Basic principles and technologies for fibre sensing

NREN Fibre Infrastructure for Sensing

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GÉANT Infoshare

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Agenda

- A brief history of fibre sensing.
- Basic principles – physics.
- Fibre sensors classification.
- Fibre sensors – deployment.

A brief history of fibre sensing.

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- Fibre as a sensor studied from 1960s.
- Standard optical telco fibre is made of silica (silicon dioxide) with dopants (like germanium dioxide).
- Temperature and/or strain make molecules to move, and it is possible to detect such external disturbances inside the fibre because light properties are changed.
  - Amplitude, frequency, phase, polarization.
  - Not all these properties are changed at the same time and under all circumstances.
- Also known as cable sensing but the real sensor is an optical fibre, not optical cables.

A brief history of fibre sensing.

free images from unsplash.com

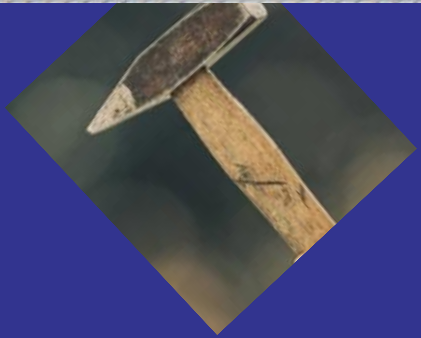
- Fibre is very tiny – comparable to human hair in diameter (approx. 100 microns).
- Let‘s try to imagine another type of sensor – any metal tube or bar and a big hammer.
- When the tube is hit by the hammer on one end, we can hear (and feel) this disturbance along the tube.
- Human ‚detectors‘ are limited, we could use better ears or better electronics.
- That‘s what we do with glass tubes/bars.

Basic principles – physics.

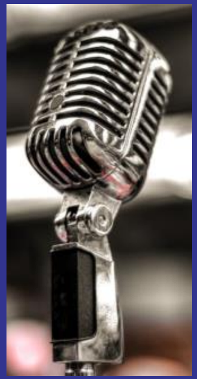
free images from pexels.com

- Metal bar as a sensor.

700 Hz to 200 kHz



20 Hz to 20 kHz



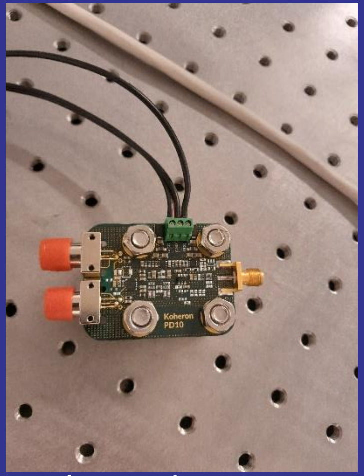
0 Hz to MHz

Basic principles – physics.

- Glass bar as a sensor
- Not hammers, but lasers.
- Not ears but photodetectors.
  - Photodetectors can be located on the same end of the fibre as laser (DAS), or on the opposite end (polarimetry/SOP).

laser

fibre



photodetector

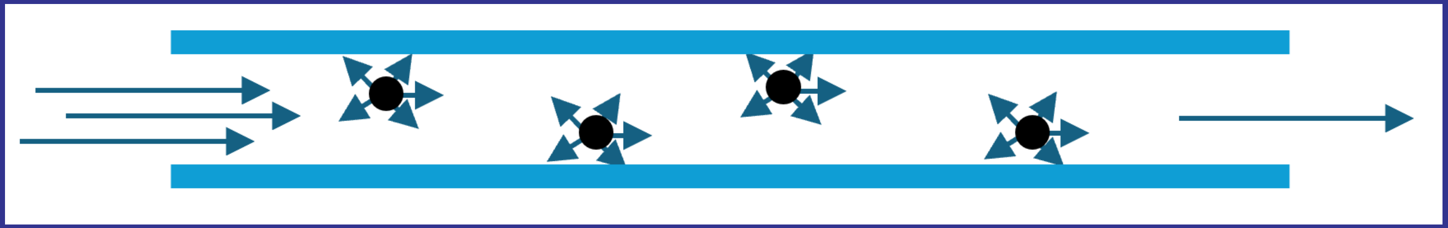
DATASTORAGE
ANALYSIS
AI classification
…

Fibre sensors – a basic classification.

