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**KA210-VET - Small-scale partnerships in vocational education and training**

## **AURALIZE**

**Innovative Course in Room Acoustics and  
Auralization for Sound Professionals**

Project No. 2024-1-IT01-KA210-VET-000245142

**Equipment and methods of recording acoustic measurements, analysis,  
and interpretation - theoretical and practical part**

**Prof. Lamberto Tronchin**

**14/04/2025 - in presence**

**Event organizer: LP - CONSORZIO FUTURO IN RICERCA, IT**





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[www.auralize.eu](http://www.auralize.eu)



CONSORZIO FUTURO IN RICERCA, IT – LEAD PARTNER



SVEUČILIŠTE U ZAGREBU, Faculty of Electrical Engineering and Computing (FER), CRO – PROJECT PARTNER

Project duration: 12 months 01/11/2024 – 31/10/2025



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## **AURALIZE - Workplan**

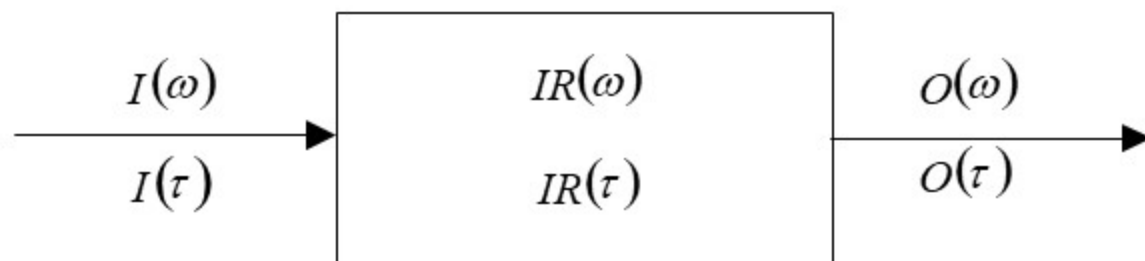
- 1.Lecture A1** - Historical overview and importance of acoustics as intangible heritage (CFR - **March 21, 2025** - online);
- 2.Lecture A2** - Fundamentals of room acoustics. (FER, **April 14, 2025** - in person - Zagreb);
- 3.Lecture A3** - Equipment and methods of recording acoustic measurements, analysis, and interpretation - theoretical and practical part (CFR in Zagreb, **April 14, 2025** - in person - Zagreb);
- 4.Acoustic measurements in Zagreb** (CRO): Vatroslav Lisinski Concert Hall and National Theatre of Zagreb - (CFR & FER, **April 15, 2025** - in person);
- 5.Acoustic measurements in Faenza** (ITA): Teatro Masini in Faenza (CFR & FER, **April 29-30, 2025** - in person);
- 6.Lecture A4** - Virtual acoustics, production workflow, and software (FER, **May 5, 2025** - in person - Zagreb);
- 7.Lecture A5** - Multi-disciplinary uses of virtual acoustics (cultural heritage, sonic archaeology, games, media, etc.) (CFR, **May 6, 2025** - in person, Zagreb).



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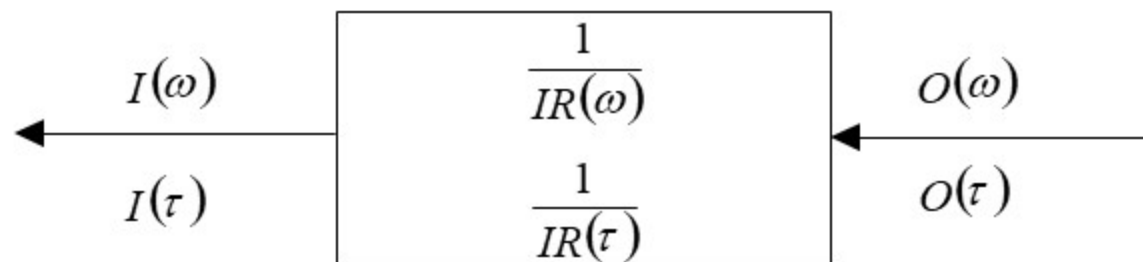
Frequency response  $\longleftrightarrow$  **Impulse Response**  $\longrightarrow$  Linear, time-invariant Systems



