Applied Acoustics, Chalmers

Introduction to Audio Technology & Acoustics

VTA 137

October 26, 2021, 8.30 – 13.30, Hörsalsvägen

Instructors: Jens Ahrens, Wolfgang Kropp, Pontus Thorsson

Questions during the exam: Jens Ahrens, Ph 2210 (will visit the examination room at 10.00 and 12.30)

Solutions will be posted on the department's bulletin board on Oct 27, 2021.

Preliminary exam results will be posted on the department's bulletin board latest Nov 15, 2021.

Questions on corrected exams can be discussed in the time slot announced together with the preliminary results.

Final results submitted to the university latest Nov 16, 2021.

Permitted material at the exam: Mathematical tables in books like the Physics Handbook, Tefyma, Beta, or similar books, acceptable calculators as defined below, the "Useful Formulae" - collection for Audio Technology and Acoustics, distributed at the course and available at the department's web site and the audio formula collection distributed at the course and available at the department's web site

An acceptable calculator is a calculator without (or cleared) text memory.

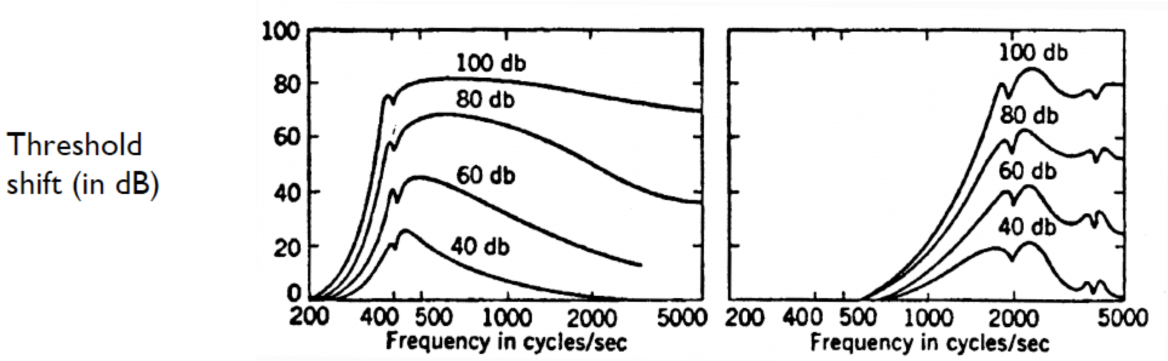
Grades: 12p = 3, 18p = 4, 24p = 5

Do not forget to specify the assumptions made in your solutions to the problems!

PROBLEM 1

a) Our hearing has the ability to mask sound. Describe the phenomenon of frequency masking and include with your text a simplified diagram. Furthermore, explain briefly the reason for frequency masking. (2p)

b) We want to reproduce a pure sinusoidal tone of A) 400 Hz and of B) 2 kHz using a loudspeaker. The sound pressure level in the listening position is 60 dB for both cases. However, at this level the loudspeaker also produces harmonics. The second harmonic has a level of –30 dB relative the fundamental (By "second harmonic" is meant a tone that has twice the frequency of the fundamental, i.e. 2*400 Hz or 2*2kHz in this case). Use the graphs below and on the next side to determine whether the second harmonic is audible in the two cases. (3p)

