TT3010 - Audio technology and room acoustics. Exercise 2 - Room acoustics Solutions

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August 13, 2020

1

The resonance frequencies of the room modes, or standing waves, in a shoebox-shaped room are:

$$f_{lmn} = \frac{c}{2}\sqrt{\left(\frac{l}{l}\right)^2 + \left(\frac{m}{w}\right)^2 + \left(\frac{n}{h}\right)^2} \tag{1}$$

where c is the speed of sound and l, m and n are integers.

To find the lowest resonance frequencies, we have to insert combinations of the lowest integers (0,1,2), for the room with length, $l = 5m$, width, $w = 10m$ and height $h = 2.5m$ and get the following frequencies:

$$f_{100} = \frac{c}{2}\sqrt{\left(\frac{1}{l}\right)^2 + \left(\frac{0}{w}\right)^2 + \left(\frac{0}{h}\right)^2} = 34.4Hz \tag{2}$$

$$f_{010} = \frac{c}{2}\sqrt{\left(\frac{0}{l}\right)^2 + \left(\frac{1}{w}\right)^2 + \left(\frac{0}{h}\right)^2} = 17.2Hz \tag{3}$$

$$f_{001} = \frac{c}{2}\sqrt{\left(\frac{0}{l}\right)^2 + \left(\frac{0}{w}\right)^2 + \left(\frac{1}{h}\right)^2} = 68.8Hz \tag{4}$$

$$f_{020} = \frac{c}{2}\sqrt{\left(\frac{0}{l}\right)^2 + \left(\frac{2}{w}\right)^2 + \left(\frac{0}{h}\right)^2} = 34.4Hz \tag{5}$$

$$f_{110} = \frac{c}{2}\sqrt{\left(\frac{1}{l}\right)^2 + \left(\frac{1}{w}\right)^2 + \left(\frac{0}{h}\right)^2} = 38.5Hz \tag{6}$$

etc

Apparantly, the three lowest ones are 17.2 Hz, 34.4 Hz, and 38.5 Hz, but the one at 17.2 Hz would have little influence in the audible range.

Around the resonance frequencies, the sound in the room will get particularly loud (if the source is emitting energy in that frequency range), but the variation of the sound level inside the room will also be much stronger (than in other frequency ranges).

2

We can find from Rossing chapter 25.3 that the angle of our sound image, θ_l, has the following relation to the angle from the median plane, θ_A, and the pressure from the left speaker, p_L, and the right speaker p_R.

$$\frac{\sin(\theta_l)}{sin(\theta_A)} = \frac{p_L - p_R}{p_L + p_R} \tag{7}$$

If the loudspeaker on the left has twice the strength than the one on the right, we can assume that $p_L = 2p_R$. By rewriting the formula and inserting this relation, we get the following:

$$\sin(\theta_l) = \frac{p_L - p_R}{p_L + p_R} \cdot \sin(\theta_A) = \frac{2p_R - p_R}{2p_R + p_R} \cdot \sin(30) = \frac{1}{3} \cdot \frac{1}{2} \rightarrow \theta_l \approx 10^\circ \tag{8}$$

As shown, the image will resemble figure 1 where the image is shifted 10 degrees to the left.

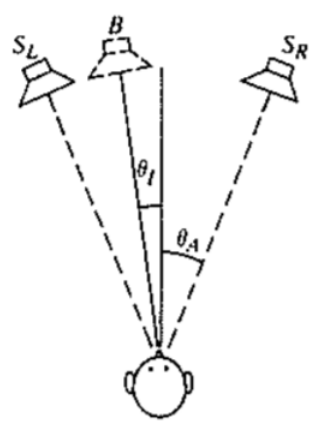


Figure 1: The changed sound image when the signal strength is increased en the left speaker.

