

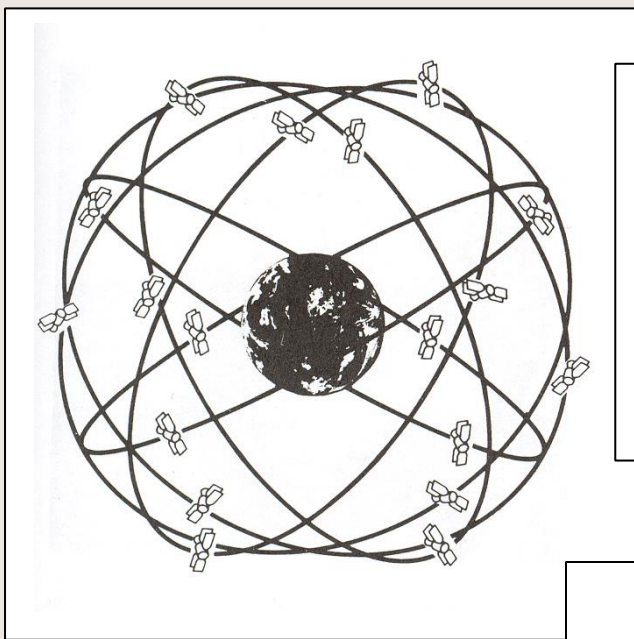
Seismic Receivers

- GPS surveying
- Electromechanical geophone
- Digital recorders
- Reminders about Analog-to-Digital (A/D) signal conversion

- Reading:
 - › Telford *et al.*, Section 4.5
 - › Sheriff and Geldart, Sections 7.5-6

Surveying

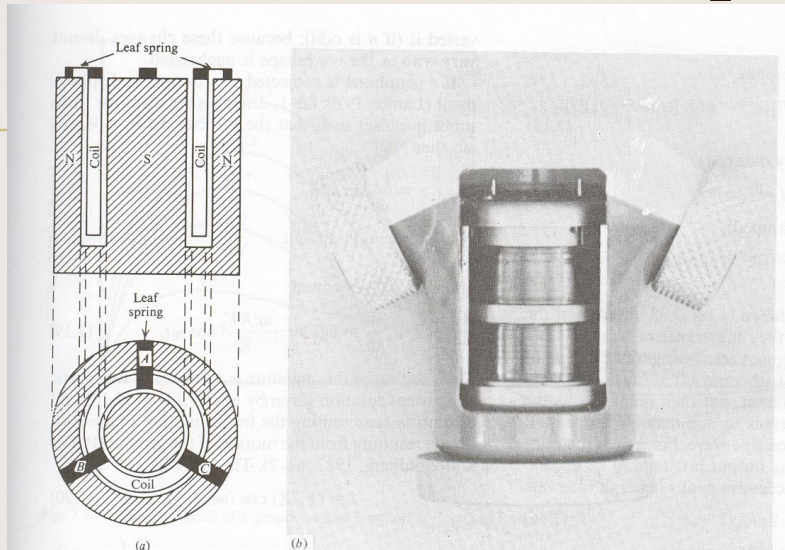
- Accurate locations (within ~10 cm) obtained from Global Positioning System (GPS)



Electromechanical Geophone

- Invented by Prince Boris Galitzine (St. Petersburg, Russia) in 1906
 - ◆ One of the founders of modern seismology

Electromechanical Geophone



Equation of motion of the coil:

$$m \left(\frac{d^2 z_c}{dt^2} + \frac{d^2 z}{dt^2} \right) = -kz_c - \tau \frac{dz}{dt} + 2\pi rnHi$$

Acceleration

Spring force

Damping (friction) force

Coil induction force

E.M.F. in the coil: $\frac{-d\Phi}{dt} = \frac{-d\Phi}{dz_c} \frac{dz_c}{dt} = -2\pi rnH \frac{dz_c}{dt} = Ri + L \frac{di}{dt}$

