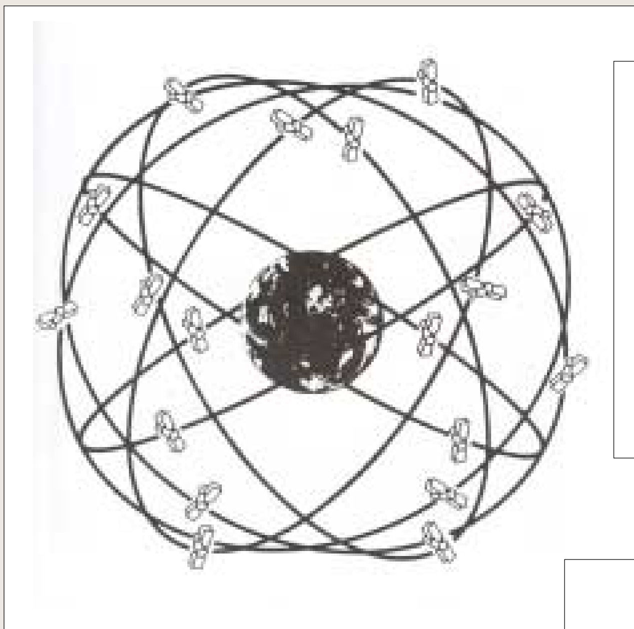
Seismic Detectors

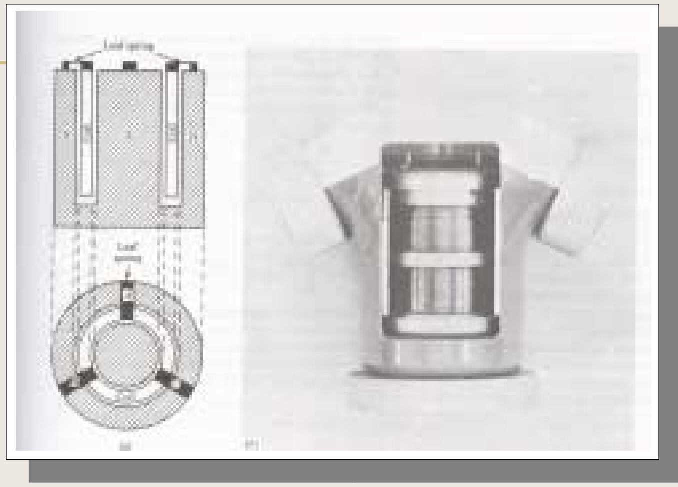
- Electromechanical geophone
- Digital recorders;
- Analog-to-Digital (A/D) converters.
- Reading:
  - Telford et al., Section 4.5
  - Sheriff and Geldart, Sections 7.5-6

Surveying

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



Electromechanical Geophone



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 by *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 simple harmonic motion:

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

ω_0^2, natural frequency

Mechanical damping (friction)

