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Online-Seminar

Sound Quality Engineering für die optimale Akustik Ihrer Produkte

Stefanie Fabian

Welcome

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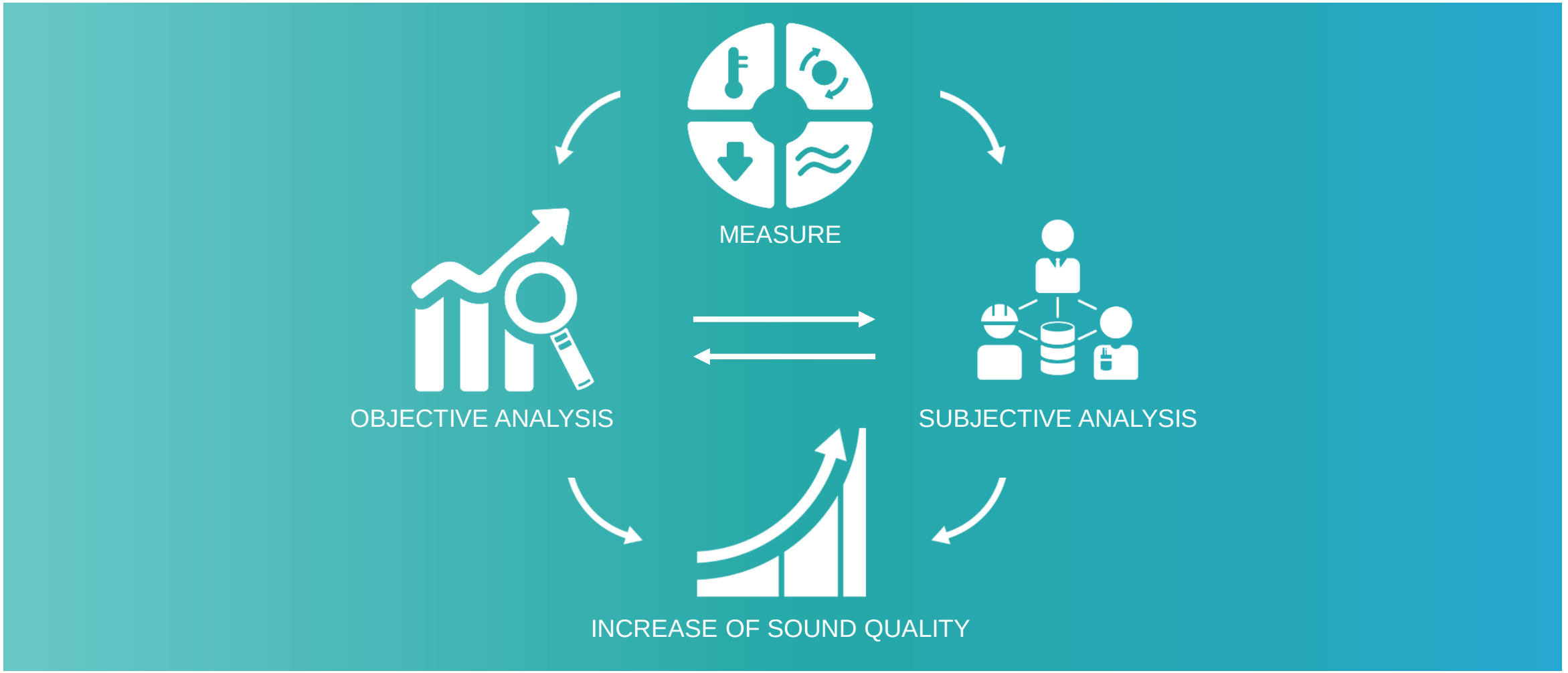
Stefanie Fabian
PreSales Consultant
Testing Solutions

phone: +49 (40) 23720534
mobile: +49 (1520) 3464954
email: Stefanie.Fabian@siemens.com

Sound Quality Process



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Agenda:

Human hearing system – Psychoacoustics
Binaural measurements
Objective analysis - Sound quality metrics
Subjective analysis - Jury Testing

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Human hearing system - Psychoacoustics

Human hearing system

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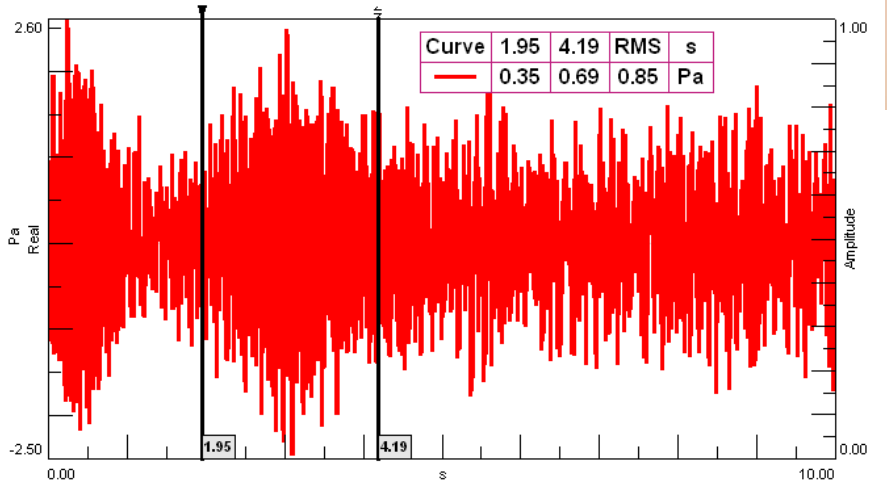
Time-averaging

Microphones measure **instantaneous** pressure fluctuations

The brain does not respond to the instantaneous pressure, instead it behaves like an integrator.

≠

$$\overline{p} = \sqrt{\frac{1}{T} \cdot \int_0^T p^2(t)dt}$$



Psychoacoustics – Auditory range

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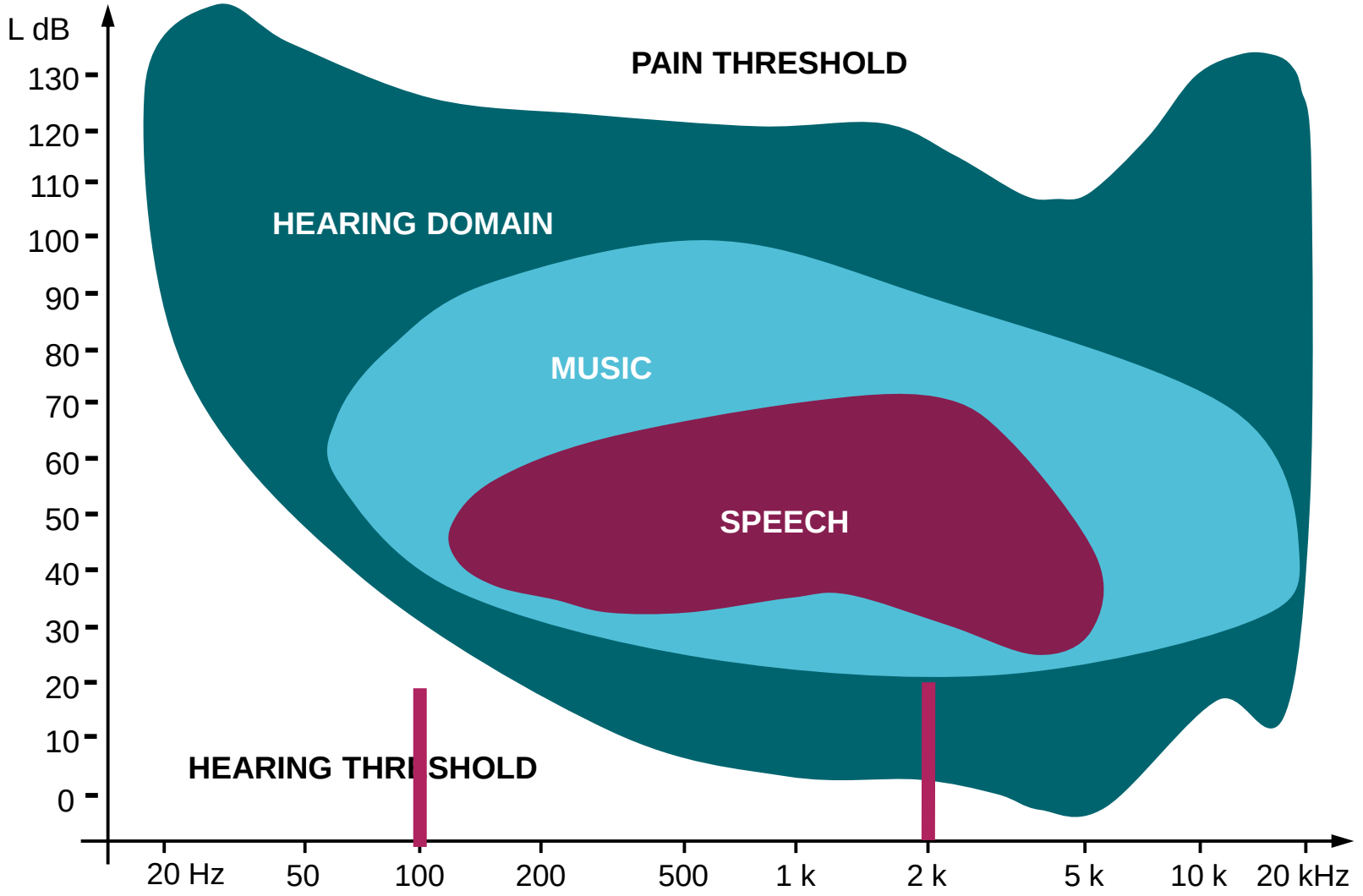
Auditory Range

