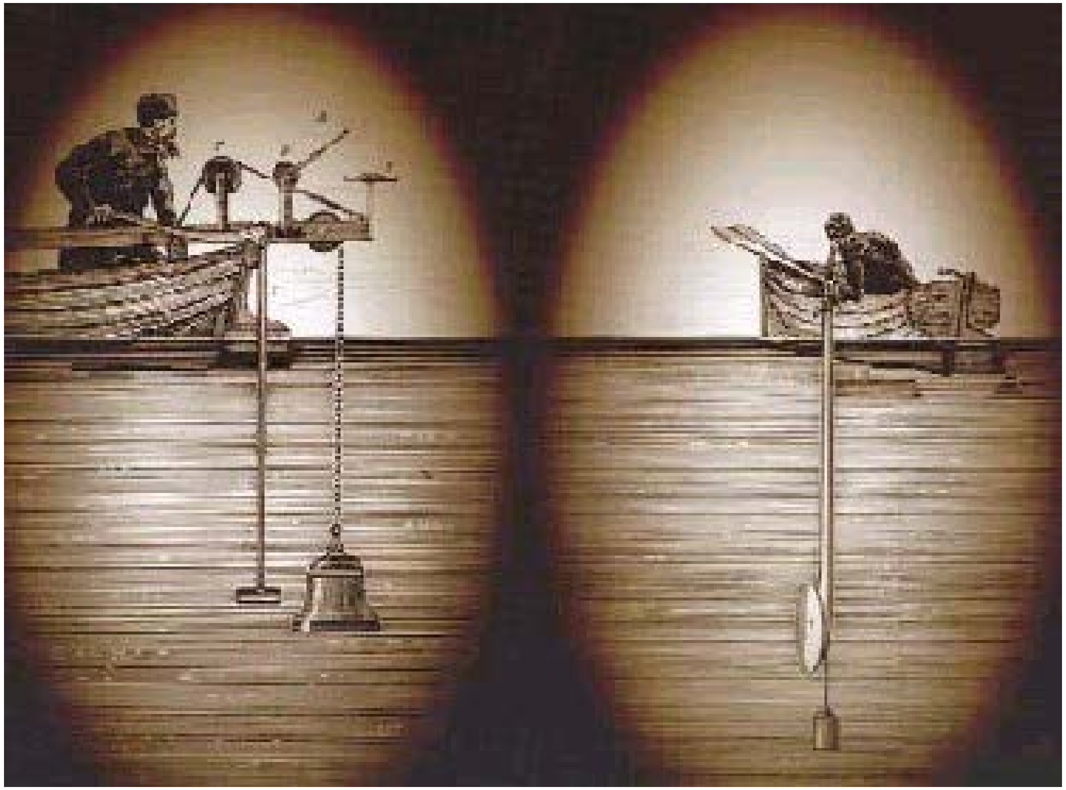
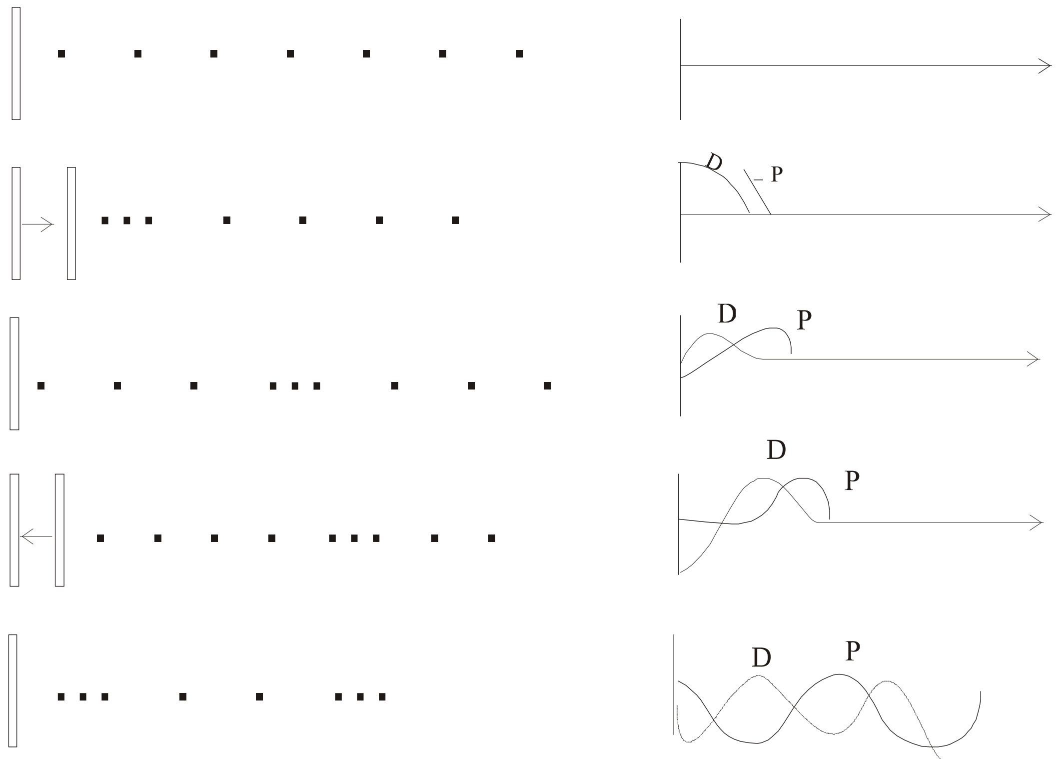
Principles of Underwater Sound



LO: Apply characteristics of sound in water to calculate sound levels.

What is Sound?

A disturbance propagated through an elastic medium causing a detectable alteration in pressure or a displacement of the particles.



Measuring Sound

Pressure (p): force/area

p = force/area, units Newton/m^2 (Pascal), $[MLT^{-2}/L^2] = [MT^{-2}L^{-1}]$

Imperial to SI conversion: 1 μBar = 10^5 μPa

Power (P): force * velocity

P = force * velocity, units watts, $[MLT^{-2} * LT^{-1}] = [ML^2T^{-3}]$

Intensity (I): power/area

I = power/area = $p^2/\rho c$

where ρ = density, mass/volume, units kg m^{-3} $[ML^{-3}]$

Quantity Relationships

Intensity is proportional to pressure squared

$$I \propto p^2$$

Pressure squared is proportional to power

$$p^2 \propto P$$

What is relationship between Intensity and Power?

