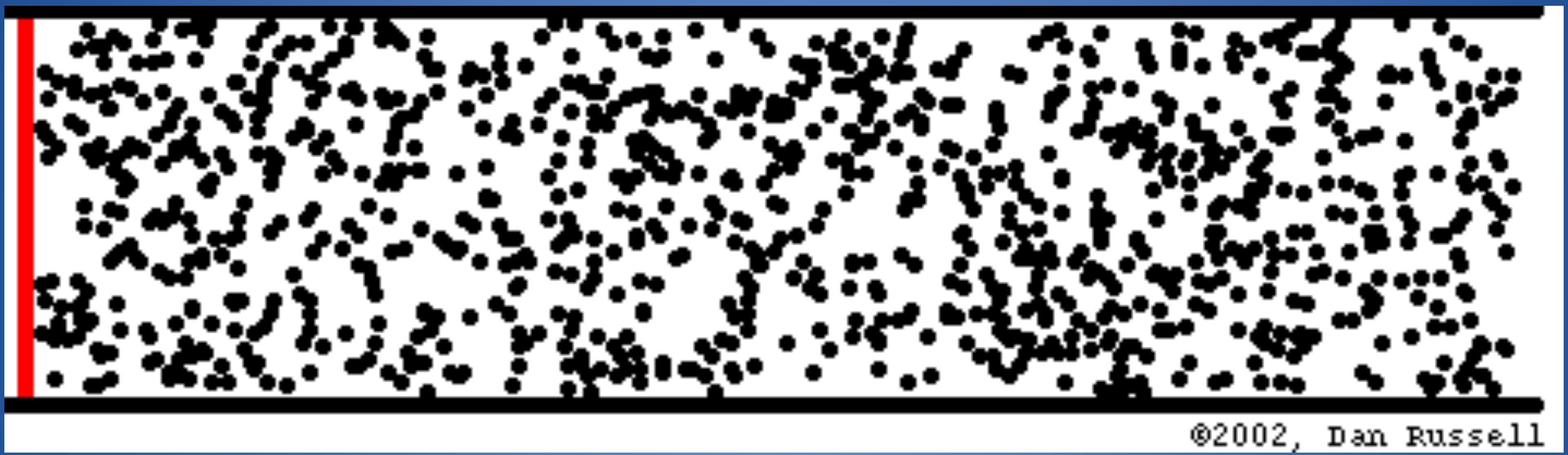
An Introduction to Underwater Acoustics



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NOAA Technician Refresher Training

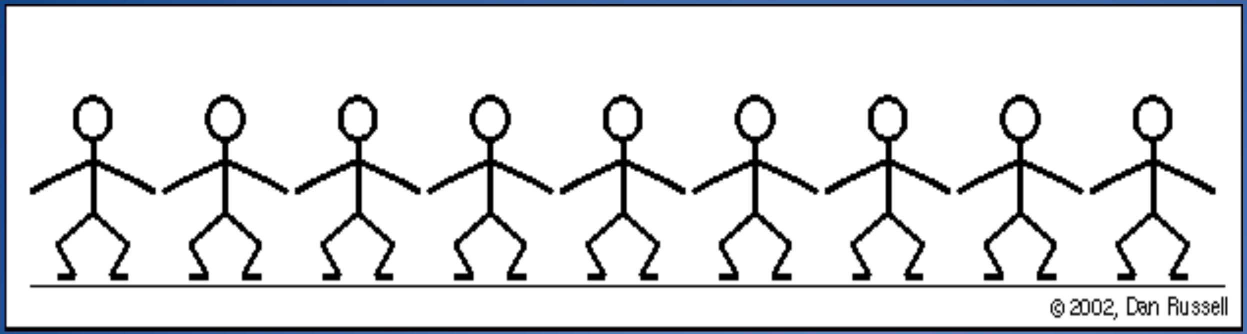
19 January 2012

Presentation Overview

- You know more than you think you do…
- Waves and their characteristics…
  - Frequency, wavelength, phase, speed
  - Intensity and Decibels
- The Sonar Equation…
  - Transmit power, target strength, absorption, spreading, noise, directivity index
- Refraction…

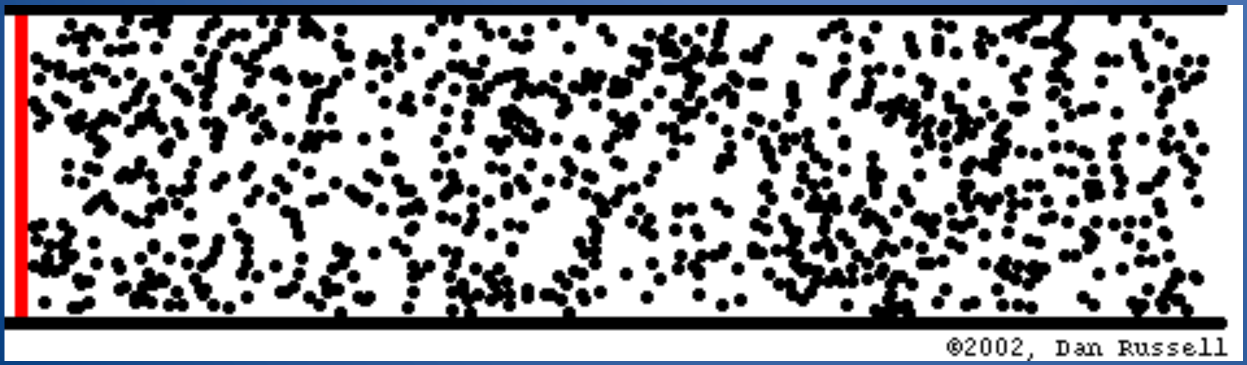
You (might) know more than you think you know…

Making Waves!!!



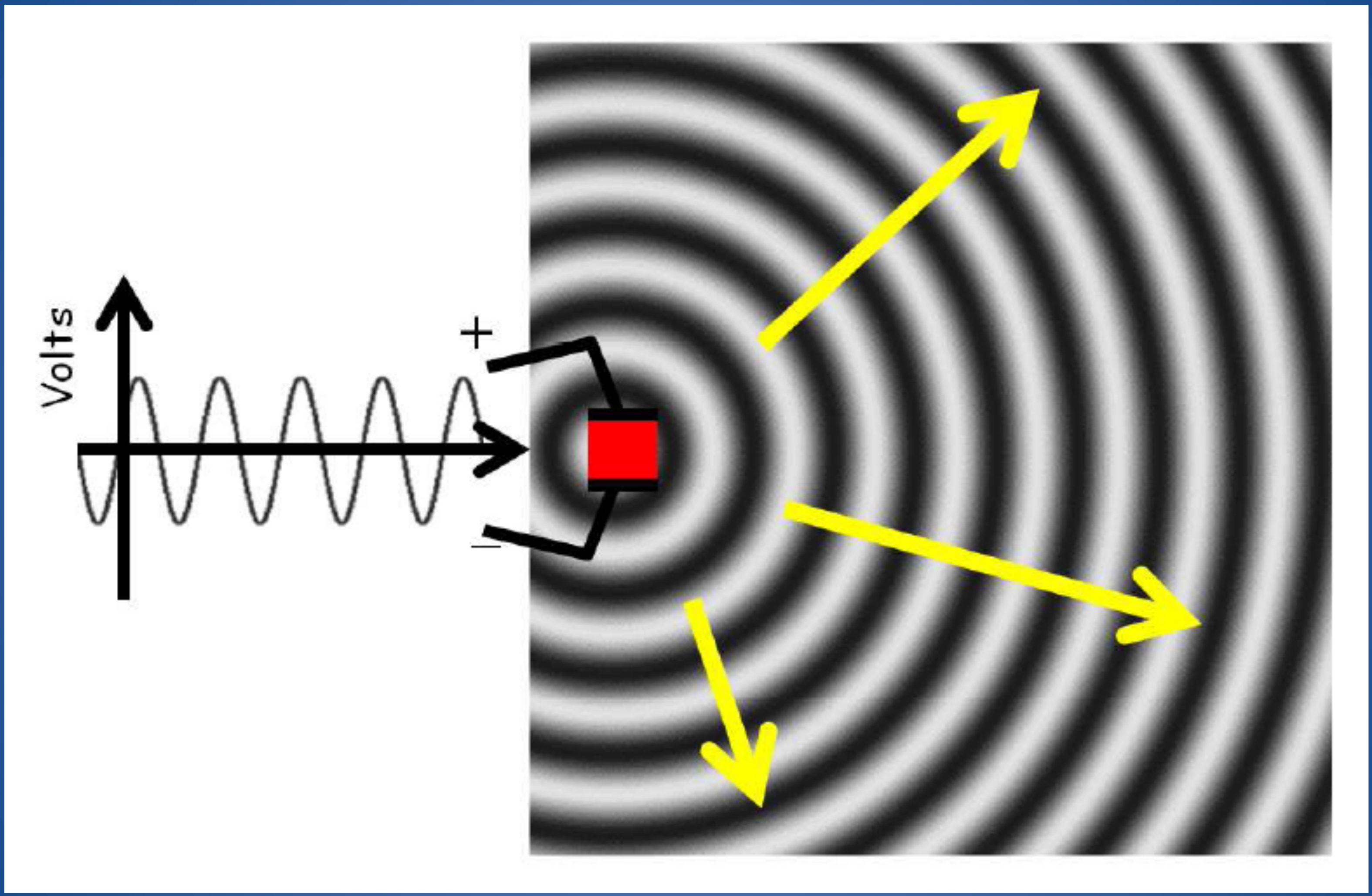
Transverse
(s wave)

Transverse
(s wave)



Longitudinal
(p wave)

