

# **An Affordable Broadband Seismometer: The Capacitive Geophone**

## **Poster F1**

<http://micromachine.stanford.edu/smssl/projects/Geophones/SSA99PosterFinal.pdf>

Aaron Barzilai<sup>1</sup>, Tom VanZandt<sup>2</sup>,  
Tom Pike<sup>2</sup>, Steve Manion<sup>2</sup>,  
Tom Kenny<sup>1</sup>

<sup>1</sup>Dept. of Mechanical Engineering  
Stanford University

<sup>2</sup>Center for Space Microelectronics Technology  
Jet Propulsion Laboratory

*Contact: [barzilai@leland.stanford.edu](mailto:barzilai@leland.stanford.edu)*

# Acknowledgements

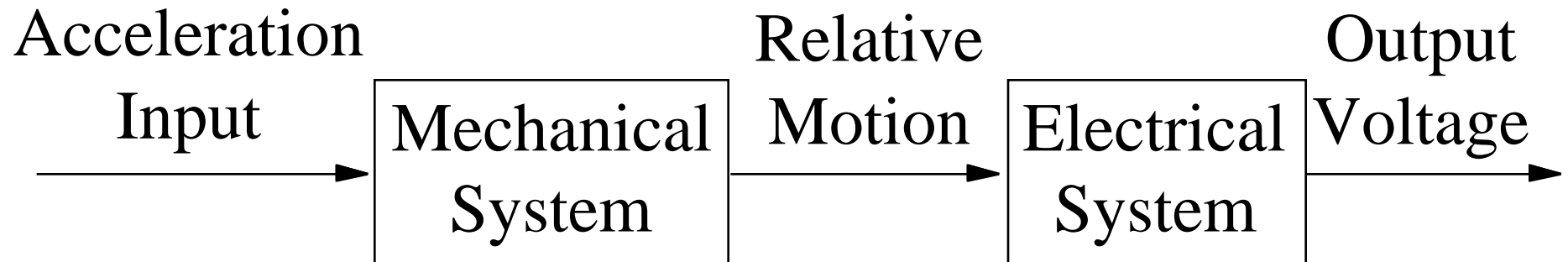
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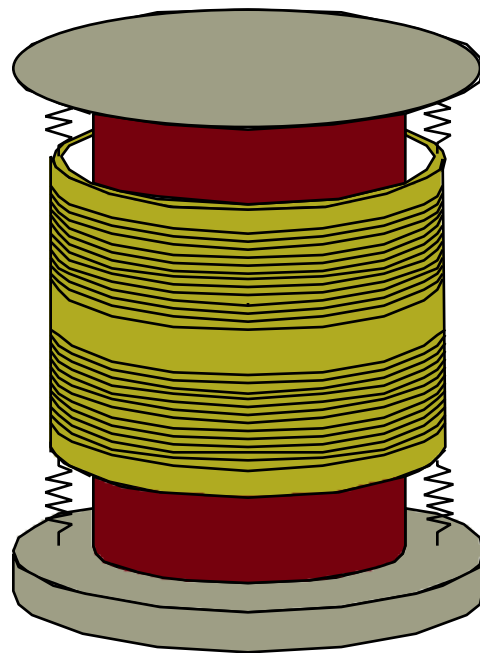
# Objective

- Develop an Affordable, Robust Broadband Seismometer
- Enhance the Ability of Seismometer Arrays to Detect Low Frequency Signals

