

Transmission Loss

The oceans form a very complex medium. Sound in the medium does many things except follow a straight path as we would want it to. We will study how the ocean affects the propagation of sound.

To this point we have introduced the passive SONAR equations and provided some mathematical definitions. From this section on, we will break the equation into the individual terms and discuss all the factors that determine the value for each.

Our first parameter is Transmission Loss, TL. Transmission Loss is the parameter that compares the amount of intensity of the signal at a specific range from the source to the source intensity at one yard. The equation for this would be:

$$TL \equiv 10 \log \frac{I(1 \text{ yd})}{I(r)}$$

Note: Due to early work in transmission loss being done referencing the intensity at one yard from the source, all quantities for the transmission loss equations typically are IN YARDS! Be careful.

Why is transmission loss defined as it is?

As you should remember, levels are expressed in decibels and are just ratios of one quantity to another. This allows us to express terms with large variations (several orders of magnitude or so) to each other rather easily. It also makes calculating quantities in the SONAR equations much easier.

For example, let us look at the combination of the source level and transmission loss, which defines the quantity, the received source level, L_s . If we substitute the definition of source level and transmission loss into the equation for the received source level, we get:

$$L_s = SL - TL = 10 \log \frac{I(1 \text{ yd})}{I_{ref}} - 10 \log \frac{I(1 \text{ yd})}{I(r)}$$

$$L_s = 10 \log \frac{I(1 \text{ yd})}{I_{ref}} + 10 \log \frac{I(r)}{I(1 \text{ yd})}$$

$$L_s = 10 \log \frac{I(r)}{I_{ref}}$$

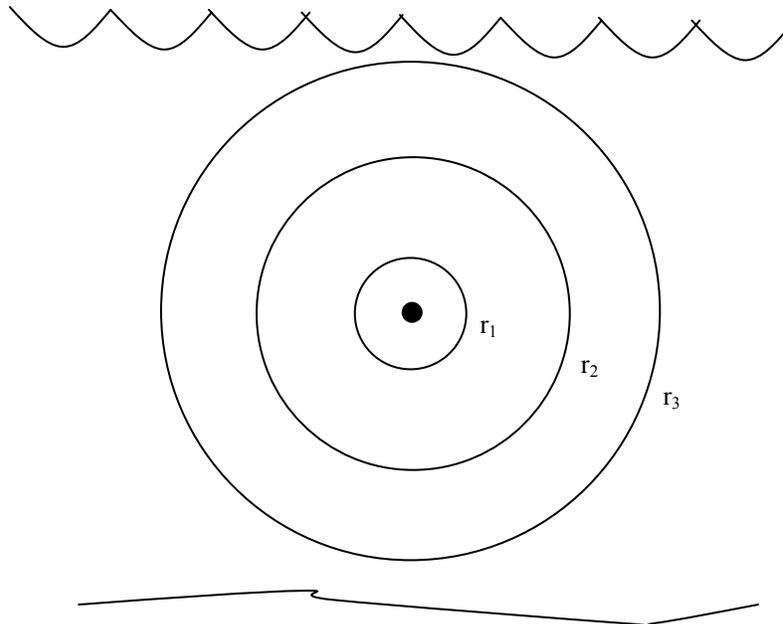
We can now see that the resultant, the received source level, is the ratio (in dB) of the actual intensity at range, r , compared to the intensity of a reference signal with an rms pressure of 1 μPa .

Transmission Loss results from:

- 1. Geometric losses due to one of two types of spreading, spherical or cylindrical.**
- 2. Attenuation due to absorption, scattering, viscosity, and thermal losses. This will be discussed more, later in the section.**

Spreading Loss

Let's assume we have a point source, which emits a signal in all directions (that is in three dimensions.) The source would produce wave fronts that were spheres that would grow in size as the wave propagates away from the source. Note that the power in each wave front



would be a constant, even though the size of the wave front would grow. (This assumes no power is lost from the wave due to attenuation.) The power of a wave front or sphere can be expressed in terms of the intensity of the wave where:

$$P = IA = I(4\pi r^2)$$

But again, we said the power of each wave front is a constant as the wave propagates so:

$$\begin{aligned} P_1 &= P_2 \\ I_1 4\pi r_1^2 &= I_2 4\pi r_2^2 \\ \frac{I_1}{I_2} &= \frac{4\pi r_2^2}{4\pi r_1^2} = \left(\frac{r_2}{r_1}\right)^2 \end{aligned}$$

Note the reversal of the subscripts on the right side of the last equation compared to the left side. As we see the intensity decreases as $1/r^2$.

Now using the definition of Transmission Loss:

$$TL = 10 \log \frac{I(1 \text{ yd})}{I(r)}$$

where

$$\frac{I(1 \text{ yd})}{I(r)} = \frac{4\pi(r)^2}{4\pi(1 \text{ yd})^2} = \frac{r^2}{(1 \text{ yd})^2}$$

thus

$$TL = 10 \log \frac{r^2}{1^2}$$

$$TL = 20 \log r$$

NOTE: The range, r, is the range in yards since the definition references the intensity at range r, to the intensity at 1 yard.

