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Developing a Capacitive Probe for Measuring Charging Effects on In-Vacuum Optics

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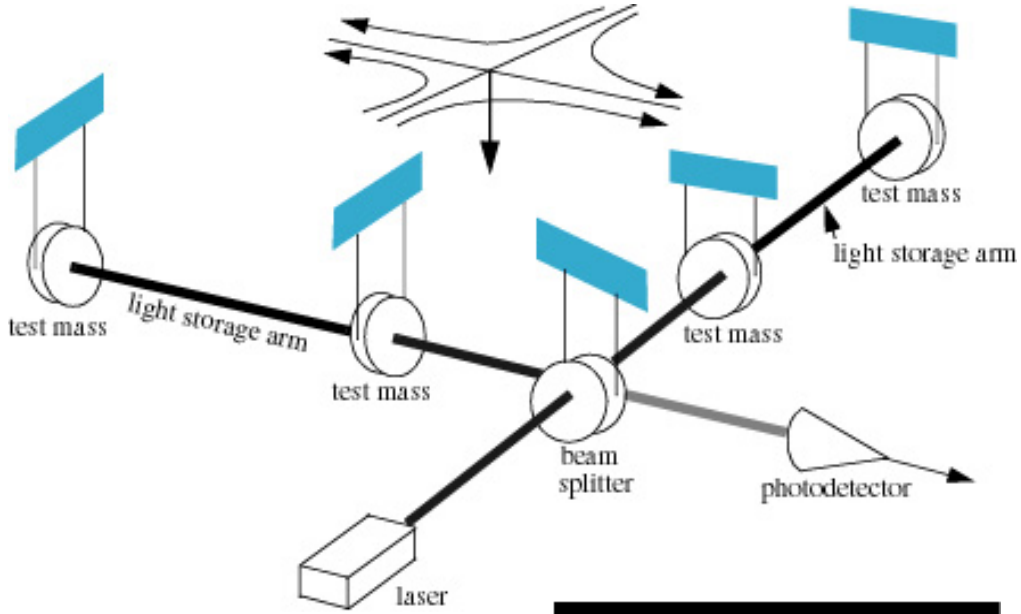
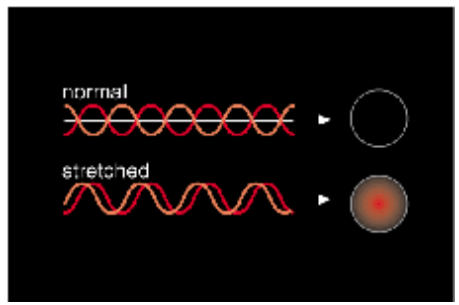
Gravitational-Wave Interferometry





Gravitational-wave detectors such as LIGO use suspended optics in a Michelson interferometer geometry to measure curvature in space from the motions of massive astronomical bodies.

