Entangled Squeezed Light for Quantum Noise Reduction in Small-Scale suspended Interferometers

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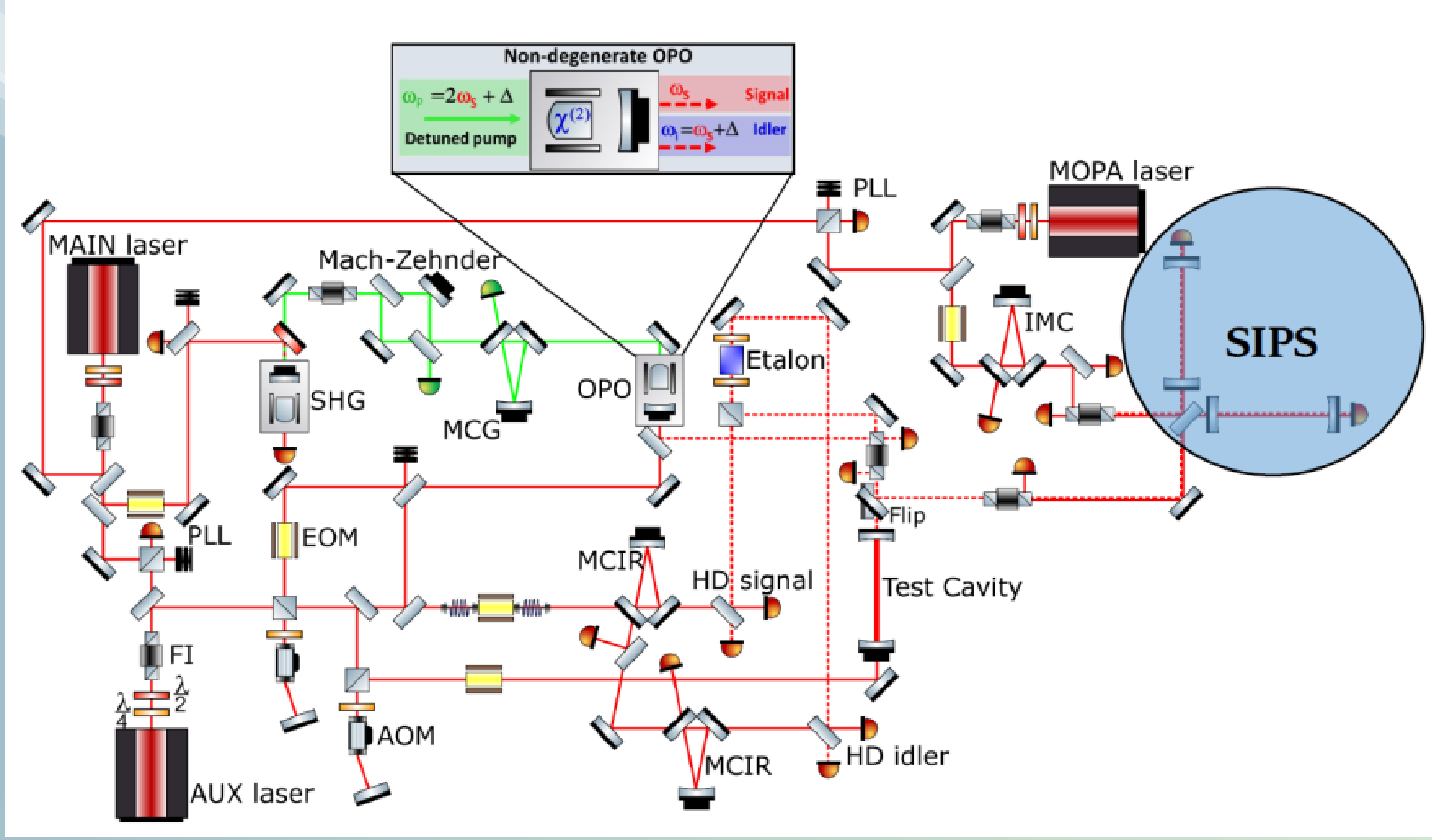
Integration of the optical bench of the EPR squeezing table-top experiment with the SIPS interferometer



[1]

In the proposed design, the EPR signal field matches the interferometer's laser frequency, making it resonant in the Fabry-Perot arm cavities. Meanwhile, the EPR idler beam is slightly detuned, treating the interferometer as a filter cavity that rotates the squeezing ellipse.