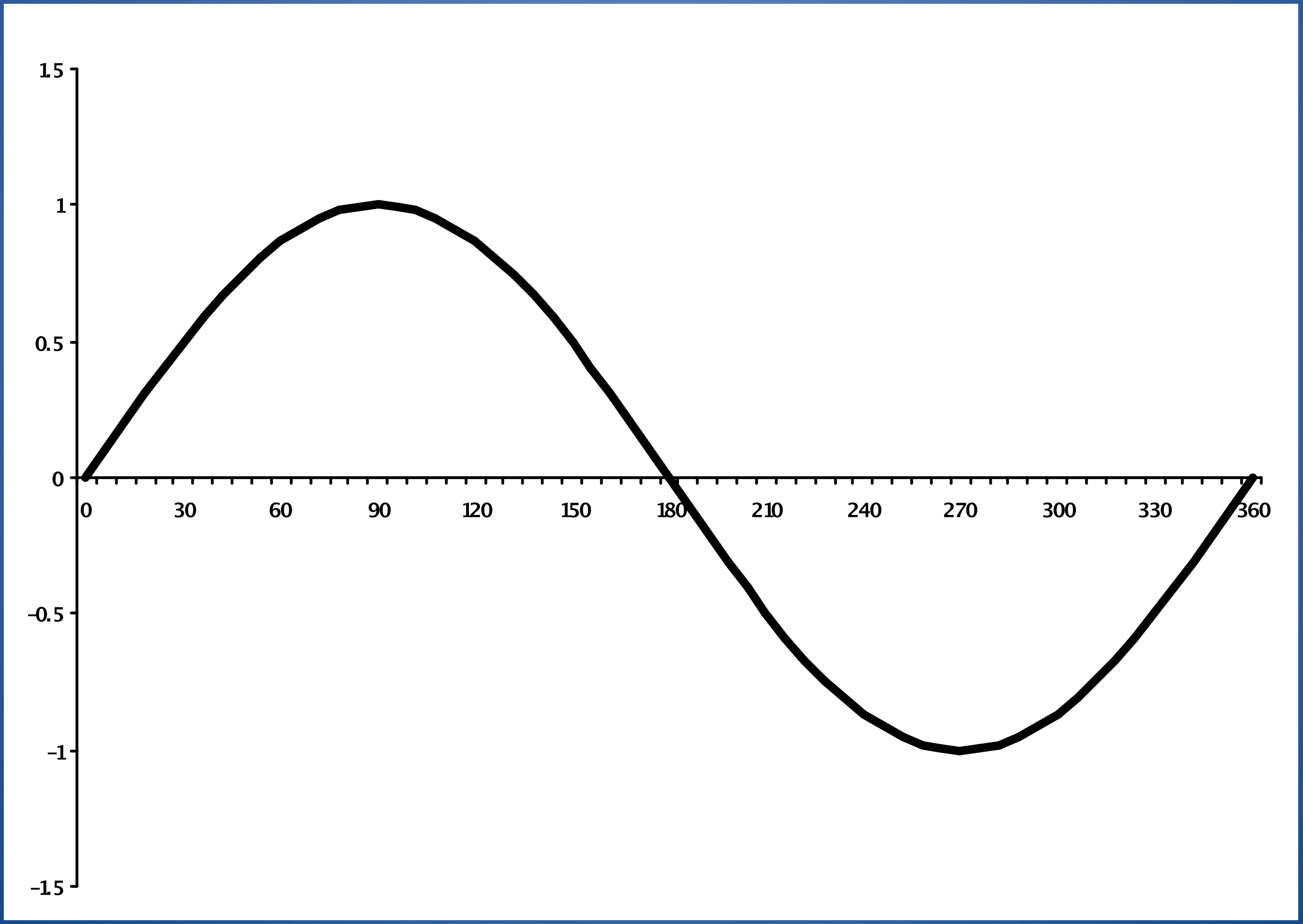
You (might) know more than you think you know…