- Hearing threshold
- Equal loudness curves
- Temporal effect
- Masking



Psychoacoustics - A-weighting

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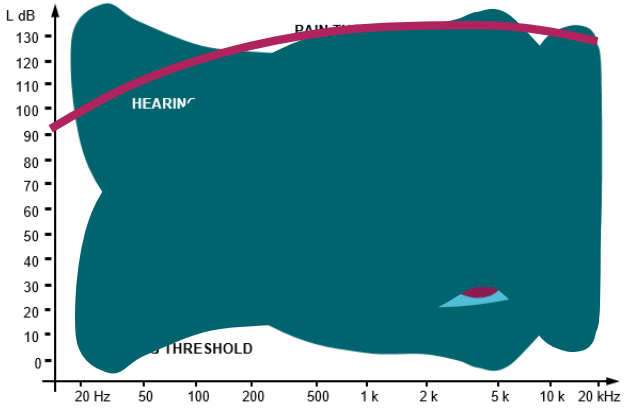
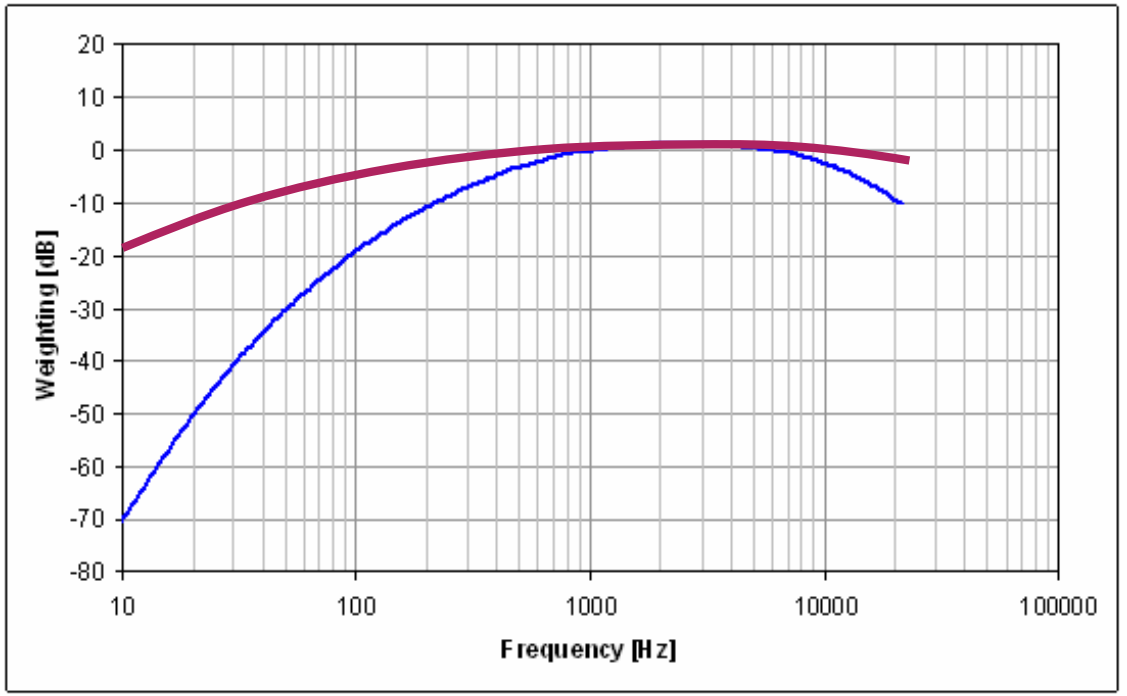
- Auditory Range
- **Hearing threshold**
- Equal loudness curves
- Temporal effect
- Masking





- Filter with similar attributes to ear
- Simple curve shape, attenuates low frequencies
- 1000 Hz - no gain/attenuation, used for microphone calibrations

Equal loudness curves

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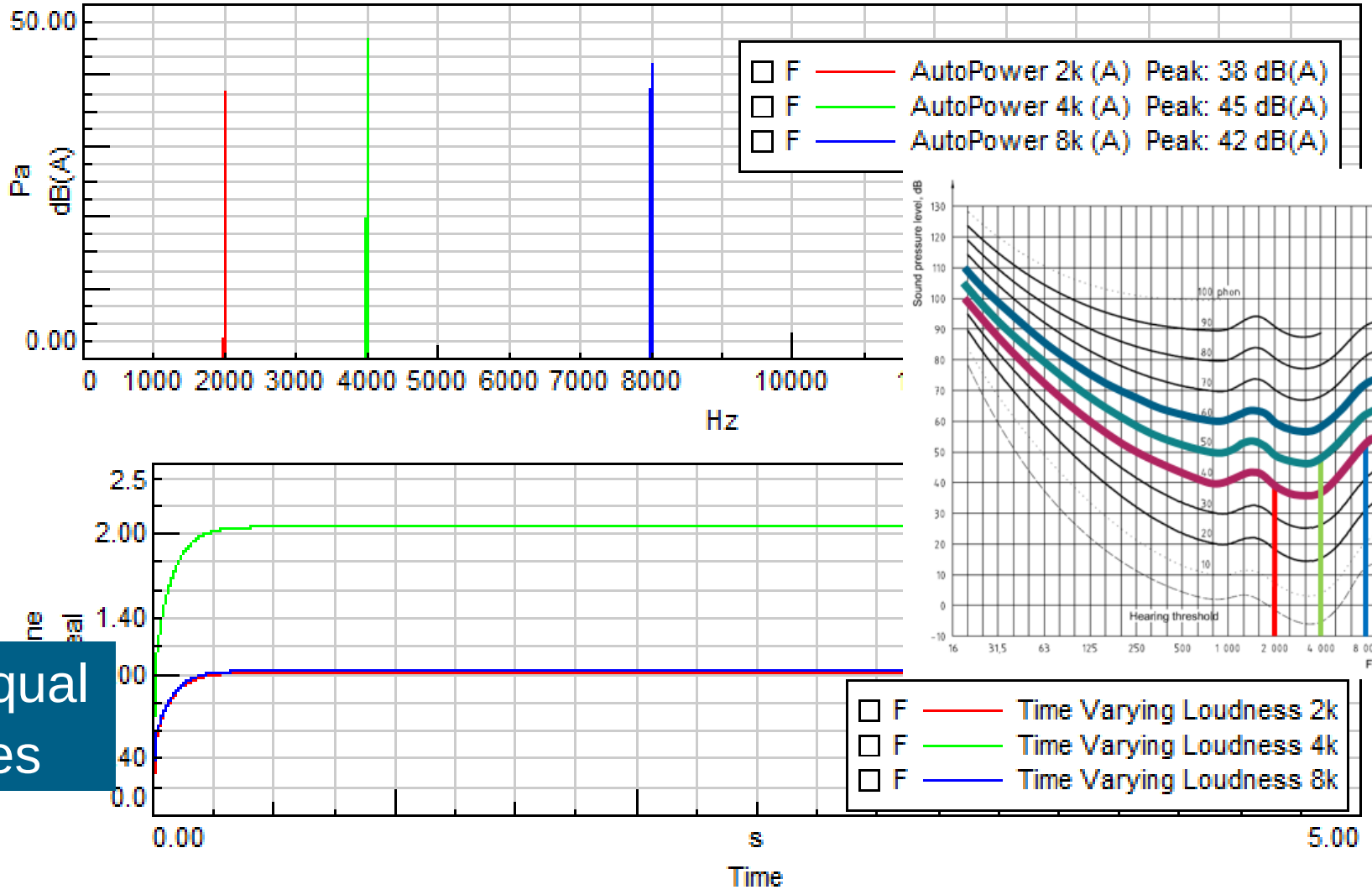
- Auditory Range
- Hearing threshold
- **Equal loudness curves**
- Temporal effect
- Masking

ISO 226:2003 Equal loudness curves



Temporal effect

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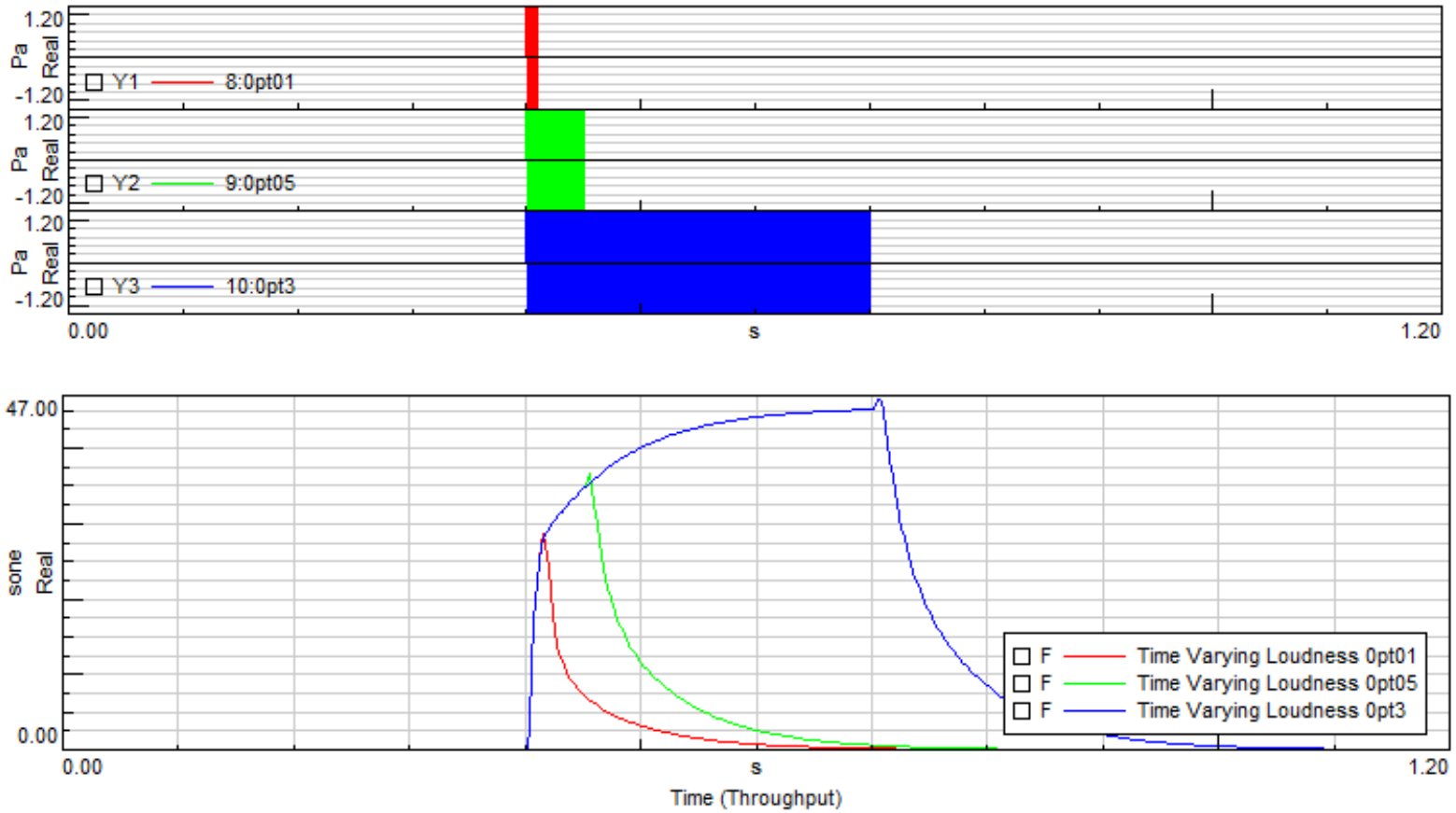
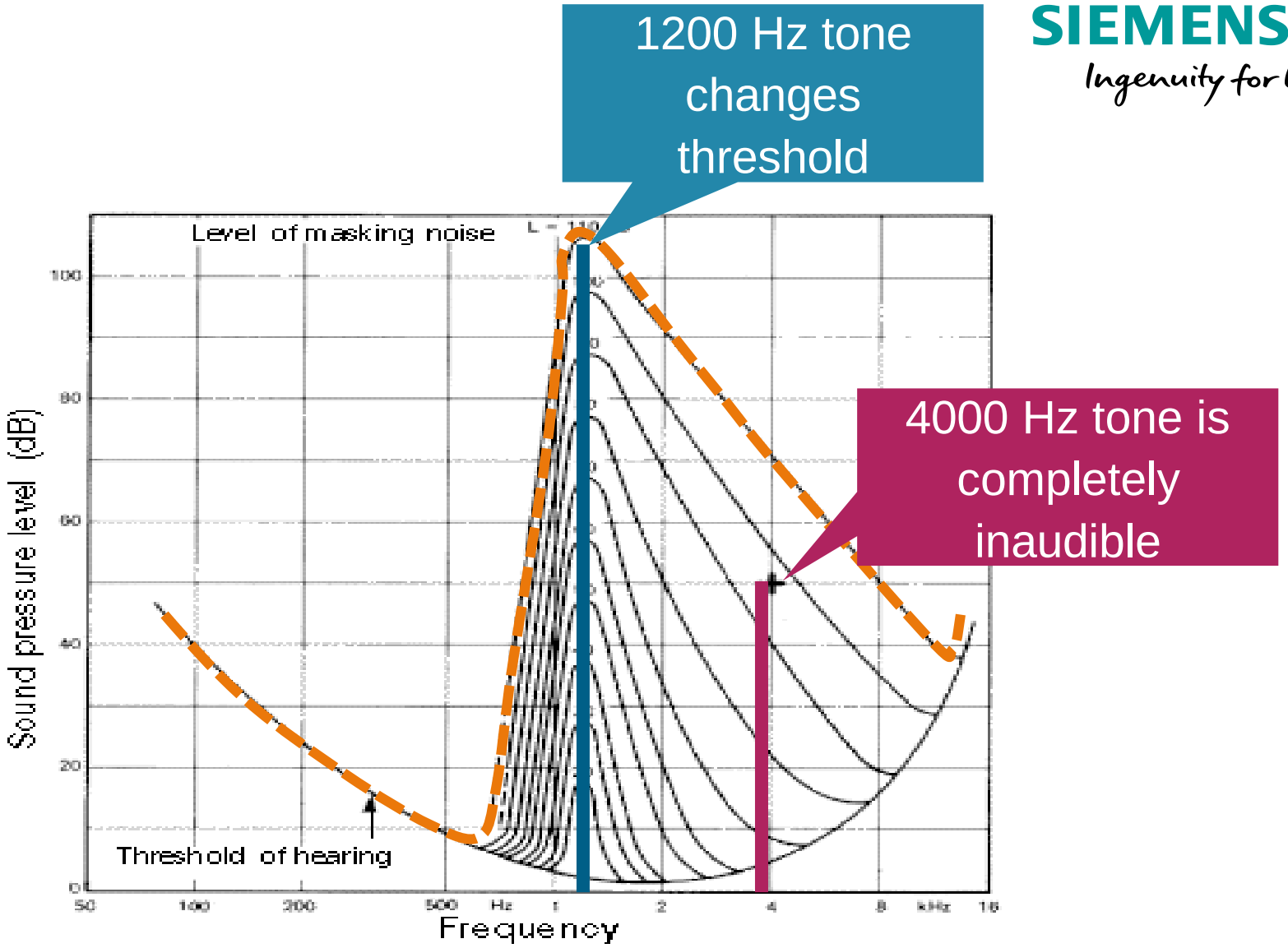
- Auditory Range
- Hearing threshold
- Equal loudness curves
- **Temporal effect**
- Masking



