

Fiber optic sensing technology, Overview

NDN2026

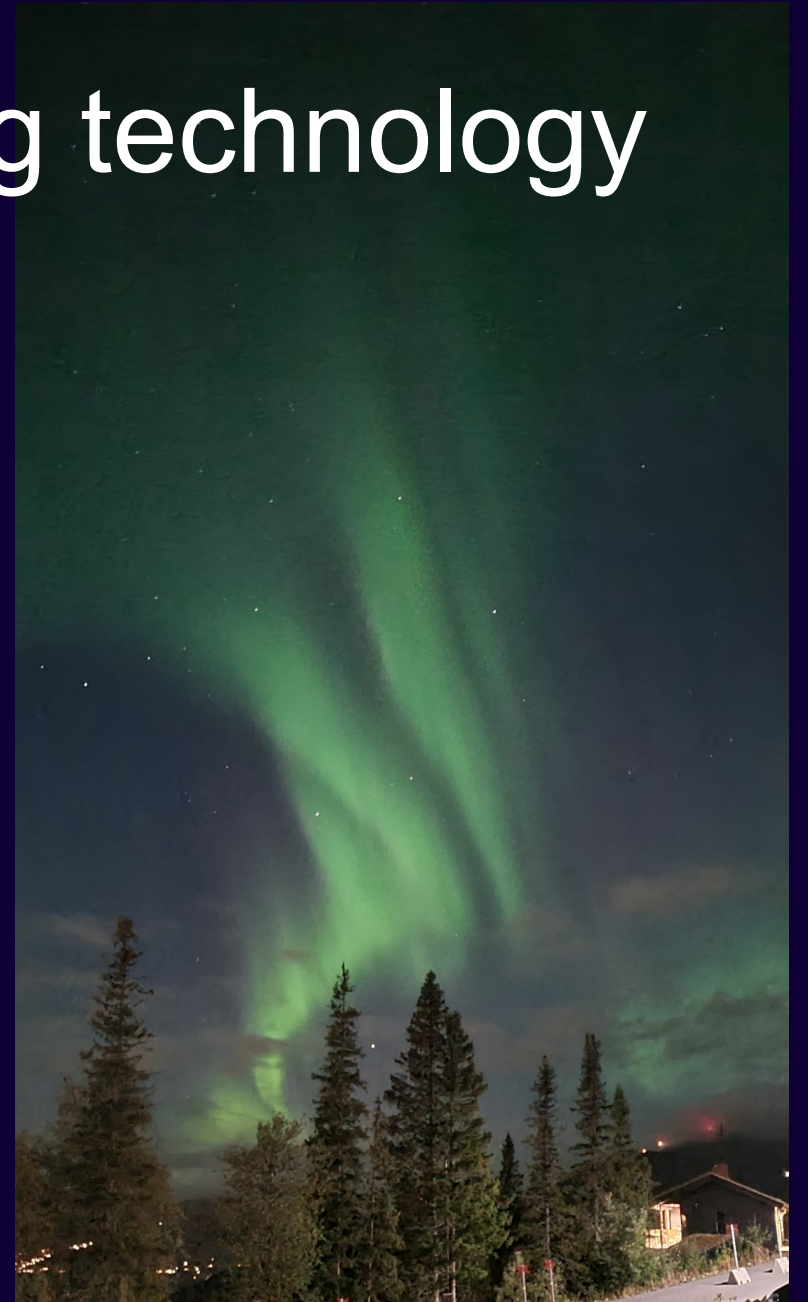
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Sikt, Norwegian Agency for Shared Services in Education and Research

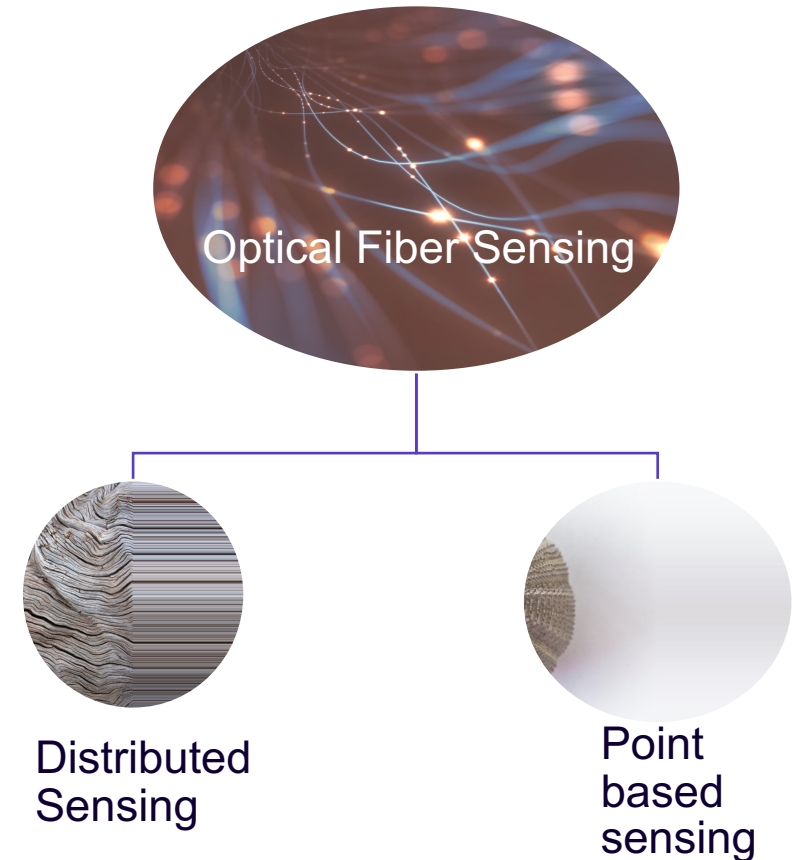
Definition: Fiber optic sensing technology

- Creating a continues interconnected sensor array along the standard optical telecommunication cables by analyzing the light changes as it travels through the fiber core.

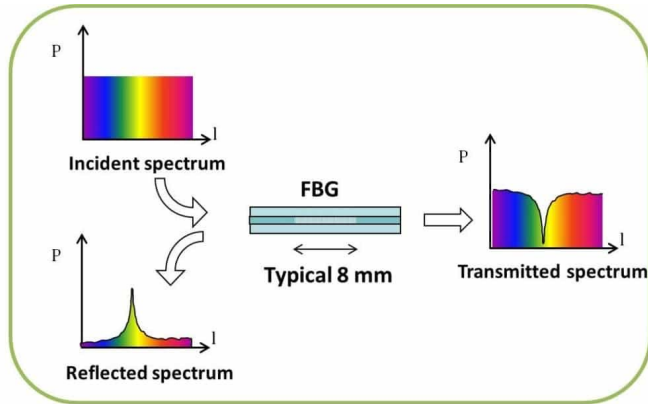


Optical Fiber sensing

- Point based sensing: discrete sensors measuring at pre-determined points
 - A widely used device for that is “Fiber Bragg Grating”
- Distributed sensing utilizes the optical fiber to enable simultaneous measurements at multiple locations along the fiber
 - Commonly based on Scattering properties of the light
 - State Of Polarization
 - Phase Interferometry