Ohm's law

$L\omega \ll R$ and so:

$$i = \frac{-2\pi rnH}{R} \frac{dz_c}{dt}$$

Current

velocity

Differentiate with respect to t :

$$\frac{d^2 i}{dt^2} + \left[\tau + \frac{(2\pi rnH)^2}{mR} \right] \frac{di}{dt} + \frac{k}{m} i = \frac{2\pi rnH}{R} \frac{d^3 z}{dt^3}$$

Natural frequency and Damping

- This was an equation of damped harmonic motion:

$$\frac{d^2i}{dt^2} + \left[\tau + \frac{(2\pi rnH)^2}{mR} \right] \frac{di}{dt} + \frac{k}{m} i = \frac{2\pi rnH}{R} \frac{d^3z}{dt^3}$$

Annotations:

- ω_0^2 , natural frequency (points to $\frac{k}{m}$)
- Mechanical damping (friction) (points to τ)
- Electromagnetic Damping (points to $\frac{(2\pi rnH)^2}{mR}$)
- External force (points to $\frac{2\pi rnH}{R} \frac{d^3z}{dt^3}$)

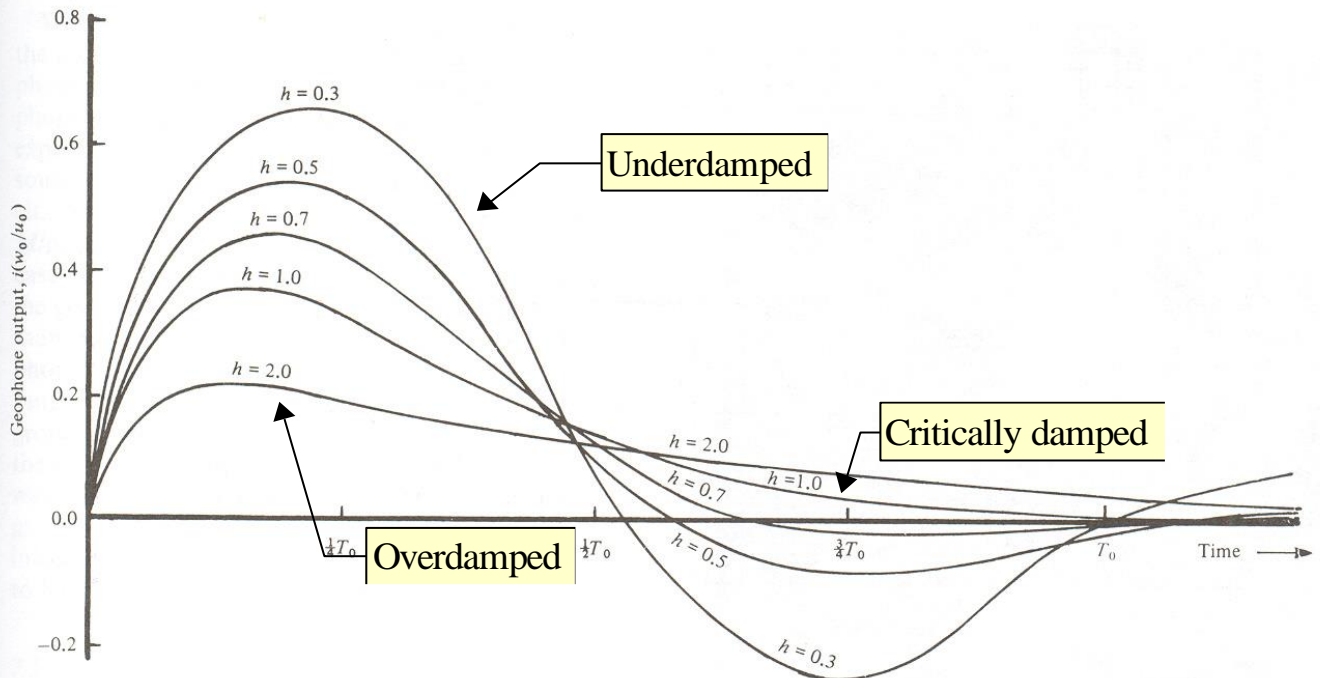
- Two key parameters of a geophone:

- Natural (resonance) frequency: $\nu_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$
 - Natural period: $T_0 = 1/\nu_0$