Frequency Masking

- Auditory Range
- Hearing threshold
- Equal loudness curves
- Temporal effect
- **Masking**



Masking for 1200 Hz Sine Tone

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Binaural measurements

How to acquire good signals to calculate sound metrics?

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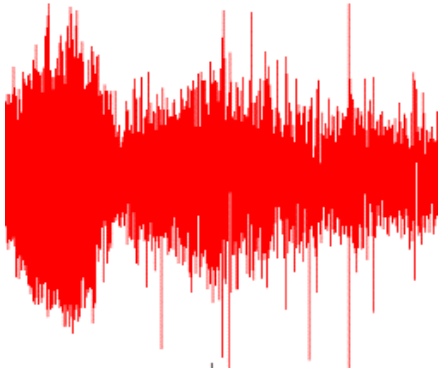
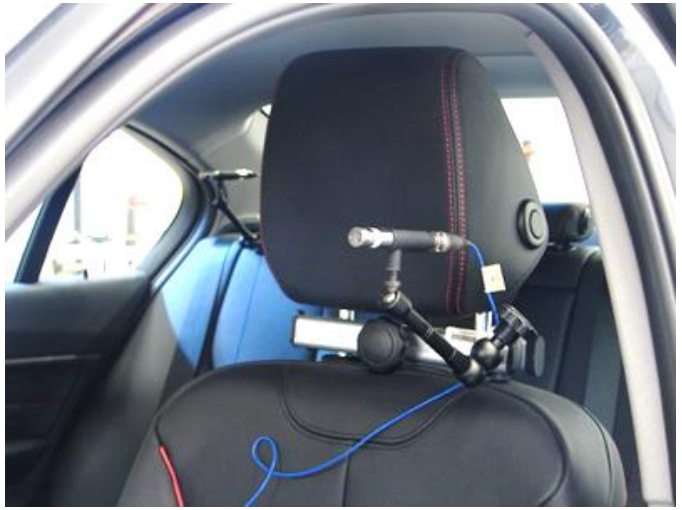
Sound recording



Single microphone ?



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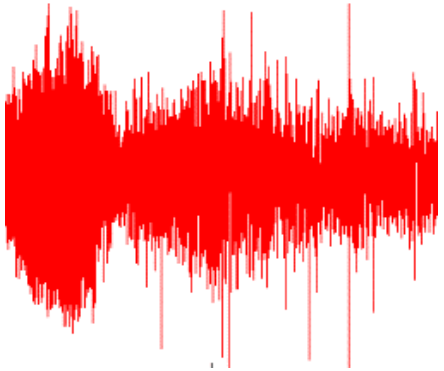

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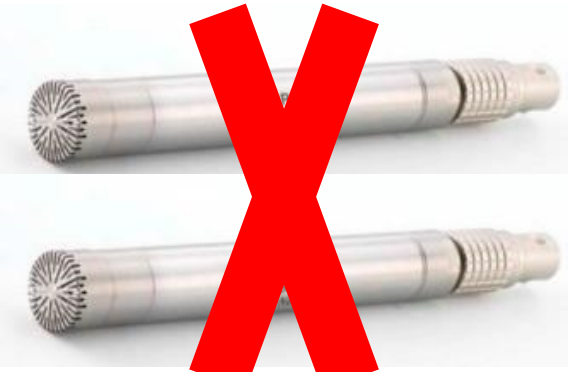

How to measure binaural recordings?

Simcenter SCADAS XS with Simcenter SCADAS 3D Binaural Headset

G.R.A.S. 45BB KEMAR Head and Torso

Binaural measurements

- ✓ Ideal for listening tests
- ✓ Stereo recordings
- ✓ Requires artificial head or a binaural headset
- ✓ Can be used for direct replay
- ✓ Recorded data is automatically equalized for analysis

Accurate audio replay – Equalization

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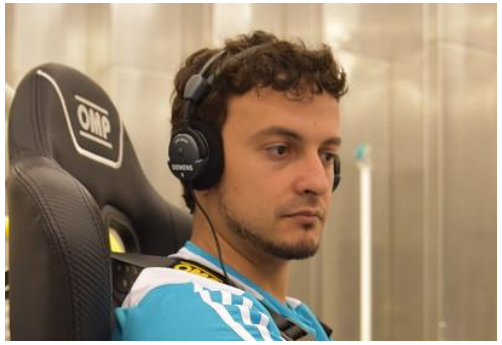
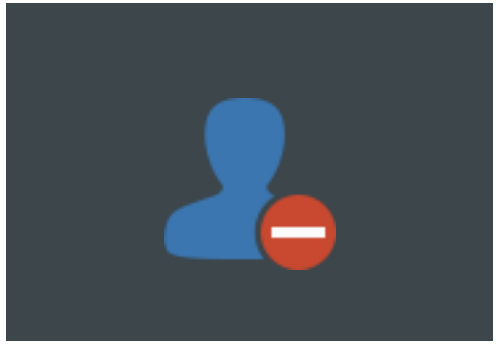
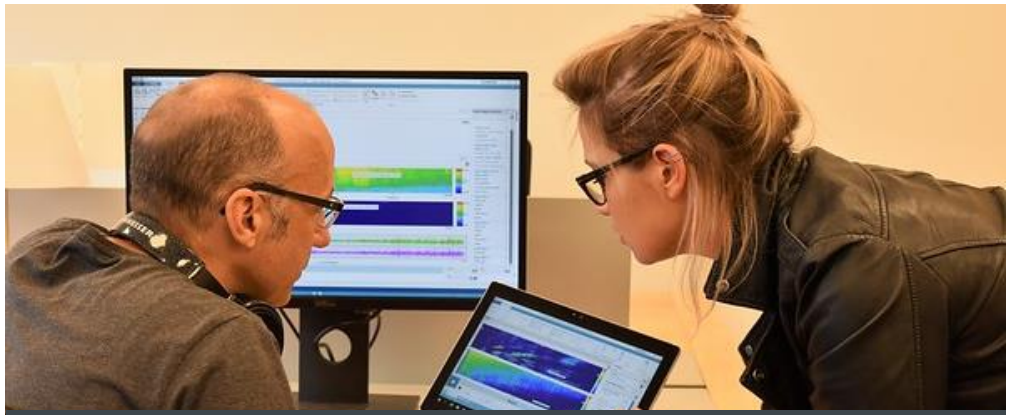
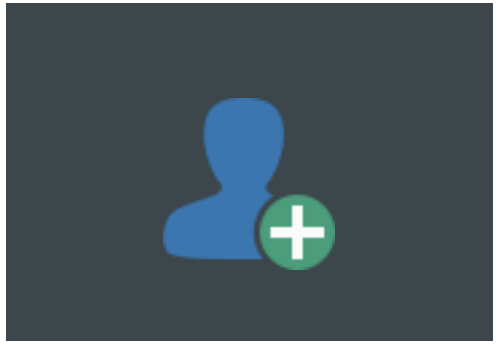
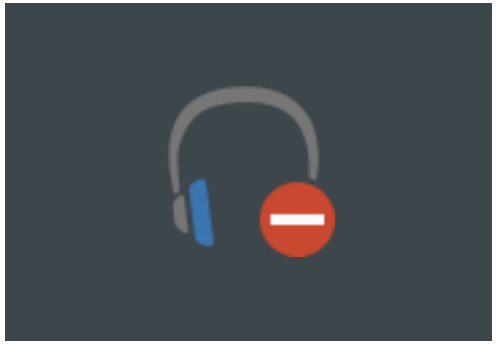






Equalization for analysis
Removing the head and torso effect





Replay equalization
Adding the head and torso effect
Removing the headphones effect

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Objective analysis
Sound quality metrics

Introducing sound quality metrics
Groups of sound quality metrics

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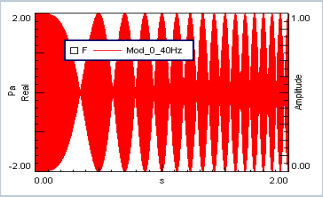
Level metrics	• Adapting recorded sounds to perception • Loudness ISO532 (A and B), Loudness Stevens VII, Time Varying loudness, …	
Speech metrics	• To quantify speech intelligibility according to the environment • Speech interference level, Articulation Index, …	
Modulation metrics	• Amplitude variation and harshness due to modulation • Roughness, fluctuation strength	
Annoyance metrics	• To quantify if the noise is disturbing or not • Noise rating, noise criterion, balanced noise criterion, sharpness	
Tonal metrics	• To quantify the perception of tonal components in real sounds • Pitch, tonality, tone-to-noise ratio, prominence ratio	

White goods – more than Sound Power

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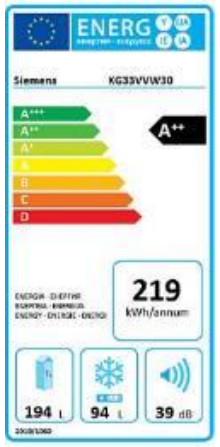
White goods	
Fridges	Operate all day – produce idle noise but during cooling, opening/closing of the doors. Main noise source: compressors and fans.
Washing machines	Various operational conditions: Opening/closing sound, different spinning velocities, drying. Main noise source: rotating drum, valves, pumps
Vacuum cleaners	Focus on loudness and annoyance. Depending on the design, the noise may be: mechanical (bearing/rotor), electromagnetic (magnetic force induced vibrations) or aerodynamic (fan).

