Wide-Band, Low-Noise, Low-Power Seismometer for SQM search and Lunar Science

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Why a Different Seismometer?

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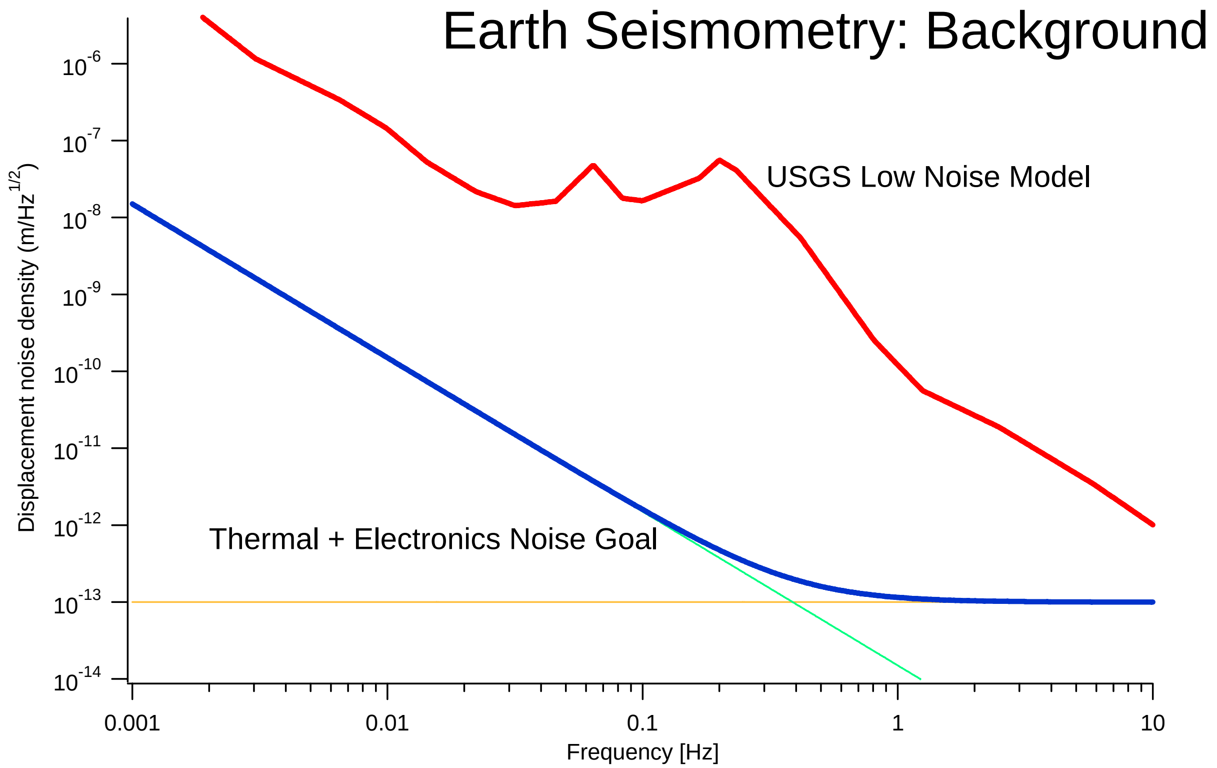

The USGS Low-Noise Model

[Peterson, J., 1993. Observations and modeling of background seismic noise. Open-file report 93-322, U. S. Geological Survey, Albuquerque, New Mexico.]

Seismometer Concept
(Contributed by Prof. Ho Jung Paik, UM)

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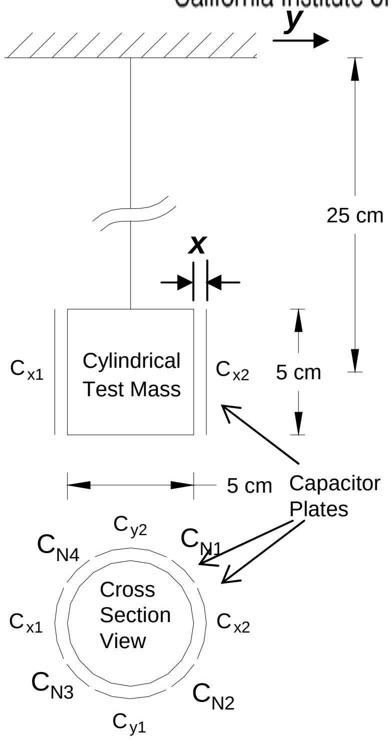
- Pendulum natural frequency = f_o = 0.4 Hz on the Moon
- Two pairs of capacitors for displacement measurement.
- Two pairs of capacitors for applying DC voltage to reduce f_o and to balance tilt.
- Why reduce f_o ?
- Thermal noise of seismometer:

$$S_y(\omega) = \frac{1}{\omega^2}\sqrt{\frac{4k_B T\omega_o}{mQ}}$$

- Target: $Q = 10^4$, $f_o = 0.01$ Hz, $m = 0.27$ kg.