- Damping parameter, h : $2h\omega_0 = \tau + \frac{(2\pi rnH)^2}{mR}$

$$\frac{d^2i}{dt^2} + 2h\omega_0 \frac{di}{dt} + \omega_0^2 i = \frac{2\pi rnH}{R} \frac{d^3z}{dt^3}$$

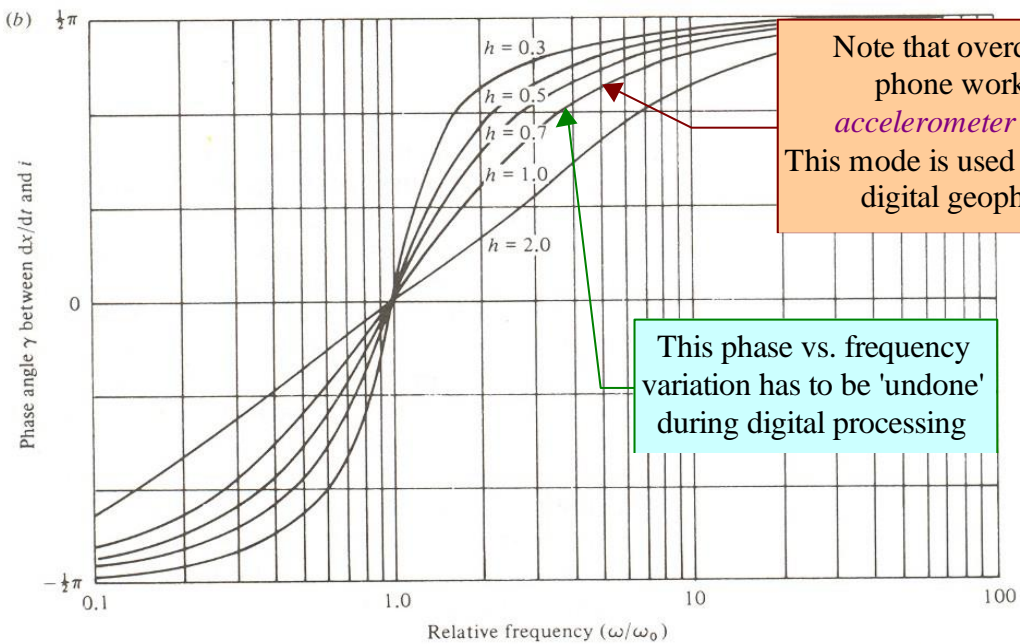
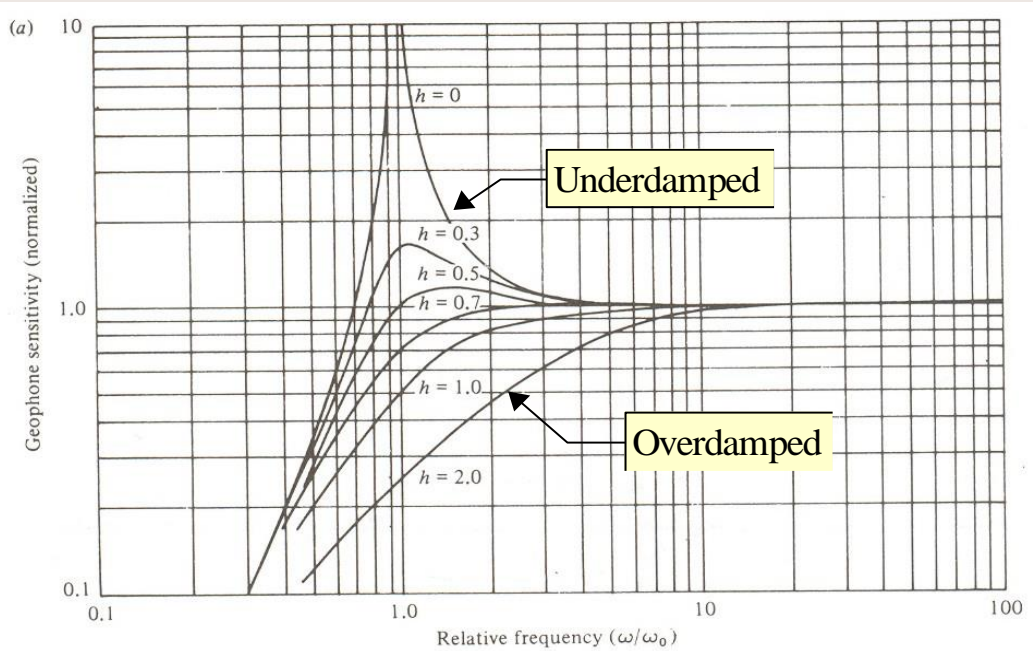
Impulse (transient) response



