Sonar Equation Problem Set #2

The purpose of this assignment is to review terms in the sonar equation and to rearrange terms to calculate variables of interest. Exercises that interpret the transducer beam plot and calculate transducer far field values provide examples of sample volume estimation, off-axis signal loss, and sampling range limitations.

Note: Assume sound speed in water is 1500 ms^{-1}.

1) Given a sound source with a source level (SL) of 100 dB || μPa @ 1m and an absorption coefficient (α) of 0.01 dB m^{-1} (appropriate for a 38 kHz frequency in a marine environment), what is the sound level on the acoustic axis at depths of 100, 200 and 300 meters?

   100 m = 59 dB_p, 200 m = 52 dB_p, 300 m = 47.5 dB_p

2) An acoustic system operating at 120 kHz has a source level (SL) of 110 dB || μPa @ 1m and an absorption coefficient (α) of 0.04 dB m^{-1}.

   Assuming 40-log R TVG (2-way) spreading loss, what would be the acoustic level (in dB and volts) at the face of the transducer returned from a single on-axis fish with a target strength of -30 dB at a range of 100 meters?

   P_{rec} = -8 dBp, or 0.398 V

3) Assume another acoustic system with a source level (SL) of 220 dB || μPa @ 1m, operating at 38 kHz with an absorption coefficient (α) of 0.01 dB m^{-1}.

   What is the target strength of a fish located on the transducer beam axis at a range of 100 m which returns an acoustic level of 60 dB to the transducer (assuming 40 log R spreading loss)?

   TS = -78 dB at the transducer face

4) The diameter of a circular transducer element determines the beam width. The table below estimates nominal beam width based on the physical diameter of the element using Urick, 1975. Based on the formula presented by MacLennan and Simmonds (1992), calculate the far field, i.e. the range beyond which the radiated pressure wave is coherent, for each specified transducer beam width.

Frequency (f)	200	kHz
Sp. of Sound (c)	1500	m/s
lamda	0.0075	m/cycle

Size of Element (meters)	Beam Width	Far Field (m)
0.04	11.06	
0.06	7.38	
0.08	5.53	
0.10	4.43	
0.12	3.69	
0.14	3.16	
0.16	2.77	
0.18	2.46	
0.20	2.21	

Size of Element (meters)	Beam Width	Far Field (m)
0.01	44.25	0.0133
0.02	22.13	0.0533
0.03	14.75	0.1200
0.04	11.06	0.2133
0.05	8.85	0.3333
0.06	7.38	0.4800
0.07	6.32	0.6533
0.08	5.53	0.8533
0.09	4.92	1.0800
0.10	4.43	1.3333
0.11	4.02	1.6133
0.12	3.69	1.9200
0.13	3.40	2.2533
0.14	3.16	2.6133
0.15	2.95	3.0000
0.16	2.77	3.4133
0.17	2.60	3.8533
0.18	2.46	4.3200
0.19	2.33	4.8133
0.20	2.21	5.3333

The sonar equation in logarithmic form can be expressed as:

$$V_o = SL + G_1 + TS + 2D(\phi,\theta) - 40 \log R - 2\alpha R + G_{tvg} + G_{rec}$$

Using the calibration data and the transducer beam pattern plot provided, answer questions 5 through 9. Y-axis units on the polar plot are dB and X-axis units are degrees from the acoustic axis.

Given:

SL = 219.73 dB||μPa @ 1 m (transducer transmit efficiency)

G_1= -170.12 dB||μPa @ 1 m (transducer receiving efficiency)

5) Assume we are surveying fish in fresh water with minimum on-axis target strengths of –55 dB. We know fish densities are low enough to count individual targets. We are using an echosounder with a G_{tvg} function that precisely compensates for signal loss due to spreading. We don't know whether it will be necessary to manipulate the receiver gain (G_{rec}) to center the system dynamic range, so we'll set G_{rec} = 0 for initial calculations in question 5a below. We assume absorption losses (α) to be either insignificant in our freshwater environment, or to have been addressed by an appropriate alpha (α) amplification by the echosounder.

a) Calculate V_0, from a –55 dB target on the acoustic axis. Express V_0 in both logarithmic and linear terms. In this case, V_0 is equivalent to our minimum echo detection threshold and will be set in the data collection software to exclude any targets smaller than –55 dB from the data record.

