PROBLEM N°7

Static speaker

Team Ecole polytechnique

IPT problem n°7: Static Speaker

Build an audio speaker ***without any moving part****. Discuss* ***the maximum bandwidth****,* ***signal-to-noise ratio*** *and* ***power efficiency*** *achieved with your design. Is it possible to modify your device to* ***use it as a microphone*** *?*

IPT problem n°7: Static Speaker

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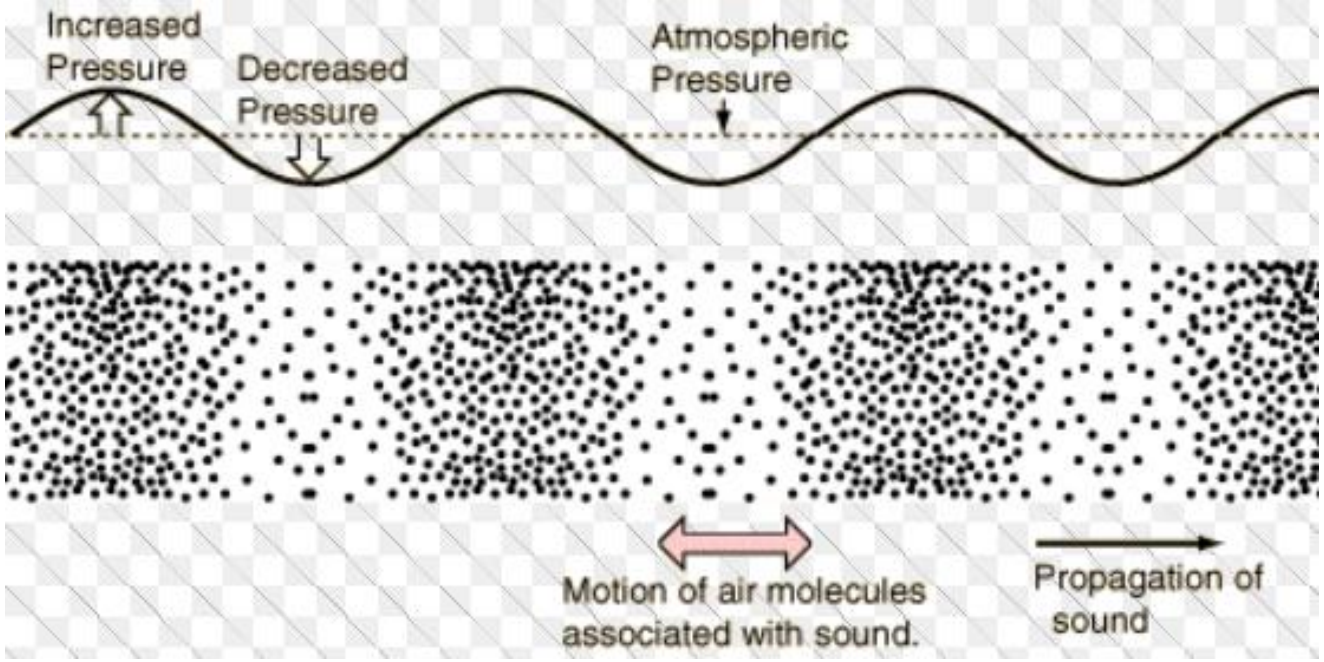
What is sound ?

- Trigger a pressure wave : $\frac{1}{c_0^2}\frac{\partial^2 p}{\partial^2 t} - \Delta_x p = source\ term$ p the pressure, c_0 the velocity of sound in air



http://hyperphysics.phy-astr.gsu.edu

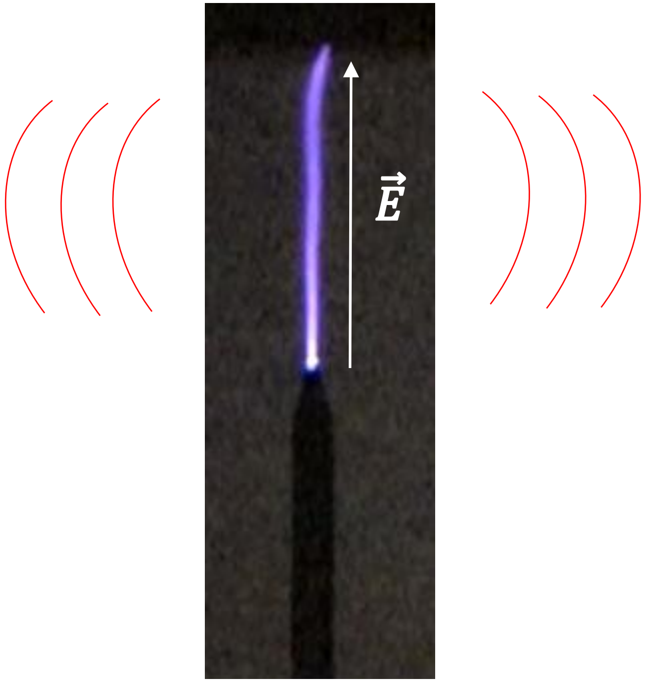
- Air particules must move.
- Objective: no mechanical part moving.

Sound out of heat?

- A way to produce a variation of **pressure** :
dilatation & contraction by quick variation of **temperature !**

- Arc = plasma = very quick heat transfert

- Electrical **modulation** of the discharge : Sound !



Sound emission in plasma

- A pressure wave : $$\frac{1}{c_0^2}\frac{\partial^2 p}{\partial^2 t} - \Delta_x p = \frac{\gamma-1}{c_0^2}\frac{\partial H}{\partial t} + \vec{\nabla}.\vec{F}$$

p the pressure, c_0 the velocity of sound in air, γ the Laplace coefficient of air

- 2 source terms
  - **Heat transfer** (Joule effect)

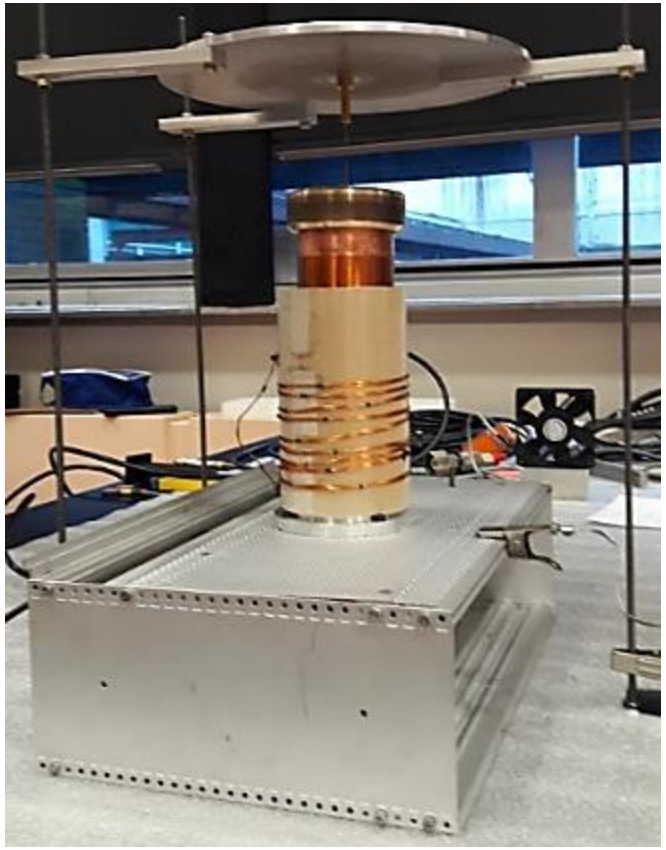
$$H = C.\vec{J}\vec{E}$$
$$< H > = H_0\left(1 + \frac{m_E + m_I}{2} + (m_E + m_I)\cos(\omega t) + m_E m_I \cos(2\omega t)\right)$$

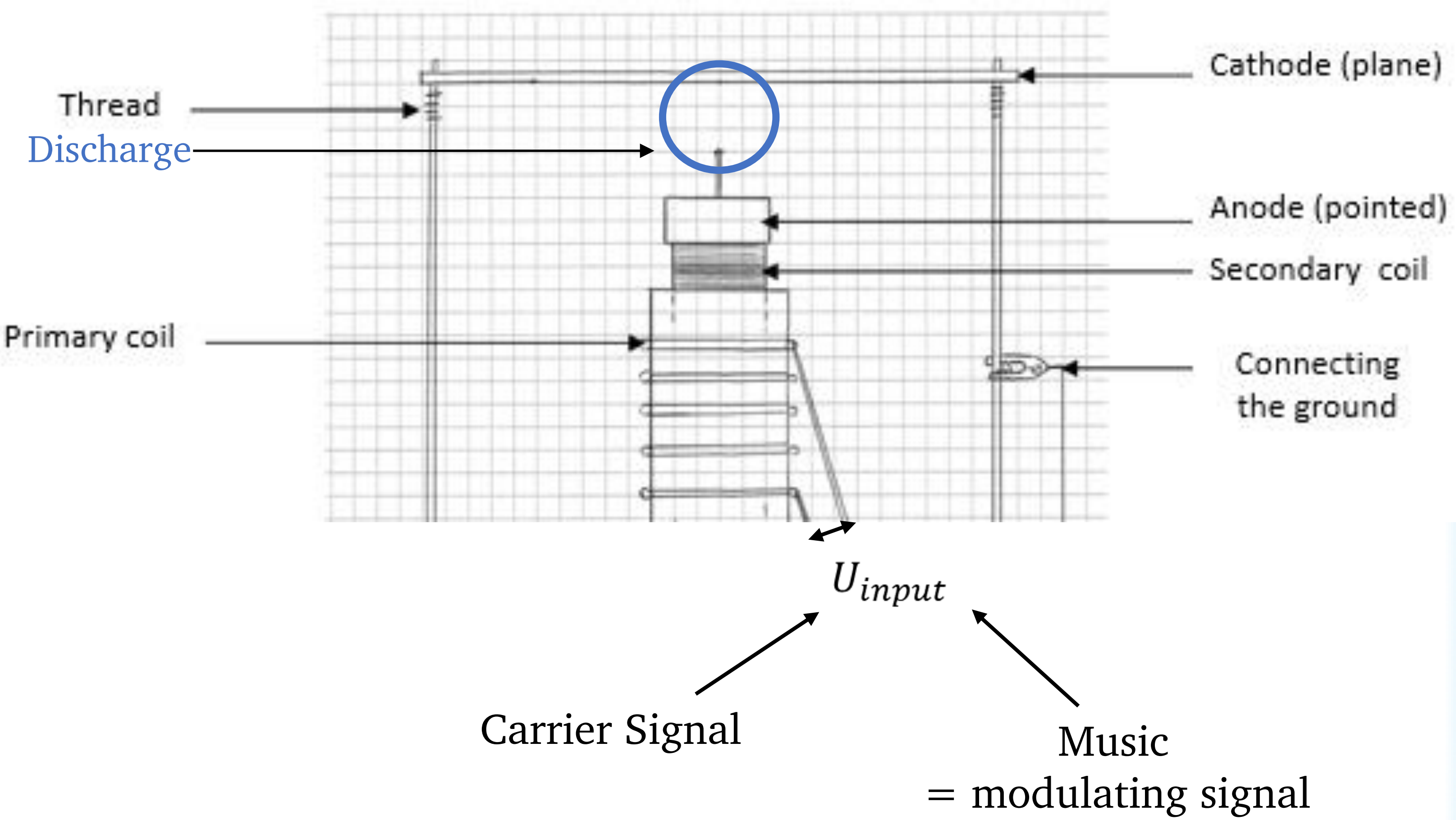
  - **Momentum transfer** (Ions motion)

$$\vec{F} = q_i N_i E$$
$$< \vec{F} > = \overrightarrow{F_0}\left(1 + \frac{m_E^2}{2} + 2m_E \cos(\omega t) + m_E^2 \cos(2\omega t)\right)$$

Building a Plasma Speaker

Arcing in air => 30 kV/cm => a transformer





Plasma Speaker : it is possible !