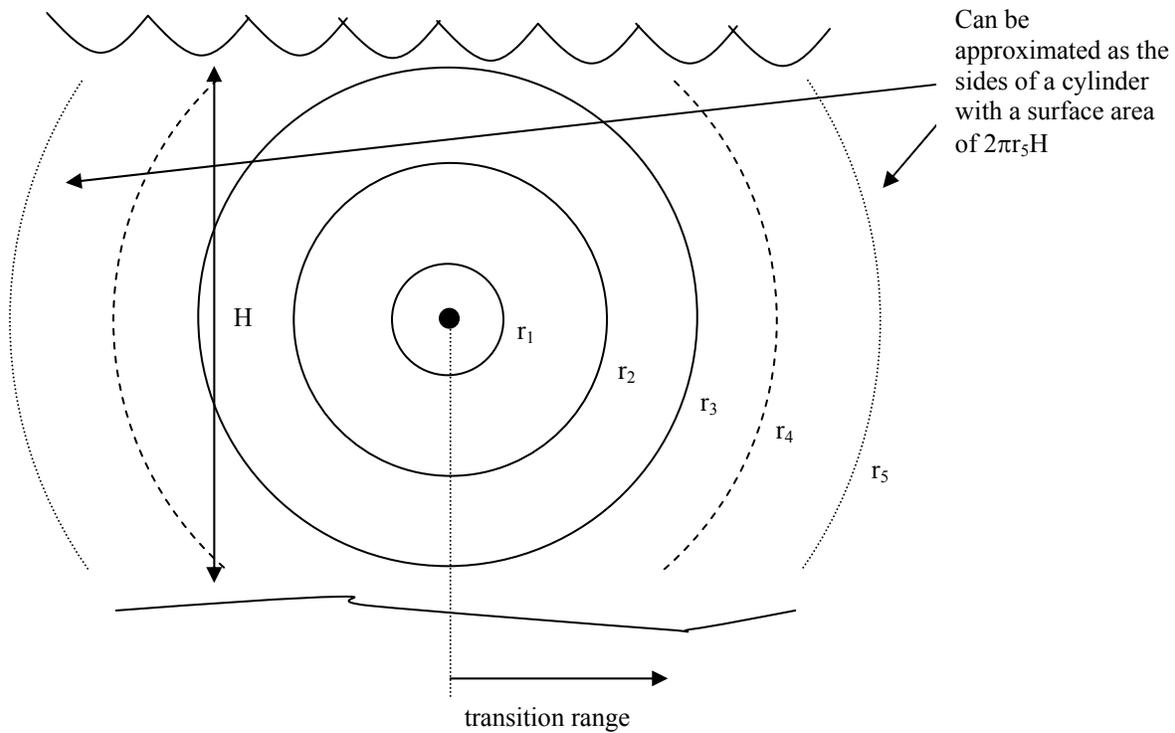
The equation above is for transmission loss only due to spherical spreading. Spherical spreading is the **most dominant factor** in the transmission loss portion of the passive SONAR equation but there are other factors that must be considered.

Cylindrical Spreading

What if the sound wave from a source does not spread out in 3-dimension but gets trapped within some boundaries such as in a surface duct? If we expand the picture that we previously used to show the wave fronts spreading out from a source, we see that the fronts at some point no longer form concentric spheres.

When the wave fronts hit the surface and the bottom, as in the case shown below, the power in the wave fronts is reflected back into the ocean and power is not lost out of the “top” of the wave fronts. All the power of the wave front is resident in the sides of the “cylinders” formed by the wave fronts. We can think of the wave front as being a concentric cylinder that spreads out from the source. Again, the power of each wave front is a constant but now the area of the cylinder where the power is resident is:

$$A = 2\pi rH$$



Note that we can neglect the surface area of the top and bottom of the cylinder because the power is reflected back at those surfaces and we assume no power is lost in the up or down direction.

Using the same mathematical process as we used for the spherical spreading case, we can determine the transmission loss if we only consider cylindrical spreading where:

$$\frac{I(1 \text{ yd})}{I(r)} = \frac{2\pi r H}{2\pi(1 \text{ yd})H} = \frac{r}{(1 \text{ yd})}$$

$$TL = 10 \log \frac{I(1 \text{ yd})}{I(r)}$$

$$TL = 10 \log r$$

The only limitation of this equation is that it does not take into account the spreading of the wave spherically until it reaches the “transition range” where the wave starts to spread cylindrically. To derive an equation that takes both factors into account, we can use one of the properties of logarithms where:

$$TL = 10 \log \frac{I(1 \text{ yd})}{I(r)} = 10 \log \frac{I(1 \text{ yd})}{I(r_0)} + 10 \log \frac{I(r_0)}{I(r)}$$

where r_0 is the transition range. If the first term accounts for the spherical spreading and the second term accounts for the cylindrical spreading, substituting in our previous equations for each, the sum becomes:

$$TL = 20 \log r_0 + 10 \log \frac{r}{r_0}$$

Thus, if there is a transition range, r_0 , we can calculate the total transmission loss due to both forms of spreading losses.

