

1 Introduction

The purpose of this laboratory exercise is

- Measure the impedance and Thiele-Small for the speakers that will be used in the loudspeaker design project.
- illustrate loudspeaker enclosure influence on both impedance and frequency response of subwoofer.

2 Theory

Every electrodynamic driver is a mechanical system with moving mass, damping and compliance in parallel. Such combination gives a resonating system. All important loudspeaker low frequency characteristics are defined by Thiele-Small parameters. The resonant frequency and some small-signal parameters can be derived from impedance curve. Following parameters of a woofer will be calculated in this work:

- F_s - driver resonant frequency. Found as a peak in impedance curve.
- Q_m - Mechanical Q of the driver at F_s

$$Q_M = \frac{f_0 \sqrt{r_c}}{f_2 - f_1} \quad (1)$$

where r_c is a ratio between DC resistance and impedance at F_s :

$$r_c = \frac{Z_{max}}{R_e} \quad (2)$$

Frequencies f_1 and f_2 are data points found measured data assuming

$$Z_r = Z_E(f_1) = Z_E(f_2) = \sqrt{R_e Z_{max}} \quad (3)$$

- Q_{es} - Electrical Q of the driver at F_s

$$Q_E = \frac{Q_M}{r_c} \quad (4)$$

- Q_T - total Q of the driver at F_s

$$Q_T = \frac{Q_M Q_E}{Q_E + Q_E} \quad (5)$$

- V_{as} - equivalent compliance volume. It is a volume that has the same compliance as driver suspension when acted upon by a piston of area same as driver diaphragm area S_d

$$V_{as} = V_c \left(\frac{F_c}{F_s} \right)^2 - 1 \quad (6)$$

where V_c - test box internal volume, F_c - resonant frequency in sealed box, F_s - resonant frequency in open air.

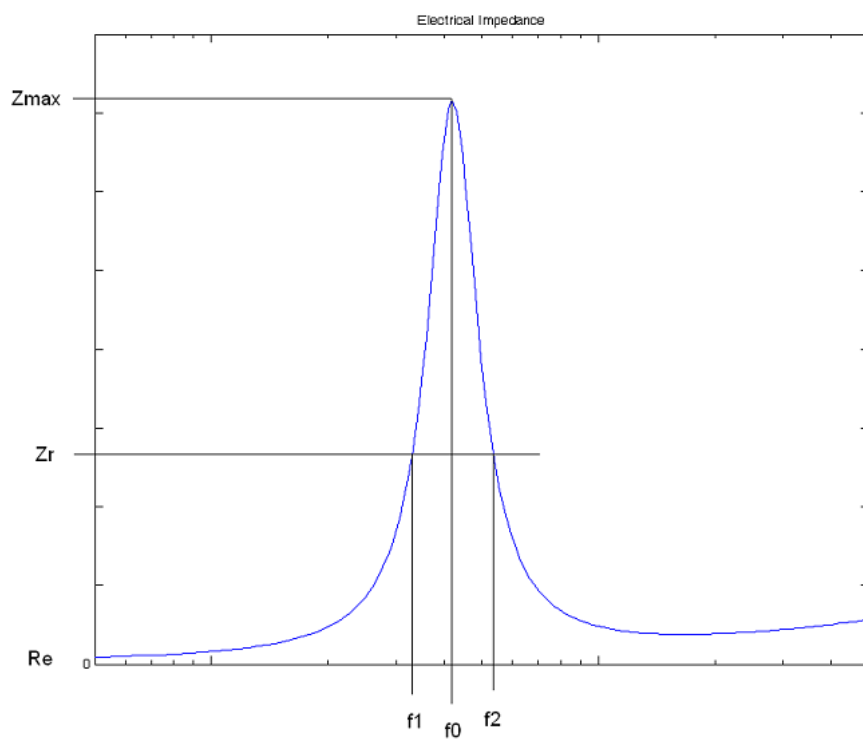


Figure 1: Loudspeaker electrical impedance

3 Methodology

3.1 DC resistance

DC resistance of a loudspeaker is measured using a ohmmeter. This parameter is not influenced by enclosure in any way.

3.2 Impedance

Impedance of a loudspeaker is measured using a simple setup (figure 2).

