STABILITY AND VIBRATION ROBUSTNESS OF A REAL-TIME SYNTHETIC DISPERSION INTERFEROMETER

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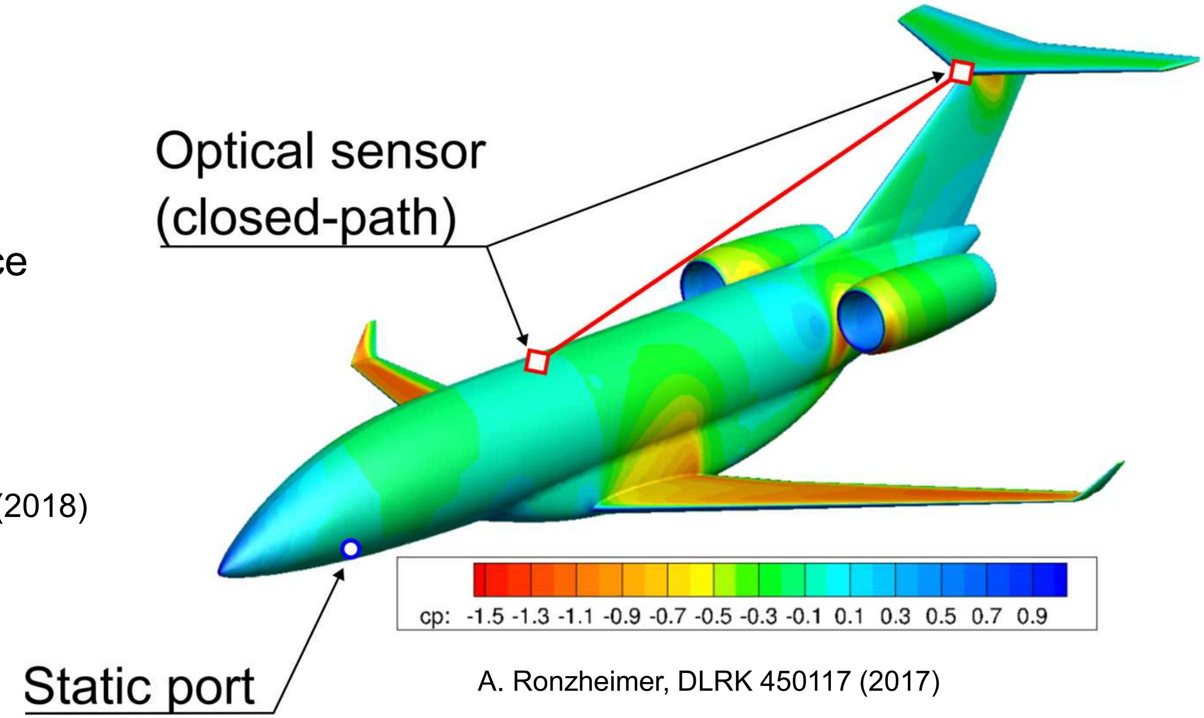
Motivation

Static pressure measurement

- Hull-mounted pressure port
- Measurement within aerodynamic influence
  - Extensive calibration required
- Risk of undetected sensor failure (icing)
  - R. Jäckel et al., Flow. Meas. Instrum. **81** (2021)
  - Y. Cao et al., Aerosp. Sci. Technol. **75**, 353-385 (2018)

Optical measurement

- Detection of sensor failure
  - Active emission of radiation
- Measurement of p_0 outside of boundary layer



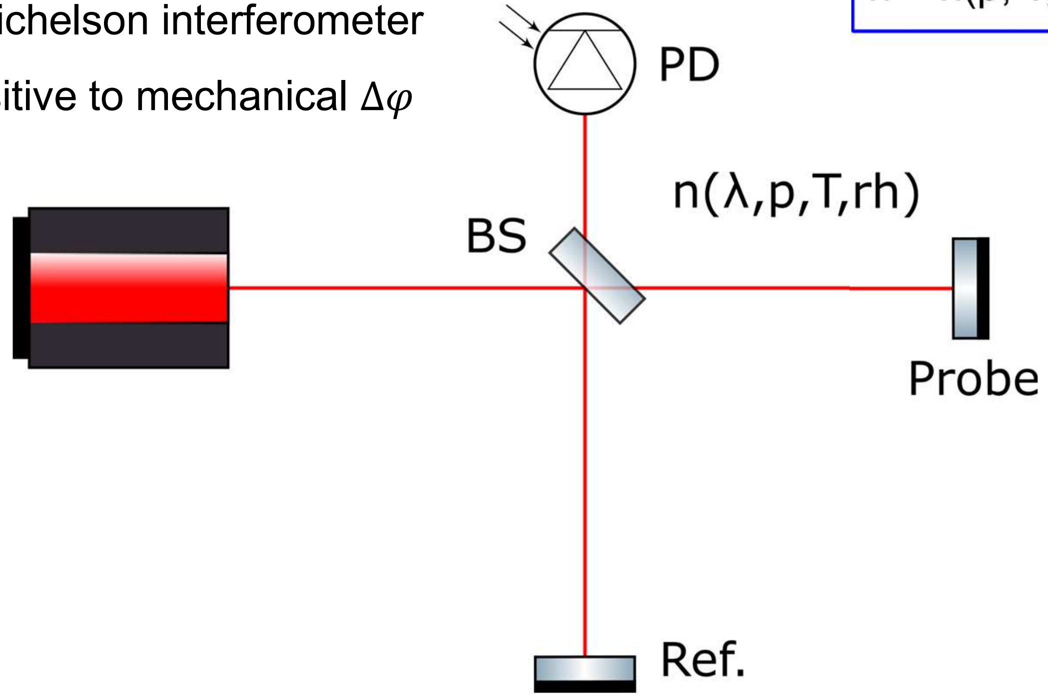
A. Ronzheimer, DLRK 450117 (2017)

