Chapter V-2 - Loudspeakers

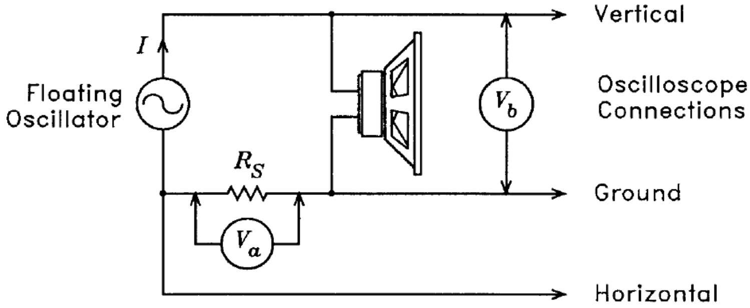
Laboratory of Signal Processing LTS2

Fall 2014

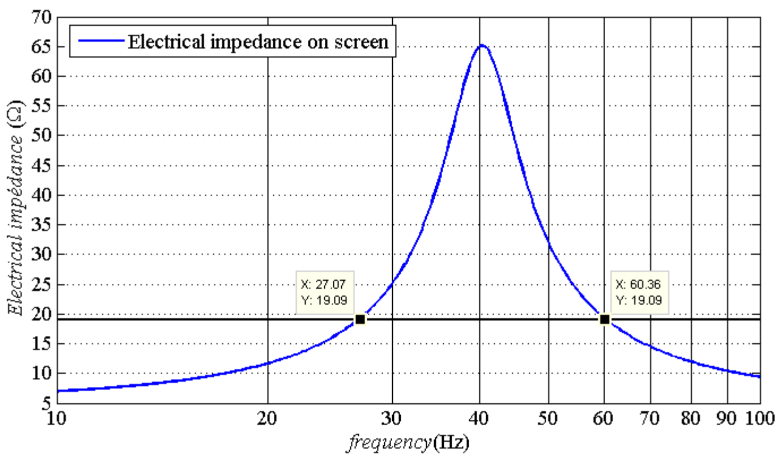
Exercise 1. Measurement of loudspeaker small-signal parameters (Thiele-Small)

Let's consider a loudspeaker of unknown small-signal parameters. We will consider in the following only the low-frequency parameters, with small signal excitation.

a . Loudspeaker on a screen
Let's first consider the loudspeaker mounted on a screen. We measure the input electrical impedance Z_{hp} at its terminals, as illustrated in the following measurement installation :



The input impedance is deduced from the known measurement resistance $R_s = 1\Omega$, as $\widehat{Z}_{hp} = R_s \dfrac{V_b}{V_a}$ and gives the following result :



- Derive the expression of the input electrical impedance Z_{hp} of the loudspeaker as a function of the DC electrical impedance R_e, the mechanical impedance Z_{ms} (R_{ms}, M_{ms}, C_{ms}) and the force factor $B\ell$.
- Remind the equivalent acoustical scheme of the wall-mounted loudspeaker, and then the equivalent electrical scheme.

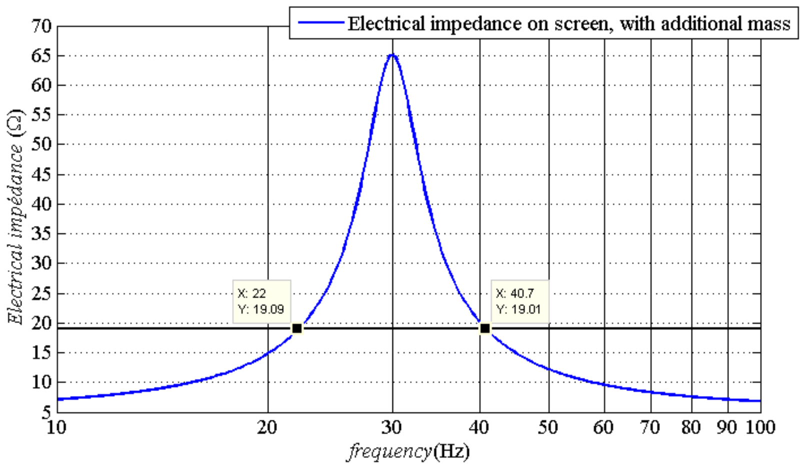
- Express the electrical input impedance as a function of the electrical resistances R_e and $R_s = \frac{(B\ell)^2}{R_{ms}}$, the resonance frequency $\omega_s = \frac{1}{\sqrt{M_{ms}C_{ms}}}$ and the mechanical quality factor $Q_{ms} = \frac{1}{\omega_s C_m s R_{ms}}$.

