Prezentacja naukowa

na bazie
wystąpienia autorskiego:

3rd I3S, 9-11.05.2019 Neapol

19th OFTA-2020, 27-31.01.2020 Białowieża

SEIA-2021, 22-24.09.2021 Mallorca

50th WSWQA ISO’2022, 18.02-4.03 2022 Szczyrk

FOSREM - difficulties about solution transfer from laboratory to field applications

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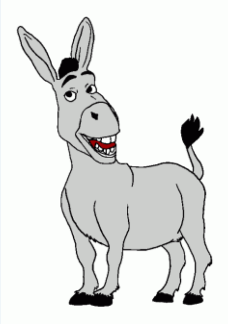
Agenda

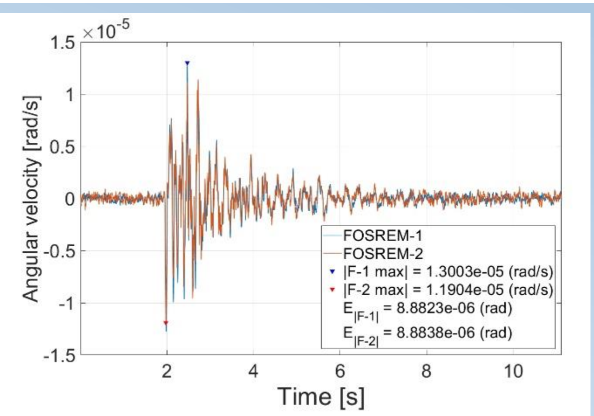
- Area of interest
- Review of existing solutions
- FOSREM - innovative idea
- FOSREM - realisation and applications

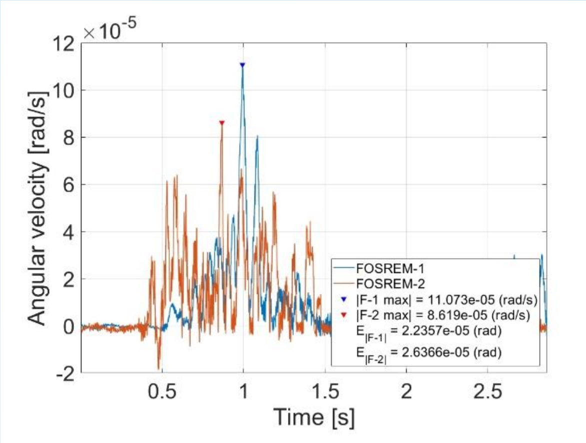
but

If - FOSREM is innovative solution

why I am so stupid???







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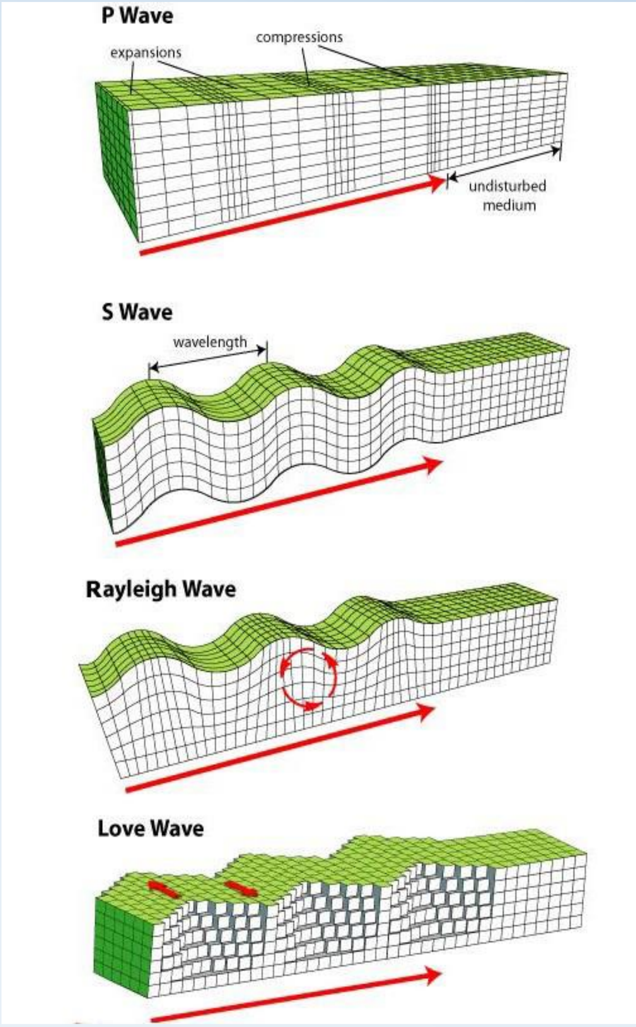
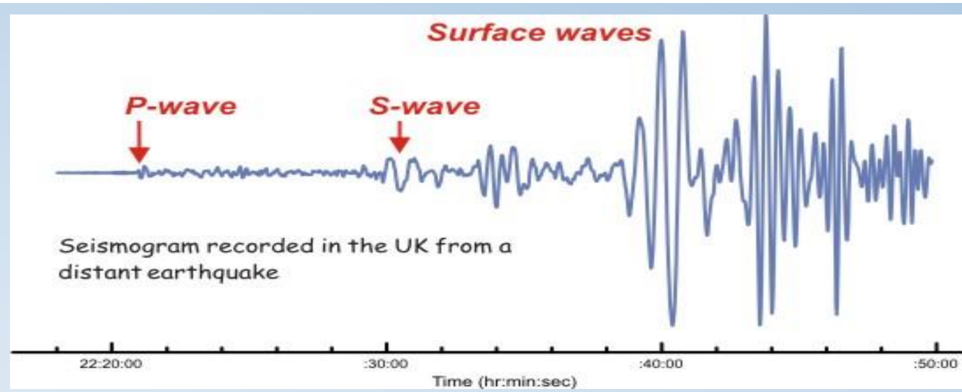
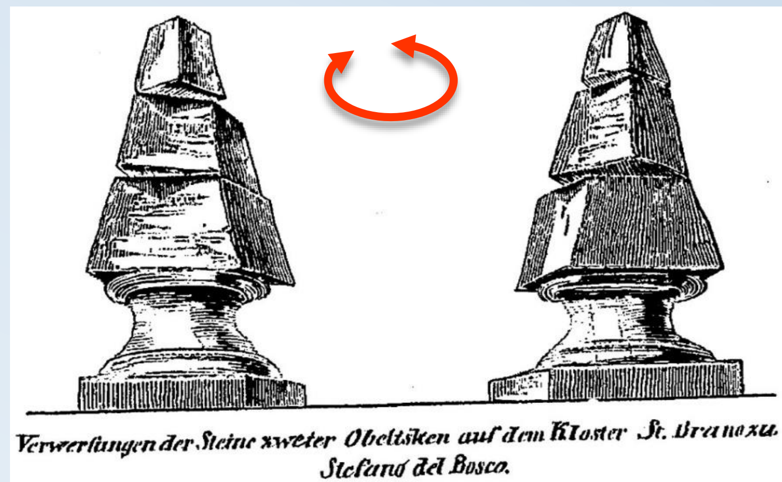


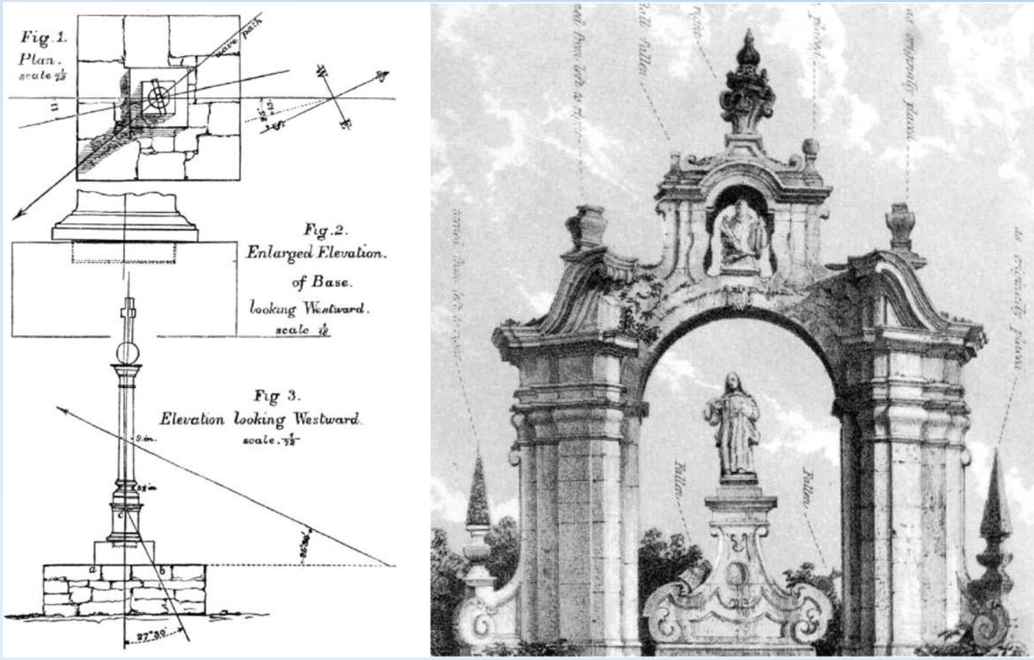


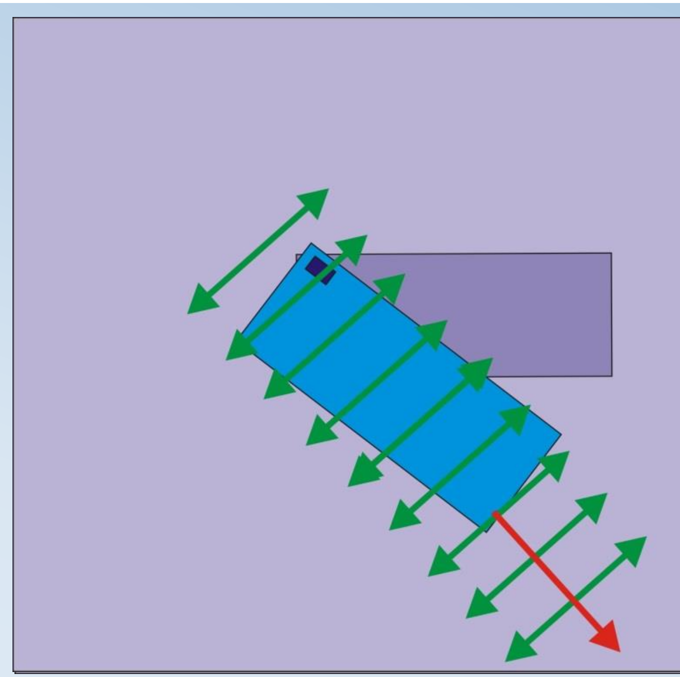


CALABRIA, 05.02.1783

[Gordon et al., *BSSA*, ***60***, 953-971, 1970]

Seismological investigation of rotation effects





[Rotational effects after Eartquacke at 1857 in Basilicata: Mallet (1862)]

Now development in seismology theories indicates that for rocks with some microstructure [*A. C. Eringen - 1999*], defects [*R. Teisseyre, W. Boratynski, 2002*], even without inner structure [*R. Teisseyre, M. Białecki, M. Górski – 2005; R. Teisseyre, M. Górski – 2009*]:

exist in grainy rocks **seismic rotational events** as rotational motions
even as rotational seismic waves [*Z. Droste, R. Teisseyre - 1997*]

[*doctor honoris causa* AGH lecture: R. Teisseyre, 2005]

Seismological aspects of rotation effects

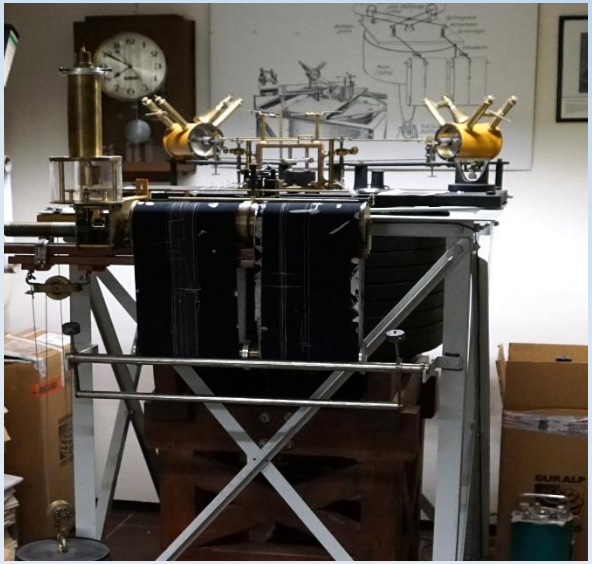
Seismological application [Lee et all, *Seis. Res. Let.*, **80**(3), (2009), 479-489]

wide range of geophysical disciplines:

- broadband seismology [Igel et al., *Geophys. J. Int.*, **168(1)**, (2006), 182–197],
- strong-motion seismology [Anderson, *The International Handbook of Earthquake and Engineering Seismology*, 2003, Chap. 57, 937-965],
- earthquake physics [Teisseyre et al., Springer, 2006; Teisseyre i inni, 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]

