PHOTONICS

5d Optical fiber sensing networks

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Summary

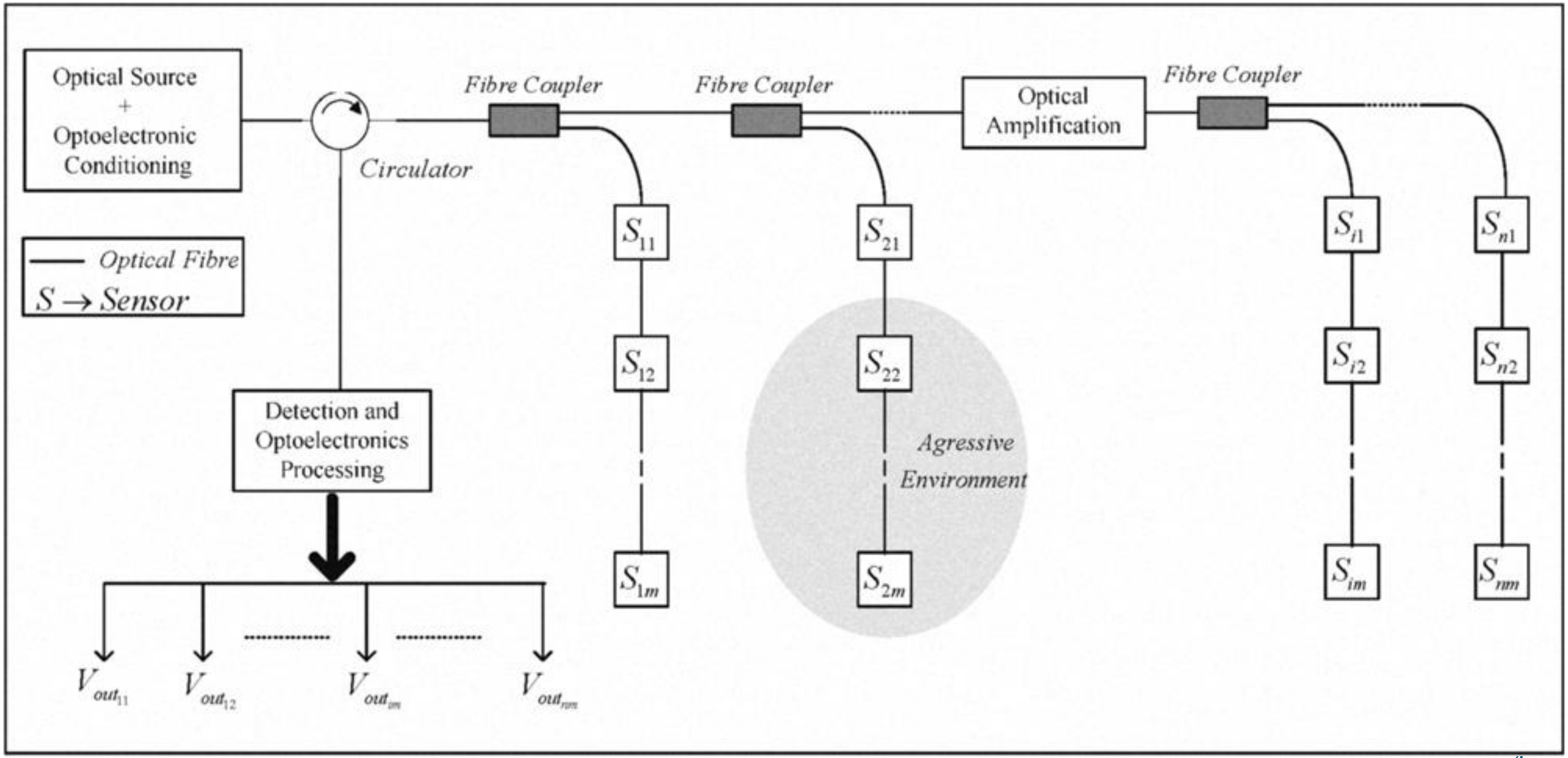
- Advantages of Fiber Optic Sensors
- FOS multiplexing
- Multi-Point Sensing
- Distributed Sensing
- Conclusions

Advantages of optical fiber sensing

- Nowadays an established technology
- FOS can be designed so that the measurand interacts with one or several optical parameters of the guided light (intensity, phase, polarization and wavelength)
- Dual functionality of OF sensing and telemetry path
- Numerous operational benefits: electromagnetically passive, no explosion risk, chemically and biologically inert, packaging can be physically small and lightweight
- Sensors can easily be placed kilometres away from the monitoring station
- Multiplexed measurements using large arrays of remote point (or distributed) sensors
- No active optoelectronic components located in the measurement area - retaining electromagnetic passiveness and environmental resistance

Multi-point sensing

- ❖ Measurement is performed in discrete points
- ❖ Located along a large area covered by FO network

