

Acoustical Measurement of Sound System Equipment according IEC 60268-21

KLIPPEL LIVE

a series of webinars presented by

Wolfgang Klippel

Previous Sessions

1. Modern audio equipment needs output based testing
2. Standard acoustical tests performed in normal rooms
3. Drawing meaningful conclusions from 3D output measurement
4. Simulated standard condition at an evaluation point
5. Maximum SPL – giving this value meaning
6. Selecting measurements with high diagnostic value
7. Amplitude Compression – less output at higher amplitudes
8. Harmonic Distortion Measurements – best practice
9. Intermodulation Distortion – music is more than a single tone
10. Impulsive distortion - rub&buzz, abnormal behavior, defects
11. Benchmarking of audio products under standard conditions
12. Auralization of signal distortion – perceptual evaluation
13. Setting meaningful tolerances for signal distortion
14. Rating the maximum SPL value for a product
15. Smart speaker testing with wireless audio input

10th KLIPPEL LIVE: **Impulsive distortion - rub&buzz, abnormal behavior, defects**

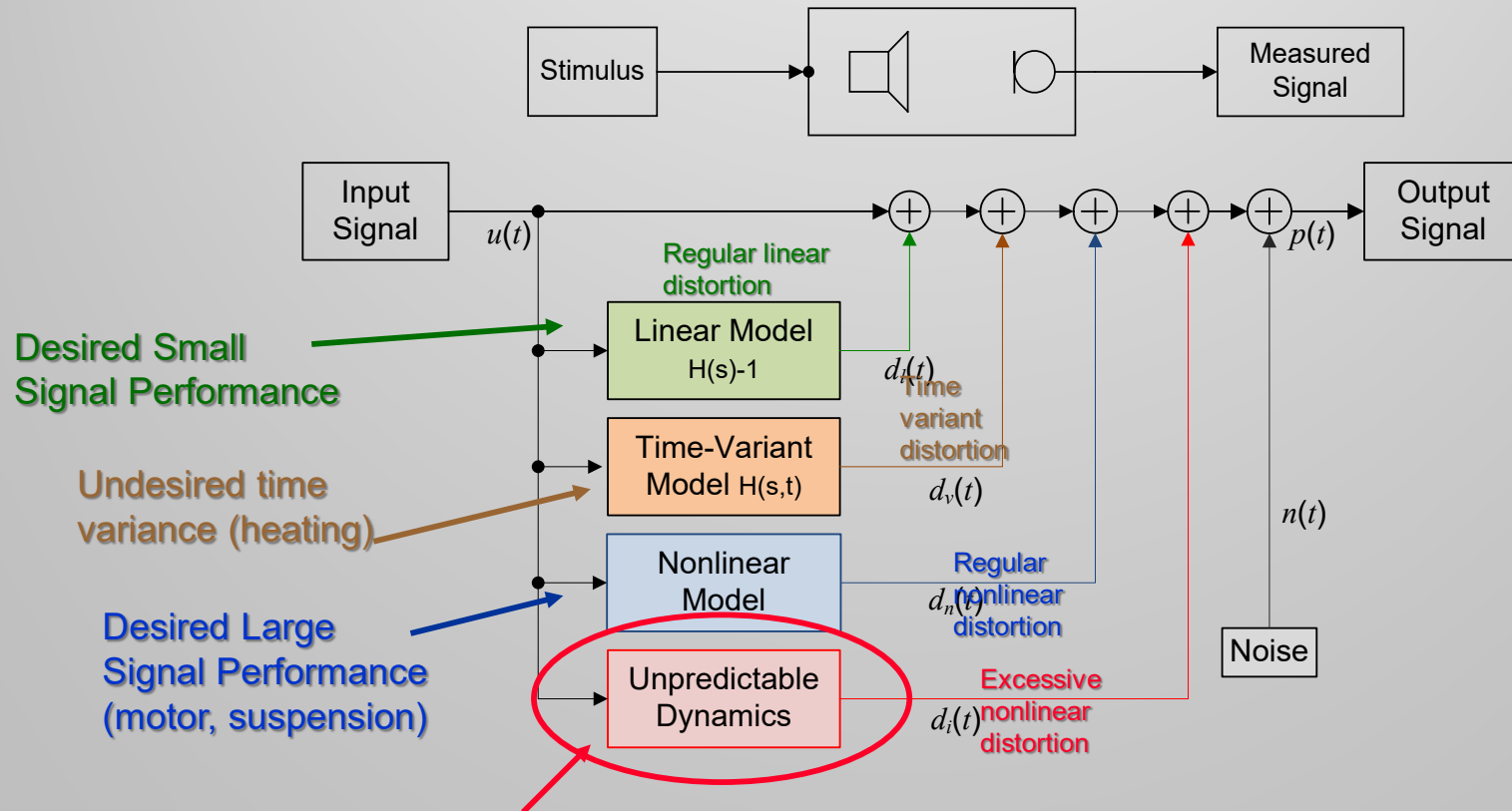
Topics today:

- Overview on irregular properties of audio devices
- Measurements according to IEC Standard 20268-21
- Measurement of impulsive distortion in the time domain
- Combining physical measurements and listening



Desired and Undesired Components ?

Generation of Signal Distortion in an Audio System



Undesired Defects

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

Poll:

How do you evaluate the rub&buzz and other irregular distortion ?

- A. By listening with music 18%
- B. Manual sweep + listening 61%
- C. Chirp + Total harmonic distortion (THD) 21%
- D. Chirp + Higher-order harmonics 15%
- E. Chirp + Time domain analysis (Time-Frequency Analysis, impulsive distortion analysis) 21%

Searching for a Critical Stimulus

Audibility of Voice Coil Rubbing

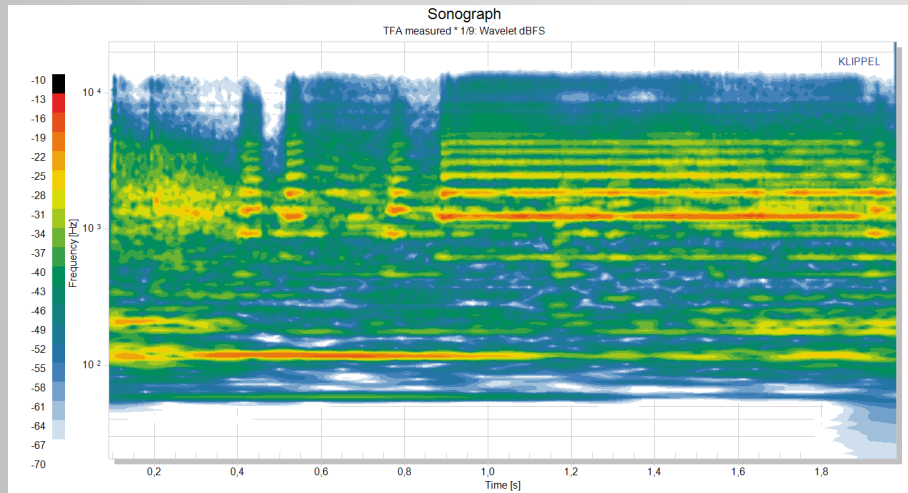
This Experiment investigates the influence of the stimuli and the input voltage

Signal	Stimulus	Output 1V	Output 2V	Output 3V
Music				
Multi-Tone 20 Hz – 20 kHz				
Multi-Tone 20 Hz – 1 kHz			 clear audible	
Sinusoidal Sweep 1 s				

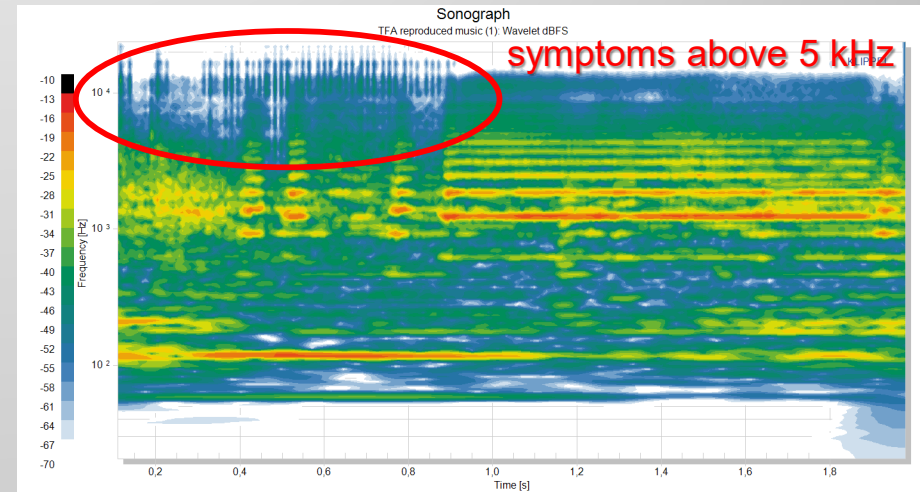
Most sensitive Stimulus

Stimuli less critical for Rub & Buzz

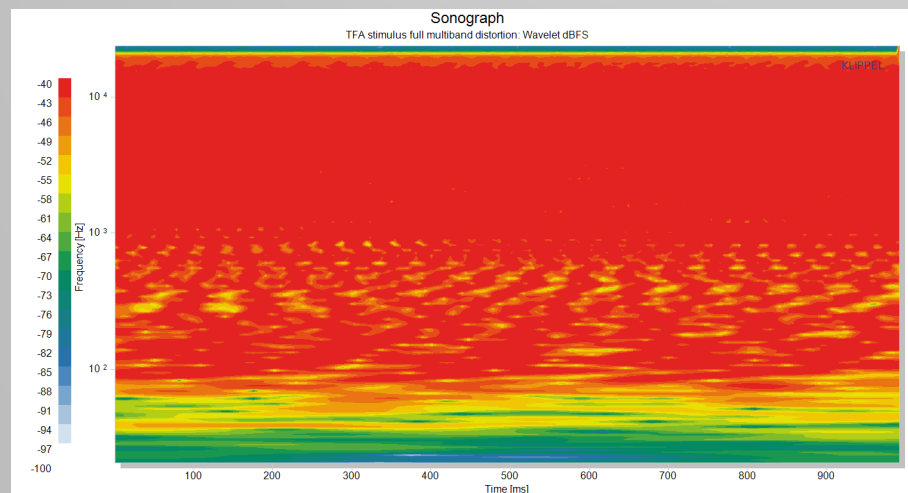
stimulus: music



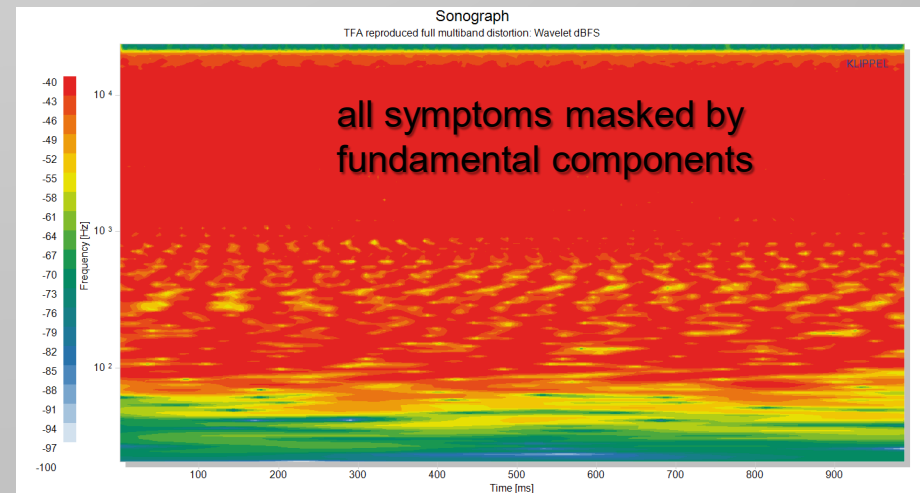
reproduced music at 3 V



stimulus: Full Band Multi-tone complex

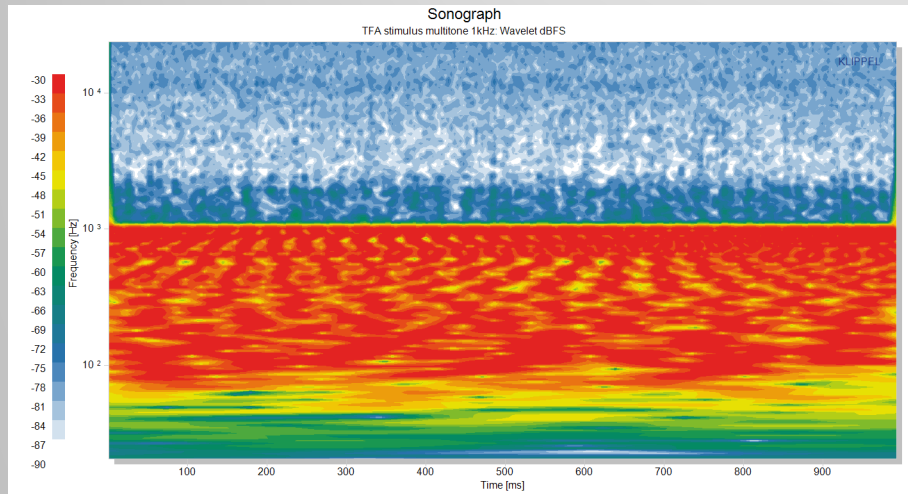


reproduced Full Band Multi-tone complex

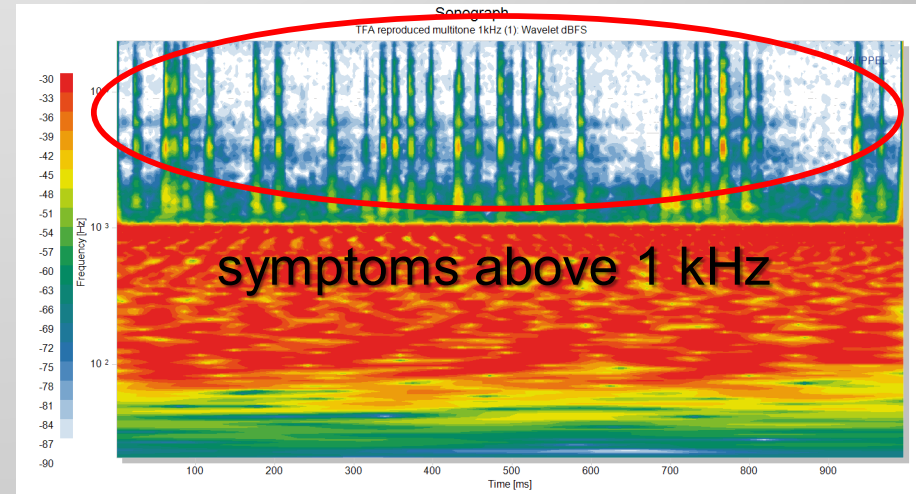


Stimuli critical for Rub & Buzz

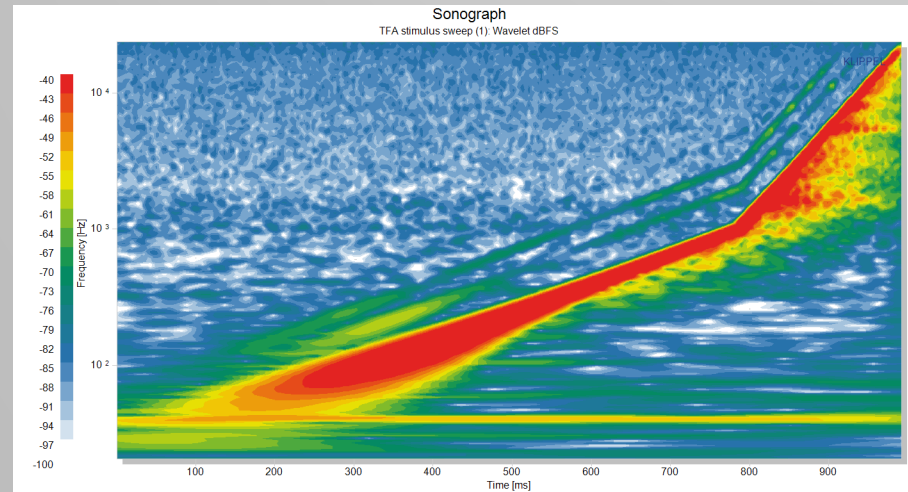
Stimulus: multi-tone distortion low pass 1 kHz