Engineering application

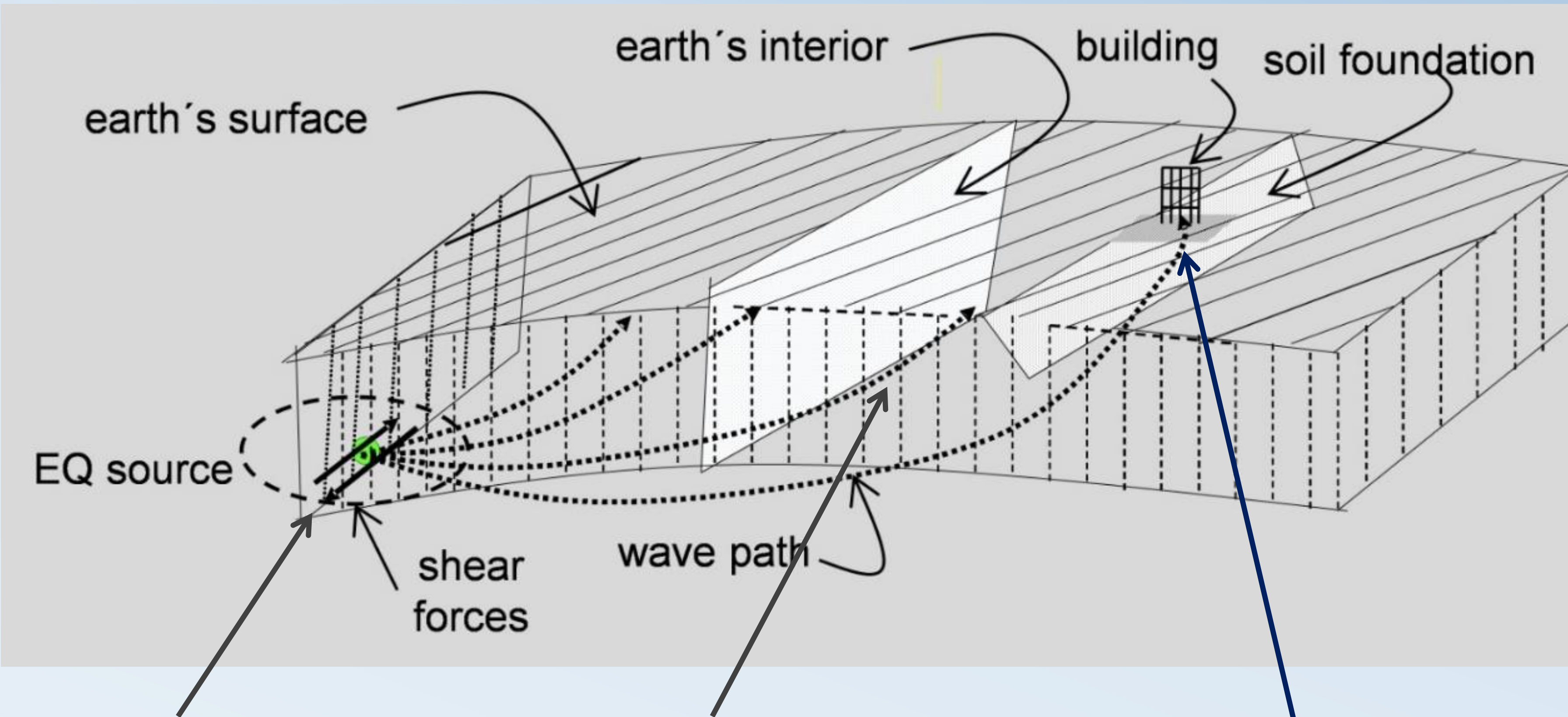
seismic behaviour of irregular and complex civil structures [Trifunac, *BSSA*, **99**, (2009), 968-97; Mustafa, InTech, 2015]



[https://www.outlookindia.com/website/story/major-quake-of-magnitude-8-likely-to-hit-north-india-says-chief-of-seismology-ce/304704]

Rotational Seismology

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



Finite size
as near field effects

(Hypothetic) rotational wave (R. Teisseyre)
"anti-Richter"

Reflection & interference „rotation
of geological blocks"

[prof. Z. Zembaty lecture, *SMOiO KM PAS* 14.10.2016]

Seismological aspects of rotation effects

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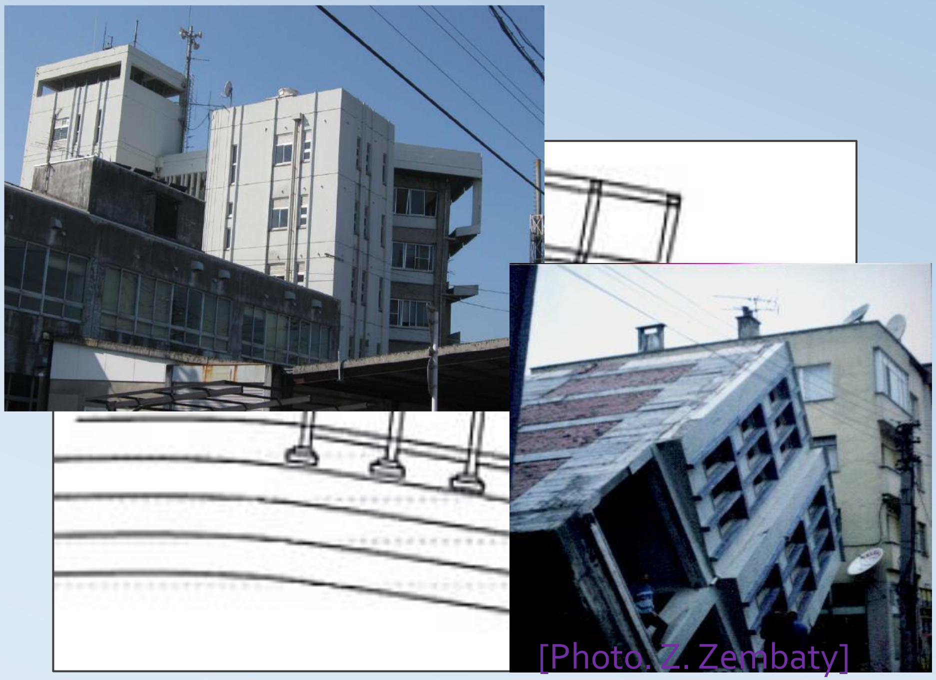


High frequency content

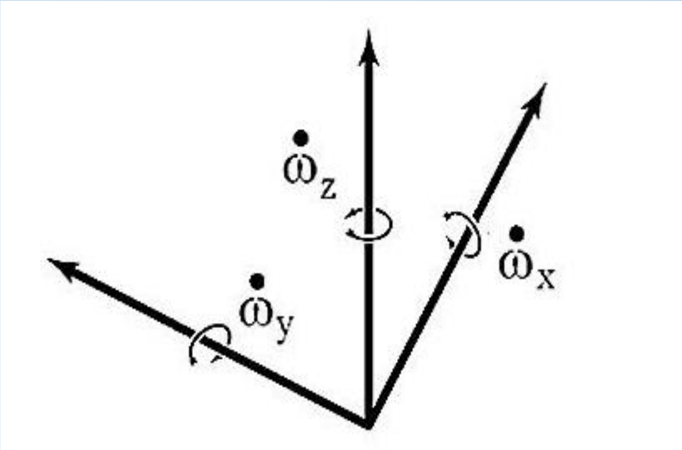
- **Local vibration of beams and columns**
- Meaningless motion of the building center of mass

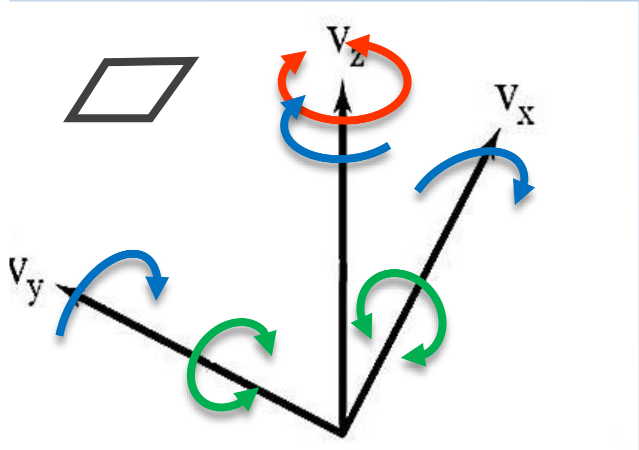
Low frequency content

- Higher stress in structural element
- **Overturning moment**
- Horizontal displacement of the center of mass

[Castellani, 2nd *IWGoRS workshop*, Masaryk's College Prague, 2010]

Effect of rotation motion on engineering structures





Torsion - rotations or strains about the vertical axis of a structure

Tilt - mean long-period rotations about a horizontal or vertical axis / only static rotations / rotations at any frequency

Rocking - rotation about horizontal axis or, as often used by engineers, of a whole structure about a horizontal axis

Twist - a shear deformation caused by torsional moment

Spin - a term that is unclear at present; in physics, it is used for rotational velocity; in continuum mechanics, it is the antisymmetric part of the velocity gradient tensor and may be also used for the proper kinetic moment of particles

A Short Glossary for Rotational Seismology

[Lee et al., *BSSA*, **99**, (2009), 945-957]

1. „Seismological" applications

[Bernauer et all, *J. Seisml.*, **16**, (2012), 595-602]

1. effectively insensitive to linear motion, or at any time, independent measurement of linear and rotational motions must be possible,
2. small (mobile) and stable with respect to ambient conditions, including changes of temperature,
3. the electrical power supply should be easily managed using batteries, at least combination with solar panels or fuel cells,
4. be able to measure amplitudes on the order of 10^{-8} rad/s at frequency range 0.01 Hz - 0.1 Hz.

2. „Engineering" applications

[Jaroszewicz et all, *Sensors*, **16**, (2016), 2161]

1. effectively insensitive to linear motion, or at any time, independent measurement of linear and rotational motions must be possible,
2. small (mobile) and stable with respect to ambient conditions, including changes of temperature,
3. the electrical power supply should be easily managed using batteries, at least in combination with solar panels or fuel cells,
4. be able to measure amplitudes up to a few rad/s at frequency range 0.01 Hz - 100 Hz.

Rotational sensor → ROTATIONAL SEISMOMETER (1-, 2- or 3- Axes)
field application → ROTATIONAL SEISMOGRAPH
network of **seismometers +** precise time source + recording device + network

Instrumental requirements

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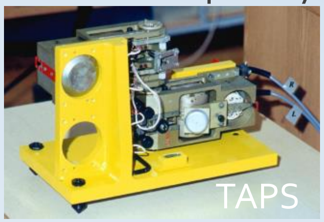
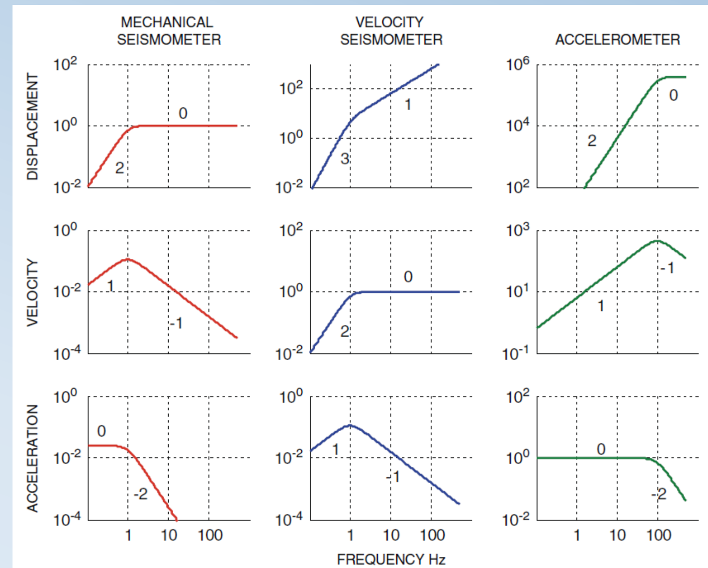
1. Mechanical type (nondirect based on velocity or accelerometer type seismometer)

Limited: frequency range, max. detectable rotation rate

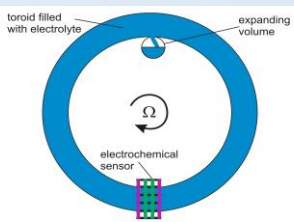


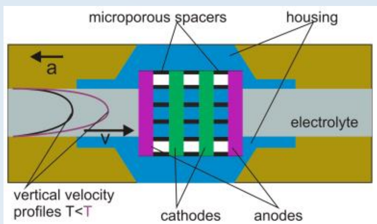


[Havskov, Alguacil, *Instrumentation in Earthquake Seismology*. Springer, 2016]

2. Electro-chemical type (direct based on liquid inertia)

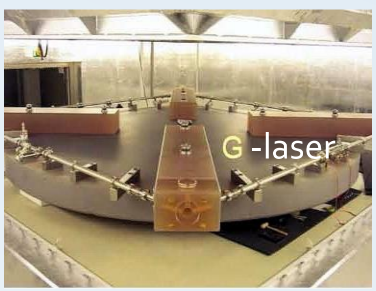
hight thermal instability, problem with electrolyte inertia





3. Optical type (direct based on Sagnac-von Laue effect)

opimal for seismological applications, but stationary system



Specialized system based on FOG

Review of existing solutions

[Jaroszewicz et all, *Sensors*, **16**, (2016), 2161]