**Time Domain:**

**Frequency Domain**

$$O(\tau) = IR(\tau) * I(\tau) \Leftrightarrow I(\tau) = O(\tau) * IR^{-1}(\tau) \quad O(\omega) = IR(\omega) \cdot I(\omega) \Leftrightarrow I(\omega) = \frac{1}{IR(\omega)} O(\omega)$$



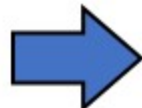


## Room acoustics: linear system?

**Acoustics:** this discipline studies the “*pressure disturbance inside a compressible fluid*”. From fluid dynamics, assuming a compressible fluid, the propagation of the perturbation inside the fluid is determined with the following **5 conditions**:

- 1) **Ideal fluid** (without thermal dissipations)
- 2) **Homogeneous fluid**
- 3) **Isotropic fluid**
- 4) «**Weightless Fluid**» (sound propagation not depending on the mass)
- 5) “**Linear acoustics**”:  $p = p_0 + p'$   $\rho = \rho_0 + \rho'$  V.J.Boussinesq, 1842-1929

*D'Alembert equation (or “wav equation”)*, which represents the mathematical basis of all the physical acoustics


$$\frac{\partial^2 \Phi}{\partial \tau^2} = c^2 \nabla^2 \Phi$$

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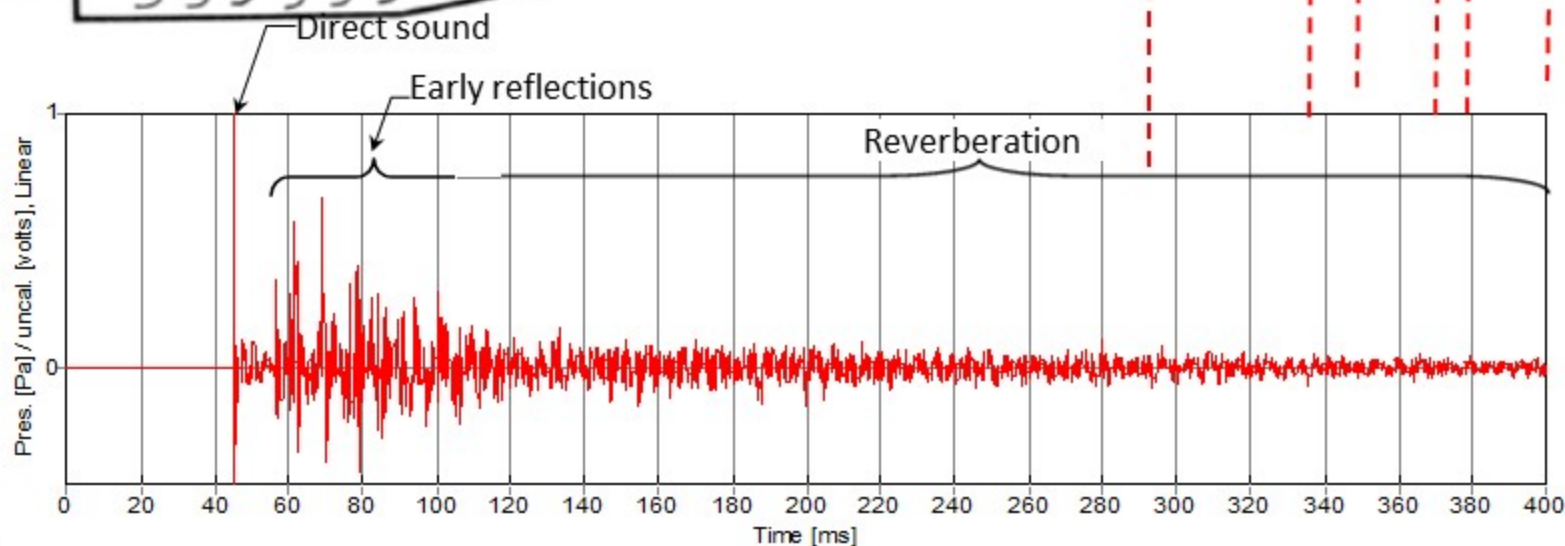
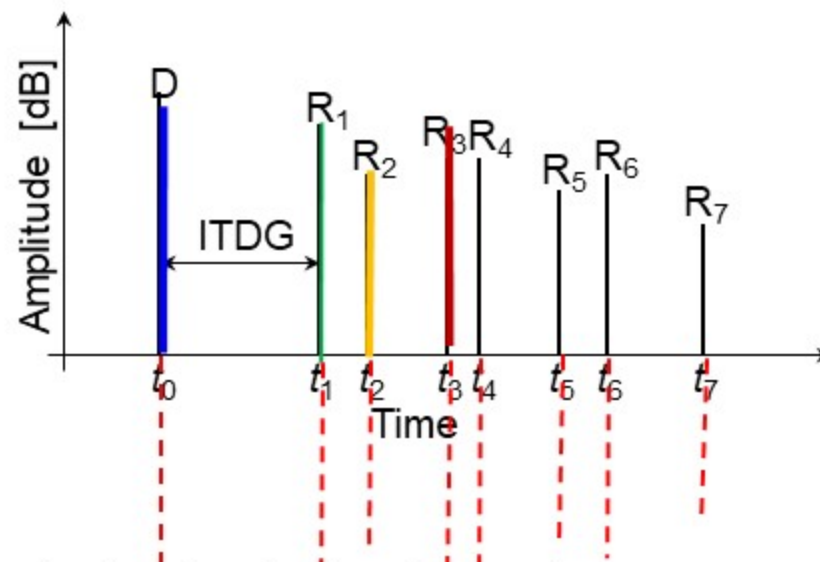
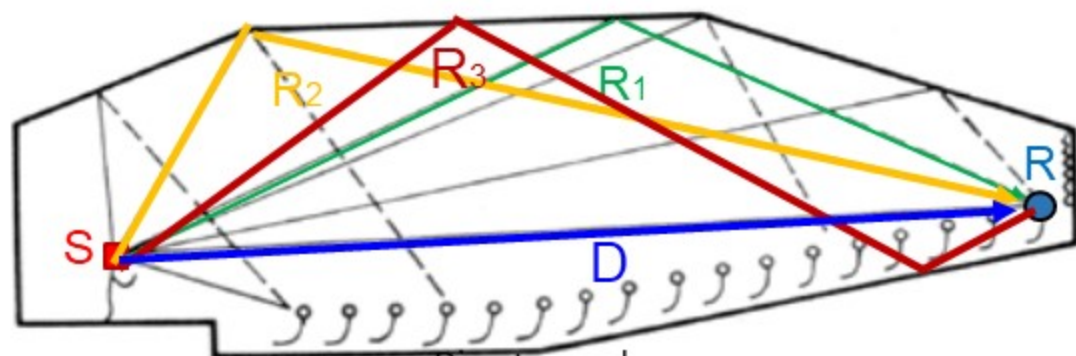


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## Room acoustics – experiment and equipment



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## The Impulse Response is fundamental.. Not only in acoustics

Every time that you hit an object with an impulse and make a judgment about the sound of the product, you determine and evaluate an “impulse response”

- In the walls (empty/full)
- On the fruits (mature or not)
- On the parmisan (seasoned or not)
- On the plasters (firm or unsafe)
- On the glasses and similar (crystals glass or not)



This allow to **listen** to the indoor room acoustics, eactly loike whern you can **taste** wine

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How can we measure the IRs?

## Direct methods for measuring the IRs

«Clapping»



**Clapping:** spontaneous and simplest method ever.

Limits: Low repeatability

Fair frequency response at medium values (250 Hz – 2 kHz)