3

The so-called hall radius can be found in two ways: either from the chart in Figure 1, or from the expression:

$$L_p = L_w + 10\log(\frac{Q}{4\pi r^2} + \frac{4}{A}) \quad (9)$$

where r is the distance, Q is the directivity factor of the sound source, A is the total absorption, L_p is the sound pressure level at the listener/receiver and L_W is the sound power level.

Method 1:

The chart shows how $L_p - L_W$ varies with distance, for various values of A. All curves flatten out for large values of distance (to the right) and as the hint says, we should look for a point where the curve is 3 dB higher than the flat part. In this task, $A = 500$, so the flat part of the curve is at -21.7 dB. Using a ruler, one can find the point on the "500"-curve which is at -18.7 dB (3 dB higher than the flat area), and that happens at $r/\sqrt{Q} \approx 3.1$, see the drawing below. Since Q was given to be 5, we find,

$$r \approx \sqrt{Q} \cdot 3.1 = \sqrt{5} \cdot 3.1 \approx 6.9m$$

Method 2: In the expression for L_p, the two terms for the direct sound and reverberation are equal when r equals the room radius

$$\frac{Q}{4\pi r^2} = \frac{4}{A} \quad (10)$$

which can be rewritten:

$$r = \sqrt{\frac{QA}{16\pi}} = \sqrt{\frac{5 \cdot 500}{16 \cdot \pi}} \approx 7m \quad (11)$$

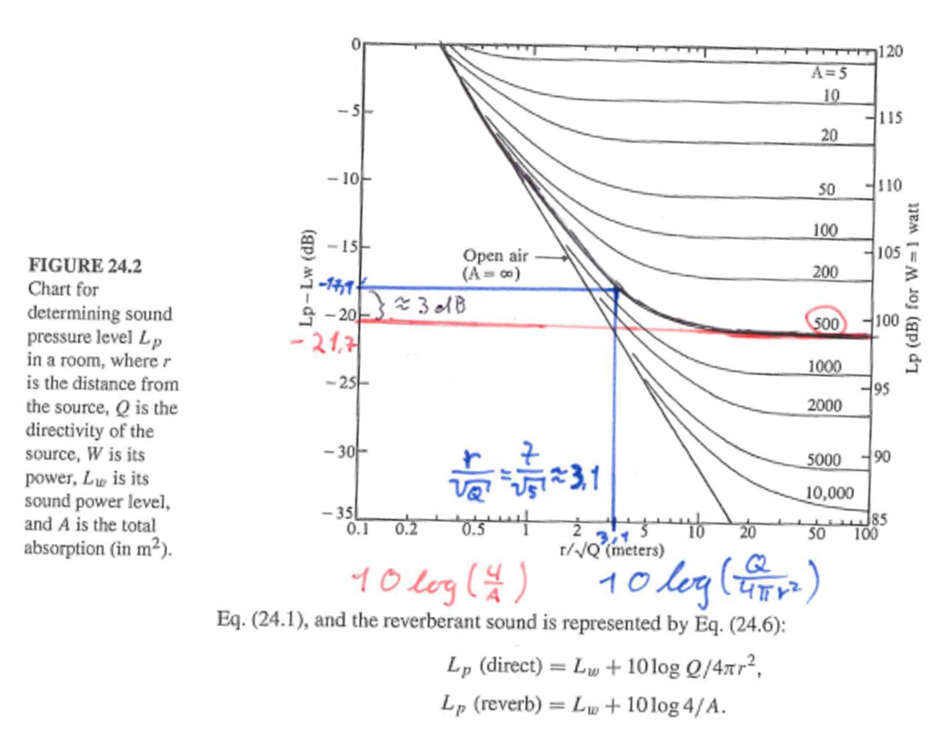


Figure 2: My attempt on drawing of the direct sound (blue) and the reverberant sound (red).

4

The sound pressure distribution for one room mode, or standing wave, can be illustrated by drawing vertical and horizontal lines, which illustrate so-called nodal lines, or zeroes. These are lines where it is very close to silent.