- Natural frequency, ν_0 , controls the duration of the response to a single pulse;
- Damping, h , controls the shape of the response:
 - $h < 1$ (underdamped) - oscillatory response;
 - $h = 1$ (critically damped);
 - $h > 1$ (overdamped) - no oscillations, slower and lower-amplitude response.

Response to a harmonic driving force

- Damping, suppresses the undesirable *resonance* near natural frequency.



Note that overdamped phone works as *accelerometer* (why?)
This mode is used in modern digital geophones

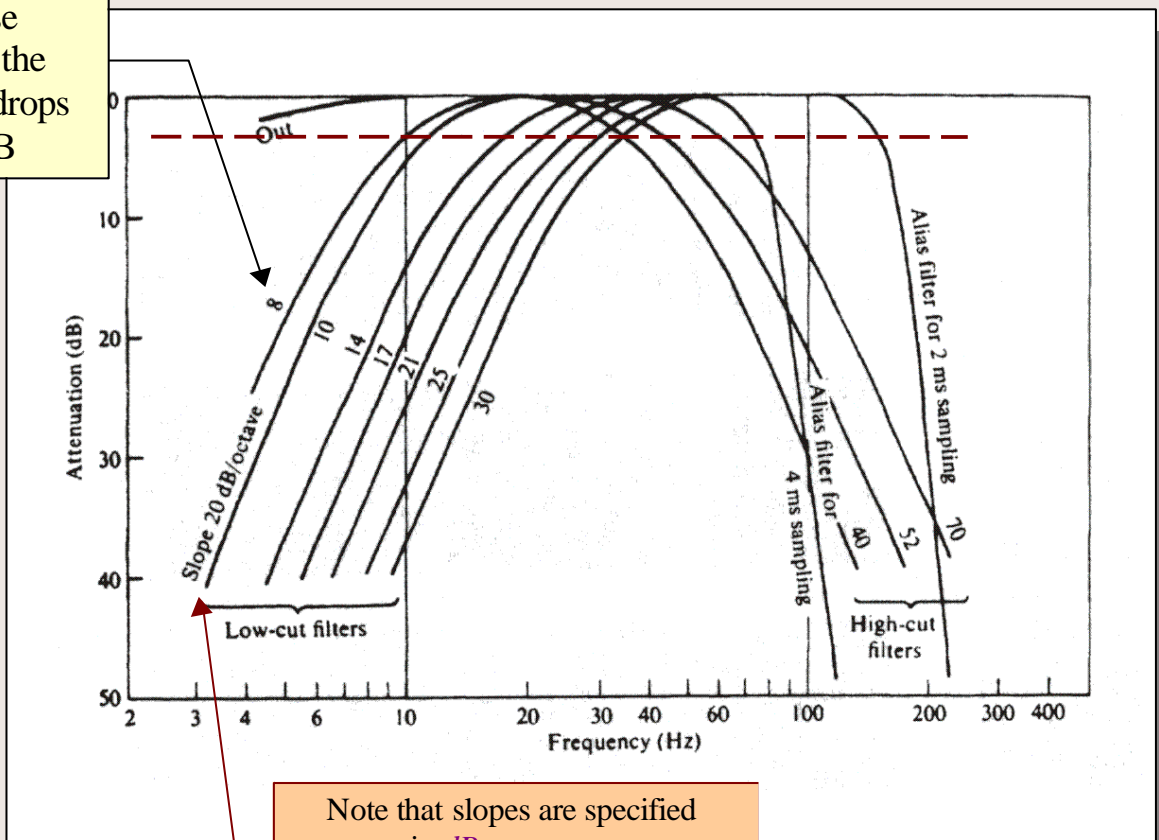
This phase vs. frequency variation has to be 'undone' during digital processing

Seismic filters

- Prior to digitization, the analog signal is always filtered to avoid aliasing (to $< f_{\text{Nyquist}}$)
- Analog or digital filtering is further used to suppress noise.