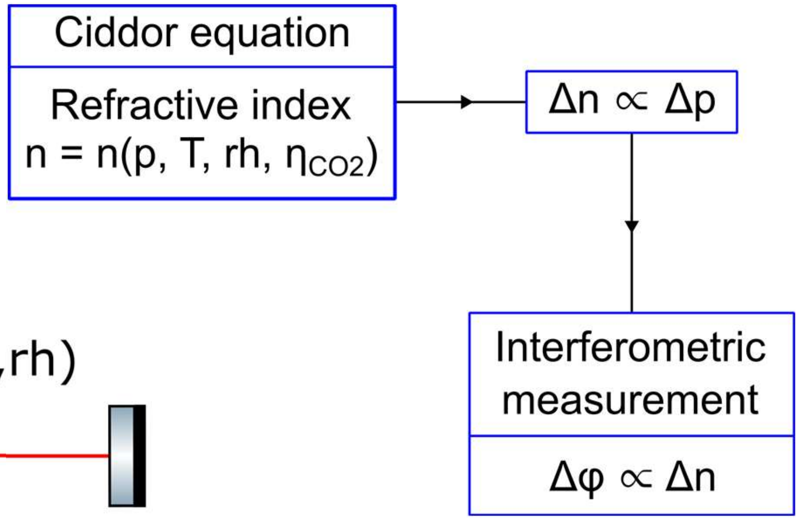
Aeronautical application reqs.
- $\Delta p \approx 30$ Pa
- Bandwidth ~ 30 Hz
- Structural vibrations

Interferometric approach

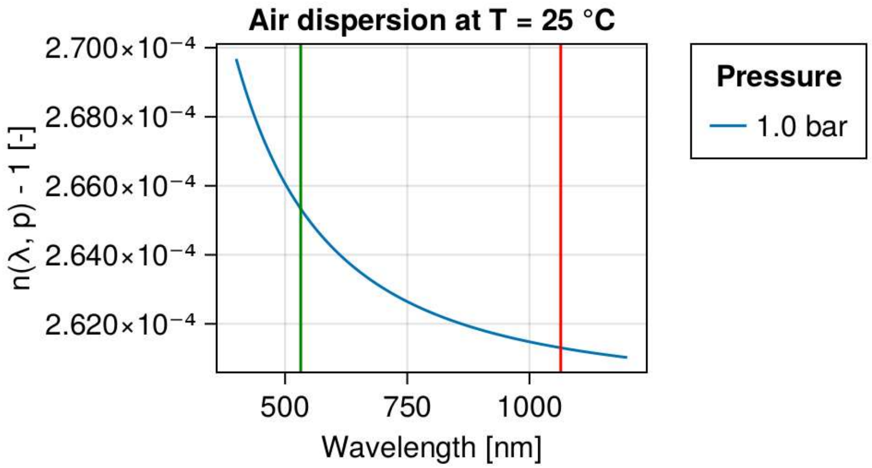
Principle

- Interferometric measurement of Δn
- Classic Michelson interferometer
- Fully sensitive to mechanical $\Delta\varphi$



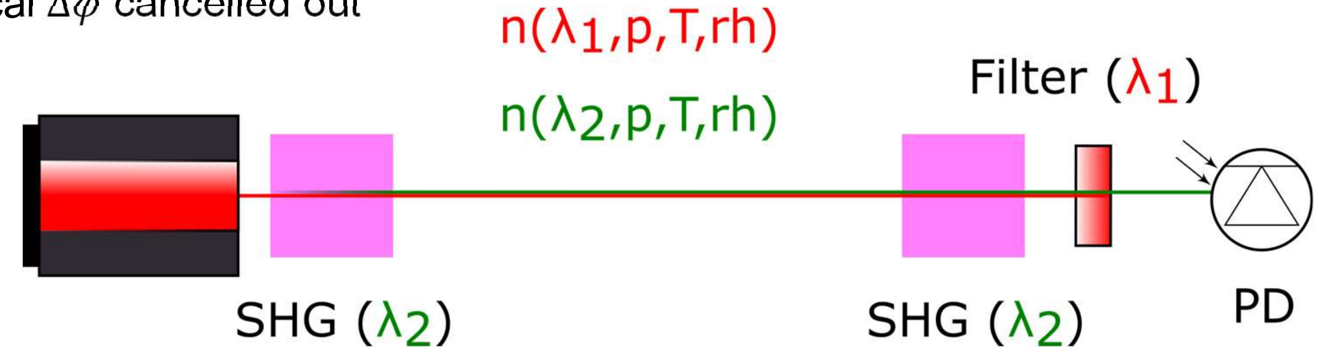


Dispersion interferometry



Principle

- Second harmonic generation (SHG)
- Single-arm design
- Mechanical $\Delta\varphi$ cancelled out



