EE1L1 IP-1 Loudspeaker Project 2025-2026

“The Booming Bass”

Overview:

What is sound?

Composition of a loudspeaker

- model of a cone loudspeaker-driver
- a bit of physics
- 1, 2, … multi driver loudspeaker system
- impedance model
- transfer function

Measurement set-up

- measuring the loudspeaker impedance

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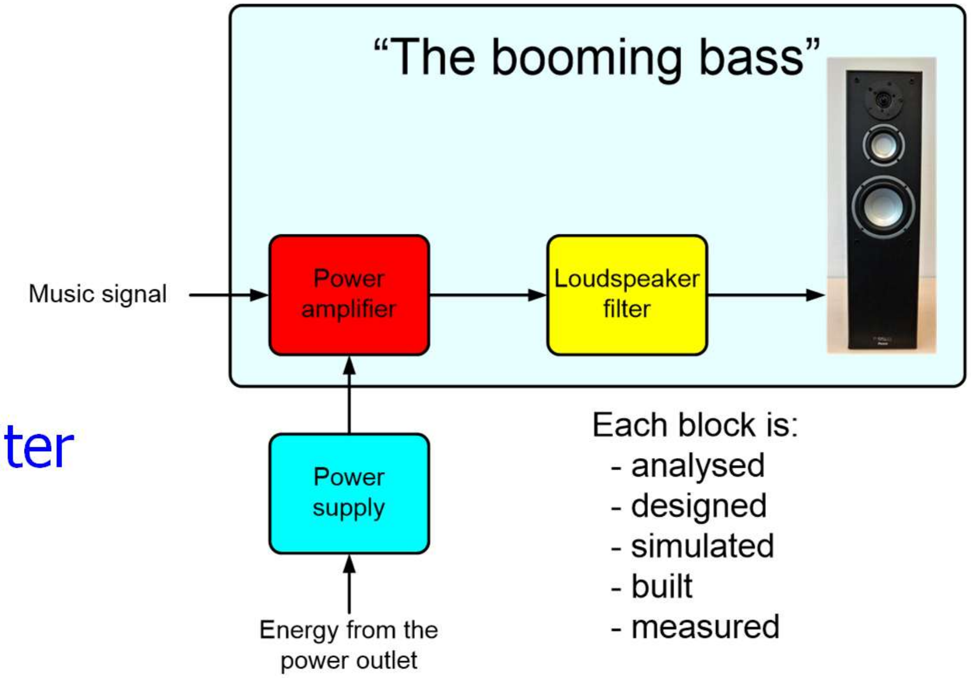
IP-1 Project: "The booming bass"

Analyzing, designing, simulating, building and testing of an audio system:

- Symmetric power supply
- Audio power amplifier
- Measuring of loudspeakers
- Passive 3-way loudspeaker filter
- "The booming bass"

  Linkwitz Transform



What is sound?

Sound is:
- a wave phenomenon,
- a pressure variation which propagates through the medium air with the speed of sound.

What is the speed of sound and what does it depend on?

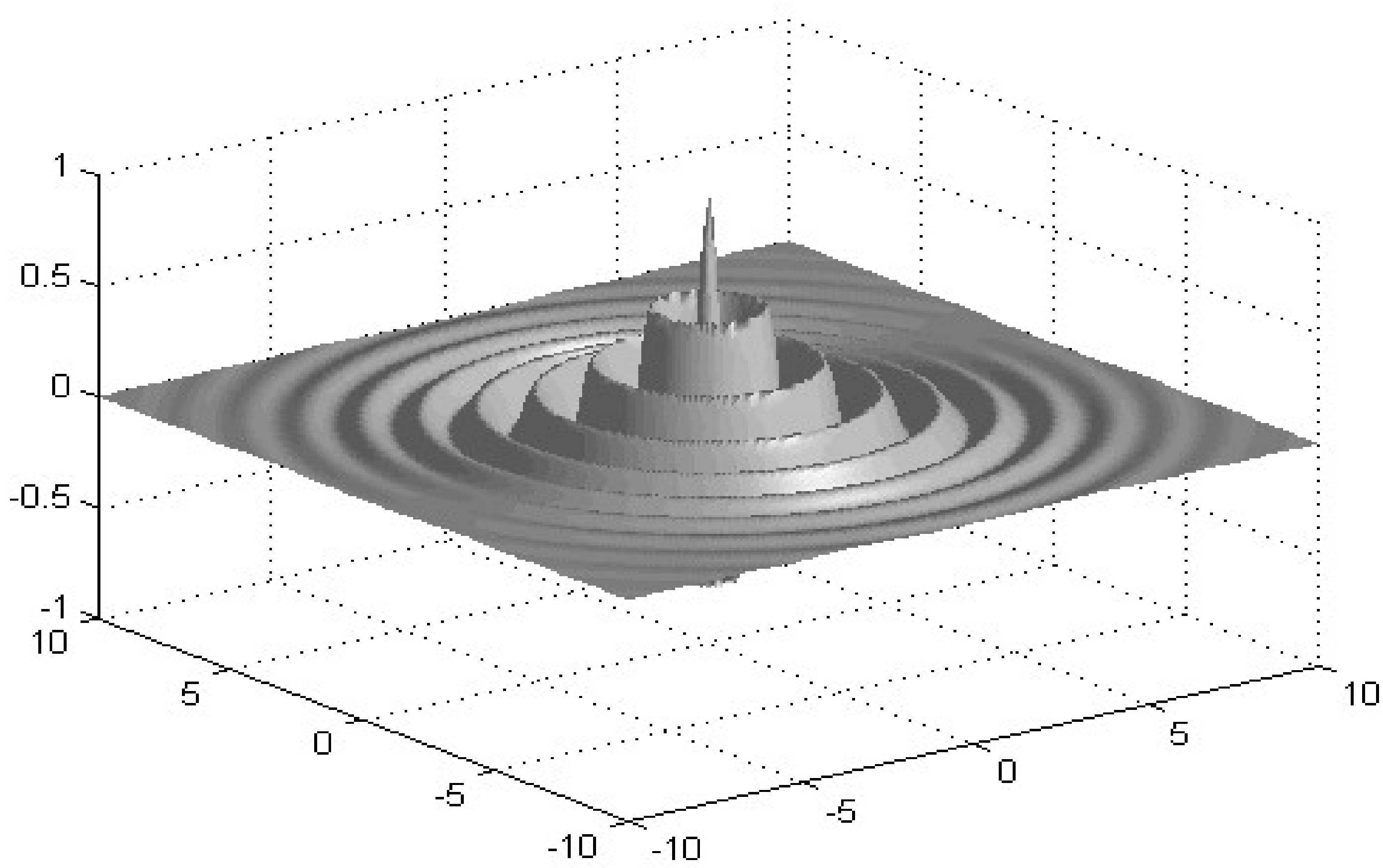
The speed of sound is $v \approx 345 \text{ m/s}$ and depends on temperature, humidity and air pressure.

What determines the pitch?

The pitch or frequency is determined by the number of (sine shaped) pressure variations per second (unit hertz [Hz]).

