Problem №2
Static Speaker

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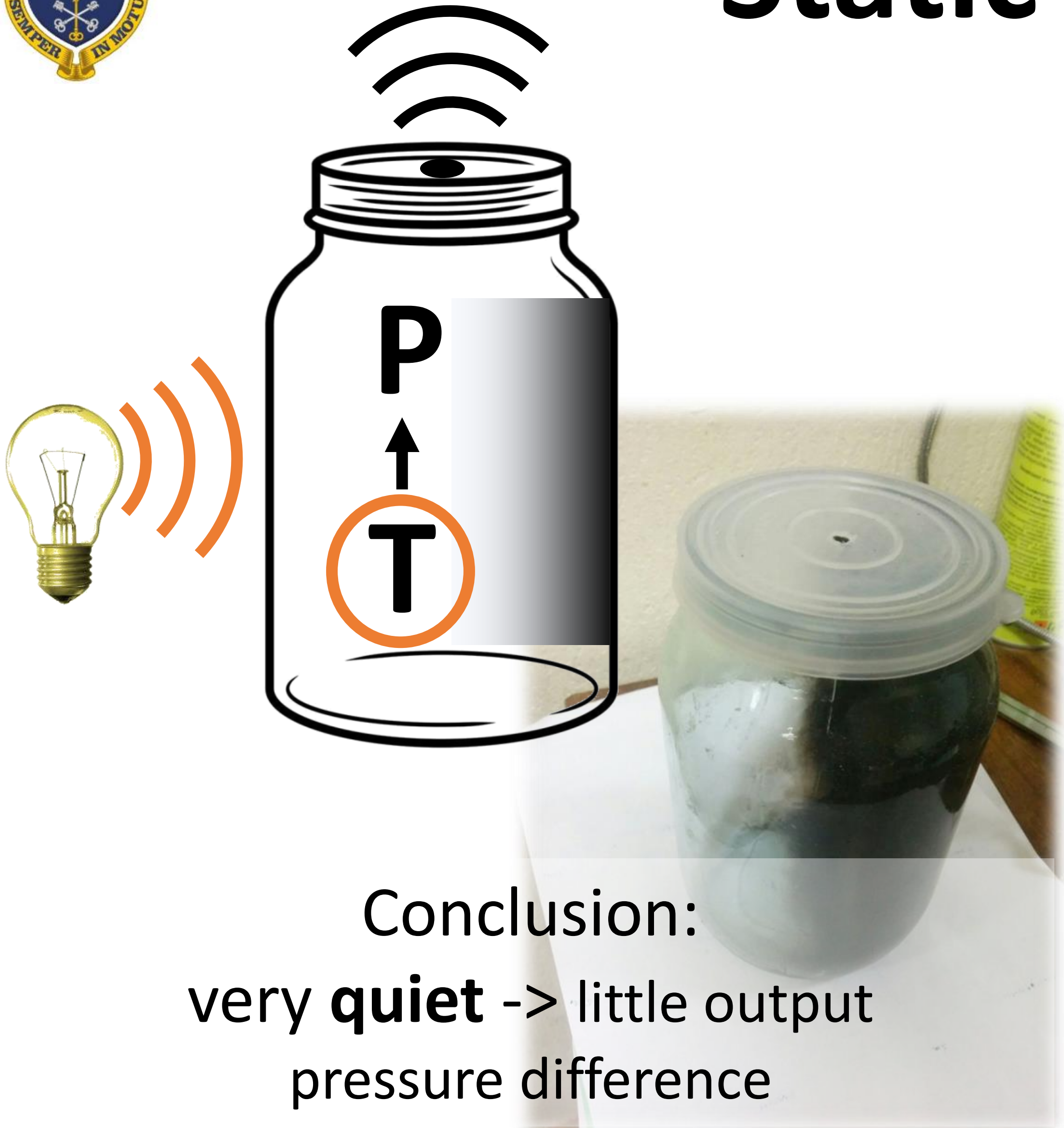
Static Speaker

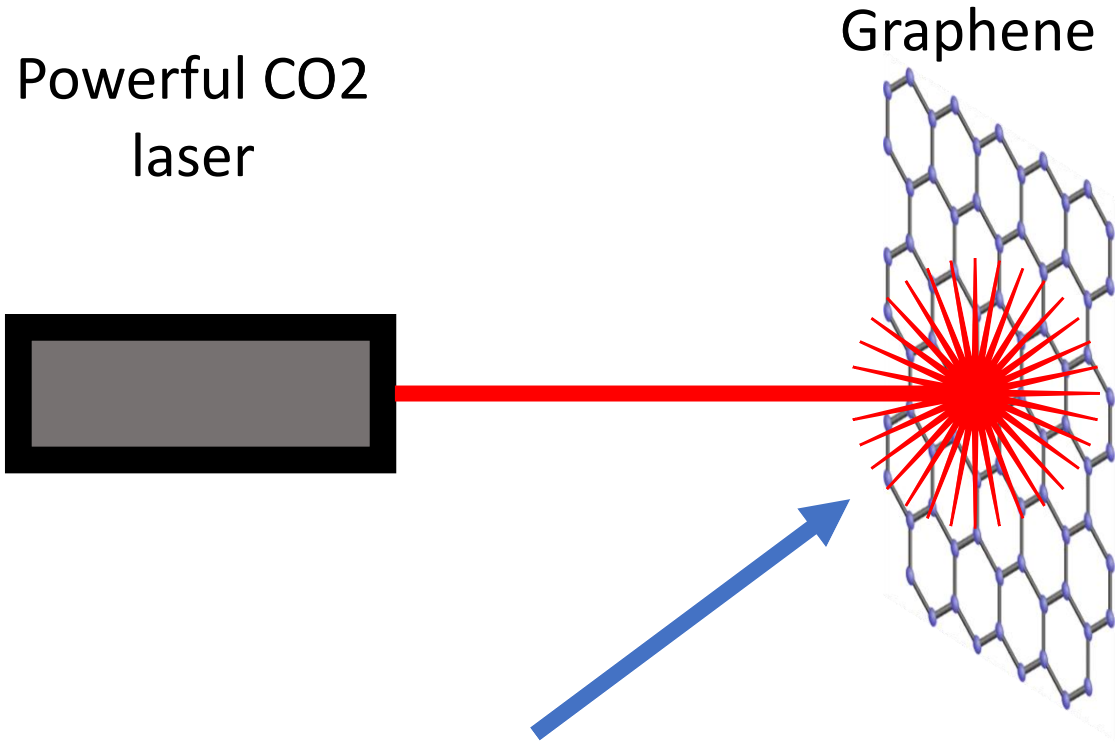
Build an audio speaker without any moving part. Discuss the maximum bandwidth, signal-to-noise ratio and power efficiency achieved with your design.

Is it possible to modify your device to use it as a *microphone*?

Static speakers



Conclusion:
very **quiet** -> little output pressure difference



thermoacoustic sound generation

Suk, J. W., Kirk, K., Hao, Y., Hall, N. A. and Ruoff, R. S. (2012), **Thermoacoustic Sound Generation from Monolayer Graphene for Transparent and Flexible Sound Sources**. Adv. Mater., 24: 6342–6347.

Discharges in gas

Corona discharge

(too quiet)

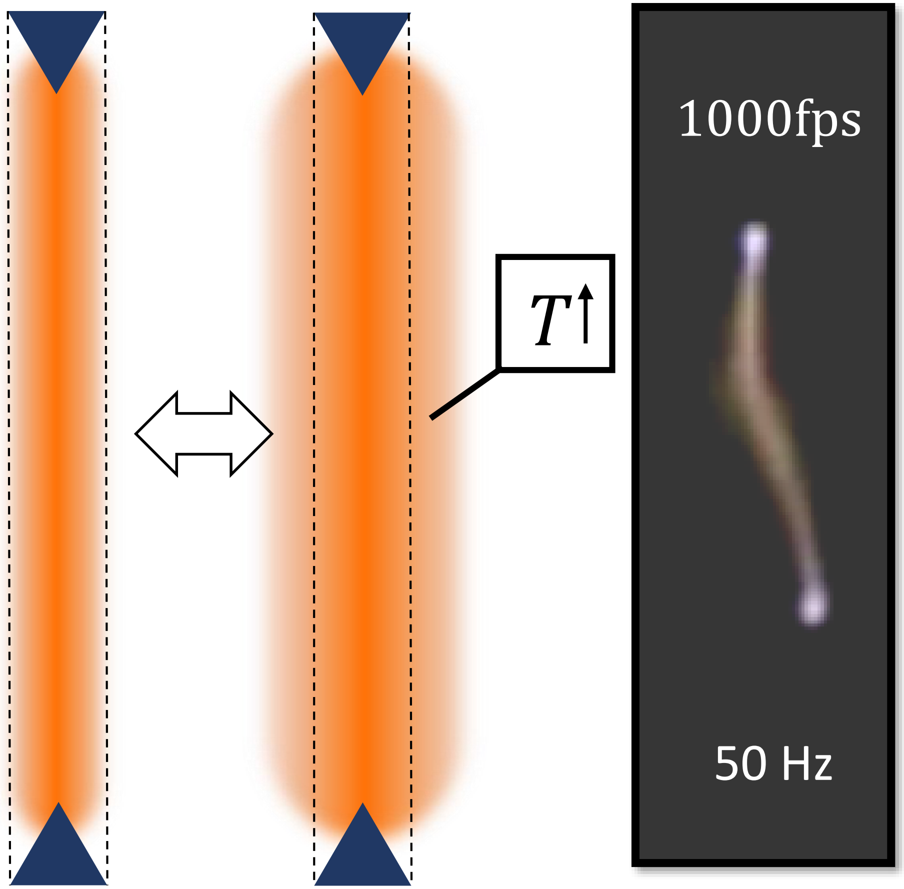
Multiple spark

(signal-to-noise ratio is bad)

Arc discharge

(the most appropriate)

Radiation of sound



Changing of current

Current density: $j \approx const$

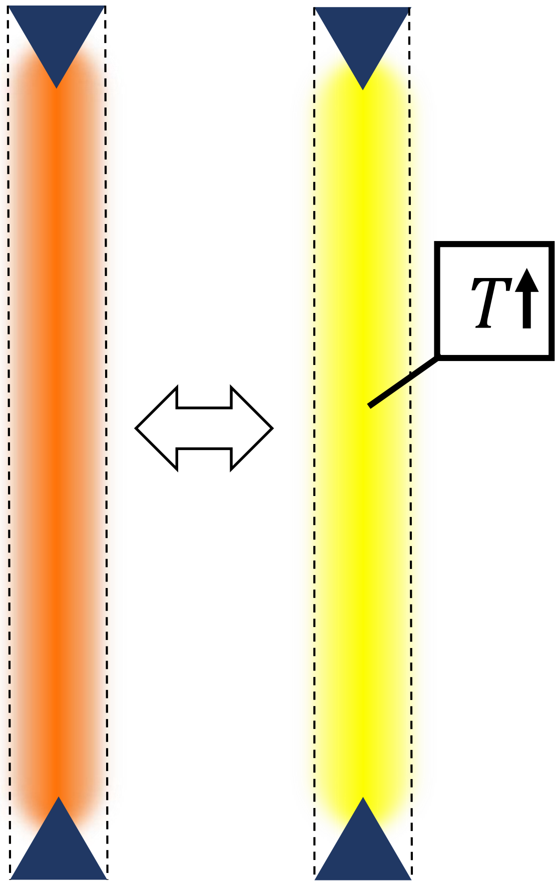
Changing of **current** leads to changing of arc diameter

Changing of **temperature** in the closest layer

$$f < f_{crit} = 6\ \text{kHz}$$

«Modeling of a dc glow plasma loudspeaker» Michael S. Mazzola and G. Marshall Molen

Radiation of sound



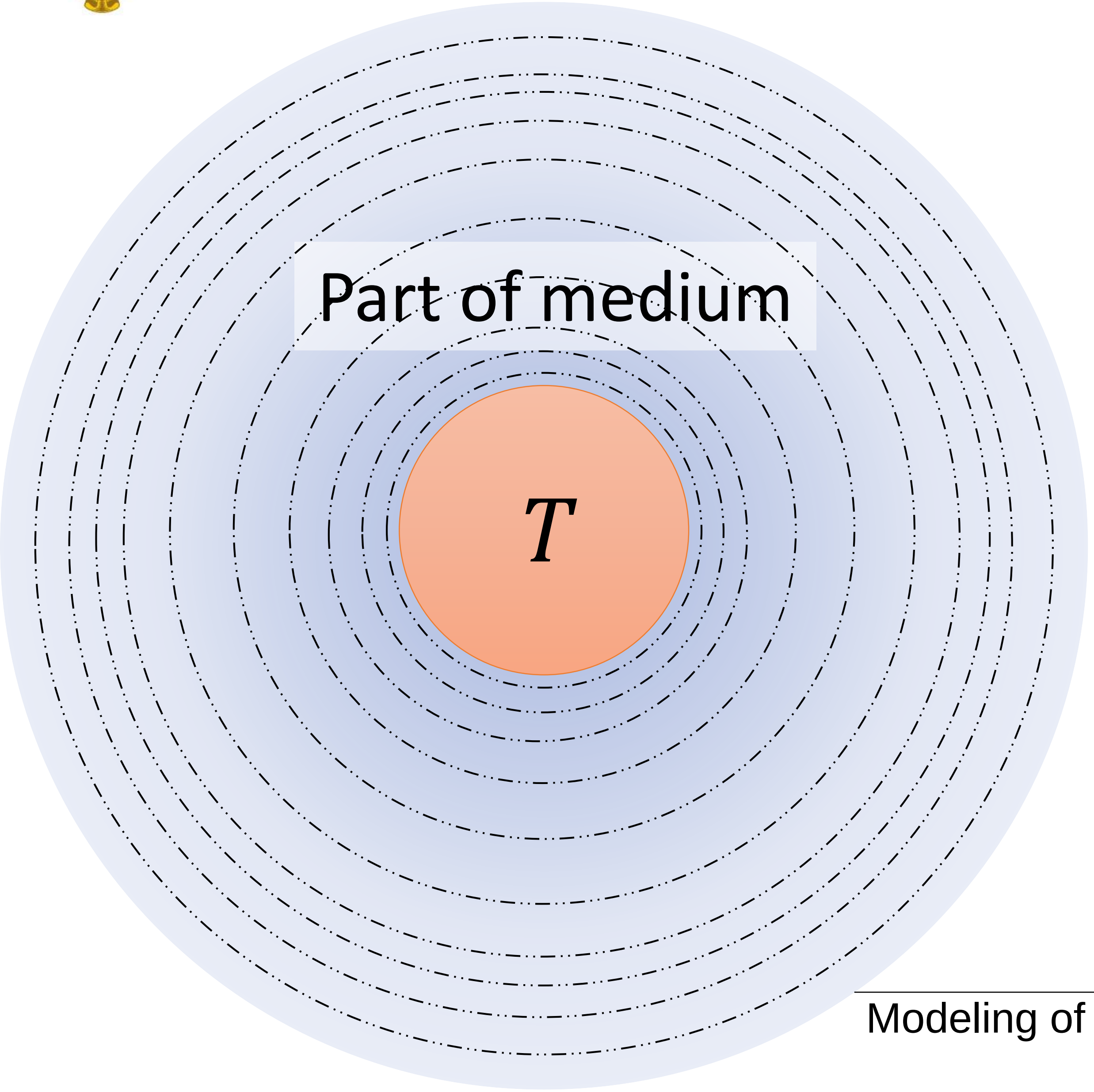
Changing of current I

Current density: $j \neq const$

Changing of current leads to changing of acr temperature due to additional ionization

$$f > f_{crit} = 6 \text{ kHz}$$

Radiation of sound



Oscillations of medium part temperature

$$\Delta T = \Delta T_0 \cos(\omega t)$$

Changing of pressure due to changing of temperature (from the adiabatic equation)