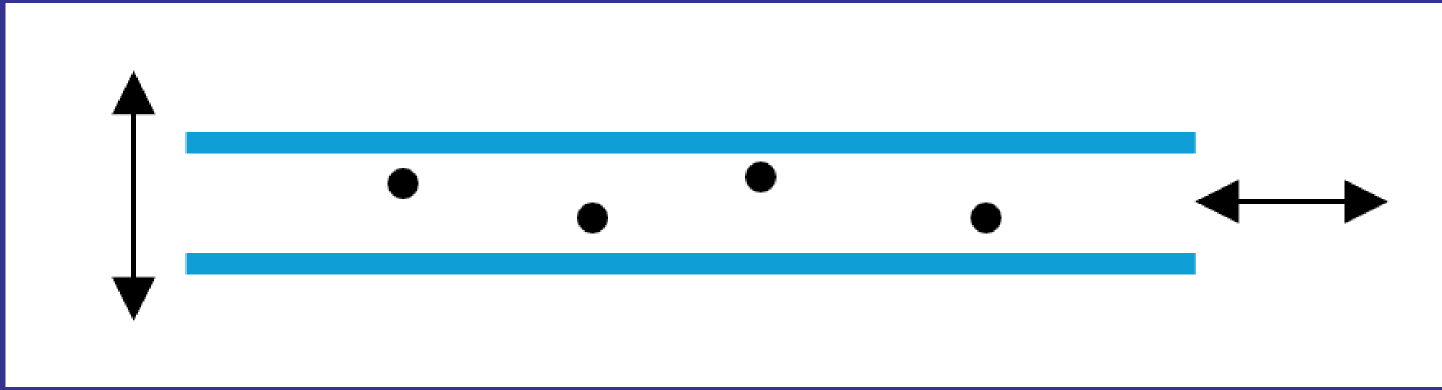
- Distributed fibre sensors are used frequently because no other elements (e.g. mirrors) are required – substantial cost reduction.
- Two basic techniques can be used: OTDR (Optical Time Domain Reflectometry) and SOP (State of Polarization).
- In the fibre industry, traditional OTDR is well known and used very frequently to check whether fibre is OK or not.
- For fibre sensing, advanced OTDR principles are used, and we have DAS (Distributed Acoustic Sensing) equipment.

Fibre sensors – a basic classification.

- DAS uses reflections from impurities in the fibre when a laser light hits them, to measure stretch and strain.



- SOP uses the changes in polarization of the laser light as it exits the fibre to detect changes made to the fibre the laser light travels through.