Cutoff frequencies

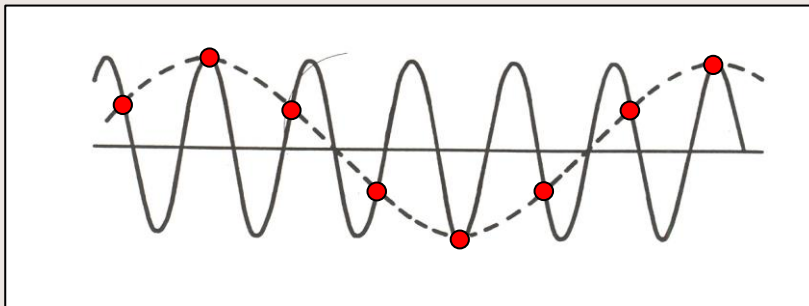
are those at which the amplitude drops by 3 dB



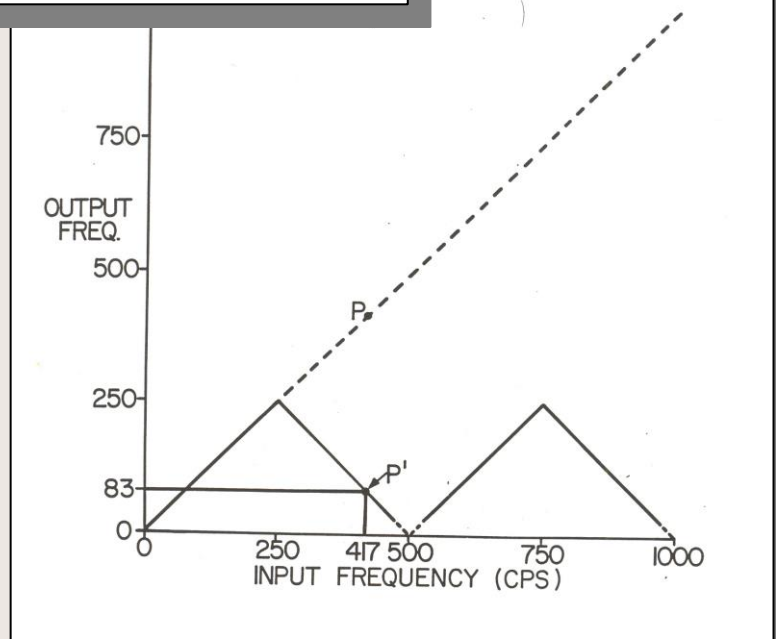
Note that slopes are specified in *dB per octave* in order to avoid Gibbs phenomenon (filter ringing)

Nyquist Frequency (reminder)

- If sampling is attempted at frequency $<$ *twice the frequency of the signal*, distortion occurs (*aliasing*)
 - High-frequency signal would appear as low-frequency:



- The largest unambiguously recoverable frequency is the *Nyquist frequency*:
 $f_N = 1/(2\Delta t)$.



Dynamic Range

(reminder)

- The amplitude 'depth' of recording is measured by its *dynamic range*, expressed in decibels (dB)
 - ♦ Dynamic range measures the ratio of the maximum and minimum amplitudes that are (or can be) correctly recorded.

$$\left(\frac{A_1}{A_2} \right)_{\text{in dB}} = 20 \log_{10} \left(\frac{A_1}{A_2} \right)$$

- In a digital recorder, the dynamic range is controlled by the *number of bits* used to store/output the values.
 - ♦ Each additional bit allows doubling the recorded values; thus, it corresponds to additional $20 \log_{10} 2 = 6\text{dB}$.
 - ♦ Modern data loggers use 24-bit AD converters; this gives about 140 dB of dynamic range

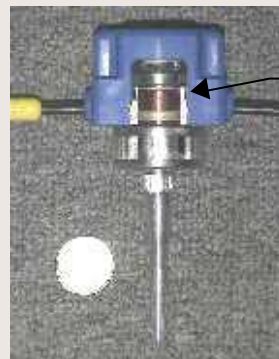
Refraction and Reflection

Geophones

- A variety of frequencies and styles
 - ♦ 1-100 Hz (natural frequencies);
 - ♦ Typically work OK up to 20 times their natural frequencies.