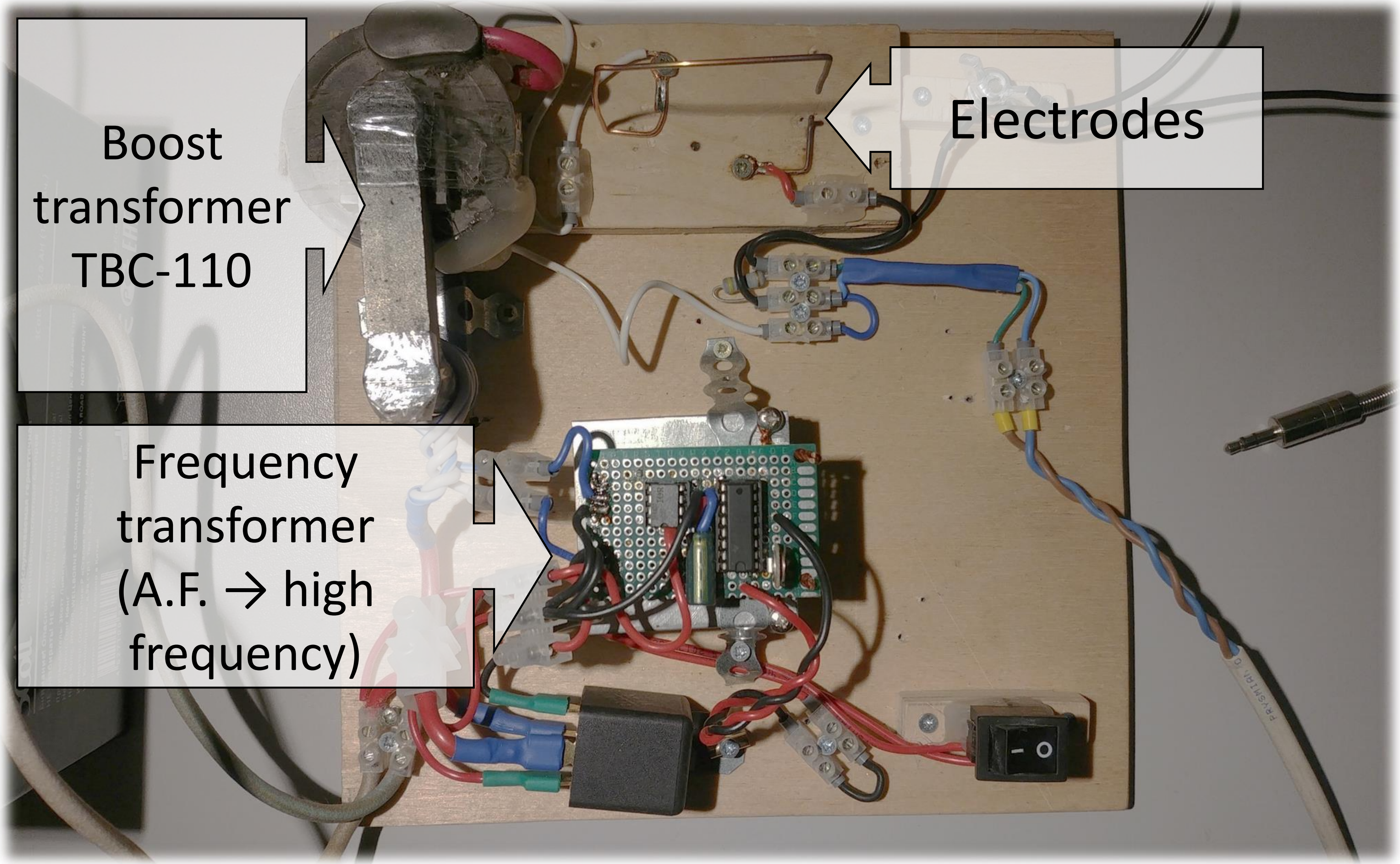
$$\frac{\Delta P}{P} = \frac{\gamma}{\gamma - 1}\frac{\Delta T}{T}$$

Local pressure oscillations

$$\Delta P = \Delta P_0 \cos(\omega t)$$

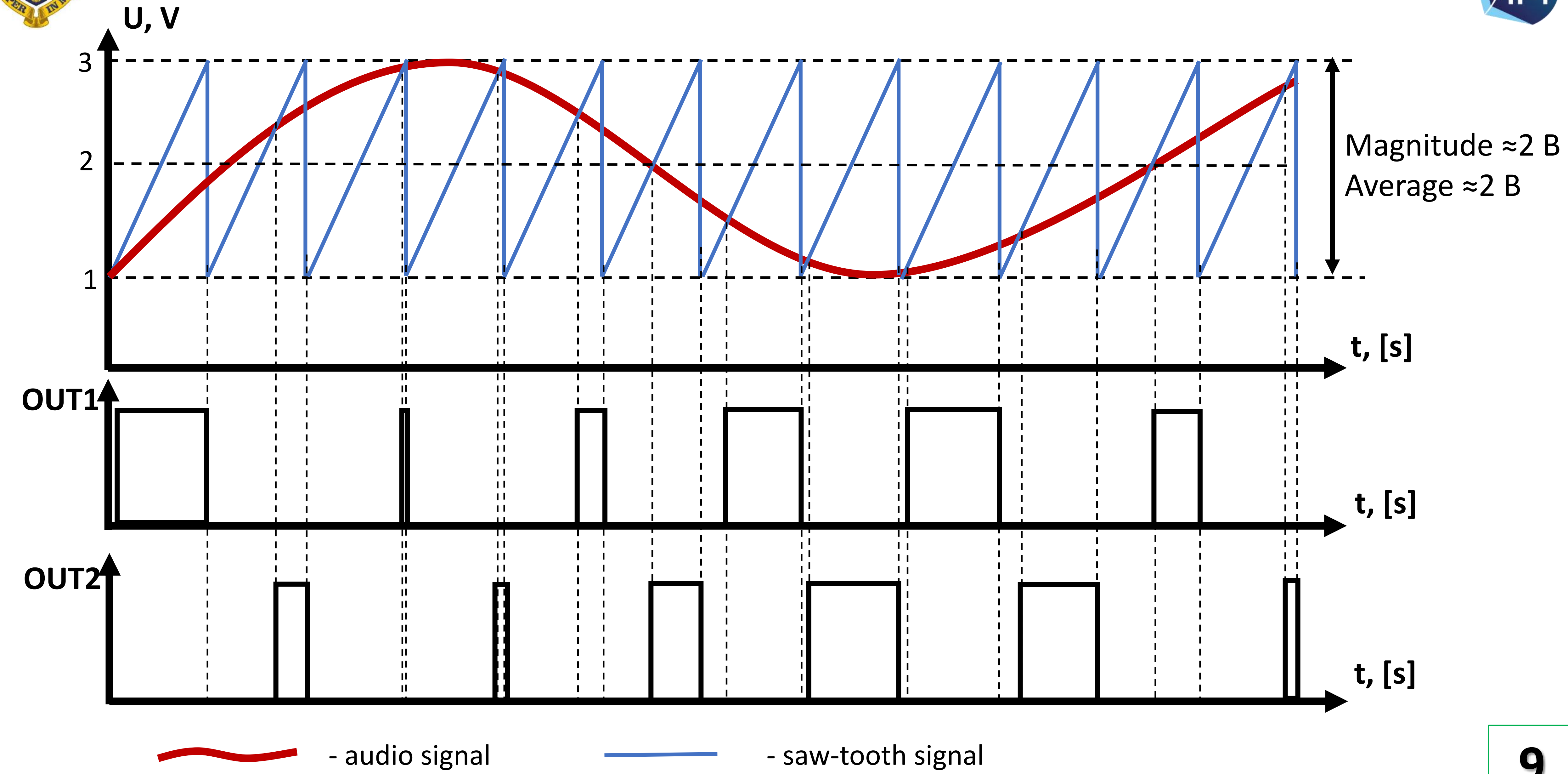
Modeling of a corona discharge microphone Journal of Physics D: Applied Physics Ph Béquin et al 2013

Ionophone

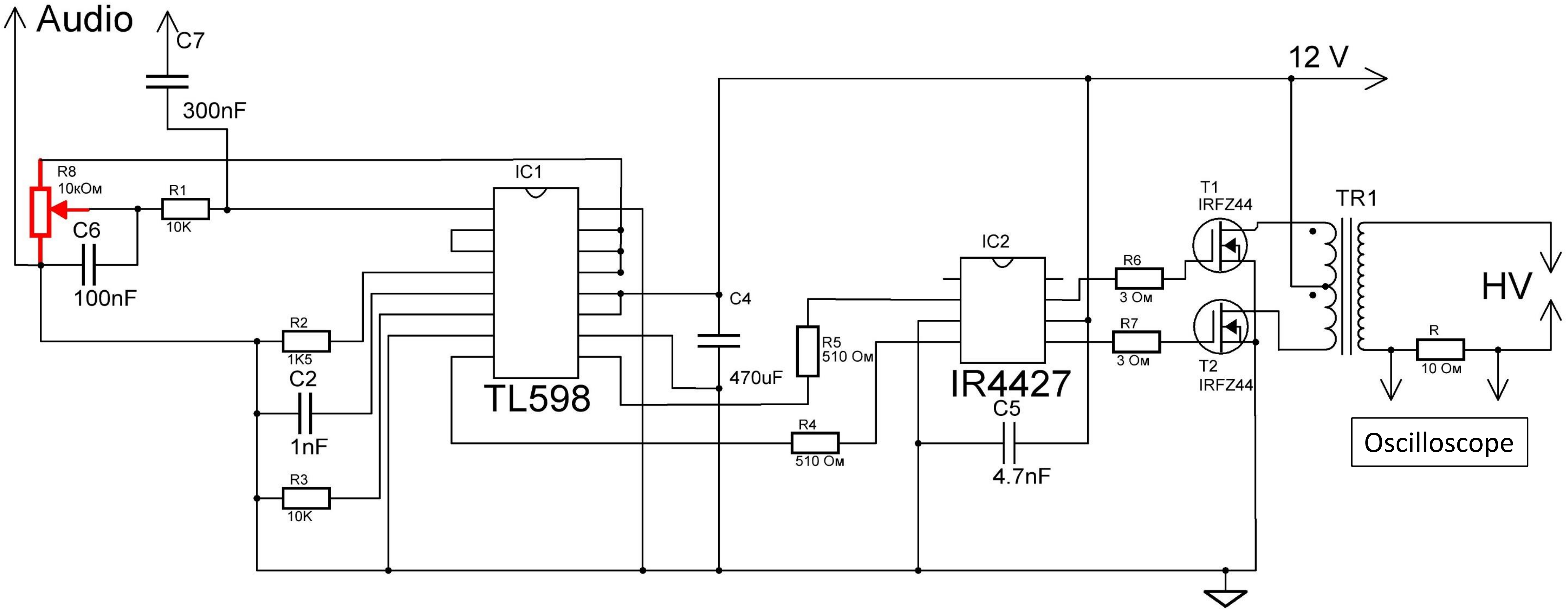


Boost transformer TBC-110
Electrodes
Frequency transformer (A.F. → high frequency)

Pulse-width modulation (PWM)