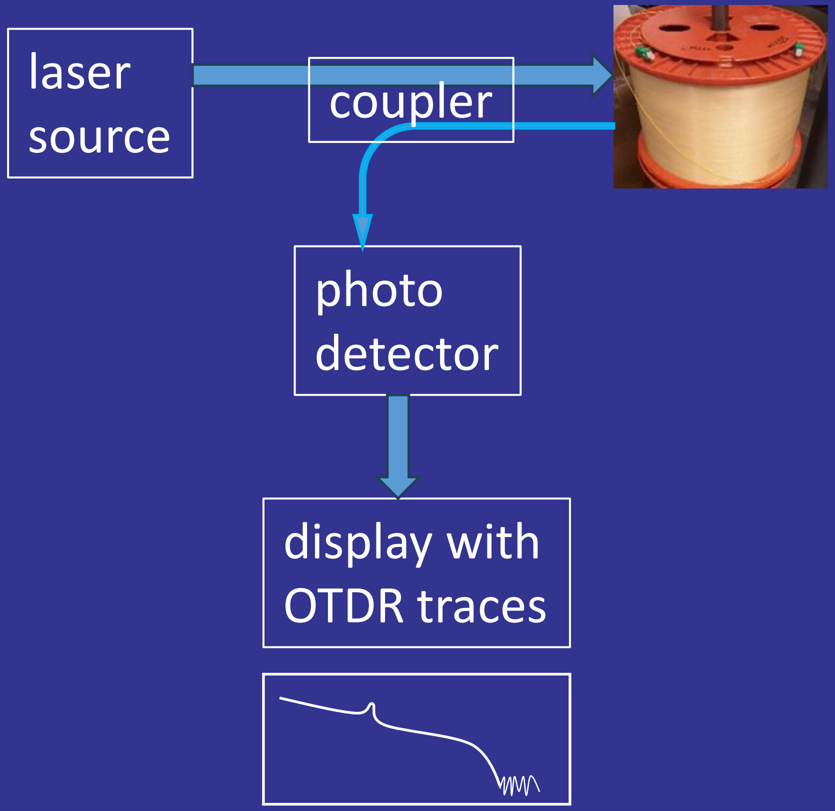


pixabay.com

Fibre sensors – a basic classification.

- Traditional OTDR utilize Rayleigh scattering.
  - Only amplitude is evaluated along the fibre so unwanted losses and breaks are easily detected.
- There are other scattering processes, like Brillouin and Raman, but these OTDR methods are used less often (weaker effects compared to Rayleigh).
- Traditional OTDR method has been improved and phase-sensitive (ϕOTDR or ϕ-OTDR) and coherent (COTDR) methods are available for DAS.
  - Amplitude and phase are evaluated.
  - A better laser is required.

