# LISA technology development at JPL


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The Laser Interferometer Space Antenna (LISA) project requires technological developments on many fronts. A physical understanding of the LISA subsystems is a precursor to tackling the requirements needed to ensure a successful mission. This can only be achieved by developing the concepts in the lab prior to developing the payload. This poster presents updates on laboratory activities intended to prove the feasibility of measuring proof mass back reaction forces of less than 3 fN/√Hz at 1 mHz; the sensing of the proof mass position within 2 nm/ √Hz above 3 mHz; and the resolution and accuracy of the phase-meter to better than 10 pm/ √Hz above 3 mHz.

## *Optical Displacement Sensor*

A nominal 2 nm/rtHz sensitivity performance for the simple optical displacement sensor for LISA application[1] can be achieved by using a 200 microns wide slit to define the beam size and therefore the sensing range. This performance nearly meets the LISA requirement at frequencies of interest. However, our observations have also shown the sensitivity proportional to the beam size. The current theory suggests an electronics noise limit. We will be examining various noise sources more carefully in the near future.

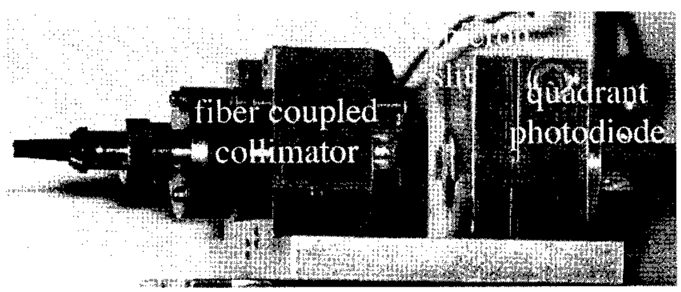



Figure 1. A typical characterization setup for the optical displacement sensor.

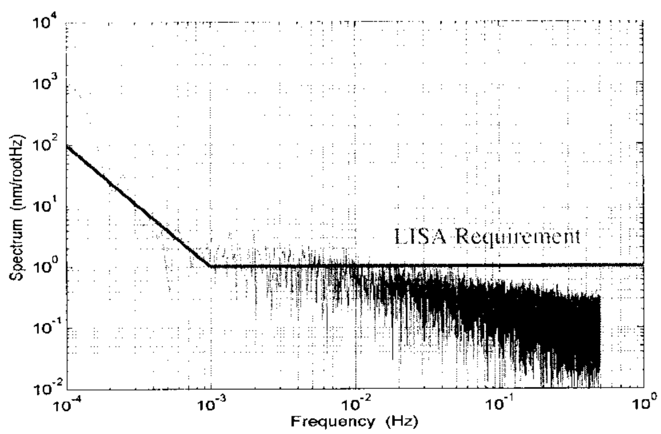



Figure 2. Best performance of the optical displacement sensor at low frequencies.

## *Membrane Sensor*

The aim of this work is to make direct ground-based measurements of back-reaction force exerted on the proof mass (PM) of a LISA Gravitational Reference Sensor. The operational constraint for the sum of all fluctuating acceleration disturbances is not to exceed $3\times10^{-15}\mathrm{m.s^{-2}}/\sqrt{\mathrm{Hz}}$ (or a force spectral amplitude of 4 fN/√Hz between 0.1mHz and 1 Hz). Ground-based measurements of disturbances to that level of sensitivity are hindered by the relatively large seismic and environmental disturbances and non uniformities in local gravitational fields. This work will construct a test bed that is insensitive to these effects but sensitive to back-reaction forces of certain candidate displacement sensors and actuators being considered for LISA. The basis for this arrangement will be a thin Membrane Reference Sensor (MRS) (shown right top), which for test purposes substitutes for the proof mass.