Reverberation times only very approximated

Not sufficient for measuring the IRs

Not suitable for auralisation



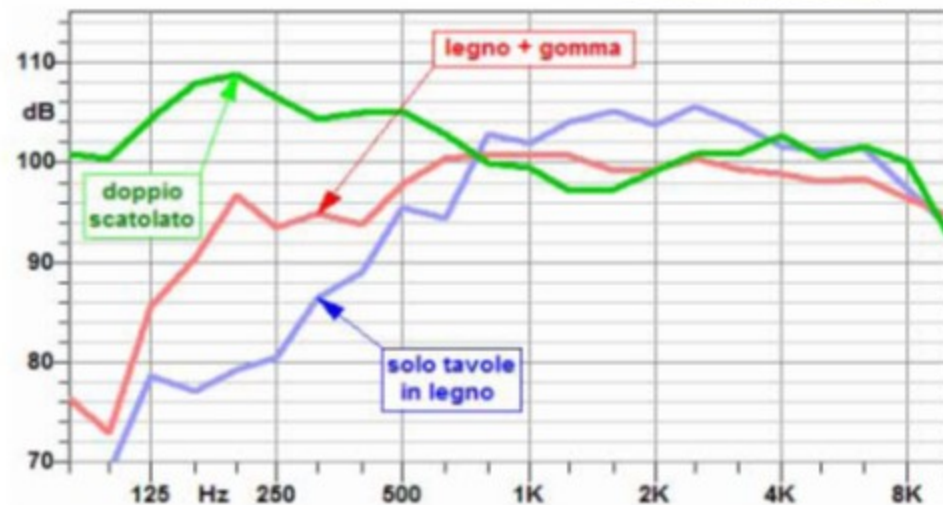
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## Direct methods for measuring the IRs



«Clapping machine»





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## Direct methods for measuring the IRs



Balloons



Pistol shots



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## Direct methods for measuring the IRs



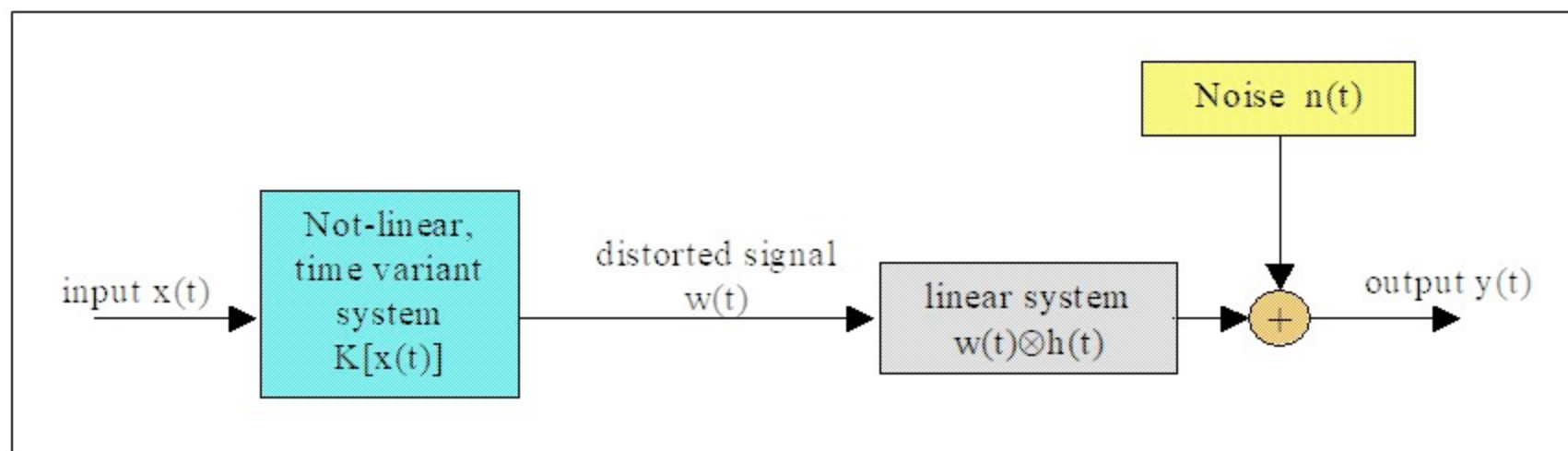
Example: [Epidauro](#)

**Firecrackers:** Omnidirectionals (little dimensions if compared with wavelengths)  
**External noises** (not suitable for reverberant rooms or indoor measurements)

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## In-direct methods for measuring the IRs