IPT problem n°7: Static Speaker

*Build an audio speaker **without any moving part.***

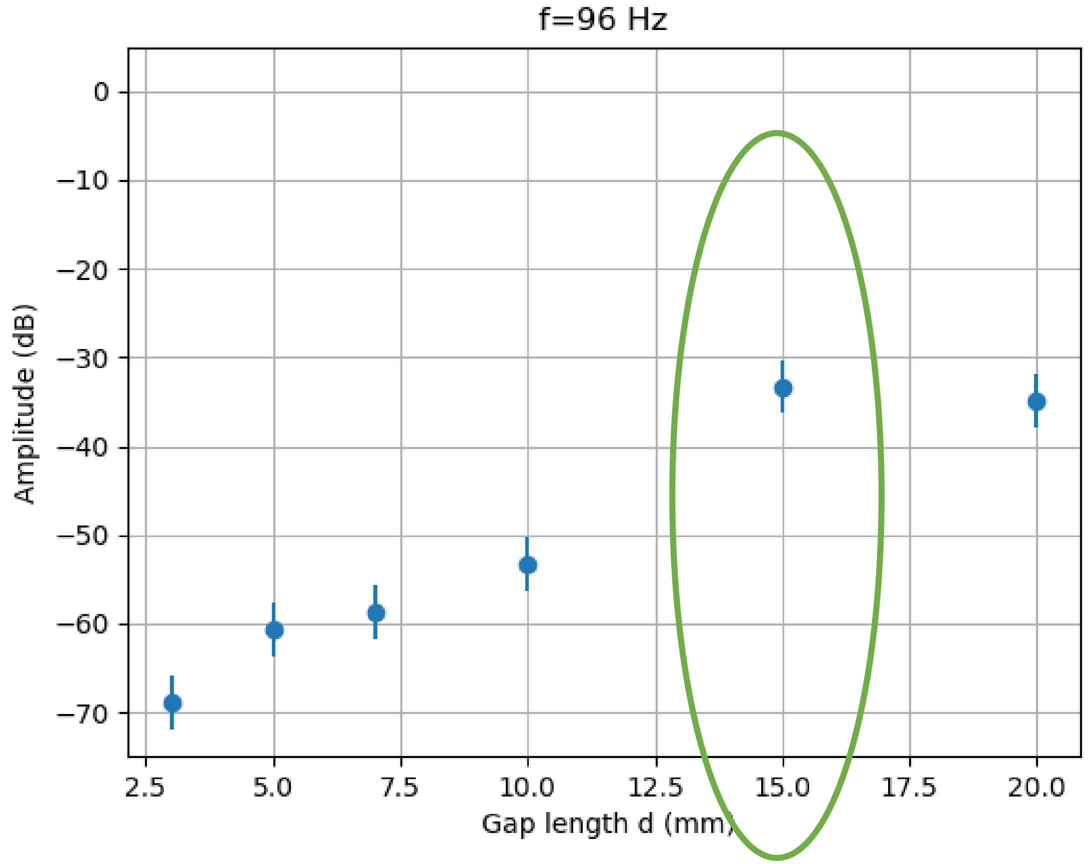
*Discuss **the maximum bandwidth**, **signal-to-noise ratio** and **power efficiency** achieved with your design.*
*Is it possible to modify your device to **use it as a microphone** ?*

Maximal bandwidth

Influence of gap length d

Maximal bandwidth

Influence of gap length d :



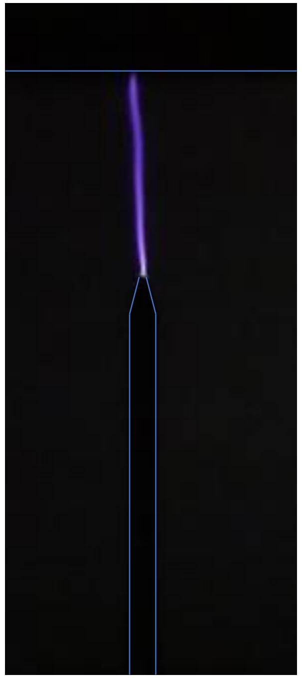
Best amplitude for $d = 15\ mm$

Maximal bandwidth

Different kinds of discharges

Heat transfer H prominent

Arc



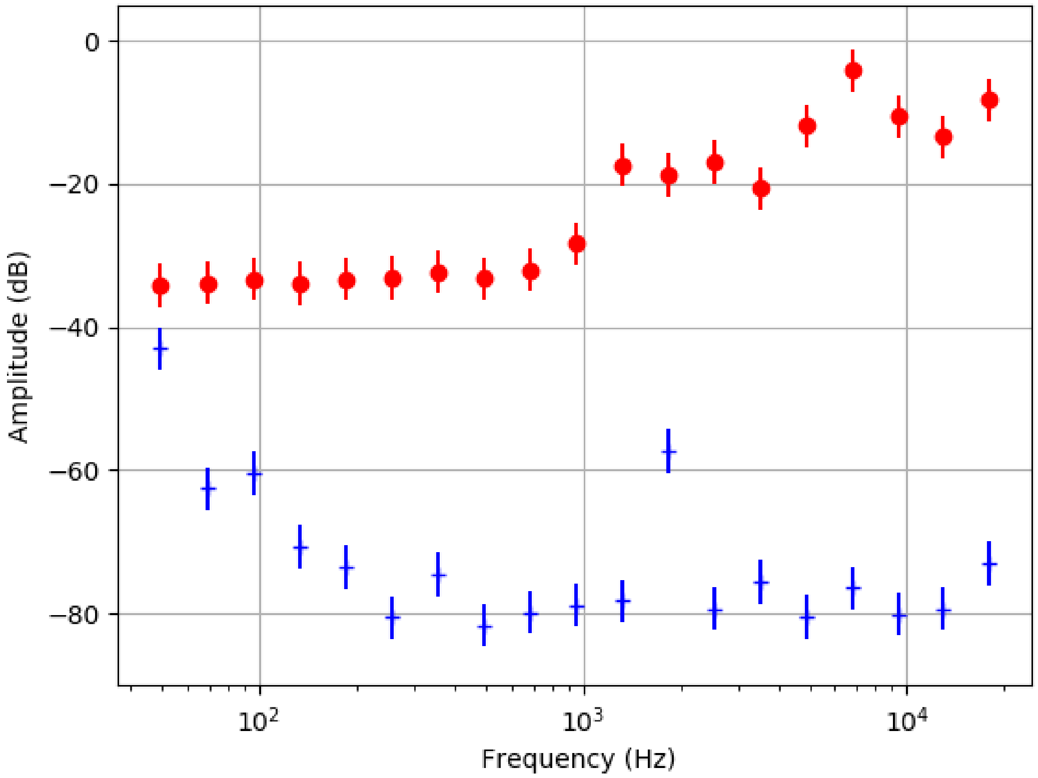
Corona

Momentum transfer prominent

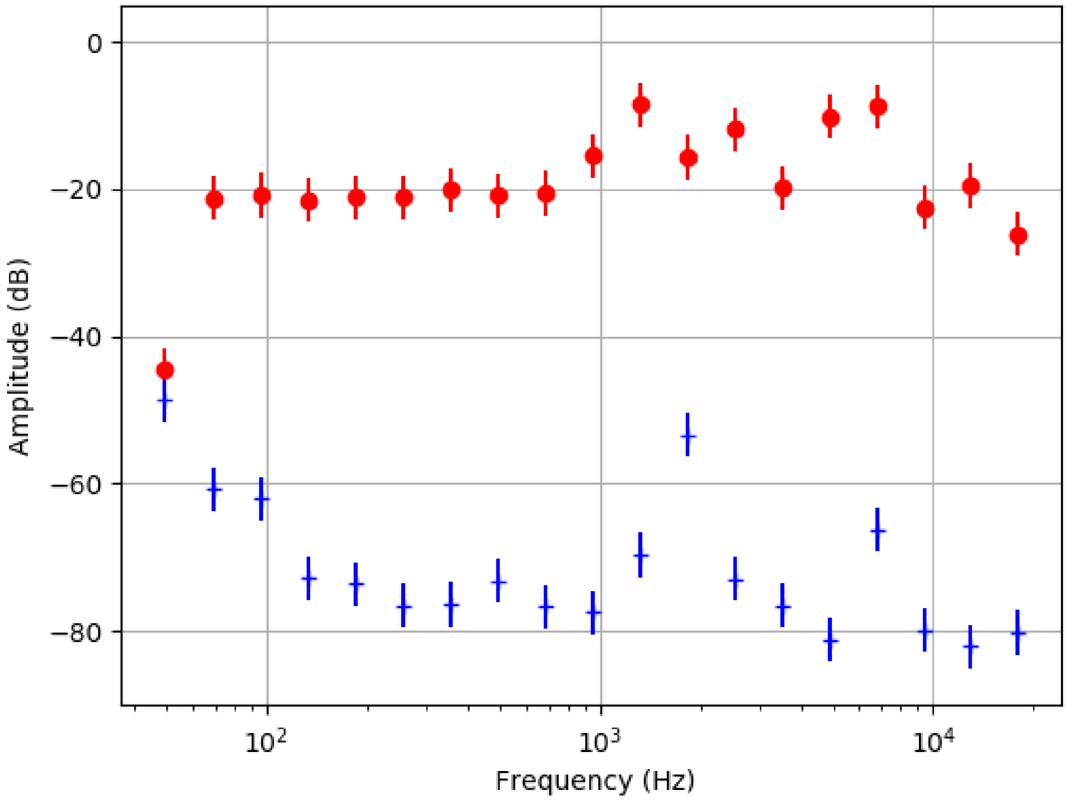
Maximal bandwidth

Influence of discharge mode :