Wave propagation

Analogy of wave propagation on the water surface:



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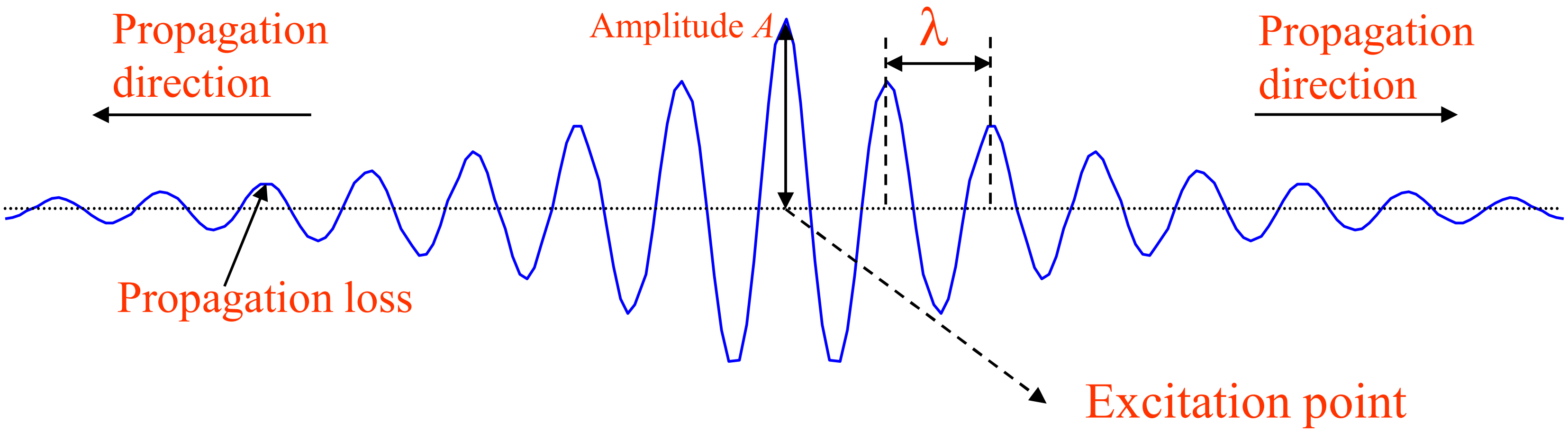
Characteristics of a sine sound wave



The wavelength λ is the distance traveled by the sound during one period of a sine shaped pressure variation.

Fundamental relation between frequency f [Hz], wavelength λ [m] and propagation speed v [m/s]:

$$v = f \cdot \lambda$$

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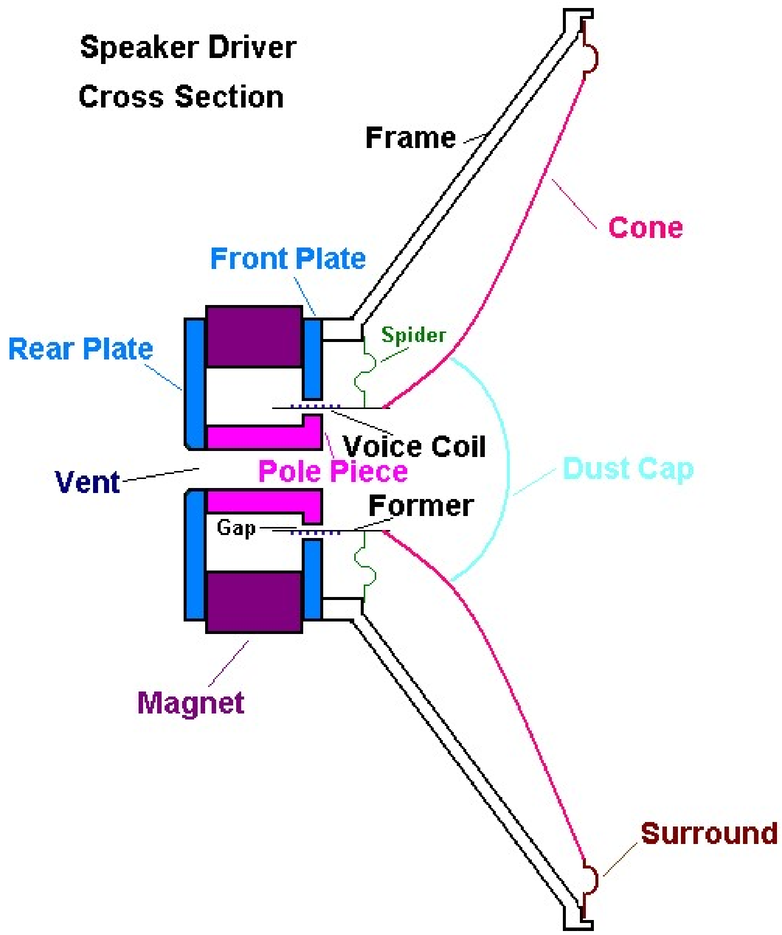
Loudspeaker-driver: electrical side

A loudspeaker-driver is an electro-mechanical transducer:
electrical energy is converted into mechanical (acoustical) energy.



Operation of a cone loudspeaker-driver:

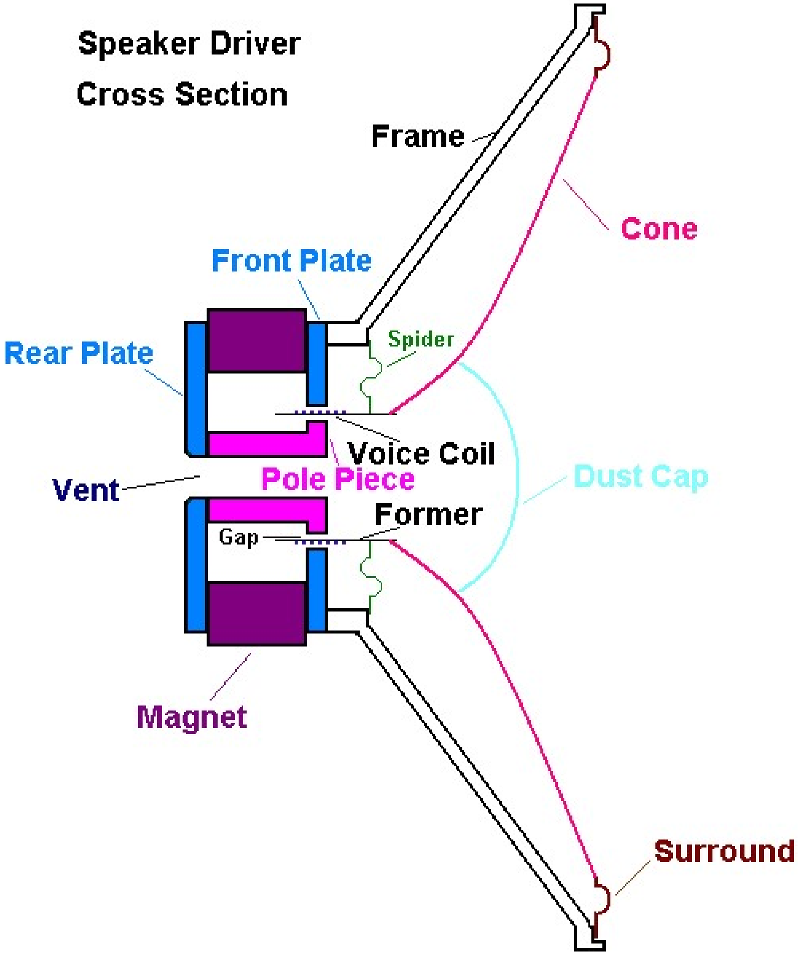
The current $\overrightarrow{I_{ls}}$ through the voice coil, perpendicular to the permanent magnetic field $\overrightarrow{B}$ in the gap, causes a force on the voice coil:

$$\overrightarrow{F_L} = l \cdot \overrightarrow{I_{ls}} \times \overrightarrow{B}$$

The Lorentz force.

We have a linear motor!

Loudspeaker-driver: mechanical side

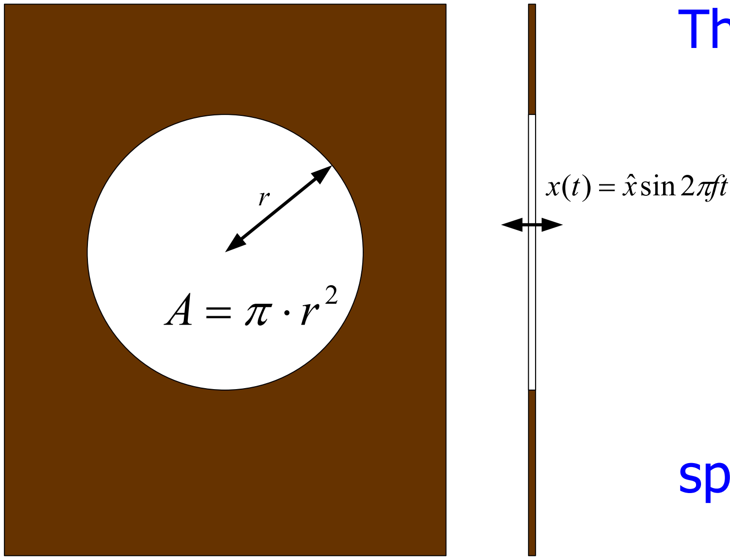


- cone movement ⇒ pressure variation ⇒ sound

- forward cone movement ⇒
  * increase of pressure at the front
  * decrease of pressure at the back
  ⇒ loudspeaker "should be" put in a box, otherwise acoustic short-circuit