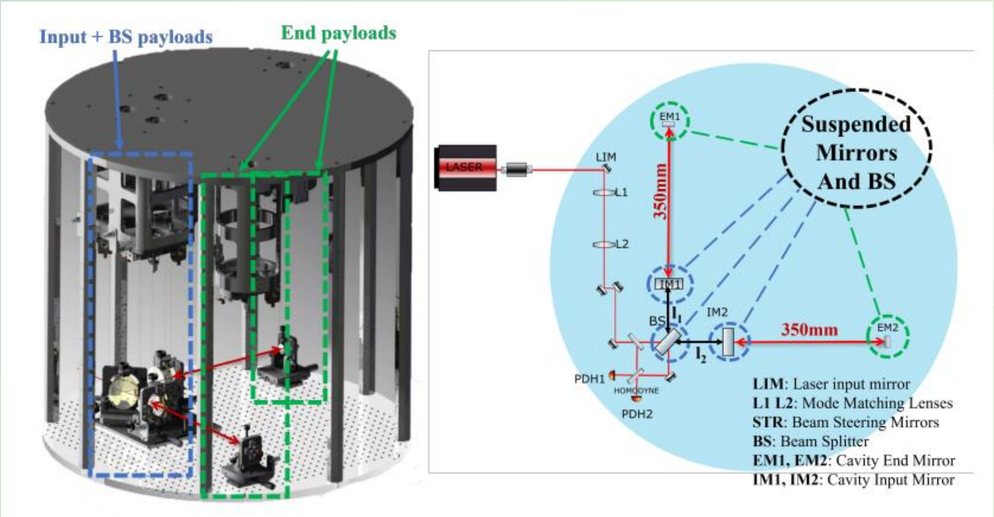
- **SIPS (Suspended Interferometer for Ponderomotive Squeezing) is an optical system designed to reduce quantum noise in gravitational wave (GW) detection.**

- Generate **Frequency-Dependent Squeezing (FDS)**

- Michelson interferometer with **Fabry-Perot arm cavities**, similar to **Virgo & LIGO**

- Utilizes **Einstein-Podolsky-Rosen (EPR) entanglement** to mitigate **Shot Noise (SN)** at high frequencies and **Radiation-Pressure Noise (RPN)** at low frequencies

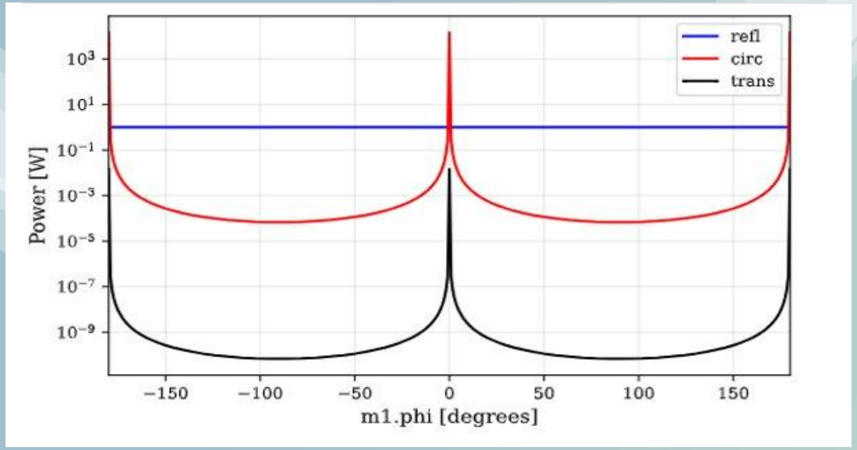
SIPS has been designed by Roma1 group to be sensitive to RPN in all the detection band of GW interferometers (1 Hz − 1 kHz).

