TTT4250 - Acoustical Measurement Techniques

Laboratory Exercise 1

Sound Power Measurement

performed by

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Report by

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Summary

This report inspects the use of three different methods based on ISO 3747:2010, ISO 3746:2010 and ISO 9614-2:1996 to determine the A-weighted sound power level of a test source, here a vacuum cleaner in a reverberant room. The first and second method calculates the sound power through sound pressure levels and method 3 uses intensity to calculate the sound power. The A-weighted sound power levels were found to be 84.71 dB for ISO 3747:2010, 85.20 dB for ISO 3746:2010 and 86.01 dB for ISO 9614-2:1996. The A-weighted sound power level is around 85.3 dB and the difference between the highest and lowest value is about 1.3 dB. The report attemps to show the differences between the methods, and try to unveil which method is best in terms of accuracy and minimizing room for human error. Method 1 and 2 both seem to be good choices, while method 3 relies to heavily on the manual conductance of the measurements, proving it difficult to get satisfactory accuracy.

Contents

1 Introduction

In this lab report we will discuss the measurements and results from measuring the sound power of a test source, with and without a reference source and using intensity measurements. We will compare different methods for measuring the sound power. All measurements are performed in a reverberant room. For the first method we will use the standard ISO 3747:2010, where both a reference and a test source is used and the microphone is placed in different positions in the room. For the second method the standard ISO 3746:2010 will be used, where one makes use of a test source only and measures along the surface of a hypothetical measurement box. The last method uses the intensity method based on the standard ISO 9614-2:1996, where a intensity probe is sweeped over the surface of a different hypothetical measurement box. The first two methods measure the sound pressure level, from which it is possible to find the A-weighted sound power level and the third method utilizes the sound intensity to find the A-weighted sound power level. The goal of the report is to discuss the methods and give reason for which method seems most promising, both in terms of reasonable results, high accuracy and minimizing the change of human error.

2 Theory

2.1 A-weighting

The A-weighting filter is used to mimick the way the human hearing works, and surpresses/amplifies different frequencies in the same manner as our hearing. This way when we weight sound pressure levels/sound power levels with this filter we get levels that are equivalent to what the ear experiences and it is possible to determine whether the levels obtained are damaging. The weighting factors for different octave bands are given in Table 2.1.

Frequency [Hz]	A_k [dB]
16	-56.7
31.5	-39.4
63	-26.2
125	-16.1
250	-8.6
500	-3.2
1000	0
2000	1.2
4000	1
8000	-1.1

Table 2.1: A-weighting constants

2.2 Method 1: ISO 3747:2010

This method caluclates the sound pressure level in octave bands with the use of a reference sound source, called RSS, and a test source, called TS. First one need to check the background noise, to see if it needs to be corrected for.

For the background noise we must check that it is low enough compared to the sound sources in order to ensure that the background noise does not disturb the measurements. This is done by inspecting the difference between the sound pressure levels of the sources and the background noise, $\Delta L'_{pi(source)}$. The criteria for the test source, $\Delta L_{pi,TS}$, is shown in Equation 2.1 and the criteria for the reference sound source, $\Delta L_{pi,RSS}$, is shown in Equation 2.2.

$$\Delta L_{pi,TS} = L'_{pi(TS)} - L'_{pi(B)} > 15 \text{ dB} \tag{2.1}$$

$$\Delta L_{pi,RSS} = L'_{pi(RSS)} - L'_{pi(B)} > 15 \text{ dB} \tag{2.2}$$

Here $L'_p i$ is the sound pressure level in octave bands for the reference source (RSS), test source (TS), and background noise (B) as noted in the subscript. If correction is needed the correction for $L_{pi(TS)}$ is given in Equation 2.3 and the correction for $L_{pi(RSS)}$ is given in Equation 2.4.

$$L_{pi(TS)} = 10\log\left(10^{L'_{pi(TS)}}\right) \tag{2.3}$$

$$L_{pi(TS)} = 10\log\left(10^{L'_{pi(TS)}}\right) \tag{2.4}$$

Furthermore, it is necessary to find the indicator ΔL_f which determines the accuracy of the measurements. ΔL_f is shown in Equation 2.5. This indicator is necessary because the reverberation can be ignored in an assumed free-field, as its effect is neglible, but in a reverberance room it is needed in order to determine accuracy. The g rade of accuracy gives an upper limit for the standard deviation of reproducibility of the A-weighted sound power level, respecitvely 1.5 dB for grade 2 and 4 dB for grade 3.

$$\Delta L_f = L_{pi(RSS)} - L_{W(RSS)} + 11 + 20 \log \left(\frac{r}{r_0} \right) \tag{2.5}$$

Here r is the distance from the measurement point to the reference source in meters and the reference length r_0 is 1 meter. $L_{W(RSS)}$ is the sound power of the reference source and can be found in Table 2.2.

Table 2.2: Sound power level of the reference sound source, $L_{W(RSS)}$

Frequency [Hz]	L_W
125	79.8
250	81.0
500	80.9
1000	84.9
2000	85.1
4000	82.7
8000	79.2
A-weighted	90.5

If $\Delta L_f \geq$ 7dB we have accuray of grade 2 and the upper value of the standard deviation for the A-weighted sound power level is 1.5 db. If $\Delta L_f <$ 7dB we can only get accuracy of grade 3 and the corresponding upper value of the deviation for the A-weighted sound power level is 4.0 dB [1]. Grade 2 is used for engineering accuracy and grade 3 is used for survey accuracy.

The sound power levels, in each octave band, is calculated using

$$L_W = L_{W(RSS)} + 10 \log \left(\frac{1}{N} \sum_{i=1}^{N} 10^{0.1\left(L_{pi(ST)} - L_{pi(RSS)}\right)} \right) \text{ dB} \tag{2.6}$$

In order to apply the A-weighting to this sound power level and calculate the total sound power level we use the following equation

$$L_{W,A} = 10 \log \left(\sum_{k} 10^{0.1(L_{W\,k} + A_k)} \right), \tag{2.7}$$

where A_k is the A-weighting constants as shown in Table 2.1.