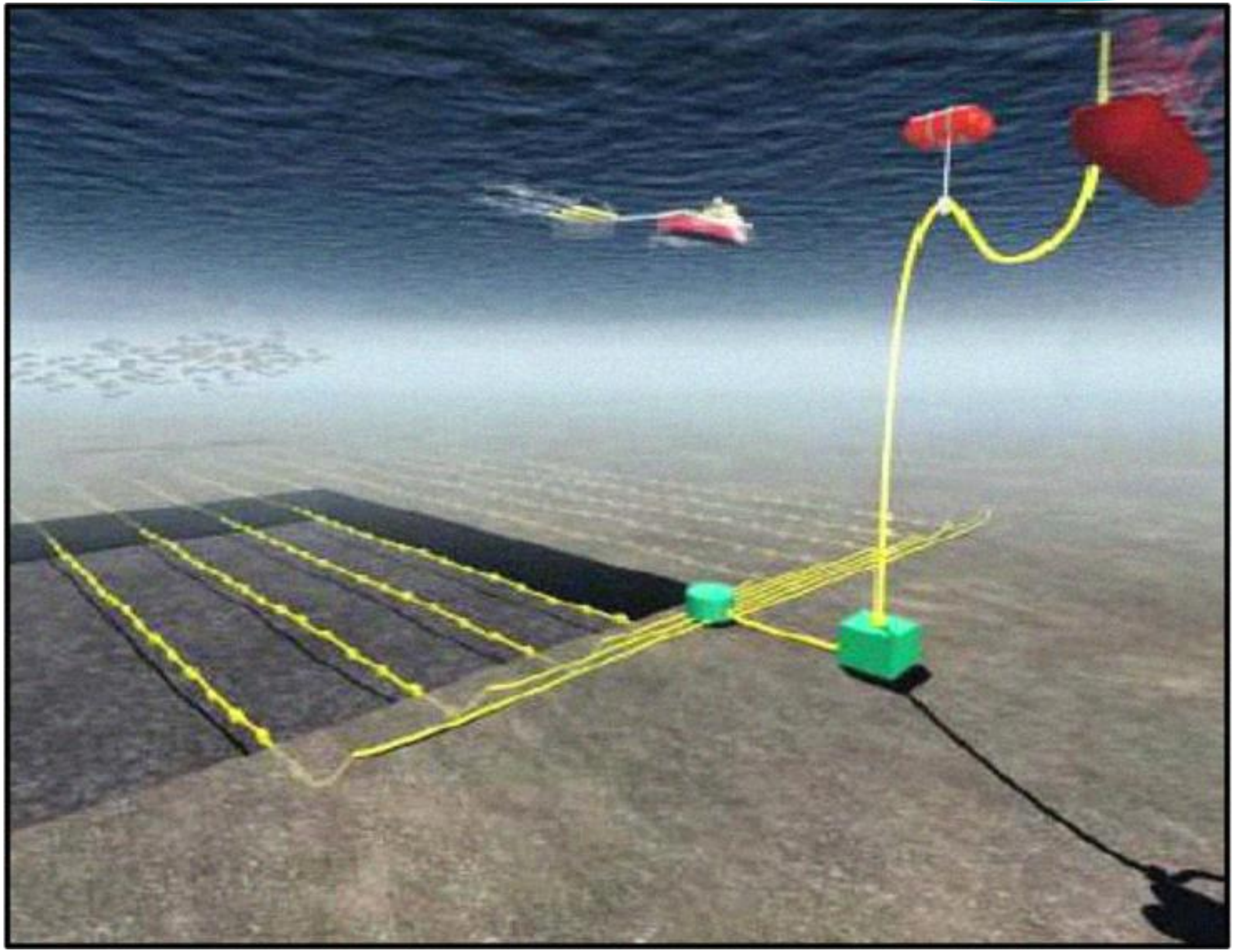


- **Processes and techniques that permit to address particular FOS**
- **Typically related with Time, wavelength, coherence, frequency or spatial addressing**

- **FOS interrogation means**
- **How to read the status of a specific sensor**
- **How to obtain information about the measurand**