Arc



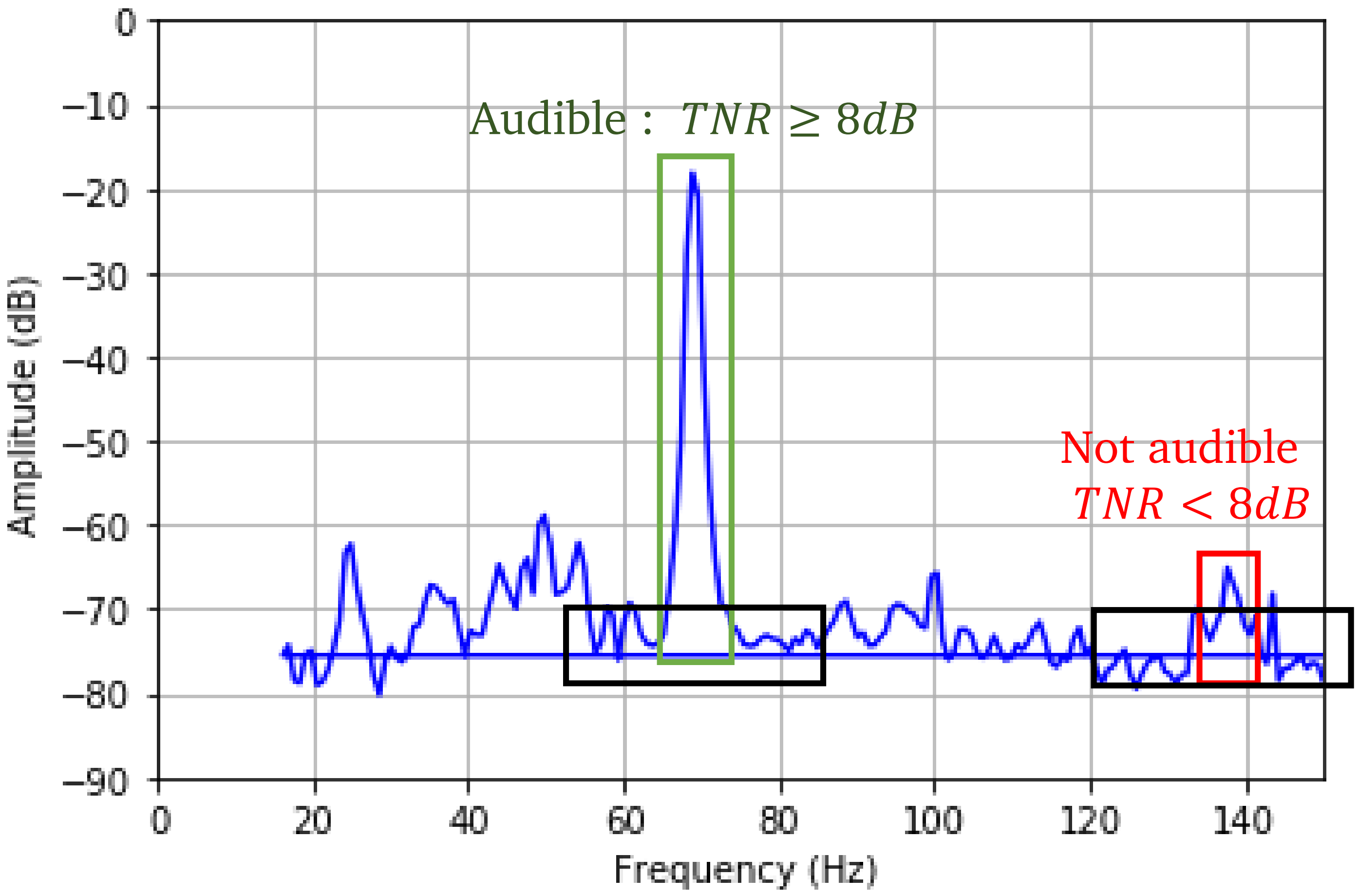
Corona



(d=15 mm, red: frequency response; blue: background)

Signal to Noise Ratio

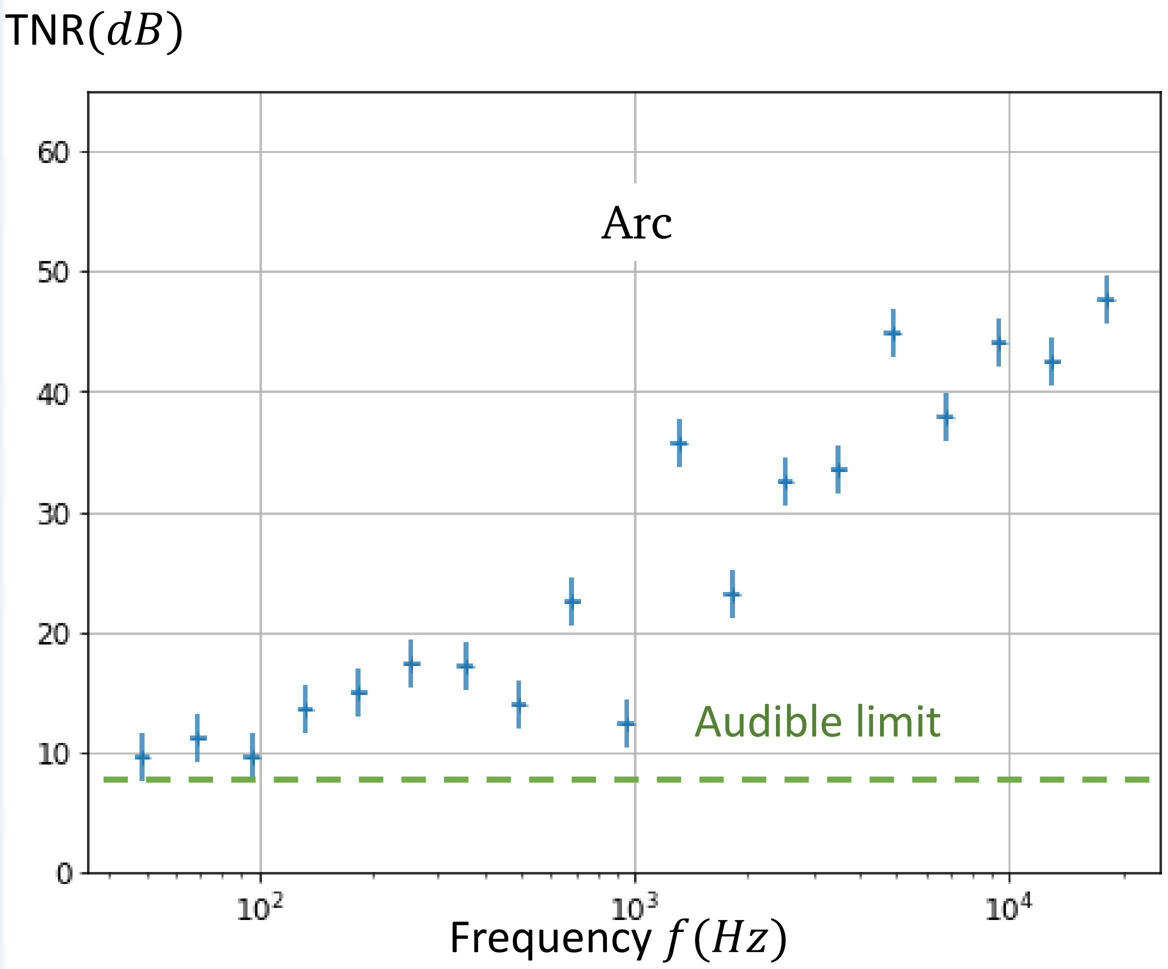
TNR (Tone to Noise Ratio) according to *ECMA-74 International norm*

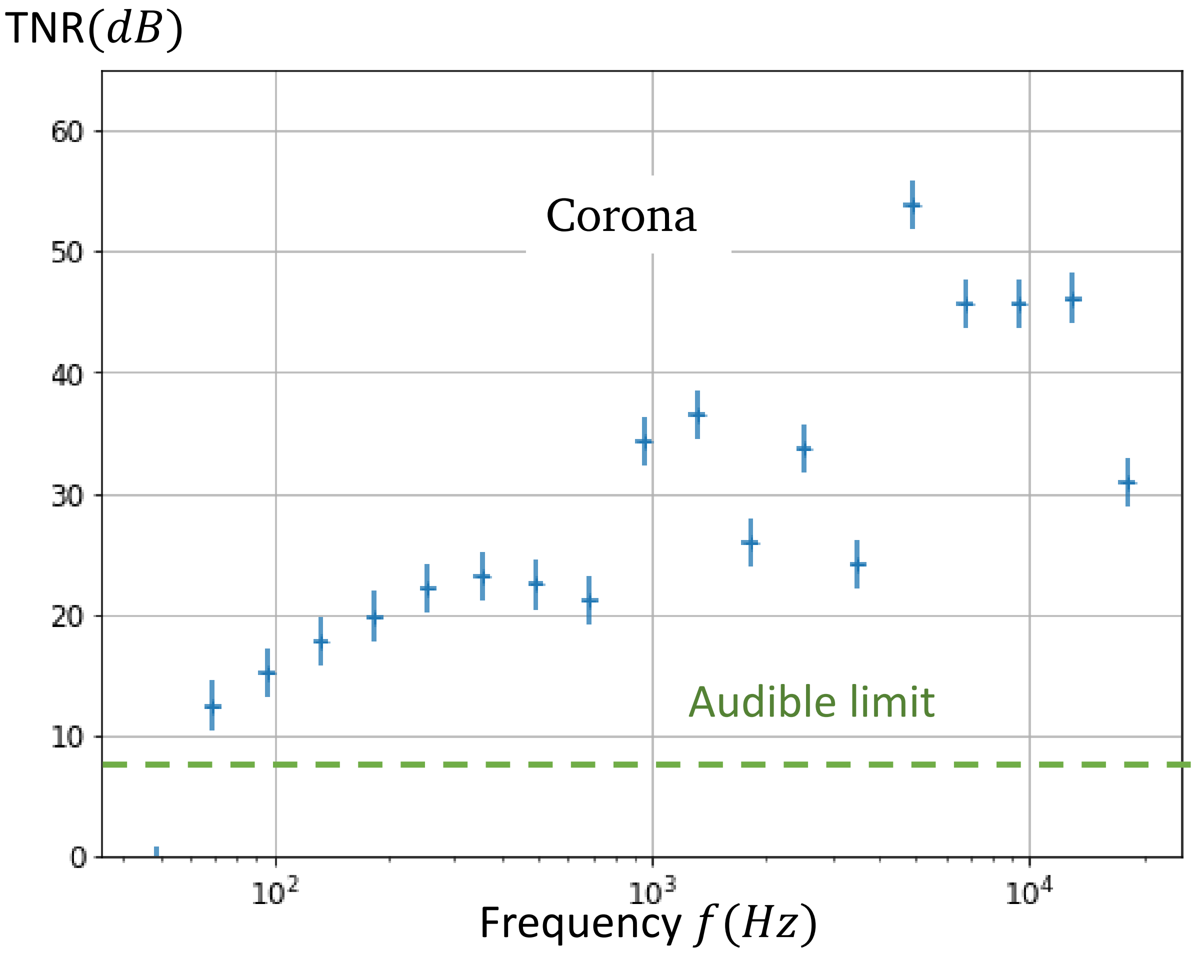


Signal to Noise Ratio

Tone to Noise Ratio

(same gap length d=15 mm)





