Static Speaker

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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?

- Maximum bandwidth
- Signal-to-noise ratio
- Power efficiency
- Microphone

What is sound?

Pressure wave: $$\nabla^2 p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0$$

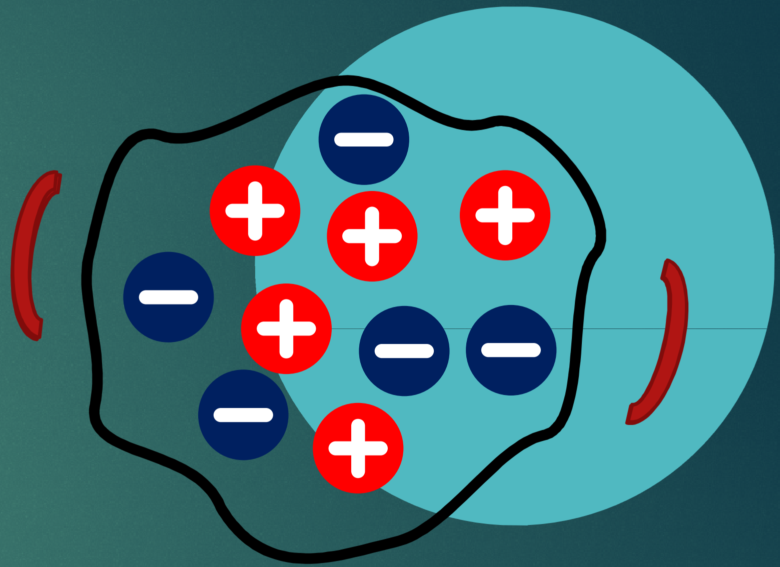
Plasma speaker

What is a plasma?

- Ionized gas
- Neutrality
- Dominated by collective effects
- Very good conductor

Plasma speaker

Modulation of the volume of a plasma with temperature to produce a pressure wave



$$pV = Nk_BT$$

$\Rightarrow$ Change T and V to modify p

Sound production

- Mass conservation

$$\frac{\partial \delta}{\partial t} + \rho_0 div \vec{u} = Q$$

- Momentum conservation

$$\rho_0 \frac{\partial \vec{u}}{\partial t} + \overrightarrow{grad}\ p = \vec{F}$$

- Energy conservation

$$\rho_0 T_0 \partial s / \partial t = H$$

- State equation

$$\delta = \left(\frac{\partial \rho}{\partial P}\right)_S + \left(\frac{\partial \rho}{\partial S}\right)_P = (1/c^2) p - (\rho_0 / c_P) s$$

Q : mass transfer rate (volumic)
$\vec{F}$: momentum transfer rate (volumic)
H: energy transfer rate (volumic)

[1]

Sound production

Equation for pressure of neutrals

Momentum transfer

$$\Rightarrow \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} - \nabla^2 p = \frac{(\gamma - 1)}{c^2}\frac{\partial H}{\partial t} - div\,\vec{F}$$

Wave propagation

Joule heating

Sound production

Hypothesis:
Collisions between electrons and neutrals

$$H \propto T_e^{3/2} N_e N_n \langle \sigma \rangle$$

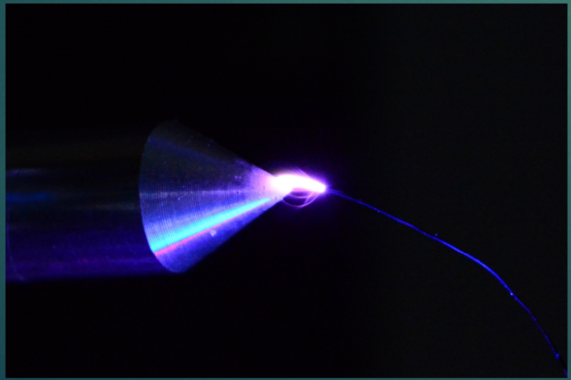
$$\frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} - \nabla^2 p = \frac{\gamma - 1}{c^2}\frac{\partial}{\partial t}\left(C \cdot N_e N_n T_e^{3/2}\right)$$

Sound from current

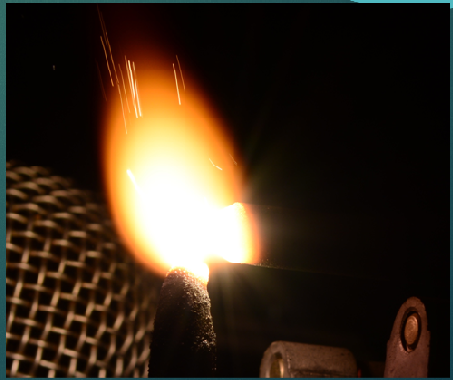
Possible setups

Joule heating speaker

RF discharge

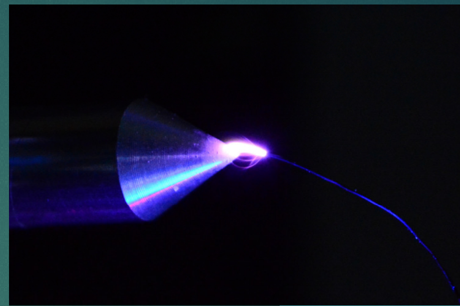


Arc discharge

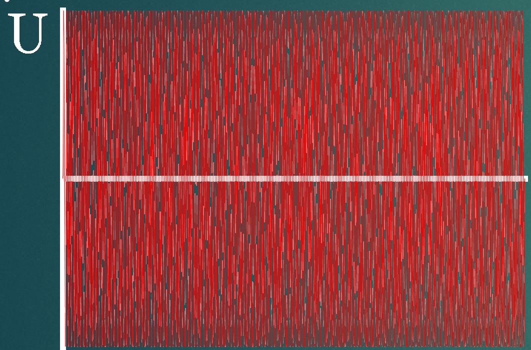


RF Discharge

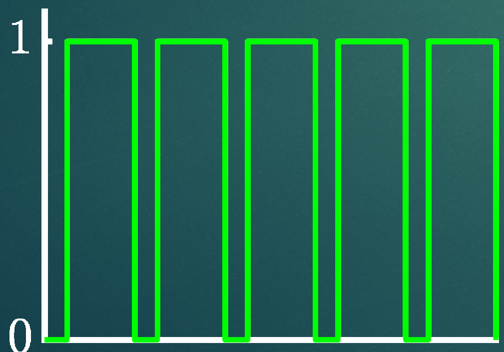
1. Produce a plasma with a high voltage



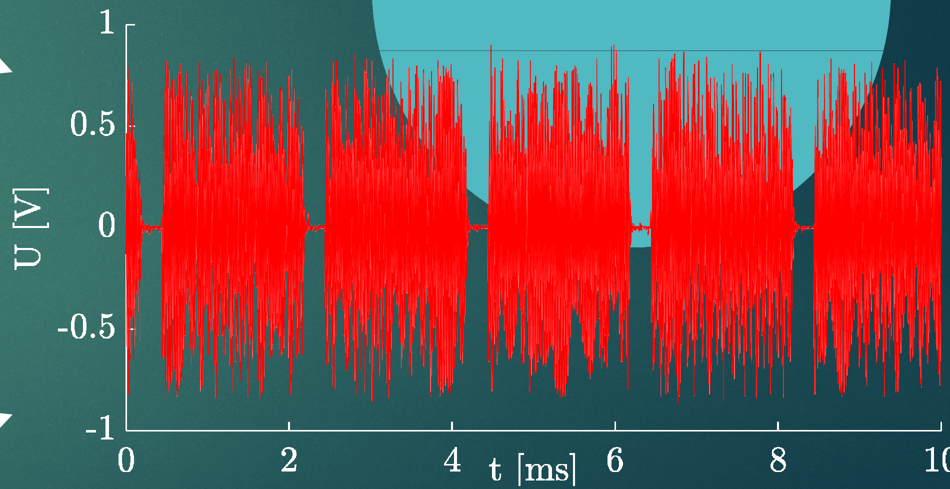
2.