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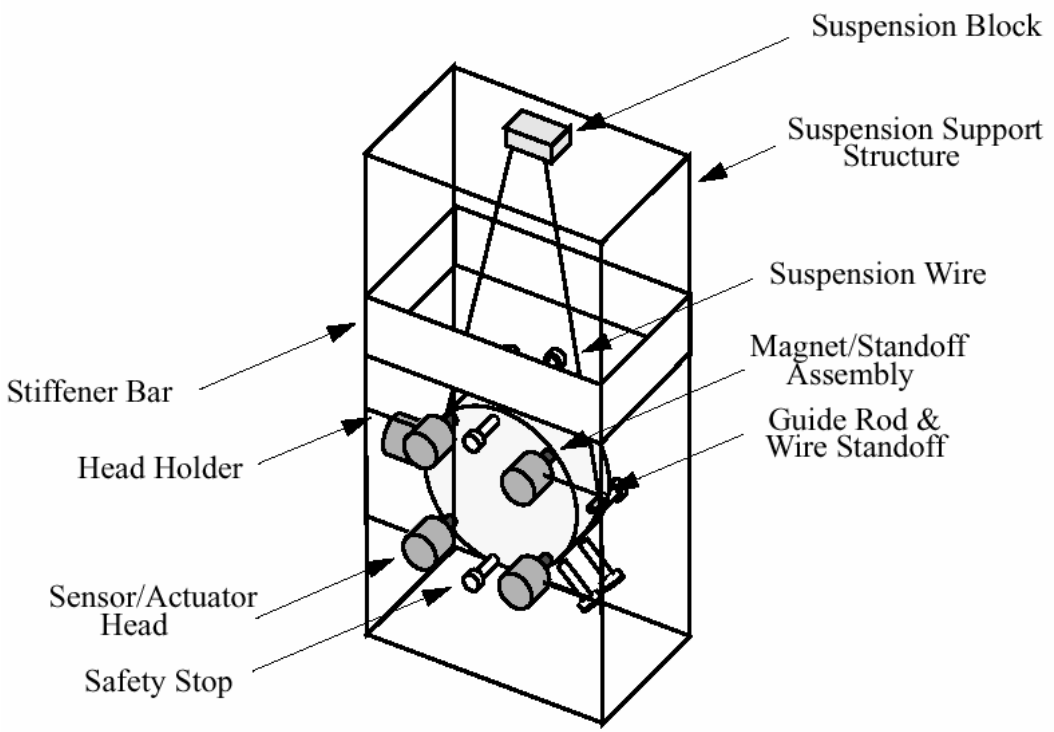
Problem: Surface Charge



- Surface charge may build up on test masses
  - » Friction with dust molecules
  - » Contact with conductors
  - » Cosmic rays
- Potential concerns
  - » Interferes with positioning magnets
  - » Fluctuating electric fields
  - » Dust attracted to optic

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What We Know/Don't Know

What we know:

- Optics experience drifts of ~10^5 e^-/cm^2/month, jumps of ~10^8
  - » 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:

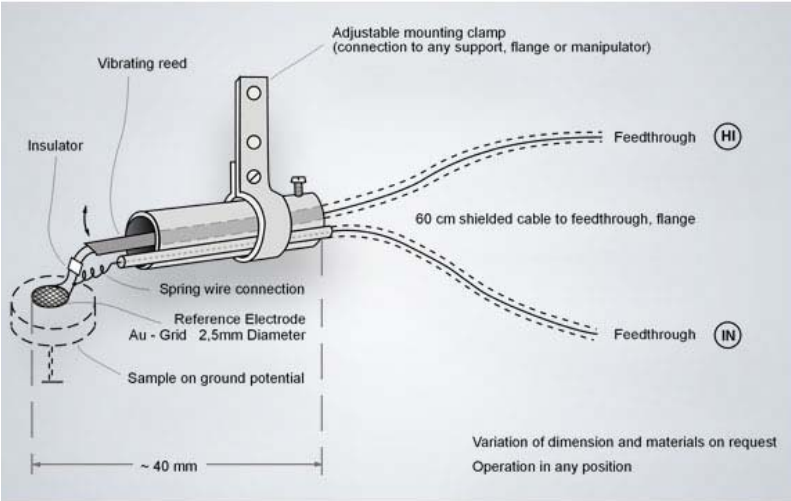
$$F^2(f) \approx \frac{2\langle F^2 \rangle}{\pi \tau_0 (2\pi f)^2}$$

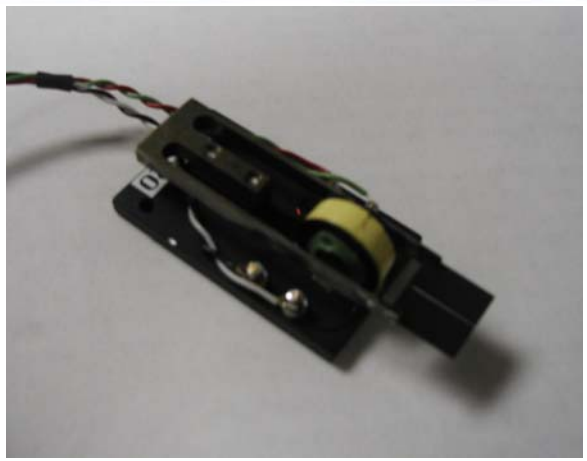
(R. Weiss, LIGO-T960137-00-E)