Commonly used sound quality metrics

- Loudness
- Spectral analysis
- Modulation analysis
- Tonality
- Sharpness



Vacuum cleaner – why do we need Loudness?

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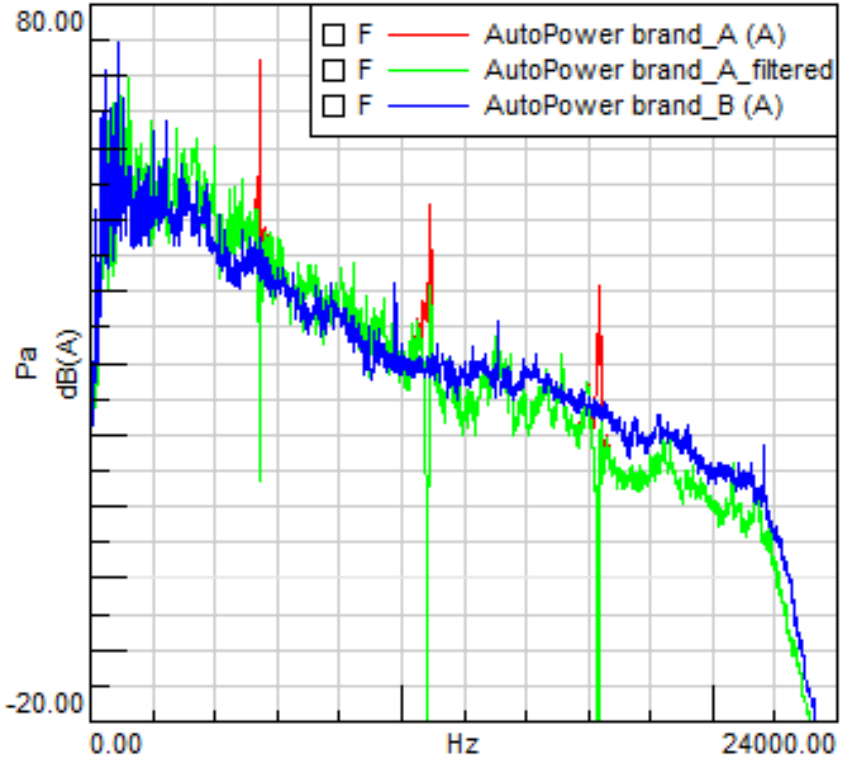

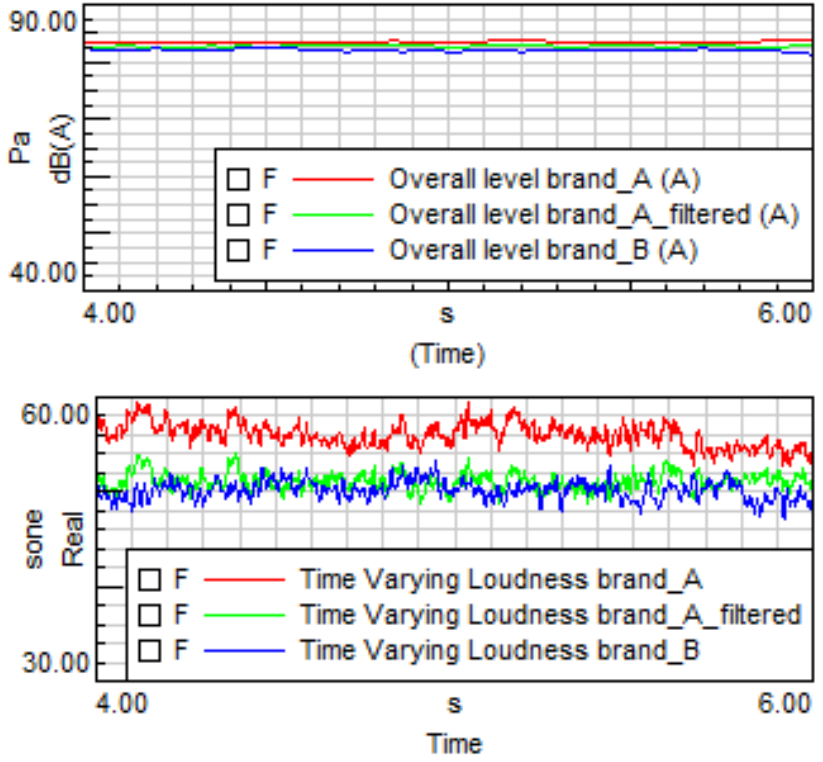

Loudness takes into account the aspects of human hearing and is more representative of the subjective preference

Sound Pressure Level and Sound Power are important, but sometimes not enough

Loudness

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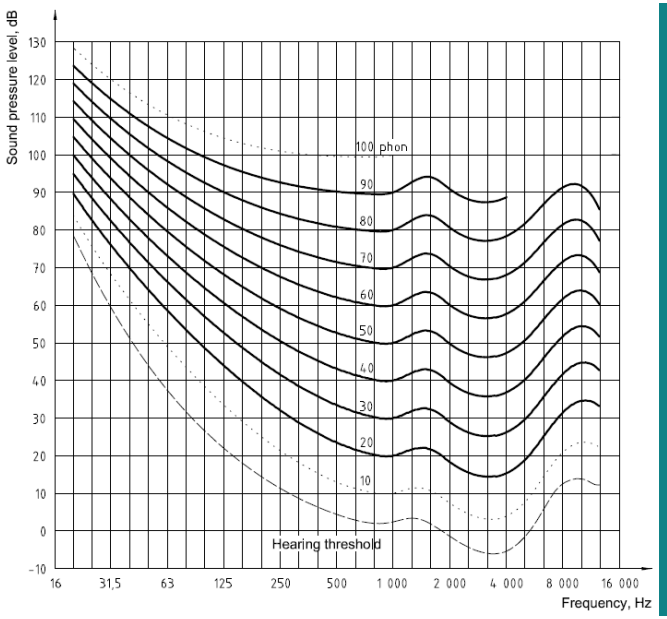
Loudness is a psychoacoustic parameter, that maps the human perception of the volume of acoustic signals to a linear scale



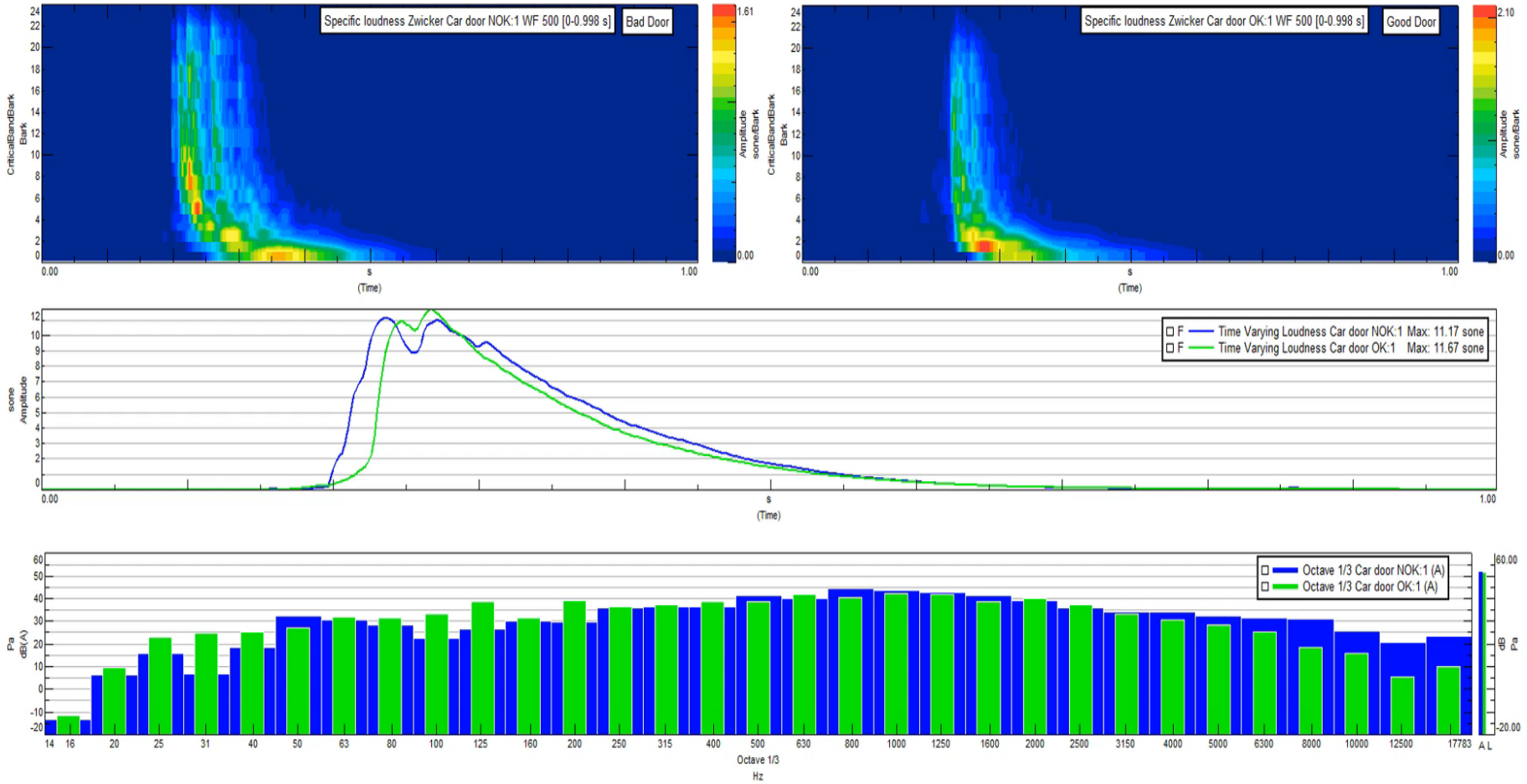
1 sone is
40 phones is
1 kHz @ 40 dB
sine tone

The metric of Loudness takes into account:

- Frequency
- Level
- Hearing threshold
- Temporal effect
- Masking

This metric is standardized:
ISO 532
DIN45631
ANSI S3.4

Door slam – frequency content



Washing Machines – how to choose the best design variant?

