Improving the Performance of a Geophone through Capacitive Position Sensing and Feedback

Aaron Barzilai

Stanford University

Tom VanZandt, Steve Manion, Tom Pike

Jet Propulsion Laboratory

Tom Kenny

Stanford University

Abstract

- The seismological community would like an affordable, broadband seismometer.
- A geophone is an affordable seismometer used for high frequency measurements.
- **Modifying a geophone to sense proof mass position capacitively enables its use in low frequency applications.**
- A capacitive geophone requires feedback to maintain its high frequency capability.

Low Frequency Seismology

- The Earth acts as a low pass filter.
- Only the low frequency components of a seismic signal will travel great distances.
  - Information about the deep structure of the Earth can be obtained from studying low frequency signals.
  - Low frequency signals are used for studying global seismicity.

Commercial Seismometers

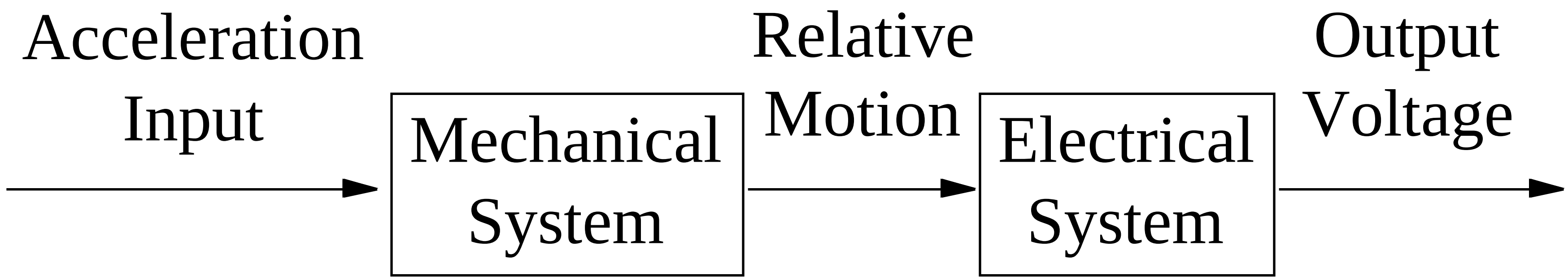
Type	Streckeisen	Guralp	Geophone
Bandwidth	8.33mHz-50Hz	33mHz-50Hz	4.5Hz-400 Hz
Resolution	0.01 ng/√Hz	1 ng/√Hz	1 ng/√Hz
Price	$20,000	$10,000	$50

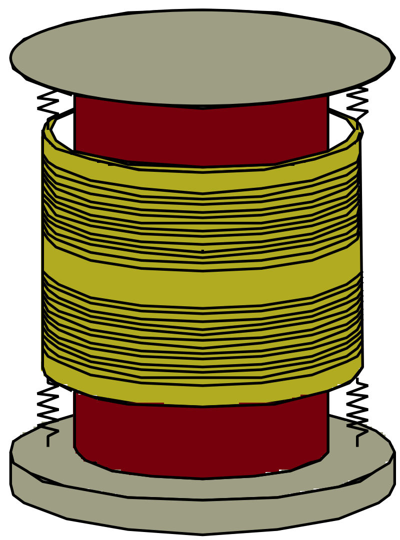
- A $500, 33mHz-50Hz seismometer with a resolution of 1 ng/√Hz would add another price-performance point to the currently available instrumentation options.

A New Broadband Seismometer: The Capacitive Geophone

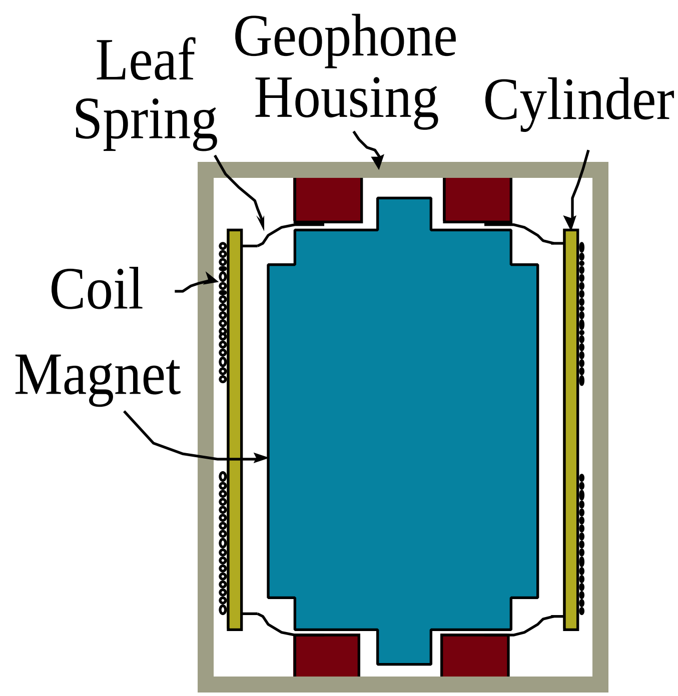
- The existing mechanical system of a geophone provides the basis of the seismometer.
- **Capacitively** measuring coil **displacement** yields excellent low frequency sensitivity and resolution.
- A capacitive geophone can be made for under $200.

