

Interferometry for Sensor Networks

Deep Frequency Modulation Interferometry for displacement and absolute ranging measurement

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Why do we need interferometry and sensor network?

- Interferometry provides...
 - Ultra-high precision measurement
 - Dynamic sensing capability
- Sensor network offers...
 - Scalable sensor nodes with the demands
 - Providing adaptive responses
 - Yielding insights for operational efficiency
- Our Objectives?
 - Compact, cost-effective, high-precision optical sensor head
 - incorporation of the technique, „Deep frequency modulation interferometry“ to reducing optical complexity, with low-cost commercial off-the-shelf lasers
 - Integration of optical sensing with distributed networks
 - Extending sensing range via test mass design aspects such as: retroreflector (corner-cube), plane mirror or converging optics (concave mirror)
 - Preferably wireless, low-power sensor node

From industrial applications to the research facilities, these kinds of measurements are crucial for operation.

Our Approach: Compact Balanced Readout Interferometer(COBRI)

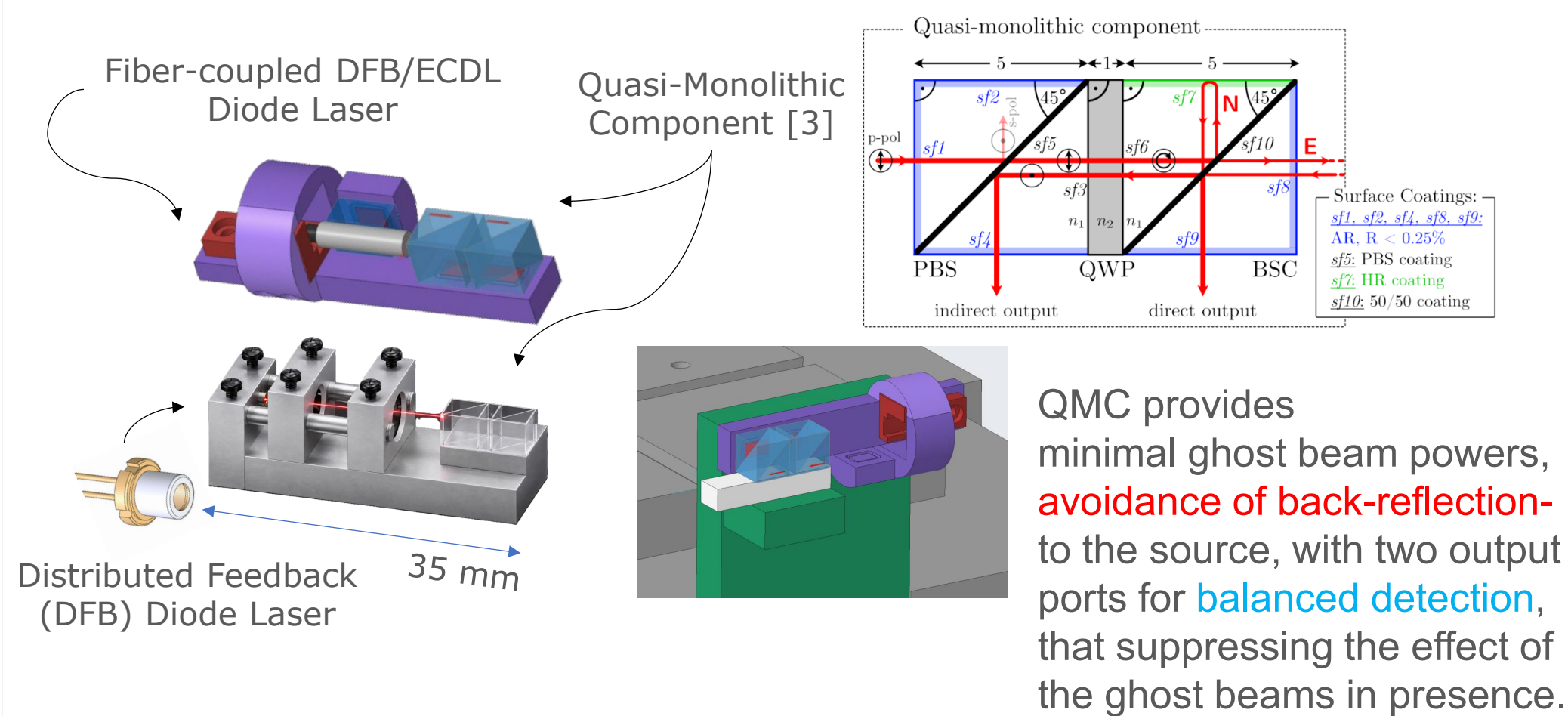
Deep Frequency Modulation Interferometry(DFMI)