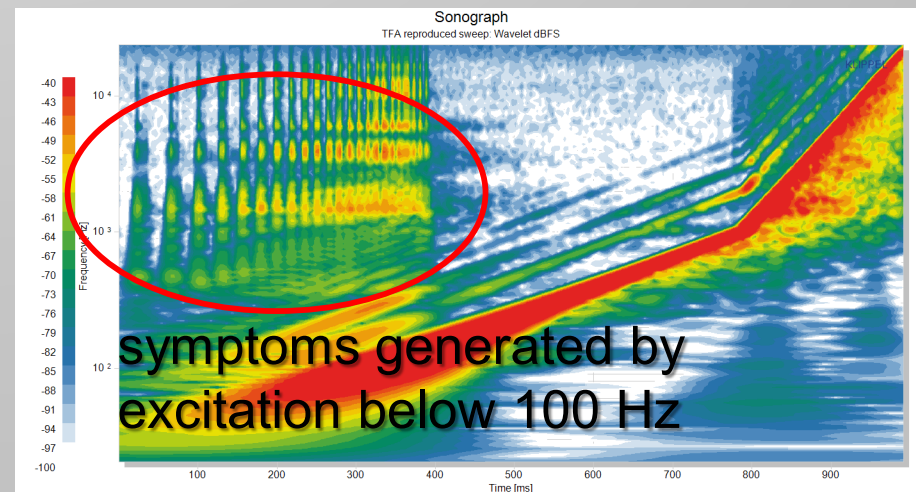
reproduced multi-tone distortion low pass 1 kHz at 3 V



Stimulus: sweep



reproduced sweep at 3 V



Irregular Behavior

Symptoms

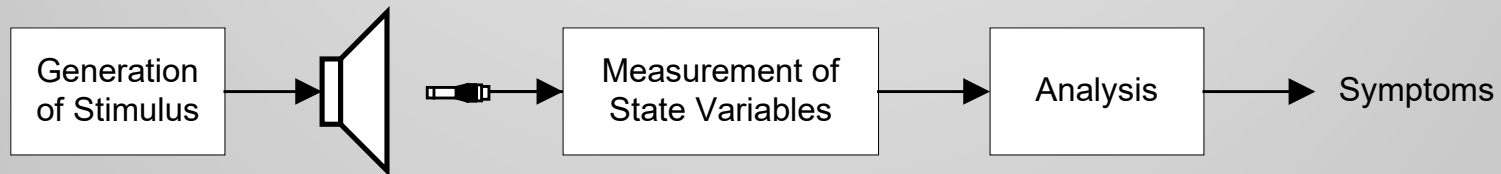
- Clicks, impulses, tone burst, modulated noise
- Low power and small rms value
- higher peak value (impulsive)
- Broad band spectrum (not only harmonics)

Special measurement technique required:

- Time-frequency analysis (amplitude spectrum not sufficient)
- Time domain analysis of the fine structure
- New distortion metrics (e.g. Impulsive Distortion as defined in IEC 60268-21)



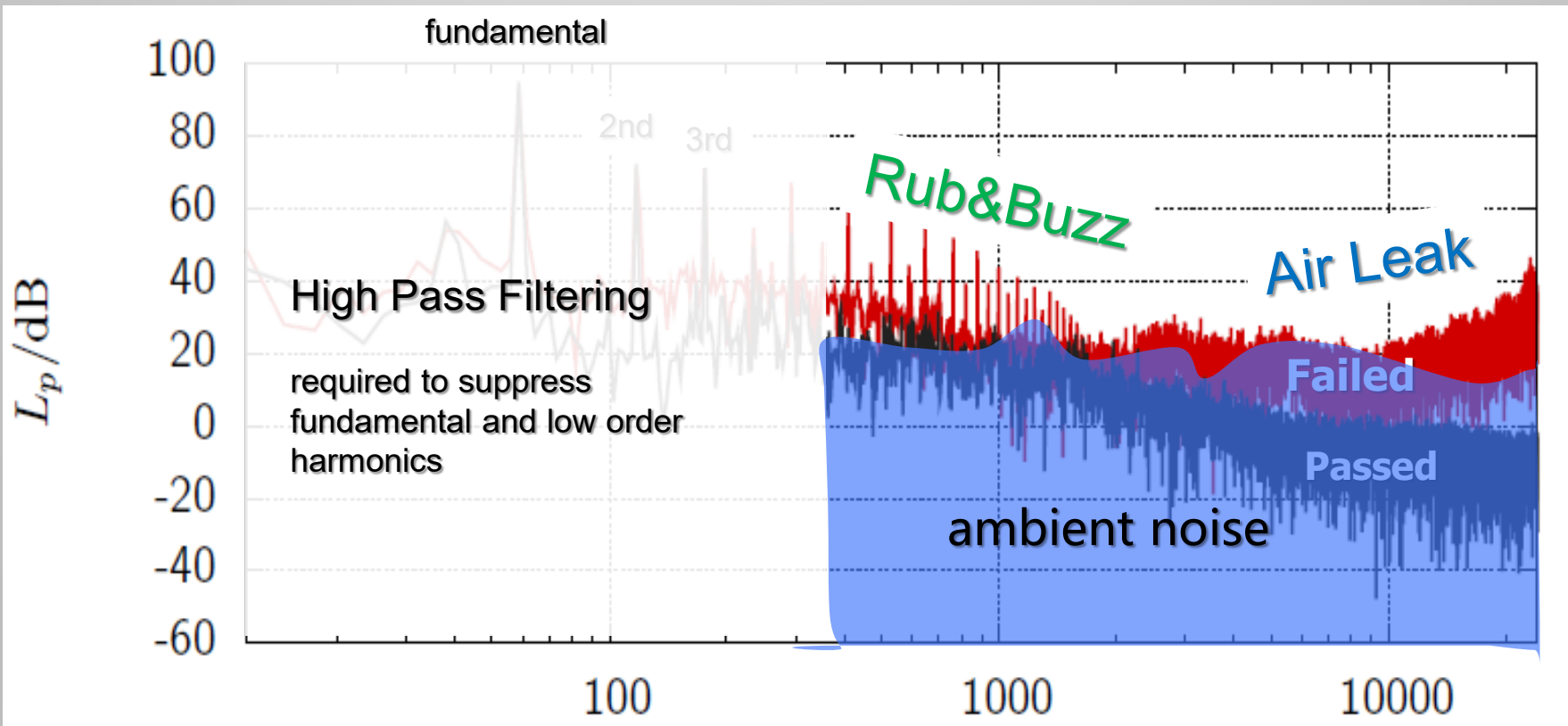
Basic Requirements to detect Irregular Loudspeaker Defects



- High amplitude is required (displacement x and/or velocity v and/or acceleration a) → Stimulus shall excite all frequencies
- Most defects only produce acoustical symptoms → Sensitive microphone required
- Defects produce high frequency components → Low-pass filtered stimulus and high-pass filtered microphone signal
- Defects are similar to ambient noise → Microphone is located close to the source (near-field measurement)

Frequency Domain Analysis

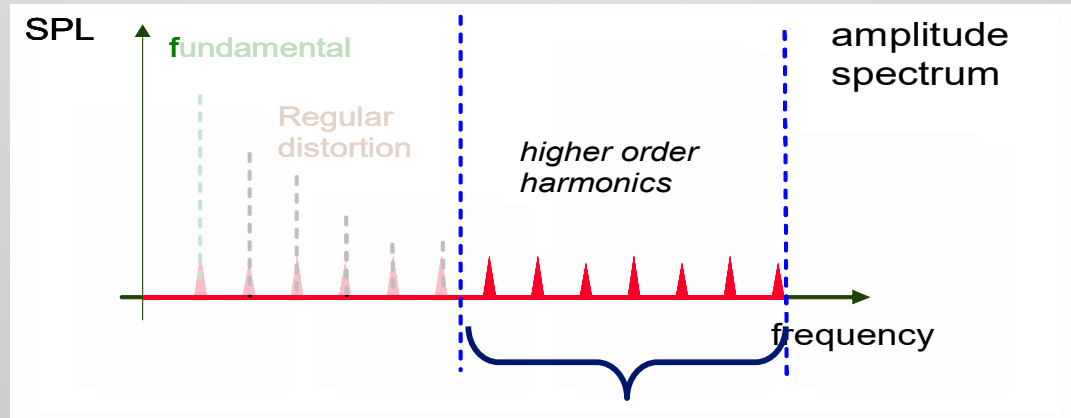
60 Hz Tone reproduced by a good and bad speaker





Simple Approach

exploiting amplitude of higher-order harmonics only



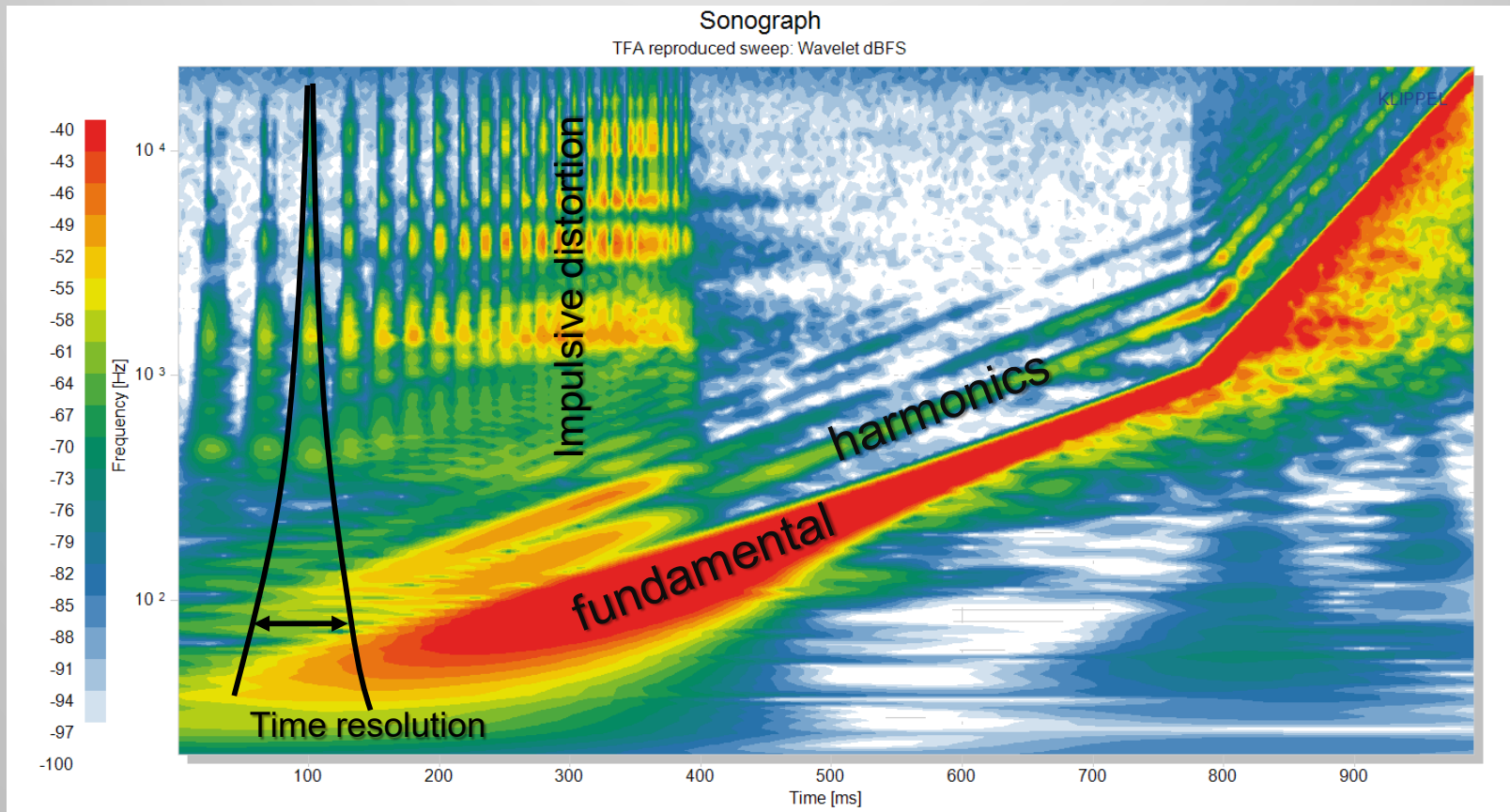
Higher-order harmonic distortion
Are defined in IEC 60268-21

RMS value of
Higher-
harmonics

PROBLEMS:

- Sensitive for deterministic symptoms only
- each harmonic is close to the noise level
- insensitive to loose particles and air leakage noise

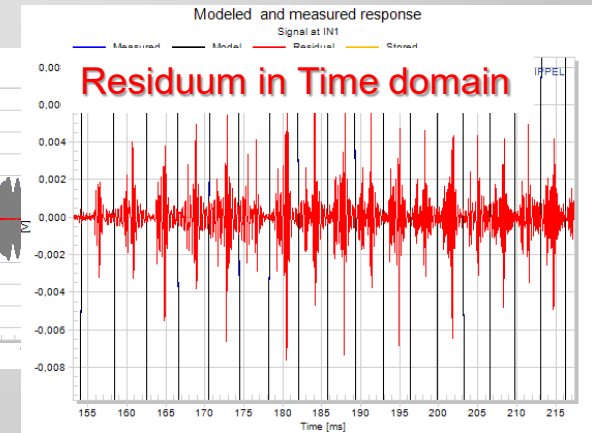
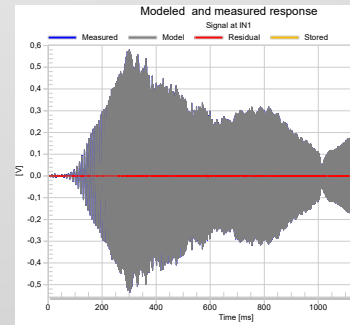
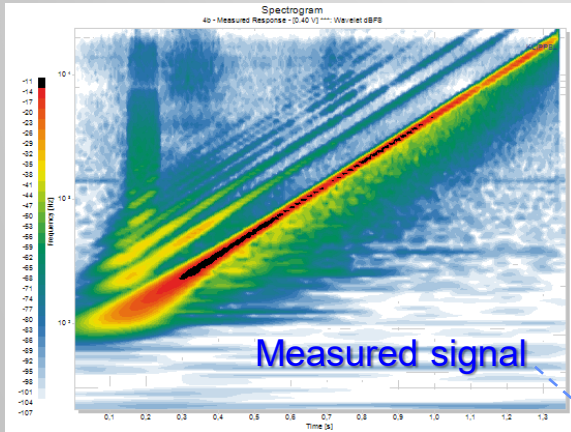
Time Frequency Analysis