Signal to Noise Ratio

Tone to Noise Ratio

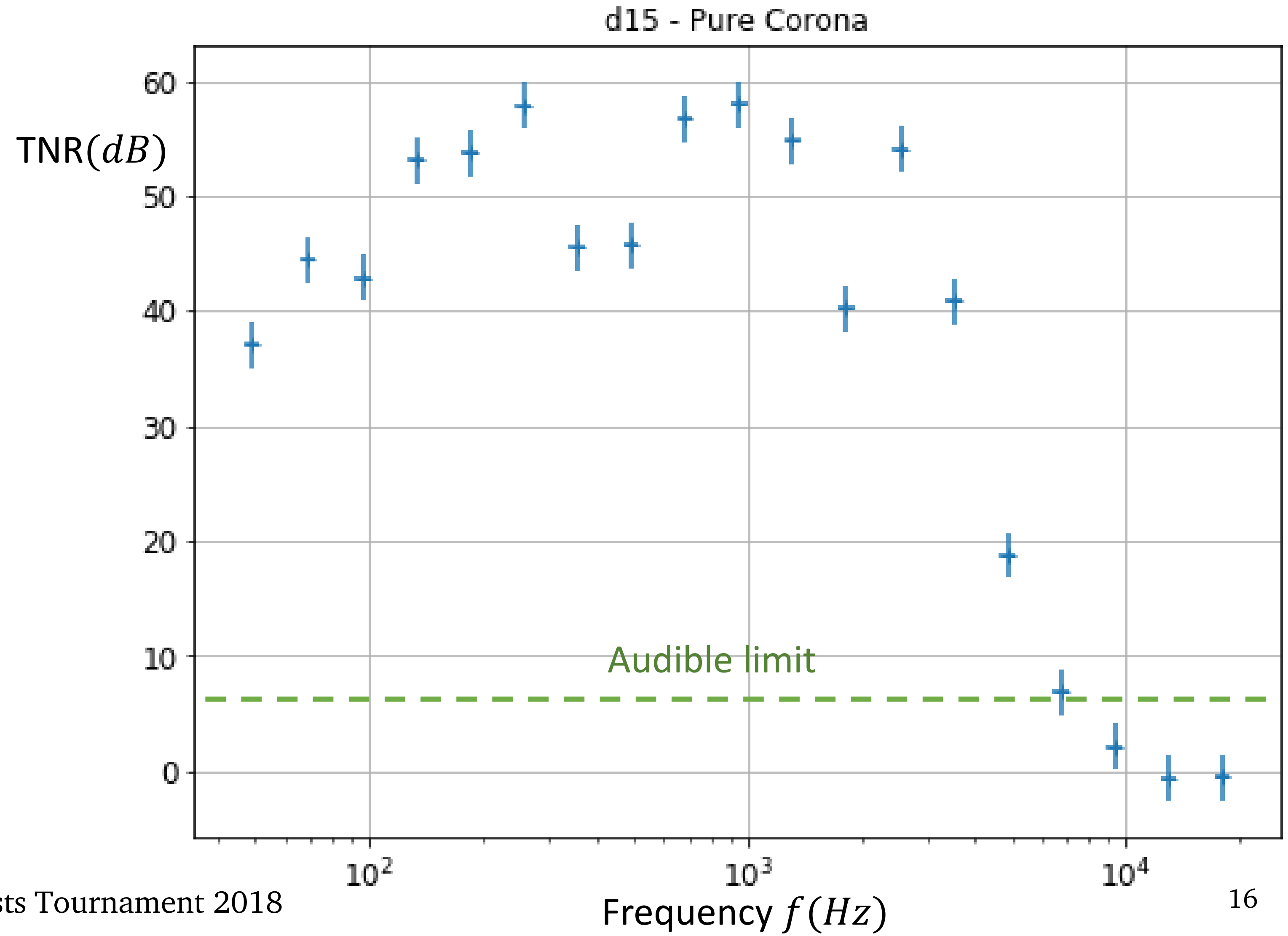
Tape

↓

Dielectric

↓

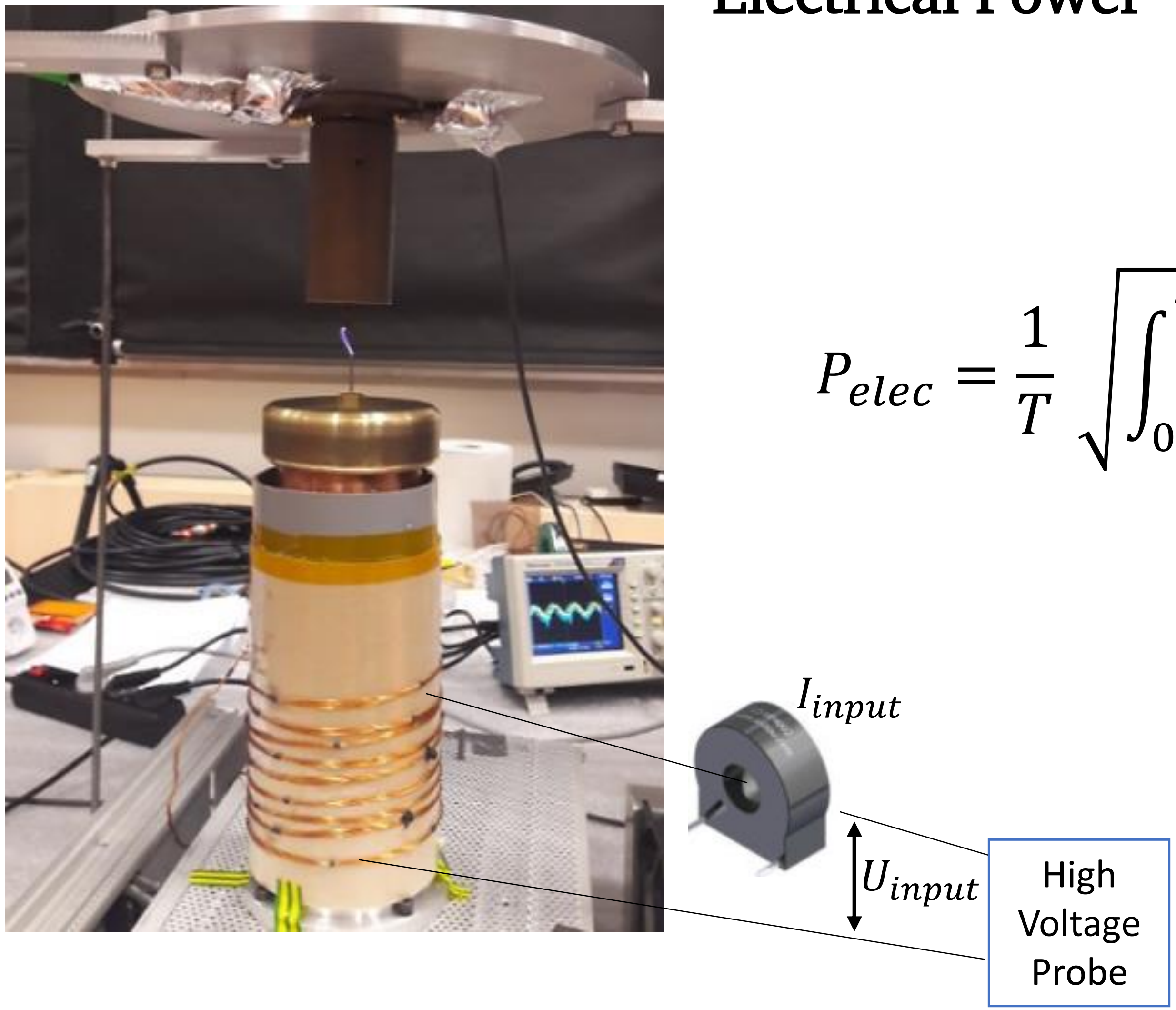
Purified Corona



Power efficiency

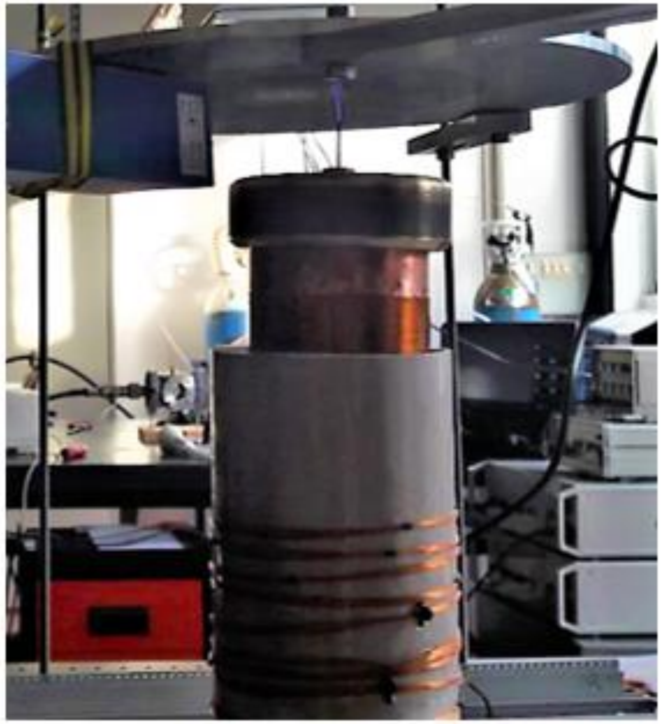
Electrical Power

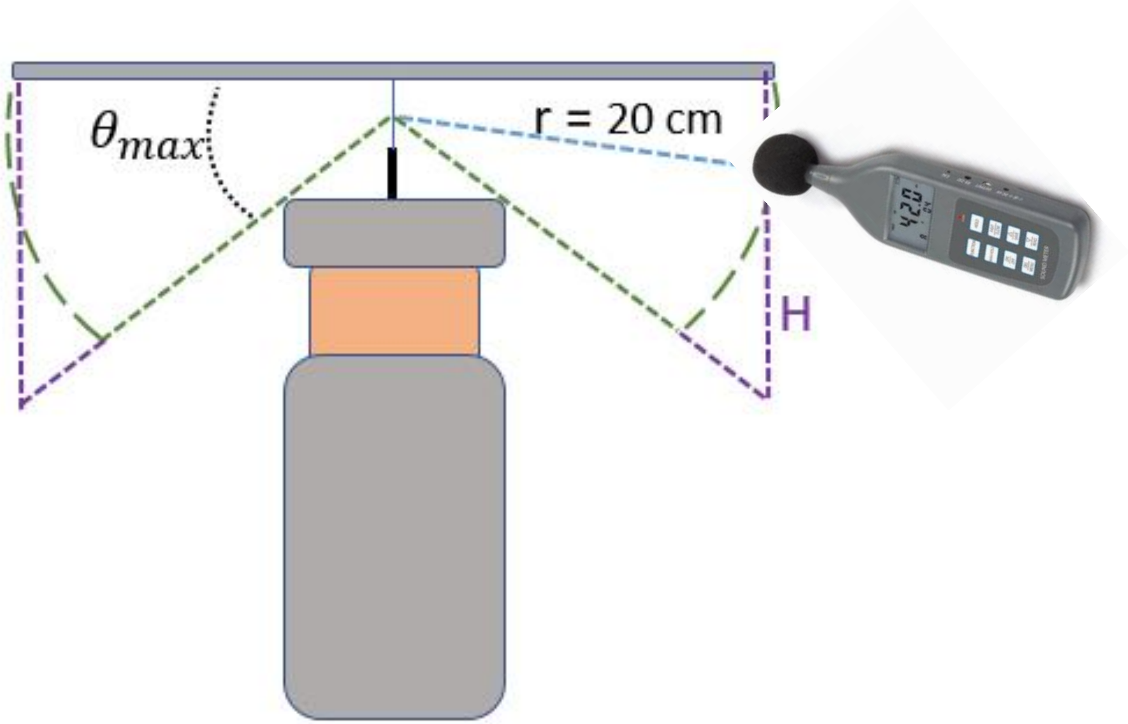
$$P_{elec} = \frac{1}{T}\sqrt{\int_0^T (I_{input}(t)U_{input}(t))^2 \, dt}$$