1-Hz



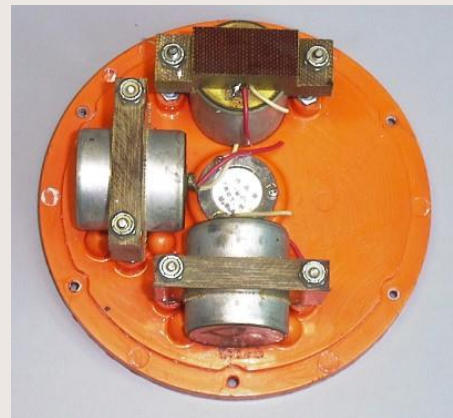
Note the coil and magnet

4-5-Hz



3-component (3C) Geophone

- 3-component geophones contain 3 sensors mounted in the same body, at 90° to each other.



Mark Products 4.5-Hz

Historical geophones



1935



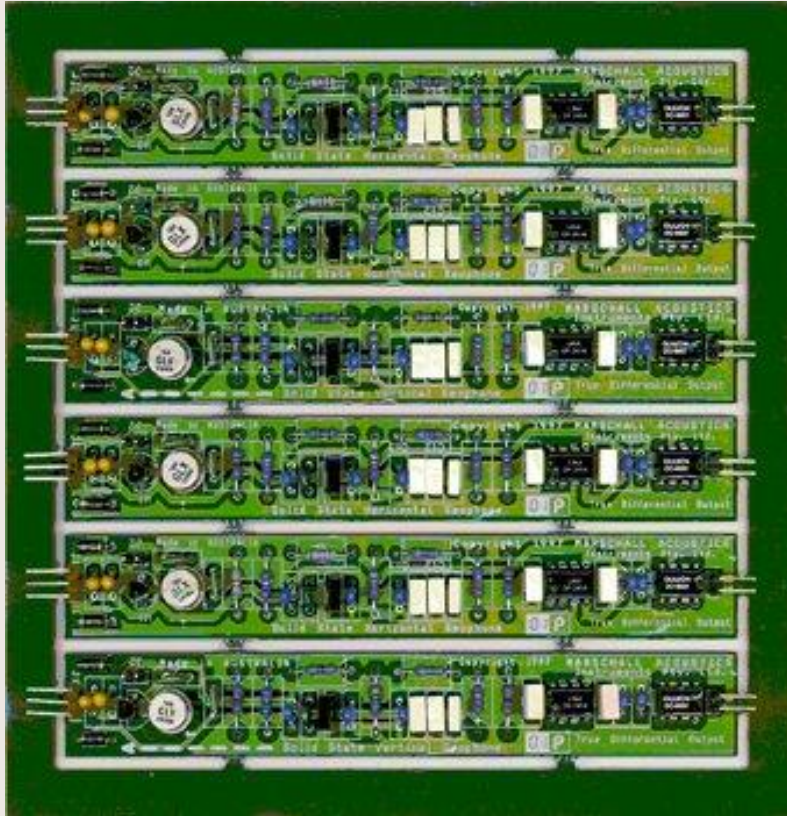
1950's



1970's

