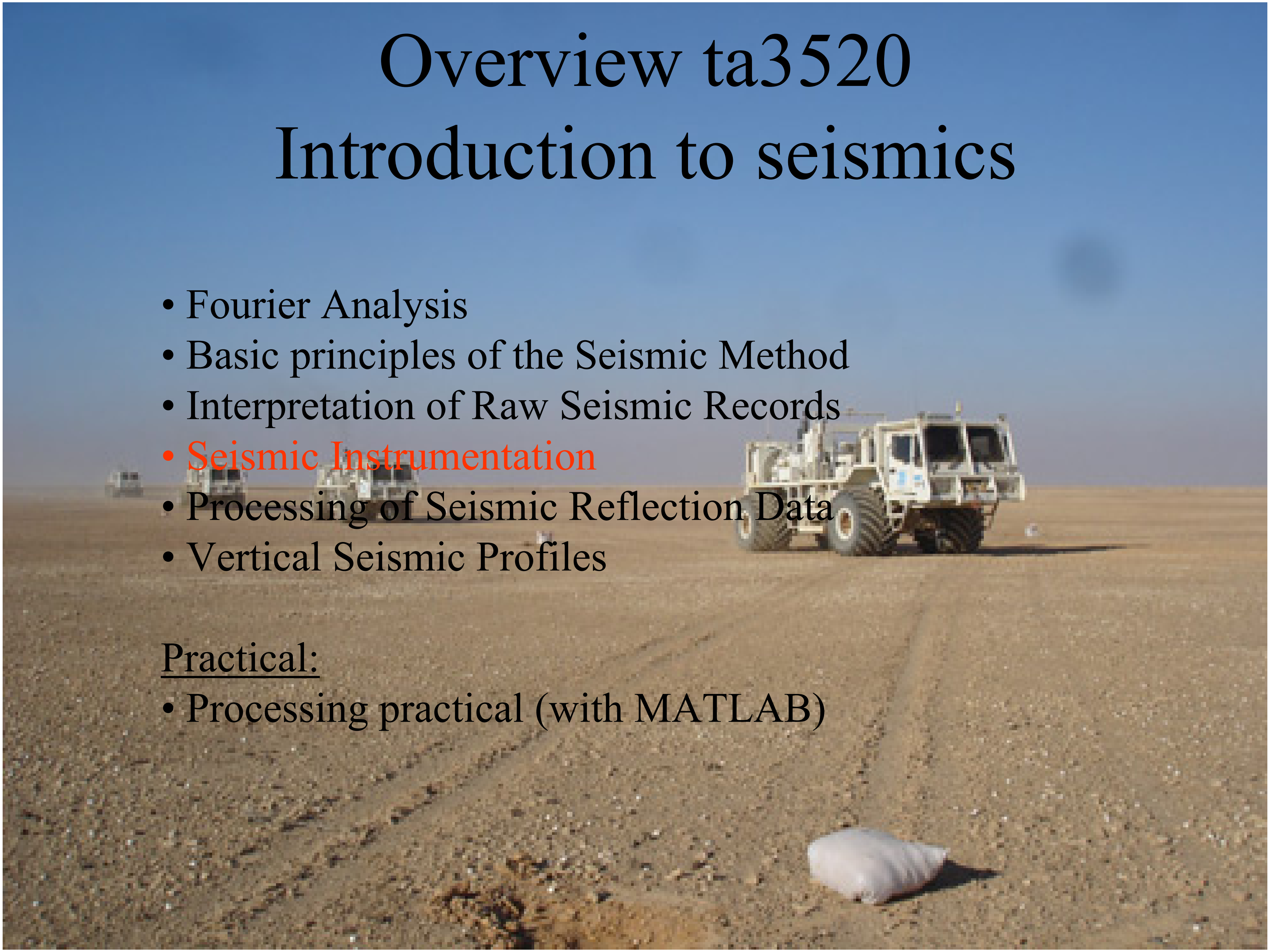
Overview ta3520
Introduction to seismics

- Fourier Analysis
- Basic principles of the Seismic Method
- Interpretation of Raw Seismic Records
- Seismic Instrumentation
- Processing of Seismic Reflection Data
- Vertical Seismic Profiles

<u>Practical:</u>

- Processing practical (with MATLAB)



Convolutional model of seismic data

In time domain, output is convolution of input and impulse responses

$$X(t) = S(t) * G(t) * R(t) * A(t)$$

where

$X(t)$ = seismogram
$S(t)$ = source signal/wavelet
$G(t)$ = impulse response of earth
$R(t)$ = impulse response of receiver
$A(t)$ = impulse response of recording-instrument

Convolutional model of seismic data

In frequency domain, output is multiplication of spectra:

$$X(\omega) = S(\omega)\, G(\omega)\, R(\omega)\, A(\omega)$$

where

$X(\omega)$ = seismogram
$S(\omega)$ = source signal/wavelet
$G(\omega)$ = transfer function of earth
$R(\omega)$ = transfer function of receiver
$A(\omega)$ = transfer function of recording-instrument

(transfer function = spectrum of impulse response)

Convolutional model of seismic data

In time domain, output is convolution of input and impulse responses

$$X(t) = \mathbf{S(t)} * G(t) * R(t) * A(t)$$

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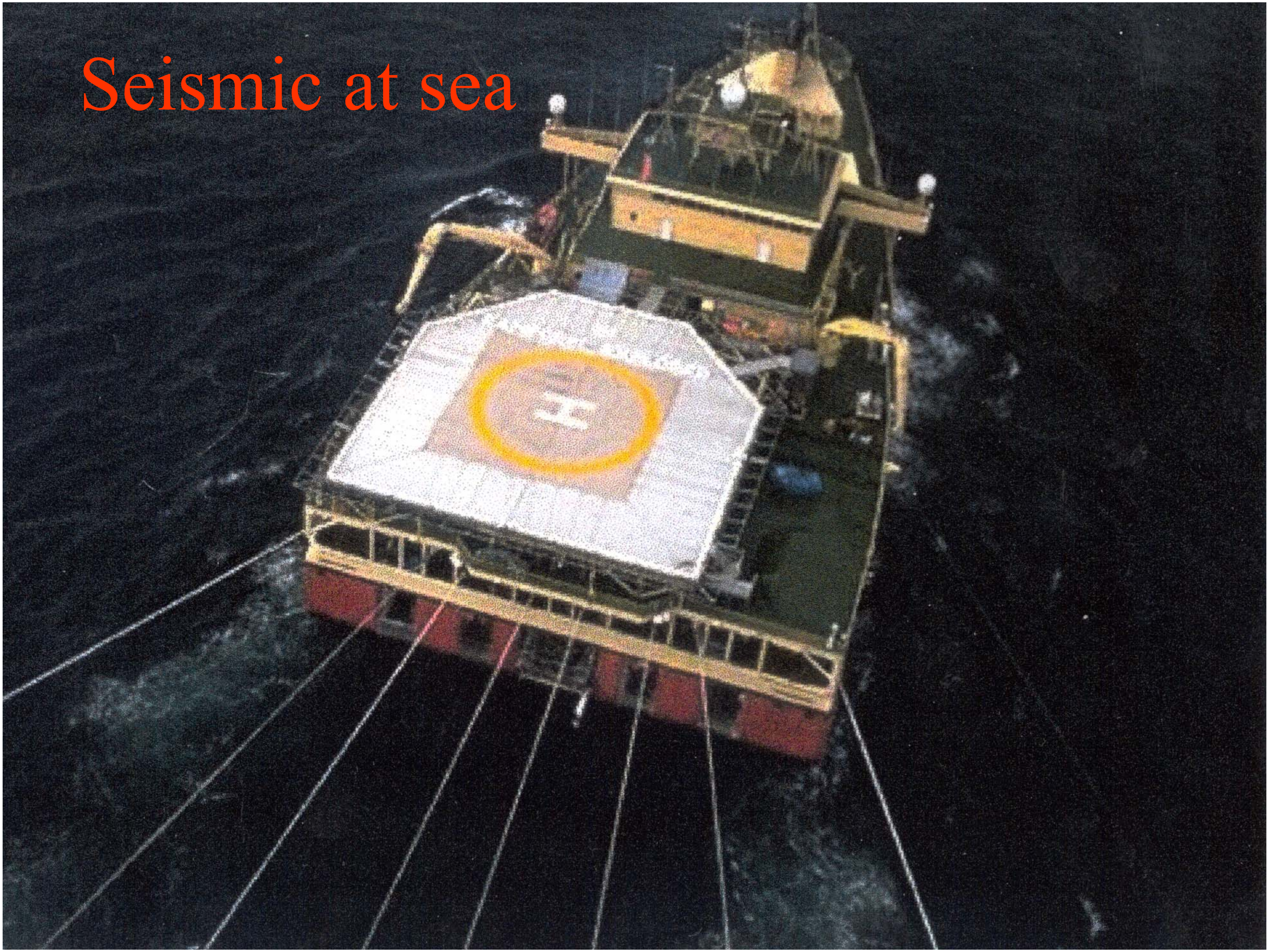
Seismic Instrumentation

- **Seismic sources:**
  - **Airguns**
  - **VibroSeis**
  - **Dynamite**
- **Seismic detectors:**
  - **Geophones**
  - **Hydrophones**
- **Seismic recording systems**