- the cone is spring-load suspended to the spider and the surround at the outer edge:
  ⇒ a mass-spring system with an eigen- or resonance frequency

A bit of acoustic theory (1)



Sound pressure of a moving piston

The sound pressure at a distance d is: $p = \dfrac{\rho \cdot U \cdot f}{2 \cdot d}$

- p is sound pressure [N/m^2]
- ρ is air density: 1.19 kg/m^3
- $U = A \cdot v$ is volume flow rate [m^3/s]
- f is frequency [Hz]
- d is distance [m]

speed piston: $v(t) = \dfrac{dx(t)}{dt} = 2\pi f \cdot \hat{x} \cdot \cos 2\pi f t$

acceleration: $a(t) = \dfrac{dv(t)}{dt} = \dfrac{d^2 x(t)}{dt^2} = -(2\pi f)^2 \cdot \hat{x} \cdot \sin 2\pi f t$

Now it follows with $v_{rms} = \dfrac{\hat{v}}{\sqrt{2}} = 2\pi f \cdot x_{rms} = \dfrac{a_{rms}}{2\pi f}$ $\quad x_{rms} = \sqrt{\overline{x^2}} = \dfrac{\hat{x}}{\sqrt{2}}$

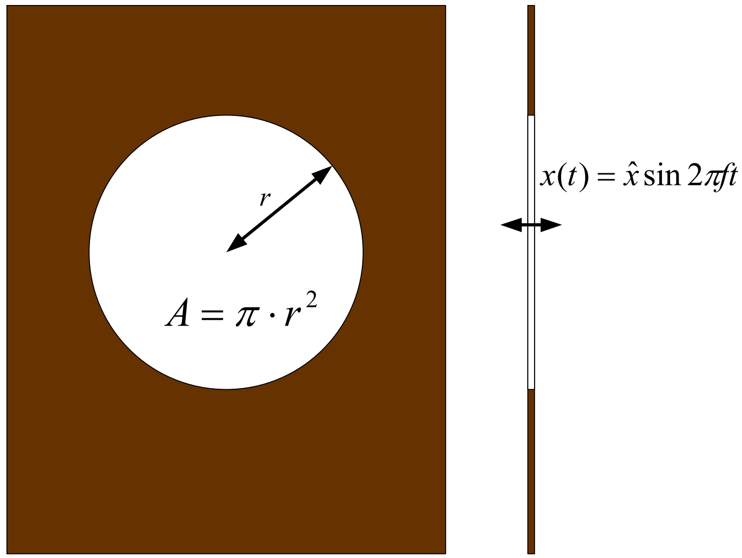
$= \text{effective value}$

and $p_{rms} = \dfrac{\rho \cdot U_{rms} \cdot f}{2 \cdot d} = \dfrac{\rho \cdot A \cdot v_{rms} \cdot f}{2 \cdot d}$

$= \dfrac{\rho \cdot A \cdot x_{rms} \cdot \pi \cdot f^2}{d} = \dfrac{\rho \cdot A \cdot a_{rms}}{4\pi \cdot d}$

$\Rightarrow p_{rms} \approx a_{rms} = 2\pi f \cdot v_{rms} = (2\pi f)^2 \cdot x_{rms}$

A bit of acoustic theory (2)



Sound pressure of a moving piston

Current v.s. acceleration v.s. sound pressure:

$$F_l = B \cdot I_{ls} \cdot l = m \cdot a \quad \text{dus} \quad a \approx I_{ls} \approx V_{ls}$$

- m = mass of the piston + voice coil [kg]
- B = magnetic flux density [T]
- I_{ls} = current through the voice coil [A]
- l = length of the voice coil wire [m]

Thus, the sound pressure, which is proportional to the acceleration a of the piston, is proportional to the voltage at the loudspeaker terminals. Since for constant sound pressure $p_{rms} \approx a_{rms}$, the volume flow rate will decrease with frequency as:

$$v_{rms} = \frac{a_{rms}}{2\pi f} \quad \text{and} \quad x_{rms} = \frac{a_{rms}}{(2\pi f)^2}$$

So, for a constant sound pressure at a 2x lower frequency, a 2x larger volume flow rate and a 4x larger cone displacement is required (for a fixed piston area A).

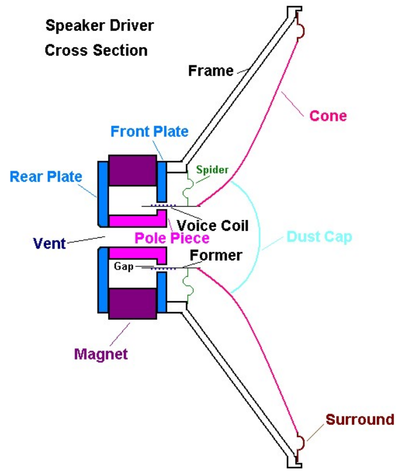
The sound intensity is $I_{ac} \approx p_{rms}^2$ [W/m²]

Sound Pressure Level is:

$$SPL = 10 \cdot \log_{10} \frac{p_{rms}^2}{p_{ref}^2} = 20 \cdot \log_{10} \frac{p_{rms}}{p_{ref}} \text{ [dB]}$$

where $p_{ref} = 2 \cdot 10^{-5}$ N/m²

Acoustic behavior loudspeaker



- to get the same sound level, lower frequencies require a larger volume flow rate (air displacement / s) than higher frequencies: lower frequencies => larger driver.

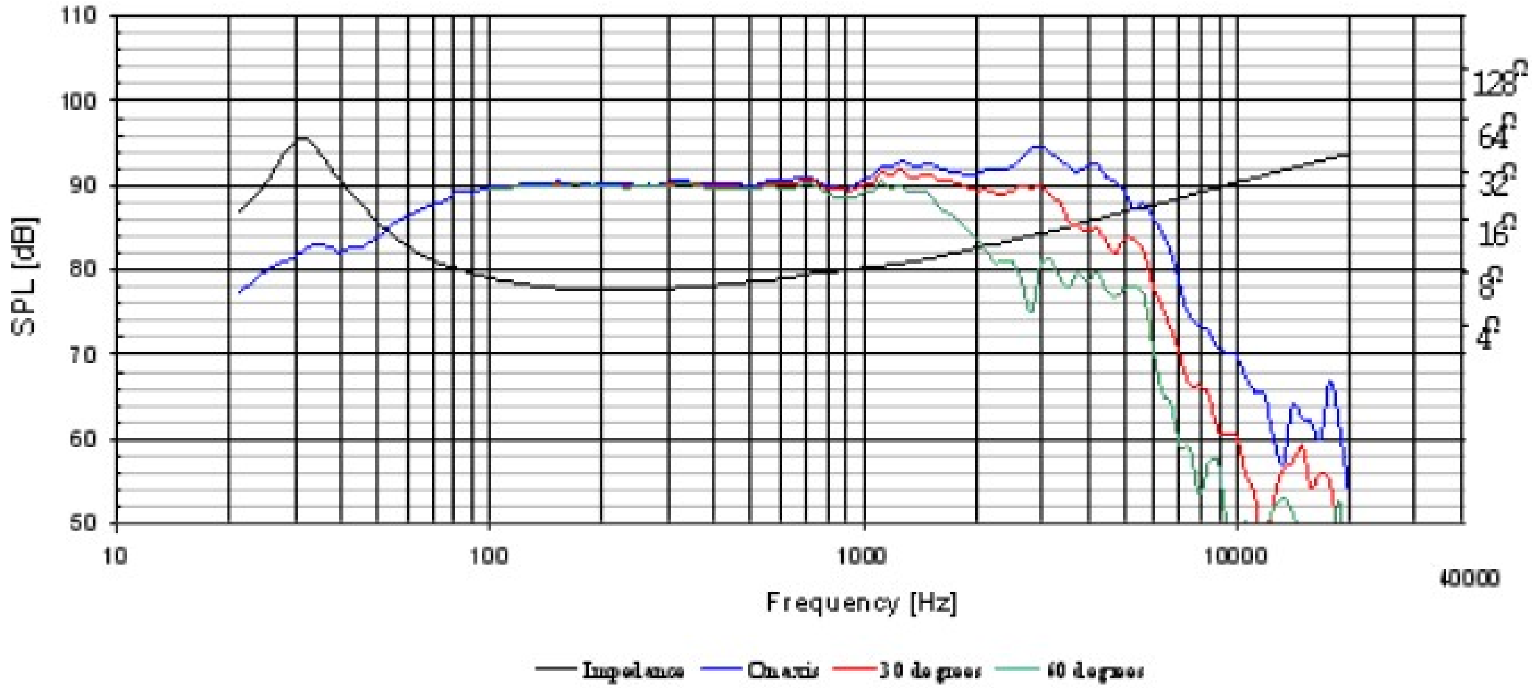
- a larger (and heavier) cone has several disadvantages when used at higher frequencies:
  * it becomes directive
  * internal damping of high frequencies
  * resonances of stiff cone materials (cone break up)