The pressure of the axial modes are at its maxima on the walls itself. For a tangential mode, the maxima is in the center of the room as well as on the walls. Figure 3, 4 and 5 shows the areas where the pressures are distributed.

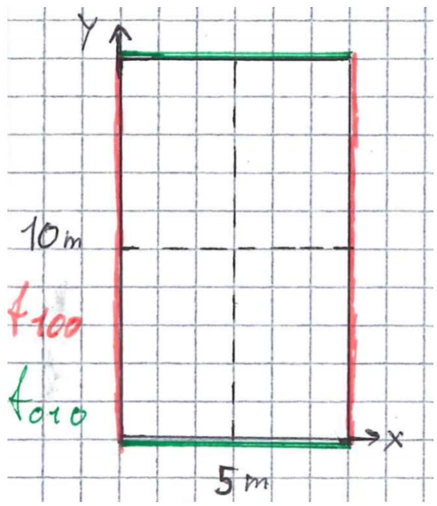


Figure 3: Axial modes with max pressure at the walls. Dashed lines are node points.

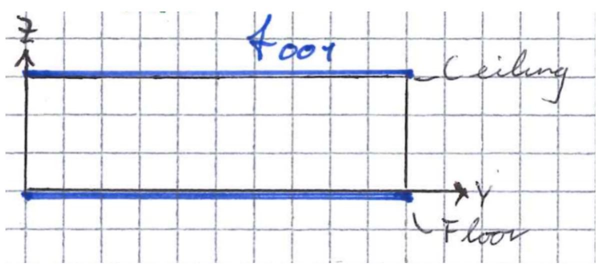


Figure 4: Axial mode with max pressure at the roof an ceiling.

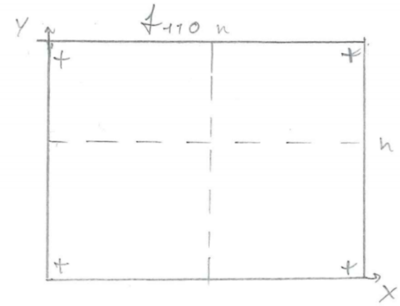


Figure 6: Axial modes on the xy plane for frequency f_{110}

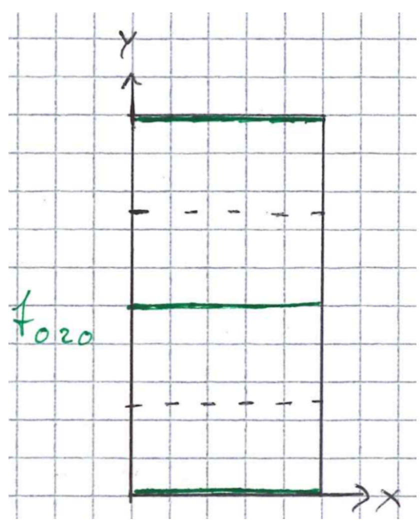
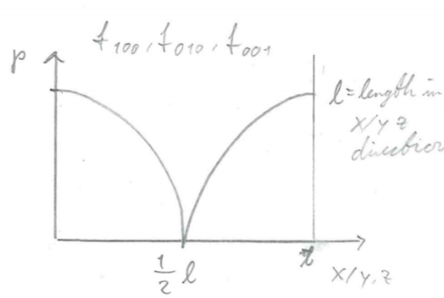
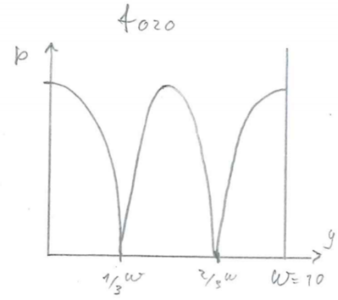


Figure 5: Tangential modes with max pressure at the walls and in the center. Dashed lines are node points.

The pressure distribution for modes f_{100}, f_{010} and f_{001} will be as follows.



The pressure distribution for modes f_{020} will be as follows.



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