Sagnac (1913)/von Laue (1911) is a result of a difference between two beams propagating around closed optical path, in opposite direction. The Sagnac phase shift induced by rotational rate Ω perpendicular to plane of sensor is equal to:

$$\Delta\varphi = \frac{4\pi RL}{\lambda c}\Omega = \frac{1}{S_0}\Omega$$

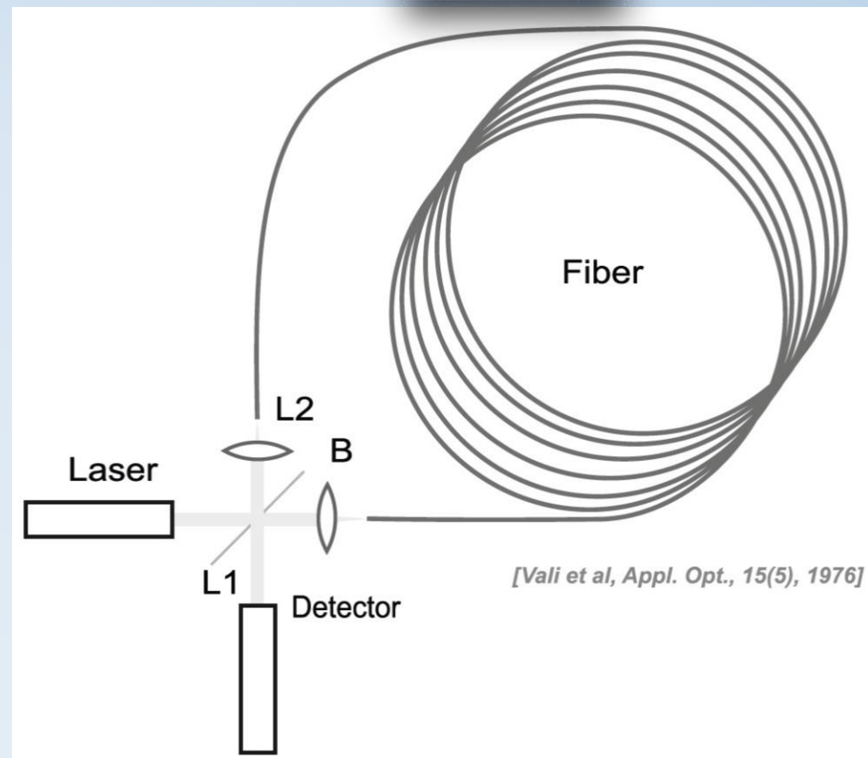
where:

L – length of the fiber in the sensor loop

λ – wavelength

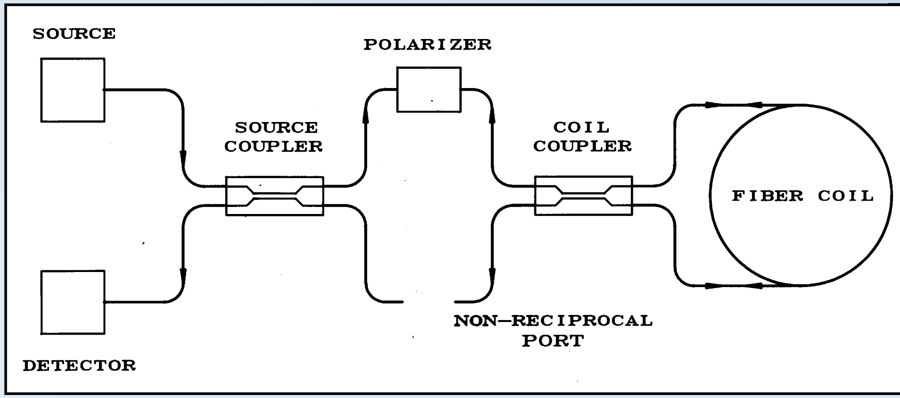
c – velocity of the light in vacuum

S_o – the optical constant of interferometer

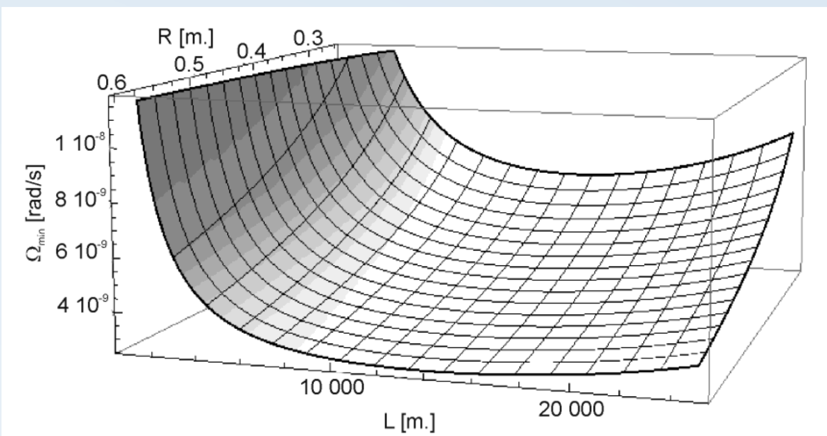


Theoretical background

Minimum configuration → **FORS** system optimization for **rotation rate** (**not angle**) detection



[private photo -*1999*] [private photo -*1999*]



AFORS optimization of optical head (gain FOG):

- **L= 15 000 [m],** 15 layers, quadrapole-bifilar winding,
- α =0.436 [dB/km],
- **loop R=0.34 [m]** with permaloy particles,
- **σ = 13.16 [dB],**
- cascade polarizers (46 and 55 [dB]),
- depolarizer with P=0.002
- $\Delta\lambda$=31,2 [nm], λ=1326.9 [nm], P_L =20 [mW],
- S=0.99 [A/W], I_A =0.06 [nA], R_0 =163 [kΩ].

- applied depolarized light for cost minimization and open-loop architecture with detection Ω as:

FORS - innovative idea

$$\Omega = S_o \tan^{-1}\left[\frac{u(t)}{S_e}\right], \qquad u(t) = \frac{A_{1\omega}}{A_{2\omega}}$$

Ω_{min} =1.93·10^{-9} [rad/sHz$^{1/2}$]

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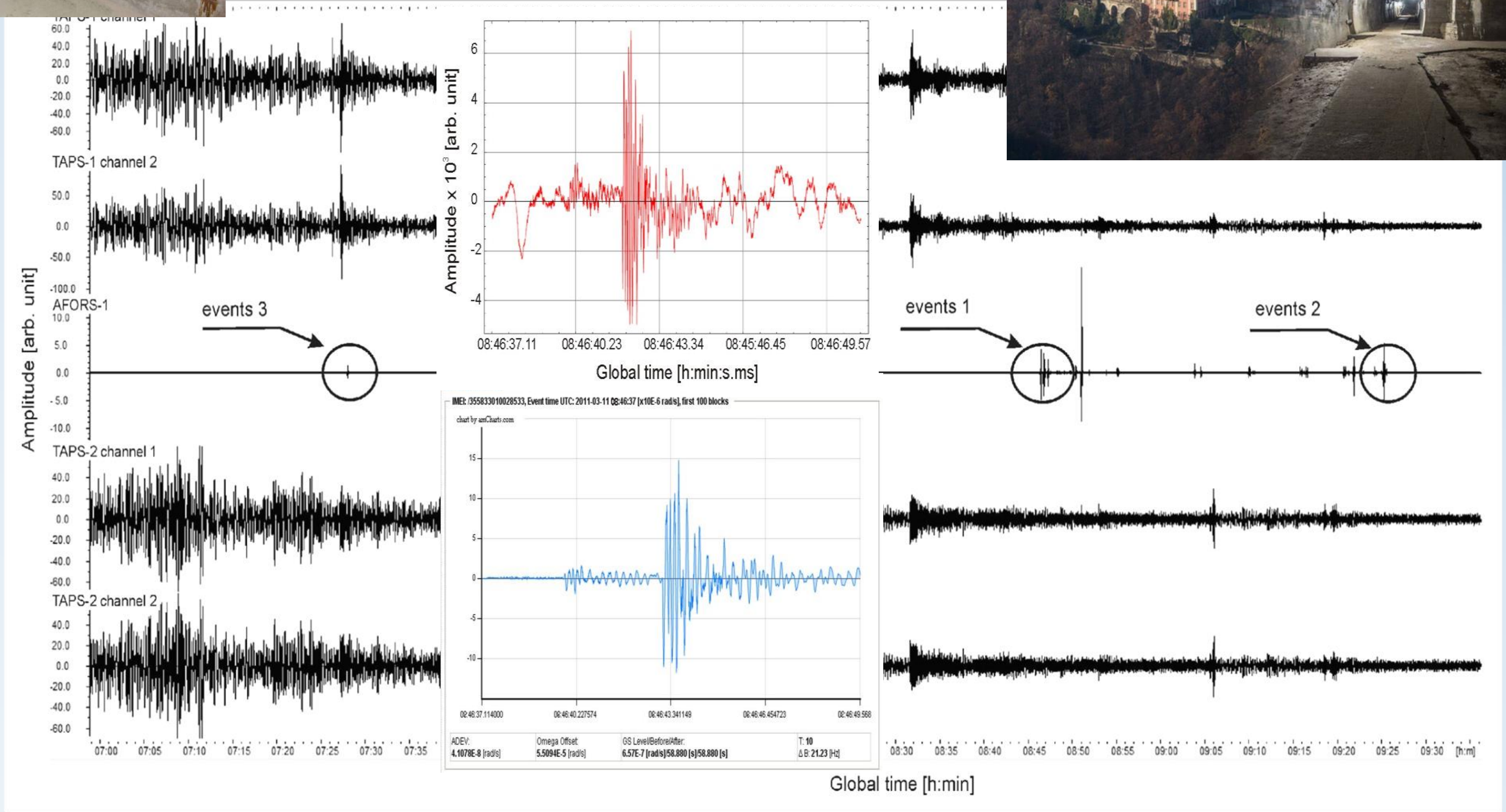
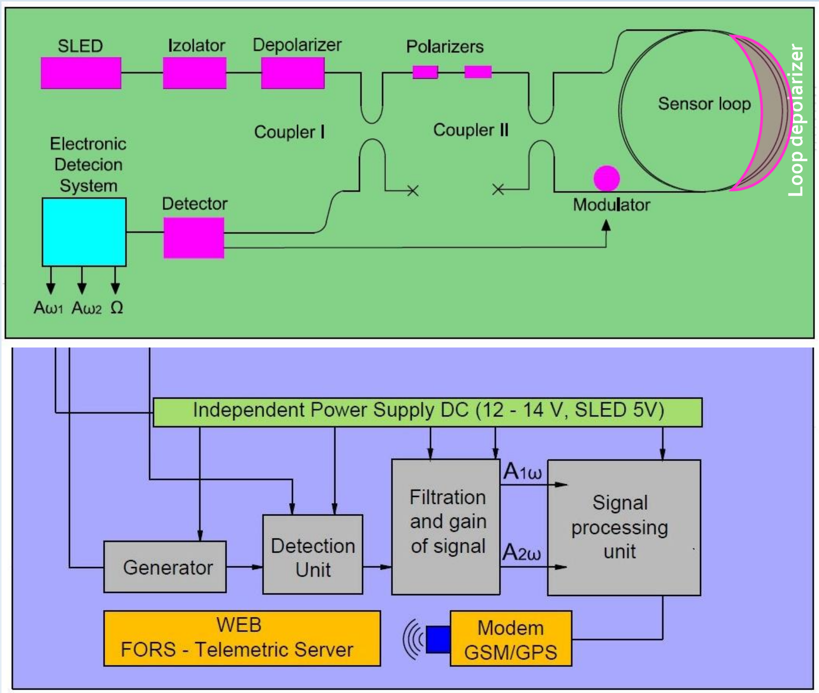
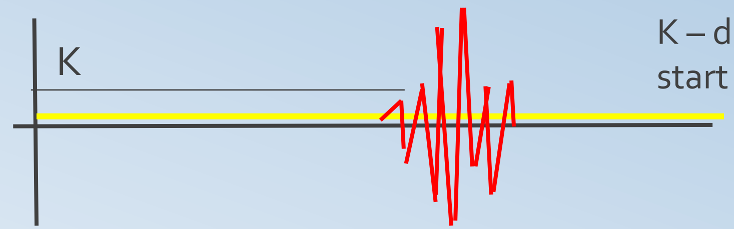
Seismogram recorded in Książ from Honshu earthquake (M=9.0) at 6:58, 11-03-2011



[Jaroszewicz et all, *J. Seismol.*, **16,** (2012), 573-586]



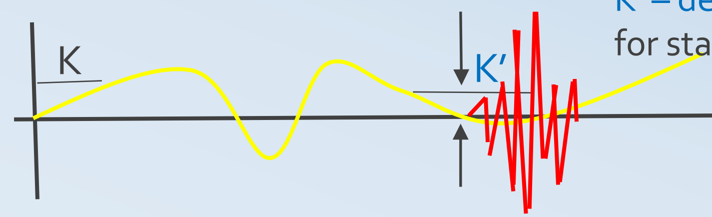
Numerical approch to Ω detection on „drifting signal"



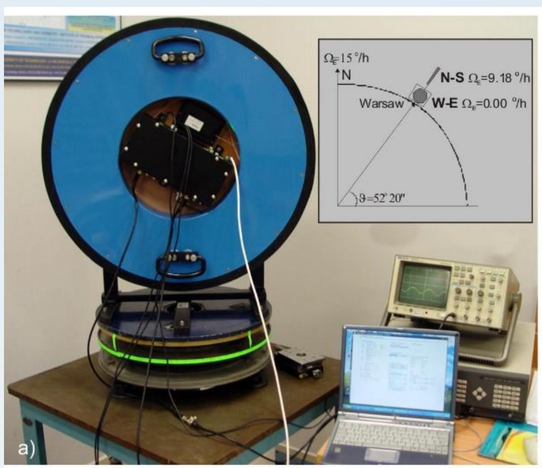
K – definied Ω level for start to recording data