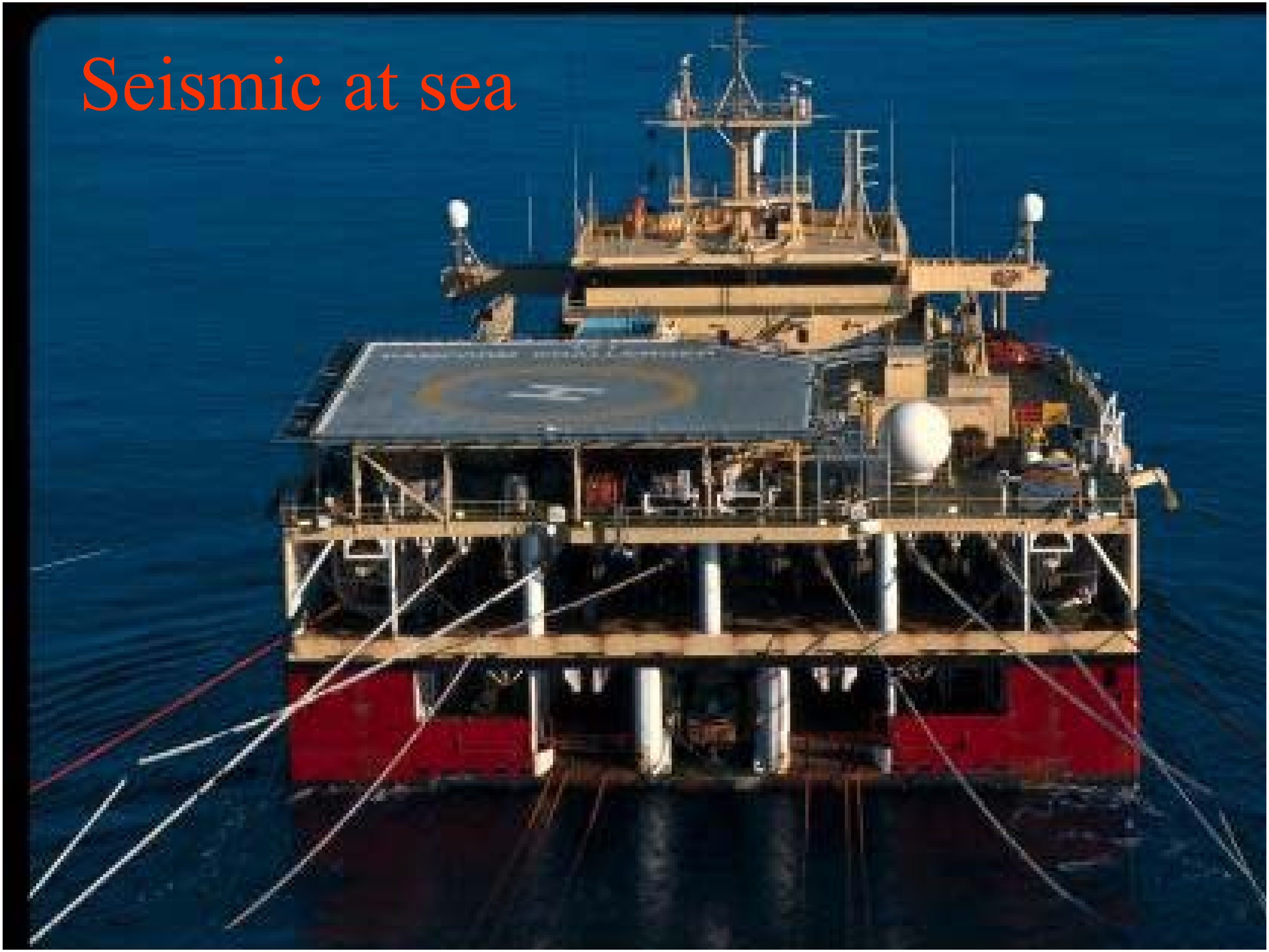
Seismic at sea

Seismic at sea



Seismic at sea

Seismic at sea



Seismic source at sea: Airgun

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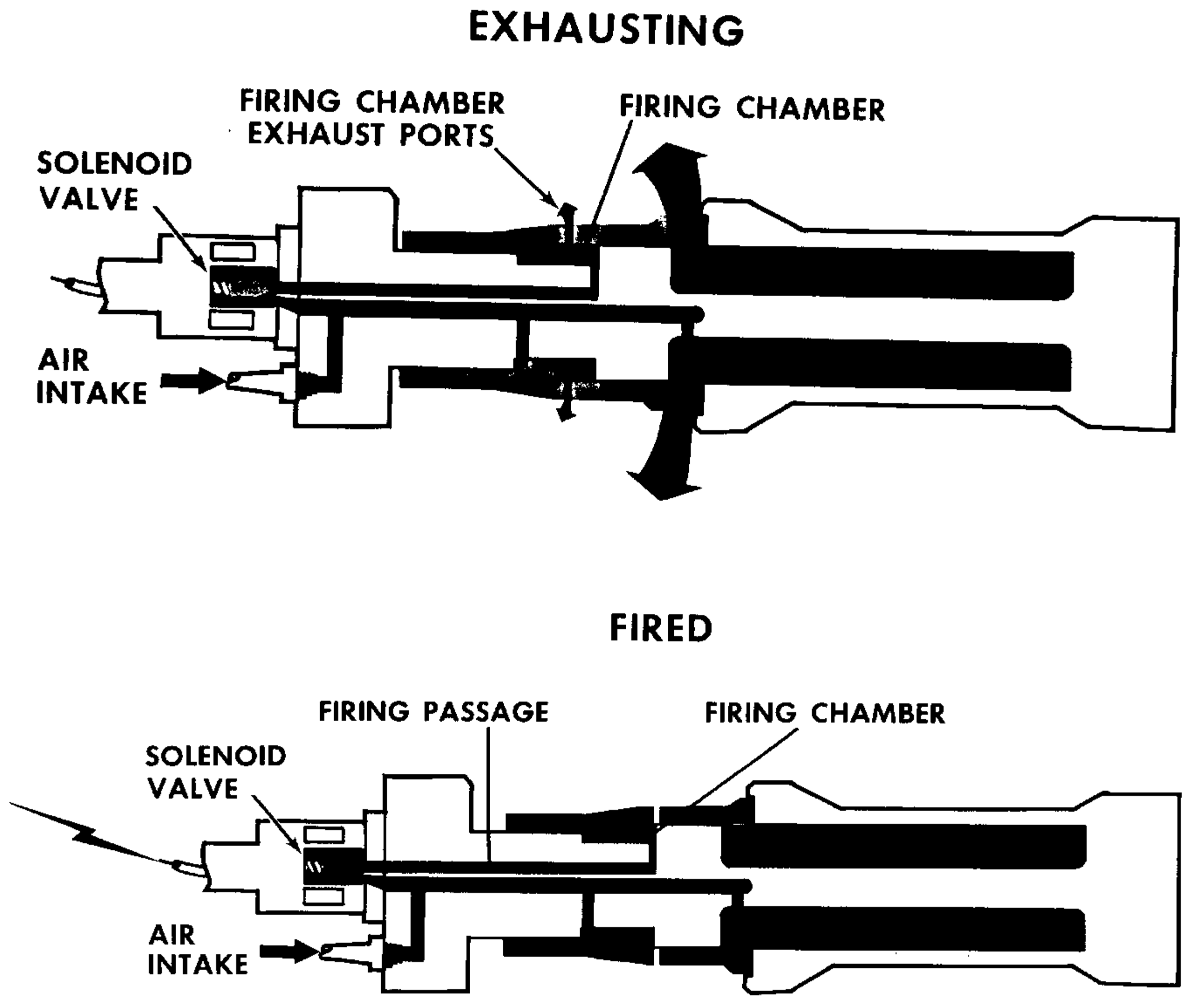
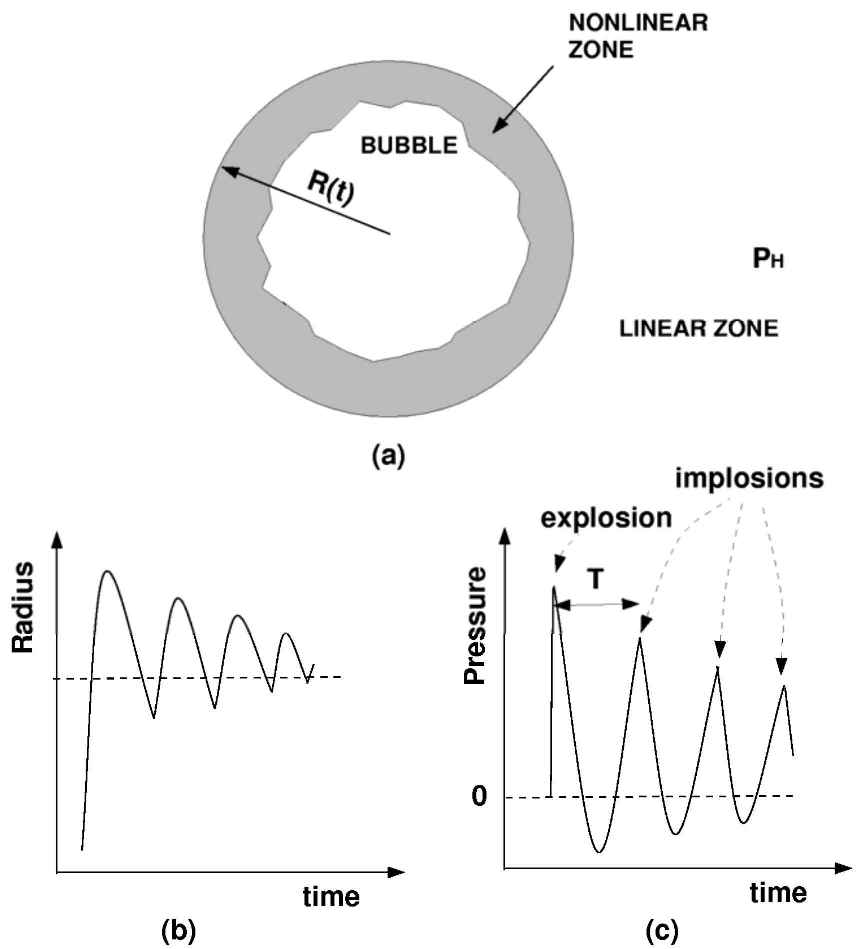
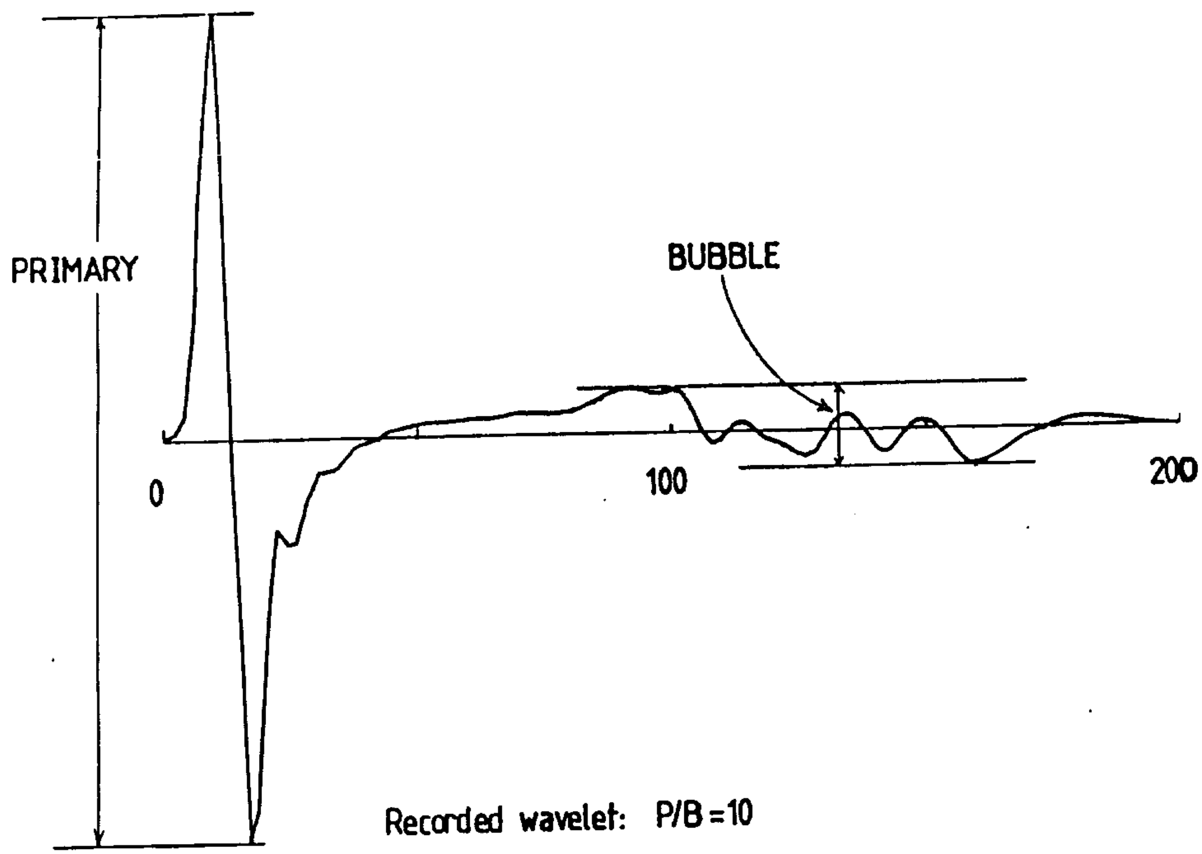