Clark, J. H., 2012

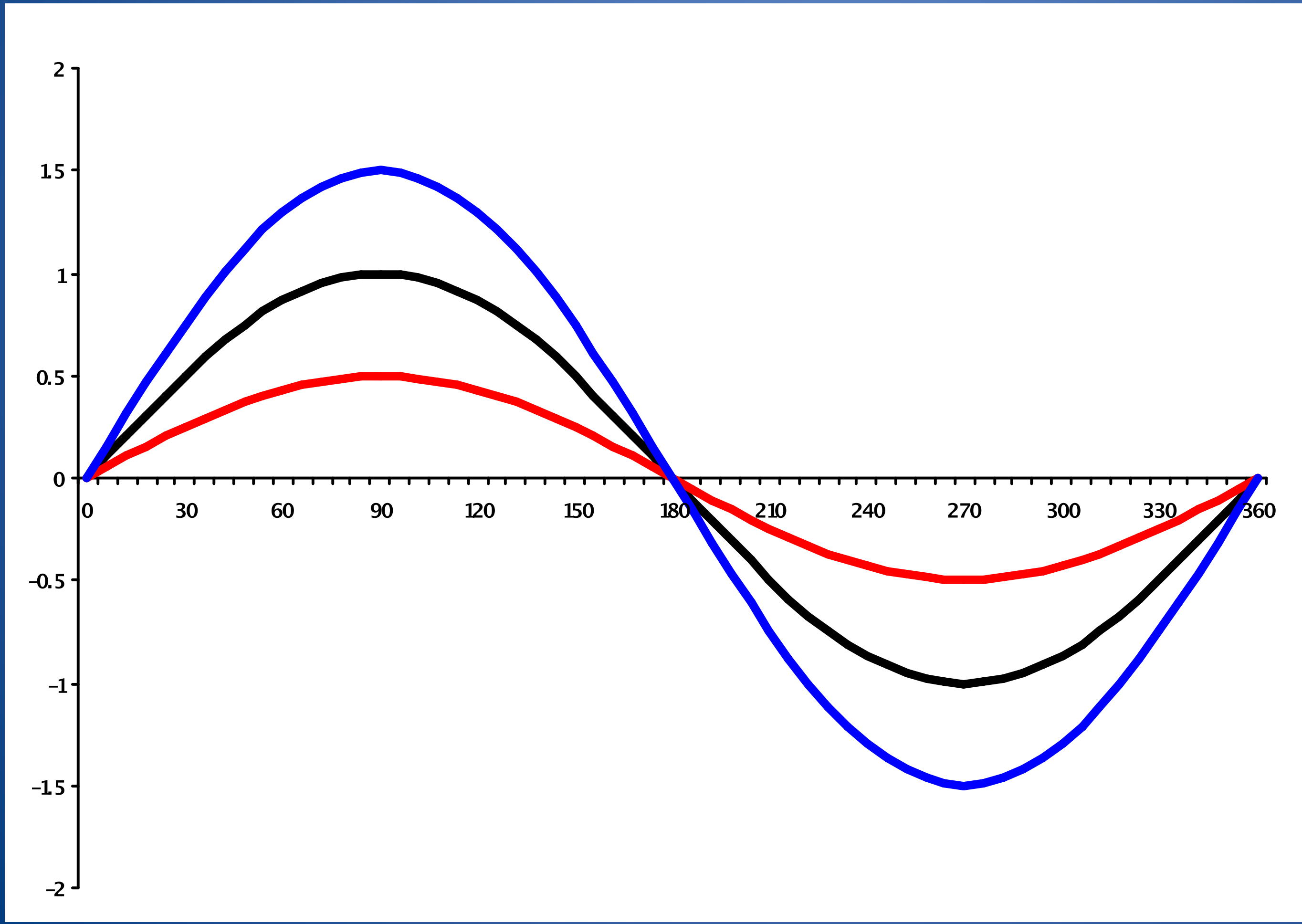
Elements of a Wave…

$$f(t) = \sin(t)$$



Elements of a Wave… Amplitude

$$f(t) = A\sin(t)$$



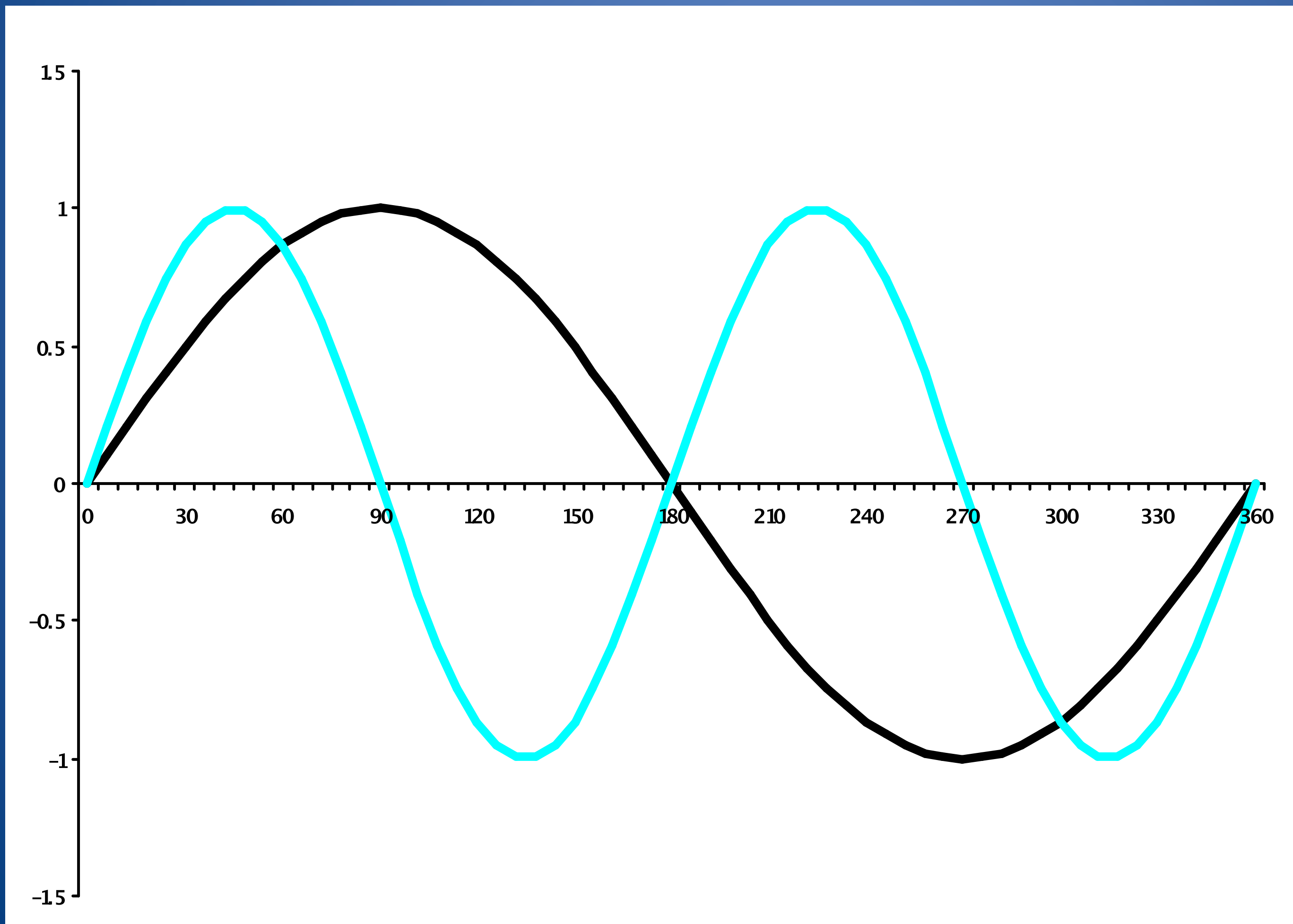
A=0.5

A=1.0

A=1.5

Elements of a Wave… Frequency/Wavelength

$$f(t) = \sin(\omega t)$$

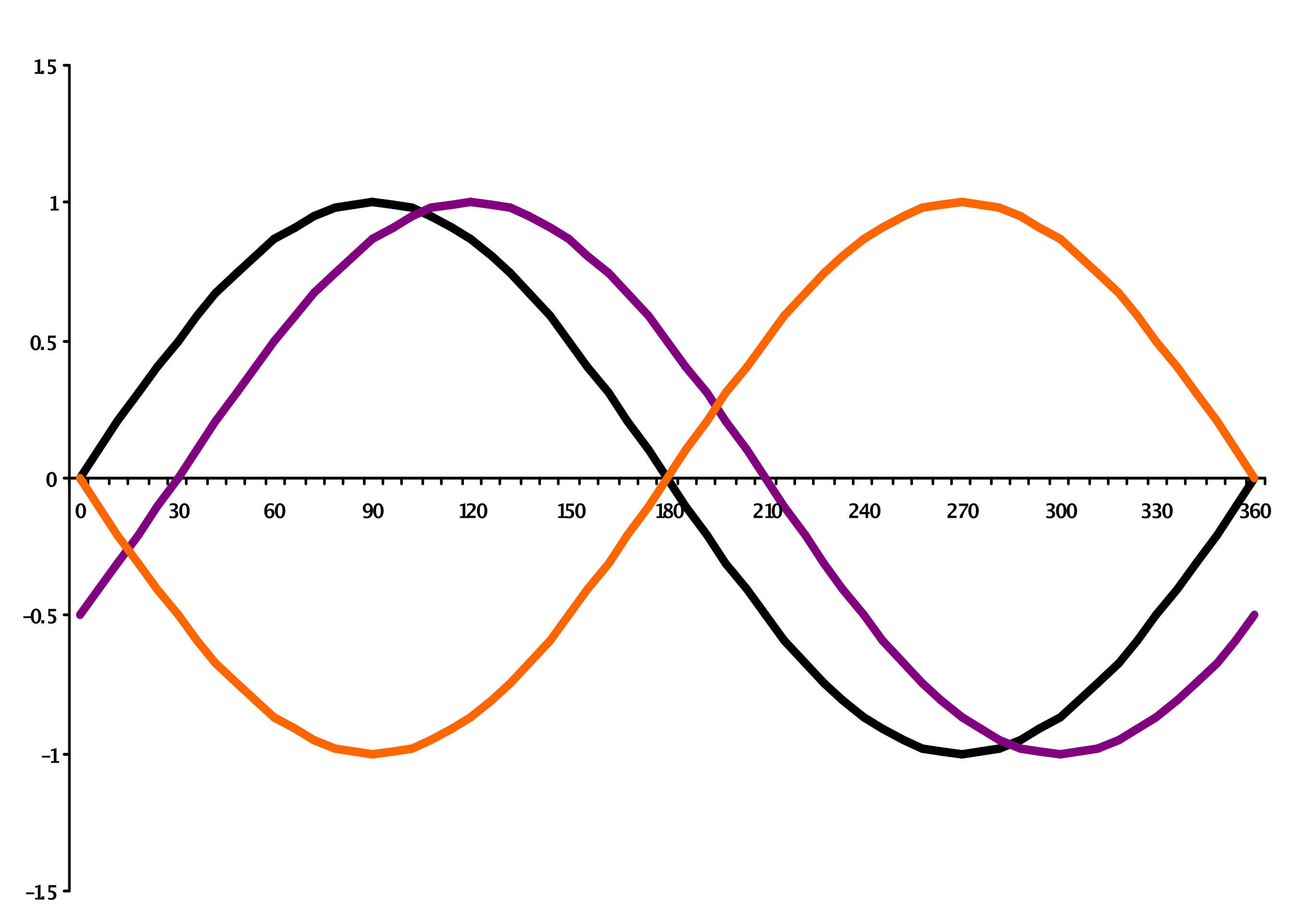


ω=2

ω =1

Elements of a Wave… Phase

$$f(t) = A\sin(\omega t + \varphi)$$

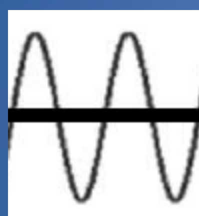


ϕ=0

ϕ =30˚

ϕ =180˚

Elements of a Sonar Wave… Oft confused terms



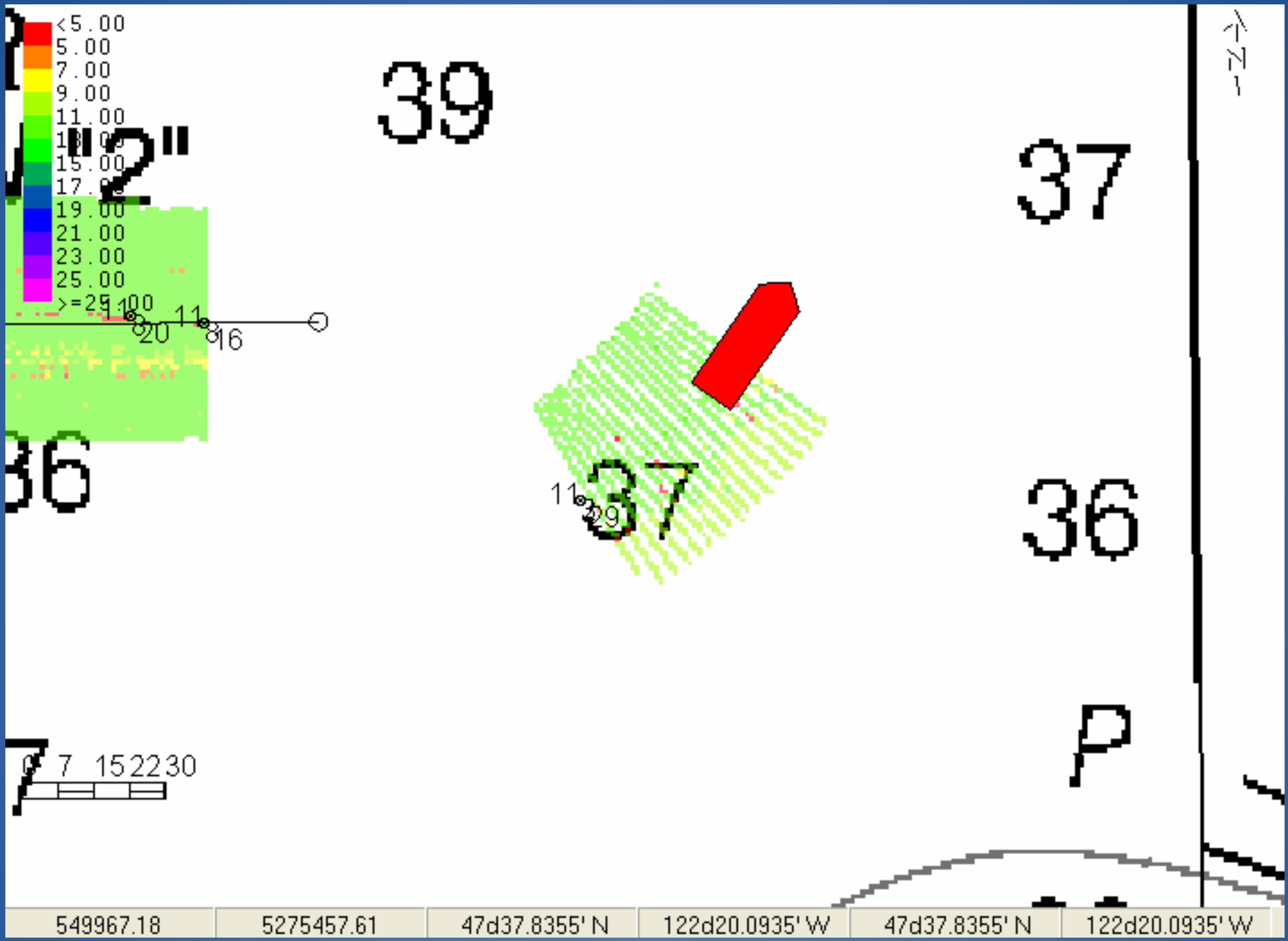
Pulse Repetition Rate (Hz)

Sonar Frequency (kHz)

Pulse Width (msec)

- Pulse Rate – How often the sonar is transmitting.
- Pulse Width – The duration of the pulse itself.
- Sonar Frequency – The frequency of the pulse.

