# Detection of Air Leaks in Loudspeaker Systems

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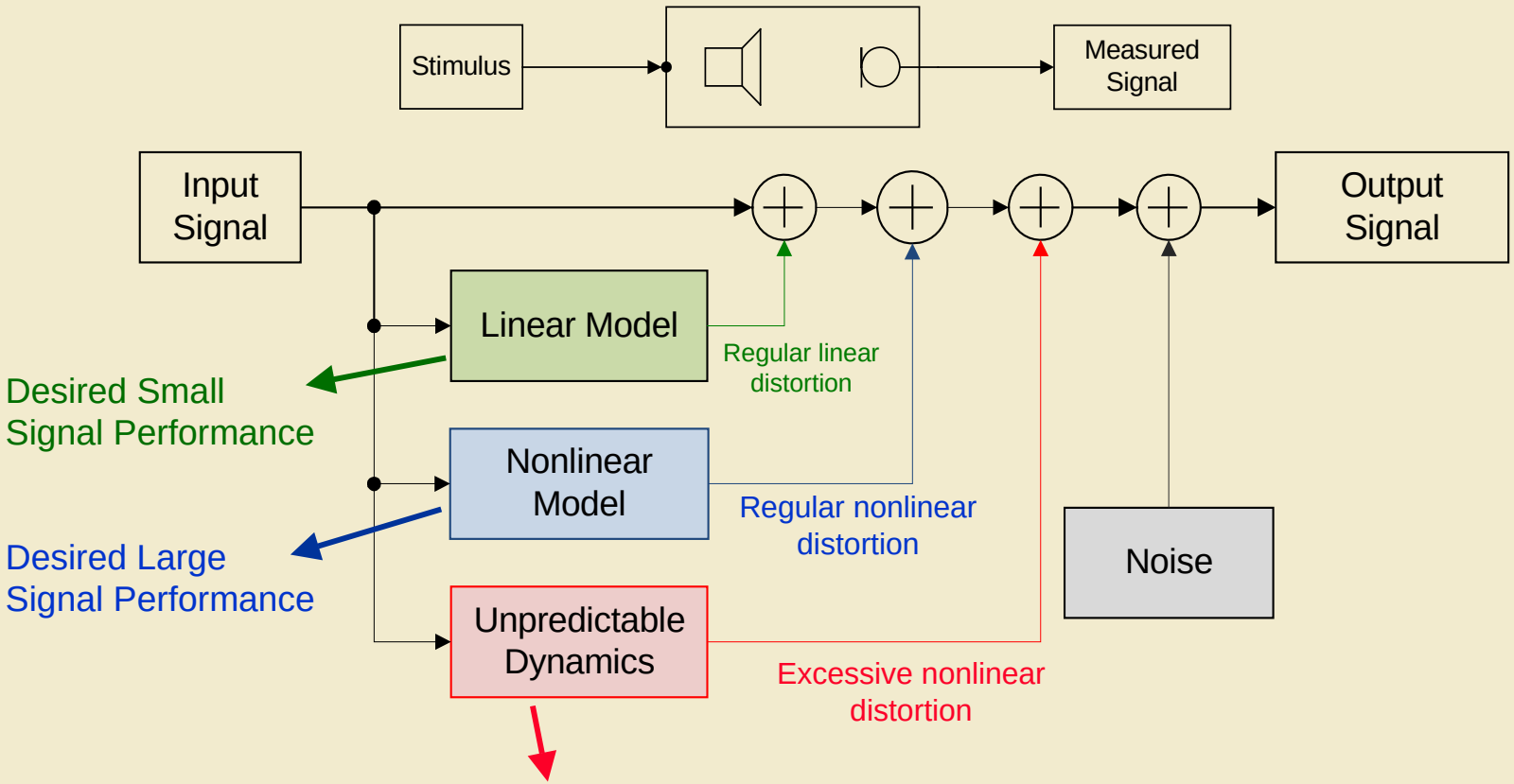
# Abstract

Air leaks in the dust cap and cabinets of loudspeakers generate turbulent noise which highly impairs the perceived sound quality as rub and buzz and other loudspeaker defects do. However, traditional measurement techniques often fail in the detection of air leaks because the noise has a large spectral bandwidth but a low power density and similar spectral properties as ambient noise generated in a production environment. The paper models the generation process of turbulent air noise and develops a novel measurement technique based on asynchronous demodulation and envelope averaging. The technique accumulates the total energy of the leak noise radiated during the measurement interval and increases the sensitivity by more than 20 dB for measurement times larger than 1s. The paper also presents the results of the practical evaluation and discusses the application to end-of-line testing.

# Questions Addressed in the Paper

- What kinds of distortion are acceptable (or even desired !) and which are not ?
- Why are air leaks critical defects in modern loudspeaker systems ?
- Why do traditional measurements fail in detecting air leaks ?
- How to exploit unique symptoms of air leaks ?
- How to distinguish leak noise and port noise in vented loudspeakers ?
- How to detect leaks in a noisy production environment ?

# Generation of Signal Distortion in Loudspeakers




**Undesired Loudspeaker Defects**

- Rubbing coils , buzzing parts
- Wire beat, coil bottoming
- Loose particles, air leak noise
- Parasitic vibration of other components

# Regular Distortion

(accepted, partly desired)

- are determined by design (geometry and material properties)
- compromised by cost, size, weight
- can be predicted by linear and nonlinear parameters
- some regular distortion improve perceived sound quality

→ subjective evaluation required in design process (listening test, nonlinear auralization)

→ objective assessment based on perceptional modeling useful (in development for many years)

# Irregular Distortion

(not acceptable)

- are symptoms of loudspeaker defects („rub & buzz“)
- not found in approved prototypes, golden reference unit
- are caused by manufacturing, overload, ambient conditions
- are not directly related to cost, size, weigth
- are inacceptable if detected by customer
- depend on the operation condition (e.g. orientation + loose particles)
- are time variant (aging) and usually become worse over time

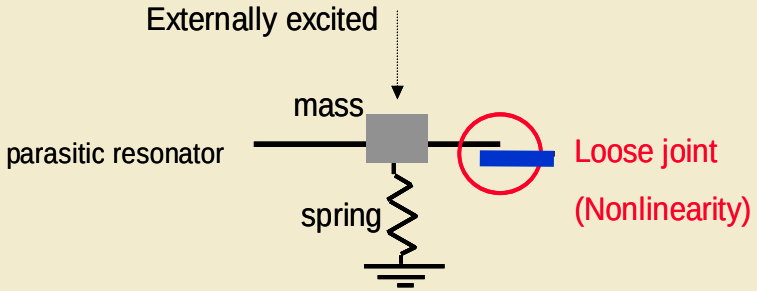
→ Defects may become audible in the final application

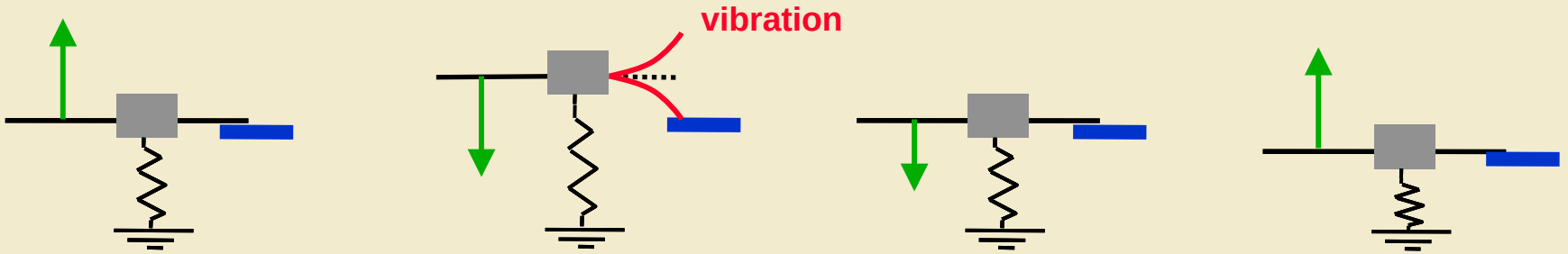
→ Quality control has to detect loudspeaker defect in the initial state by using trained human testers or most sensitive measurement equipment

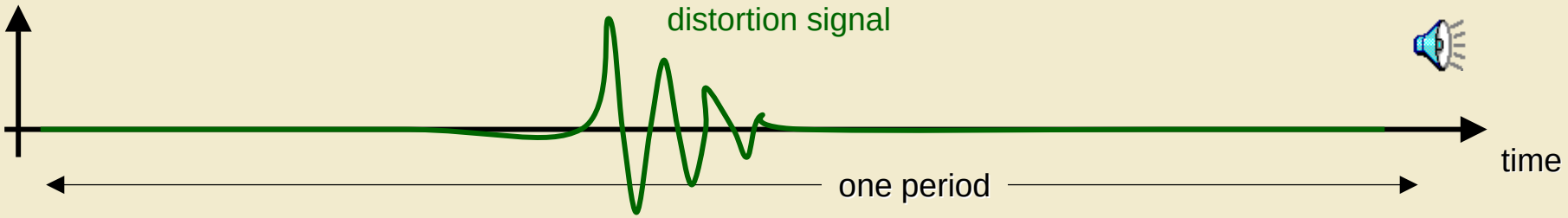
# Loudspeaker Defect: *Buzz problem*

Most defects behave as a **nonlinear oscillator**

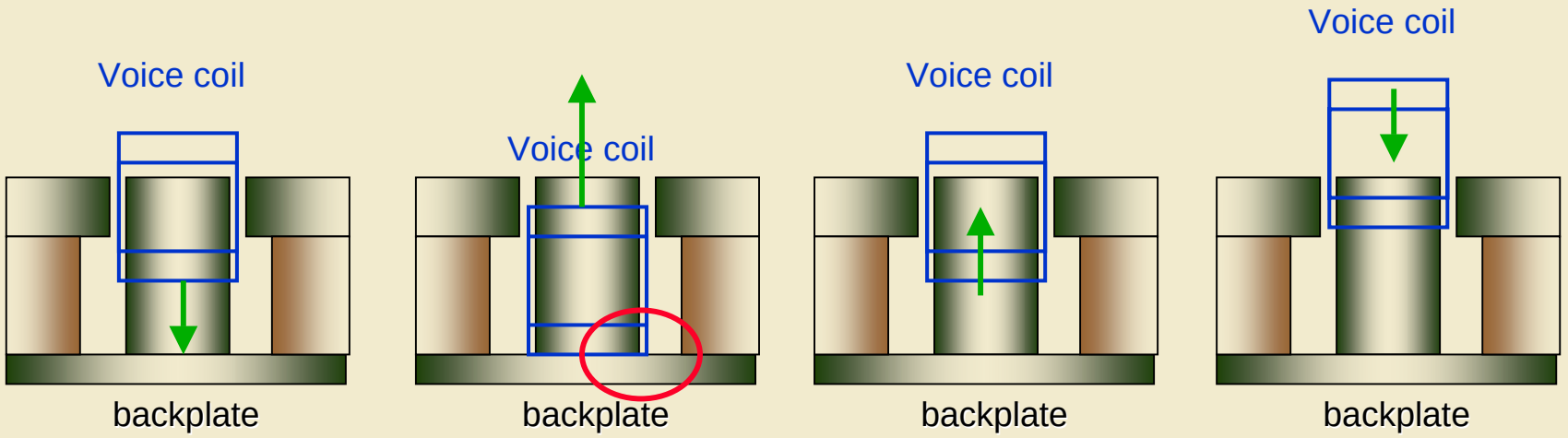
- active above a critical amplitude
- new mode of vibration
- powered and synchronized by stimulus
- constant output power