To ensure that the placement of the sources has a sufficiently small effect on the sound power level the ratio between the sources must be as

$$0.8 \leq \frac{d_{RSS}}{d_{TS}} \leq 1.2, \tag{2.8}$$

where d is the distance from the microphone to the two different sound sources and the sources are noted as a subscript. As long as this criteria is fulfilled the zoning effect is negligible [2].

2.3 Method 2: ISO3746:2010

In this method it is necessary to create an imaginary reference and measurement box. The reference box is in this case the smallest hypothetical rectangular box that is able to enclose the sound source, while the measurement box is the hypothetical surface of area S, which lies around the sound source and has meaurement points on the surface. For this measurement a rectangular box was chosen as the measurmenet surface. Because of directivity of the probe it is best to have the microphone perpendicular to the measurement surface. This ensures maximum transfer of the pressure waves to the microphone mebrane.

The environment factor is a factor gives an indication of how reverberant the room is. In order to calculate it one must first determine the equivalent sound absorption area of the room, which is given by

$$A = \alpha \cdot S_V, \tag{2.9}$$

where S_V is the total surface of the room and α is the absorption coefficient of a (nearly) empty room with hard, smooth walls. The recommendation in ISO 3746, [2], is that = 0.05.

The environment correction factor K_{2A} is then given as

$$K_{2A} = 10 \log \left(1 + \frac{4S}{A} \right), \tag{2.10}$$

where S is the area of the measurement box and A is the absorption area given in Equation 2.9.

For this method the background noise must be corrected if $\Delta L_A = \overline{L'_{pA}} - \overline{L'_{pA(B}} > 10$ dB. Here $\overline{L'_{pA}}$ is the averaged A-weighted sound pressure level, as shown in 2.11, and $\overline{L'_{pA(B}}$ is the A-weighted background sound pressure level.

$$\overline{L'_{pA}} = 10 \log \left(\frac{1}{N} \sum_{i=1}^{N} 10^{0.1 L'_{pA_i}} \right) \text{ dB} \tag{2.11}$$

If this criteria is not held the background noise must be corrected by K_{1A} as

$$K_{1A} = -10 \log \left(1 - 10^{-0.1 \Delta L_a} \right) \text{ dB}, \tag{2.12}$$

which is added to the total A-weighted sound power level. The A-weighted sound power level is then calculated by using Equation 2.13.

$$L_{W,A} = \overline{L'_{pA}} - K_{1A} - K_{2A} + 10 \cdot \log \left(\frac{S}{S_0} \right) \tag{2.13}$$

2.4 Method 3: ISO9614-2:1996

The principle behind this method is that the intensity component is measured normal to a new measurement surface which encloses the source under test, using different sweep techniques. The measurement surface needs to be defined and scanned with the test source on. The reference box is the same as in Method 2, but the measurement box is smaller. The effective frequency range is determined by the thickness of the spacer used between the two intesity probes. The sound power level is found as

$$L_W = 10\left(\sum_{i=1}^{N}\frac{W_i}{W_0}\right) = \overline{L_{In}} + 10\left(\frac{S}{S_0}\right) \tag{2.14}$$

The field indicator F_{pl} is an indicator for the surface pressure-intensity and given as

$$F_{pl} = \overline{L_p} - L_W + 10\left(\frac{S}{S_0}\right) = \overline{L_p} - \overline{L_{In}}, \tag{2.15}$$

by inserting Equation 2.14

This indicator determines the grade of accuracy. It is compared to the dynamic capaiblity index and Equation 2.16 must be satisfyed for the selected measurement surface to be satisfactory for determining the sound power level of the source.

$$L_d > F_{pI} \tag{2.16}$$

L_d is the dynamic capability index and is determined by the measurement system and the defined grade of accuracdy. It is defined as shown in Equation 2.17.

$$L_d = \delta_{pI_0} - K, \tag{2.17}$$

where δ_{pI_0} is the pressure-residual intensity index and K is the bias error index. In this measurement system δ_{pI_0} is 18.8 dB and K is 10 for enigneering accuracy of grade 2 and 10 for survey accuracy of grade 3 [1]. This means that F_{pI} must be below 8.8 dB for grade 2 and below 11.8 dB for grade 3. There also exists grade 1 (precision), but for most cases grade 2 is satisfactory.

3 Method and Equipment

3.1 Measurement procedure

3.1.1 Measurements of the room

All measurements took place in room D0016 at NTNU Gløshaugen Elektro D+B2. The room in which the measurements took place is a reverberant room. The dimensions of the room are presented in Table 3.1.

Table 3.1: Measurements of the room in which all measurements took place.

	Length [m]	Width [m]	Heigt [m]	Surface area [m^2]
Measurement room	8.5	6.0	5.2	531.5

Illustration of the room can be seen in Figure3.1. There were several objects in the room, such as reflecting plastic screen suspended from the roof, stairs, etc.