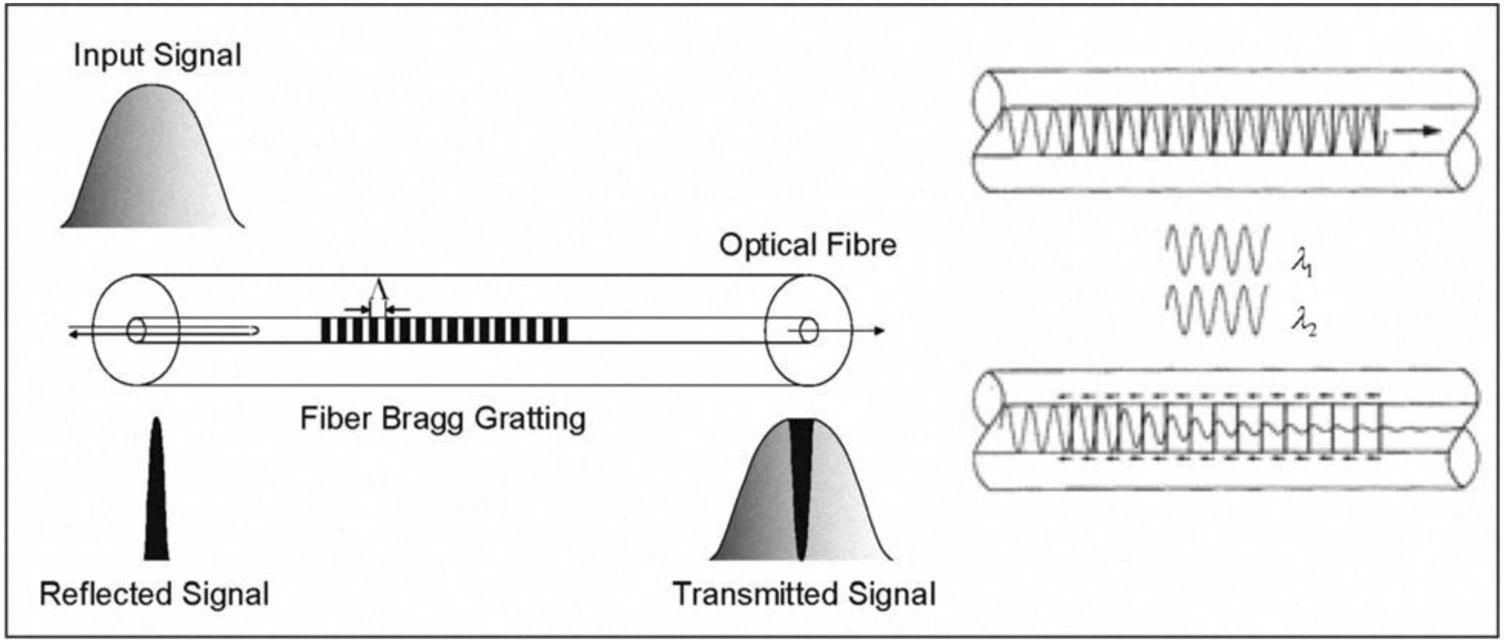
Possible applications

- Historicaly military underwater acoustic detection - hydrophones
- Nowadays seismic maps for monitoring of oil and gas reservoirs
    - Interferometric FO sensing systems may require over 30 000 sensors
    - More that 250 sensors supported by a single fiber pair
    - Specific combination of time and wavelength multiplexing