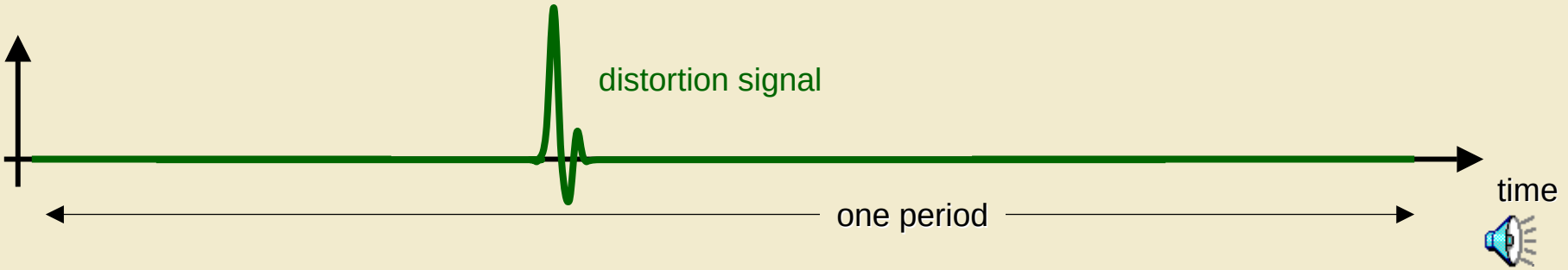


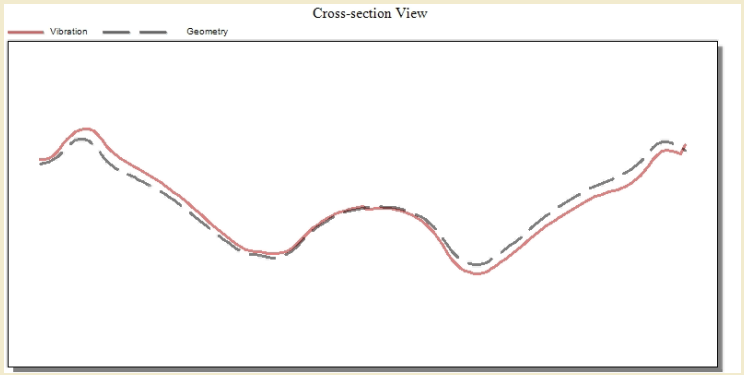
# Loudspeaker Defect: *voice coil hits the backplate*



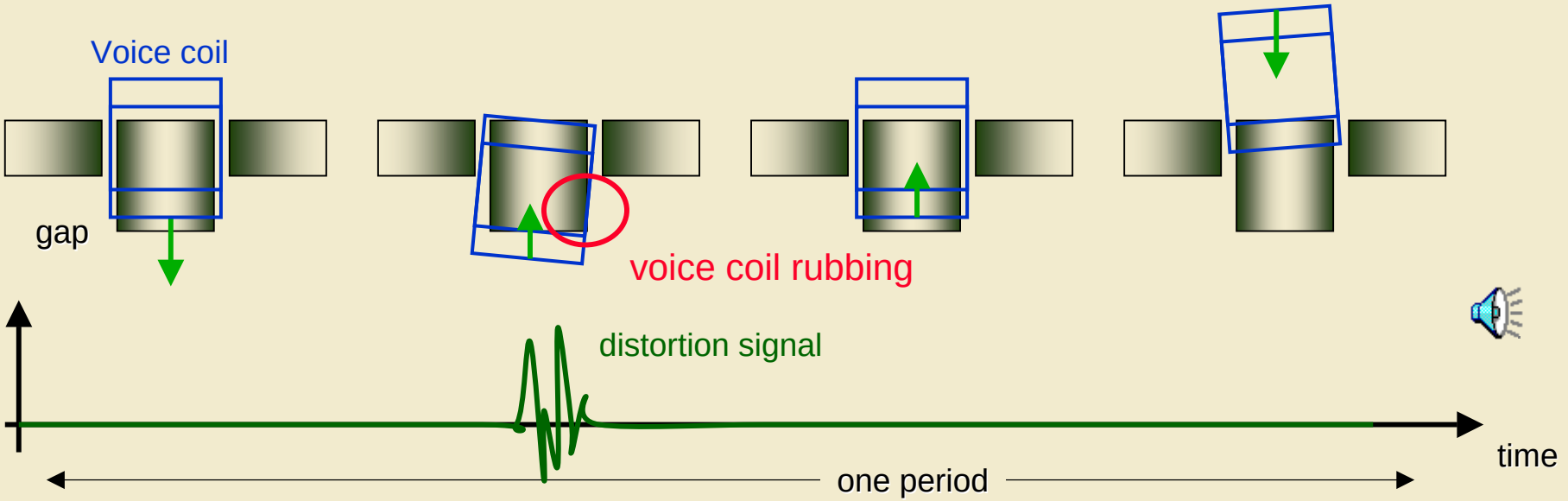




Short impulse, deterministic symptom

# Loudspeaker Defect: *voice coil rubbing*

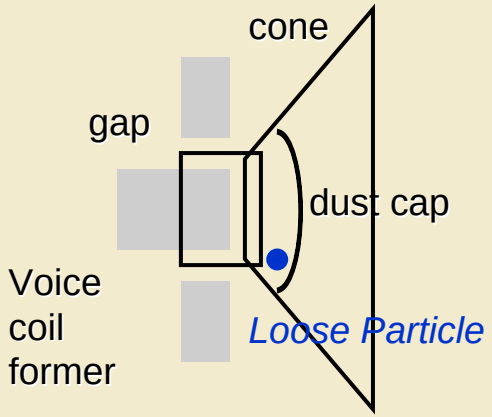


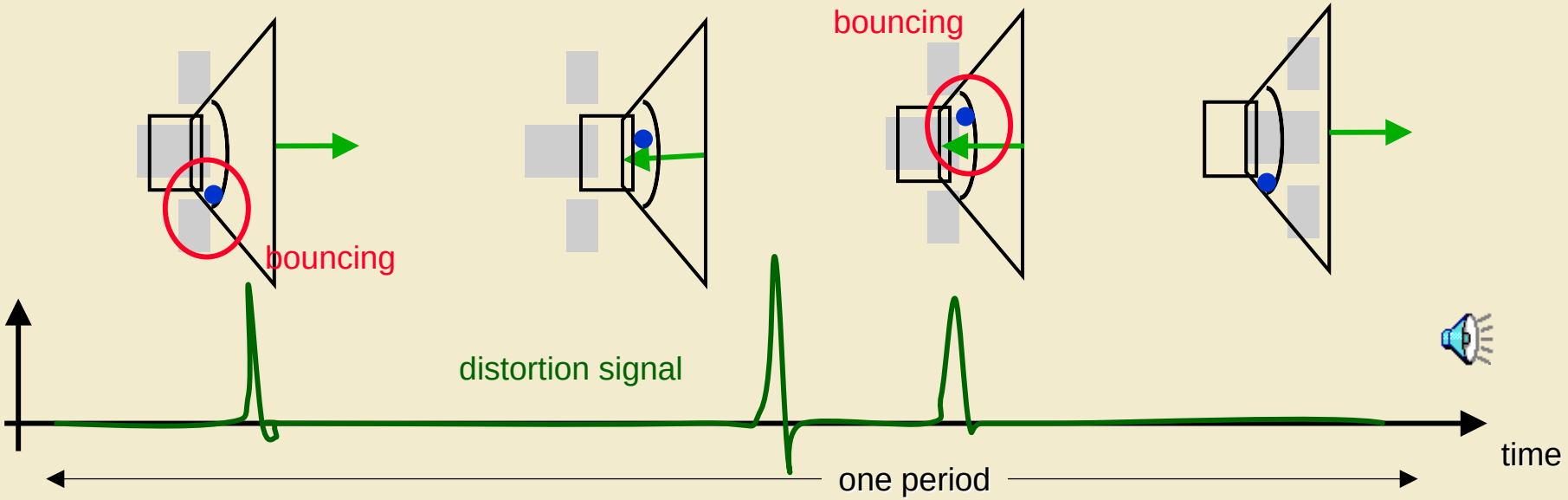

Rocking mode may cause at 328 Hz



# Loudspeaker Defect: *Loose Particles*

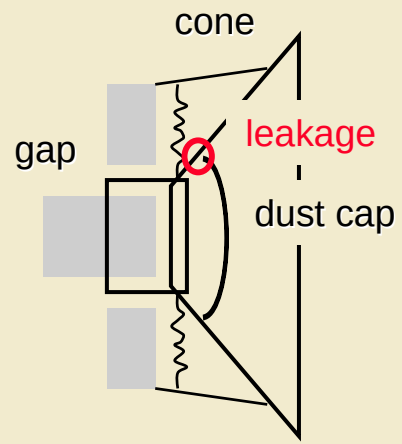
- stochastic process
- particles are accelerated by cone displacement
- not synchronized with stimulus
- constant output power