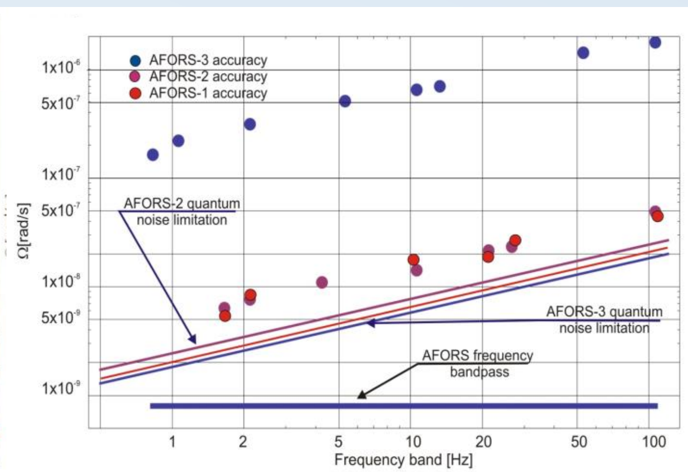
Ideal approach (without drift - no bias phenomena)

K' – definied local Ω level for start to recording data



Real situation `drifting signal` (bias exist)





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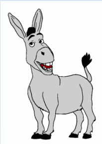
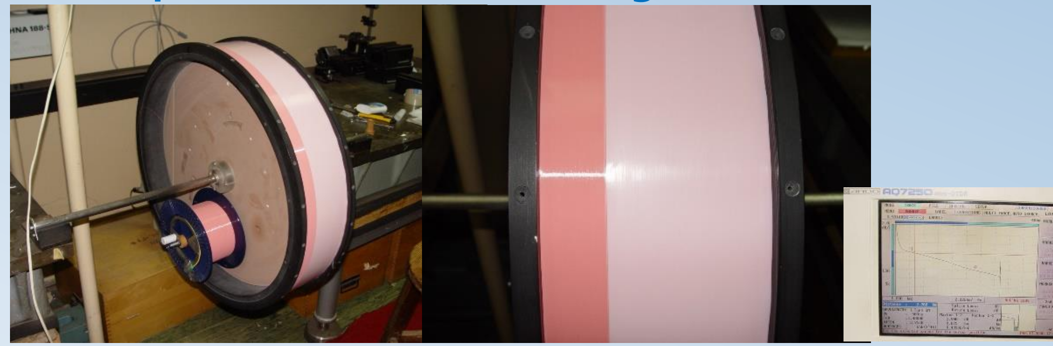


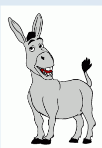
1. Large loop:

- large moment of inertia
- hand made in long time,
- expensive device,

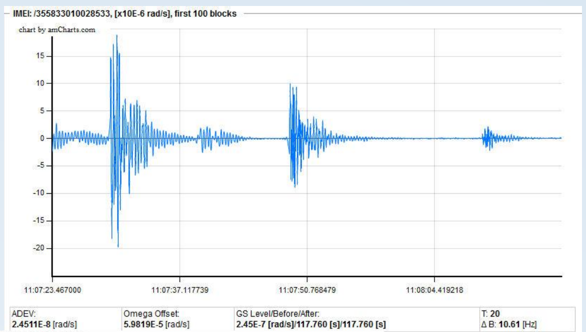
Limited numer of devices

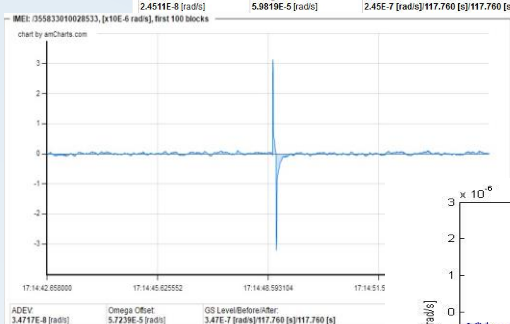
2. Dust problem – microbending sensor

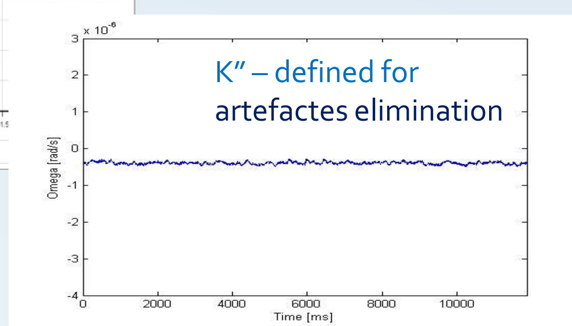


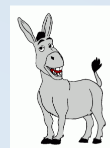


4. ADC – limited accuracy

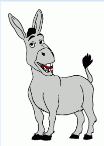




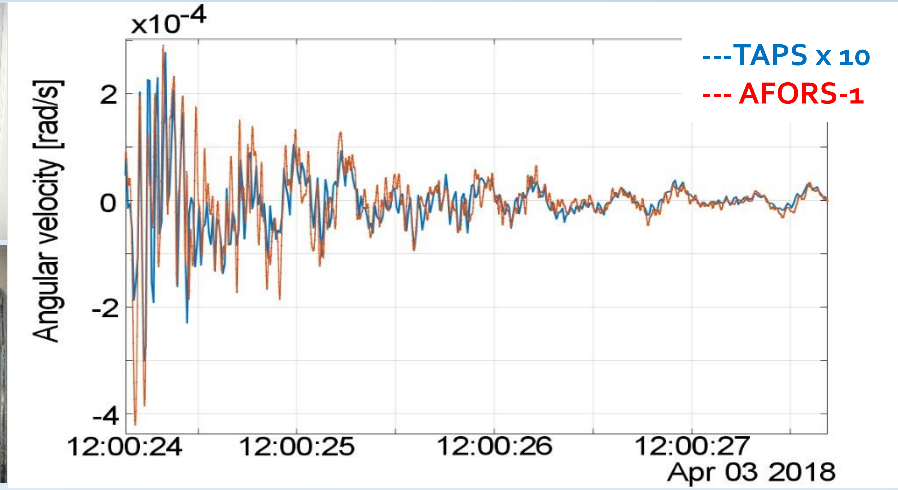


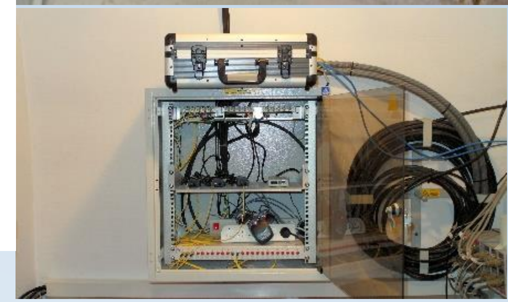


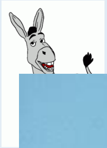
3. GPS/GSM antena – connection problem



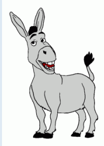
5. Non-compability of recording system







6. SLED fantastic long (7 years work) but rats



7. Long fiber:

- too low max. Ω (only 0.006 rad/s),
- too big low frequency (only 0.83 Hz)

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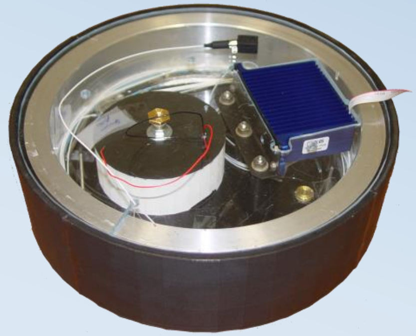
FOSREM-SS

Optical module



[Kurzych et all, *Opto-Electron.Rev.*, **24**, (2016), 134-143]

FOSREM-BB

Electronic module

Analog & ADC

DSP & μ–computer

Laser

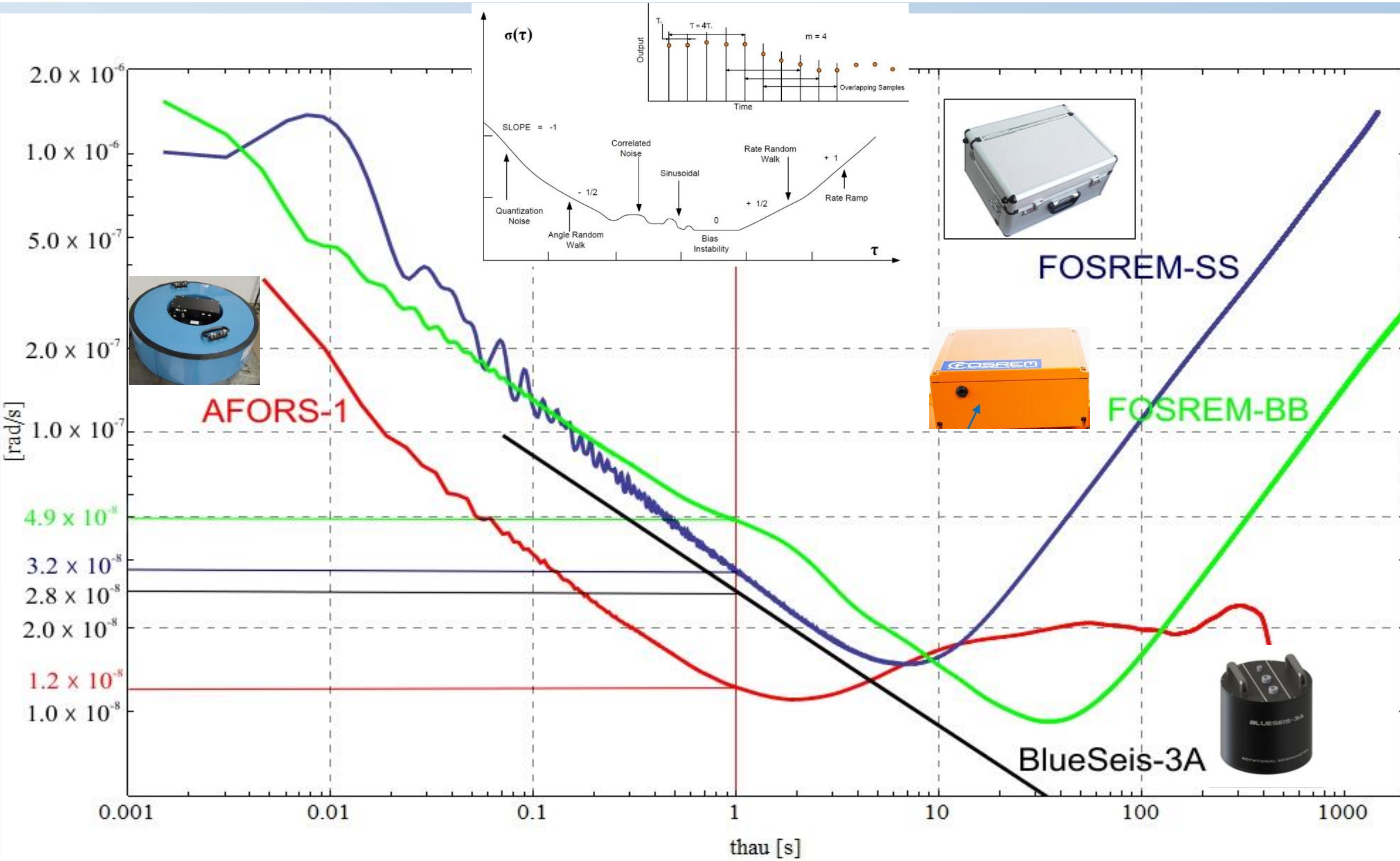
Power supply

FOSREM ® advantages:

- Optimised optical head (**5 km** SMF-28, **diameter 0,25 m**);
- 3D printing structure – low cost;
- Long-life source (SLED);
- **Theoretical sensitivity $2\cdot10^{-8}$ rad/s/Hz$^{1/2}$**;
- Open-loop, digital processing
- Passband from **DC** to discrete value from 2.56 - **328.12 Hz**);
- **Max. rotation rate a few rad/s;**
- **Mobility** (36x 36x16 cm, **weight: 10 kg**);
- Remote control via internet;
- Power supply: 230AC PCU, PoE 48V from PCU (3 seismometers)

FOSREM ®- towards final success

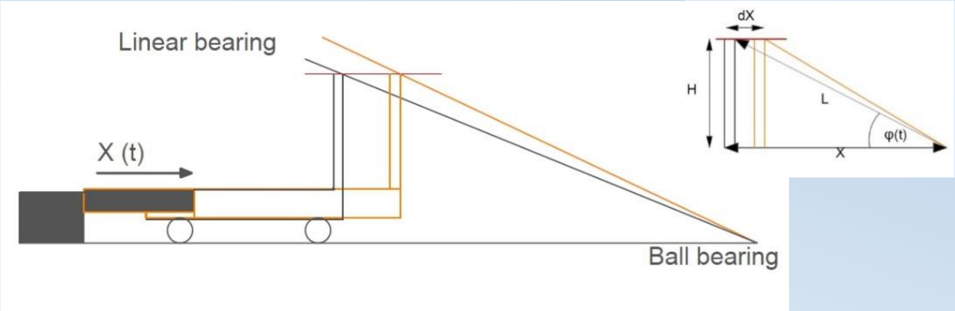
Fibre-Optic System for Rotational Events & Phenomena Monitoring