Conventional Geophone



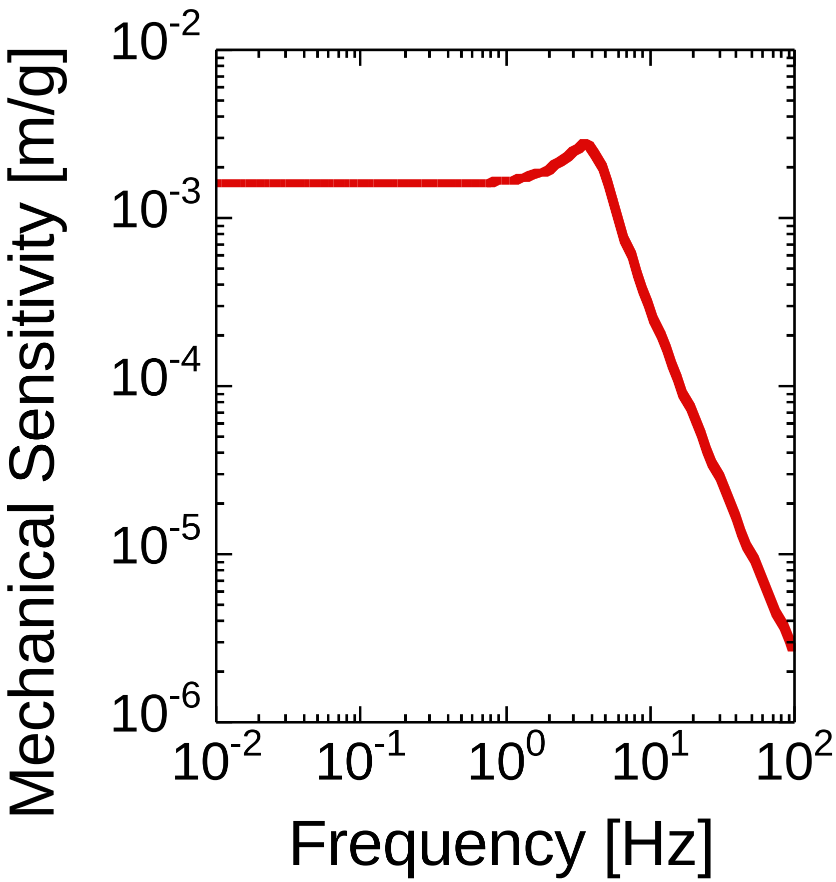


Schematic



Cross-section

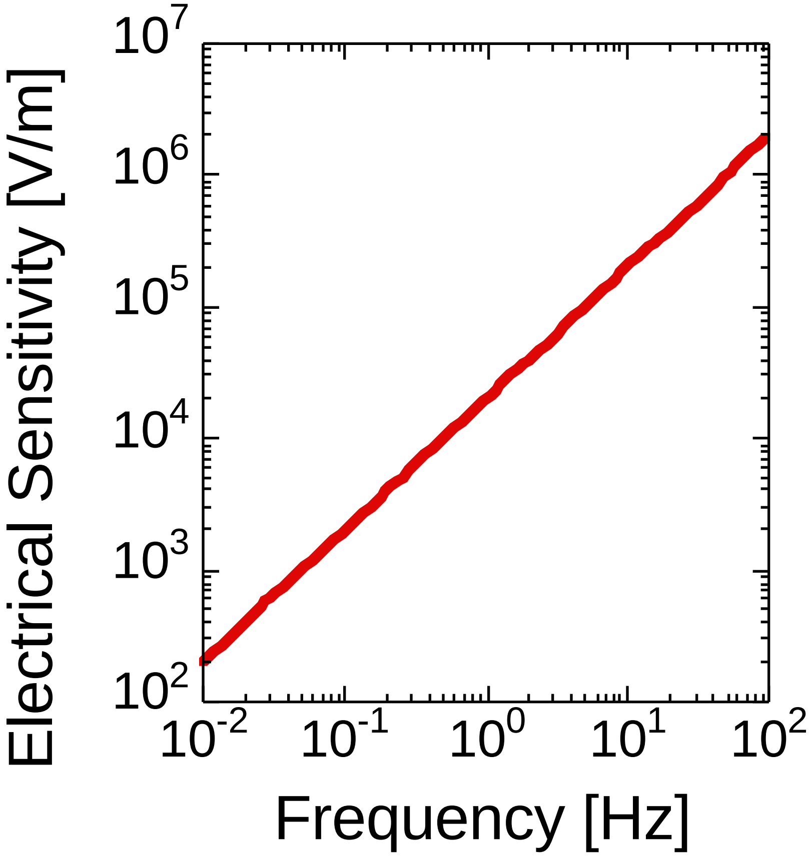
Mechanical Sensitivity



- Acceleration Causes Relative Motion Between the Coil and the Housing

