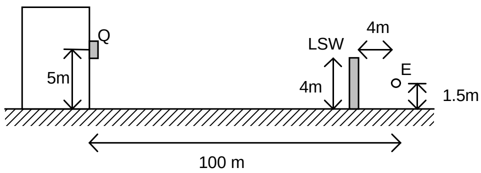
Kurt Heutschi, Acoustics I, 2011-10-03

Exercise A1-8: Ear and sound propagation outdoors

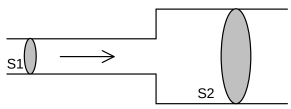
1. A signal consists of three components. The first component is narrow band noise around 250 Hz and produces at the listener's ears 68 dB. The second component is narrow band noise around 2 kHz and is perceived with a loudness of 55 phon. The third component is narrow band noise around 2.2 kHz and corresponds to a loudness of 3 sone. What's the loudness in phon and sone if all three components are played simultaneously?

2. A source Q with omnidirectional radiation characteristics and sound power L_W according to the Table below is mounted on a vertical facade of a building. Calculate the A-weighted sound pressure level L_p(E) at the receiver position E with and without noise barrier LSW (air temperature 20°, rel. humidity 70%, for the ground effect calculation the approximative A-level formula shall be used, for the barrier attenuation neutral conditions with $K_{met} = 1$ are assumed).

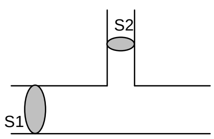
	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz
sound power level of Q in octave bands [dB]	55	98	100	95	69
A-weighting curve [dB]	-16.1	-8.6	-3.2	0.0	1.2



3. A plane wave propagates in a tube of cross sectional area S_1. Calculate the reflection factor R for an abrupt enlargement of the cross sectional area to S_2. It is assumed that the wave lengths are much larger than the diameter of the tube sections and that the tubes extend to infinity. For the solution, an incident, a reflecting and a transmitted wave shall be assumed. At the position of the cross sectional discontinuity, appropriate conditions for sound pressure and sound particle velocity shall be formulated.



4. Similarly to task 3, a plane wave is assumed to propagate along a tube of cross sectional area S_1. The tube has a side branch of cross sectional area S_2. As a consequence of this discontinuity, a portion of the wave will be reflected, a portion will continue to travel to the right in tube S_1 and finally a third portion will be transmitted into the side branch S_2. Calculate the corresponding amplitudes if the amplitude of the incident wave is p_e.



Solutions

1.
The 2 kHz and 2.2 kHz components lie within the same critical band. Therefore the corresponding intensities sum up: 3 sone = 56 phon, 55 phon + 56 phon = 59 phon = 3.7 sone.

The 250 Hz component and the rest lie in different critical bands. Therefore the corresponding loudness values sum up: 68 dB @ 250 Hz = 60 phon = 4 sone, 4 sone + 3.7 sone = 7.7 sone = 69 phon.

2.
Basic equation:

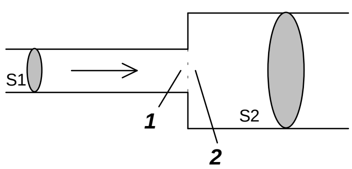
$$L_p(\mathrm{E}) = L_W + D - \sum A \tag{1}$$

where
D: directivity correction of the source
A: attenuation during propagation

Note: in the case *with* the noise barrier, no longer a ground effect has to be considered as the sound propagation is now high above ground (over the top edge of the barrier).

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	A-weighted level
L_W	55	98	100	95	69	
D	3	3	3	3	3	
A_{div}	-51	-51	-51	-51	-51	
A_{atm}	0.0	-0.1	-0.3	-0.5	-0.9	
A-weighting	-16.1	-8.6	-3.2	0.0	1.2	
		41.3	48.5	46.5		51.1
A_{ground}						-3.5
D_Ω						+3.0
						51 dB(A)
		41.3	48.5	46.5		
$A_{\mathsf{screen}}, z = 0.66m$		-11.0	-13.5	-16.2		
		30.3	35.0	30.3		**37 dB(A)**

3.
Three waves have to be considered: incident (e), reflected (r) and transmitted (t).



The following conditions have to be fulfilled:

1. continuity of pressure: the total sound pressure at position 1 has to be equal to the total sound pressure at position 2 (any pressure discontinuity would correspond to a large force and induce an equalization movement.) $\rightarrow p_t = p_e + p_r$
2. conservation of mass: incident volume flow = transmitted volume flow (volume flow = sound particle velocity × cross sectional area) $\rightarrow v_e S_1 - v_r S_1 = v_t S_2$

For plane waves with impedance $Z_0 = \rho_0 c$, the conservation of mass can be written as

$$\frac{p_e}{Z_0}S_1 - \frac{p_r}{Z_0}S_1 = \frac{p_t}{Z_0}S_2 \tag{2}$$

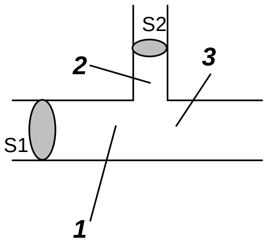
Insertion of the pressure continuity condition in (2) yields:

$$p_e(S_1 - S_2) = p_r(S_1 + S_2) \tag{3}$$

and the reflection factor R is found as:

$$R = \frac{p_r}{p_e} = \frac{S_1 - S_2}{S_1 + S_2} \tag{4}$$

4.
Four waves have to be considered: incident (e), reflected (r) and transmitted into tube 2 ($t2$) and transmitted to the right side of tube 1 ($t1$).



The following conditions have to be fulfilled:

1. continuity of pressure: the total sound pressure at position 1 has to be equal to the total sound pressure at position 2 and the total pressure at position 3 $\rightarrow p_{t1} = p_{t2} = p_e + p_r$
2. conservation of mass: incident volume flow = transmitted volume flow $\rightarrow v_e S_1 - v_r S_1 = v_{t2} S_2 + v_{t1} S_1$

For plane waves the conservation of mass can be written as

$$\frac{p_e}{Z_0}S_1 - \frac{p_r}{Z_0}S_1 = \frac{p_{t2}}{Z_0}S_2 + \frac{p_{t1}}{Z_0}S_1 \tag{5}$$

Insertion of the pressure continuity condition in (5) yields:

$$p_e - p_r = (p_e + p_r)\frac{S_2}{S_1} + p_e + p_r \tag{6}$$

Therefore p_r:

$$p_r = -\frac{S_2}{2S_1 + S_2}p_e \tag{7}$$

and p_t:

$$p_{t1} = p_{t2} = \frac{2S_1}{2S_1 + S_2}p_e \tag{8}$$