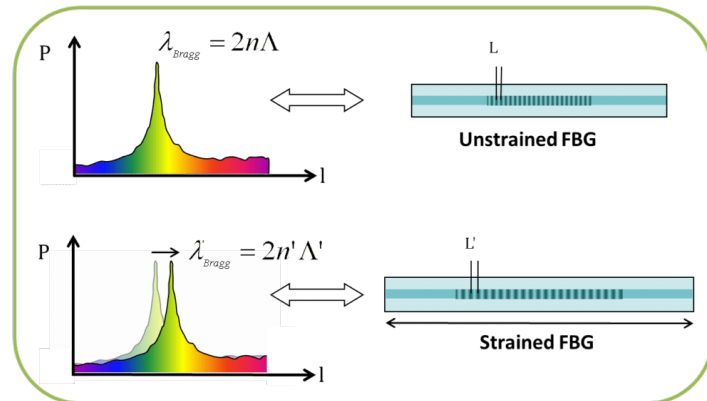


Fiber Bragg Grating



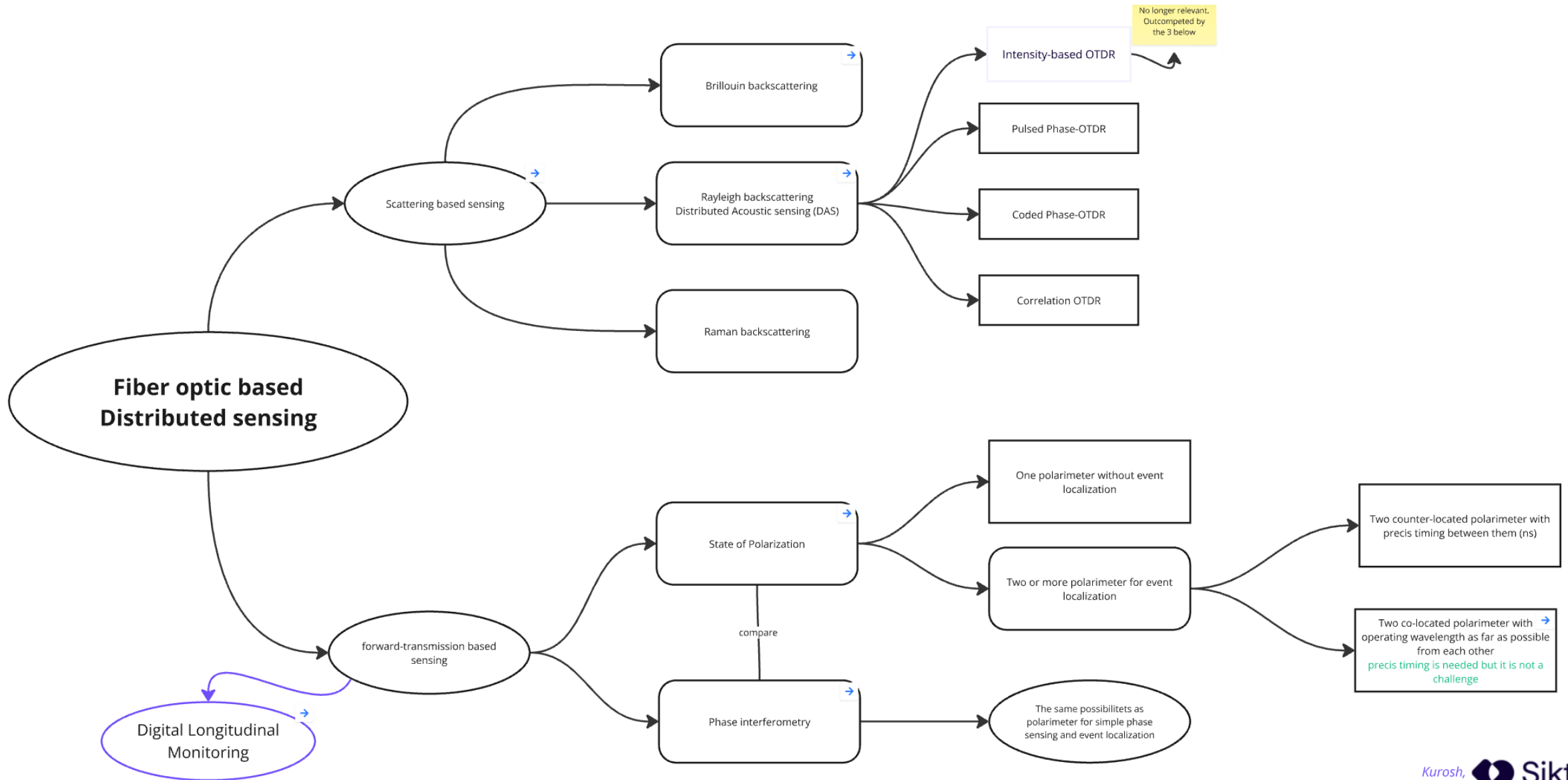
- FBG is one of the components which is widely used at Point based sensing
- A FBG is a kind of fiber grating based reflector which reflects a particular wavelength depending on the grating period

$$\lambda_B = 2 n_e \Lambda$$



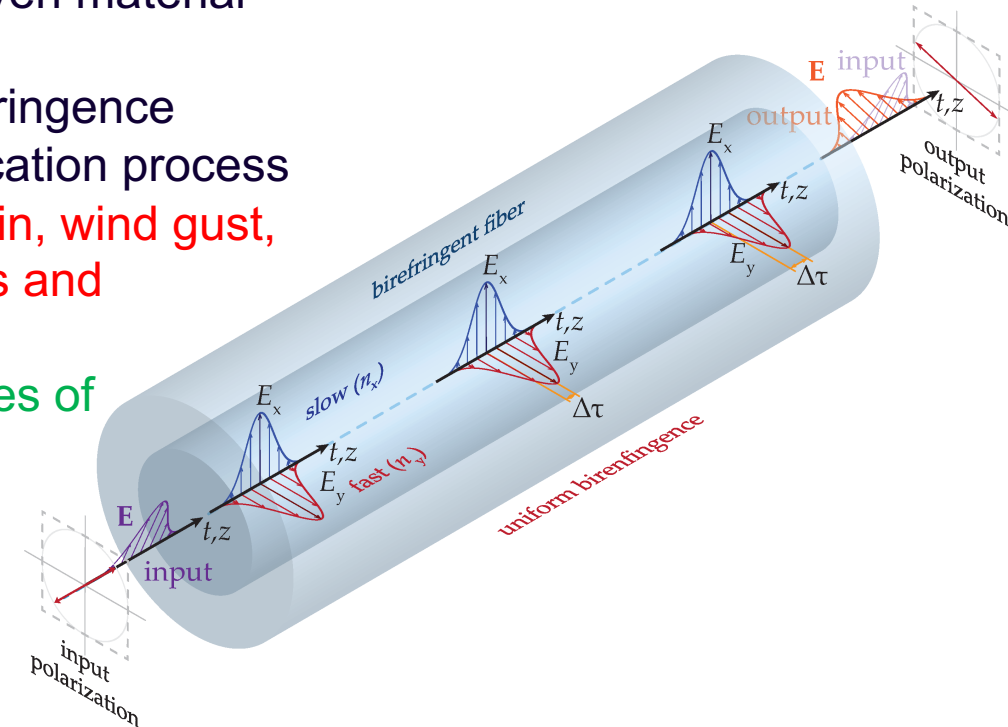
Images: <https://fbgs.com/technology/fbg-principle/>

- First have been demonstrated in 1978.
- In 1989, The technique uses the interference pattern of ultraviolet laser light to create grating pattern.



What is the State Of Polarization (SOP)

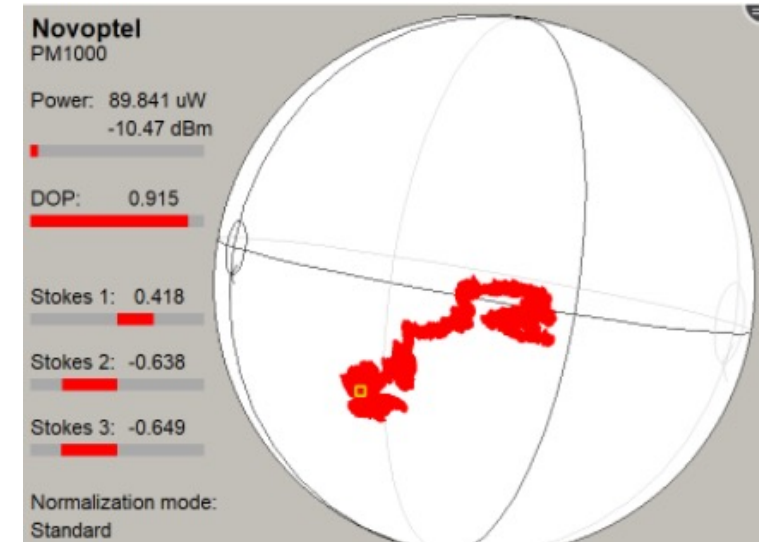
- Light beam is composed of two **orthogonal electrical vector field** components. Polarized light occurs when these two components differ in **phase or amplitude**.
- Different polarized optical waves propagate with different propagation constants which is related to intrinsic fiber **birefringence**
- The **intrinsic fiber birefringence** arises from the imperfect fiber manufacturing, such as **core ellipticity**, bending, twisting, or even material impurities and inhomogeneities
- Both **internal and external factors** can influence the fiber birefringence
 - Internal issues relate mostly to imperfections of the fabrication process
 - **external factors: changes in environmental conditions (rain, wind gust, snow, heat, or temperature variations), mechanical stress and pressures**
- **Measured SOP in a given time is a result of stochastic changes of polarization along the fiber path**