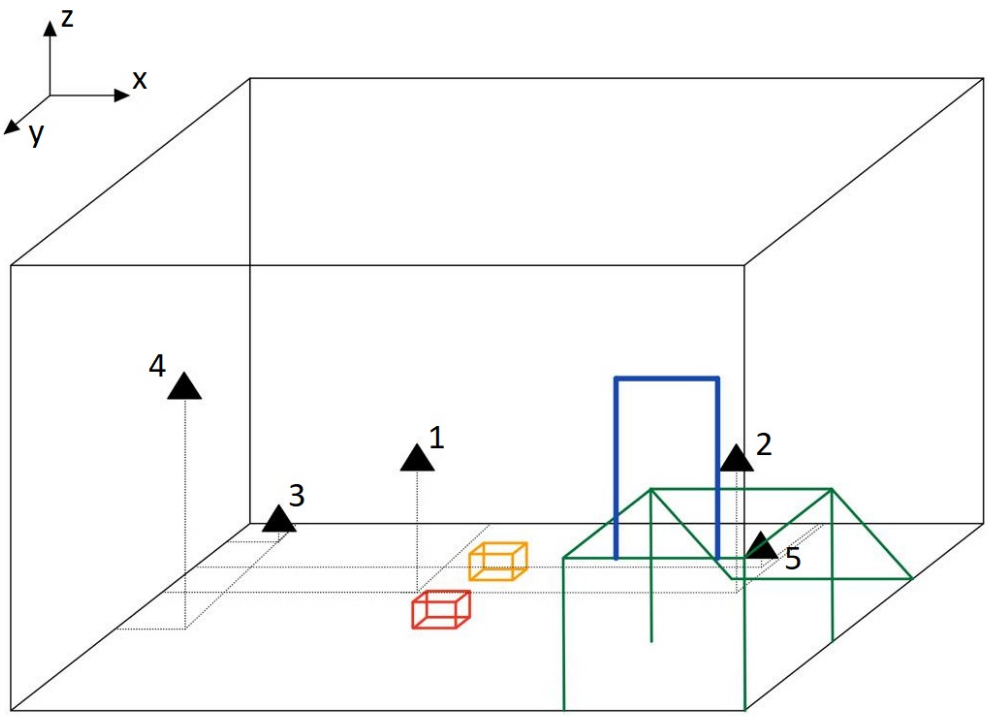


Figure 3.1: Sketch of the room with the microphone positions marked [3]. The stairs are marked in green and the door is marked in blue. The red box is RSS and the orange box is TS. Obstacles and refelctive screens are not included.

3.1.2 Background Noise Measurments

In order to measure the background sound pressure level $L'_{pi(B)}$ we placed the microphone in the same positions as for the first method, depicted in Figure 3.1. We took 5 background noise measurements with the same specifications as for Method 1.

3.1.3 Method 1: ISO 3747:2010

Firstly the microphone was calibrated. The calibration function of the NOR150 was used and a calibration tool that produces 124 dB at 250 Hz was placed over the microphone. Post-calibration was also done after the measurements for both Method 1 and Method 2 was completed. This is necessary in order to ensure that nothing has happended during the measurement that could affect the result. The pre- and post-calibration should be measured to be equal, or very close to equal.

The test source and reference source were placed close to the center of the room. The distance between the two sources was 1.5 m and the closest reflecting surfaces was more than 1 meter away from the sources. The microphone positions were detemined from appendix B in ISO:3746:2010, [4], while simultaniously satifying the ratio in Equation 2.8.

For all five microphone positions we measured the sound pressure level with the test source on and the reference source off, and then with the test source off and the reference source on. The distance from the microphone to the test source and from the microphone to the reference source was measured and the ratio between the two taken, as noted in Table 3.2.

Table 3.2: Distances between the microphone (M) and the test source (TS), reference source (RSS), the height and the ratio between the distance M-RSS and M-TS.

	M-TS [m]	M-RSS [m]	M-Height [m]	Ratio
Position 1	1.75	1.52	1.47	0.87
Position 2	2.28	2.48	1.47	1.09
Position 3	2.44	2.90	0.38	1.19
Position 4	4.02	3.47	2.14	0.863
Position 5	2.14	2.22	0.38	1.04

3.1.4 Method 2: ISO 3746:2010

When using method 2 we only get the A-weighted sound pressure levels. First we have to define the reference box and measurement surfaces, as shown in Figure3.2.

The microphone positions are on the measurement surface. In this case the measurement surfaces are small enough that it is sufficient with only one microphone position per side of the box, which is placed in the centre of the surface. The measurement surface was selected to be a rectangular box. It was 1 meter from the reference box in all directions. The measurements for the reference and measurement boxes are shown inTable 3.3.

Table 3.3: Dimensions of the reference and measurement boxes.

	Length [m]	Width [m]	Height [m]	Surface area [m^2]
Reference box	0.465	0.3	0.25	0.522
Measurement box	2.465	2.03	1.25	16.241

For method 2 we need background noise measurement, and the measuremnts of the background noise that were taken for method 1 was reused for method 2.

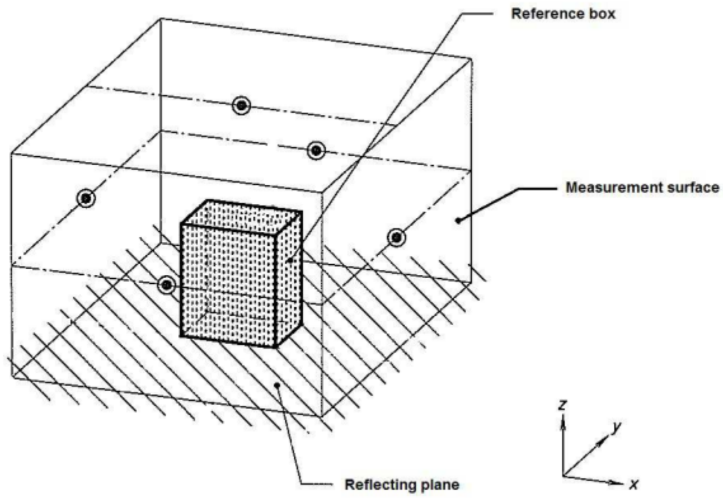


Figure 3.2: Set-up for method 2 showing the reference box, the measurement box and the measurement points (black dots).

3.1.5 Method 3: ISO 9614-2:1996

For method 3 we used another set-up for the measurement. The NOR150 was set up to be used as a intensity probe by two microphones with a 10 mm spacer. The spacer used with the intensity probe has an effective frequency range of 100 Hz - 5000 Hz.

The measurement surface was defined to be a rectangular box with the same reference box as used in method 2, and an additional 0.28 m in all directions. The measurements of the boxes are shown in Table 3.4.

Table 3.4: Dimensions of the reference and measurement boxes for the intensity method.

	Length [m]	Width [m]	Height [m]	Surface area [m^2]
Reference box	0.465	0.3	0.25	0.522
Measurement box	0.763	0.58	0.53	1.94

When scanning we used two scanning patterns. One horizontal and one vertical, as shown in Figure3.3. The scanning was done manually and with a speed within the range of 0.1 m/s - 0.5 m/s and should not last shorter than 20 s [1]. The measurements took approximately 40 s to complete.

3.2 Equipment

The equipment list is shown inTable 3.5.