Electromagnetic Damping

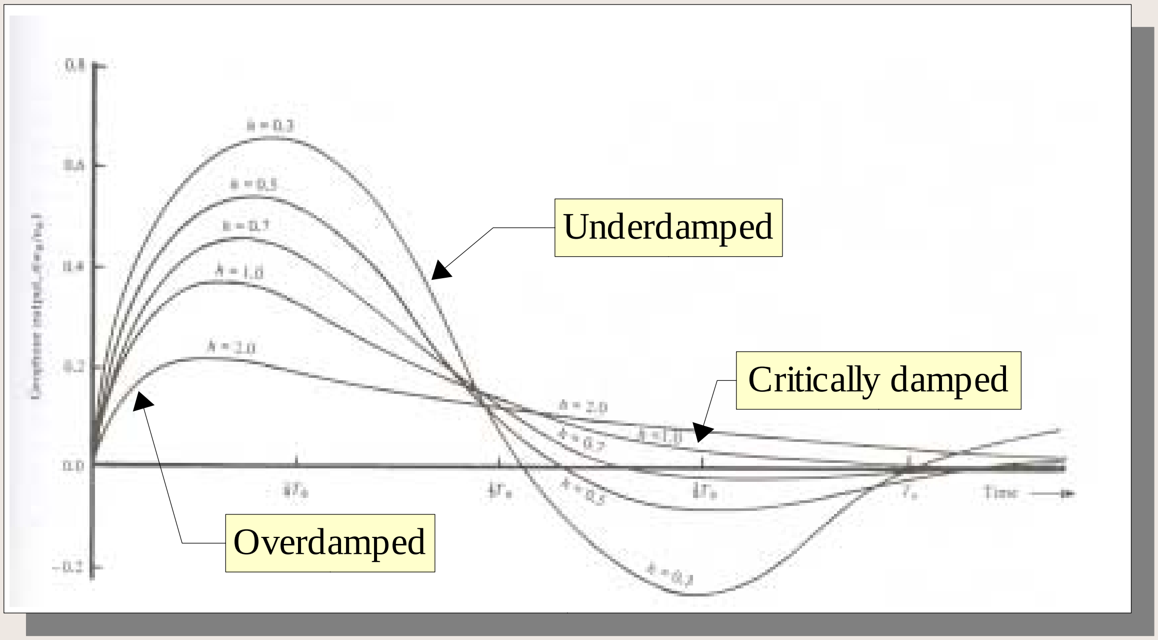
External force

- <u>Two key parameters of a geophone:</u>

  - 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*: $2h\omega_0 = \tau + \frac{(2\pi rnH)^2}{mR}.$