Sea ground seismic monitoring with an OF sensing network

FBG technology $\lambda_B = 2n\Lambda$

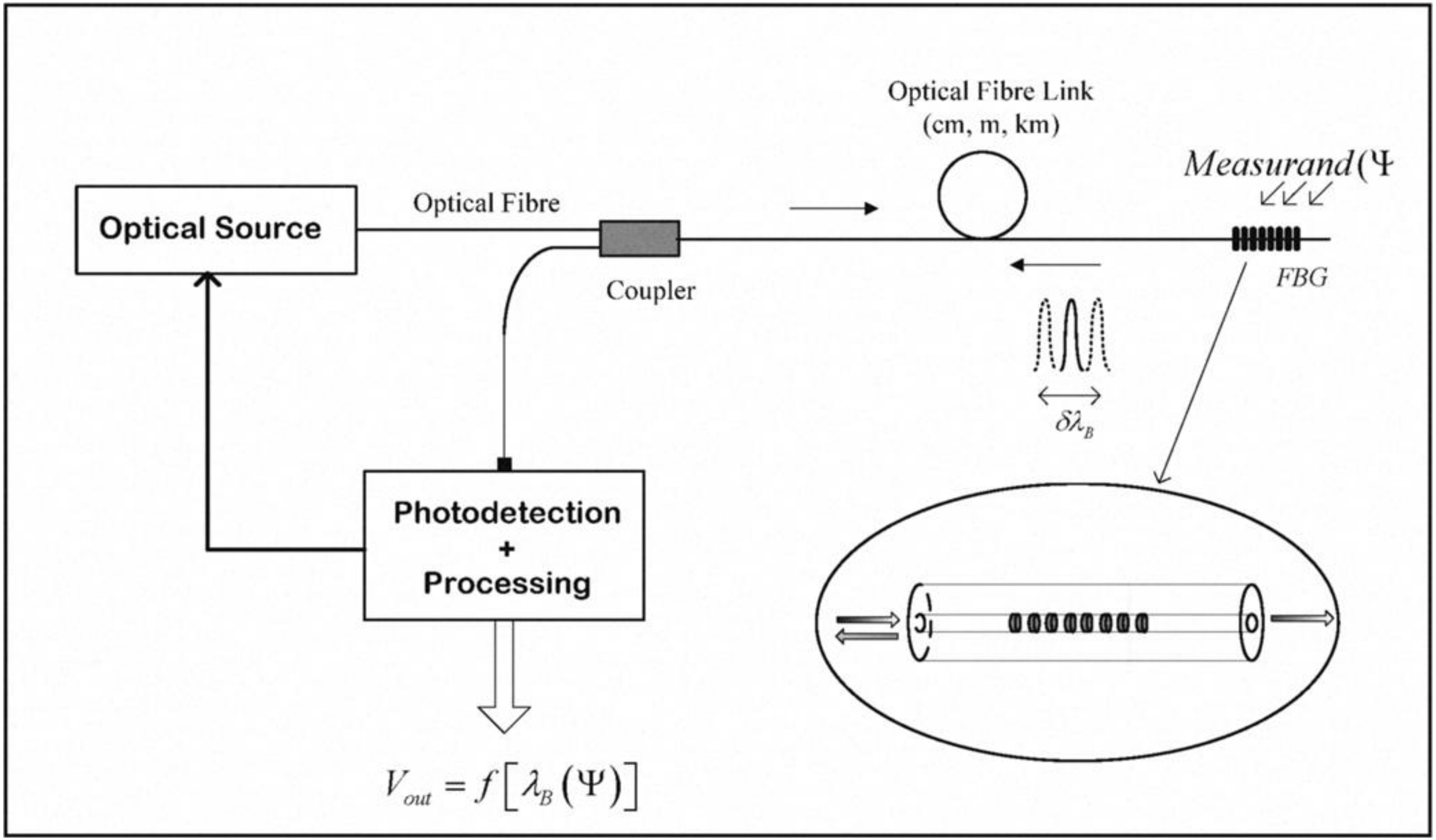


- **Reflected wavelengths are in a spectral window with a width of - 0.1-0.2 nm around λ_B**
- **All other wavelengths are transmitted**
- **Changes in the period Λ, or in the refractive index *n, originate a shift in* λ_B - *i.e., a small variation occurs* in the "colour" of the reflected light**

FBG interrogation

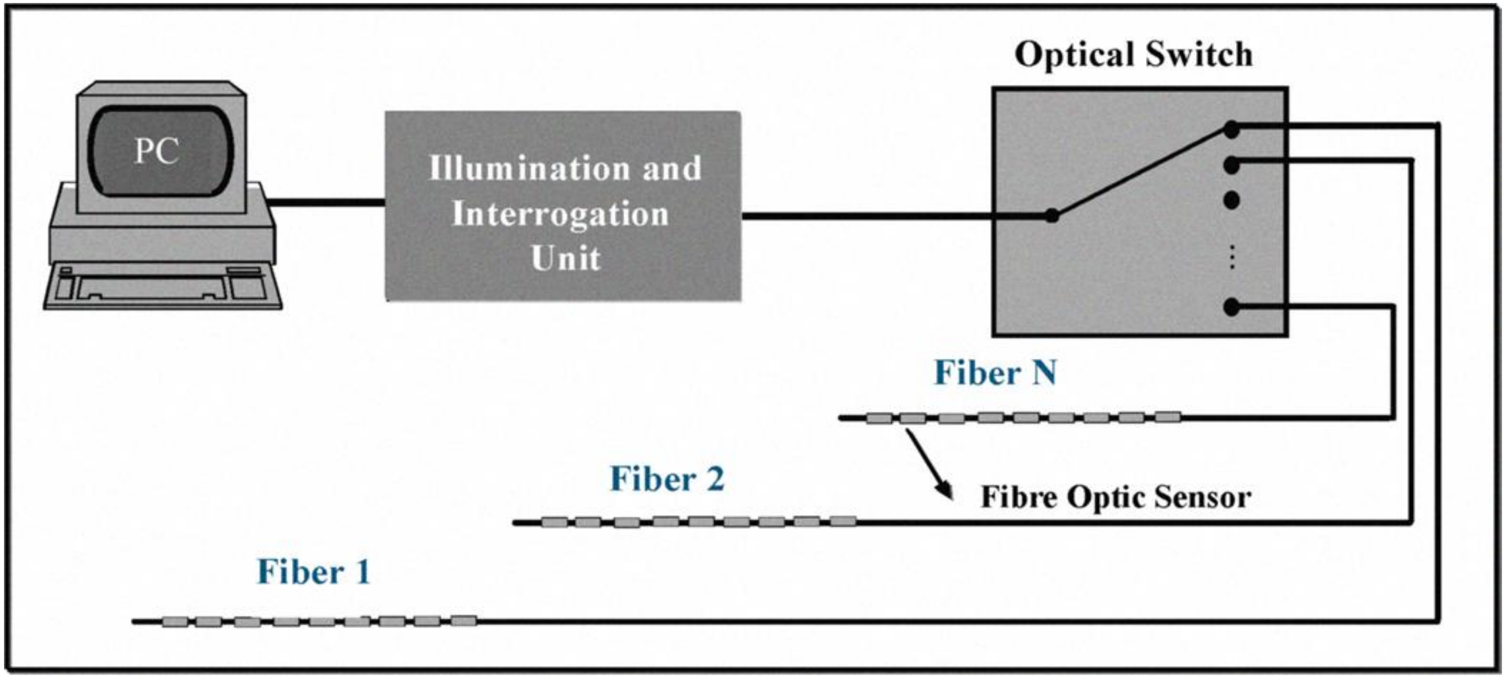
- Colour is absolute parameter
- FBG sensing process is insensitive to variations that may occur in other light parameters along the optical system
- Broadband source - LED, SLD, ASE, Supercontinuum
- FBGs are intrinsically sensitive to temperature and strain applied to OF
- Possible to build up sensing heads supported by FBGs to detect a large spectrum of physical, chemical and biochemical parameters