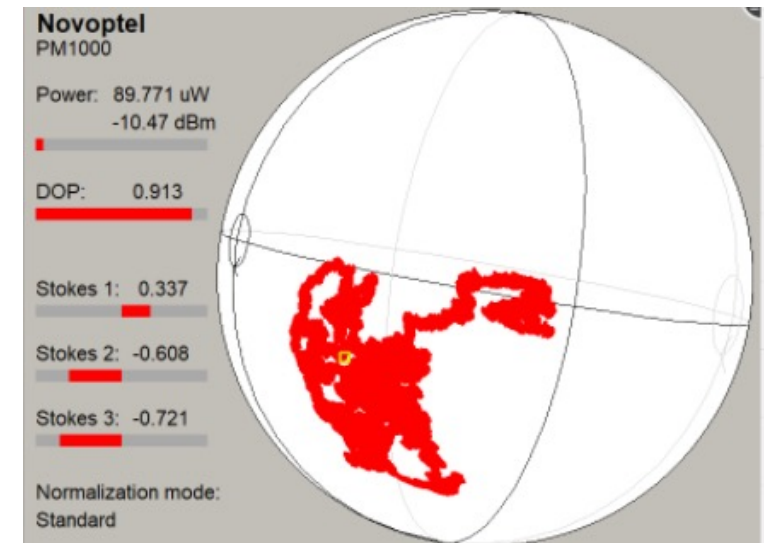
The State Of Polarization

Measurement tools

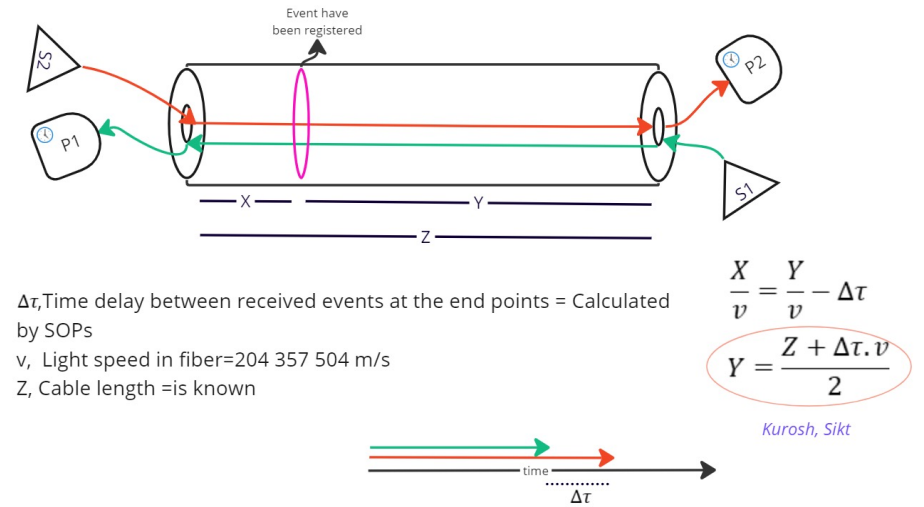
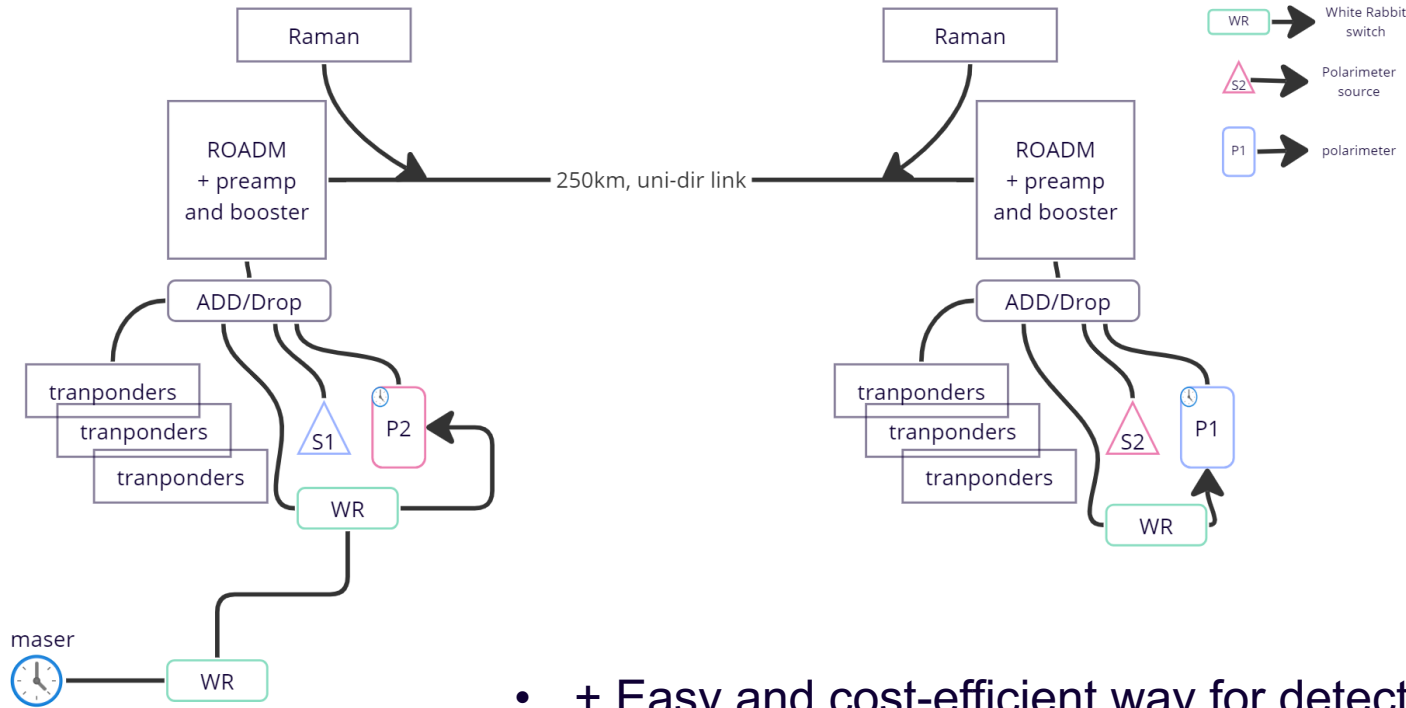
- The Stokes parameters are a set of values that describe the polarization state
- Stokes parameters are used in polarimeter to monitor the state of Polarization
- In 1852, Sir George Gabriel Stokes (1819 - 1903, mathematician, physicist, politician and theologian of Ireland), found that any **state of polarized light could be completely described by four measurable quantities**
 - The total intensity of the light (polarized + unpolarized) S_0
 - The intensity of linear horizontal or vertical polarization S_1
 - The intensity of linear $+45^\circ$ or -45° polarization S_2
 - The intensity of right or left circular polarization S_3



Poincare Spheres



Field test 2024: Event detection and localization by SOP the concept and test layout



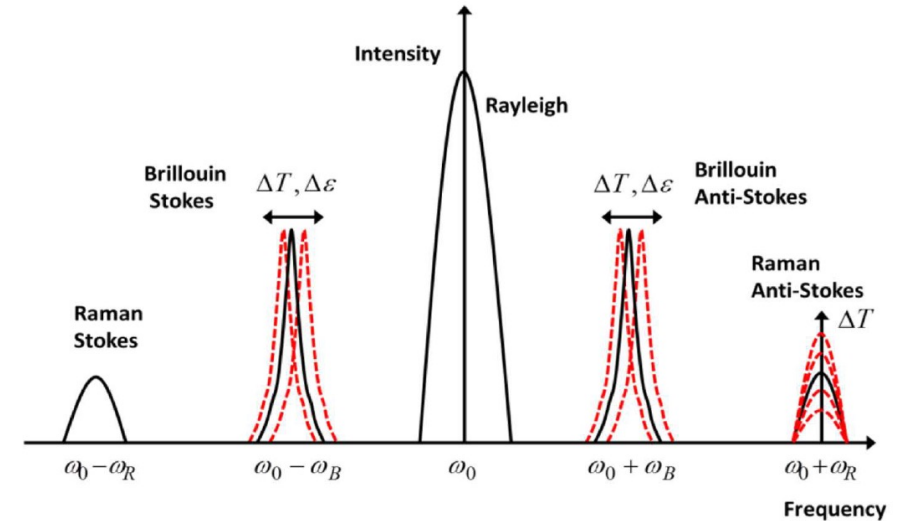
- + Easy and cost-efficient way for detection and localization of event (2 polarimeter with high level of time synchronization)
- Event identification is limited
- multiple simulations event can't be detected separately

Scattering based sensing



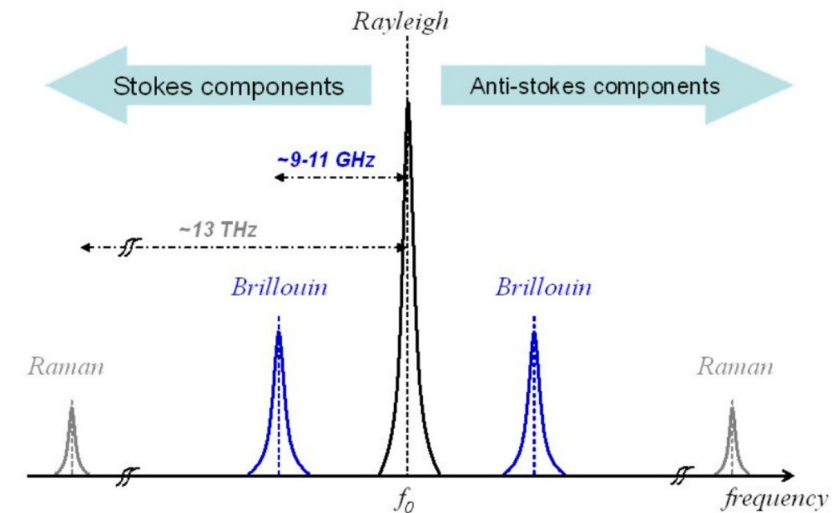
Spontaneous and stimulated scattering in optical fibers

- Scattering in general caused by interaction of light with atomic structures and particles in the fiber in one way or another
- The scattering mechanism used for sensing
 - Rayleigh Backscattering (RBS),
 - Spontaneous Raman Scattering (SpRS)
 - Spontaneous Brillouin Scattering (SpBS) and Stimulated Brillouin Scattering (SBS)
- Each scattering process is always present in optical fibers
 - no fiber is free from microscopic defects or thermal fluctuations which originate the three processes.