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

The Kelvin Probe

- We need a charge sensor that is small, vacuum-compatible, and inexpensive
- 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 chopper





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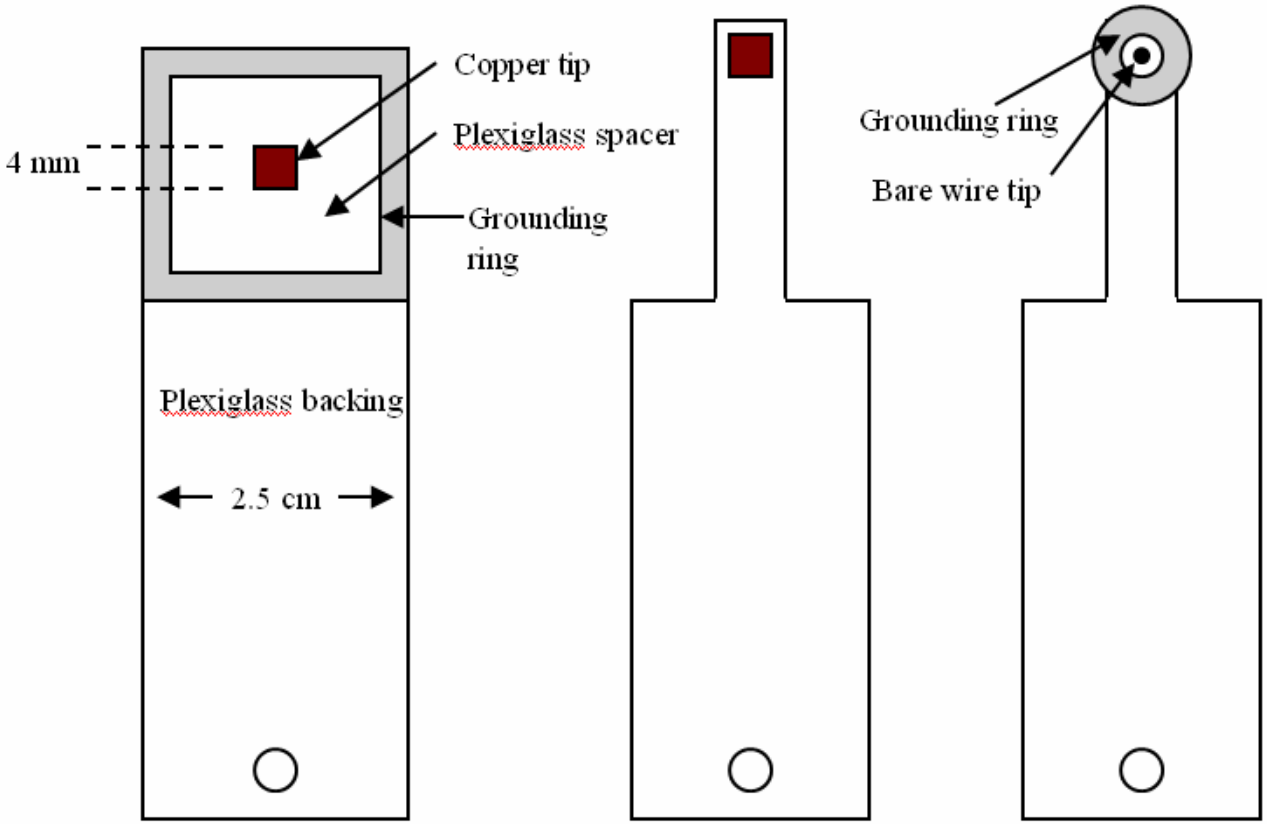
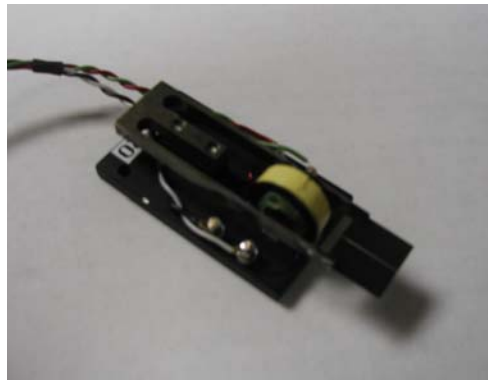
Probe Designs