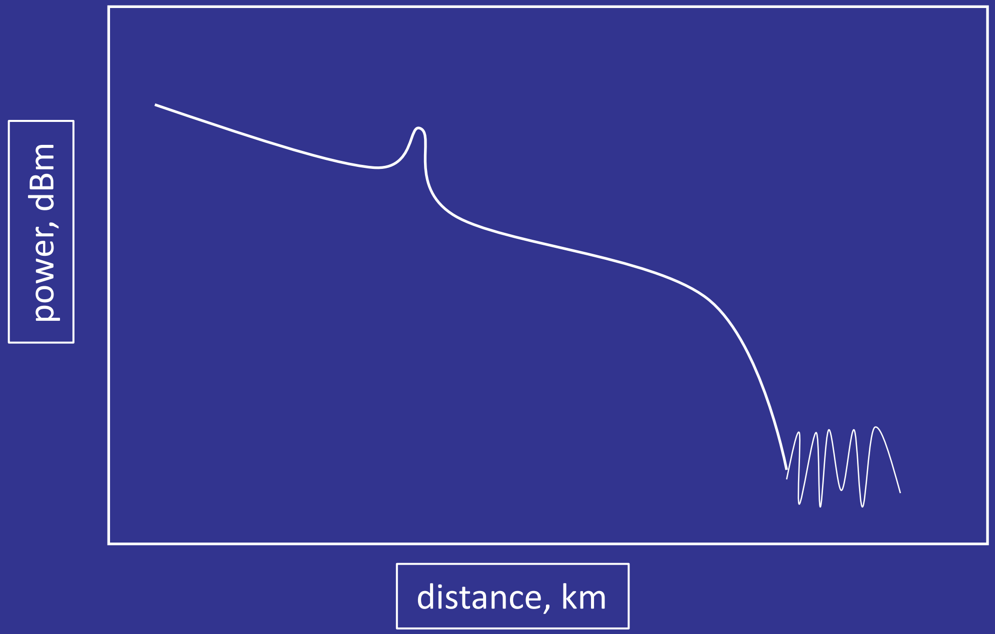
OTDR basic principle

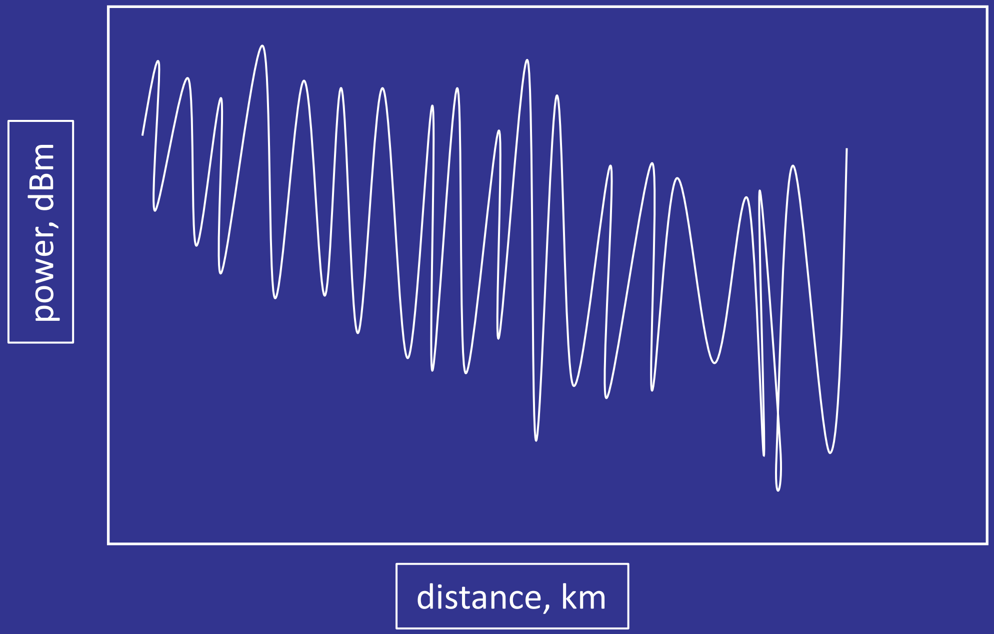


real OTDRs have more components

Fibre sensors – a basic classification.

- OTDR vs DAS-OTDR measurements.

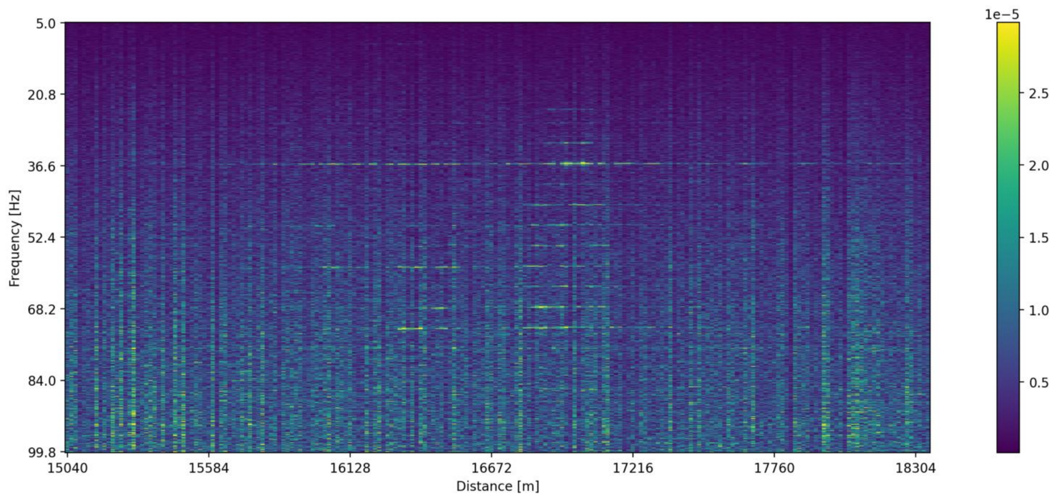




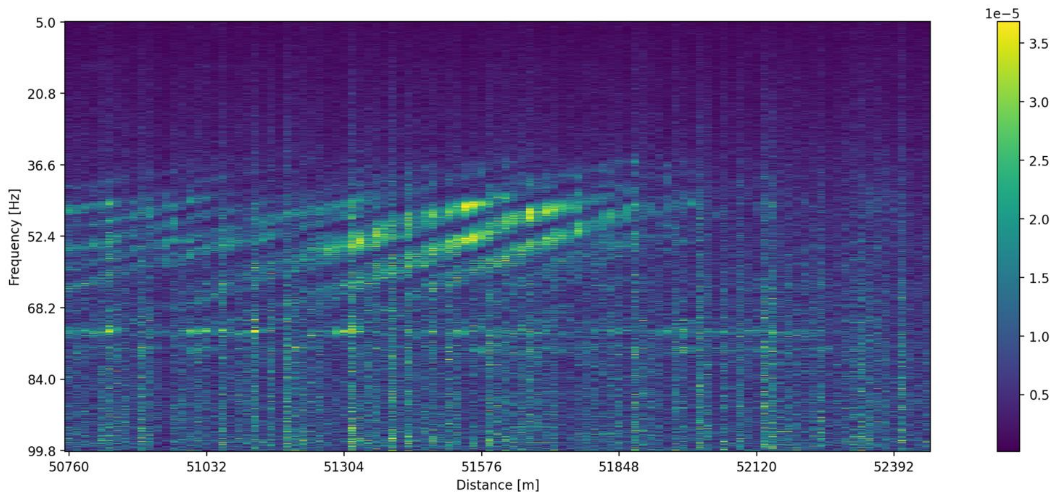
Fibre sensors – a basic classification.