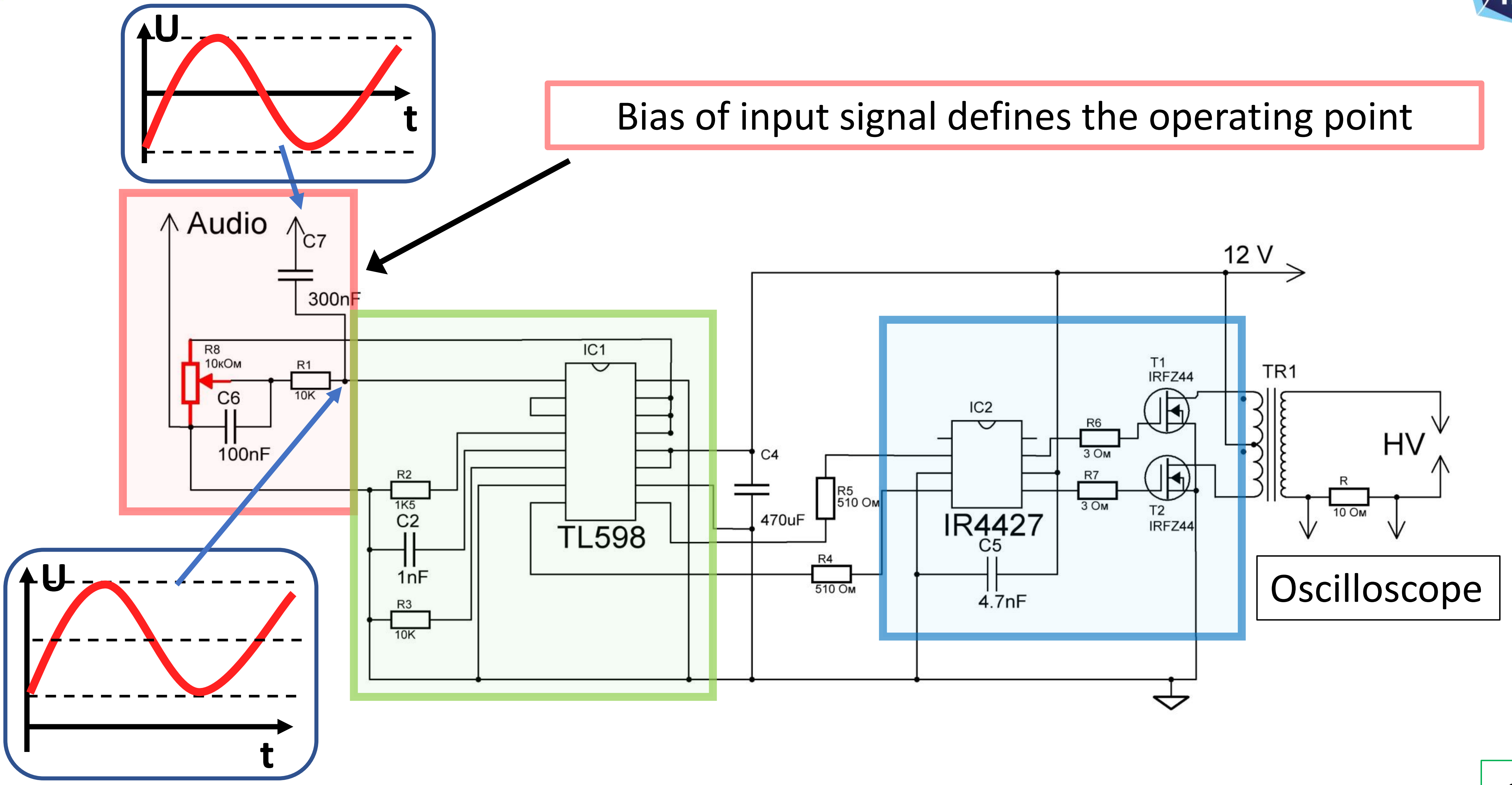


Electrical circuit



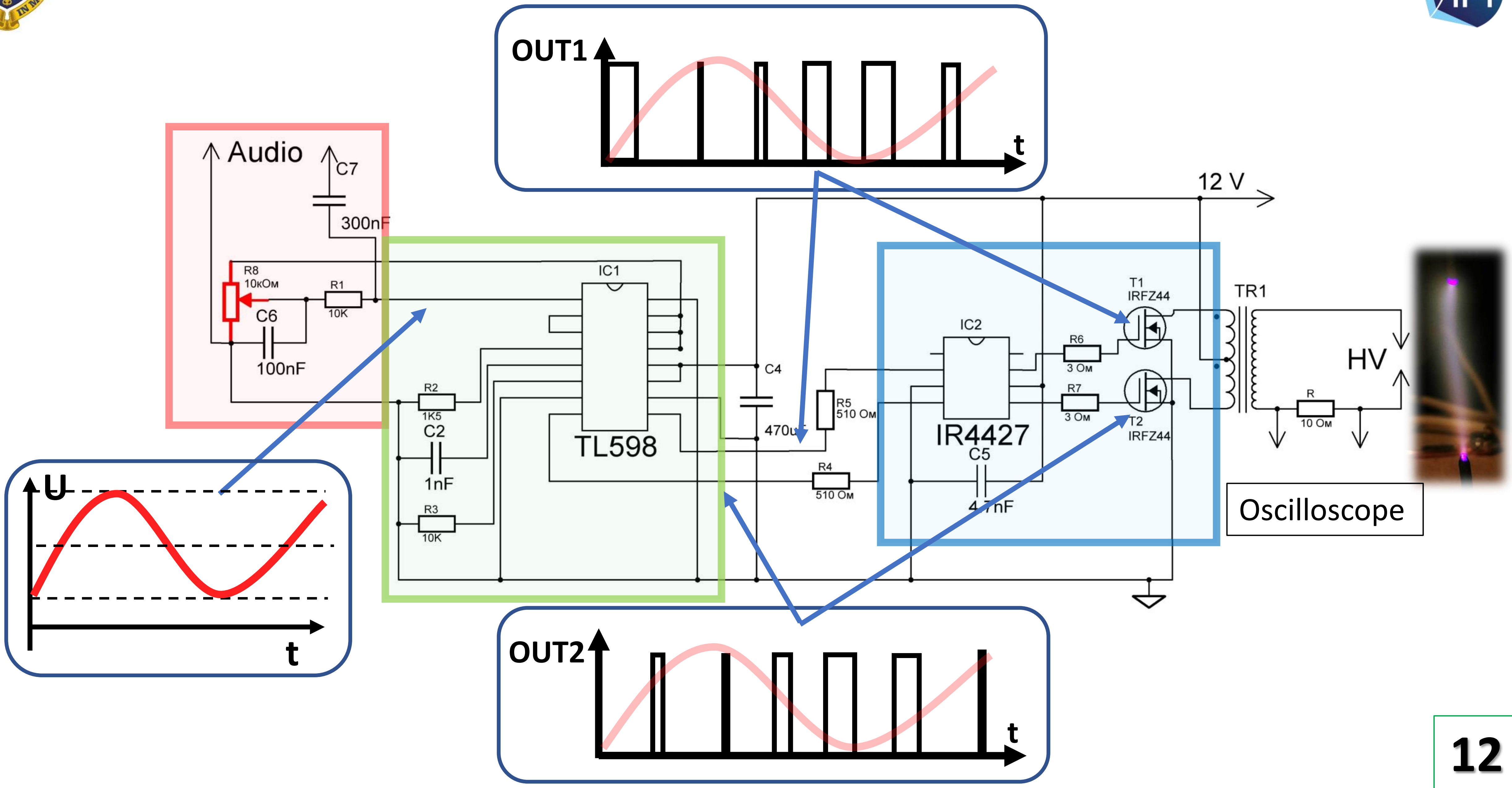
Electrical circuit

Bias of input signal defines the operating point

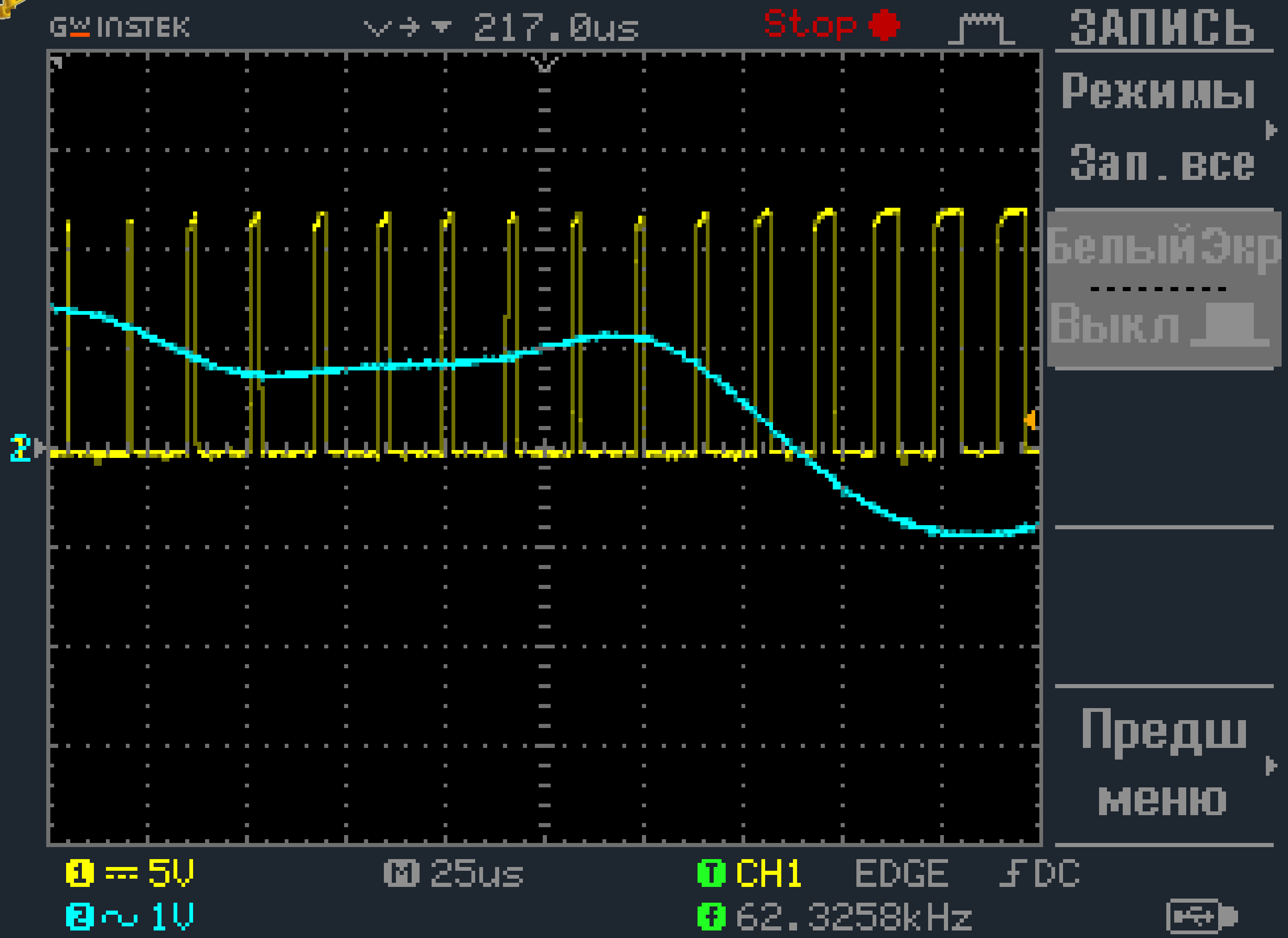


Oscilloscope

Electrical circuit



Oscillogram of PWM-signal



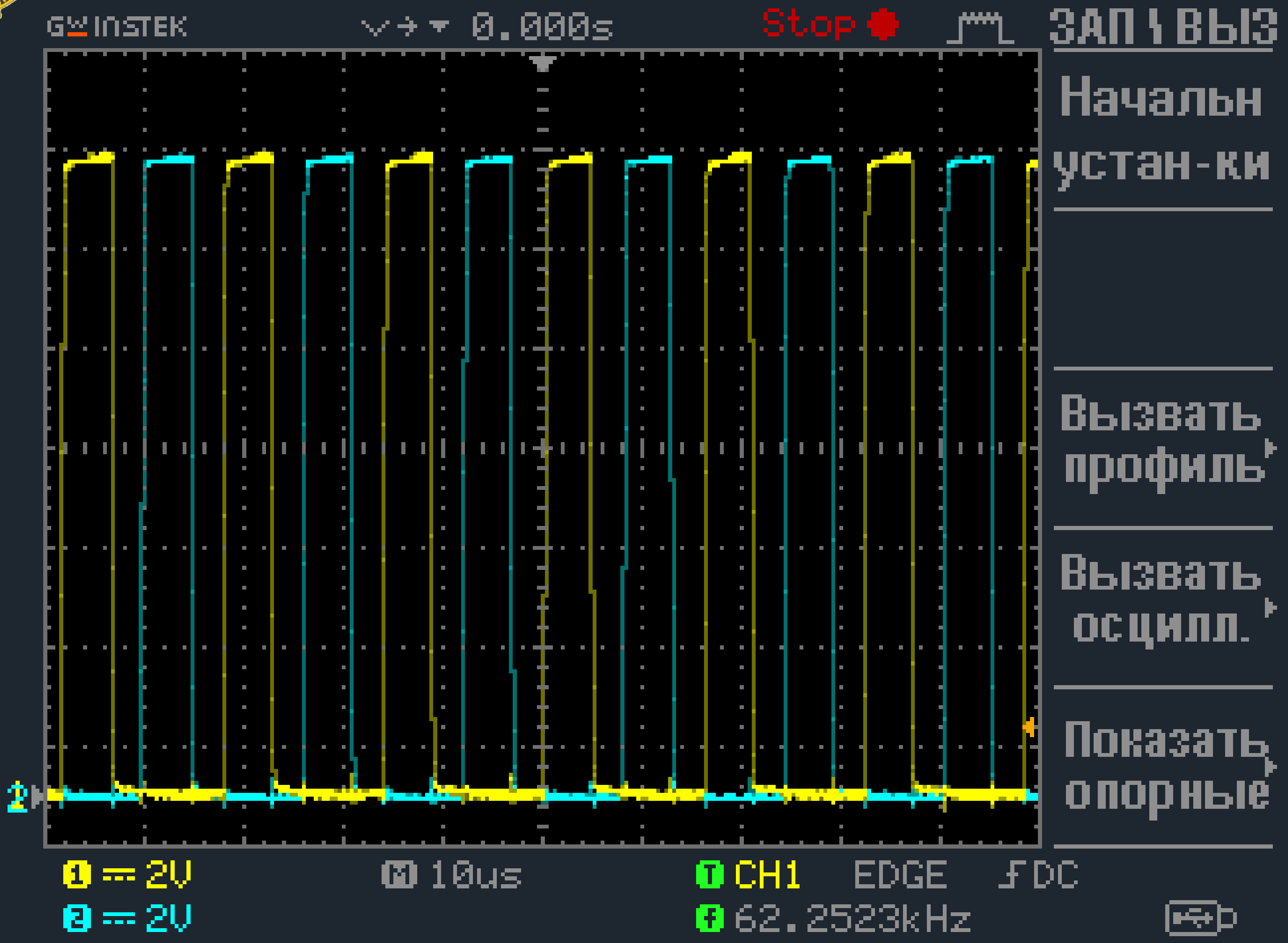
Changes:

- Duty factor
- Arc power

Modulated signal

Input signal

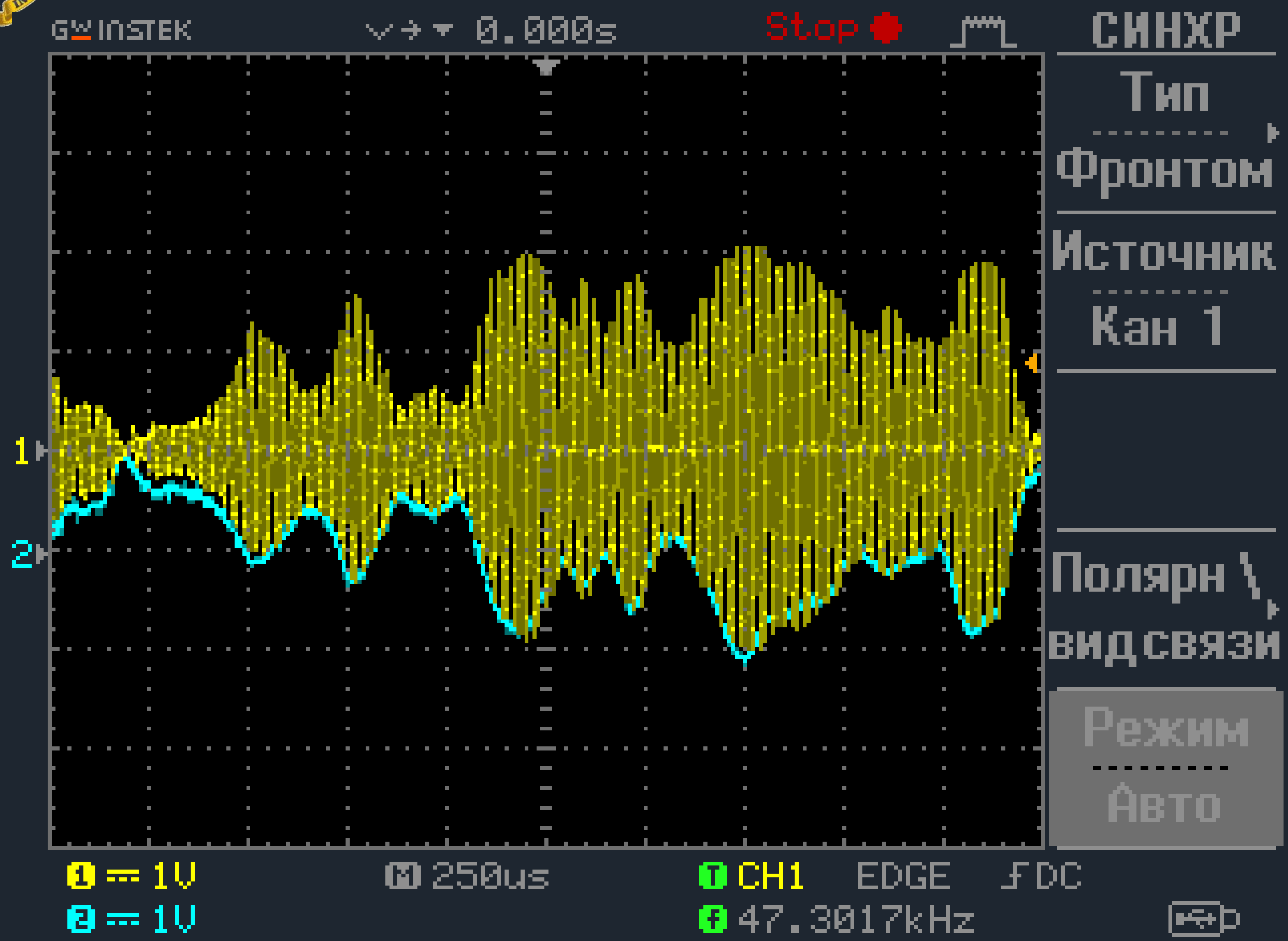
Reversed phase signal



-- OUT_1

-- OUT_2

Ionophone output



Arc current

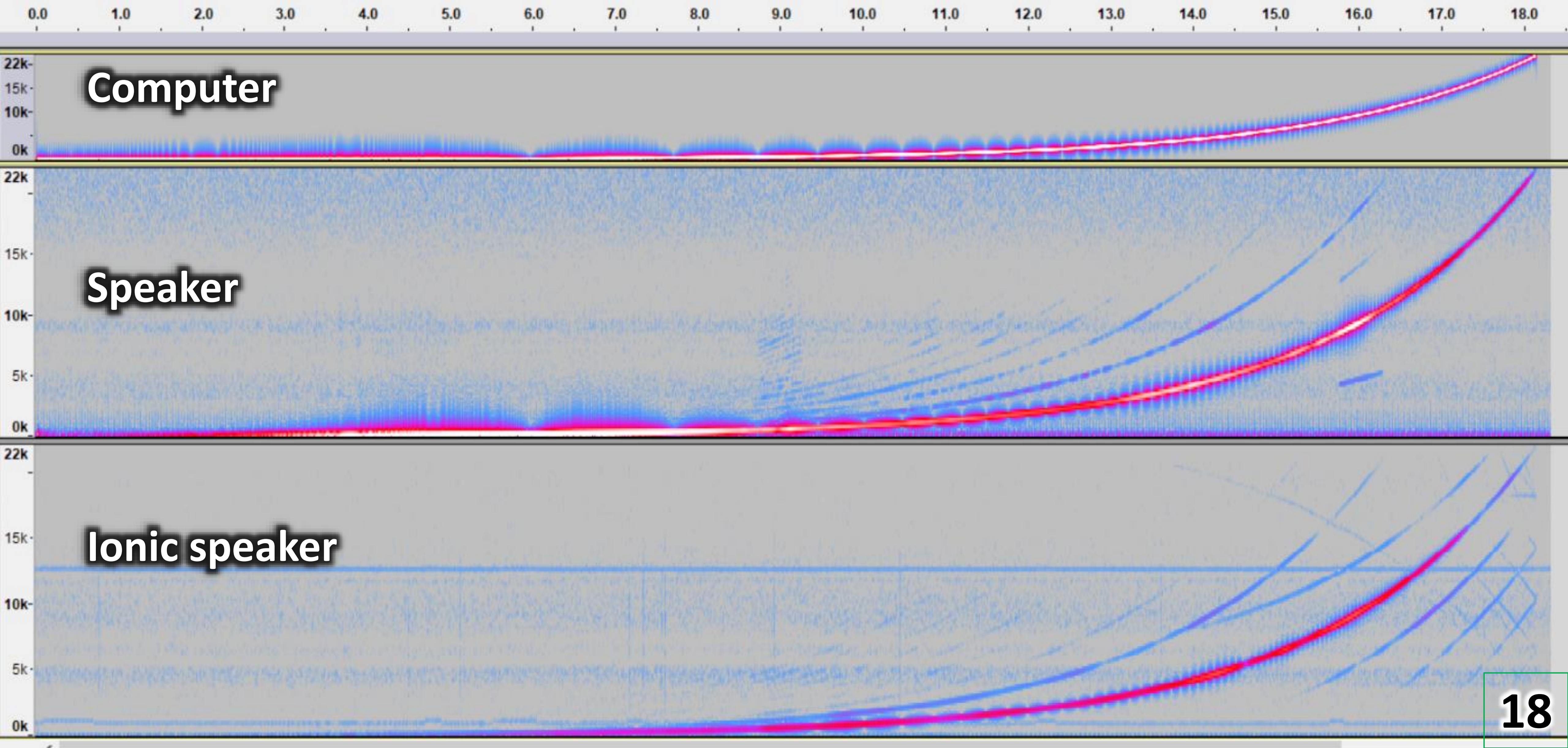
Audio output

Demonstration!

