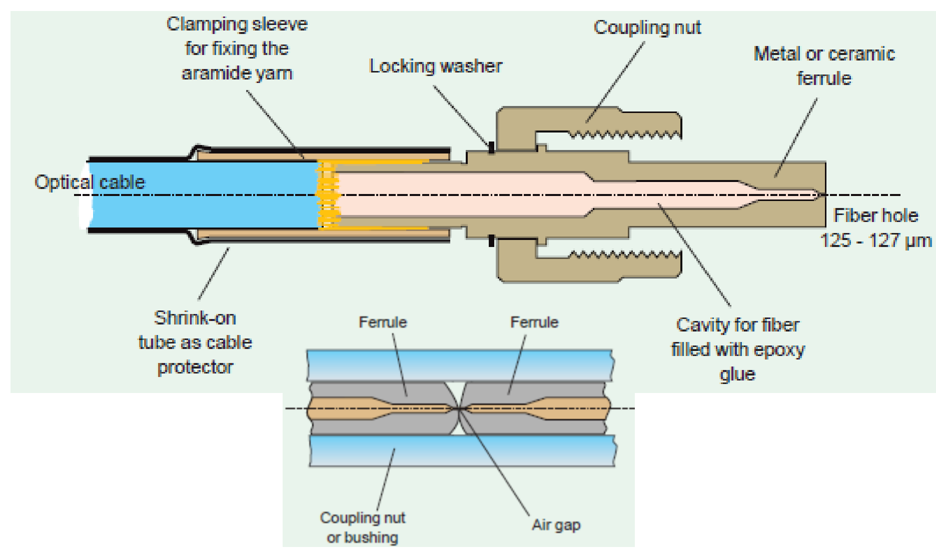
- Losses
  - fiber-related losses
  - losses related to the material in connectors and splices.

- Mode field difference
- Different numerical apertures (NA)
- Different core diameters
- Different cladding diameters
- Non-circularity of core and/or cladding
- Core/cladding non-concentricity.

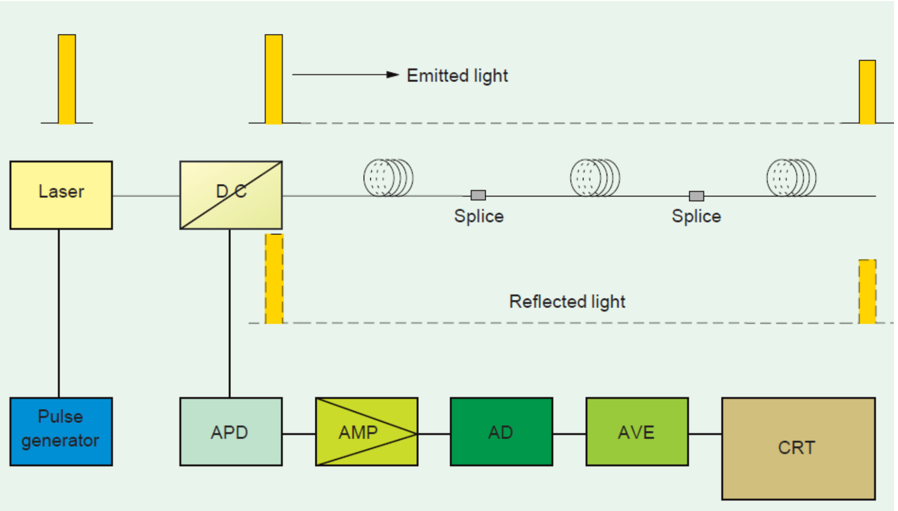
- radial misalignment
- longitudinal separation
- angular deviation
- vertex misalignment (applies primarily to PC-connectors)
- surface finish (semipermanent splices only).