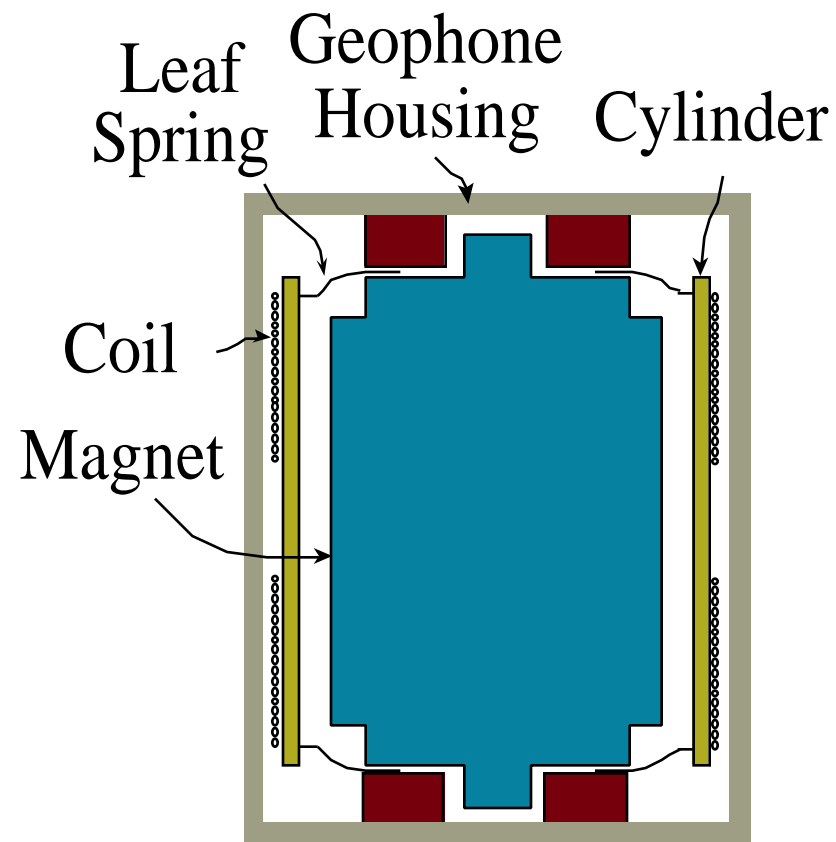
# Seismometer Information Flow



# A Conventional Geophone: OYO Geospace 4.5 Hz GS-11D

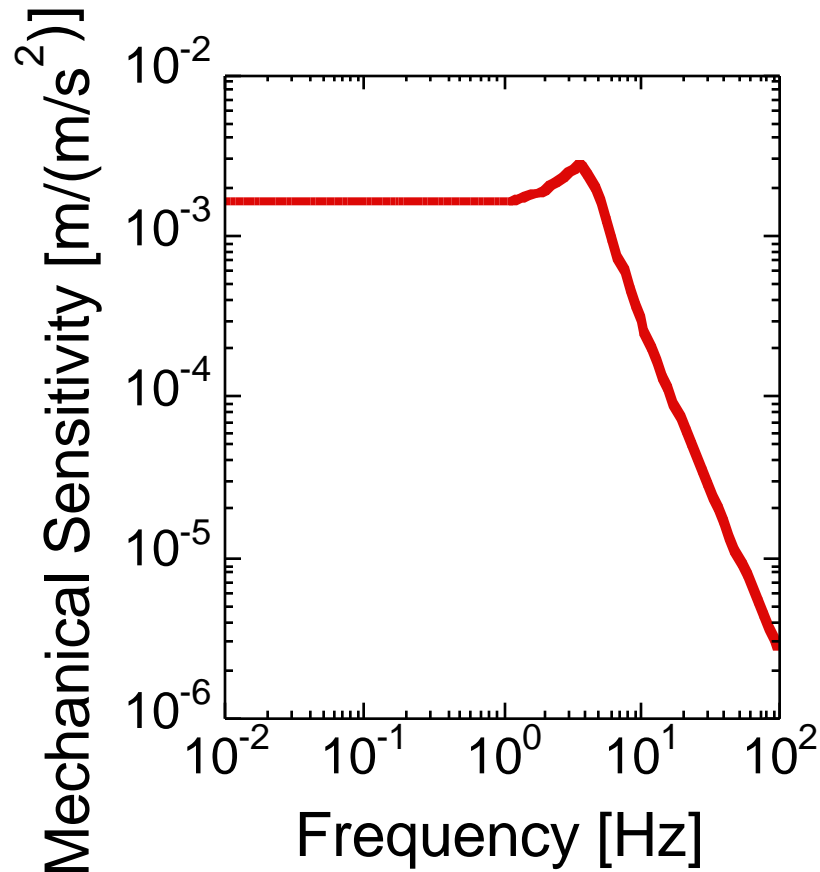


Schematic



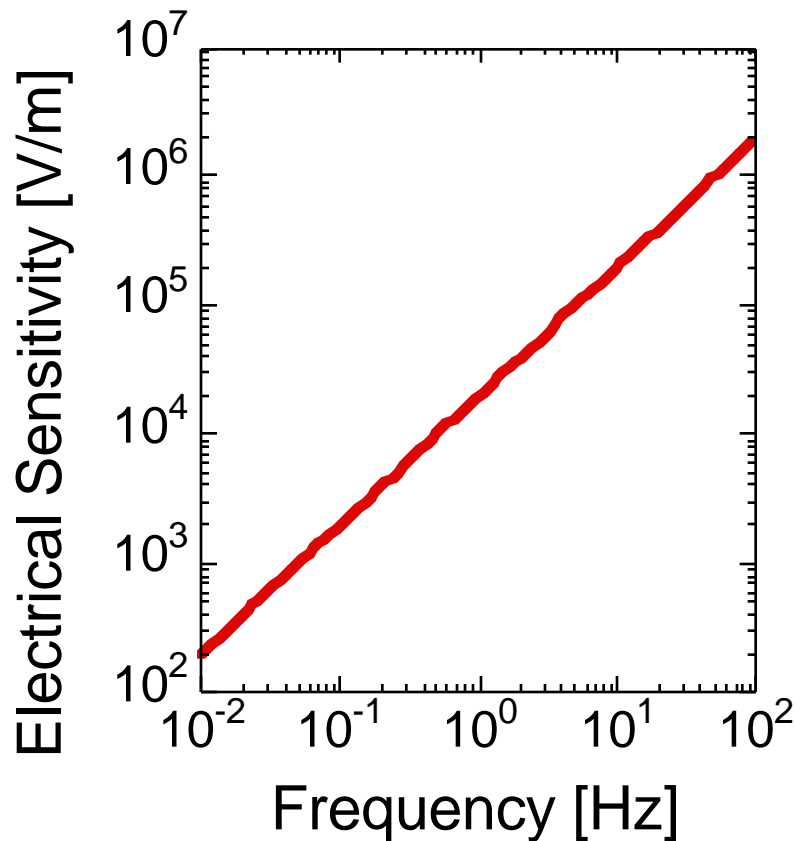
Cross-section

# Mechanical Sensitivity



- Acceleration Causes Relative Motion Between the Coil and the Housing
- Constant Sensitivity Below the Resonant Frequency

