Developing a Kelvin Probe for Measuring Surface Charge on LIGO Optics

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The Surface Charge Problem

- Surface charge may build up on test masses
- Sources of charge buildup
  - » Friction with dust molecules during pumpdown
  - » Mechanical contact with conductors (earthquake stops)
  - » Cosmic rays (Moscow State group)
- Potential concerns
  - » Fluctuating electric fields can interfere with positioning control
  - » Source of low-frequency suspension noise
  - » Dust may be attracted/held to optic surface, increasing absorption

What We Know/Don't Know

What we know:

- Optics experience drifts of ~10^5 e^-/cm^2/month
  - » Mitrofanov *et al., Phys. Lett.* **A300**, 370 (2002).
- Negligible effects on mechanical Q
  - » Mortonson *et al., Rev. Sci. Inst.* **74**, 4840 (2003).

What we don't know:

- The correlation time for charge mobility, which affects force as:

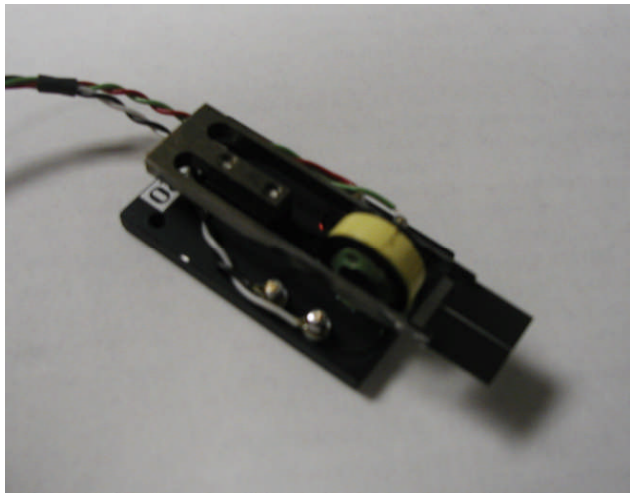
$$F^2(f) \approx \frac{2\langle F^2 \rangle}{\pi \tau_0 (2\pi f)^2}$$

(R. Weiss, LIGO-T960137-00-E)

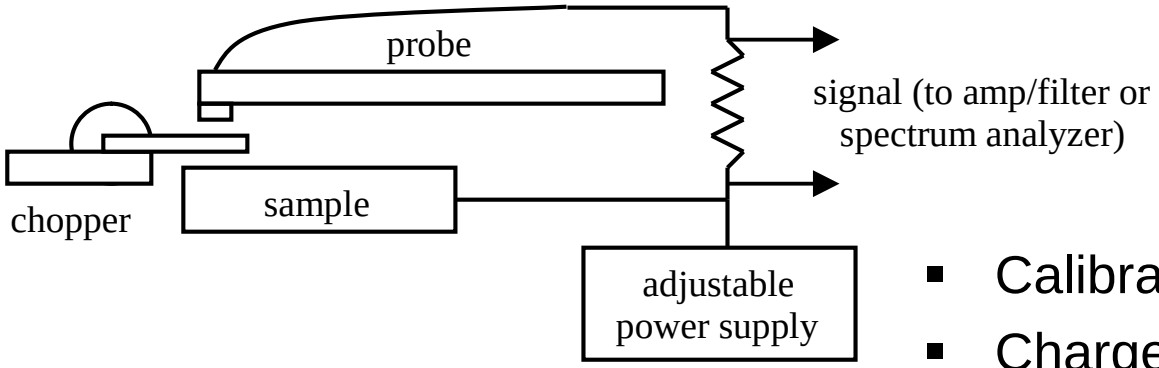
- The effectiveness of charge reduction techniques
  - » Slightly conducting ionic coating
  - » Shield test mass with conductors to terminate electric fields
  - » UV light (next talk)