  The measurement of the DC asymptote of $\widehat{Z}_{hp}$ gives 5.6 Ω.
- What is the value of R_e ?

  We also observe that the maximum of $\widehat{Z}_{hp}$ occurs at f_s, with a value of 65 Ω.
- What is the expression of $\widehat{Z}_{hp}$ at its maximum ? Is it possible to retrieve a parameter from this measurement ?

  We now will derive the value of the mechanical, electrical and total quality factors Q_{ms}, Q_{es}, Q_{ts}. Let's denote $r_0 = \frac{\widehat{Z}_{hp,max}}{R_e}$, and introduce $r_1 = \sqrt{r_0}$. We observe on that the curve crosse the line $Z_{hp} = r_1 R_e$ at two frequencies, that we denote f_1 and f_2.
- Show that $\sqrt{f_1 f_2} = f_s$. Give the values of r_0 and r_1.
  The measurement gives $f_1 = 27Hz$ and $f_2 = 60.4Hz$.
- Determine f_s
- Show that $Q_{ms} = r_1 \frac{f_s}{f_2 - f_1}$
- Show that $Q_{es} = \frac{Q_{ms}}{r_0 - 1}$
- Give the values of Q_{ms}, Q_{es}, and Q_{ts}.

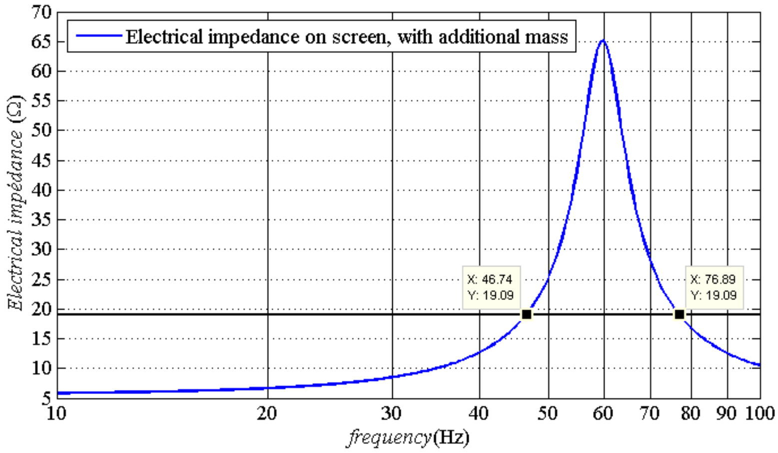
b . Loudspeaker with an additional mass Now we add a mass $M_{add} = 9$ g on the diaphragm, and repeat the same protocol. It gives the following measurement.



The measurement gives the two new frequencies $f_1' = 22Hz$ and $f_2' = 40.7Hz$.
- What is the value of the new resonance frequency f_s'
- Show that $\frac{f_s^2}{f_s'^2} = 1 + \frac{M_{add}}{M_{ms}}$
- Deduce M_{ms} and C_{ms}
- Can you deduce R_{ms} and $B\ell$ now ?

The remaining parameter is S_d. We should derive it from another measurement.

c . Loudspeaker with a closed-box cabinet We now remove the masse M_{add} and close the rear face of the loudspeaker with a sealed cabinet of volume $V_b = 20$ L. We do once again the same measurement, which gives :



We introduce the compliance factor $\alpha = \dfrac{C_{as}}{C_{ab}}$, where $C_{ab} = \dfrac{V_b}{\rho c^2}$

- Show that the new resonance frequency $f_c \approx \sqrt{1+\alpha} f_s$
- Show that the new electrical quality factor is $Q_{ec} \approx \sqrt{1+\alpha} Q_{es}$
- Express α as a function of f_c, $Q_e c$, f_s, $Q_e s$. Deduce the value of V_{as}
- Deduce the value of S_d

Numerical values : $\rho = 1.18$ kg.m^{-3}, $c = 343$ m.s^{-1}