Recording of the rotational events in Poland – Time horizon & Fascinating Future of Fiber-Optic Seismograph

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Agenda

01 **Fibre-Optic Seismograph in Poland historical brief**

02 **Rotational seismology**

03 **Construction of Fiber Optic Seismograph**

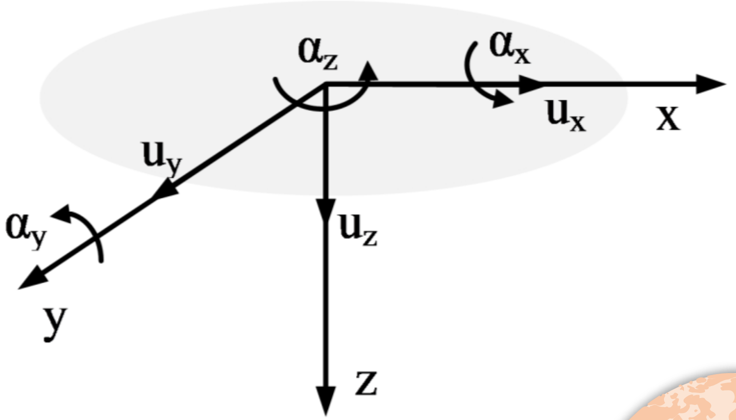
04 **Conclusions**


[https://www.britannica.com/list/7-women-warriors]


[https://www.businessinsider.com/earthquake-taiwan-east-coast-2018-2?IR=T]


[https://atoday.org/philippines-earthquakes-rock-southern-island-of-mindanao/]


https://www.stanlay.in/environmental-test-equipment/seismometer-seismic-recorder/veloget-seismometer-1hz/




https://physicsopenlab.org/2019/09/23/geophone-seismometer/

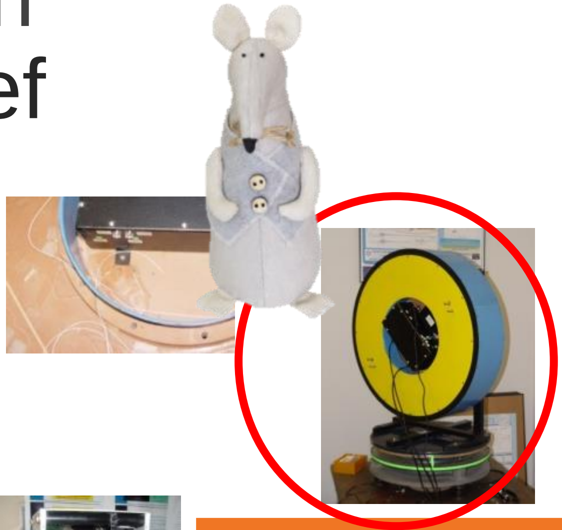
Fibre-Optic Seismograph historical brief

1998

GS-13P
Ω_{min}: $3.49 \cdot 10^{-3}$rad/s
SL: 380 m PANDA
Radius: 0.1 m

2001

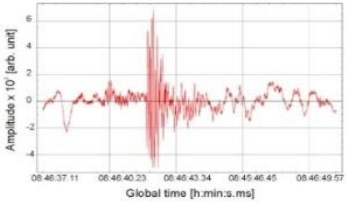
FORS-I
Ω_{min}: $2.2 \cdot 10^{-6}$ rad/s
Ω_{max}: $4.8 \cdot 10^{-4}$ rad/s
SL: 400 m PANDA
Radius: 0.1 m

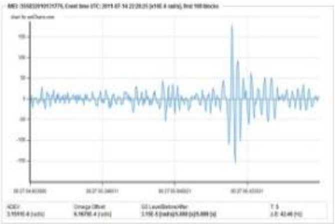


2004, 2010

FORS-II, FOS1
Ω_{min}: $4.2 \cdot 10^{-8}$ rad/s
Ω_{max}: $4.8 \cdot 10^{-4}$ rad/s;
SL: 11 000 m SMF
Radius: 0.34 m

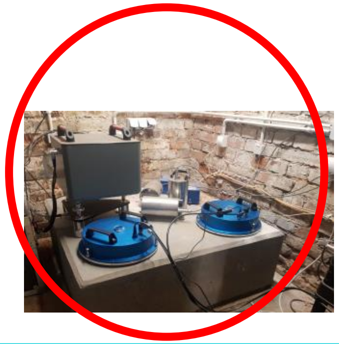
FOS2
Ω_{min}: $4 \cdot 10^{-9}$ rad/s,
Ω_{max}: $6.4 \cdot 10^{-3}$ rad/s
SL: 15 000 m SMF
Radius: 0.34 m





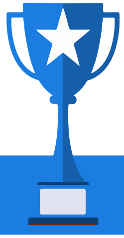
2015

FOSREM – FOS3 & FOS4
Ω_{min}: $2 \cdot 10^{-8}$ rad/s,
Ω_{max}: few rad/s
SL: 5 000 m SMF
Radius: 0.125 m



2018

FOS5
Ω_{min}: $7 \cdot 10^{-8}$ rad/s,
Ω_{max}: 10 rad/s
SL: 5 000 m SMF,
Radius: 0.125 m



Fibre-Optic Seismograph FOS6
3- Axis
Ω_{min}: several dozen nrad/s
Ω_{max}: 10 rad/s
SL: 6 000 m SMF
Radius: 0.125 m
Weight: 10 kg

Motivation

6-DOF

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

Rotational Seismology

[Lee et al. BSSA, 2009, 99, 945-957] a new, emerging field for the study of all aspects of rotational ground motion induced by earthquakes, explosions, and ambient vibrations

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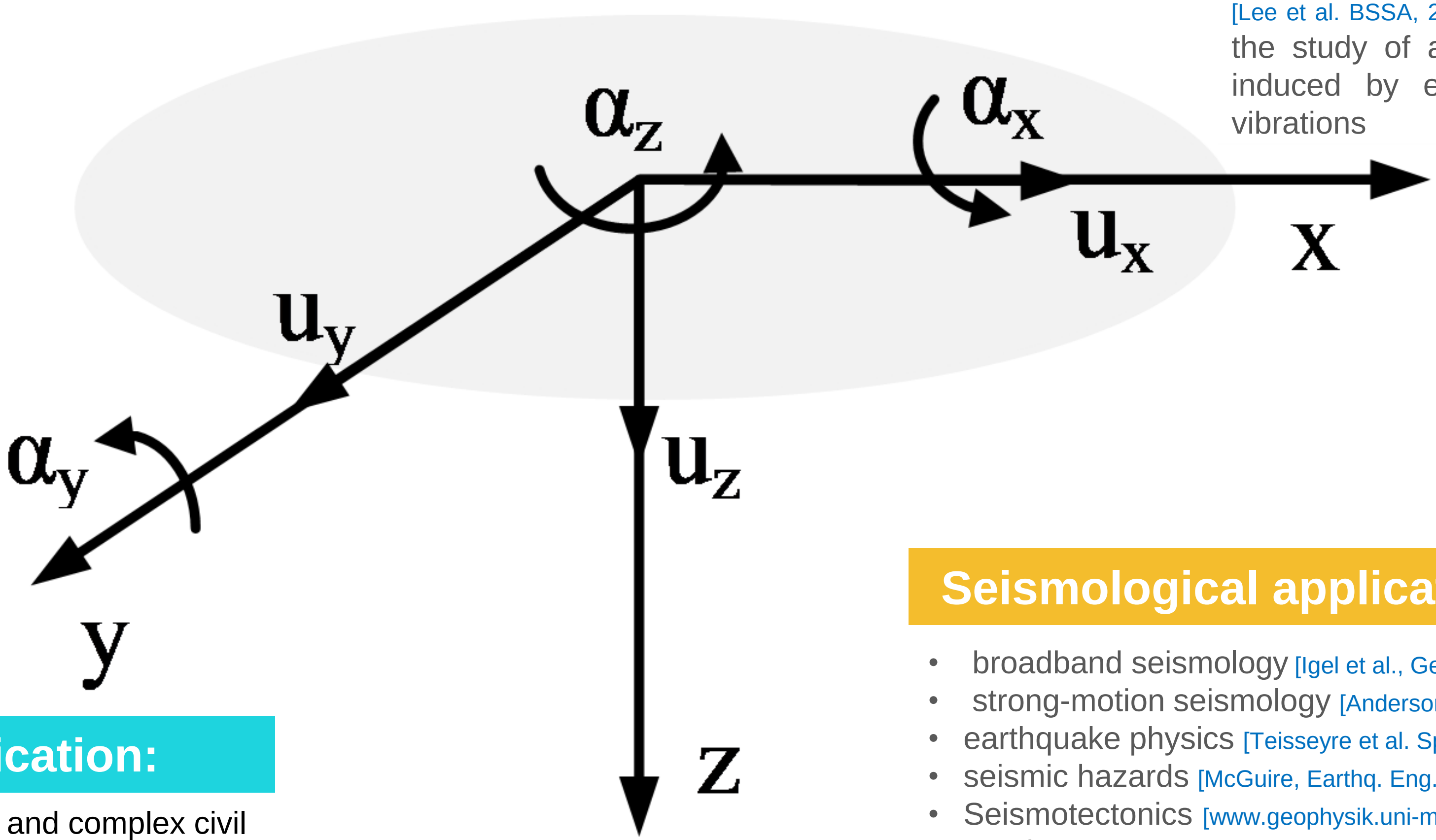