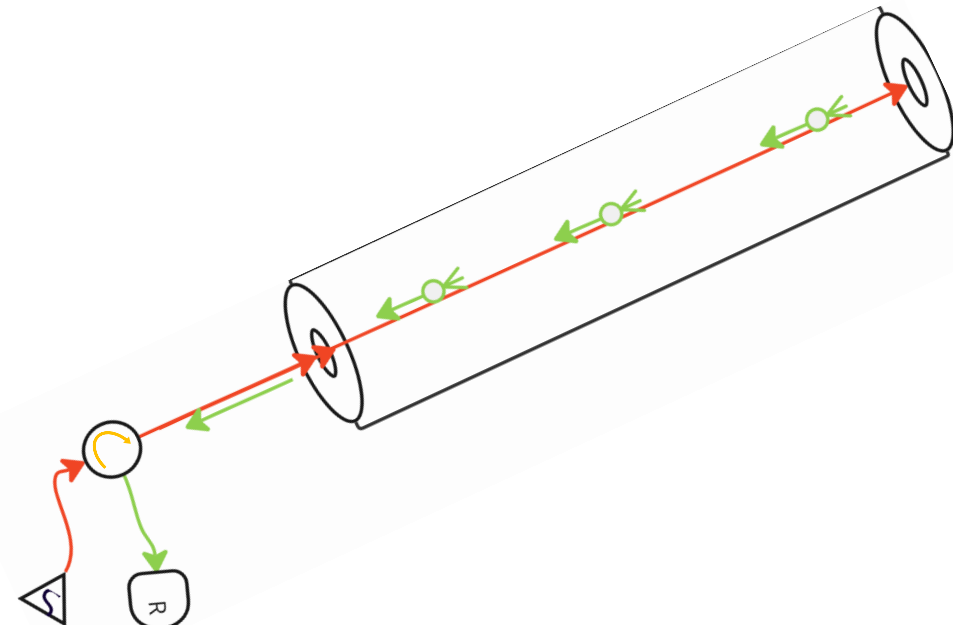
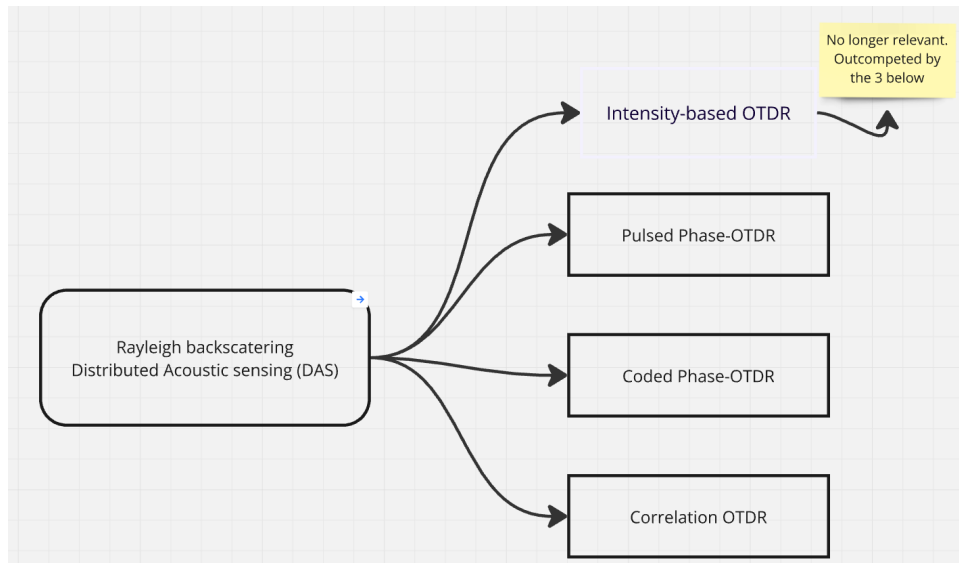
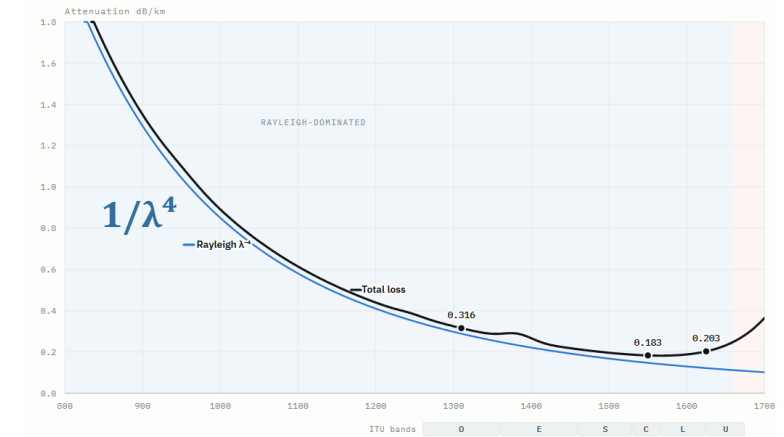
Stokes scattering — the photon gives up energy to excite the molecular vibration further (dominates in fiber)

Anti-Stokes scattering — the photon absorbs energy from a molecule already vibrationally excited

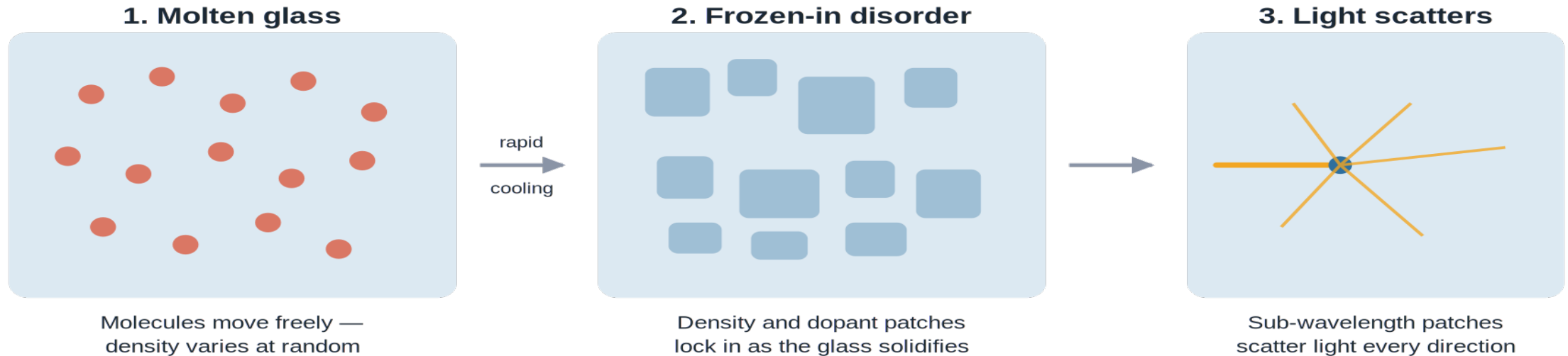


Rayleigh backscattering based Sensing Distributed Acoustic Sensing (DAS)

- Elastic collisions between the light wave and the silica molecules result in **Rayleigh scattering**.
- Rayleigh scattering accounts for over **80%** of attenuation in optical fiber in 1550nm area.
- Rayleigh backscattering can be used to measure the Strain. Since the strain is often caused by acoustic vibrations, the term DAS is normally used for these measurements.



