# Acoustics (VTAN01) – Exam 12th January 2017 (08.00-13.00)

Maximum score is 60 p. For passing, 30 p are needed.

Grades:

| Fail | 3- | 3+ | 4- | 4+ | 5- | 5+ |
|---|---|---|---|---|---|---|
| 0-29p | 30-34p | 35-39p | 40-44p | 45-49p | 50-54p | 55-60p |

Allowed aids are calculator and formulae.
The tasks are not sorted after degree of difficulty.
*Det går bra att skriva svar och lösningar på svenska!*

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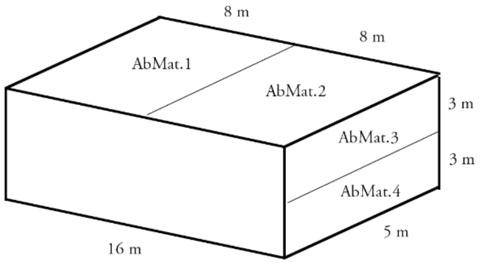
**1.** A rectangular room has the dimensions given in the drawing below. The ceiling is covered with two different materials, namely *AbMat.1* and *AbMat.2*, whereas the rear wall is composed of two different materials, viz. *AbMat.3* and *AbMat.4*. The absorption coefficients (for a diffuse field) for all the materials are presented in the table below. The surfaces which are not covered with any of the cited materials can be considered fully reflected. Answer the following:



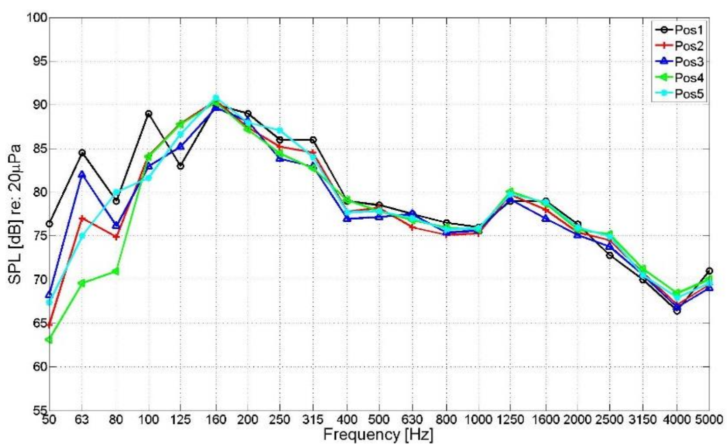

| Material | Absorption coefficient α |
|---|---|
| AbMat.1 | 0.24 |
| AbMat.2 | 0.37 |
| AbMat.3 | 0.15 |
| AbMat.4 | 0.22 |

a. Define reverberation time and describe the two procedures employed in the *Lab-2* of the course to measure it. Which differences are there between them? Which one would you say it is more accurate? *(2p)*

b. Calculate the reverberation time of the above described room according to Sabine's formula. What do you think about the obtained value? Is it too low? Too high? *(2p)*

c. If the previously calculated reverberation time is to be reduced (due to some regulations) by 10% and you only have at your disposal a new material (*AbMat.5*) whose absorption coefficient is 0.35 to be placed on the long walls. How much of their surface should be covered so that the previous requirement is fulfilled? *(3p)*

d. Calculate the Schroeder frequency $f_s = 2000(T_{60}/V)^{0.5}$ of the room in (c) and relate it to the plot below. How does it affect our listening experience? How would you characterise the sound field above and below $f_s$? *(3p)*



**2.** The intensity level of the siren of a ship, perceived by a sailor on the deck 10 m away from it, is 70 dB. Calculate:

a. The intensity level of the siren 1 km far away from it. *(3p)*

b. Distance to which the siren stops being audible. *(3p)*

c. RMS pressure of the sound wave at the distance calculated in (b), i.e. when it stops being audible. *(2p)*

d. Calculate the sound pressure level associated with the previously calculated RMS pressure. *(2p)*

DATA: the audio perception reference intensity threshold is $I_0=10^{-12}$ W·m$^{-2}$, the density of the air 1.20 kg·m$^{-3}$, and consider the speed of propagation of sound to be 340 m/s. Spherical propagation is assumed.