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

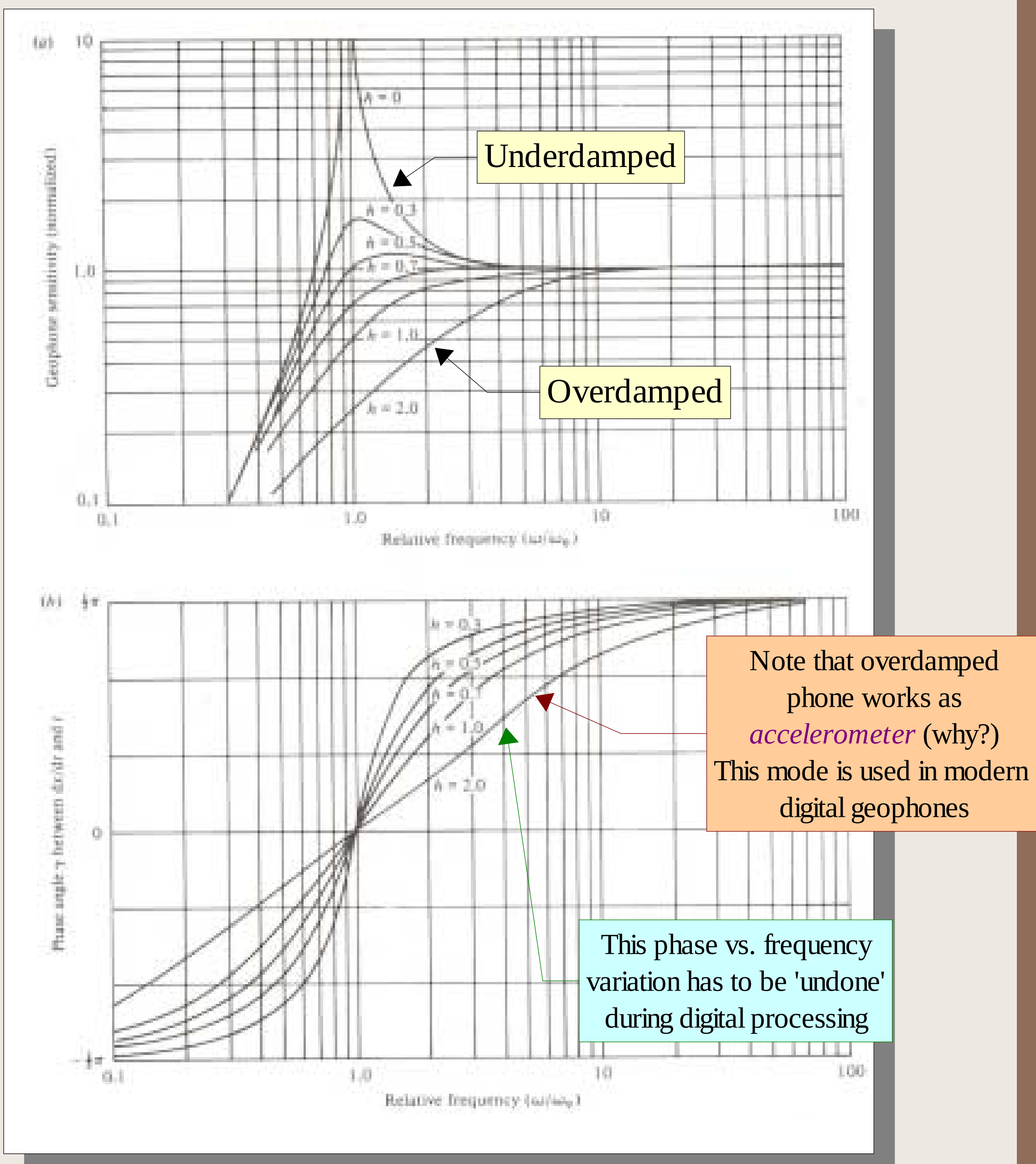
Impulse (transient) response



- 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

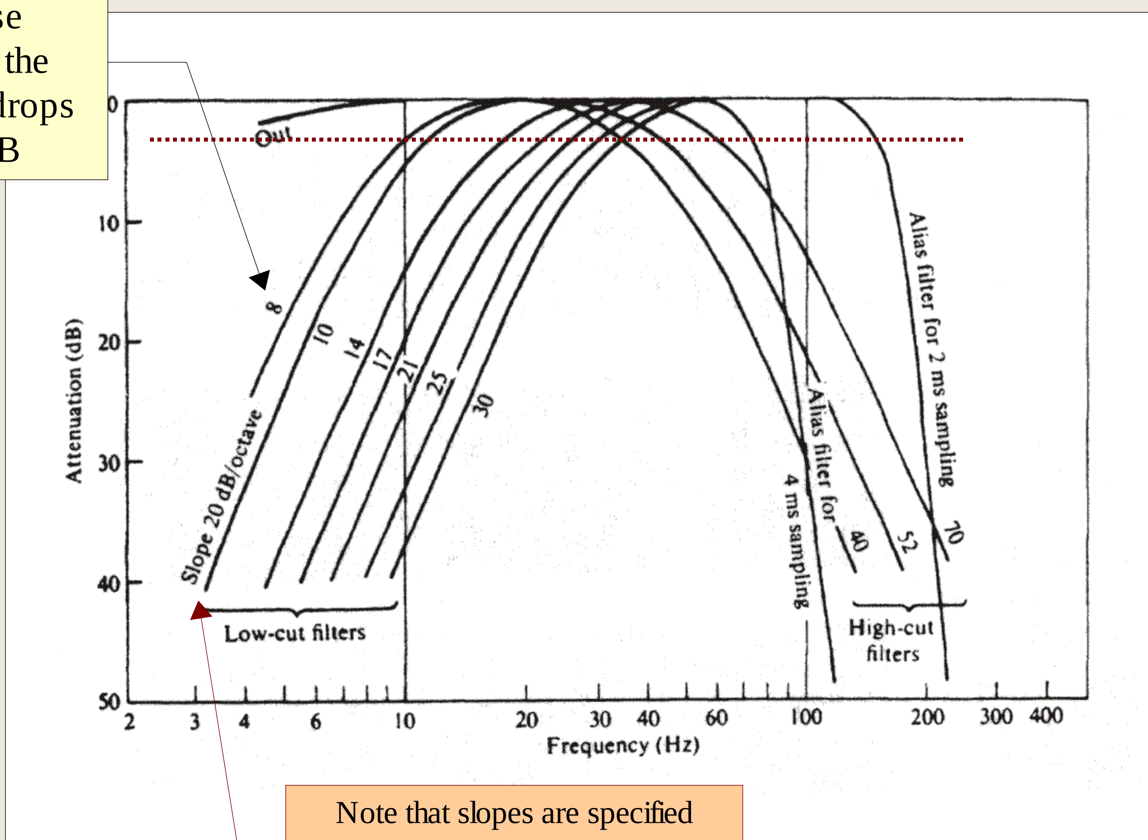
- Damping, suppresses the undesirable *resonance* near natural frequency.