Engineering application:

seismic behaviour of irregular and complex civil structures [Trifunac, *BSSA*, **99**, (2009), 968-97; Mustafa, InTech, 2015]

Seismological application

- broadband seismology [Igel et al., Geophys. J. Int., 168(1), (2006), 182–197],
- strong-motion seismology [Anderson, 2003, Chap. 57, 937-965],
- earthquake physics [Teisseyre et al. Springer, 2006; Teisseyre et al., Springer, 2008],
- seismic hazards [McGuire, Earthq. Eng. Struct. D., 37, (2008), 329–338],
- Seismotectonics [www.geophysik.uni-muenchen.de/~igel/Lectures /Sedi/sedi_tectonics.ppt],
- geodesy [Carey, Expanding Earth Symposium, (1983), 365-372],
- physicists using Earth-based observatories for detecting gravitational waves [Ju et al., Rep. Prog. Phys., 63, (2000), 1317–1427; Lantz et al., BSSA, 99, (2009), 980-989]

Requirements

Seismological application

Measuring range

signal amplitude:
from 10^{-8} rad/s,
frequency:
0.01 Hz – 0.1 Hz

COMMON

ROTATIONAL SEISMOGRAPH
network of seismometers + precise time source + recording device + network

Common

- Insensitivity to linear motion, or at any time opportunity to detect linear and rotational motions independently
- Mobility, stability with respect to environmental conditions, including changes of temperature
- Independent power supply
- Dynamic range 10^{-8} - 10 rad/s
- Frequency band 0.01 - 100 Hz
- Power consumption 5 – 8 W
- Thermal stability <0,1% / ^{o}C

Engineering application

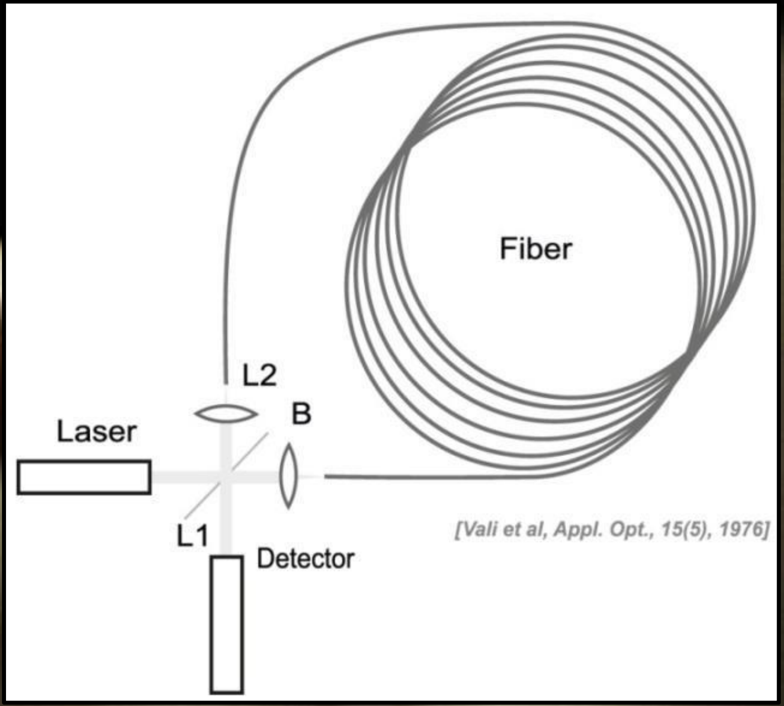
Measuring range

signal amplitude:
up to 10 rad/s,
frequency:
0.01 Hz – 100 Hz

[Jarozsewicz et al., Sensors, 16, 2161 (2016)]
[Bernauer et al., J. Seismol., 16, (2012)]

BACKGROUND

The direct utilization of the Sagnac effect

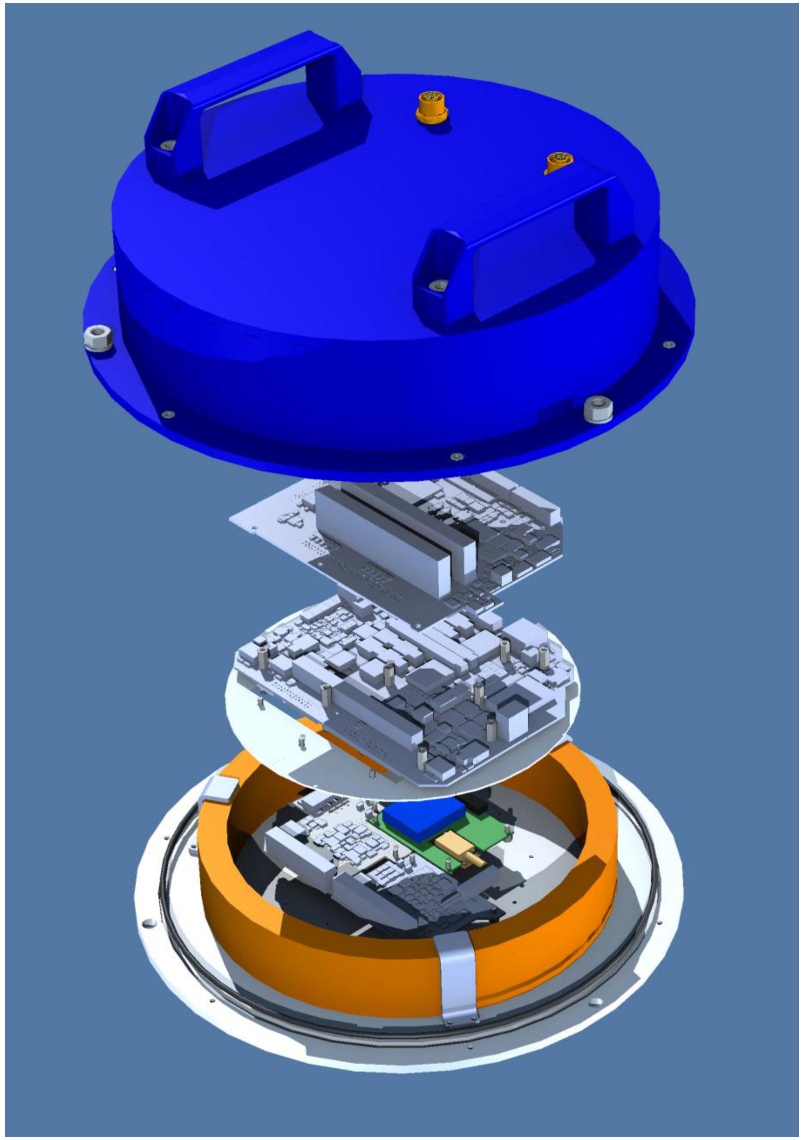


Sagnac effect shows the difference between phase of two beams propagating around closed optical path, in opposite direction when this path is rotating with rotational rate Ω. In a fiber-optic implementation the rotation rate Ω is expressed by induced phase shift $\Delta\varphi$ as:

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

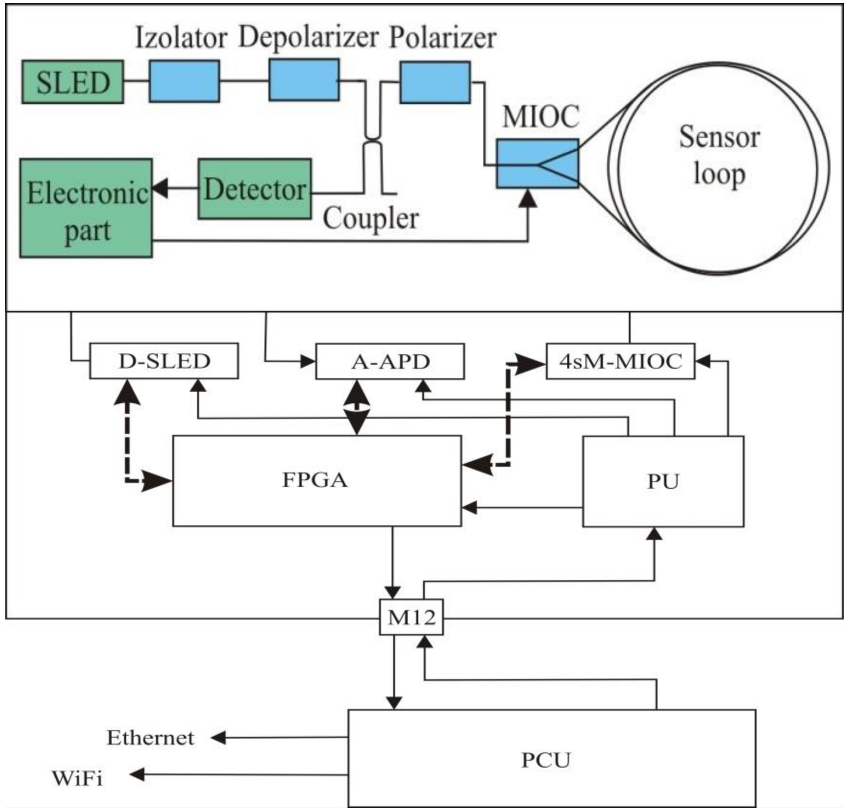
L – length of the fiber in the sensor loop, R – sensor loop radius, λ – wavelength of used source, c – velocity of the light in vacuum, S_0 – the optical constant of interferometer

Fiber Optic Seismograph



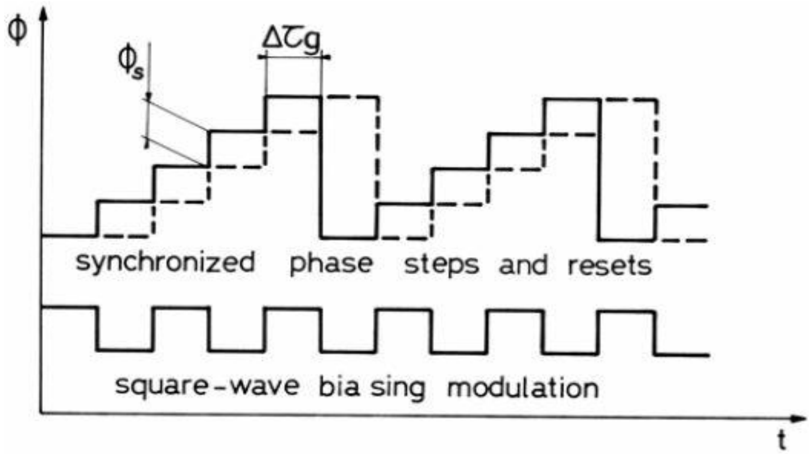
01 OPTICAL PART

generates the phase shift Δφ proportional to the measured rotation rate Ω which is perpendicular to the sensor loop plane



02 ELECTRONIC PART

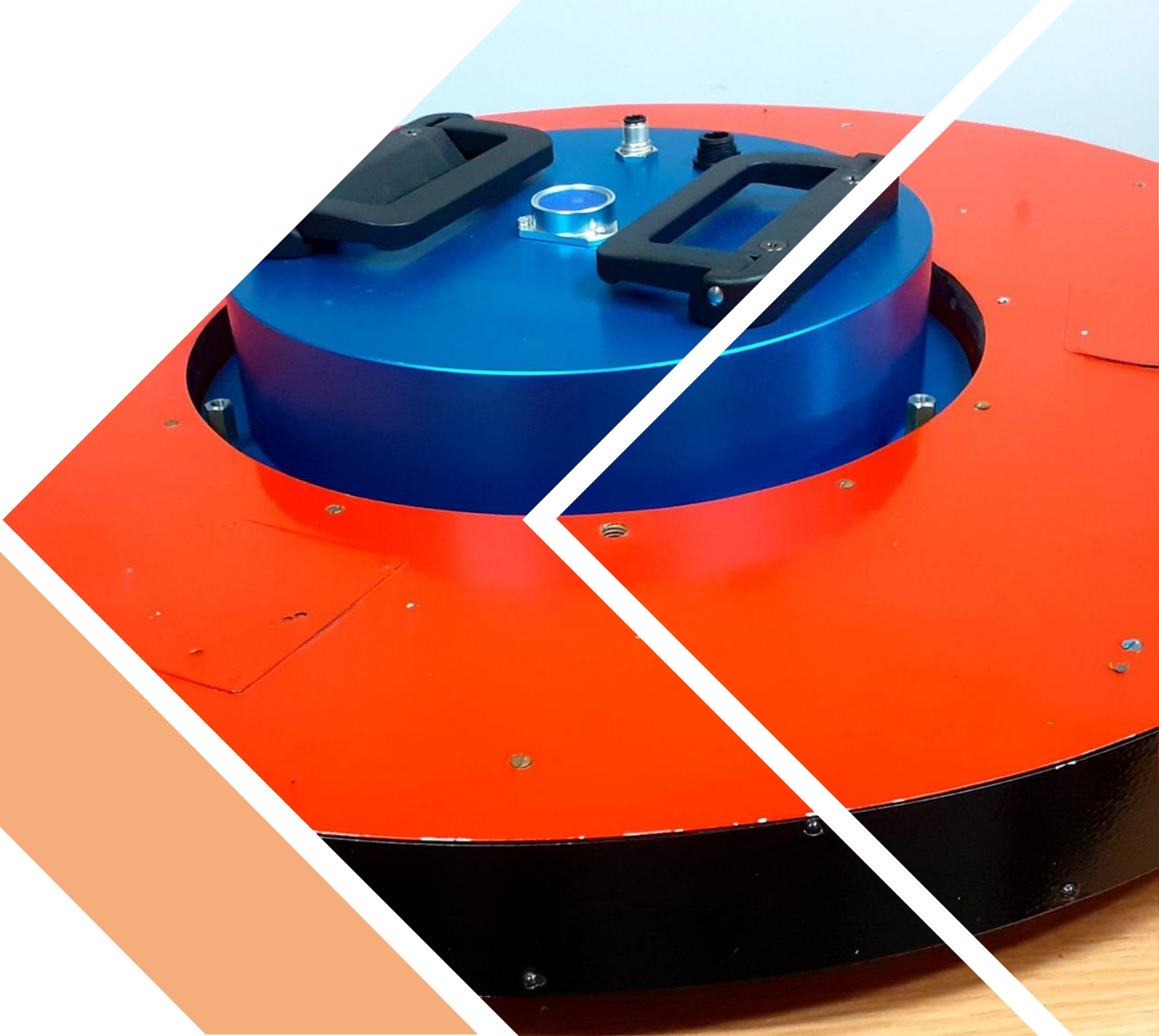
enables to calculate and record information about rotational motions via digital closed-loop signal processing