Allan variance

[Kurzych et al., *J. Lightwave Techn.*, 36(4), (2017)]

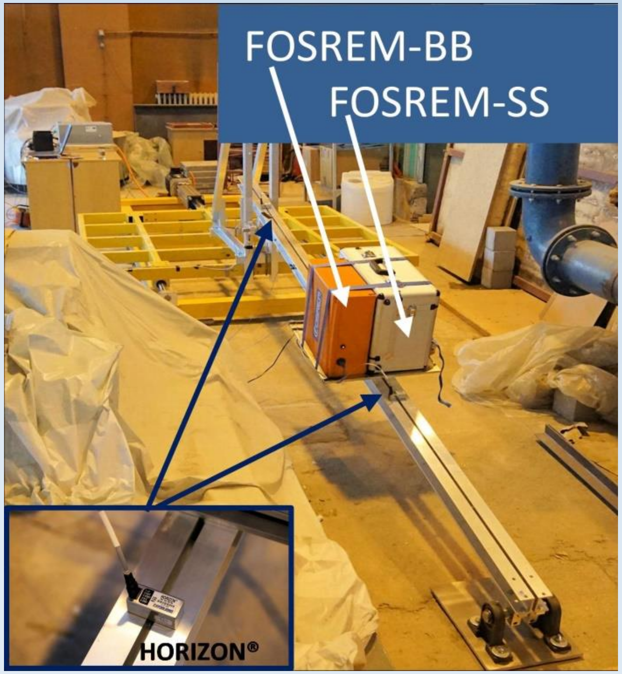
(method of analyzing a sequence of data in the time domain – oscylator frequency stability measurement)



$$\varphi(t) = \mathrm{arcctg}\left[\frac{X - dX}{H}\right]$$

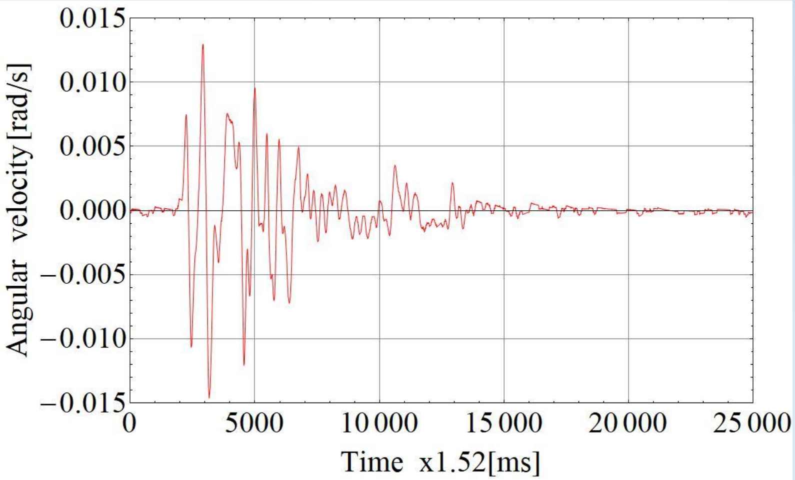
$$\Omega(t) = \frac{d\varphi(t)}{dt} = 0.0356V(t)$$

v(t) from digitalized data of Earthquakes

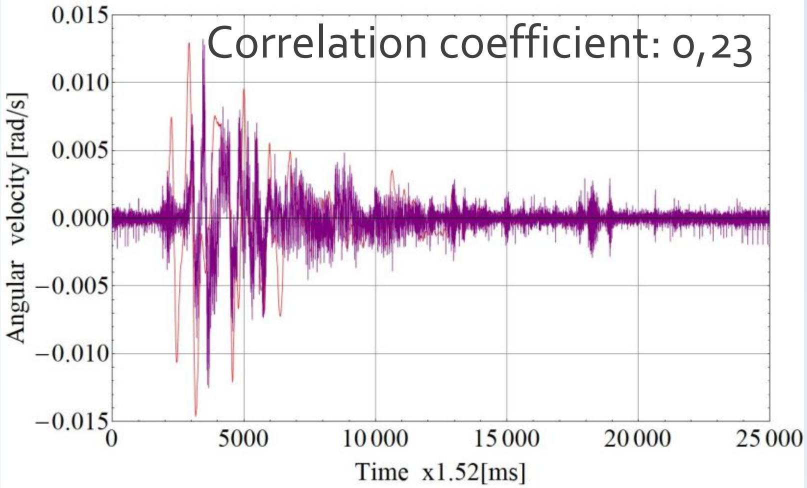


Testing with Earthquakes simulation

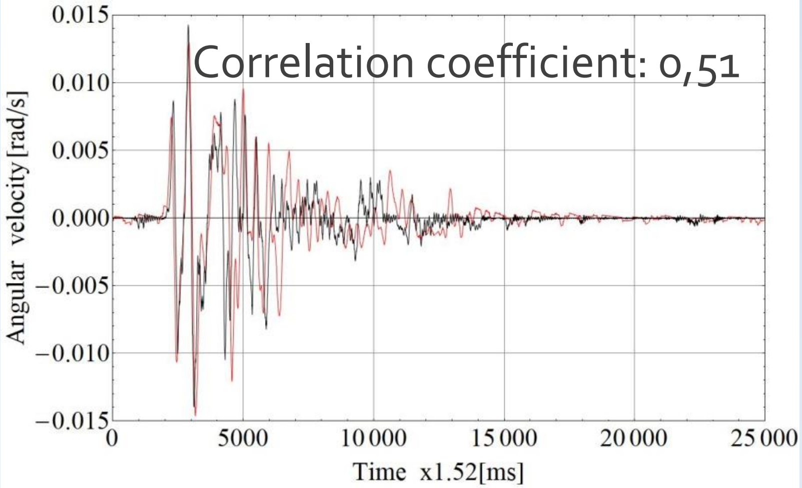
Calculation from formule (1) for Kobe earthquake , January 17th, 1995



Data from Horizon HZ1-100-100



Data from FOSREM-SS



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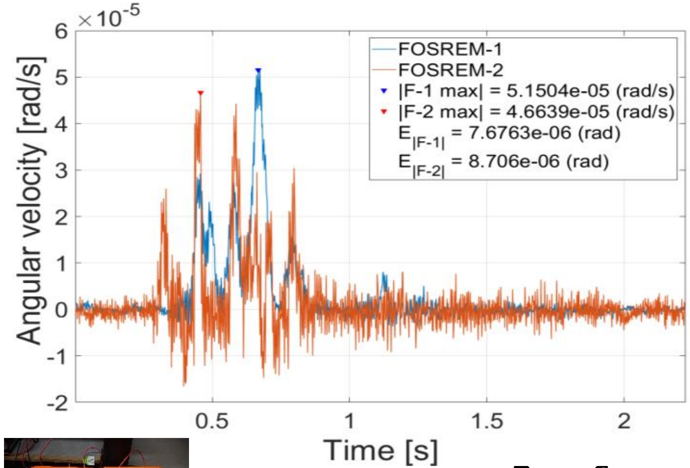
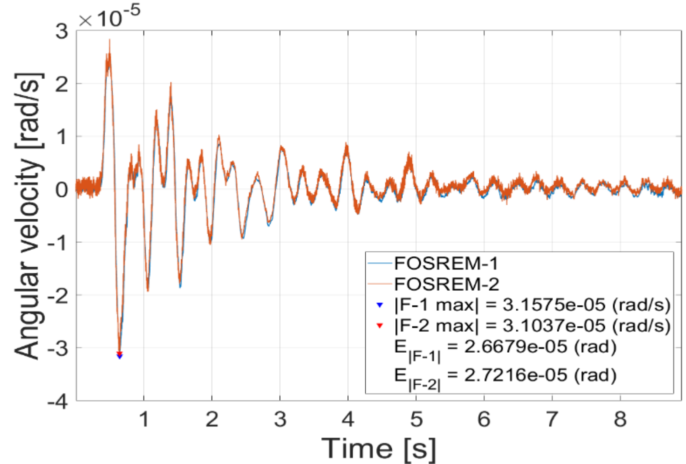
FOSREM – Książ observatory

[W.H.K. Lee, *BSSA*, **99**, (2009), 1082–1090]

Recordings of tilt

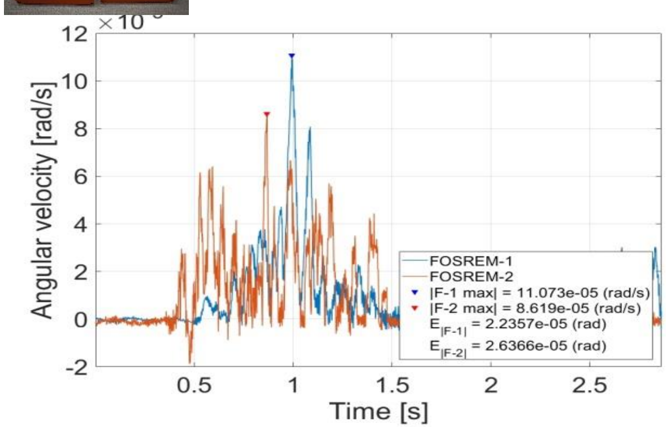
Recordings of torsion

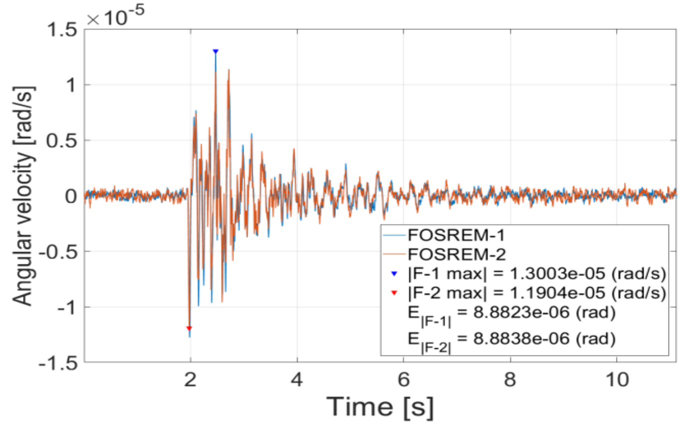




P_c=0.65±0.05

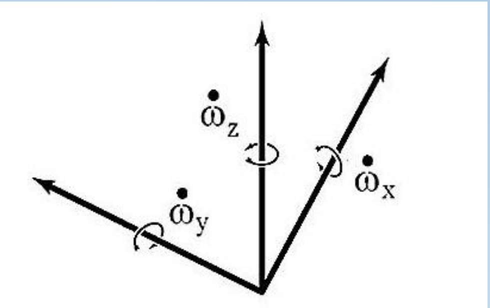
P_c=0.91±0.02





P_c=0.63±0.06

P_c=0.96±0.03



Torsion - rotations or strains about the vertical axis of a structure

Tilt - long-period rotations about a vertical axis (only static rotations) rotations at any frequency

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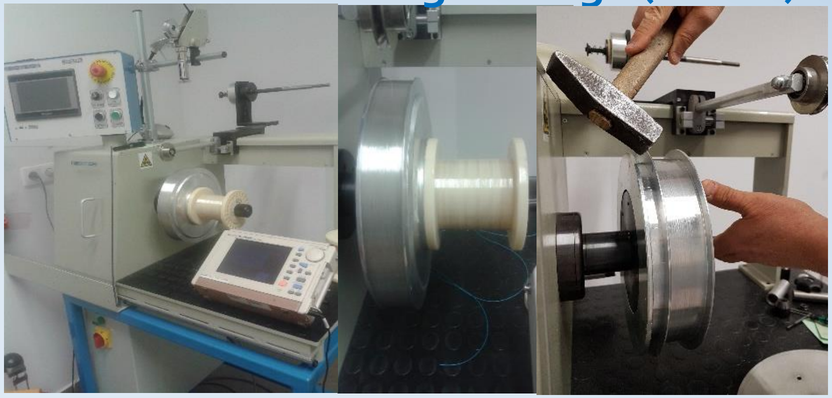
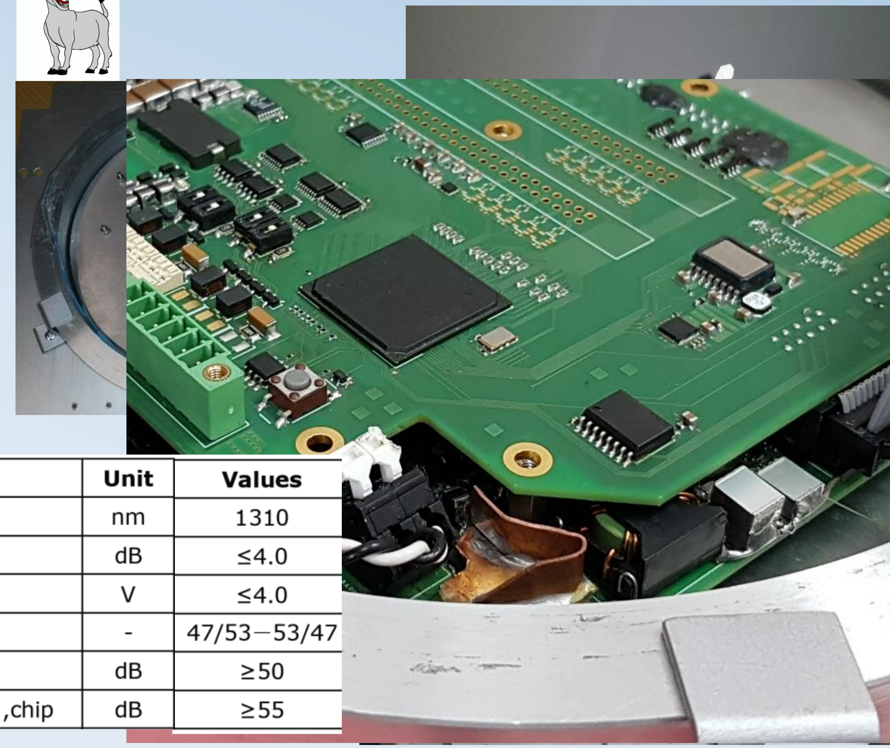
8. Automatic winding – wedge (hamel)