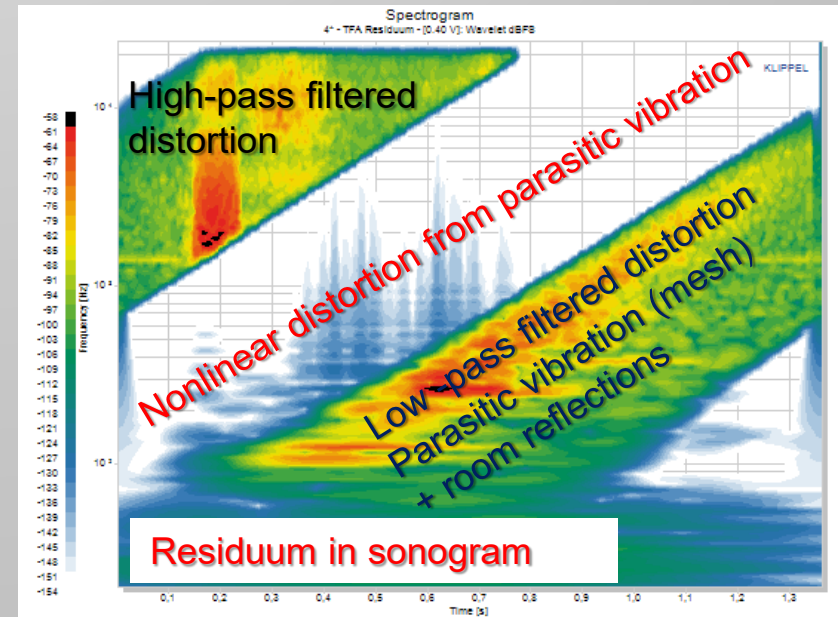
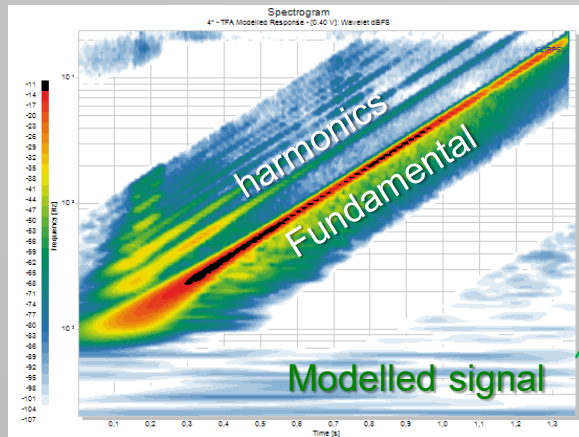
Time-Frequency Analysis (TFA)

- Wavelet Transformation
- Best compromise between frequency and time resolution
- Energetic metric (amplitude information)
- Phase information is not used (Most fine structure in the time domain is lost)

Time Domain Analysis

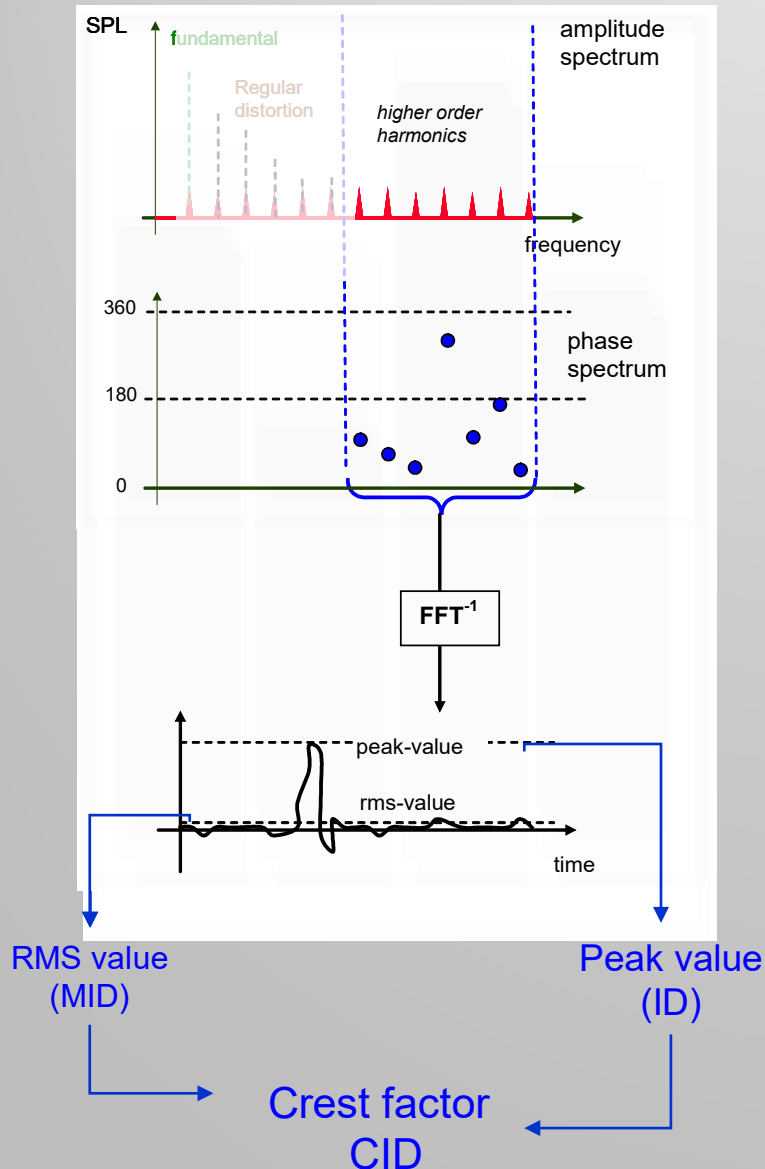


Residuum $p_{\text{res}}(t) = p_{\text{meas}}(t) - p_{\text{model}}(t)$





Time Domain Analysis



Analysis Techniques:

- Residuum (nonlinear modeling)
- High-pass filtering
- IEC 60268-21

- Exploiting amplitude and phase of higher-harmonics and all non-harmonic components
- Peak value reveals small transients (clicks)
- Sensitive for all loudspeaker defects

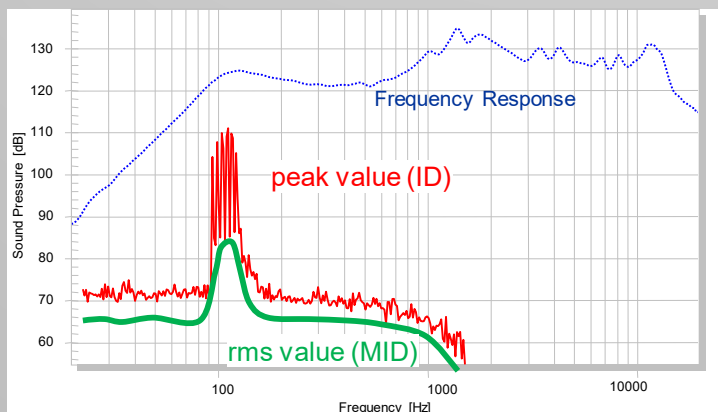
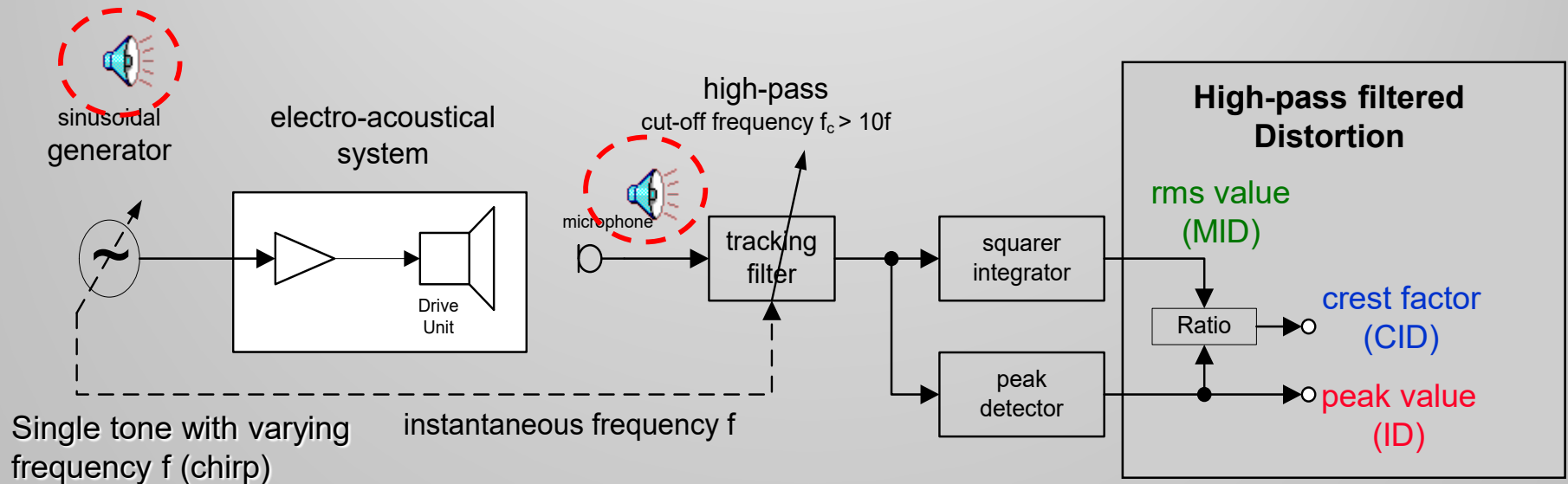
most loudspeaker defects generate impulsive distortion with high crest factor

but

regular loudspeaker distortions, electrical and microphone noise have lower crest factor

Peak value Contra rms-Value

Measurement technique defined in IEC 60268-21



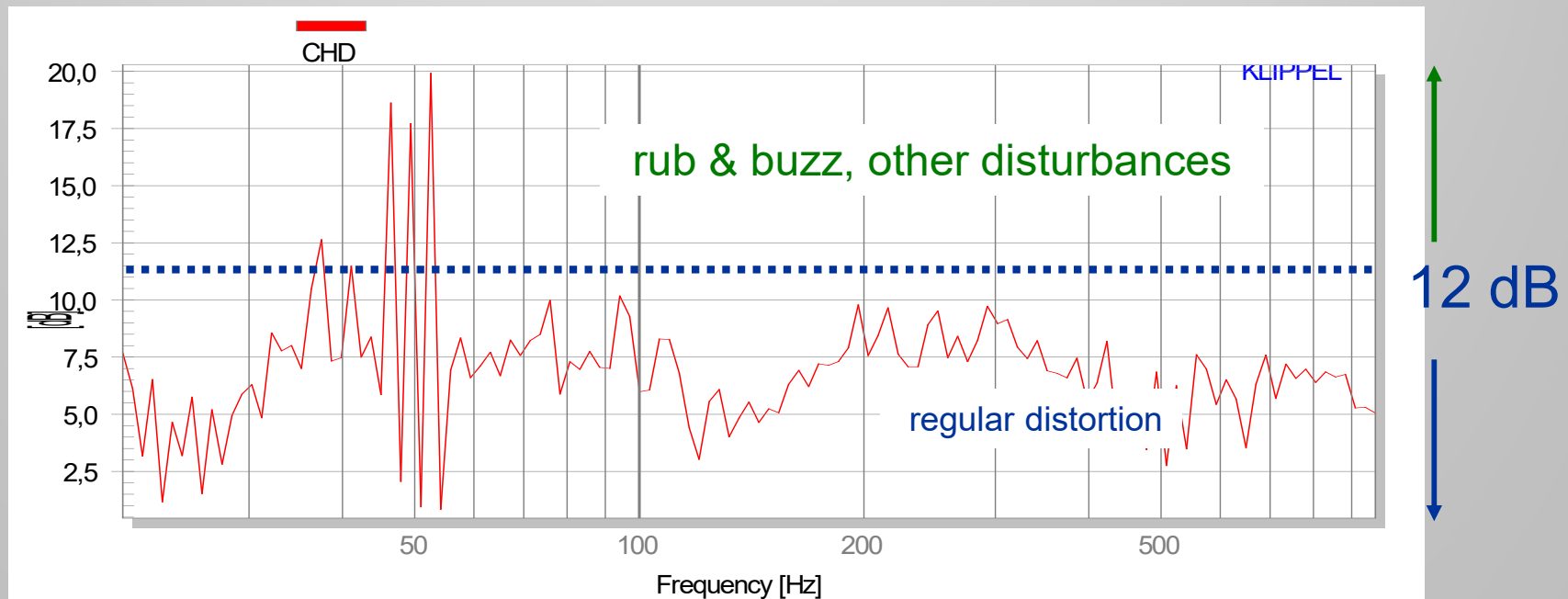
Impulsive Distortion (ID) is a sensitive measure for most irregular defects such as „rub and buzz“, loose particles !!