Transition Range

The range at which spreading losses switch from spherical to cylindrical spreading is not easily determined. The best method to determine the transition range would be to use a complex computer model of the ocean and determine the transition range. One approximation that can be used is presented in Urick, **Principles of Underwater Sound** on page 153. In the book, the author presents one formula where:

$$r_0 = \sqrt{\frac{RH}{8}} \sqrt{\frac{H}{H-d}}$$

where the terms in the equation are defined as:

H = mixed layer thickness

d = depth of the source

$R = \frac{c_n}{g \cos \theta_n}$ = radius of curvature of sound ray

This equation has some **severe limitations**. One, it is only good for the case of a well-defined surface layer (the most likely case where cylindrical spreading will occur) of depth, H , with a constant gradient, g . Two, this is only valid for **one particular ray** of sound from the source. Any other ray that leaves the source at a different angle θ will have a different transition range. Thus, at best this equation can only be used as a rough approximation.

In summary, the student may assume that only spherical spreading occurs unless told otherwise in a problem. Further, the student should not expect to calculate the transition range but should be given a value when one is required.

Attenuation

Attenuation is the lessening of the intensity per unit distance the sound travels. Attenuation losses occur from both **absorption** losses and **scattering** losses. Seawater is a dissipative medium, it absorbs part of the energy of the transmitted wave.

Absorption is the conversion of acoustic energy to heat in the fluid. There are three main causes of absorption losses:

1. Viscosity – Shear and Volume viscosity where as the molecules “rub” together, acoustic energy is converted to thermal energy heats up the fluid.
2. Change in Molecular Structure – Molecules in the seawater are disassociated or broken down into component ions which then recombine after the sound wave travels over the molecule. Above 100 kHz this involves the relaxation of MgSO_4 and above 1kHz the relaxation of $(\text{B}(\text{OH})_3)$.
3. Heat Conduction – This process is negligible and we will not present it here.

This attenuation causes a decrease in the amplitude of the wave and an exponential decrease in the acoustics pressure resulting in more spreading loss. To account for attenuation in the transmission loss equation, we must define a new term, α , the attenuation coefficient. Using this new term, we can calculate the transmission loss using the equation:

$$TL_{\text{attenuation}} = \alpha(r - (1\text{yd})) \times 10^{-3} \text{ dB}$$

where r is in yards.

Generally, since the range, r, is usually much greater than 1 yard, we can ignore the -1 yard term in the equation. Thus the transmission loss can be expressed as:

$$TL_{\text{attenuation}} = \alpha(r \times 10^{-3}) \text{ dB}$$

The student should also note that α will be expressed in dB/kyd or dB per thousand yards. In the equation, that is accounted for by the $\times 10^{-3}$ to convert the range, r, from yards to kiloyards (kyd).

The most difficult problem will be to determine a correct value for α , the attenuation coefficient.

Viscosity

The viscosity losses are due to two distinct effects. Each of these effects are dependent on not only how the molecules act together in the medium as defined by the coefficients of both shear and volume viscosity but also the frequency of the sound waves.

The first, shear viscosity must be accounted for due to the movement between layers in the medium itself or the shearing of the medium. A theoretical prediction for how shear viscosity affects the attenuation coefficient, α , is given by the equation:

$$\alpha_{shear} = \frac{16\pi^2}{3\rho c^3} \mu_s f^2$$

where μ_s is the shear viscosity coefficient, which is a property of the medium.

The second viscosity effect, volume viscosity, must be accounted for due to the “time lag” of molecules filling in holes in the molecular structure of the medium. A theoretical prediction for the volume viscosity affect is given by the equation:

$$\alpha_{volume} = \frac{16\pi^2}{3\rho c^3} \left(\frac{3}{4}\right) \mu_v f^2$$

where μ_v is the volume viscosity coefficient, again a property of the medium.

When both terms are combined and nominal values used for the density, speed of sound and the coefficients, the value for the attenuation coefficient becomes:

$$\alpha = 2.75 \times 10^{-4} f^2$$

where f is the sound wave frequency in kHz. This theoretical value is still 3 times less than actual measure values for higher frequencies. Another factor must account for further attenuation.

Ionic Relaxation

The most dominant disassociation-re-association process in the attenuation coefficient for seawater involves the finite time that it takes for magnesium sulfate ($MgSO_4$) ions to dissociate and reassociate as a sound wave passes through the medium.



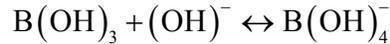
If the period of the wave is different than the time necessary for the molecule to recombine itself (relaxation time), the process is reproduced at every change in density as the wave moves by and permanently dissipates energy. An equation to describe how this process affects the attenuation coefficient is:

$$\alpha_{MgSO_4} = \frac{40f}{4100 + f^2}$$

where once again, the frequency, f , is in kHz.

It is particularly interesting that this process has such a large affect on the attenuation coefficient when $MgSO_4$ makes up less than 5% (by weight) of the total dissolved salts in seawater.

Another disassociation-re-association process that becomes a dominant factor in determining the attenuation coefficient below approximately 1 kHz, is the boron-borate relaxation process.