Frozen-in disorder from the melt



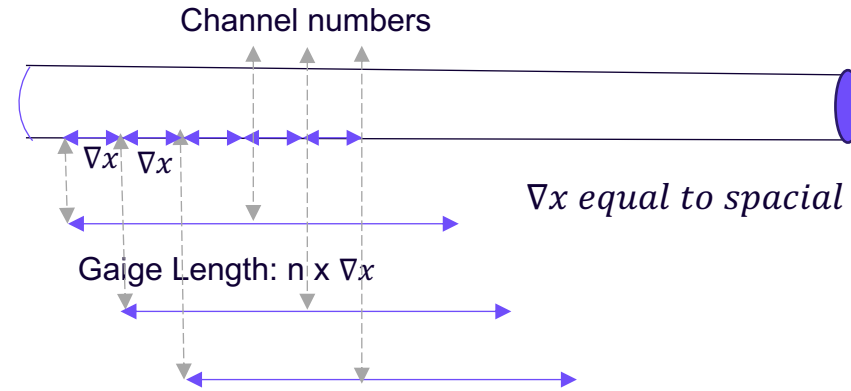
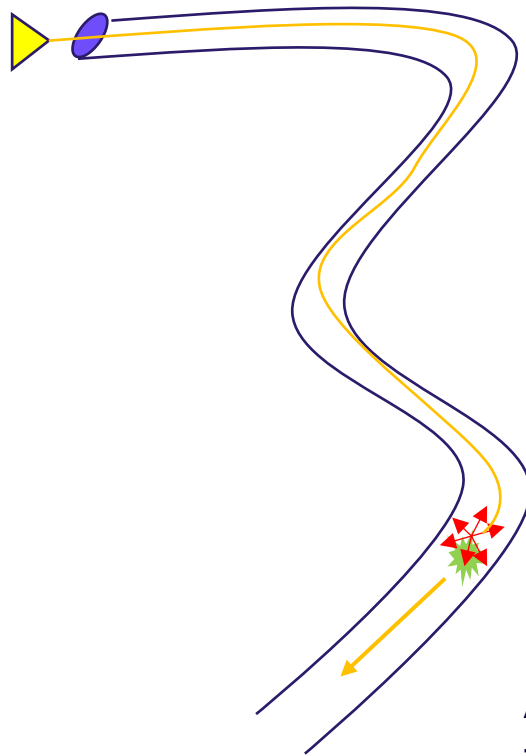
$\sim 10^{-6}$

typical refractive index variation Δn

a few nm

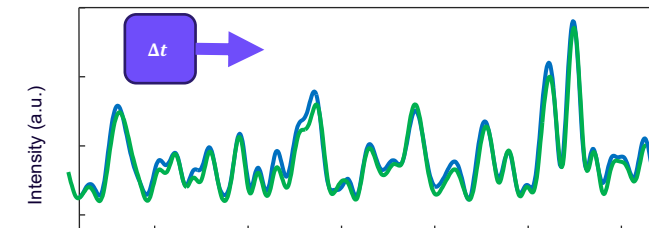
correlation length of each fluctuation

Measurement principle of DAS



∇x equal to spacial resolution determined by pulse width

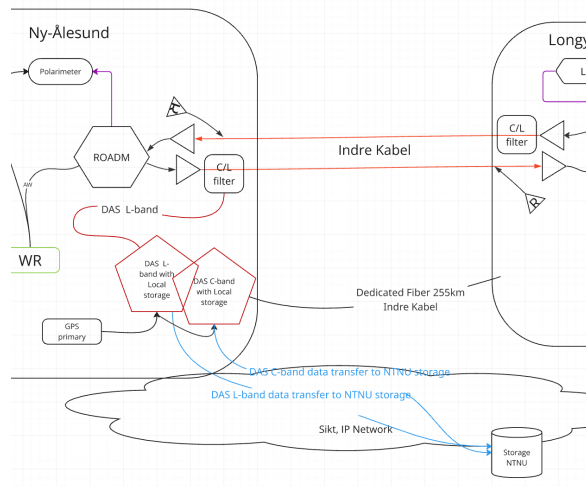
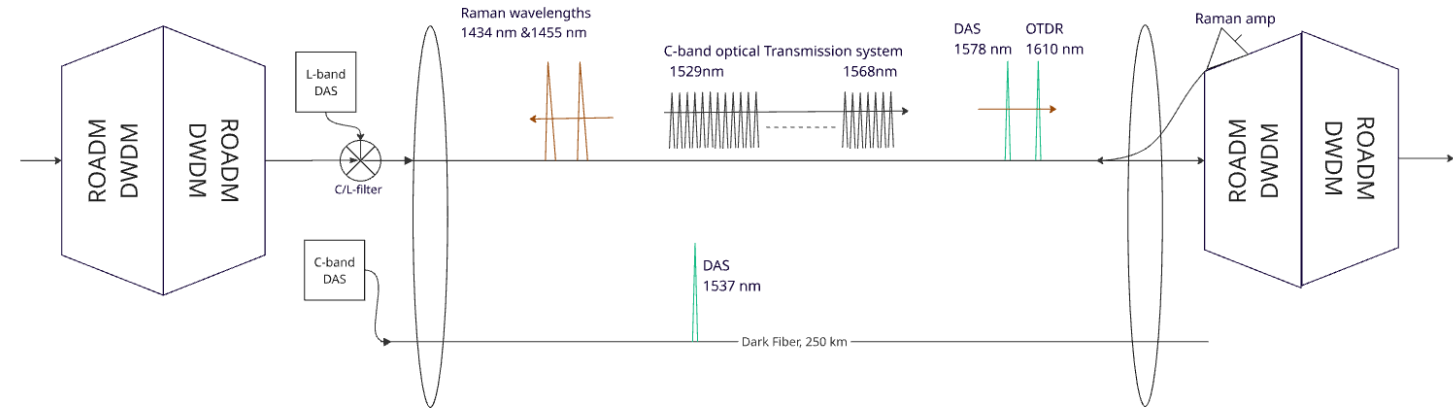
Acoustic frequency measurement is done by detecting the phase shift of the signal during Gauge length which is corresponding to the detected acoustic frequency of the signal originated caused by an object like ship.



DWDM and DAS coexistence (Sikt)

We run DAS in coexisting with DWDM in several different operational environment

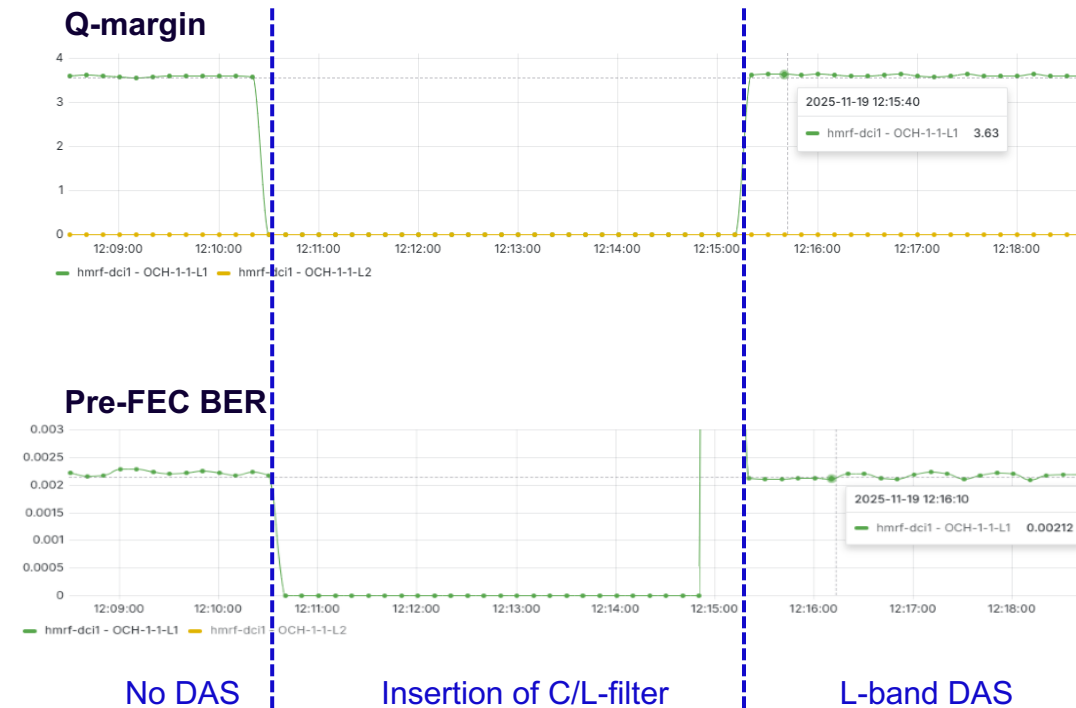
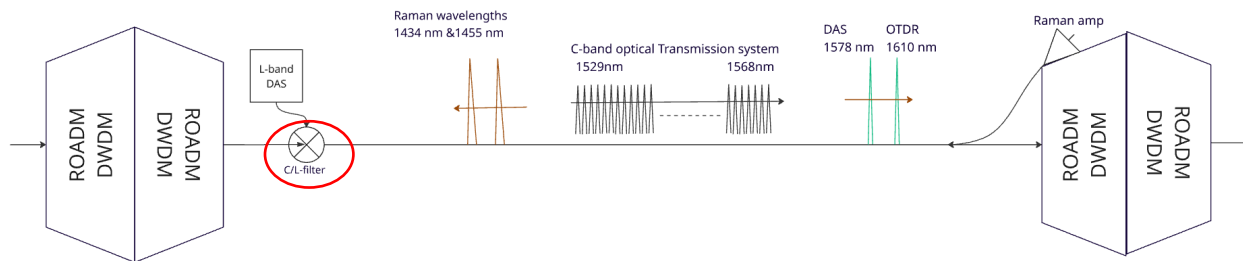
- LAB
- Terrestrial
- Passive submarine cable