Crest factor of high-pass filtered distortion (CID)

Stimulus: Sinusoidal sweep

$$CID(f) = \frac{ID(f)}{MID(f)}$$

peak-value within one period
Rms-value averaged over one period

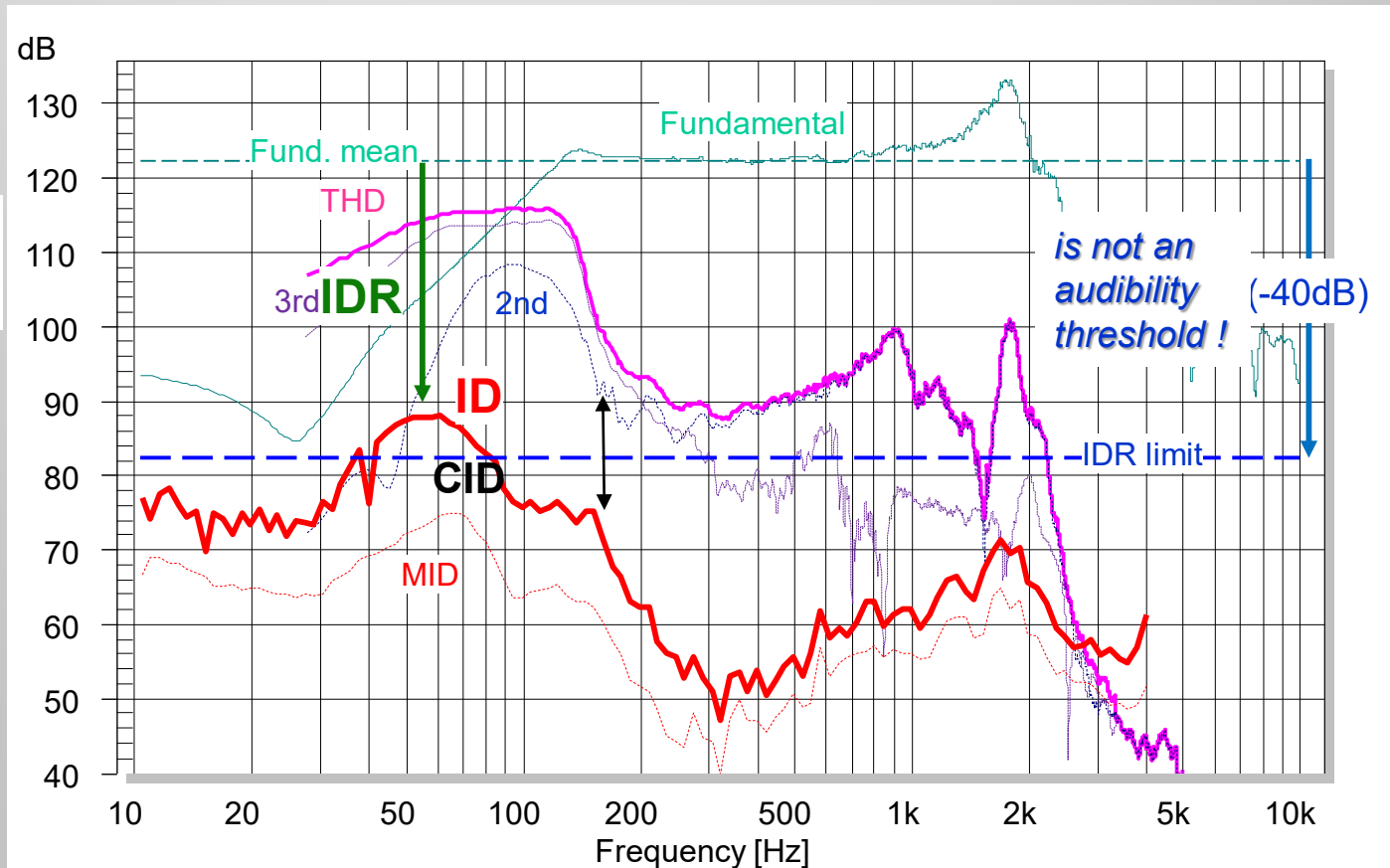


CID can be interpreted on an absolute scale !

CID exploits the phase information of all high frequency components

Loudspeaker Defect or Noise ?

Impulsive distortion ratio (IDR) is defined in IEC 60268-21



Symptoms of a significant defect:

1. Impulsive distortion ratio $IDR > -40\text{dB}$
2. Crest factor of impulsive distortion $CID > 12\text{dB}$

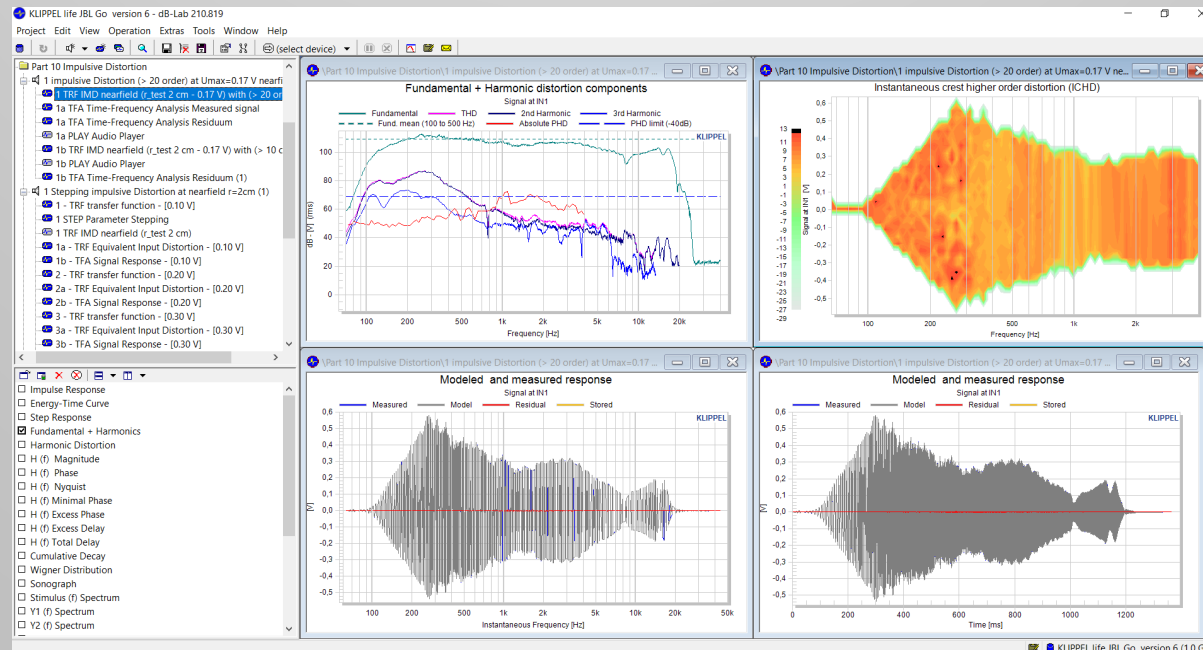


Check for coincidence !
(microphone noise is not impulsive)

Demo

Tools: Using dedicated software modules of the KLIPPEL Analyzer

- Transfer Function Measurement (TRF PRO)
- Transfer Function Measurement (TRF Stepping)



Cross Reference

for Characteristics used in TRF

Characteristics in IEC 60268-21		Characteristics in TRF	
Name	Symbol	Name	Symbol
Impulsive Distortion	ID	Peak value of higher-order distortion	PHD
Mean Impulsive Distortion Level	MID	Mean value of higher-order distortion	MHD
Crest factor of Impulsive Distortion	CID	Crest factor of higher-order distortion	CHD

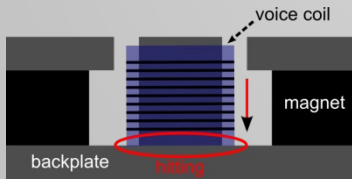
Poll:

How do you fix defects or other irregular behavior such as rub&buzz ?

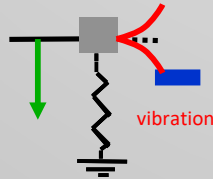
- A. Trial and error 36%
- B. Visual inspection (disassembling the device) 54%
- C. Further testing with modified stimuli (amplitude variation) 14%
- D. Correlation with other physical characteristics 43%
- E. Other ways 4%

Characteristic Features of Loudspeaker Defects

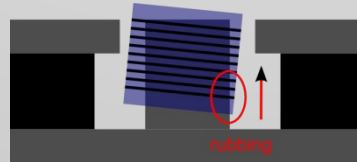
Coil hitting backplate



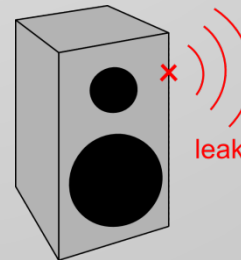
Buzzing loose joint



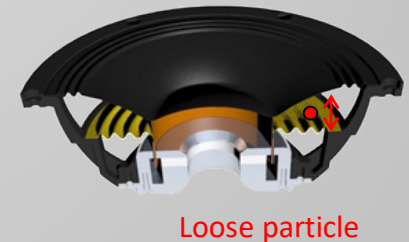
Rubbing voice coil



Flow noise at air leak



Loose particle hitting membrane



Deterministic

**Semi-random
(mixed characteristic)**

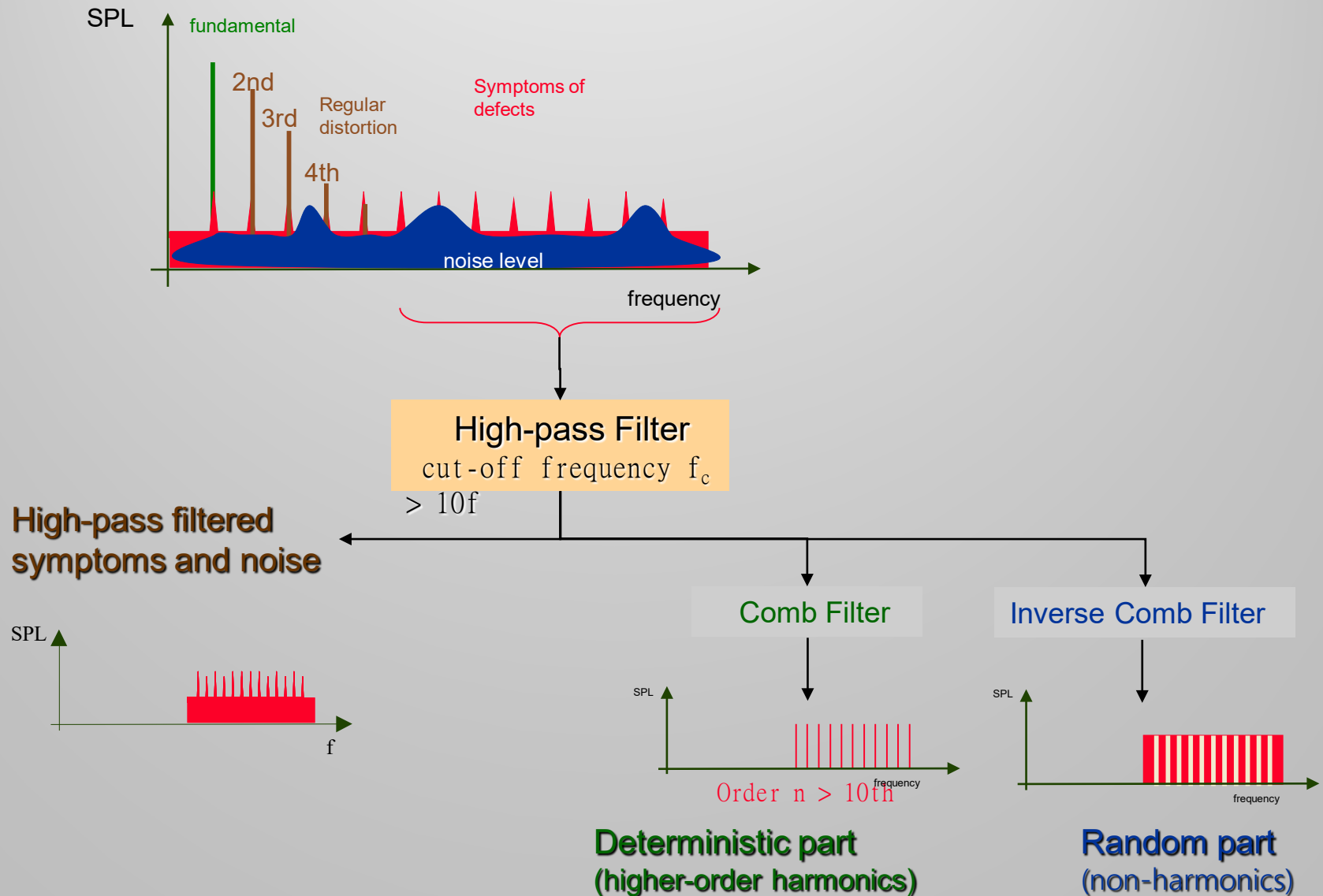
Random

Waveform is completely reproducible

Envelope is reproducible
(Waveform is not)

Waveform is not reproducible

Separating Symptoms of a Defect

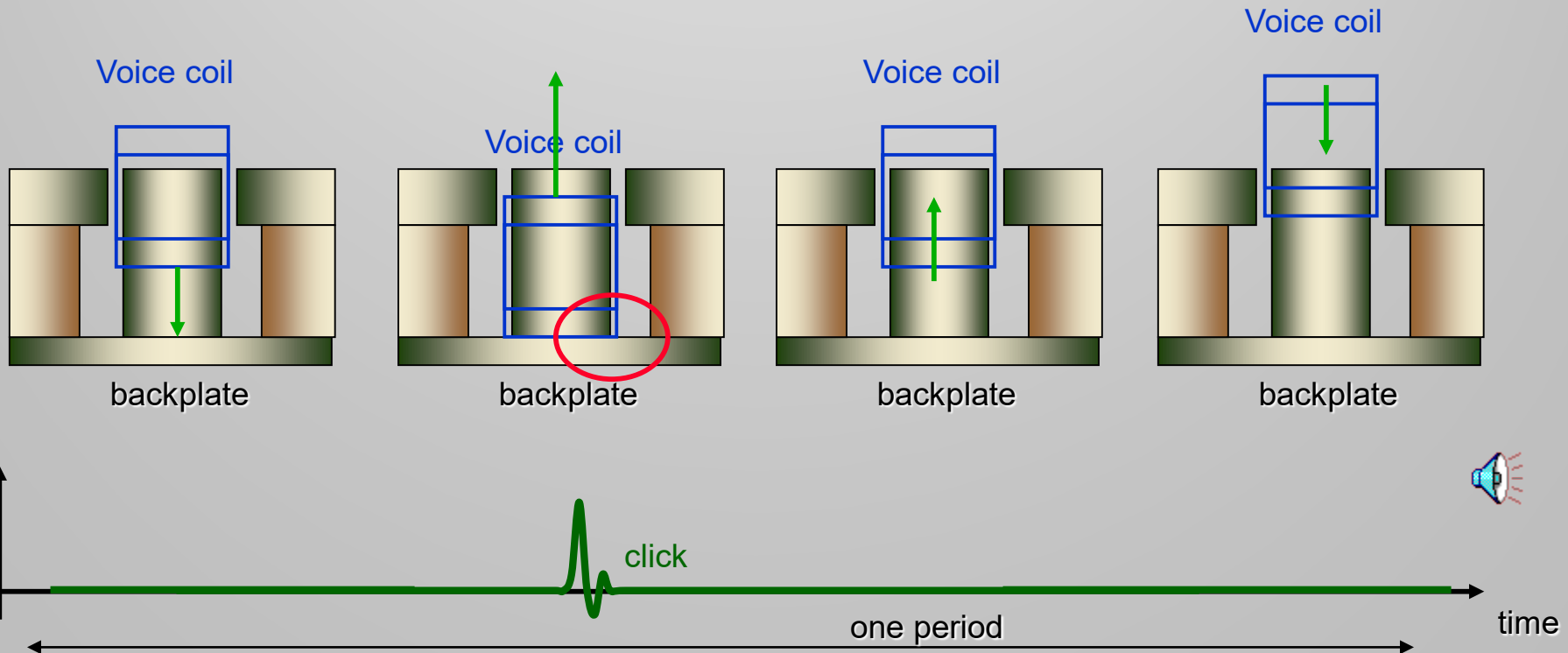


Loudspeaker Defect: Voice Coil Bottoming

Root causes:

- offset in rest position, DC displacement
- high voice coil excursion
- hard limiting of the voice coil displacement

Symptoms: impulsive, deterministic, click at peak excursion



Deterministic Distortion

Example:

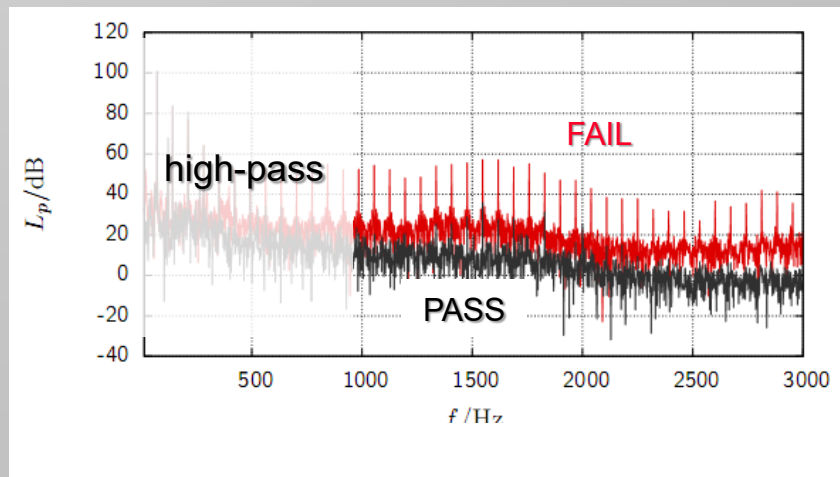
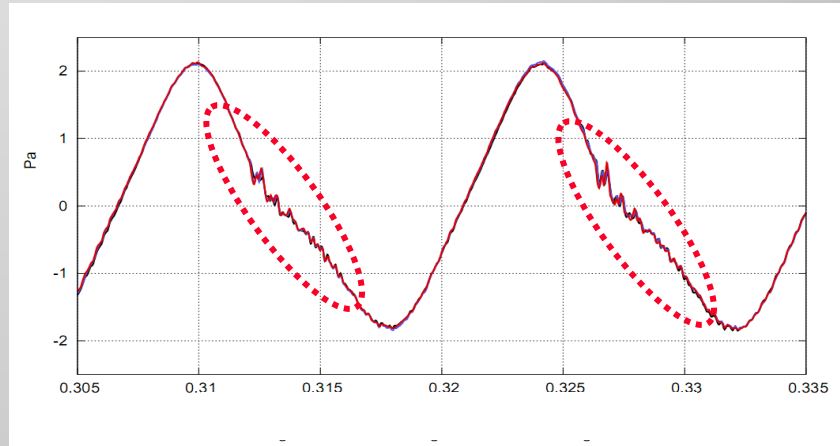
tensile slap, bottoming

Symptoms:

- Reproducible, repeatable
- Related with stimulus
- impulsive distortion
- Deterministic amplitude and phase of higher-order ha



Results of three measurements

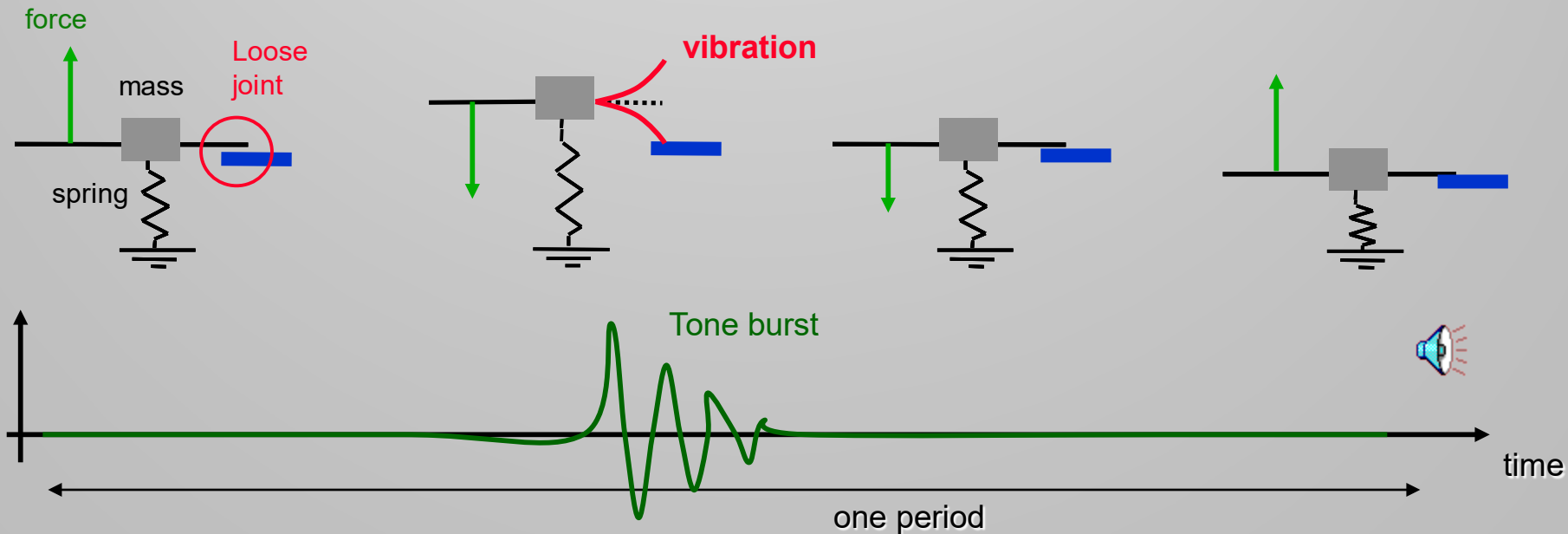


Loudspeaker Defect: *Buzz problem*

Root cause

- loose part behaves as a nonlinear oscillator
- powered and synchronized by stimulus
- active above a critical amplitude
- new mode of vibration

Symptoms: short tone burst at characteristic frequency, partly deterministic, impulsive



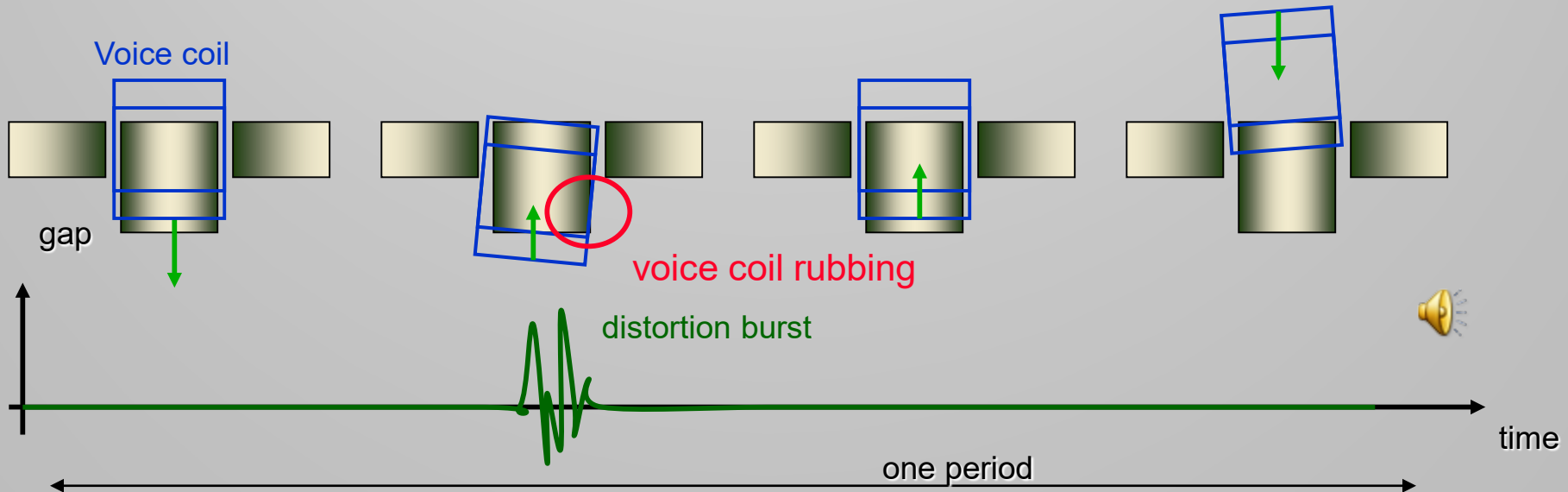
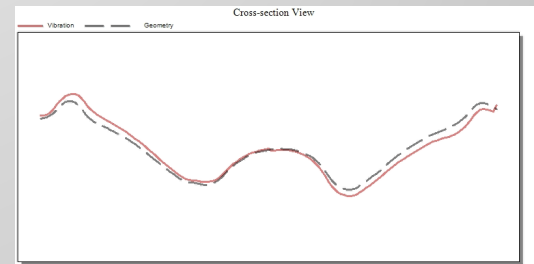
Loudspeaker Defect: Voice Coil Rubbing

Root causes:

- imbalances in mass, stiffness, BI distribution
- high coil displacement excites rocking mode
- coil rubbing at a certain coil position

Symptoms: stochastic signal, modulated by the stimulus, impulsive burst

Cause: rocking mode at 328 Hz

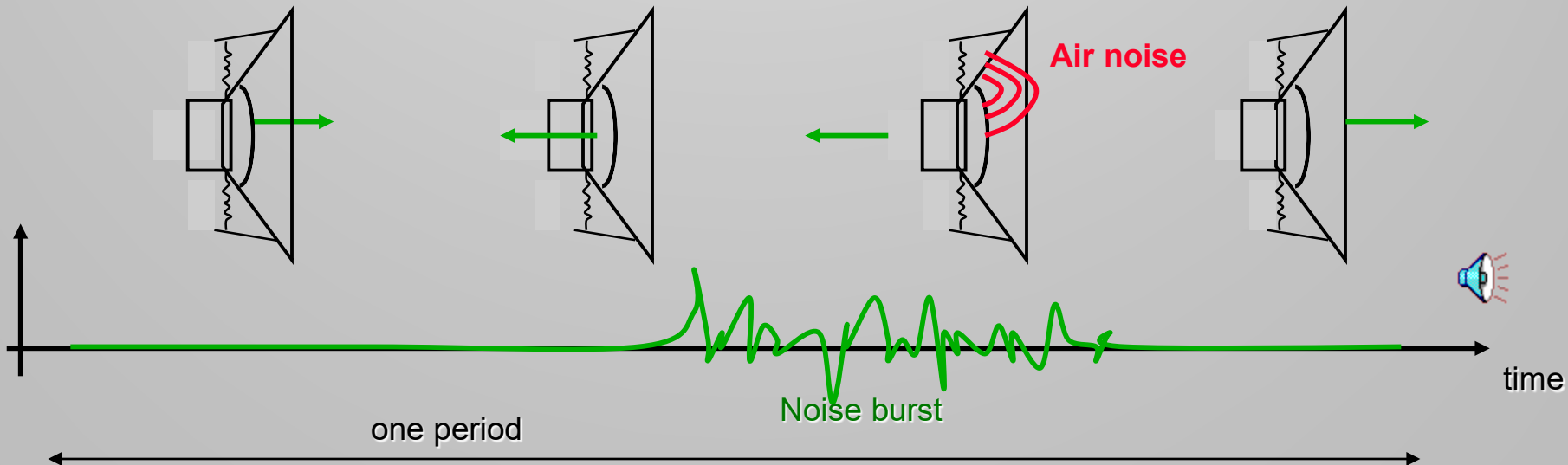
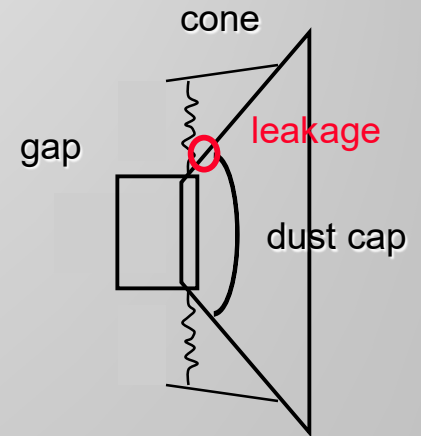


Loudspeaker Defect: Air Noise

Root cause:

- leakage in dust cap, box, ...
- coil displacement generates air pressure
- High pressure causes high air velocity at the leakage
- Turbulences generate a noise burst in the period

Symptoms: stochastic signal, noise is modulated by the stimulus, impulsive noise burst



Random Distortion

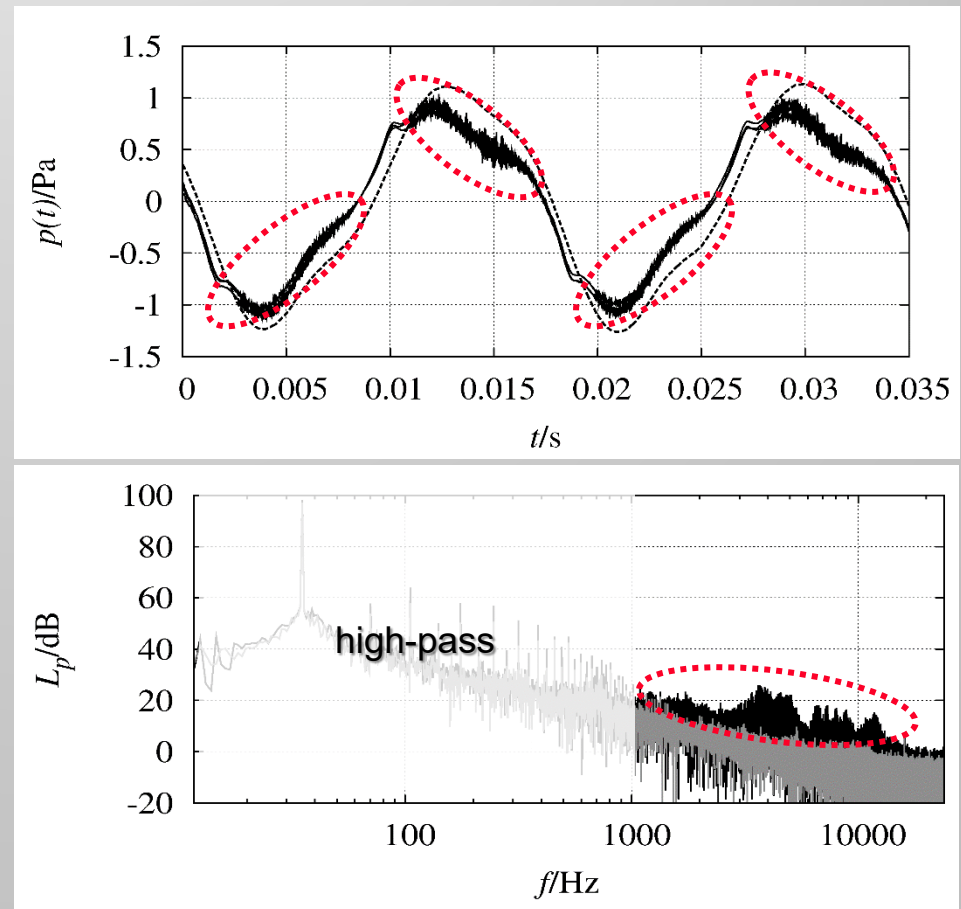


Example:

Turbulent air noise generated at leaks, coil rubbing

Symptoms:

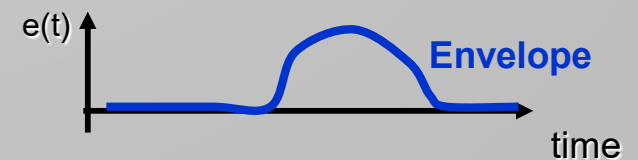
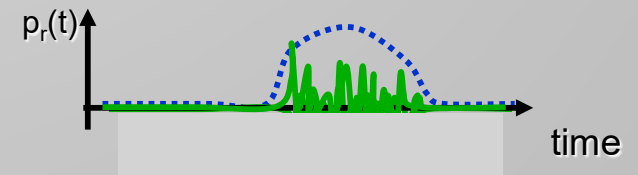
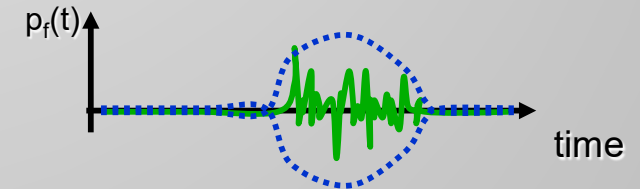
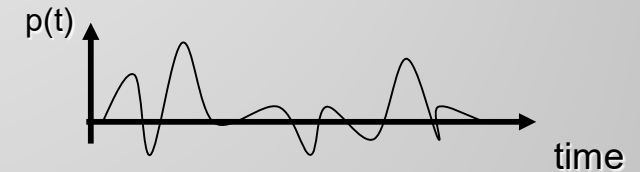
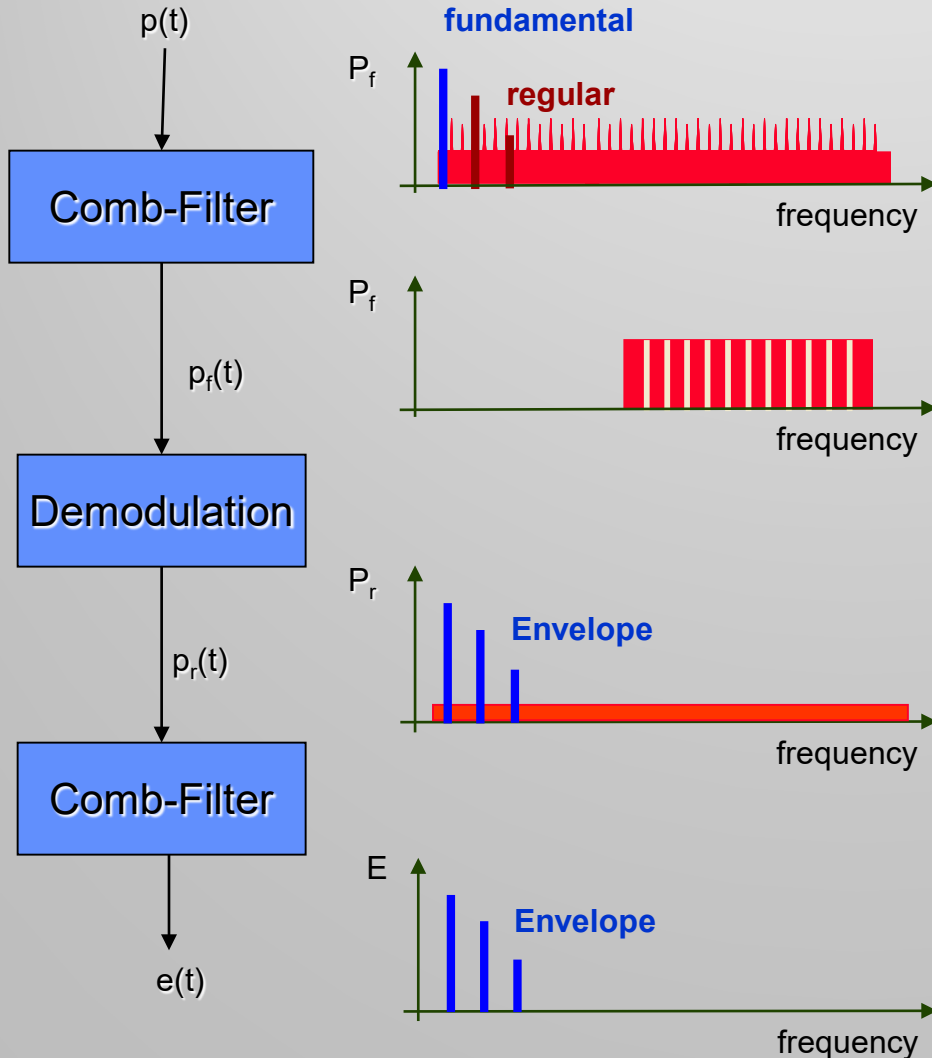
- Distortion are NOT reproducible
- Distortion occur at particular times
- Dense spectrum (cover audio band and beyond)



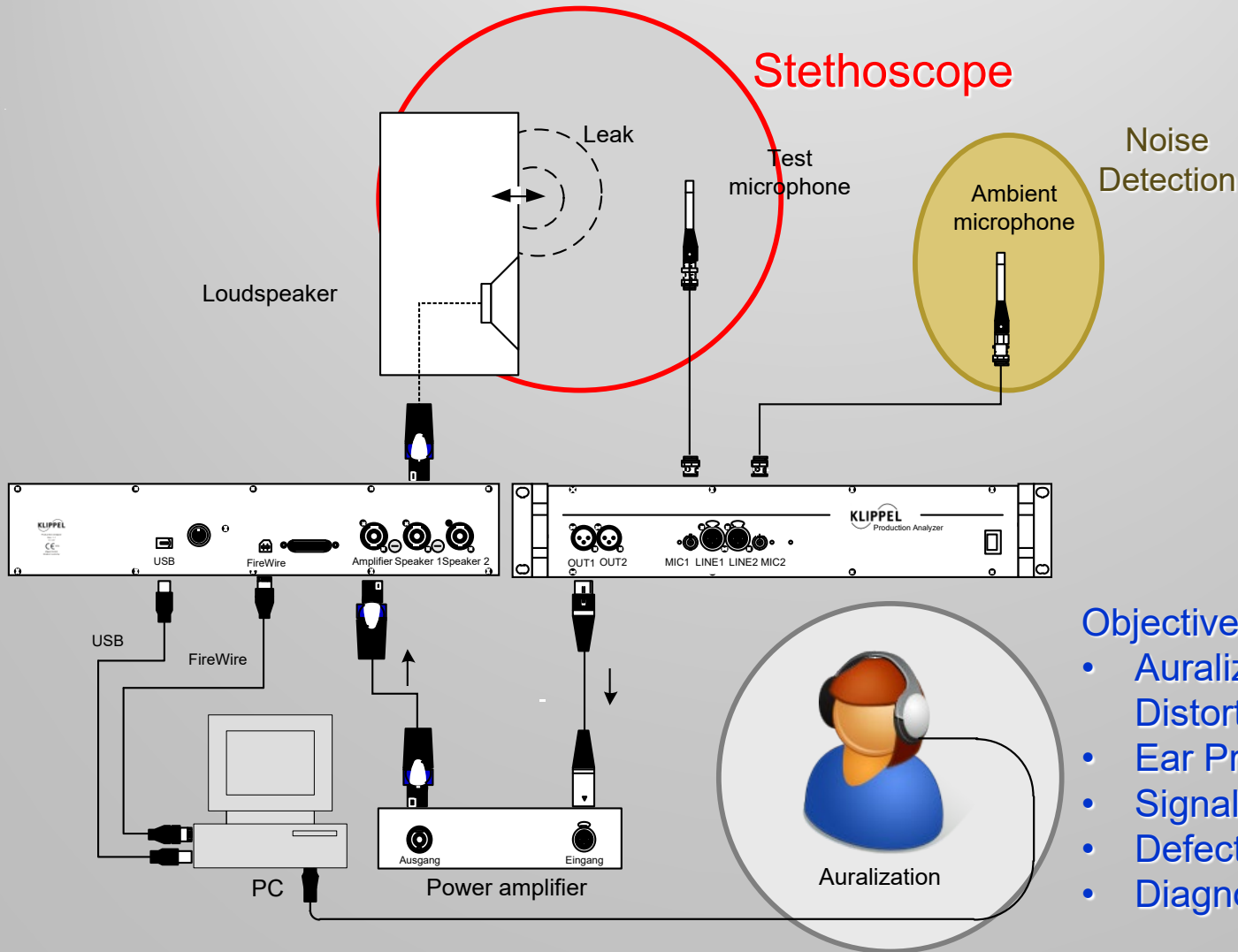


How to Calculate the Envelope ?

Single tone



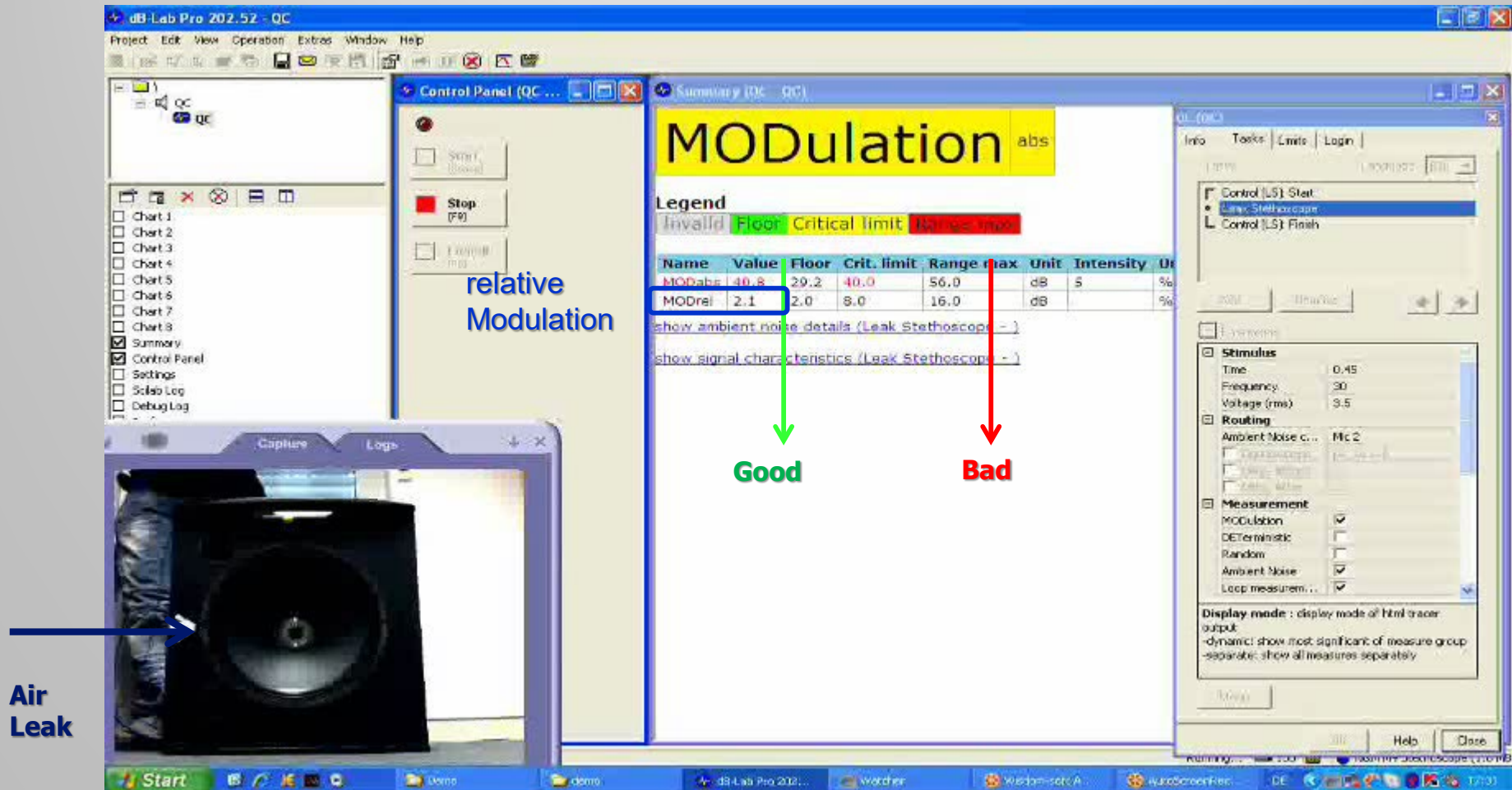
Combining Subjective and Objective Assessment



Objectives:

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

Localization of Loudspeaker Defects

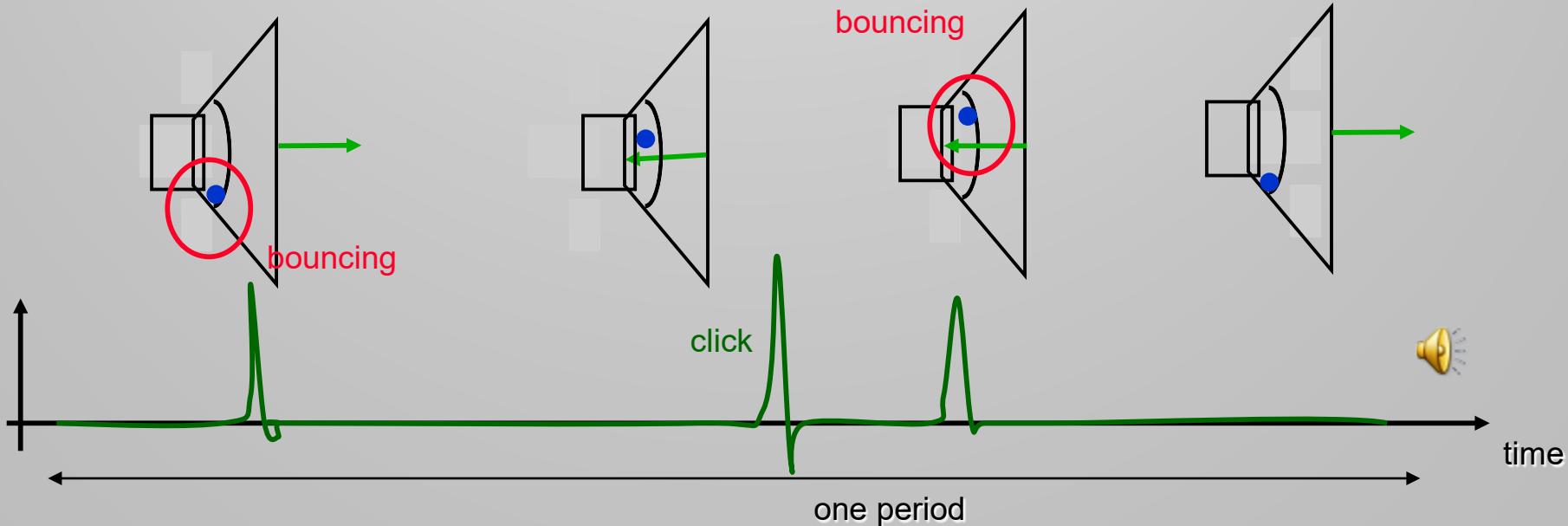
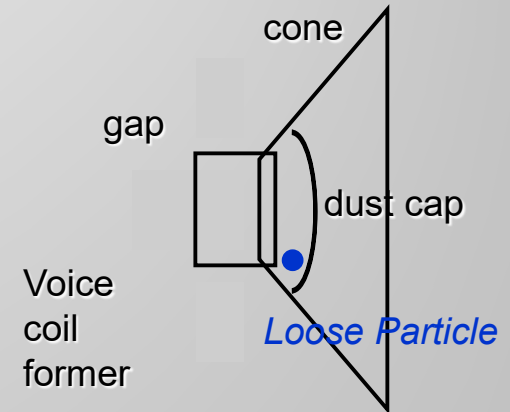