**3.** A tuning fork is stroked emitting a pure tone of frequency 612 Hz, which propagates through the air at 340 m/s and reaches a receptor. Considering this wave to be planar, answer the following questions:

a. If the peak pressure created by the wave is $2 \cdot 10^{-4}$ Pa, give the equation of the travelling wave and its wavelength. *(2p)*

b. Calculate the sound pressure level that the previous wave produces. *(2p)*

c. Sketch (roughly) how this wave would be represented in the frequency domain. Explain in your own words how the leap between the time and the frequency domains is performed. *(2p)*

d. If you were to measure this wave with the help of a computer, you would need to digitise/digitalise the signal (i.e. convert a continuous signal into a number of discrete values). The distance between two consecutive points is given by the sampling frequency. In this one case, which sampling frequency (at least) would you need to consider so you assure a good reconstruction of the signal once acquired by the computer? Which theorem/criterion gives this? *(2p)*

e. If 4 identical tuning forks as the one described above are played at the same time, what is the total sound pressure level that a sound level meter would record? Note: consider uncorrelated sources. *(2p)*

**4.** Working as an acoustic consultant, you get an assignment to assess a noise problem in a concrete building. The inhabitants living in those dwellings are recently complaining about the poor sound insulation present in the aforementioned construction, since they often hear their neighbours performing their daily activities. Your task is to perform airborne sound measurements according to the current ISO standards between two given neighboring apartments in the building in order to calculate the apparent sound reduction index. Unfortunately, you agenda is fully booked and you cannot perform the measurements yourself, so you have to send one of your less experienced colleagues. This colleague has never done such an accredited measurement before, so she/he has to be instructed.

a. Write instructions for your colleague on how airborne sound insulation measurements are performed according to the ISO 717-1 / ISO 16283-1 in order to get the sound reduction index of the wall in question (including also instructions on how to measure reverberation time). You colleague will not be able to phone you during the assignment so try to be as detailed as possible and explain exactly how to proceed, what equipment to bring and so forth. *(2p)*

b. Consider that your colleague understood correctly your explanations and that he/she brought back to the office the (correct) data shown in the table below. In there, you can find data from a sound reduction index measurement between two neighboring rooms, denoted as 1 (sending room, $V_1$=50 m$^3$) and 2 (receiving room, $V_2$=70 m$^3$). A loudspeaker is emitting noise in Room 1. Calculate the sound reduction index curve as a function of frequency in 1/3-octave bands supposing that the surface of the wall is 10 m$^2$. Note that you do not need to apply the procedures described in the standards to calculate the apparent sound reduction index $R'_w$, just draw the curve $R'(f)$ versus frequency. *(3p)*

c. Sketch by hand, in an approximate way, the shape of the sound reduction index curve which would be obtained analytically/theoretically by applying the exact method of the above mentioned wall, indicating the main features in it (regions, separating frequencies...). What are the dips one can see in the curve? Explain the phenomena that cause them. *(2p)*

d. After you checked the airborne sound insulation performance of the construction, you think about the possibility of analysing how the building behaves in terms of impact sound insulation. Can you say something about that with the data that your colleague collected given in the table below? Justify your answer. *(1p)*

e. The previous wall has a weighed apparent sound reduction index $R'_{w,wall}$=44 dB. If a 2 m$^2$ window whose $R'_{w,window}$=25 dB is installed. What is the total $R'_{w,Total}$ of the new wall? *(1p)*

f. After mounting the window in the wall, measurements performed *in-situ* reveal that the sound reduction index of the combined wall is 4 dB less than the one calculated in (e). We assume that this is due to a leakage that produces this decrease. Calculate the size (the area) of the leak. Describe in your own words possible practical solutions that can be taken on site so as to reduce such negative effects. *(1p)*