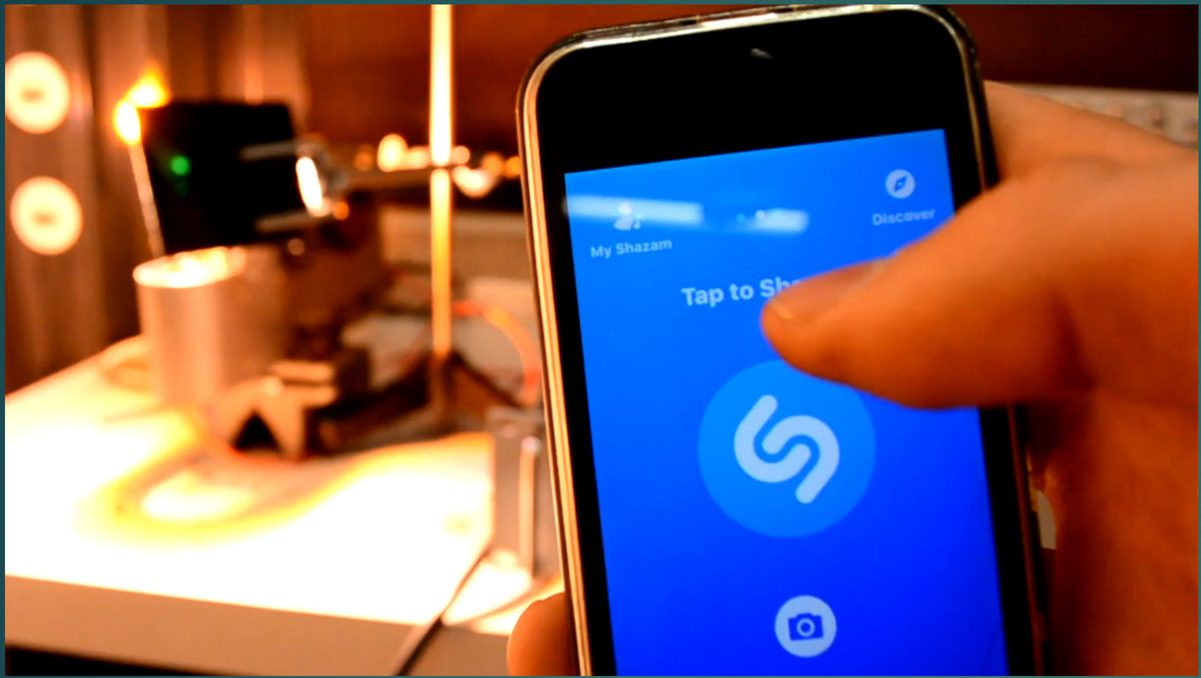
3 MHz

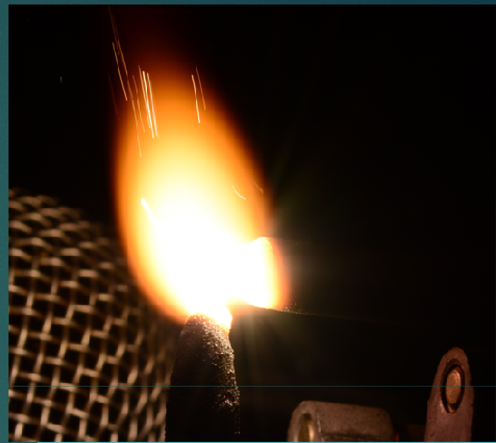


500 Hz



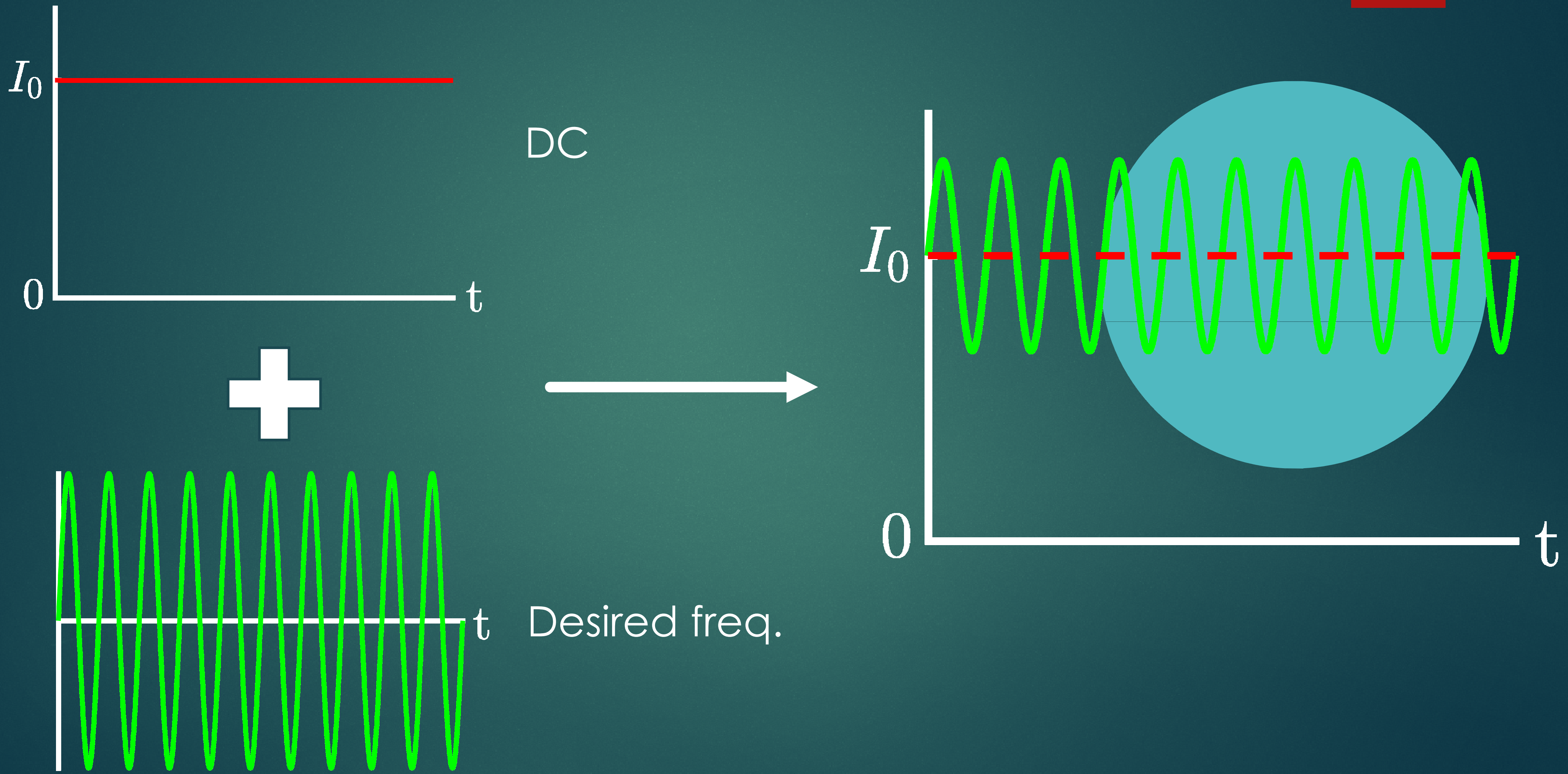
Arc discharge



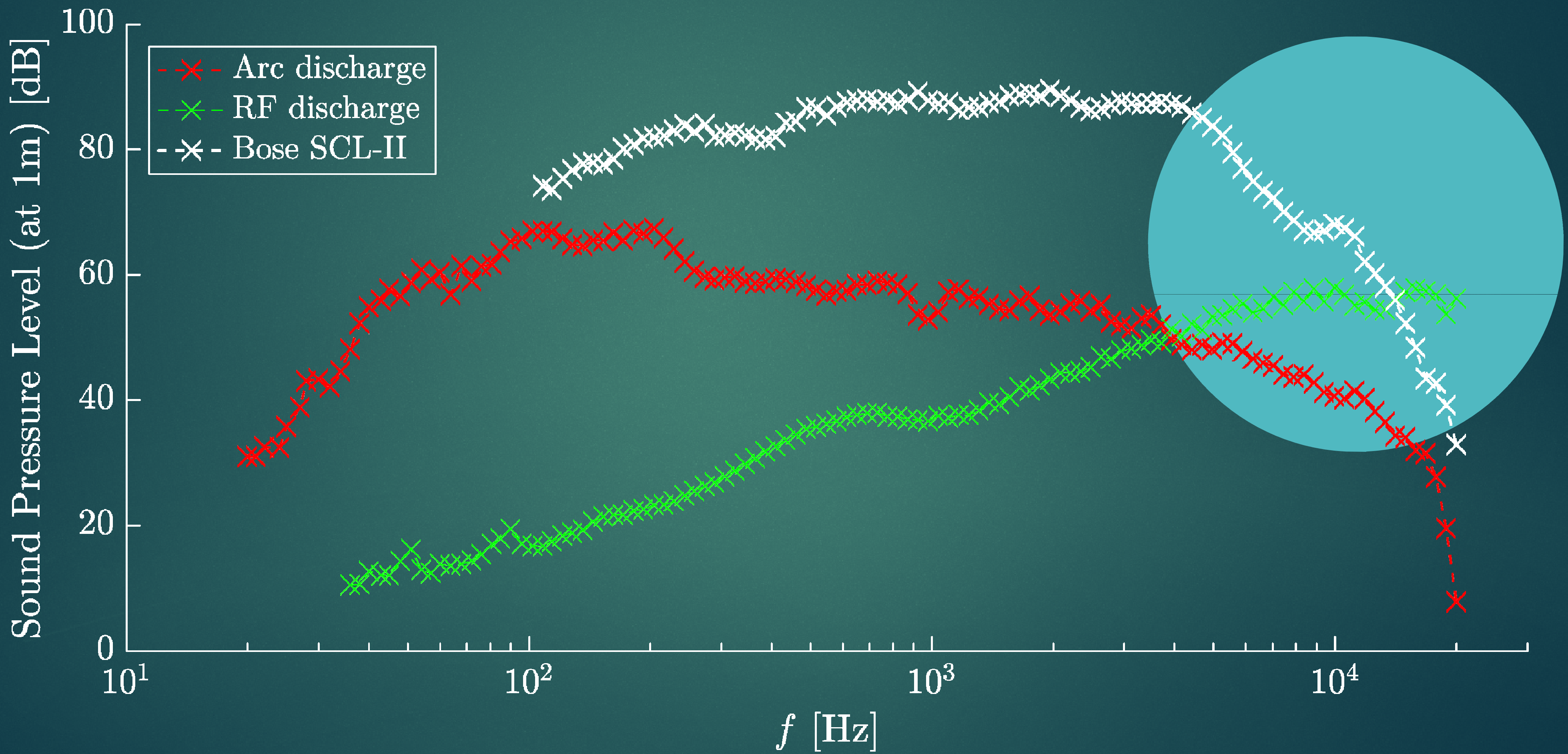


Freq Gen — Power Supply — Arc Speaker