Power efficiency

Acoustic Power





Acoustic Power : $P_{ac} = S \times \frac{p^2}{\rho\ c}$

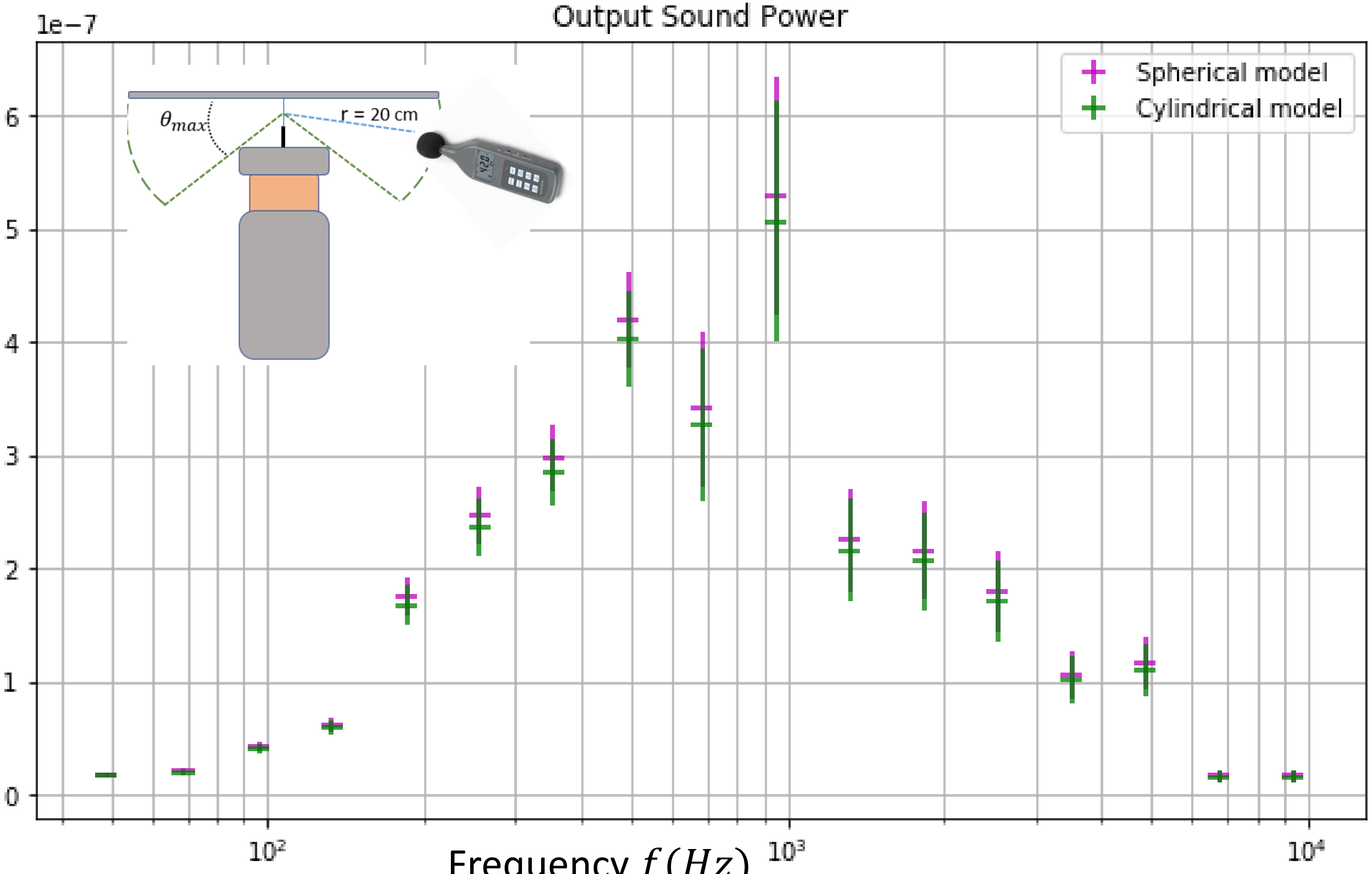
S = 2 possible models : sphere or cylinder

ρ , c , p= air density , speed of sound, air pressure

Power efficiency

Acoustic Power

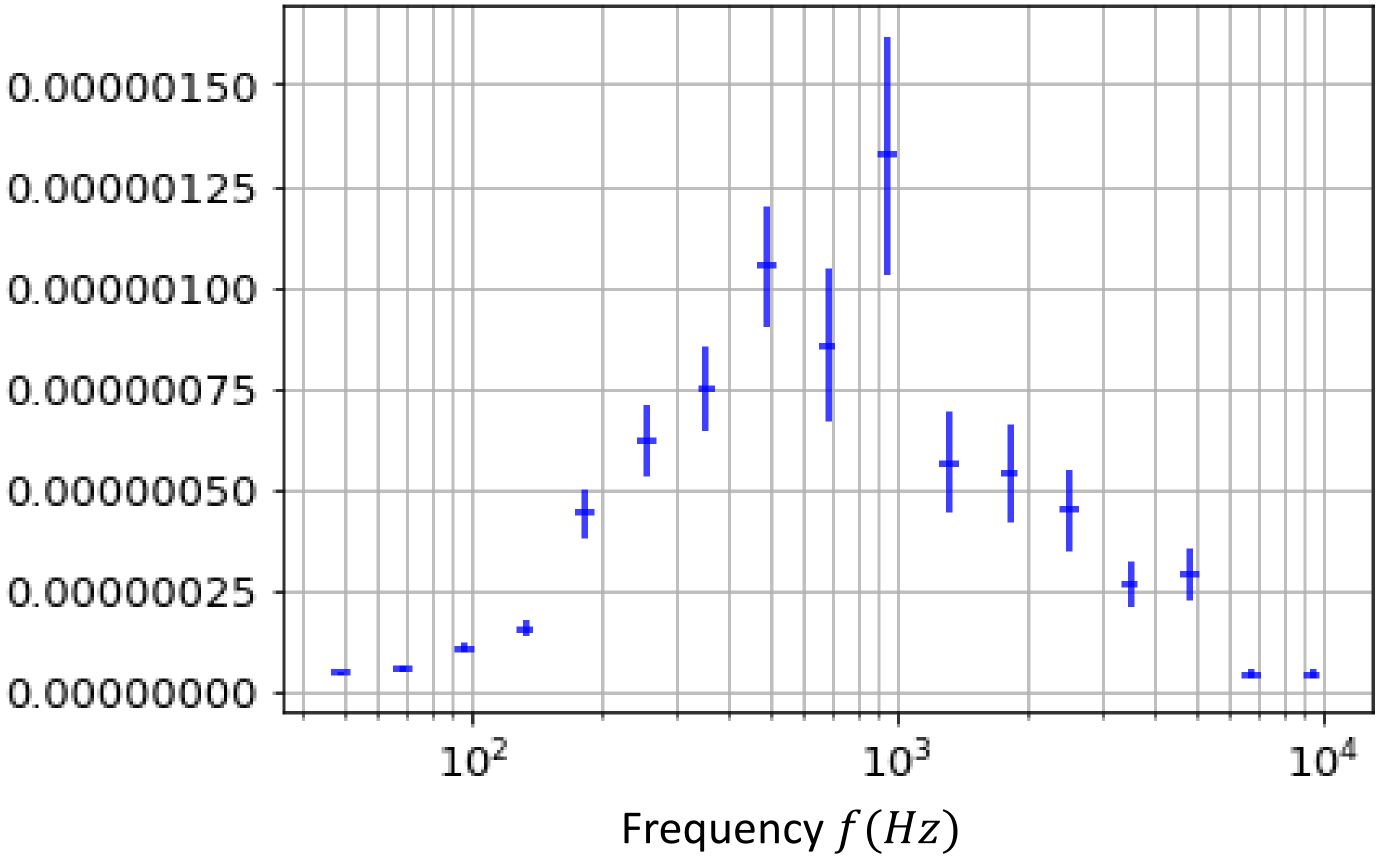
Output Power
$P_{ac}(W)$



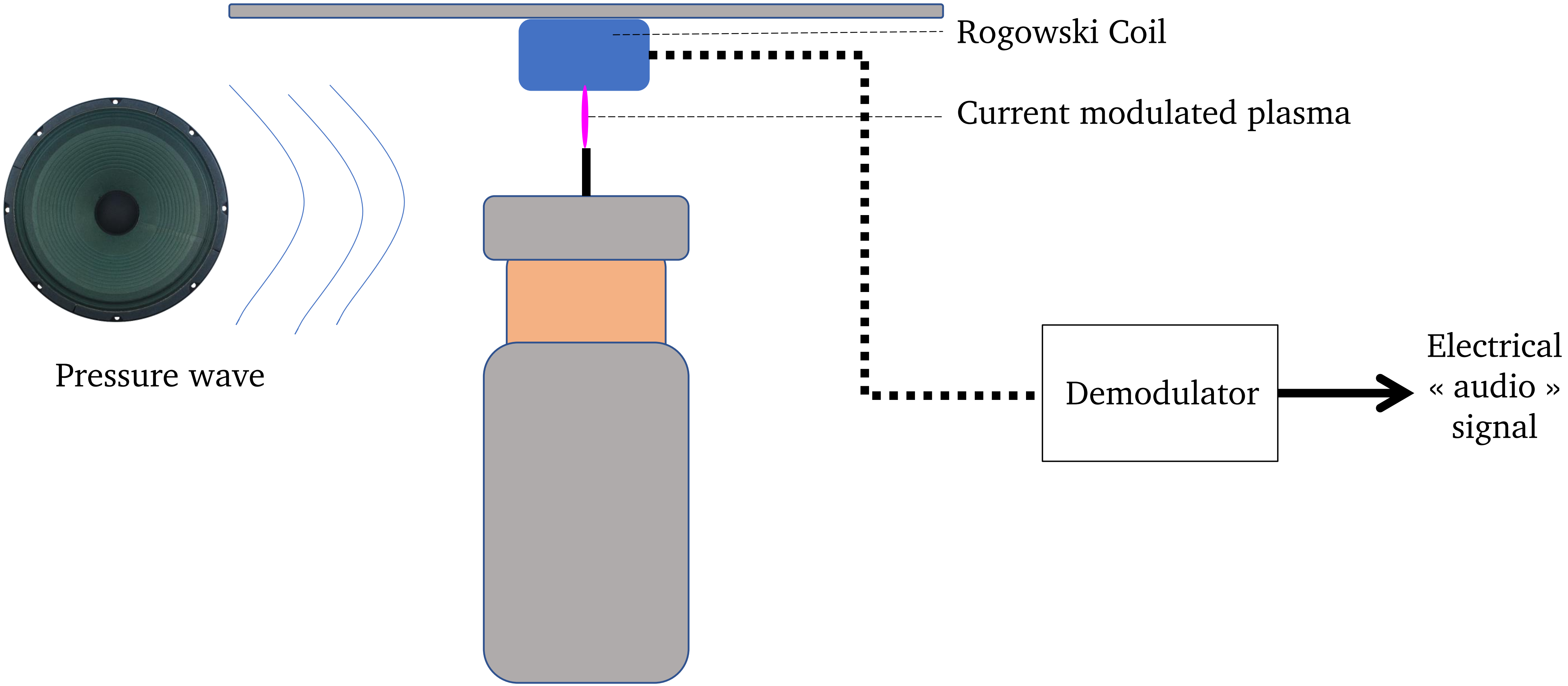
Frequency $f\,(Hz)$

Power efficiency

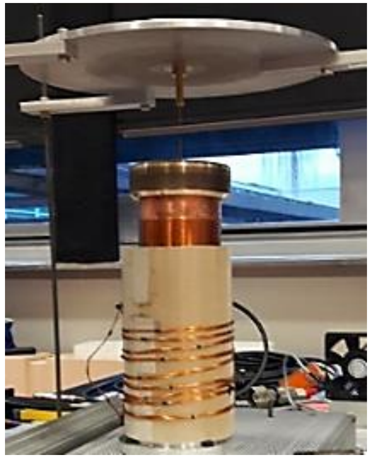
Efficiency = $\frac{P_{ac}}{P_{elec}}$ (%)



A « plasmicrophone »



Conclusion



Main objectives of the problem:

*« Build a **static speaker** »:* Plasma speaker is OK.