	No Raman	Raman
Co-propagating with C-band channels	With normal DAS operation power range, there will be no issue on running channels. With full DAS power the higher modulation format, will be degraded but QPSK channel is less affected. To totally isolate the DAS signal from the channels it could be good to use a C/L-filter at receiver side (1,5dB insertion penalty)	DAS with normal operating power range has no negative impact on performance quality on the running channels. We see a change on noise floor (1-1,5dB)
Counter-propagating with C-band channels	We see no signal degradation on running channel.	Not possible We can't insert C/L-filter on Rx side of DWDM where we have the Raman pump

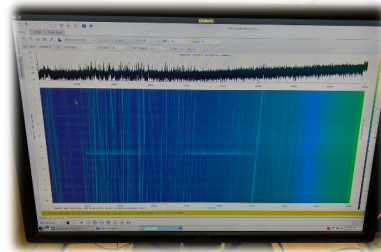
A typical live L-band DAS deployment scenario

- L-band DAS deployed in a commercial network
→ No detour, no connectors; DAS connected to live carrying fiber through spliced C/L-filter → No excess loss for the DAS
- 16QAM modulated telecom channel monitored for transmission performance
- No increase in pre-FEC or post-FEC bit error rate and no degradation of Q-margin when inserting the L-band DAS



DAS co-exist with DWDM in Sunet

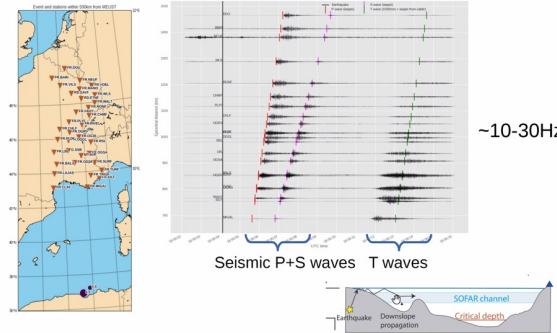
- Tests in various scenarios on
 - Aerial fiber
 - Roadside fiber
 - Submarine fiber
- Installation
 - Three installed in the network, running continuous measurements.
 - One for mobile research.
 - Three more are in use by researchers in the university community.
- L-band DAS
 - Filtering is easier when working with C-band DWDM.
 - Tests been done in the C-band with OADM filters for a dedicated 50 GHz wavelength, wavelength needs to be blocked in the DWDM system. Have more impact on the DWDM when running co-propagating.
- Co-propagating DAS
 - Works better with Raman amplifiers in the Sunet line system.
 - Filters before the following EDFA are important. DAS pulses will trigger the EDFA pumps to oscillate.
 - The amplitude of the DAS energy pulse must be controlled so it does not drive the fiber into nonlinearity. In Coherent optics see an increased bit error rate and eventually fail.
- DAS amplification with DWDM raman amplifiers



A sample of DAS applications

T waves

M6.0 earthquake in Algeria 18/03/2021

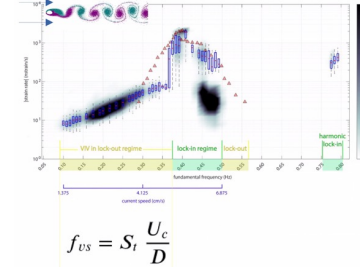


~20Hz

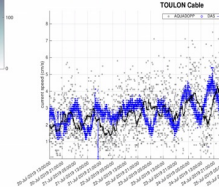
~10-30Hz

Deep-sea currents

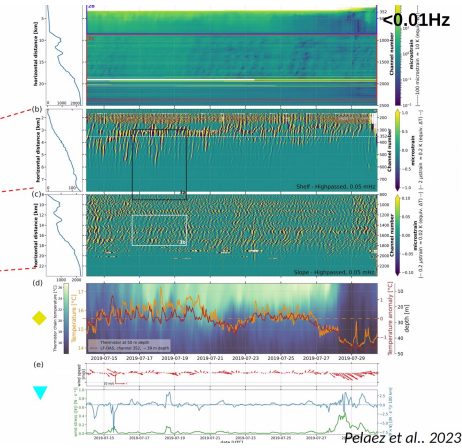
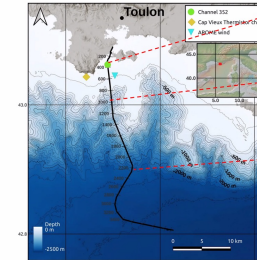
Vortex Induced Vibrations (VIV)



Validation with a nearby ADCP

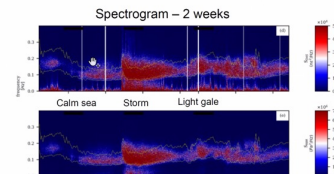
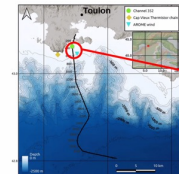


Thermometry with LF-DAS



LSPM cable, Toulon - 2 weeks, 2019

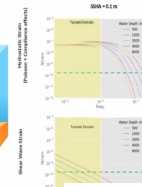
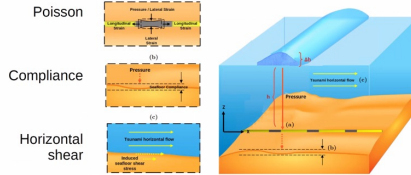
Surface gravity waves



0.1Hz

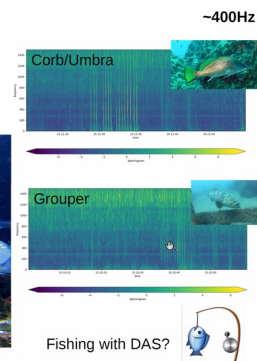
Can we detect tsunami waves?

3 candidates for DAS signal:



Biophony (at a lower volume)

Experiment with Oceanographic Museum in Monaco

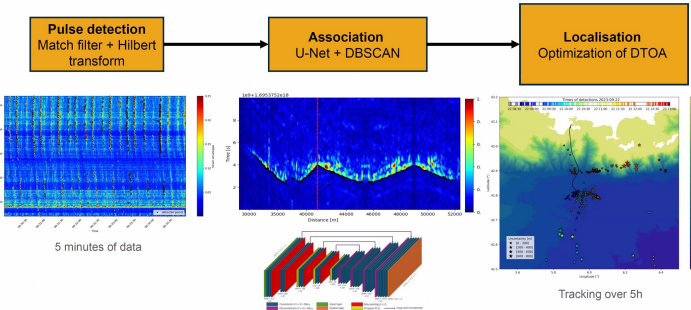


Fishing with DAS?

Tracking of fin whales

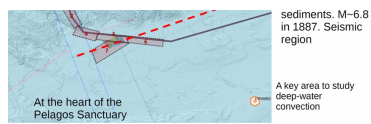


~20Hz



N Dumont, Master intern, Avril-Août 2024

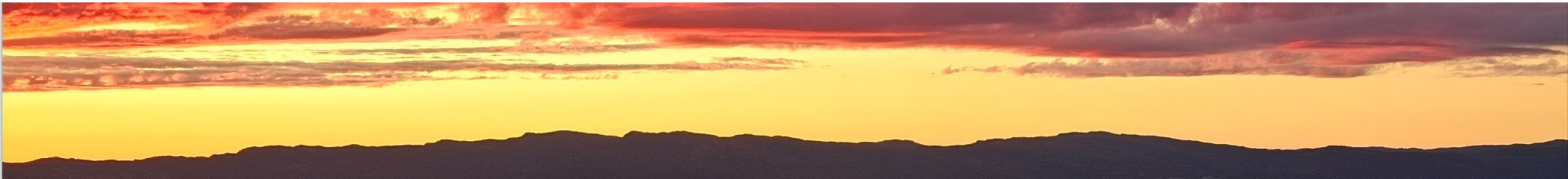
Samuel Meulé, Julien David Pelaez Ourfonnes, Frédéric Bouchelle, et al. Reconstruction of nearshore surface gravity waves from Distributed Acoustic Sensing data. Earth and Space Science, accepted. DOI: 10.22471/essoc.170957099.99814320v1