Seismic filters

- Prior to digitization, the analog signal is always filtered to avoid aliasing (to < $f_{Nyquist}$)
- 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)

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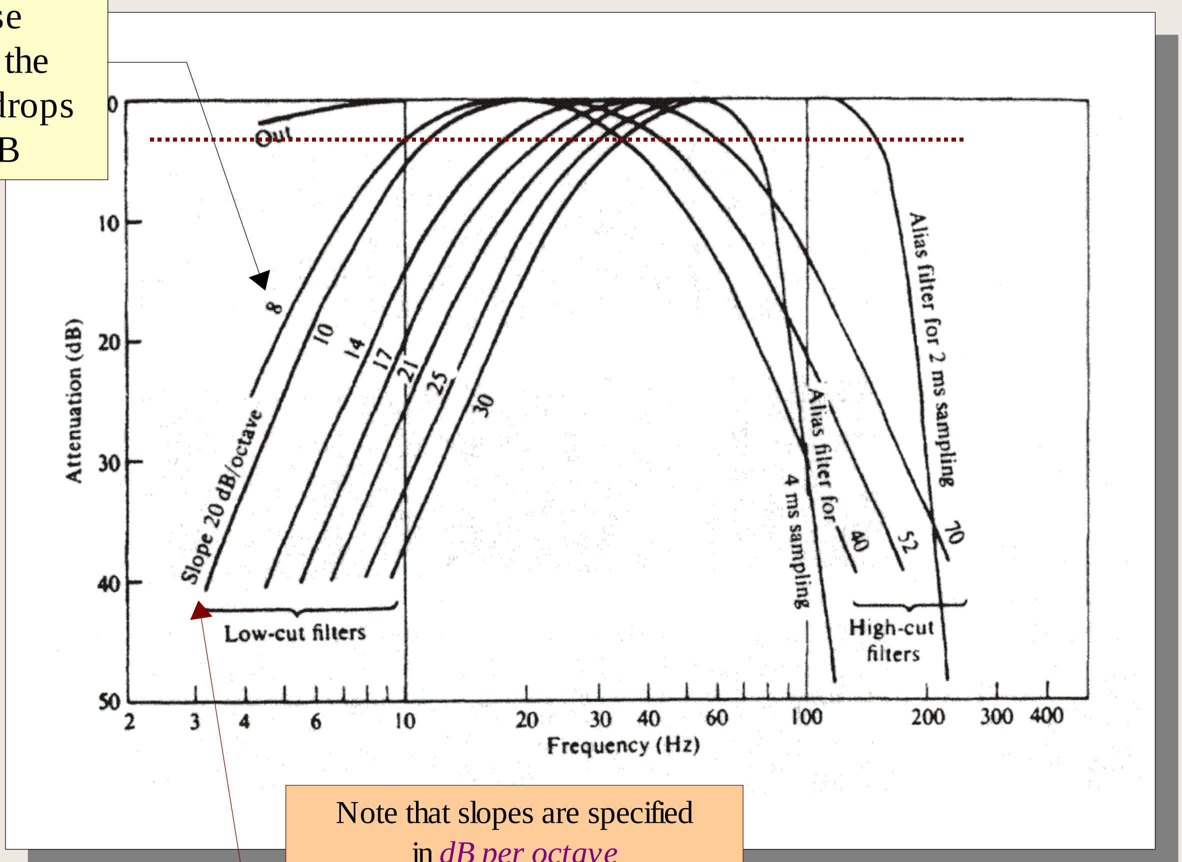