Seismometer Fabrication
(Contributed by Prof. Ho Jung Paik, UM)

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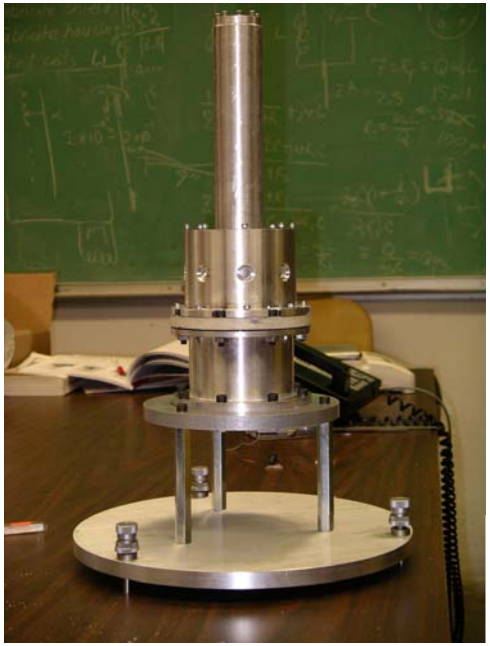
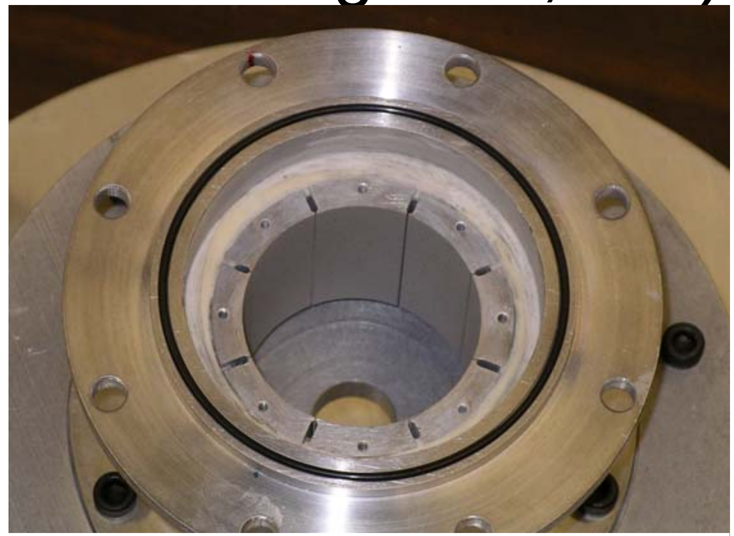
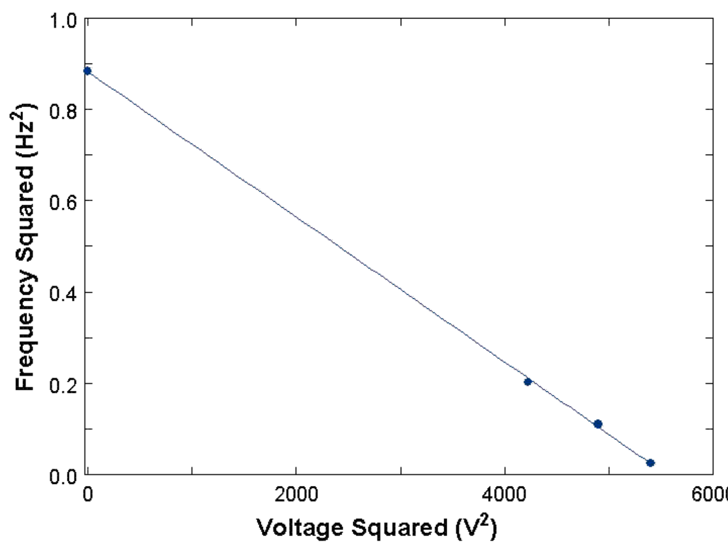


Seismometer Housing



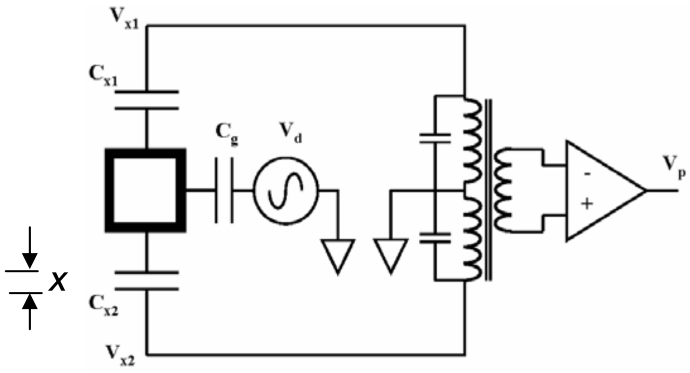
Seismometer Capacitor Plates



Q = 4000. Frequency reduced from 1 Hz to 0.35 Hz.