Though many factors affect this complex process, simply suffice it to say that an equation for this process' affect on α would be:

$$\alpha_{boron-borate} = \frac{0.1f^2}{1+f^2}$$

A non-absorption factor, scattering

The last factor that we will discuss is the scattering of sound energy due to inhomogeneities in seawater. This factor we can approximate as a constant, not dependant on frequency and would only be a dominant factor below 100 Hz or so. This can be expressed as:

$$\alpha_{scattering} = 0.003 \text{ dB/kyd}$$

Attenuation Summary

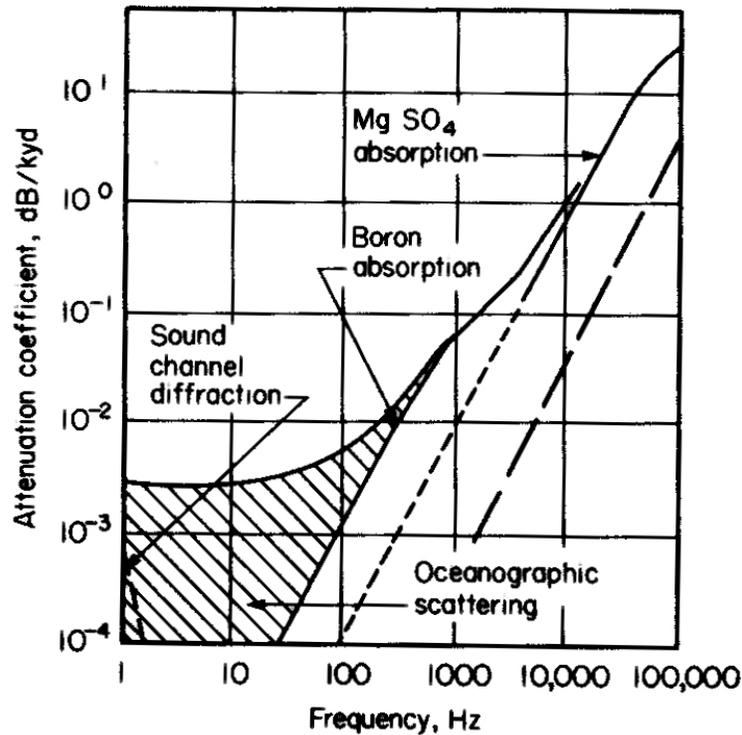
When all these factors are combined, the equation for transmission loss then becomes:

$$TL = \alpha(r \times 10^{-3}) \text{ dB}$$

where

$$\alpha = \left(0.003 + \frac{0.1f^2}{1+f^2} + \frac{40f^2}{4100+f^2} + 2.75 \times 10^{-4} f^2 \right) \text{ dB/kyd}$$

A plot of the transmission coefficient, α , as a function of frequency, is shown below.



(Source: **Principles of Underwater Sound**, Third Edition, Robert J. Urick, McGraw-Hill Book Company, 1983, p. 111) One should note from the graph that the attenuation coefficient is **very** small for any frequency below 10,000 Hz. Below 10 kHz, the attenuation coefficient is less than 1 dB **per thousand yards**. Generally speaking, one can usually neglect attenuation at any frequency below 10,000 Hz.

Francois-Garrison Attenuation Model

(Source: **An Introduction to Underwater Acoustics**, 1st Edition, Xavier Lurton, Springer-Verlag, 2002, p. 21)

$$\alpha = A_1 P_1 \frac{f_1 f^2}{f_1^2 + f^2} + A_2 P_2 \frac{f_2 f^2}{f_2^2 + f^2} + A_3 P_3 f^2$$

The first term is for Boric acid, the second for Magnesium Sulfate and the third for viscosity. For frequencies less than 1 kHz, this results in $\alpha < 0.01$ dB/km, for $f = 10$ kHz, $\alpha \approx 1$ dB/km, for $f = 100$ kHz, $\alpha \approx 30 - 40$ dB/km, resulting in max ranges of @ 1km, and for $f = 1$ MHz limits the max range to @ 100m.

Depth Dependence

Depth can have a large impact on sidescan sonar and underwater data transmission. If the frequency is high enough so that MgSO_4 is the major attenuation effect, we can multiply α by the pressure effect, P_2 . As an example, $\alpha = 40$ dB/km at the ocean surface, 30 dB/km at 2000 m, and 22 dB/km at 4000 m.

Active Transmission Loss

For the case of active sonar, the one way transmission loss is determined exactly the same as the passive case. The return echo experiences exactly the same transmission loss on its way back. Because of this, the active transmission loss is **twice** that of the passive case for the same range. Note that because spherical and cylindrical spreading are logarithmic, it would be incorrect to double the range.

Summary

What is the dominant factor in transmission loss? Does the frequency of the signal determine the amount of transmission loss? Can any of the factors in the transmission loss equation be neglected? These are some of the questions that the student should try to answer before using the transmission loss equations.