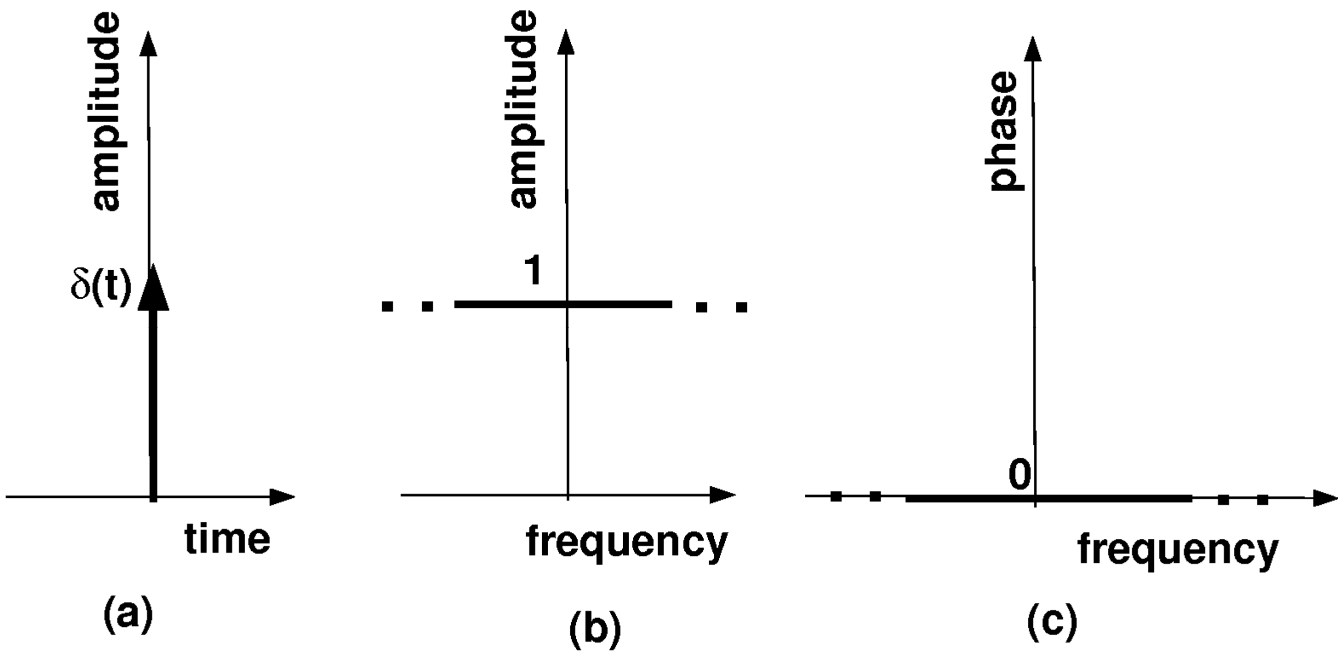
Airgun: mechanical behaviour



Source signals: airgun



Source signals *S(t)*: Vibrator source



Seismic source on land: VibroSeis

Seismic source on land: VibroSeis

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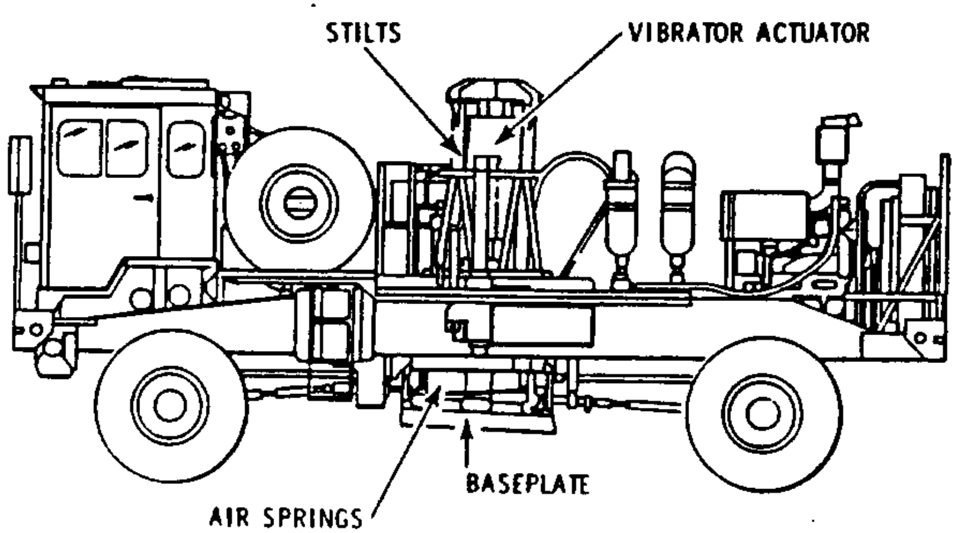
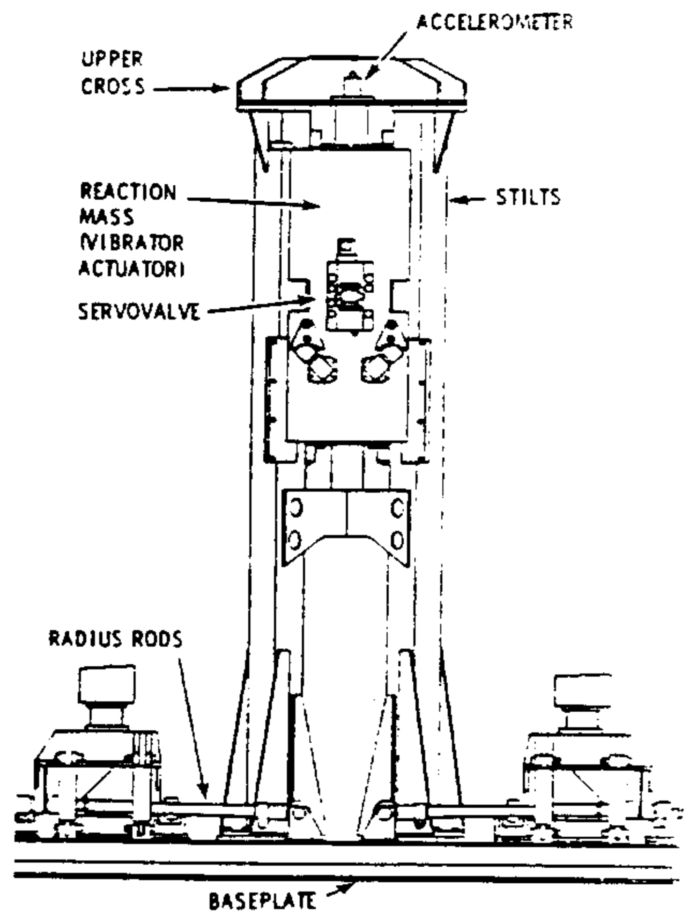
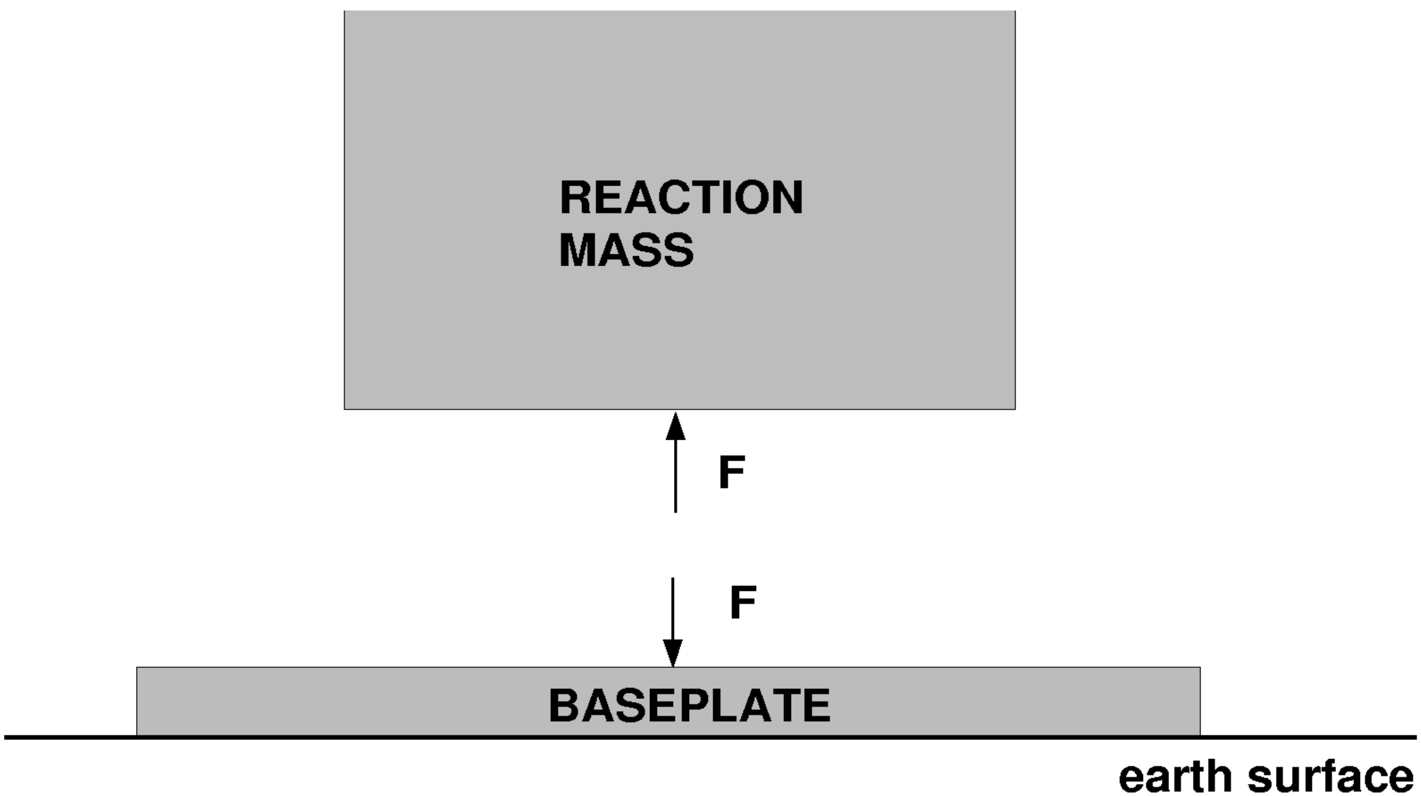
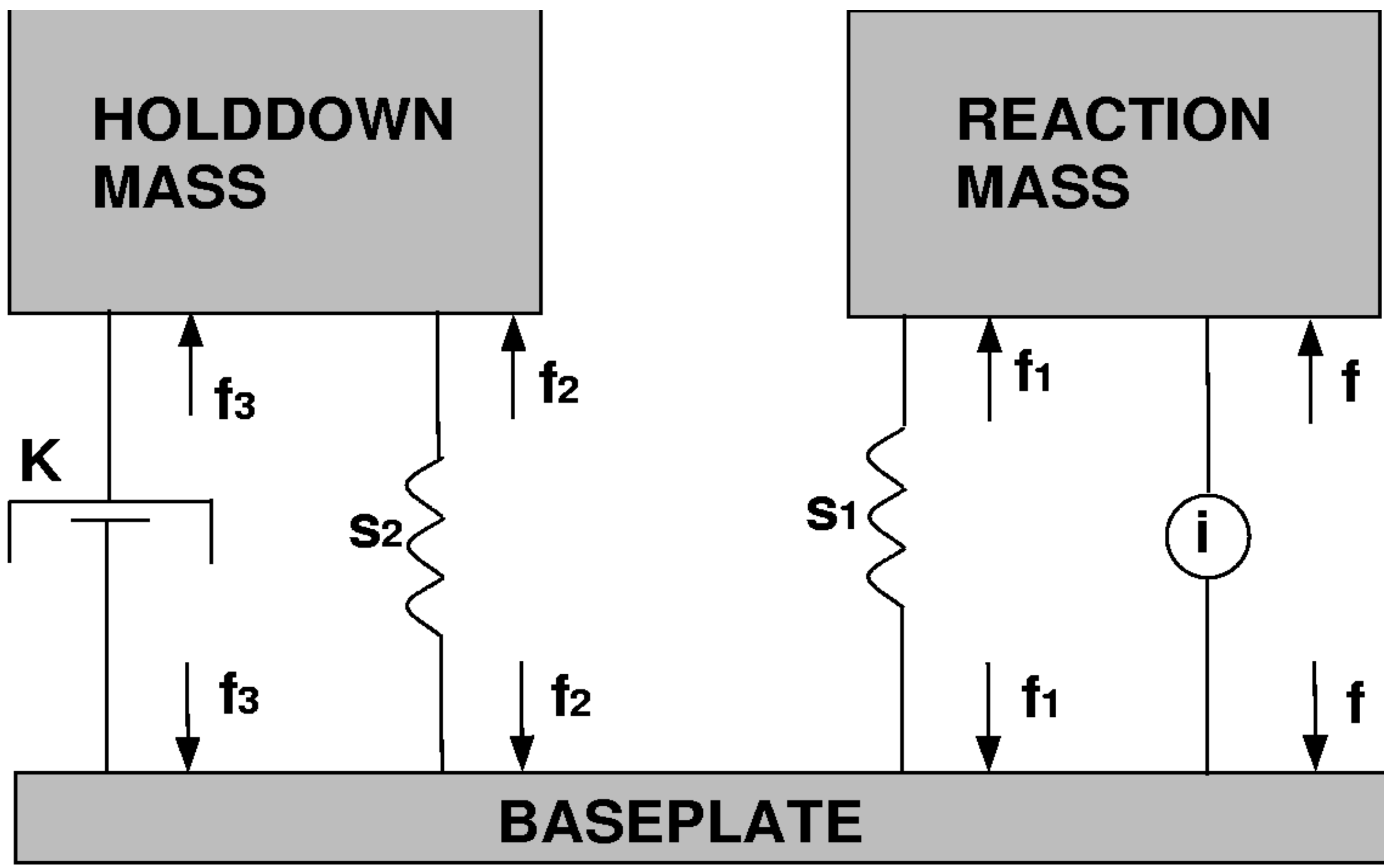




VibroSeis: simple mechanical model



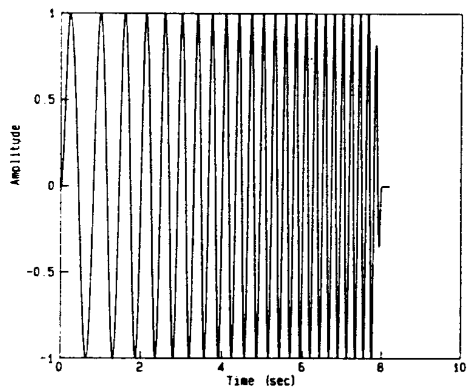
VibroSeis: mechanical model



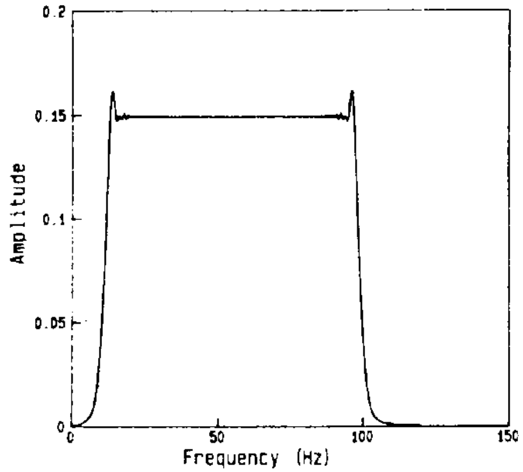
Source signals *S(t)*: Vibrator source

<u>frequency domain</u>

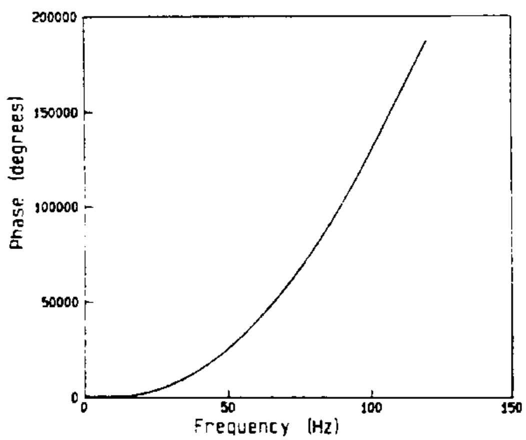
<u>Time domain</u>



(a)