- DAS results displayed as OTDR traces can be difficult to read.
- DAS results are displayed as waterfalls.
- Distance vs frequency or strain.

ship

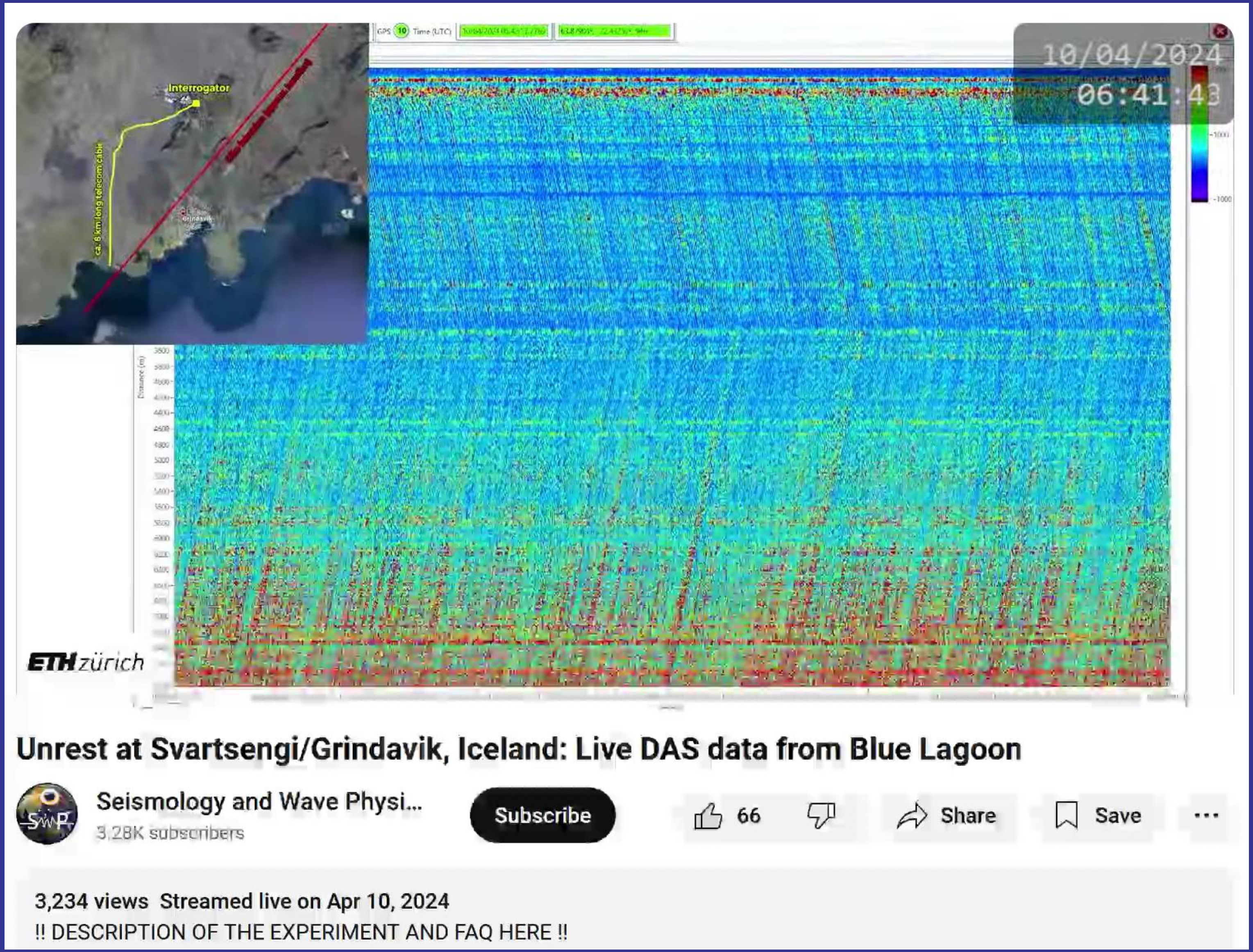


whales



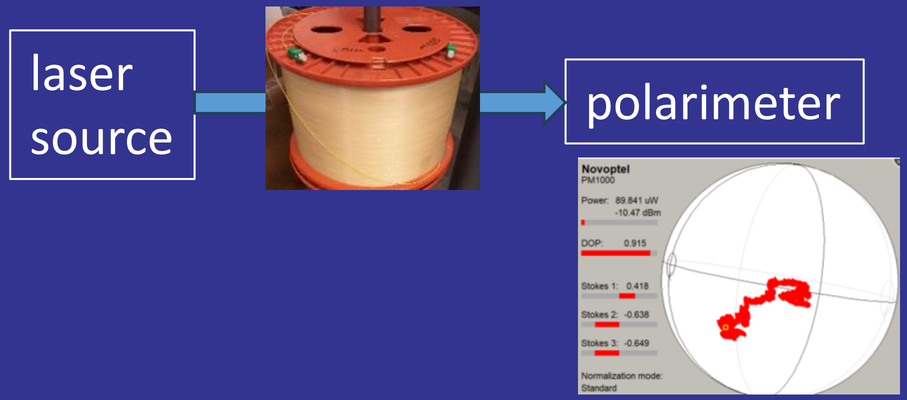
Fibre sensors – a basic classification.

- **Live DAS data from Blue Lagoon**
- https://www.youtube.com/watch?v=s3LokeYGUZI
- horizontal axis: time
- vertical axis: distance
- colours: proportional to the recorded strength in strain rate