The most dominant factor in all of the transmission loss problems will be spherical spreading. If we have a source level 1 yard from our source, at what distance will the received signal level drop by 3 dB ($\frac{1}{2}$ original intensity)? In other words, due to spherical spreading, at what range, r , will the transmission loss be 3 dB? Solving for this using the spherical spreading equation:

$$TL = 3 \text{ dB} = 20 \log\left(\frac{r}{(1 \text{ yd})}\right)$$

$$\therefore r = 1.4 \text{ yds}$$

In other words, the intensity drops quickly due to spherical spreading. If we do the same for a signal at 50 kHz and only consider attenuation, the range where the intensity drops to $\frac{1}{2}$ its original intensity would be:

$$TL = 3 \text{ dB} = \alpha(r - (1 \text{ yd}) \times 10^{-3})$$

$$\alpha = 3.16 \text{ dB/kyd from graph above}$$

$$\therefore r = 950 \text{ yds}$$

This is a significantly further range than calculated for the spherical spreading case. Notice also that the frequency was very high. If the frequency were lower, the range for a 3 dB attenuation transmission loss would increase significantly. **Thus spherical spreading is usually the only significant factor in figuring transmission loss.**

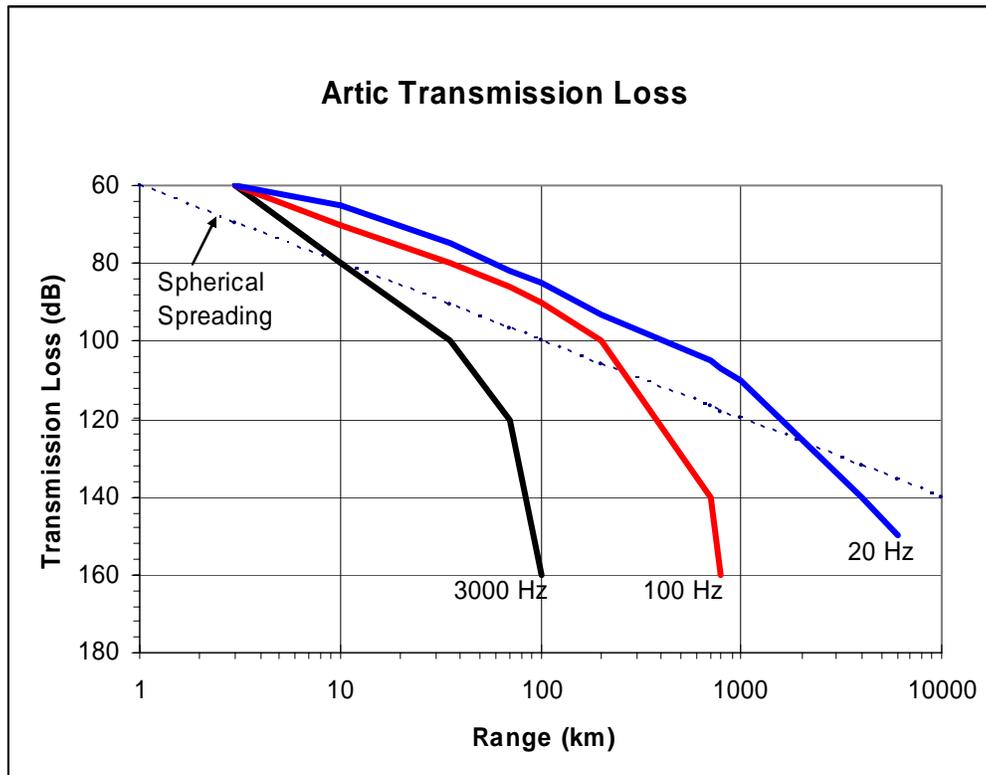
Problems:

1. Calculate the transmission loss for the following:
 - a) spherical spreading only at 10 yds, 100 yds, 1000 yds.
 - b) cylindrical spreading only at 10 yds, 100 yds, 1000 yds. (assume transition range, $r_0=1\text{yd}$)
2. What is the transmission loss over a range of 70 kyds if the transition range is 30 kyds? (Ignore attenuation.)
3. For only spherical spreading with absorptive losses, calculate the transmission loss for a 5 kHz sound at:
 - a) 1 km
 - b) 5 kyds
 - c) At what range would the transmission loss be 70 dB?

The following information is to be used to do the next problem:

4. An acoustic signal is used to control a remote sub. The signal has a source level of $220 \text{ dB}_{\text{re } 1 \mu\text{Pa}}$ at 1 yard from the source attached to the bottom of the research ship.
 - a) If the absorption coefficient of seawater at a particular frequency is 0.095 dB/Kyd , at what distance would the acoustic signal lose $\frac{1}{2}$ of its intensity due to absorption?
 - b) Given the signal above, at what range from the source would the signal lose $\frac{1}{2}$ its intensity due to spherical spreading?
 - c) What is the absorption coefficient of seawater if the frequency of the transmitter is raised to 10 kHz?
5. Where is cylindrical spreading more likely to occur?
6. A Sonarman on an Aegis is trying to calculate the expected two-way transmission loss of an active sonar ping directed at a target 20,000 yards away. If he assumes that absorption losses are negligible and IMAT tells him that the transition range is 6000 yards for the current environment, what is the **two-way** transmission loss?
7. A submarine is attempting to detect an aircraft carrier transiting the Straits of Malacca. The aircraft carrier has a source level of 90 dB. The submarine's passive sonar has a directivity index of 20 dB and a detection threshold of 15 dB. Biological noise in the Straits is 54 dB. The submarine's self noise is 50 dB. Assuming spherical spreading and neglecting attenuation, at what range can the carrier be detected.
8. Arctic transmission loss measurements are made at the three frequencies as a function of range in km and shown in the below graph. Theoretical spherical spreading is also shown for comparison by the dashed line. If 100 Hz frequency signals with a source level of 150 dB are propagating, find the detection range of the source using an omni directional hydrophone

(DI = 0 dB) operating in a total noise level of 60 dB. The signal to noise level of detection (DT) is 10 dB. Ignore attenuation at 100 Hz.