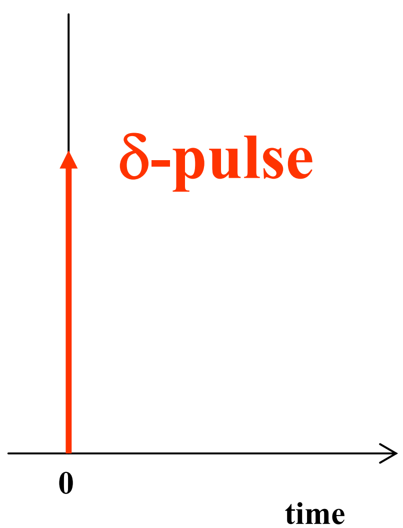
(b)



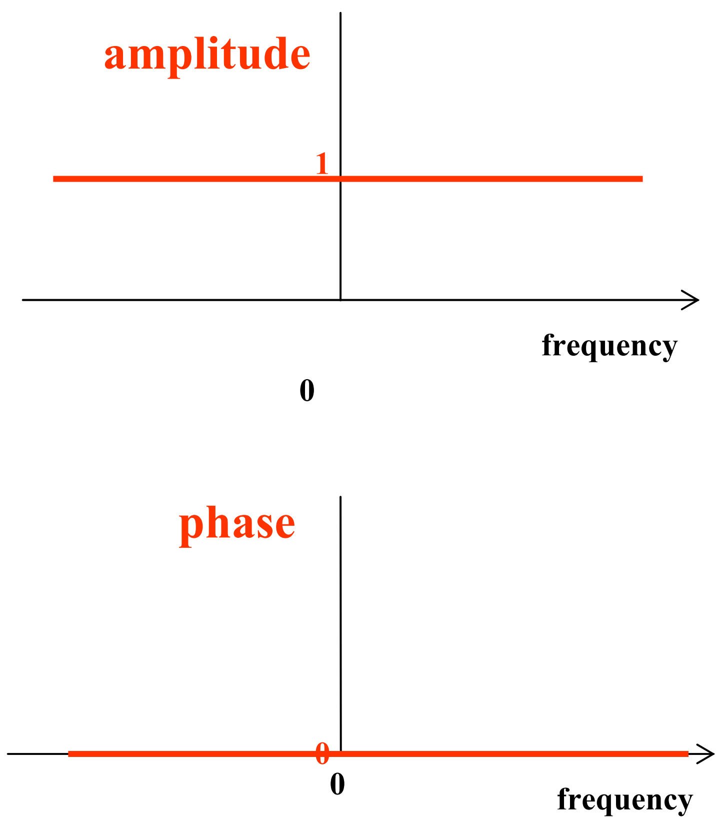
(c)

Source signal: δ-pulse

<u>Time domain</u>

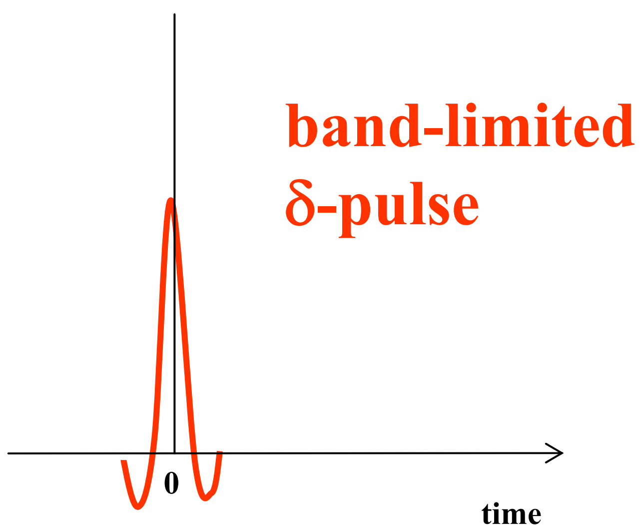


<u>Frequency domain</u>

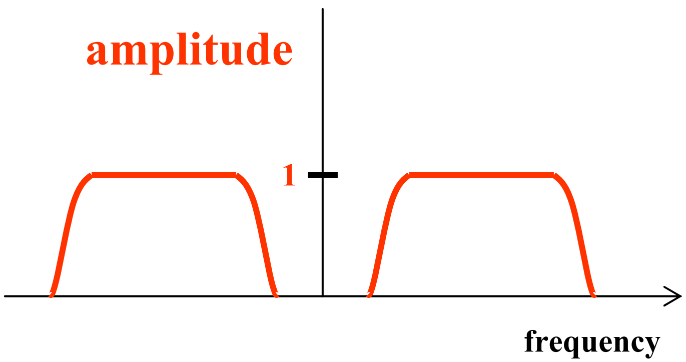


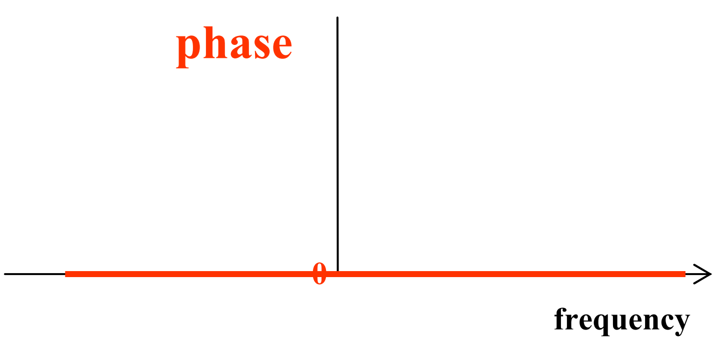
Source signal: band-limited δ-pulse

Time domain



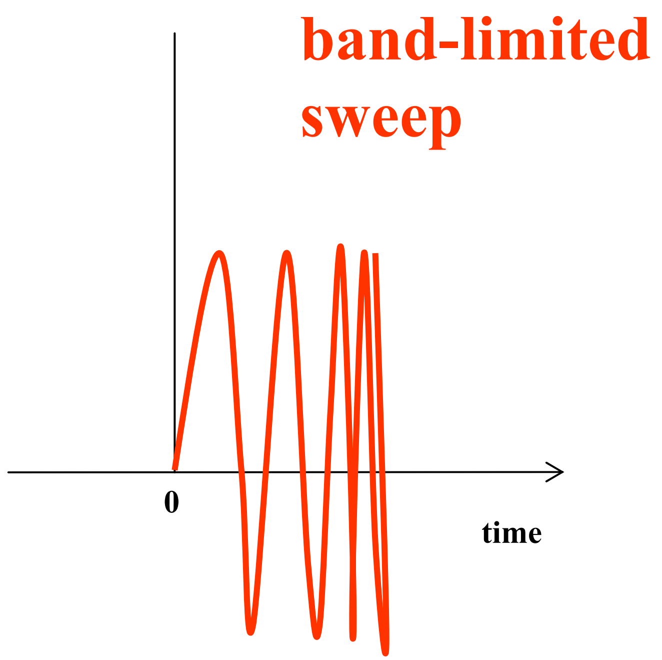
Frequency domain



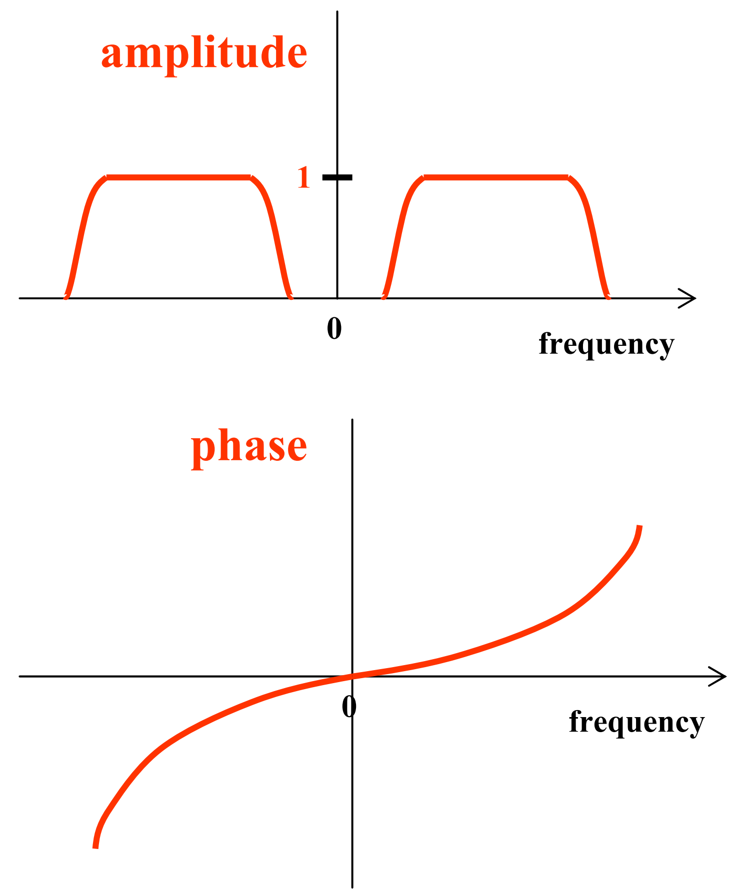


Source signal: band-limited sweep (=VibroSeis)