- more Earth shaking = more deformations = more intense colours

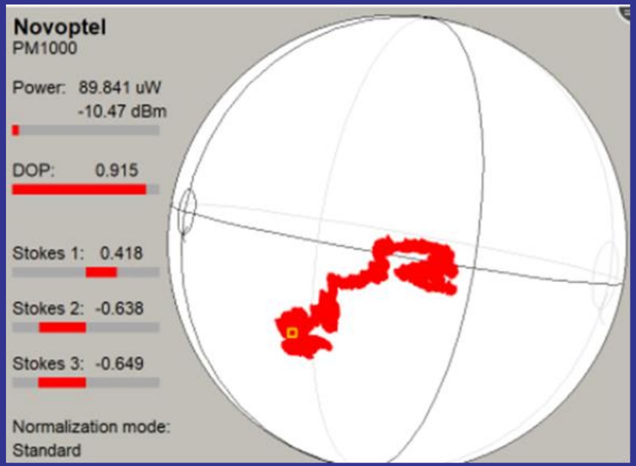


Fibre sensors – a basic classification.

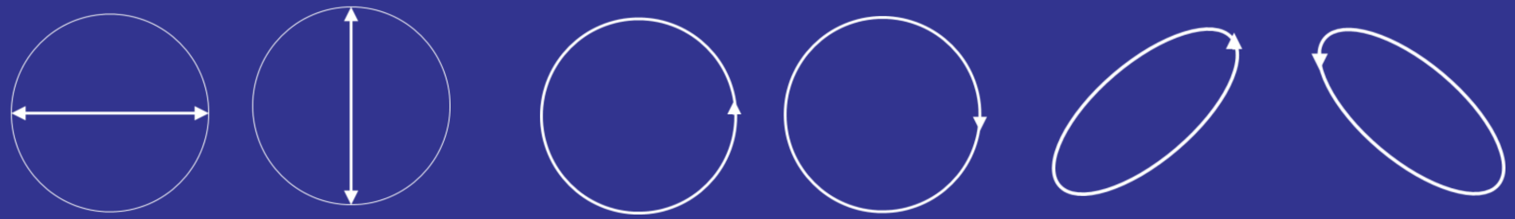
- All OTDR methods mentioned so far can be described as ‚single ended‘ i.e. source of the signal (laser) and detector are placed in the same instrument.
- SOP is different.
- In this case we can use any signal transmitted in fibre (e.g. data signals, optical supervisory signals) and use a polarimeter, which is located at the end of the fibre.