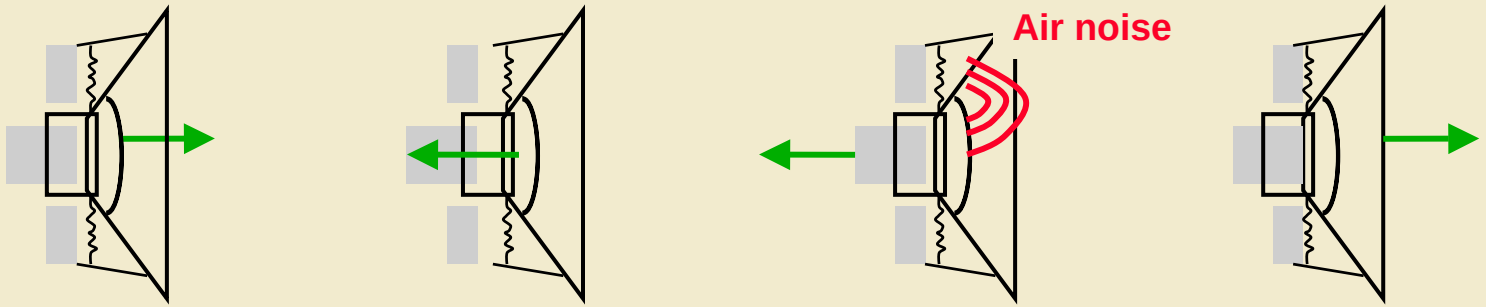


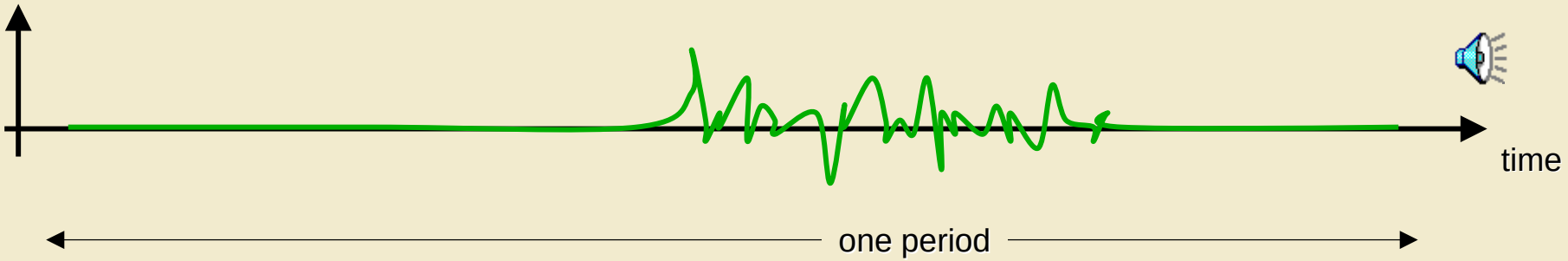



# Loudspeaker Defect: *Air Noise*

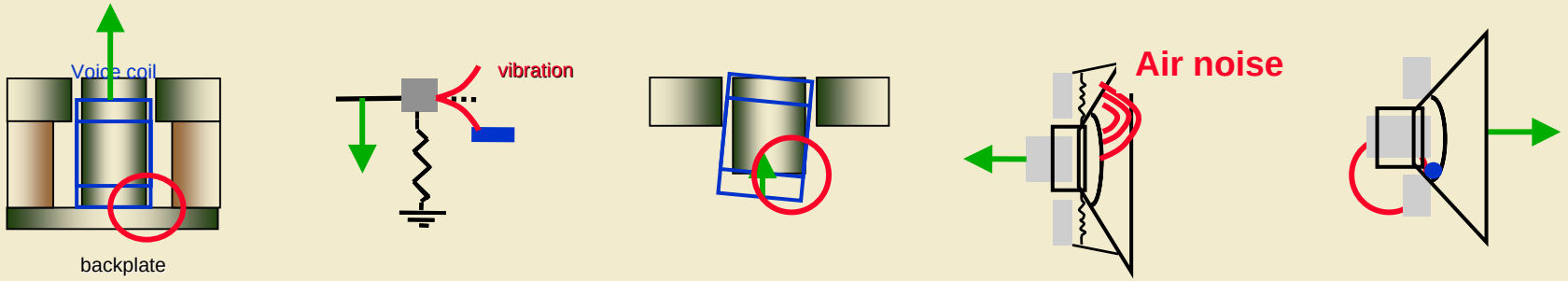
- stochastic process
- air pressure is changed by coil displacement
- synchronized with stimulus



# Classification of Loudspeaker Defects




*hitting backplate* | *Buzzing* | *Coil rubbing* | *Air leakage* | *Loose particles*

**Deterministic Distortion** | **Semi-Random Distortion** | **Random Distortion**

Waveform is completely reproducible

Envelope is reproducible (Waveform is not)

Symptoms are not reproducible

# Deterministic Distortion

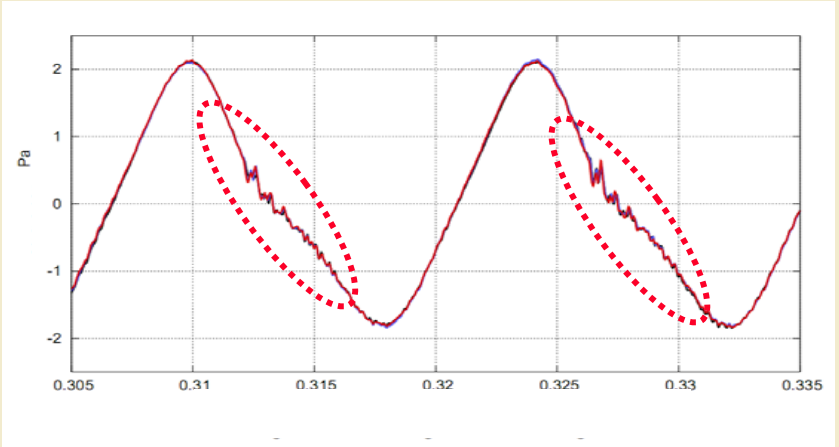
**Examples:**

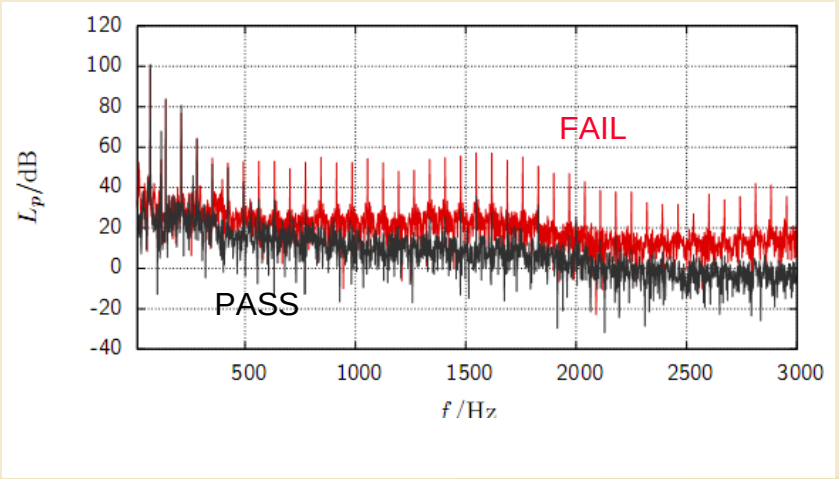
- Wire beat,
- hitting backplate

**Symptoms:**

- reproducible, repeatable
- related to the stimulus
- impulsive distortion
- deterministic amplitude and phase of higher-order harmonics

Results of three measurements



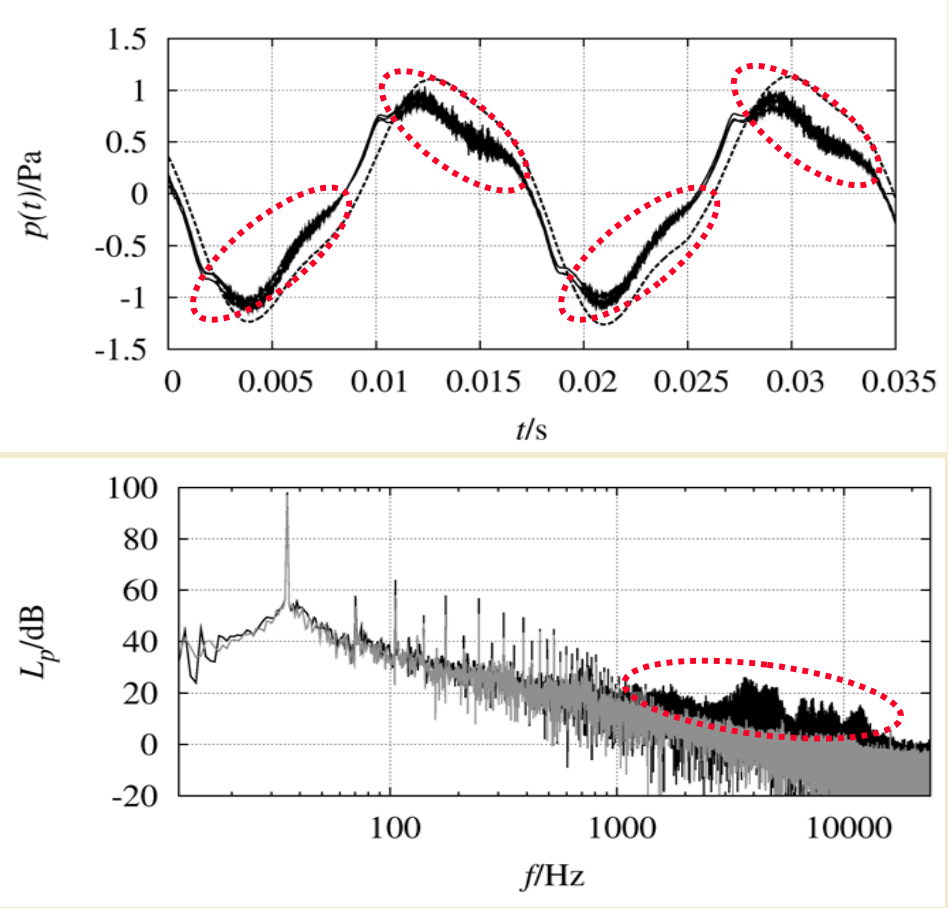
# Semi-Random Distortion

**Examples:**

- Turbulent air noise generated at leaks
- coil rubbing

**Symptoms:**

- Waveform of distortion is NOT reproducible
- Distortion occur at particular times
- Dense spectrum (cover audio band and beyond)



# Where Are Air Leaks Critical ?

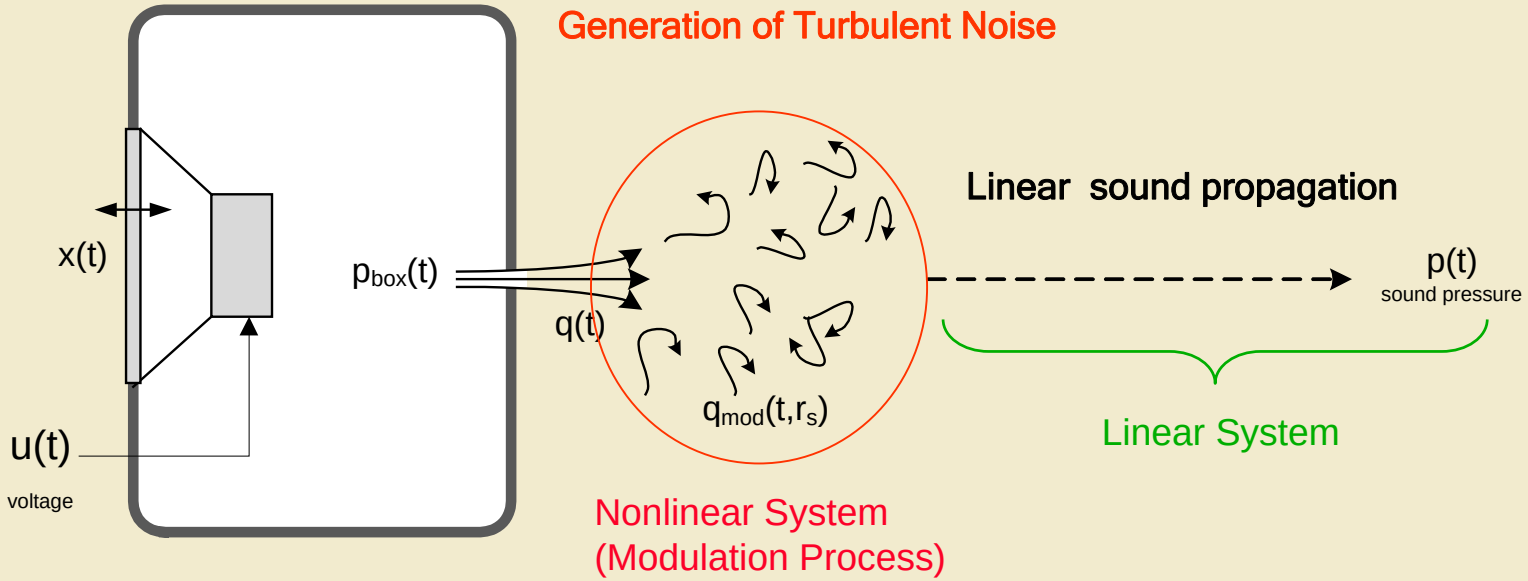
1. Transducers (woofer, tweeter)

- High sound pressure below dust cap → good radiation of turbulent sound

2. Loudspeaker Systems

- Woofers mounted in SMALL enclosures and operated with bass enhancement
- Subwoofers reproducing a bass signal only

