AN INTERFEROMETRIC READOUT FOR SEISMOMETERS

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CONTEXT & OBJECTIVE

Seismometers are now likely to be placed on other planets. Indeed, 3 Very Broad Band seismometers (VBB) will land on Mars next year (NASA InSight mission[1]). But compared to Earth, the expected signal on the Moon or on Mars will be much lower and buried in noise.

Therefore, a new generation of displacement sensors is required with improved performances in terms of linearity and noise level.

This work is performed in the context of a collaboration between APC (AstroParticle and Cosmology) and IPGP (Institut of Earth Physics in Paris). The APC will bring its expertise in interferometric measurements at low frequencies and very low noise levels, that was acquired during the development of the eLISA space project[2].

The objective is to improve the sensitivity by 2 orders of magnitude compared to the current seismometers performances (InSight VBBs : 4pm at 1Hz).

Limitations:

- Possible drift
- Predicted thermal sensitivity (cavities deformation)

-> In this case with 2 cavities : symmetric deformation expected

GENERAL PRINCIPLE

The general principle is described on Fig. 1.

The chosen technique is to measure the difference of resonance frequency between 2 short length, back-to-back, Fabry-Perot (FP) cavities.

A laser beam (1542 nm) is emitted and sent to a first electro-optical modulator (EOM) working at about 80 MHz. This modulation is used to compute the locking error signal using the Pound-Drever-Hall technique[3] (PDH).

The laser frequency is locked on one of the cavity while the difference of resonant frequencies is tuned using a second EOM working at a few GHz.

The central mirror is mounted on the arm of the seismometer whose displacement is a measure of seismic acceleration. This movement has the effect of decreasing the resonance frequency of one cavity while increasing the other one. The correction that the feedback system has to apply on the EOM, is proportional to the length difference of both cavities, hence the arm displacement.

The PDH technique is widely used to stabilize the laser frequency by locking on a ultra stable cavity. In the present work, the laser frequency change is used to measure the cavity length.

