Surface Potential Measurements with the LISA Kelvin Probe

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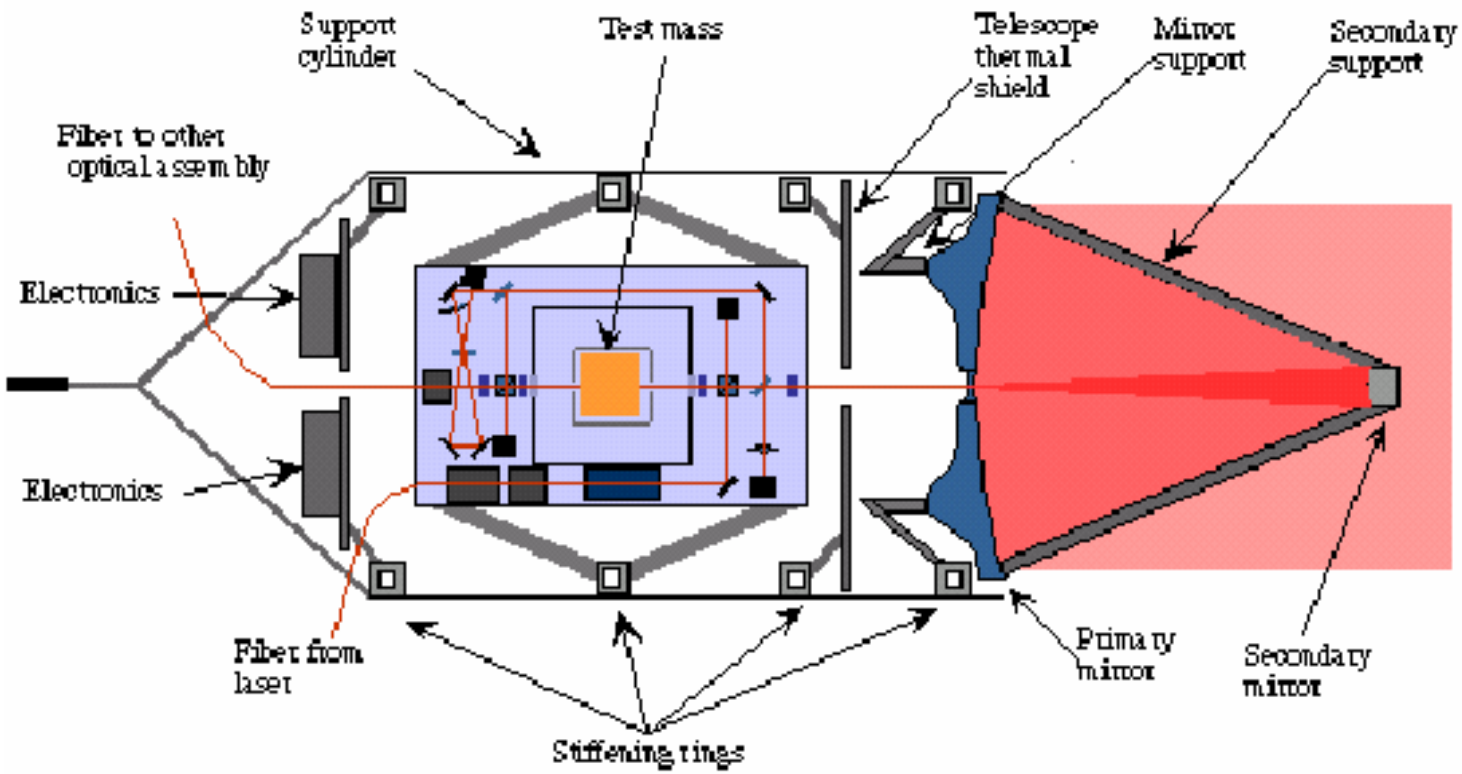
Acceleration Noise in LISA

- LISA measurement sensitivity is 10^{-12} m over 1000 sec
- A force of 10^{-16} N will produce this displacement in 1000 sec!
- Many sources of force noise at this level: magnetic, residual gas pressure, thermal, etc.
- The least understood, highest risk noise source is believed to be from test mass *fluctuating surface potentials*
  - This effect has been seen on GP-B

LISA Test Mass Optical Layout



Estimate of surface potential forces

- The test mass and corresponding electrode can be viewed as a capacitor

- $E_{cap} = C V^2$ (V is TM-electrode voltage difference)
- $F_{cap} = C V^2 / w$ (w is gap size)
- $dF = 2 C V dV / w$ (dV is fluctuation of voltage)

- with $F = 10^{-16}$ N, w ~ 1 mm, C ~ 10 pf, V ~ 1 mV
  → dV < 0.01 mV over 1000 seconds

- → need a high precision, high stability measurement of voltage variations at this level

What's the big deal about 0.01 mV surface potential stability?