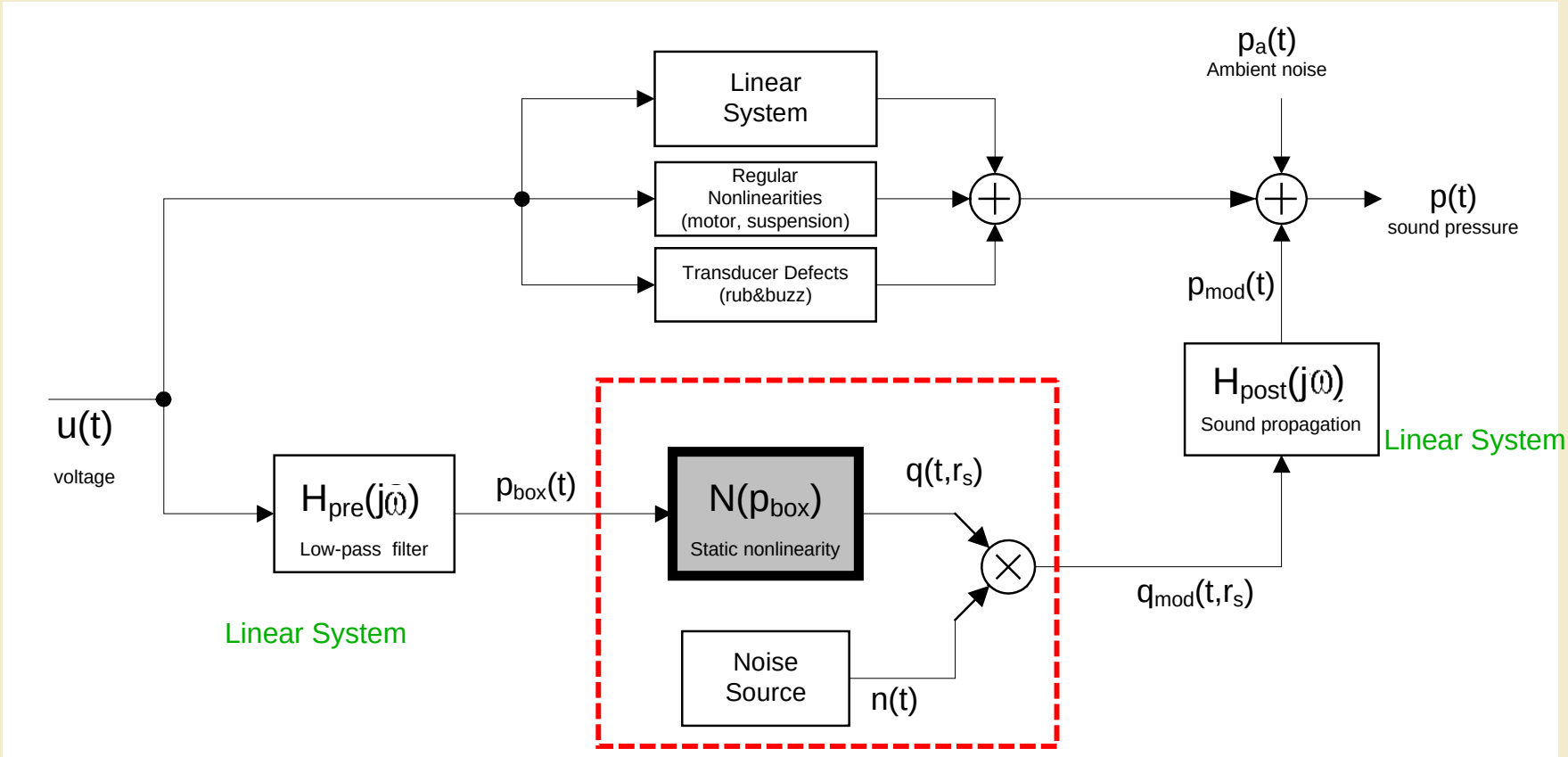
# Generation of Turbulent Air Distortion



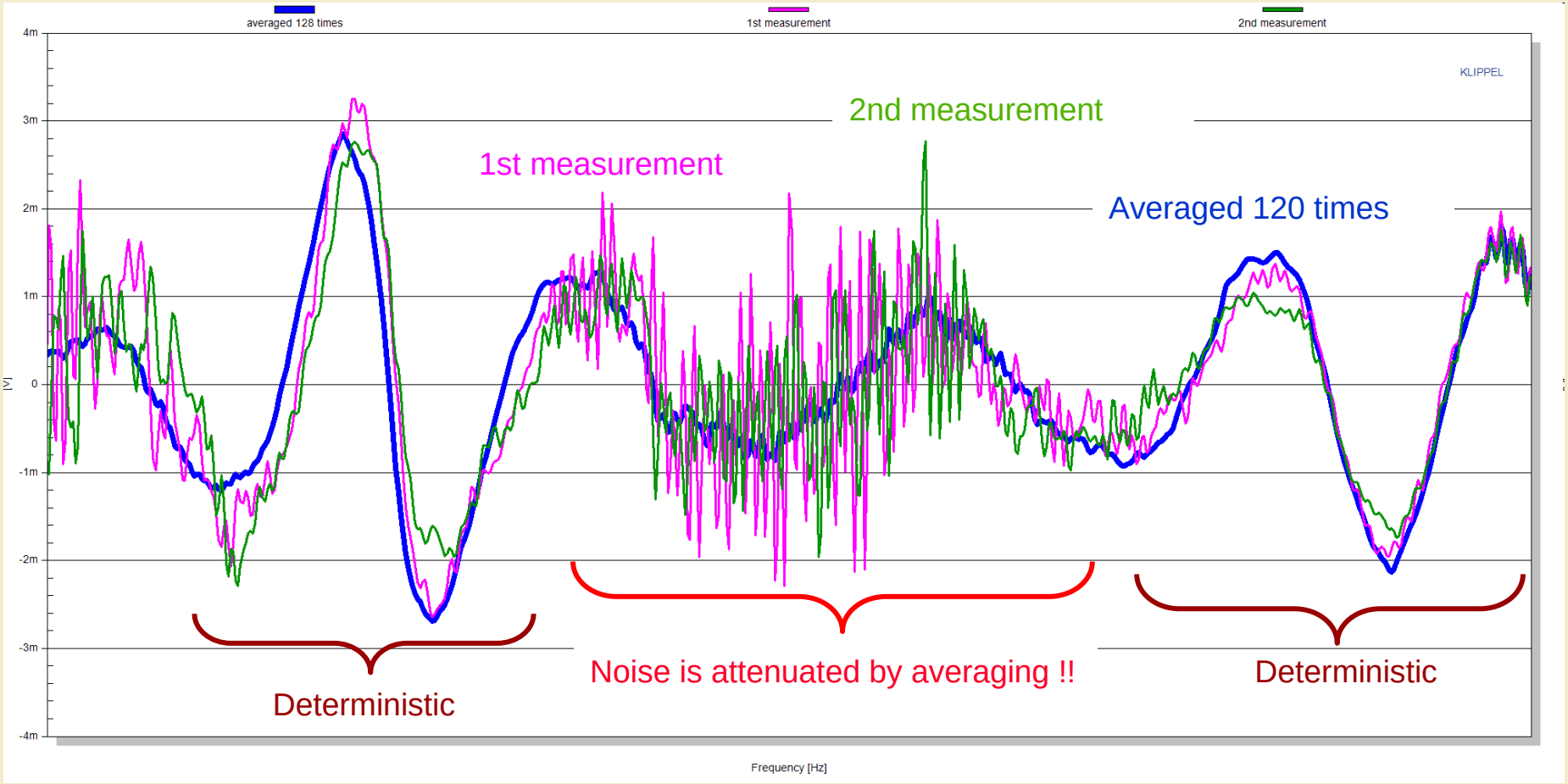

**Generation of High Volume velocity q(t)**
Voltage → displacement → sound pressure → volume velocity

Linear System

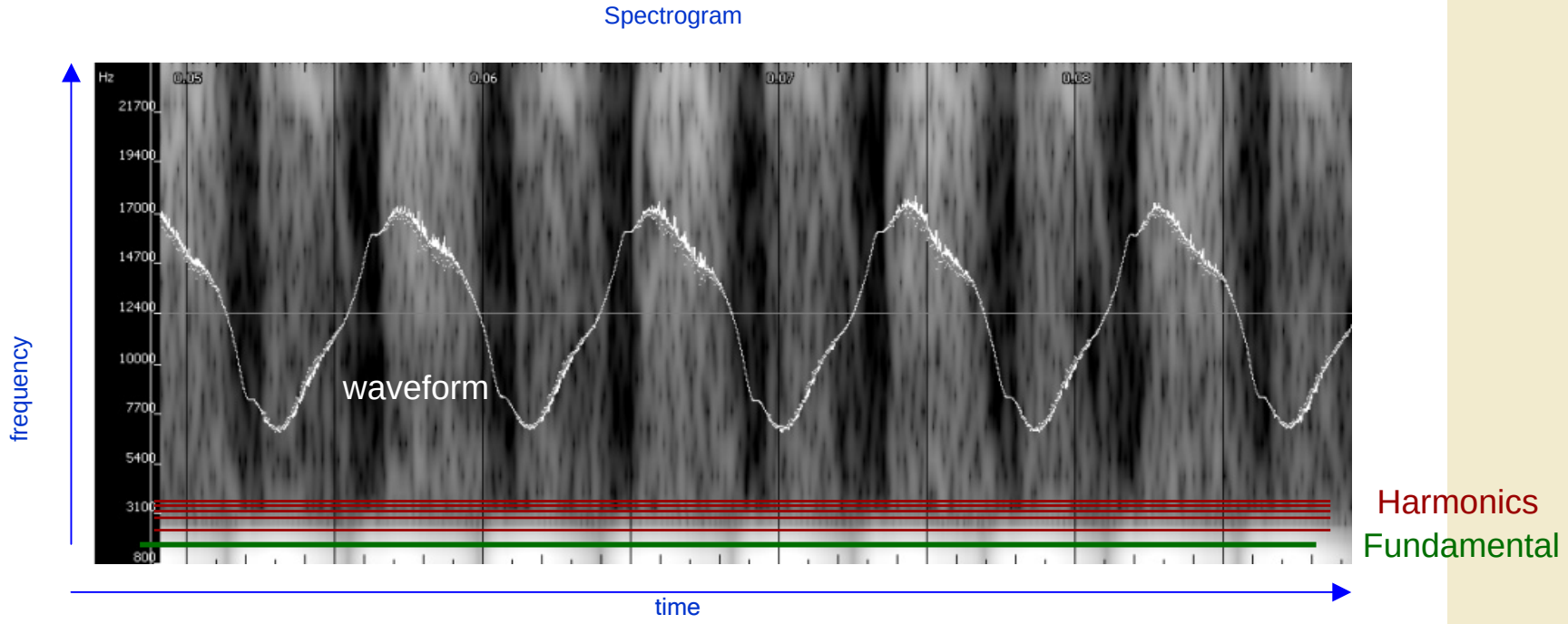
# Modeling by a Signal Flow Chart



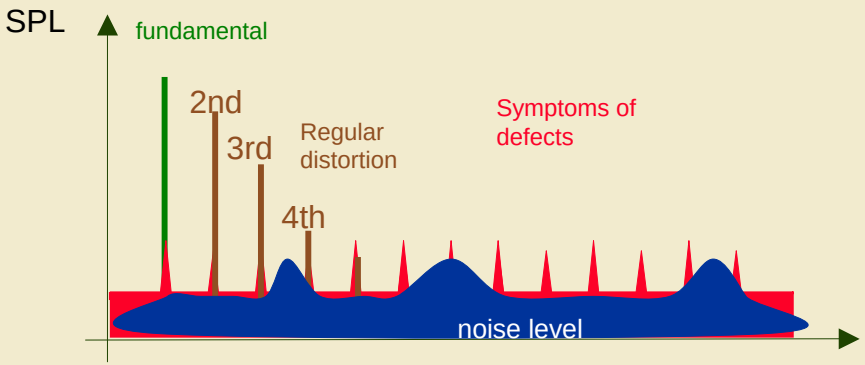
# Why Are Traditional Measurements Not Sensitive for Air Leaks ?



