Fall 2002 13.00 Problem Set 9 — Answers

---

1. Ocean Acoustic Tomography System

(a.)

Location	Distance from source	travel time	change in travel time per 1 m/sec
Aluetian Islands	3000 km	.55	1.33
Tokyo	6200 km	1.14	2.75
Brisbane	7500 km	1.38	3.33
Punta Arenas	12000 km	2.22	5.33
San Fransisco	3800 km	0.70	1.69

(b.)

SL = 171 + 10 $\log \mathcal{P}$ + DI = 184

Mixed propagation model: TL = 10 log 5000 + 10 $\log r$ + $\alpha * 0.001 * r$ for each of the five different values of r.

Location	Distance from source	TL
Aluetian Islands	3000 km	122
Tokyo	6200 km	148
Brisbane	7500 km	158
Punta Arenas	12000 km	191
San Fransisco	3800 km	129

First, let's make a pessimistic assumption about noise, e.g., high shipping traffic, high sea state, gives NL of approximately 74 dB.

Location	Distance from source	SL - TL - (NL-DI)
Aluetian Islands	3000 km	4.5
Tokyo	6200 km	-21
Brisbane	7500 km	-30
Punta Arenas	12000 km	-64
San Fransisco	3800 km	-2.1

Clearly the system won't work at the far away stations under these conditions. Next, let's make a more pessimistic assumption about noise, e.g., low shipping traffic and a low sea state, gives NL of approximately 48 dB.

Location	Distance from source	SL - TL - (NL-DI)
Aluetian Islands	3000 km	30.5
Tokyo	6200 km	5
Brisbane	7500 km	-4
Punta Arenas	12000 km	-38
San Fransisco	3800 km	23

Clearly, the system will still not work for the far away stations! In practice, there are signal processing "tricks" to detect very weak signals. If a coded waveform is used as the transmitted signal, it is possible to detect signals as weak as -20 or -30 dB (c.) Need to solve SL - TL = 120

184 - TL = 120

TL = 64; this occurs at approximately 1580 meters.

(d.) This is probably too large a distance for near Hawaii which has a large whale population.

2. Odyssey navigation system performance analysis

The operating frequencies of the two systems are 10 kHz and 300 kHz. Using the absorption table on page 15 of the notes, the values for alpha are approximately 1 dB/km and 63 dB/km.

1. The transition range R_t is given by the formula $R_t = \frac{8680}{\alpha} = 8680$ meters at 10 kHz and 137 meters at 300 kHz.

2. The table below shows the one-way transmission loss TL for each system, using the formulas $\mathrm{TL} = 20 \log r + \alpha r \times 10^{-3}$ for spherical spreading and $\mathrm{TL} = 10 \log r + \alpha r \times 10^{-3}$ for cylindrical spreading. All answers are in dB re 1 meter.

	f = 10 kHz		f = 300 kHz	
range	TL (spherical)	TL (cylindrical)	TL (spherical)	TL (cylindrical)
10	20	10	20.6	11
100	40.1	20.1	46.3	26.3
1000	61	31	123	93
10K	90	50	710	670

3. Solve the passive sonar equation for TL:

$$\mathrm{TL} = \mathrm{SL} - (\mathrm{NL} - \mathrm{DI}) - \mathrm{DT}$$

$$190 - (80 - 0) - 20) = 90 \text{ dB re 1 meter.}$$

From the table above, we see that TL = 90 dB at 10 km range, and so we are done.

4. Again, solve the passive sonar equation for TL:

$$\mathrm{TL} = \mathrm{SL} - (\mathrm{NL} - \mathrm{DI}) - \mathrm{DT}$$

$$190 - (100 - 0) - 20) = 70 \text{ dB re 1 meter.}$$

So, we need to solve the equation

$$70 - 20 \log r + 63 \cdot r \times 10^{-3}$$

The answer is 301 meters.

5. The SHARPS system is more accurate because at a higher frequency, we can measure the travel time of an acoustic pulse more accurately. Hence, we can measure the range between the AUV and each of the beacons more accurately. A good signal detection method should be able to measure the travel time of an acoustic pulse to within ten periods of the carrier frequency, $\frac{10}{f}$, which equals 1 millisecond for the standard LBL system and 33 microseconds for the SHARPS system. In actual practice, the 10 kHz LBL system is accurate to a few meters and the SHARPS system is accurate (repeatable) to within a few centimeter. In addition to timing resolution, one additional important source of error in the navigation calculation is uncertainty in the calibration of the positions of the beacons.

3.

(a.) max_range = 300

$\alpha = 10/(\text{max\_range} * .001) = 33$

pick f = 100kHz which has a $\alpha = 31$

$\lambda = 1500/f = 0.015$

$\theta = \pm$ 10 degrees

D = 29.5*λ/θ = 0.044 meters

DI = $20 \log \frac{\pi D}{\lambda} = 19.3$

pick NL = 30 dB (between sea states 3 and 6 on graph)

target: sphere with radius = 0.25 meters

TS = $10 \log \frac{r^2}{4}$ = -18 dB

For TL, use spherical spreading + absorption

TL = $20 \log r + \alpha * 0.001 * r$ for $r = 300$ = 58.8 dB

let's assume a value of DT = 10 dB

SL - 2 TL + TS - (NL - DI) = DT

SL = 2TL - TS + NL - DI + DT

SL = 2*58.8 - (-18) + 30 - 19.3 + 10 = 156 dB

SL = $171 + 10 \log \mathcal{P}$ + DI

$156 = 171 + 10 \log \mathcal{P} + 19.3$

$10 \log \mathcal{P}$ = 156 - 171 - 19.3 = -34.3 dB

$\mathcal{P}$ = .3 mWatts

(These may seem a small value, but this is OK)

We can compute τ, from the desired range resolution. This is not asked for in the problem but a reasonable value is to use the size of the object we are looking for (0.5 meters).

$\delta = .5 = c * \tau/2$

$\tau = 1/1500 = 6.667$ mSec

Average power:

Time of flight T: 2*300/1500 = 0.4 seconds

Set ping interval T_P equal to time of flight (0.4 seconds)

$\overline{\mathcal{P}} = \mathcal{P} * \frac{\tau}{T_P}$ = 0.5 microWatts

(b.) Dolphin can detect a 3 cm ball bearning at 72 meters range with NL = 100. Can our system do this? How do we need to change the design?

r = 72 meters

TS $= 10\log((0.03/2)^2/2) = -42$ dB

SL - 2 TL + TS - (NL - DI) = DT

156 - 2 * (20 * $\log r + \alpha * r * 0.001$) - 42 - (100-19.3) = -45 dB

Our system cannot do this. We would need to increase SL by 55 dB for this to work. The power must be dramatically increased