Loudspeaker-drivers are usually designed to reproduce a limited range of frequencies: $10 < f_{\max} / f_{\min} < 100$.

In a loudspeaker system, the frequency range 20 Hz – 20 kHz is therefore often reproduced by 2 or 3 loudspeaker-drivers, that each cover a part of the frequency range:
  * bass and treble: 2-way system
  * bass, mid and treble: 3-way system

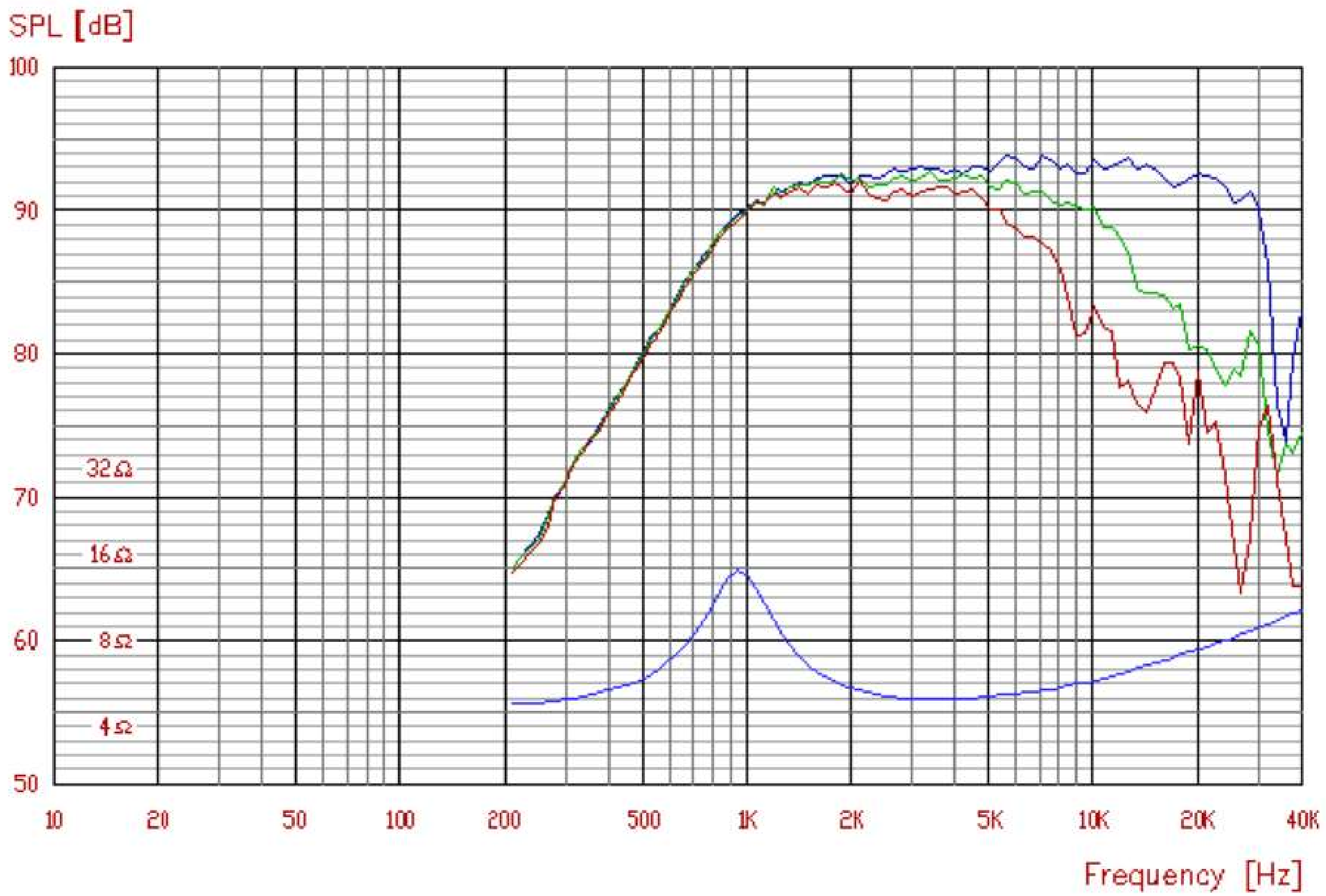
Frequency response of a loudspeaker

The acoustic frequency response or transfer function of a loudspeaker-driver shows the produced Sound Pressure Level (SPL) as a function of frequency at a distance of 1 m for a constant voltage of 2.83 V at the loudspeaker terminals (2.83 V at an 8Ω loudspeaker equals an input power of 1 Watt).



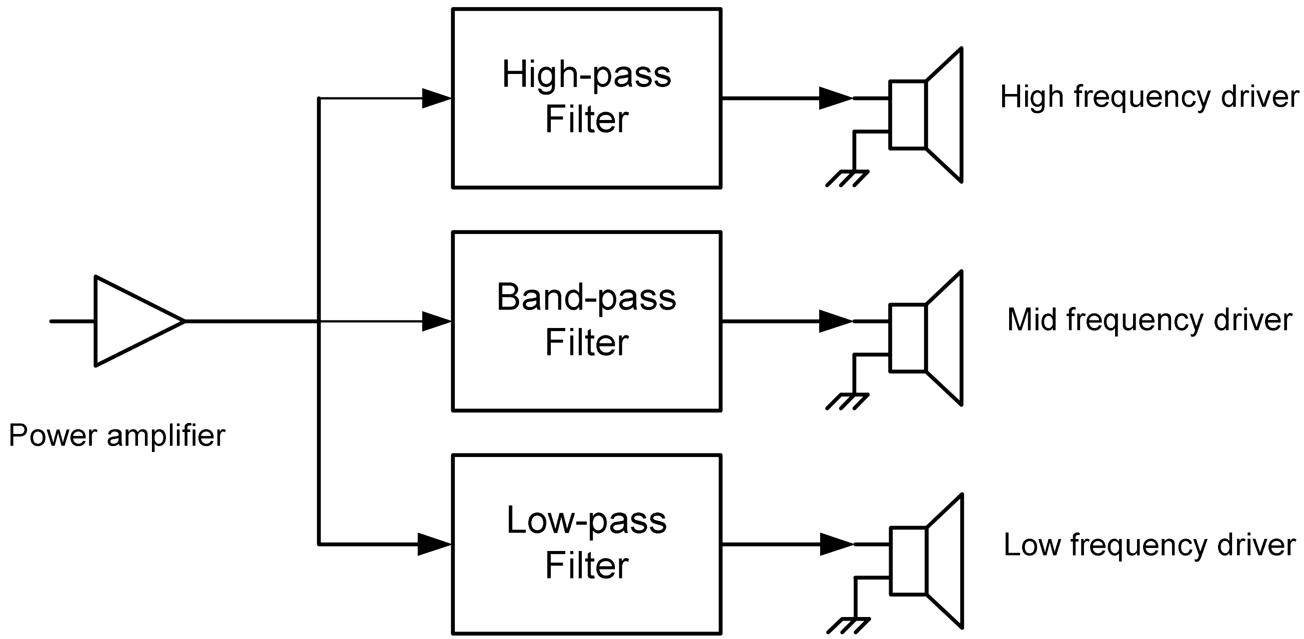
Impedance and sound pressure (at angels of 0, 30 and 60 degrees) as a function of frequency for a Peerless 830868 8 inch woofer.