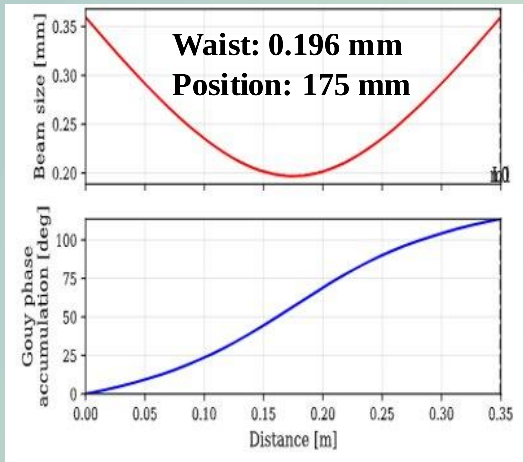


[2]

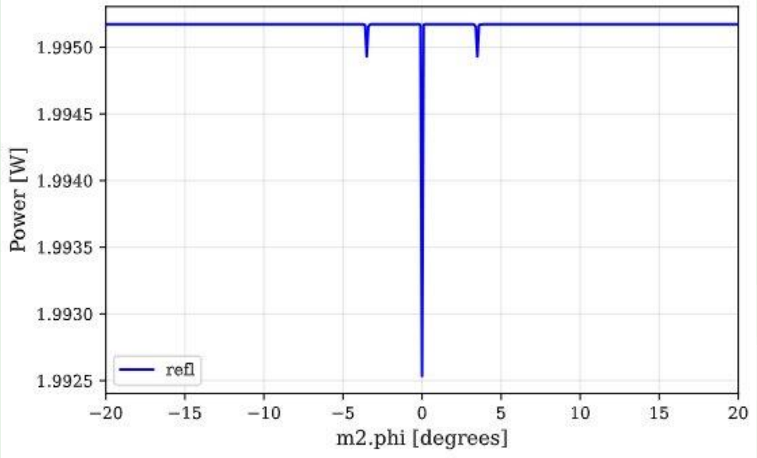
Preliminary study with FINESSE3: SIPS Arm Cavity