*« Discuss the **maximum bandwidth** » :* Whole spectrum accessible, best gap length is $\approx 15\ mm$
Corona better for $f < 1kHz$, arc better for high frequencies

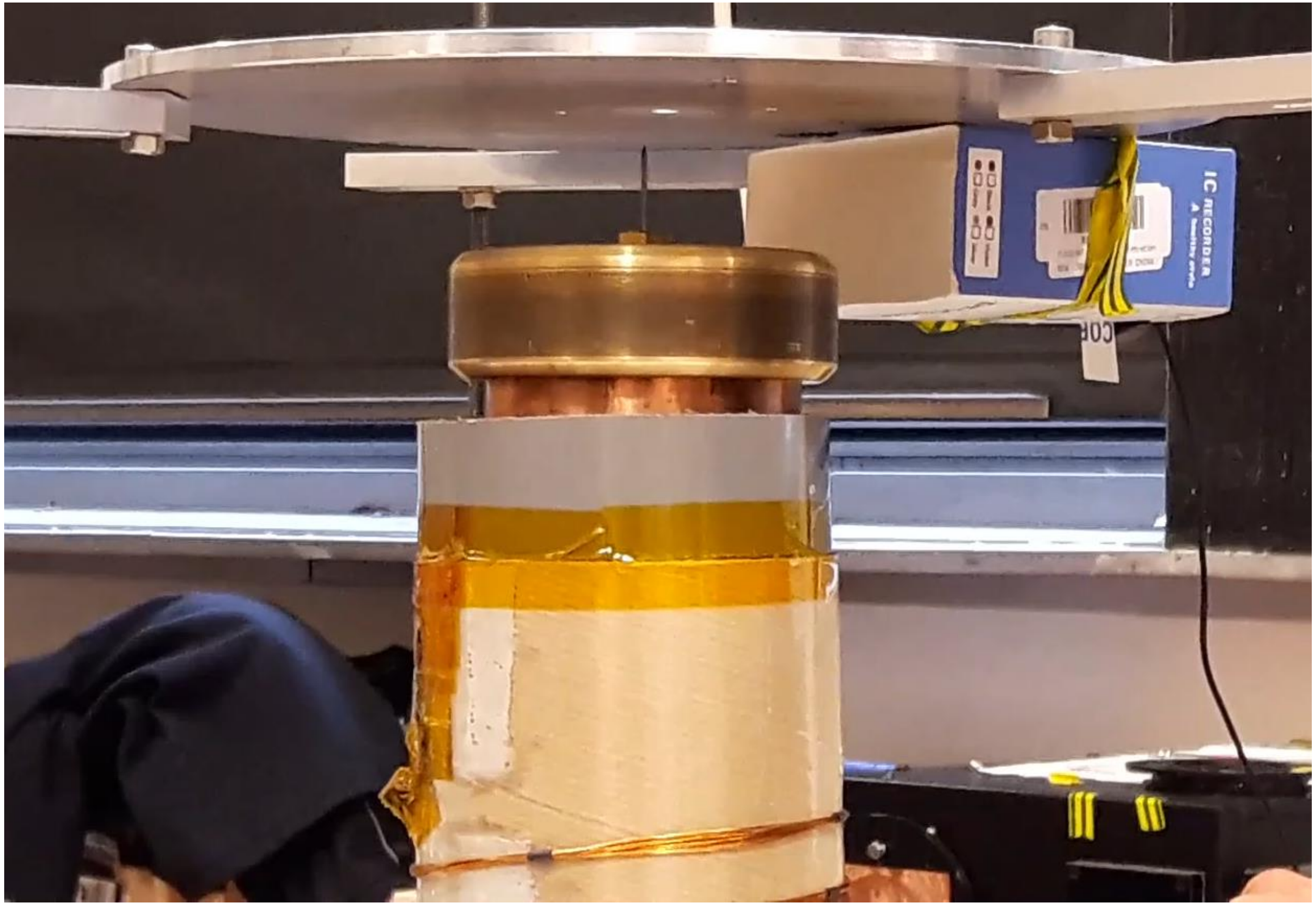
*« **Signal To Noise Ratio** » :* Best **Tone to Noise Ratio** (up to 60dB) reached with a « pure » corona discharge

*« and **Power efficiency** »:* **Weak** efficiency (2.10^{-7} %) for **low**, **better** (15.10^{-7} %) for **medium high frequencies**

*« use it as a **microphone?** »* Theoretically possible.

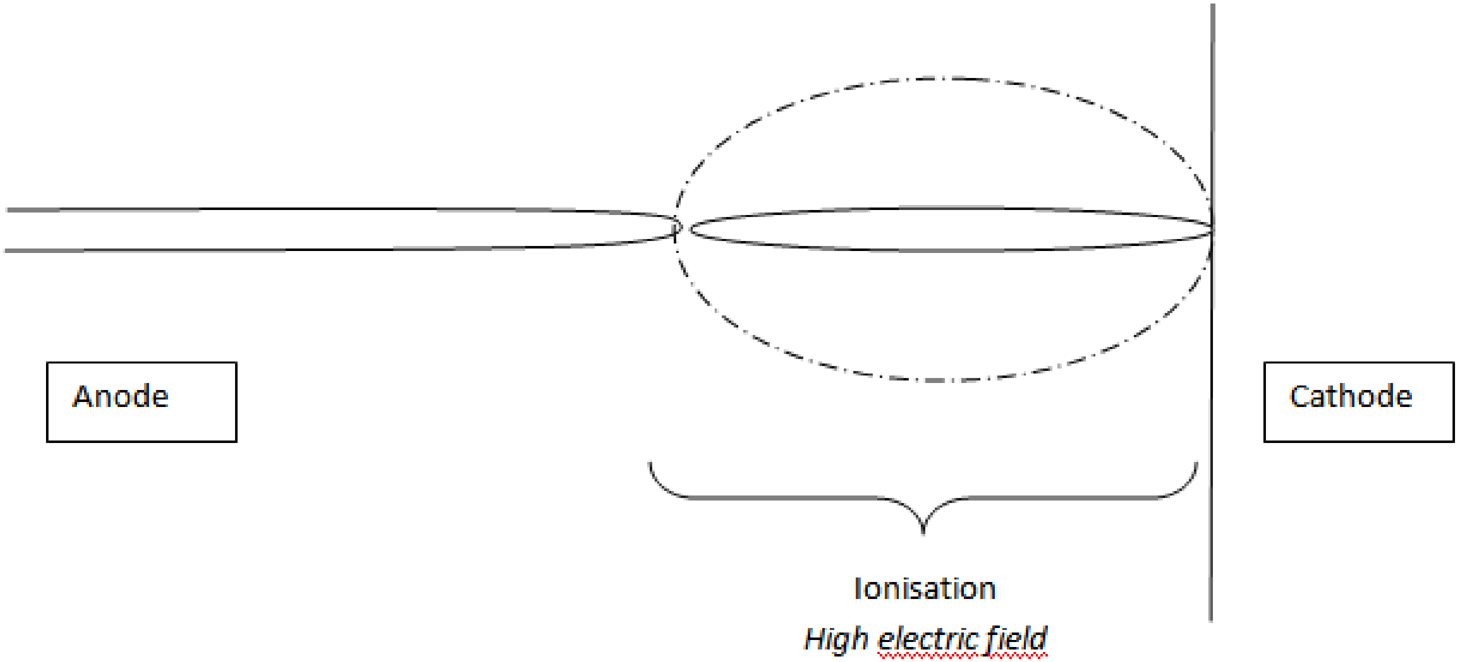
Thank you for listening !

The sound is really created by the plasma



Theory of plasma speakers

Different kinds of discharges

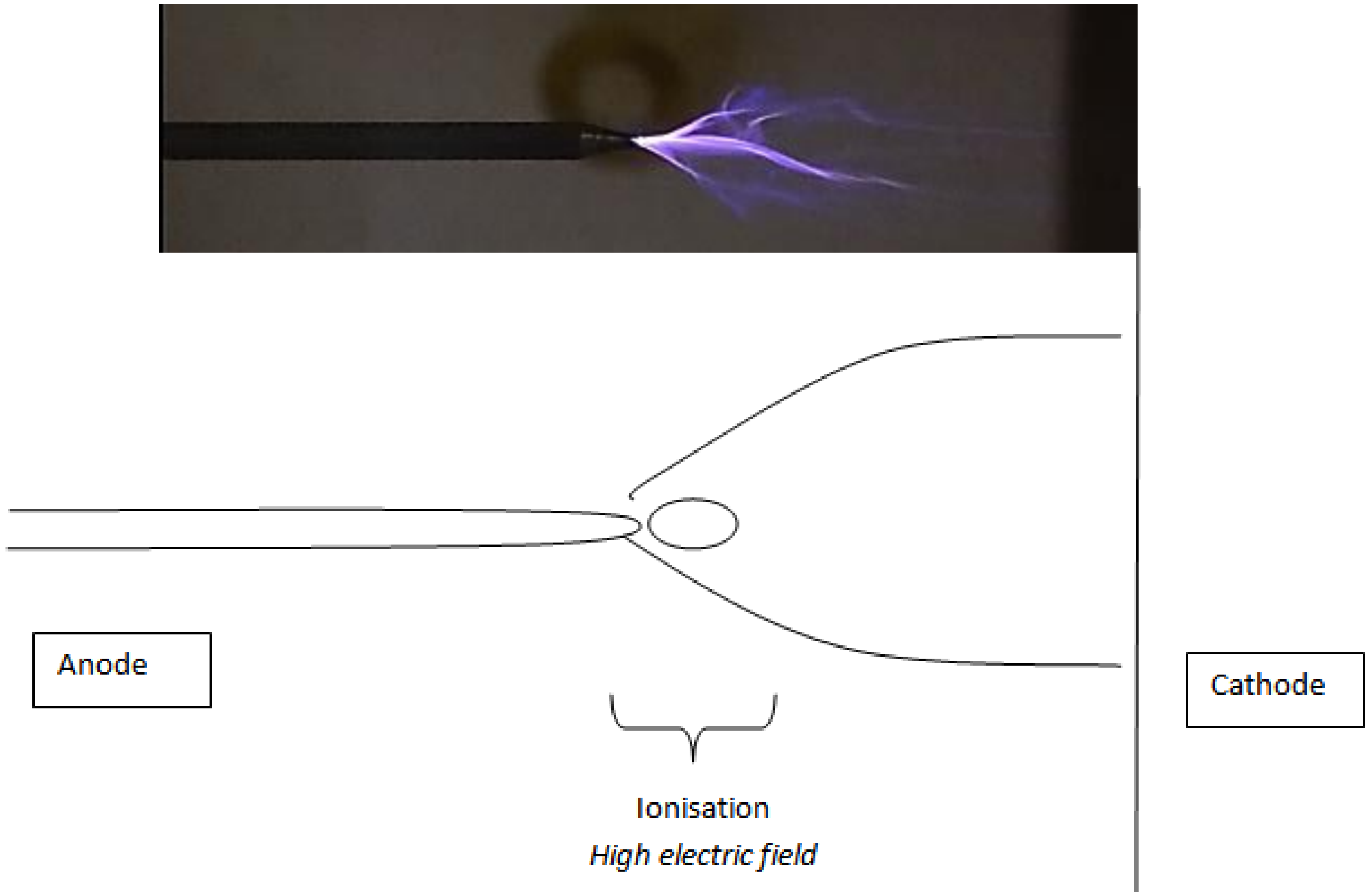


ARC DISCHARGE:

- high voltage, big ionisation
- Heat transfer H is prominent

Theory of plasma speakers

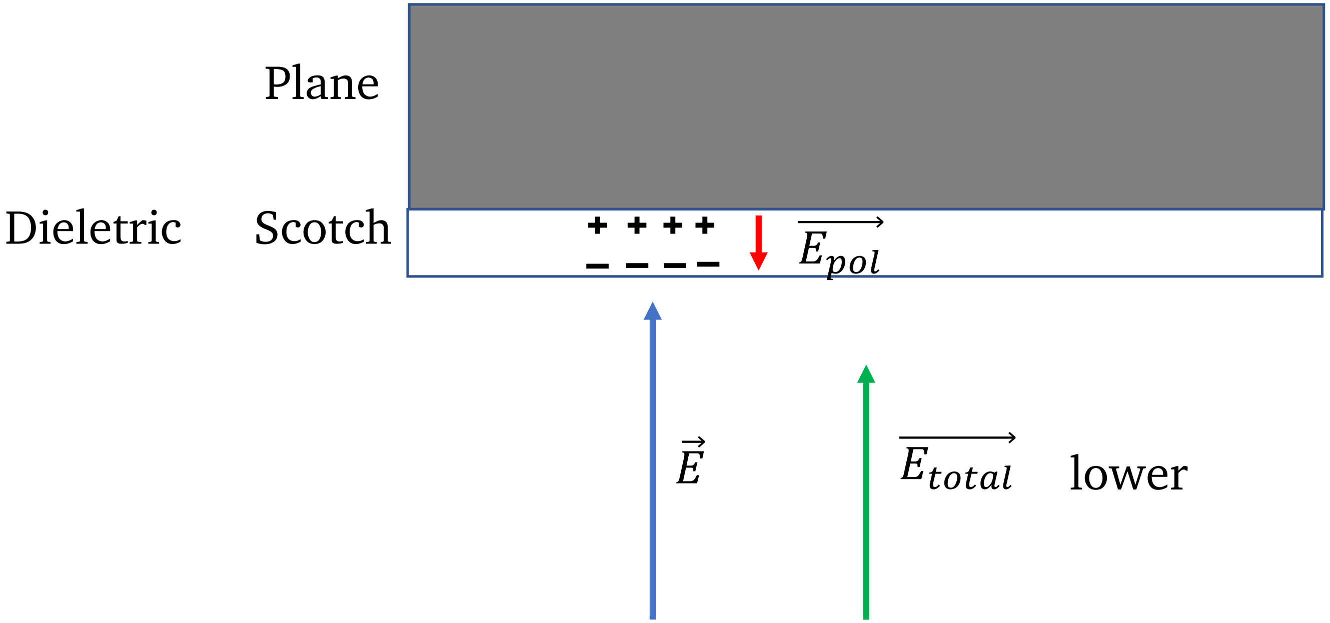
Different kinds of discharges



CORONA DISCHARGE:

- Complex geometry
- Lower current than in arc
- Momentum transfer is prominent

« Purifying » corona : Scotch tape !