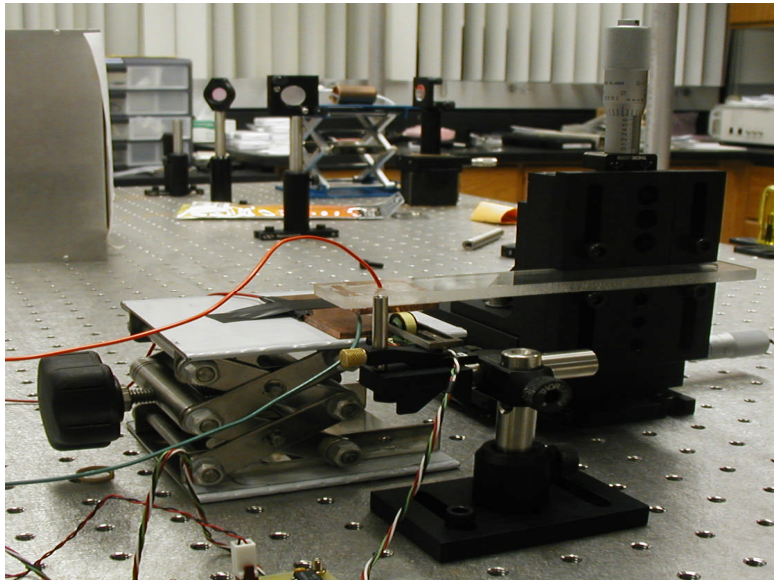
The Kelvin Probe

- The Kelvin probe measures the contact potential difference between the probe and sample
- Commercial probes modulate the difference by vibrating the probe tip by PZT or voice coil -- expensive
- Instead modulate difference with optical “tuning-fork” chopper



Experimental Setup

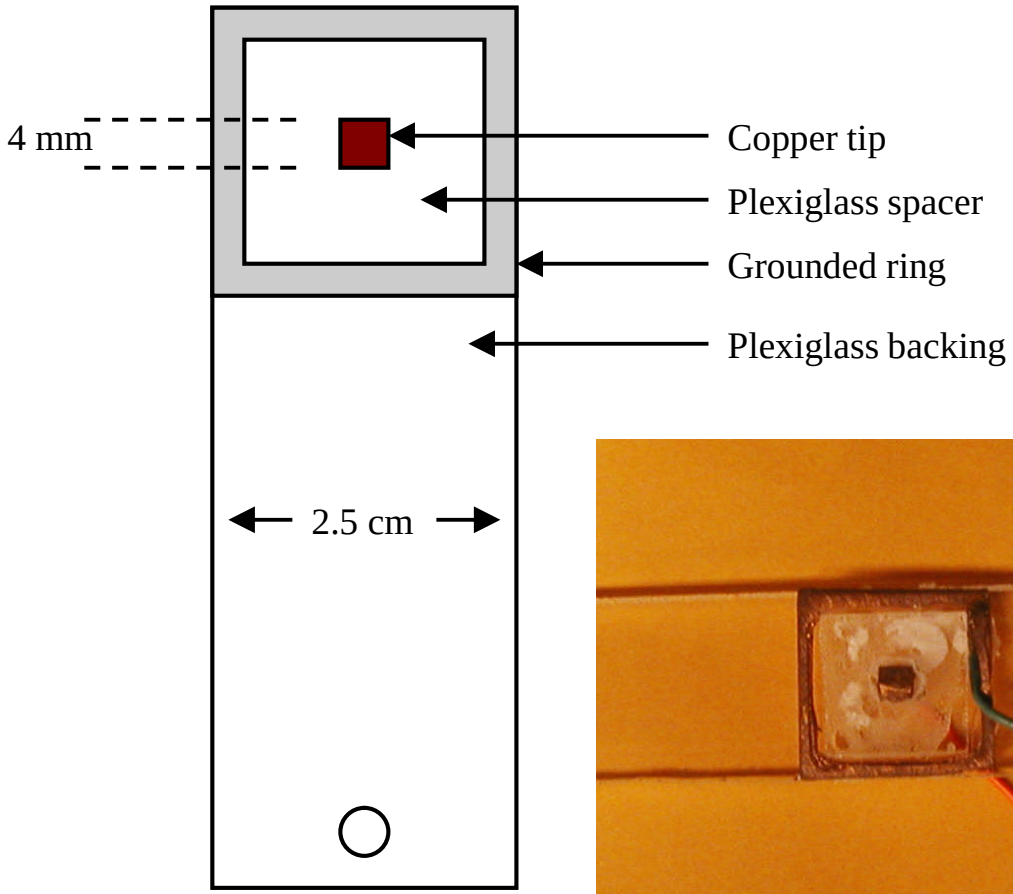


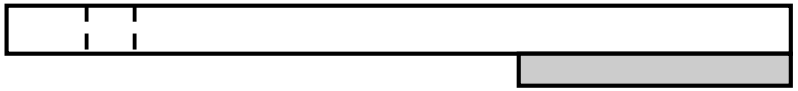


- Calibrate with conducting sample
- Charge insulator, measure change over time
- Repeat calibration in vacuum
- Use XY stage to scan sample, measure charge vs. position