Arc discharge

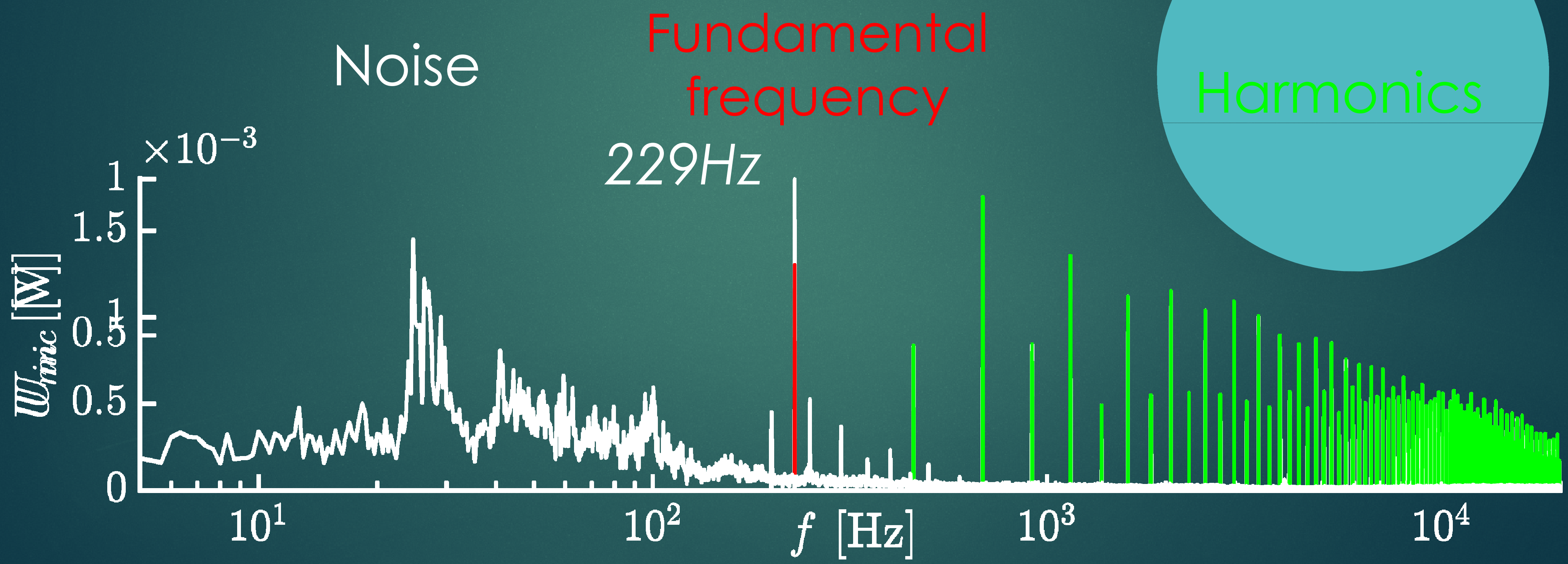


Frequency Response

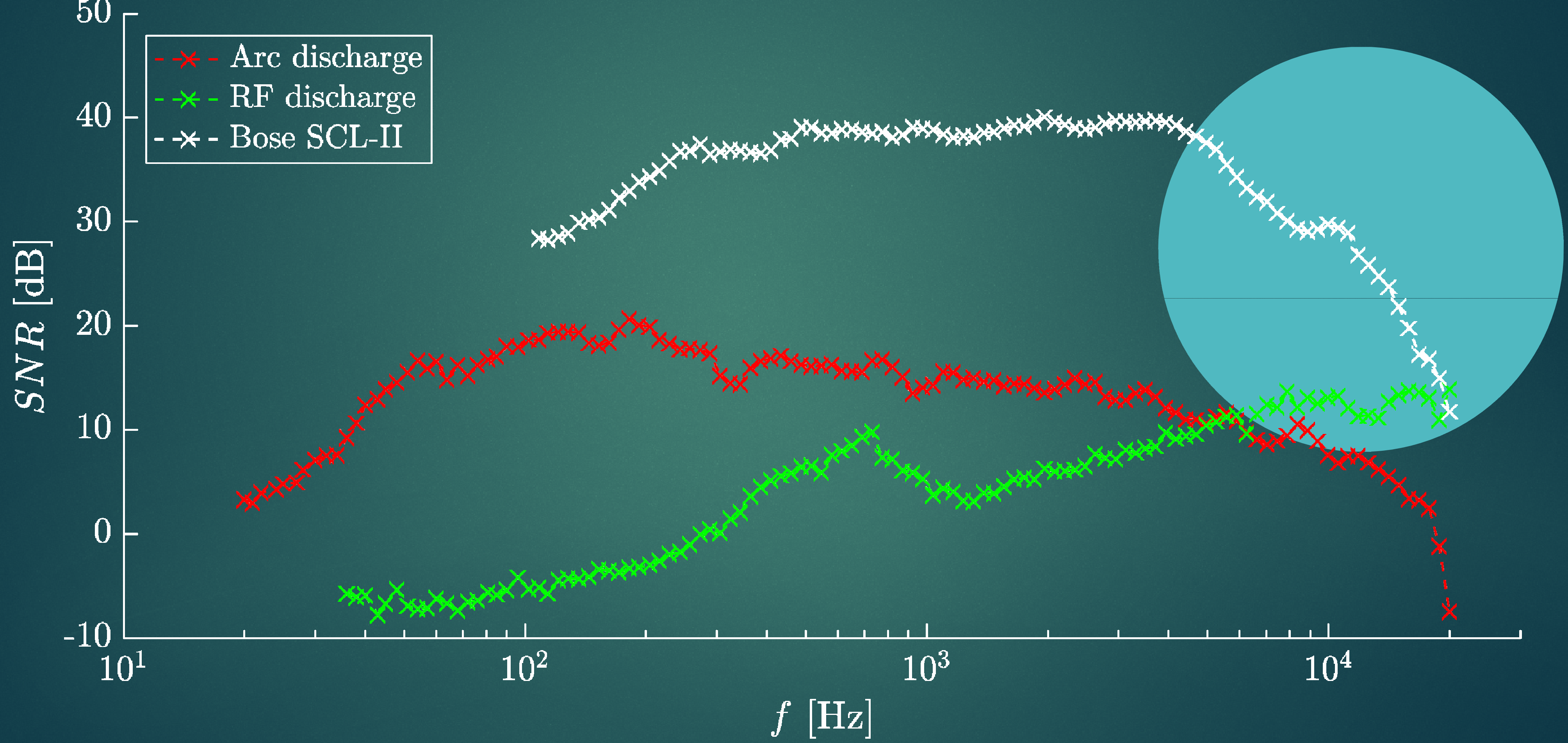


Signal-to-noise ratio

$$SNR = \frac{P_{signal}}{P_{noise}}$$

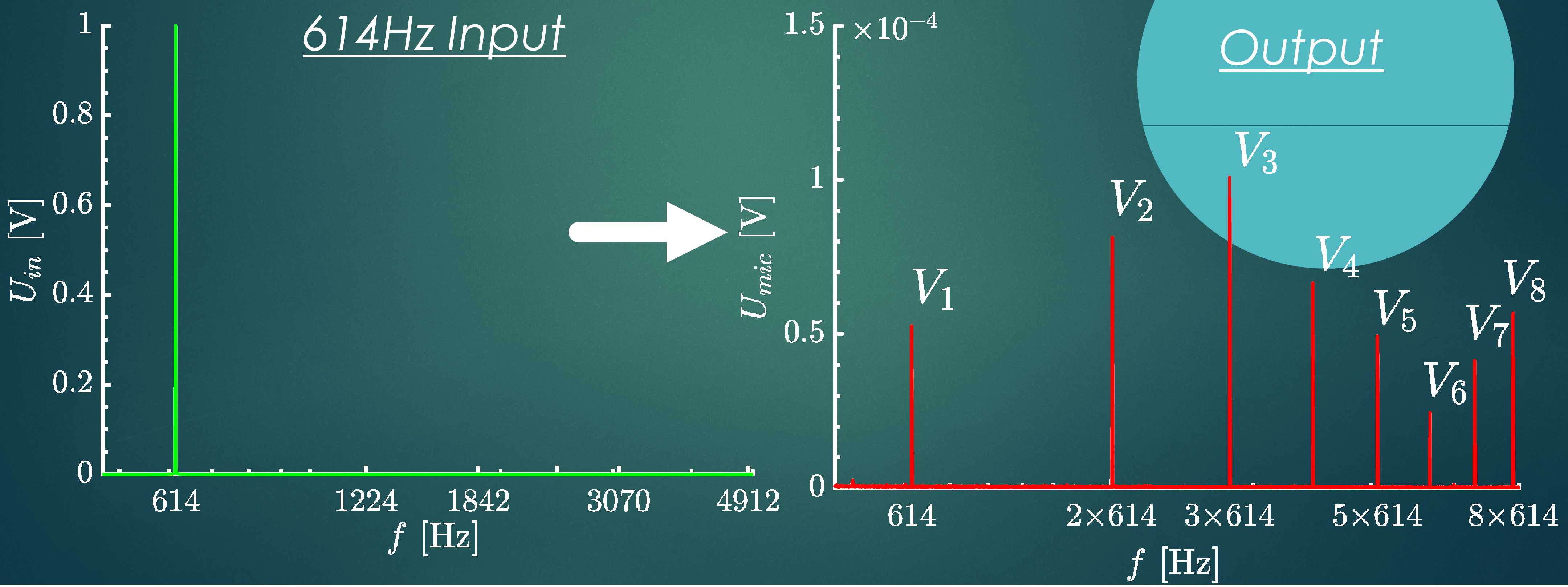