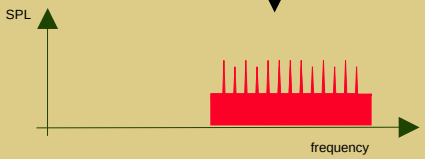
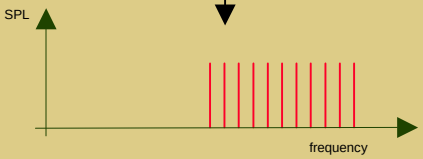
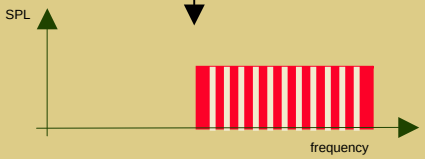
# Spectrogram
# of the Turbulent Air Leakage Noise



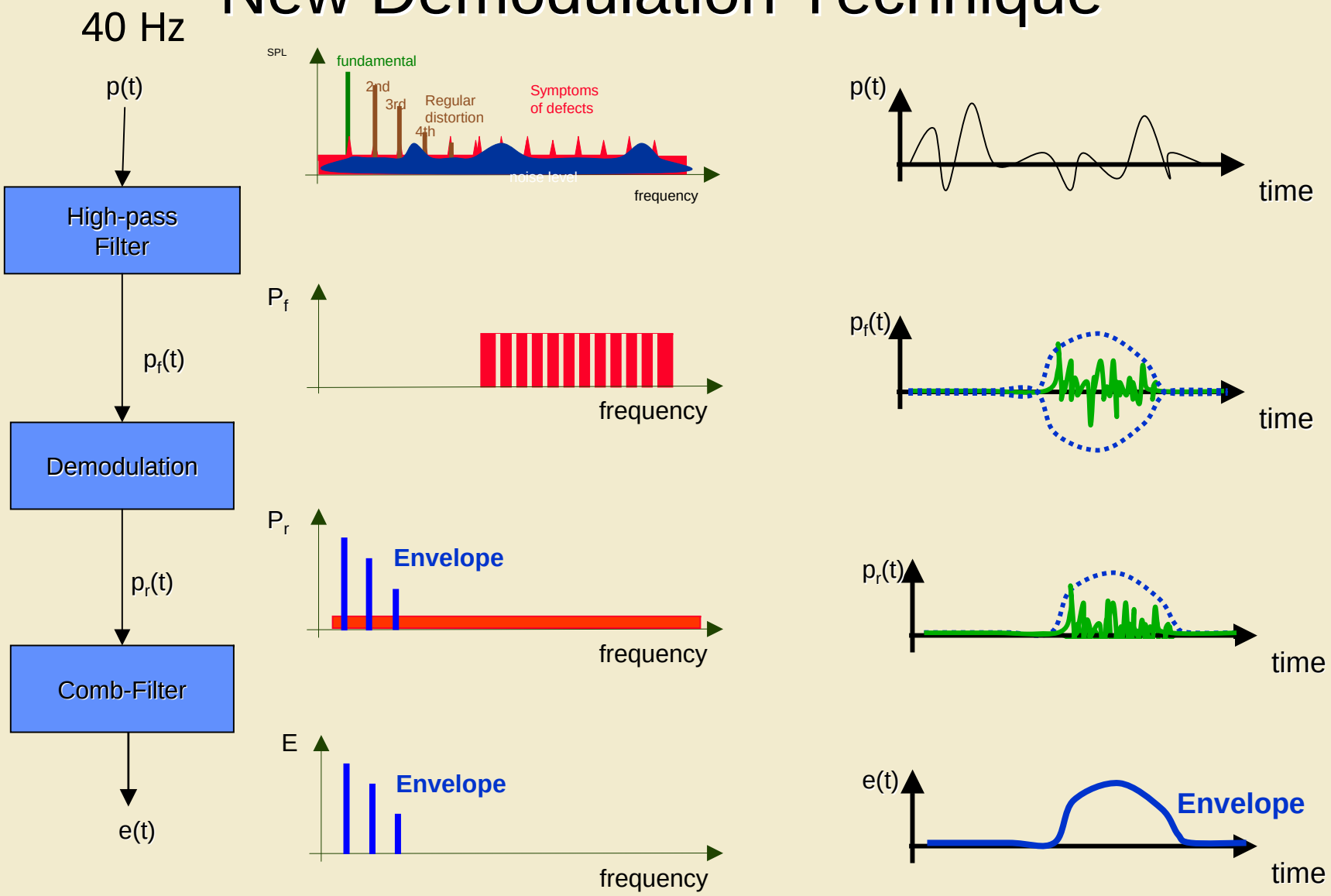
# Symptoms Derived From a Sinusoidal Stimulus




Order n > 10th

| | High-pass Filter | Comb Filter | Inverse Comb Filter |
|---|---|---|---|
| Frequency Domain |   Complex Spectrum (Amplitude + Phase) |   Harmonic distortion (n > 10) |   non-harmonic distortion (n > 10) |
| Time Domain | Total Distortion | Deterministic distortion | Random distortion<br>Semi-random distortion<br>Ambient noise |

# New Demodulation Technique




→ The envelope corresponds with the total power of the modulated noise

# Absolute Modulation Level

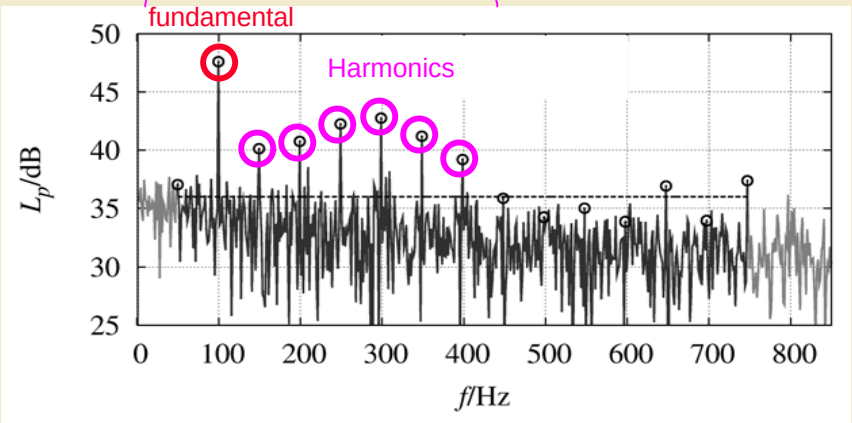
Peak value of the envelope

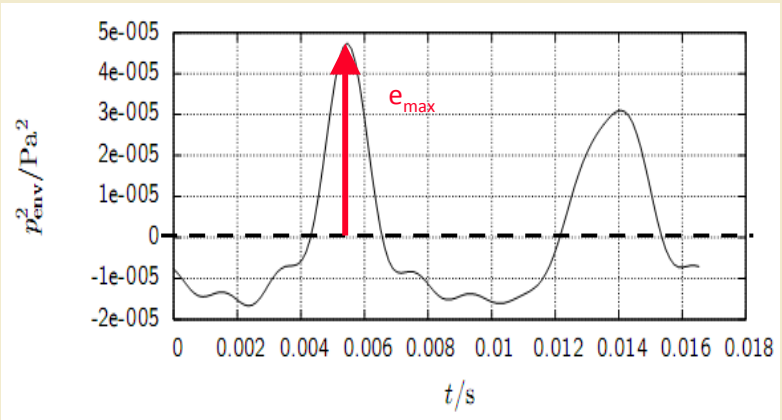
$$\mathrm{MOD}_{\mathrm{abs}} = 10 \lg \left( \frac{e_{\max}}{2 p_0^{\,2}} \right)$$

Absolute hearing threshold $p_0$

- **Shows the peak value of the envelope**
- **is in dB referred to the absolute hearing threshold $p_0$**
- **good for PASS/FAIL decisions**

**deterministic components**



# Relative Modulation Level

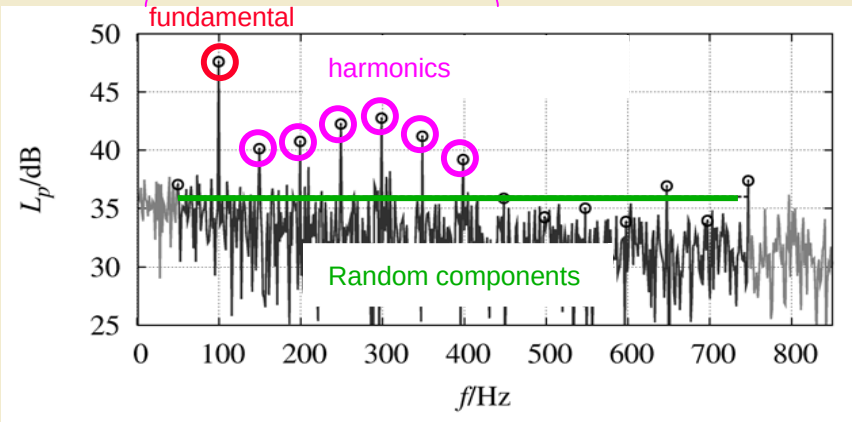
Peak value of deterministic part

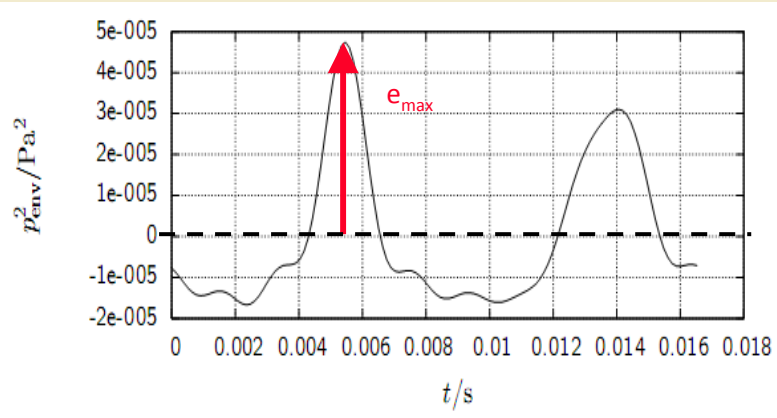
$$\mathrm{MOD}_{\mathrm{rel}} = 10\,\lg\left(\frac{e_{\max}}{\tilde{r}^{\,2}}\right)$$