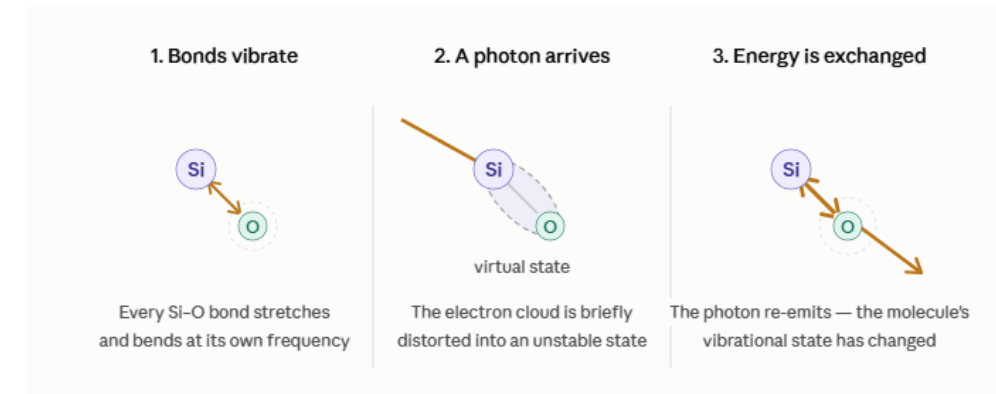
sediments, M-6.8 in 1887. Seismic region

A key area to study deep-water convection

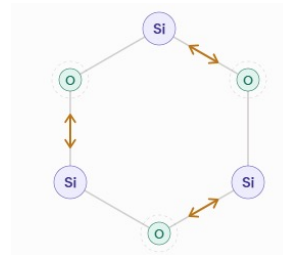
Raman and Brillouin Scattering



Raman Scattering and sensing concept



Spontaneous Raman Scattering is resulting from the interaction of light with the **vibrational or rotational modes of molecules** in the fiber core.



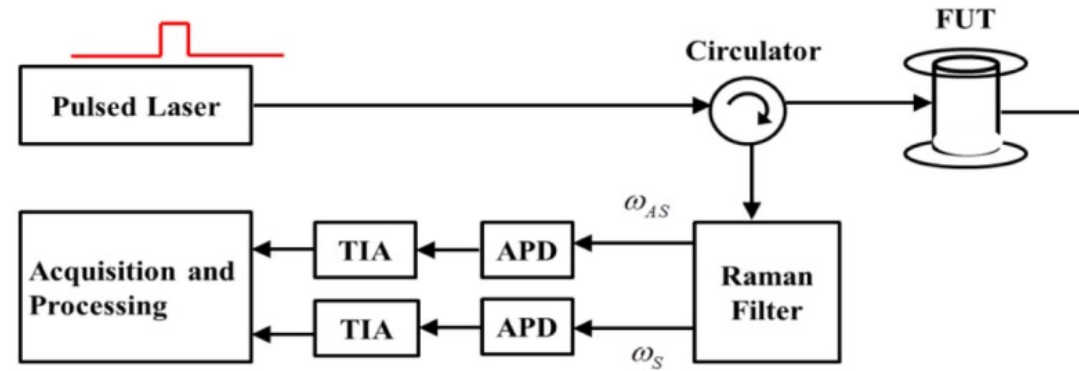
A **molecular vibration** is a periodic motion of the atoms of a molecule relative to each other, such that the center of mass of the molecule remains unchanged.

The **intensity of anti-stokes scattered component** is strongly depends on the temperature around the fiber

This make it possible to measure **distributed temperature in the time domain**.

Known as Raman Distributed Temperature Sensing (**RDTS**)

The concept of Raman Distributed Temperature Sensing (RDTS)



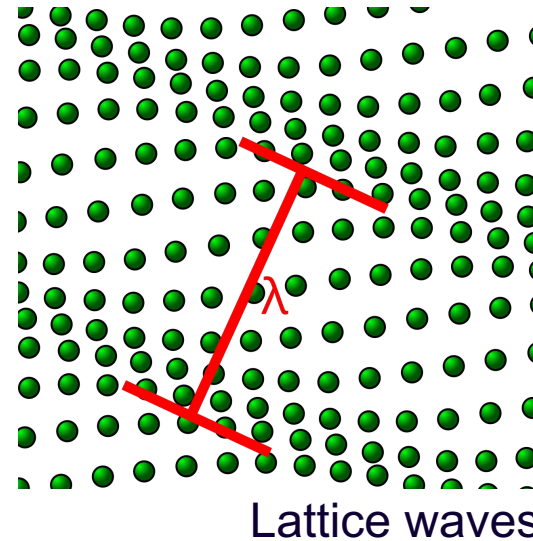
- RDTS allows distributed temperature measurements without any cross-sensitivity with other parameters such as strain

(Spontaneous and stimulated) Brillouin Scattering

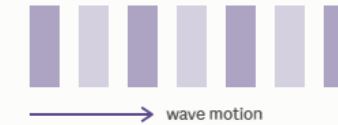
Brillouin scattering occurs due to the interaction of light with the sound waves or the acoustic phonons of a material.

A **phonon** is just the quantized unit of mechanical vibration in a solid — the material's version of a photon.

Acoustic phonons: atoms move *in phase* with their neighbors — entire regions of the material shift together, in the same direction, at the same time.



1. a traveling acoustic wave is a moving grating



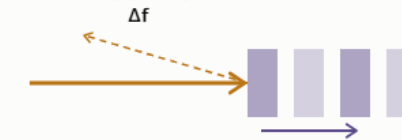
a traveling density wave acts as a moving grating

2. a photon partially reflects off it



a small fraction reflects off it, bragg-like

3. the moving grating shifts it



a moving grating gives a doppler-shifted echo

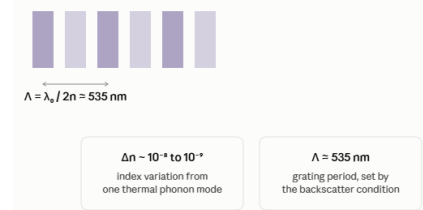
4. energy and momentum are conserved

$$\omega_{out} = \omega_{in} \mp \omega_{phonon}$$

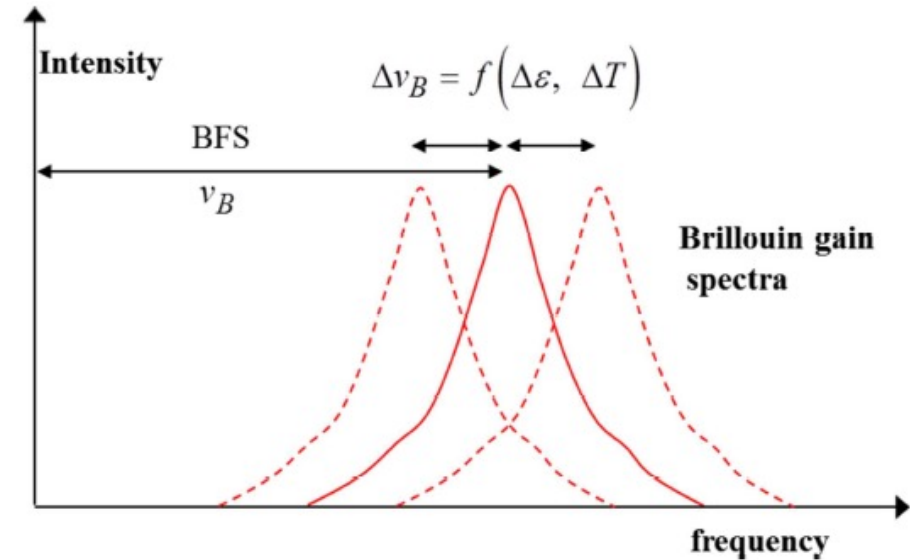
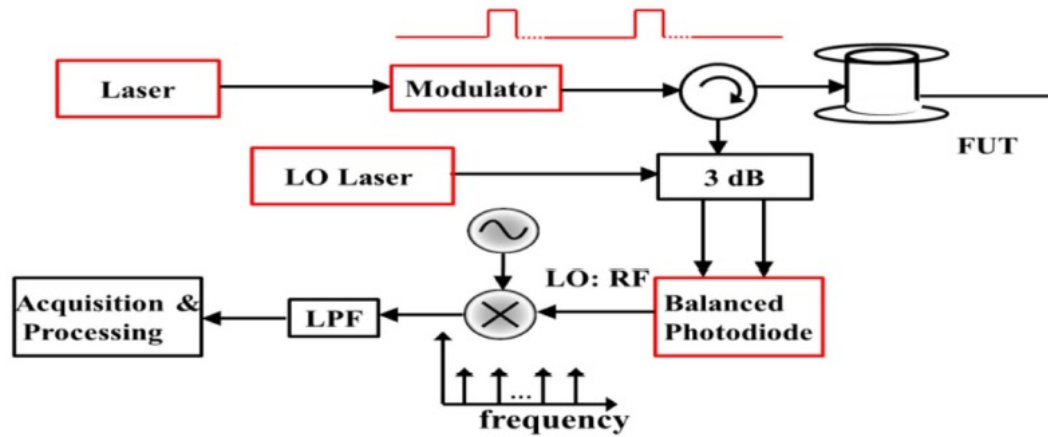


net result: scattering ends up mostly backward

Stimulated Brillouin Scattering happens when the intensity of the light is high enough to change the intensity of the material in fiber core



The concept of Brillouin Optical Time Domain Reflectometry (BOTDR)



- Brillouin Frequency Shift (BFS), is linearly dependent on the strain or temperature at each point of the fiber
- Sensing is based on measuring the frequency offset between the peak of the Brillouin Gain Spectrum (BGS).
- Distributed measurement with this technique boils down to determining the distributed BFS along the fiber.
- Brillouin-based sensors suffer from cross-sensitivity of temperature and strain which require other techniques to resolve.