Signal-to-noise ratio

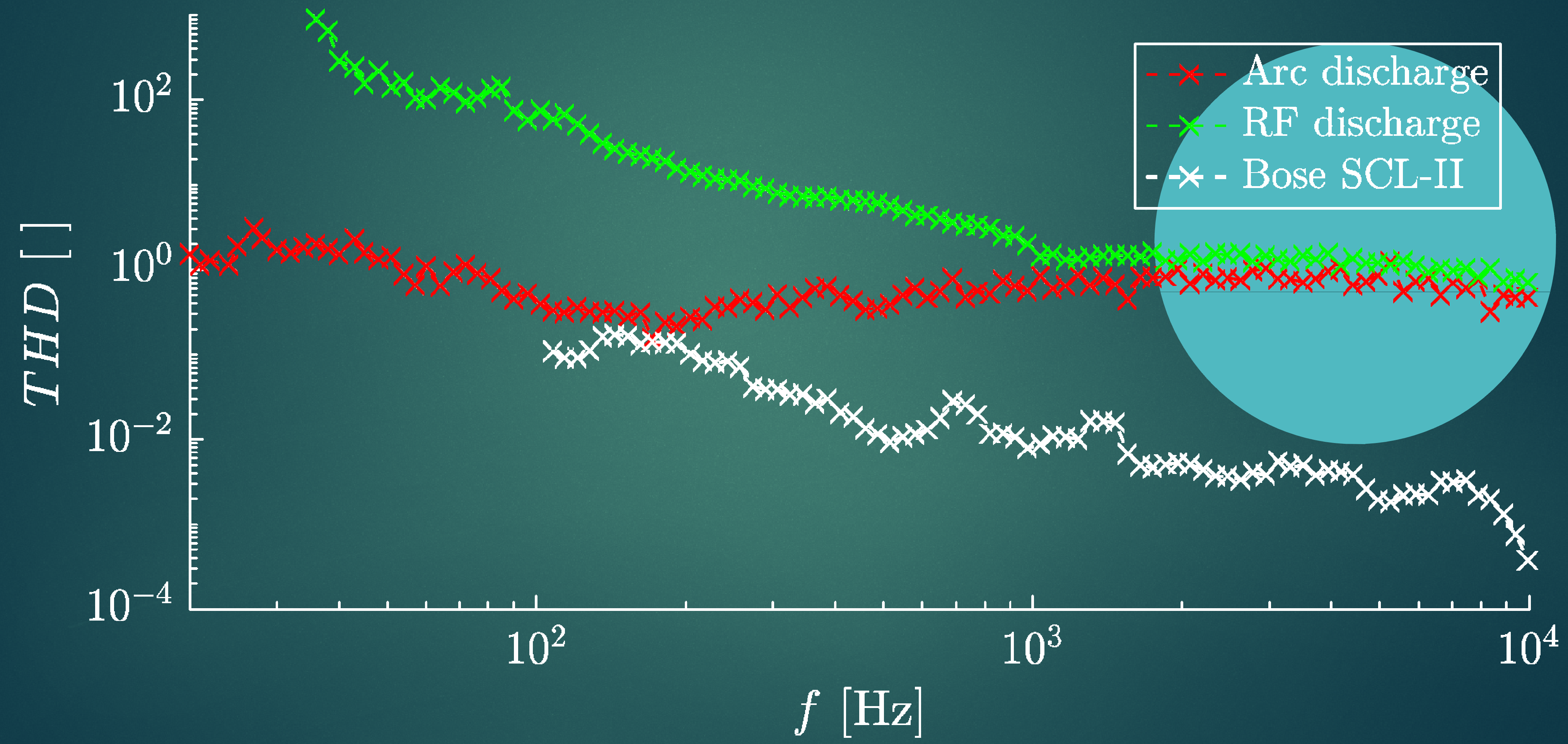


Total harmonic distortion

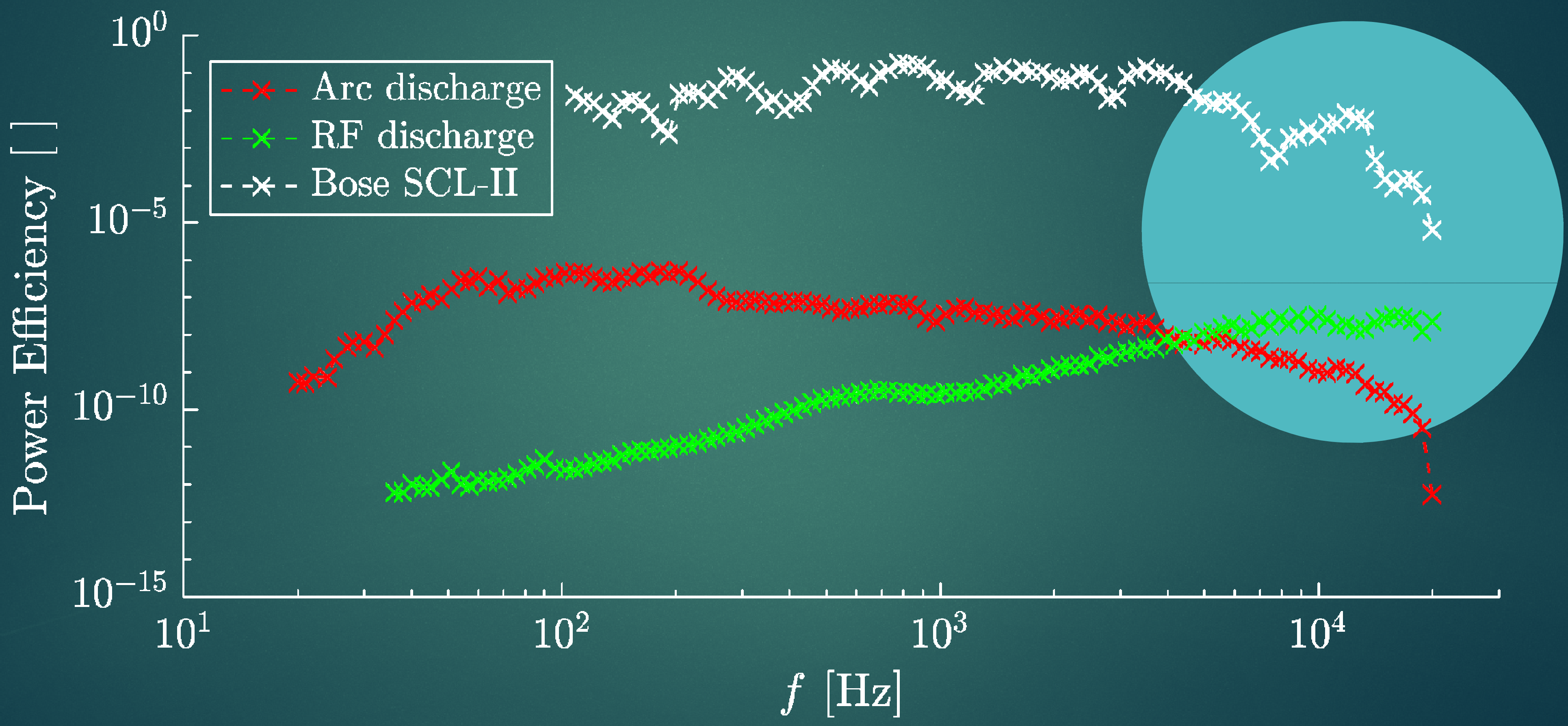
$$THD_F = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \ldots}}{V1}$$