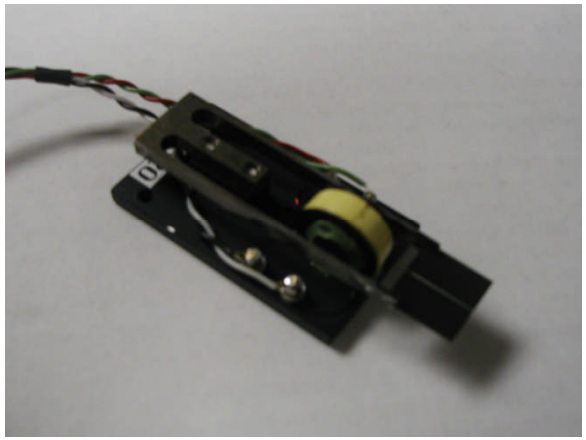
Probe system is then available as testbed for optical material, charge reduction techniques

Kelvin Probe Version 1

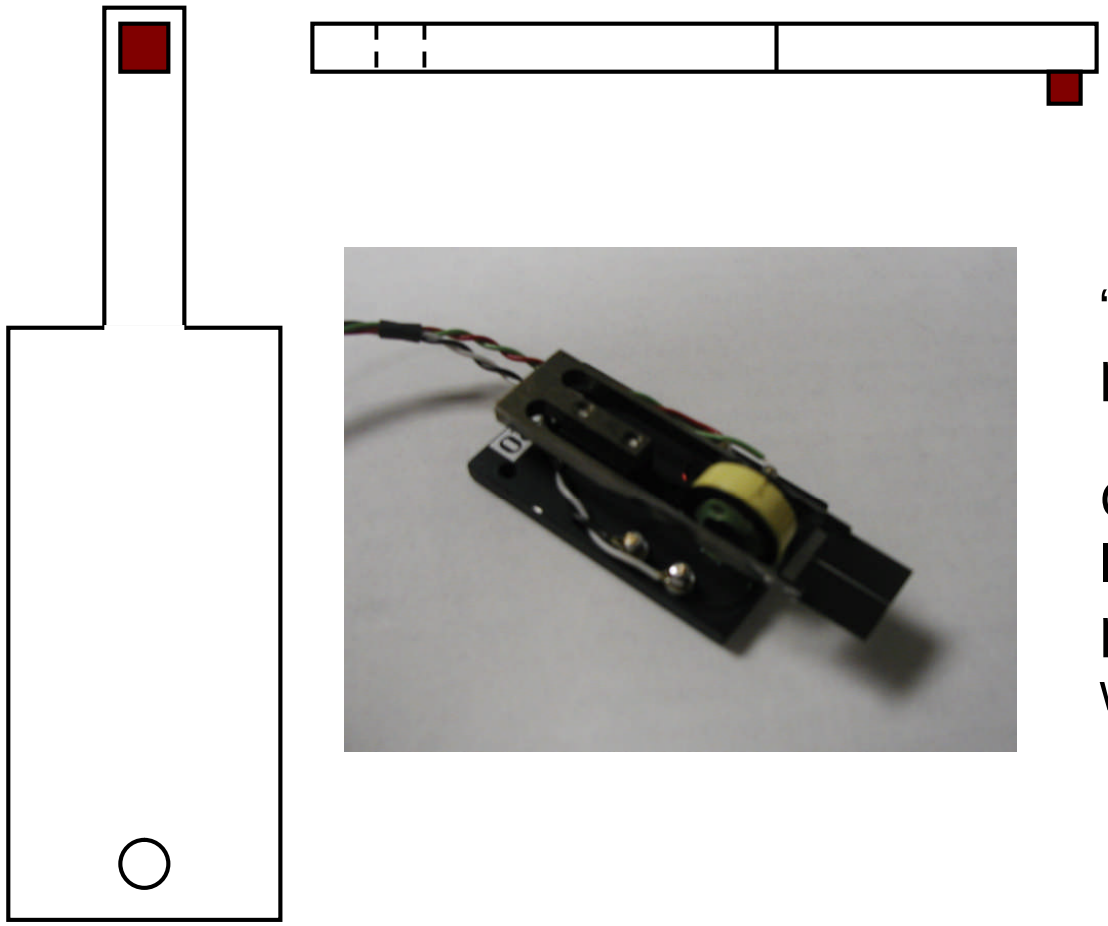




Grounding ring too large, coil on chopper prevented the probe from getting closer than 1 cm.