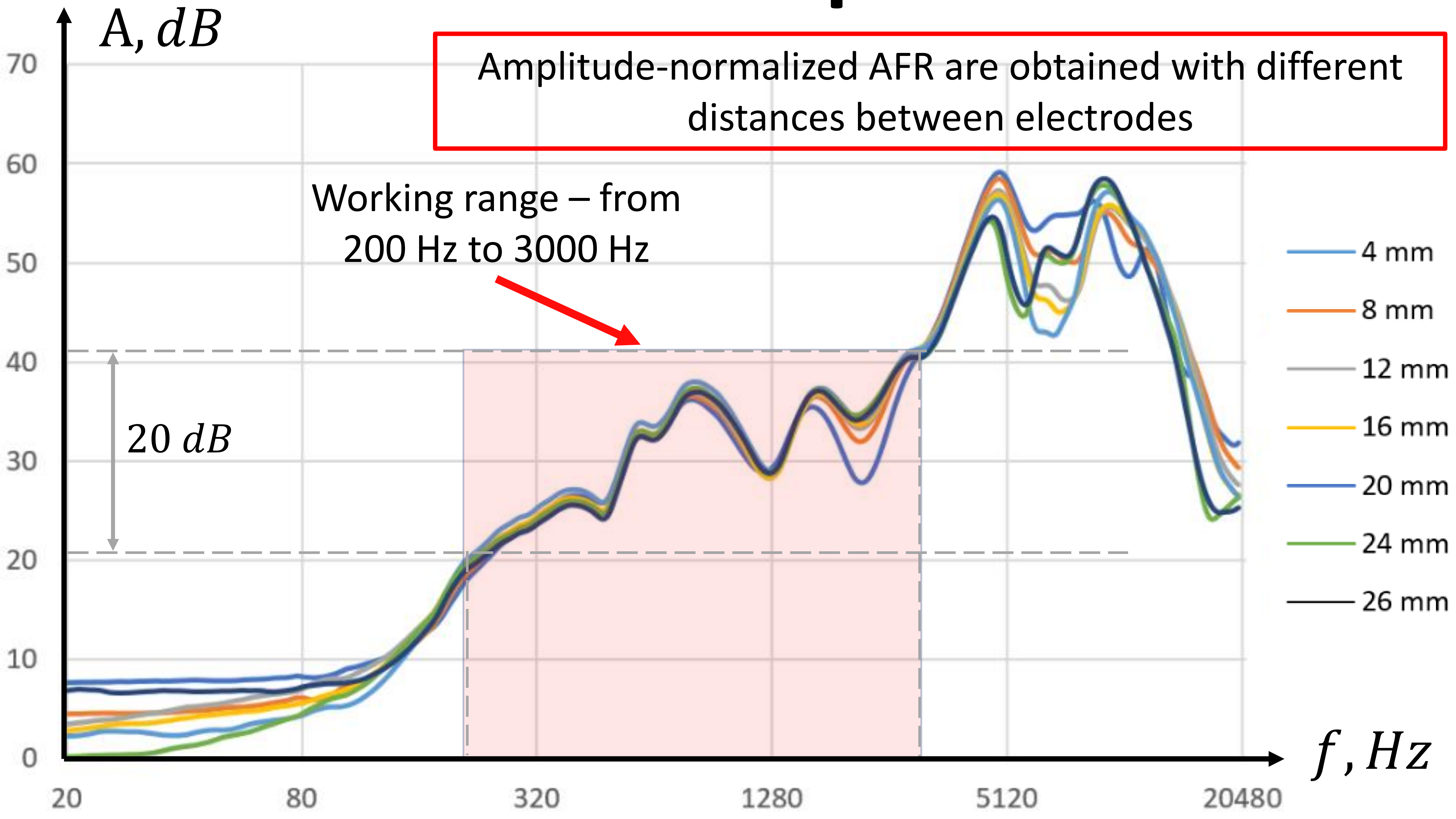
Investigation methodology

- Fixed electrodes
- Shielded microphone
- Grounded setup
- Distance to microphone ≈200 mm
- Soft: **RightMark Audio Analyser** 6.4.2
- Soft: **Audacity** 2.1.3
- External soundcard: Lexicon Alpha
- Microphone BBK CM-998