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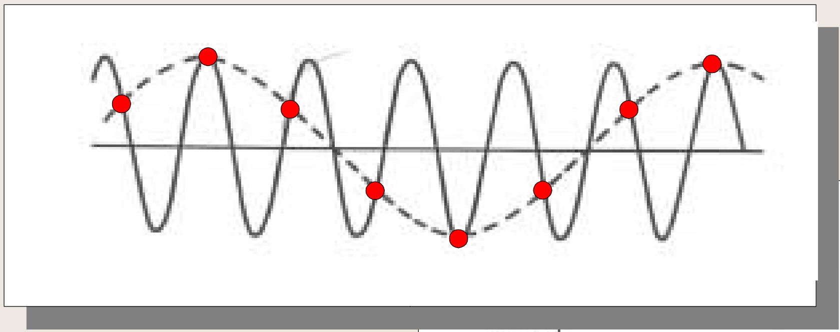
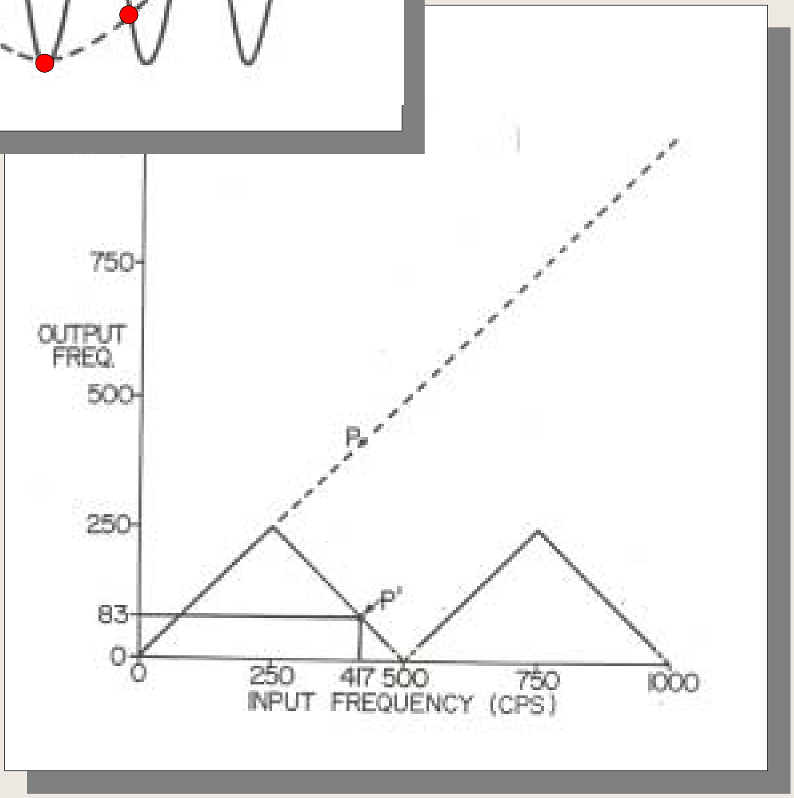
Nyquist Frequency
(Aliasing)

- 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

- 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.

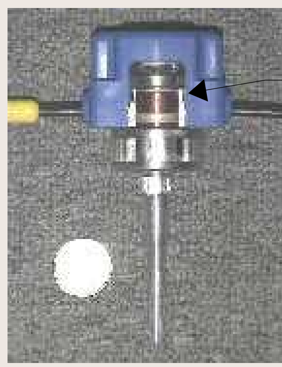
$$\left(\frac{A_1}{A_2}\right)_{\text{in dB}} = 20\log_{10}\left(\frac{A_1}{A_2}\right)$$

- 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 $20\log_{10}2 = 6$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