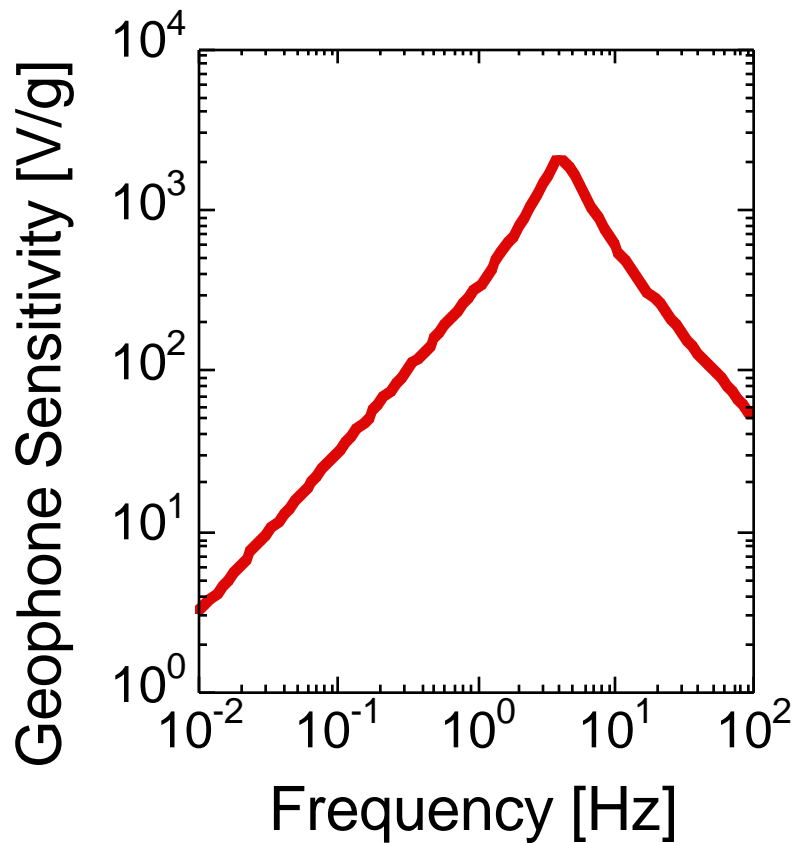
# Electrical Sensitivity



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



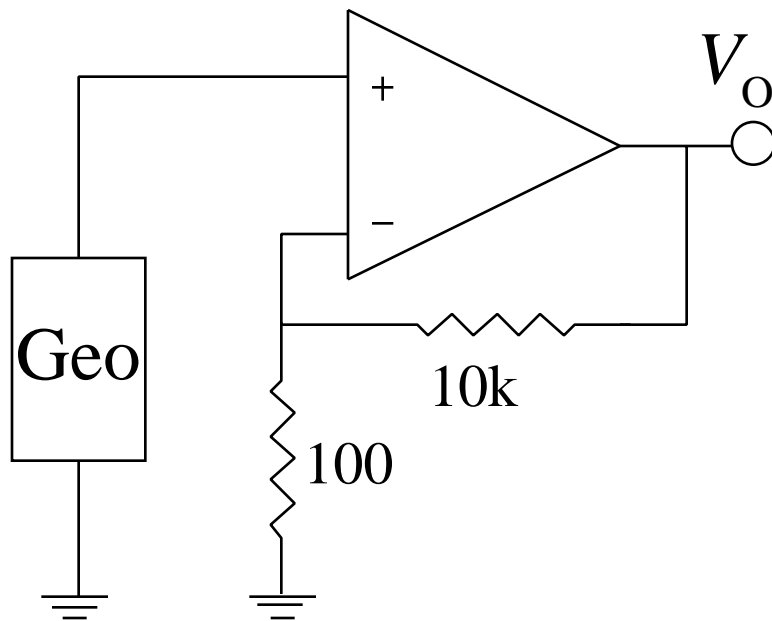
# Total Sensitivity



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

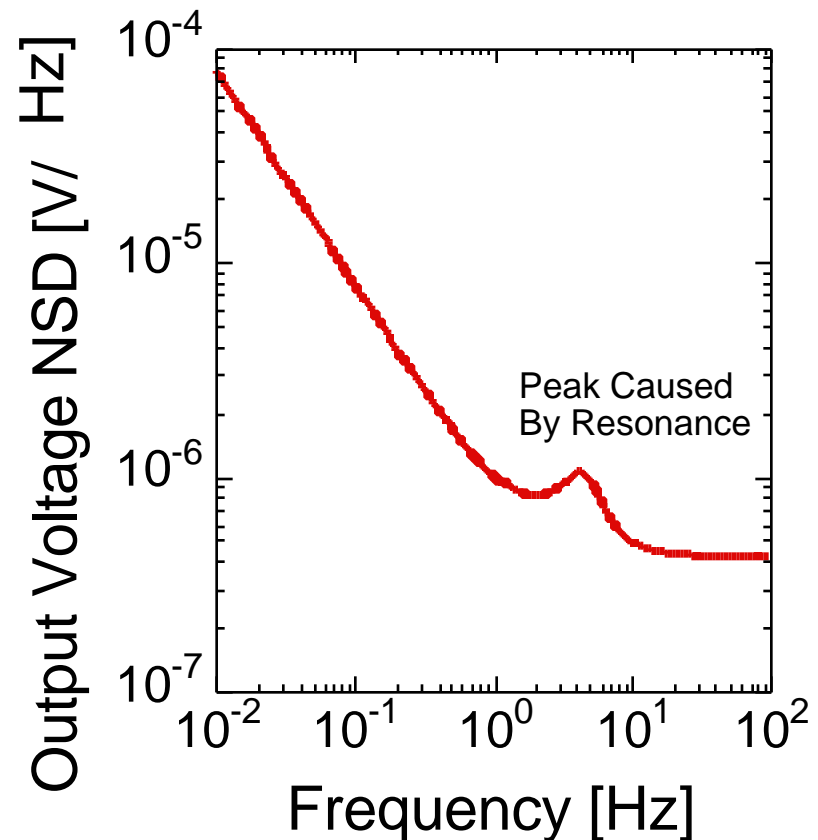
# Circuitry Noise

## Typical Circuit



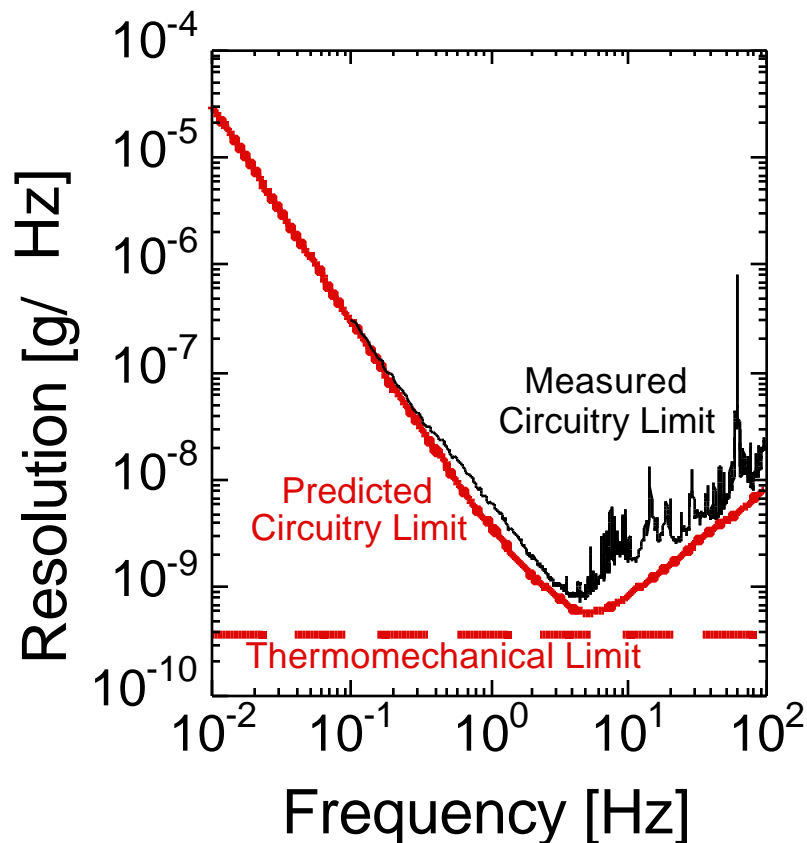
100x Amplifier

## Output Voltage Noise Spectral Density



# Conventional Geophone Resolution

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