What is a Decibel ?

A ratio in logarithmic form.

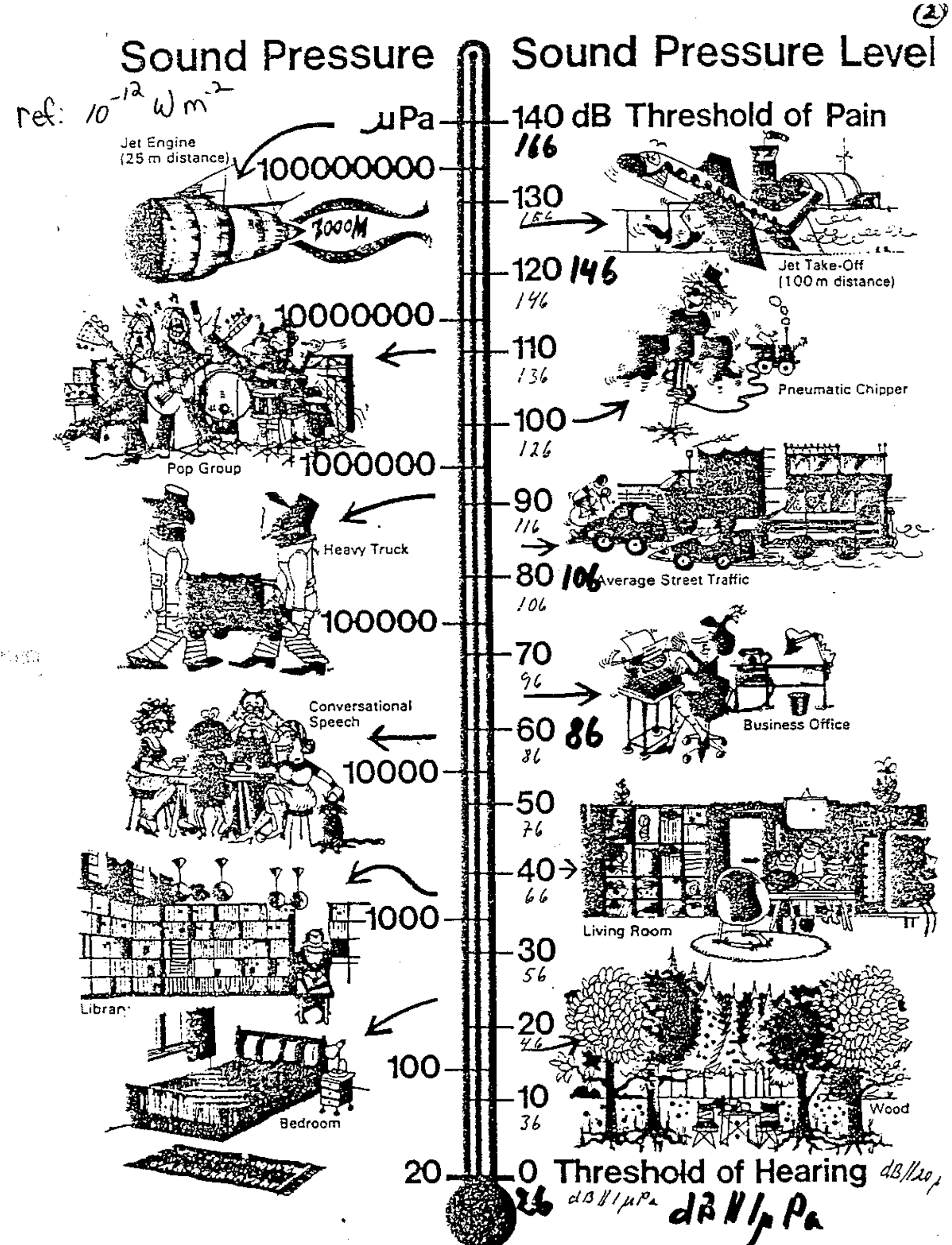
Intensity ratio: $10 \log (I/I_o)$ where I_o is the reference intensity at 1 m

Pressure ratio: $10 \log (p^2/\rho c/ p_o^2/\rho c) = 20 \log (p/p_o)$ where p_o is a reference pressure (1 μPa) at 1 m

Example:

If $I_o = 1\ Wm^{-2}$
Then $I = 100\ Wm^{-2}$ becomes $10 \log(100/1) = 20$ dB || $1\ Wm^{-2}$

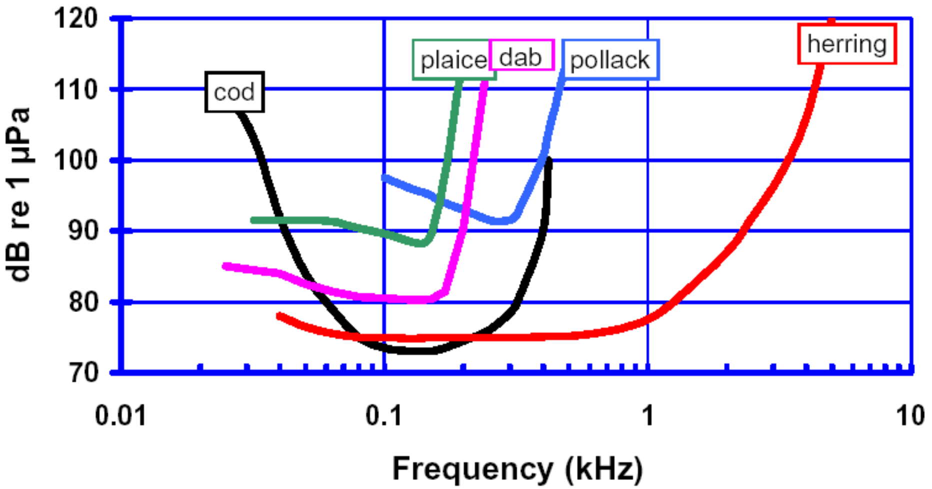
If $p_o = 1\ \mu Pa$
Then $p = 100{,}000\ \mu Pa$ becomes $20 \log(100{,}000/1) = 100$ dB || $1\ \mu Pa$