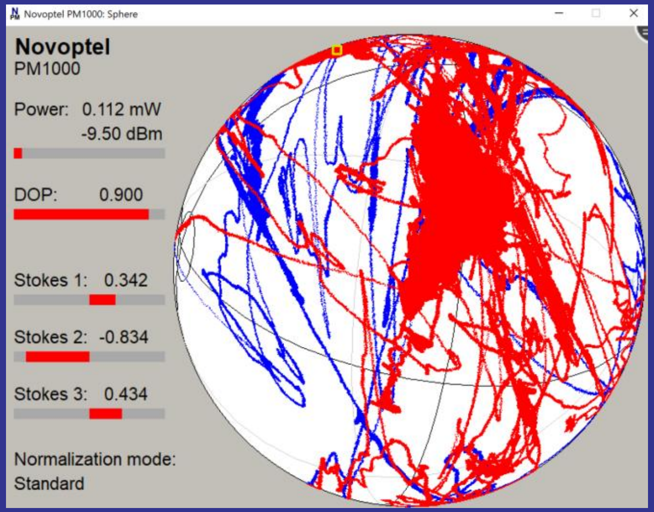


Fibre sensors – a basic classification.



- State of Polarization – SOP. How the vector of the electric field behaves.
- Linear, circular, elliptical polarizations.





- Results can be displayed on so called Poincaré sphere.

Fibre sensors – SOP pros and cons.