Related publications:

- V.P. Drachev, Meas Tech **33**, 1125–1127 (1990)
- F. Brandi et al., Opt. Lett. **32**, 2327-2329 (2007)

Pressure-phase relation

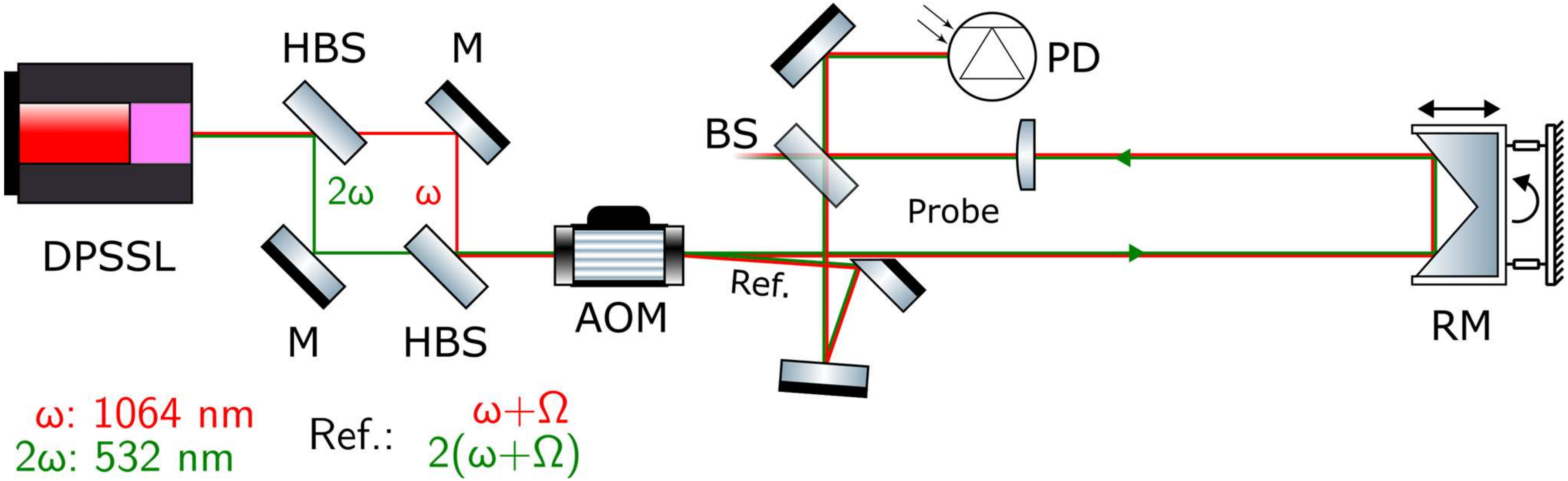
$$\Delta\varphi = \frac{2\pi}{\lambda_{2\omega}} \cdot [n(\lambda_{2\omega}, p) - n(\lambda_{\omega}, p)] \cdot l$$

Synthetic Dispersion Interferometer (SDI)

Setup

Related publications:
- J. Irby et. al., Rev. Sci. Instrum. **70**, 699 (1999)
- D.-G. Lee et al., Rev. Sci. Instrum. **92**, 033536 (2021)
- H. Uittenbosch et al., Opt. Express **31**, 6356-6369 (2023)

- Two-color heterodyne measurement of $n(\lambda, p, T, rh)$
  - cw DPSS laser with intracavity SHG
- Acousto-optic modulator (AOM) generates ref.
  - 1st diffraction order of λ_1 collinear with 2nd diffraction order of λ_2