First -- area around tip too wide, collides with chopper

Second– lots of noise without grounding ring

Final version

In-vacuum model

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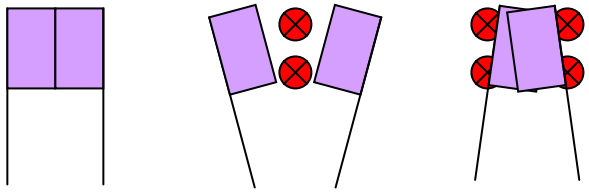
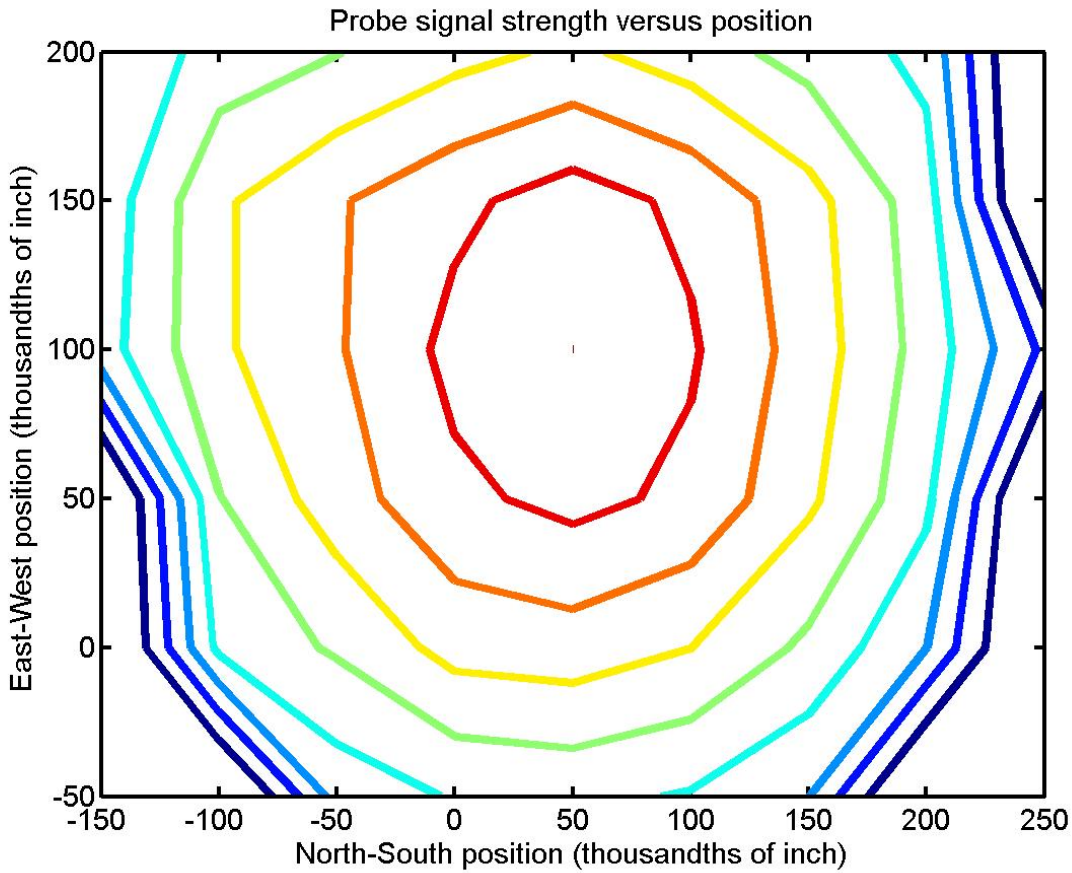
Readout Frequency



⊗ = field lines

Because the chopper has a 50% duty cycle, the signal is generated at twice the chopping frequency. This helps avoid noise from the chopper's current coil.