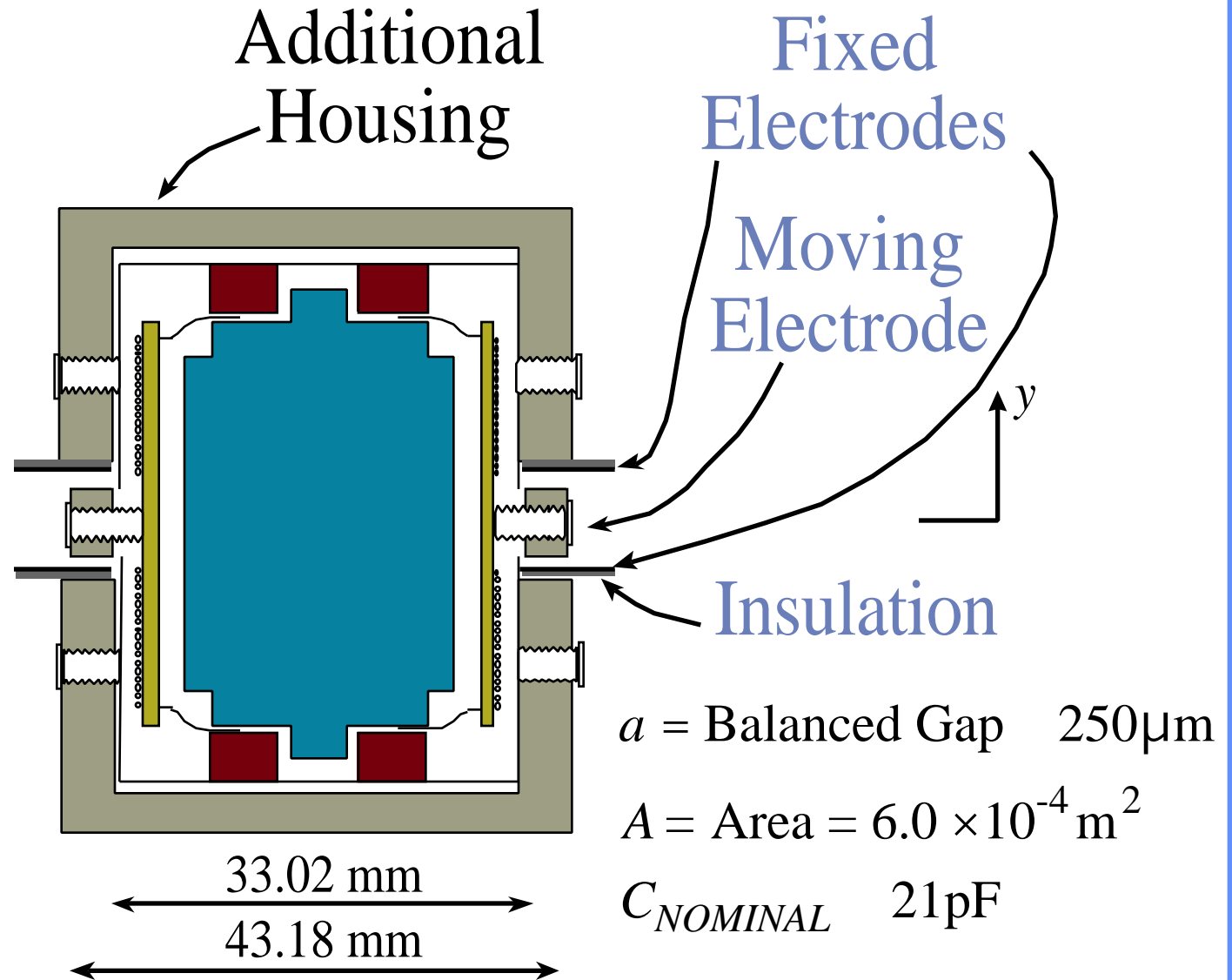
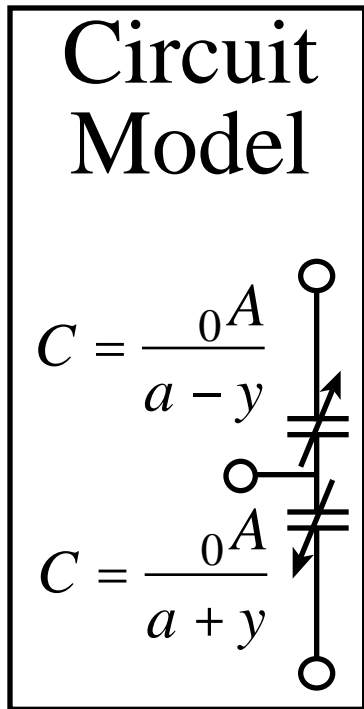
- **Poor Resolution at Low Frequency**  
Exacerbated by  
Reduced Sensitivity
- Resolution not at  
Thermomechanical  
Limit

Barzilai et al., "Technique for Measurement of the Noise of a Sensor in the Presence of Large Background Signals," Rev. Sci. Instrum., July 1998, Vol. 69, Num. 7, pp. 2767-2772