Time domain

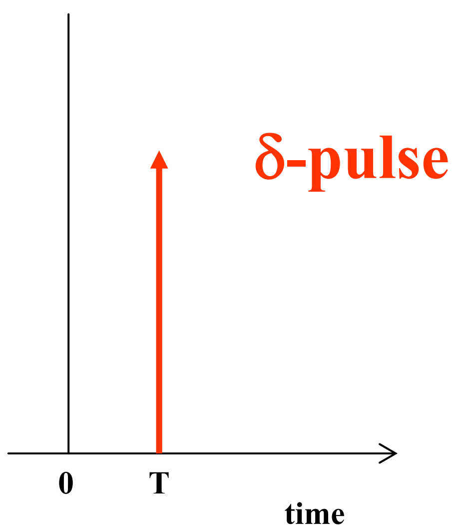


Frequency domain

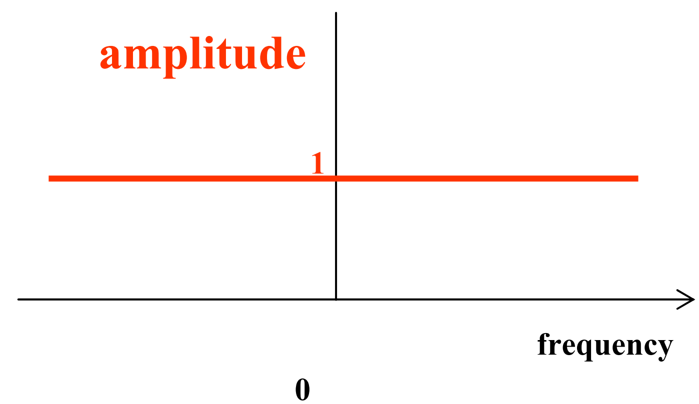


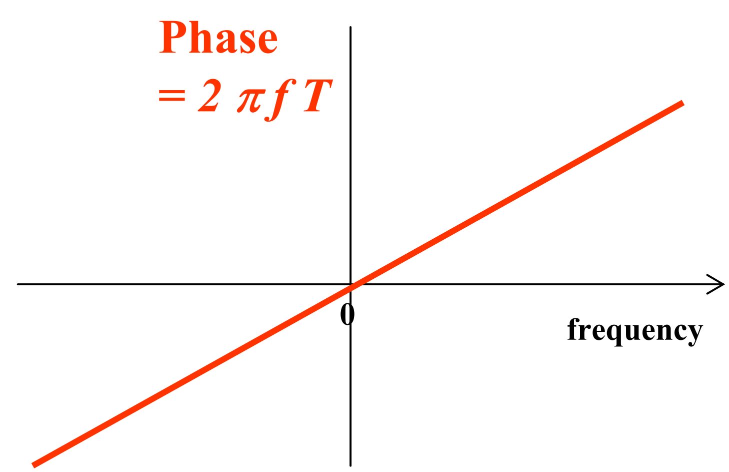
Source signal: shifted δ-pulse

<u>Time domain</u>



<u>Frequency domain</u>: *exp(-2π i f T)*

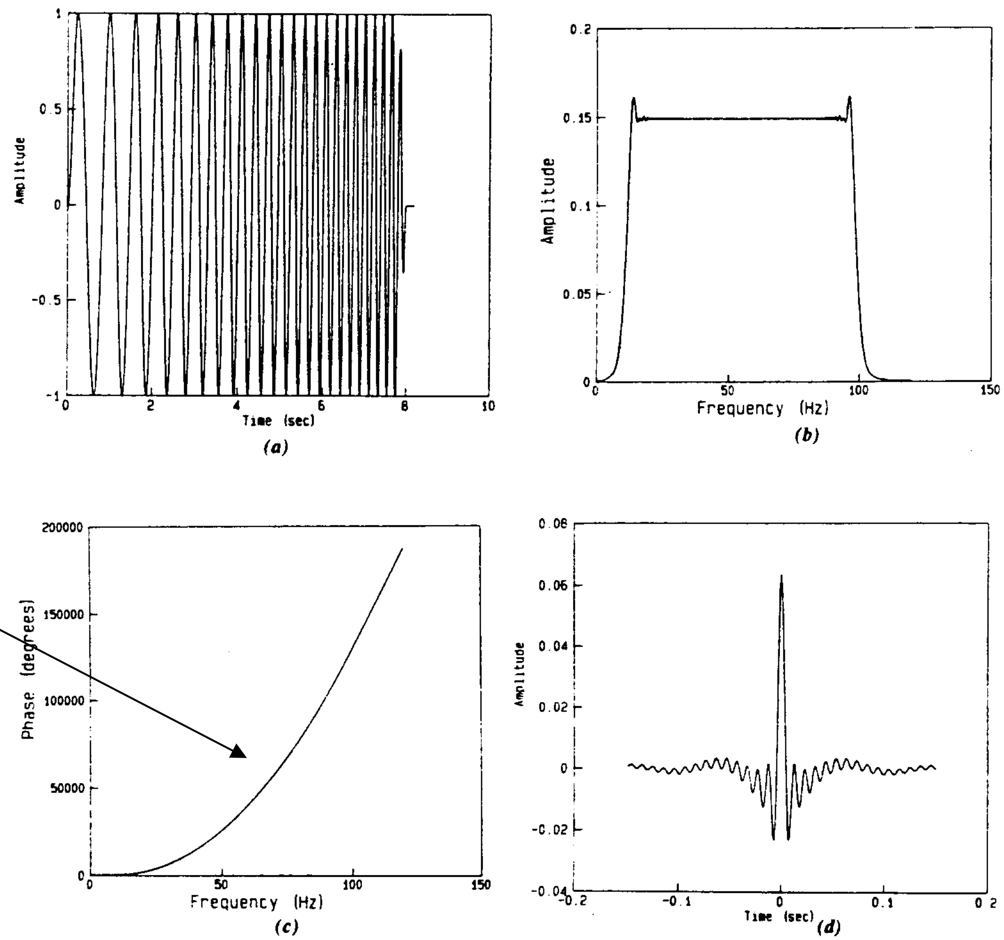




Source signals: Vibrator source

For sweep:
Higher frequencies,
later in time

So: $-2\pi f T$
non-linear
(more quadratic)



Source signals: Vibrator source

Undoing effect source signal (phase ***and*** amplitude): deconvolution

$$F(\omega)X(\omega) = \frac{X(\omega)S^*(\omega)}{S(\omega)S^*(\omega) + \epsilon^2}$$

Notice that **numerator** of stabilized deconvolution is **correlation**

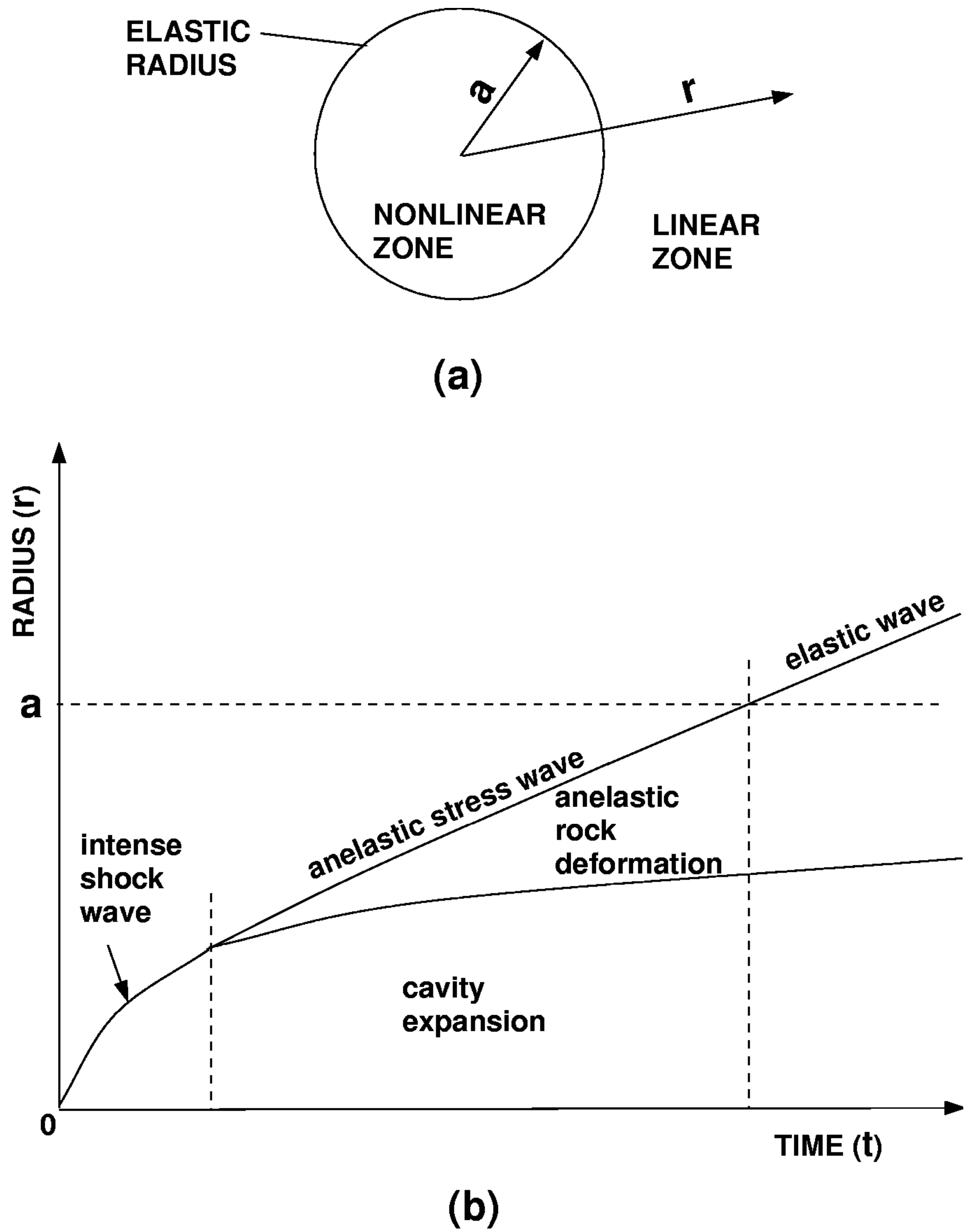
Source signals: Vibrator source

Seismic source on land: dynamite

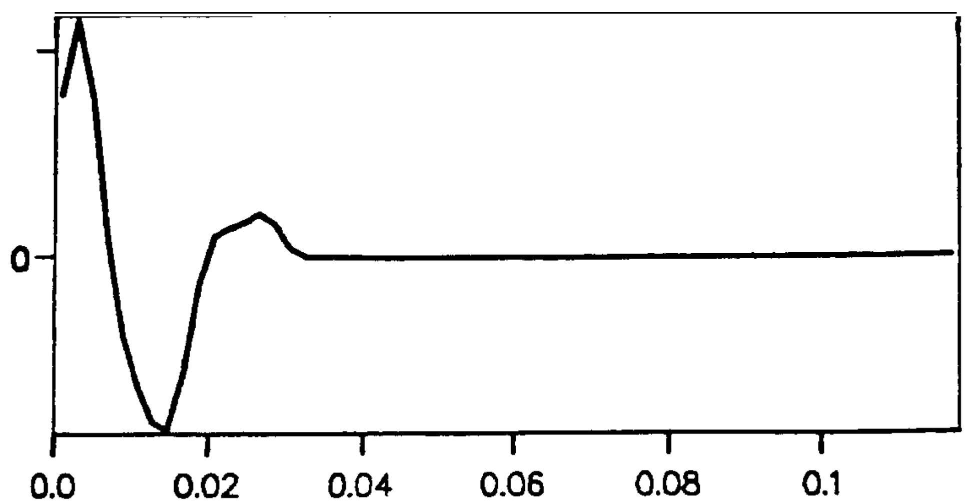
Dynamite

Dynamite

Dynamite: model

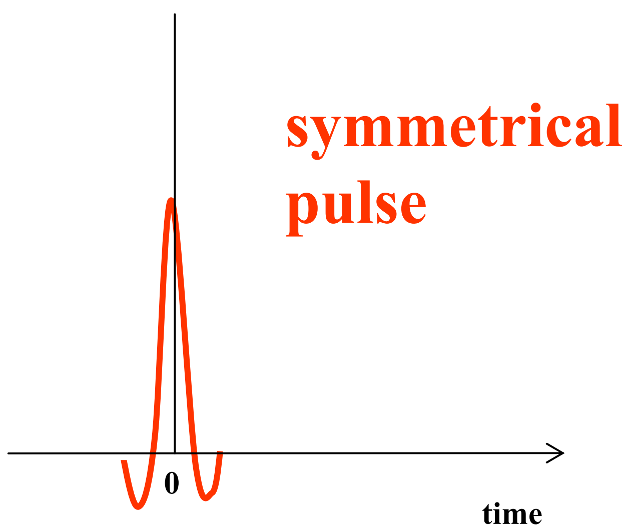


Source signals *S(t)*: Dynamite

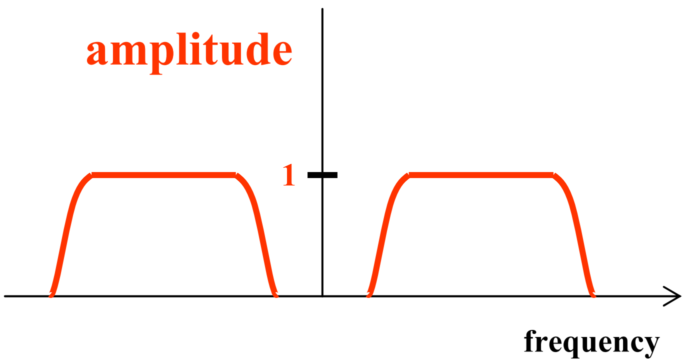


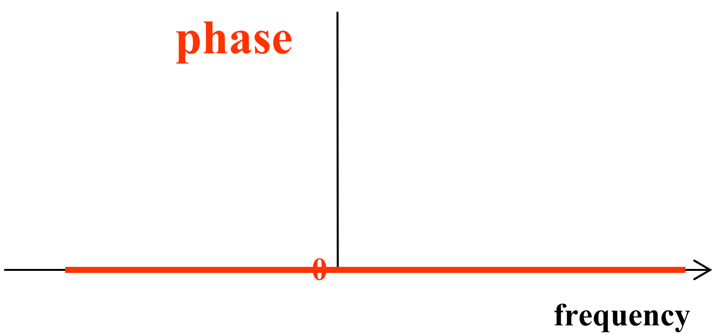
Source signal: symmetrical signal

Time domain



Frequency domain





symmetrical signal in time

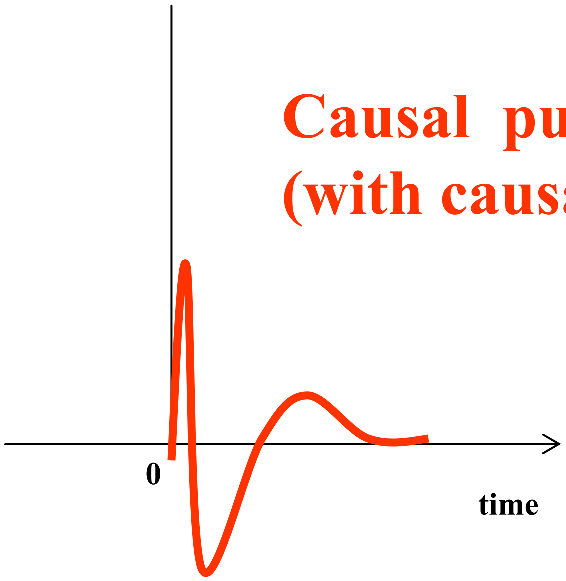
=

spectrum is purely real, so zero phase

Source signal: causal signal (with causal inverse)