Loudspeaker Defect: Loose Particles

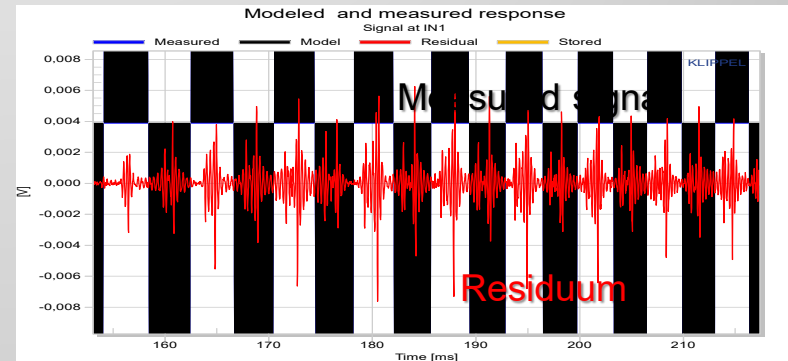
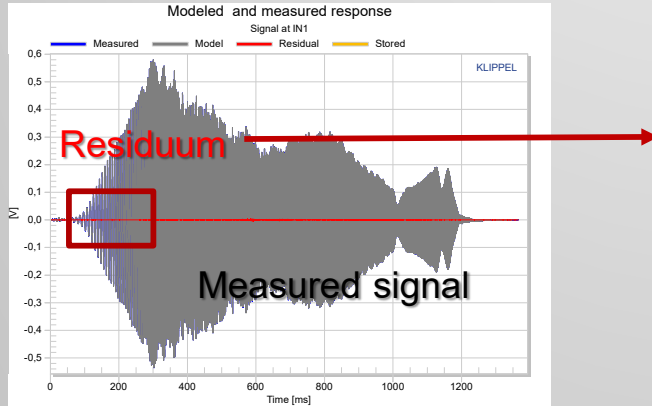
Root Cause

- particles are accelerated by cone displacement
- bouncing generates a short click any time

Symptoms: random, not synchronized with stimulus, high peak SPL but low output power, impulsive



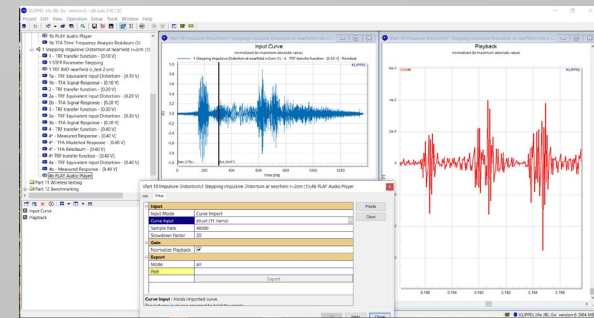
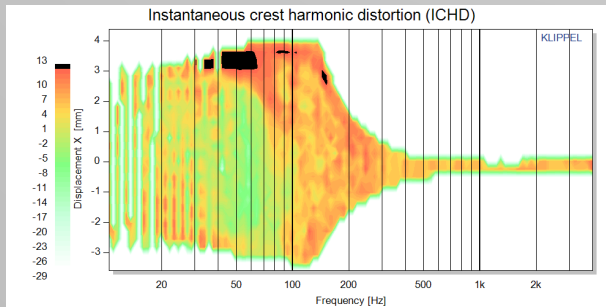
Fine Structure Analysis



1) Mapping the residuum (instantaneous crest factor ICID) versus transducer state

- Voice coil displacement
- Sound pressure (acceleration)

2) Human ear listening to the upsampled residuum (slowdown factor 10)



Impulsive Distortion mapped versus State Signal

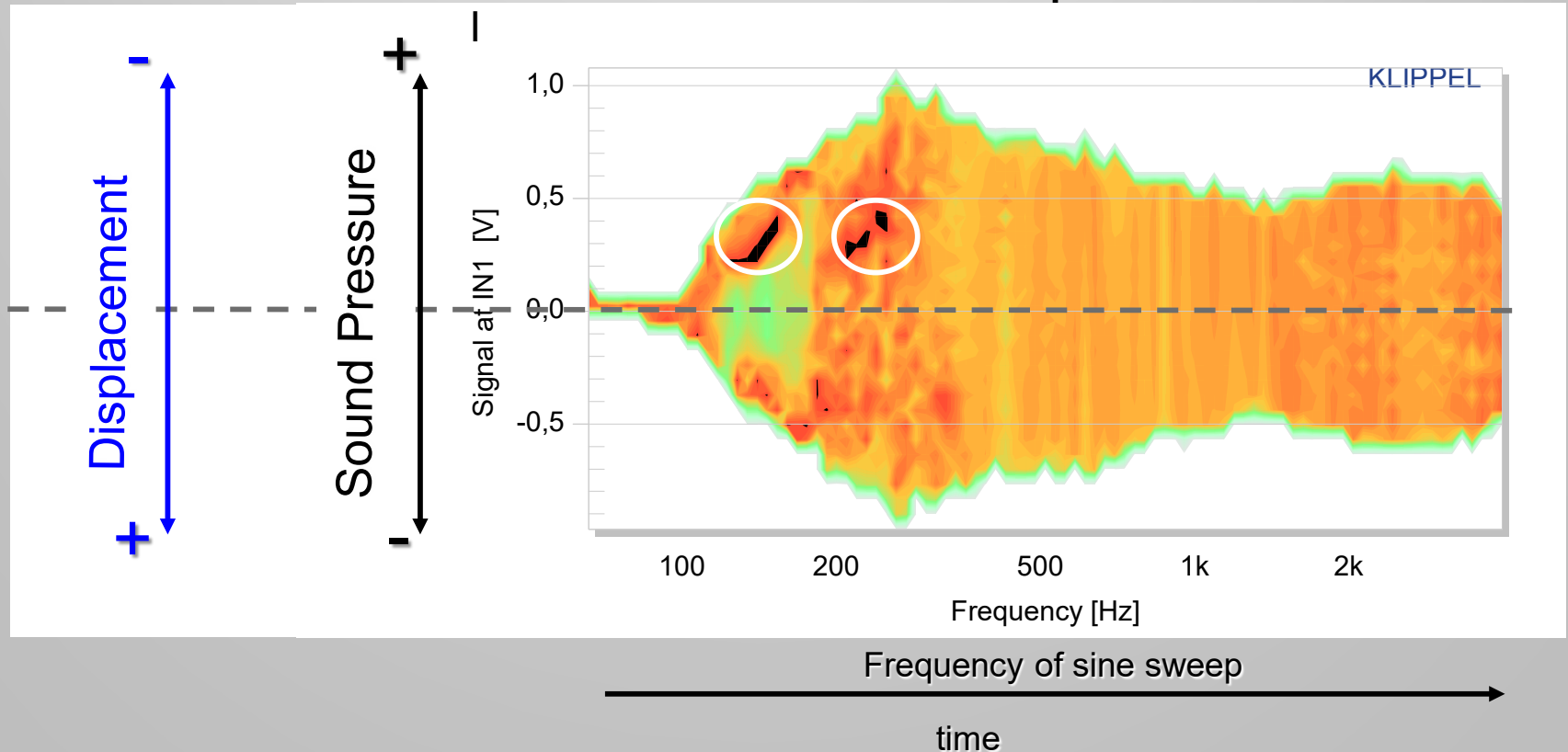
Instantaneous crest factor of impulsive distortion (ICID)



good

12 dB

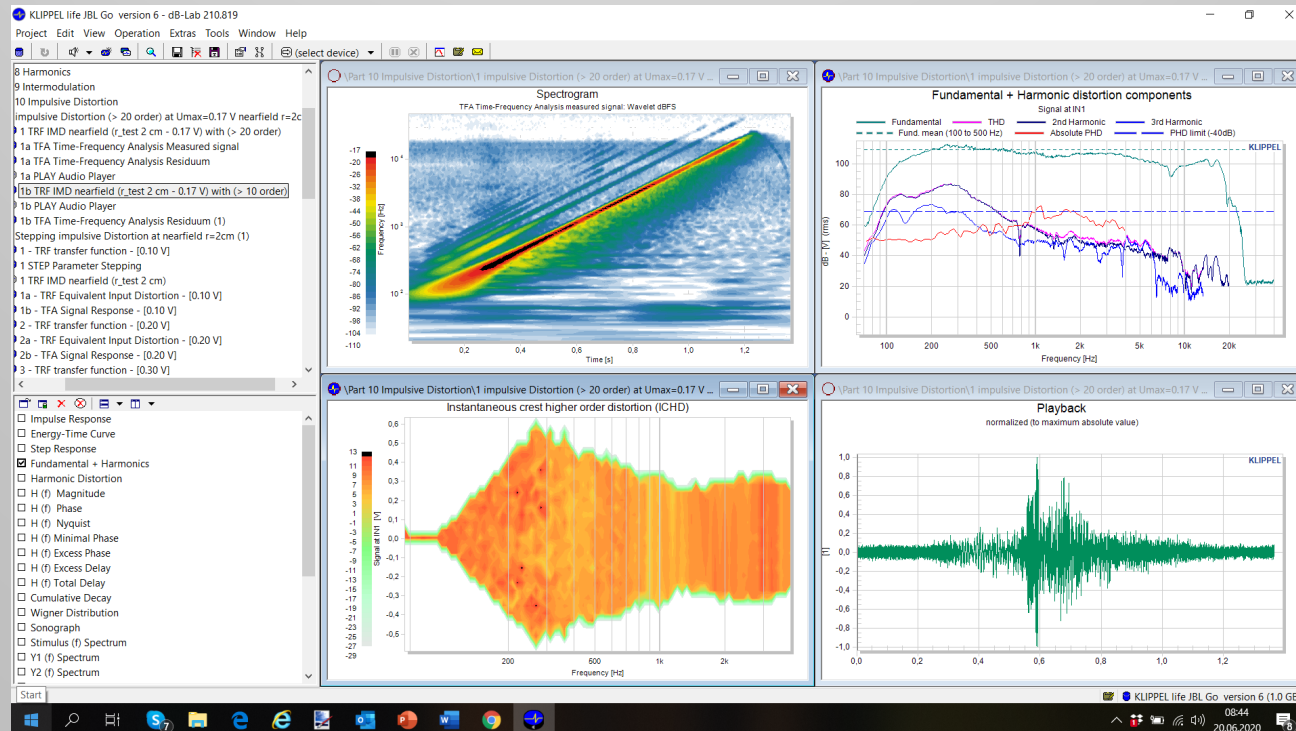
bad



Demo

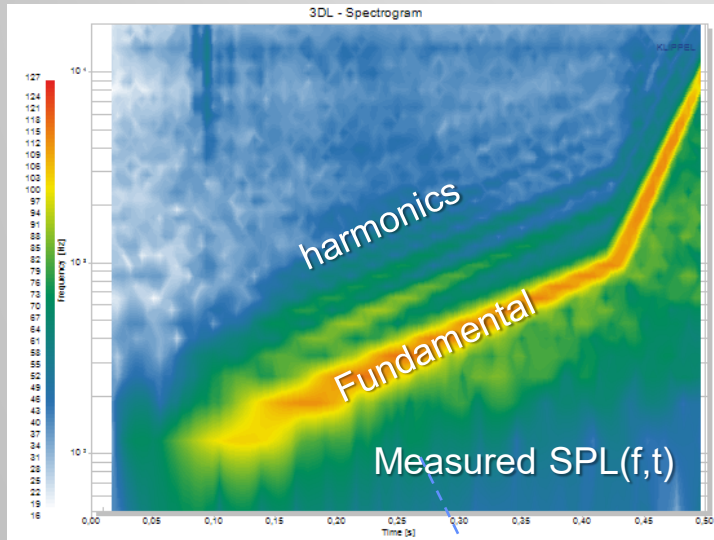
Tools: Using dedicated software modules of the KLIPPEL Analyzer

- Transfer Function Measurement Pro (TRF-Pro)
- Transfer Function Measurement Stepping (TRF)
- Time Frequency Analysis (TFA)
- Audio Player for fine structure analysis (PLAY)

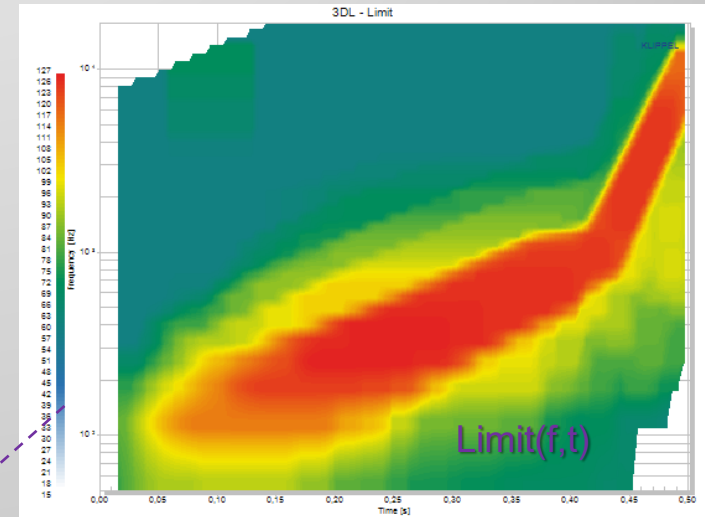


3D Limits in End-of-Line Testing

LIMIT MODE (GOLDEN REFERENCE Device)



Limit
calculation

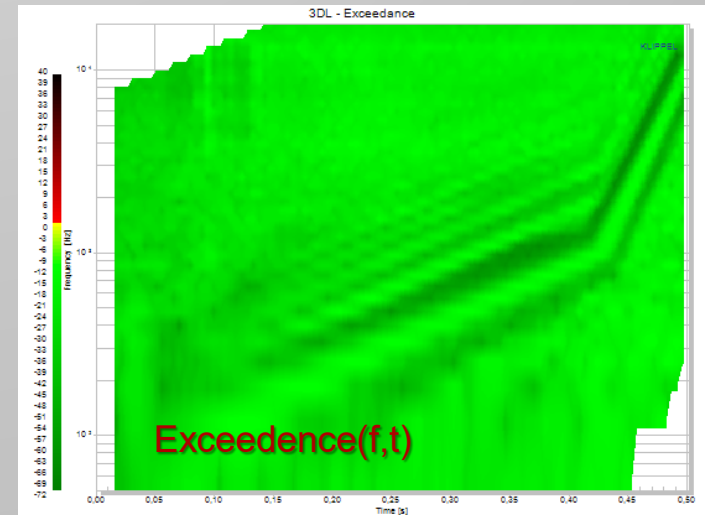


$$\text{Exceedence}(f, t) = \text{SPL}_{\text{meas}}(f, t) - \text{Limit}(f, t)$$

Classification:

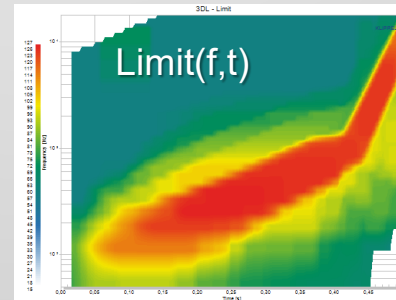
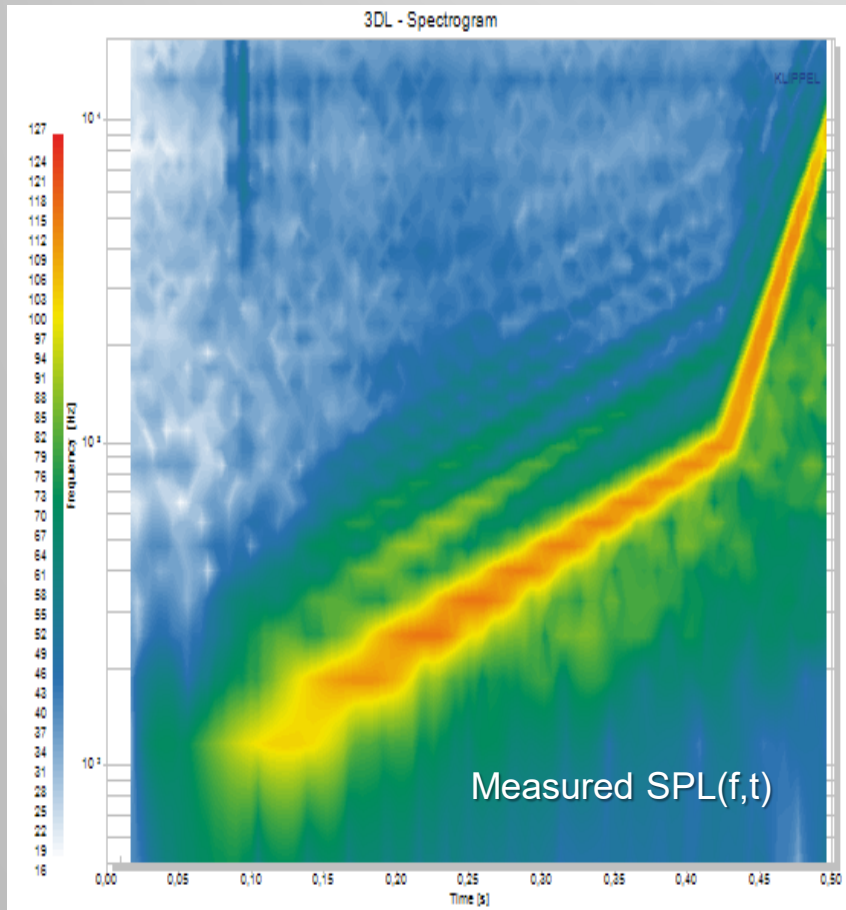
PASS: negative exceedence value (green)

FAIL: positive Exceedence value (red)



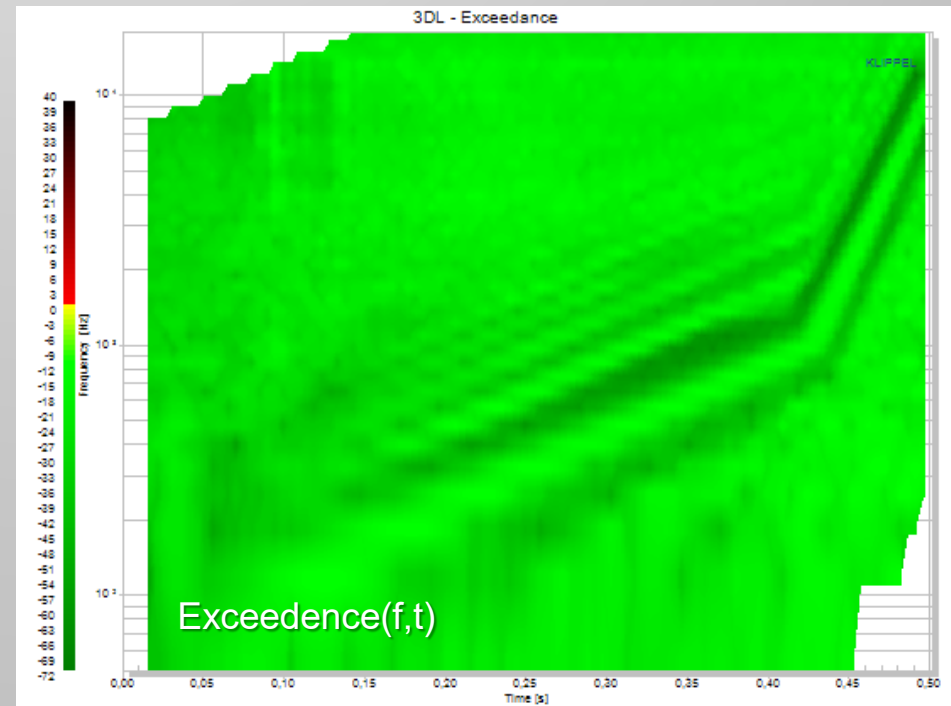
3D Limits in End-of-Line Testing

On-Line MODE
(DUT without defect)



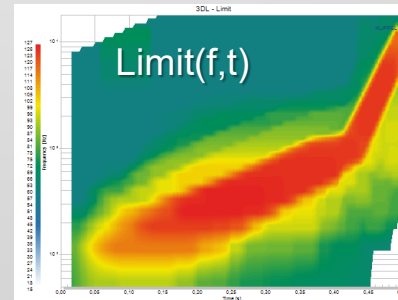
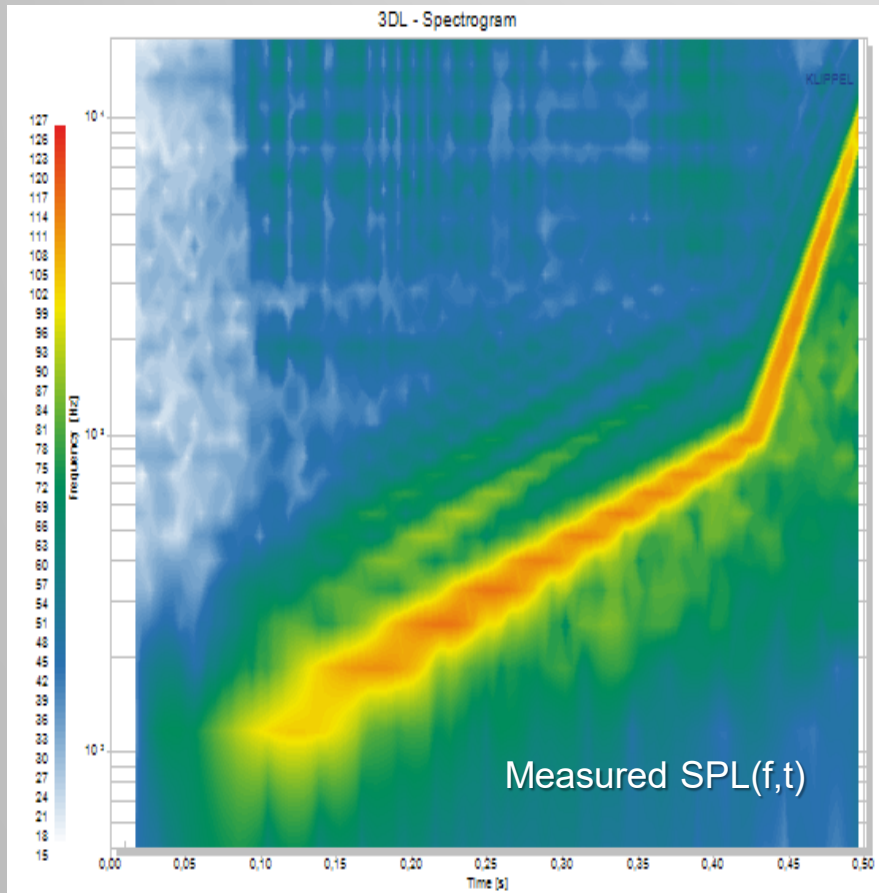
PASS

Frequency Response
Average Level
Polarity
THD
2nd Harmonic
3rd Harmonic
Rub+Buzz
3DL - Spectrogram



3D Limits in End-of-Line Testing

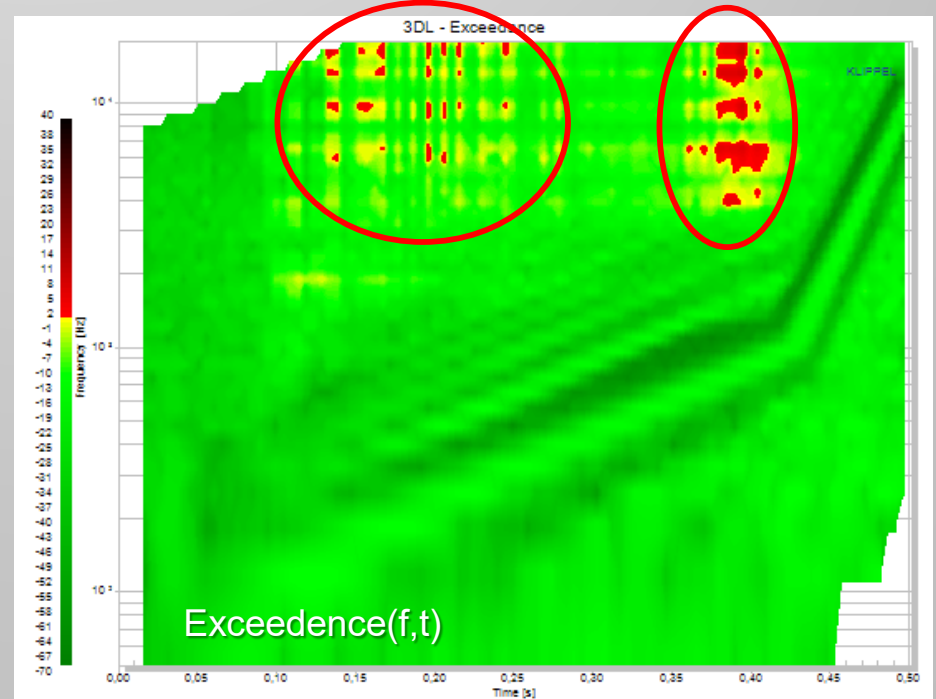
On-Line MODE
(DUT with defect)



FAIL

Frequency Response
Average Level
Polarity
THD
2nd Harmonic
3rd Harmonic
Rub+Buzz
3DL - Spectrogram

Statistics:

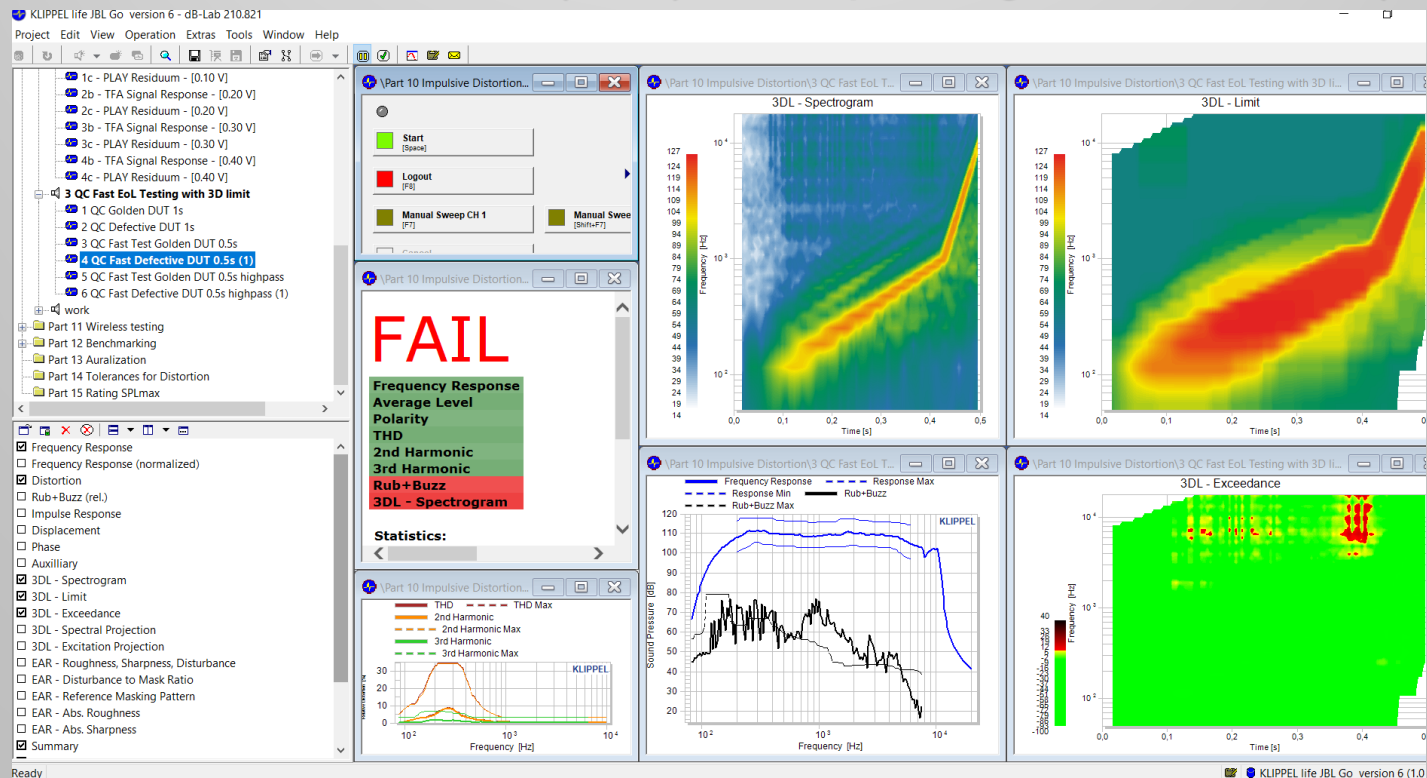


Demo

Tools: Using dedicated software modules of the KLIPPEL Analyzer

- QC Software

Sound Pressure Task (SPL) with Spectrogram 3D Limits (3DL)



Discussion

Summary

- A sinusoidal signal (chirp) is a very sensitive stimulus for irregular distortion
- Use a sensitive microphone place in the near field
- Inspect the distortion (residuum) in the time domain
- Search for the root cause and fix it
- Listen to the up-sampled distortion signal to inspect the fine structure
- Do not ship a defective unit to a customer (most irregular distortion become worse over time) !

Open Questions

Up to now we have used the conventional analog input channel for testing. How can modern equipment with a digital and even a wireless input be tested ?

The next 11th KLIPPEL live webinar entitled
Pitfalls in Testing Wireless Audio Devices (July 22nd)

will address the points:

- Overview on new problems
- Coping with long and variable time delay, sample rate drift, dropouts, glitches
- How to perform accurate phase measurements required for holographic testing and 3D sound application
- Simple and practical solutions for R&D and QC end-of-line

Next Section

1. Modern audio equipment needs output based testing
2. Standard acoustical tests performed in normal rooms
3. Drawing meaningful conclusions from 3D output measurement
4. Simulated standard condition at a single evaluation point
5. Maximum SPL – giving this value meaning
6. Selecting measurements with high diagnostic value
7. Amplitude Compression – less output at higher amplitudes
8. Harmonic Distortion Measurements – best practice
9. Intermodulation Distortion – music is more than a single tone
10. Impulsive distortion - rumble & buzz, abnormal behavior, defects

ASK KLIPPEL (July 1st)

--- summer break ---

11. Pitfalls in Testing Wireless Audio Devices (July 22nd)
12. Benchmarking of audio products under standard conditions
13. Auralization of signal distortion – perceptual evaluation
14. Setting meaningful tolerances for signal distortion
15. Rating the maximum SPL value for product