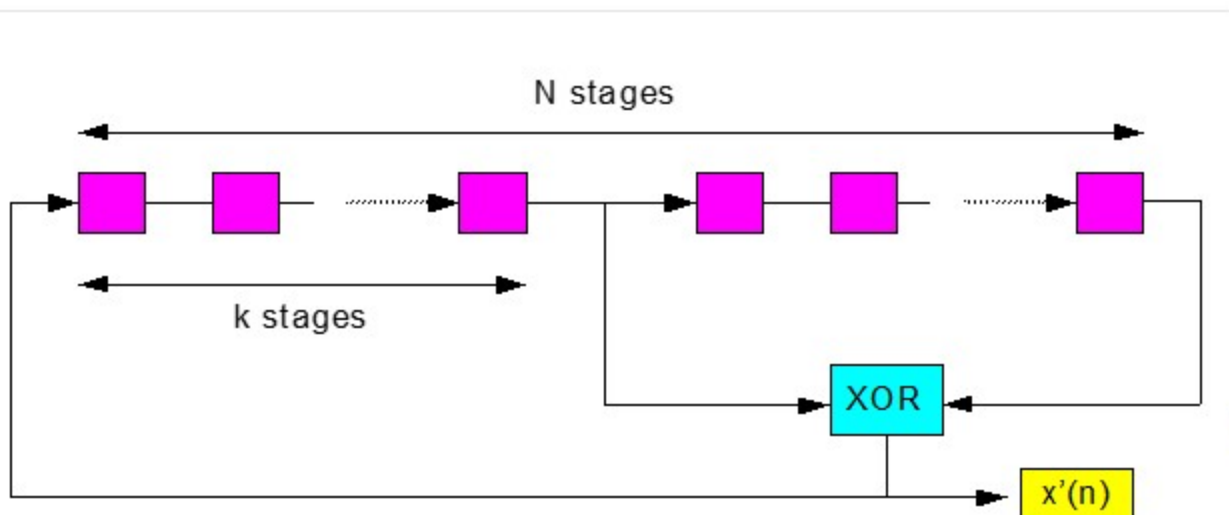
**Hypothesis:** the acoustic system is characterized only by linear components the electronic system is also characterized by non-linearity

**NB: The non linearities can be measured and emulated**



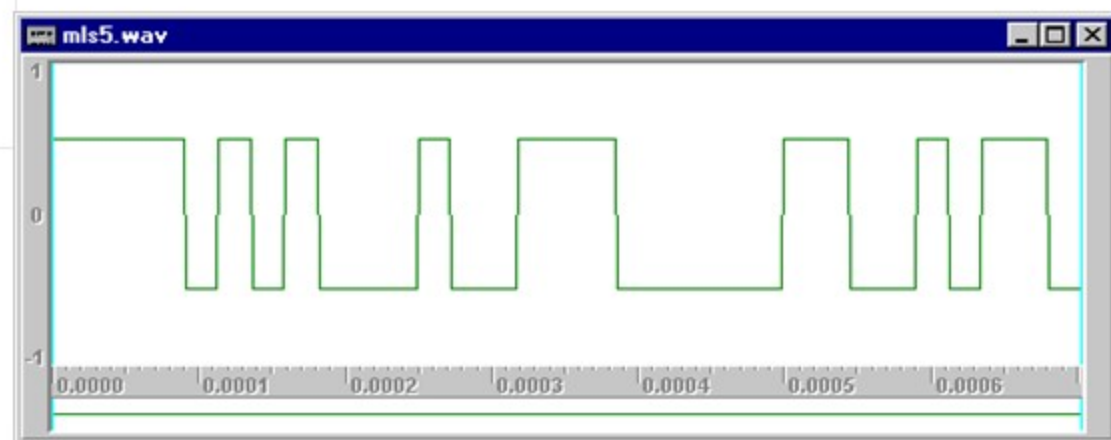
## Indirect methods for measuring the IRs

### MLS – Maximum length sequence (1)



$X(t)$  is a binary periodic signal obtainable with a specific shift-register, properly configured.