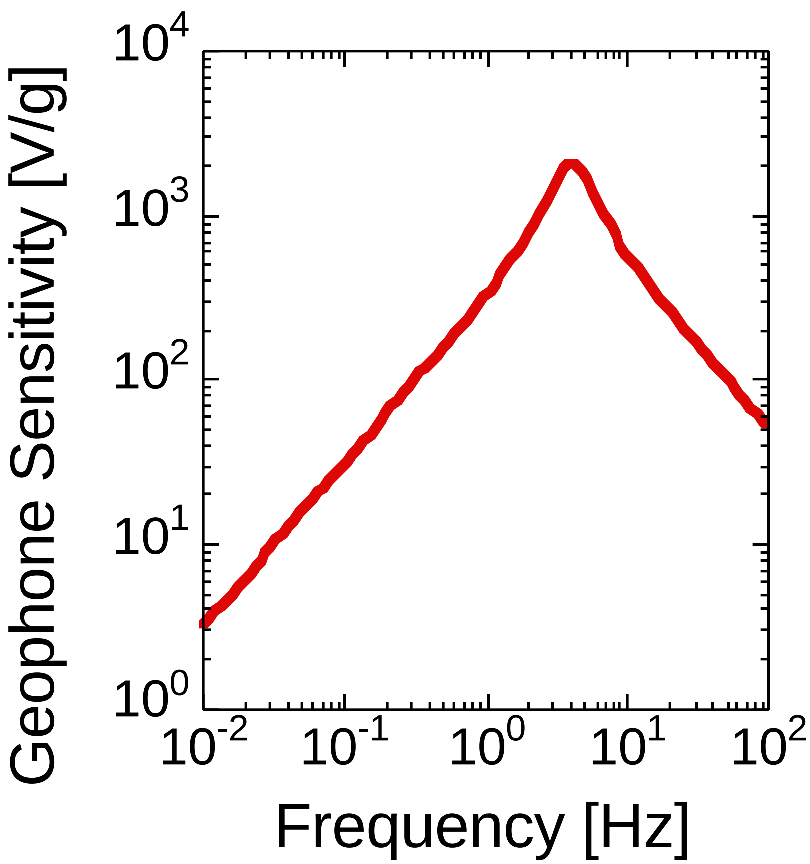
- Constant Sensitivity Below the Resonant Frequency

Electrical Sensitivity



- **Inductively** Measure Motion of the Coil Relative to the Magnetic Field
- Output Voltage Proportional to the Proof Mass **Velocity**