Seismometer Electronics Concepts

Concept: A



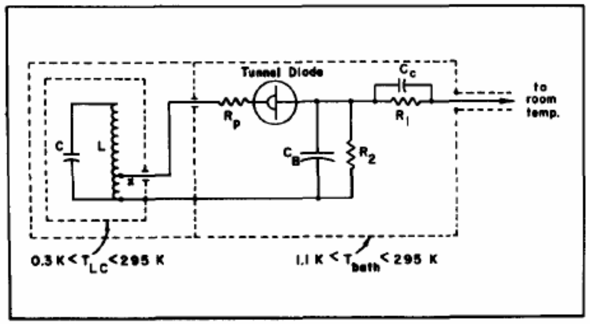
- Used by LISA.
- LISA measurement scales to 10^{-14} m-Hz$^{-1/2}$ in x for $x = 10^{-4}$ m.

[W. J. Weber et al., Class. and Quantum Grav. 19, 1751, 2002.]

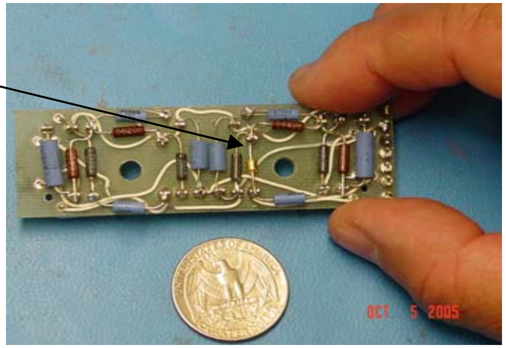
Concept: B

Based on 0.001 ppm tunnel-diode oscillator

[C. T. Van Degrift, Rev. Sci. Instrum. 46, 599 (1975).]



Tunnel Diode



A circuit board with two tunnel-diode oscillator circuits. It was populated with only one tunnel-diode for testing.

Seismometer Based on Tunnel-Diode Oscillators

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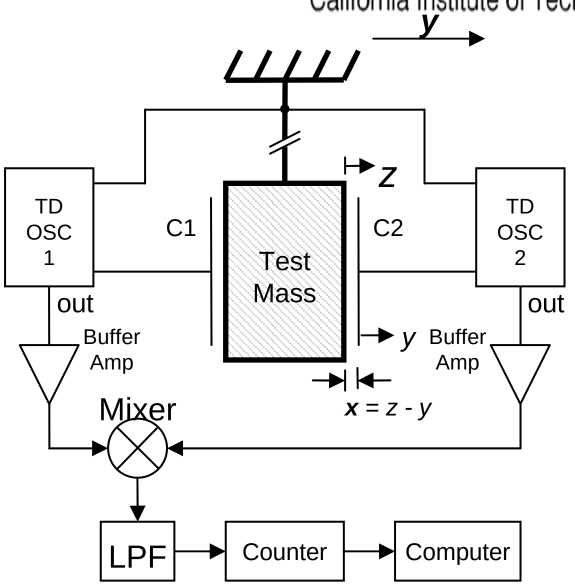
- Operates at wide temp. range: 400 K to 1K.
- Use very low power: <10 mW.
- Suitable for operation thru lunar night.
- A 5 kg Lithium Ion can supply 1 W through lunar night.
- Radioisotope Heater Unit (RHU) to keep electronics warm.



Seismometer based on tunnel-diode oscillator.

Tunnel-Diode Oscillator Evaluation (Contributed by Joseph Young)