Interrogation of FBG sensors

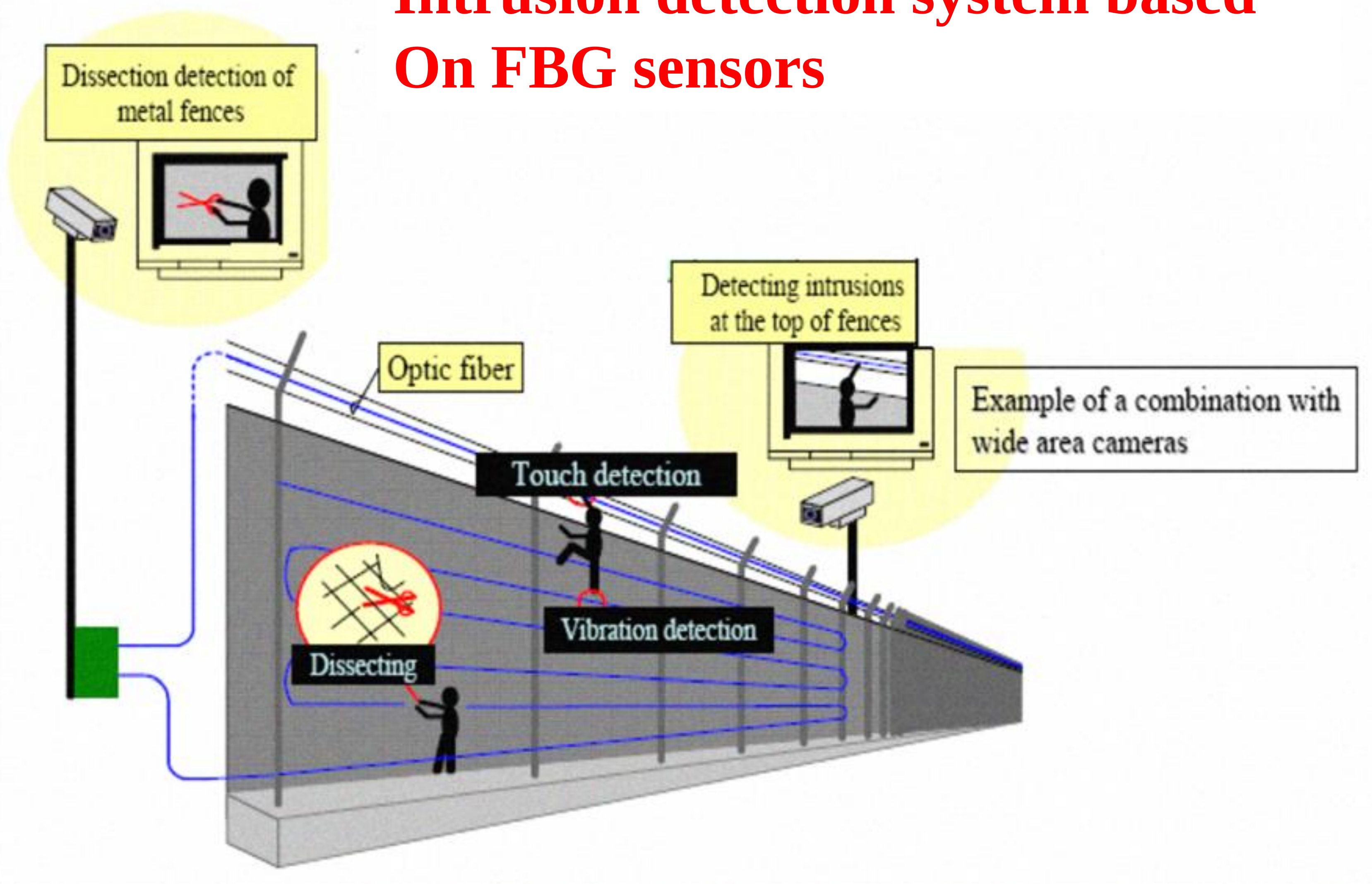


FBG sensing applications

- Monitor large structures in the field of Civil Engineering
- Environmental monitoring - distribution of temperature of water along the 12 km extension in the Portuguese lagoon *Ria de Aveiro*