Total Sensitivity

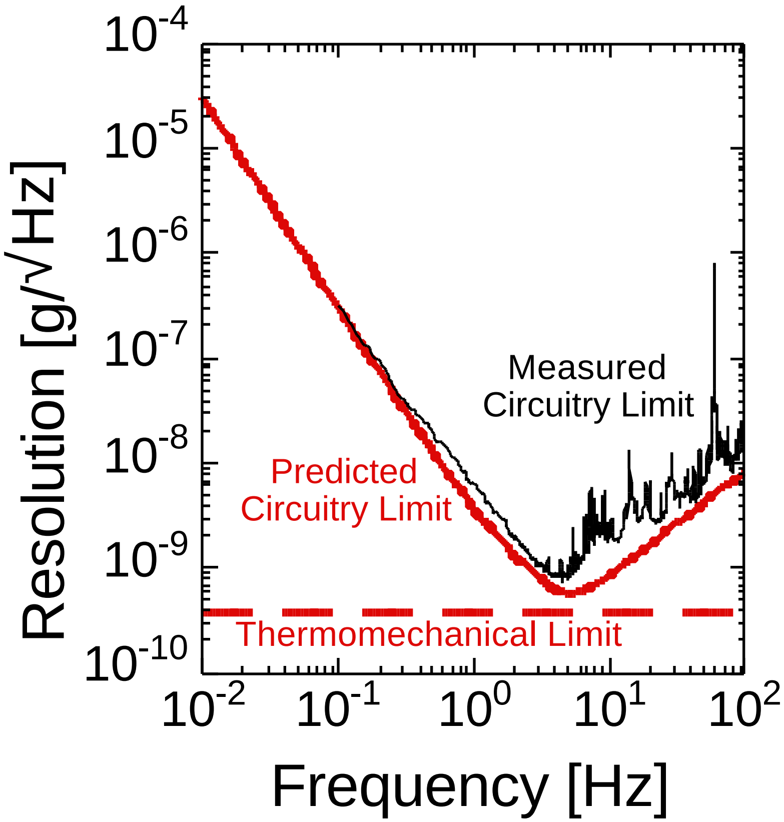


- At Low Frequency, Measurement of Proof Mass **Velocity** Reduces Sensitivity

- At High Frequency, Mechanical System Reduces Sensitivity

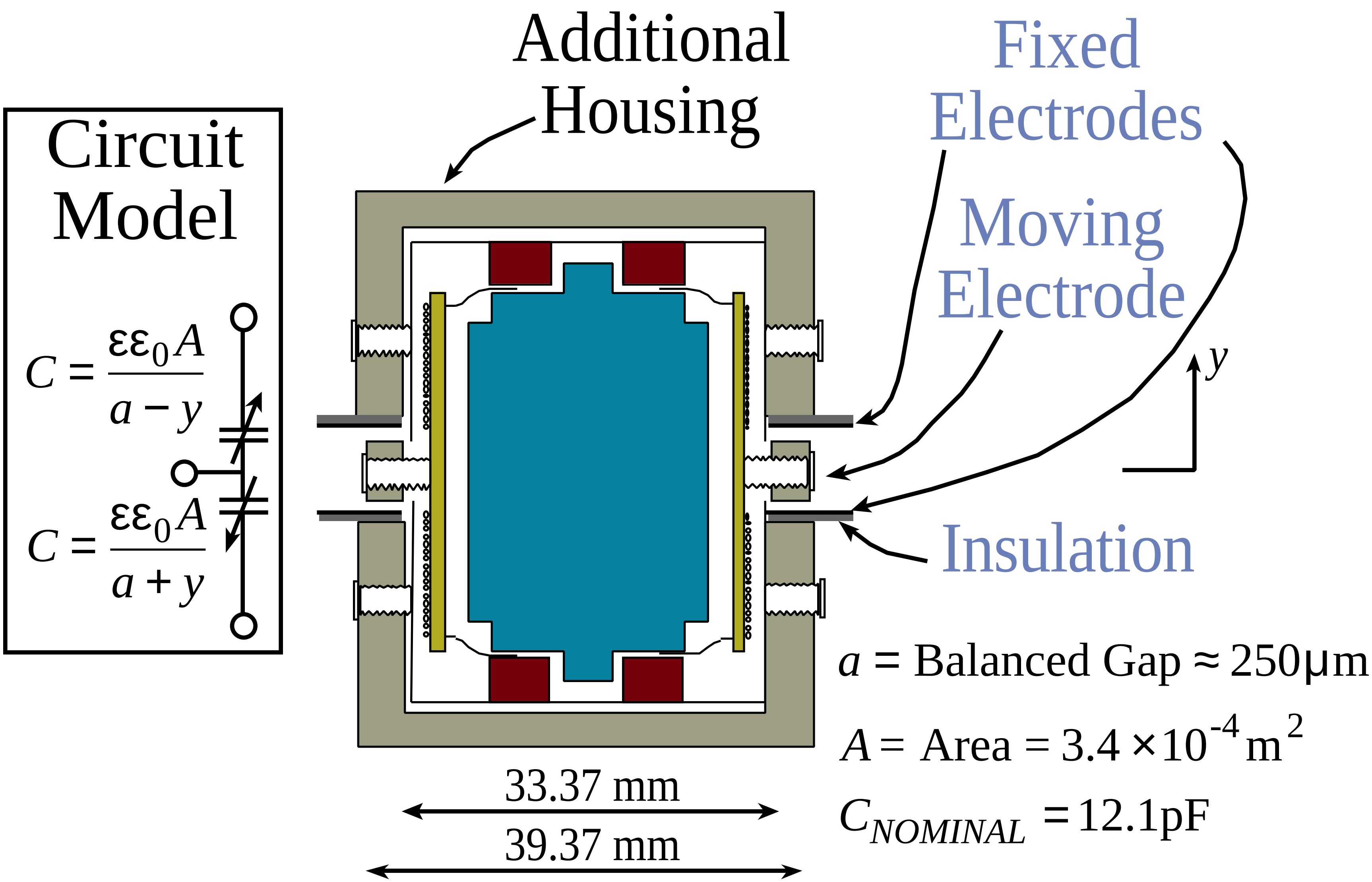
Conventional Geophone Resolution

$$\text{Resolution}\left[\frac{g}{\sqrt{\text{Hz}}}\right] = \frac{\text{Noise}\left[\frac{V}{\sqrt{\text{Hz}}}\right]}{\text{Sensitivity}\left[\frac{V}{g}\right]}$$



- **Poor resolution at low frequency** is caused by reduced sensitivity.