Total harmonic distortion

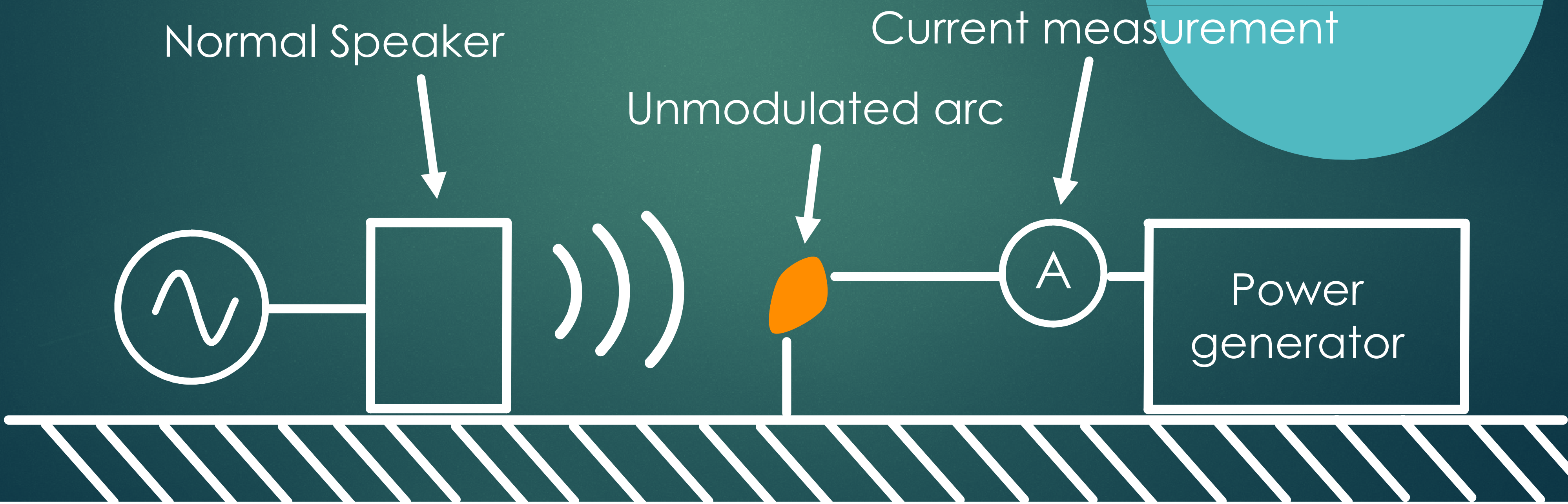


Power efficiency

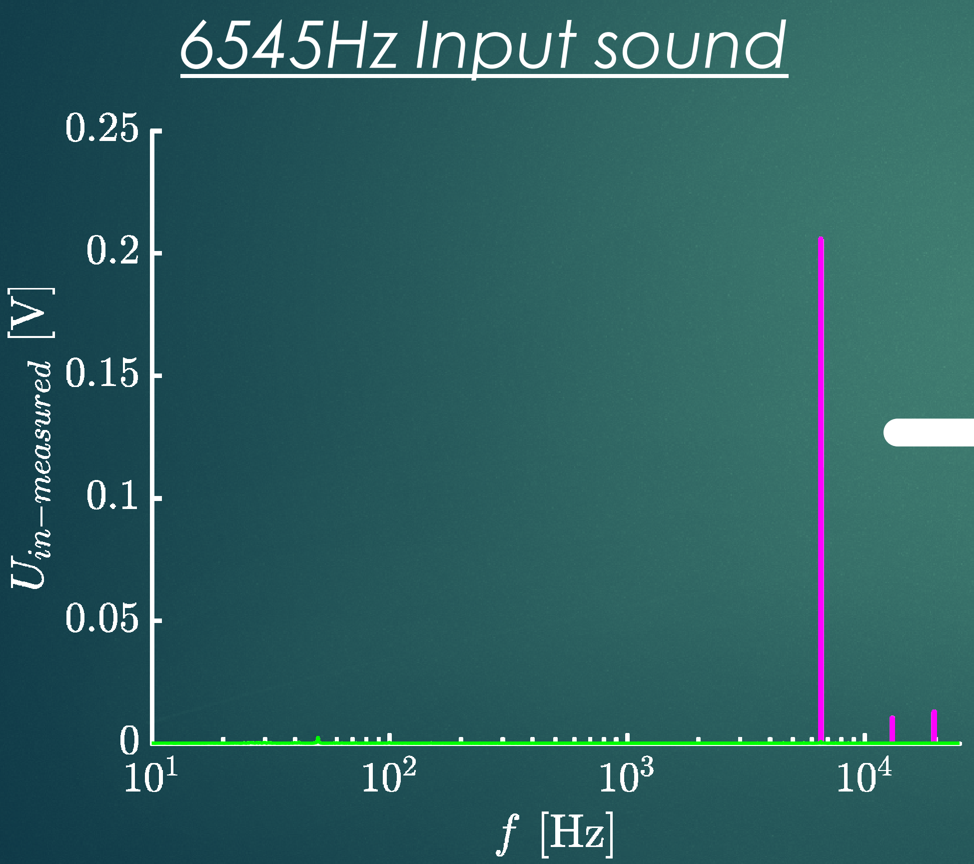


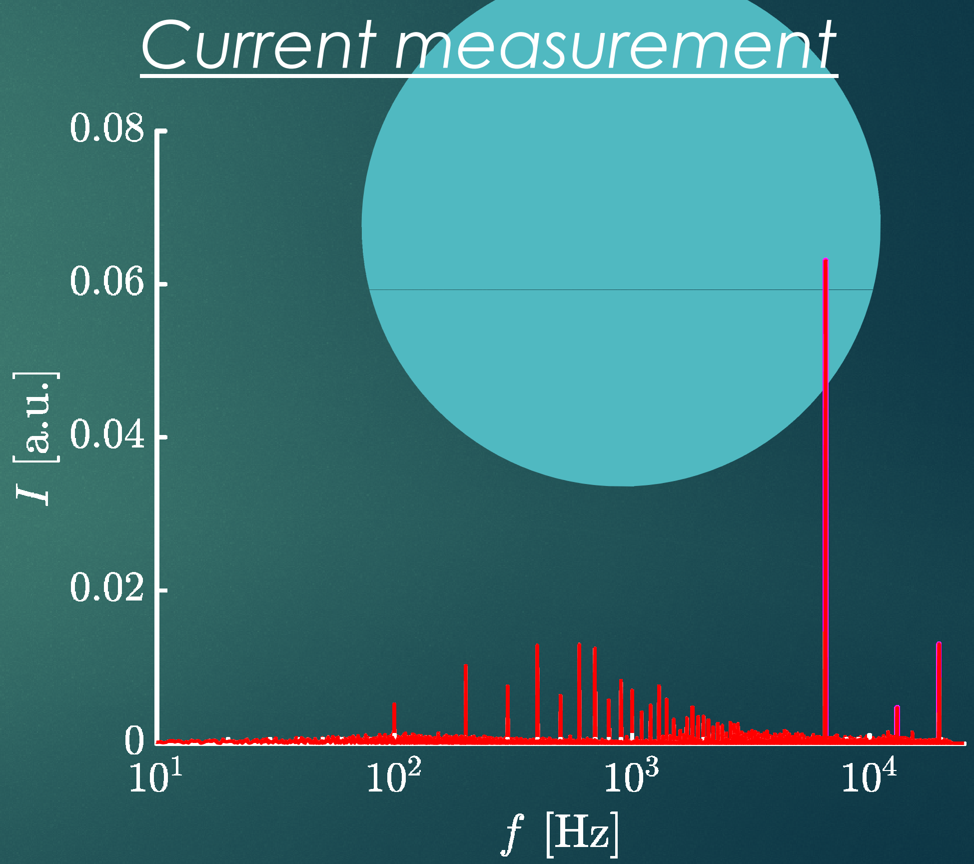
Microphone?

$$\nabla^2 p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = -\frac{\gamma - 1}{c^2}\frac{\partial H}{\partial t} + \nabla \cdot \mathbf{F}$$

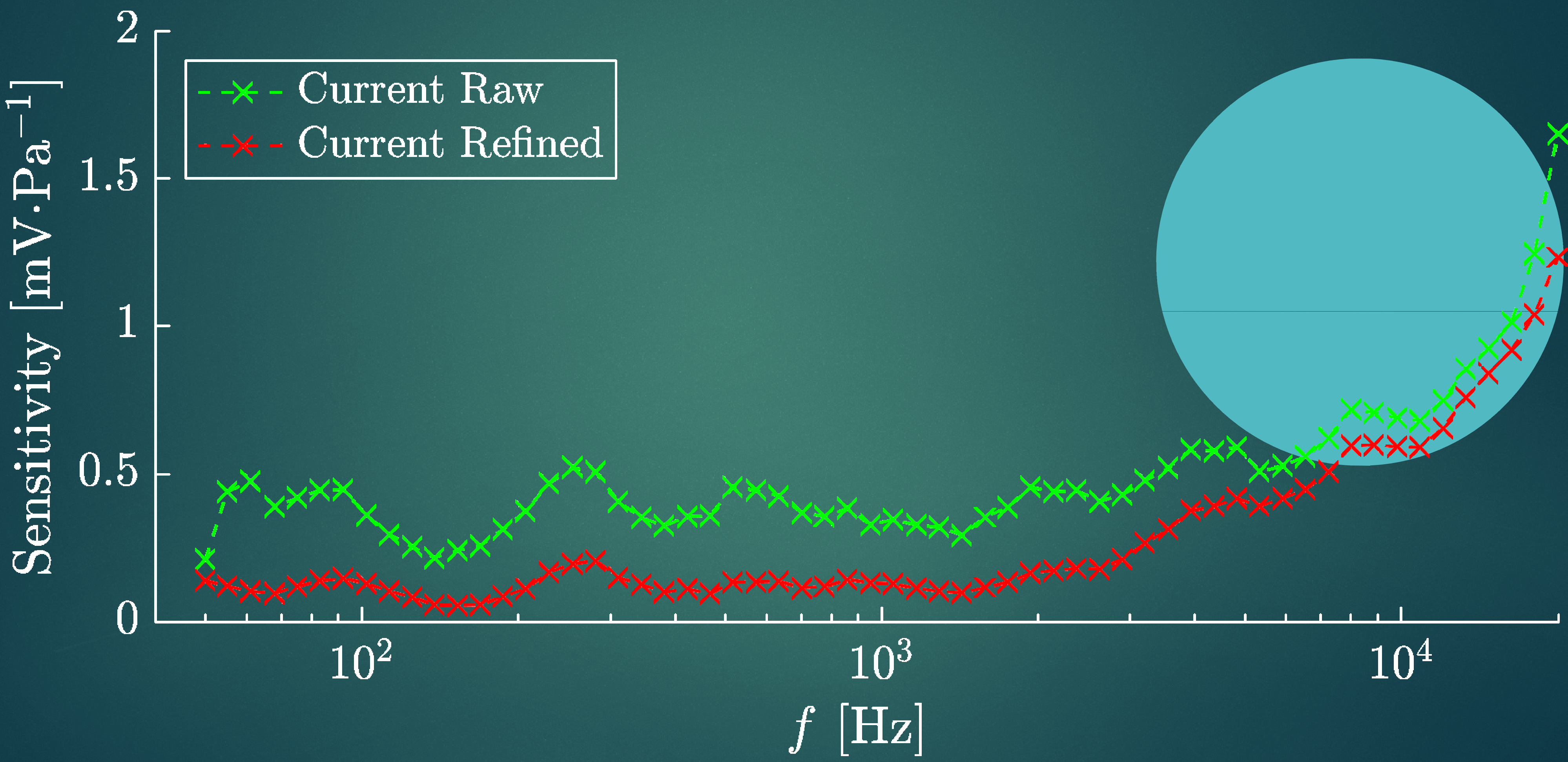


Microphone?


6545Hz Input sound
0.25
0.2
0.15
0.1
0.05
0
$U_{in-measured}$ [V]
10^1
10^2
10^3
10^4
f [Hz]


Current measurement
0.08
0.06
0.04
0.02
0
I [a.u.]
10^1
10^2
10^3
10^4
f [Hz]

Microphone Sensitivity



Conclusion

- Explained sound production using plasma
- Built a working plasma speaker
  - Compared it with another model and a normal speaker
- Studied the properties of the Speaker
  - Frequency response, SNR, THD, Power efficiency.
- Turned it into a microphone

Limitations

- Safety issues
  - Flame
  - Ozone production
- Unpractical solution
  - High current (20A)
  - Low power efficiency
- Melting carbon rods shape

Further improvements

- 3-way speaker (tweeter, mid-range & woofer)
- Add substance to increase ions density
- Study optimal gap and position of the rods

Thank you for your attention!