About non-linearities

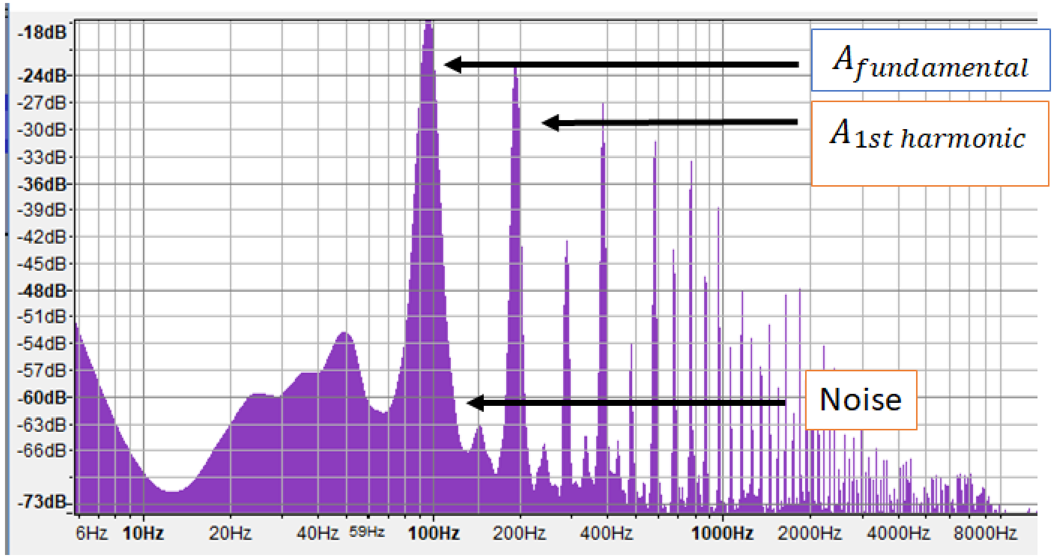
Two source terms :

$$< H > = H_0 \left(1 + \frac{m_E + m_I}{2} + (m_E + m_I)\cos(\omega t) + m_E m_I \cos(2\omega t) \right)$$

$$< \vec{F} > = \overrightarrow{F_0} \left(1 + \frac{m_E}{2} + 2m_E \cos(\omega t) + m_E^2 \cos(2\omega t) \right)$$

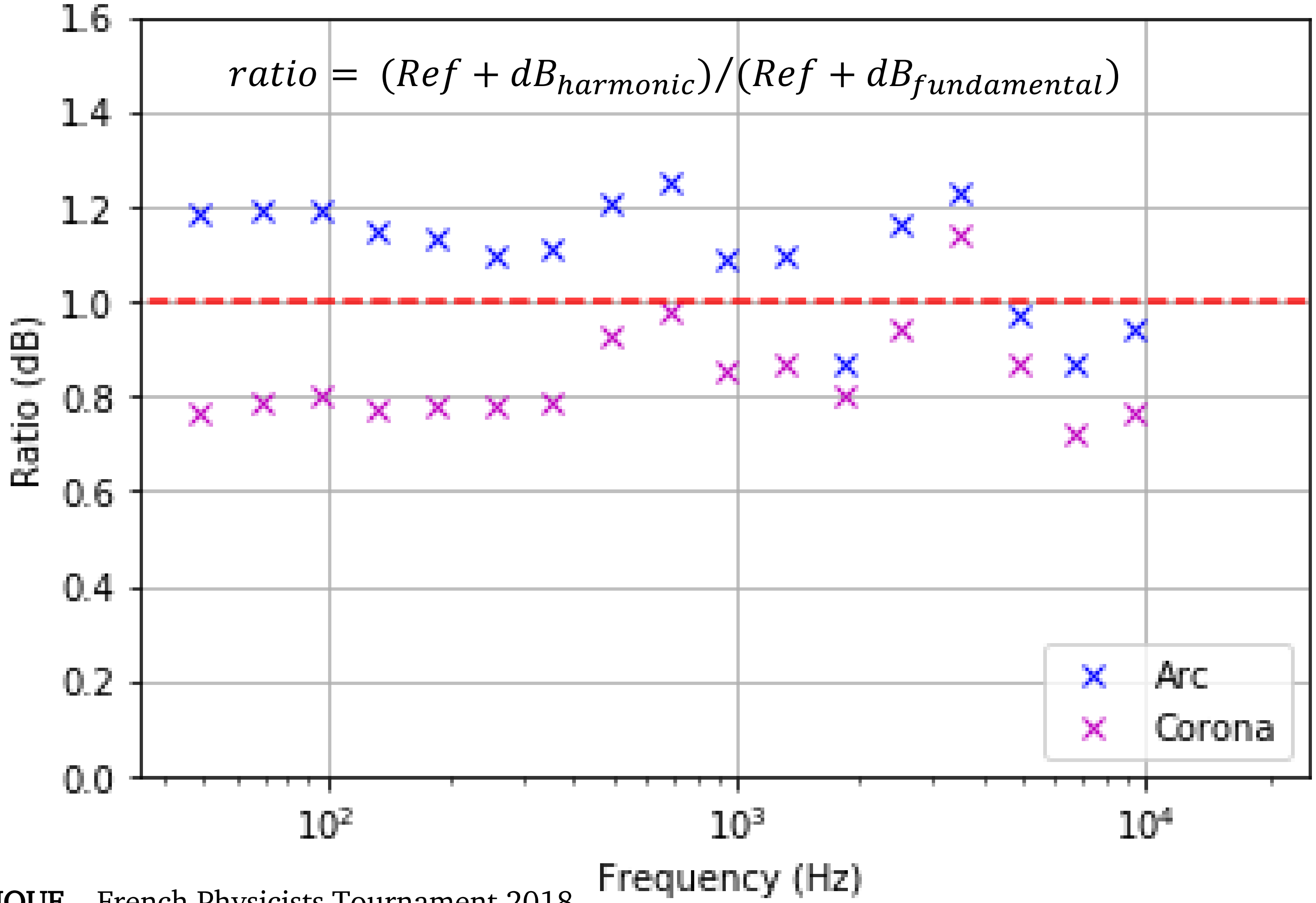
m_I, m_E : modulation rates of tension and current

Non-linearities occur with signal overmodulation



About non-linearities

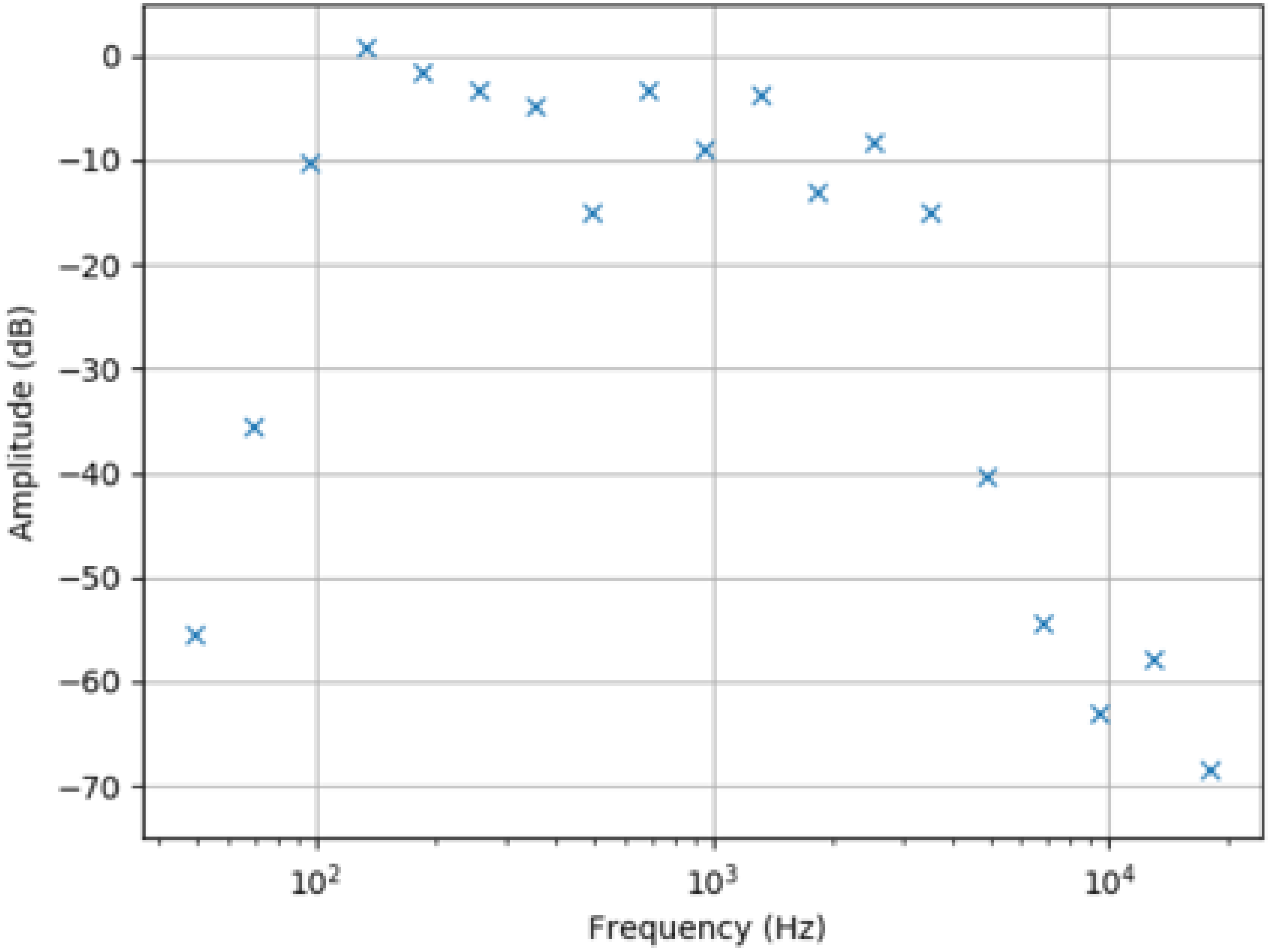
importance of the 1st haromonic (2ω)