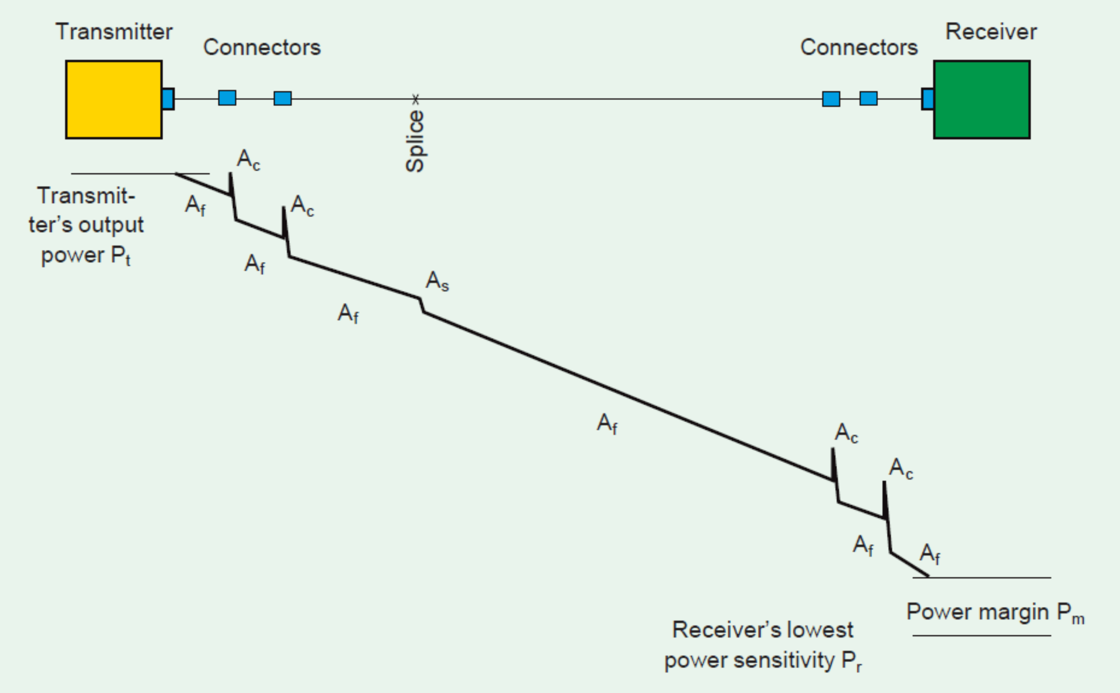
Ex: MFD difference

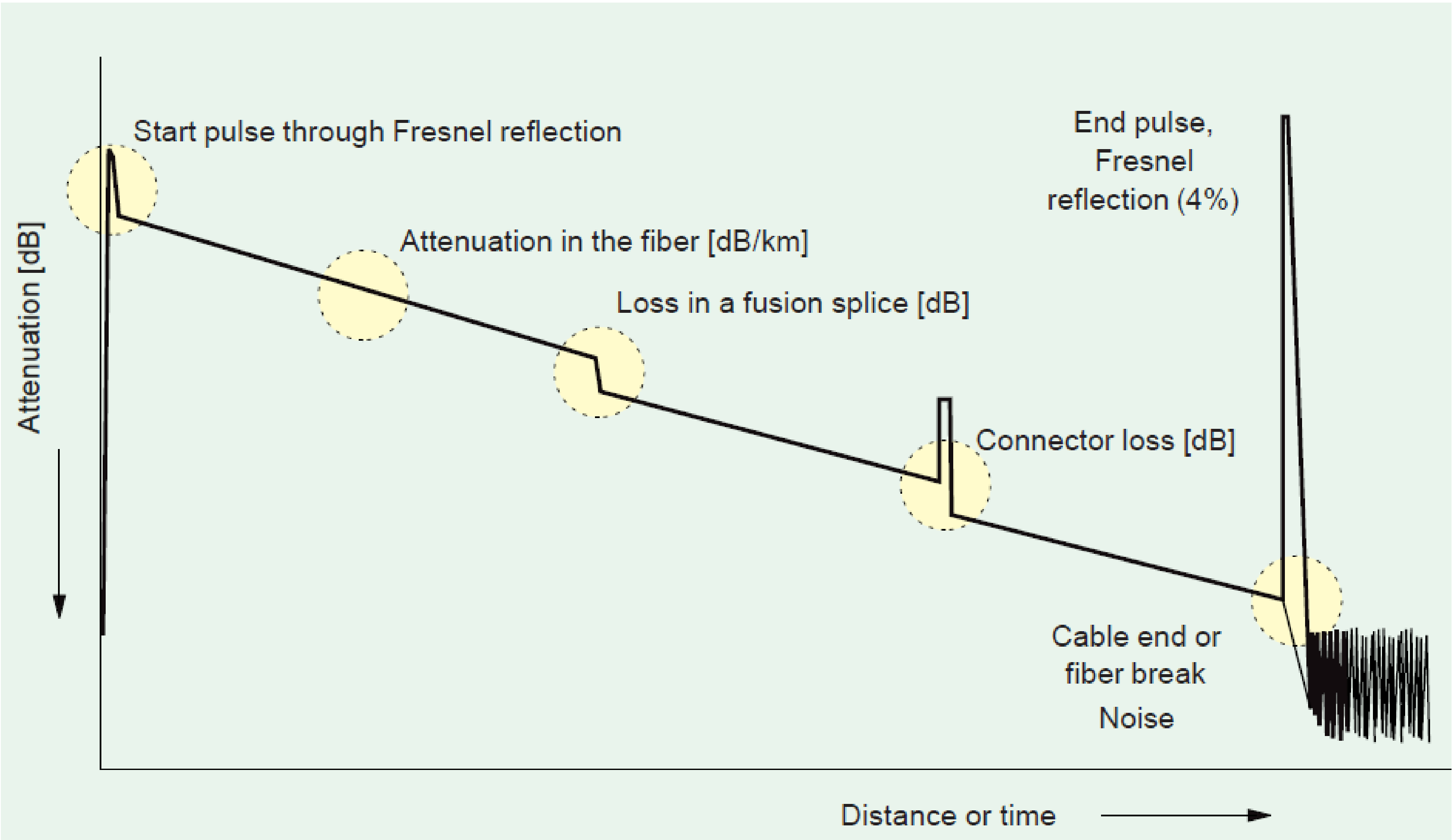




Fiber splicing







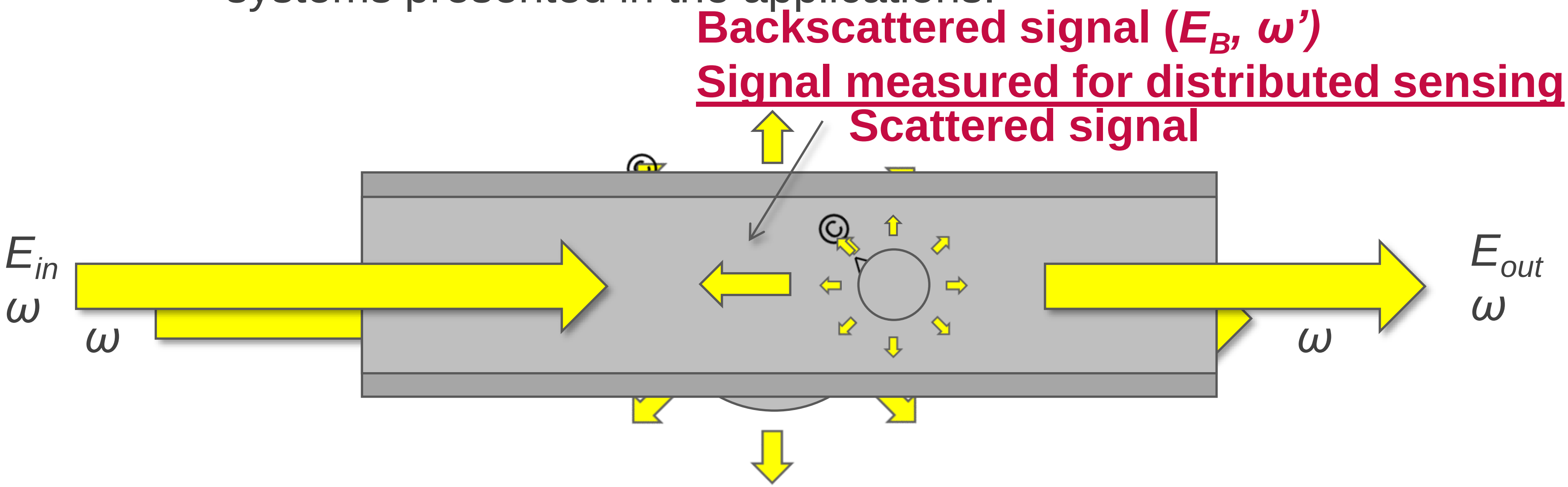
Start pulse through Fresnel reflection
Attenuation in the fiber [dB/km]
Loss in a fusion splice [dB]
Connector loss [dB]
End pulse,
Fresnel
reflection (4%)
Cable end or
fiber break
Noise
Attenuation [dB]
Distance or time

OTDR

Figure 13.6. Portable OTDR for making measurements in the field. (Model FTB-400, photo provided courtesy of EXFO; www.exfo.com.)

The content of this talk ranges from physical concepts to applications

The scattering effects are the physical phenomenon that will be **detected/quantified/treated** by every sensing systems presented in the applications.