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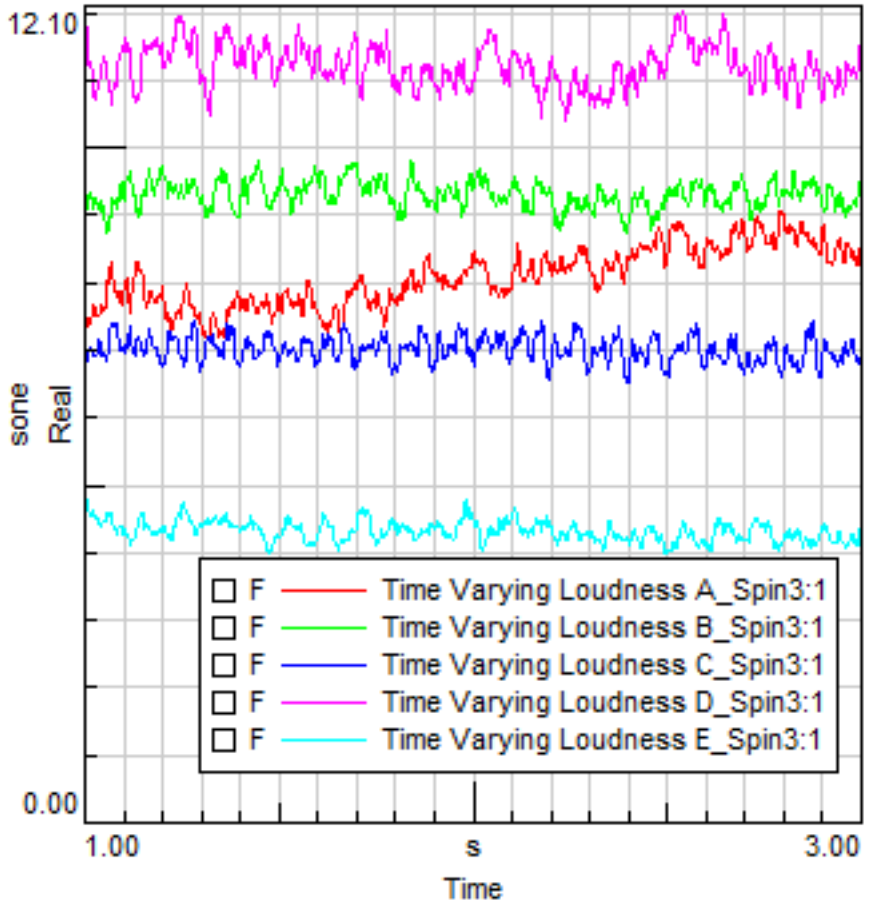
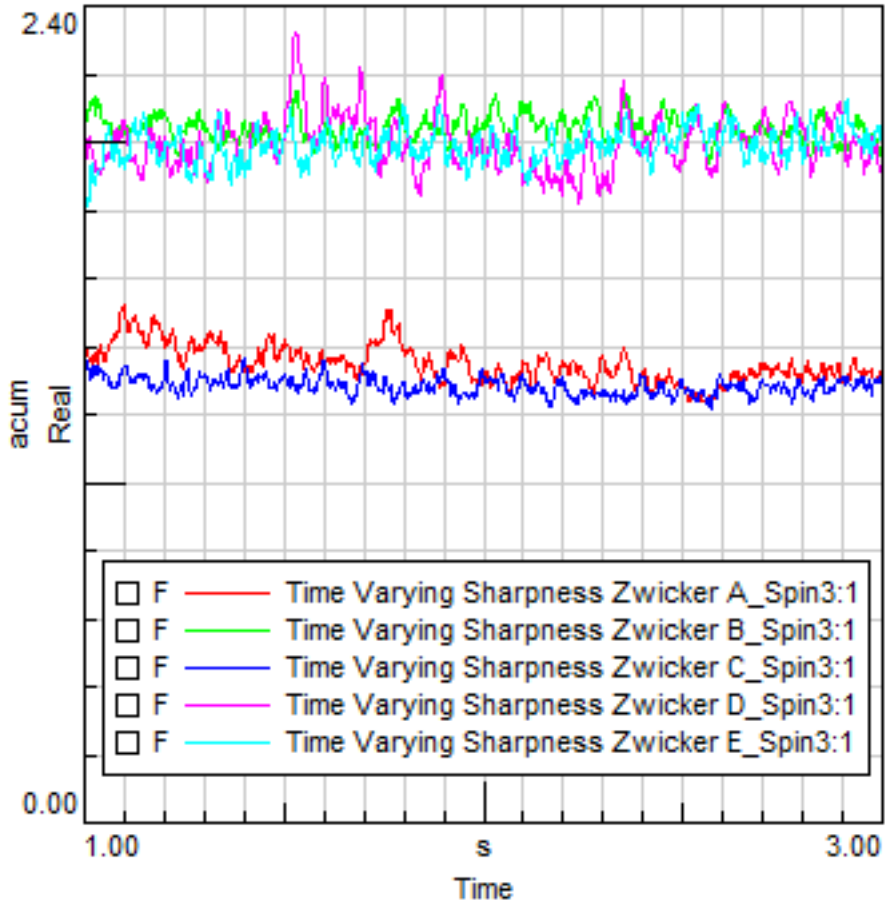
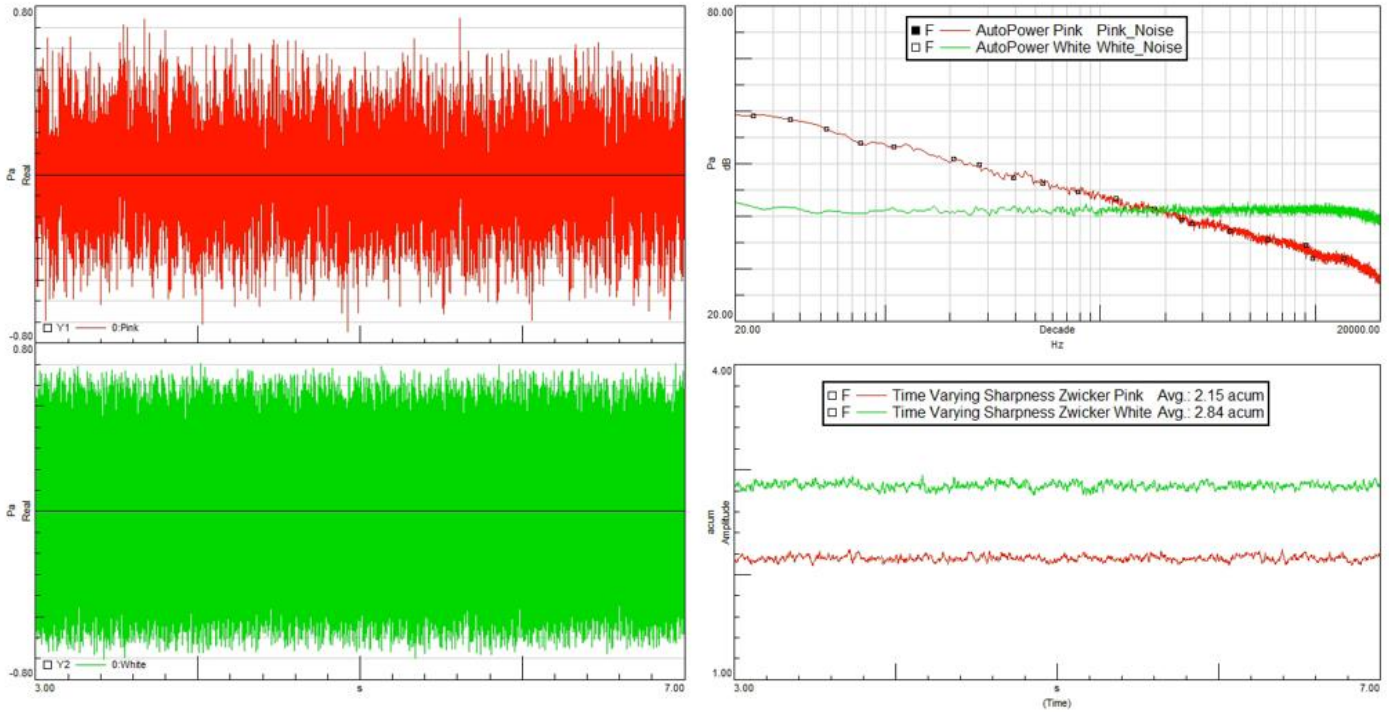




Sound Quality analysis is often the task of **striking the balance**. A fix of the valve may decrease loudness, but affect the sharpness.

Sharpness

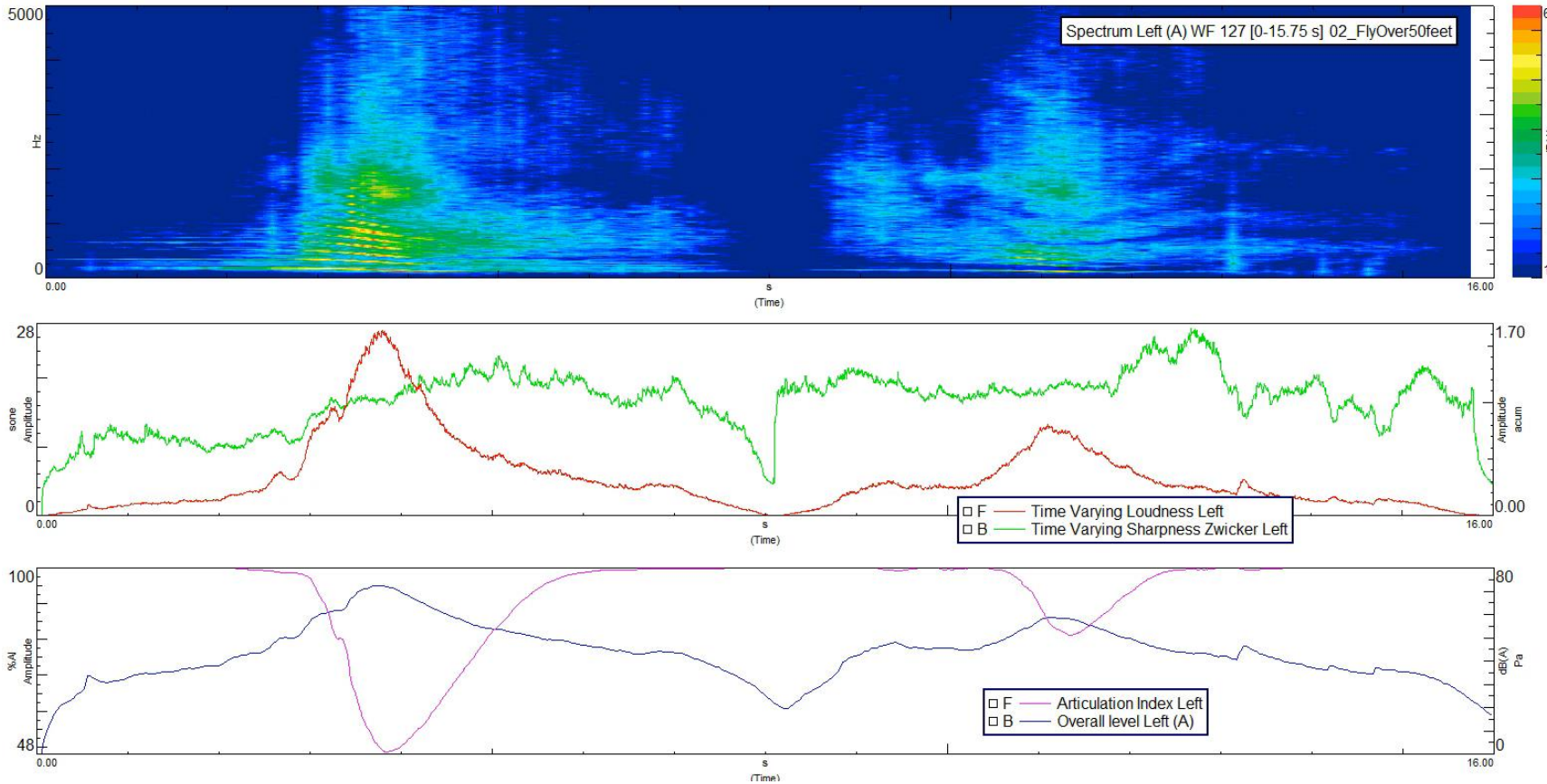
Sharpness is a measure of the high frequency content of a sound; the greater the proportion of high frequencies the ‘sharper’ the sound.