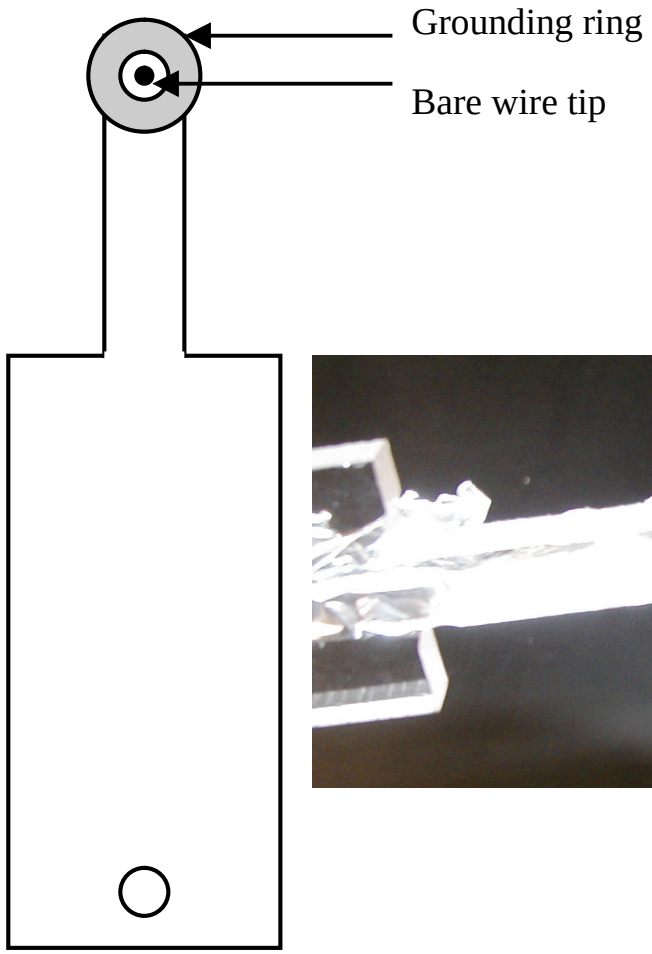
Kelvin Probe Version 2



"Tongue" shape allows probe tip to get closer.

Coil on chopper emits large 500 Hz signal, picked up by probe without grounding ring.

Kelvin Probe Version 3



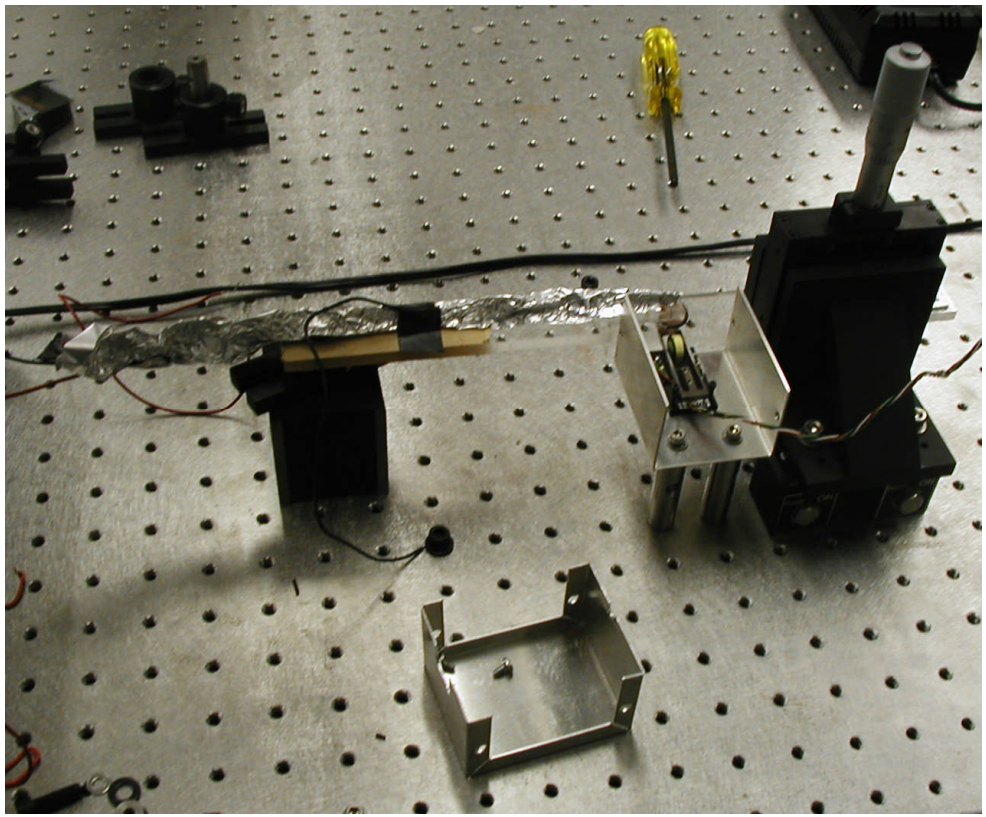
Chopper coil noise reduced by:

- Adding grounding ring
- Isolating chopper power supply
- Wrapping grounded aluminum foil around probe leads
- Encasing chopper in grounded aluminum box

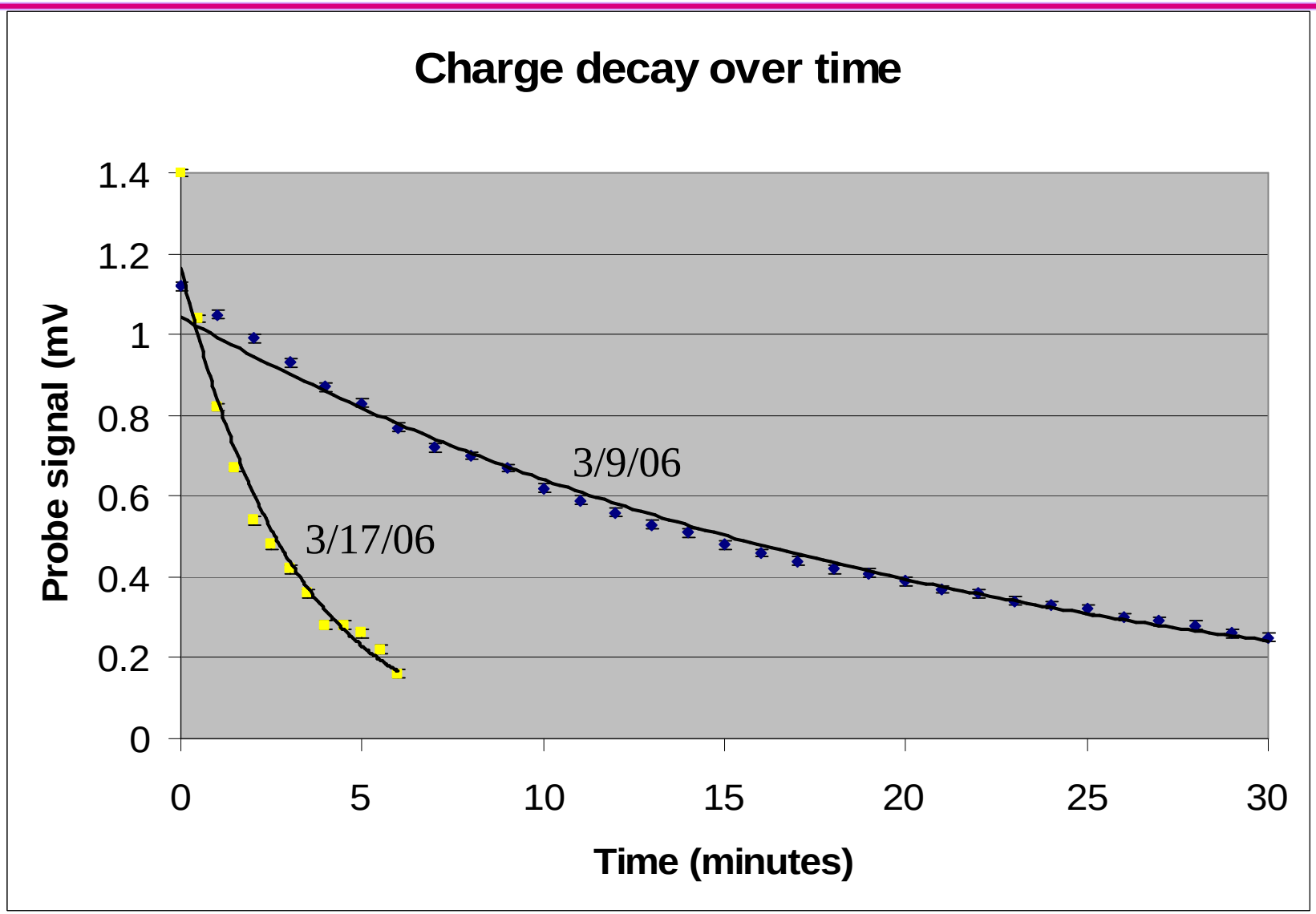
Noise peak reduced to 0.1 mV

Observations

- Cannot see signal from conducting sample, with voltage varied from 0 – 15V.
- Plexiglass sample rubbed with felt/wig/Allen wrench gives 1-3 mV signal (10-30 times larger than noise).
- Signal shows exponential decay, rate varies greatly from day to day.



Charge Decay Over Time



Further Improvements

- Use electrostatic voltmeter to check insulating sample potential, calibrate
- Improved shielding, grounding to reduce noise peak
- Better chopper (drive freq. different than signal freq. – rotary?)
- Place in vacuum