This is how most geophones look until now

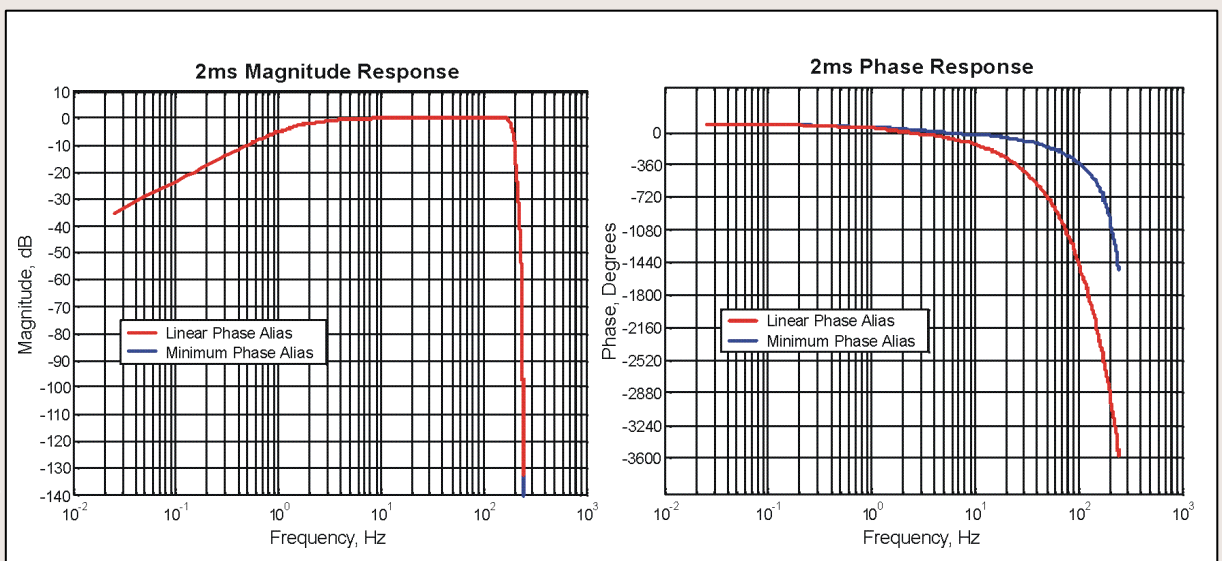
Modern solid-state geophone



- ◆ Digital from the phone;
- ◆ No moving parts;
- ◆ Robust;
- ◆ Lightweight;
- ◆ Economical;
- ◆ Full Self Testing.

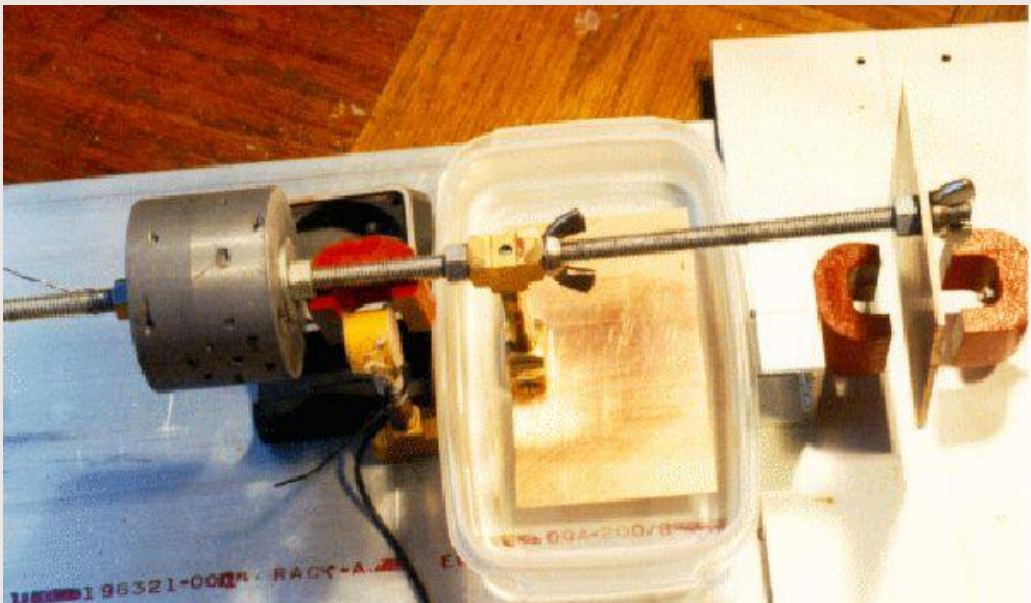
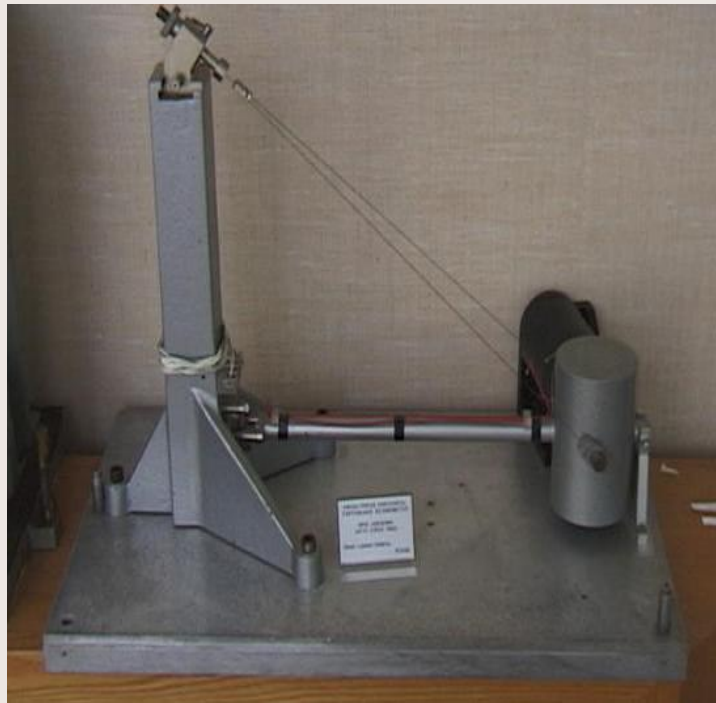
VectorSeis by Input/Output