Air ref. = 0 dB

Water ref. = 26 dB

Animal Hearing Thresholds & Ranges



Human Hearing: 20 Hz to 20 kHz

courtesy of R. Mitson

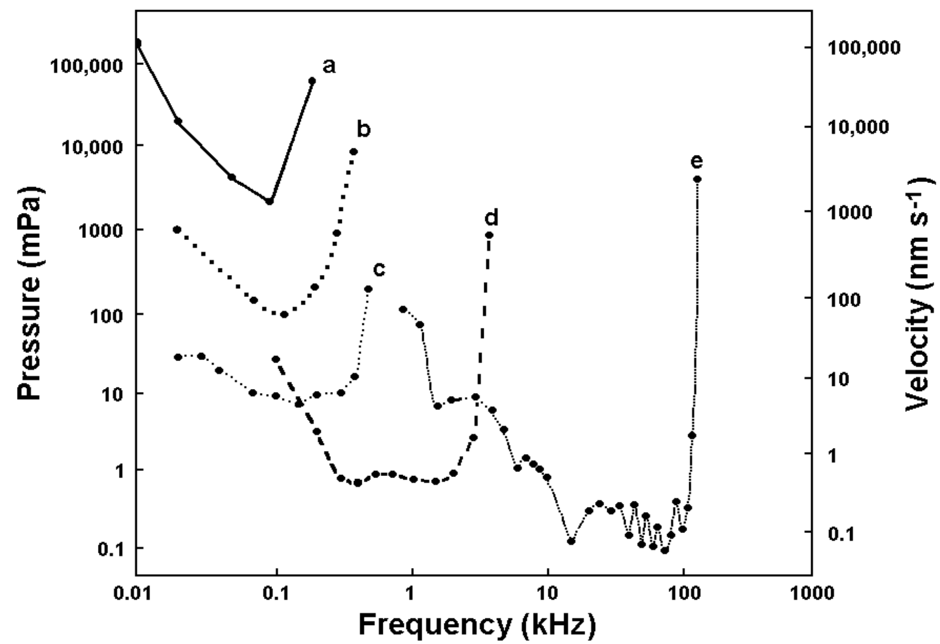
a) lobster

b) Atlantic salmon

c) Atlantic cod

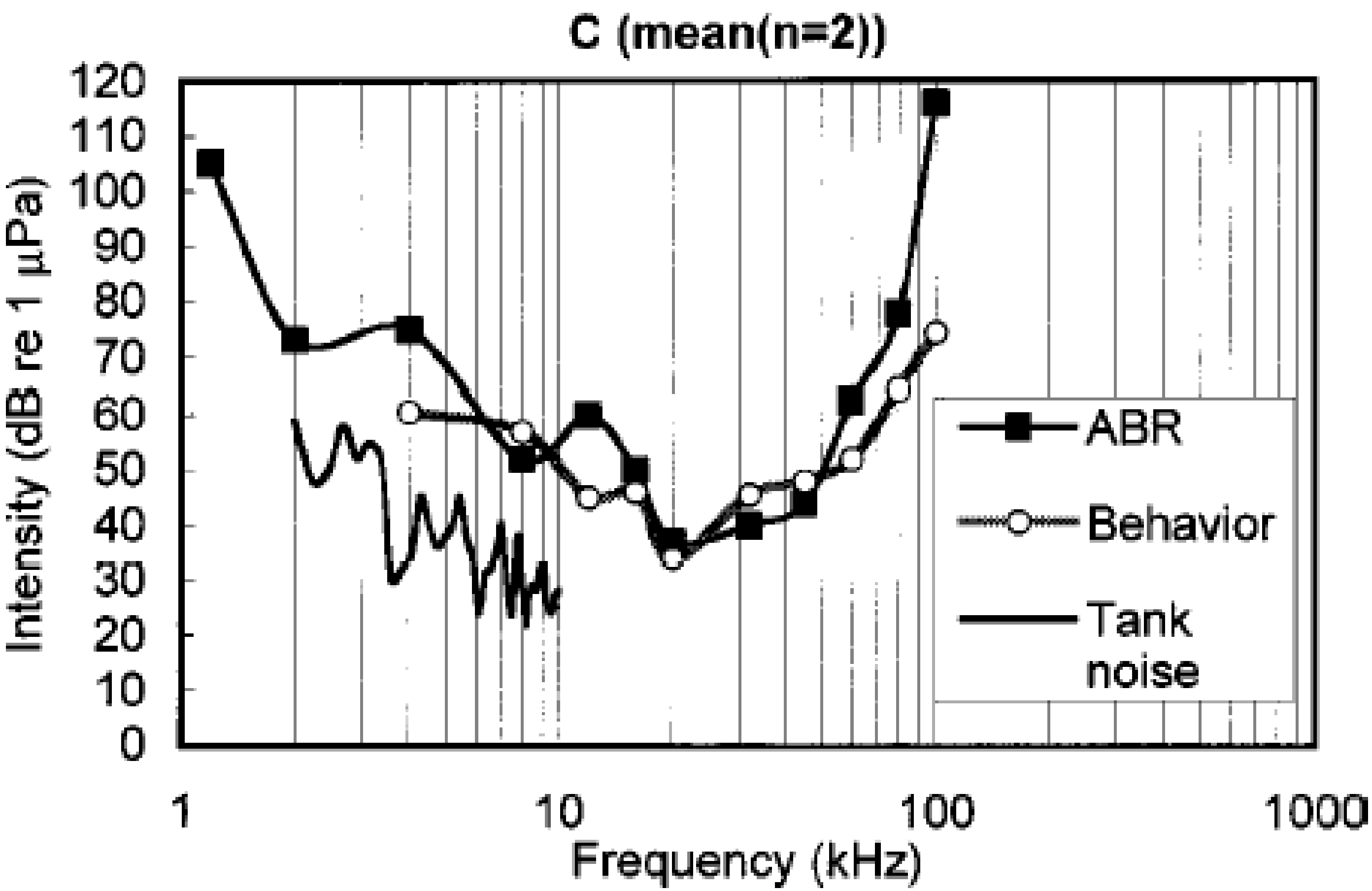
d) soldier fish

e) bottle-nose dolphin



MacLennan & Simmonds 1992

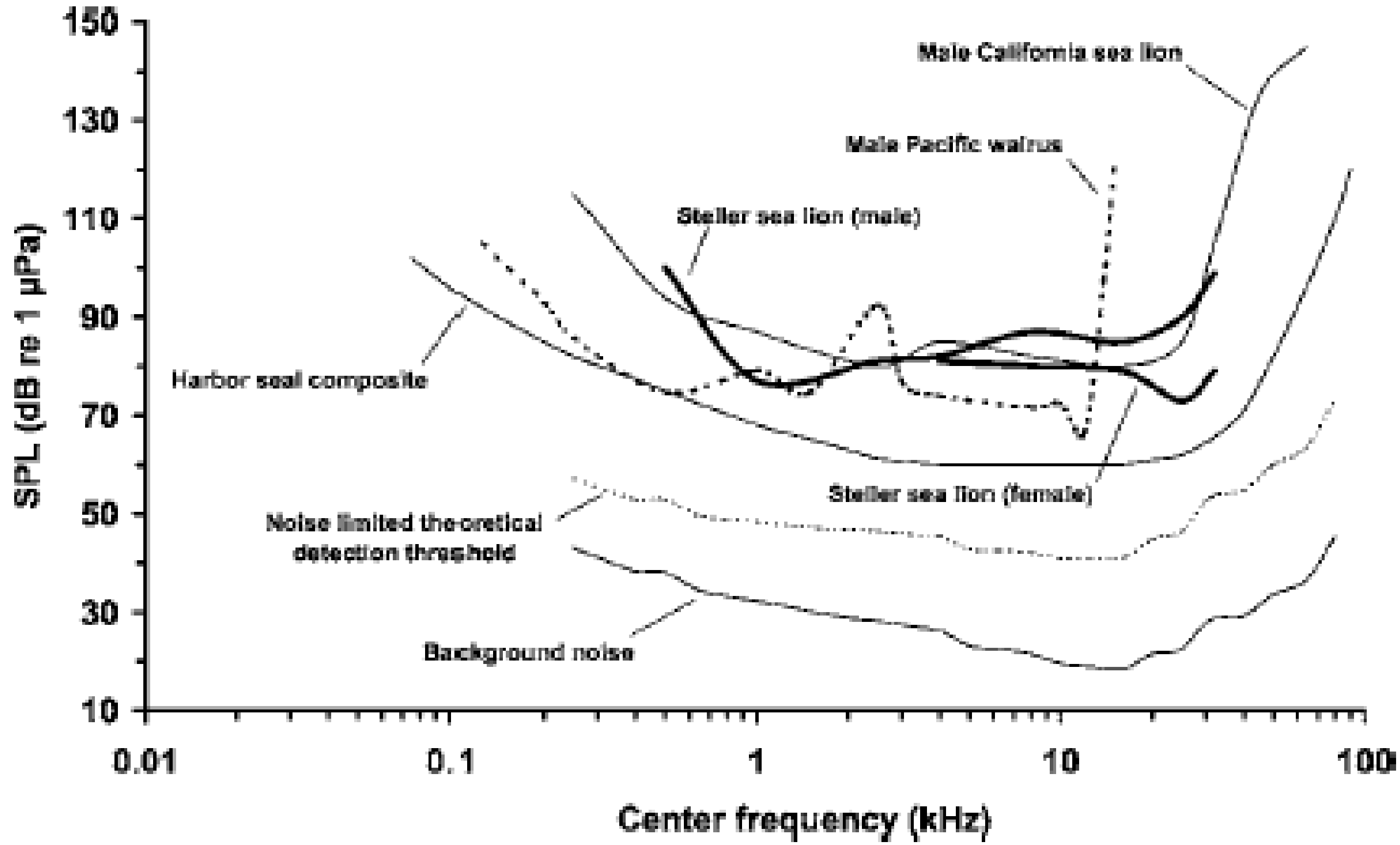
Killer Whale Hearing Thresholds



Szymanski et al. 1999