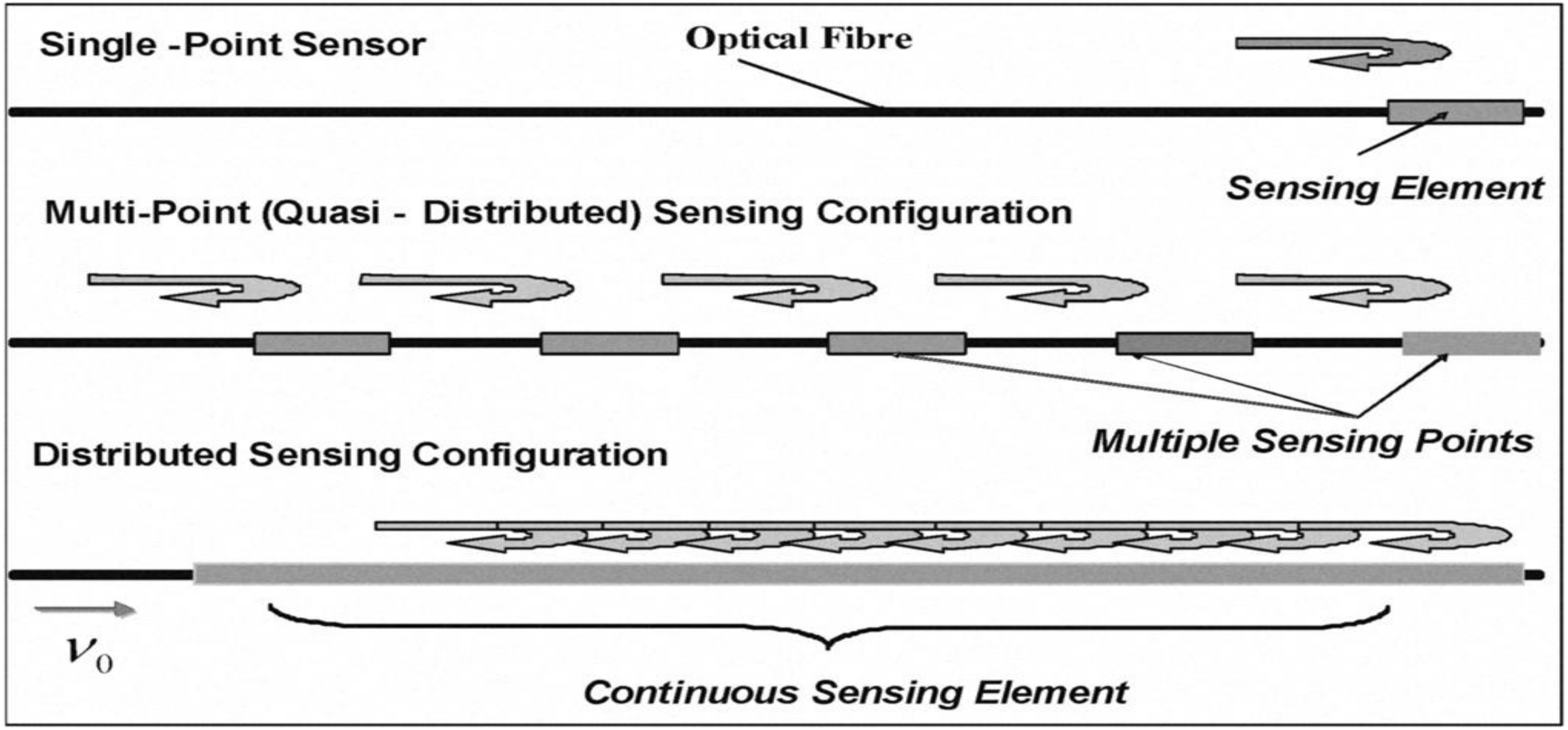


Intrusion detection system based On FBG sensors

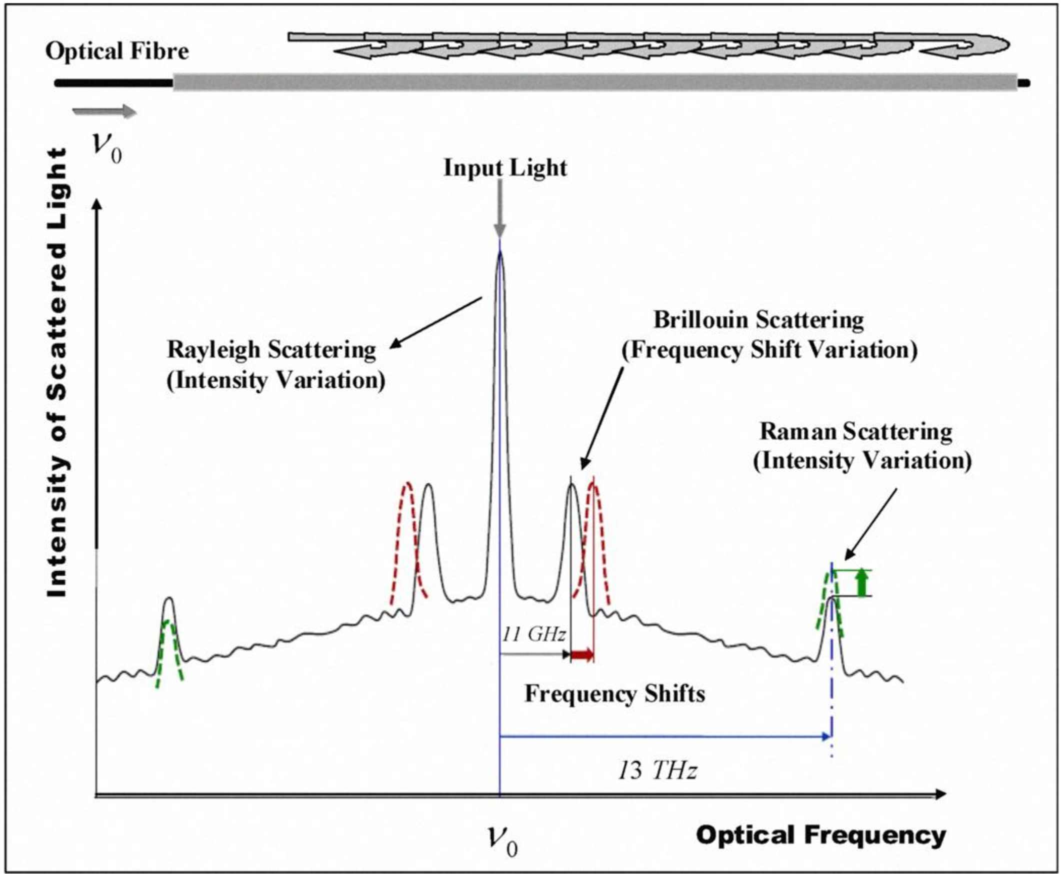


Distributed sensing

- Distributed refers to the ability to simultaneously detect scale and location of a measurand anywhere along a continuous length of sensing OF