Rms value of random components

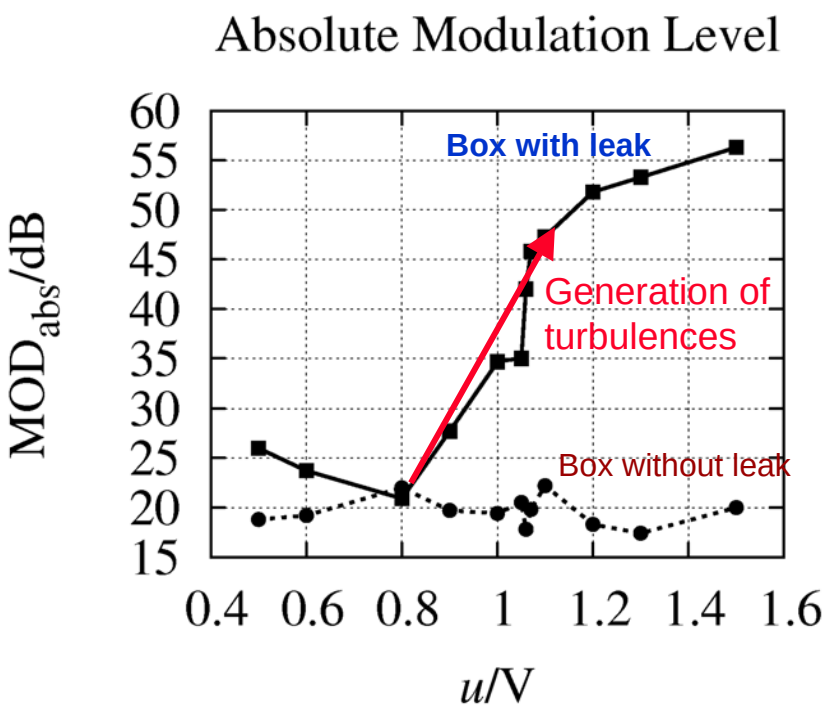
- **Considers the ratio of deterministic and random parts of the envelope**
- **Shows significant modulation ($MOD_{rel}$ > 0)**
- **Is in dB**
- **good for PASS/FAIL decisions**

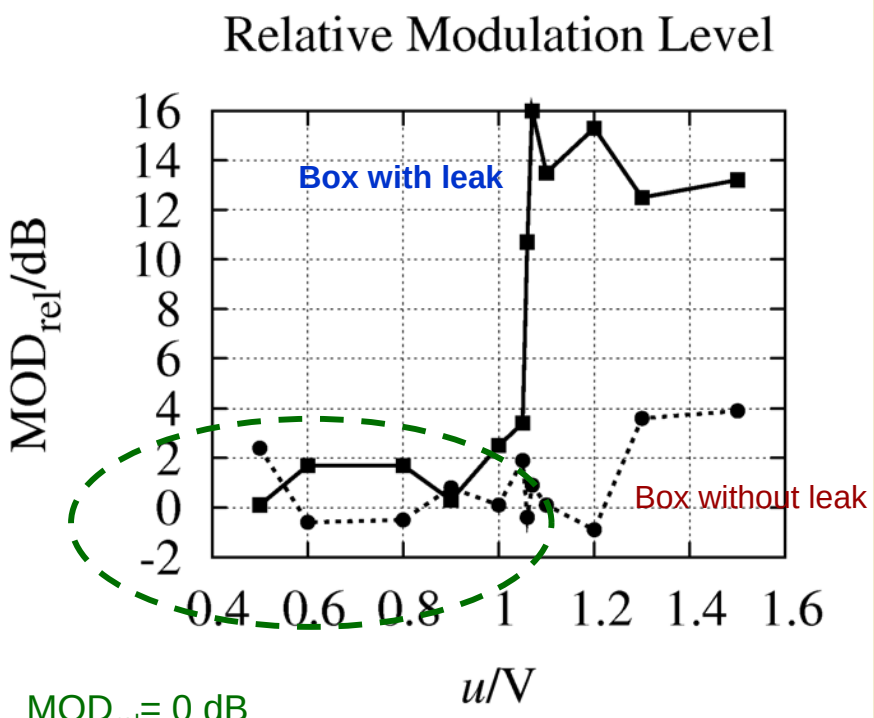
**deterministic components**



# Influence of Excitation Voltage

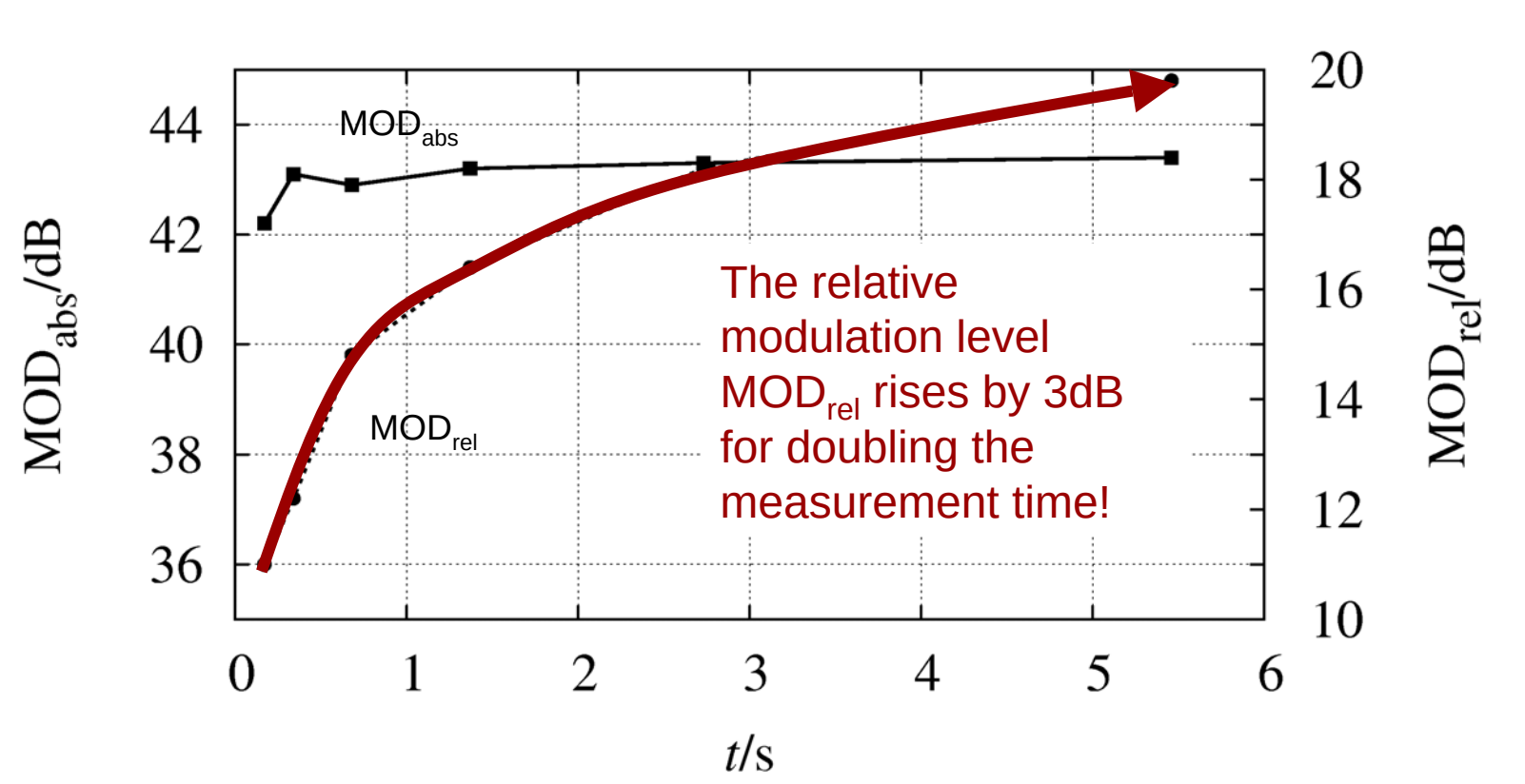



$MOD_{rel}$= 0 dB indicates no modulation

- Turbulent air leakage noise set in abruptly if the velocity of the air at the leak exceeds a critical value.
- Search for the critical voltage of the stimulus !!

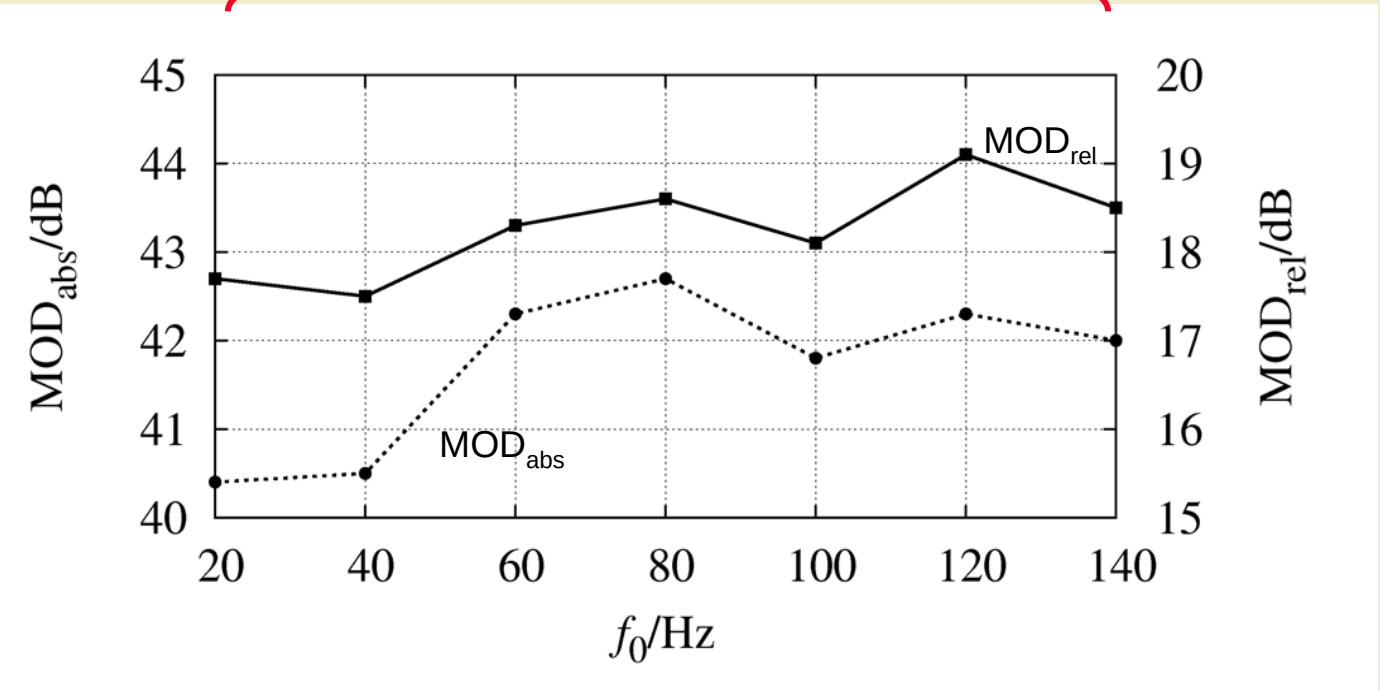
# Influence of Measurement Time




A 1s stimulus of 100 Hz will increase the sensitivity by 20 dB for semi-random distortion !

