PHYS 536 Problem Set 2 solutions

Eqn references are for Kinsler 4th ed (different chapter numbers than 3rd ed)

1. $r_1 = 1.48 \times 10^6$ Pa·s/m $\quad r_2 = 8.0 \times 10^6$ Pa·s/m $\quad f = 1$ kHz

(*a*) Because the concrete is assumed infinitely thick, there is only a transmitted wave, and since $r_2 > r_1$ the reflected pressure wave is in phase with the incident at the boundary. (Recall the discussion in Section 6.2.) Consequently, the phase angle $\theta = 0$ and (10.4.2) gives

$$\frac{B}{A} = \frac{8.0 - 1.48}{8.0 + 1.48} = 0.69 \qquad SWR = \frac{1 + B/A}{1 - B/A} = \underline{5.45}$$

(*b*) $20 \log 5.45 = \underline{14.7 \text{ dB}}$

(*c*) $\lambda_1 = 1480/1000 = 1.48$ m From (10.4.6) the first node is at $k\Delta x = \pi/2$ where Δx is measured from the wall into the fluid. This is a quarter wavelength, so the first three nodes are located at distances from the wall of

$$\lambda/4 = \underline{0.37} \text{ m} \qquad 3\lambda/4 = \underline{1.11} \text{ m} \qquad 5\lambda/4 = \underline{1.85} \text{ m}$$

2. $S = 0.3^2 = 0.09 \text{ m}^2 \qquad a = 0.08$ m

$S_b = \pi a^2 = 0.020 \text{ m}^2 \qquad L' = 0 + 1.7a = 0.136$ m

(*a*) The filter is most effective at resonance $\omega_0 = 2\pi f_0 = c\sqrt{\dfrac{S_b}{L'V}}$

$$V = \frac{c^2 S_b}{4\pi^2 f_0^2 L'} = \frac{343^2 \cdot 0.020}{4\pi^2 \cdot 30^2 \cdot 0.136} = \underline{0.49 \text{ m}^3}$$

3. (*a*) 60 dB *re* 20 μPa at 100 Hz

From Fig. 11.7.1, $L_N = 50$ phon

From (11.8.1), $N = 0.046 \times 10^{L_N/30} = 0.046 \times 10^{5/3} = \underline{2.1 \text{ sone}}$

(*b*) For a loudness of 0.21 sone, the relation between loudness and loudness level is no longer given by (11.8.1) so use Fig. 11.8.1 to get L_N about 23 phon and then Fig. 11.7.1 to obtain L_I about $\underline{40 \text{ dB } re\ 10^{-12} \text{ W/m}^2}$

(*c*) For a loudness of 21 sone, use (11.8.1)

$$21 = 0.046 \times 10^{L_N/30} \quad \text{and} \quad L_N = 80 \text{ phon}$$

and from Fig. 11.7.1 L_I about $\underline{85 \text{ dB } re\ 10^{-12} \text{ W/m}^2}$

4. (*a*) 100 Hz at 60 dB gives 50 phon from Fig. 11.7.1 and 2.1 sone from (11.8.1)
200 Hz at 60 dB gives 60 phon and 4.6 sone
500 Hz at 55 dB gives 63 phon and 5.8 sone
<u>500 Hz tone is the loudest</u>

(*b*) Let ⊕ represent combination according to the nomogram of Fig. 11.3.1

$$(60 \oplus 60) \oplus 53 = 63 \oplus 53 = \underline{64 \text{ dB } re \text{ } 20 \ \mu\text{Pa}}$$

(*c*) The tones are separated beyond the critical bands so the loudnesses add

$$\sum N_i = 2.1 + 4.6 + 5.8 = 12.5 \text{ sone} = 0.046 \times 10^{L_N/30}$$

$$L_N = \underline{73 \text{ phon}}$$

5.

$$L_{eq} = 10 \log \left[\frac{1}{24} \sum_{24} 10^{L_h/10} \right], \quad L_h = \text{ hourly SPL samples}$$