- DFMI [1,2] is an interferometric technique that has...
- Simple, reduced system complexity
 - Multi-fringe readout capability as in heterodyne interferometry
 - Enabling absolute distance measurement capability, with sub-picometer-level displacement noise
- Frequency carrier modulation of the laser generates power signal as:

$$P_{out}(t) = \frac{P_{in}}{2} + \frac{P_{in}}{2} C \cos(\phi + 2\pi\Delta f \tau \cos[\omega_m t + \psi])$$

microscopic distance change macroscopic distance change

Parts Design and Assembly



Fraunhofer IOF develops upscale construction process for the COBRIs.

Optical Simulation

- We simulate with library IfoCAD to explore the following aspects of the COBRI:
- Investigation on geometrical noises such as misalignment of a component
 - Providing assembly tolerances that needs to be achieved
 - Estimation of test mass behavior under the motion of interests (translation, rotation) with differential signals, contrast and longitudinal pathlength signal
 - Exploration of Test Mass design aspects to extend sensing range

Mehrwert für die Bundeswehr

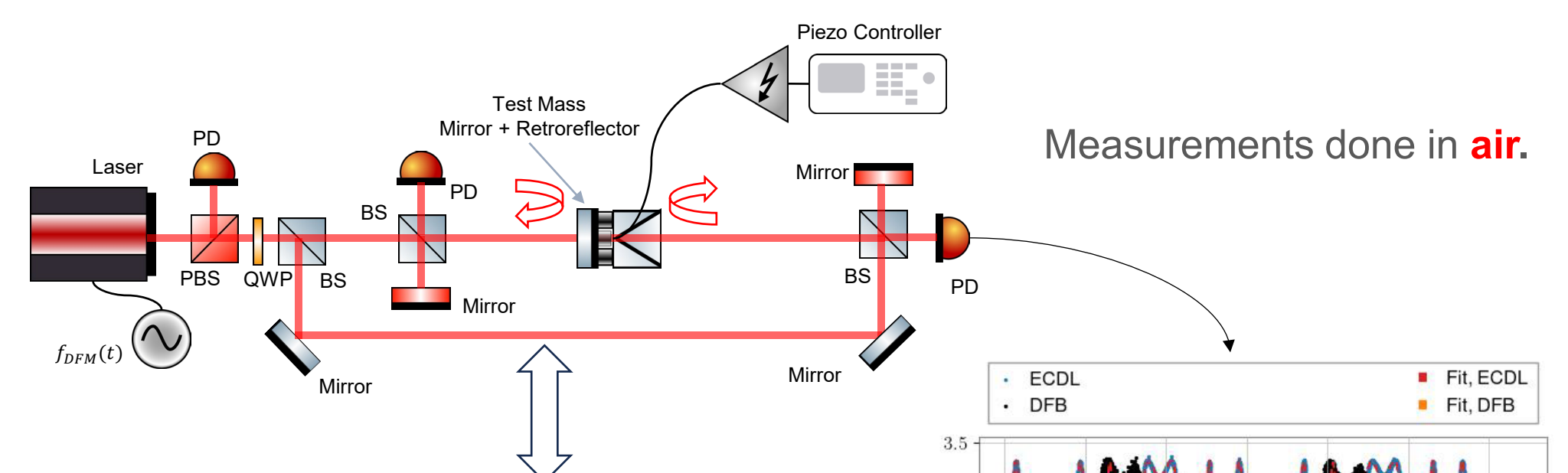
- Identification of surface deformation via displacement measurements with COBRI
- Scalability with interchangeability of the laser source depending on the demands