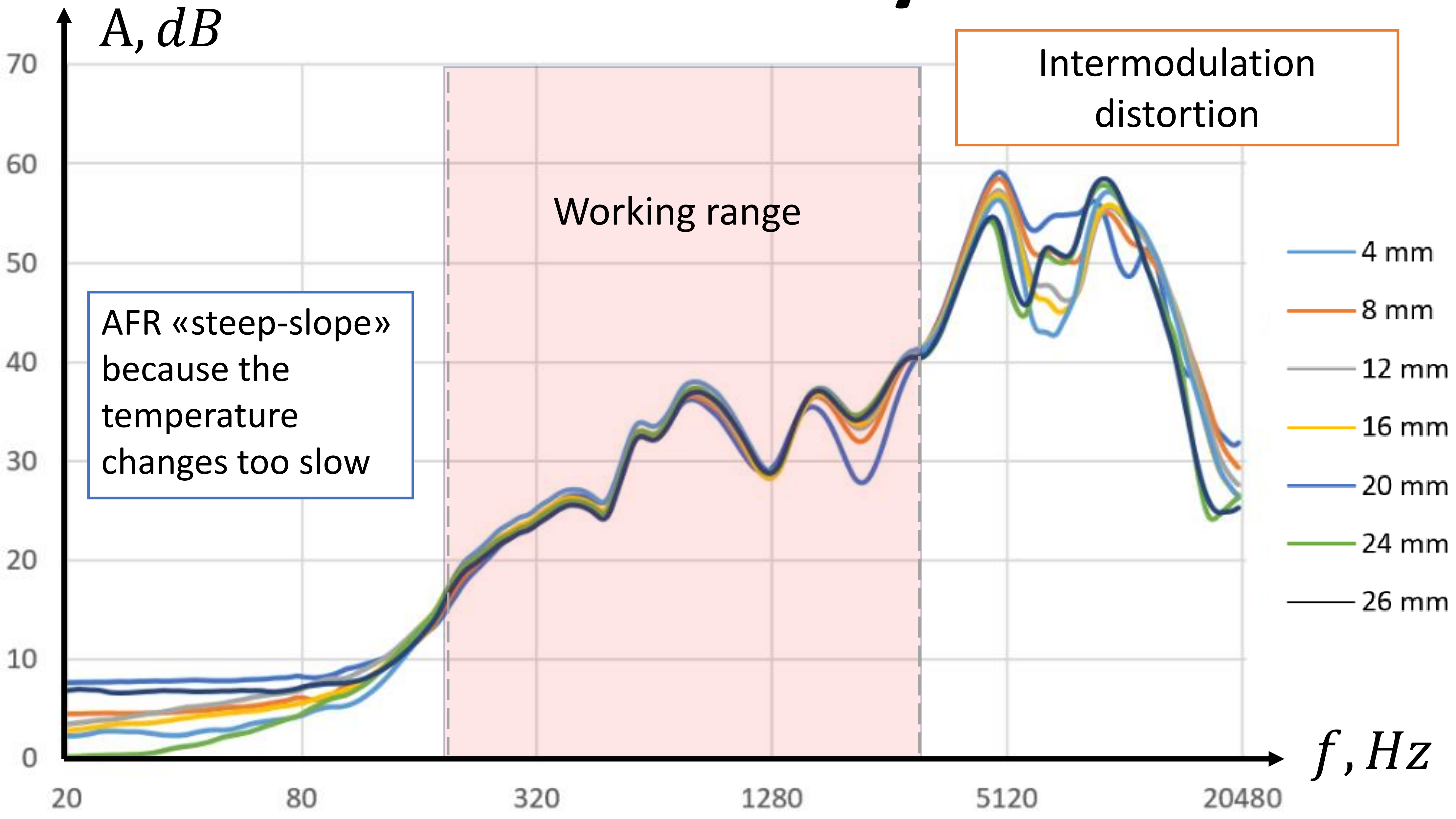
Spectrograms



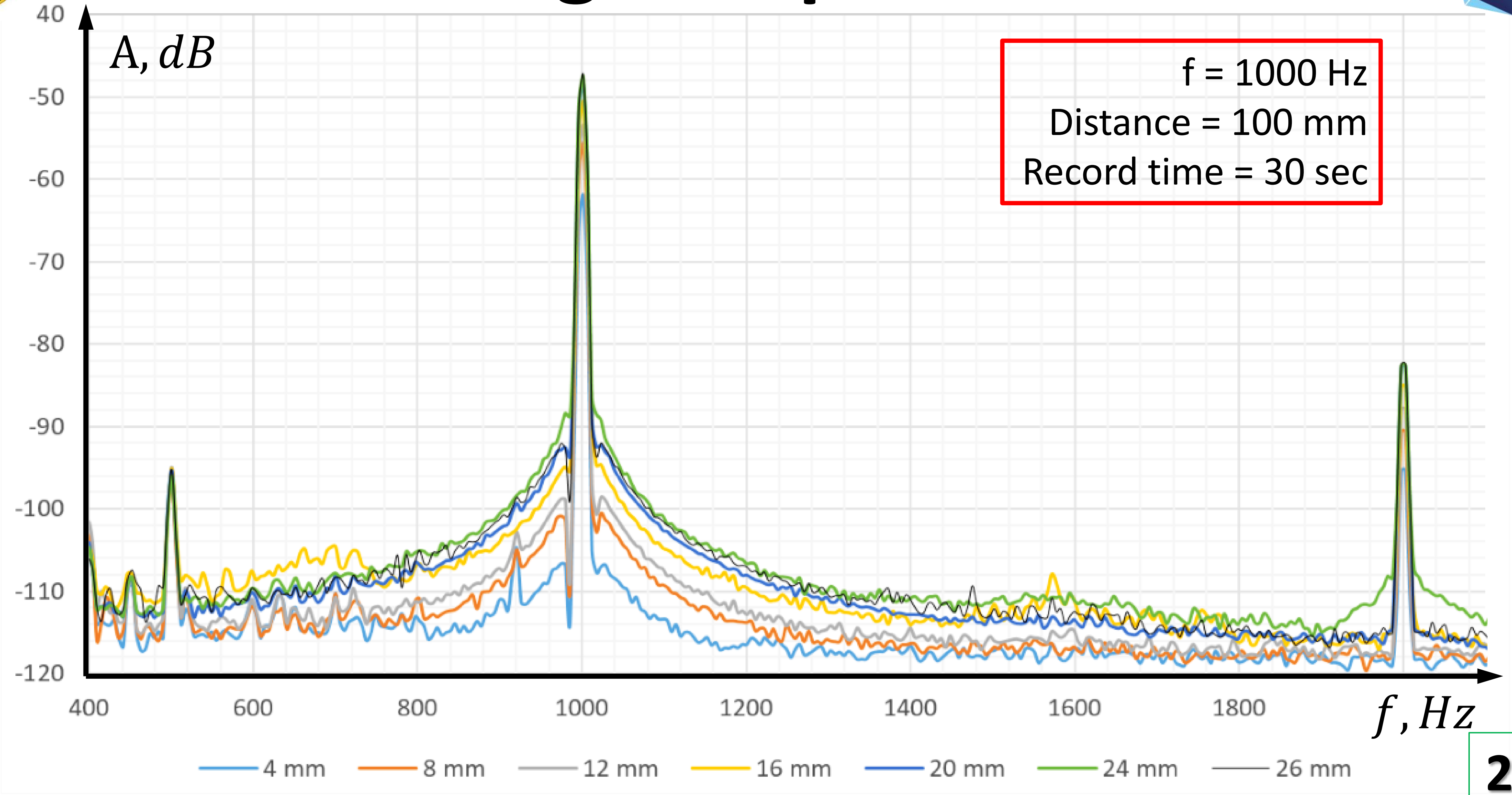
AFR of ionophone



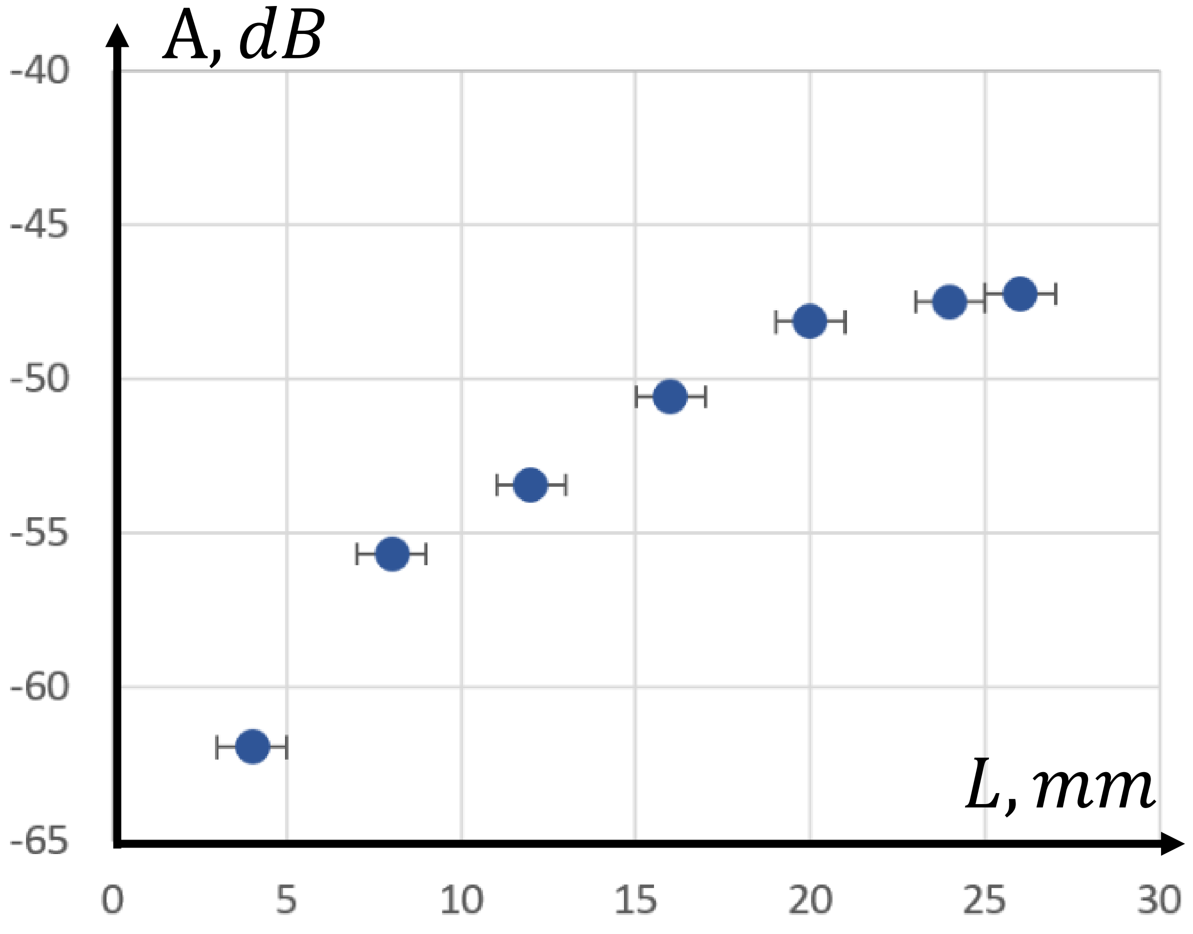
AFR analisys



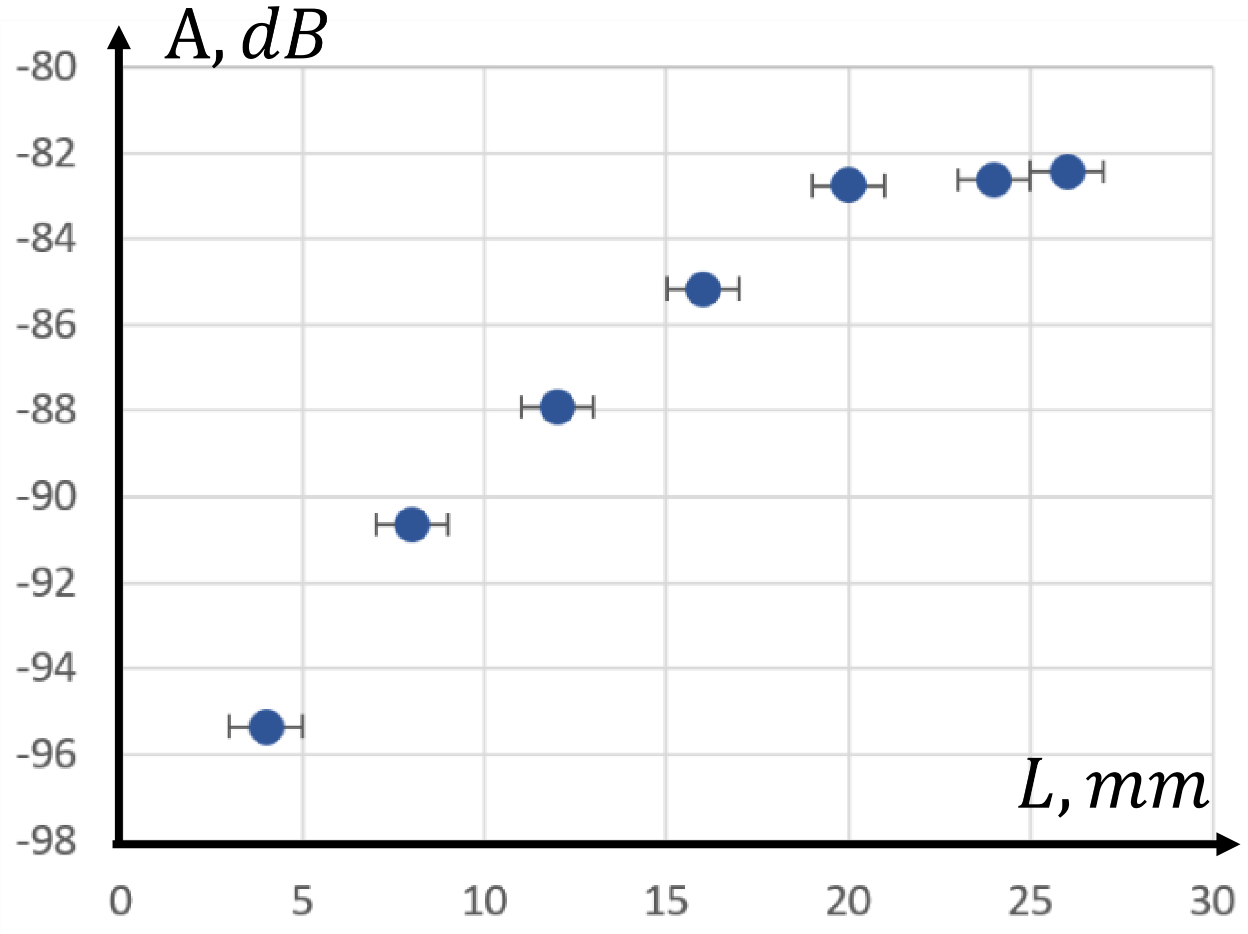
Arc length dependence



Arc length dependence

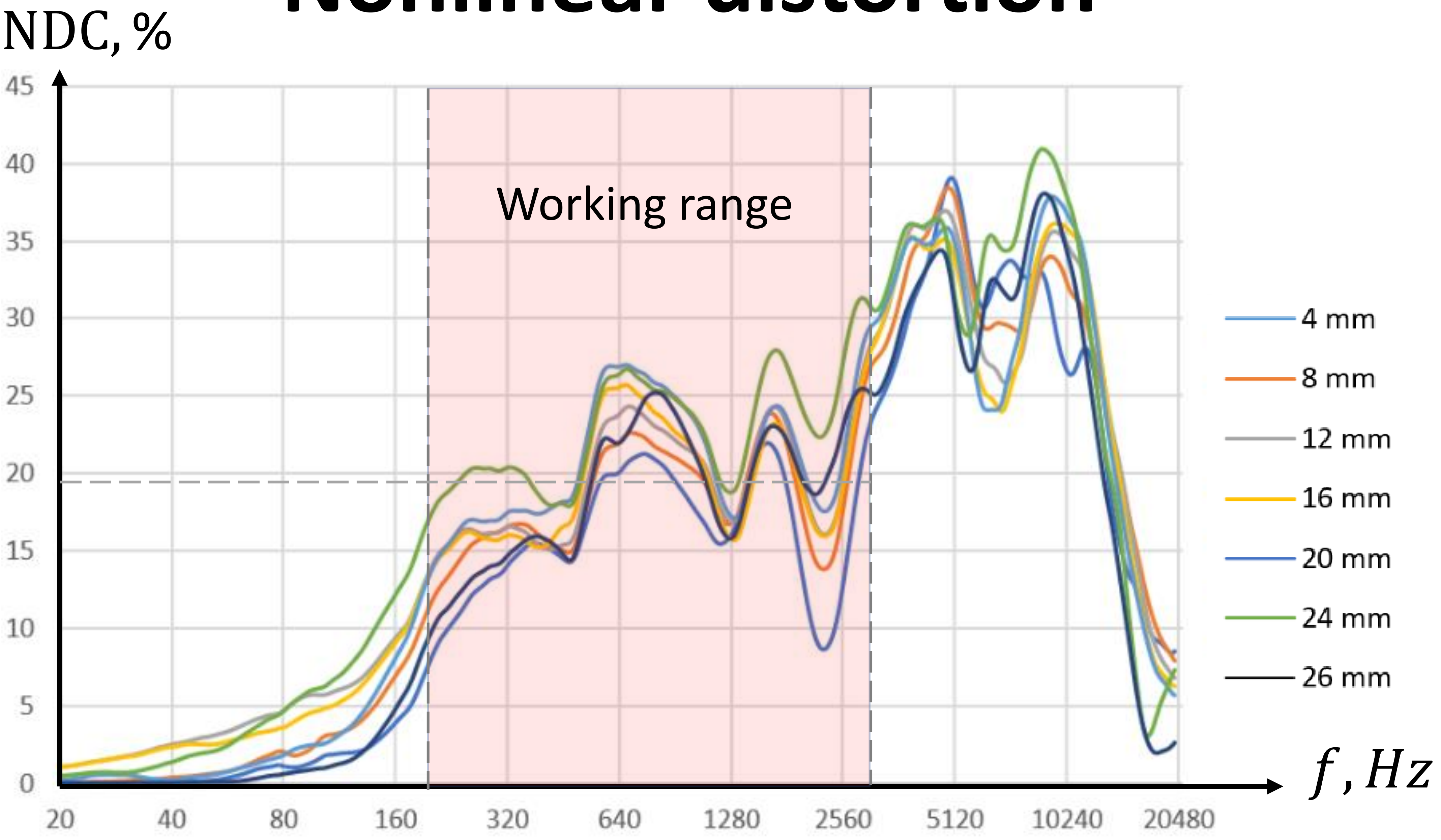


$f_0 = 1000\ Hz$

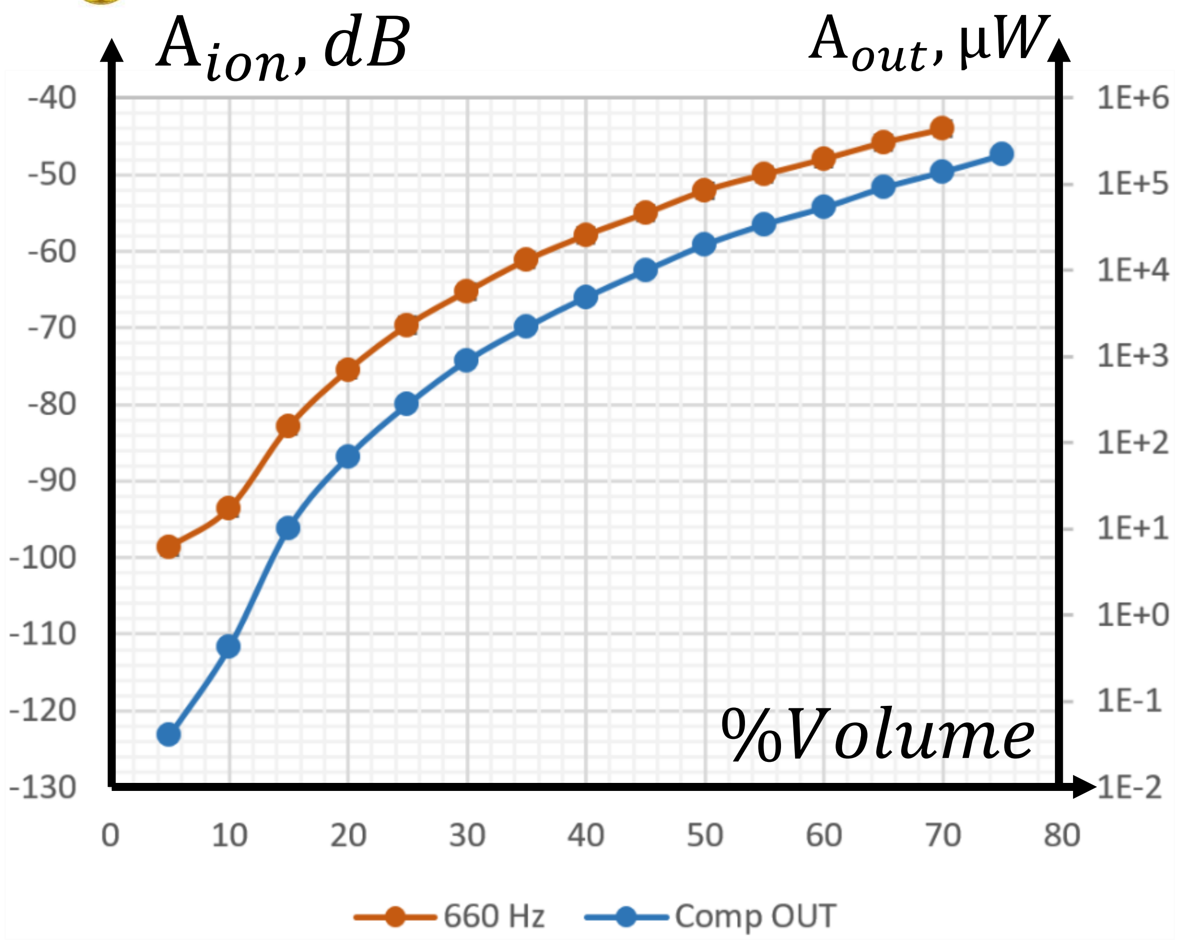


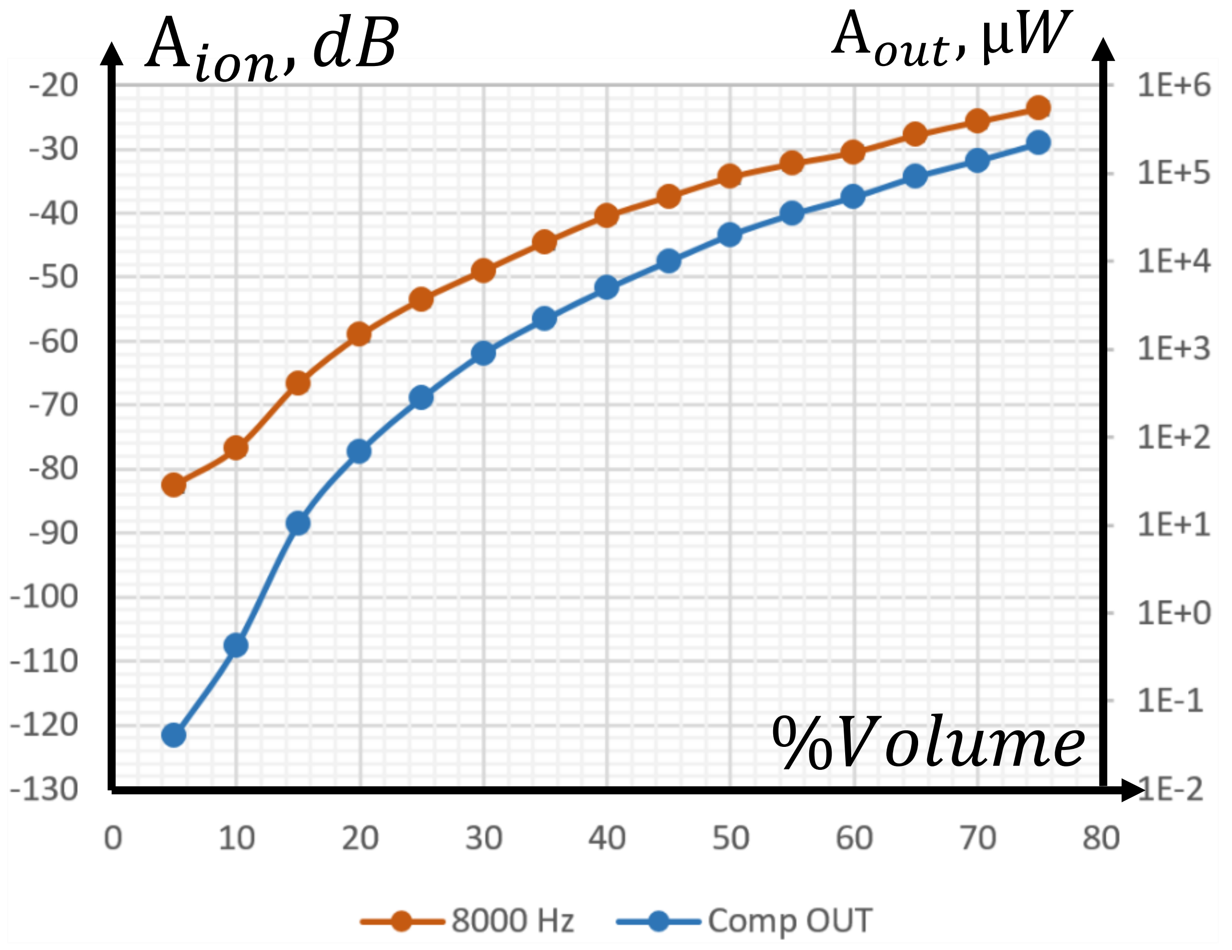
$f_1 = 2000\ Hz$

Nonlinear distortion



Linearity of ionic speaker



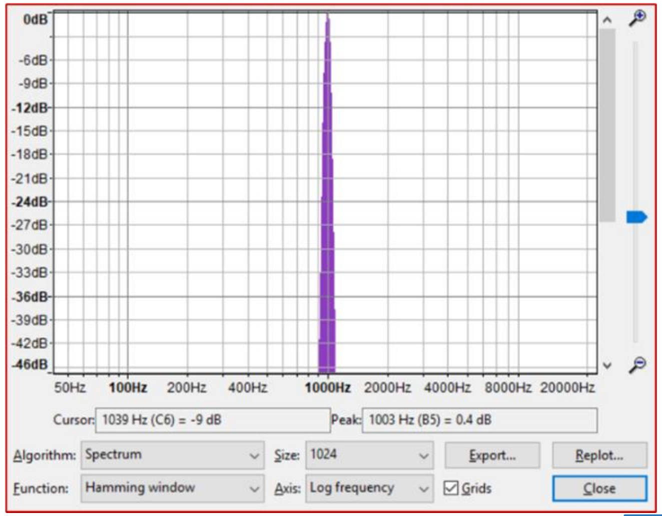


$f_0 = 660\ Hz$

$f_0 = 8000\ Hz$

ionic *computer*

Harmonic distortion



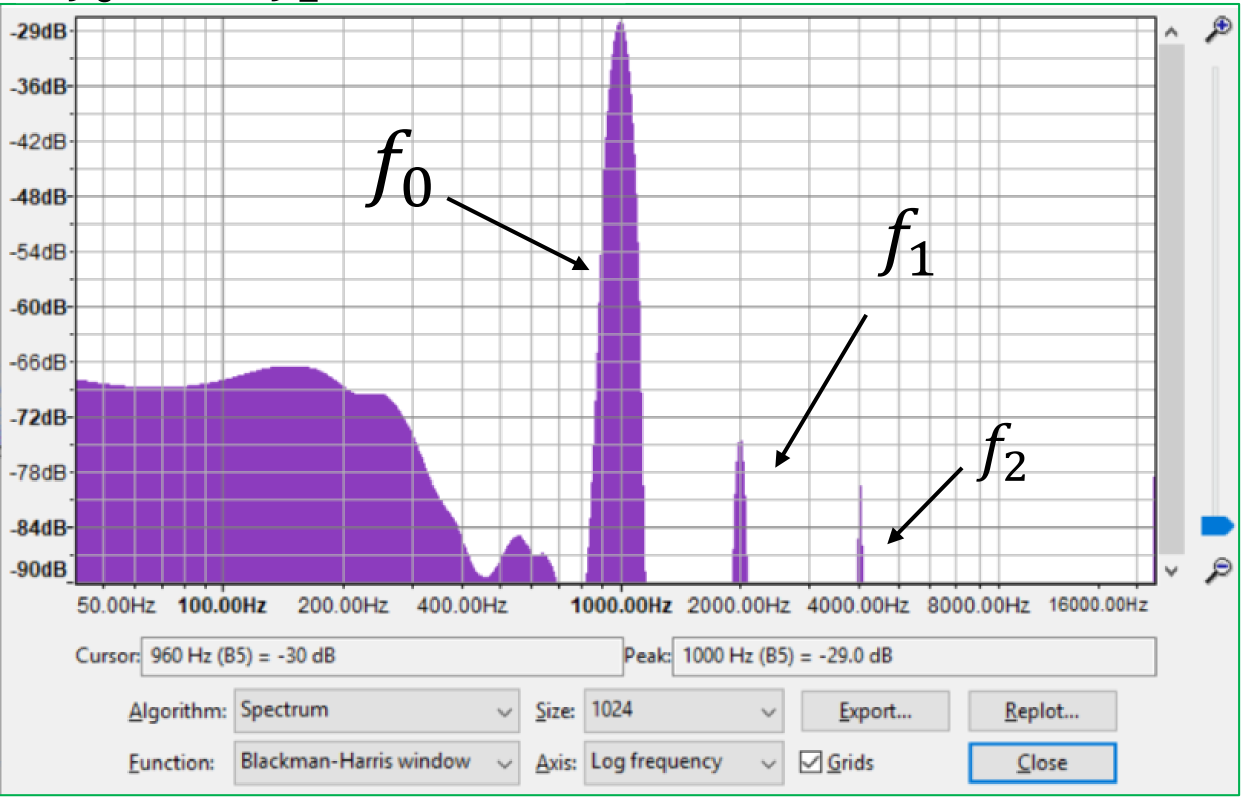
Computer

$A_{f_0} - A_{f_1} > 100\ dB$

f_1 – 1st harmonic

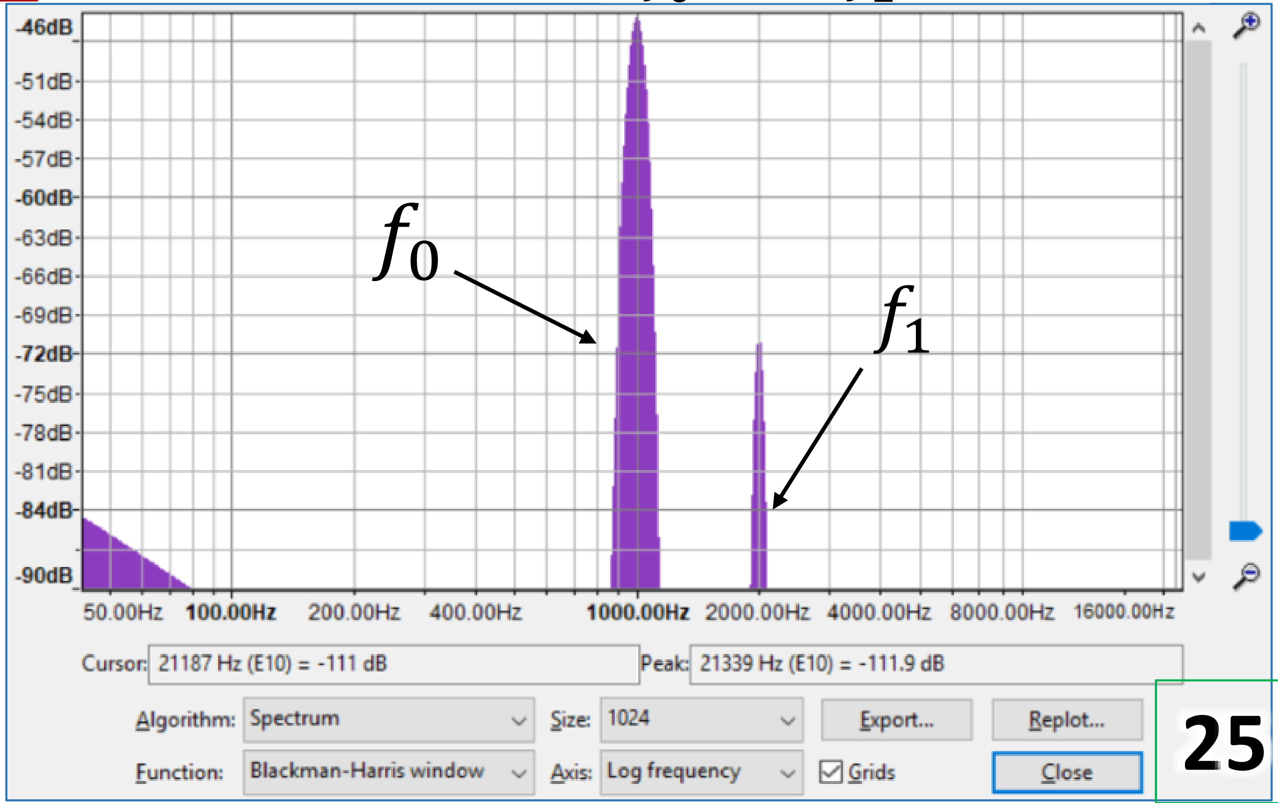