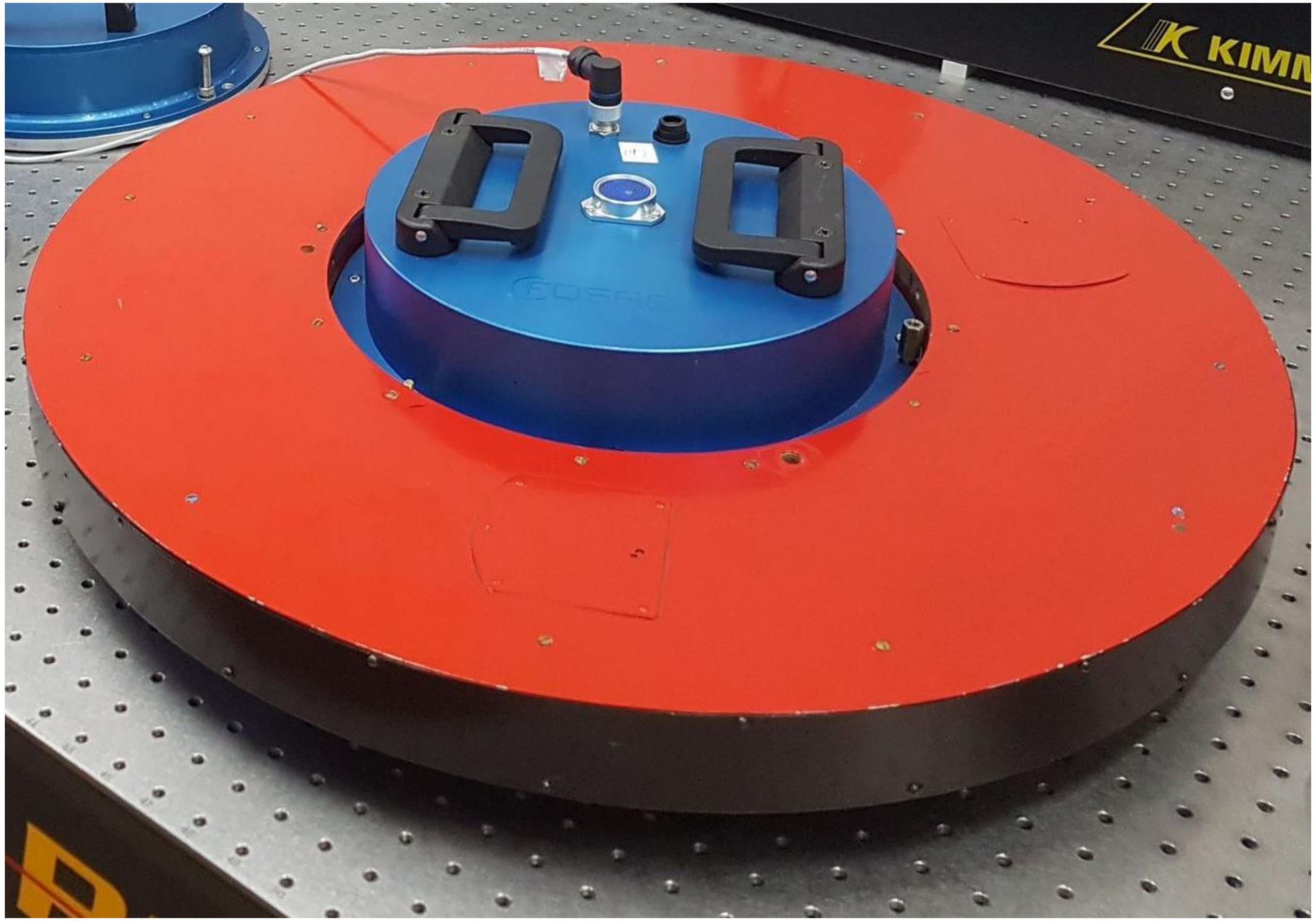
Large Fiber-Optic Seismograph

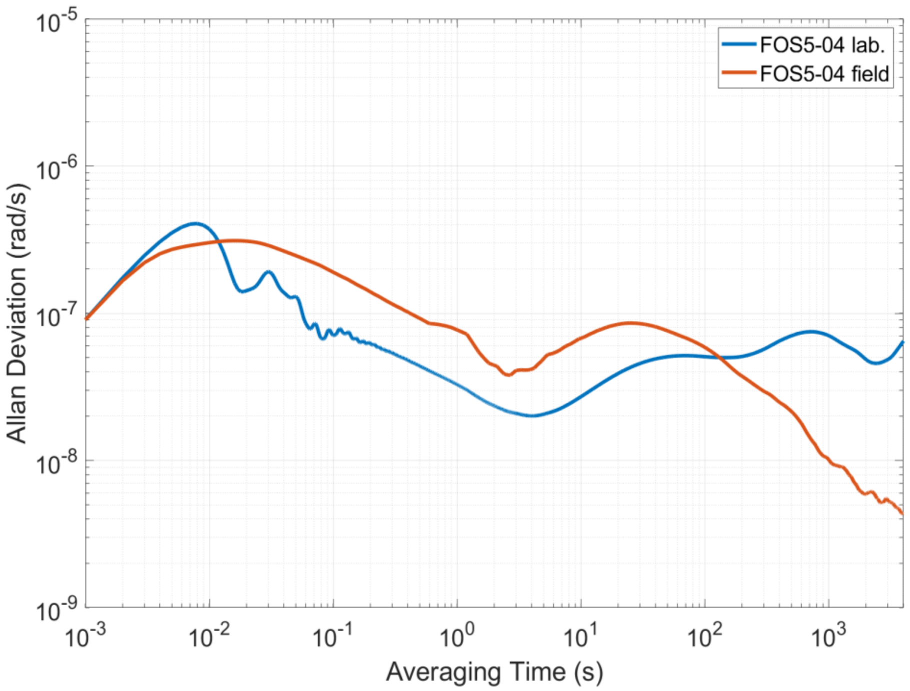
THEORETICAL SENSITIVITY
$1.14 \cdot 10^{-9}$ rad/(s√Hz)

FOS5-04 uses a 15 km long fiber wound in loop of 0.61 m in diameter.
Transmission optical losses equal to 17.41 dB



Fibre optic seismograph – Allan variance analysis

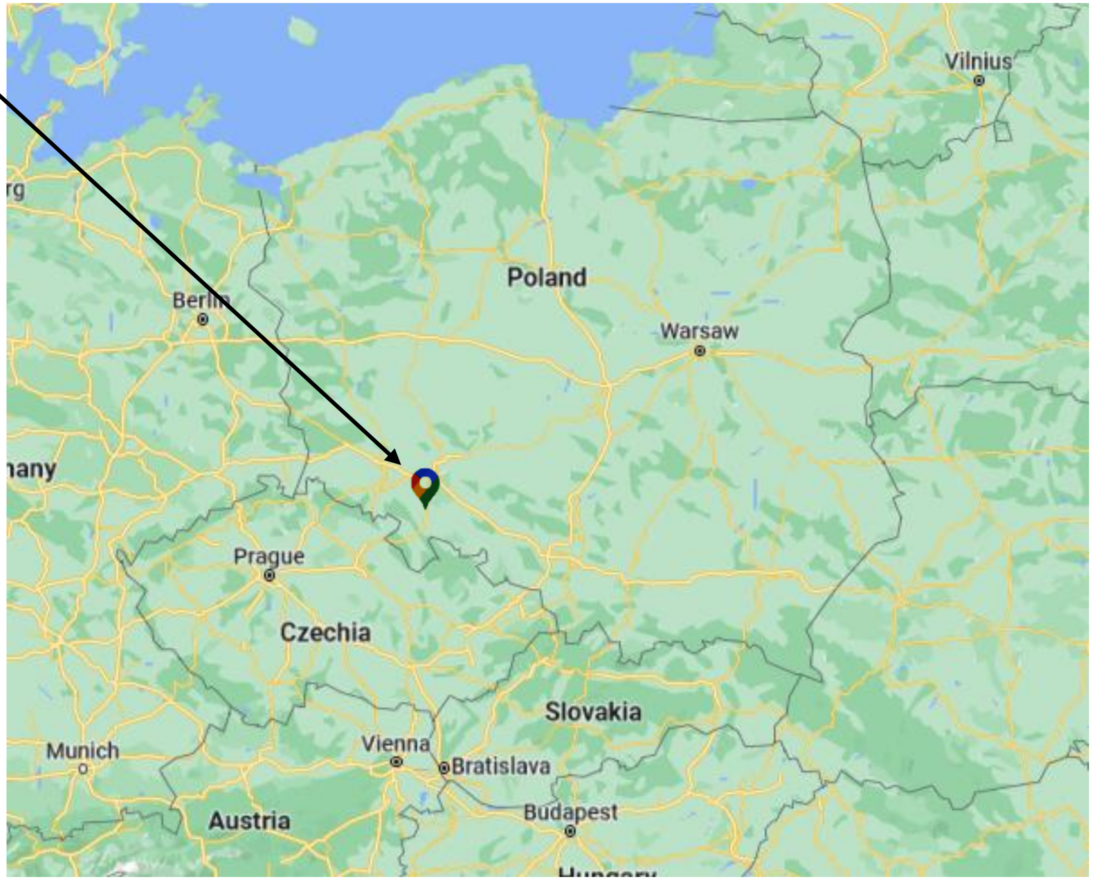




Position	Angle Random Walk [rad/√s]	Bias instability [rad/s]
Lab.	$3 \cdot 10^{-8}$	$2 \cdot 10^{-8}$
Field	$8 \cdot 10^{-7}$	$4 \cdot 10^{-8}$

Fibre optic seismograph – field application

Seismological observatory in the basements of Książ Castle in Wałbrzych, Poland 50°50'34"N 16°17'35"E

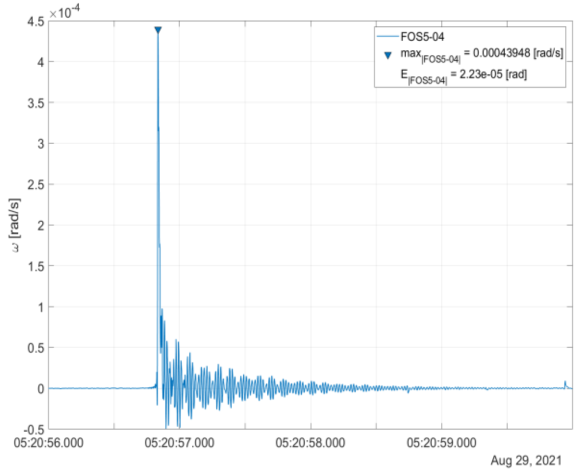


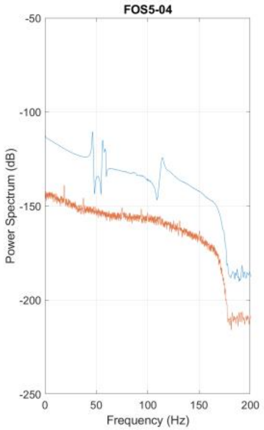
The observatory is located about 60 km away from the city of Legnica, which is the largest center of the Legnica-Głogów Copper District (LGCD)