Mirrors RoC: 250 mm
Stability 0< g1 g2 <1 : 0.16



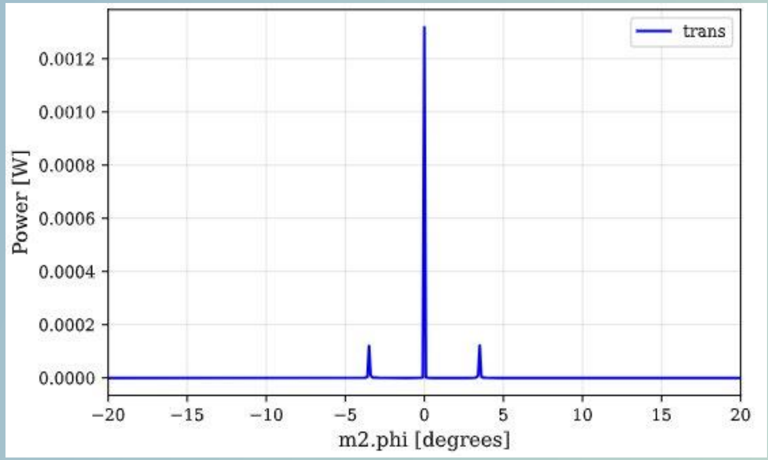


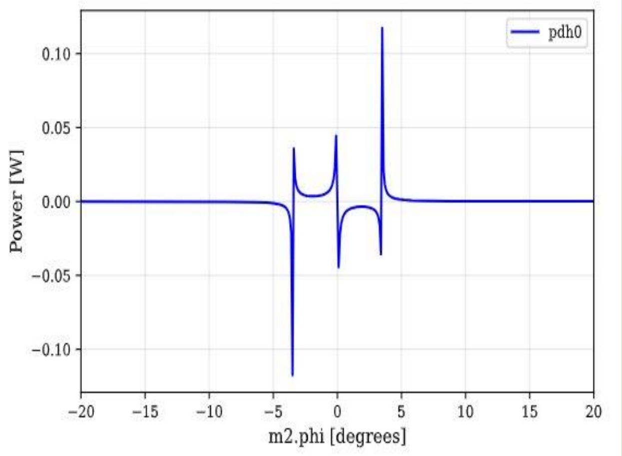
Phase shift between the carrier and sidebands, making the sideband contributions more prominent in the error signal.



Pound–Drever–Hall Technique

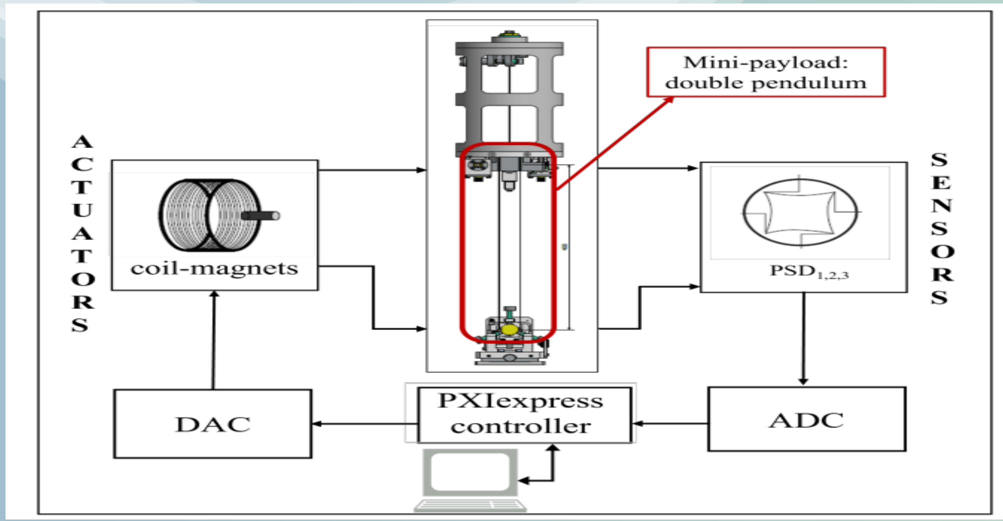
The Pound-Drever-Hall (PDH) locking technique stabilizes the laser frequency by detecting phase shifts in the reflected light using an electro-optic modulator (EOM) and photodetectors (PDs) to generate an error signal that corrects the laser frequency.





Local control digital system

The **end mini-payload of SIPS ITF** is monitored by **three PSDs**, with sensor signals processed via **ADC, PXI-express controller, and DAC** to generate feedback for actuators.