- Surface potential related to dipole layer at surface
  - Surface potential variations come from 2 sources
    - Different elemental composition
    - Different crystal orientation of same element
  - Typical value for $\Delta V \sim 100$ mV

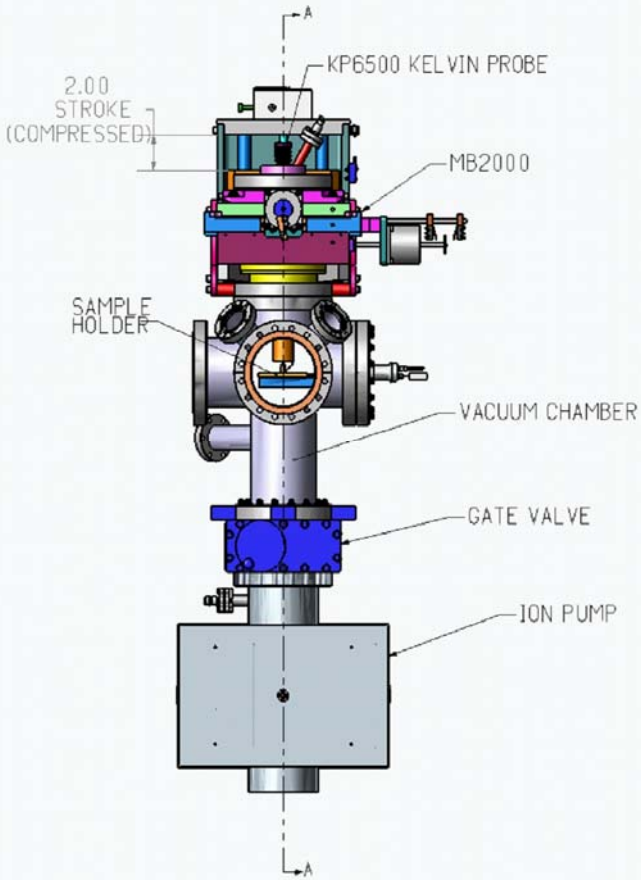
- Assume outgassing of hydrocarbon is coating test mass surface
  - Typical HC partial pressure of 10^{-11} torr
  - Will coat 1 monolayer (100 mV) in 10^5 seconds if all molecules stick to surface
  - Will coat 10^{-4} monolayer (0.01 mV) in 1000 second if 1% of all molecules stick

- Very little data on 0.01 mV surface potential stability

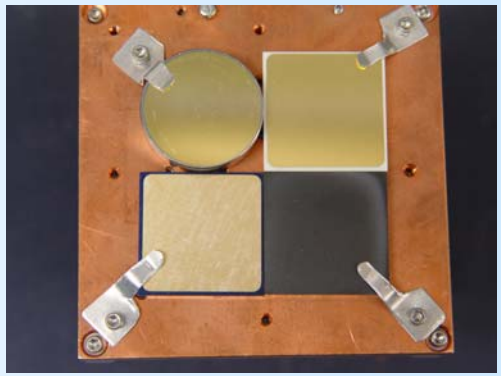
Kelvin Probe for surface potential scan

- GSFC Kelvin Probe
  - Vibrating probe tip held above surface induces current proportional to surface potential
    - I = (dC/dt) * V
  - 3 mm probe size
  - Probe translates laterally over 10 cm diameter
    - Height above surface is servoed to be constant
- Bakable UHV chamber
- Ports for leak of contaminants (water, hydrocarbons)
- Programmable, automated surface scans

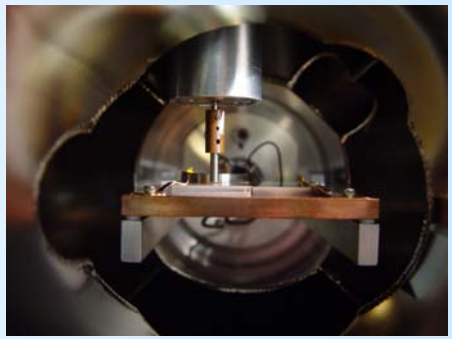
Kelvin Probe: Measurement of Surface Potentials on LISA Test Mass Coating



Vibrating probe induces current proportional to surface potential

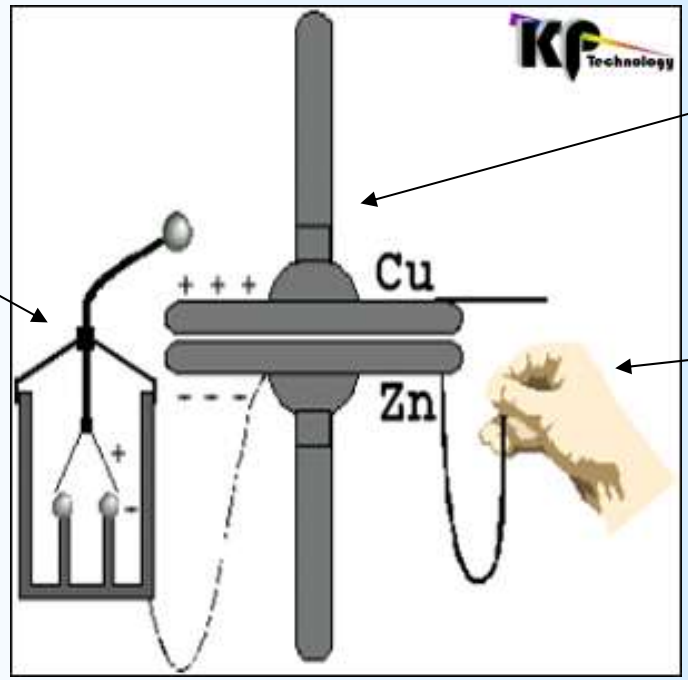


Coated Samples



Sample under test

Older version of Kelvin Probe (1891)