ABR = Auditory Brainstem Response

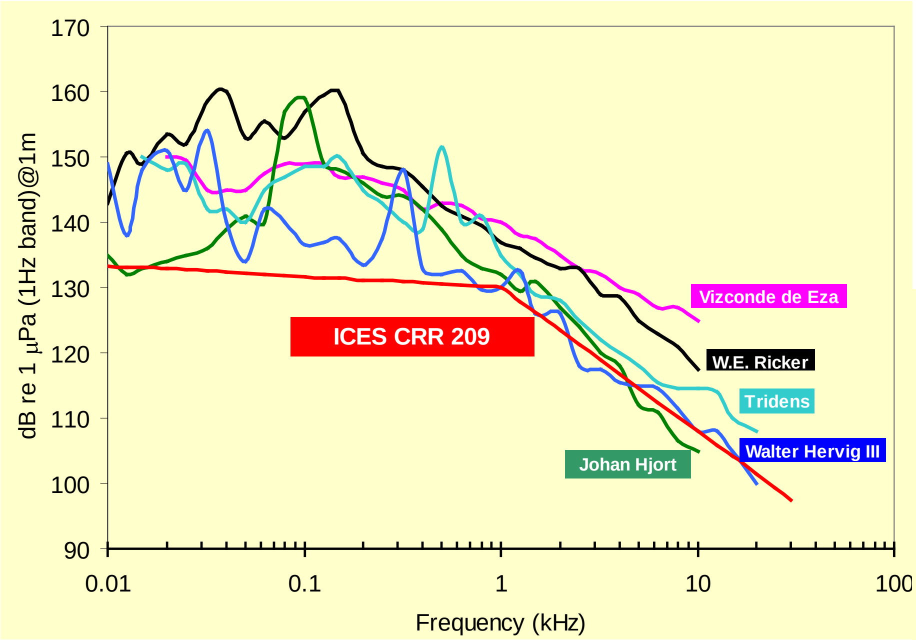
Steller Sea Lion Hearing



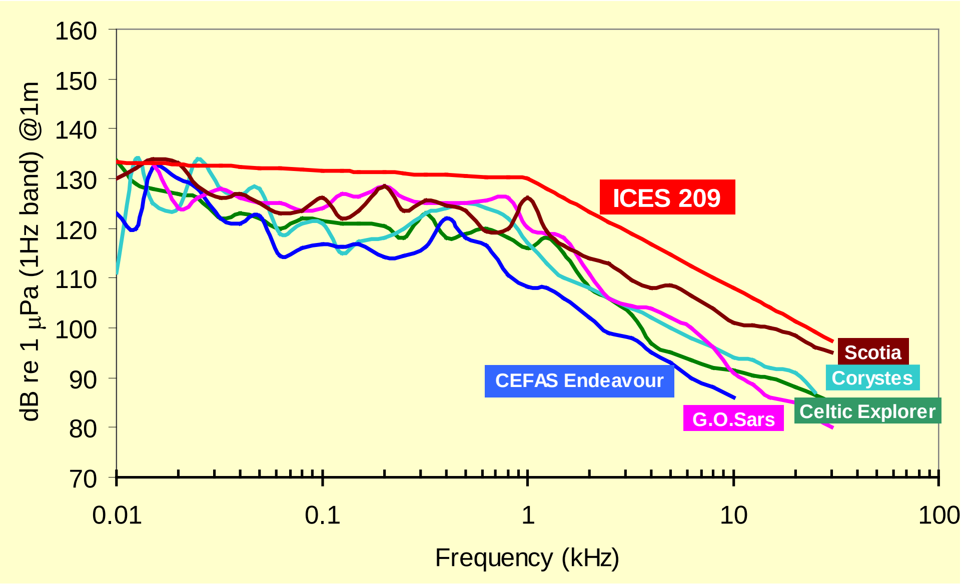
Kastelein et al. 2005

Vessel Noise: ICES 209

'Noisy' Research Vessels

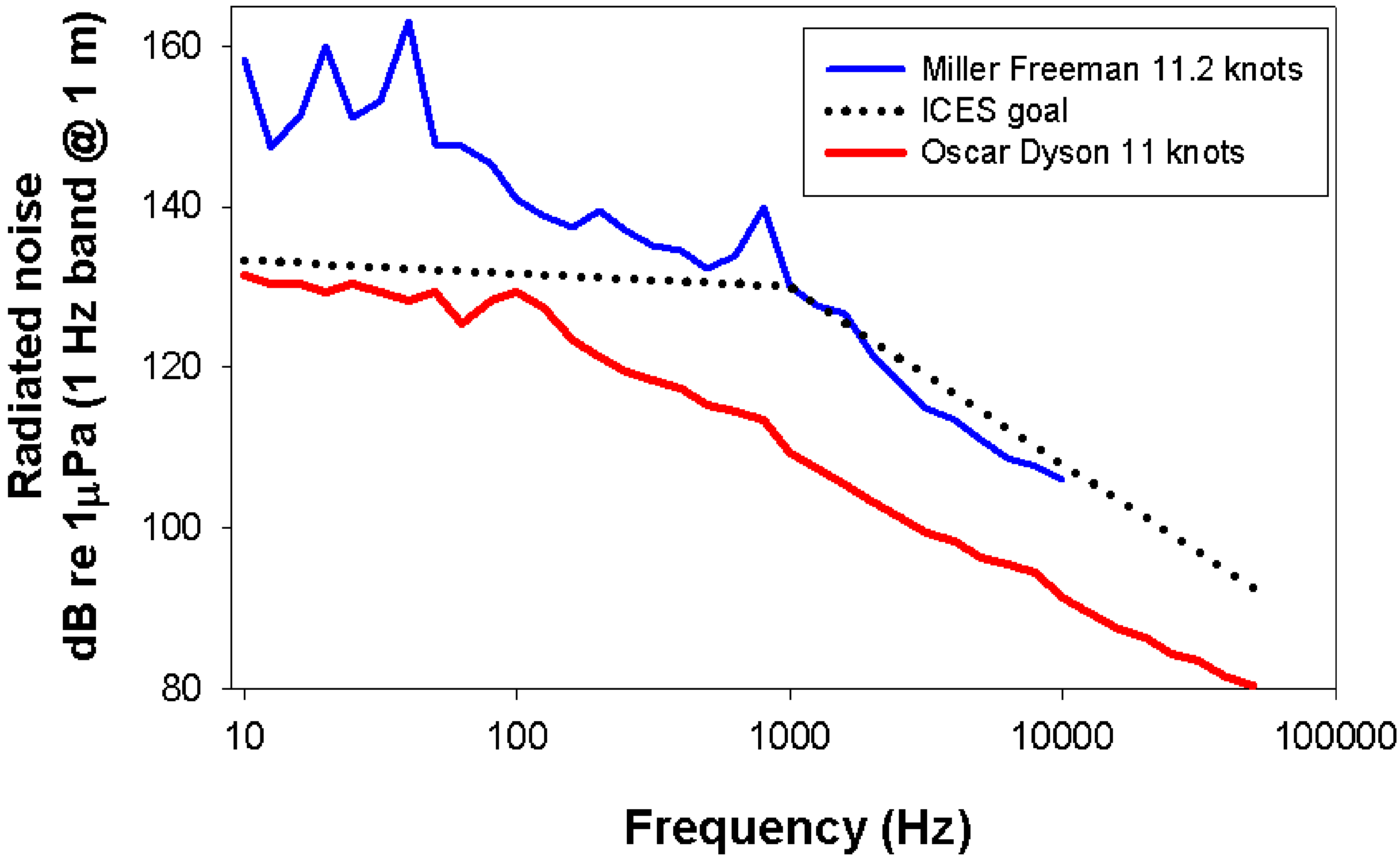


'Quiet' Research Vessels

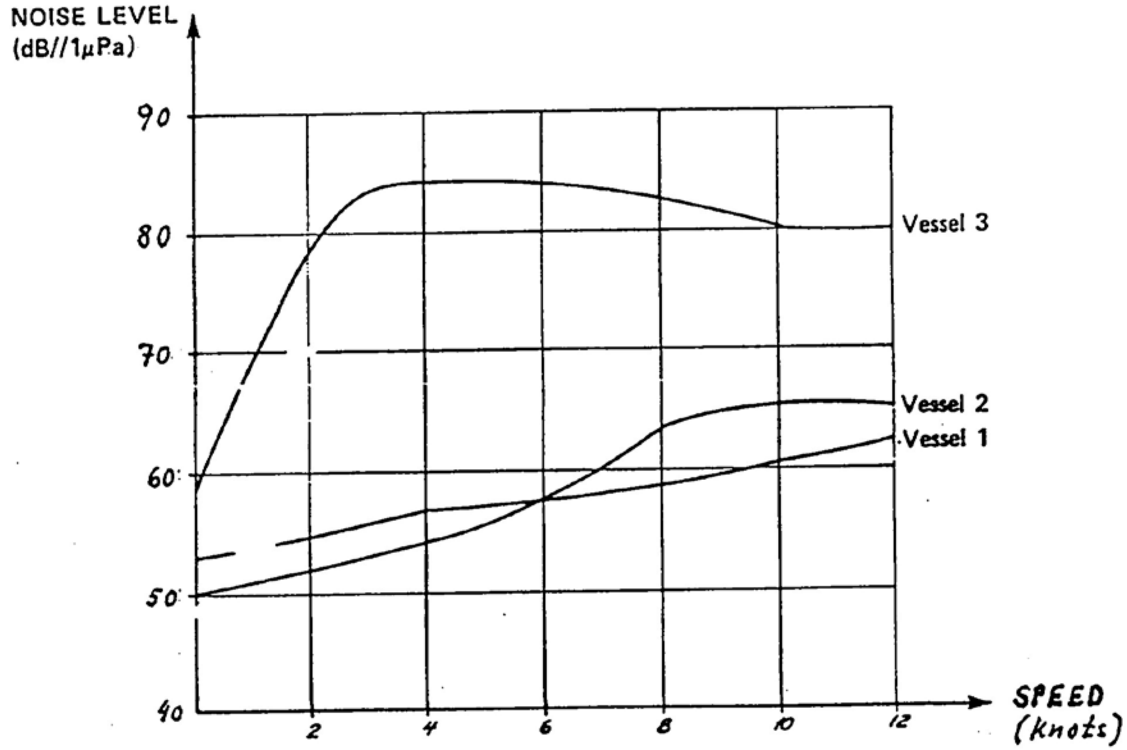


plots courtesy of R. Mitson

NOAA Vessels



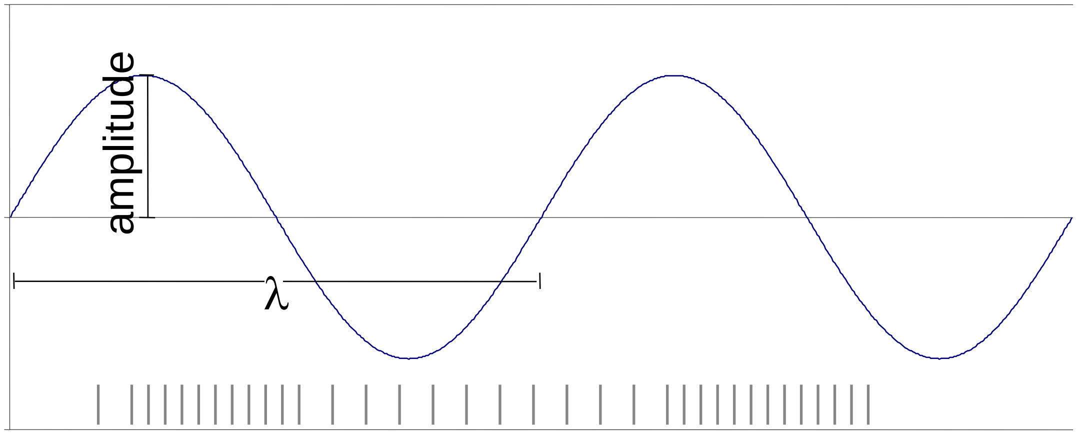
Vessel Noise α Vessel Speed