Capacitive Hardware

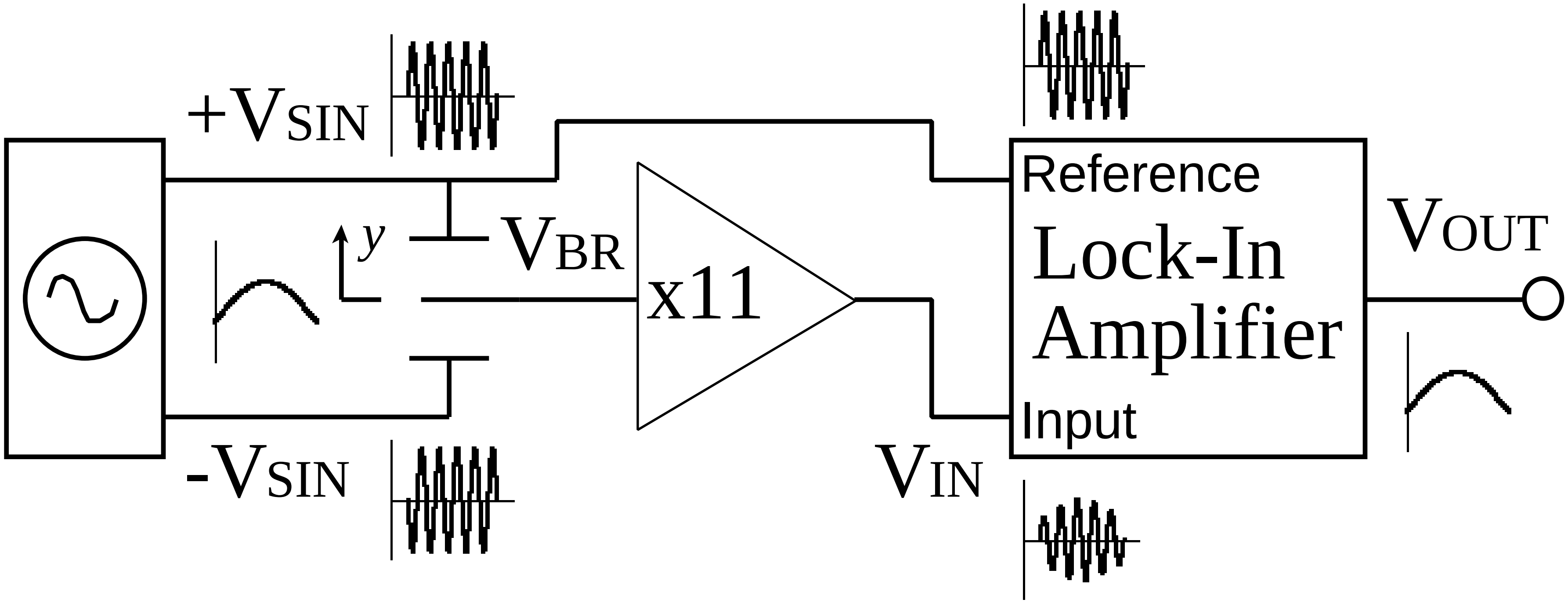


a = Balanced Gap ≈ 250μm

A = Area = $3.4 \times 10^{-4}\,m^2$

$C_{NOMINAL} = 12.1pF$

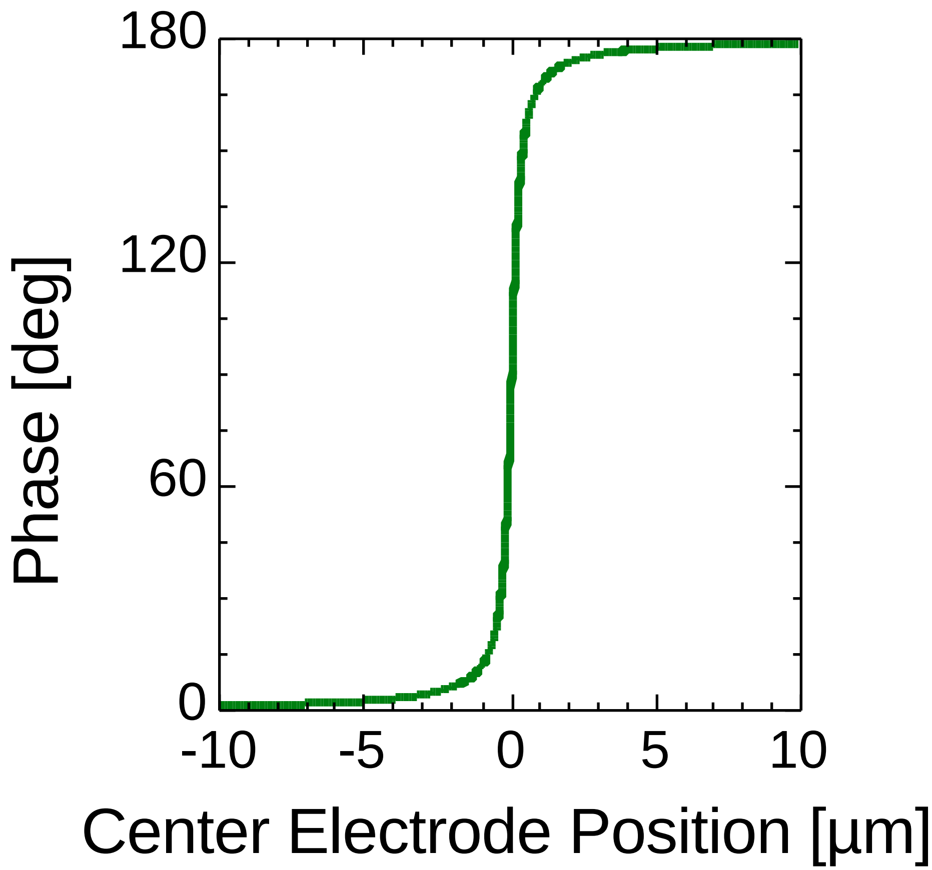
Capacitive Electrical System



- V_{BR} is a sine wave at the drive frequency with amplitude and phase modulated by *y*.
- A Lock-In Amplifier demodulates V_{BR} and outputs the amplitude and phase of the signal.