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Calibration

The probe is calibrated by comparing the readout for a plastic sample to the reading from a surface DC voltmeter, whose reading can be converted to a charge density.

The ~1 μV fluctuations in the probe signal correspond to a charge density of 3×10^5 e/cm^2.

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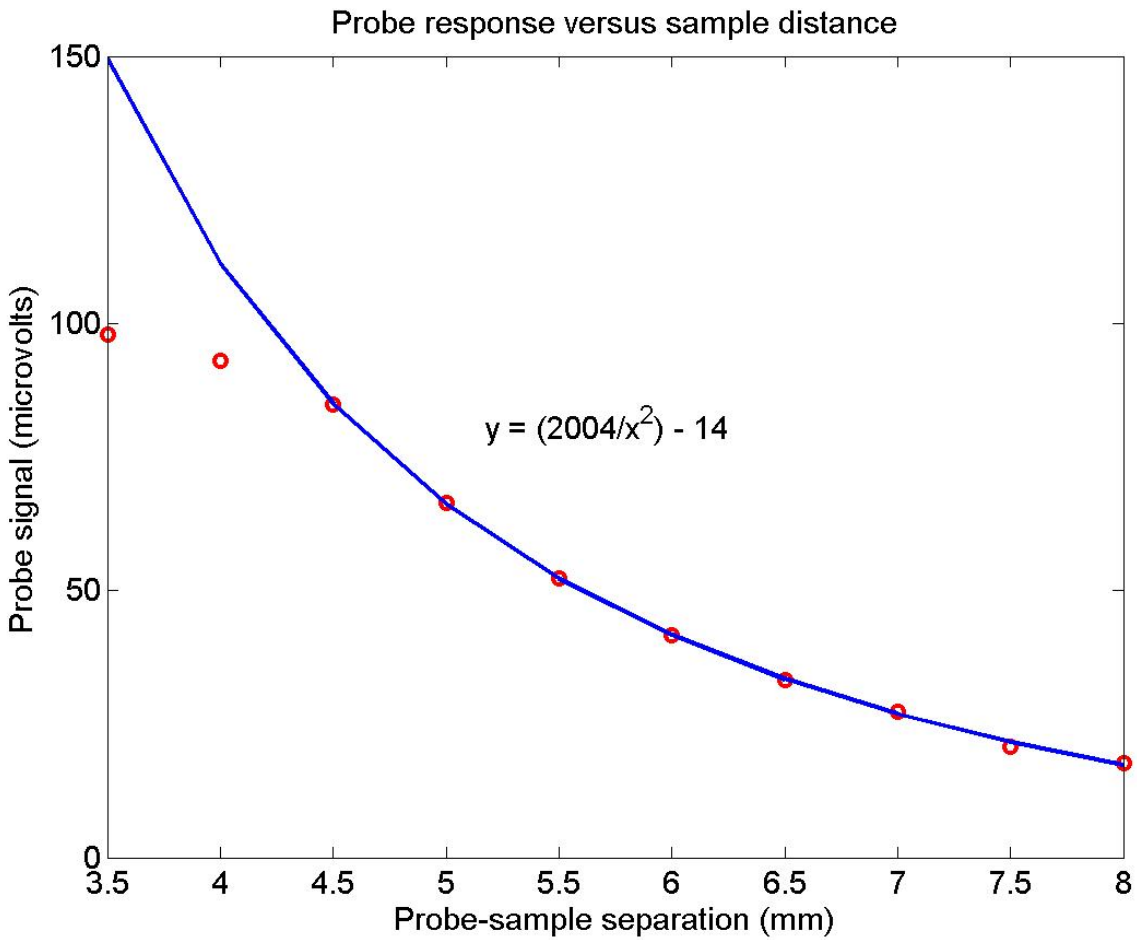
Signal vs. Distance

- Measured for metal sample at +15V
- Used rotary chopper
- Deviation from inverse square due to charge on chopper blade