1 acum is as *sharp* as a 1 kHz @ 60 dB band of +-80 Hz width

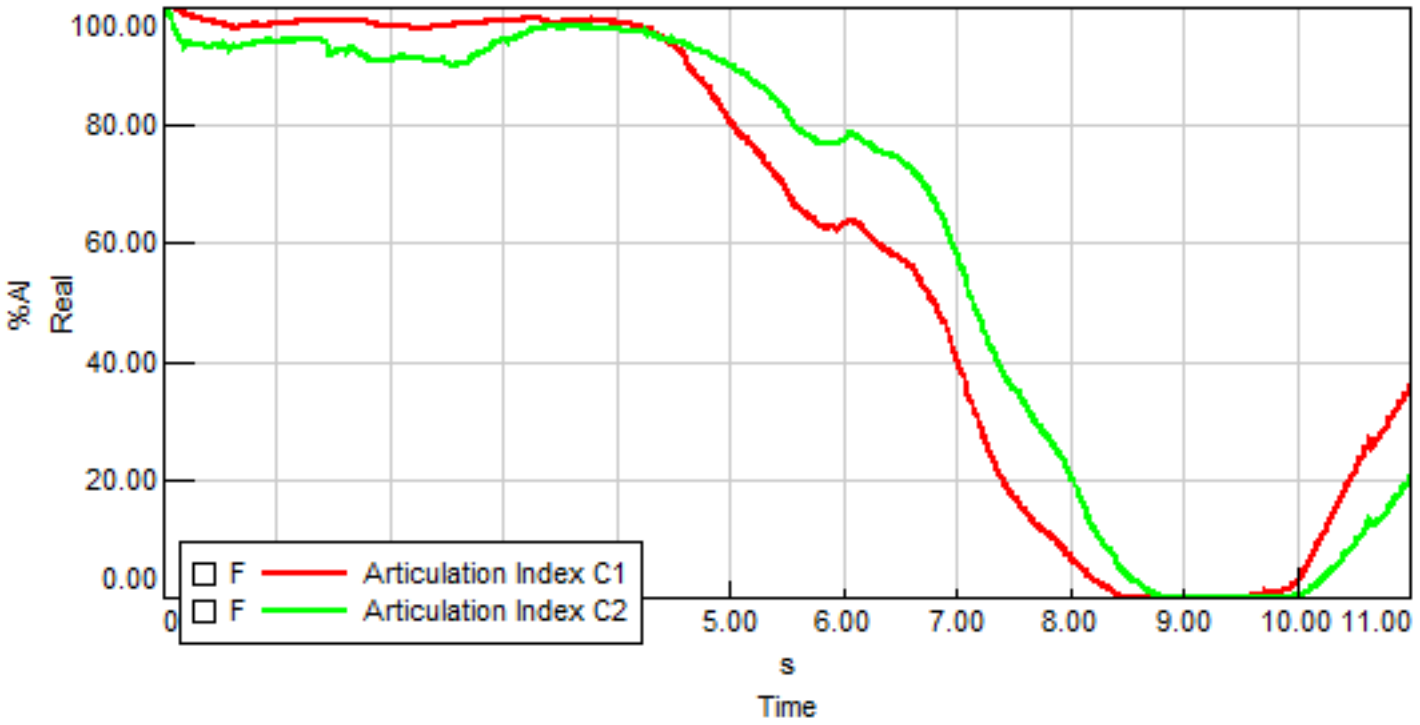
This metric is standardized:
DIN 45692
Multiple methods exist:
Zwicker & Fastl, von Bismarck, Aures (includes Loudness)

Aviation: Siemens e-aircraft



50 feet fly-over noise from a traditional and electric aircraft

Articulation Index



Articulation Index – How well is speech understood in the presence of the analyzed sound. Analysis is done in 1/3 Octave bands

Modulations

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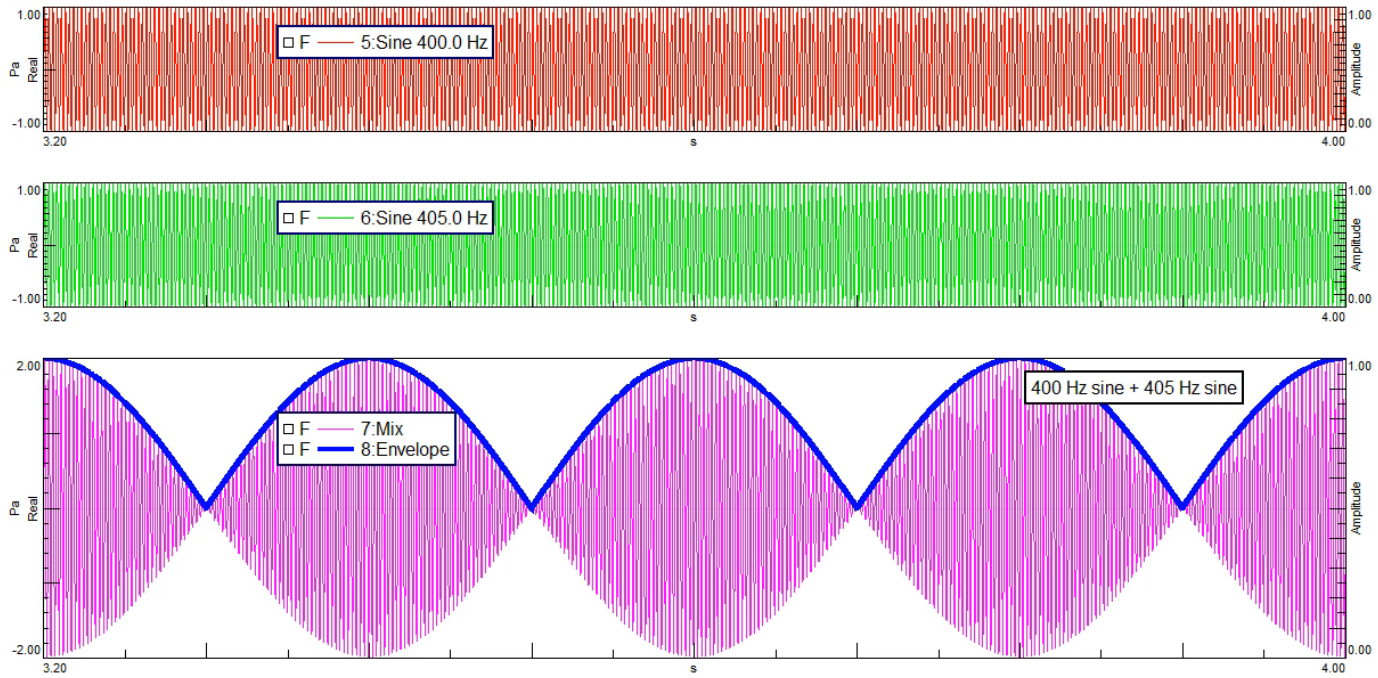
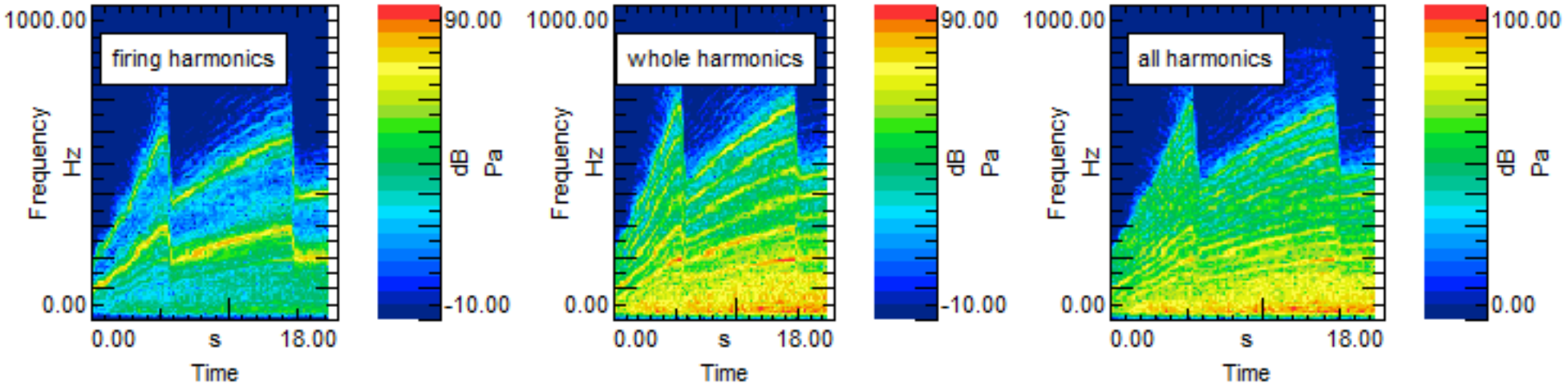
Phase shift between signals causes modulation in amplitude – these can be often perceived as annoying