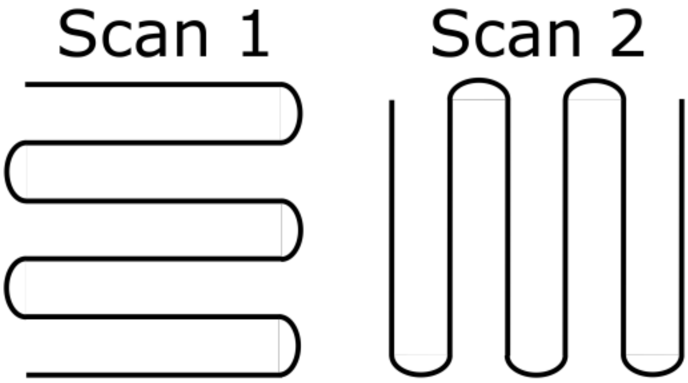


Figure 3.3: Scanning patterns for method 3 [1].

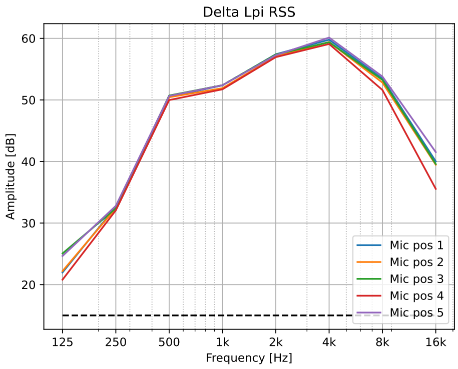
Table 3.5: Equipment list.

Equipment	Model number/type	Serial number
Laser measure	Leica DISTO X310	
Vacuum cleaner (Test source)	Siemens Z 5.0	
Fan (Reference sound source)	Brüel & Kjær type 4202	1265855
Sound and Vibration Analyser	NORSONIC Nor 150	15030749
Pressure and phase calibrator	Brüel & Kjær Pistophone type 4220	1475923
G.R.A.S Soung&Vibration	0.5" Intensity Microphpne pair 40AK	
Foam windscreen for microphone		
Microphone stand	K&M	
Cables	NORSONIC Nor 1408A 5 metre	
Microphone/Measurement probe	NORSONIC Type 1201/30490	
Microphone/Measurement probe	NORSONIC Type 1209 Spacer	10 mm spacer

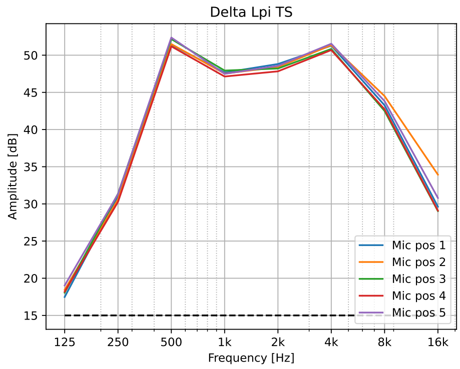
4 Results

4.1 Method 1: ISO3747:2010

The plot for the $\Delta L_{pi(RSS)}$ and $\Delta L_{pi(RSS)}$ is shown in Figure4.1.



(a) Difference between sound pressure and background noise for the reference source for octave bands and for the different microphone positions.The black slashed line indicates the limit for correction.



(b) Difference between sound pressure and background noise for the test source for octave bands and for the different microphone positions. The black slashed line indicates the limit for correction.

Figure 4.1: ΔL_{pi} for RSS and TS.

We see that $\Delta L_{pi(RSS)}$ is above 15 dB for all octave bands and therefore no background noise correction is needed, according to Equation 2.2. The same applies for $\Delta L_{pi(TS)}$ shown in Figure 4.1(b). Also here the criteria stated in Equation 2.1 is fulfilled and no correction is needed.

The indicator ΔL_f is plotted in Figure 4.2.

For ΔL_f we see that we achieve accuracy of grade 2 for 500 Hz, 1 kHz, 2 kHz and 4 kHz. We have grade 3 for 125 Hz and for 250 Hz and 8 k Hz the accuracy grade differs for the different microphone positions.

The first microphone position was very clos to both sources. From Figure 2.5 it is clear that this microphone position performs differently from the rest of the positions. This is reasonable due to the close proximity to the sources. ¨

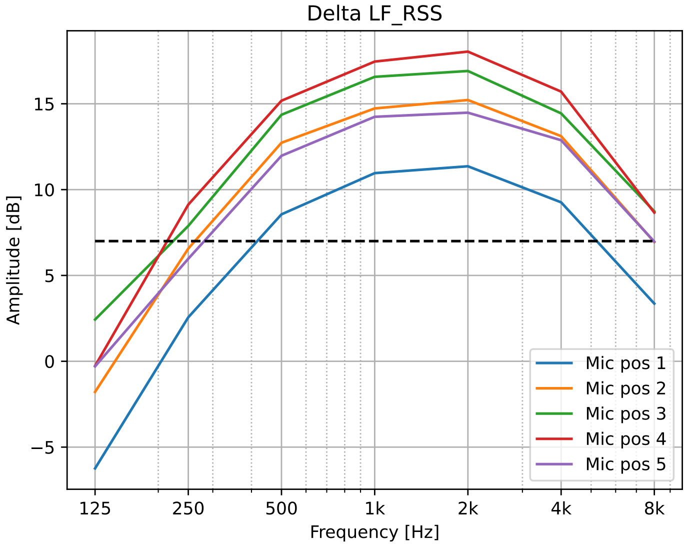


Figure 4.2: Indicator ΔL_f plotted for the different microphone positions and octave bands. The black slashed line indicates the limit for correction.

After calculating the A-weighted sound power level in octave bands using Equation 2.6 the total A-weighted sound power level $L_{W,A}$ was calculated to be 84.71 dB using Equation 2.7.

4.2 Method 2: ISO 3746:2010

The background noise from method 1 was reuased for method 2 and then applied A-weighting to and is plotted against the A-weighted sound pressure level, calculated from Equation 2.11, in Figure 4.3. The environment correction, K_{2A}, was calcuated to be 0.2455 from Equation 2.10.