9. The intensity level 200 m from a sound source is measured as 100 dB re 1 μ Pa. What is the intensity level at 2000 m assuming:
 - a) Spherical spreading
 - b) Cylindrical spreading

10. For a given shallow water homogeneous bounded water column, the transition range between spherical and cylindrical spreading occurs at 1500 yards. Assuming only geometric spreading losses (no attenuation), plot transmission loss vs. range from 500 yds to 10,000 yds.

11. The absorption coefficient is 2 dB/kyd. Calculate the transmission loss due to spherical spreading and absorption:
 - a) At a range of 5,000 yds.
 - b) At a range of 10,000 yds.

12. The intensity level at 4,000 yards from a source is 150 dB and at 12,000 yards is 130 dB. Assuming that this loss is due to spherical spreading plus absorption, calculate the absorption coefficient in dB/kyd.

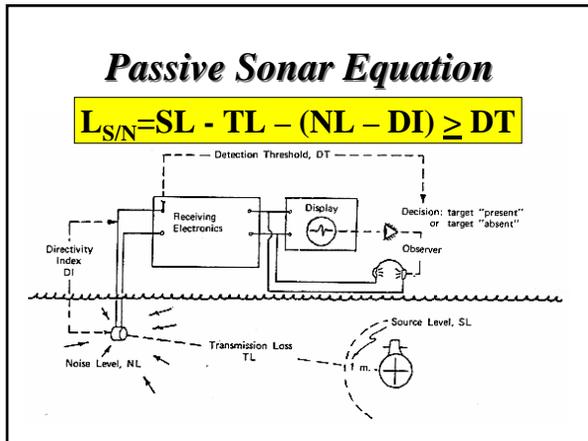
Transmission Loss

Review of Passive Sonar Equation

Terminology

- **Signal to Noise**
The ratio of received echo from target to background noise produced by everything else.
- **Detection Threshold (DT)**
The measure of return signal required for an operator using installed equipment to detect a target 50% of the time.

$$L_{S/N} = L_S - L_N \geq DT$$



The Passive Sonar Equation

$$L_{S/N} = SL - TL - (NL - DI)$$

$$SL = 10 \log \left(\frac{I_S}{I_0} \right) \quad NL = 10 \log \left(\frac{I_N}{I_0} \right)$$

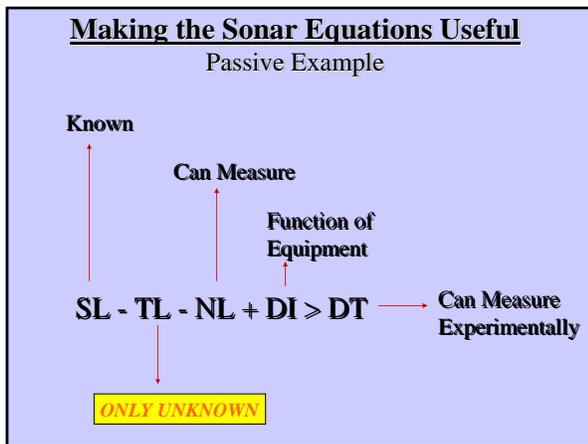
$$TL = 10 \log \left(\frac{I_S}{I_R} \right) \quad DI = 10 \log (d)$$


Figure of Merit

- Often a **detection threshold** is established such that a trained operator should be able to detect targets with that $L_{S/N}$ half of the time he hears them. Called "**Recognition Differential.**" (**RD**)
- Passive sonar equation is then solved for TL allowable at that threshold. Called "**Figure of Merit.**" (**FOM**)

$$TL_{\text{allowable}} = \text{Figure of Merit} = SL - L_{S/N \text{ Threshold}} - (NL - DI)$$

- Since TL logically depends on range, this could provide an estimate of range at which a target is likely to be detected. Called "**Range of the Day.**" (**ROD**)
- Any $L_{S/N}$ above the Recognition Differential is termed "**Signal Excess.**" (**SE**) Signal Excess allows detection of targets beyond the Range of the Day.

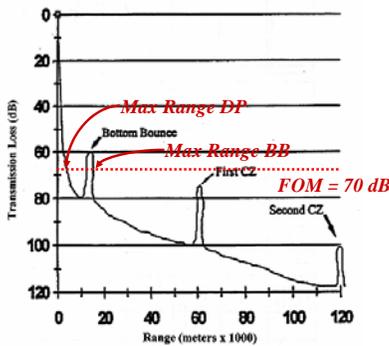
Range ???