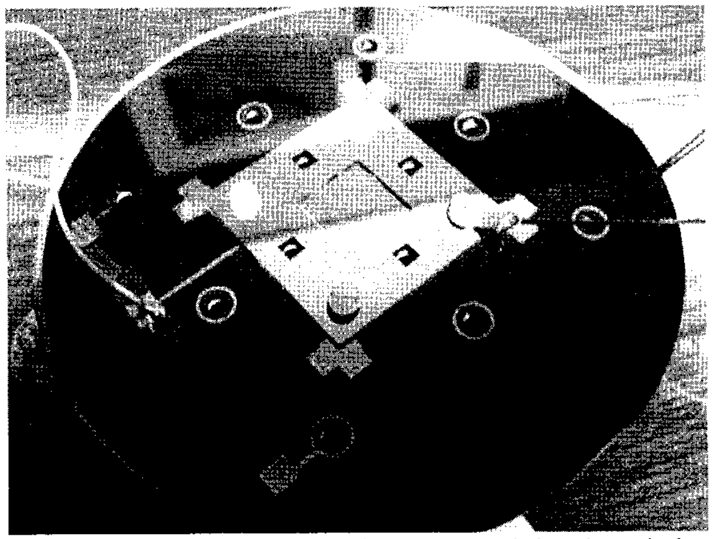
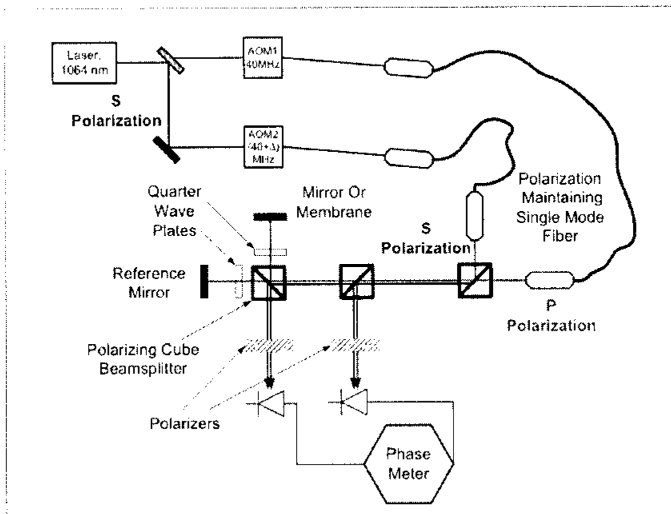


Figure 3: above the membrane reference sensor, below the optical arrangement used to measure the motion of the MRS.




The experimental arrangement (shown right bottom) utilizes a polarization sensitive Michelson interferometer to produce a beat signals at 10 kHz that can be compared to a reference 10 kHz signal. One arm of the Michelson has a reference mirror while the other arm has either a mirror, which is used for initial setup, or the MRS.

The advantages of this arrangement are that:

1. Gravity effects are eliminated;
2. Ground vibrations are common to both membrane and capacitor plate; and
3. Membrane motion is much greater for a given force than on the PM

This setup allows us to measure the sensor degradation when exposed to different environments, as well as optimizing the sensor drive electronics so that back reaction forces can be minimized.

The physical properties of the MRS are shown in figure 4. The MRS is a 1.2 cm square strip of silicon nitride coated chromium and gold, as shown. The total thickness of the membrane is 0.64 μm. This corresponds to a mass of $5.5 \times 10^{-7}$ kg. In this configuration the membrane is bonded on all four sides to the silicon backing plate. The gap between the membrane and the adjacent electrode (top plate in figure 4) is 15 μm.

Figure 5 shows the transfer function of the MRS, as taken by a Stanford Research Systems SR785 dynamic signal analyzer. The first resonance of the membrane occurs at 8.6kHz, with a Q of 1000. Higher order resonances are also observed. The high value for the resonant frequency is attributed to residual manufacturing stresses that occur when the silicon nitride is deposited onto the silicon. Altering the membrane design to only be attached to the silicon on two of the four sides can elevate the stresses. We are presently working to reduce these stresses and hence reduce the first resonant frequency to 100Hz.

Figure 6 shows the spectral noise density of the MRS as compared to a mirror, under the condition of being excited by a 3.5 fN force at 1 mHz plus a 1.6 μN DC bias (red curve) and then a 3.5 fN force at 250 mHz plus a 1.6 μN DC bias (blue curve). The black curve is the noise floor of the system as measured by a reference mirror. These data runs were taken over 80000 sec with a 2 Hz sampling rate and the PSD was calculated using pwelch in Matlab. Future work will to increase the absolute motion of the system by reducing the resonant frequency of the MRS.

Figure 4. MRS design parameters.

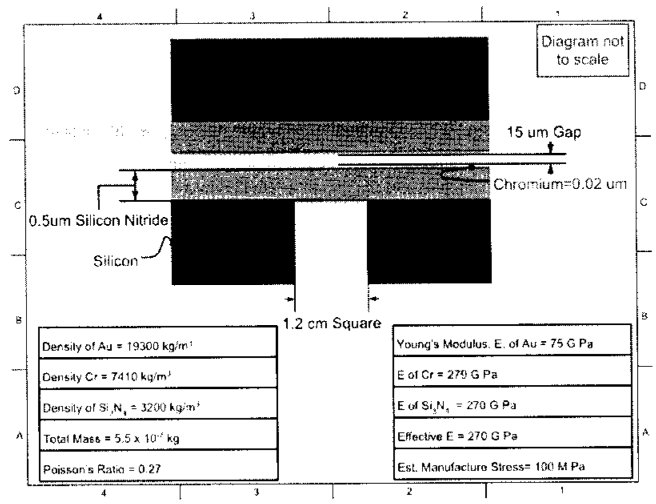



Figure 5: transfer function of MRS.