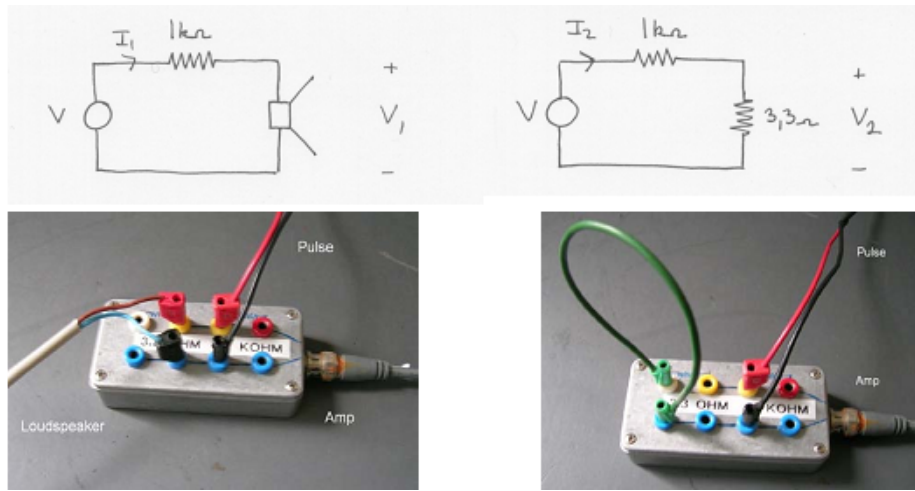


Figure 2: Impedance measurement setup

Speaker is connected to the amplifier in series with $1\text{ k}\Omega$ resistor to form a resistive divider. Another measurement is made with a $3,3\ \Omega$ resistor. Assuming current is the same in both cases, loudspeaker impedance is:

$$\overline{Z_{sp}} = 3,3\Omega \frac{\overline{V_{sp}}}{\overline{V_{ref}}} \quad (7)$$

where $\overline{V_{sp}}$ is complex voltage across speaker terminals and $\overline{V_{ref}}$ is complex voltage across reference resistor terminals.

Impedance was measured using 2 channel FFT module of the Pulse system. Such measurement provides possibility to check if the measurement was influenced by noise or distortion. Channel 1 was used to sample amplifier output and the channel 2 was used to sample the measured voltage drop across the load. Actual measurement is done by calculating transfer function from channel 1 to channel 2.

3.3 Near field frequency response

Frequency response measurement below 100 Hz is a complicated process because it is hard and very expensive to make a anechoic conditions in this frequency range. Near field pressure response at low frequency range is the same as far field frequency response only with a higher level. If microphone is positioned very close to the speaker, any recorded ambient reflections would have much lower amplitude than the direct signal and this way room contribution could be minimised. Same method can be used both for subwoofer and vent frequency response measurement. In order to have correct absolute value of the frequency response, a calibration should be done for every measured device independently, but this is out of the scope of this work thus vent and subwoofer frequency responses are not directly comparable and are given normalised.

4 Measurement results and analysis

4.1 DC resistance

DC resistance of the drives is given in table 1. Driver impedance close to 0 Hz should be the same. The first data points from appropriate impedance curves from figure 3 are also given for comparison in table 1. It can be seen that DC and low frequency measurement correspond with each other very well. This result also suggest that absolute value of loudspeaker impedance is measured and calculated correctly.

Speaker	DC resistance	Impedance	Frequency
Woofers	6,3 Ω	6,28 Ω	1 Hz
Midrange	6,0 Ω	6,12 Ω	2 Hz
Tweeter	5,5 Ω	5,40 Ω	4 Hz

Table 1: DC resistance

4.2 Impedance

Impedance of three drivers was measured and is shown in figure 3 for comparison. Woofer impedance was measured in various acoustical conditions:

- closed box (figure 5);
- open air (figure 5);
- short vent (figure 4);
- long vent (figure 4).

Figures show that every impedance curve has same pattern: there is a resonant peak due to mechanical resonance and impedance rise at high frequency due to voice coil inductance.

Figure 4 shows a woofer impedance curves with longer and shorter vents.