Speaker

$A_{f_0} - A_{f_1} = 46\ dB$

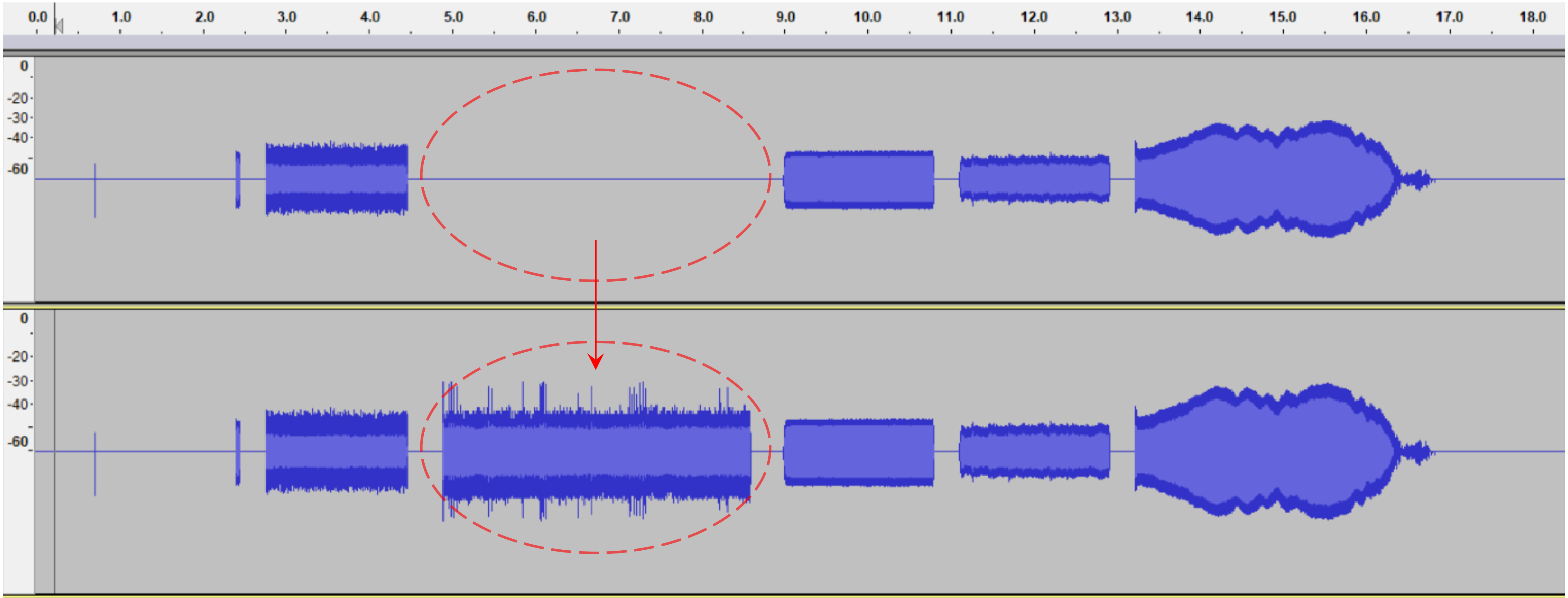


Ionic speaker

$A_{f_0} - A_{f_1} = 25\ dB$



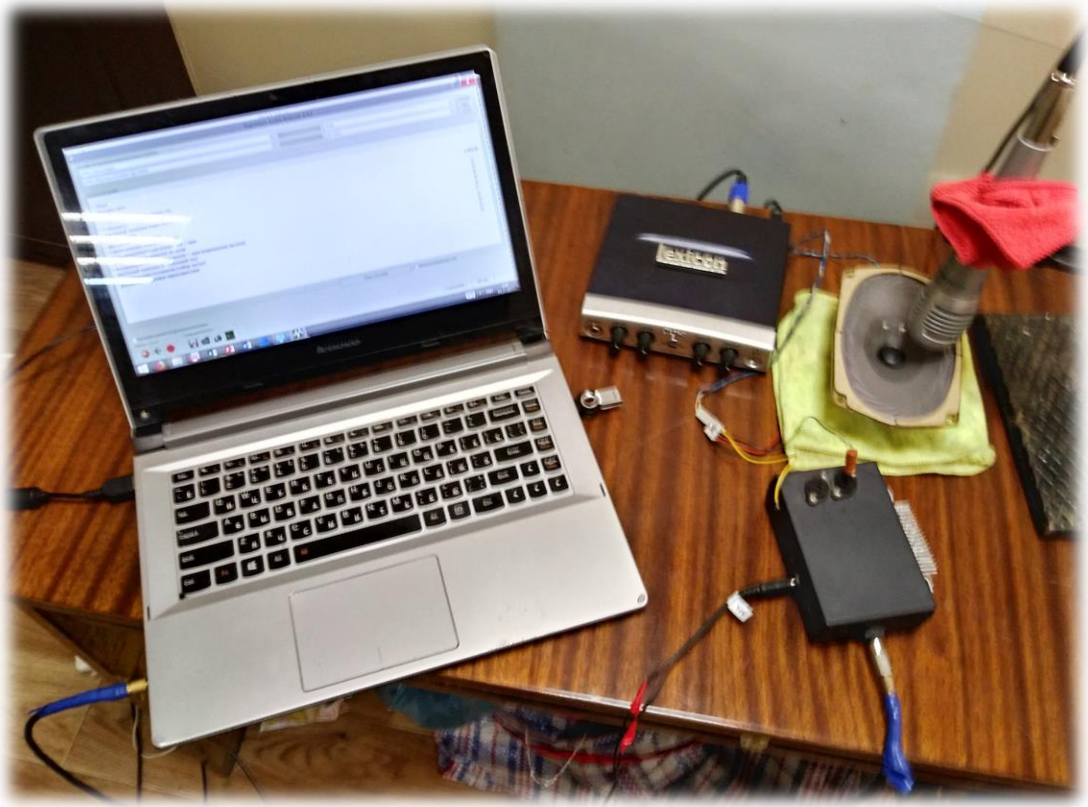
Signal-to-noise ratio



- 2 the same audio tracks (copied)
- Amplified noise (arc without any modulation)

$$SNR = S_{out}/N_0 \approx 32\ dB$$

Power efficiency of ionophone

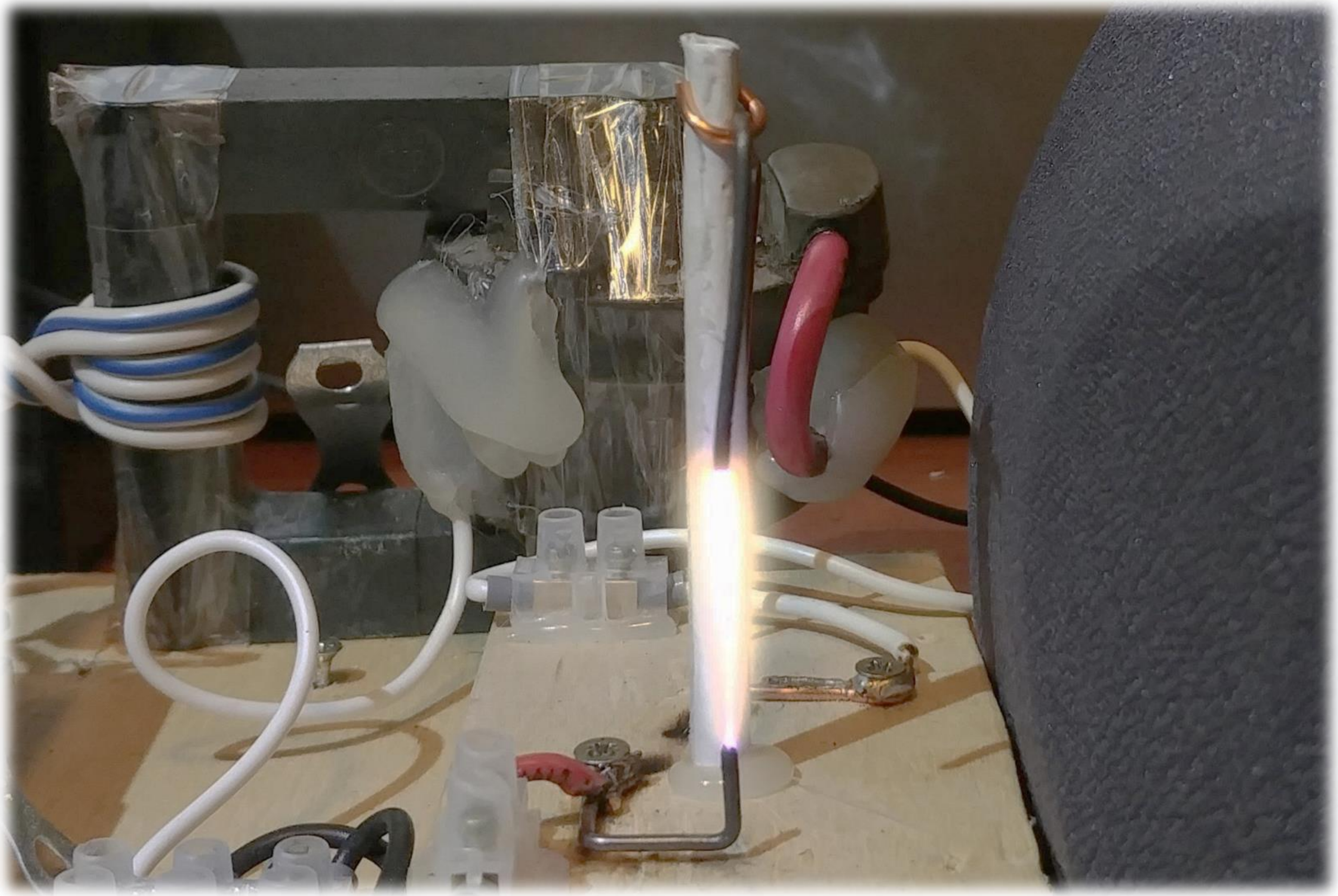


- f = 1000 Hz
- Ionophone volume – max possible
- Distance to microphone – 200 mm
- Volume measurement (dB)
- Speaker: 3-ГДШ, microphone – on 200 mm from the speaker
- Speaker volume = ionophone volume
- Comparison of power
- We estimated efficiency of the ionophone calculating from well-known speaker's efficiency