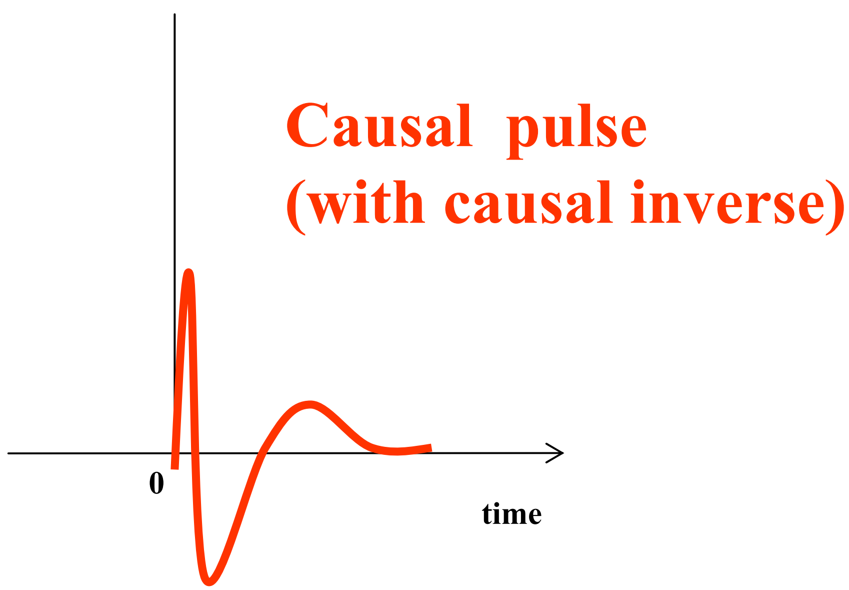
Causal signal
=
Amplitude zero before zero time

Time domain

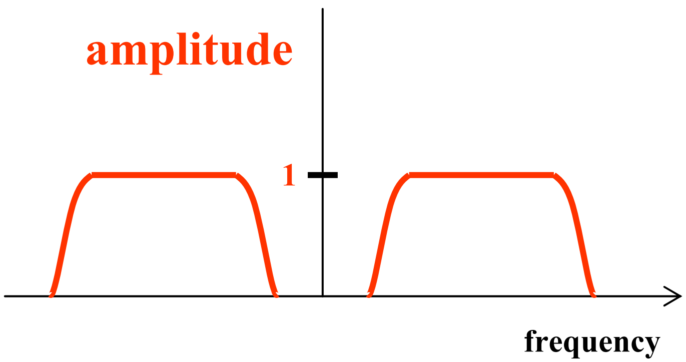


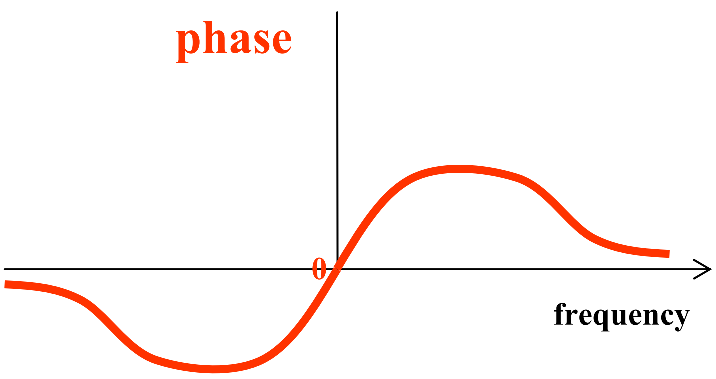
Source signal: causal signal (with causal inverse)

Time domain



Frequency domain





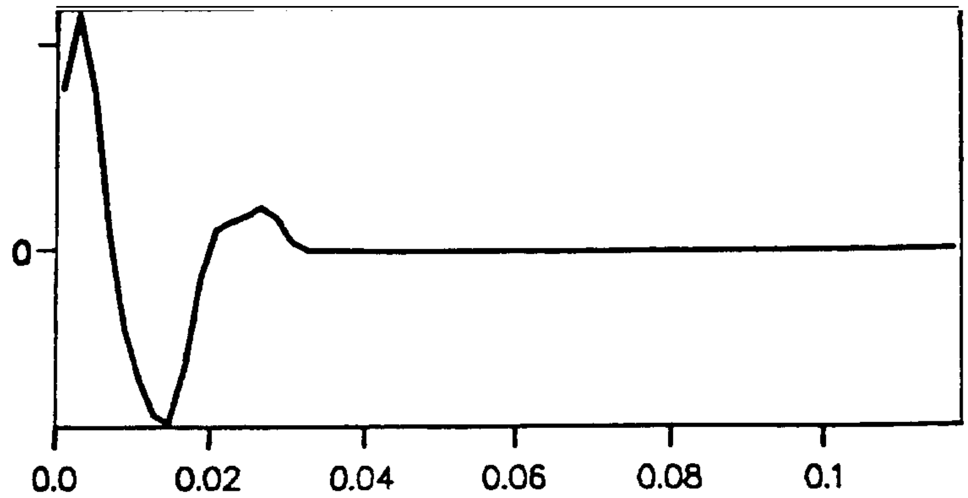
causal pulse with causal inverse in time

=

phase spectrum is minimally going through 2π, so minimum-phase

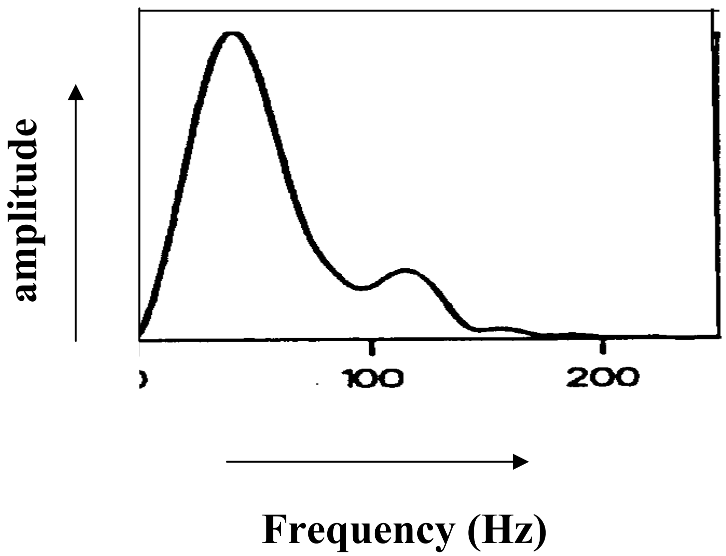
Minimum-phase pulse has most of its energy in the beginning

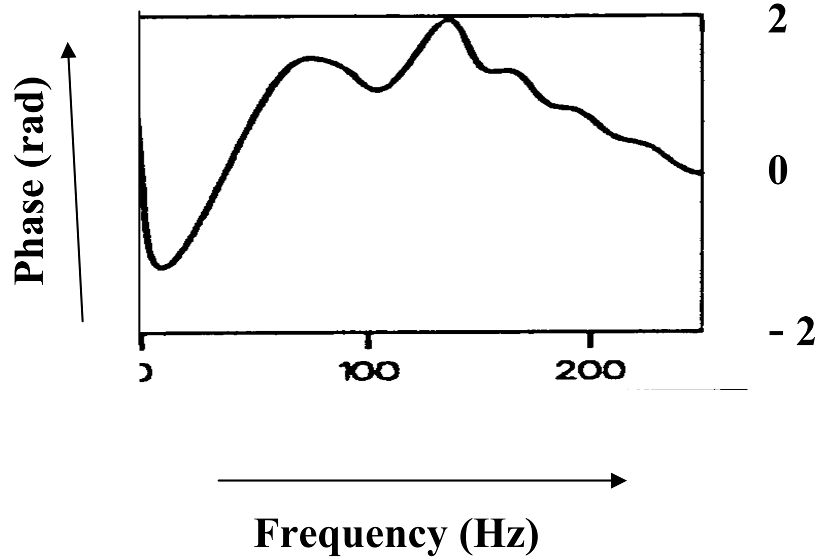
Source signals *S(t)*: Dynamite



Dynamite signal seen as minimum-phase signal

Dynamite: spectrum





Convolutional model of seismic data

In time domain, output is convolution of input and impulse responses

$$X(t) = S(t) * \mathbf{G(t)} * R(t) * A(t)$$

where

$X(t)$ = seismogram
$S(t)$ = source signal/wavelet
$G(t)$ = impulse response of earth
$R(t)$ = impulse response of receiver
$A(t)$ = impulse response of recording-instrument

Impulse response of earth $G(t)$

Desired for processing

Still: undesired events need to be removed

Convolutional model of seismic data

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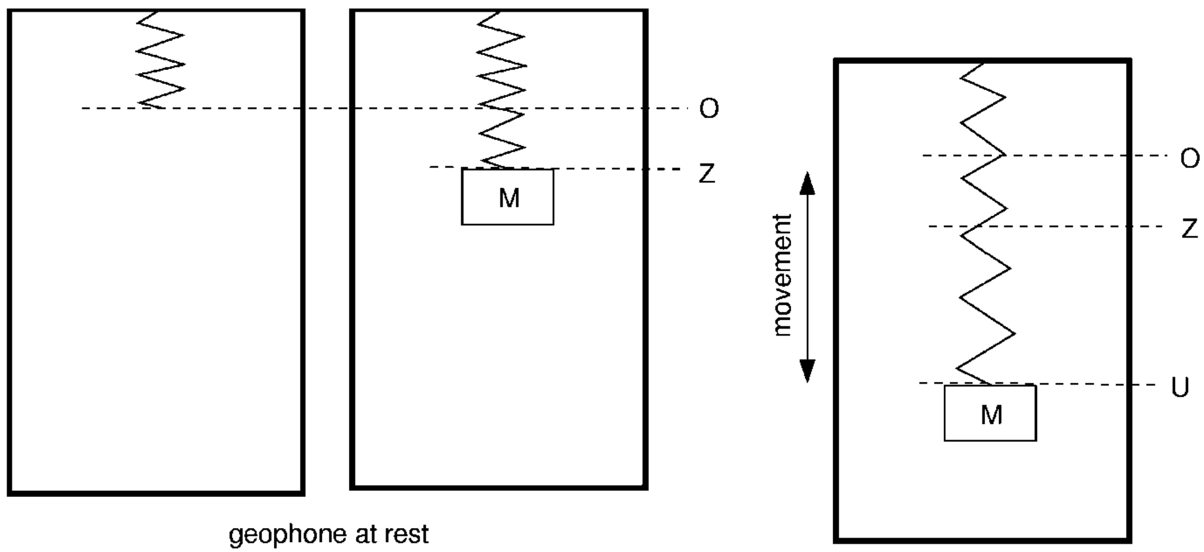
Seismic detector on land: geophone (velocity sensor)

Seismic detector on land: geophone

Geophone



Spectrum of geophone $R(\omega)$

$$R(\omega) = \frac{\text{Voltage}}{\text{Particle Velocity}}$$

$$= \frac{V(\omega)}{v_z(\omega)} = \frac{\omega^2 K}{\omega^2 - 2ih\omega\omega_0 - \omega_0^2}$$

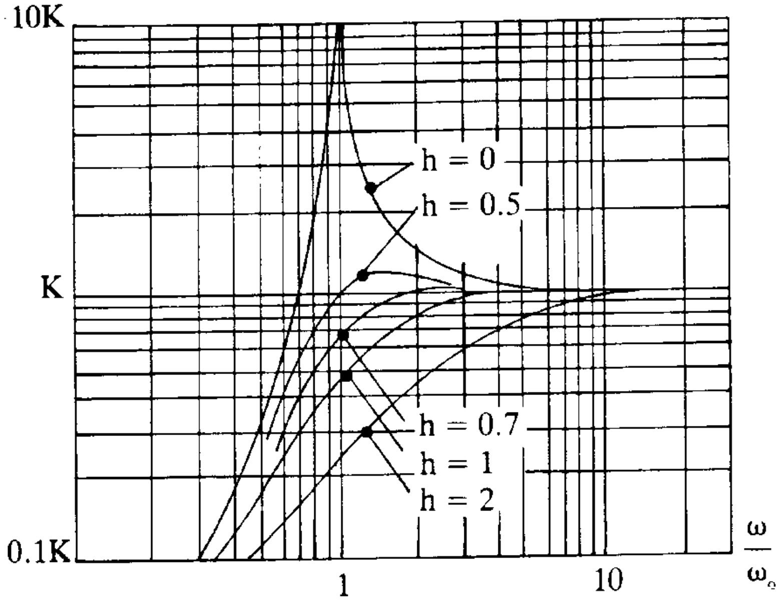
Spectrum of geophone *R(ω)*

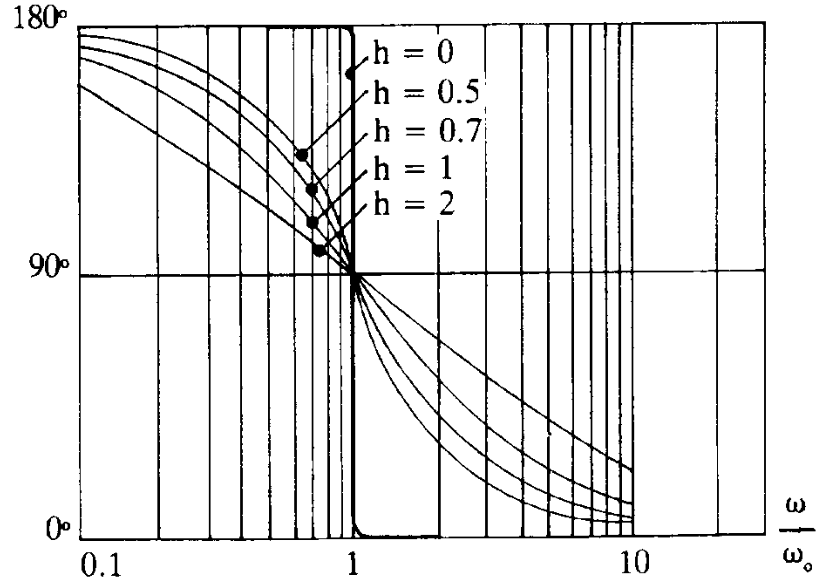
$$\omega \rightarrow 0: \qquad R(\omega) \rightarrow -\frac{\omega^2}{\omega_0^2} K = \frac{\omega^2}{\omega_0^2} K \exp(\pi i)$$