Elements of a Sonar Wave… Pulse Rate



- Pulse Rate – How often the sonar is transmitting.
- Pulse Width – The duration of the pulse itself.
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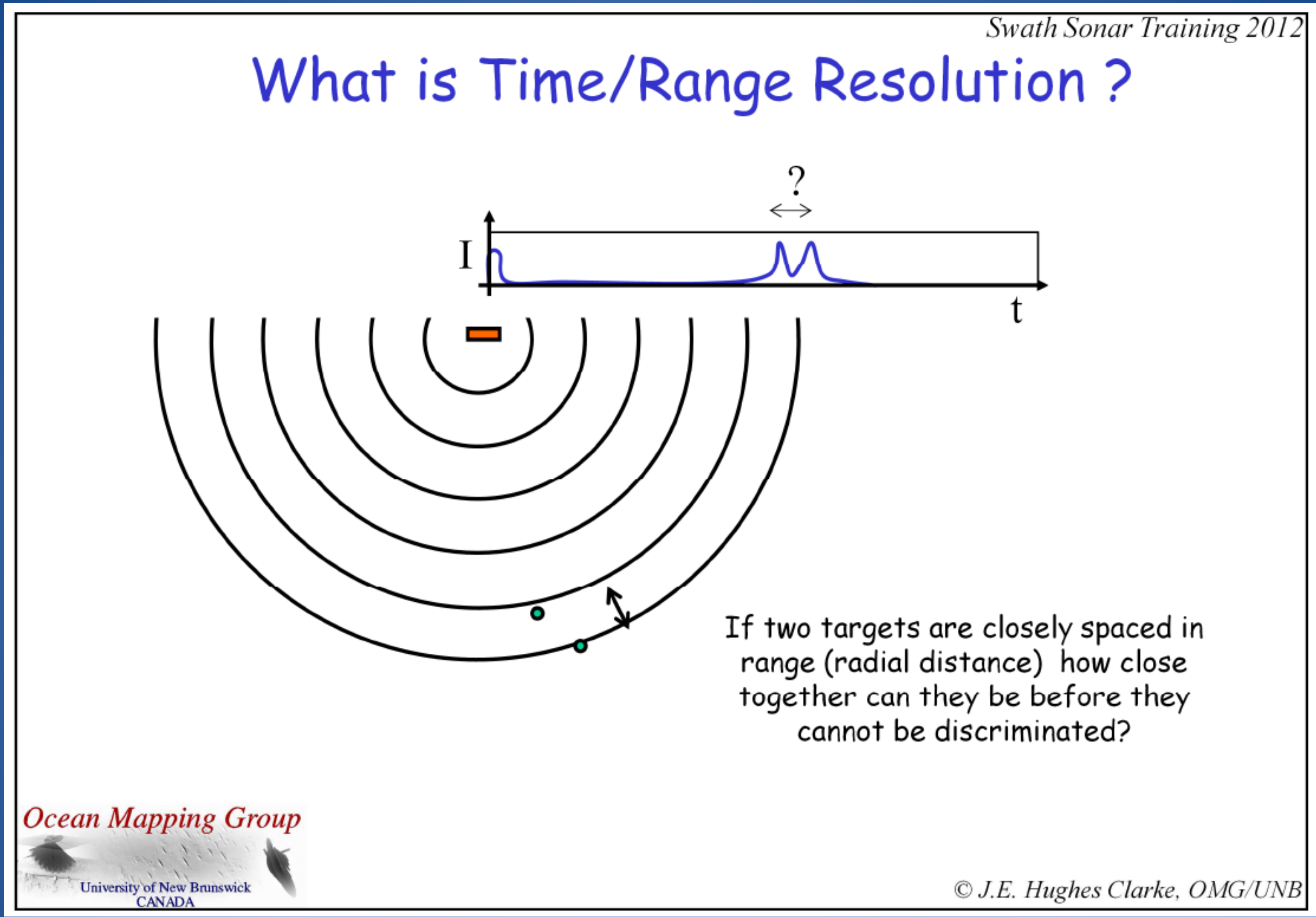
Elements of a Sonar Wave… Pulse Width



- Pulse Rate – How often the sonar is transmitting.
- Pulse Width – The duration of the pulse itself.
- Sonar Frequency – The frequency of the pulse.

Speed of Sound

- Speed of sound is usually represented by "c"
- Dependent upon the medium
  - About 6100 m/s for steel
  - About 1500 m/s for sea water (13°C)
  - About 1435 m/s for fresh water
  - About 343 m/s for air (20°C)

- Speed = (Wavelength) x (Frequency)
  (m/sec) (m) (1/sec)

The decibel

The usefulness of logarithms:

$$\log_{10}[0.001] = -3$$
$$\log_{10}[0.01] = -2$$
$$\log_{10}[0.1] = -1$$
$$\log_{10}[1] = 0$$
$$\log_{10}[10] = 1$$
$$\log_{10}[100] = 2$$
$$\log_{10}[1000] = 3$$

The decibel:

If p_2 and p_1 are the pressure amplitudes of two acoustic waves that differ by one decibel, then:

$$10\log_{10}|p_2^2| - 10\log_{10}|p_1^2| = 1 \text{ dB}$$

In this equation, we would refer to p_1 as the *reference* above which p_2 is 1 dB.

60 POPULAR SCIENCE MONTHLY May, 1929

Curious "Log House" Built of Drainpipes

The house with drainpipe walls. Left: Corner of dwelling, showing "log cabin" method of joining.

A "LOG house," in which the "logs" are formed by common red drain-pipe tile, has been built in Kingsville, Ontario, Canada. Charles Miner, who erected the unique dwelling, chose tile for the material because it provides dead-air space in the walls to protect the interior from cold in winter and heat in summer.

The house stands on a foundation of cement blocks, except for the porch and steps, which are supported by the tiles. A wooden framework, sheathed with boards in the usual manner, was first erected and the tile "logs" were laid in courses like brick veneer up the sides. At corners, the ends of the tiles overlap in criss-cross fashion, much as did logs in the cabins of pioneer days. Where the ends of the tiles are exposed, they are closed with cement colored to match. This insures dead-air space and prevents birds and squirrels from entering.

The cost of the unusual house is said to have been moderate as compared with the cost of constructing a conventional type wood or brick home.

Trees Worth Millions

WHAT is a tree worth? In answer to that question, Dr. Ephraim P. Felt, former New York State entomologist, reports that fifty fair-sized elms were sold recently at $5,000 apiece and that many trees are worth $10,000. He estimates that the trees of Greenwich, Connecticut, for which the town is noted, are worth at least one fourth the assessed value of the town. This would place the total value of the trees at approximately $25,000,000.

Do You Know a "Decibel?" It's a New Unit

WHEN you hear someone speaking of a "decibel," it is not a man with a cold in his head talking about a decimal. It is a telephone engineer using the latest addition to the list of scientific units.

At a recent conference between representatives of the Bell System and the International Advisory Committee on Long Distance Telephony in Europe, the new term, referring to the efficiency of telephone circuits, was adopted. It takes the place of the former expression "transmission unit."

The original unit name decided upon was "bel," named in honor of Alexander Graham Bell, inventor of the telephone. Because the "bel" is larger than is needed in practice, a unit one tenth as large, called a decibel, was accepted for practical use by the engineers.

Helps You Pick a Cinder Out of Your Eye

A SAFETY-FIRST device, small enough to carry in a vest pocket, has been invented by A. F. Ouellet, of New York City, to aid in removing cinders or dust particles from your eyes. A five-power magnifying mirror, one inch in diameter, is fitted with a wire clamp by which it is attached to the little finger of the left hand. While the mirror is held before the irritated eye, the thumb and forefinger of the same hand push back the eyelids, and a folded piece of soft paper, cut to a point, is manipulated by the right hand to remove the dust speck. The eye that is being treated observes the action.

Besides magnifying the eye, the mirror reflects light on the spot where the irritating particle is located. The mirror and clamp fit into a small case for carrying in a man's pocket or in a woman's hand bag.

Mirror is clamped to little finger of left hand while the right hand fishes for cinder.

A Pattern of Progress

EACH month scores of achievements in many fields of research and invention go to make up the variegated pattern of scientific progress. POPULAR SCIENCE MONTHLY reports the news of these achievements in understandable stories and pictures. In these pages you will find a wealth of fascinating new facts to widen your knowledge, ingenious ideas that can be put to use, and entertaining glimpses that will keep you in touch with what other men are doing.

Dual Control for Piano Stops Pupil's Mistakes

PLEASANT news for sensitive-eared parents, to whom the hours when the teacher comes and tries to teach Junior and Mary to coax music from a piano mean sheer agony, emanated the other day from Germany. There an inventor has perfected a device whereby the music teacher may correct the piano pupil's mistakes even before they happen!

The contrivance consists principally of a keyboard like that of a piano. Through electrical impulses sent by way of connecting wires, the teacher can control the interior workings of his pupil's piano from his silent keyboard.

The invention is an adaptation of the principle of dual controls used to instruct students of aviation.

Lights Rout Two Enemies of Fruits and Plants

HANGING festoons of electric lights on apple trees, as is done on Christmas trees, is an effective way of keeping aphids, or plant lice, out of orchards, Prof. A. Franklin Shull, of the University of Michigan, reported recently. Some of the aphids grow wings and fly away from the trees on which they are born; others are wingless and remain to destroy the budding fruit. Dr. Shull discovered that the wingless aphids have not been exposed to sufficient light, but will grow wings if properly illuminated.

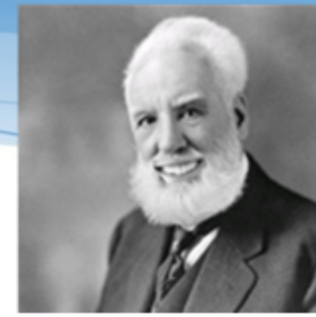
The tobacco farmer's most dreaded pest, "mosaic disease," which ruins the leaf for market by forming a mosaic pattern upon it, can be killed by less than fifteen seconds' exposure to ultra-violet rays from a quartz mercury vapor arc, Dr. John M. Archer, of Boyce Thompson Institute for Plant Research, says.

Produces Shapely Pickles

STREAMLINED pickles that will appeal to the eye as well as the appetite are being sought, according to a recent announcement of the Pickle Packers Association. Professor George E. Starr, of the University of Michigan, has spent five years experimenting with cucumbers to evolve new shapes that would combine beauty and edibility, the report states.

The result is said to answer both requirements, and the latest model of pickles will soon be put on the market.

Fun with decibels



Fact 1: The dB is unitless

Fact 2: As a unitless quantity, the dB has little value unless a reference is given.

I had 30 dB of peas with dinner last night = ????

I had 30 dB of peas re 1 pea with dinner last night = I had 1000 peas.

Further note: we often abuse this reference, and so in practice the meaning of dB values is often situational dependent.

We often refer to values in dB as *levels.*

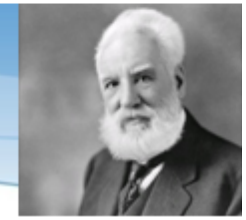
Take, for example, the Intensity Level of an acoustic wave in water whose amplitude is 100,000 Pa:

$$I = \frac{p^2}{2\rho c} = \frac{100,000^2}{2(1000)(1500)} = 3,333\ Watts \qquad I_{ref} \cong \frac{\left(1\times10^{-6}\right)^2}{(1000)(1500)} = 3.333\times10^{-19}\ Watts$$

$$IL = 10\log_{10}\frac{I}{I_{ref}} = 10\log_{10}\frac{3,333\ W}{3.333\times10^{-19}\ W} = 220\ dB\ re\ 3.333\times10^{-19}\ Watts$$

*The standard reference for intensity in underwater acoustics is the intensity of a 1 µPa plane wave.