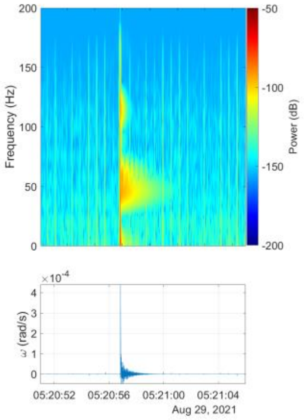
Fibre optic seismograph – recordings

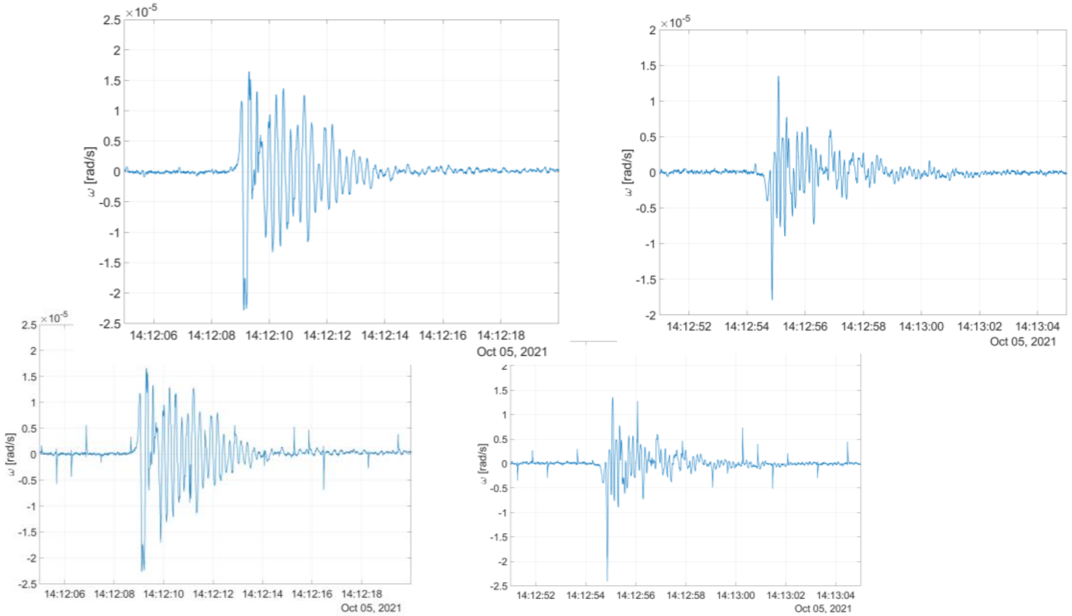
Analysis

- Initial amplitude of about 0.44 mrad/s and signal duration of about 6 s
- Some low-amplitude perturbations repeating with a period of about 0.6 s
- Two examples of rotational events recorded on 5th October, 2021
- The maximum amplitudes of the recorded signals are equal to $1.62 \cdot 10^{-5}$ rad/s and $1.35 \cdot 10^{-5}$ rad/s
- A dedicated algorithm was implemented in post-processing









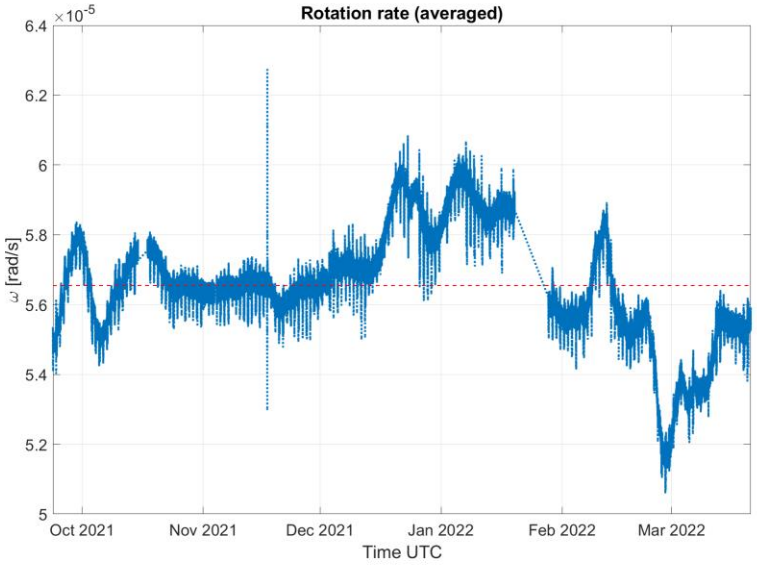
[Jaroszewicz et al., Opto-Electronics Review, 29, 4 (2021)]

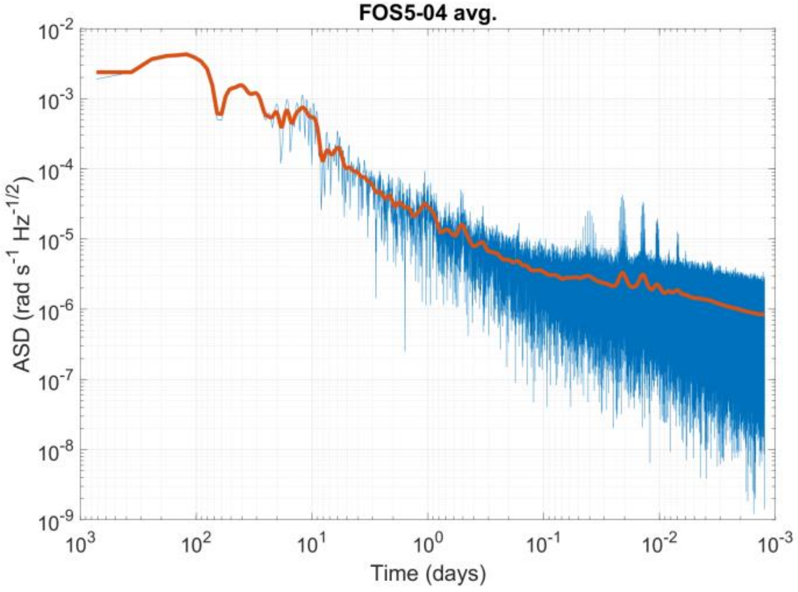
Fibre optic seismograph – recordings

“

Analysis

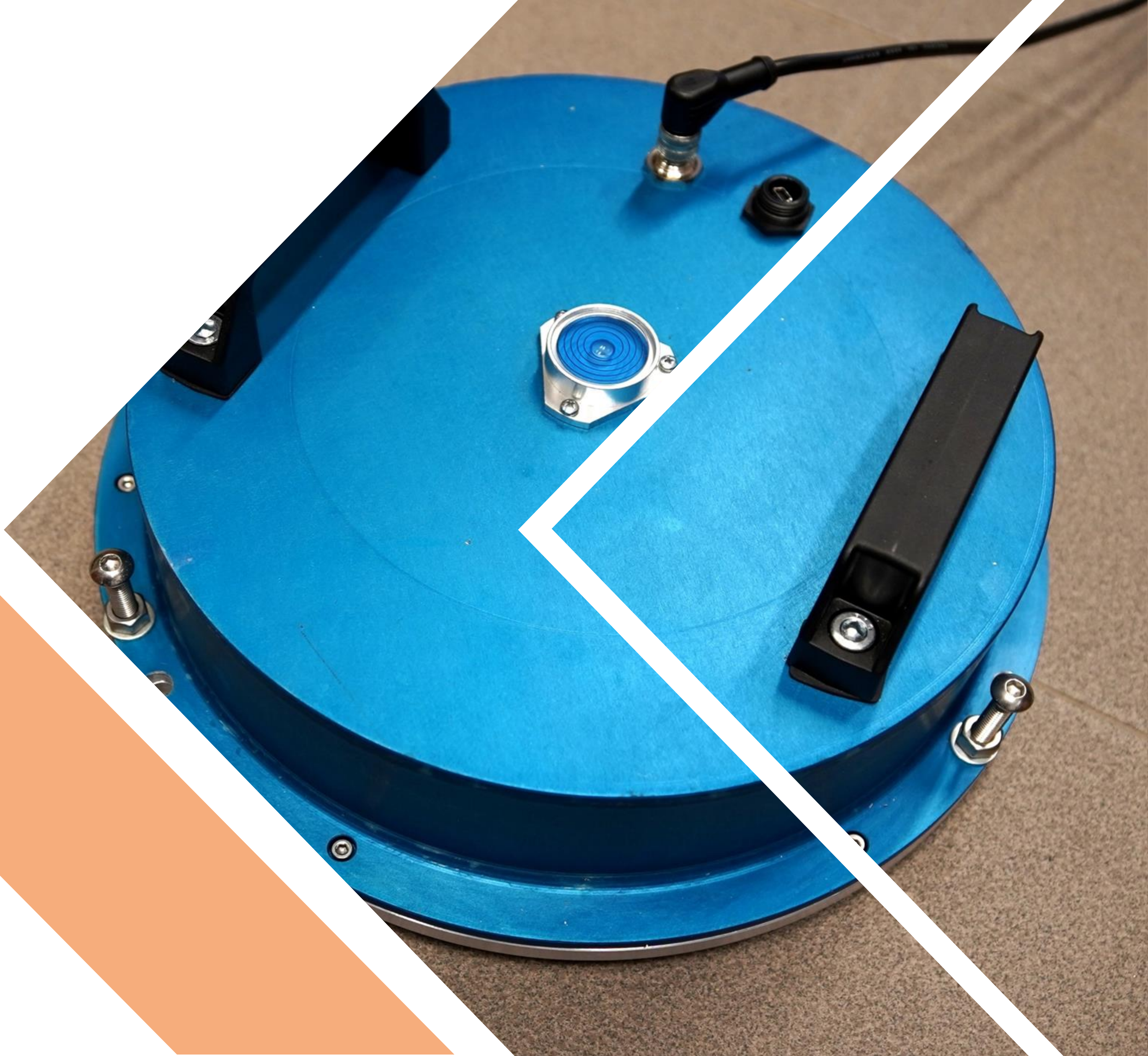
- A long-term recording of averaged signal (50 s window) in the period from October 2021 to March 2022 together with the theoretical value of rotation rate calculated for this location (50°50'34"N 16°17'35"E)
- The observed peaks for 60 min, 30 min, 20 min, 15 min and 10 min are directly connected with touristic activity in the Książ Castle basements between 10:00 AM and 6:00 PM
- Increases of the amplitude at the periods of approximately one day and half a day can be directly connected with changes of Earth’s rotation rate due to diurnal polar motions, as well as diurnal and semidiurnal tides.