-5.39 dBV, 0.538V

b) Most scientific echosounders output voltages between 0-10 volts DC. We want to set our detection threshold (V_0) near the lower end of this range to maximize system dynamic range (i.e. the ability to measure small targets above background noise and not saturate the receiver with returns from the largest targets of interest). For this survey we observe a background noise level of 25 millivolts (0.025 volts) on the oscilloscope. We would like to set a detection threshold that is 2-4 times (6-12 dB) higher than the observed background noise to ensure that targets are not masked by noise returns. Based on the observed noise level, we decide to set the threshold to 100 mV (0.10 volts).

What system receiver gain (G_{rec}) will be required to detect a –55 dB fish on the acoustic axis using a detection threshold of 0.10 volts? That is, solve for G_{rec}, given SL, G_1, TS, V_0 and assuming that any attenuation and absorption losses are addressed by the echo sounder.

Note that our –55 dB on-axis target detection threshold remains unchanged with the new G_{rec} and minimum voltage threshold (relative to the settings in question 5a above). We can vary either V_0 or G_{rec} to achieve a given TS detection threshold.

-14.61 dB

c) Given a system receiver gain of 0 dB, estimate V_0 for a –35 dB fish target located off of the transducer beam axis such that the directivity coefficient D (θ,ϕ) = -9 dB. Again, express Vo in both dB and voltage terms.

-3.39 dBV = 0.677 volts

6) Based on the transducer beam plot, what is the nominal beam width of this transducer? Nominal beam widths are defined as the width at the half-power (i.e. –3 dB) points on this one-way (receive) polar plot.

10 degrees

7) Using the polar plot, estimate the loss in signal intensity (units dB), for a target at 5, 10, 15, and 20 degrees from the transducer axis (if the plot is asymmetric, average).

-3 dB, -11 dB, -21 dB, and –29 dB

8) All transducers have "side lobes", or regions of lower sound intensity surrounding the main lobe of the acoustic beam. The laws of physics predict that we should observe side lobes at –12 dB for a mechanical piston transducer. Transducer "shading" (applying less power to the outside of a transducer element array) can reduce side lobes over theoretical predictions. Relatively "low" side lobes are one indication of a well-designed and constructed transducer. How many decibels "down" on the polar plot do you observe the first side lobe? List two benefits of minimizing transducer side lobes for scientific acoustic sampling.

First side lobe at –30.5 dB. Benefits of low side lobes: increased ability to monitor close to boundaries or structure, better S/N performance, able to accurately position targets (split-beam) over a greater dynamic range

9) A researcher is told to ensure that the swath of the echosounder is at least a 5 m on either side of a transect survey line. From bathymetric maps he observes that the depth along the transect ranges from 90 to 130 m. What is the minimum transducer beam width he can use for the survey that will provide this sampling coverage?

6.4 degrees

10) A split-beam echo sounder outputs an amplitude of 0.195 volts from an off-axis fish at some range. By estimating the target position, and thus the signal loss due to beam directivity $D(\theta,\phi)$, the echosounder accurately estimates the target strength. Based on the system calibration, we calculate that an echo from this target should return an on-axis target strength of 0.257 volts. Estimate the directivity coefficient (also termed the beam pattern factor), for this fish.

=(20 log (v1)-20 log (v2))/2 = -2.4 dB (2-way BPF). Divide by two to obtain the one-way $D(\theta,\phi)$ = -1.2 dB.

11) Express a target strength (TS) of –45.65 dB re 1 μPa as a backscattering cross-section (σ_{bs}).

TS = 10 logσ_{bs} = 10 ^TS/10 = 10^-45.65/10 = 2.721 E -05 m^2