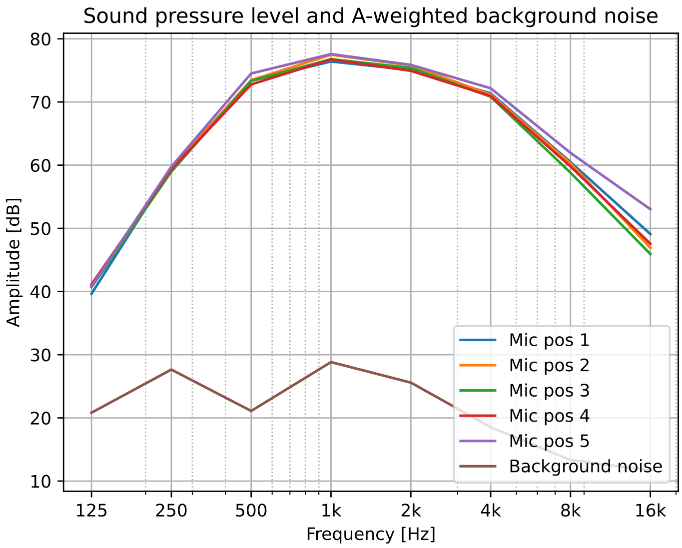


Figure 4.3: Sound pressure level for the test source and A-weighted plotted per octave band for all five microphone positions.

Table 4.1: ΔL_A for the different octave bands, showing $\Delta L_A > 10$ dB is fulfilled and no correction is needed.

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	16 kHz
ΔL_A	19.9 dB	31.8 dB	52.4 dB	48.2 dB	49.8 dB	52.8 dB	47.0 dB	37.6 dB

As we see from Table 4.1 the criteria in Equation 2.12 is satified and no correction is needed. The total A-weighted sound power level was calculated to be 85.20 dB using Equation 2.13.

4.3 Method 3: ISO 9614-2:1996

The surface pressure-intensity indicator F_{pl} is shown in Figure 4.4.

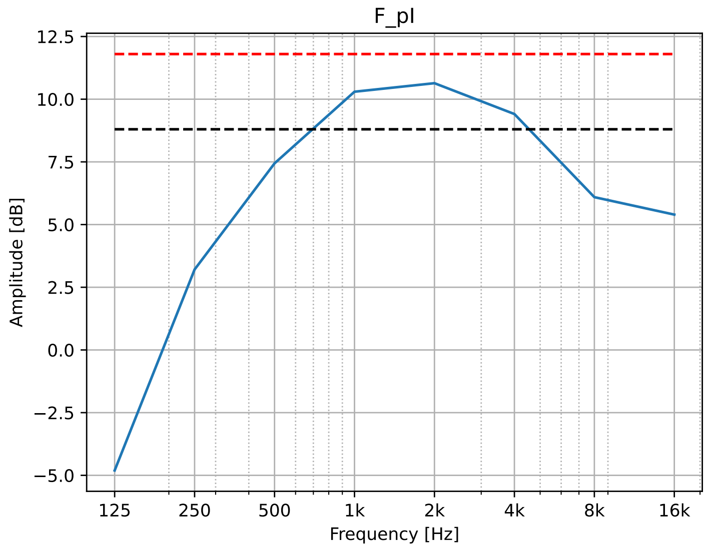


Figure 4.4: F_{pI} plotted for the octave bands. The black slashed line indicates the upper limit of accuracy grade 2 and the red slashed line indicates the upper limit of accuracy grade 3.

From the figure we see that only part of the frequncies satisfy accuracy of grade 2, but all octave bands fulfill accuracy of grade 3. This condition is given in 2.16.

The total A-weighted sound power level was found to be 86.01 dB using Equation 2.14.

4.3.1 A-weighted sound power and sound pressure levels for all methods

The most noteable result is the A-weighted sound power levels for the different methods. For summary, these levels are presented in Table 4.2.

Table 4.2: A-weighted sound power levels for the three different methods.

	A-weighted sound power level [dB]
Method 1	84.71
Method 2	85.20
Method 3	86.01

The A-weighted sound pressure levels for the three methods are plotted in Figure 4.5.

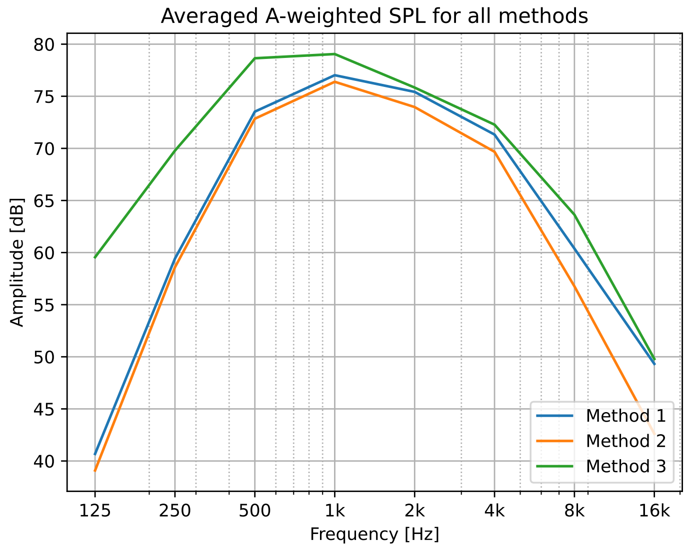


Figure 4.5: Averaged A-weighted sound pressure levels for method 1, 2 and 3.

The A-weighted sound power levels for the three methods are plotte in Figure 4.6.

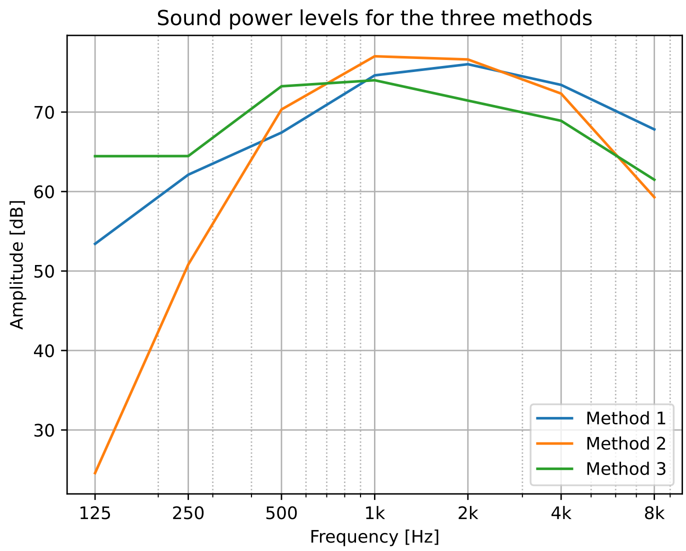


Figure 4.6: A-weighted sound power levels for method 1, 2 and 3.