Frequency response of a tweeter



Impedance and sound pressure (at angels of 0, 30 and 60 degrees)
as a function of frequency for a Vifa D27TG05-06 tweeter.

Loudspeaker system



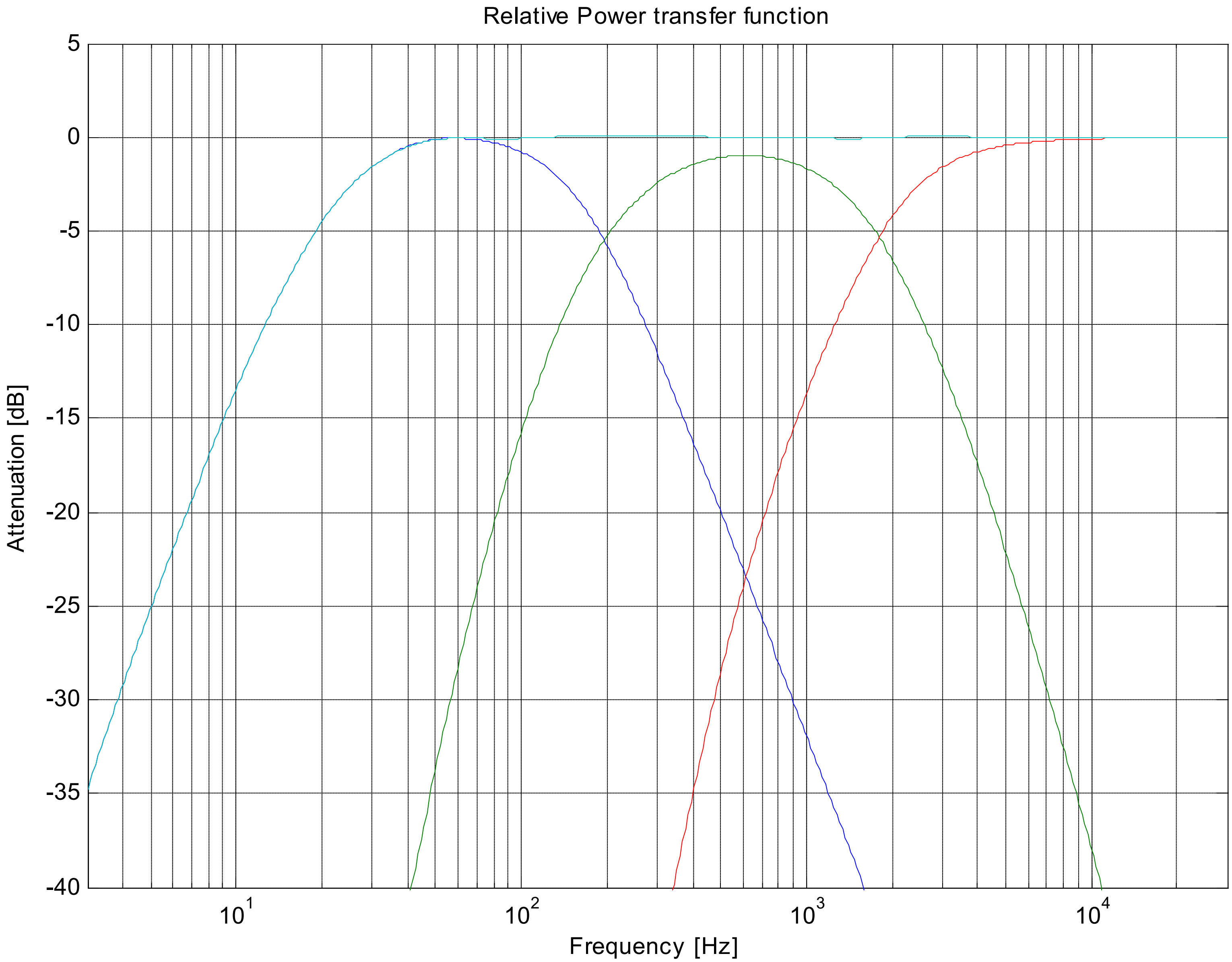
Symposium!!!

Loudspeaker: electro-mechanical transducer which converts an electric signal into an acoustic pressure wave

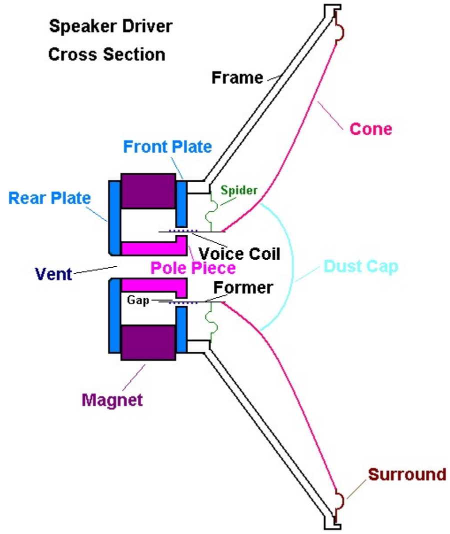
⇒ it is about the acoustic result: the bass, mid and treble should acoustically add up to a flat frequency response (transfer function) over the whole audio frequency range,

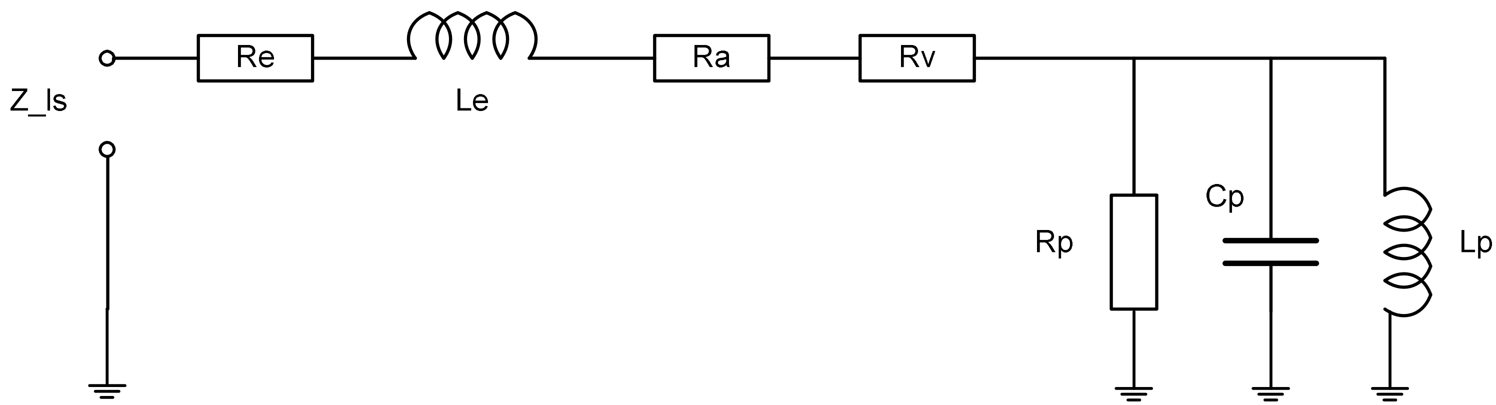
⇒ mutual influencing in the transition areas.