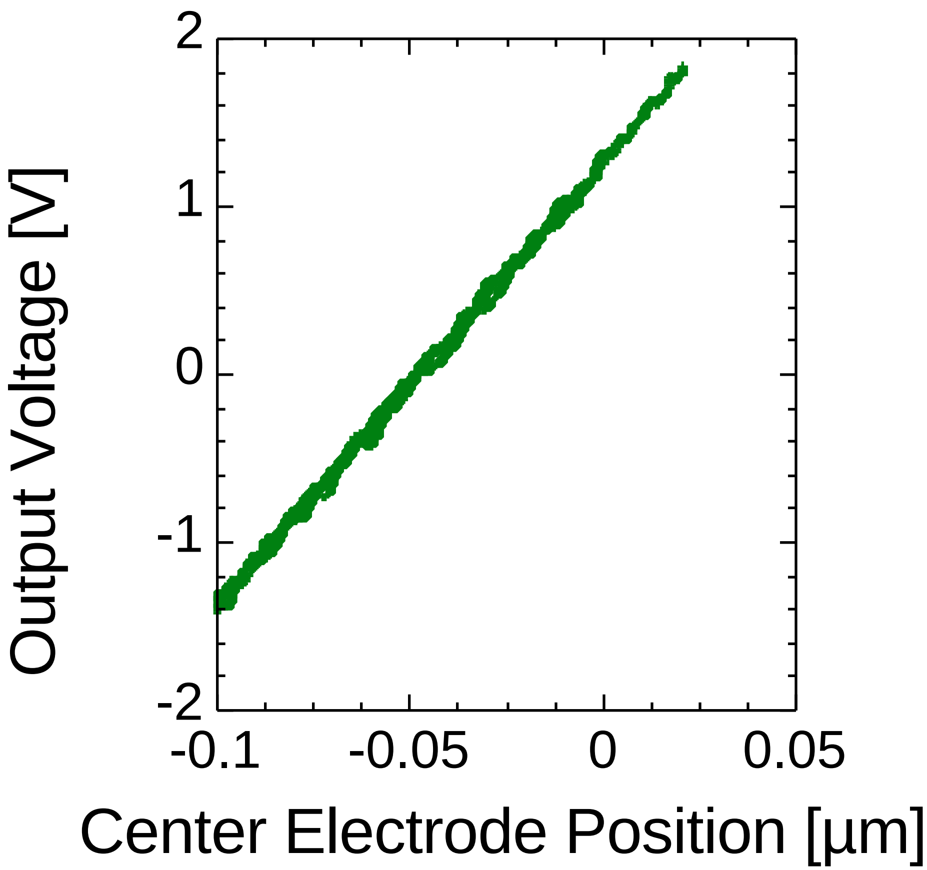
Phase Proportional to Position

Predicted

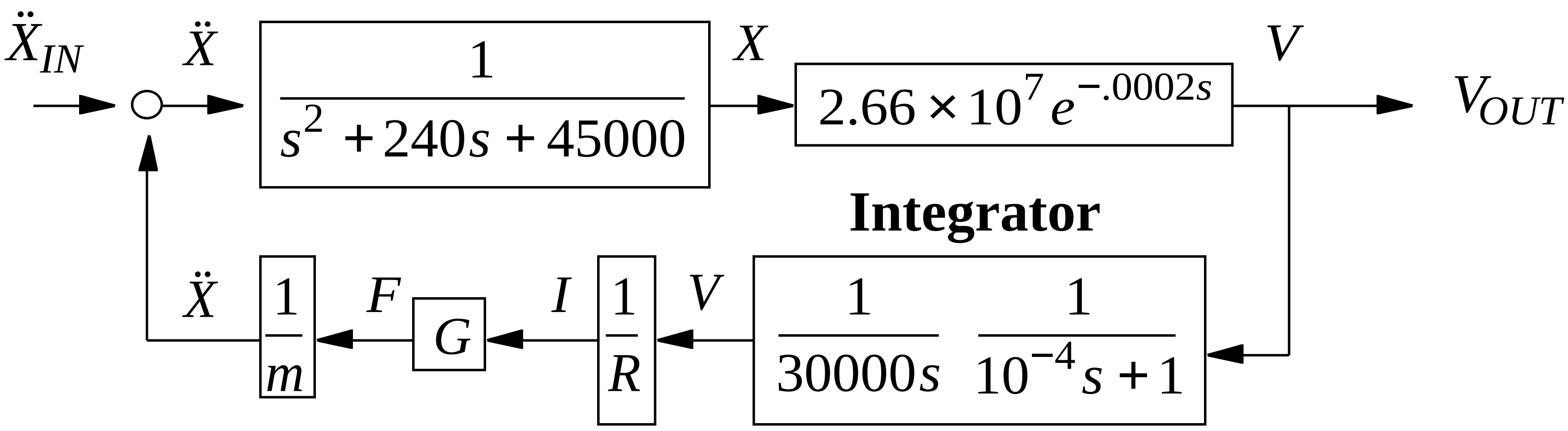


Measured

Sensitivity = 2.66×10^{7} V/m

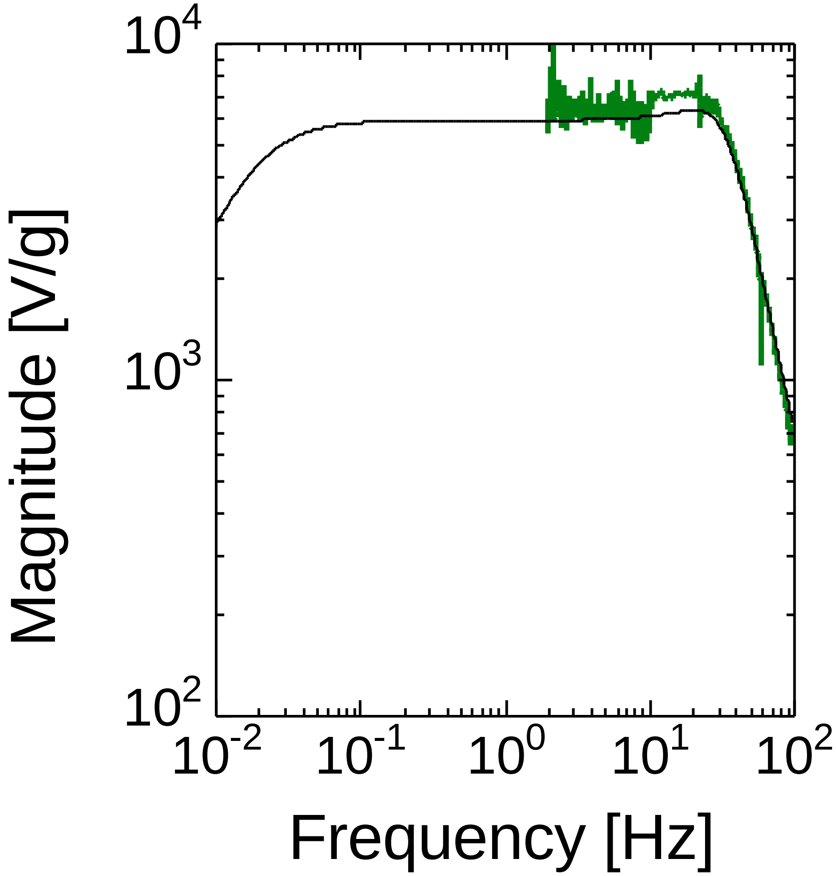