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Sound pressure level

$$SPL_p = 20 \log \frac{p}{p_0} \;\; [dB]$$

$$p_0 = 2 \cdot 10^{-5} Pa$$

$0\ dB$
Hearing threshold

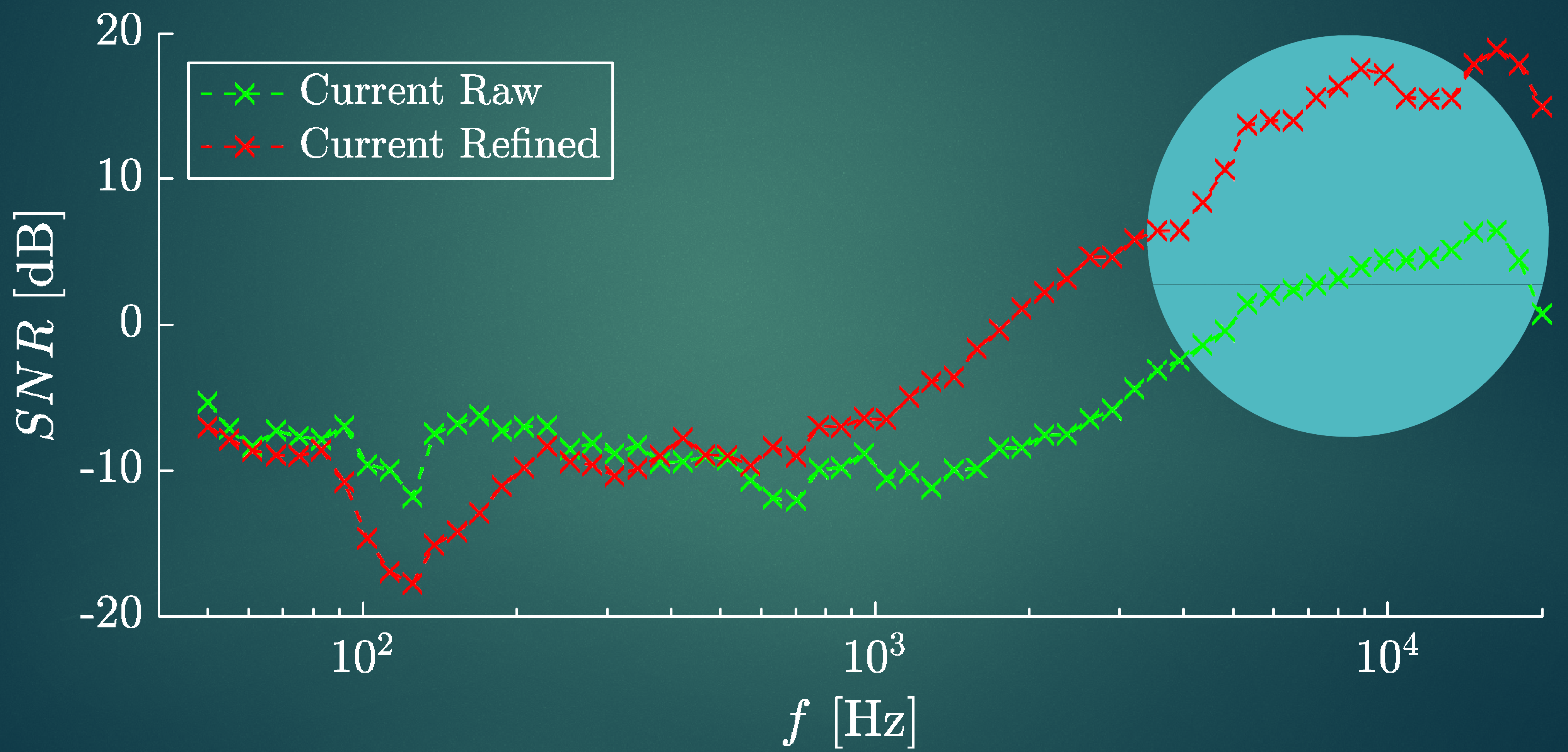
65 – 70 dB
Human voice

140 – 180 dB
Fighter jet launch

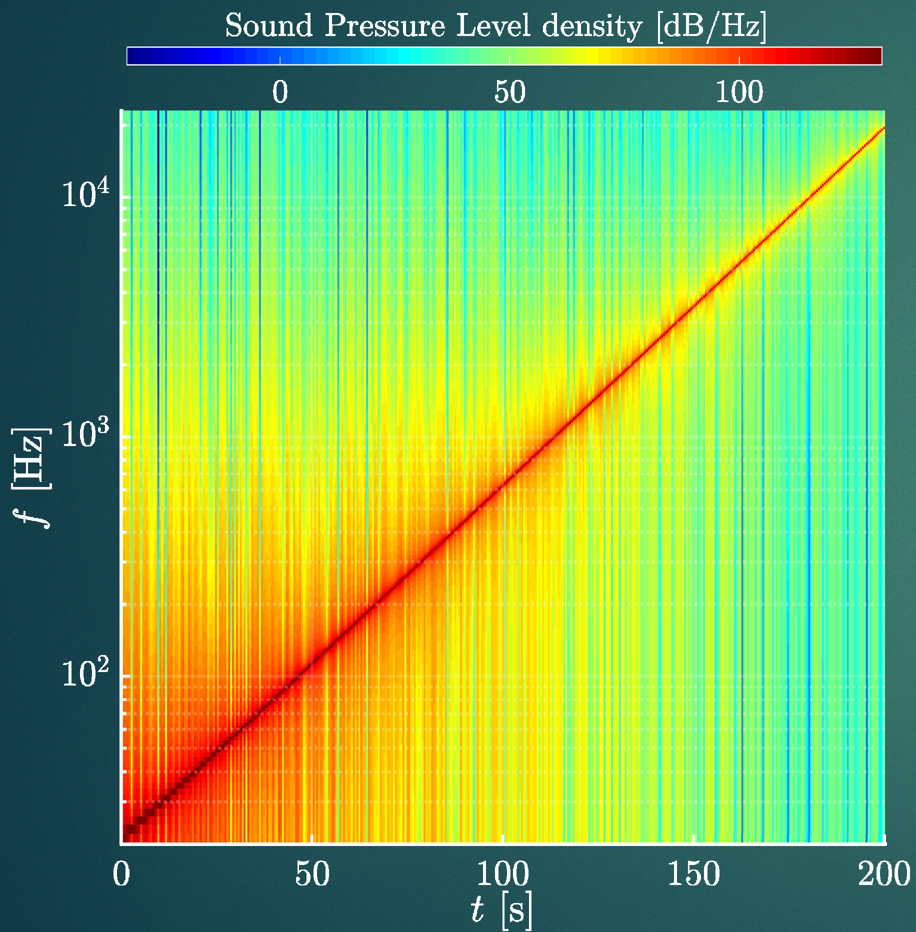
Whisper
15 – 25 dB

Orchestral Climax
100 – 110 dB

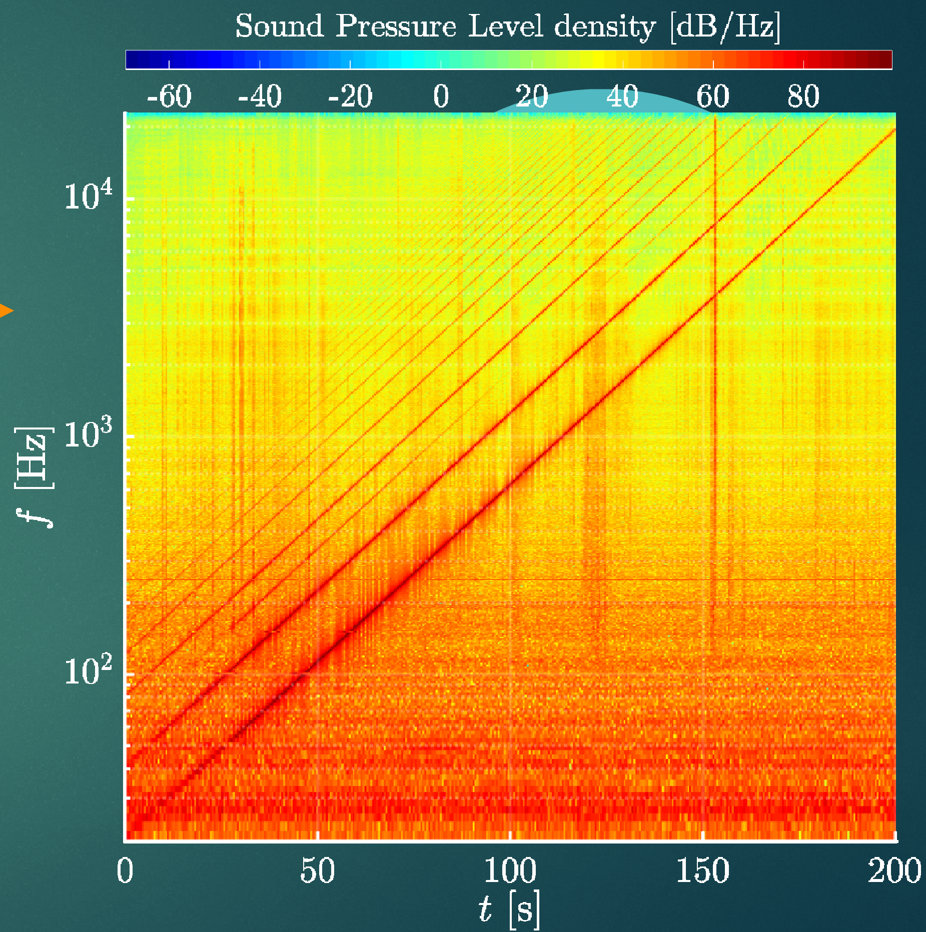
Microphone SNR



Spectrogram

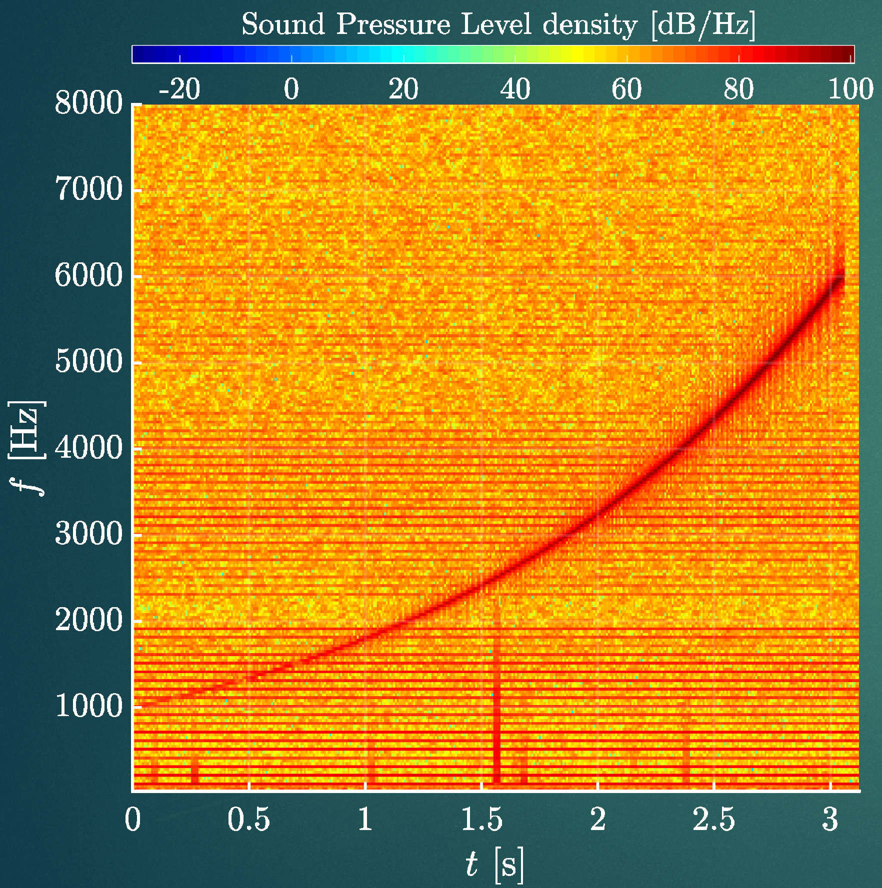


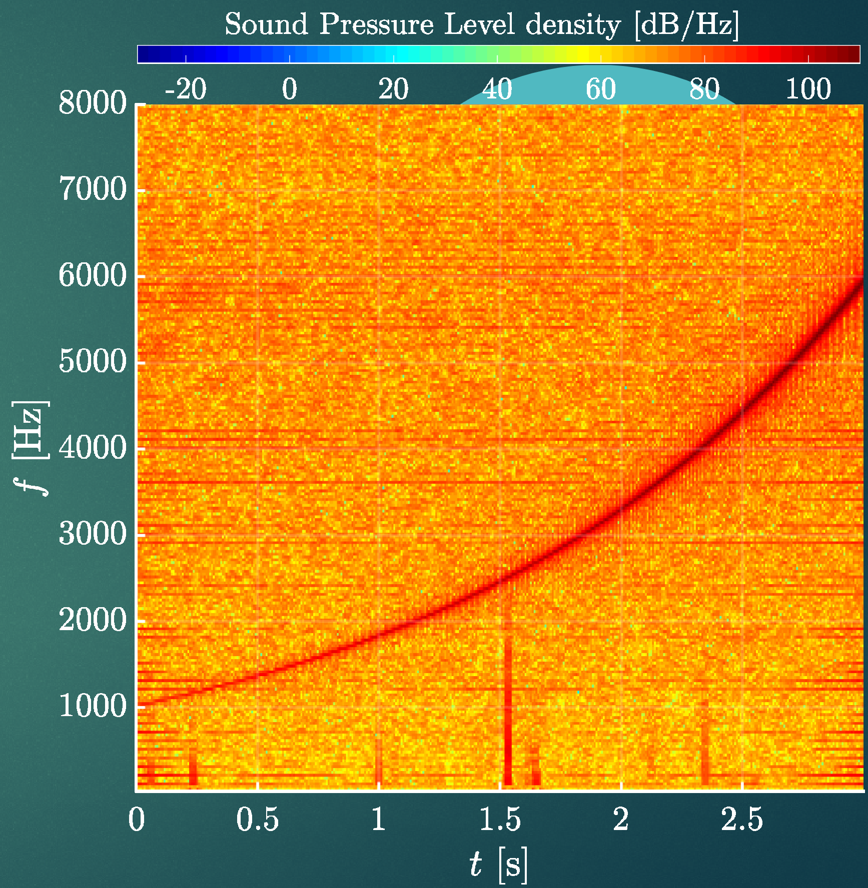
Input



Output

Microphone spectrogram





Before processing

After processing

Sound production

$$A = C\left(\frac{d(IV)}{dt}\right)$$ [1]

A - amplitude of the sound wave
I - current across the electrodes
V - voltage between the electrodes
C - constant coefficient

Square/ triangular wave harmonics

Square:

$$x(t) = \frac{4}{\pi} \sum_{k=1}^{\infty} \frac{\sin\left(2\pi(2k-1)ft\right)}{2k-1}$$