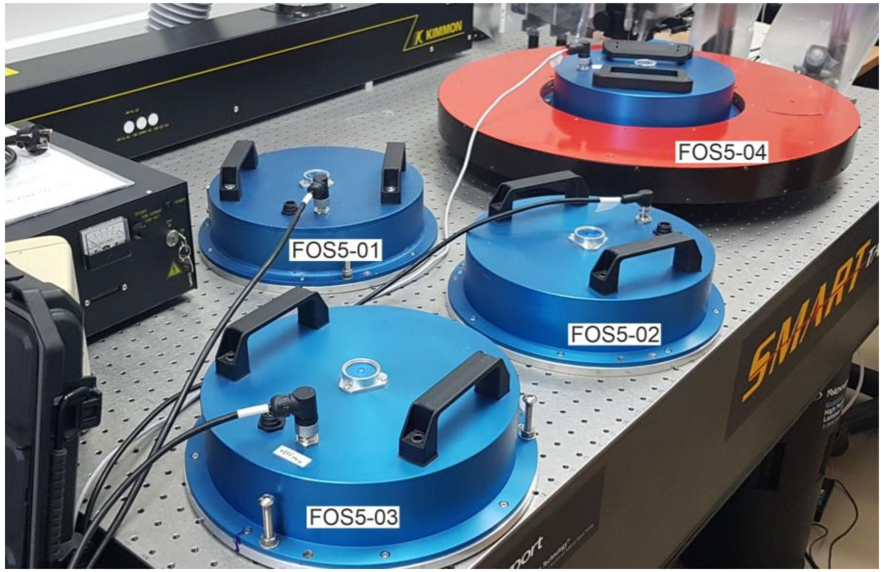
Compact Fiber-Optic Seismograph

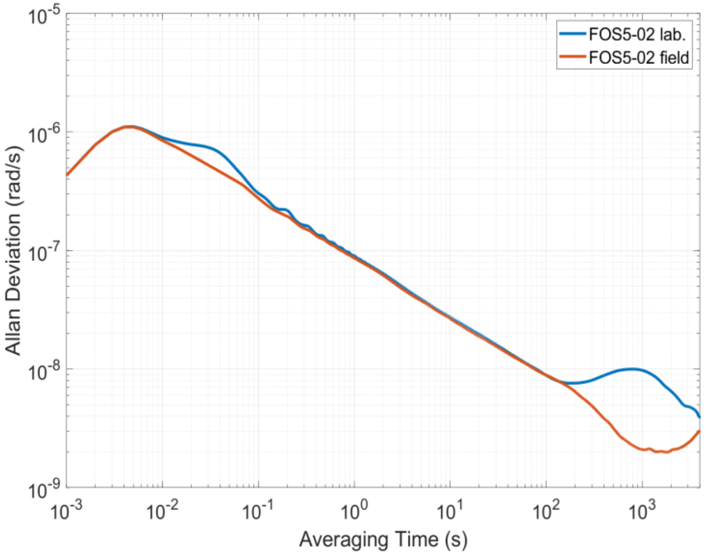
THEORETICAL SENSITIVITY
$3.41 \cdot 10^{-8}$ rad/(s√Hz)

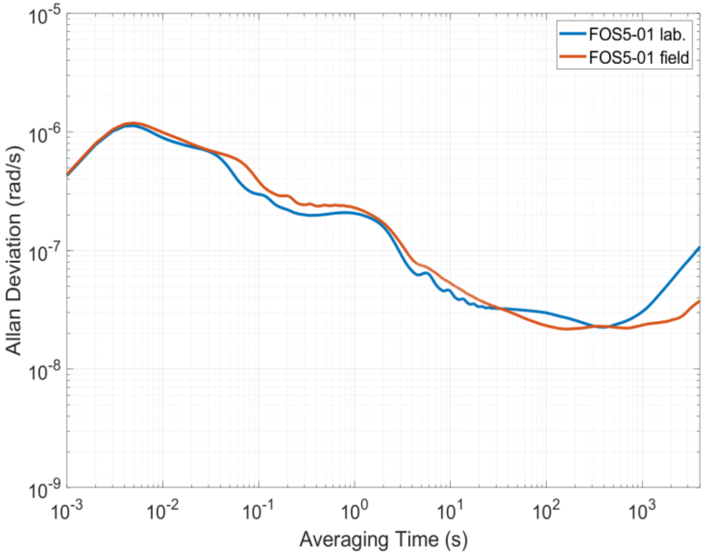


FOS5-01, 02 use a 5 km long fiber wound in loop of 0.25 m in diameter.