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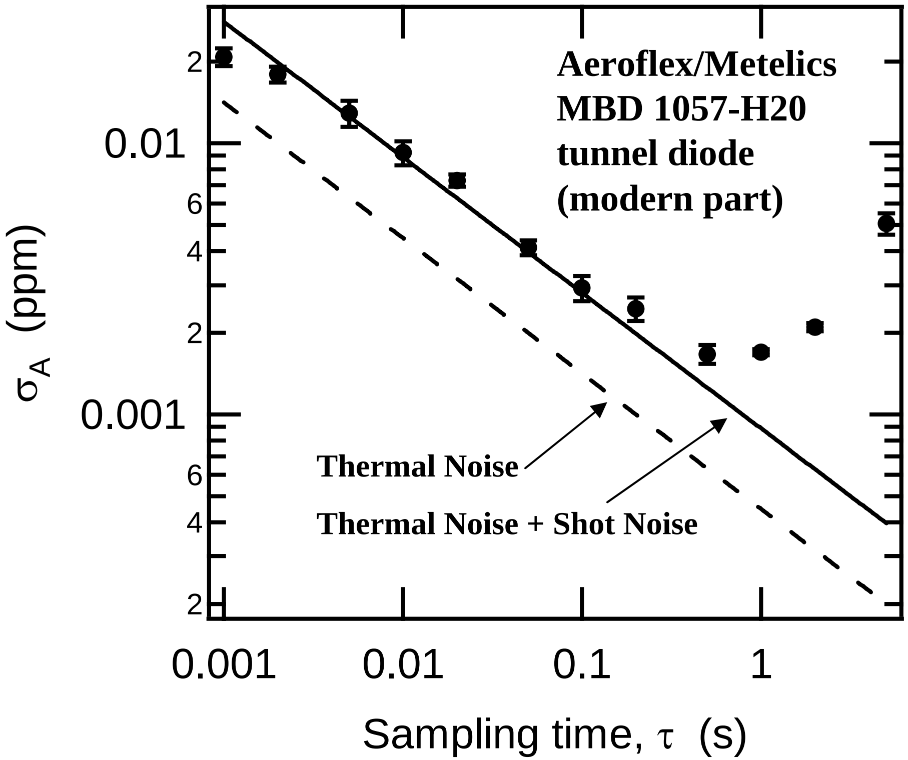
Square-root of the Allan variance σ_A



Thermal Noise Limit:

$$\sigma_A = \frac{\Delta f}{f} = \frac{1}{Q_e}\sqrt{\frac{k_B T}{2P\tau}}$$

$$Q_e = 67$$

$$P = 2.4\ \mu\text{W}$$

Shot Noise density $= \sqrt{2ei_d}$

$$i_d = \text{Diode Bias Current}$$

$$= 138\ \mu A$$

Tunnel-Diode Oscillator Evaluation (Contributed by Joseph Young)

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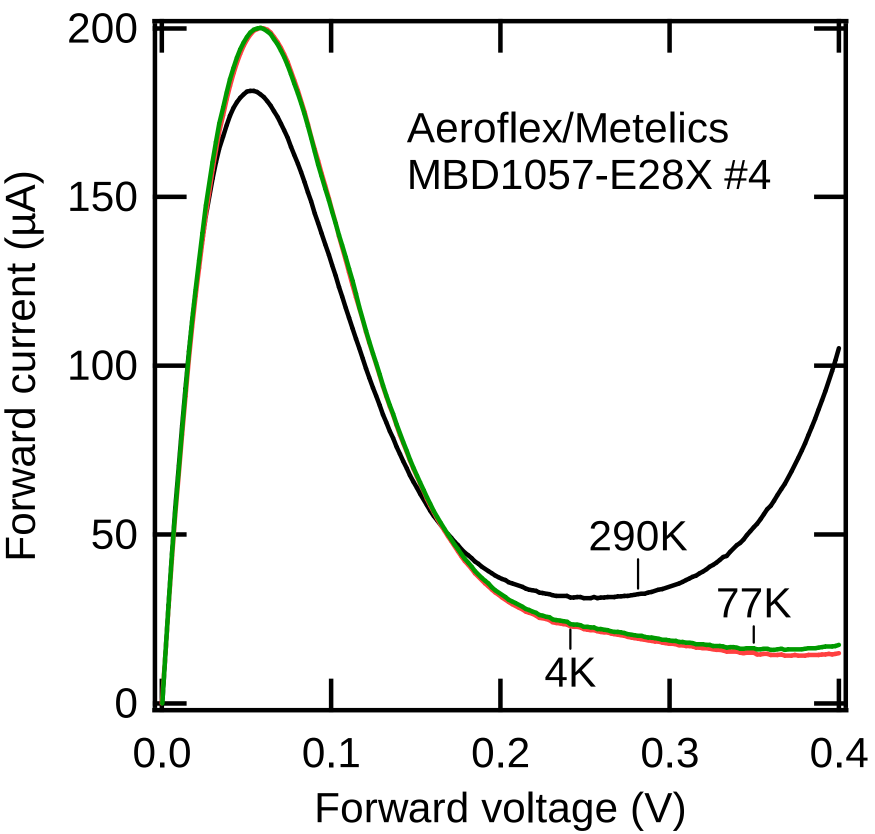
Relative freq. change of a 10 MHz Oscillator versus Temp.

Temp.	Change
290 K	0%
77 K	+1.6%
4.2 K	+3.7%

Operates from 300 K to 4 K without adjustment

Thermal Cycles:
20 times to 77K
6 times to 4K

Continuously operated over 1 month.



Expected Seismometer Displacement Noise Density $S_y(f)^{1/2}$

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