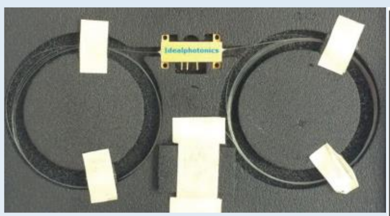


9. Accuracy of hole preparation



10. MIOC – large attenuation!

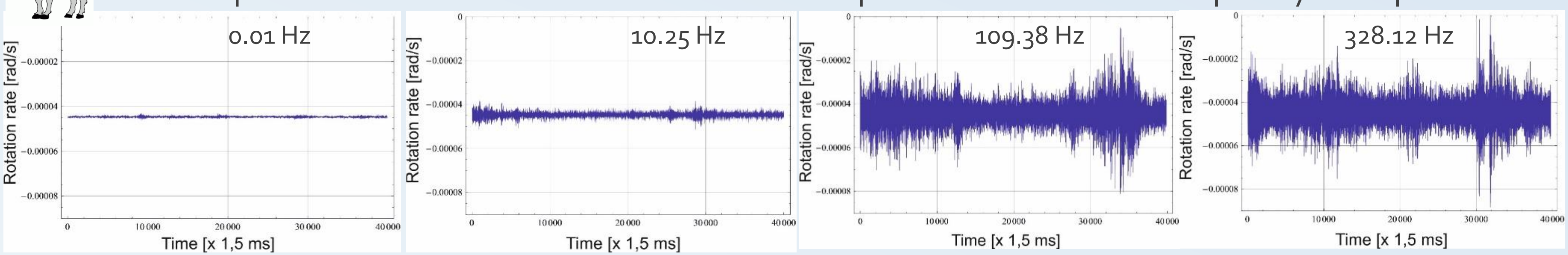
14.06 dB → 19.63 dB



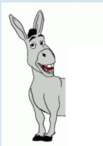
Parameter	Unit	Values
Wavelength	nm	1310
Insertion	dB	≤4.0
Half wave Voltage	V	≤4.0
Splitting Beam Ratio	-	47/53—53/47
Optical Return	dB	≥50
Polarization extinction ,chip	dB	≥55

11. Urban noise - 1

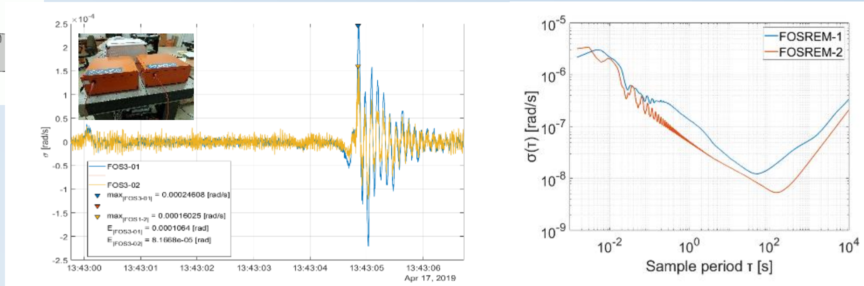
Example of measured Earth's rotation rate component at a various frequency bandpass:

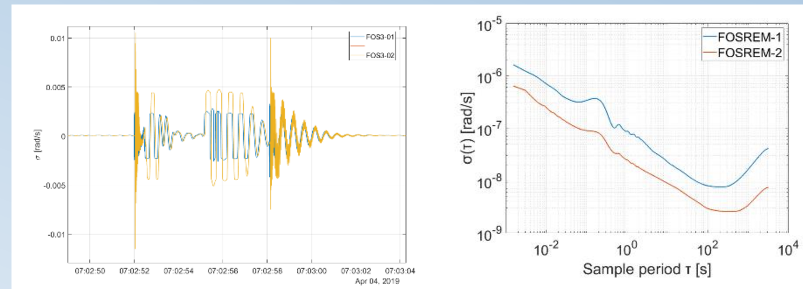


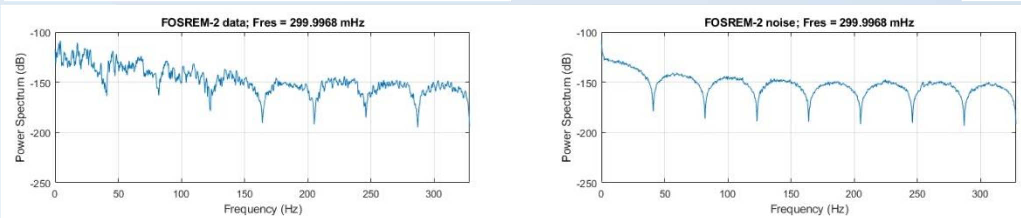
[Kurzych et al., *Proc. SPIE*, **9916**, (2016), 99100K]



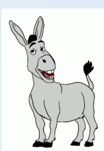
11. Urban noise - 2





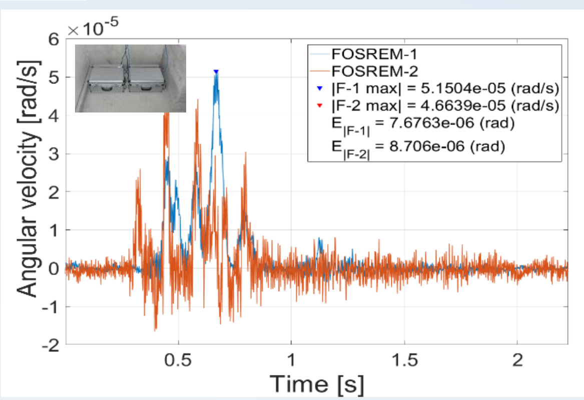


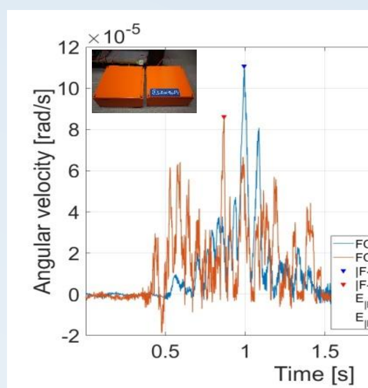
	Sturdy flat floor		Active optical table	
	ARW [rad/√s]	BI [rad/s]	ARW [rad/√s]	BI [rad/s]
FOSREM-1	$1.33 \cdot 10^{-7}$	$1.81 \cdot 10^{-8}$	$8.66 \cdot 10^{-8}$	$1.13 \cdot 10^{-8}$
FOSREM-2	$5.26 \cdot 10^{-8}$	$8.08 \cdot 10^{-9}$	$2.45 \cdot 10^{-8}$	$3.91 \cdot 10^{-9}$



12. Tilt – proper stick on seismologic pedestal

If torsion has P_c above 0.90 why tilt has P_c only 0.60 ?





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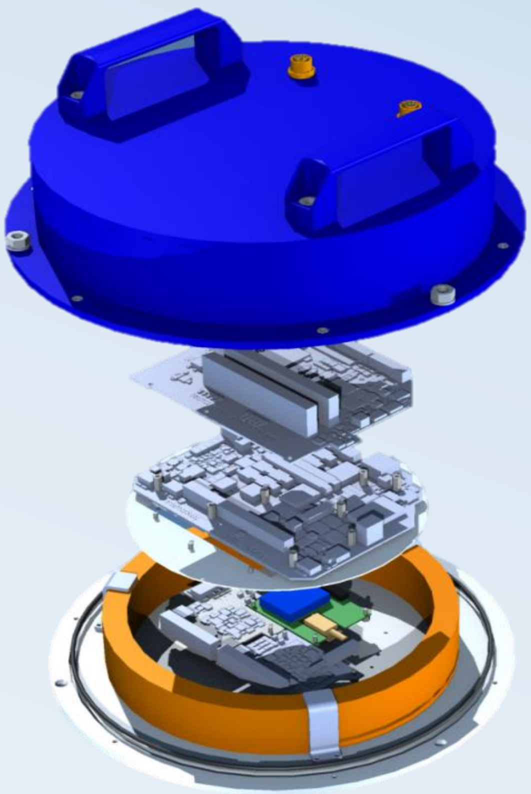

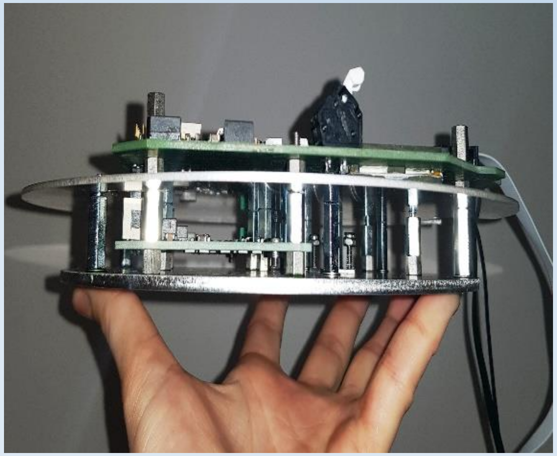

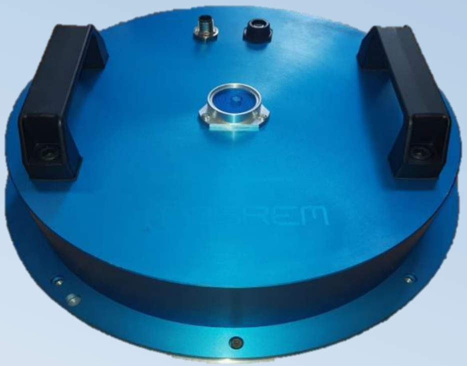

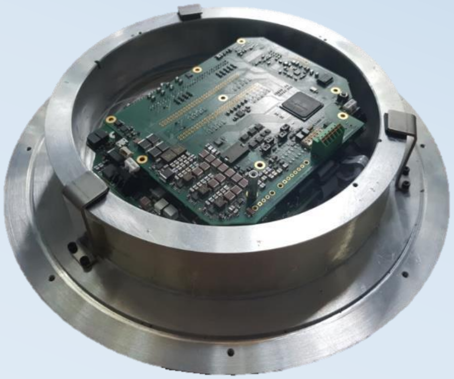

The latest FOS5 fiber-optic rotational seismometer is designed to continues operation in hard working conditions.

FOS5 – the youngest close-loop our childern

How long from final success we still are?

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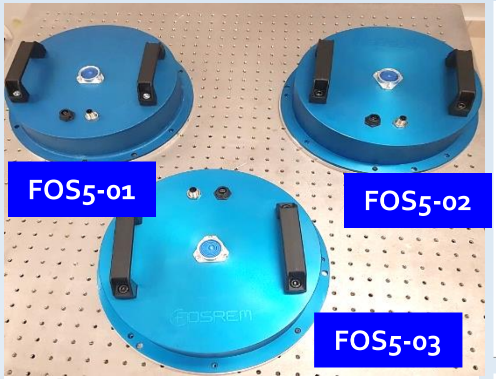
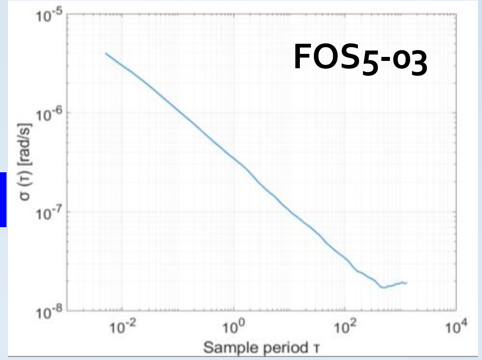
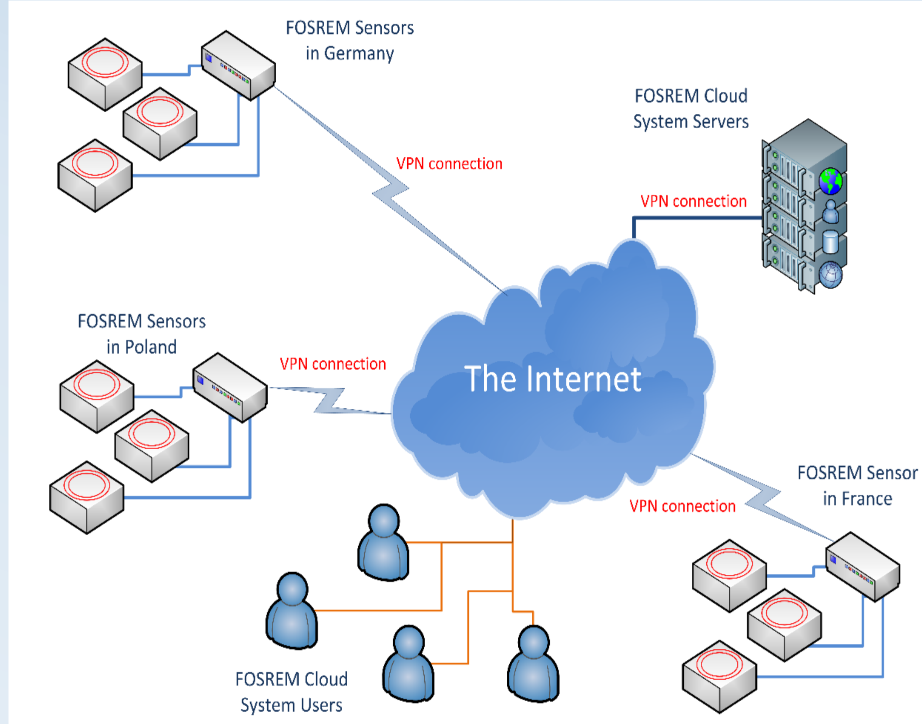
Maximum rotational rate: 10 rad/s
Sensitivity: $2.18 \cdot 10^{-9}$ rad/s/√Hz
ARW (AV investigation): 20 nrad/s
BI (AV investigation): 8 nrad/s
Pass band: from DC to 100 Hz
Configuration: closed-loop with digital processing