- FOM helps to predict RANGE.
 - The **higher** the FOM, the **higher** the signal loss that can be suffered and, therefore, the **greater** the expected detection range.
- Probability of Detection
 - Passive
 - If FOM > TL then > 50% prob det
 - If FOM < TL then < 50% prob det
- Use Daily Transmission Loss (Prop Loss/FOM) curve provided by Sonar Technicians

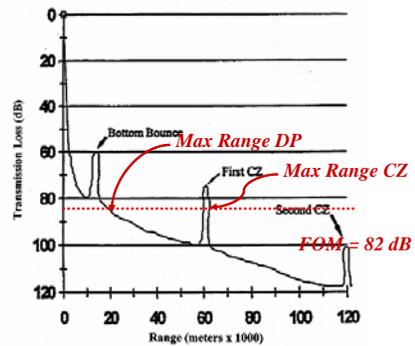
HW Example

- A submarine is conducting a passive barrier patrol against a transiting enemy submarine. The friendly sub has a directivity index of 15 dB and a detection threshold of 8 dB. The enemy sub has a source of 140 dB. Environmental conditions are such that the transmission loss is 60 dB and the equivalent isotropic noise level is 65 dB.
- What is the received signal level?
- What is the signal to noise ratio in dB?
- What is the figure of merit?
- Can the sub be detected? Why?

Prop Loss Curve



Prop Loss Curve

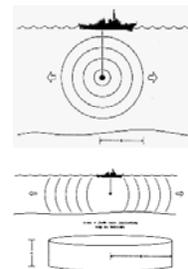


Transmission Loss

- Sound energy in water suffers two types of losses:
 - Spreading
 - Attenuation
- Combination of these 2 losses:
- TRANSMISSION LOSS (TL)**

Spreading

- Spreading
 - Due to divergence
 - No loss of energy
 - Sound spread over wide area
 - Two types:
 - Spherical
 - Short Range: $r_0 < 1000$ m
 - Cylindrical
 - Long Range: $r_0 > 1000$ m



$$TL = 20 \log r$$

$$TL = 10 \log \frac{r}{r_0} + 20 \log \frac{r_0}{l}$$

Spherical component

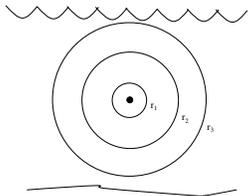
Spherical Spreading

$$TL = 10 \log \left(\frac{I_s}{I_r} \right)$$

$$P_1 = P_2$$

$$I_1 4\pi r_1^2 = I_2 4\pi r_2^2$$

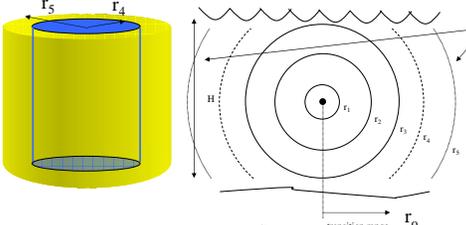
$$\frac{I_1}{I_2} = \frac{4\pi r_2^2}{4\pi r_1^2} = \left(\frac{r_2}{r_1} \right)^2$$

$$TL = 20 \log \left(\frac{r_2}{r_1} \right) = 20 \log \left(\frac{r}{1} \right) = 20 \log r$$


Cylindrical Spreading

$$TL = 10 \log \frac{I(1 \text{ yd})}{I(r)} = 10 \log \frac{I(1 \text{ yd})}{I(r_0)} + 10 \log \frac{I(r_0)}{I(r)}$$

spherical cylindrical



Can be approximated as the sides of a cylinder with a surface area of $2\pi r_0 H$

$$TL = 20 \log r_0 + 10 \log \frac{r}{r_0}$$

Spherical to Cylindrical Transition Range in a Mixed Layer

$$r_0 = \sqrt{\frac{RH}{8}} \sqrt{\frac{H}{H-d}}$$

H = mixed layer thickness
 d = depth of the source
 $R = \frac{c_n}{g \cos \theta_n}$ = radius of curvature of sound ray

Attenuation

- 2 Types
- Absorption
 - Process of converting acoustic energy into heat.
 - Viscosity
 - Change in Molecular Structure
 - Heat Conduction
 - Increases with higher frequency.
- Scattering and Reverberation
 - All components lumped into Transmission Loss Anomaly (A).
 - Components:
 - Volume: Marine life, bubbles, etc.
 - Surface: Function of wind speed.
 - Bottom Loss.
 - Not a problem in deep water.
 - Significant problem in shallow water; combined with refraction and absorption into bottom.