First objective: **description of the basic physical principle of scatterings in optical fibres (Rayleigh, Brillouin, Raman)**

The content of this talk ranges from physical concepts to applications

Rayleigh

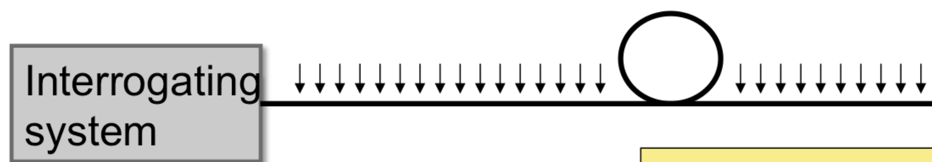
- Monitoring for telecommunication purposes (OTDR)
- ϕ-OTDR (Phase-OTDR) for intrusion and vibration sensing

Brillouin

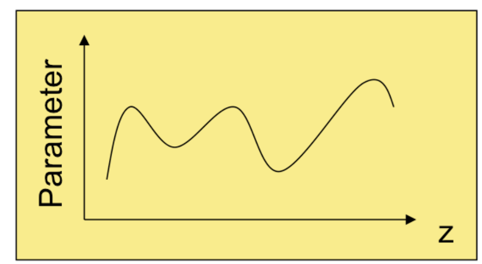
Brillouin reflectometer for temperature and strain sensing

Raman

Temperature sensing



Distributed measurement

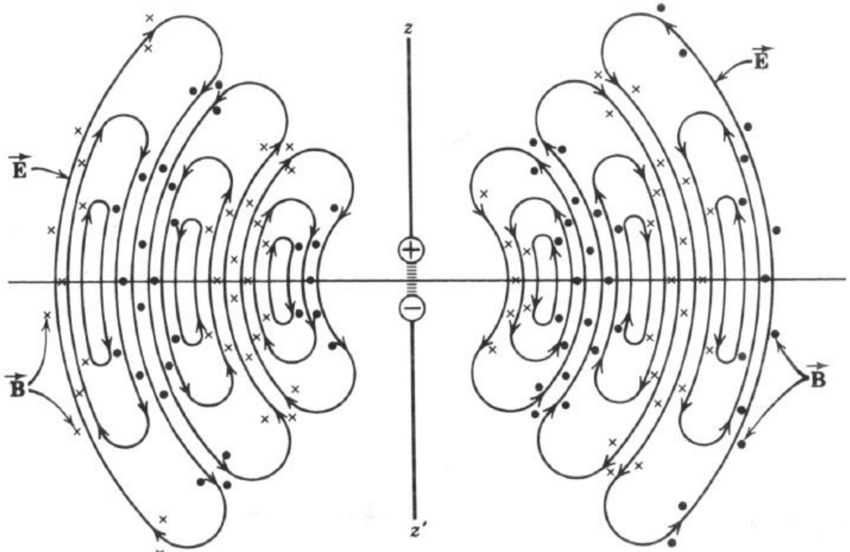


Second objective: **introduction to measurement using scattering effects**

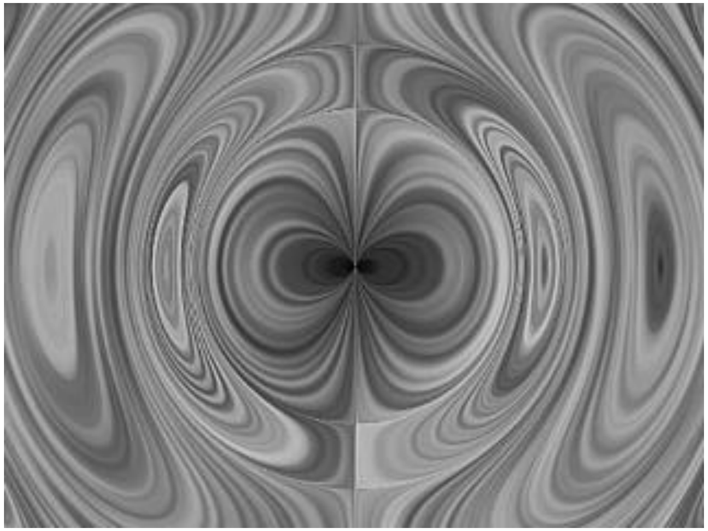
Scattering results from light-matter interactions

→ A monochromatic electromagnetic wave interacts with the medium particles by **stimulating the atomic electrons to oscillate**

→ The electrons radiate in the manner of **elementary electric dipoles**



From R. Resnick and D. Hallyday, Ondes, optique et physique moderne, Editions ERP, 1980



From http://www.vis.uni-stuttgart.de/ufac/dipole/