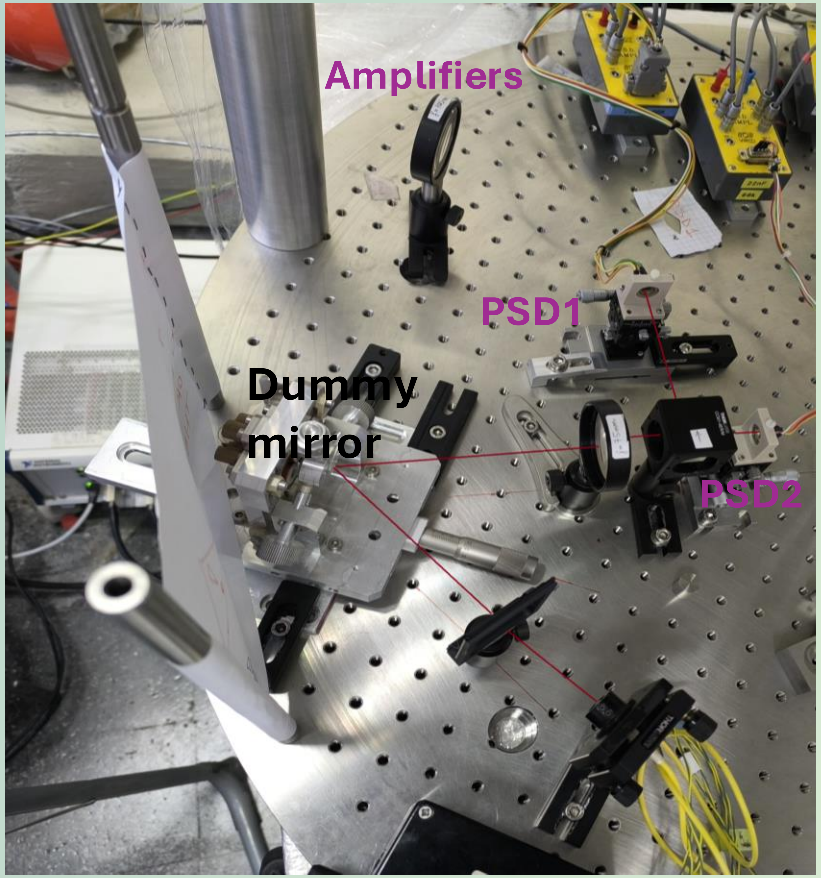
[3]

The variations along the two coordinates of the PSD are given by

$$\frac{(UR + DR) - (DL + UL)}{UL + UR + DL + DR} = A_x$$

$$\frac{(UL + UR) - (DL + DR)}{UL + UR + DL + DR} = A_y$$

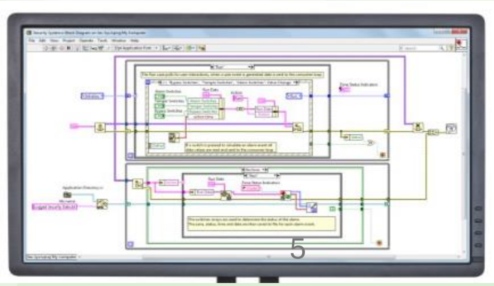
Current Status



BNC

PXIe

LabVIEW



To optimize the alignment of the beam to ensure proper focusing on the image plane and minimize aberrations.

Conclusion

- The Suspended Interferometer for Ponderomotive Squeezing (SIPS) is designed to reduce quantum noise in gravitational wave detection using Frequency-Dependent Squeezing (FDS) and Einstein-Podolsky-Rosen (EPR) entanglement.
- The system includes a Michelson interferometer with Fabry-Perot arm cavities, stabilized using the Pound-Drever-Hall (PDH) technique.
- A local control system with PSDs, PXI controllers, ADC, and DAC ensures accurate alignment and feedback control.

Next Step

- **Testing and Calibration**

  Conduct performance tests on the SIPS mini-payload.

  Fine-tune sensor alignment and actuator response.

- **Data Acquisition and Analysis**

  Collect and analyze data from PSD signals using PXI and LabVIEW.

  Optimize signal processing for improved noise reduction.

References

[1] Di Pace, Sibilla, et al. "Small scale Suspended Interferometer for Ponderomotive Squeezing (SIPS) as test bench of the EPR squeezer for Advanced Virgo." *2 nd Gravitational-waves Science & technology Symposium (GRASS 2019)*. 2020.

[2] **Giacoppo, L.** (Year). *Towards an optimal control system of an opto-mechanical resonator for quantum noise reduction in GW interferometers* (Thesis). Tutor: Prof. Ettore Majorana, Docente guida: Prof. Antonio Carcaterra.

[3] **Giacoppo, L.** (Year). *Towards an optimal control system of an opto-mechanical resonator for quantum noise reduction in GW interferometers* (Thesis). Tutor: Prof. Ettore Majorana, Docente guida: Prof. Antonio Carcaterra.

Any Question?