(not so much) Fun with decibels



AIR: SPL = 140 dB re 1 μPa

Jet engine at about 100' distance

$$10\log_{10}\frac{I}{I_{ref}} = 140 \;\; dB \;\; re \;\; 20 \;\; \mu pa$$

$$\frac{I}{I_{ref}} = 10^{140/10} = 10^{14}$$

$$I = 10^{14} I_{ref} = 10^{14}\frac{20\times 10^{-6}}{(1.2)(343)} = 97 \;\; W/m^2$$

Ocean: SPL = 200 dB re 1 μPa

A 'loud' sonar at about 100' distance

$$10\log_{10}\frac{I}{I_{ref}} = 200 \;\; dB \;\; re \;\; 1 \;\; \mu pa$$

$$\frac{I}{I_{ref}} = 10^{200/10} = 10^{20}$$

$$I = 10^{20} I_{ref} = 10^{20}\frac{1\times 10^{-6}}{(1000)(1500)} = 67 \;\; W/m^2$$

The sonar equation (power transmitted v. received)

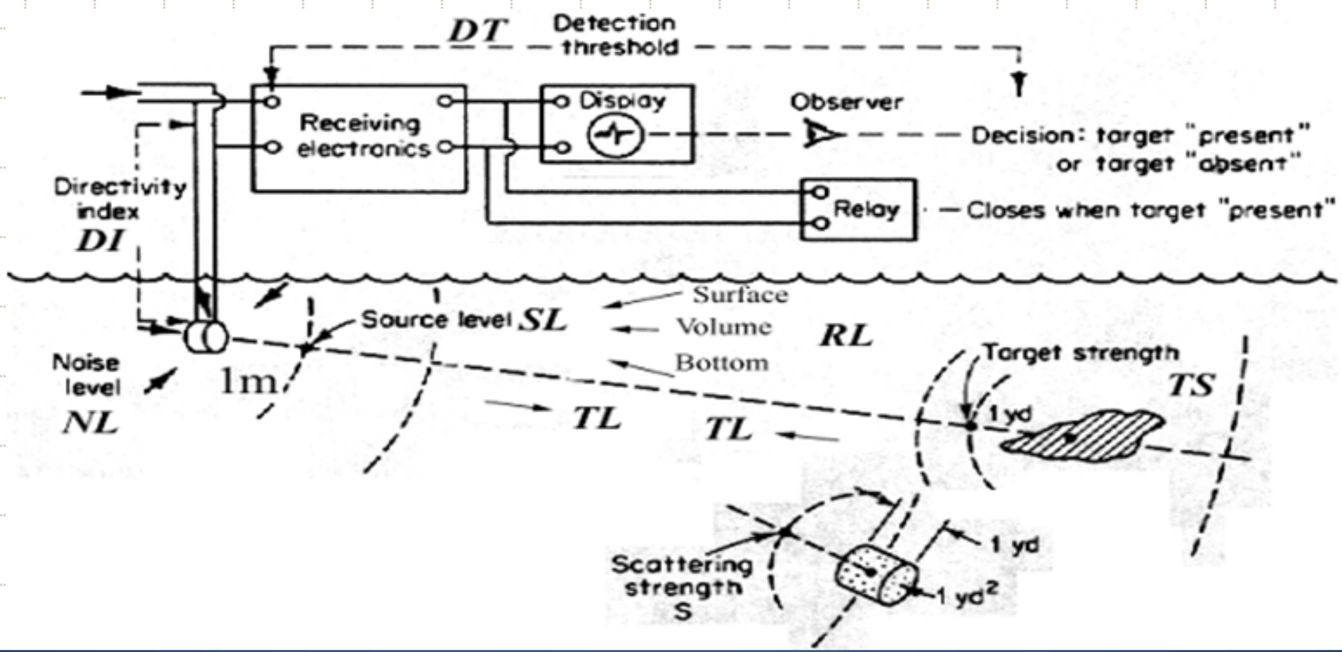
Signal-to-Noise = Power [Source Level] – 2(Spreading[2] + Absorbtion[1])

+ Target Strength – (Background Noise – Directivity Index)

+ Gain [Detection Threshold]

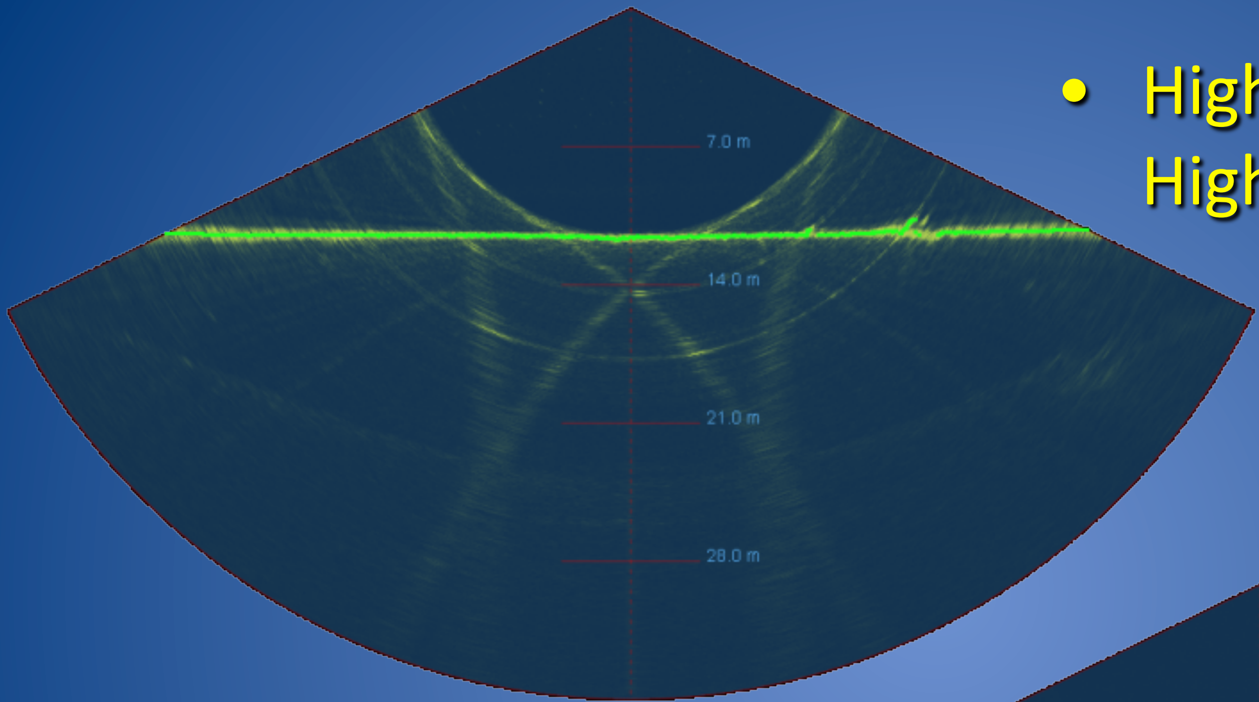
For *just* being detected:

- ACTIVE: SNR = SL-2TL+TS-(NL-DI) +DT
- PASSIVE: SNR = SL-TL-(NL-DI) + DT

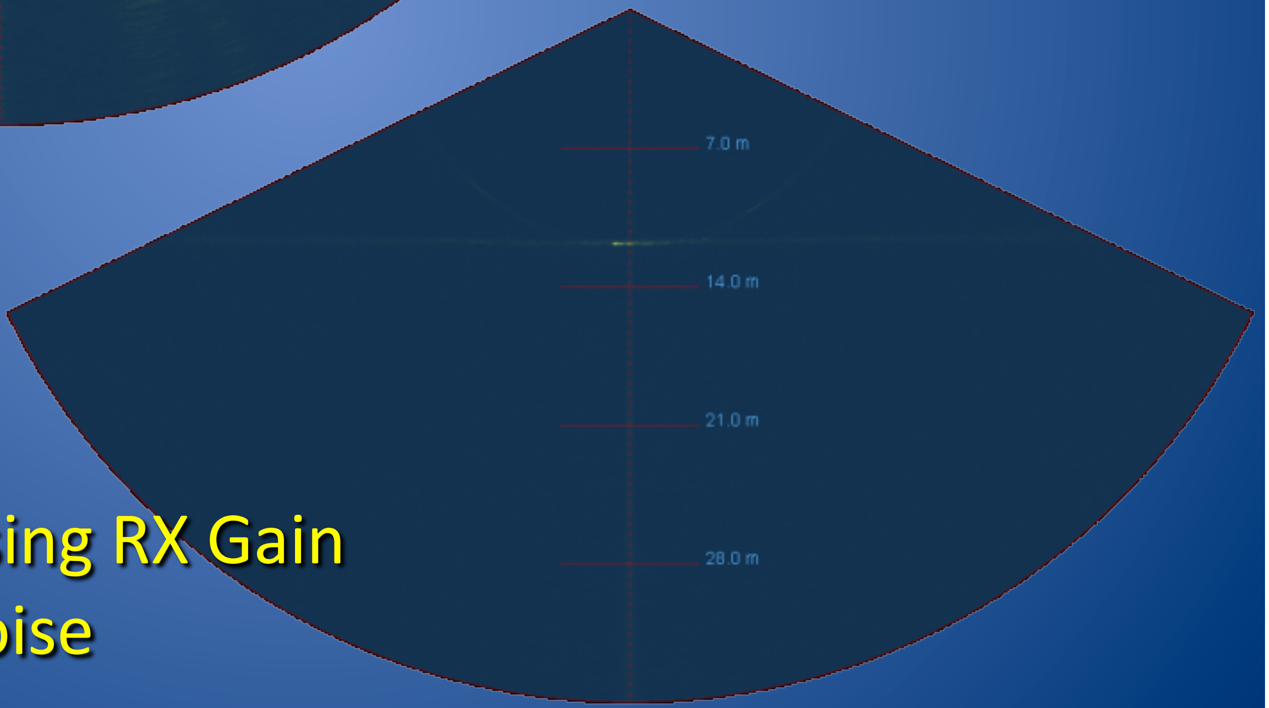


The sonar equation – Power and Gain

(good)



- High TX Power, High RX Gain



- Low TX Power, Low RX Gain
- Beware – Increasing RX Gain also increases Noise

The sonar equation – Spreading Loss

(bad)