Vessel	Propeller	R.P.M.	Size
1. Trawler	Fixed pitch	30 - 113	223 feet
2. Purse seiner	Adj. pitch	100 - 300	245 feet
3. Trawler	Adj. pitch	375	299 tons

Sound Propagation

Longitudinal Compression Wave



λ = wavelength, units m

$\lambda = c/f$ where: c = speed of sound (ms^{-1})

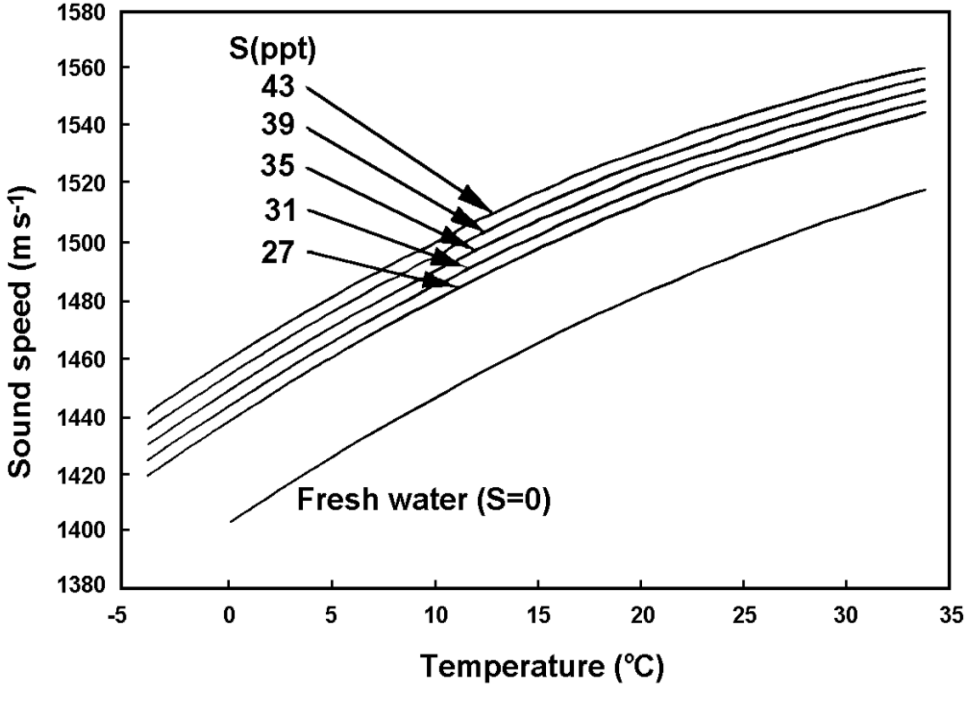
f = frequency (cycles s^{-1}, Hz)

Speed of Sound

Speed of sound (c) = *f* (temperature (T), salinity (S), depth (z)), units ms^{-1}

$$c = 1449.2 + 4.6 (T) - 0.055(T)^2 + 0.00029(T)^3 + (1.34 - 0.01(T)) (S-35) + 0.016z$$

Freshwater ~ 1500 ms^{-1} Salt water ~ 1460 – 1550 ms^{-1} Air ~ 330 ms^{-1}



Effect of T > S

Target Resolution and Travel

Target Resolution:

f (target distance (Δr), speed of sound (c), pulse duration (τ))

$$\Delta r = c\,\tau/2$$

* independent of frequency

Acoustic Pulse Travel Time:

$$\text{time to echo} = 2r/c$$

where r = range (m)