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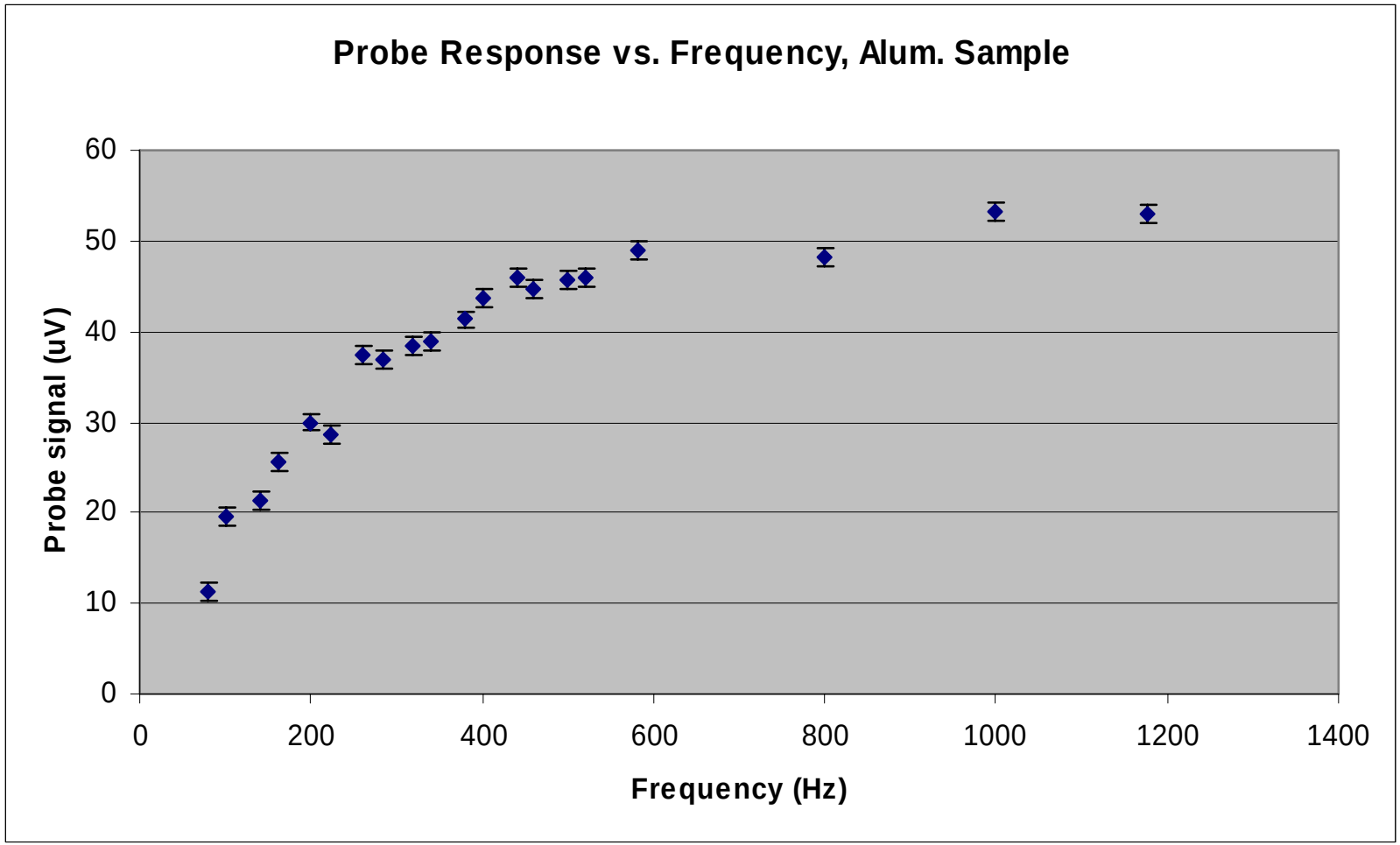
Frequency Response