Absorption

- Decrease in intensity, proportional to:
 - Intensity
 - Distance the wave travels
- Constant of Proportionality, a

$$dI = -aI dr$$

$$\frac{I_2}{I_1} = e^{-a(r_2 - r_1)}$$

Absorption Coefficient

$$TL = 10 \log \frac{I_1}{I_2} = 10 \log e^{a(r_2 - r_1)}$$

$$TL = a(r_2 - r_1) 10 \log e = 4.343a(r_2 - r_1)$$

$$TL = \alpha(r_2 - r_1)$$

$\alpha = 4.343a$ Has units of dB/yard

$$TL = \alpha(r_2 - r_1) \times 10^{-3}$$

α Has units of dB/kiloyard

Example

- Spherical Spreading
- Absorption coefficient, $\alpha = 2.5$ dB/kyd
- Find the TL from a source to 10,000 yards
- Find the TL from 10,000 yards to 20,000 yards

$$TL = 20 \log \left(\frac{r_2}{r_1} \right) + \alpha (r_2 - r_1) \times 10^{-3}$$

General Form of the Absorption Coefficient

$$\alpha = \frac{A f_r f^2}{f_r^2 + f^2}$$

f_r = relaxation frequency. It is the reciprocal of the relaxation time. This is the time for a pressure shifted equilibrium to return to 1/e of the final position when pressure is released

f = frequency of the sound

When $f \ll f_r$,

$$\alpha = \frac{A f^2}{f_r}$$

Estimating Absorption Coefficient

- Viscosity – Classical Absorption - Stokes

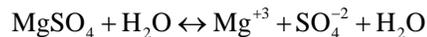
$$\alpha = \frac{16\pi^2}{3\rho c^3} \mu f^2$$

$$\mu = \mu_s + \frac{3}{4} \mu_v \quad \text{Shear and volume viscosity}$$

$$\alpha = 2.75 \times 10^{-4} f^2 \quad \text{For seawater, dB/m, } f \text{ in kHz}$$

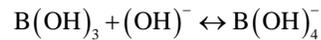
Chemical Equilibrium

Magnesium Sulfate:



$$\alpha = \frac{40f^2}{4100 + f^2} \quad f \text{ in kHz}$$

Boric Acid:



$$\alpha = \frac{.1f^2}{1 + f^2} \quad f \text{ in kHz}$$

Scattering

- Scattering from inhomogeneities in seawater

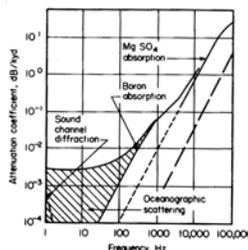
$$\alpha = 0.003 \text{ dB/kyd}$$

- Other scattering from other sources must be independently estimated



All lumped together as Transmission Loss Anomaly

Attenuation Summary



Note that below 10000Hz, attenuation coefficient is extremely small and can be neglected.

$$TL = \alpha (r \times 10^{-3}) \text{ dB}$$

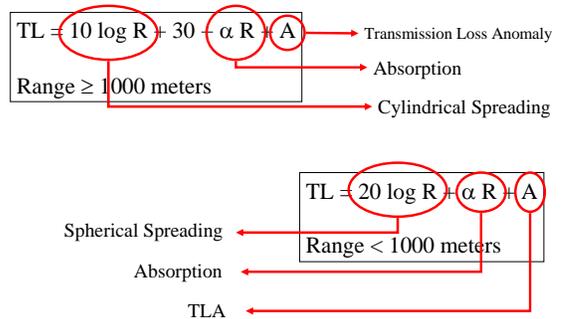
where

$$\alpha = \left(0.003 + \frac{0.1f^2}{1 + f^2} + \frac{40f^2}{4100 + f^2} + 2.75 \times 10^{-4} f^2 \right) \text{ dB/kyd}$$

Example

- Submarine sonar systems include a forward looking, high resolution active sonar which can be used to detect moored mines and ice keels. This system operates at 30 kHz and emits a source level of 130 dB re 1 μ Pa.
 - Calculate the attenuation coefficient
 - Assuming a transition range of 1000 yards, what is the transmission loss at a range of 5000 yards?
 - What is the Signal Intensity Level received by a second submarine 5000 yards away.
 - At this frequency, Noise Level is 40 dB and DI for the receiving sub is 20 dB. What is the signal to noise level?
 - If the Detection Threshold is 25 dB, will the second sub detect the first?

Transmission Loss Equations



Terminology

- Source Level (SL)
 - For **ACTIVE** sonar operations:
 - The SONAR's sonic transmission (transducer generated)
 - For **PASSIVE** sonar operations:
 - Noise generated by target
- Noise Level ($NL = NL_s \oplus NL_A$)
 - Self (NL_s)
 - Generated by own ship at the frequency of interest.
 - Ambient (NL_A)
 - Shipping (Ocean Traffic), Wind and Weather - Sea State (Hydrodynamic)
 - Biologic and Seismic obtained from other methods

Terminology

- Directivity Index (DI)
 - Receiver directional sensitivity.
 - $L_N = NL - DI$
- Transmission Loss (TL)
 - Amount the Source Level is reduced due to spreading and attenuation (absorption, scattering).

Passive SONAR Equation (Signal Radiated by the Target)

- SNR required for detection = DT
- To achieve detection > 50% of the time...
 - $SNR > DT$
 - $L_S - L_N > DT$
 - $L_S = SL - TL$ (one way)
 - $L_N = NL - DI$
 - Remember $NL = NL_s \oplus NL_a$
- Therefore...

$$L_{S/N} = SL - TL - (NL - DI) \geq DT$$