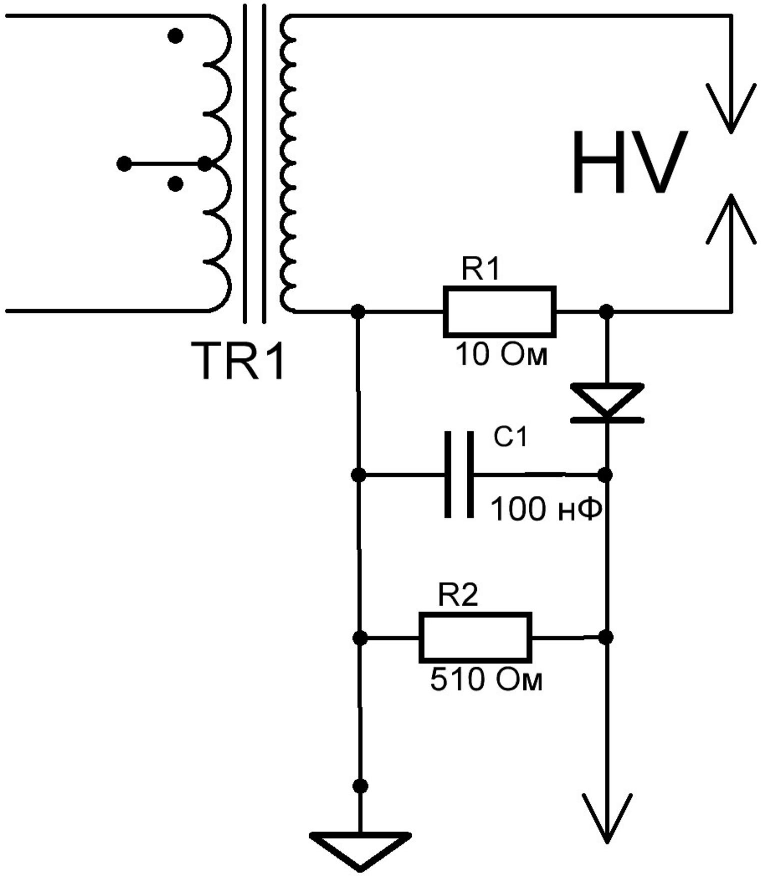
$$\eta = \frac{P_{spkr} * \eta_{spkr}}{P_{ionophone\ input}} \approx 0.05\%$$

Experimental setup in «microphone mode»

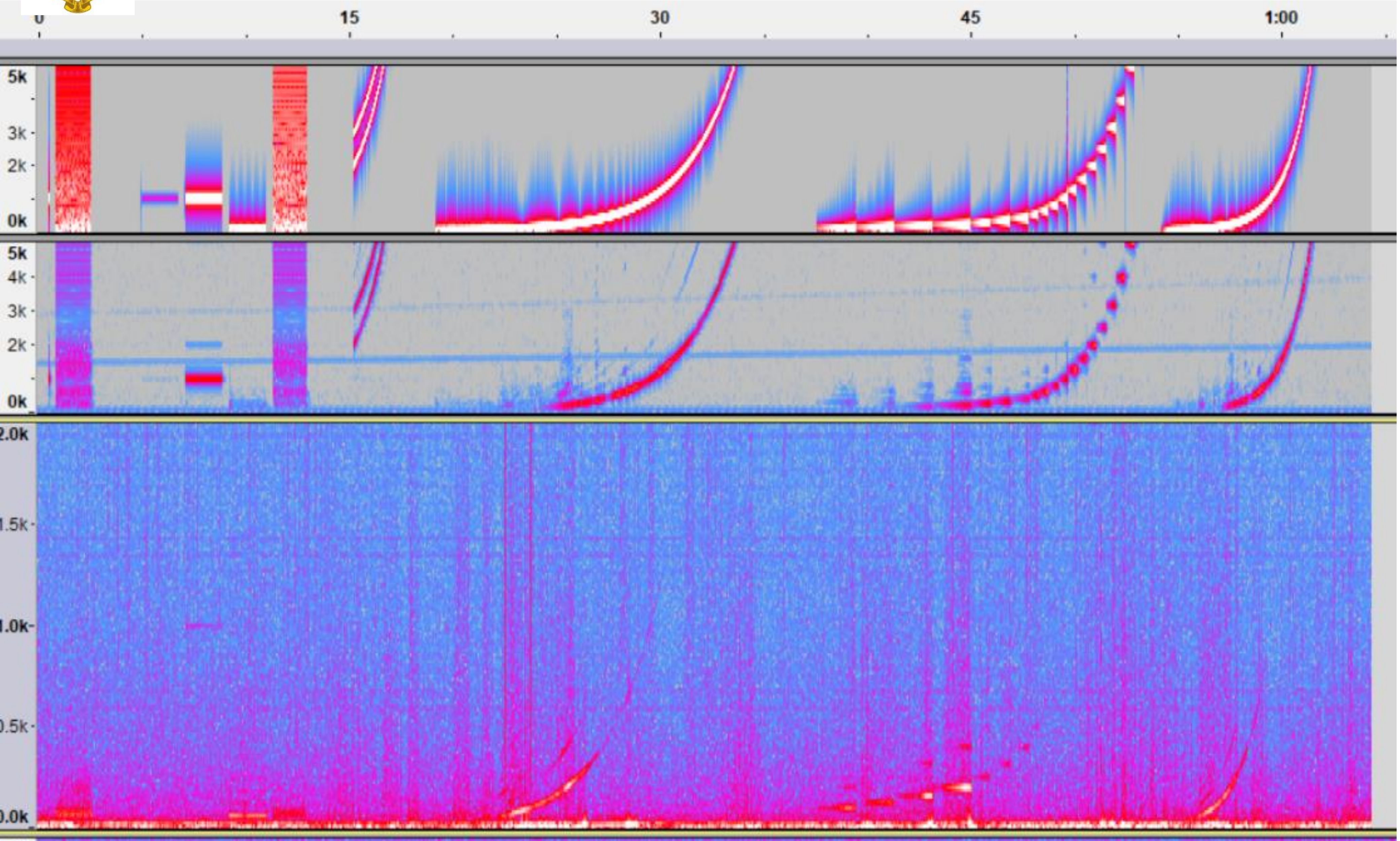
Microphone mode investigation



- Distance from radiator – 50 mm
- There is no input signal
- (input electrodes are shorted)