Fibre optic seismograph – Allan variance analysis





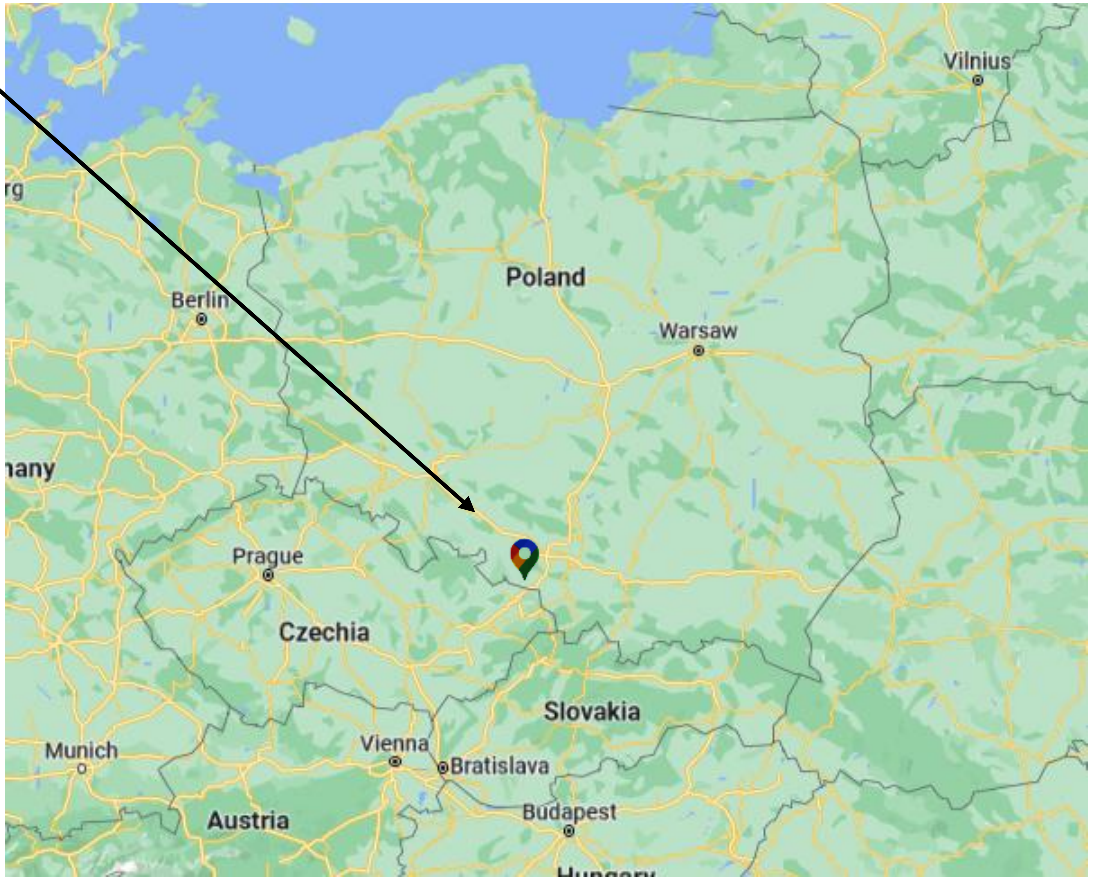


Position	FOS5-01		FOS5-02	
	ARW [rad/√s]	BI [rad/s]	ARW [rad/√s]	BI [rad/s]
Lab.	$2 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$9 \cdot 10^{-8}$	$2 \cdot 10^{-9}$
Field	$2 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$9 \cdot 10^{-8}$	$1 \cdot 10^{-8}$

Fibre optic seismograph – field application

Historic Mine Ignatius, Rybnik, Poland 50°03'44,6"N 18°28'00,7"E

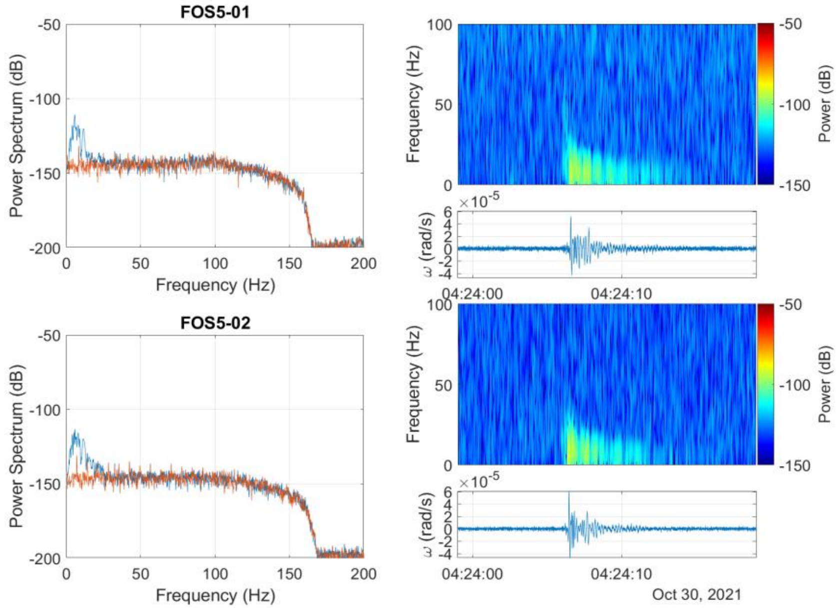
- *FOS5-01, -02 installed on a concrete pedestal seismically isolated from the surrounding building in order to monitor seismic activity in the lower Silesian coal basin caused by coal mines.*
- *Seismic activity is not uniform*
- *The variability of the geological structure of the area, including the lithological formation of the rocks in the vertical and horizontal profile, results in a varied number and intensity of rock bursts*

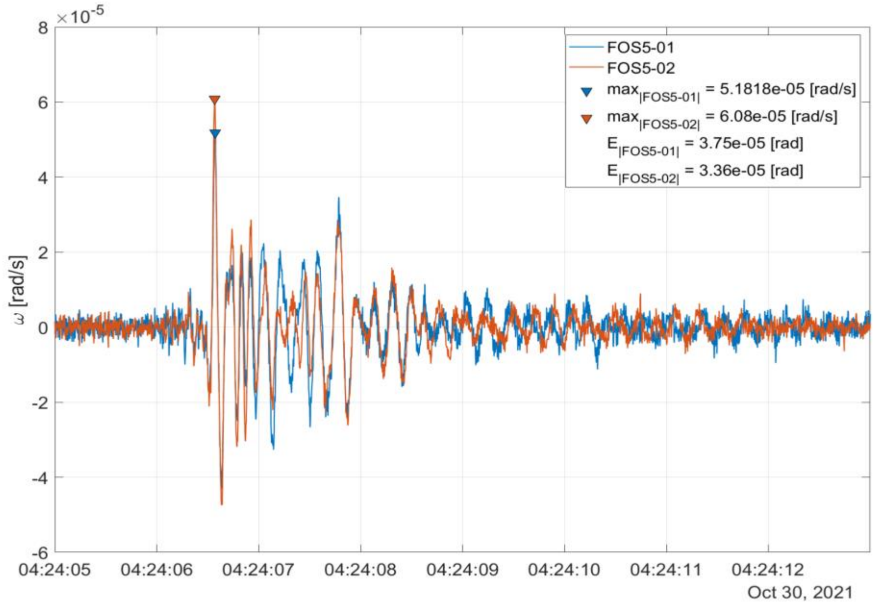


Fibre optic seismograph – recordings

Analysis

- Maximum amplitude of the recorded signal was about 0.06 mrad/s
- Most of the signal's spectral components were below 20 Hz
- Pearson's correlation coefficient equal to 0.80





[Jaroszewicz et al., Opto-Electronics Review, 29, 4 (2021)]

Fibre optic seismograph – recordings

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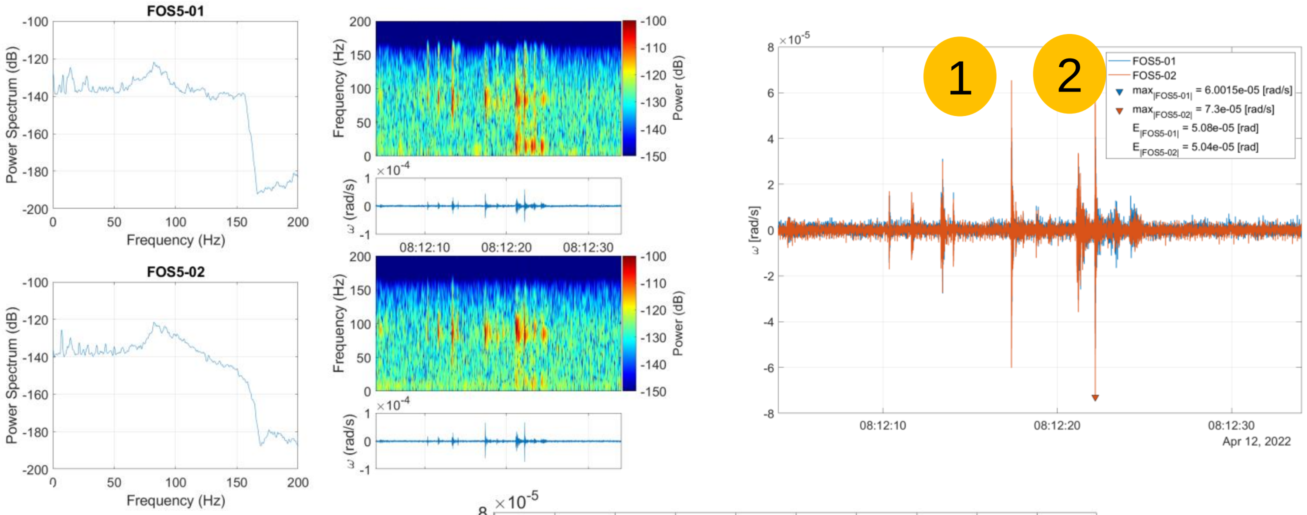
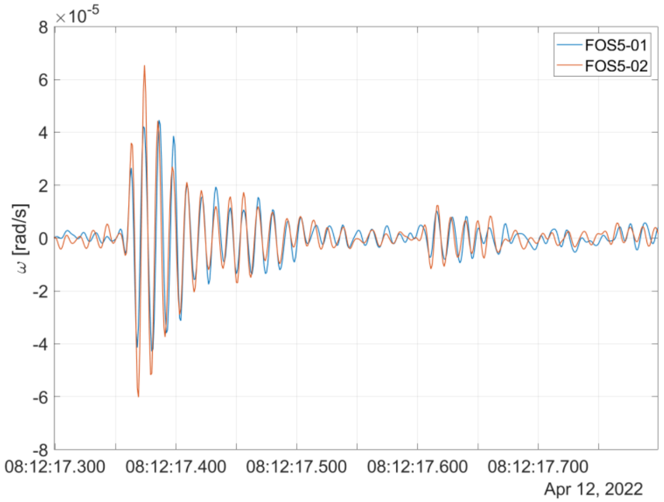
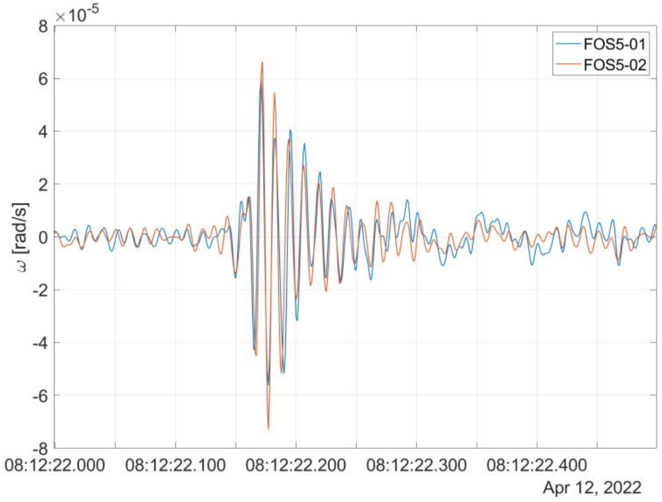
Analysis