- ◆ Fully 24-bit digital
- ◆ 3-component
- ◆ Insensitive to deployment tilt (returns gravity magnitude for all three sensors);
- ◆ Flat frequency and phase response across seismic range;
- ◆ 0.4% channel gain accuracy



Long-Period Seismometer

(detection of earthquakes, 10-1000 s periods)

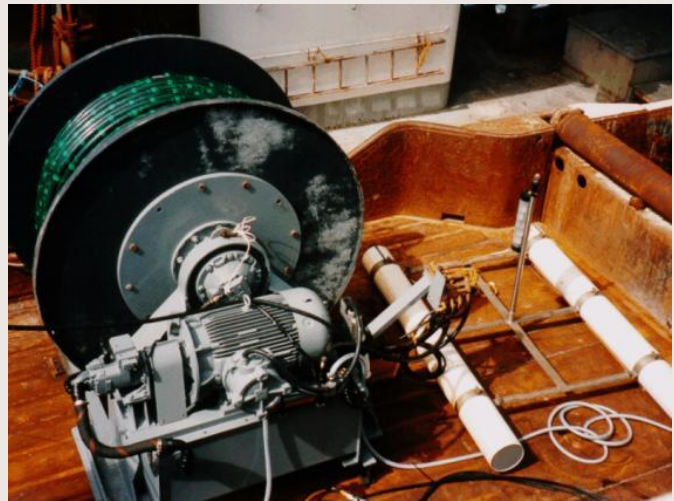


Hydrophones

- Pressure (pressure gradient) sensors



1965, refraction
hydrophone



NIWA streamer



Hydrophone array

Modern seismic vessel (*Magellan*, WesternGeco)

- Multiple steerable streamers



Hi-res recording gear



University of Wyoming
high-res reflection line,
July 2001



Small cable recording systems

- For shallow and engineering work
- Battery-powered
- Based on a PC, typically 24-96 channels



Scalable portable digital cable recording systems

- Lightweight, battery-operated;
- Data download via standard Internet connection to a laptop;
- 24-channel systems chained up to a 1000 channels.



“Geode” by Geometrics

Portable seismographs



- Such instruments were used primarily in long-range refraction experiments
- Thousands of similar ‘pod’ systems in use today
 - Three-channel
 - Broadband