# Testing a prototype broadband fiber-optic gyro

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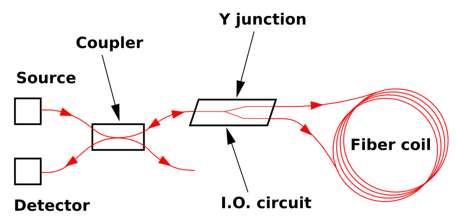
# Introduction

**Requirements for a portable rotational motion sensor**

| Dynamic range | Frequency range | Power consumption | Temperature sensitivity |
|---|---|---|---|
| 1 nrad/s - 5 $\mu$rad/s | 0.001 Hz - 20 Hz | 5 - 8 W | $< 0.1\%/^\circ$C |

# Introduction

## The interferometric fiber-optic gyroscope (IFOG)




after Lefèvre, 2014, Artech House

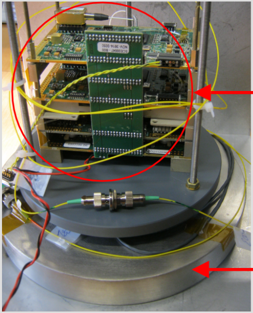
Pros:

- Sagnac interferometer
- no moving parts
- flat response over a large frequency range (DC - ∼kHz)
- inherently not sensitive to translational motion

Cons:

- high sensor self noise in the required frequency band
- high power consumption

# The iXBlue Prototype





nominal performance characteristics (from manufacturer):

| fog | Power [W] | ARW [m°h$^{-1/2}$] |
|---|---|---|
| 10cm/1km | 8 | 0.5 |
| 18cm/2km | 8 | 0.1 |

**The sensor unit from iXBlue:**

- sensor unit incompliant for navigational purpose
- two sensor coils with different diameter and length (fog10cm/1km and fog18cm/2km)
- RS232-port to readout 100 Hz data (without absolute time stamping)

**Our tasks:**

- build an appropriate housing
- data acquisition with absolute time stamping

→ focus on the 18cm/2km coil

# The iXBlue Prototype

**Key features:**

- single component
- special housing design allows vertical or horizontal orientation
- 24 V DC power supply
- l × w × h: 25 cm × 25 cm × 27 cm
- < 10 W power consumption (including data acquisition system)
- GPS/PPS synchronized Raspberry Pi for data acquisition

# Test procedures

## Concepts

- **Allan deviation (*ADEV*):** A measure to characterize the sensor self noise signal in the time domain. With the averaged rotation rate signal $\Omega_k(\tau)$ for an averaging time $\tau$, the Allan deviation is defined as:

  $$ADEV(\tau) = \left\langle \frac{(\Omega_{k+1}(\tau) - \Omega_k(\tau))}{2} \right\rangle^{1/2}$$

  pure white noise $\rightarrow -1/2$ slope of $ADEV(\tau)$
- **Angle random walk (ARW):** A measure to quantify sensor self noise.
  typically: $ADEV(\tau)$ at $\tau = 1\,\mathrm{h}$
- **Power spectral density (PSD):** A measure to quantify sensor self noise in the frequency domain.
- **Operating range diagram:** A way to make sensor self noise comparable to seismic signals. Integrating the PSD of a self noise signal over half octave frequency bands gives the lower limit of the operating range diagram (Evans et al. 2010, SRL).

# Test procedures

### Sensor self noise

Record the sensor output without any input ground movement or other ambient noise sources.

- place the sensor next to a traditional broadband sensor (STS2) in a seismic vault
- search for a period with input ground movement as weak as possible

Allan deviation, Power spectral density, Operating range diagram $\Longrightarrow$ Conservative estimation of the upper limit of sensor self noise

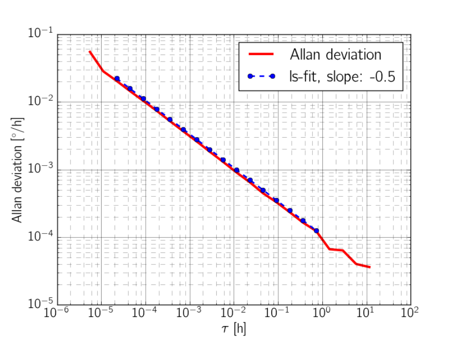
# Test procedures

## Temperature sensitivity

- sensor with sensitive horizontal axis on step table (CT-EW 01)
- heat the whole setup to temperatures of approx. 10°C, 20°C, 30°C, 40°C and 50°C
- wait approx 2 h for each temperature step to reach uniform temperature in the sensor
- generate a constant input rotation
- calculate the scale factor (SF) for each temperature