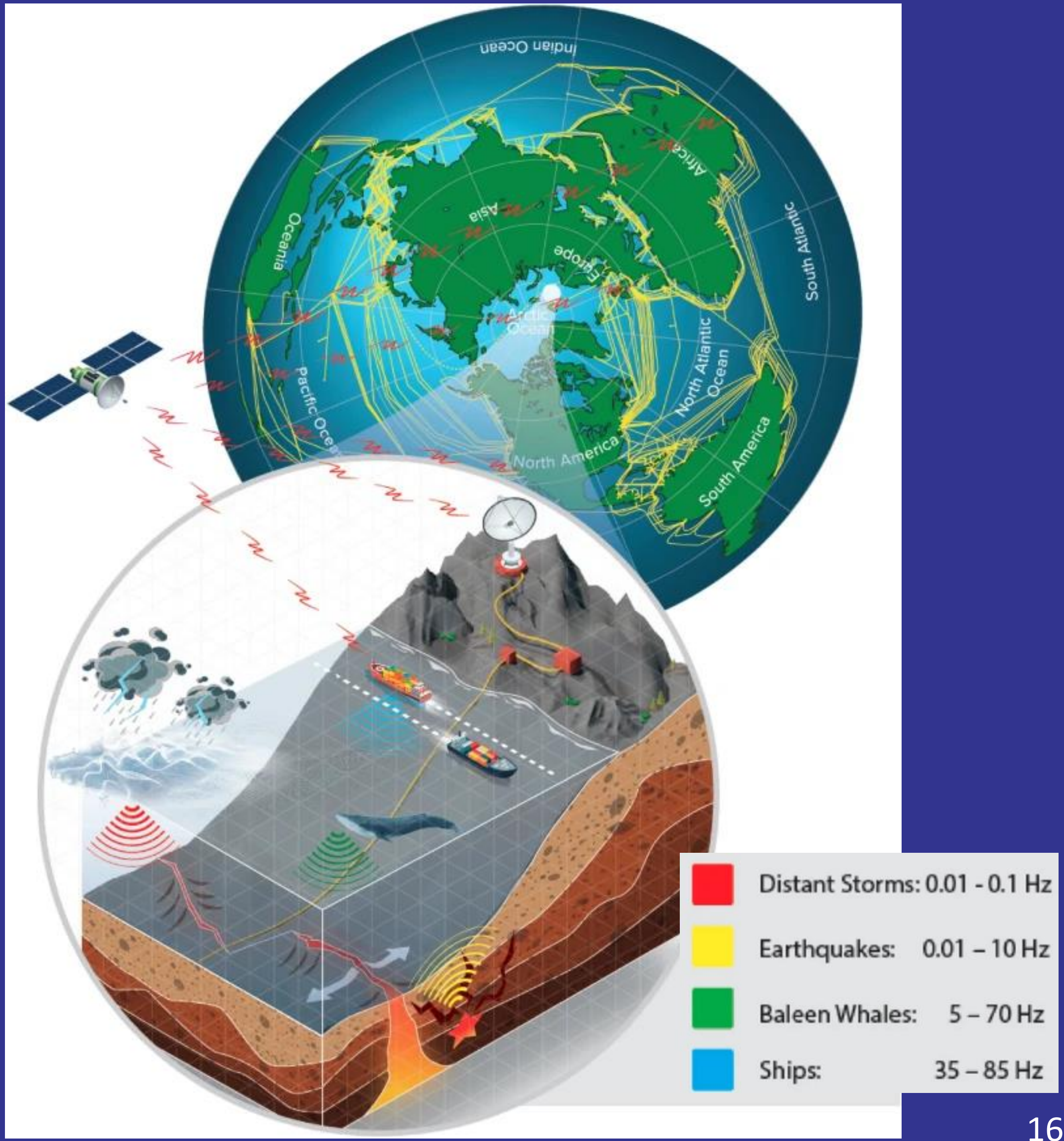
- Rather easy to implement, cost effective (no high-quality lasers required).
- Long distances – hundreds of kilometres (through amplifiers).
- Localization of events along the fibre is not possible.
- But when we use two signals with different wavelengths (‚colours'), this ‚event location' problem can be improved.
    - Different wavelengths travel at different speeds – this effect is called Chromatic Dispersion CD. We can calculate the distance where something happened.
    - We can use 2 wavelengths spaced enough, or 2 close wavelengths with precise time stamping (White Rabbit).

APEX technologies

Novoptel

Fibre sensors – DAS pros and cons.

https://www.nature.com/articles/s41598-022-23606-x



- De facto standard.
- Localization of events is very good.
- Distance is limited, as with any OTDR (amplifiers block it).
- Higher price.

OptaSense

Fibre sensors – deployment.

- In NRENs/GEANT fibre networks, two different fibre sensors are used and deployed.
- DAS.
  - OTDR (phase or coherent, not traditional) method.
  - Reach limited but de facto standard.
- SOP.
  - Using external polarimeters these days but high speed digital coherent receivers are waiting round the corner.
- There are other methods – interferometry.
  - Not so widespread for sensing. Rather expensive but was here before DAS. Utilizing coherent (i.e. very stable) frequency sources - lasers. Time and frequency networks are necessary, precise timestamping is a must.

Fibre sensors – deployment.

- **Fibre sensing can be used together with data transmissions** – all signals are transmitted in one fibre.
  - Using wavelength multiplexing, Dense or Coarse WDM technologies (DWDM, CWDM).
  - Polarimetry can be deployed without any problems, even Optical Supervisory Channels (OSC) can be used for sensing.
  - DAS may interfere with data – precaution is desirable (as always).
- All this is relatively easy – but how to discover/find the useful signals in the noise?
- Much more difficult. Huge amount of (not only) raw data. More on this later.

Resources (free, no logins required)

- https://www.edmundoptics.co.uk/knowledge-center/application-notes/optics/introduction-to-polarization/
  - Really nice animations for SOP.
- https://www.mdpi.com/1424-8220/20/22/6594
- https://www.mdpi.com/1424-8220/19/19/4114
- https://www.nature.com/articles/s41598-022-23606-x
- https://subtelforum.com/stf-mag-feature-using-existing-submarine-cables-as-a-tsunami-warning-network/

- untagged pictures provided by authors

Thank You

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