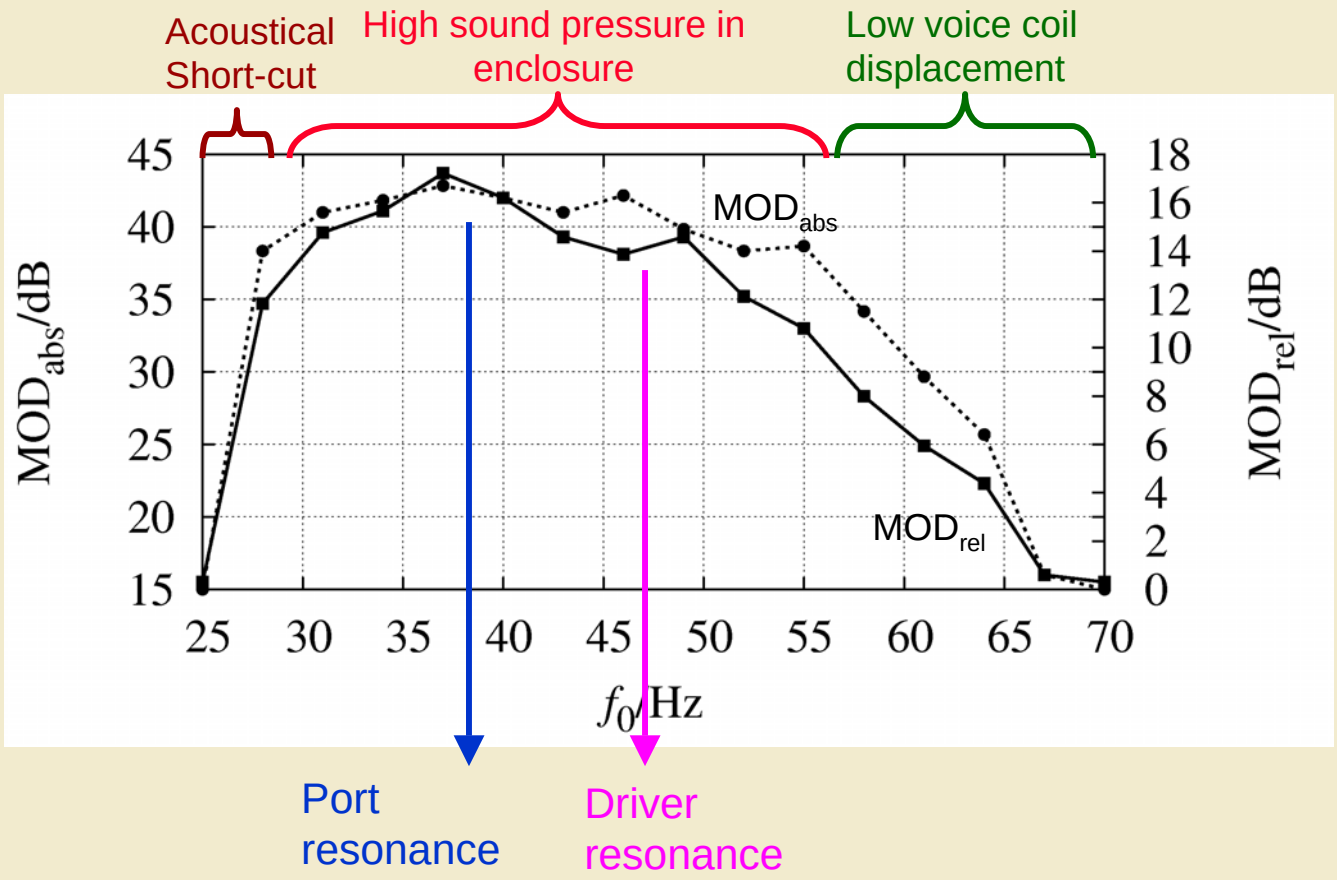
# Closed-Box Loudspeaker Systems

High sound pressure in enclosure



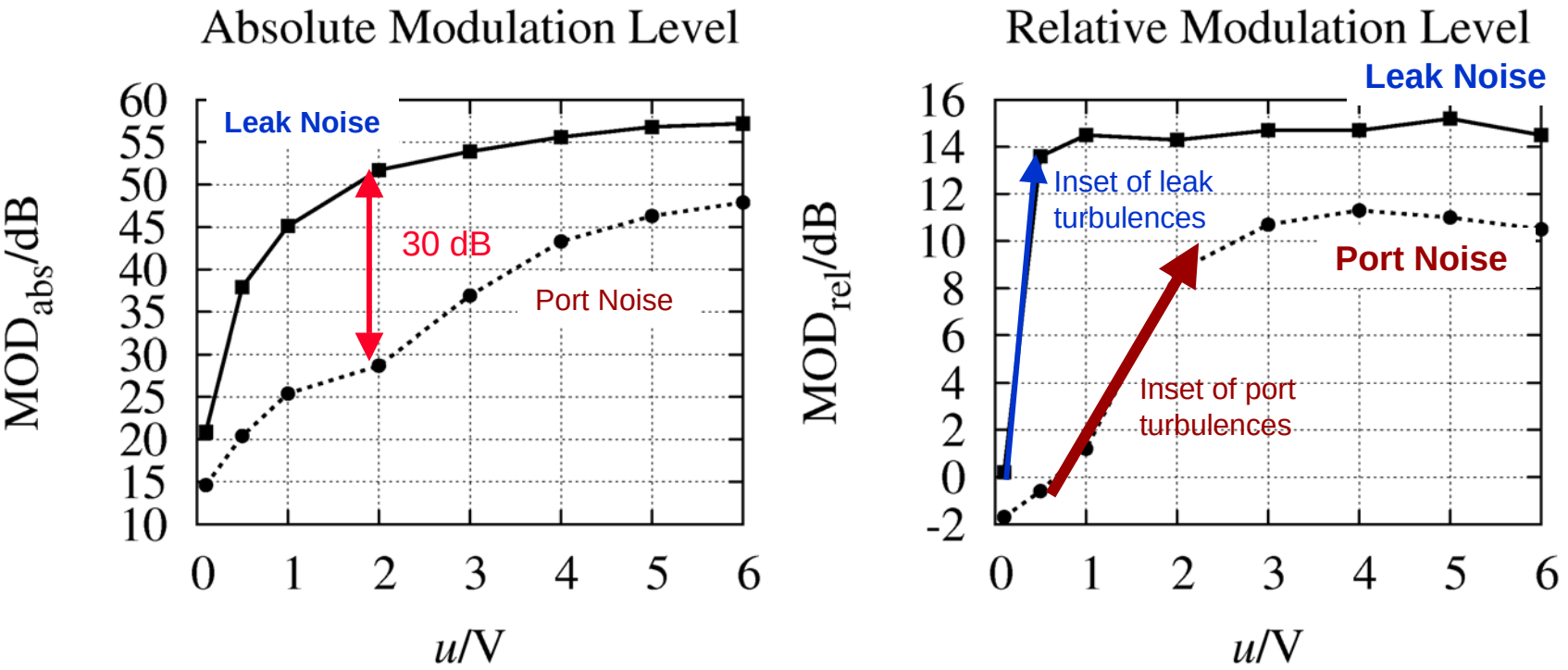

Set frequency of sinusoidal stimulus just below system resonance !

# Vented-Box Loudspeaker Systems




Set frequency of sinusoidal stimulus just above port resonance and below driver resonance !

# How to Separate Port and Leak Noise ?

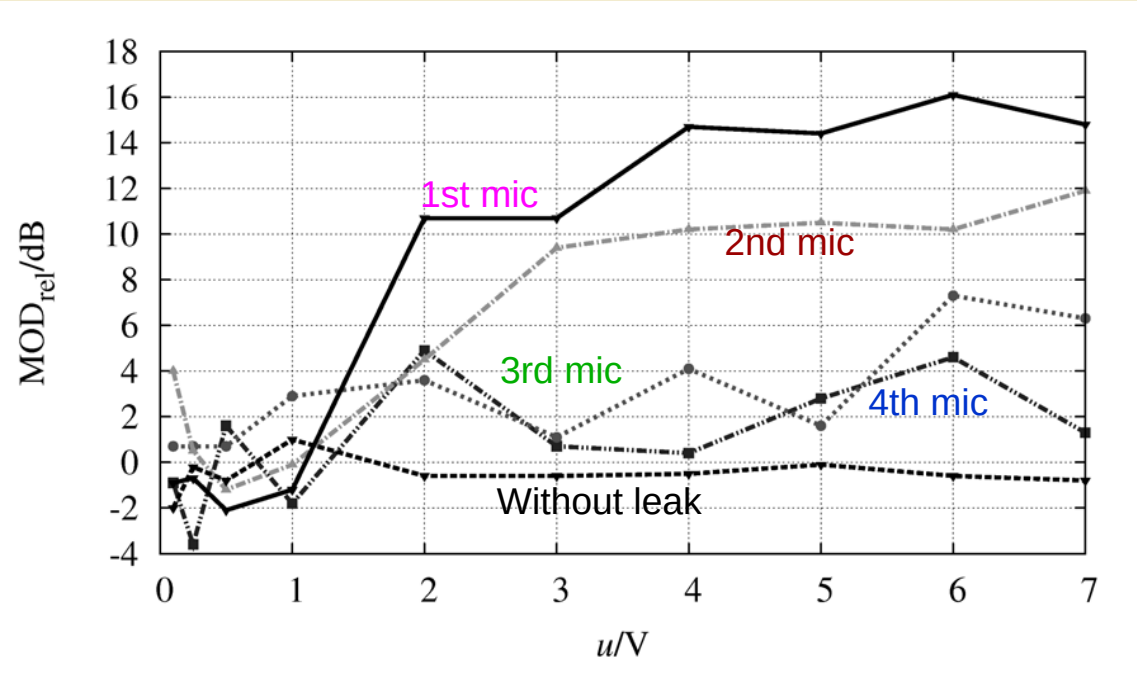


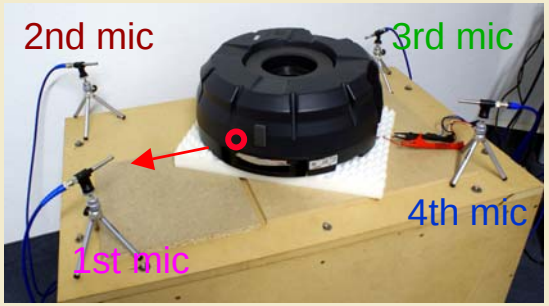

- Close the port for leakage detection (if possible)
- Select optimal excitation voltage (e.g. 1-2 Volt) between inset of leak and port turbulences
- Shield test microphone from port noise
- Choose optimal microphone position
- Use directional microphone

# Influence of Microphone Position

- Air Leaks are a directional sound source
- There is not much diffraction of the high-frequency components
- Microphone may be shadowed by large loudspeaker systems