Frequency, Wavelength & Wavenumber

Frequency (f) = λ per unit time, units cycles s^{-1} (Hertz)

$$f = c/\lambda \ (ms^{-1}/m)$$

Wavelength (λ)

$$\lambda = c/f \ (ms^{-1}/s^{-1})$$

Wave number (k)

$$k = 2\pi/\lambda \ (\text{rad } m^{-1})$$

Frequency and Period

Frequency (f) = λ per unit time, units cycles s^{-1} (Hertz)

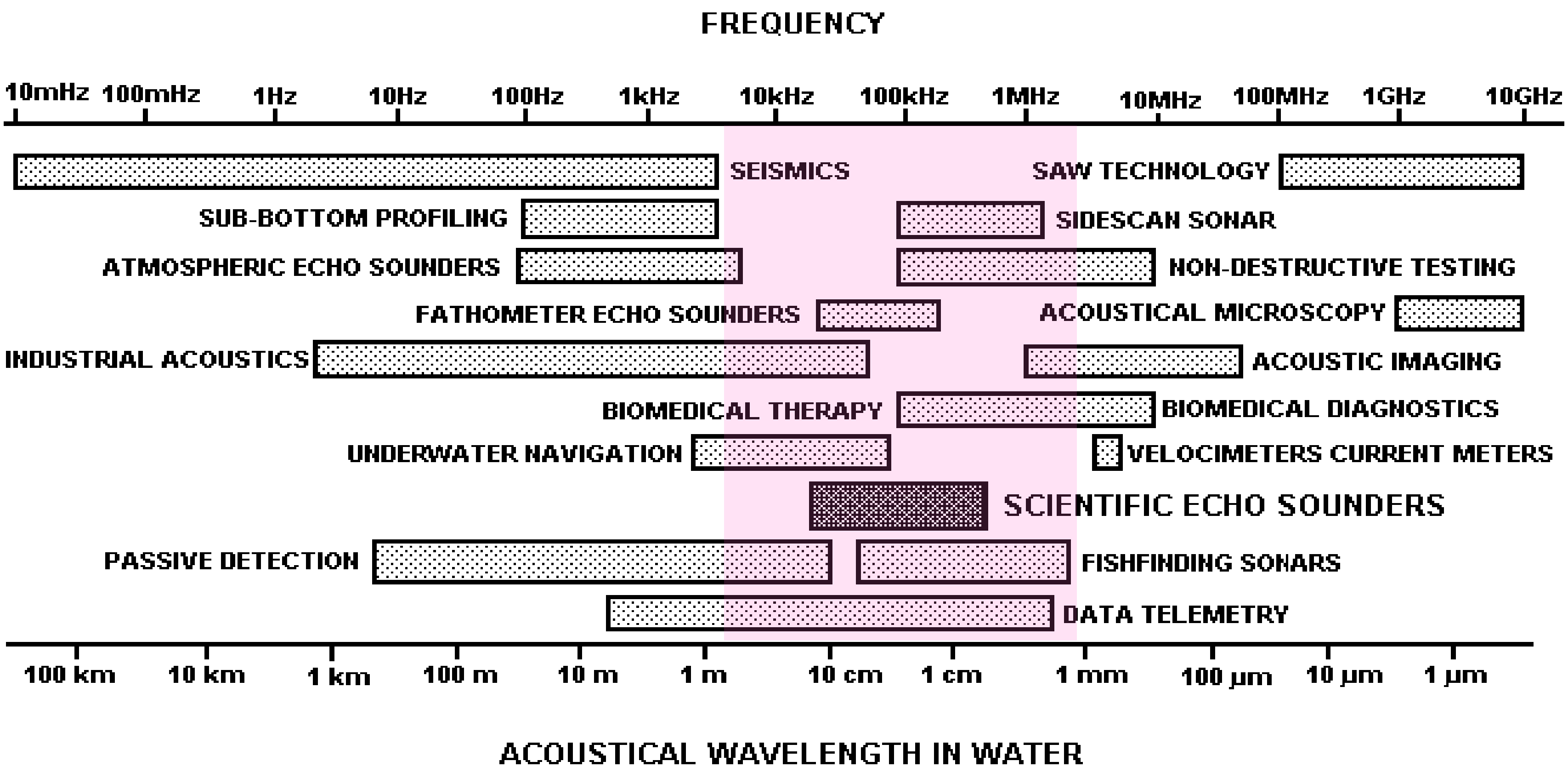
$$f = c/\lambda$$

Period (τ):

$$\tau = 1/f$$, units s

in active acoustics this is the ‘pulse length’ or ‘pulse width’