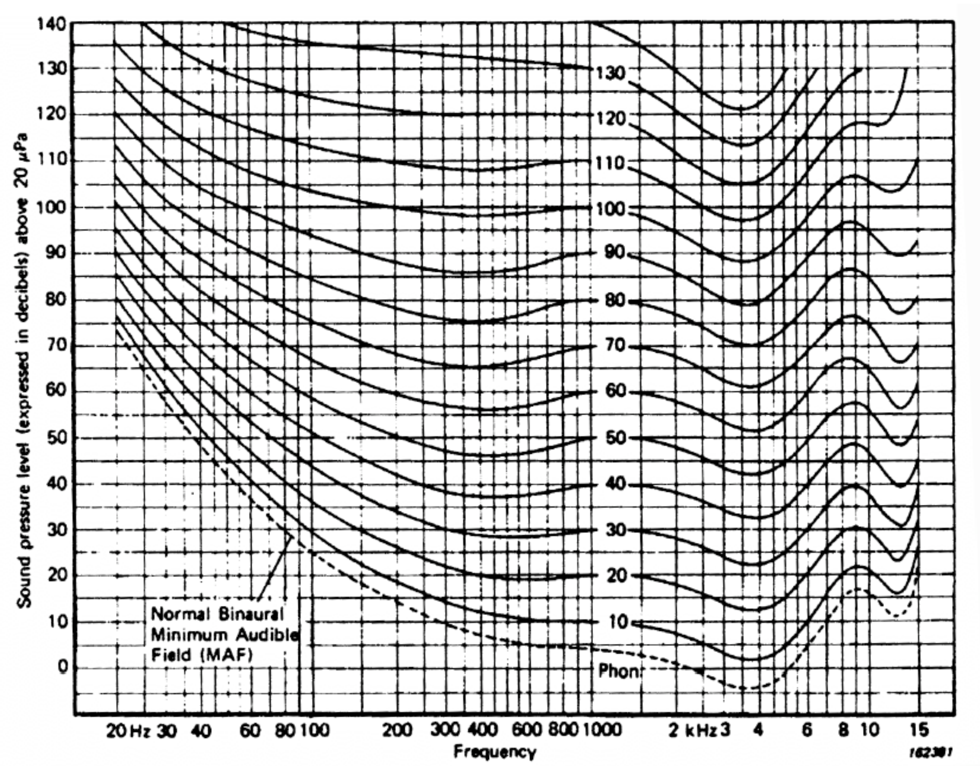


A. 400 Hz   B. 2 kHz

Masking of one pure tone by another

Problem 1 is continued on the next page!

Sound
pressure level
(dB)



Equal loudness curves

PROBLEM 2

Sven and Malte decide to buy a small old barn out in the country and convert it into a small-scale recording studio for their choir. In order to properly insulate the building for temperature control, the previous owner covered the walls with a fiberglass material which happens to have an absorption coefficient of α = 0.8 in the frequency range of interest, i.e., the 1 kHz-octave band. As a result, the reverberation time in the room is about 0.36 s, which is too short in comparison with their desired reverberation time of at least 1.4 s at 1000 Hz. Ever creative, the two young men decide to reduce the room absorption by covering the walls with a number of square table tops, donated by a local carpenter who happens to have two children in the choir. The solid heavy table tops have an absorption coefficient of α = 0.01 and have an area of 1 m^2. The floor and the ceiling have equal absorption, which is not necessarily the same as the walls' (or table tops') absorption coefficient. The volume of the room (L*W*H=10*10*3 m^3) is small enough that air absorption can be neglected.

a) How many table tops are necessary to cover the absorbent wall insulation so that the desired reverberation time is achieved? (State and justify your assumptions! May Sabine's formula be used?)

(3.5 p)

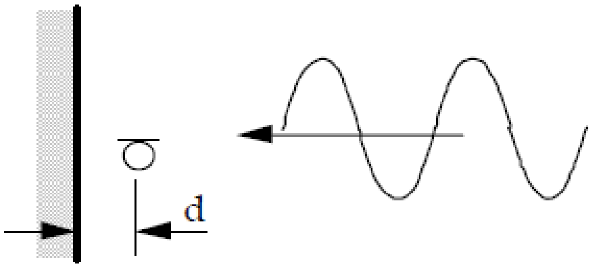
b) If the two instead decided to increase the volume of the barn, they would theoretically be able to reach the same desired reverberation time (if one assumed, e.g., that the new surfaces would have very small α). Would this solution achieve the same perceived acoustical environment as the other solution from a), i.e., would one experience a difference between the two solutions? Justify your answer. (Hint: Consider the sound pressure level for both cases.)

(1.5 p)

(Speed of sound in air: c=343 m/s)

PROBLEM 3

Placing an omnidirectional microphone on a rigid wall produces an increase of the sound pressure level due to an incident sound field of 6 dB relative to the case without the wall. If the microphone is placed at a short distance *d* from the wall as depicted in the figure below, then the sound pressure level increase will reduce as *d* increases.



a) Calculate the maximum distance *d* so that the level increase relative to the free field will be at least 3 dB at all frequencies up to 15 kHz for a plane wave that impinges perpendicularly. Assume that the wall is perfectly reflecting. (Speed of sound in air: $c = 343$ m/s)

(2 p)

b) Now assume that the wall is not perfectly reflecting but instead has r = 0.9. Calculate the maximum possible increase in level that occurs. Use the distance *d* that you calculated in a).