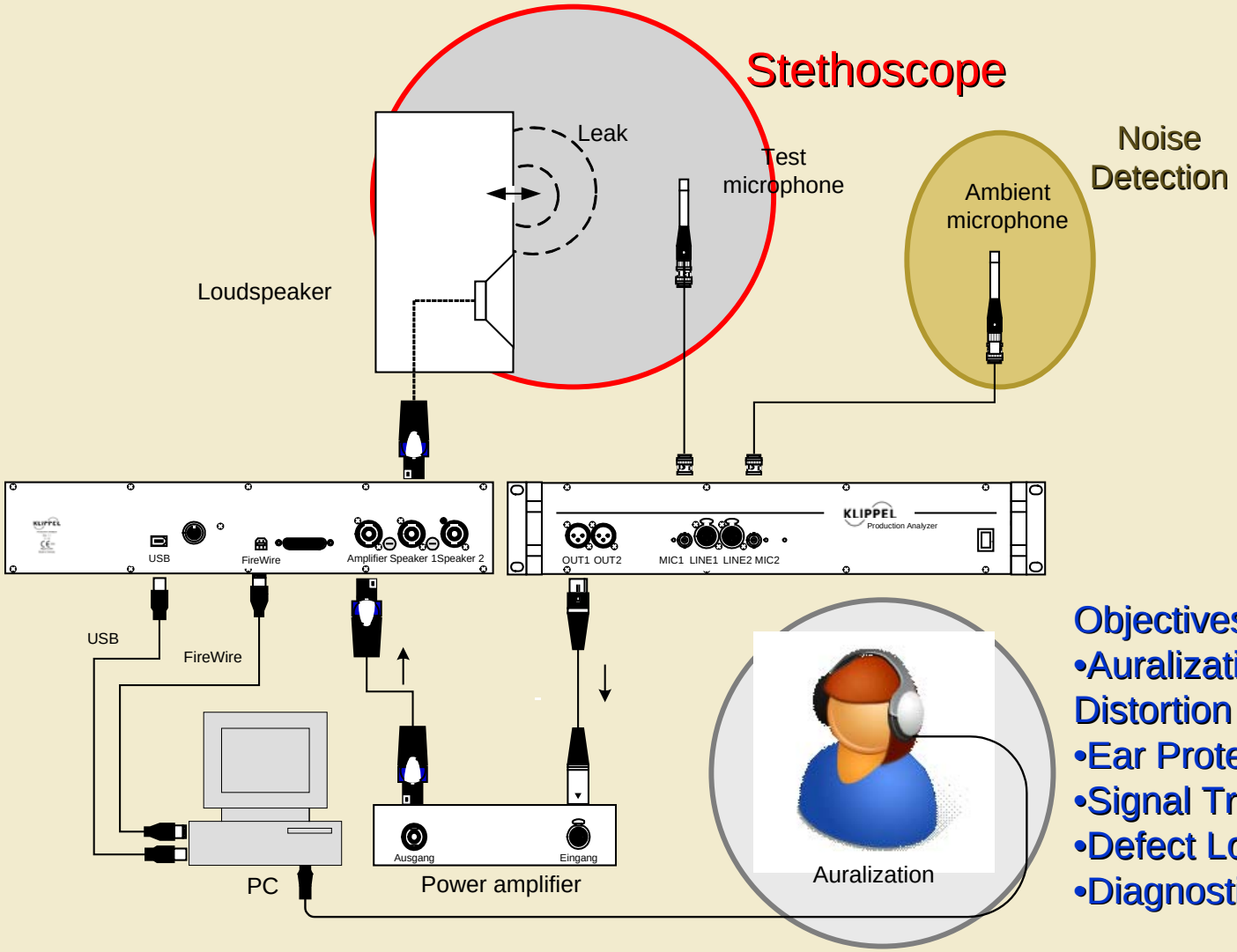
→ Multiple microphones are required




Example: Reliable detection of 1 mm leaks in an automotive speaker by using 4 microphones

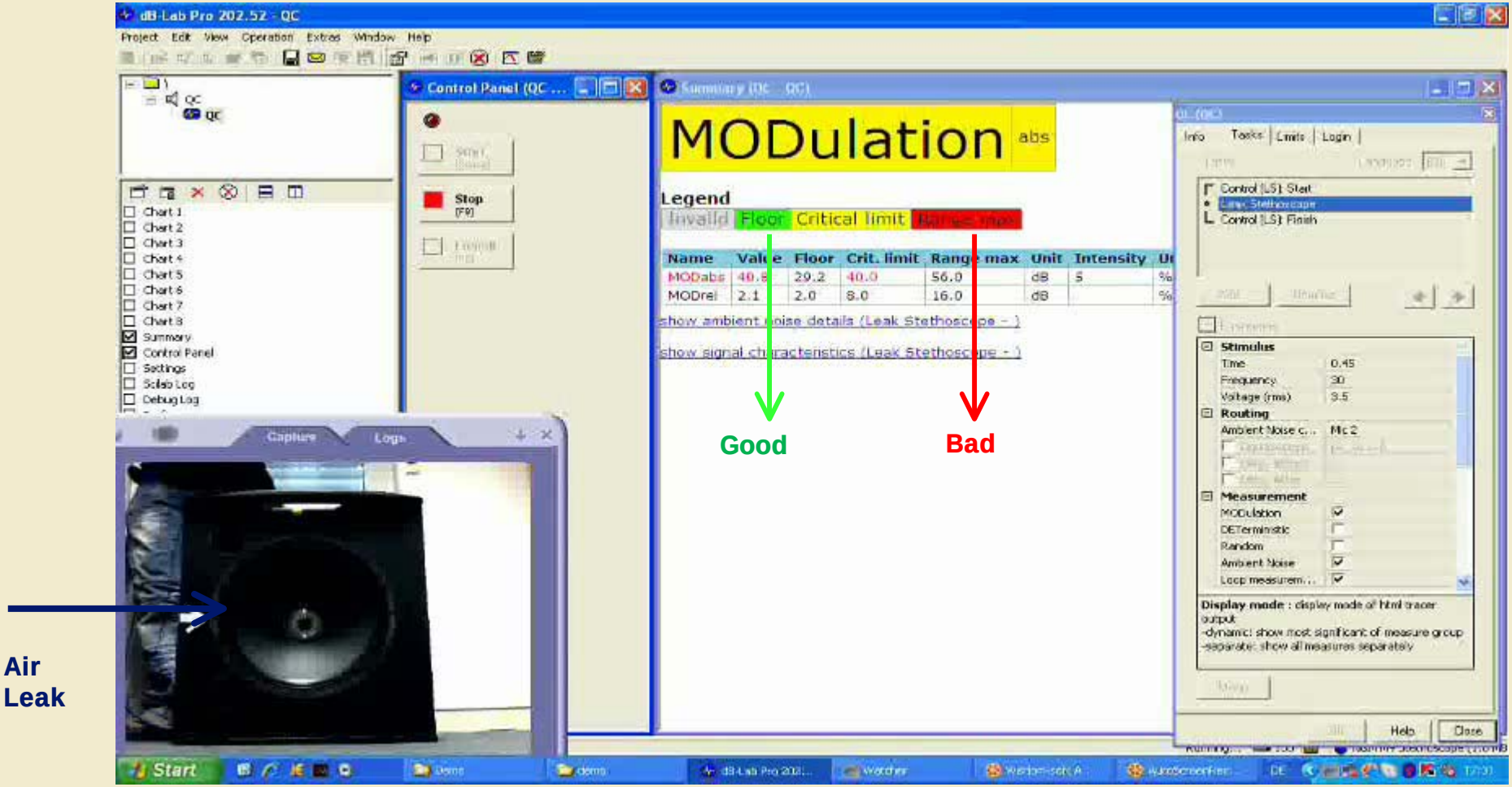
# Combining Subjective and Objective Assessment



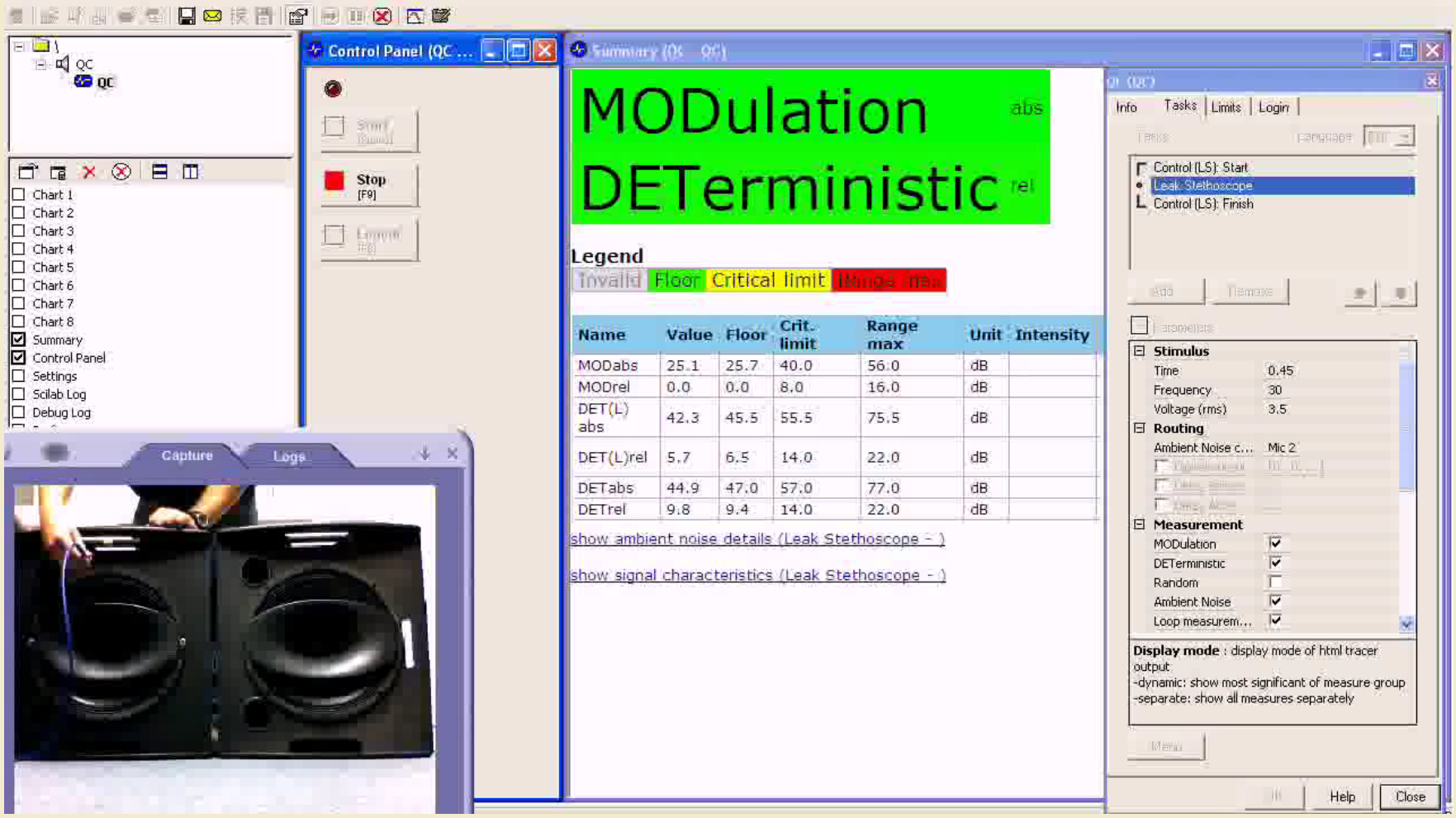

**Objectives:**

- Auralization of Irregular Distortion
- Ear Protection
- Signal Transformation
- Defect Localization
- Diagnostics

# Localization of Loudspeaker Defects



# Localization of Loudspeaker Defects




**Good** **Bad**

# Conclusions

- Transducers driven by electronic bass enhancement produce high sound pressure in small sealed enclosures
- Air leaks in loudspeaker system produce distortion having a high impact on sound quality
- Turbulent noise has a dense spectrum of low power density and can not detected reliably by conventional techniques
- A new demodulation technique accumulate the total noise energy by averaging the envelope (→ more sensitive than a human ear)
- Defects can be detected in the initial stage which become audible in the final application
- Using multiple microphones gives full ambient noise immunity in a production environment

# Many Thanks !