Operate with Integral Feedback



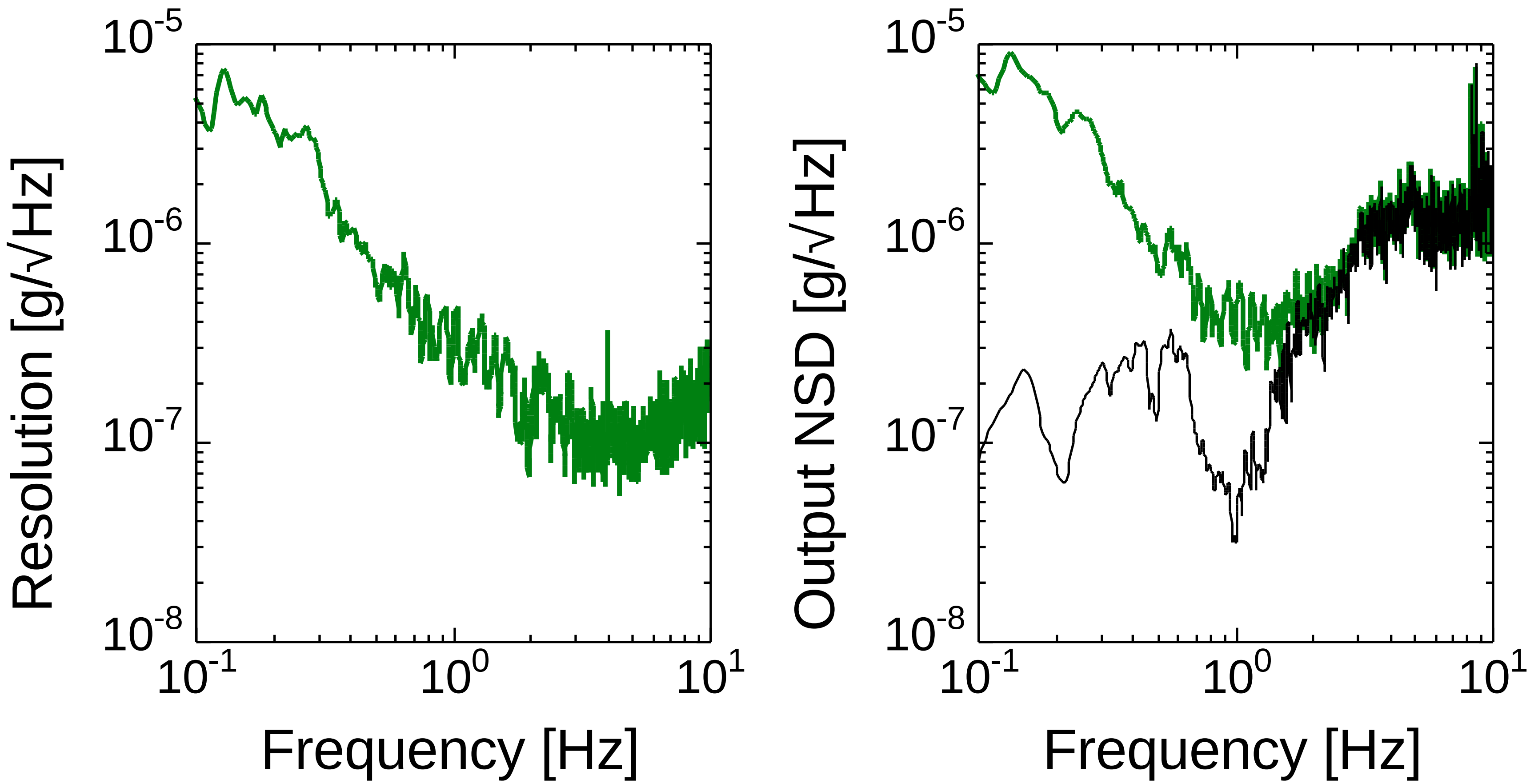
- Integral feedback applies forces at frequencies below the range of interest to keep the coil centered and the gaps balanced.