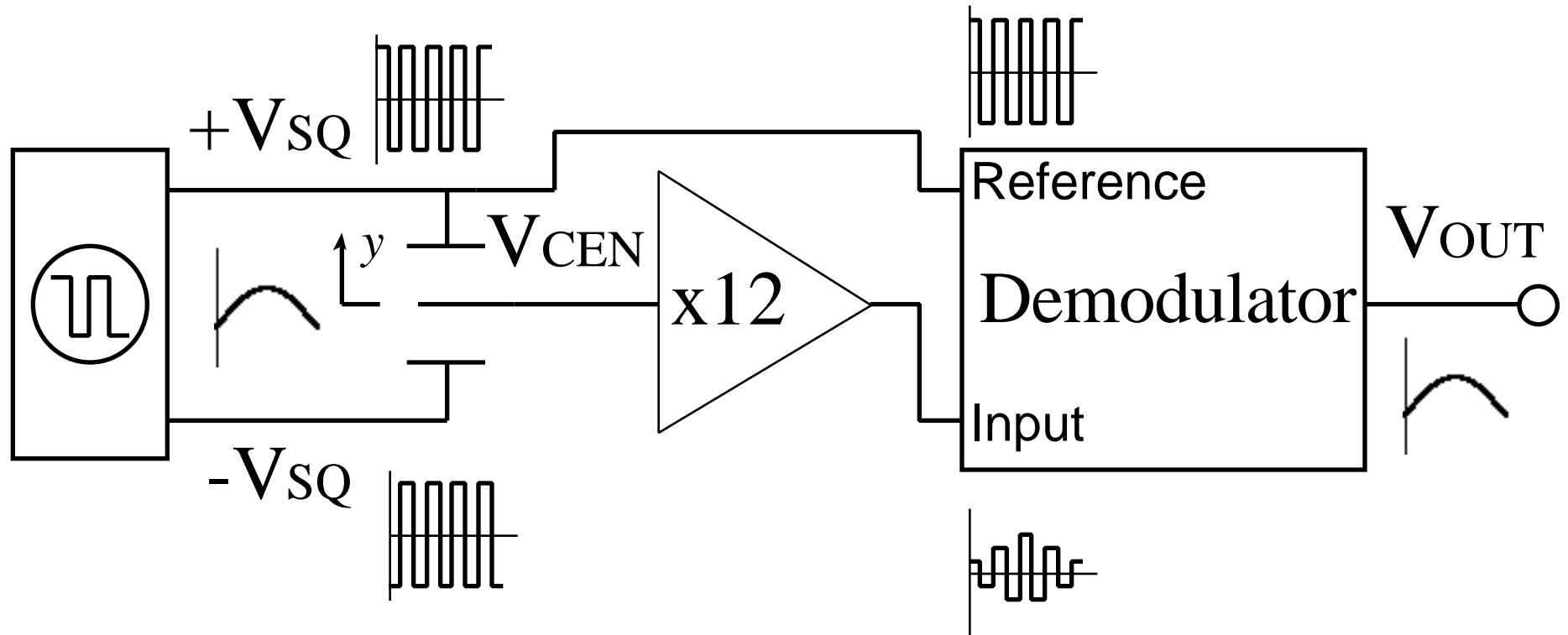
# An Improved Seismometer: A Capacitive Geophone

- Use a Commercial, Off The Shelf Geophone as the Mechanical System
- Improve Low Frequency Sensitivity by **Capacitively** Measuring Proof Mass **Displacement** with only Simple, External Modifications