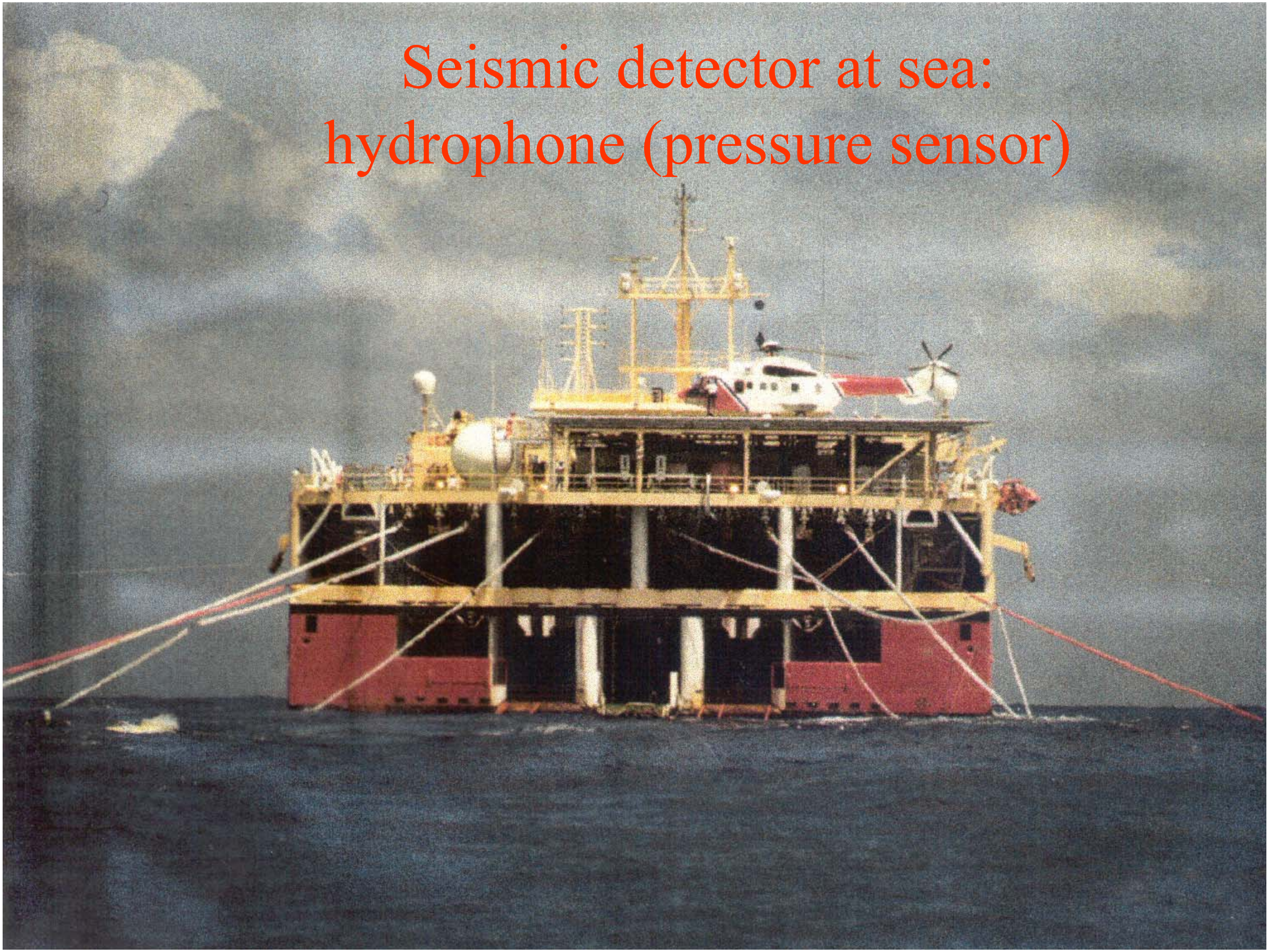
$$\omega = \omega_0: \qquad R(\omega) \rightarrow \frac{K}{-2ih} = \frac{K}{2h} \exp(\pi i/2)$$

$$\omega \rightarrow \infty: \qquad R(\omega) \rightarrow K$$

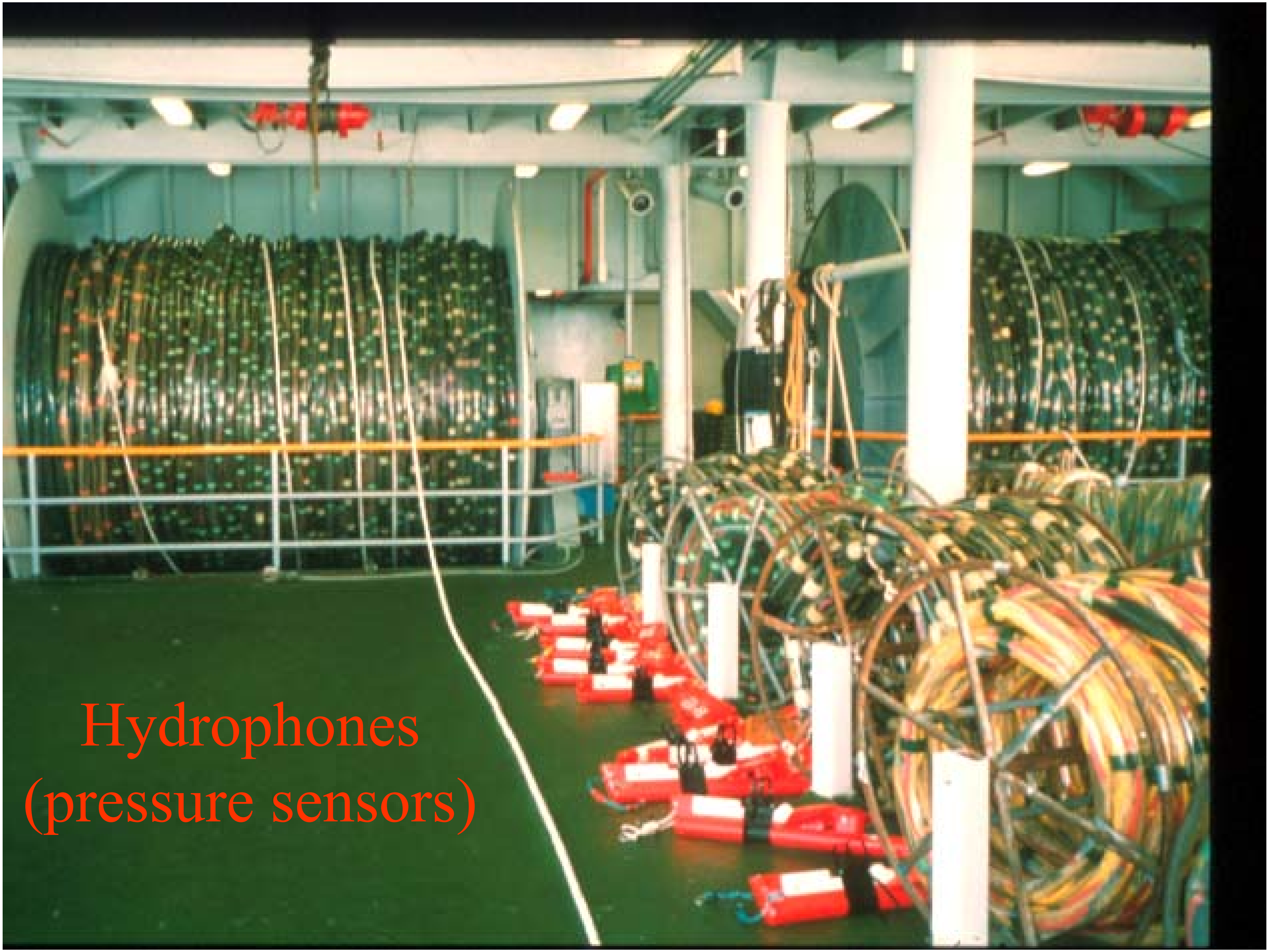
Spectrum of geophone *R(ω)*



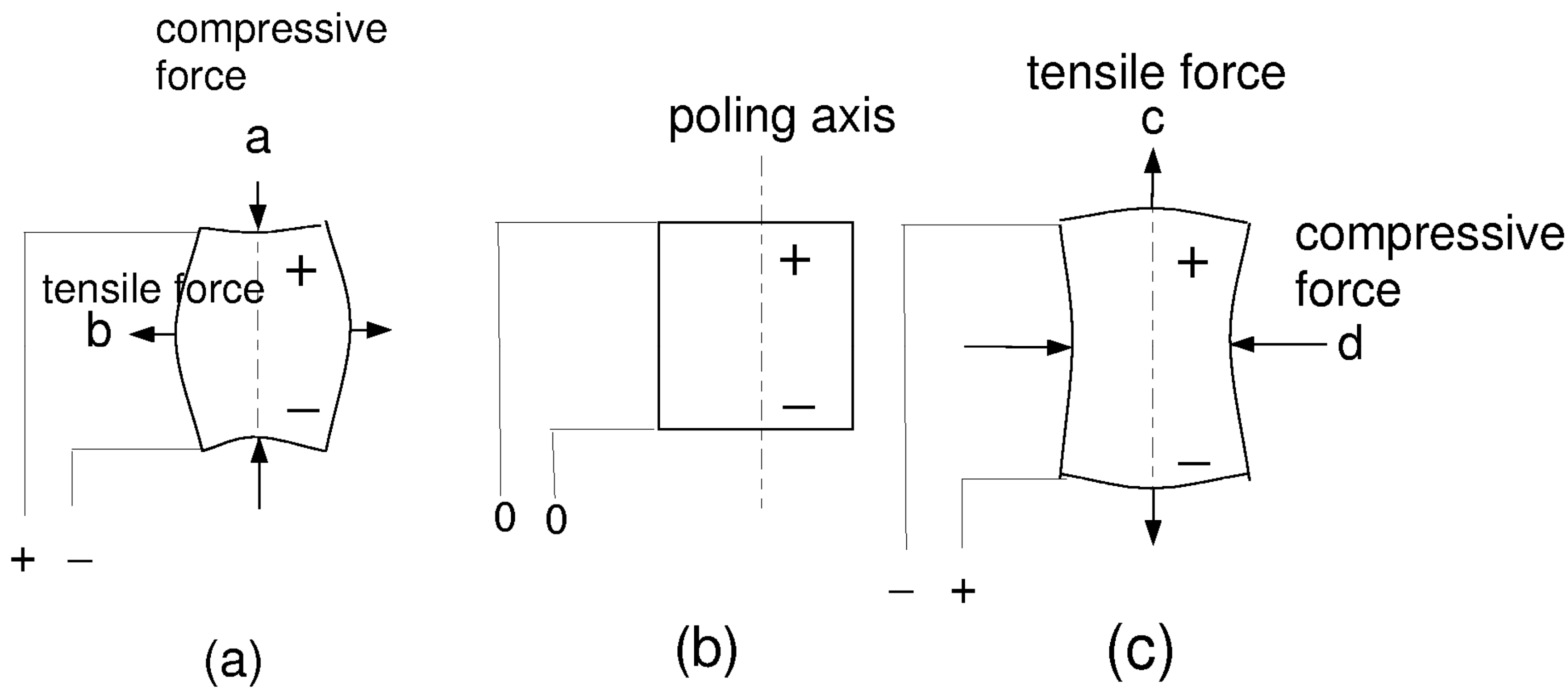



Seismic detector at sea:
hydrophone (pressure sensor)