5 Discussion

From Figure 4.2 we see that the measurements does not satisfy an accuracy of grade 2 for all frequenices. Also for microphone position 1 the results satisfy grade 3 for almost all of the octave bands. This is probably due to the microphone being placed very close to the test and the reference source. In order to avoid this problem the microphone should have been placed further away from the sources.

The background noise was in all cases not significant, and there was no need for correction. It should be noted that the microphone is directional and the angle between the incident wave will possibly affect the result. This could cause som e room for human error in method 3, where the scanning was done manually. There are many factors that could affect the uncertanty of this methos, such as whether the intensity probe had a constant speed within the range of the standard [1], whether the measurement surface was exactly the same size as measured and used in the post-processing and the direction of the probe with regards to the sound source. The grade of accuracy for method 3 satisfyes grade 3 for all frequencies, and grade 2 for some of the frequenices.

The results vary slightly, and the biggeest difference is between method 1 and method 3, with a difference of 1.3 dB. A choice in the post-processing, where the third octave bands where summed up to octave bands, could be the reason the sound power level for method 3 is higher than for the other methods. A weakness in the performing of the measurements in method 1 and 2 is that the direction of the microphone was not considered, whch could have lead to lower sound power levels. Another factor which could contribute to the difference in results between methods is the placement of the people doing the measurement. It was attempted to stand far enough from the microphone, but the measurements had to be conducted manually and it is a possible source of error.

6 Conclusions

The A-weighted sound pressures were found for the test source by using three different methods based on, respectively, ISO3747:2010 , ISO3746:2010 and ISO9614-2:1996 The amount of required post-processing differs, and also the data collected from the different methods are not the same. The methods serve different purposes and especially method 3 gives a lot of information, also in 1/3-octave bands, while from method 2 we can only get the A-weighted sound power level. However, all the methods work as to find the A-weighted sound power level.

The A-weighted sound power level was found of a test source was found to be 85.3 dB, with the range from the highest to the lowest value spanning 1.3 dB. The accuracy of the methods were between grade 2 and grade 3. For method 1 there was one microphone position that perfomed unexpected, in terms of accuracy, probably due to a not optimal placement relative to the sources. Results are presented in 6.1.

Table 6.1: A-weighted sound power levels for the three different methods.

	A-weighted sound power level [dB]
Method 1	84.71
Method 2	85.20
Method 3	86.01

All three methods gave similar results. Method 1 and 2 were easier to conduct, and the main problem with method 3 was the human error in moving the intensity probe at a steady speed, angle and correct height. The preferred method is method 2 due to simplicity and accuracy.

Bibliography

[1] TTT4250 Acoustical Measurement Techniques Laboratory Exercise Compendium, Chapter 2

[2] ISO 3747:2010, Acoutsics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering/survey methods for use in situ in a reverberant environment, International Standard, Third Edition, 2010-12-01

[3] Berg, Erlend K., Laboratory exercise 1, 2022.

[4] ISO 3747:2010, Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Survey method using an enveloping measurement surface over a reflecting plane, International Standard, Third Edition, 2010-12-01

[5] Bestemmelse av lydeffektnivå for støykilder ved bruk av lydintensitet Del 2: Sveipemetode , ISO 9614-2:1996, Norsk Standard, 1. edition, april 1996, ICS 17.140.01

A Appendix: Measurement data

Measuremnt data are found in the attachments.