- Basis of distributed sensing is the scattering of light that propagates in the OF core, particularly the back-scattering to permit the propagation of the scattered light back to the detection unit
  - Elastic – linear: Rayleigh scattering
  - Inelastic – nonlinear: Brillouin and Raman scattering



Optical Time Domain Reflectometry (OTDR)

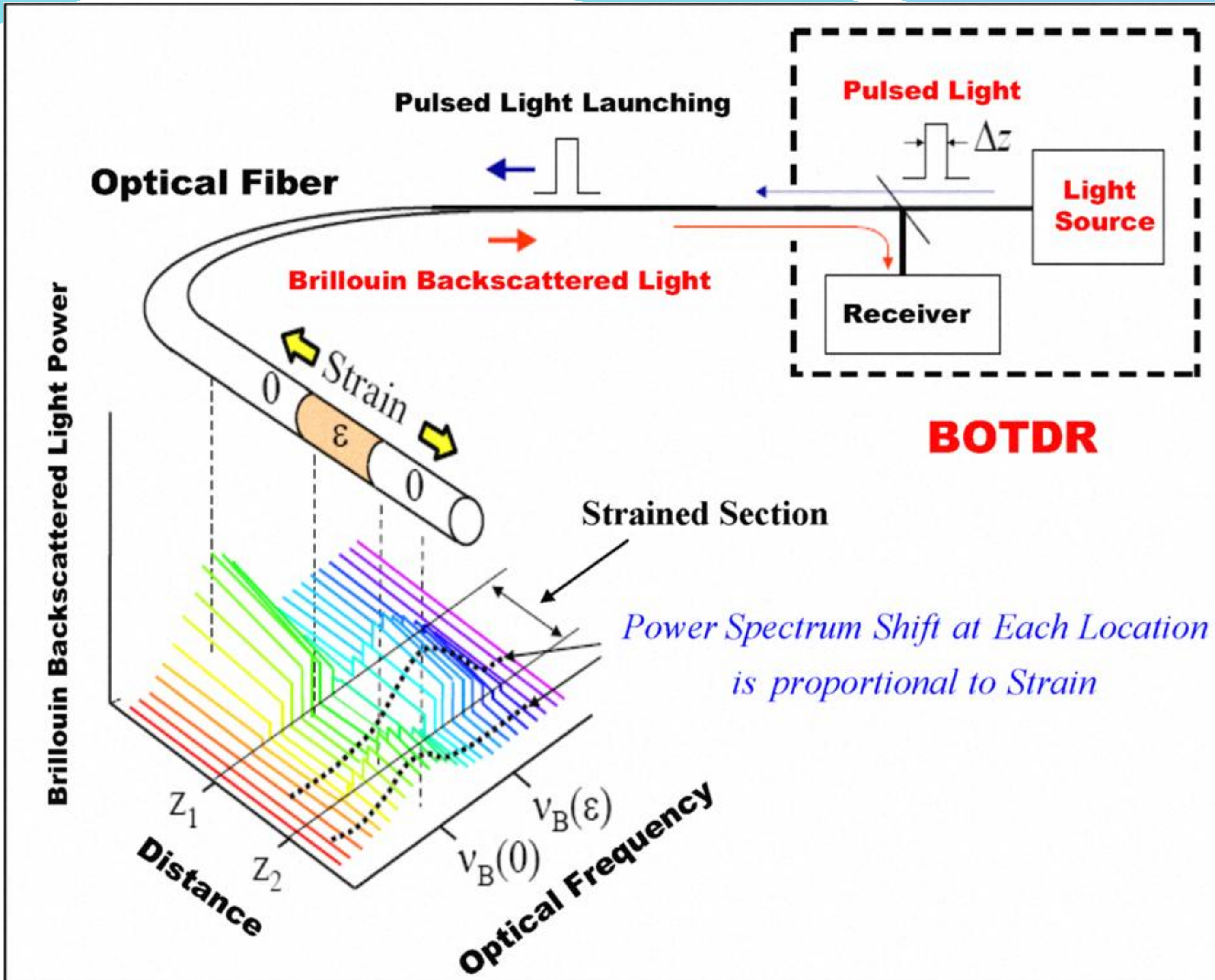
based on the monitoring of the Rayleigh backscatter

- **To achieve spatial resolution, the light injected into the system is short pulsed**
- **The intensity of the scattered light relatively to adjacent regions permits the measurement of the loss in that region**

Rayleigh scattering based OTDR concept rarely has been used for sensing

- ❖ **Frequency domain reflectometry (OFDR) has opened Rayleigh scattering techniques to applications in sensing**
- ❖ **External perturbations (strain and temperature) on a OF result in a shift or change in *periodicity of this finger print and, using* suitable algorithms, the magnitude and location of perturbations can be recovered with (sub)mm spatial resolution**
- ❖ **Permitting temperature and strain sensitivitivies in the order of a fraction of 1°C and few microstrains in OF lengths up to 70 m**