Combined frequency response



Electrical impedance of a loudspeaker (1)



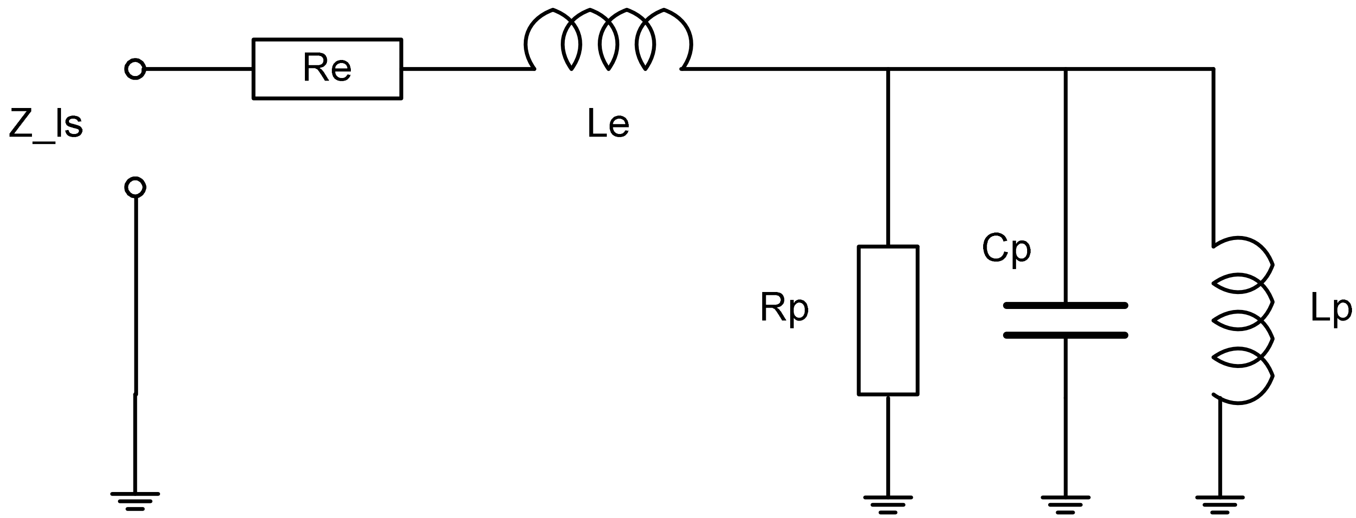


Impedance **model** of a loudspeaker-driver.

Here:

- R_e is the DC resistance of the voice coil
- L_e is the self-inductance of the voice coil
- R_a models the acoustic radiation resistance
- R_v models the mechanical loss resistance
- the parallel circuit of R_p, L_p and C_p, represents the electrical effects of the spring-load suspended cone (mass-spring system)

Electrical impedance of a loudspeaker (2)



Simplified impedance **model** of a loudspeaker-driver.

A practical loudspeaker has an acoustic efficiency in the order of 1%.

The mechanical power that is ”lost” due to friction is also of the same order:

$$\Rightarrow R_a, R_v \ll R_e$$

What happens with most of the electrical power we feed into a loudspeaker?

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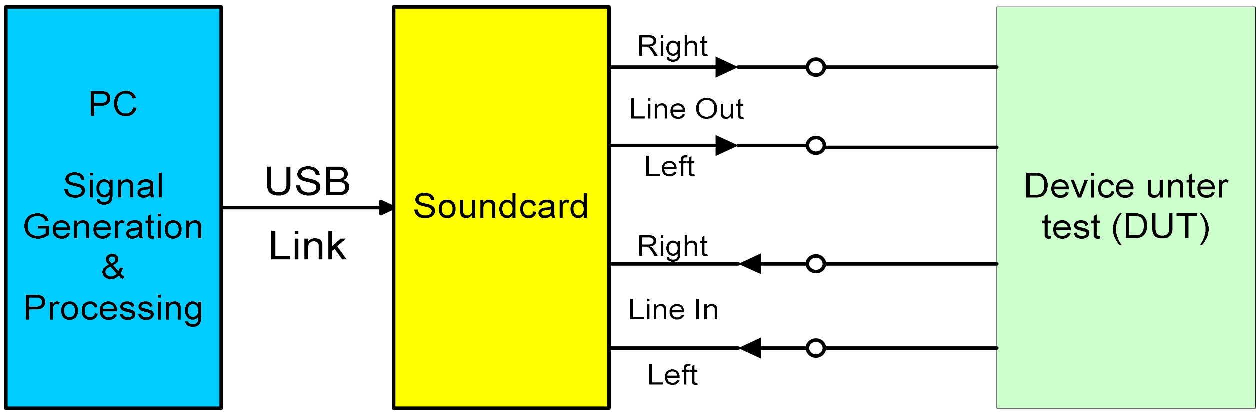
Basic measurement setup and measurement signals



- The measurement signals are generated in the PC and sent via the “Line Out” outputs of the soundcard to the “Device under test”.
- The output signals of the “DUT” are read via the “Line In” of the soundcard into the computer and processed to obtain the desired information.
- As measurement signal often a “white noise”-like is used, but in principle other measurement signals in the audio frequency band can be used as well.
  White noise: all frequencies are present and contain the same amount of power.
- Some measurements will be performed with the help of a teaching assistance.

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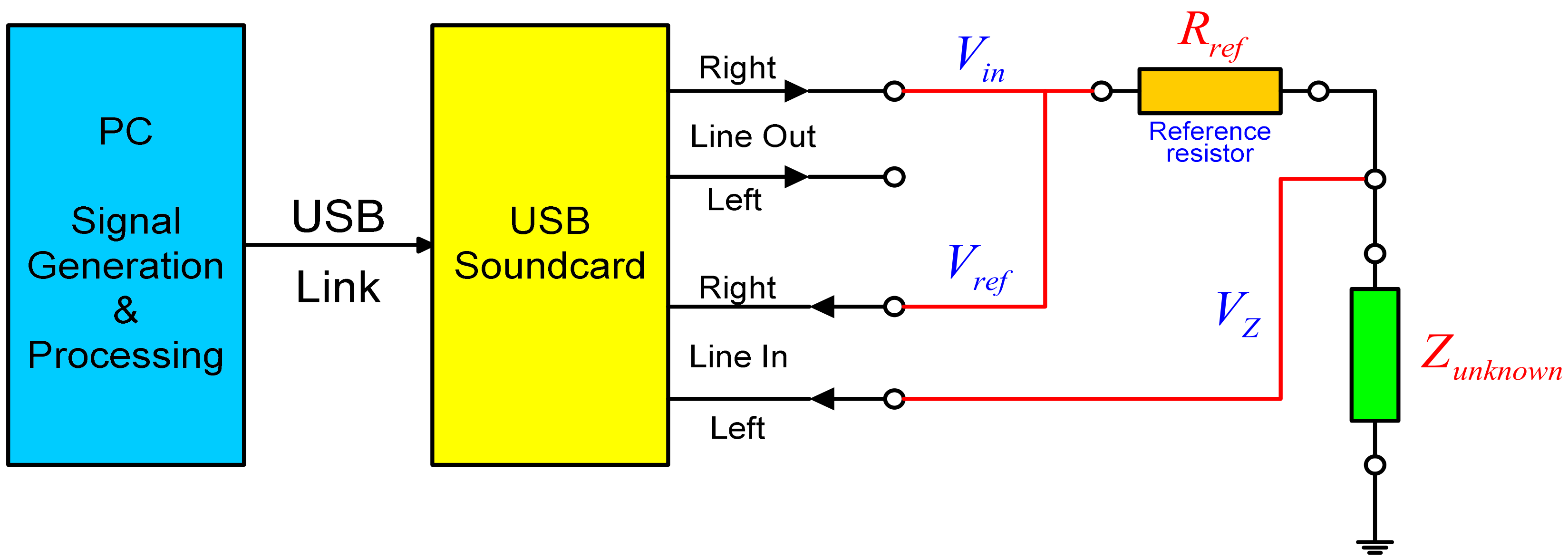
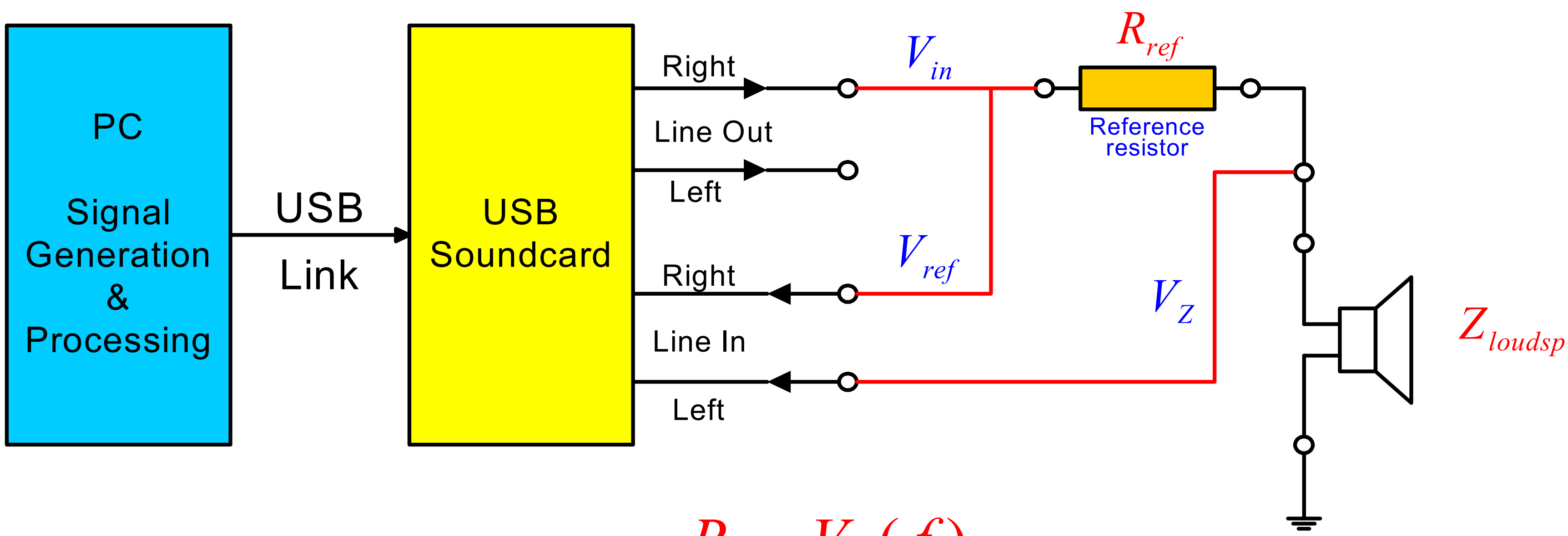
Measuring of an unknown impedance