Further readings

Submerse deliverables

22 deliverables <https://submerse.eu/deliverables/>

Deliverables

The SUBMERSE project has a range of deliverables associated with the activities. These will be made available on this page once published.

D4.6 Exploitation and sustainability - final



Published date | 5 May 2026

This deliverable outlines the final discussions on sustainability and exploitation of project's results. This final report includes an overview of pathways to impact emerging from the project activities and how the consortium conveys sustainability actions regarding key concepts such as governance, infrastructure as well as data management and uptake, including cross-cutting security issues.

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D4.4 Training report



Published date | 5 May 2026

This training report details the capacity-building activities organised by the SUBMERSE project to bridge knowledge gaps in using submarine fibre-optic cables as environmental sensing infrastructure.

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D4.3 Stakeholder engagement and outreach report - final



Published date | 5 May 2026

This deliverable is the final report on the stakeholder engagement and outreach activities performed within the frame of SUBMERSE project. The report is related to Work Package 4 Communication, Exploitation and Impact.

Download PDF

D3.4 Use case and community engagement report



Published date | 5 May 2026

The SUBMERSE project demonstrates the successful deployment and operation of fibre-optic sensing technologies - Distributed Acoustic Sensing (DAS), State of Polarisation (SOP), and SOP-OTDR - across multiple submarine and terrestrial cable infrastructures in Europe.

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D2.3 Open source research software for automatic earthquake detection, data ingestion in standard seismological software, cetology, oceanography



Published date | 5 May 2026

The sharing of software through public repositories is crucial for making sure that methodological innovations are usable by others. Software has been developed as part of the project to allow streaming of selected channels or processing outputs through the SeedLink protocol, which makes those streams immediately accessible for ingestion into EIDA archives and to be integrated into monitoring workflows.

Download PDF

D2.2 Continuous DAS and SOP waveforms and parametric data archive, delivered through EIDA nodes and HCMR for solid earth and marine communities

2.2 Ideal deployment scenario as we see it today

The necessary infrastructure and equipment needed to create a good sensing environment on existing telecom fiber infrastructure are as follow.

2.2.1 Cable and Fiber

Single mode and solid core fiber with low loss are preferable fiber type. Coupling of the fiber to the subsurface has shown to greatly affect the data quality of DAS data. In the Svalbard dataset, where most of the data is from a submarine environment, we see a clear difference between buried and unburied fiber section. The portion of fiber buried in 0 to 2 m of sediments shows a significantly higher signal quality than the fiber portion located directly on bedrock. The burial depth is not crucial. This is because the wavelength of what is to be detected is long in relation to how quickly the wave field decreases downwards in the sediments and the typical burial depth of such cables, i.e. 0-3 meters. We have not seen particularly large variations in the type of seabed for buried cables.

In other terrestrial applications the same pattern is observed. There are many sources of waves that propagate on land. Thus, a fibre will be stretch-modulated by many more signals than those you are typically looking to measure. The picture here is therefore much more complex! On land, you can get strong DAS signals with fiber cable laid in a cable duct and directly buried in the ground.

In aerial able is often the oscillations in the poles that contribute to the strongest signals. This means it is easy to detect signals from waves in the land that cause the poles to oscillate. There can be many sources for this. In addition to wind that directly causes oscillation of the poles.

The ideal fibre deployment scenario is the environment with lowest possible noise where the cable is buried or properly in touch with the ground surface.

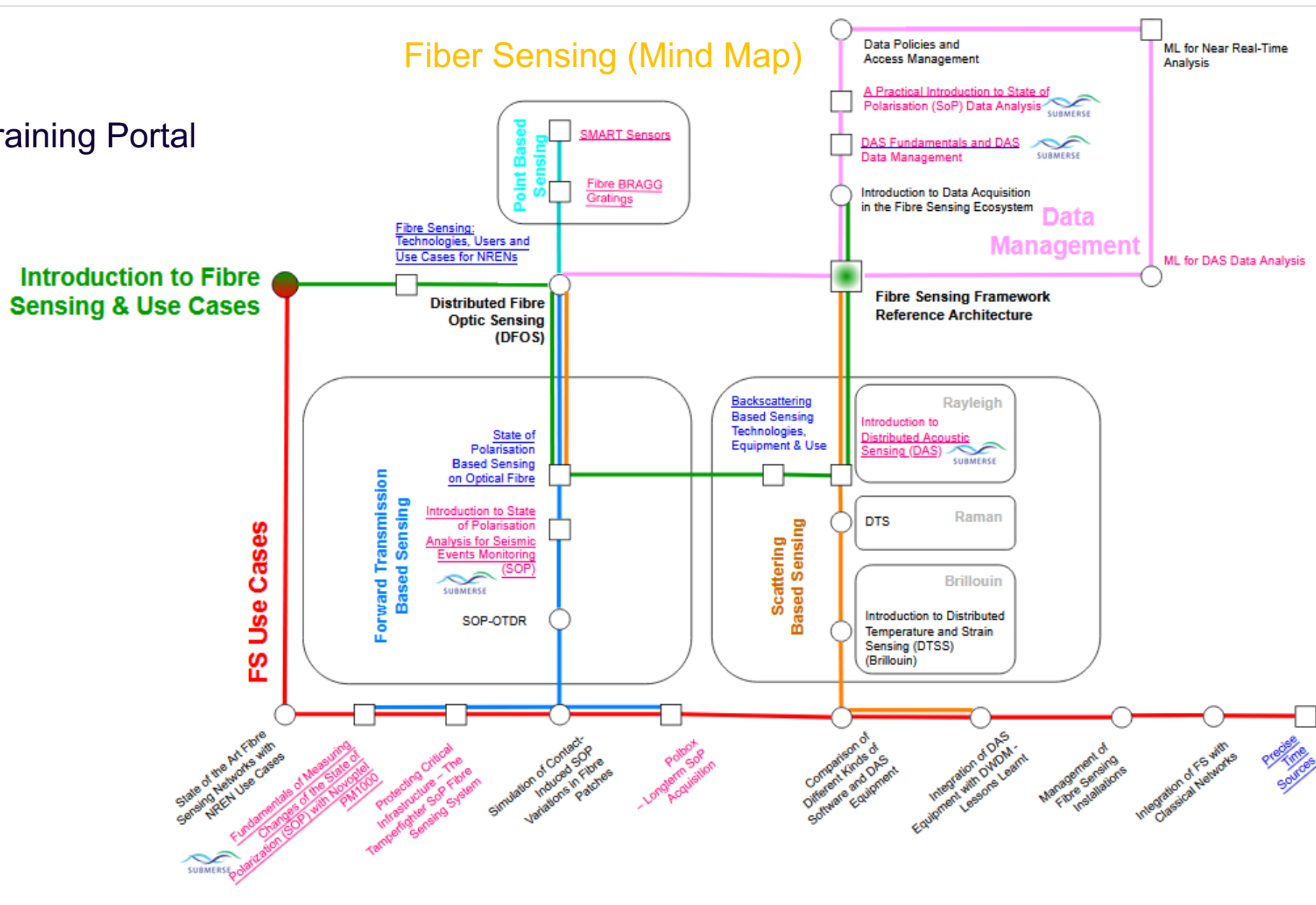
2.2.2 Site condition

The sensing unit installation site should have low acoustic noise and low vibrational acceleration level. Typical sources for such a noise are accelerating fan.

2.2.3 Sensing instruments

In our trials we have been using devices which can detect the state of polarization and it's changes and Rayleigh scattering-based distributed acoustic sensing (DAS) devices.

K. Bozorgebrahimi et al., " Deliverable D2.8 Research Instrument proof of concept operation evaluation" Submerse <https://submerse.eu/deliverables/>





Thank you!