Charge amplifier

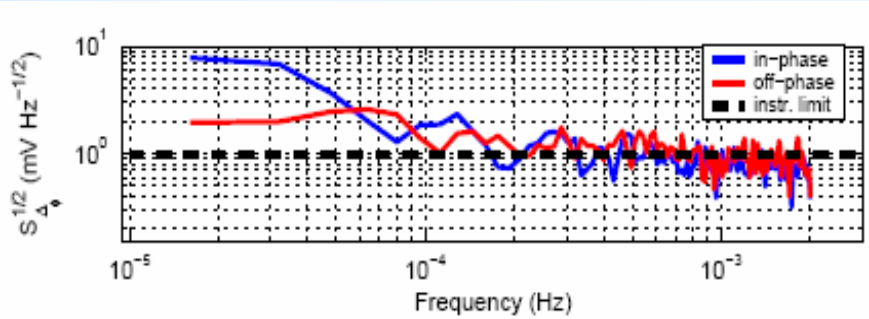
Probe

Equalizing Fermi levels of conductors

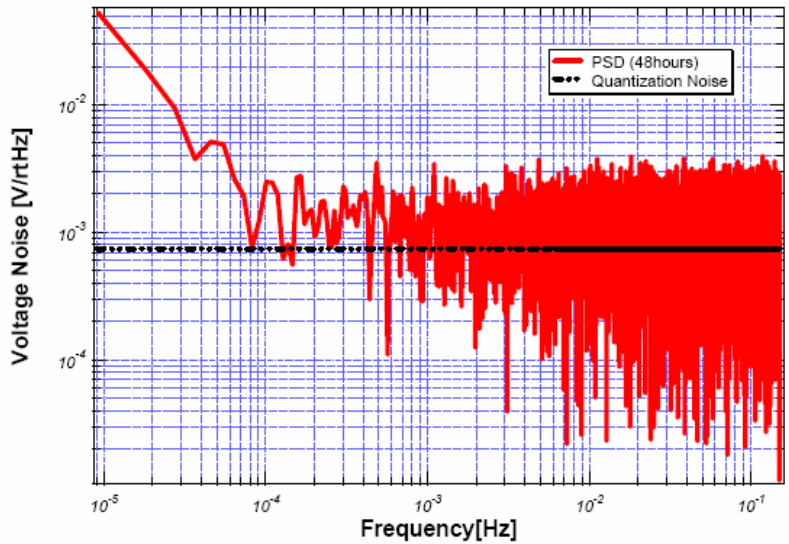
Diagram from Lord Kelvin (William Thompson) 1891

Kelvin probe measurement of time-varying Au surface potential

- Excess low frequency voltage noise of gold surface measured with KP and Torsion Pendulum
  - Few mV / $Hz^{1/2}$ below 10^{-4} Hz
  - Noise floor of 1 mV / $Hz^{1/2}$
- KP noise floor needs to be lowered
  - Factor 10 for LISA Pathfinder
  - Factor 100 for LISA



Torsion Pendulum



Kelvin Probe

Kelvin Probe at Goddard

- KP study of ST-7 samples done at Goddard
  - Norna Robertson will discuss data from these samples
- Higher resolution ADC installed
  - ADC noise now 0.1 mV
- Have not yet measured full KP noise with this ADC

Other Possible Noise Sources

- Temperature
  - Effect on Fermi levels in conductors
- Probe height variance above surface
  - Causes probe capacitance to change
  - I = V (dC/dt)
- Gas "bursts" from vacuum system virtual leaks
- *Is noise from sample or instrument?*
  - Possibly the hardest problem as sensitivity increases

Testing Plans

- Immediate goals are to provide data useful to LPF
  - Spatial, temporal variation of patch fields
    - Gold coated electrode spare
    - Gold coated sample of test mass material
  - Variation of patch fields from exposure to water vapor, hydrocarbons

- Process Control is critical!
  - We are *not* interested in materials physics
  - We *are* interested in establishing process to ensure low surface potential variations on test mass and electrode
    - Contaminant level, material sticking fractions, etc.

LISA Project Schedule

- LPF test flight in 2010
  - Test of drag-free technology
  - Validation of noise models

Near term studies

- LISA Technology Development 2009 - 2012
- Design and Fabrication 2012 - 2016
- Integration and Test 2016 - 2018
- Launch 2018