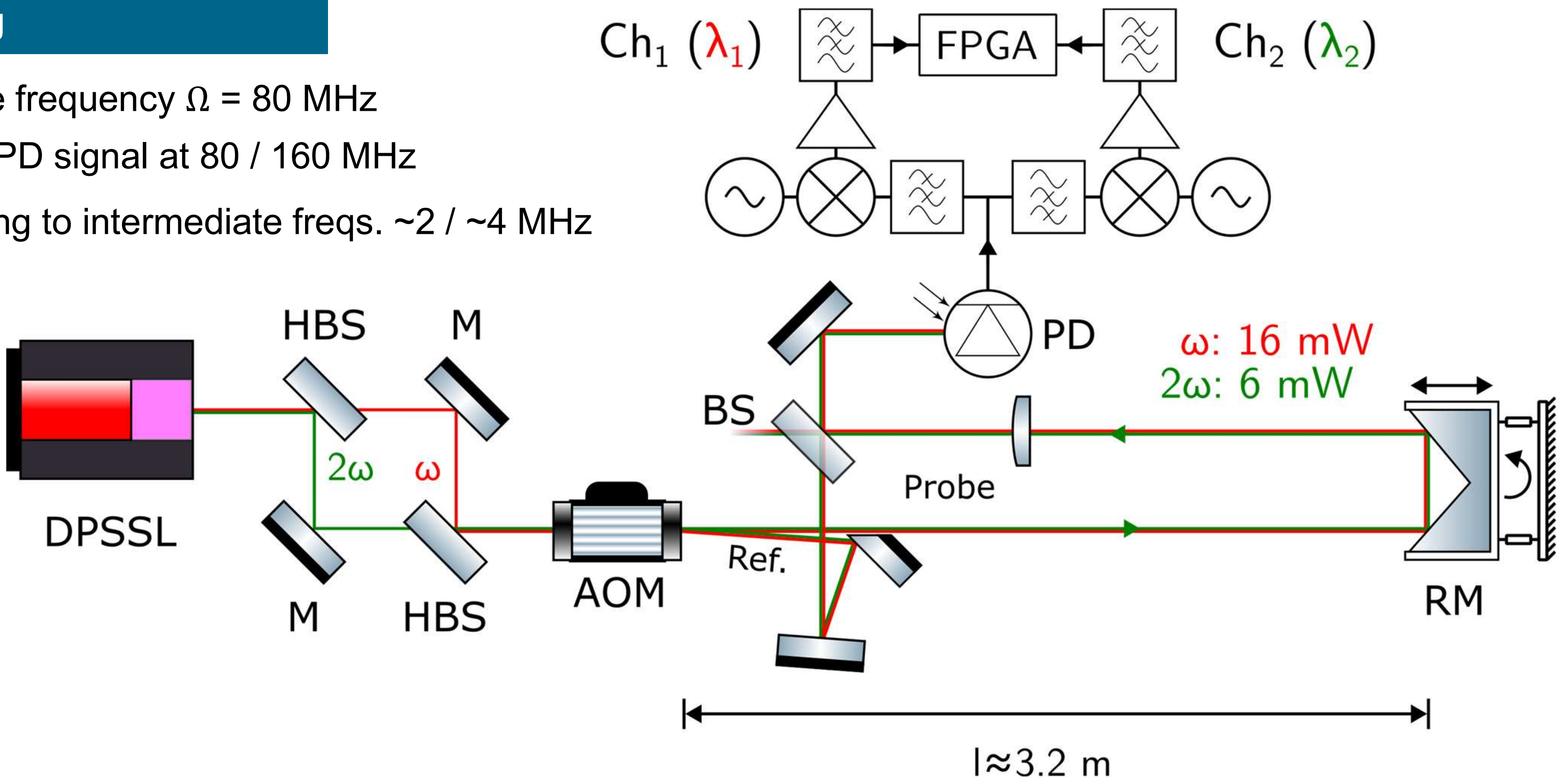


SDI – digital demodulation

DLR

Downmixing

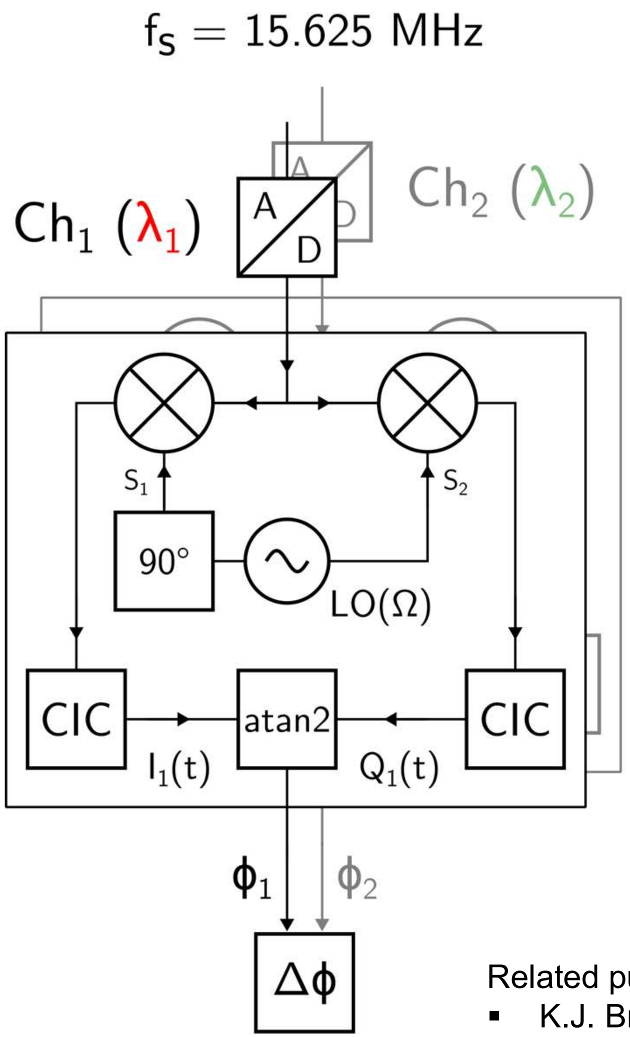
- AOM drive frequency Ω = 80 MHz
- Two-tone PD signal at 80 / 160 MHz
- Downmixing to intermediate freqs. ~2 / ~4 MHz