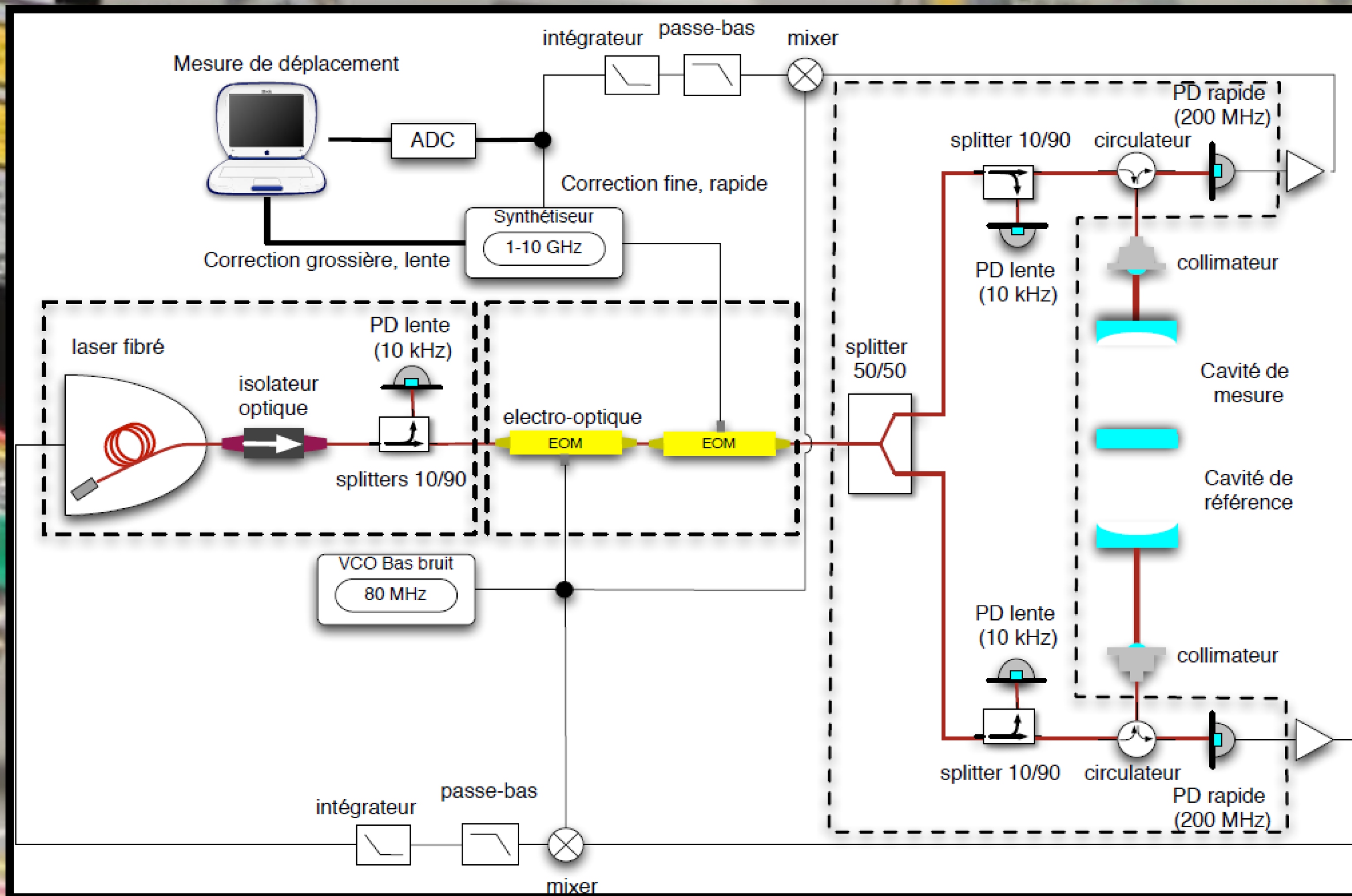

Fig 1. Experiment schema, using PDH (Pound-Drever-Hall) technique. FP cavities are on the right side, blue on the diagram.

PHYSICAL PRINCIPLE

After passing through an EOM, a laser field may be considered as the superposition of 3 components: the laser carrier (at frequency ω) and 2 symmetrical sidebands (at $\omega+\omega_m$ and $\omega-\omega_m$ frequencies), produced by the phase modulation of the signal : $\beta.\sin(\omega_m.t)$.

$$V(t) = V_0.e^{i(\omega t+\beta\sin(\omega_m.t))}$$

Which at first order in β can be written as :

$$V(t) = V_0.e^{i\omega t} + V_0.\frac{\beta}{2}.e^{i(\omega+\omega_m)t} - V_0.\frac{\beta}{2}.e^{i(\omega-\omega_m)t}$$

This signal is represented on the upper curve in Fig. 2. In our case with 2 EOM, 9 peaks are produced.

The reflected light E_r out of the FP cavity is related to the light E_{in}, incident on the cavity, by a given transfer function. The new signal contains the unaltered sidebands and the phase shifted carrier. This phase depends on the offset between the frequency of the incident signal and the resonance of the cavity. The power P_r of the reflected light E_r can be written as :

$$P_r = P_0.|R(\omega)|^2 + P_0.\frac{\beta^2}{4}\{|R(\omega+\omega_m)|^2 + |R(\omega-\omega_m)|^2\}$$
$$+ P_0.\beta\{Re[\chi(\omega)]\cos(\omega_m t) + Im[\chi(\omega)]\sin(\omega_m t)\} + (terms\ in\ 2\omega_m)$$

χ is the ultimate quantity of interest (function of $\omega-\omega_{res}$). It can be extracted from P_r as follows : the reflected beam passes through a photodiode to produce a voltage V_r which is then mixed with a phase-delayed version of the original signal. This mix is sent through a low pass filter to remove the oscillating terms. Finally, the recovered signal, which only contains the terms χ, is demodulated.

The lower curve in Fig. 2 shows the signal after mixing. The "locking" point of the cavity corresponds to the one in the central 'zero' crossing.