| $f$ (Hz) | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $L_1$ (dB) | 89 | 89 | 89 | 89 | 89 | 89 | 90 | 90 | 91 | 91 | 92 |
| $L_2$ (dB) | 64 | 62 | 61 | 59 | 58 | 56 | 55 | 53 | 53 | 53 | 60 |
| $T_{60,1}$ (s) | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 |
| $T_{60,2}$ (s) | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 |
| $f$ (Hz) | 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | |
| $L_1$ (dB) | 92 | 91 | 91 | 90 | 90 | 89 | 89 | 89 | 89 | 89 | |
| $L_2$ (dB) | 52 | 49 | 47 | 43 | 40 | 38 | 36 | 34 | 32 | 30 | |
| $T_{60,1}$ (s) | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | 0,7 | |
| $T_{60,2}$ (s) | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | |

**5.** The following task will be about calculation of airborne sound insulation between two rooms accounting for flanking transmission. Here are some room and material data (note: these two rooms have nothing to do with the two rooms from the previous exercise):

Room 1: $L \times B \times H$ = 6×4×2.5 m$^3$

Room 2: $L \times B \times H$ = 5×4×2.5 m$^3$

All walls are made of dense concrete, where $S$ denotes the area between the two neighboring rooms: $S$=4×2.5 m$^2$ (i.e. the area of the wall that is to be analysed). All walls numbered from 1 to 4 in Figure 1 are single leaf concrete walls with the same density and thickness and a weighted reduction index of $R_w$=48 dB. The apartment separating wall, labelled with the number 5 in Figure 1, is also a single leaf concrete wall with the same density and thickness as the others, but its weighted sound reduction index is $R_w$=52 dB.

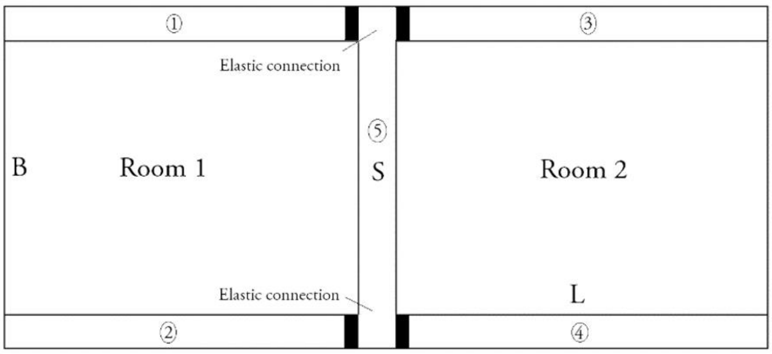



*Figure 1. Room 1 and 2 from above.*

a. From the provided laboratory measurements (i.e. the different $R_w$ for all walls), calculate the apparent sound reduction index $R'_w$ applying the procedures described in EN 12354-1:2000 (i.e. taking flanking transmission into consideration). Some useful expressions and diagrams from the lecture notes are inserted below. Consider just the flanking paths that you can "see" in Figure 1, i.e. the flanking transmission of the flooring system and ceiling can be neglected (i.e. 2D situation, only 7 paths). *(7p)*

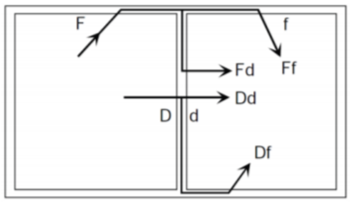
b. If pink noise is produced with the help of a loudspeaker and an amplifier in Room 1, with a sound pressure level of 90 dB, calculate the sound pressure level in Room 2 taking flanking transmission into consideration (i.e. using the apparent weighted sound reduction index calculated in the previous task). Consider that the ceilings are the only partitions absorbing sound, covered with perforated metal panels whose absorption coefficients are (constant for all frequencies) α=0.4 in Room 1, that will act as the sending room, and α=0.7 (also constant for the whole spectrum) in Room 2, that will be the receiving room. *(3p)*