- **Brillouin interaction causes the coupling between optical and acoustic waves when a resonance condition is fulfilled**
- **The resulting back-scattered light shows a frequency shift relatively to the incident light of > 11 GHz, which is strain and temperature dependent**
- **Determining this Brillouin shift directly provides a measure of temperature or strain**



Distributed fibre optic sensing based on Brillouin scattering (adapted from Hiroshi Nasure, Mie University, Japan)

- **Performance achieved with the system**

  Strain resolution of 2 μstrain

  Temperature resolution of 0.1 ^{0}C

  Spatial resolution of 1 m over 5 km, or 2 m over 25 km

- **Another possible approach for Brillouin distributed sensing based on the synthesis of the optical-coherence function does not require pulse modulation of the light into the system, but instead sinewave intensity modulation**

  Spatial resolutions of the order of 1 cm have been obtained, but at smaller fibre lengths

Distributed sensing based on Brillouin scattering applications

- Monitoring of large structures
  mainly strain measurement
- Monitoring of oil and gas wells and pipelines
- Dams and bridges
- Power lines
- Security borders
- Highways

- Raman scattering in optical fibres has a much higher power
- Threshold for OF with attenuation of 0.5 dB/km at 1300 nm core diameter of 6 μm
  - Brillouin scattering ~ 80 mW
  - Raman scattering ~ 1.4 W,
- Raman scattered light has a much larger frequency shift ~ 13 THz

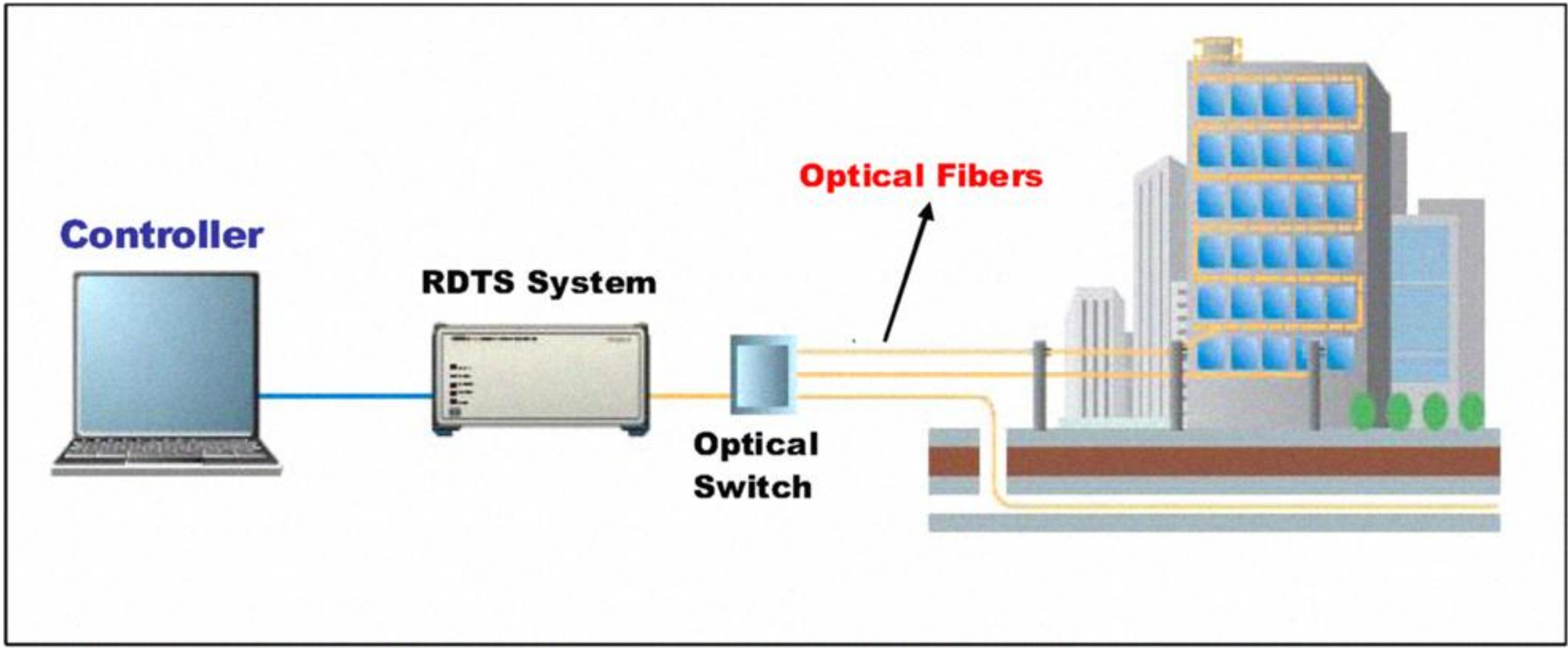
Raman based distributed temperature measurement (ROTS)

- ❖ Temperature resolutions of 1°C
- ❖ Spatial resolution of 50 cm
- ❖ Measurement length ~ 2 km

❖ Distributed temperature monitoring of large structures

❖ Gas and oil tanks (where a local temperature change can be an indication of leakage)

❖ Important application of ROTS is in building fire detection



1l1ustrative application ofa Raman based distributed temperature measurement system in building fire detection (adapted from Yokogawa, 2007)

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