Field programmable gate array (FPGA)-based digital demodulation

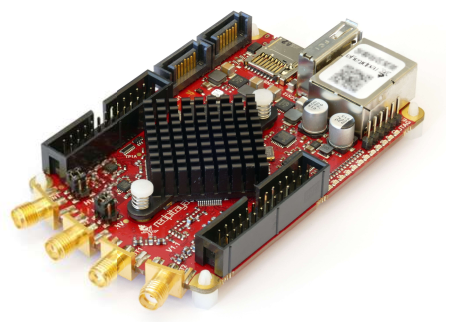
Concept

- Real-time IQ demodulation
  - RedPitaya STEMlab 125-14
- $\frac{f_s}{4}$ at root of CIC filter
- Output bandwidth ~488 kHz
- $\Delta\phi = \phi_2 - 2 \cdot \phi_1$
  - Digital “frequency doubling”
- Output values
  - $\Delta\phi$, ϕ_1, ϕ_2, z_1 and z_2



S_1: cos(Ωt)
S_2: sin(Ωt)

RedPitaya PCB
Geek3 (2019)
CC BY-SA 4.0



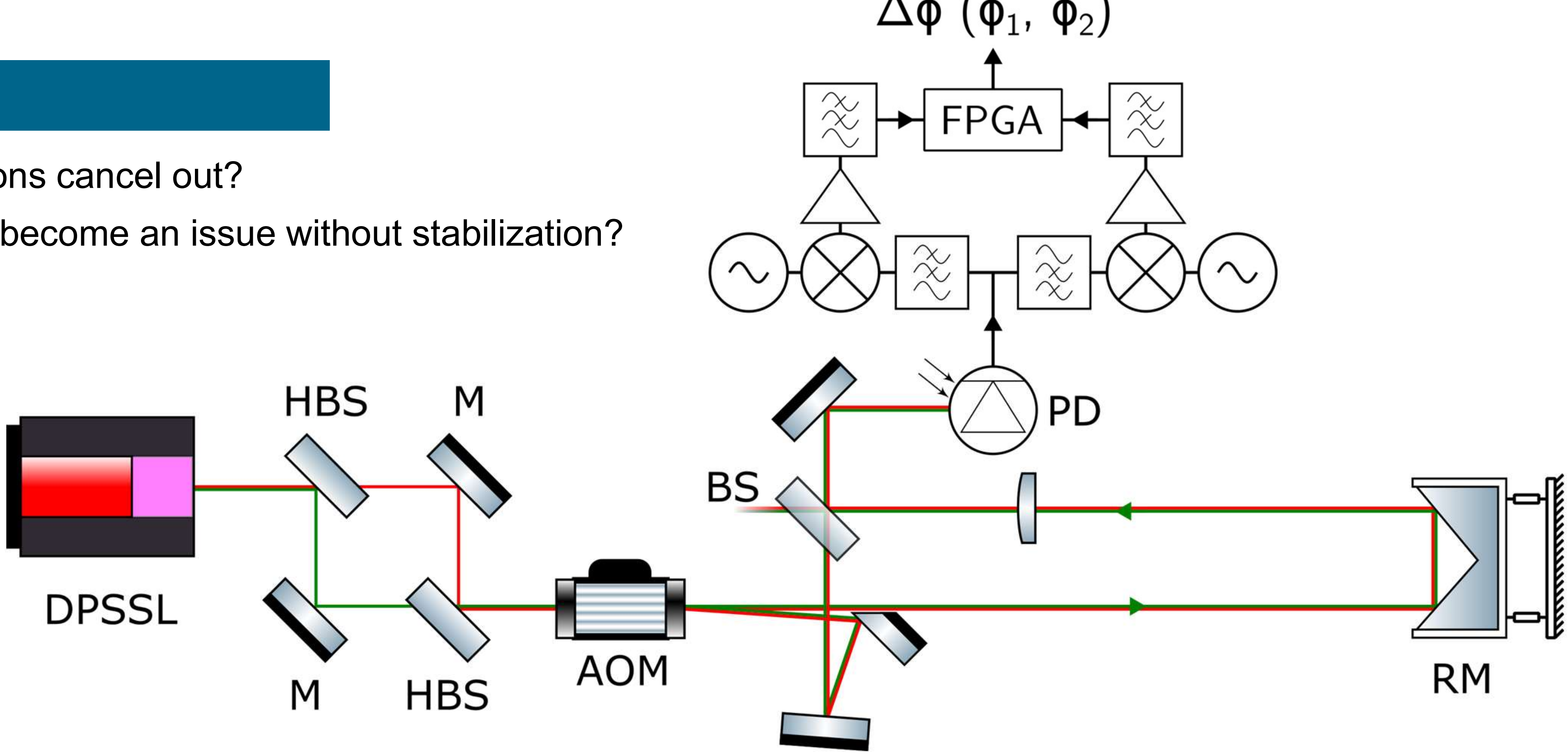
Related publications:

- K.J. Brunner et al., JINST **13**, P09002 (2018)