Sensitivity with Integral Feedback



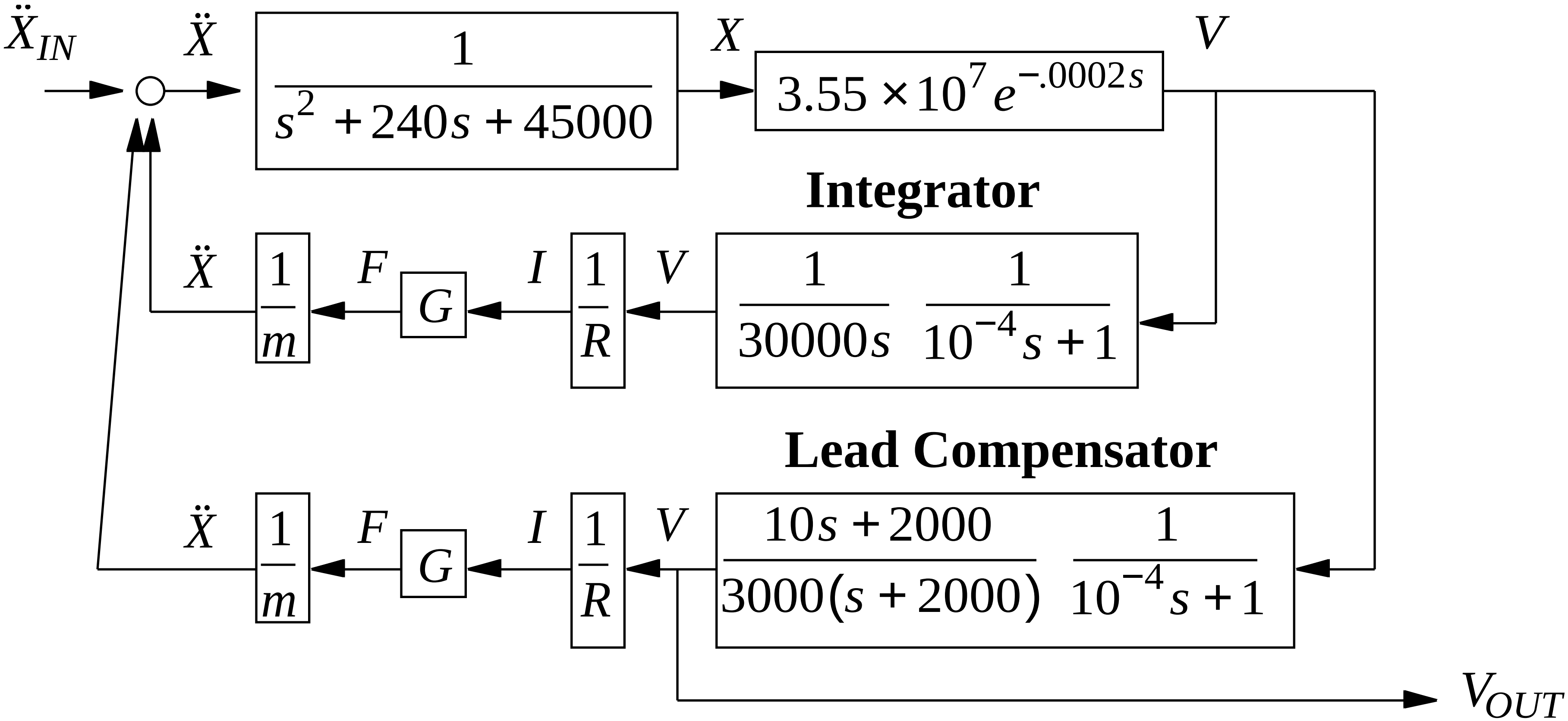
- **Constant Sensitivity At Low Frequency** since Output is Proportional to Proof Mass **Displacement**
- Attenuation at very Low Frequencies caused by Integral Control

Capacitive Geophone Resolution



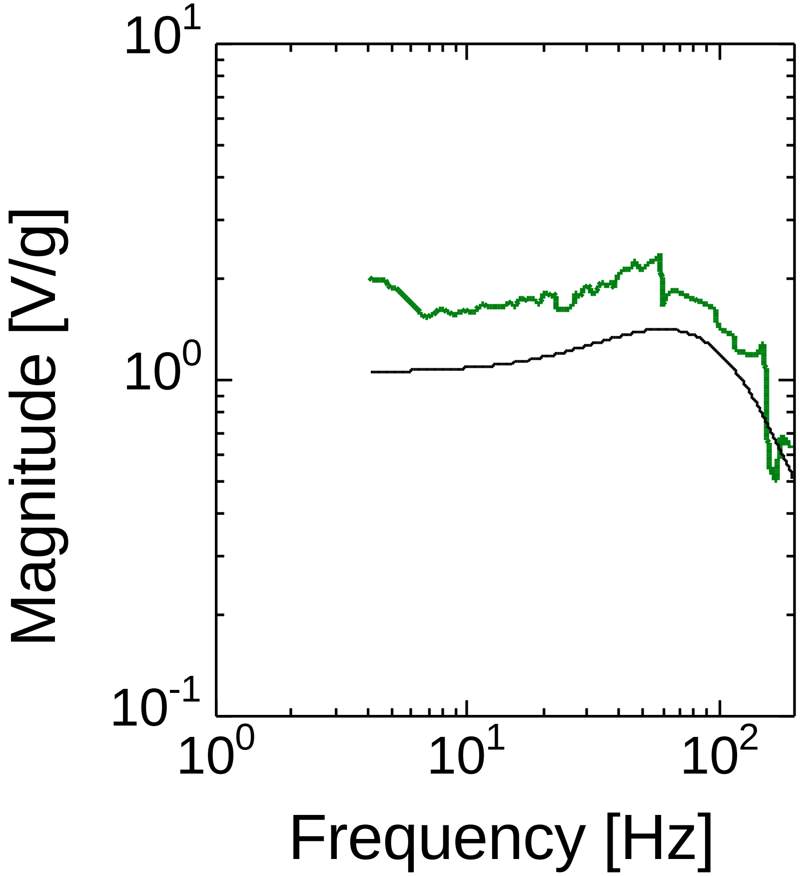
- The resolution is currently worse than target.
- The likely cause is noise in the biasing circuitry.

Add Lead Compensator



- The outer loop extends the bandwidth beyond the mechanical resonant frequency.

Closed Loop Sensitivity



- The bandwidth has been extended to 100 Hz.
- Discrepancies are based at 60 Hz and 180 Hz

Conclusions

- Modifying a geophone into a capacitive sensor leads to an affordable, broadband seismometer.
- A capacitive geophone has been fabricated based on a 40 Hz geophone.
- Current results are promising, but more testing needs to be performed.
- Future goals include obtaining resolution at the fundamental limits, implementing the modifications on a 4.5 Hz geophone, and measuring phase without a Lock-In amplifier.

Acknowledgments

- Marcos Alvarez at PASSCAL
- Center for Space Microelectronics Technology,
  Jet Propulsion Laboratory,
  California Institute of Technology
- NASA Office of Space Access and Technology
- NSF Career Award ECS-9502046
- Charles Lee Powell Foundation
- Terman Fellowship