System	f_b
Short vent	29 Hz
Long vent	24 Hz

Table 2: Helmholtz frequencies of ported systems

There are two peaks instead of one in each curve. The dip between peaks represent the Helmholtz frequency f_b where resonance of cavity (enclosure volume) and neck (vent) occurs. Values are given in table 2. When using shorter vent, Helmholtz frequency increases with decreasing air mass in the vent as it should. Furthermore, when the two peaks are of the same value, system resonant frequency is approximately equal to the fundamental resonant frequency of the

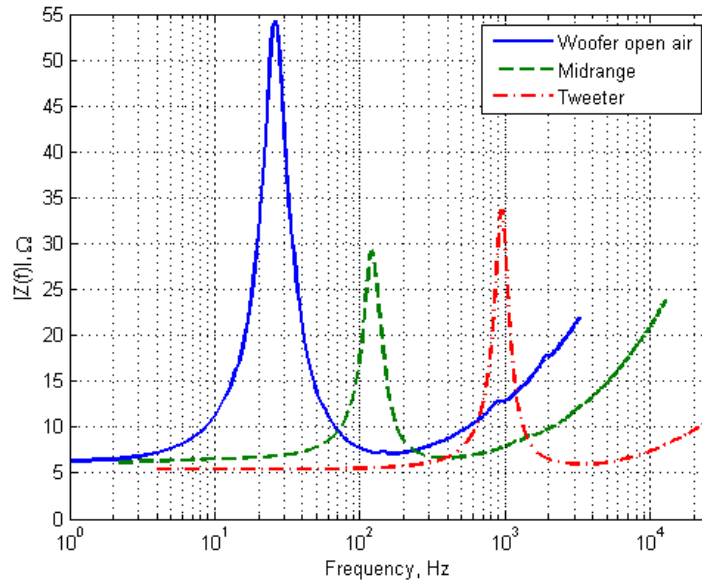


Figure 3: Loudspeaker impedance over frequency

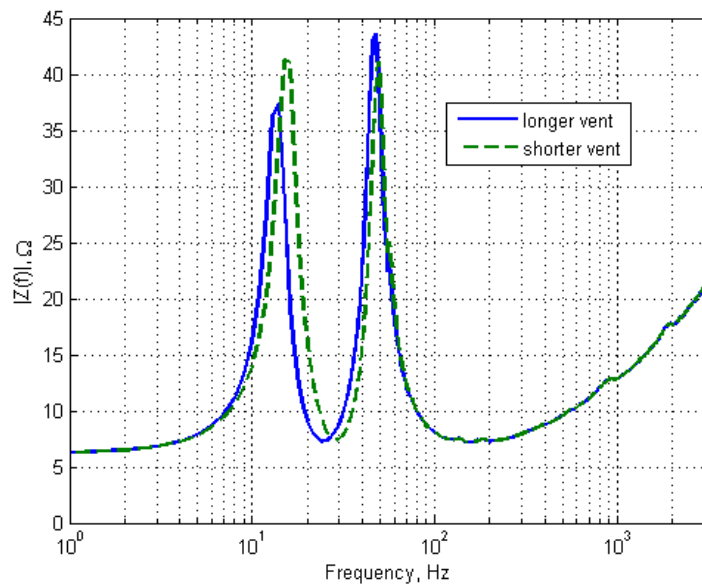


Figure 4: Woofer impedance over frequency with shorter and longer vents

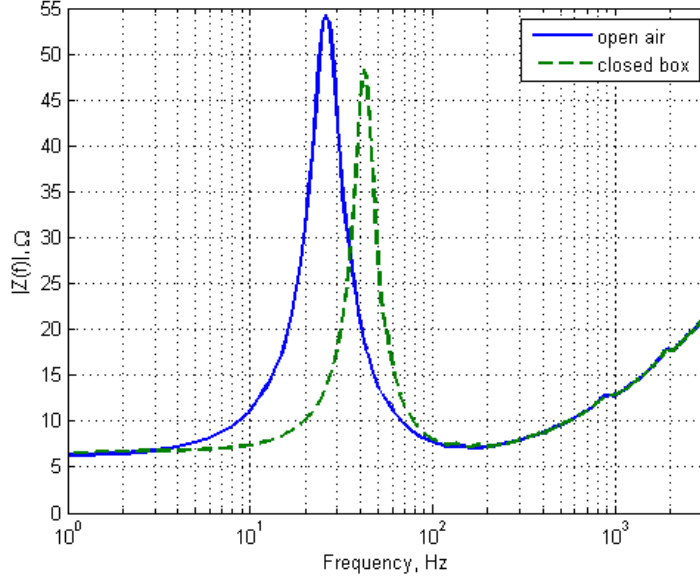


Figure 5: Woofer impedance over frequency

driver $f_b \simeq f_s$ [1, p. 131]. Measurement results agree with this as open field f_0 (table 3) is close to long vent system f_b (table 2).