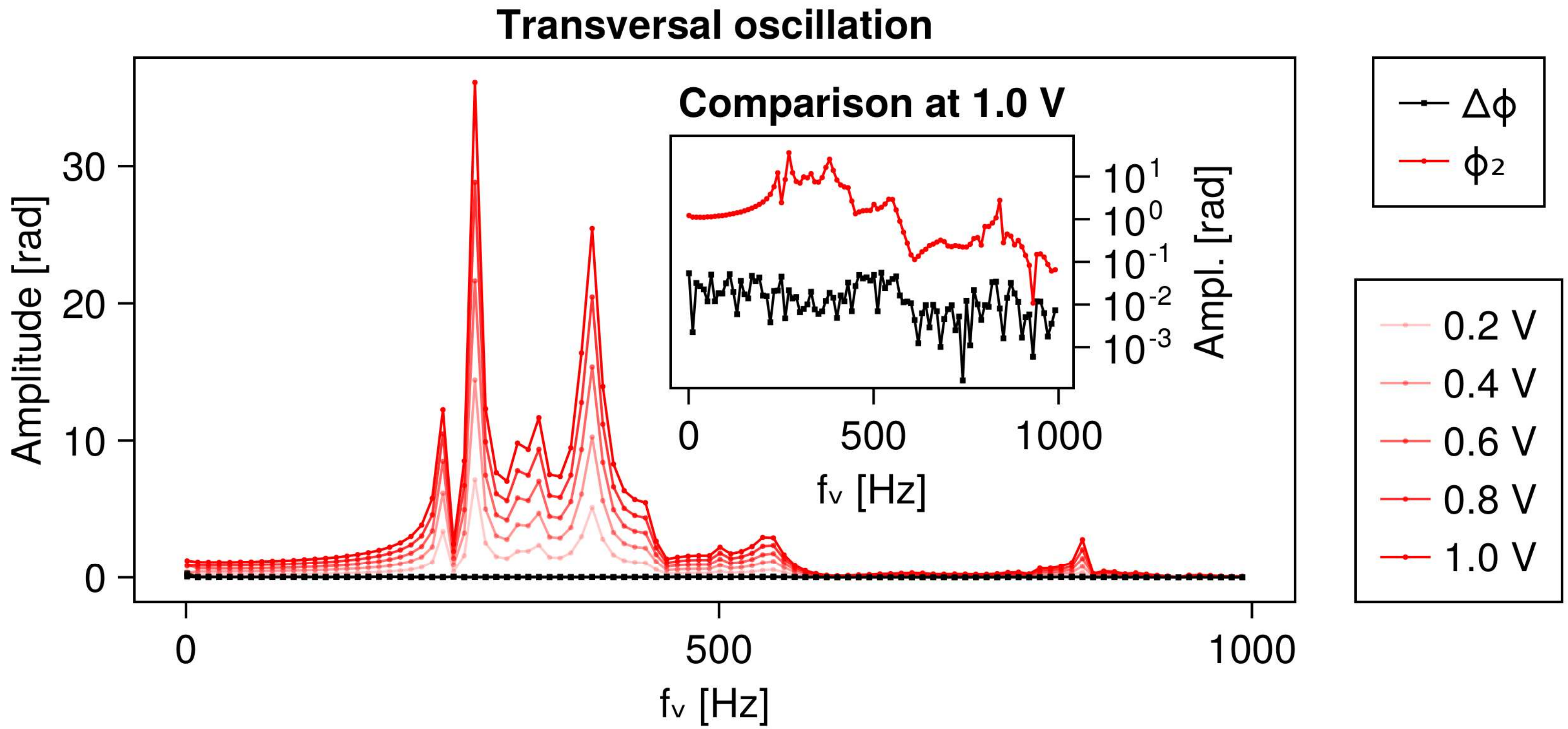
Mechanical and long-term stability

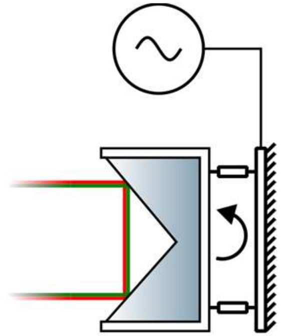
Questions

- Do vibrations cancel out?
- Does drift become an issue without stabilization?