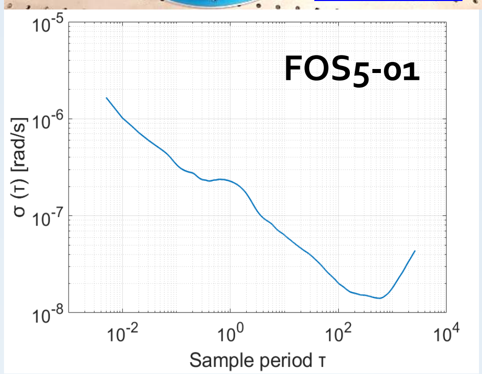
Interfaces
- FOS-5: 2xRS-485, USB2.0
- PCU:1Gbps RJ-45, 5G LTE (PCU)

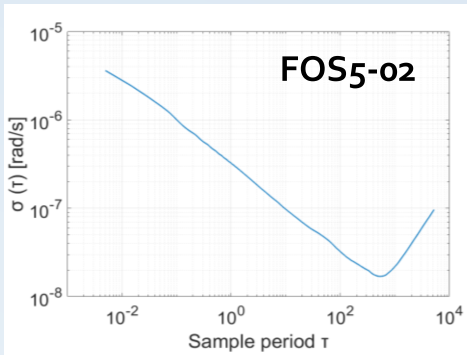
Data storage: 128 GB SSD (up to 14 days of measurement data)
Management: Local and remote management and data acquisition over Internet
Power Supply: 24VDC/20W, 85-240VAC (via PCU)
Ingress protection: IP67
Dimensions
- FOS-5: 320 x 120 mm
- PCU: 240 x88 x 65 mm



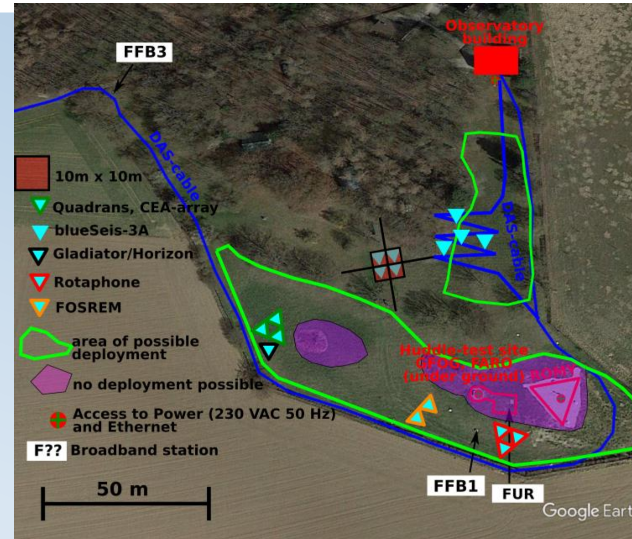


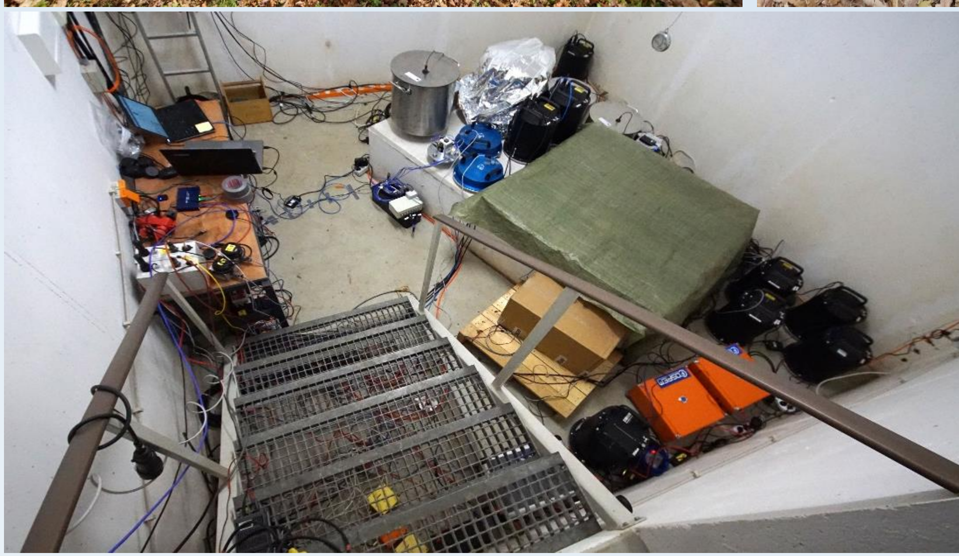






FOS5-01		FOS5-02		FOS5-03	
ARW [rad/√s]	BI [rad/s]	ARW [rad/√s]	BI [rad/s]	ARW [rad/√s]	BI [rad/s]
$2.16 \cdot 10^{-7}$	$2.28 \cdot 10^{-8}$	$3.24 \cdot 10^{-7}$	$2.55 \cdot 10^{-8}$	$3.47 \cdot 10^{-7}$	$2.83 \cdot 10^{-8}$





Rotaion and strain in Seismology: A comparative Sensor Test Fürstenfeldbruck 19-22.11.2019

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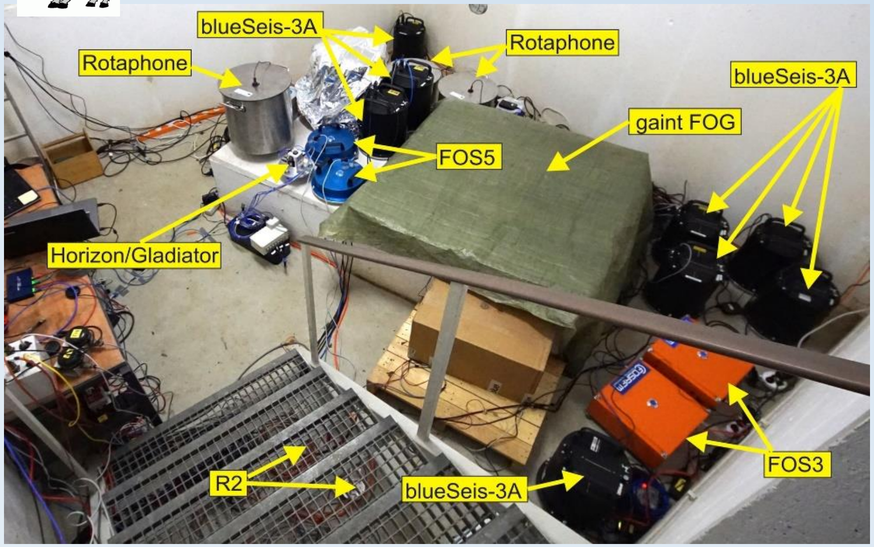
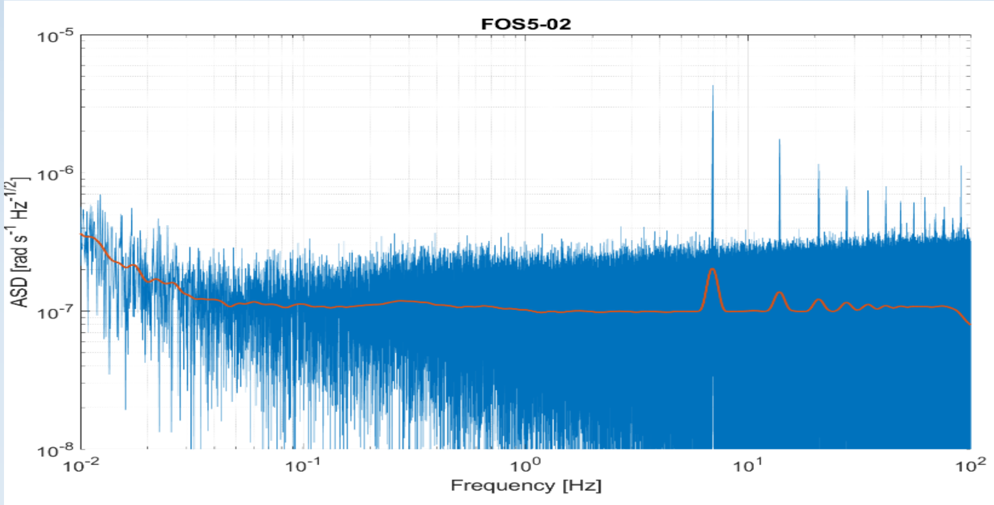
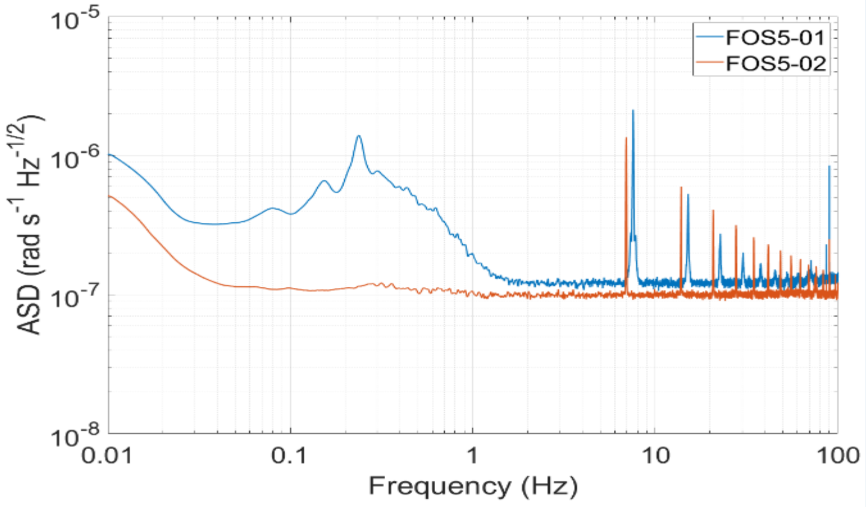
13. FOS5 – derramping needs for high frequency spikles elimination