Ldn = Leq but with a 10 dB penalty added to samples during the nighttime hours of 22:00 to 07:00.
CNEL (Community Noise Equivalent Level) = Ldn but with additional penalty of 5 dB for the evening hours or 19:00 to 22:00.
For given data, Leq=57.6 dBA, Ldn=59.6 dBA, CNEL=60 dBA

1 6. For automobiles, use (13.8.1)

$$L_A = 71 + 23 \log(v/88) = 71 - 9.6 = \underline{61 \text{ dBA at 44 km/hr}}$$
$$= 71 - 0 = \underline{71 \text{ dBA at 88 km/hr}}$$

For motorcycles, use (13.8.2)

$$L_A = 78 + 25 \log(v/88) = \underline{67 \text{ dBA at 44 km/hr}}$$
$$= \underline{78 \text{ dBA at 88 km/hr}}$$

7. expected traffic density, composition, and road geometry. As a simplified example, consider a straight, two-lane road of infinite length, zero grade, and negligible truck traffic. The receiver is located at a distance d from the centerline of the nearest lane. Also needed for the calculation are the average speed v (in kilometers per hour) and the flow rate Q (in vehicles per hour). The A-weighted noise level L_{eq} is found from

$$L_{eq} = 39 + 10 \log Q + 22 \log(v/88) + \Delta L$$
$$\Delta L = \begin{cases} 0 & d \le 15 \text{ m} \\ -a \log\left[\dfrac{d}{15} + \left(\dfrac{d-15}{75}\right)^2\right] & d \ge 15 \text{ m} \end{cases} \qquad (13.8.4)$$

where $a = 13.3$ over ground and 10.0 if the line of sight from the road surface to the receiver is 10° or more above the slope of the terrain. From the values of L_{eq} determined for the times of interest, the desired sound levels (L_{10}, L_{50}, etc.) can be found.

As a numerical example, let us calculate L_{eq} for $Q = 6000$/h, $v = 88$ km/h (55 mph), $d = 61$ m (200 ft), and $a = 13.3$. From (13.8.4), $L_{eq} = 76$ dBA and $\Delta L = -8$ dBA. The equivalent continuous noise level is 68 dBA. For details on handling more realistic conditions consult Harris (*op. cit.*).

8. $f = 30$ kHz $\quad SPL = 140$ dB *re* 1 μPa at 1000 m

Figs 8.7.1 and 8.7.2 $\quad a = 7.4$ dB/km $= 7.4 \times 10^{-3}$ dB/m

(*a*) $\quad SPL = SL - 20\log r - ar$

$$140 = SL - 20\log 1000 - 7.4\times 10^{-3}\cdot 1000 = \underline{207.4 \text{ dB } re \text{ } 1\mu\text{Pa}}$$

(*b*) $\quad SPL = 207.4 - 20\log 2000 - 7.4\cdot 2 = \underline{127 \text{ dB } re \text{ } 1 \text{ } \mu\text{Pa}}$

(*c*) $\quad 100 = 207.4 - 20\log r - 7.4\times 10^{-3} r$

$$20\log r + 7.4\times 10^{-3} r = 107.4$$

r	20 log *r*	*ar*	*SPL*
10000	80	74	154
4000	72	27	99
5000	74	37	111
4500	73.1	33.3	106.4
4600	73.3	33.9	107.2
4700	73.4	34.6	108

$\underline{r = 4.6 \text{ km}}$

(*d*)

r	20 log *r*	*ar*
100000	190	740
10000	80	74
12000	81.6	88.8
11000	80.83	80.96
10500	80.42	77.28
10900	80.79	80.22
10980	80.81	80.81