Vibration suppression

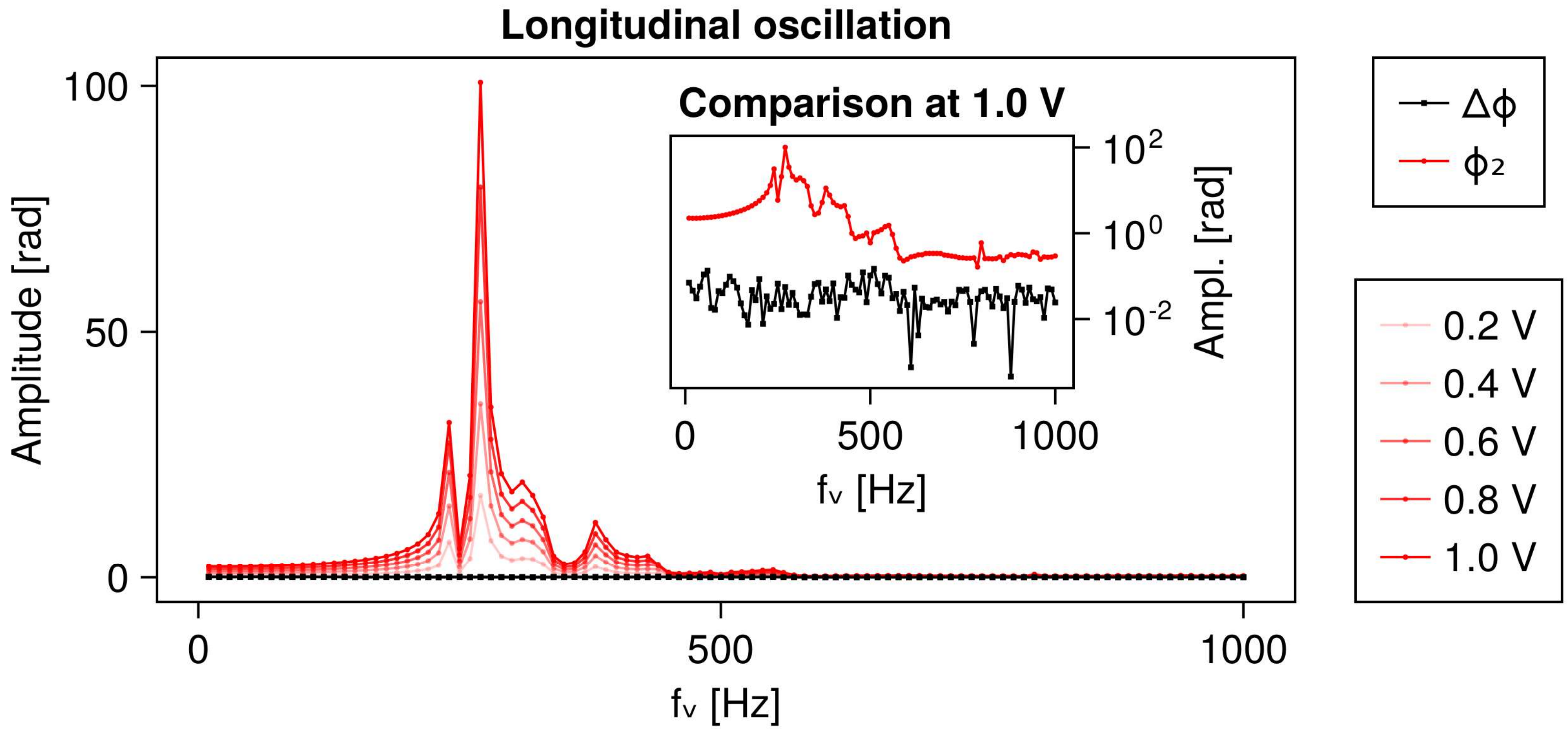


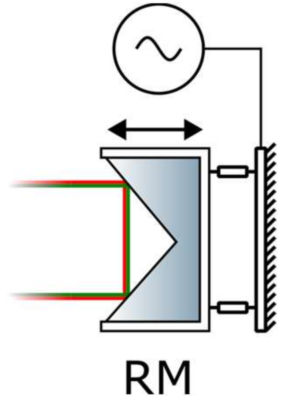


RM

- Piezoelectric adjuster induces vibrations of retroreflector as $\mathrm{A}_0 \cdot \sin(2\pi f_v \cdot t)$
- AM of $\Delta\phi(t)$, $\phi_1(t)$ and $\phi_2(t)$ at f_v obtained via IQ-demodulation