$Ref = 100\ dB$

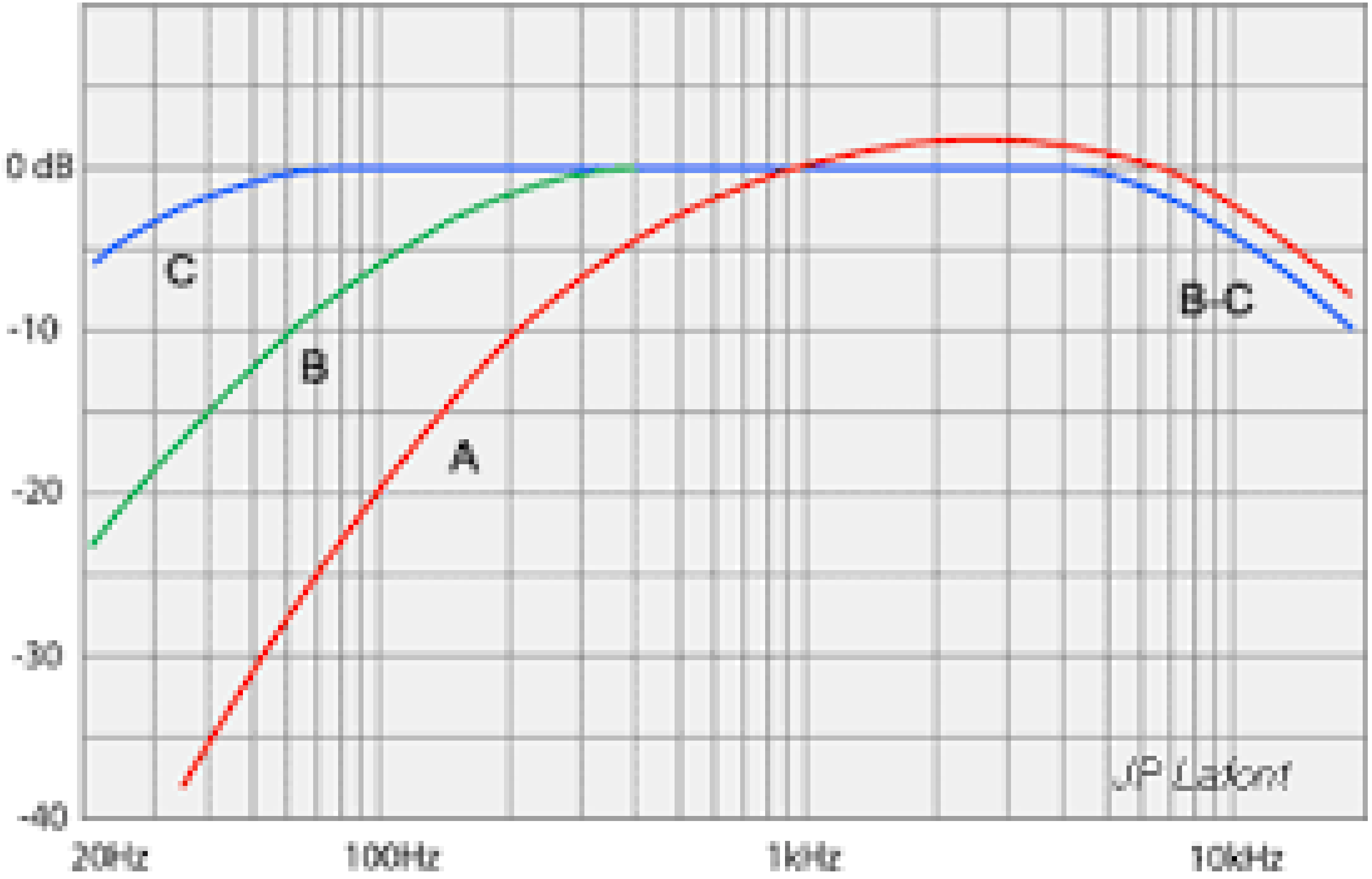
Sound Measurement

Influence of the microphone



Sound Measurement

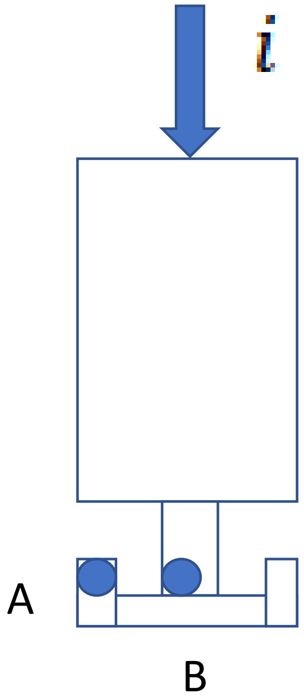
Influence of the sonometer



Chose the sonometer weighting :
A, B, C
or **nothing**

Voltage and Current Measurements

Rogowski coil

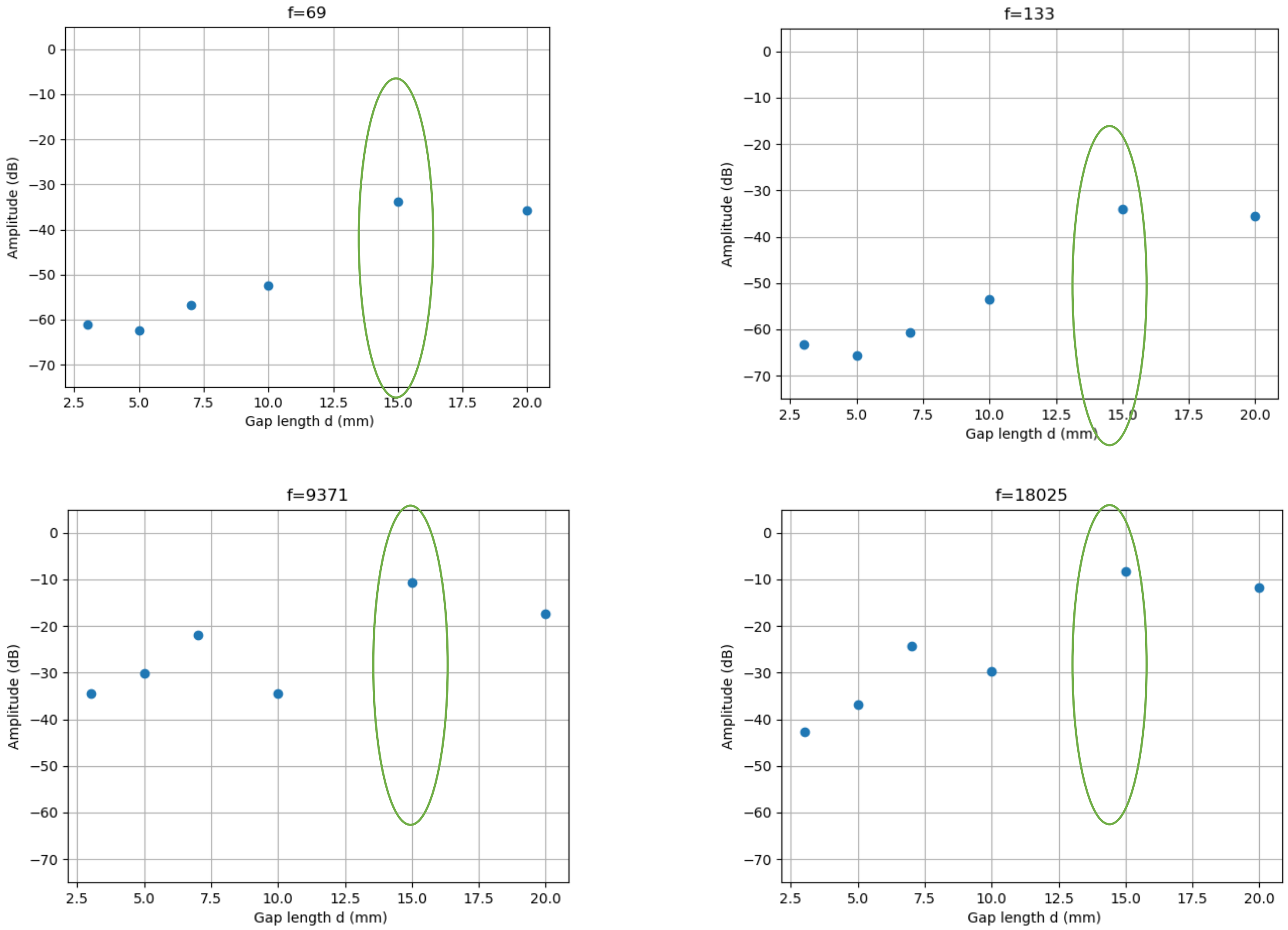


Inductive Shunt coil

$$u_{AB} = L\frac{di}{dt}$$

$L = 1.1\ nH$

Influence of the distance inter electrode

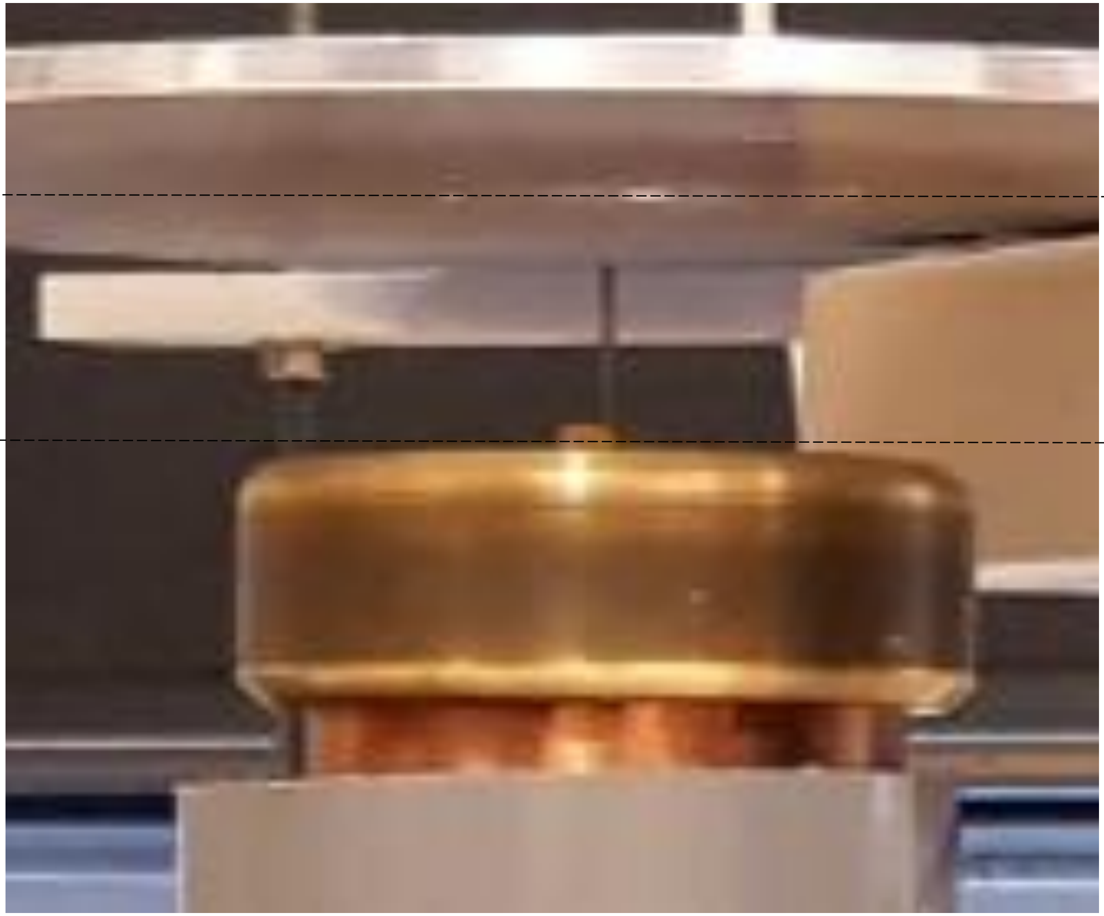


Whole range of the audio spectrum:

$d = 15mm$ is an overall good distance

Stationary waves selected

2 obstacles at a distance L



L

$$2L = n\,\lambda\,,\, n \epsilon\, \mathbb{N}$$
$$\lambda f = c_0$$

$$\boldsymbol{f_n = \frac{nc_0}{2L} \approx n\, 3.5\ kHz}$$