B Appendix: Python script for method 1 and 2

```python
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd

octave_band = [125, 250, 500, 1000, 2000, 4000, 8000, 16000]
A_weighting = np.array([-16.1, -8.6, -3.2, 0, 1.2, 1, -1.1, -4])
x_ticks_octaveband = ["125", "250", "500", "1k", "2k", "4k", "8k",
    "16k"]
p0 = 20 * 10 ** (-6)
LW_RSS_A_tot = 90.5
r = np.array([1.524, 2.480, 2.899, 3.469, 2.220])
LW_RSS_short = np.array([79.8, 81.0, 80.9, 84.9, 85.1, 82.7, 79.2])
A_weighting_modded = A_weighting[:-1]
mic_pos = 5

MEASUREMENT = {
    "LFEQ": 0,
    "LFMAX": 1,
    "LFMIN": 2,
    "LFE": 3
}

unmodded_file_ref = "Trykk_Lab1.csv"


# = "intensitet_lab1.csv"


def read_csv(filename):
    return np.genfromtxt(filename, skip_header=1, delimiter=';')


# Array of type:  [ROWS, OCTAVEBANDS]
def pl tt(array, title, name_of_file, use_A_Weight=True, short=
    False, ) ->
    object:
    fig, ax = plt.subplots()
    for i in  range(array.shape[0]):
        if not short:
            ax.semilogx(octave_band, array[i] + (A_weighting * np.
                array(use_A_Weight).astype(
                int)),
                         label=f"Mic pos {i + 1}")
```

```
        else:
            ax.semilogx(octave_band[:-1], array[i] + (A_weighting *
                np.array(use_A_Weight).astype(
              int))[:-1],
                        label=f"Mic pos {i + 1}")
    # plot magic
    ax.grid(which="major")
    ax.grid(which="minor", linestyle=":")
    ax.set_xlabel("Frequency [Hz]")
    ax.set_ylabel("Amplitude [dB]")
    ax.set_title(title)
    if not short:
        ax.set_xticks(octave_band)
        ax.set_xticklabels(x_ticks_octaveband)
    else:
        ax.set_xticks(octave_band[:-1])
        ax.set_xticklabels(x_ticks_octaveband[:-1])

    #plt.legend(loc="lower right")
    plt.savefig(name_of_file)
    plt.show()


def background_noise_correction(L_marked_pi):
    L_pi = 10 * np.log10(10 ** (L_marked_pi / 10) - 10 ** (
        L_marked_pi / 10))


def db_to_pressure(measurements):
    return 10 ** (measurements /10)


def pressure_to_db(measurements):
    return 10 * np.log10(measurements)





# Reading the files
data = read_csv(unmodded_file_ref)[:-1, 4:]  # All rows minus the
    last, header is fucked anyway, fuck the first 4 colums
print("data shape", data.shape)

bg_noise = data[[0, 5, 6, 9, 12], :]
print("bg noise shape", bg_noise.shape)

ref_noise = data[[1, 4, 8, 11, 14], :]
print("ref noise shape", ref_noise.shape)

test_noise = data[[2, 3, 7, 10, 13], :]
print("test", test_noise.shape)

method_2_data = data[[15, 16, 17, 18, 19]]
```

```python
print('method 2 data', method_2_data.shape)
#
# data_method3 = pd.read_csv(filelist, sep=";")
# data_method3 = np.array(data_method3)
# print('data 3', data_method3.shape)
# print('data3', data_method3)

# Trash the first 15 columns as they are not relevant for the octavebands
# Split into microphone positions, measurement and octavebands
reference_splitted = ref_noise[:, 15:].reshape(-1, 4, 11)[:, :,3:]  # The three first octave bands are invalid due to measurement equipment limitation
background_splitted = bg_noise[:, 15:].reshape(-1, 4, 11)[:, :, 3:]
test_splitted = test_noise[:, 15:].reshape(-1, 4, 11)[:, :, 3:]
method_2_splitted = method_2_data[:, 15:].reshape(-1, 4, 11)[:, :, 3:]
# method_3_splitted = data_method3[10:,[0,2,4,5]]

# print('met3 shape', method_3_splitted.shape)
# print('met3 ', method_3_splitted)


print("Microphone positions, measurements, octavebands", reference_splitted.shape)
to_plot_ref = reference_splitted[:, MEASUREMENT["LFEQ"], :]
to_plot_back = background_splitted[:, MEASUREMENT["LFEQ"], :]
to_plot_test = test_splitted[:, MEASUREMENT["LFEQ"], :]
to_plot_method2 = method_2_splitted[:, MEASUREMENT["LFEQ"], :]

# Calculate average background noise per octaveband
background_pressure = db_to_pressure(to_plot_back)
print("PRessure_vec shape", background_pressure.shape)

pres_avg = np.average(background_pressure, axis=0)

# From pressure to dB
average_background = pressure_to_db(pres_avg)

#################################


# pl tt([to_plot_ref, to_plot_test], "Reference sound source", name_of_file='ref_method1_plt.pdf')
# pl tt(to_plot_test, 'Test sound source', name_of_file='test_method1_plt.pdf')

# Calculating delta Lpi,RSS and delta Lpi,TS
delta_ref = to_plot_ref - average_background
delta_test = to_plot_test - average_background

# pl tt(delta_ref, 'Delta Lpi RSS', name_of_file='deltapi_ref_method1_plt.pdf')
```

```
# pl tt(delta_test, 'Delta Lpi TS', name_of_file='
    deltapi_test_method1_plt.pdf')

# Calculating delta Lf
print('plot ref', to_plot_ref.shape)
print('lw_rss', LW_RSS_short.shape)

delta_lf_short = to_plot_ref[:, :-1] - LW_RSS_short + 11 + 20 * np.
    log10(r.reshape(1, -1).transpose())

# pl tt(delta_lf_short, 'Delta LF', name_of_file='
    deltalf_method1_plt.pdf', short=True)

# Calculation of Sound Power Levels
sum_sound_pressure_short = db_to_pressure(to_plot_test[:, :-1] -
    to_plot_ref[:, :-1])
print('test unmodded', to_plot_test)
print('test', to_plot_test[:, :-1])
print('test pressure', db_to_pressure(to_plot_test[:,:-1]))

print('ref unmodded', to_plot_ref)
print('ref', to_plot_ref[:, :-1])
print('ref pressure', db_to_pressure(to_plot_ref[:,:-1]))



print('sum sound pressure', sum_sound_pressure_short)
# import sys
# sys.exit(1)

print('sum sound pressure', sum_sound_pressure_short)
print(sum_sound_pressure_short.shape)

sound_pressure_avg = pressure_to_db(np.average(db_to_pressure(
    sum_sound_pressure_short)))
print(sound_pressure_avg)

L_W_short = LW_RSS_short + 10 * np.log10((1 / mic_pos) *
    sound_pressure_avg)
print('lw', L_W_short)
# pl tt(np.array([L_W_short]), title='Sound Power Levels, L_W',
    name_of_file='lw_met1.pdf', short=True)

# Calculating A-weighted sound power
# pressure_vec_short = db_to_pressure(L_W_short + A_weighting[:-1])
# print('pressure ve c short',pressure_vec_short)
# total_pressure = np.sum(pressure_vec_short, axis=0)
# print('total pressure',total_pressure)

L_W_A = pressure_to_db(np.
    sum(db_to_pressure(L_W_short +A_weighting[-1])))
print('L_W_A', L_W_A)


