

An ultra-stable thermal environment in high precision optical metrology

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Outline

- GRLOW
- Ultra-stable thermal environment
 - Passive thermal shields
 - Mathematical model
 - FEM simulations
 - Experimental Transfer Funcitons
 - Thermal Stability



- Mach Zehnder Interferometer
- OPTOMETER
- Future Work
- Conclusion



General Information

GRLOW: Low-frequency technology test bed

- **Aim:** develop an infrastructure to test GW technologies at low frequencies
- Main objectives:
 - Implement a low-frequency stabilised thermal environment(10⁻⁴ Hz). •
 - Implement a basic interferometer, based in deep phase modulation scheme.
 - Combine both to test key technologies at very low frequencies: materials, • optoelectronics, etc.





Passive Thermal Shields

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- Multi-layer thermal radiation insulator (mirror polished steel) •
- Low thermal conductivity supports between cylinders ٠











- Mathematical Model
 - Transfer function estimate:

$$\tilde{H}_{ij}(\omega) = \frac{\tilde{T}_j(\omega)}{\tilde{T}_i(\omega)} = \frac{1}{1 + \frac{m_j c_j \beta_{ij}}{4\sigma A_j T_0^3}} i\omega$$

Multi-layer transfer function

$$\begin{split} \tilde{H}(\omega) &= \frac{1}{1 + \sum_{k=1}^{N} \frac{1}{(2k)!} \frac{(N+k)!}{(N-k)!} (i\omega\tau)^{k}} \\ &= (1 + \frac{1}{4}i\omega\tau)^{1/2} \quad sec \left[(2N+1) \quad csc^{-1} \right] \end{split}$$





$$-1\left(\frac{(1+i)}{\sqrt{\omega\tau/2}}\right)$$



• FEM simulations



Frequency [Hz]











Experimental Transfer Function









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Experimental Transfer Funciton









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Thermal Stability

- Electronic measuring noise: $S_{T, \rm sensor}^{1/2}(\omega) \leq 10^{-5}\,{\rm K}/\sqrt{{\rm Hz}}$
- LISA Pathfinder requirements: $S_T^{1/2}(\omega) \le 10^{-4} \,\text{K}/\sqrt{\text{Hz}} \;, \quad 1 \,\text{mHz} \le \omega/2\pi \le 30 \,\text{mHz}$





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 $V_{PD} = A[1 - c\cos(\varphi + m\cos(\omega_{mod}t + \psi))]$



Phase can be extracted through non-linear minimisation:

$$\chi^2 = \sum_{n=1}^{10} |\widetilde{V}_{PD}(n) - a_n(m,\phi)e^{i\,n\,\Psi}|^2$$

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• Experiment: Thermo-elastic effects







• Experiment: Thermo-elastic effects





OPTOMETER

- Opto-mechanical resonators
 - **Aim:** Design and development on an innovative on-chip temperature sensor with high precision and stability for use in applications with high sensitivity and environmental purity, such as space missions.
 - Main objectives:
 - Construction of an ultra-stable thermostat at low-frequency range.
 - Validate the use of technologies in the band of very low frequencies.
 - application



Miniaturisation of the technology to reach a final prototype and qualify if it for an space

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OPTOMETER

Status: Preliminary statement, main elements in the lab, starting optical layout





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Future work

- Thermal enclosure:
 - Attenuate outer fluctuations with a passive insulator curtain.
 - Active thermal control using a thermo-electric cooler.







e insulator curtain. ctric cooler.



Conclusions

- Although we need more data processing, mathematical model, FEM simulations and experimental results seems quite similar.
- Temperature stability set to 10⁻⁵ K Hz^{-1/2} at the band of the mHz with passive thermal shields.
- We have develop a Mach-Zehnder interferometer with a sensitivity of 100nm • $Hz^{-1/2}$ at the frequency range of the mHz.
- Keep working to achieve a high precision thermal sensor in the next months.



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Questions?

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