Figure 5 shows open air and closed box impedance curves and table 3 shows measured and calculated as described in section 2. For vas calculation the internal volume of sealed box was estimated. The enclosure used during the measurement has total volume of $69,721^3$. Inside the enclosure there is an isolated midrange driver volume which occupies $4,081^3$ and must be subtracted to calculate effective volume. Volume occupied by woofer is assumed to be many times smaller and thus insignificant. Resultant effective volume is assumed to be $V_c = 65,641^3$. This gives $V_{as} = 170,31^3$

4.3 Near field frequency response

Measurement results are shown in figure 6. Measurement results are shown in figure 6. Both vent and woofer frequency responses were measured and normalised as absolute value is of no meaning. In theory, speaker output should drop in Helmholtz frequency neighbourhood. On the other hand, vent output should be maximum at this frequency. This is exactly what measurement results show. Furthermore, tables 2 and 4 show that Helmholtz frequency from impedance curve exactly matches one from vent amplitude curve.

Parameter	Open field	Closed box
Z_{max}	54,26 Ω	48,27 Ω
R_e	6,3 Ω	6,3 Ω
f_0	26 Hz	42 Hz
f_1	15 Hz	42 Hz
f_2	30 Hz	58 Hz
Z_r	18,5 Ω	17,4 Ω
R_c	8,61	7,66
Q_m	2,82	4,15
Q_e	0,37	0,62
Q_t	0,33	0,54
V_{as}	170,3 l ³	

Table 3: Driver small signal parameters

System	f_b
Short vent	29 Hz
Long vent	24 Hz

Table 4: Helmholtz frequencies of ported systems. Near field frequency response measurement.

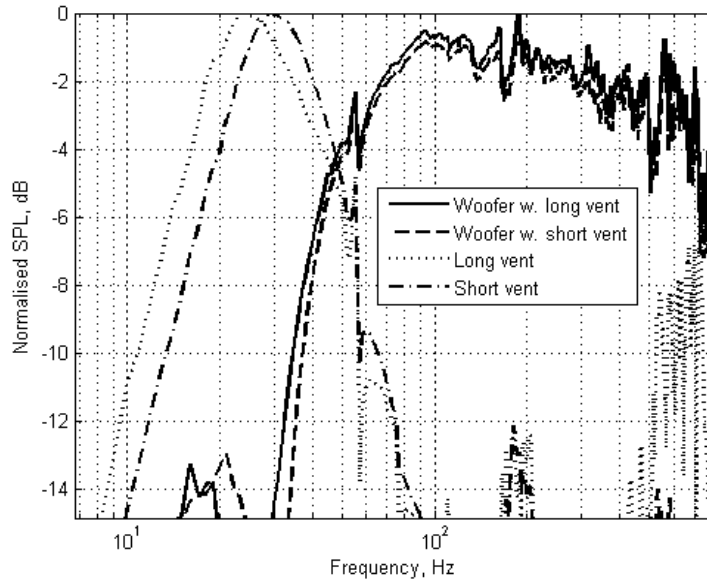


Figure 6: Woofer impedance over frequency

5 Enclosure design

With speaker data from section 4 a vented box enclosure was designed and tested using PSPICE.

The design process described in [1, p. 135] is as follows:

1. box quality factor is estimated to be $Q_t = 7$ as for a moderate size box
2. using figure 7 and having $Q_t = 0.33$ from table 3 values for $\alpha = 2.2$ and $h = 1.2$ are found. From these values box volume is $V_{AB} = V_{AS}/\alpha = 170,31 = 77,41$ and Helmholtz frequency is $f_b = hf_s = 1.2 \cdot 26 = 31,2$ Hz
3. Half-power frequency is estimated from 7 to be $f_t = qf_s = 1.45 \cdot 26$ Hz = 37,7 Hz
4. having a $S_d = 30$ cm² port chosen it's length is calculated from formula 8:
 $L_P = 11,4$ cm

$$L_P = \left(\frac{c}{2\pi f_b} \right)^2 \frac{S_P}{V_{AB}} - 1.463 \sqrt{\frac{S_P}{\pi}} \quad (8)$$