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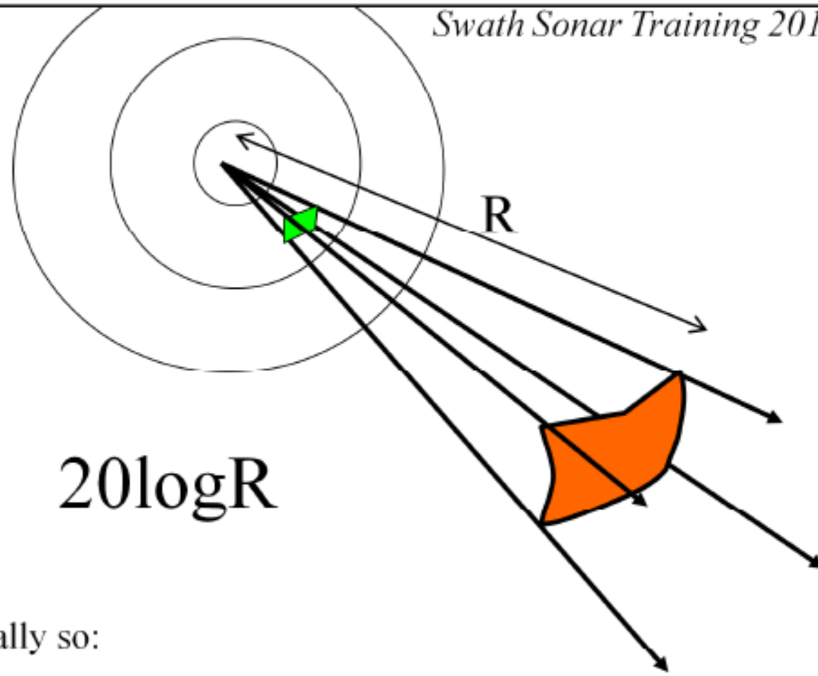
Spherical Spreading:

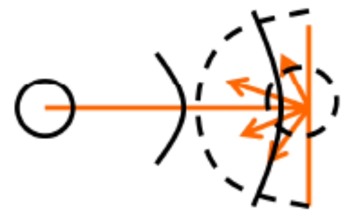
Energy per unit area
decays with $1/r^2$
(same energy distributed over the surface of a growing sphere.
frequency <u>independent</u>)



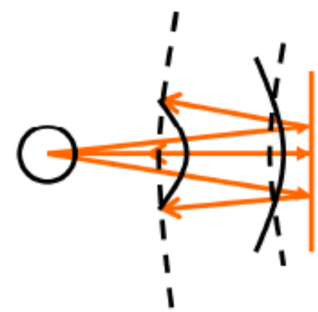
20logR

Incoherent scattered case:
Target scatters and re-radiates energy spherically so:
$1/R^2 \;\; 1/R^2 = 1/R^4$

Total: **-40 log R**



coherent reflected case – (seismics λ >> rms roughness),
Energy is coherently reflected so case is:



$$1/(2r)^2 = \; -20 \log (2R)$$

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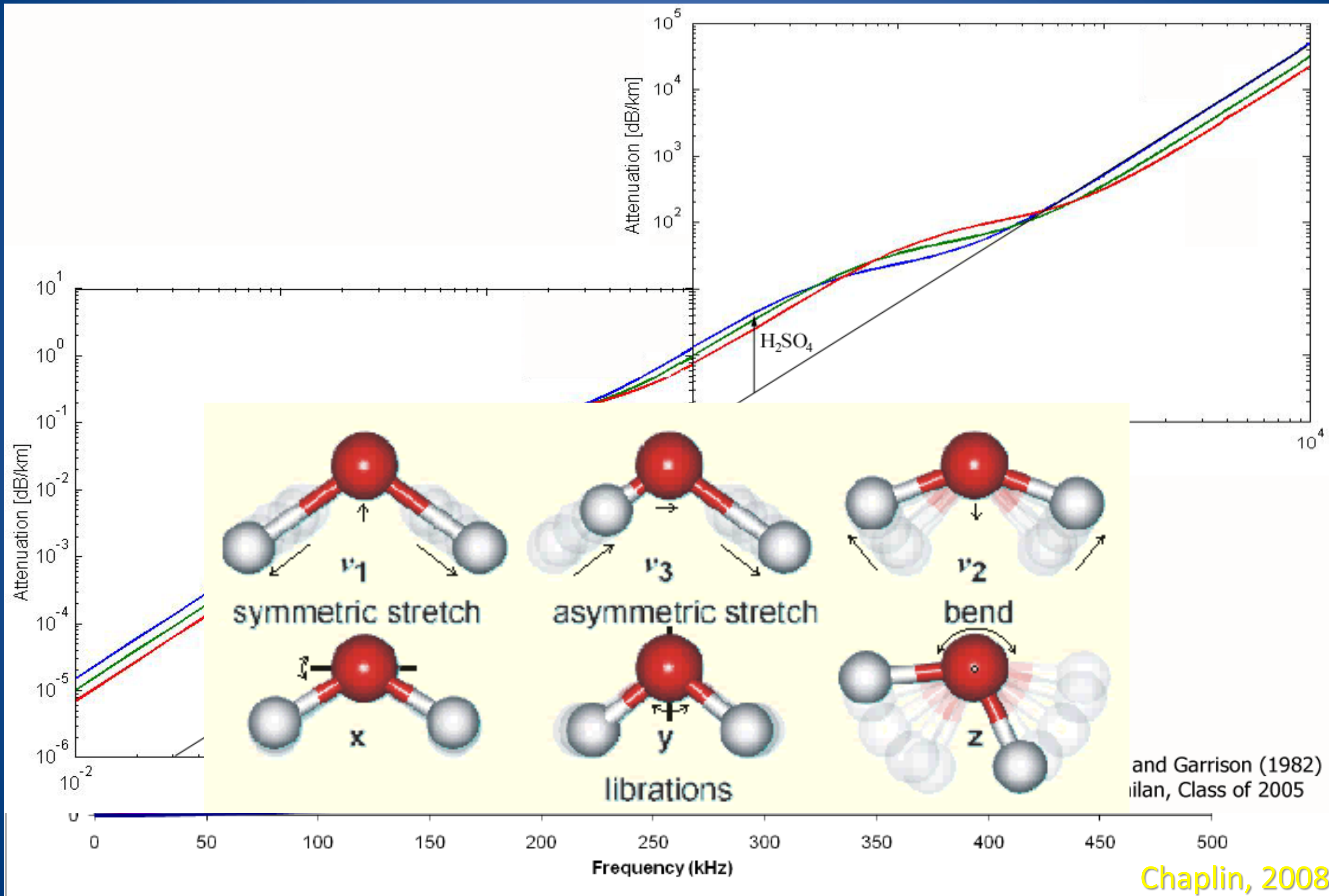
The sonar equation – Absorption Loss

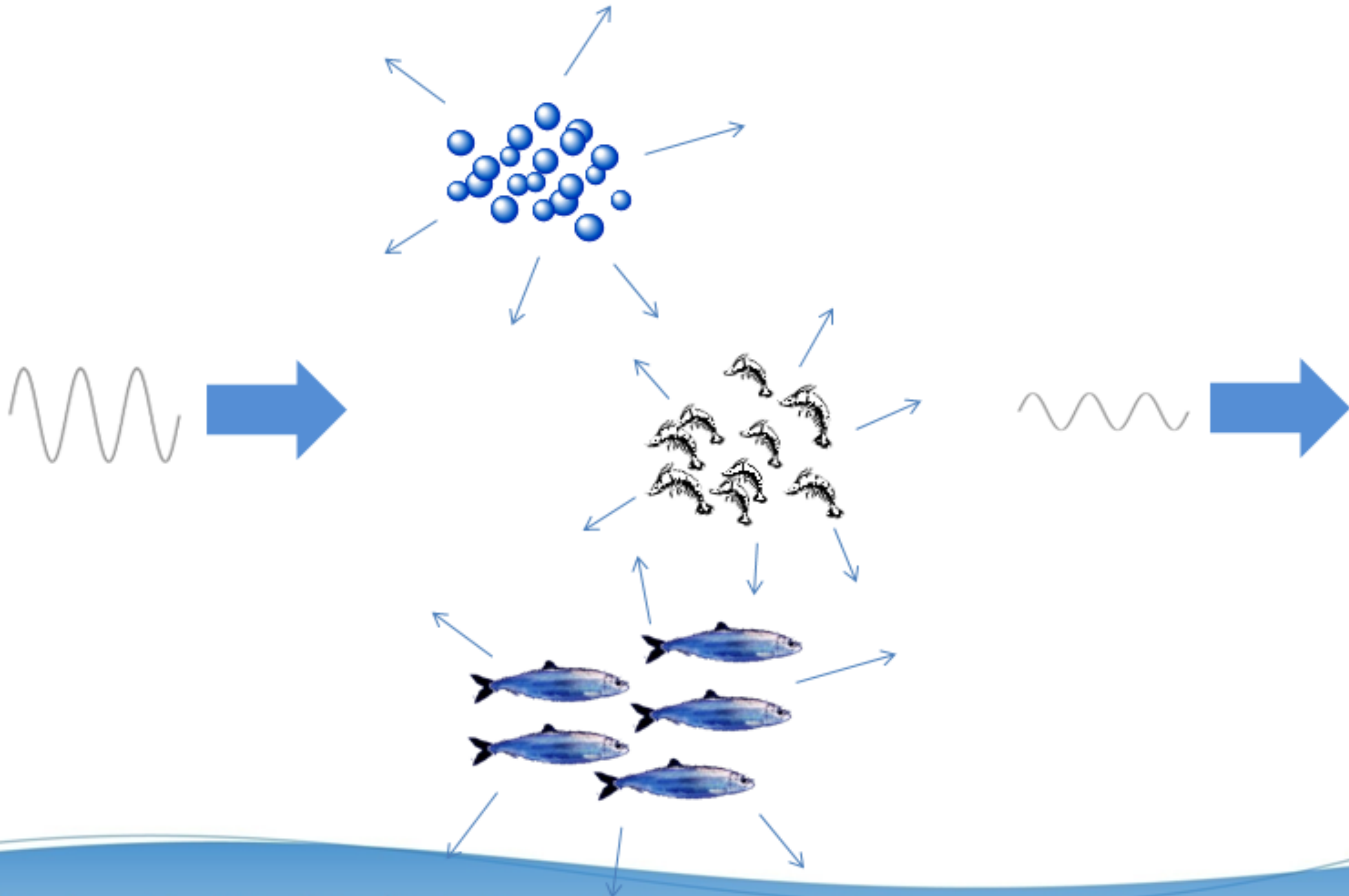
(bad)