# Test results

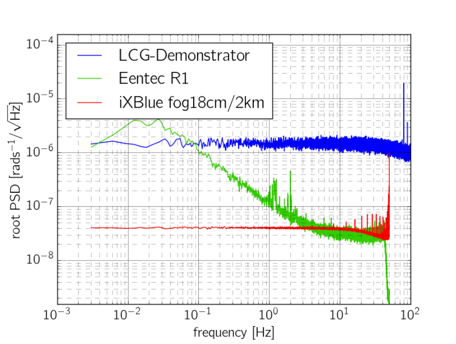
## Allan Deviation




- white noise over a large frequency range
- angle random walk at 1 h integration time: $0.1\,\mathrm{m}^\circ\mathrm{h}^{-1/2}$ matches very well the nominal value.
- $6.3\,\mathrm{m}^\circ\mathrm{h}^{-1}\mathrm{Hz}^{-1/2} = 30\,\mathrm{nrads}^{-1}\mathrm{Hz}^{-1/2}$ white noise at 1 s integration time

# Test results

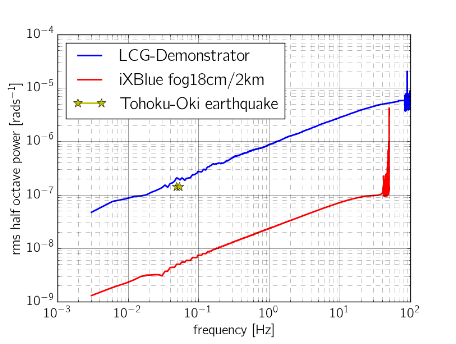
## Power spectral density




- 40 nrad$s^{-1}$Hz$^{-1/2}$ root power spectral density
- constant power over a large frequency range (0.003 Hz - 10 Hz)
- White noise level is more than one order of magnitude lower than for previously used FOG.
- For frequencies lower than 2 Hz, the noise level is up to two orders of magnitude lower than for liquid based rotational seismometer R1.

# Test results

## Operating Range




- Yellow stars represent the maximum rotation rate signal from the $M_w$9.0 Tohoku-Oki earthquake measured by G-Ring in Wettzell, Germany.
- Noise level is low enough to record such large teleseismic events.

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# Test results

## Temperature sensitivity

without temperature modeling!

| Temperature [°C] | SF $[10^9 (\text{rads}^{-1})^{-1}]$ |
|---|---|
| 6.8 | $9.899 \pm 0.007$ |
| 17.4 | $9.898 \pm 0.006$ |
| 28.6 | $9.908 \pm 0.006$ |
| 43.1 | $9.932 \pm 0.040$ |
| 53.8 | $9.951 \pm 0.006$ |

mean value: $(9.918 \pm 0.01) \cdot 10^9 \ (\text{rads}^{-1})^{-1}$

temperature sensitivity of scale factor (SF):
$0.01\%/^\circ\text{C}$

# Conclusion

- **Power consumption:** acceptable for many applications in seismology but still very high compared to other seismic instruments. With very low effort power consumption can be brought to $\sim 4\,\mathrm{W}$.
- **Sensor self noise:** significant improvement compared to previously used rotational sensors
- **Temperature sensitivity:** Even without temperature modeling, it meets the requirements for applications in seismology.

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# Future work

- analyze collocated recordings of ambient noise (small aperture array + iXBlue prototype)
- lab and field tests of a 3-component prototype with even better resolution ($\sim 20\,\mathrm{nrad\,s^{-1} Hz^{-1/2}}$, **BlueSeis-3A** launched at the end of the year by iXBlue)
  $\rightarrow$ **for more information please come to the poster by Frederic Guattari**

# Acknowledgment

IXBLUE
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Thank you!