- maximum amplitude of the recorded signal was about 0.07 mrad/s



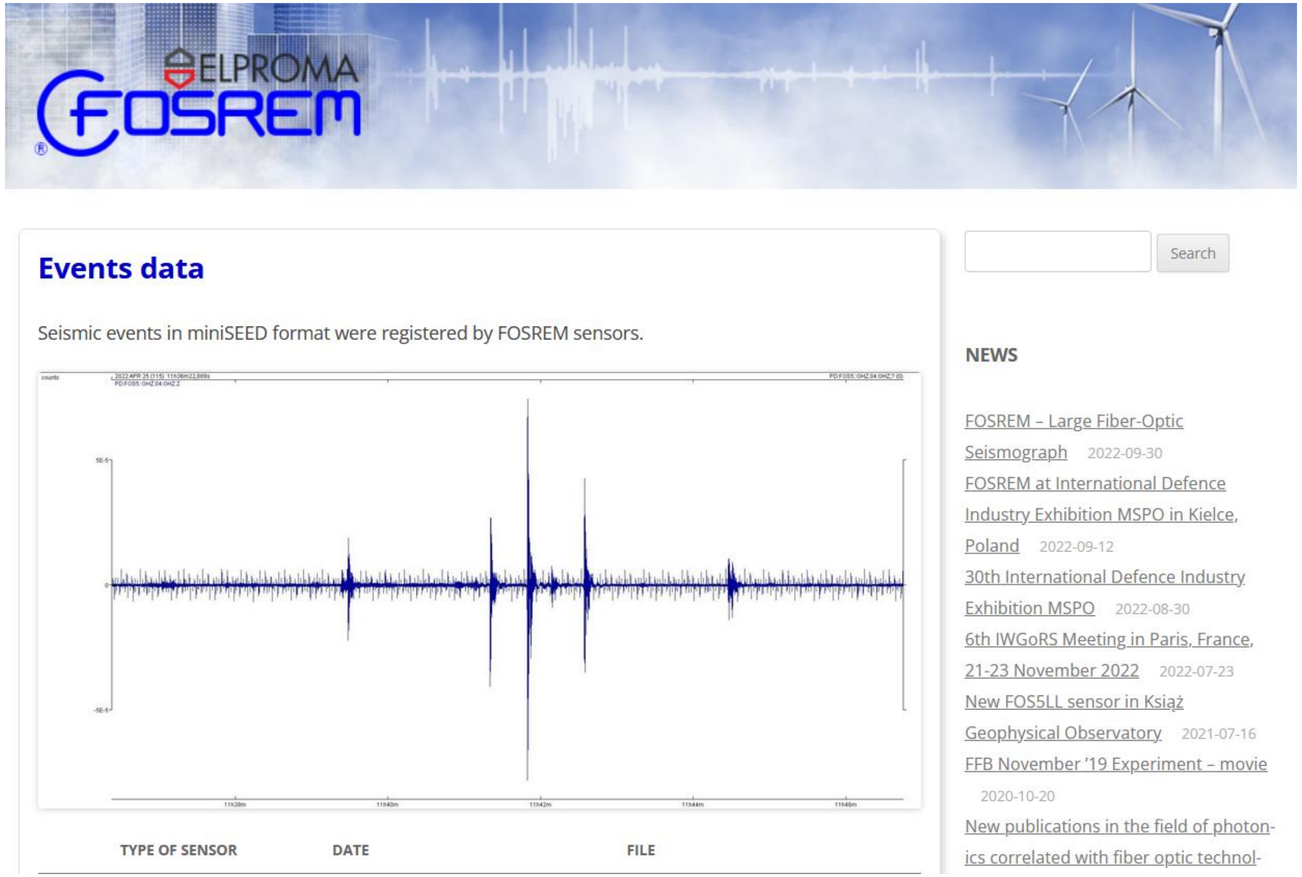




1 Pearson’s correlation coefficient equal to 0.86

2 Pearson’s correlation coefficient equal to 0.81

Seismic events in miniSEED format registered by FOSREM sensors available online



https://fosrem.eu

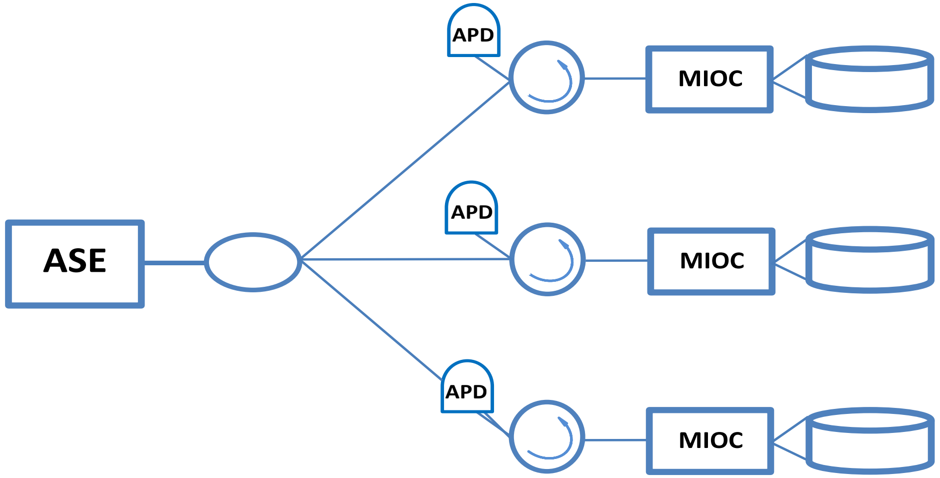
POSTER SESSION:
FOSREM - from Sky across Ground up to Underground

Conclusions

1 **Rotational seismology** undergoes a rapid development. FOS5-04 is capable to detect changes in Earth’s rotation rate.

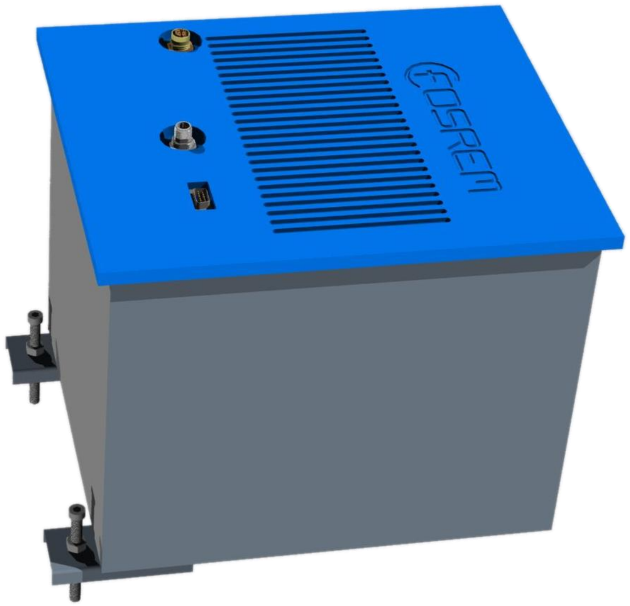
2 Future plans - next generation of FOS6 with three perpendicular axes

FOS 6
FROM SKY ACROSS GROUND UP TO UNDERGROUND



THREE AXES

- Measuring range from several dozen nrad/s to 10 rad/s (dynamics of 180 dB)
- Frequency detection bandpass: from 0.01 to 100 Hz
- Built-in time scale synchronization system
- 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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