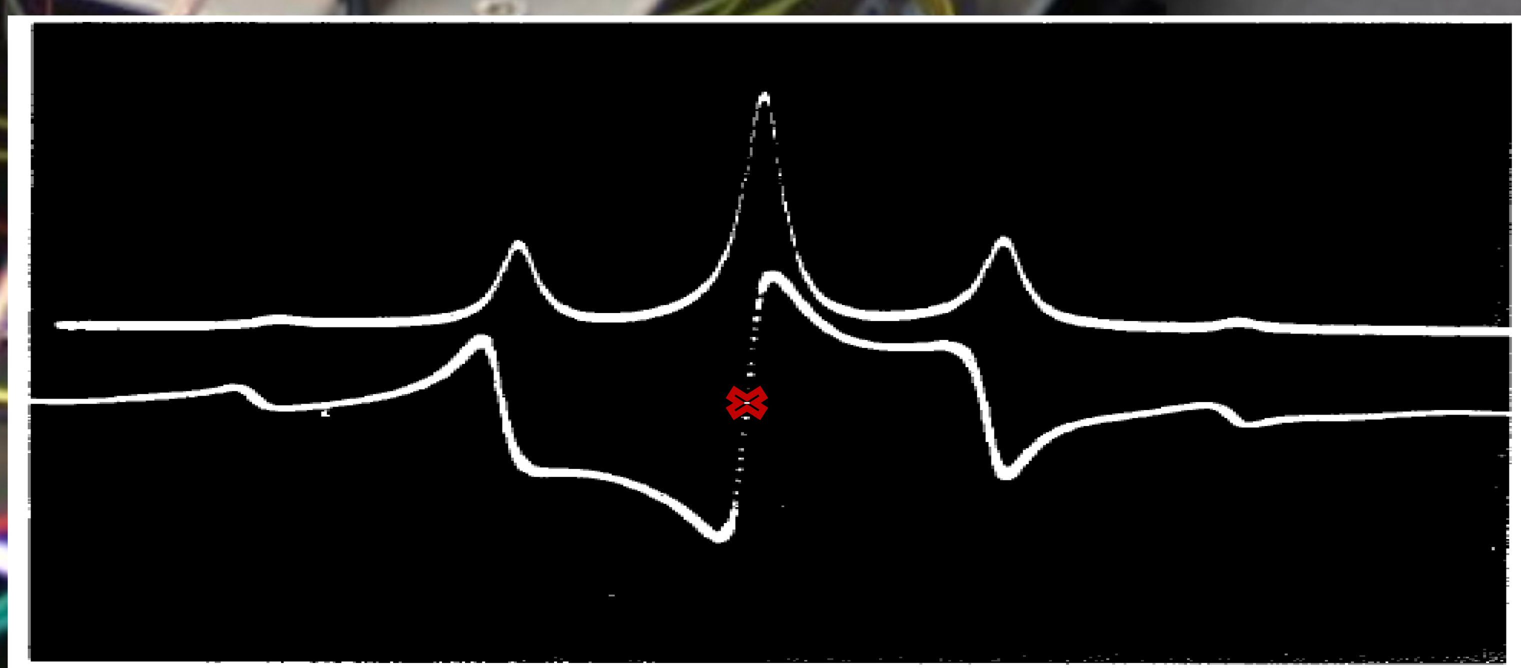

Fig 2. Drever et al. (1983), Appl. Phys. , modified.

WORK IN PROGRESS

The next step is to have a first resonating cavity. Its geometry was already calculated (as seen on Fig. 3).

Once the cavity is locked on its resonance frequency, the second cavity will be tuned and first performance measurements performed.

The noise level will be compared to the noise level of existing capacitive sensors.

The all system will be put in a vacuum chamber.

CONCLUSION

The final objective is to make a real optical seismometer prototype which might represents the next generation of planetary seismometers, provided the noise level meets our expectations.

First experimental results are expected within a year. Such a seismometer on Moon would allow a better knowledge of the Moon and Mars internal structure.

REFERENCES

[1] Dandonneau, P.-A., et al. 'The SEIS InSight VBB Experiment'. 44th Lunar and Planetary Science Conference, held March 18-22, 2013 in The Woodlands, Texas. LPI Contribution No. 1719, p.2006.

[2] https://www.elisascience.org/whitepaper/

[3] Drever, R. W. P., Hall, J. L., Kowalski, F. V., Hough, J., Ford, G. M., Munley, A. J. H. Ward (1983). "Laser phase and frequency stabilization using an optical resonator". Appl Phys B 31 (2): 97

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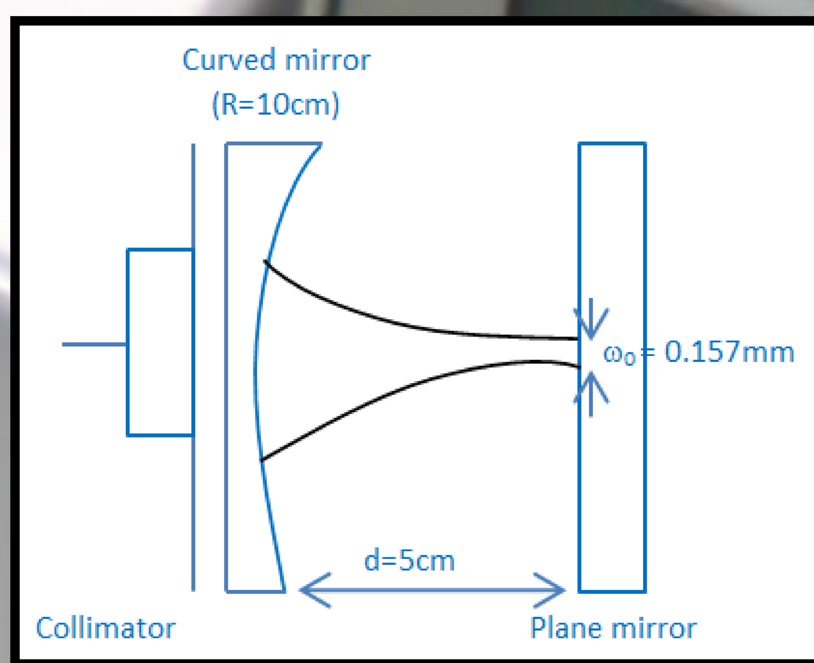

Fig 3. First theoretical FP cavity