$\underline{r = 11.0 \text{ km}}$

(*e*) $\quad TL = 20\log r + ar \qquad \log r = \ln r / \ln 10$

$$\frac{d}{dr}(TL) = \frac{20}{2.3}\frac{1}{r} + a = \frac{8.7}{r} + a$$

Rates of increase are equal when $\quad a = \dfrac{8.7}{r}$

$$r = \frac{8.7}{7.4\times 10^{-3}} = \underline{1180 \text{ m}}$$

9. $SL = 220$ dB *re* 1 μPa $\qquad f = 1$ kHz

$EL = 110$ dB *re* 1 μPa $\qquad r = 1000$ m

$$SL - 2TL + TS = EL$$

$$TL = 20\log r + ar = 20\log 1000 + 5.25\times 10^{-5}\cdot 1000 = 60 \text{ dB}$$

$$TS = 110 - (220 - 2\cdot 60) = \underline{10 \text{ dB}}$$

10.

A beam of sound waves is incident normally on a plane interface of air and an infinite body of fluid of unknown impedance. If half of the sound energy is reflected, find the unknown impedance.

Sound energy reflected is described by the sound power reflection coefficient given by equation (2) of Problem 4.2,

$$\alpha_r = \left[\frac{R_1 - z_2}{R_1 + z_2}\right]^2 = \left[\frac{415 - z_2}{415 + z_2}\right]^2 = 0.5 \quad \text{or} \quad z_2 = 72 \text{ rayls}$$

where $R_1 = \rho_1 c_1 = 1.21(343) = 415$ rayls is the characteristic impedance of air, and z_2 is the characteristic impedance of the fluid.

11.

(a) The transmission coefficient for acoustic pressure amplitude is

$$\frac{p_t}{p_i} = \frac{2\rho_2 c_2}{\rho_2 c_2 + \rho_1 c_1} = \frac{2(415)}{415 + 1{,}480{,}000} = 5.63 \times 10^{-4}$$

where $\rho_1 c_1 = 1{,}480{,}000$ and $\rho_2 c_2 = 415$ rayls are the characteristic impedances of water and air respectively at standard temperature and atmospheric pressure. Thus the pressure of the transmitted wave in air is

$$p_t = 5.63 \times 10^{-4}(100) = 5.63 \times 10^{-2} \text{ nt/m}^2$$

(b) The intensity of the incident wave in water is

$$I_i = \frac{p_i^2}{\rho_1 c_1} = \frac{100^2}{1{,}480{,}000} = 6.78 \times 10^{-3} \text{ watt/m}^2$$

and the intensity of the transmitted wave in air is

$$I_t = \frac{p_t^2}{\rho_2 c_2} = \frac{[5.63(10)^{-2}]^2}{415} = 7.6 \times 10^{-6} \text{ watt/m}^2$$

(c) $$\frac{I_t}{I_i} = \frac{7.6(10)^{-6}}{6.8(10)^{-3}} = 1.13 \times 10^{3} \quad \text{or} \quad 10 \log(1.13 \times 10^{-3}) = -29.5 \text{ db}$$

(solution for prob 12 is on the next page)

13.

The loudness level required is 120 phons. Then at a frequency of 1000 cyc/sec, the intensity level is 120 db. Using

$$\text{IL} = 10 \log(I/10^{-12}) \text{ db}$$

the intensity of one such tone is

$$60 = \log(I/10^{-12}), \qquad I = 10^{-12} \text{ antilog } 6 = 10^{-6} \text{ watt/m}^2$$

and the intensity of all the tones together would be

$$120 = \log(I/10^{-12}), \qquad I = 10^{-12} \text{ antilog } 12 = 1.0 \text{ watt/m}^2$$

Thus the number of tones required $= 1/10^{-6} = 10^6$.

Let the midpoint between S_1 and S_2 shown in Fig. 3-7 be the reference point O for the radiation pattern. Acoustic pressure at point A_1, a great distance from the sources, will be the vector sum of pressures radiated from S_1 and S_2.

For harmonic diverging spherical acoustic waves,

$$p = \frac{A}{r} e^{i(\omega t - kr)} = \frac{A}{r} e^{i(\omega t - 2\pi r/\lambda)}$$

which shows that the phase angle of acoustic pressure decreases linearly with the radial distance from the source.

