Development of 3-Axis Fibre-Optic Seismograph for direct and autonomous monitoring of rotational events

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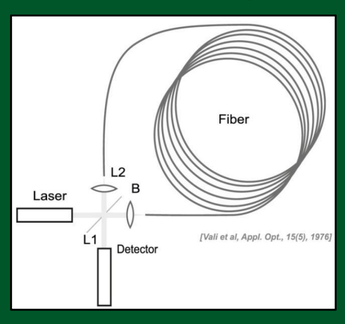
The presented FOSs (Fibre-Optic Seismographs) have been constructed fotr rotational seismology investigation. They were applied for rotational movements monitoring in building, in an international comparative sensors test, for seismic events recording as well. The area of FOS applications is enormous from seismic rotational waves recording in seismological observatory to wind farm or glaciers monitoring. Having such instrumentation it is extremely important to gather data and their analysis in order to better understand the origin of earthquakes and in particular to relate them to the geological context as well as to analyze engineering aspects of high and complex construction.

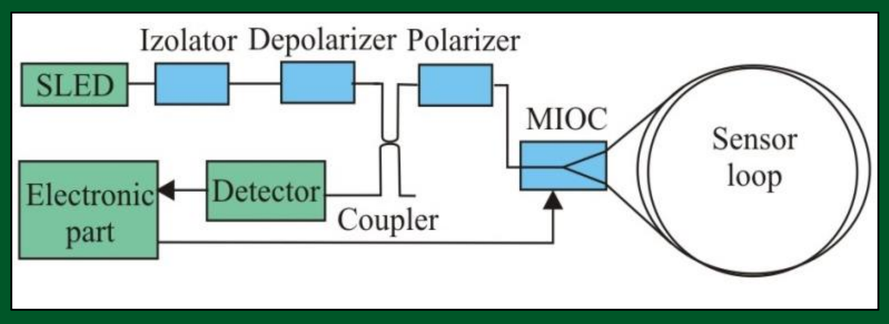
Theory

Sagnac effect shows the difference between phase of two beams propagating around closed optical path, in opposite direction when this path is rotating with rotational rate Ω. In a fiber-optic implementation the rotation rate Ω is expressed by induced phase shift Δφ as:

$$\Omega = So \cdot \Delta\varphi = \frac{\lambda c}{4\pi RL} \cdot \Delta\varphi$$

L – length of the fiber in the sensor loop, R – sensor loop radius, λ – wavelength of used source, c – velocity of the light in vacuum, S_0 – the optical constant of interferometer

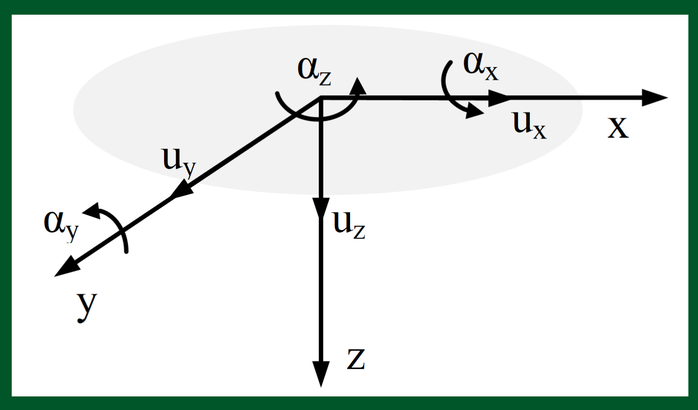




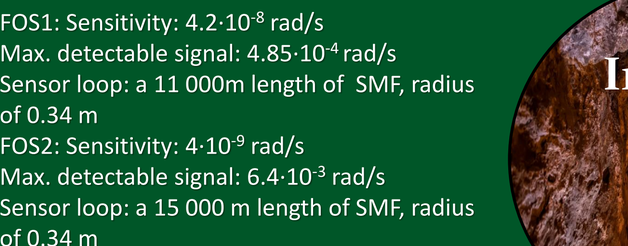
Motivation

Application domains of 6-Dof (3 translations + 3 rotations) ground motion observations:

- Earthquake sources,
- Tilt correction,
- Wavefield separation,
- Wave direction,
- Wave dispersion,
- Scattering properties,
- Seismic imaging.