References

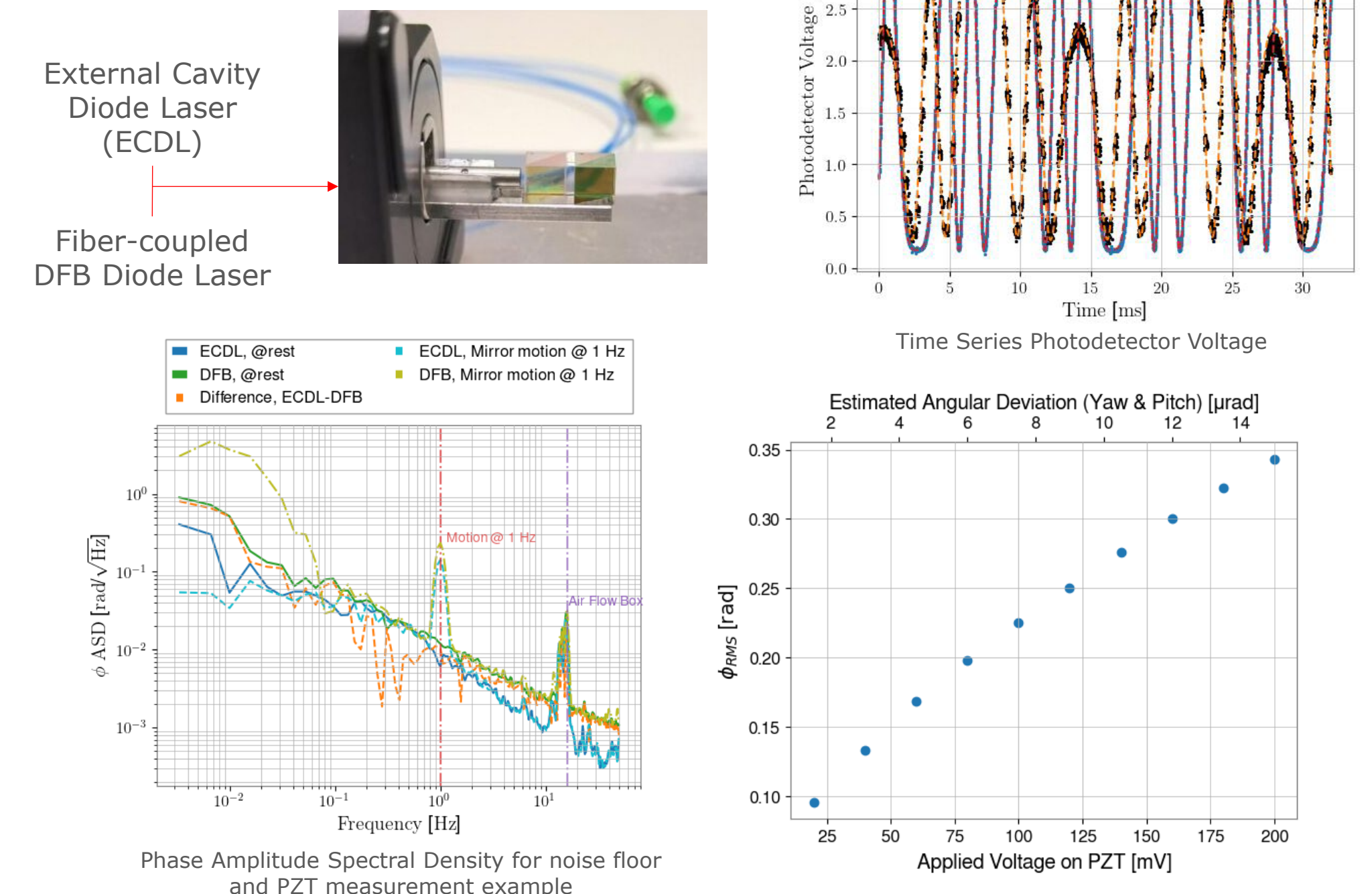
- [1] O. Gerberding. "Deep Frequency Modulation Interferometry". DOI:10.1364/OE.23.014753.
- [2] K.-S. Isleif et al. "Experimental Demonstration of Deep Frequency Modulation Interferometry". DOI: 10.1364/OE.24.001676.
- [3] O. Gerberding et al. "Ghost Beam Suppression in Deep Frequency Modulation Interferometry for Compact On-Axis Optical Heads". DOI: 10.3390/s21051708

Sensor Characterization

- Free-Space Simple Michelson Interferometer with Test-Mass in the Middle(TMitM) experiment



- COBRI with TMitM experiment



- DFB and ECDL phase noise measurements show expected behavior, with the DFB laser shows higher noise floor above 1 Hz (factor of 2.30 higher noise floor at 10 Hz).
- With DFB laser, using current modulation to achieve carrier frequency modulation, which exhibits strong amplitude modulation(AM) on top of the interferometer signal.
 - limits the phase readout if not corrected via reference measurement of AM signal or adjusted readout algorithm. Without the correction, 0.1% phase error for 1% amplitude modulation. (Plot shows 5% AM for DFB, <0.1% AM for ECDL)

We will further study on the balanced readout with the DFB diode lasers, as well as with quadrant photodetectors as readout sensor, to validate the simulated prediction of signal behaviours and find out the noise limitations of the sensor with given laser types and test mass designs.

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