Chaplin, 2008

The sonar equation – Scattering Loss

(bad)



The sonar equation – Background Noise

(bad)

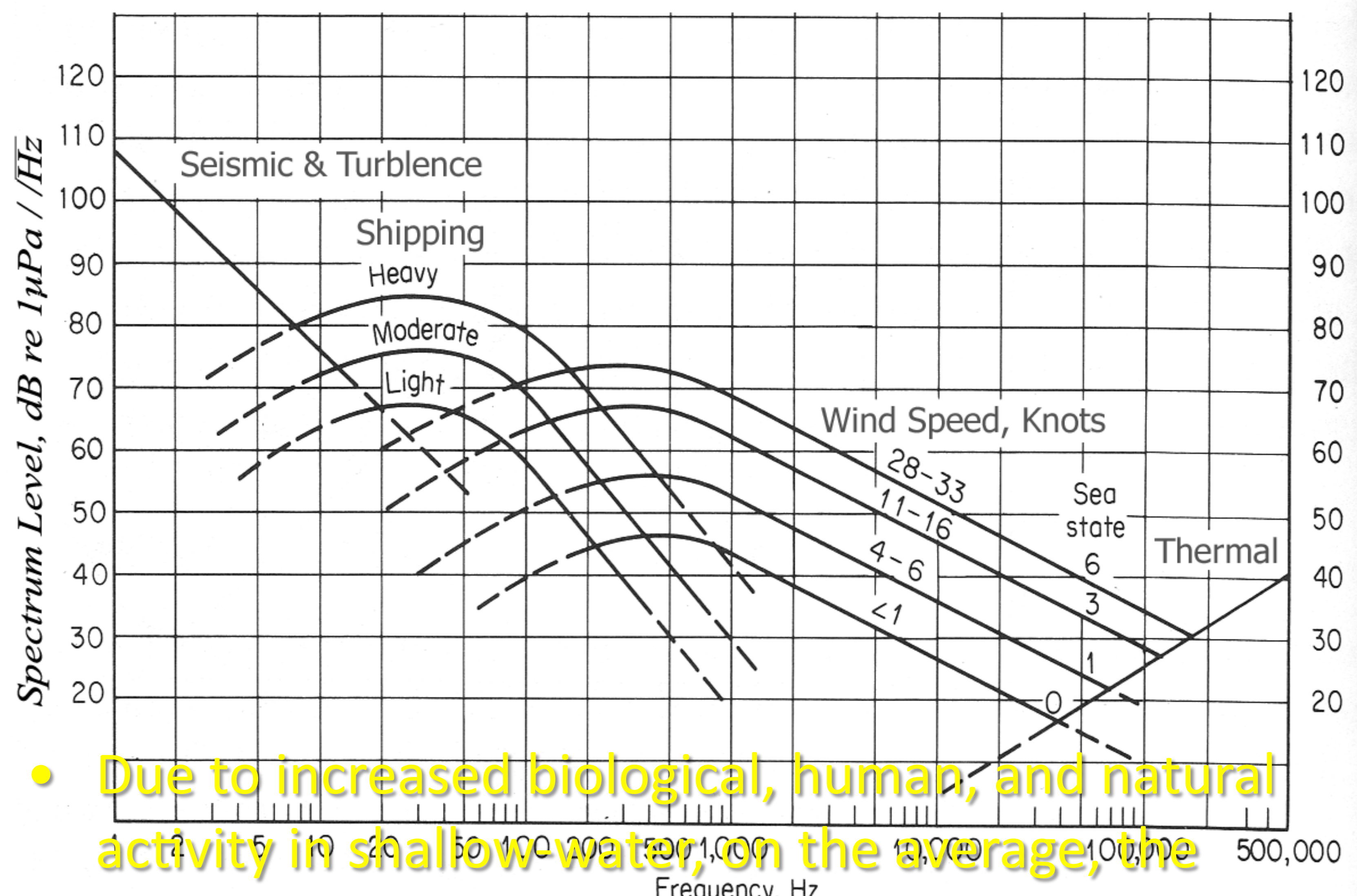


fig. 7.5 Average deep-water ambient-noise spectra.

- Due to increased biological, human, and natural activity in shallow water, on the average, the ambient noise is about 9 dB higher than it is in deep water and is much more variable.

Urick, 1983

The sonar equation – Directivity Index

(good)

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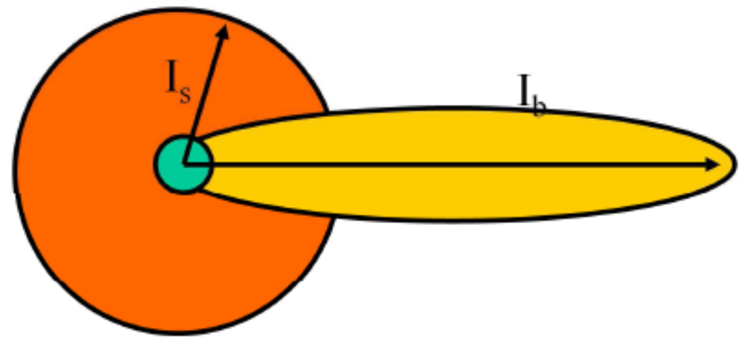
Directivity

How focused is the intensity distribution about the beamformed boresite direction with respect to an equivalent spherical source?

$$DI = 10\log(I_b/I_s)$$



The acoustic power is not uniformly distributed.

The more it is "directed" towards to target of interest, the higher the likely level incident there.

TRANSMIT DIRECTIVITY (DI_T):
normally built into the source level(SL).

RECEIVE DIRECTIVITY (DI_R):
normally subtracted from the noise level (NL) term as that is assumed omnidirectional.

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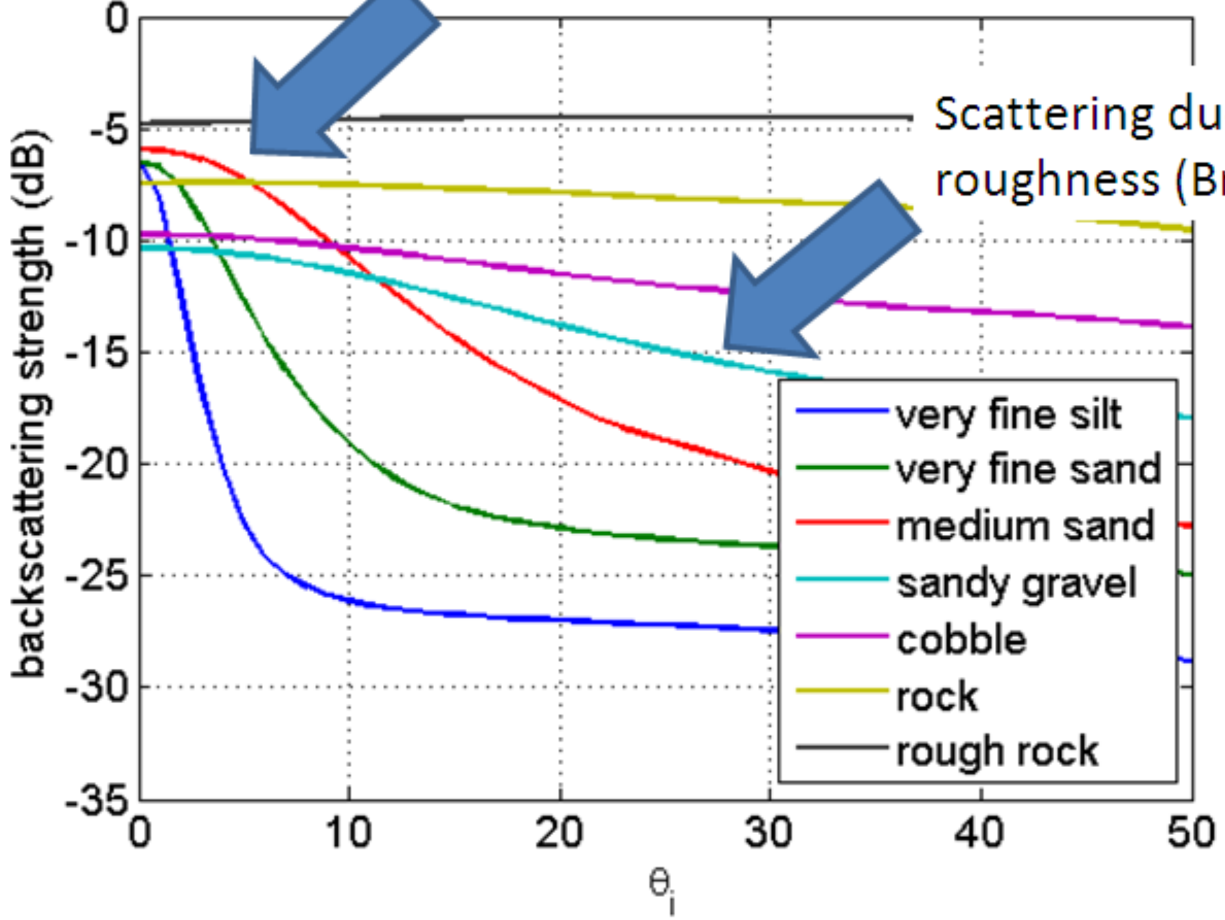
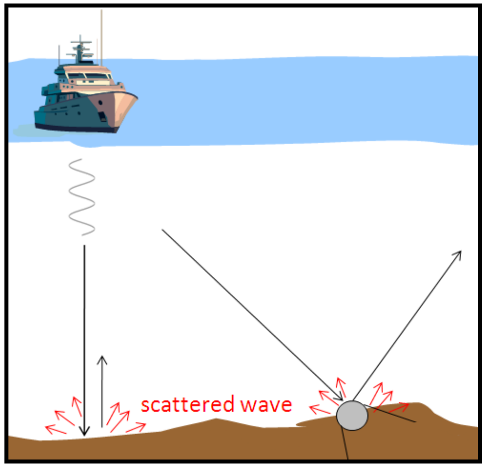
The sonar equation – Target Strength

(good)