$$Z_{unknown}(f) = \frac{R_{ref} \cdot V_Z(f)}{V_{ref}(f) - V_Z(f)}$$

- From the input voltage $V_{in}(f) = V_{ref}(f)$ and the measured voltage $V_Z(f)$ after voltage division across R_{ref} and $Z_{unknown}$, the absolute value and the phase of the unknown impedance is determined at all frequencies $f < 24\ \mathrm{kHz}$.

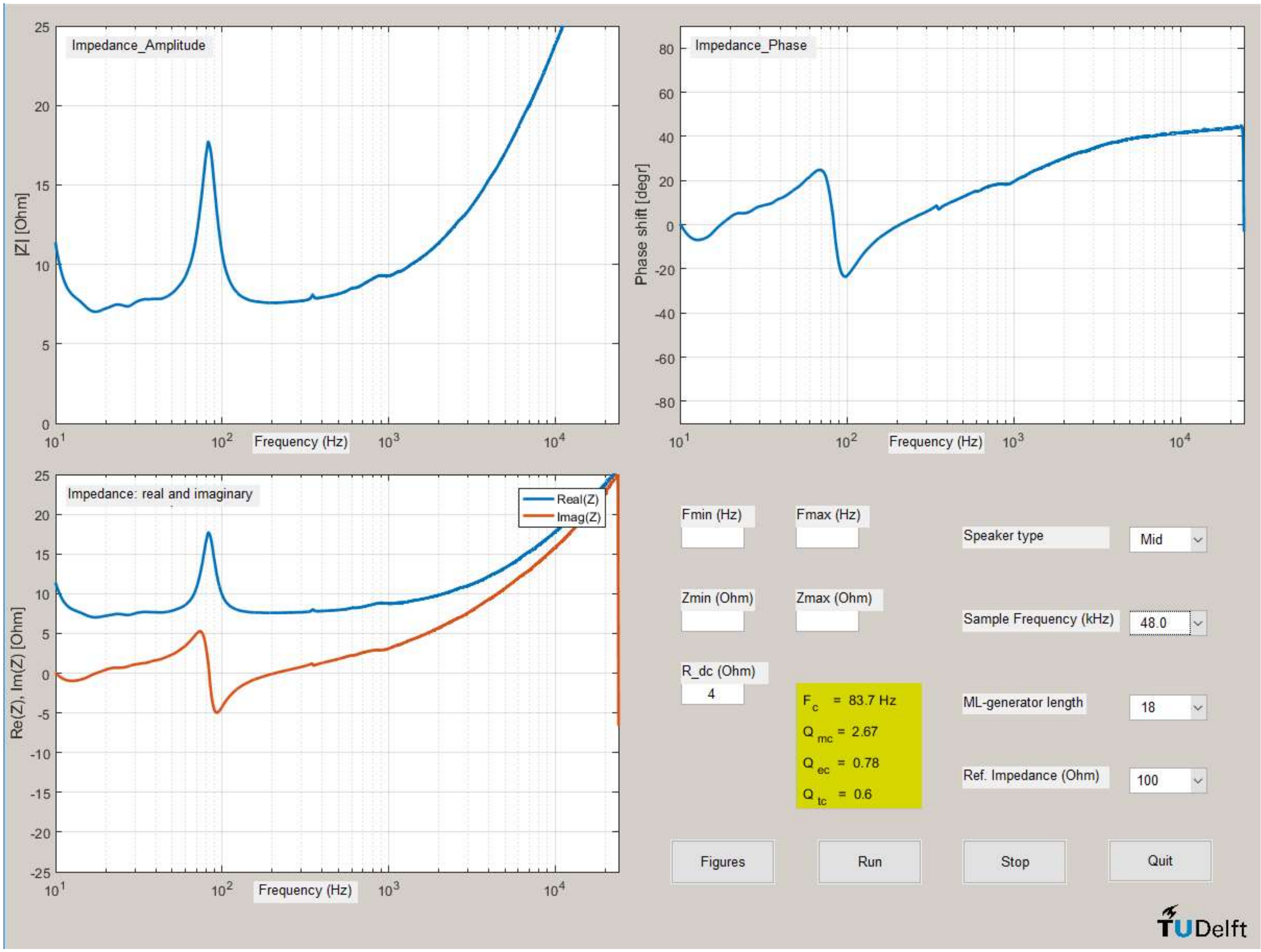
Measuring of loudspeaker parameters (1)



$$Z_{loudsp}(f) = \frac{R_{ref} \cdot V_Z(f)}{V_{ref}(f) - V_Z(f)}$$

- From the amplitude and phase of the loudspeaker impedance $Z_{loudsp}(f)$ a number of characteristic loudspeaker parameters can be derived: the resonance frequency f_c, the mechanical, electrical and total quality factors: Q_{mc}, Q_{ec} and Q_{tc} , and the Ohmic resistance R_e.
- This method can also be applied when the loudspeaker is mounted in a box (this will show slightly altered parameters compared to the unmounted loudspeaker).

Measuring of loudspeaker parameters (2)



R_dc: enter the resistance measured with an Ohm-meter.

Speaker type: select the type of loudspeaker to be measured: Bass, Mid, High.

ML-generator length: determines the duration of the measurement signal.

Ref. Impedance: choose the reference resistance equal to the one used in the measurement box (100 Ω).

Fmin, Fmax: herewith you set the minimum and maximum frequencies of the figure axes.

Zmin, Zmax: the same for the absolute value of the impedance.

Figures: Generates the figures. You will also obtain the data in Excel format to generate the figures for your logbook or report.

Run: start measurement.

Stop: user initiated stop of the measurement.

Where does this journey end ... ?