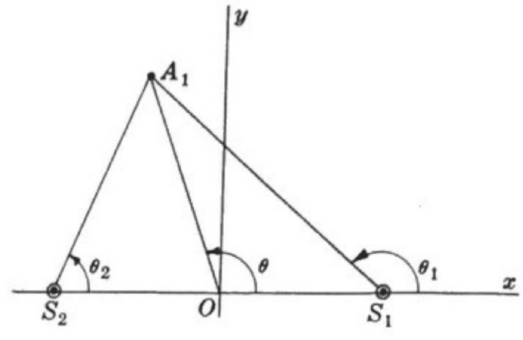

Fig. 3-7

Now $\theta_1 \doteq \theta_2 = \theta$, and sound waves from S_1 travel $\frac{1}{2}\lambda \cos\theta$ farther than waves from S_2 in reaching A_1. There will be a phase difference of $\frac{1}{2}\lambda(\cos\theta)(2\pi/\lambda)$ or $\pi\cos\theta$ rad between the waves. In other words, the wave from S_1 lags that from S_2 by $\pi\cos\theta$ rad. Acoustic pressure at A_1 becomes

$$p = \frac{A}{r} e^{i\omega t} + \frac{A}{r} e^{i(\omega t - \pi\cos\theta)}$$

When $\theta = 0$, we have two sound waves of equal magnitude but 180° out of phase with each other; hence $p = 0$. When $\theta = 90°$, we have two sound waves of same magnitude and phase; hence $p_0 = 2A/r$.

Continuing in this fashion with a locus of points equidistant from the reference point O, we obtain a polar plot of pressure versus angular displacements as shown in Fig. 3-8, which is the radiation pattern or directivity of this particular arrangement of two simple sound sources.

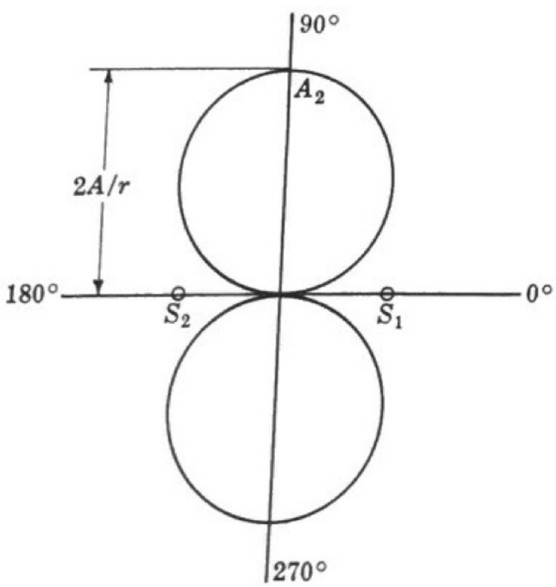

Fig. 3-8

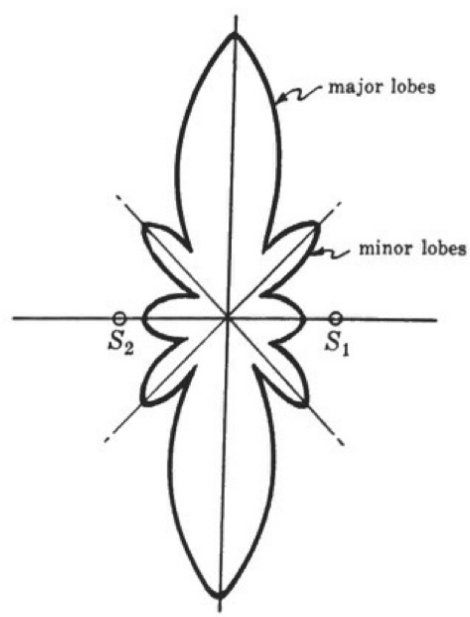

Fig. 3-9