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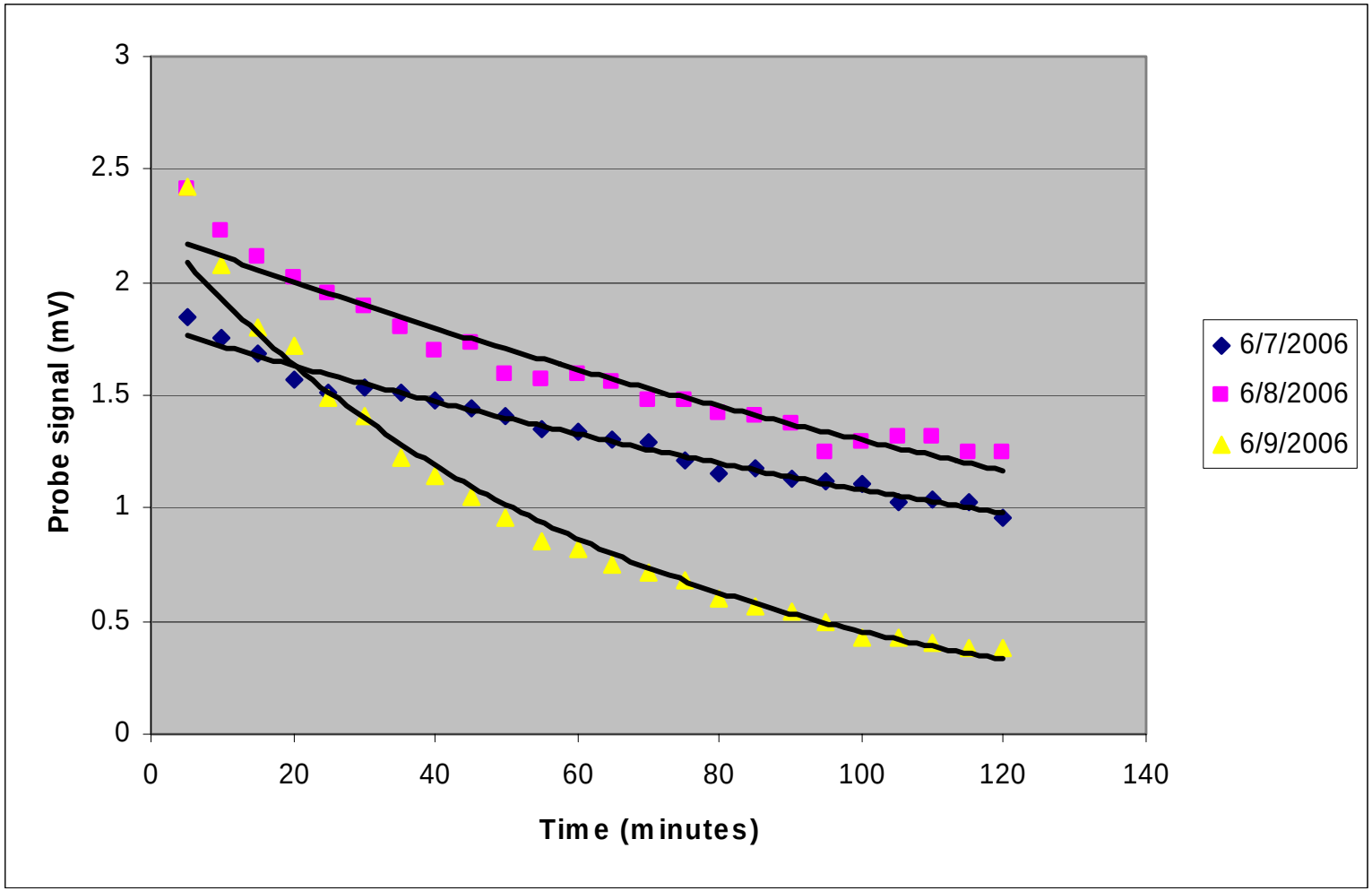
Charge Decay Over Time



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Future Work

- Move probe into ~10^{-5} torr vacuum chamber
- Measure charge buildup and time constant for optical material
- Measure variations for different coatings, cleaning methods, etc.