Ionic microphone - spectrograms

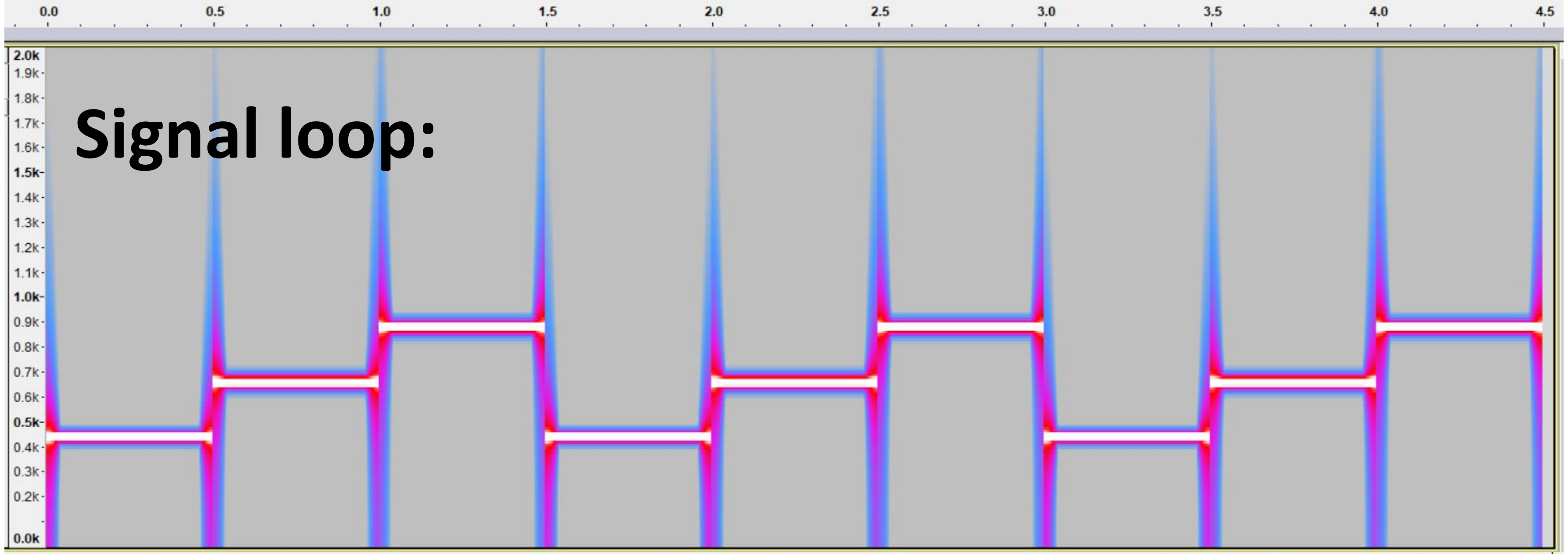


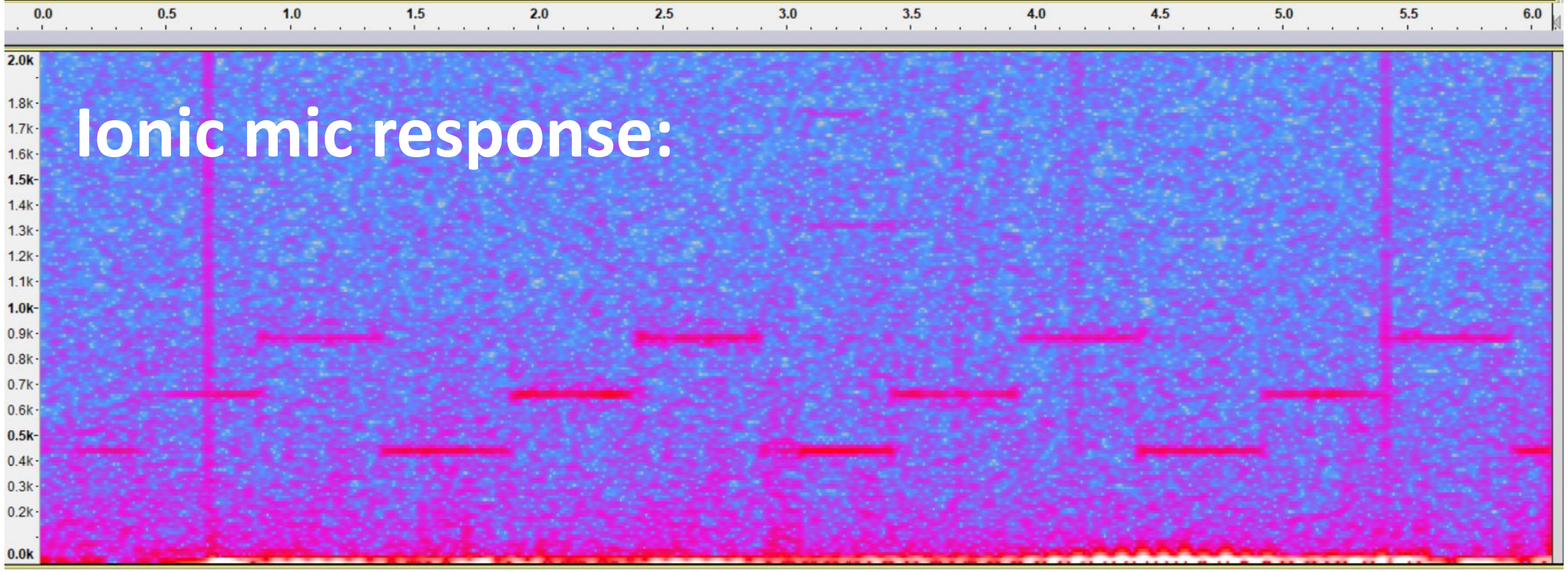
Computer

Speaker

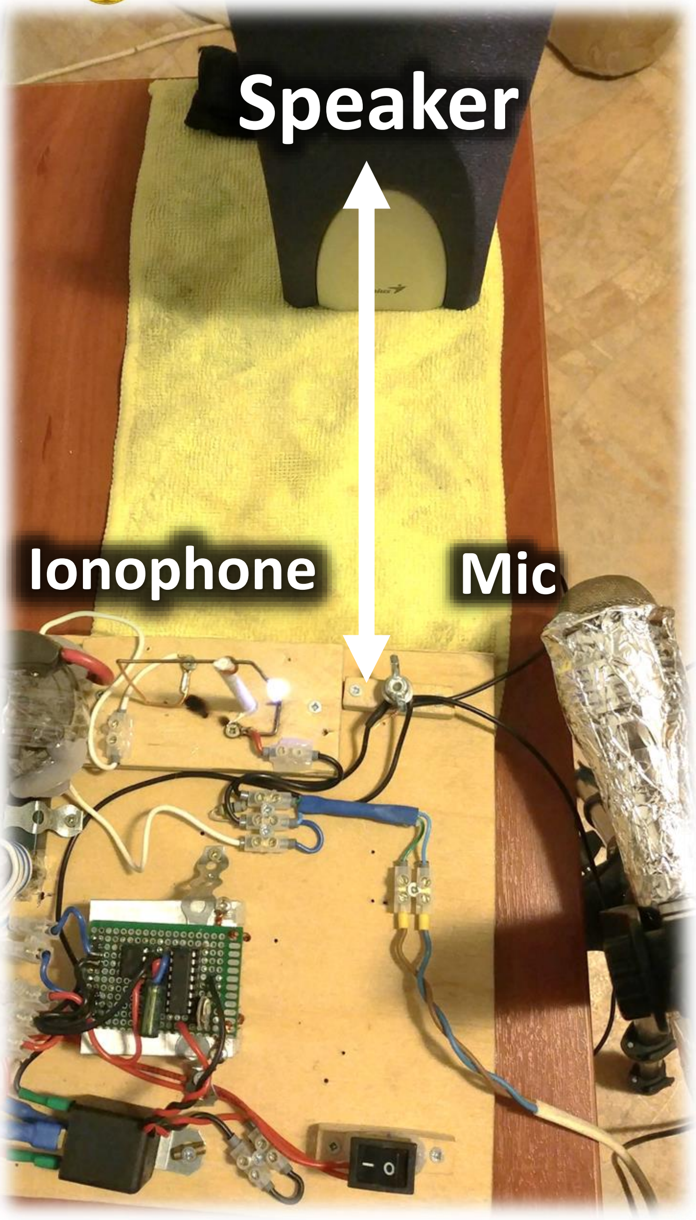
Ionic speaker

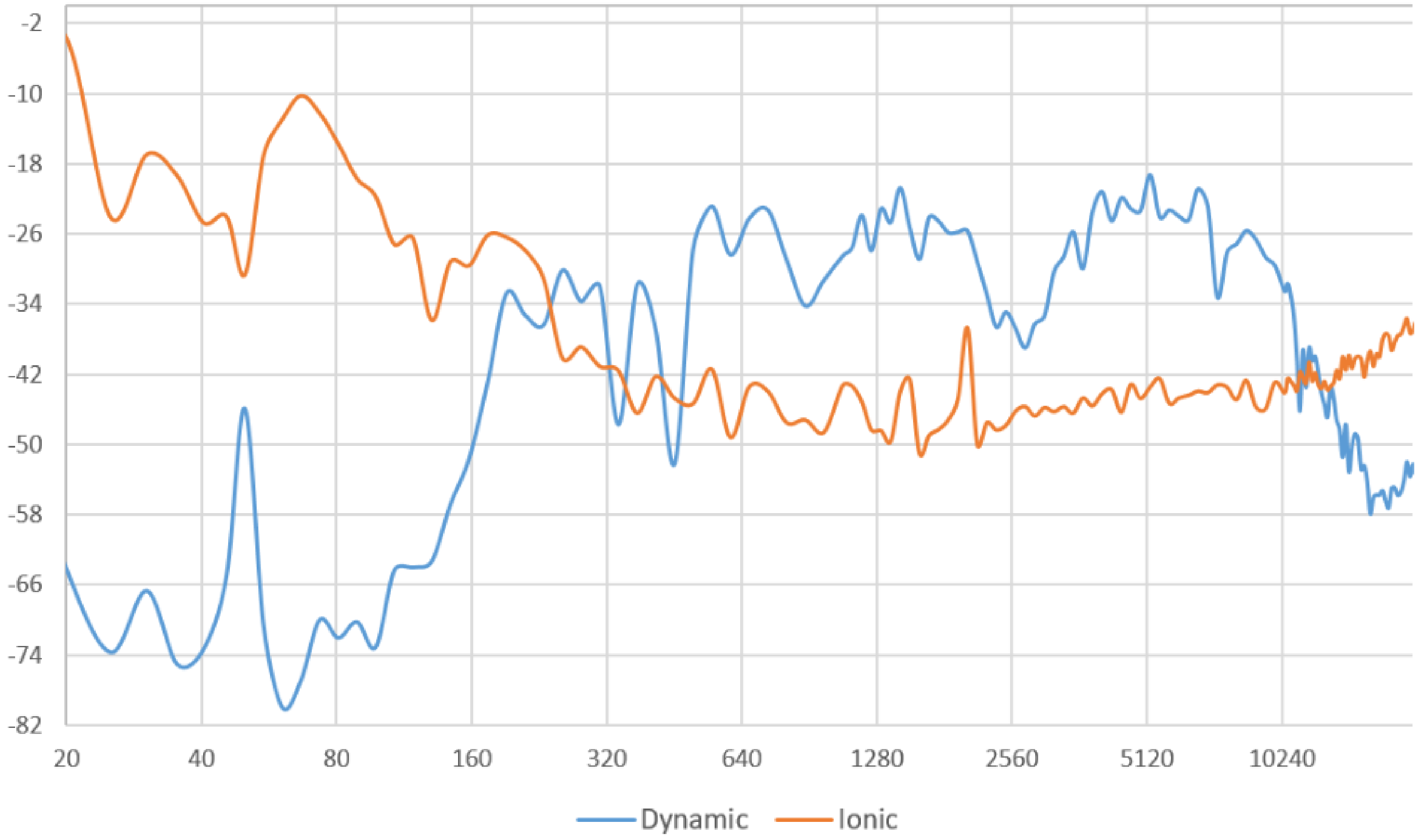
Ionic mic – tones





AFR of ionic microphone





Blue curve – AFR of electrodynamic microphone
Orange curve – AFR of ionophone in microphone mode

Operating principle of ionic mic

Current in arc defines by the conductance

↓

Oscillations of pressure change the conductance of arc

↓

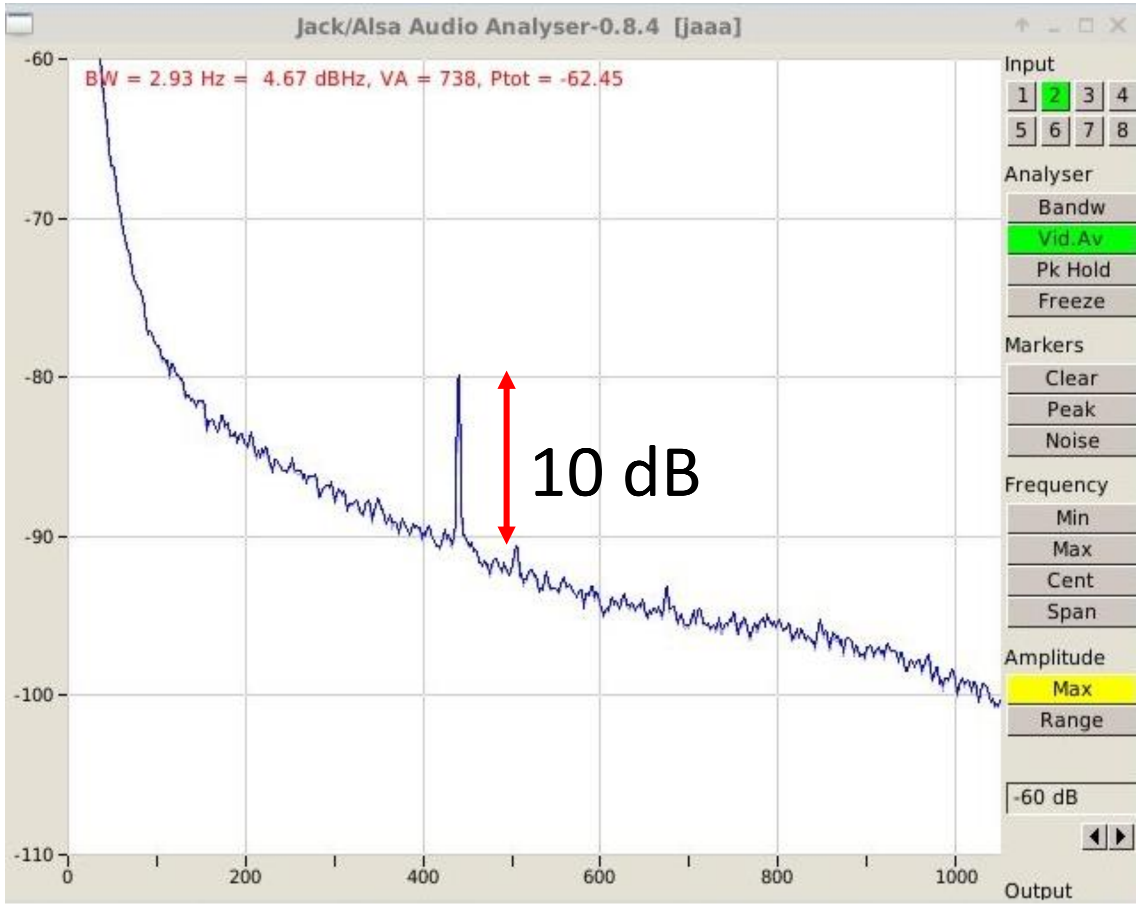
Current in secondary coilof transformers changes

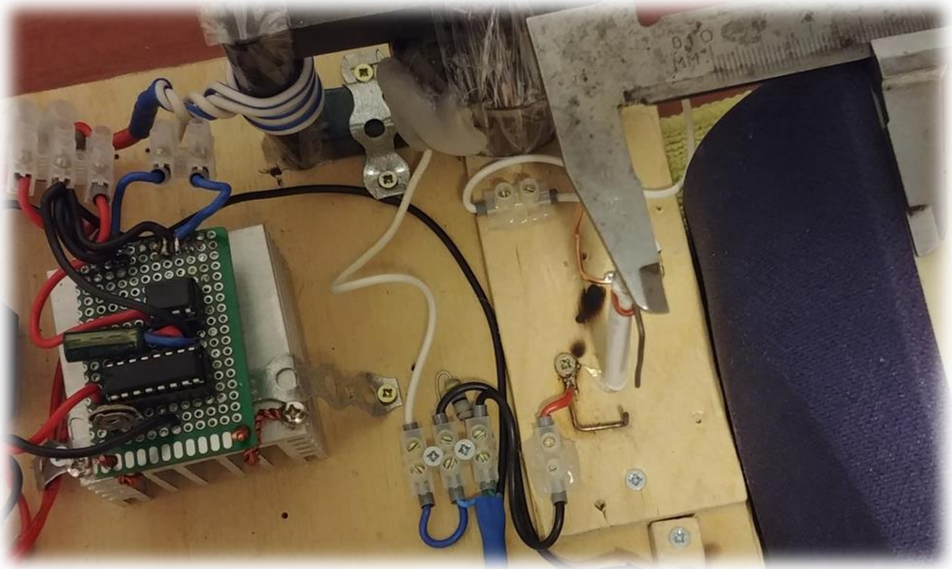
Modeling of a corona discharge microphone Journal of Physics D: Applied Physics Ph Béquin et al 2013

Ionic microphone, signal-to-noise ratio

- Speaker's frequency = 440 Hz
- Speaker's volume = 72,5 dB

Criteria: $SNR = S_{out}/N_0 \approx 10\ dB$





Conclusions

The task:

- Speaker without any moving part
- Max bandwidth
- Signal-to-noise ratio
- Power efficiency

- Microphone
- Max bandwidth of mic
- Sensibility

Done:

- Experimental setup
- From 200 Hz to 3000 Hz
- SNR = 32 dB
- Efficiency ≈ 0.05%

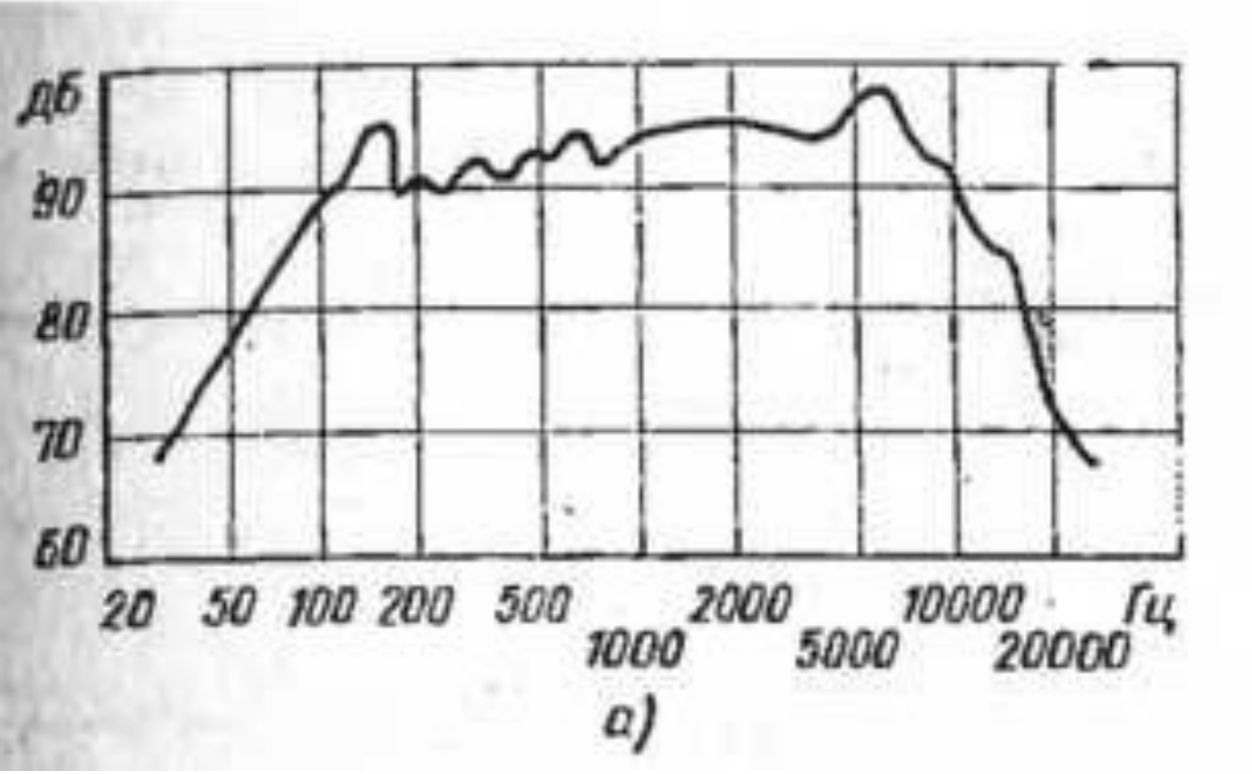
- It works!
- From 100 Hz to 1200 Hz
- Sensitivity level ≈ 72,5 dB

Thank you for your attention!

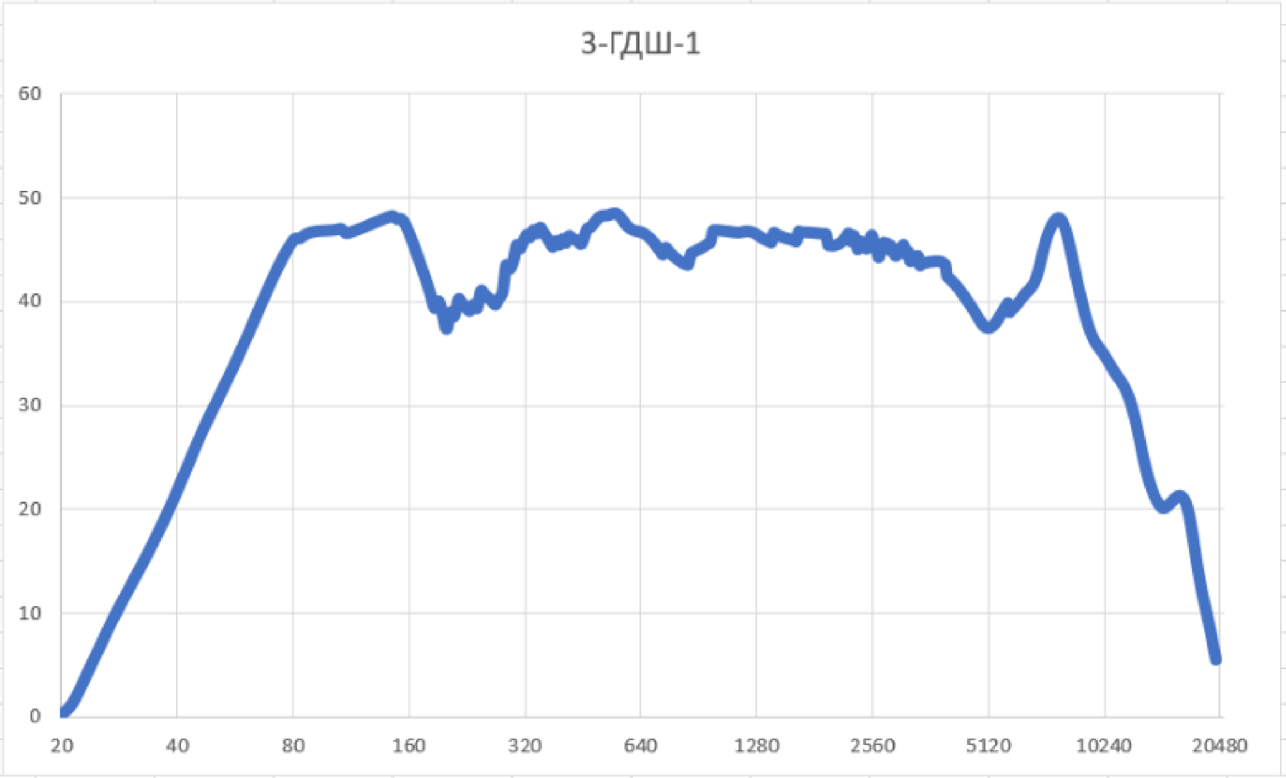
Quotation

1. Landau L. D., Lifshitz E. M., Electrodynamics of continuous medium. — M.: Science, 1982. — 624 p. — («Theoretical physics», том VIII).
2. Suk, J. W., Kirk, K., Hao, Y., Hall, N. A. and Ruoff, R. S. (2012), Thermoacoustic Sound Generation from Monolayer Graphene for Transparent and Flexible Sound Sources. Adv. Mater., 24: 6342–6347.
3. Qin Zhou *and* A. Zettl (2013), Electrostatic graphene loudspeaker,. Appl. Phys. Lett. 102,
4. Texas Instruments «TL598 pulse-width-modulation control circuits»
5. Infineon «Data Sheet No. PD60177 Rev. F. IR4426/IR4427/IR4428»
6. Infineon «PD - 94053 IRFZ44N»
7. Site «Radio-kote»: http://radiokot.ru/circuit/audio/other/10/ «Modern Ionophone»
8. Rzhevkin S. N. «Theory of sound». pub.: MSU, Moscow, 1960

Appendix A



АЧХ динамика 3-ГДШ-1, указанная в документации



АЧХ динамика 3-ГДШ-1, полученная экспериментально