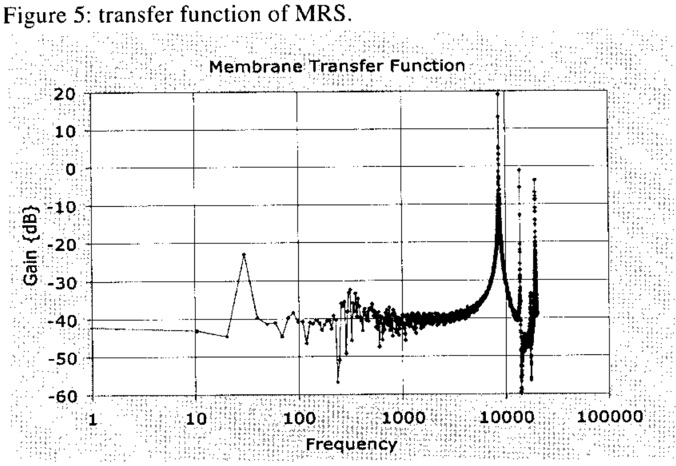
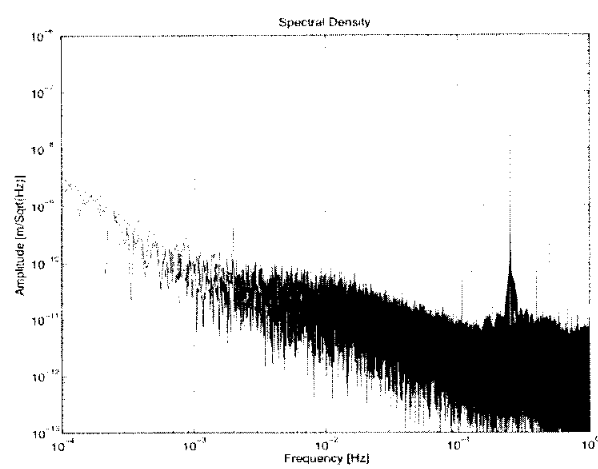



Figure 6. The spectral noise density of the MRS under excitation.



## FPGA Phasemeter

The FPGA phasemeter consists of two digital inputs whose relative phase difference is of interest. Both signals are sampled with one bit resolution at the ultra-stable oscillator (USO) frequency. At present we are using a 50 MHz USO, but there is a work in progress to increase that frequency.

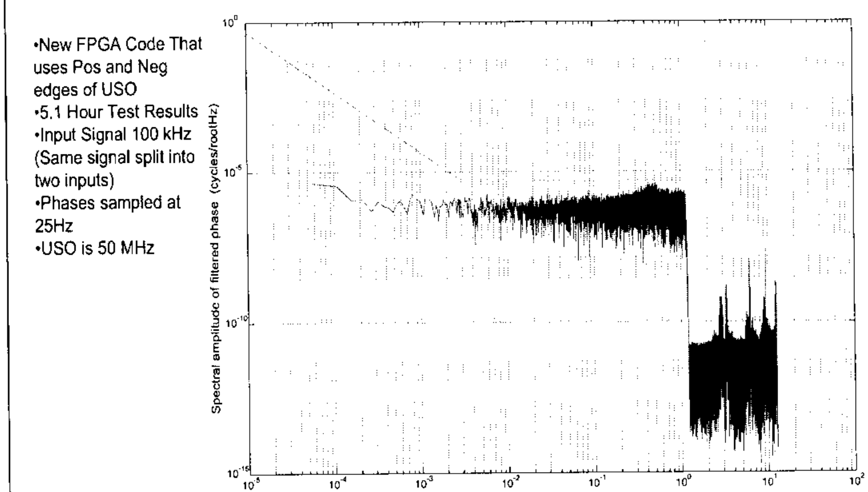



Figure 7. Phase meter performance (blue) compared to LISA requirements (red).

The phase is determined by measuring zero crossings of the digital signals. In this process each input signal is strobed on every rising and falling edge of the USO clock signal. A decision is then made when positive or negative zero crossings of the unknown signal occurs. On each of these events the phase counter is incremented by pi (or by 1/2 cycle). Also on every clock cycle the total accumulated sum of phase is calculated. The accumulated phase is dumped to disk at a rate of 10 Hz and then differenced from the value that occurred 100 ms prior. This gives the accumulated sum of the signal phase over last 100 ms. Then this value is divided by the number of USO cycles in 100 ms, and the result is average signal phase over last 100 ms. We assumes that the signal does not contain frequencies higher than 5 Hz.

The resolution of this system is set by the duration of one USO cycle. Hence the output of the phasemeter could be specified down to 20 ns. Exactly same technique is used in each channel of the phasemeter. The results presented in figure 7 show the phasemeter performance when two 100 kHz signals were input into the system. The PSD of the time series is presented here that shows a performance that is below the LISA requirements.

## Future Work

The results presented in this paper show that we are well on our way to meeting LISA requirements in a laboratory environment. We are continuing to improve these technologies, and are confident that we will meet the strict demands required for a successful LISA mission.

## Acknowledgements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[1] M.P. Chiao, F.G. Dekens, and A. R. Abramovici, "Optical displacement sensor (ODS): an inertial reference sensor candidate for LISA", Proc. SPIE **4856**, 98 (2003).