(1 p)

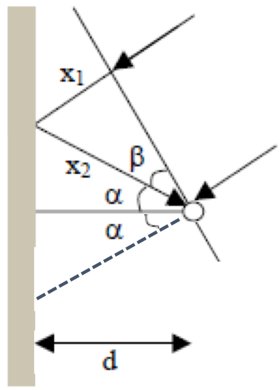
c) Now, the sound wave incidence is not perpendicular to the wall but instead at an angle of $\alpha = 30°$ relative to the normal direction. What is the lowest frequency at which incident and reflected sound cancel out each other perfectly? Use the distance *d* that you calculated in a) and assume again that the wall is perfectly reflecting.

(2 p)

Problem 3c) continues on the subsequent page.

Hint: The reflected wave travels a distance (x_1+x_2) longer than the direct path (see figure below). You may also want to use the identity

$$\sin(90° - 2x) = 2\cos^2 x - 1 \quad .$$



(Speed of sound in air: c=343 m/s)

PROBLEM 4

Measurements in a rectangularly shaped office room showed high sound pressure levels near the corners of the walls. These high levels occur since the room mode (q_x q_y q_z) = (1 1 0) is excited by machine noise from the adjacent workshop. The dimensions of the office are (l_x l_y l_z)= (3.9 3.6 2.4) m .

a) What resonance frequency should an absorbent be designed for if you want to damp this (1 1 0)-mode? (1p)

b) Design a Helmholtz absorber for the resonance frequency calculated in a). Available material is a 10 mm perforated panel with hole diameters of 5 mm and distance between center of holes of 120 mm. (3p)

c) Would it be possible to damp the resonance frequency calculated in a) efficiently by the use of a porous absorber? Why/ why not? (1p)

(Speed of sound in air: c=343 m/s)

PROBLEM 5

Vera listens to her radio and her husband Todd is in an adjacent room reading a book. The wall between the rooms has very poor sound insulation properties since it is made of a thin, single gypsum board. The door between the rooms has a diffuse field reduction index of 20 dB for all frequencies of interest.

a) What is the total reduction index of the wall including the closed door, for the octave bands with center frequencies 500 and 1000 Hz?

(Assume that the octave band values can be approximated by the values at the center frequencies and that the sound field is diffuse in both rooms. See additional data below.)

Total wall area (including the door) = 12 m^2, Door area = 2 m^2

The gypsum boards is 13 mm thick, has a density of 840 kg/m^3, coincidence number K_c=32 m/s, and a bending wave loss factor of 0.02. (2p)

b) The radio's power levels are given below, as well as the data for the two rooms. Vera is in Room 1 and her husband in Room 2. What is the total A-weighted sound pressure level in Todd's room (Room 2)?

Octave band:	500	1k	[Hz]
L_W	84	88	[dB]

Volume, Room 1=40 m^3 (4x4x2.5 m^3) Reverberation time, Room 1=0.4 s

Volume, Room 2=60 m^3 (6x4x2.5 m^3) Reverberation time, Room 2=0.45 s

Assume that the radio radiates as a point source and that both people are in the reverberant fields of their respective rooms.

(Speed of sound in air: c=343 m/s)

(2p)

(Problem 5 cont. on next page.)

(Problem 5 contd.)

c) Vera and Todd agree to change rooms. Vera will then listen to her radio in Room 2. She will adjust the volume knob of the radio so that the sound pressure level in the reverberant field is the same as when she listened in Room 1. What will the A-weighted sound pressure level be that Todd now experiences, in Room 1?

(1p)

PROBLEM 6

a) Make a sketch of a microphone capsule with a figure-of-eight directivity and describe in words how it comes that the directivity is a figure-of-eight.

(3 p)

b) Name two ways with which one can achieve a microphone with a cardioid directivity.

(2 p)