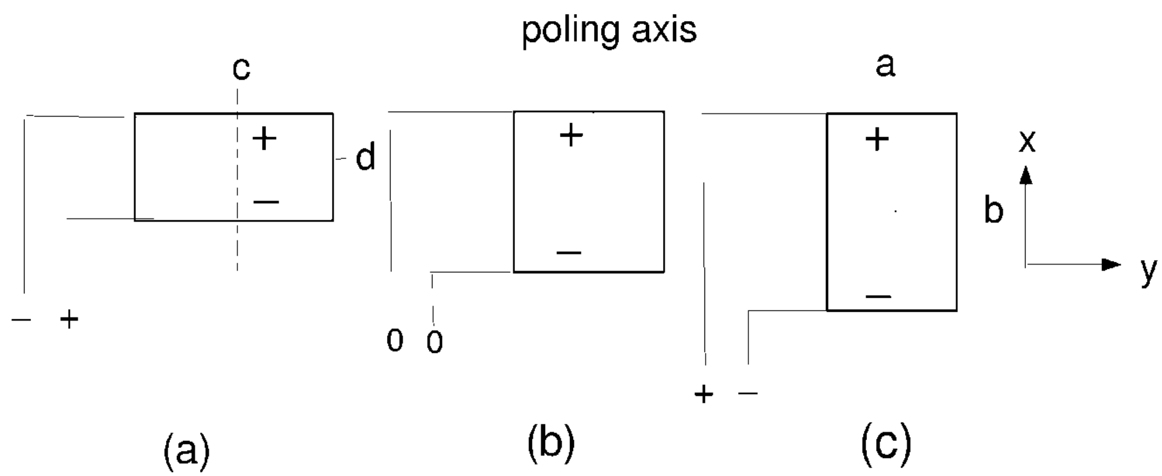
Hydrophone (pressure sensor)


Hydrophones
(pressure sensors)

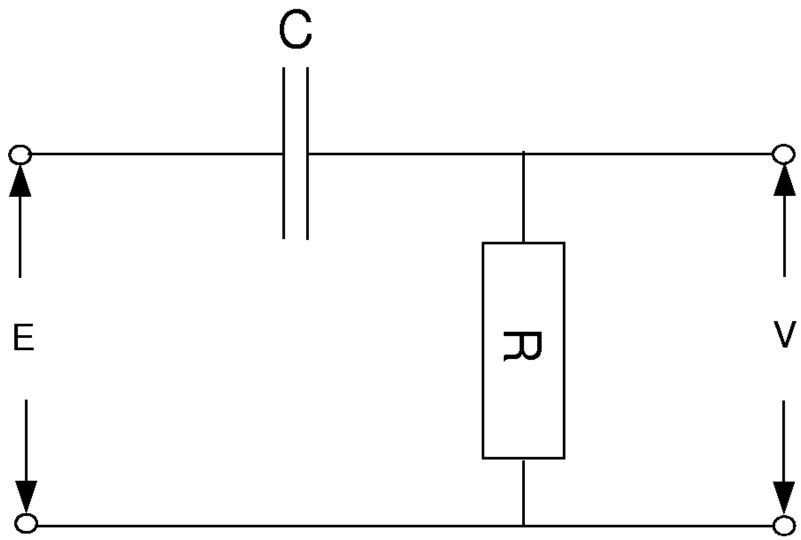
Hydrophone model: piezo-electricity



Hydrophone: piezo-electric



Hydrophone: piezo-electric



Spectrum of hydrophone *R(ω)*

$$R(\omega) = \frac{\text{Voltage}}{\text{Pressure}}$$

$$= \frac{V}{E} = \frac{R}{R + \frac{1}{i\omega C}} = \frac{i\omega CR}{1 + i\omega CR}$$

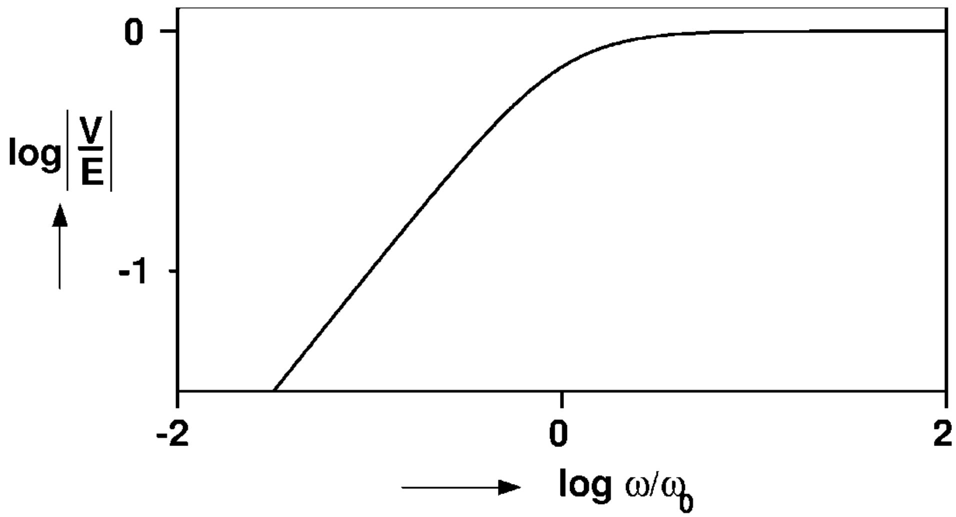
Spectrum of hydrophone *R(ω)*

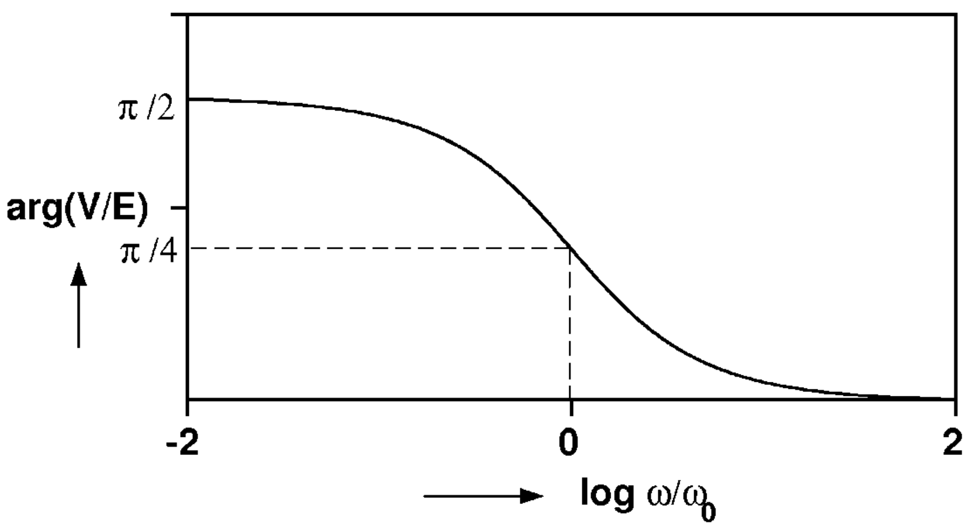
$$\omega \to 0: \qquad \frac{V(\omega)}{E} \to i\omega CR = \omega CR \exp(\pi i/2)$$

$$\omega = 1/CR: \qquad \frac{V(\omega)}{E} \to \frac{i}{1+i} = \frac{1}{2}\sqrt{2}\exp(\pi i/4)$$

$$\omega \to \infty: \qquad \frac{V(\omega)}{E} \to 1$$

Spectrum of hydrophone *R(ω)*





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On-board QC


RECORDING

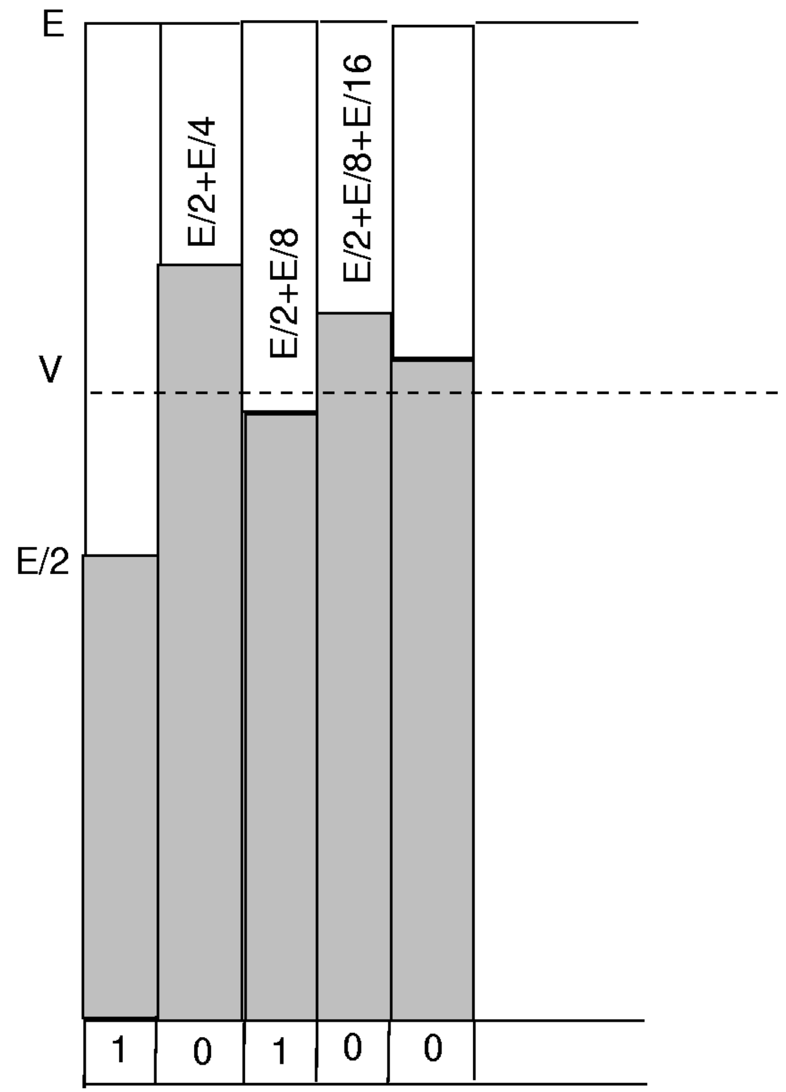
Storage:

IBM 3592 tapes (right-hand corner above)

Seismic recording systems

Main tasks:

- **Convert Analog signals to Digital signals**
- **Store data**



Recording Instrument

Sample data correctly:

Nyquist is determined by setting time-sampling interval Δt:

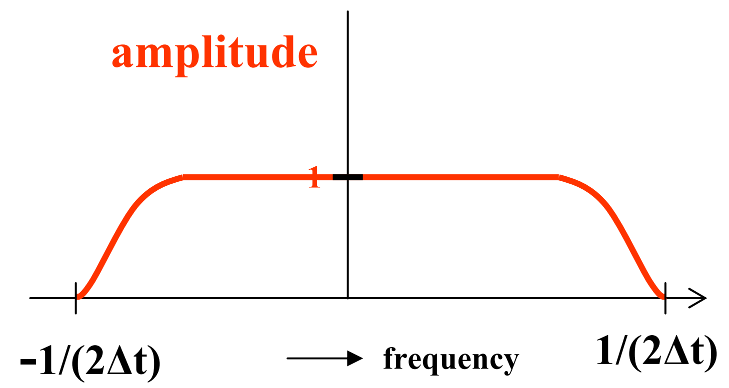
$$f_{Nyquist} = 1 / (2\ \Delta t)$$

Then:

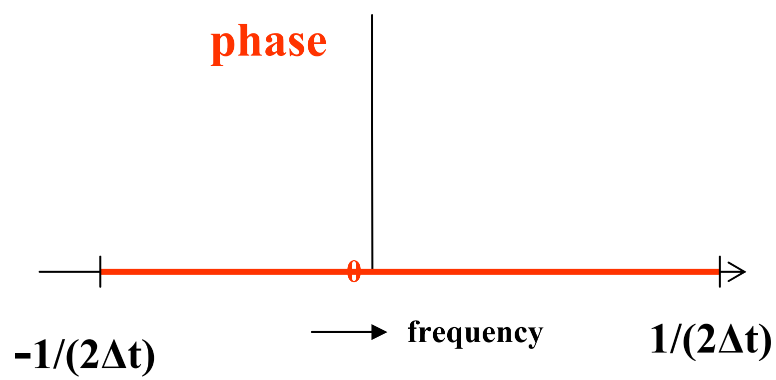
Cut high frequencies such that above $f_{Nyquist}$ analog signal is damped below noise level

Recording instrument A(ω): high-cut filter

Frequency domain



High-cut filter
=
Anti-alias filter



Total response of instrumentation

In frequency domain, output is multiplication of spectra:

$$X(\omega) = \mathbf{S(\omega)}\, G(\omega)\, \mathbf{R(\omega)}\, \mathbf{A(\omega)}$$

where

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$S(\omega)$ = source signal/wavelet
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$R(\omega)$ = transfer function of receiver
$A(\omega)$ = transfer function of recording-instrument

(transfer function = spectrum of impulse response)

Total response of instrumentation

In frequency domain, output is multiplication of spectra:

$X(\omega) = S(\omega)\ G(\omega)\ R(\omega)\ A(\omega)$

$$
\begin{aligned}
X(\omega) &= |S(\omega)||G(\omega)||R(\omega)||A(\omega)| \exp(i\phi_S) \exp(i\phi_G) \exp(i\phi_R) \exp(i\phi_A) \\
&= |S(\omega)||G(\omega)||R(\omega)||A(\omega)| \exp\{i(\phi_S + \phi_G + \phi_R + \phi_A)\}
\end{aligned}
$$

Total response of instrumentation