Frequency Ranges of Acoustic Sensors

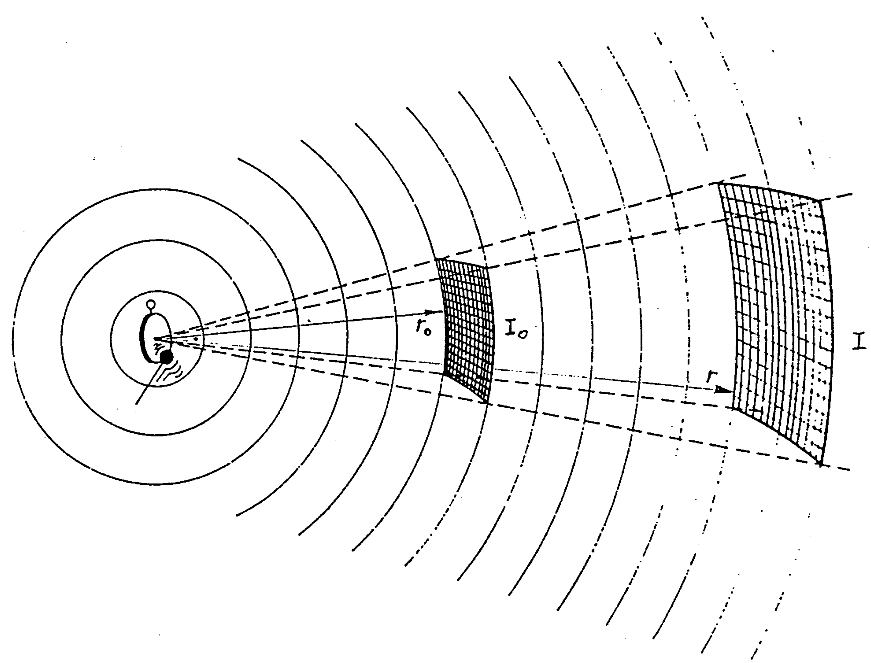


redrawn from Coates 1989

Transmission Losses

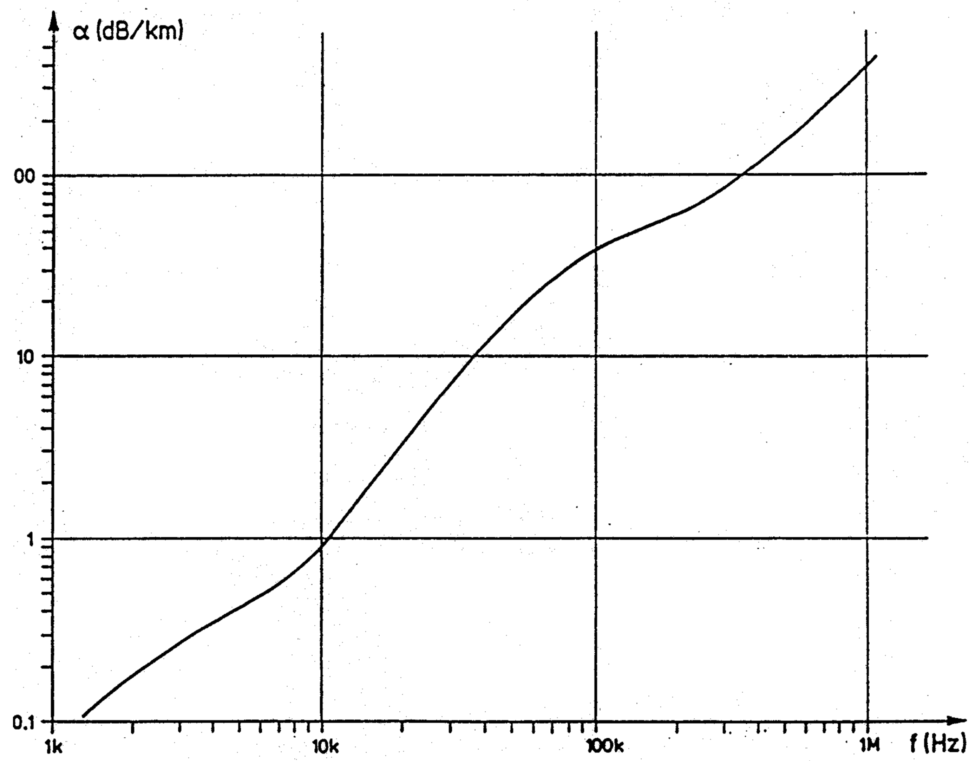
Geometric Spreading
- pressure decreases as the 1/distance from source
- spherical spreading from a point source (e.g. transducer)
- non-spherical or directed spreading (e.g. fish)
- 2-way spreading increases as range^2
- independent of frequency

$$\Delta I \; \alpha \; 1/r^2$$



Transmission Losses

Absorption
- attenuation of pressure due to friction (α, units nepers/m or dB/m)
- proportional to range (r)
- dependent on frequency



one way: α r
two way: 2 α r

What is a neper? natural log ratio

Which Loss is Greater?

Absorption

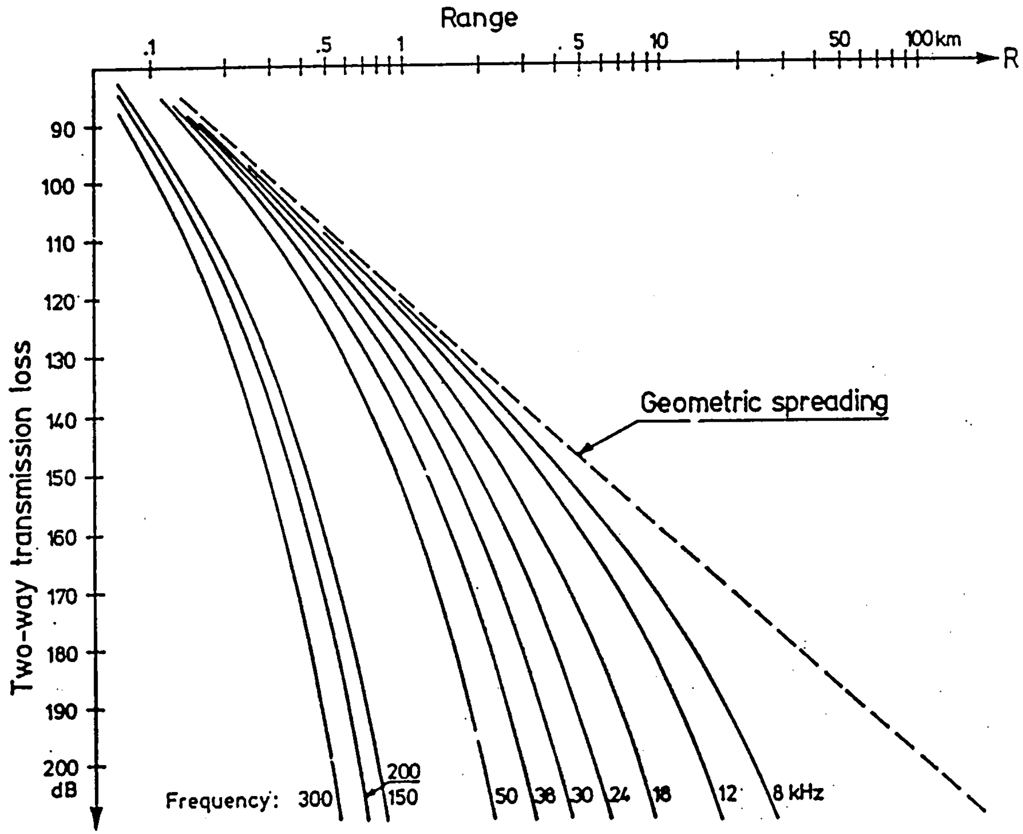
Frequency	Loss Rate
1 kHz	0.05 dB/km
10 kHz	0.5 dB/km
100 kHz	20 dB/km
1 MHz	300 dB/km

Spreading

~ 60 dB at 1 km

Spreading loss >Absorption loss at freqs. < 100's kHz

Total Transmission Loss



TWO WAY TRANSMISSION LOSS VS. FREQUENCY.

2 way: $40 \log(r) + 2\alpha r$

Why Not Use Light?

Sound Level

Sound Level = Sound Pressure Level – Transmission Loss

Sound Pressure Level = initial intensity
(a.k.a. Source Level)