```

```python

##########################################################
# Method 2
##########################################################

# Environment Correction

# Equivalent absorption area
alpha = 0.005
Surface = 2 * (6.042 * 5.174) + 2 * (5.174 * 8.501) * 2 * (8.501 *
    6.042)
Absorption_area = alpha * Surface
meas_length = 0.465
meas_width = 0.3
meas_height = 0.25
meas_surface = 2 * (meas_width * meas_height) + 2 * (meas_width *
    meas_length) + 2 * (meas_length * meas_height)
K_2A = 10 * np.log10(1 + 4 * (meas_surface) / Absorption_area)

# Calculating averaged A-weighted background noise

weighted_background = average_background + A_weighting
pl tt(np.array([weighted_background]), title ='A-weighted
    background noise', name_of_file ='background_method2_plt.pdf')

# Calculating average sound pressure levels per octave band
background_pressure = db_to_pressure(to_plot_back)
pres_avg = np.average(background_pressure, axis=0)

# From pressure to dB
average_background = pressure_to_db(pres_avg)
meas_pressure = db_to_pressure(to_plot_method2)
pres_avg_method2 = np.average(meas_pressure, axis = 0)
avg_spl_metod2 = pressure_to_db(pres_avg_method2)

# avg_spl_metod2 = pressure_to_db(np.average(db_to_pressure(
    to_plot_method2, axis=0)))


#averaged spl
pl tt(np.array([avg_spl_metod2]), title='Averaged A-weighted SPL',
     name_of_file='avg_spl_met2.pdf')
#Sound pressure level
# pl tt(to_plot_method2, title='Sound pressure level',
    name_of_file='spl_met2.pdf')

# Calculate backgroun noise correction
delta_LA = avg_spl_metod2 - average_background
print('delta la', delta_LA)
pl tt(np.array([delta_LA]), title='Delta LA', name_of_file='
    deltala_method2.pdf')

# Calculate A-weighted Sound Power Level
```

```
K_1A = 0
LW_2 = avg_spl_metod2 - K_1A - K_2A + 10 * np.log10(meas_surface)
LWA_2 = avg_spl_metod2 + A_weighting[-1] - K_1A - K_2A + 10 * np.
    log10(meas_surface)
LWA_2_tot = pressure_to_db(np. sum(db_to_pressure(LWA_2)))
LW_TOT = pressure_to_db(np. sum(db_to_pressure(LW_2)))
pl tt(np.array([LWA_2, LW_2], dtype=
    object), title='Sound Power Level L_W,A', name_of_file='
    lwa_method2_zweight.pdf', use_A_Weight=False)
#pl tt(np.array([LWA_2]), title='Sound Power Level L_W,A',
    name_of_file='lwa_method2_aweight.pdf', )

print('LWA2tot', LWA_2_tot)
print('LWtot', LW_TOT)
```

C Appendix: Python script for method 3

```
import matplotlib.pyplot as plt
import numpy as np

#octave_band_i =
    [10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27]#,28,29,30]

octave_band = [125,250,500,1000,2000,4000, 8000, 16000]
A_weighting = [-16.1, -8.6, -3.2, 0, 1.2, 1, -1.1, -4]
x_ticks_octaveband = ["125", "250", "500", "1k", "2k", "4k", "8k",
    "16k"]


def pl tt(array, title, name_of_file, use_A_Weight=True, short=
    False, ) ->
    object:
    fig, ax = plt.subplots()
    for i in  range(array.shape[0]):
        if not short:
            ax.semilogx(octave_band, array[i] + (A_weighting * np.
                array(use_A_Weight).astype(
                int)),
                        label=f"Mic pos {i + 1}")
        else:
            ax.semilogx(octave_band[:-1], array[i] + (A_weighting *
                 np.array(use_A_Weight).astype(
                int))[:-1],
                        label=f"Mic pos {i + 1}")
    # plot magic
    ax.grid(which="major")
    ax.grid(which="minor", linestyle=":")
    ax.set_xlabel("Frequency [Hz]")
    ax.set_ylabel("Amplitude [dB]")
    ax.set_title(title)
    if not short:
        ax.set_xticks(octave_band)
        ax.set_xticklabels(x_ticks_octaveband)
    else:
        ax.set_xticks(octave_band[:-1])
        ax.set_xticklabels(x_ticks_octaveband[:-1])

    #plt.legend(loc="lower right")
    plt.savefig(name_of_file)
    plt.show()

```

```
def db_to_pressure(measurements):
    return  10 ** (measurements / 10) #fjerna p0, se om d funker da


def pressure_to_db(measurements):
    return 10 * np.log10(measurements) #fjerna deling av
        measuremnts p  p0


LW = [81.8, 77.4, 77.6, 76.2, 78.4]

def get_octave_bands(filename):
    data = np.genfromtxt(filename, delimiter=';', skip_header=1,
        skip_footer=3)
    selected_data = data[10:, [2,4,5,7]]
    data_press = db_to_pressure(selected_data)
    print(" sorted pressure data", data_press.shape)

    d1 = data_press.shape[1]
    d3 = 3
    d2 = data_press.shape[0]//d3
    assert (data_press.shape[0]/3).is_integer() # Safety first
    octave_band_pressure = data_press.transpose().reshape(d1, d2,
        d3).
        sum(axis=2).transpose()
    octave_bands = pressure_to_db(octave_band_pressure)
    return octave_bands

octave_band_top = get_octave_bands('I_Top.csv')
octave_band_front = get_octave_bands('I_Front.csv')
octave_band_back = get_octave_bands('I_Back.csv')
octave_band_left = get_octave_bands('I_Left.csv')
octave_band_right = get_octave_bands('I_Right.csv')

combined = np.swapaxes(np.dstack((octave_band_top,octave_band_front
    ,octave_band_back, octave_band_left,octave_band_right)),0,1).
    transpose()
combined_pressure = db_to_pressure(combined)


L_W_pressure = np.average(combined_pressure[:,:,0],axis = 0)
L_W_db = pressure_to_db(L_W_pressure)
print(L_W_db)

L_W_tot = pressure_to_db(np. sum((L_W_pressure)))+A_weighting[-1]
print('LWTOT', L_W_tot)

L_I_pressure = np.average(combined_pressure[:,:,1], axis =0)
L_I_db = pressure_to_db(L_I_pressure)


LP_pressure = np.average(combined_pressure[:,:,2], axis = 0)
LP_db = pressure_to_db(LP_pressure)
print('LPdb', LP_db)
```

```python

FPI_pressure = np.average(combined_pressure[:,:,3], axis = 0)
FPI_db = pressure_to_db(FPI_pressure)
print('FPI', FPI_db)

#Checking that the dynamic capacity index is greater than FPI
L_d = 18.8 - 10
diff_ld_fpi = FPI_db-L_d
print('diff', diff_ld_fpi)

pl tt(np.array([L_W_db]), title='Sound Power Level', name_of_file=
    'power_met3.pdf')

# LI_avg = np.average(db_to_pressure(octave_band_back[:,1])+
    db_to_pressure(octave_band_right[:,1])+db_to_pressure(
    octave_band_left[:,1])+db_to_pressure(octave_band_front[:,1])+
    db_to_pressure(octave_band_top[:,1]))
# L_W = LI_avg + 10*np.log10(5)
# print(L_W)
# print(L_W-L_W_db)
```