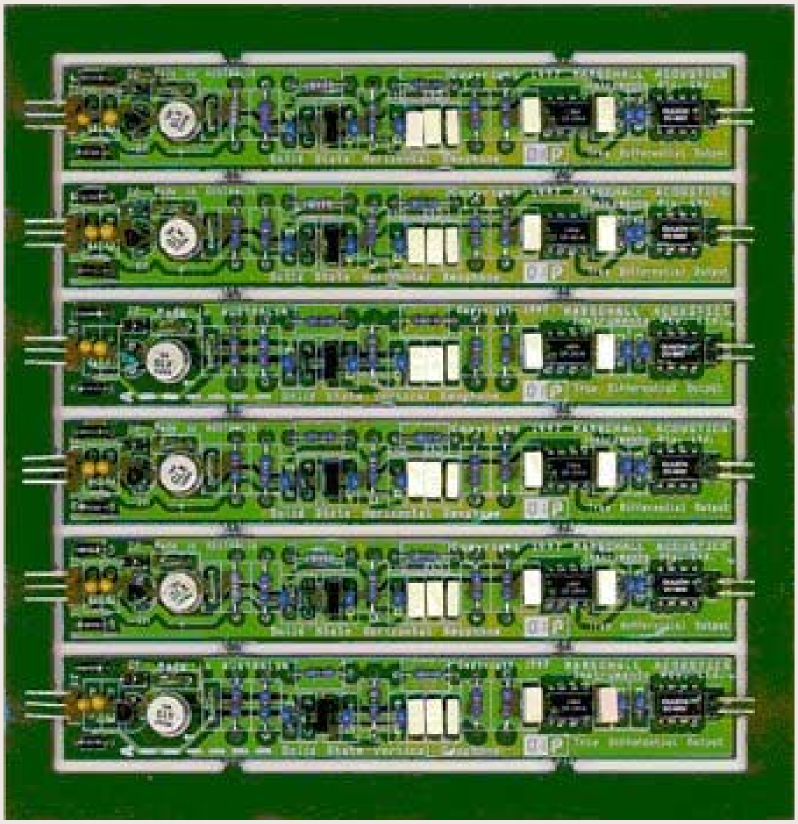
1935

1950's

1970's

This is how most geophones look until now

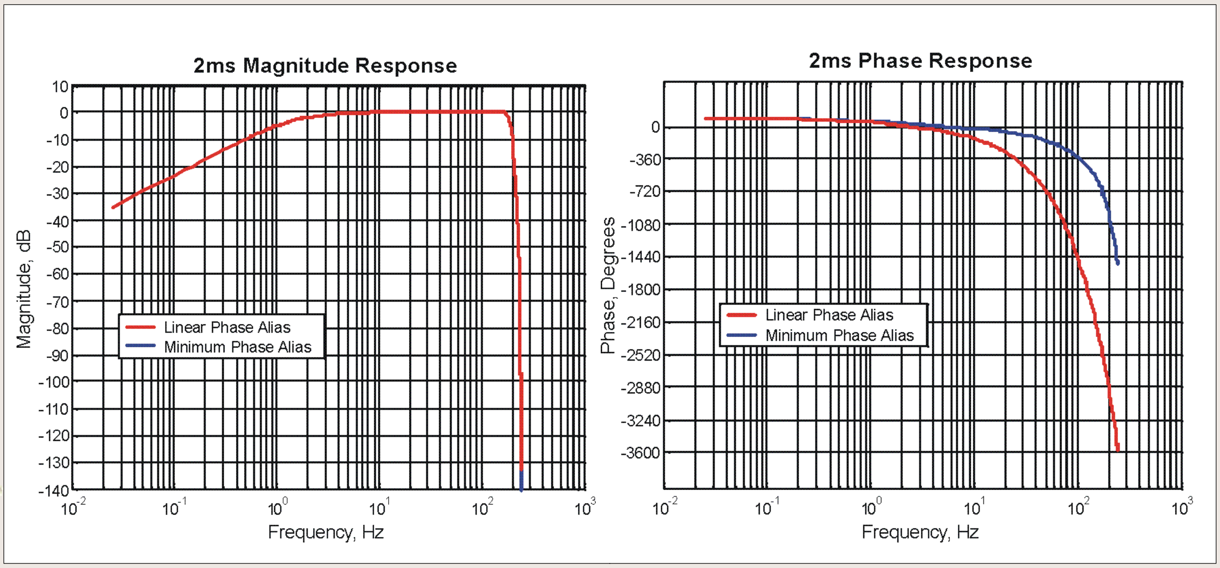
Solid-state geophone



- Digital from the phone;
- No Moving Parts;
- Robust;
- Lightweight;
- Economical;
- Full Self Testing.