$$x_{\text{triangle}}(t) = \frac{8}{\pi^2} \sum_{k=0}^{\infty} (-1)^k \frac{\sin\left((2k+1)\omega t\right)}{(2k+1)^2}$$

Hissing noise

> Crater shape formation on carbon rods [2]
> Oxygen reaching the crater and combining with local carbon
> Results in drop of current leading to noise

References

Modeling of a dc glow plasma loudspeaker

Michael S. Mazzola, and G.Marshall Molen

F Bastien 1987 *J. Phys. D: Appl. Phys.* **20** 1547

[1] Ingard U 1966 *Phys. Rev.* **145** 41-46

[2] Ayrton, “The hissing of he electric arc”, Journal of the Institution of Electrical Engineers (Volume: 28, Issue: 140, June 1899)

Saha law

y : ionisation rate

$$\frac{y^2}{1-y} = \frac{1}{n}\left(\frac{2\pi m_e k_B T}{h^2}\right)^{3/2} \exp\left(-\frac{\chi}{k_B T}\right)$$

$$a = \frac{1}{n}\left(\frac{2\pi m_e k_B T}{h^2}\right)^{3/2} \exp\left(-\frac{\chi}{k_B T}\right) > 0$$

$$y = \frac{-a + \sqrt{a^2 + 4a}}{2}$$

UV from arc discharge