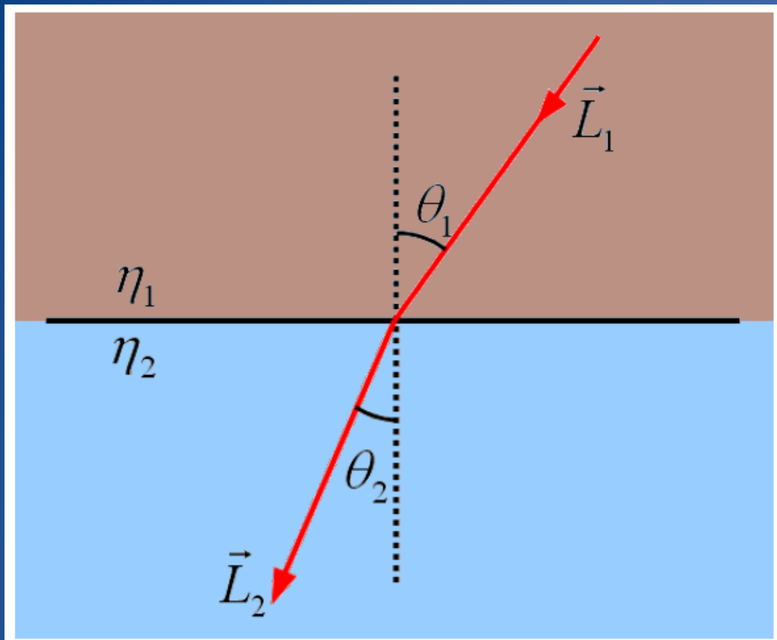
Scattering from 'facets' (specular reflections from portions of the seafloor)

Scattering due to microscale roughness (Bragg scattering regime)





Refraction



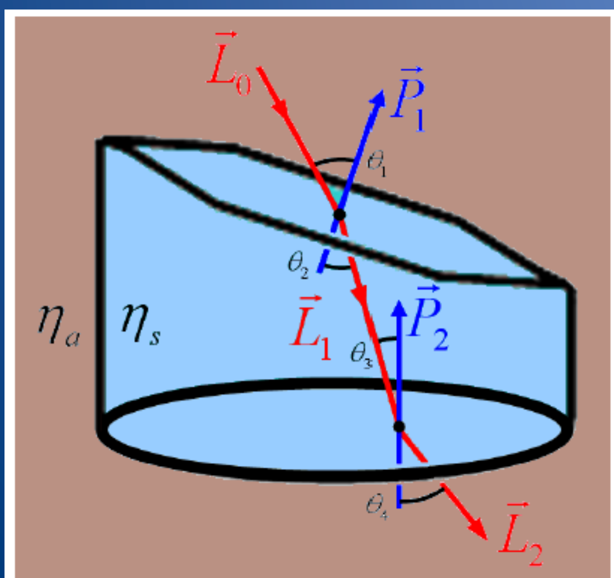
$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\eta_2}{\eta_1}$$

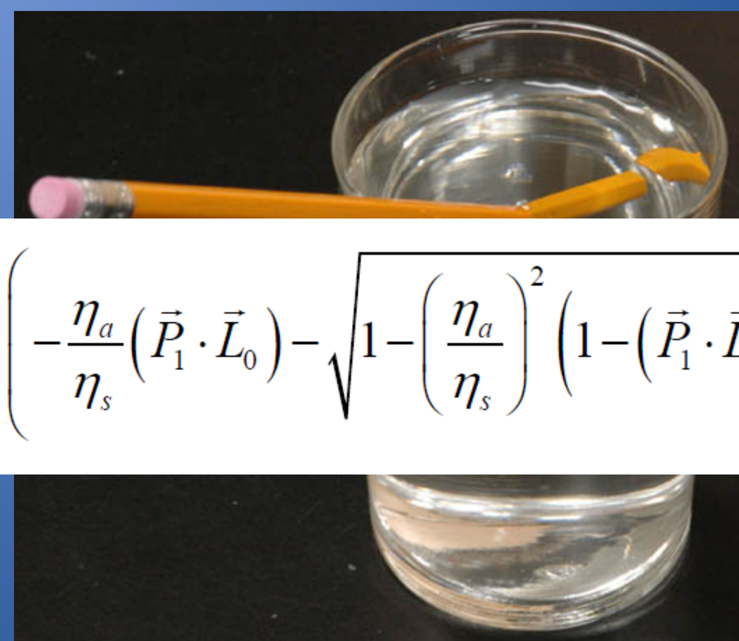
η_1 = refractive index of upper medium

η_2 = refractive index of lower medium

θ_1 = angle of incidence

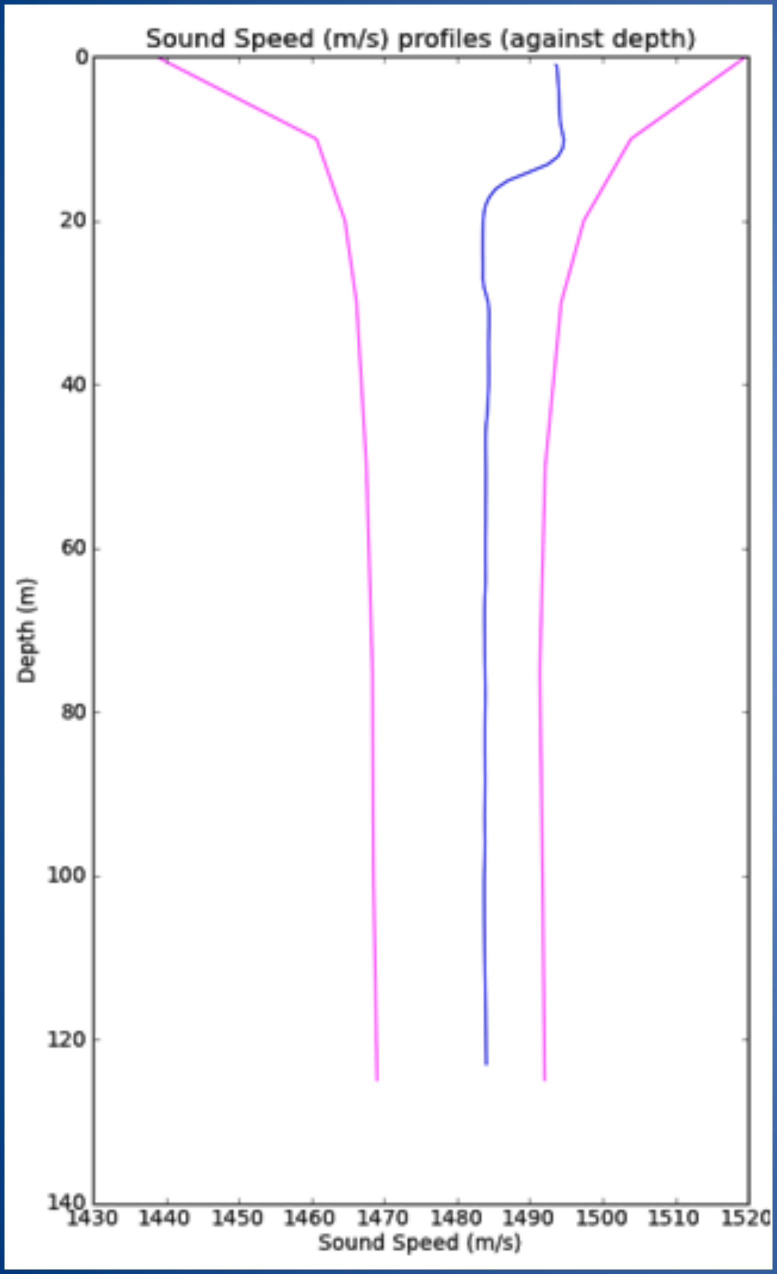
θ_2 = angle of refraction

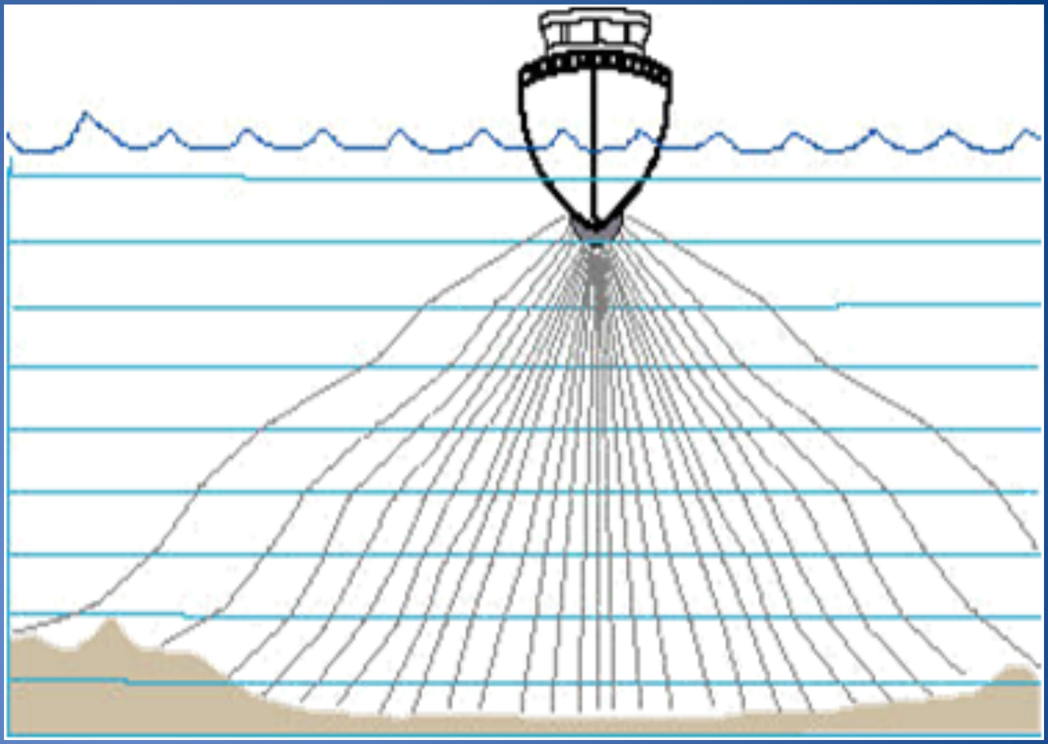




$$\vec{L}_1 = \frac{\eta_a}{\eta_s}\vec{L}_0 + \left(-\frac{\eta_a}{\eta_s}\left(\vec{P}_1 \cdot \vec{L}_0\right) - \sqrt{1 - \left(\frac{\eta_a}{\eta_s}\right)^2 \left(1 - \left(\vec{P}_1 \cdot \vec{L}_0\right)^2\right)} \right)\vec{P}_1$$

Refraction





RESON Inc.(2011)

Questions?

Thank you
for your time!

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