VectorSeis by Input/Output

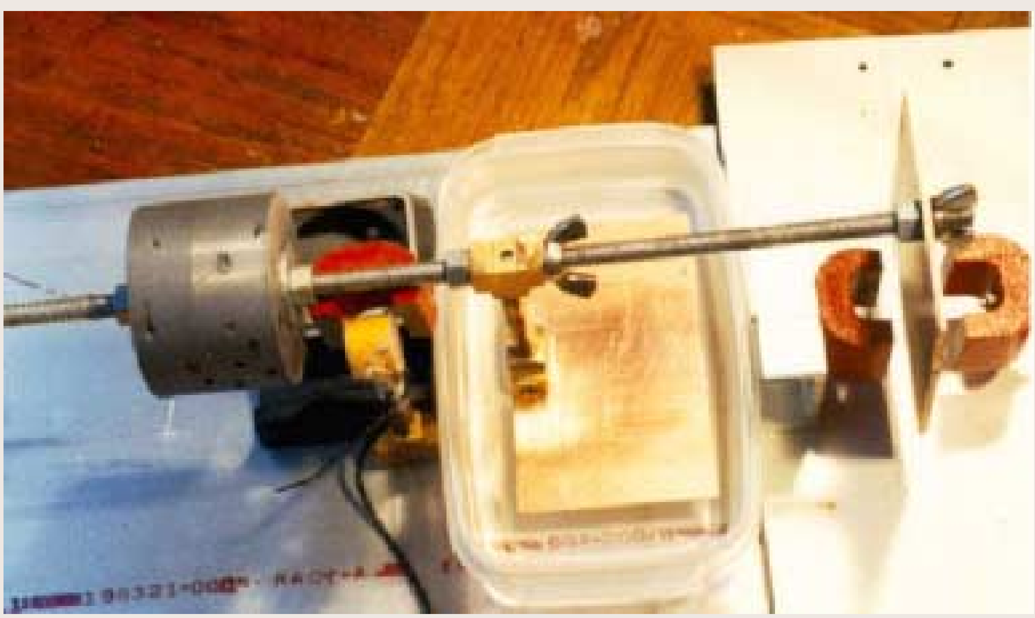
- Fully 24-bit digital
- 3-component
- Insensitive to deployment tilt (returns gravity magnitude for all three sensors);
- Flat frequency and phase response across seismic range;
- 0.4% channel gain accuracy



GEOL 483.3

Long-Period Seismometer

(detection of earthquakes, 10-1000 s periods)



Hydrophones

- Pressure (pressure gradient) sensors

1965, refraction hydrophone

NIWA streamer

Hydrophone array

Hi-res recording gear

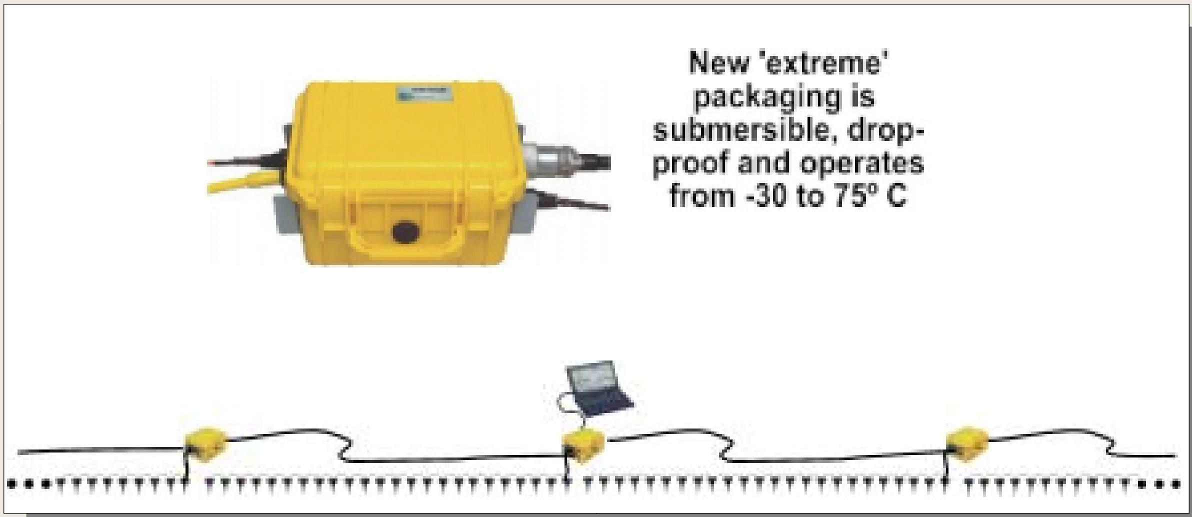
University of Wyoming
high-res reflection line,
July 2001

Digital 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

- This instrument is used primarily in long-range refraction experiments.