Vibration suppression



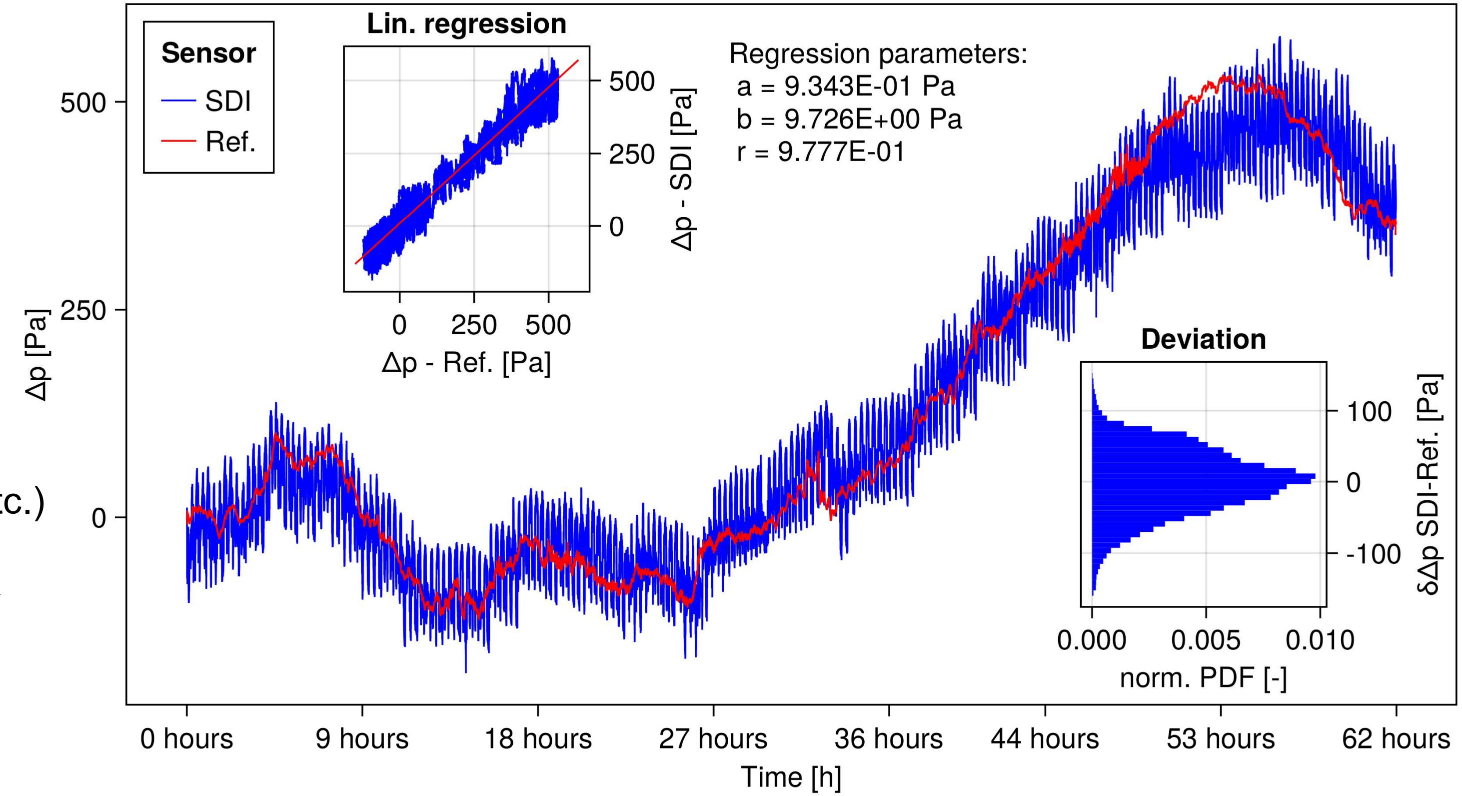


- Non-common phase errors in probe arm:
  - mod. of $\Delta\phi$ suppressed by several orders of magnitude
  - mod. of $\Delta\phi$ uncorrelated with respect to ϕ_1 and ϕ_2

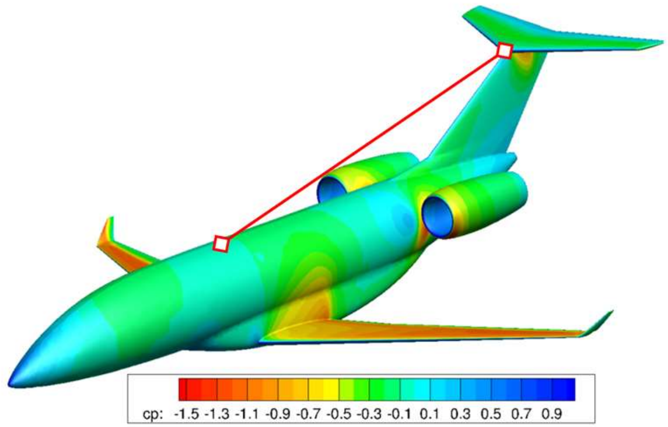
Long-term stability

Exp. setup

- Ambient pressure meas.
  - $p_0 = 0.955 \cdot 10^5$ Pa
- Piezoresistive ref. sensor
  - Keller Series 33X (10 Hz)
- -2.386 mPa/s linear drift
  - Electronics (cables, PLL, etc.)
- $|\Delta p_{Ref.} - \Delta p_{SDI}| \leq 159$ Pa
  - $\delta\Delta\phi \leq 0.48$ rad
- Single-Arm DI
  - $\delta\Delta\phi \leq 0.5$ rad after correction over 48 hours
  - K.J. Brunner et al., JINST **14**, P11016 (2019)



Summary

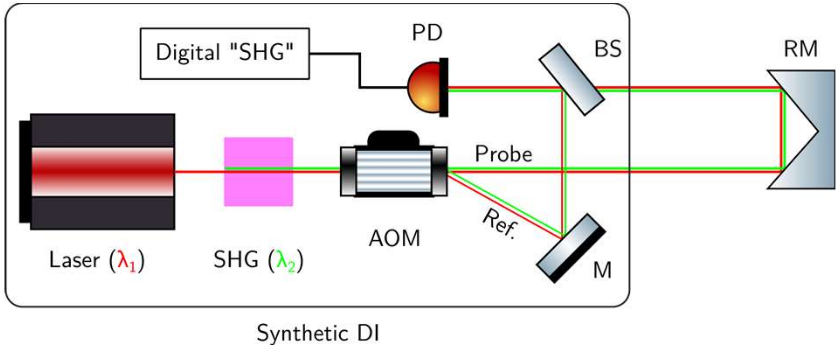


Optical, contact-free variometer in aviation

- Self-diagnosis capability
- Measurement outside of aerodynamic influence
- Low optical power (eye-safety)
- Closed beam-path

Outlook

- Laboratory proof-of-concept
  - Opt. Express **31**, 6356-6369 (2023)
- Simple setup with good prospect for integration
- Lower Δp required
  - Reduction of system noise
  - Optimization of interference fringes



Thank you for your attention!