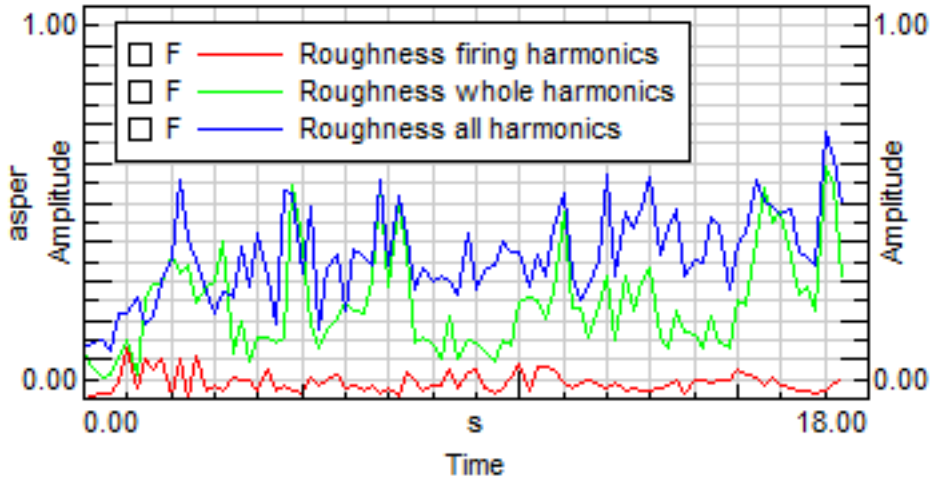


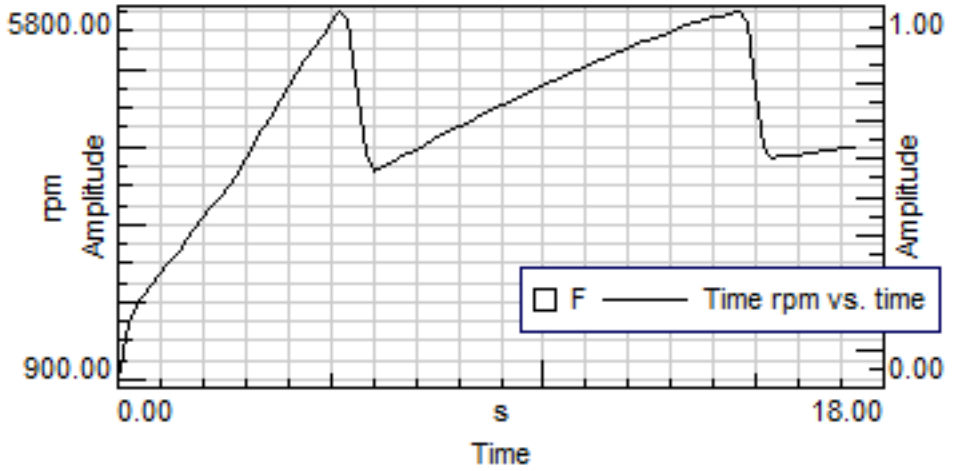
Sounds which vary in amplitude "slowly" over time

- Electric Motor "warble"
- Exhaust/Intake "Growl"
- Aircraft Turbo Props
- Cooling fan and engine running at same speed

Roughness



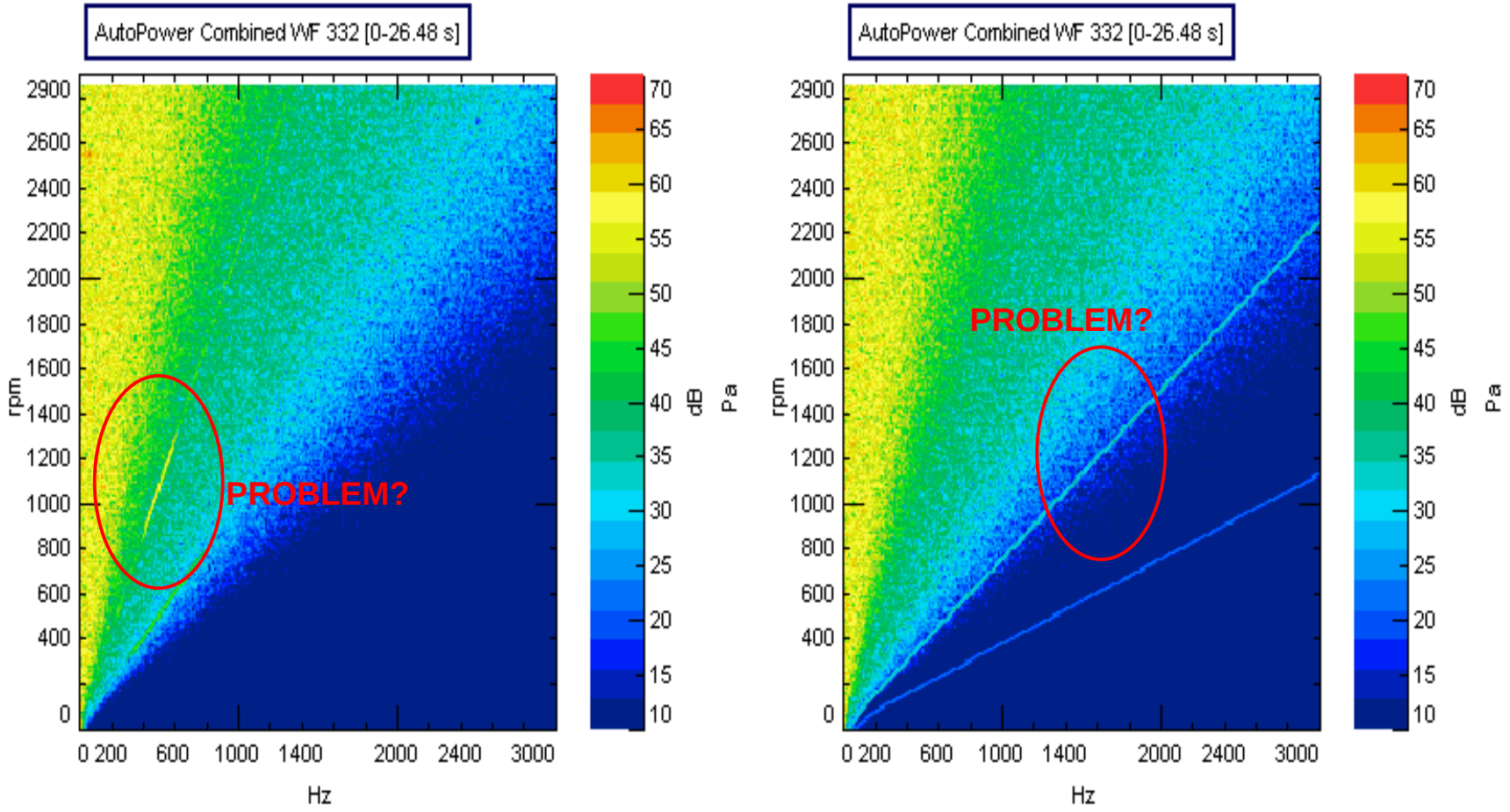




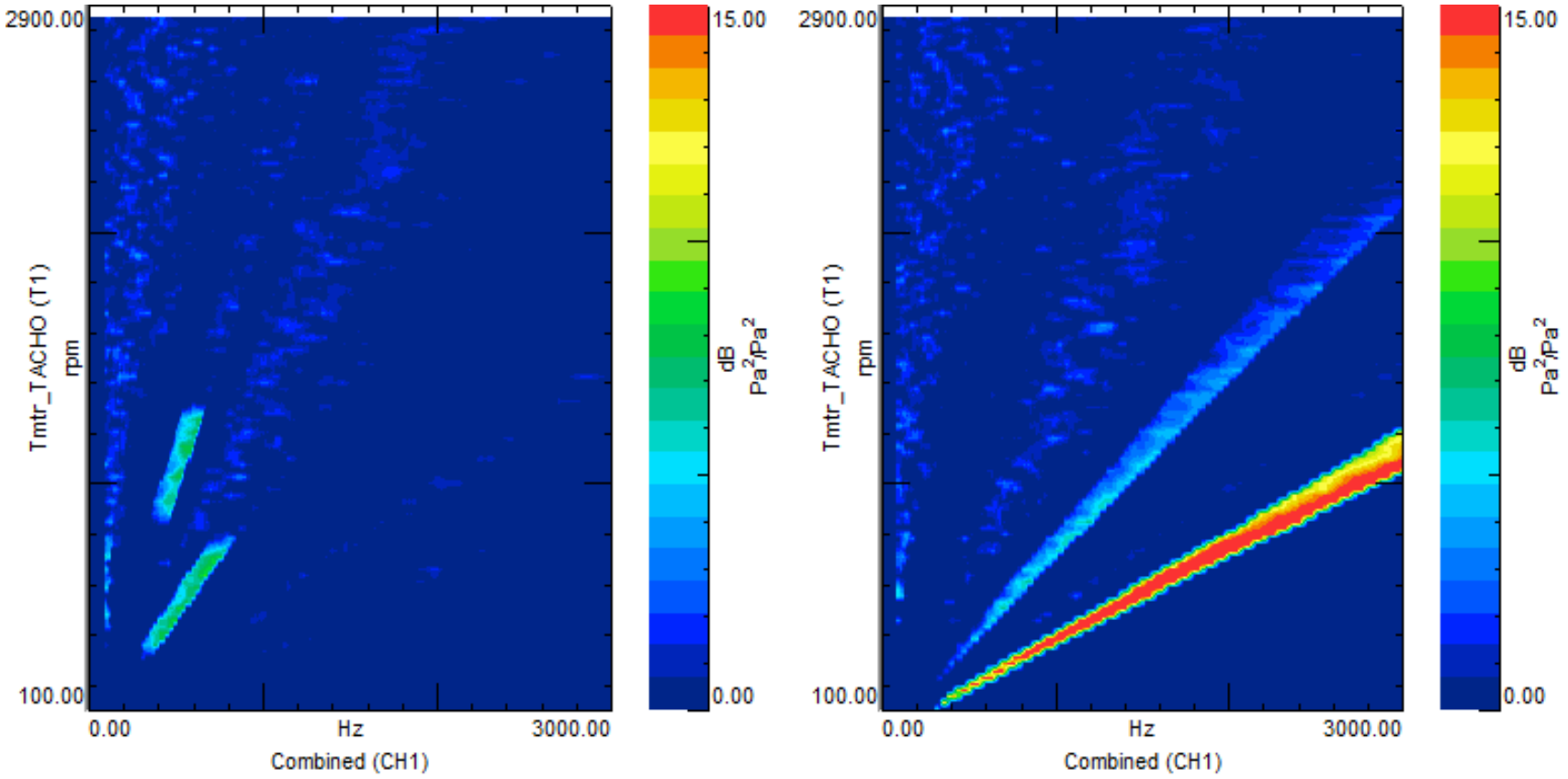
Roughness focuses on faster modulations, between 20 and 300 Hz, max at 70 Hz

1 asper is *roughness* produced by a 1000 Hz tone of 60 dB which is 100% amplitude modulated at 70 Hz