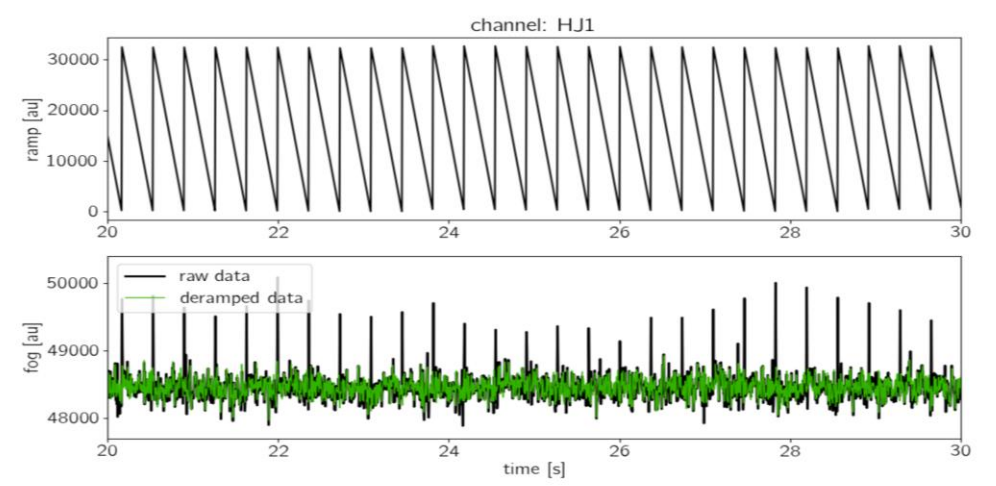




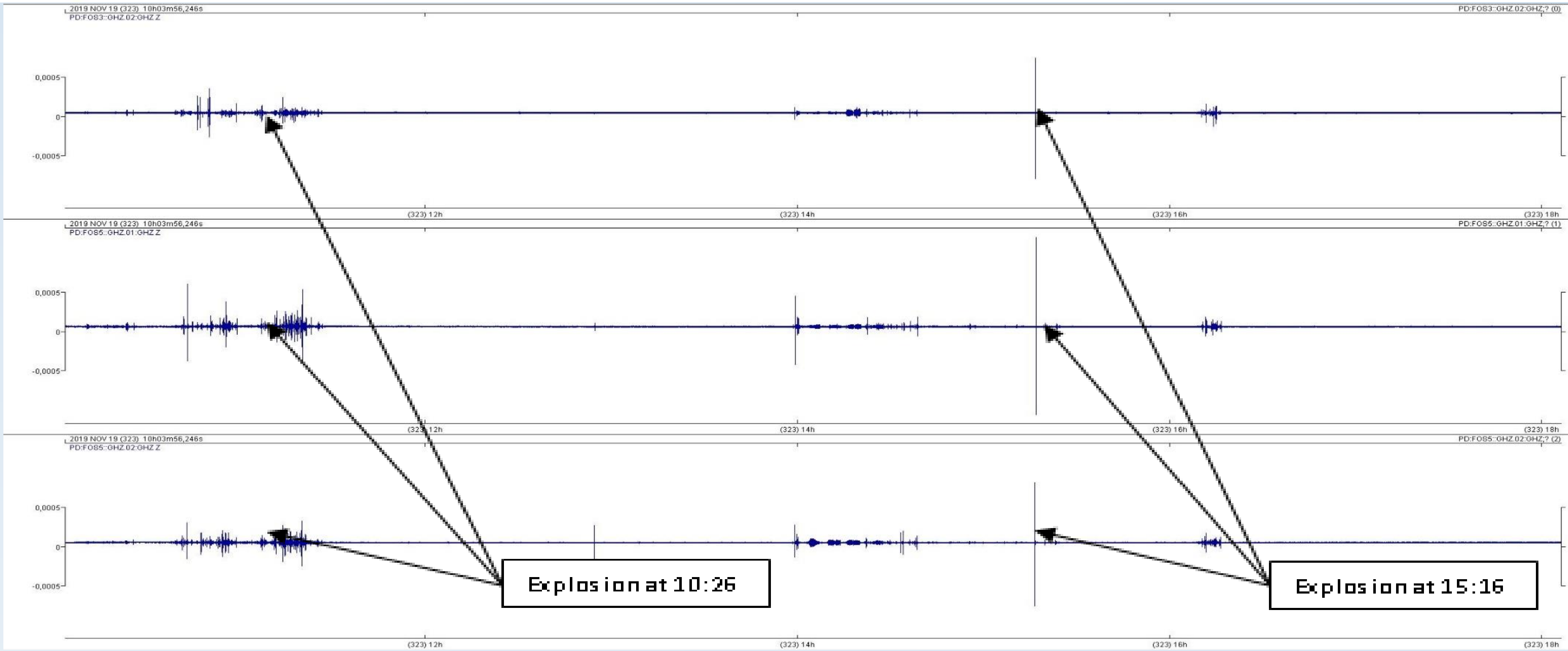
blue – raw data, red – Konno-Ohmachi filter with a smoothing coefficient 40.

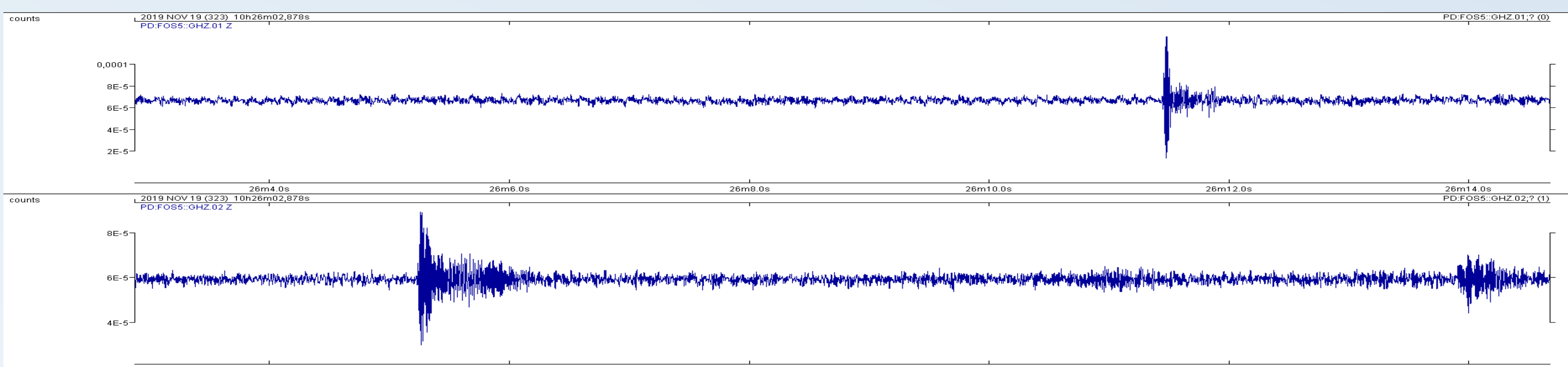


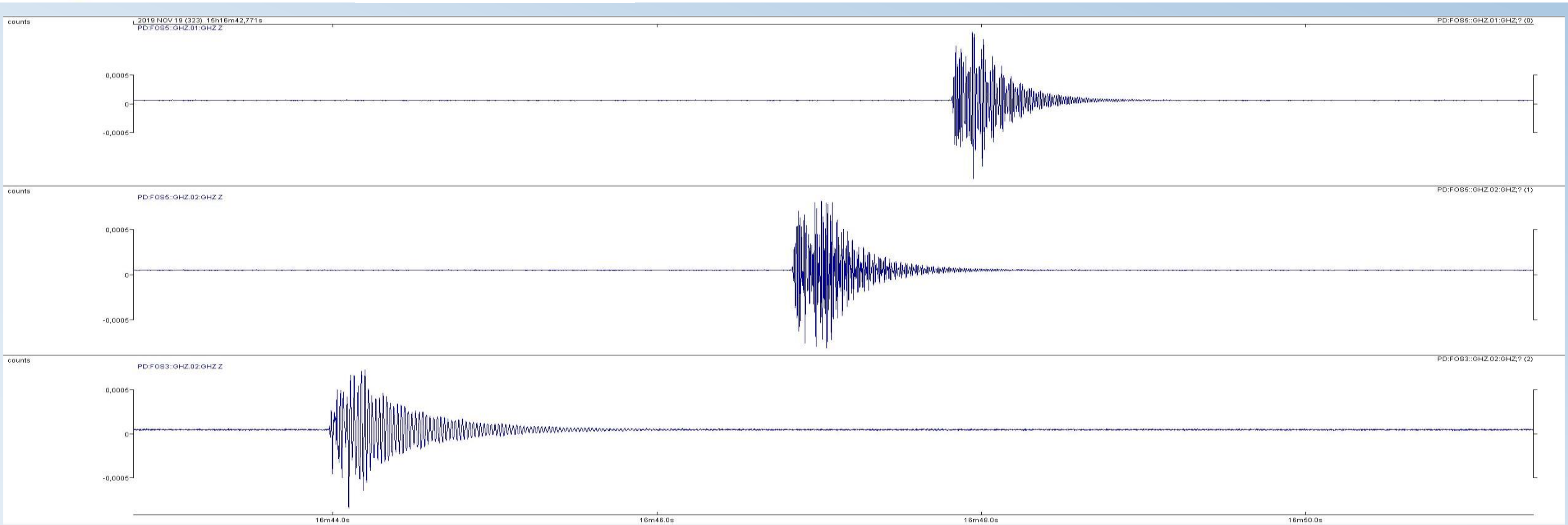
[A. T. Kurzych, *et al.* „Towards uniformity of rotational events recording…", *Opto-Electron. Rev.*, **29** (2021), 39]

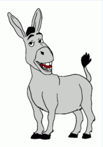


[https://github.com/fbernauer/blueseis_sandbox – thanks Felix Bernauer]

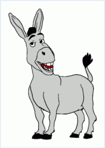

2019 NOV 19 (323) 10h03m56,246s
0,0005
0
-0,0005
(323) 12h
(323) 14h
(323) 16h
(323) 18h
Explosion at 10:26
Explosion at 15:16


counts
2019 NOV 19 (323) 10h26m02,878s
PD:FOS5::GHZ.01 Z
PD:FOS5::GHZ.02 Z
0,0001
8E-5
6E-5
4E-5
2E-5
26m4.0s
26m6.0s
26m8.0s
26m10.0s
26m12.0s
26m14.0s

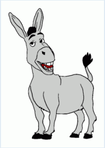




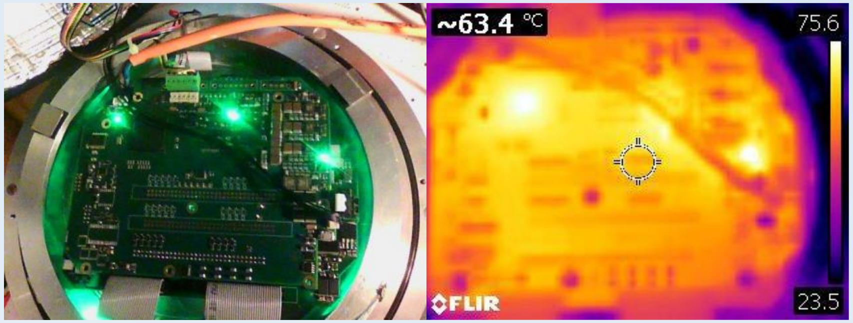
14. FOS5 – data reliability (amplitude, frequency and precise time recording)



15. FOS5 – still spikes



16. FOS5 – heating problem



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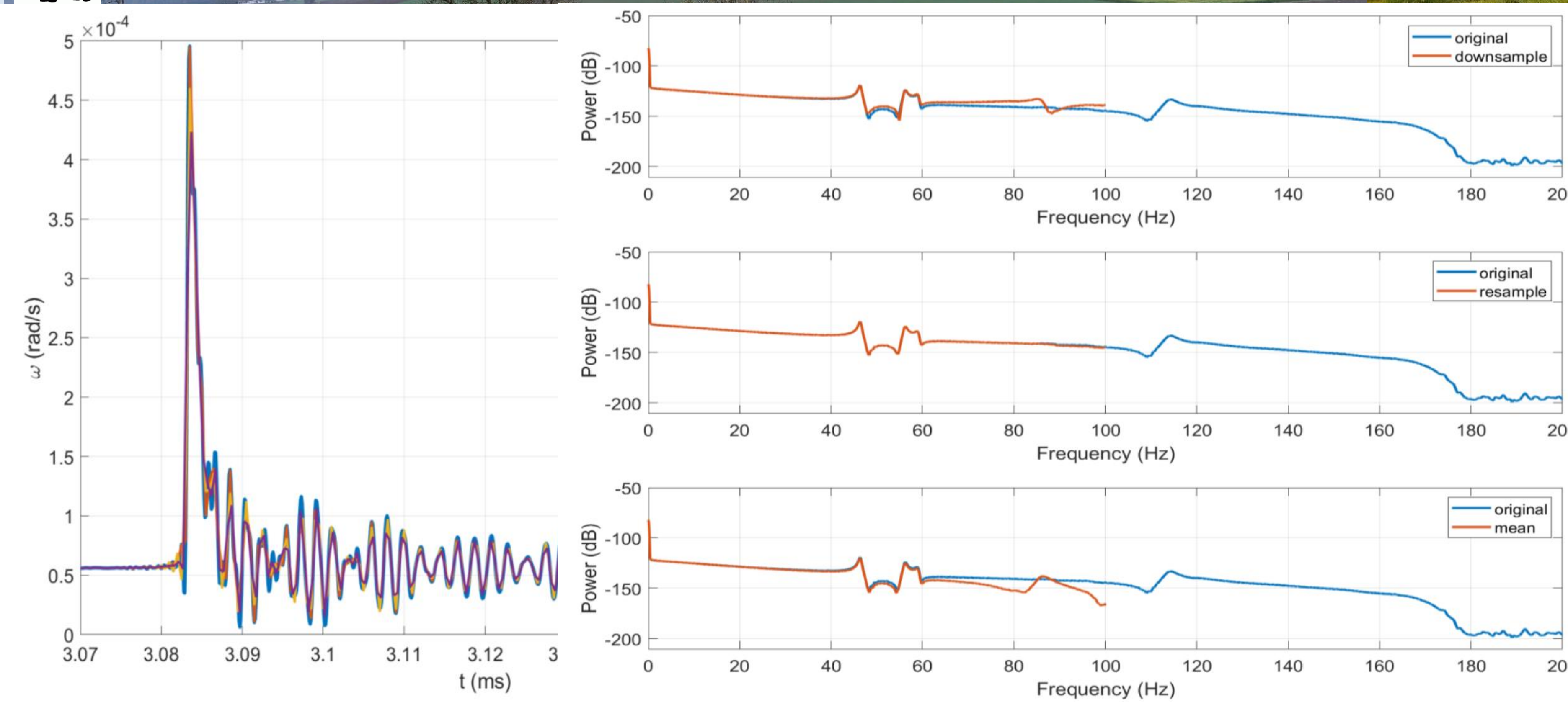
1000 Hz -> miniSEED about 115 MB/h/channel => 24h miniSEED ~ 8.2 GB
☹☹☹ SeisGram2K needs to 80-100 MB – 17. resampling to 200 Hz.



Final REMARK:

my friend is physical scientist and he always known how something should work,
I'm only technical physicist and try to known how something works…

belive me it is gigantic diffrence

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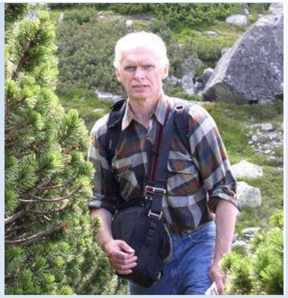

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Thank you for attention

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