# Capacitive Hardware



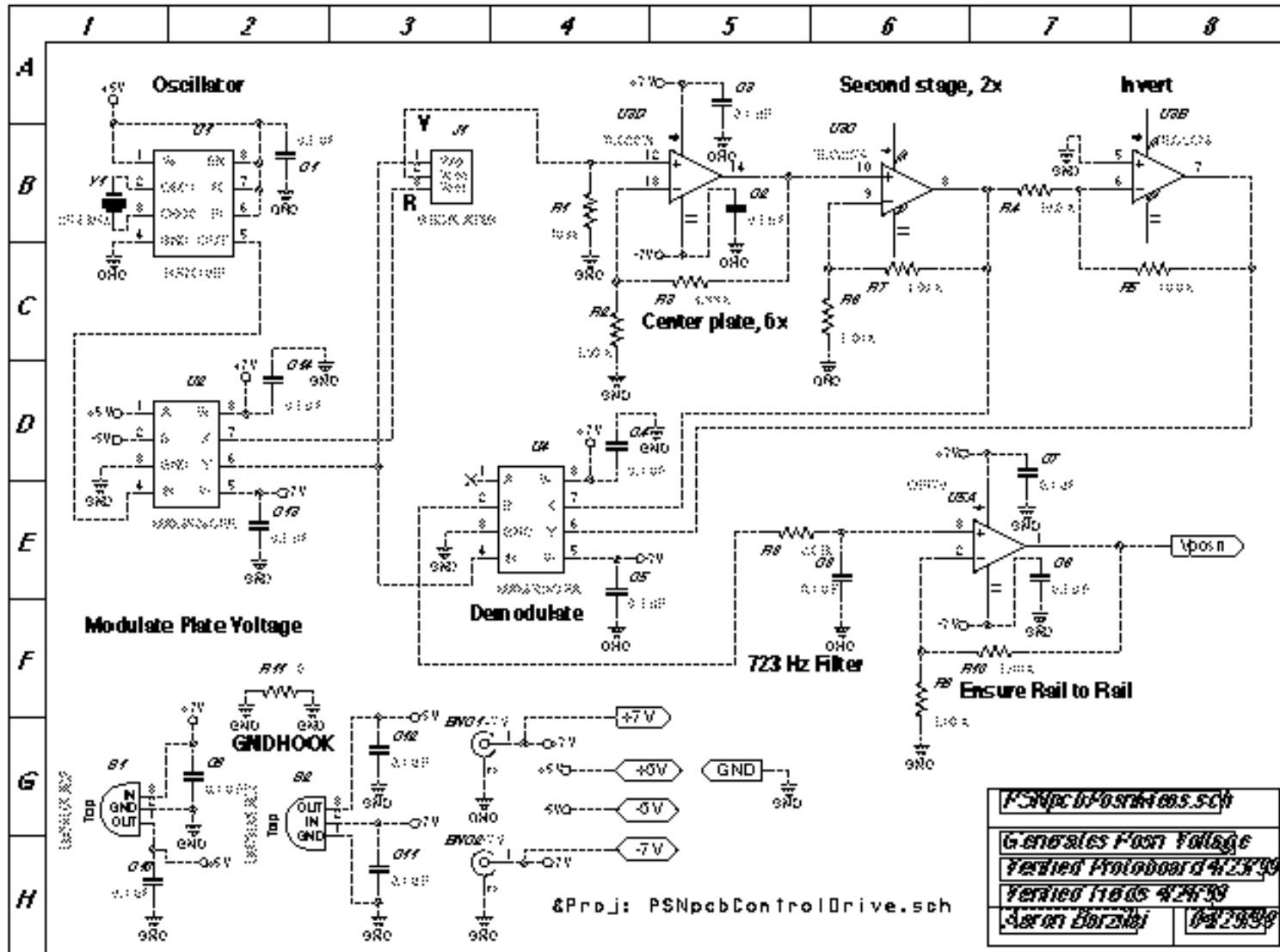
# Electrical System Overview



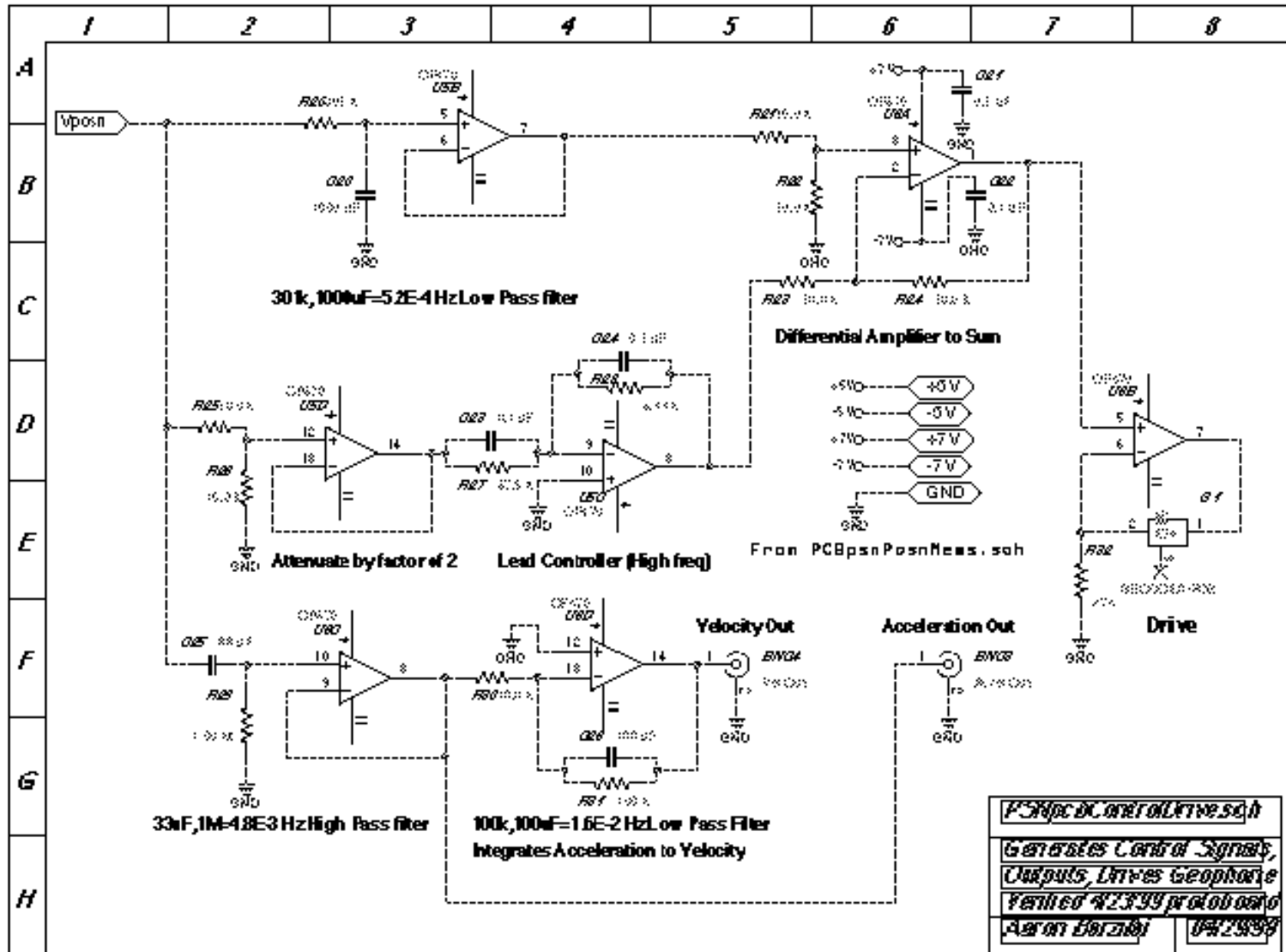
$V_{CEN}$  is a Square Wave at the Same Frequency as  $V_{SQ}$  with Amplitude Modulated by  $y$ .

$V_{CEN}$  is Demodulated to Produce an Output that is Proportional to the **Displacement** of the Proof Mass.

