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Remote optical interferometric displacement technology development for planetology

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The Apollo seismic experiment yielded unique seismology data from the Moon. However understanding of the Moon's interior structure remains constrained by the limitations of the Apollo's sensors. Fifty years later, the Mars seismometer Insight/SEIS demonstrated reduced self-noise and enhanced resolution. A spare model will be deployed to the Moon in 2026 as part of the FSS (CLPS 12) mission. Nevertheless, it is still far from meeting the International Lunar Network (ILN) requirements. This is the reason why a technological breakthrough is needed.

By switching from electrostatic displacement sensors to optical interferometric ones, an improvement of several orders of magnitude is made in mitigating parasitic forces (electrostatic noise to pressure radiation). Additionally, this approach allows us to minimize the electronic components within the deployed sensor. This reduction is made possible by employing remote optical readout of the displacement via an optical link connecting the deployed sensor to the lander. Since the objective is to operate without force feedback, the primary challenge lies in meeting two simultaneous requirements: accommodating proofmass rebalancing up to a few millimeters across a 100°C thermal variation and achieving an exceptionally fine resolution to detect proofmass displacements as small as 10^{-12} m @ 1 Hz induced by seismic activities.

This challenge led to the use of a laser source within a phase-modulated Michelson interferometer. The critical objective is to isolate the interference between the two moving mirrors while minimizing the impact of all parasitic back reflections. Whereas, it is well-known that a -60dB parasitic reflection results in a -30dB variation of the interference pattern. Consequently, both experimental and theoretical work are conducted to characterize, model and quantify the effect of each parasitic reflection, depending of its position within the optical design. In this frame, the use of Rayleigh Optical Frequency Domain Reflectometry (OFDR) to characterize the interferometer will be described, in addition to the use of collected information in the model to explain the observed fringe patterns.

In conclusion, a comparative analysis of the performance of this optical readout technique in relation to other published methods is performed, taking into account benefits and drawbacks of each of them. Notably, the capability of achieving remote readout of the signal is emphasized. Indeed, as the ability to minimize electronic components within the sensor is crucial for low-noise applications, we will explore the synergy with remote optical readout technology, such as the one developed at ESEO (Engineering School in Angers, France). This opens the path to broader applications across various type of geoscience sensors.