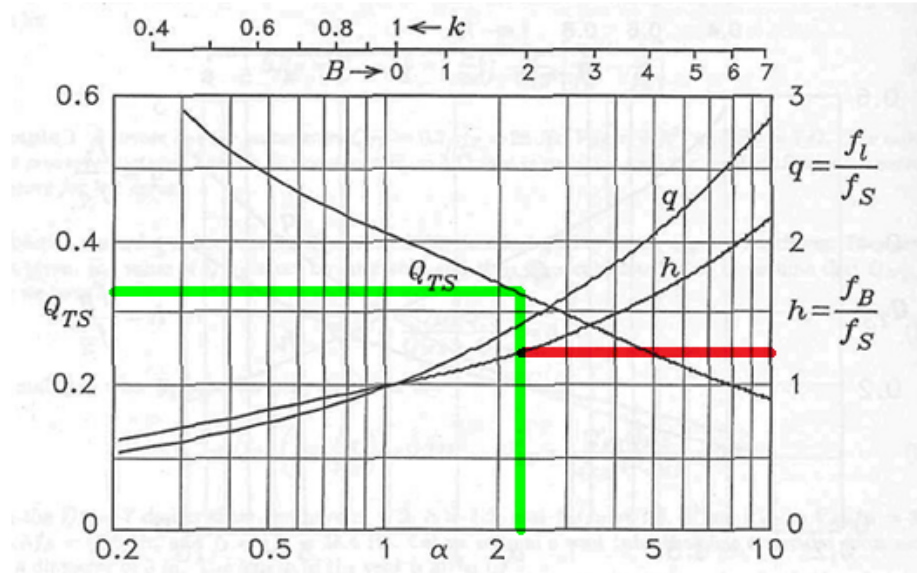


Figure 7: Vented-box alignment chart for $Q_L = 7$

The designed system can now be modelled using SPICE software. OrCad PSpice was used in this exercise. Equivalent circuit used is shown in figure 8. The left part represents electrical model consisting of electrical resistance. Voice coil inductance is emitted as not important in low frequency range. Middle part represents mechanical system of mass M_{MS} , damping R_{MS} and compliance

C_{MS} . The right part represents acoustical system in front and behind the woofer. Here M_{AB} is acoustical back load mass, M_{A1} is front load, M_{AP} is moving air mass in the port, C_{AB} is compliance of the enclosure and R_{AL} is acoustical resistance of the enclosure. Electrical and mechanical circuits are connected via sources with gain equal to Bl and mechanical and acoustical circuits are connected via sources with gain equal S_d . All necessary parameters are calculated as follows:

$$C_{ms} = \frac{V_{as}}{\rho_0 c^2 S_d^2} \quad (9)$$

$$R_{ms} = \frac{1}{2\pi f_s C_{ms} Q_m} \quad (10)$$

$$M_{ms} = \frac{1}{4\pi^2 f_s^2 C_{ms}} \quad (11)$$

$$B_l = \sqrt{\frac{2\pi f_s M_{ms} R_e}{Q_e}} \quad (12)$$

$$M_{ab} = \frac{2B\rho_0}{S_d} \quad (13)$$

$$M_{a1} = \frac{1.2266\rho_0}{S_d} \quad (14)$$

$$M_{ap} = \frac{\rho_0}{S_p} \left(L_p + 1.462\sqrt{\frac{S_p}{\pi}} \right) \quad (15)$$

$$C_{ab} = \frac{V_{ab}}{\rho_0 c^2} \quad (16)$$

$$R_{al} = \frac{Q_l}{\sqrt{\frac{C_{ab}}{M_{ap}}}} \quad (17)$$

Calculated values are given in figure 8

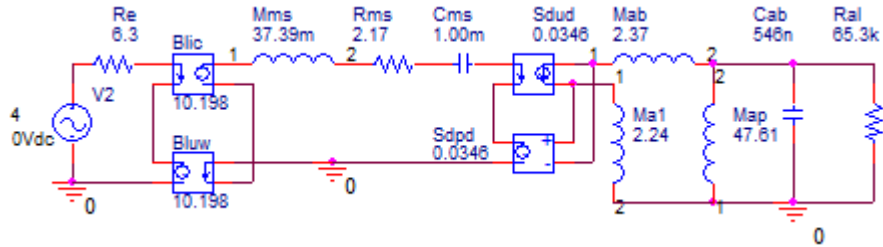


Figure 8: PSpice model of designed system

6 Conclusions

In conclusion

References

- [1] Jr. W. Marchal Leach. *Introduction to electroacoustics and amplifier design*. Kendall/Hunt Publishing company, 3 edition, 2033.