1. Gyro System for Platform Investigation (GS-13P), 1998

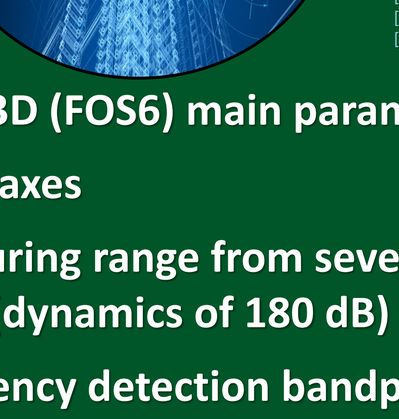


Sensitivity: $9.7 \cdot 10^{-7}$ rad/s
Max. detectable signal: $4.8 \cdot 10^{-4}$ rad/s
Sensor loop: a 380 m length of PANDA fiber, radius of 0.1 m

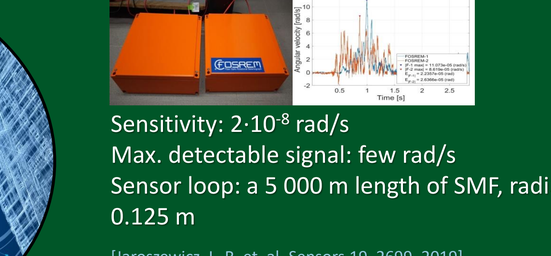
[Jaroszewicz, L. R. et al., Proc. SPIE 3479, 1998]

FOSREM-3D

Fibre Optic Seismograph from Sky across Ground up to Underground



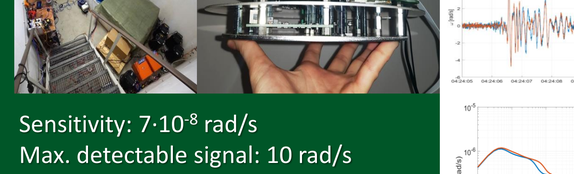
2. Fibre-Optic Rotational Seismometer (FORS-I), 2001



Sensitivity: $2.2 \cdot 10^{-6}$ rad/s
Max. detectable signal: $4.8 \cdot 10^{-4}$ rad/s
Sensor loop: a 400 m length of PANDA fiber, radius of 0.1 m

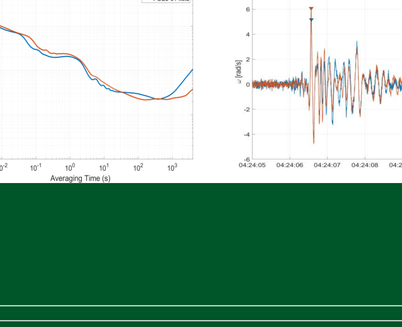
[Krajewski, Z. et al., Proc. SPIE, 5484, 2004]
[Jaroszewicz, L. R., et al., Molecular and Quantum Acoustics, 22, 133-144, 2001]

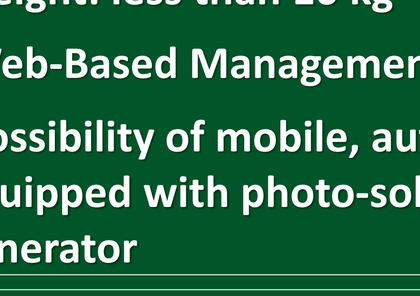
3. Autonomous Fibre-Optic Rotational Seismograph (FORS-II or FOS1, AFORS or FOS2), 2004, 2010



FOS1: Sensitivity: $4.2 \cdot 10^{-8}$ rad/s
Max. detectable signal: $4.85 \cdot 10^{-4}$ rad/s
Sensor loop: a 11 000m length of SMF, radius of 0.34 m
FOS2: Sensitivity: $4 \cdot 10^{-9}$ rad/s
Max. detectable signal: $6.4 \cdot 10^{-3}$ rad/s
Sensor loop: a 15 000 m length of SMF, radius of 0.34 m

[Jaroszewicz, L. R. et al., Acta Geophysica, 59, 578-596, 2011]
[Kurzych, A. et al., Sensors, 14(3), 5459-5469, 2014]





4. Fibre-Optic System for Rotational Events and Phenomena Monitoring (FOSREM – FOS3 & FOS4), 2015

Sensitivity: $2 \cdot 10^{-8}$ rad/s
Max. detectable signal: few rad/s
Sensor loop: a 5 000 m length of SMF, radius of 0.125 m

[Jaroszewicz, L. R. et. al.,Sensors,19, 2699, 2019]
[Kurzych, A. T. et. al., JLT, 36, 879-884, 2018]
[Kurzych, A. T. et. al., JLT 37(18), 4851-4857, 2019]

5. Fibre-Optic Seismograph (FOS5), 2018

Sensitivity: $7 \cdot 10^{-8}$ rad/s
Max. detectable signal: 10 rad/s
Sensor loop: a 5 000 m length of SMF, radius of 0.125 m

[Kurzych, A.T. et al., Sensors, 20, 6107, 2020]
[Bernauer, F. et al., Sensors, 21, 264, 2021]
[Jaroszewicz, L. et al., Opto-electron Rev. 29(4), 2021]

FOSREM-3D (FOS6) main parameters:

- **Three axes**
- **Measuring range from several dozen nrad/s to 10 rad/s (dynamics of 180 dB)**
- **Frequency detection bandpass: from DC to 100 Hz**
- **Built-in time scale synchronization system (accuracy 10 µs)**
- **Weight: less than 10 kg**
- **Web-Based Management Interface**
- **Possibility of mobile, autonomous operation; equipped with photo-solar cells, battery or wind generator**

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