# Full Circuit Diagram Part I

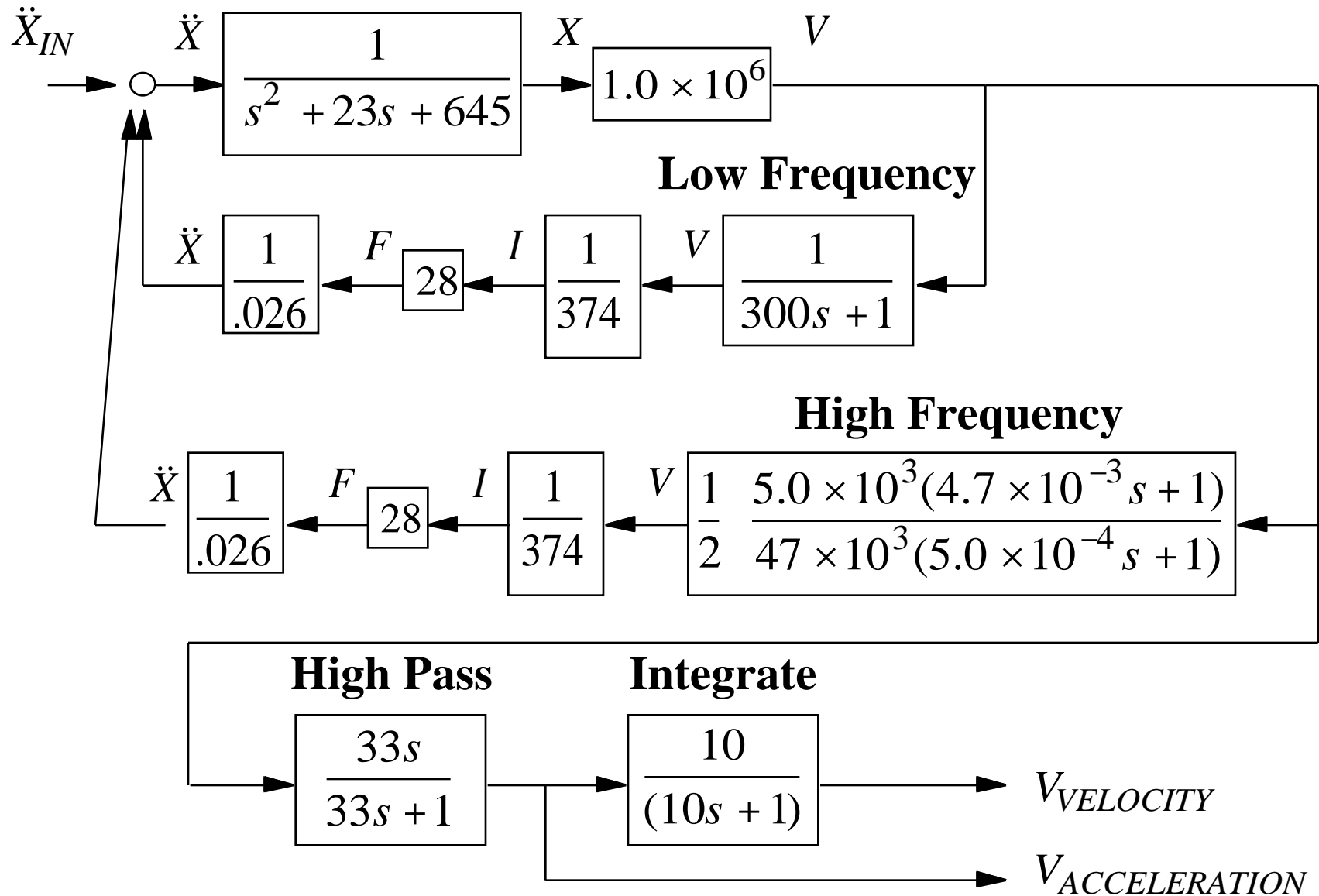


# Full Circuit Diagram Part II

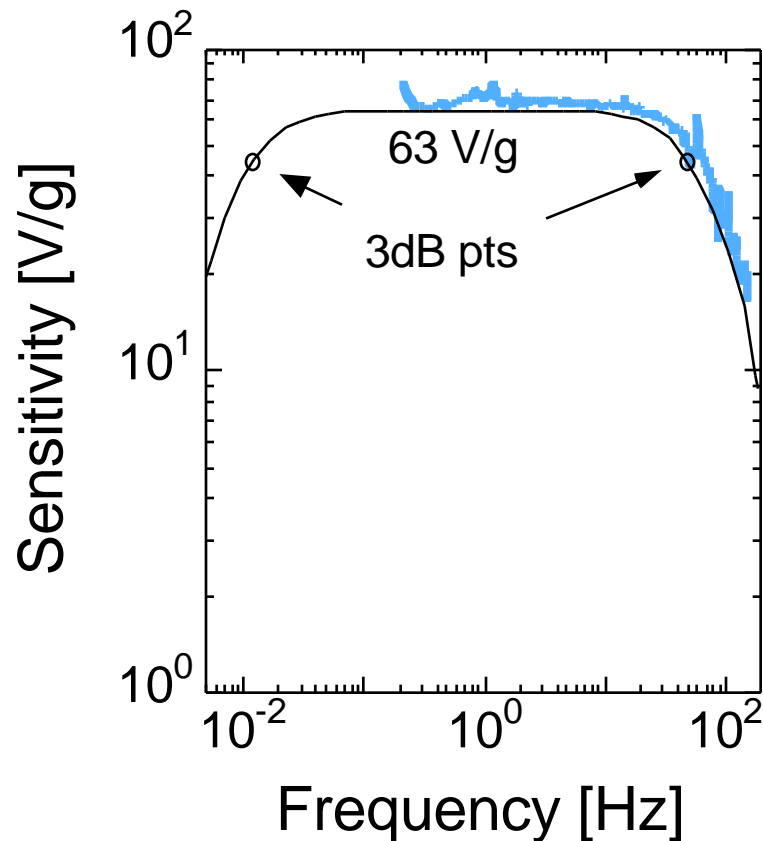




# Block Diagram

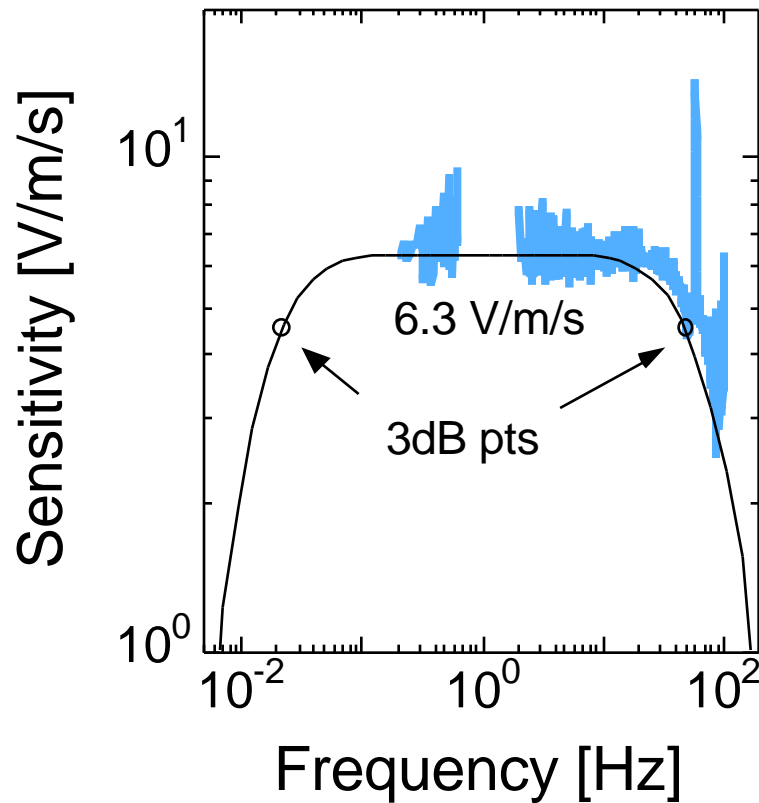


# Acceleration Sensitivity



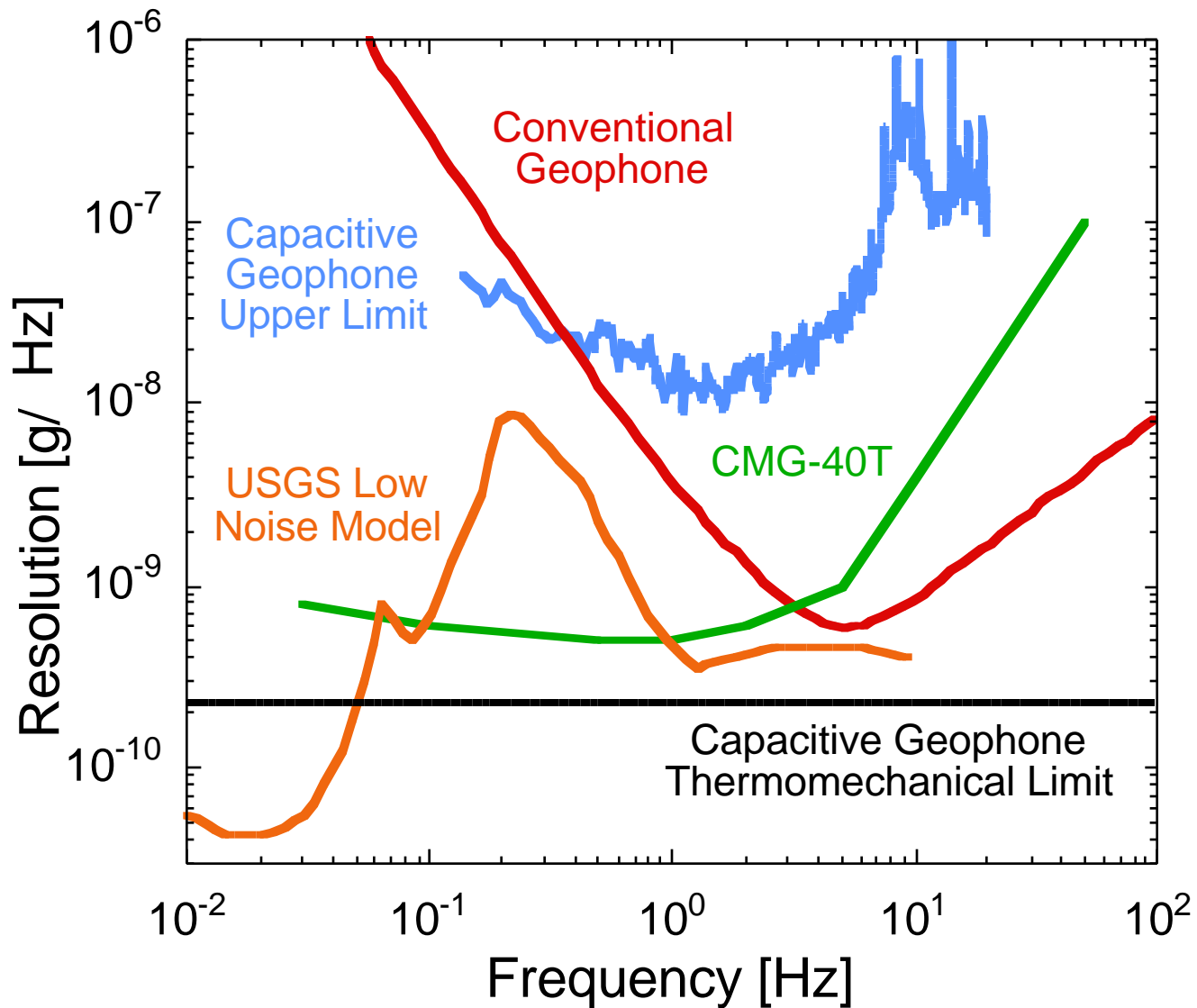
- **Constant Sensitivity At Low Frequency** since Output is Proportional to Proof Mass **Displacement**
- Bandwidth from 83 sec to 50 Hz Defined by Controller

# Velocity Sensitivity



- Velocity Output Produced by Integrator Circuit
- Bandwidth from 45 sec to 50 Hz Defined by Controller and Integrator

# Resolution Comparison



Capacitive Geophone Measurement Limited by Ambient Seismic Noise

USGS LNM: Seismic Noise At Quietest Sites On Earth

# Conclusions

- Need to collaborate with a vault operator to take data at a quieter site
- The Low Frequency Resolution of a Geophone can be Improved by Adding **Capacitive Detection**
- A Capacitive Geophone is an affordable seismometer suitable for broadband use