- Apparent sound reduction index (13 paths)

$$R'_w = -10\log\left[10^{\frac{-R_{Dd,w}}{10}} + \sum_{F=f=1}^{n} 10^{\frac{-R_{Ff,w}}{10}} + \sum_{f=1}^{n} 10^{\frac{-R_{Df,w}}{10}} + \sum_{F=1}^{n} 10^{\frac{-R_{Fd,w}}{10}}\right]$$

- If only *Ff* paths are assumed:

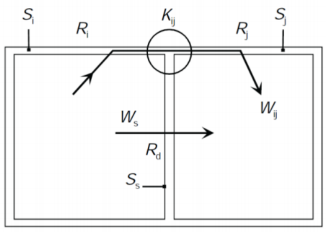
$$R'_w = -10\log\left[10^{\frac{-R_{d,w}}{10}} + \sum 10^{\frac{-R_{f,w}}{10}}\right]$$




- Flanking sound reduction index $R_{ij}$ (approximation given in the standard SS-EN 12354:2000)

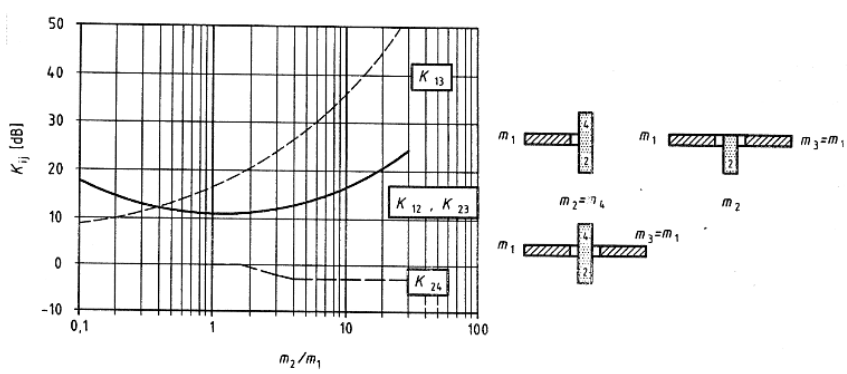
$$\left(R_f\right)_{ij,w} = R_{ij,w} = \frac{R_{i,w} + R_{j,w}}{2} + K_{ij} + 10\log\left(\frac{S_s}{l_0 \cdot l_{ij}}\right)$$

$R_i$ & $R_j$ : sound reduction index of flanking element *i* and *j*
$K_{ij}$ : vibration reduction index (junction dependent)
$S_s$: floor / wall surface
$l_0$ = 1m
$l_{ij}$ : junction common length




- Vibration reduction indexes $K_{ij}$
  – SS-EN 12354-1:2000 (Annex E)

**Wall junction with flexible interlayers**



**6.** Answer the following questions (they are not related to each other):

a. What are octave and 1/3-octave band spectra and why are they used? How do you, in principle, create an octave band spectrum from a narrow band spectrum? *(2p)*

b. What is A-weighting? Why is it used? What is the A-weighting curve based on? *(2p)*

c. Explain the quantities *sound pressure*, *RMS value* (of sound pressure), *sound pressure level* and *reference sound pressure*. What do they express? How are these quantities related to each other? What is a level? What does the reference sound pressure value correspond to? *(2p)*

d. Suppose that the SPL at a large road in the vicinity of an airport is measured and logged during an entire day. Calculate the equivalent SPL ($L_{eq,24h}$) and the maximum SPL ($L_{max}$) for the following two situations: (i) 60 dBA during 12 h and quiet the remaining 12 h; and (ii) 95 dBA for 15 minutes, 101 dBA for half an hour and quiet the rest of the time. *(2p)*

e. What is the effective value for the sound pressure corresponding to $L_p$ = 0 dB? What is the sound pressure level that corresponds to absolute silence? Explain the physical meaning of the previous two cases. *(2p)*

***Good luck!***