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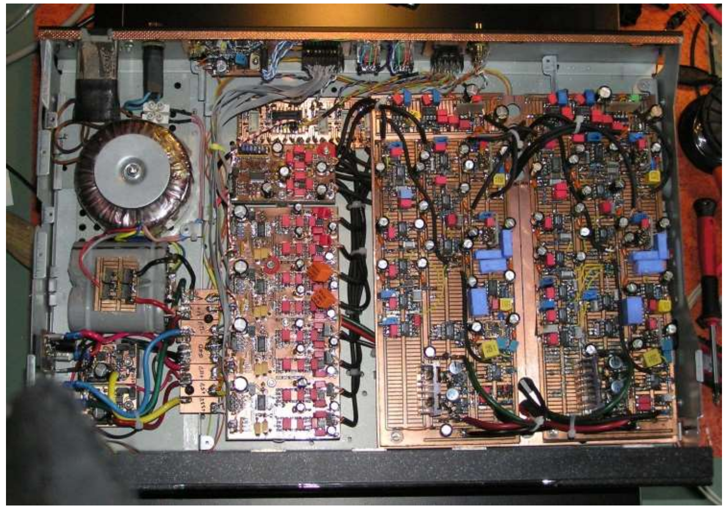
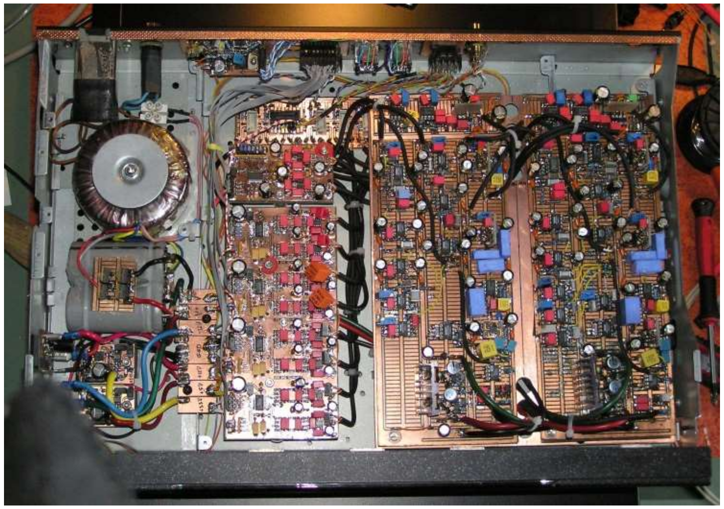
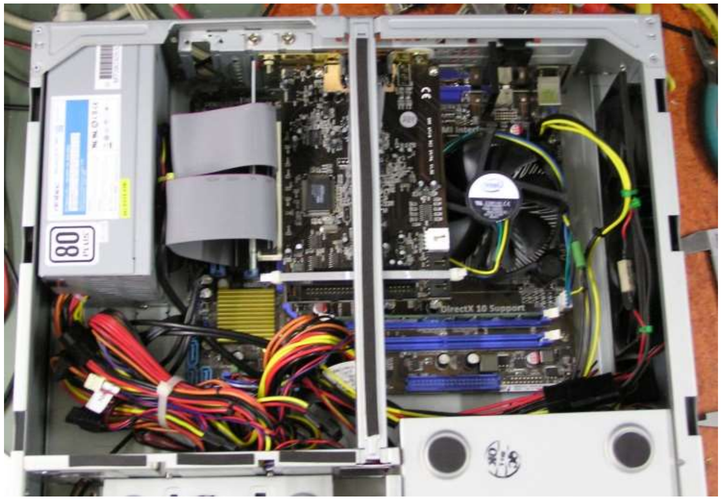
Or … ?



Or … ?





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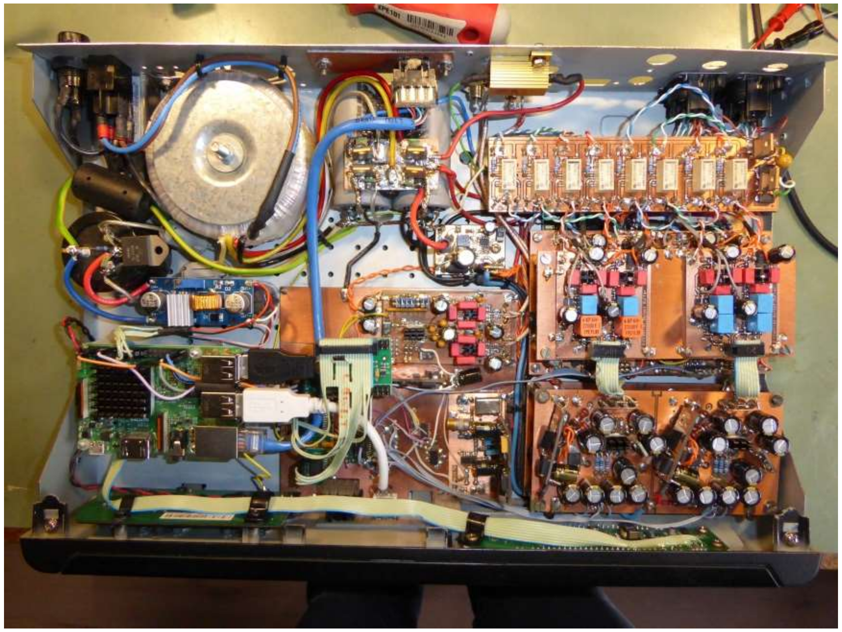
Or ... ?



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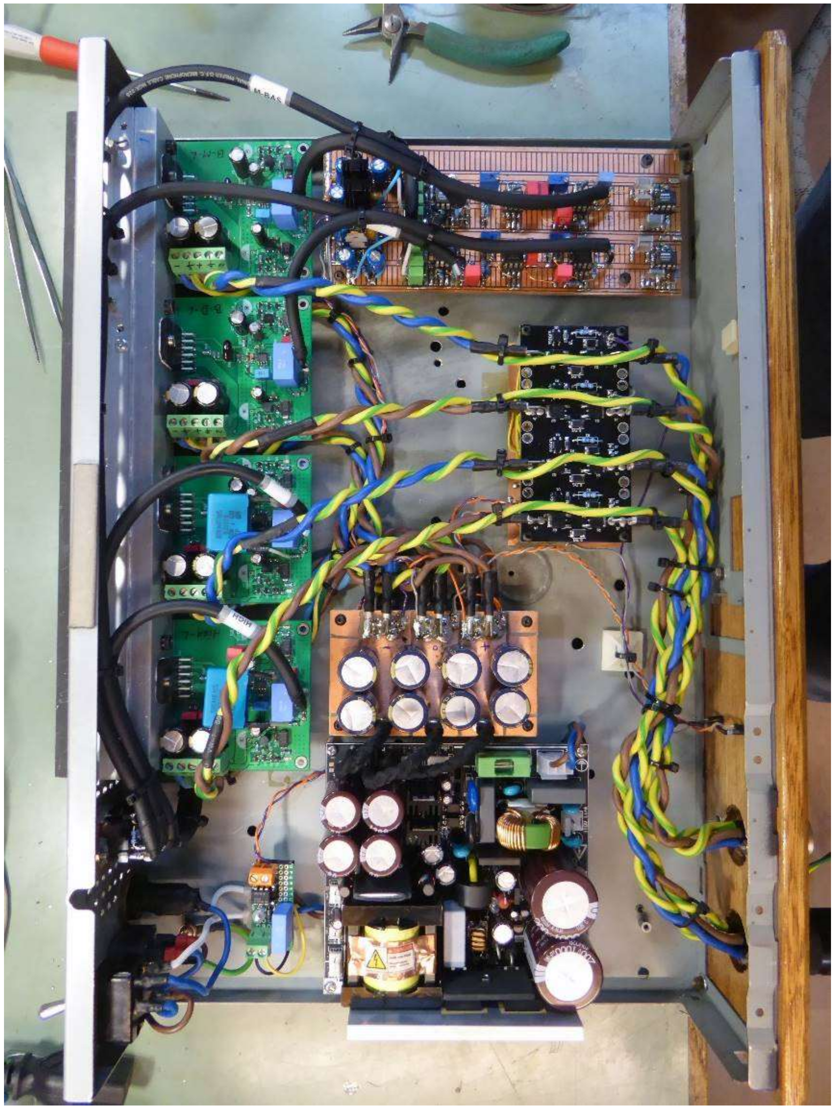
Or … ?


Or … ?