The length of the signal  $L$  is:  $L = 2^{N-1}$



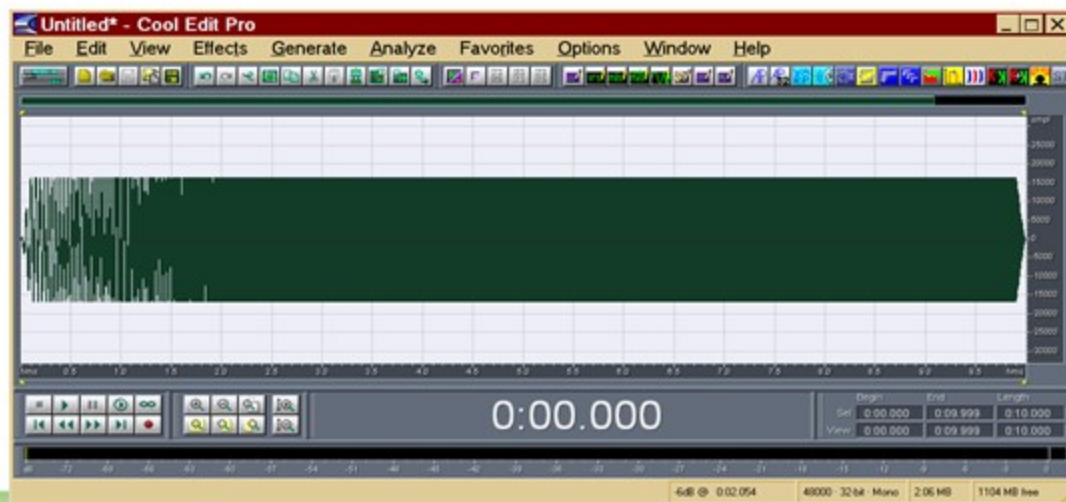


## Indirect methods for measuring the IRs

### Exponential Sine Sweep (ESS)

$x(\tau)$  is a sinusoidal signal, which frequency varies exponentially in the domain, from frequency  $f_1$  until frequency  $f_2$ .

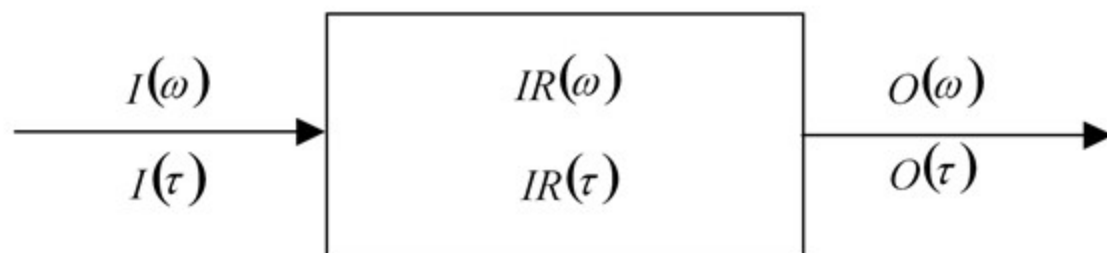
$$x(\tau) = \sin \left[ \frac{2 \cdot \pi \cdot f_1 \cdot T}{\ln \left( \frac{f_2}{f_1} \right)} \cdot \left( e^{\frac{\tau}{T} \ln \left( \frac{f_2}{f_1} \right)} - 1 \right) \right]$$



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### Exponential Sine Sweep (ESS)



$$O(\tau) = I(\tau) * h(\tau)$$

$$h(\tau) = O(\tau) *^{-1} I(\tau)$$

$$h(\tau) = O(\tau) * I^{-1}(\tau)$$

$$h(\tau) = O(\tau) * I^{-1}(\tau)$$

$$I(\tau) = \text{ESS}(\tau);$$

$$I^{-1}(\tau) = \text{INV-ESS}(\tau)$$

$$h(\tau) = O(\tau) * \text{INV-ESS}(\tau)$$



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## The measurements today (2020-2025)

● *Bruel&Kjaer*

● *Sennheiser Ambeo*



● *Neumann KU-100*

● *Eigenmike EM64*



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**Thank you for your participation**