Prominence Ratio



Prominence Ratio Maps



Prominence Ratio

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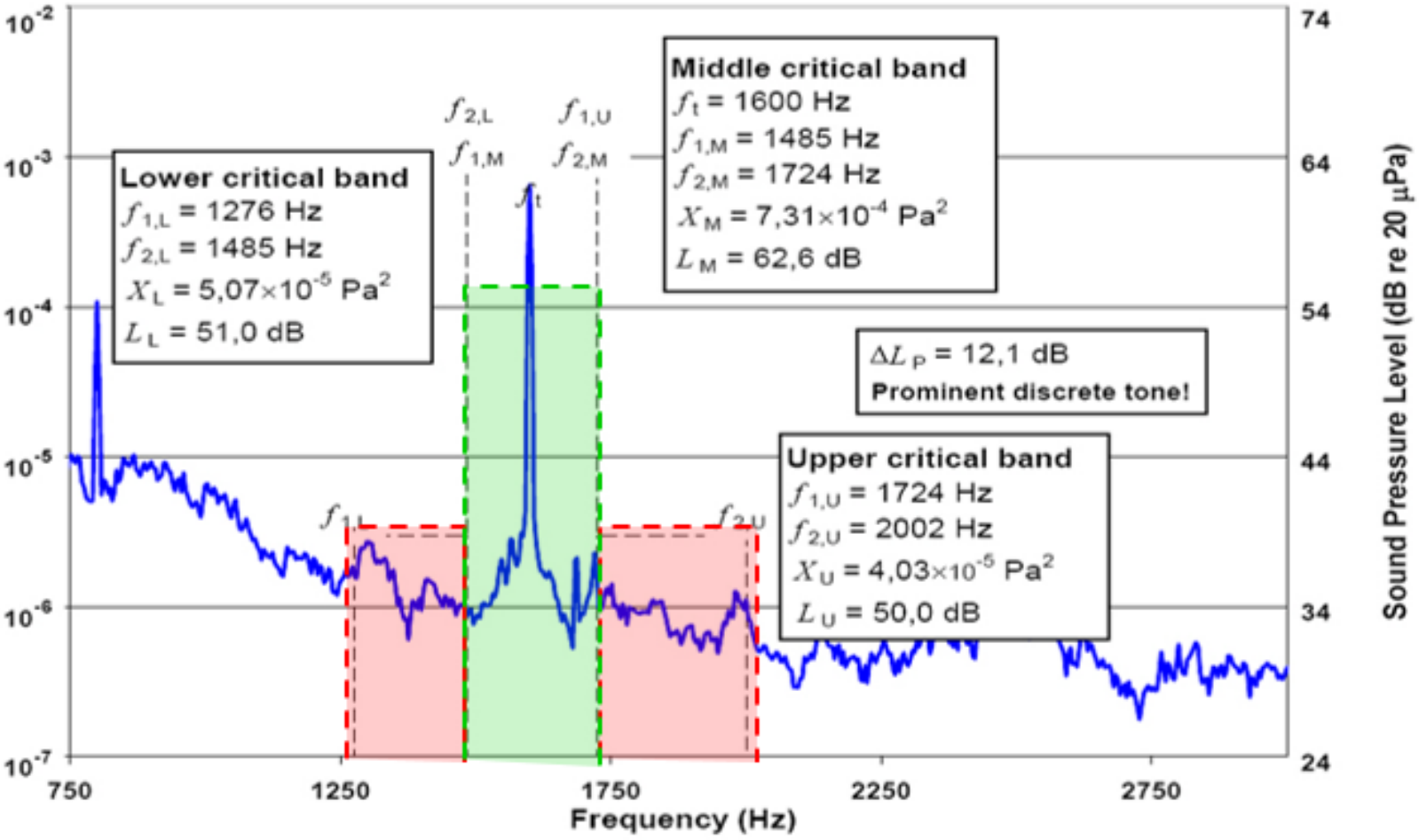
Prominence Ratio

ECMA-74 and ISO 7779 describe the calculation

Average SPL of the critical band centered around the tone is higher than surrounding critical bands



Customer actuated sounds

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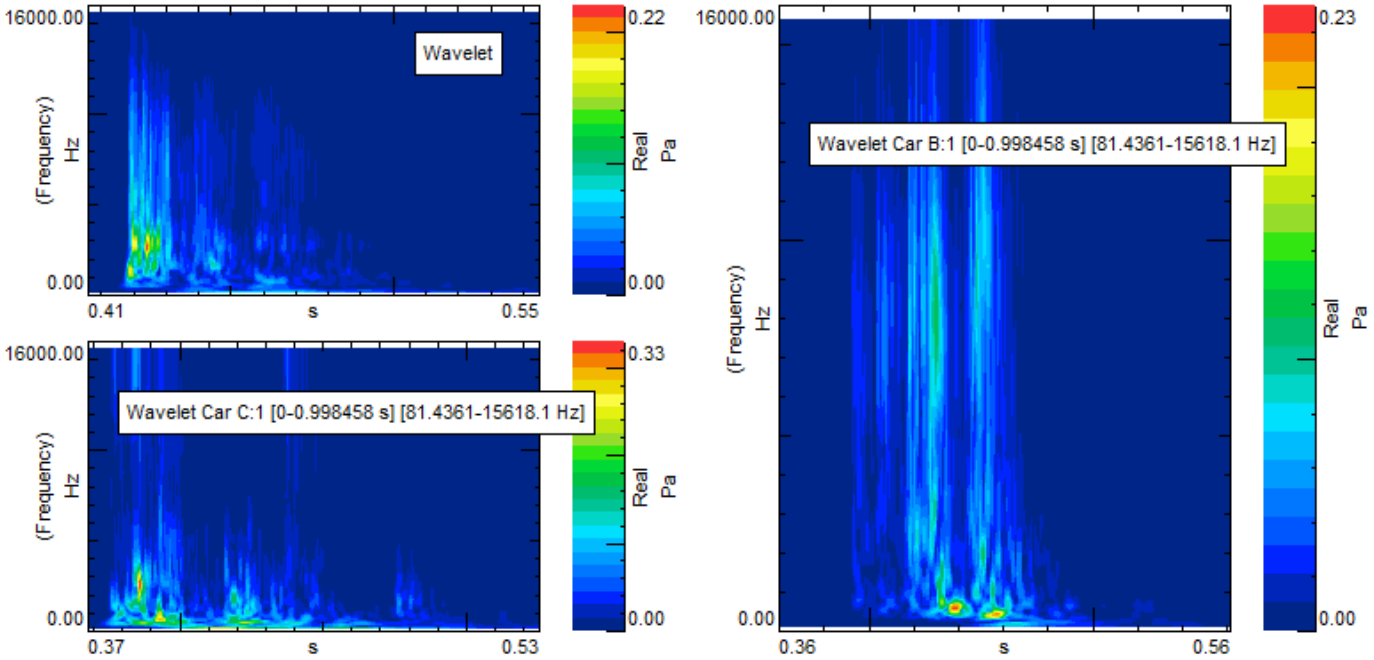
Customer actuated sounds	
Door closure	Transient, impact type of sounds. Play a significant role in the sound quality image of the complete vehicle.



Typical noise problems

- Hollow sound when closing
- Multiple impact sensation
- Bad sound quality image, not robust
- Ringing

Commonly used sound quality metrics

- Time Varying Loudness
- Time Varying Sharpness
- Ringing – time the sound takes to converge back to the background level
- Wavelets

Wavelets

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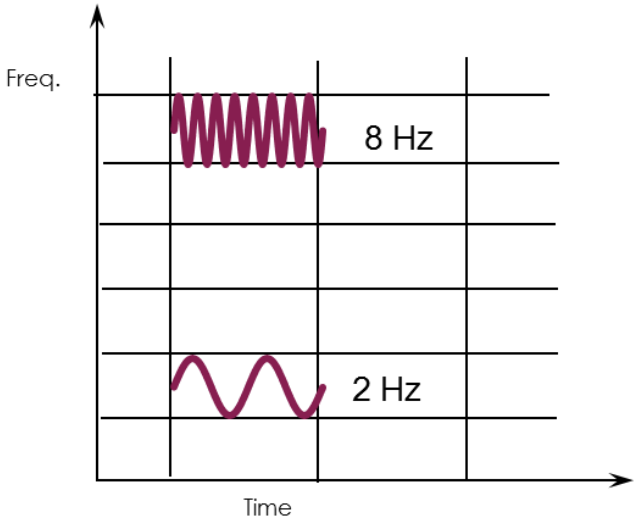
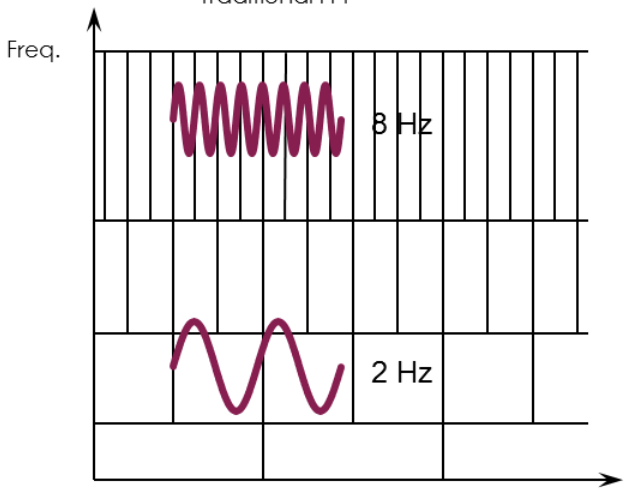
Traditional FFT methods do not work well on transient events:

- Good Time Resolution → Bad Frequency
- Good Frequency Resolution → Bad Time

Wavelet analysis uses filtering and flexible FFT settings to achieve the best results of the complete frequency range. It is best suitable for short, transient sounds



Traditional FFT



Wavelet

Introducing sound quality metrics
Groups of sound quality metrics

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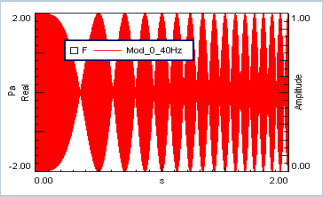
Modulation metrics	• Amplitude variation and harshness due to modulation • Roughness, fluctuation strength	
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Subjective Analysis
Jury Testing

From subjective to objective

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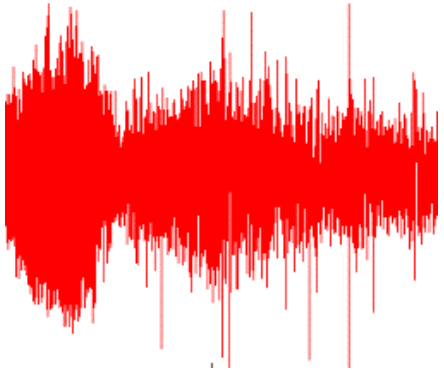
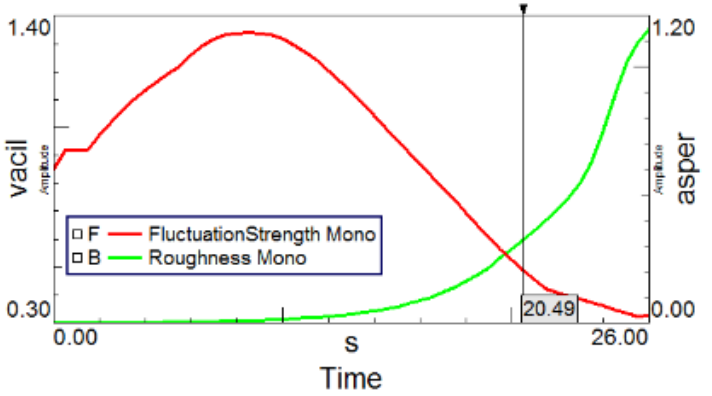
Sound recording
MEASURE



Calculate sound quality metrics
OBJECTIVE ANALYSIS

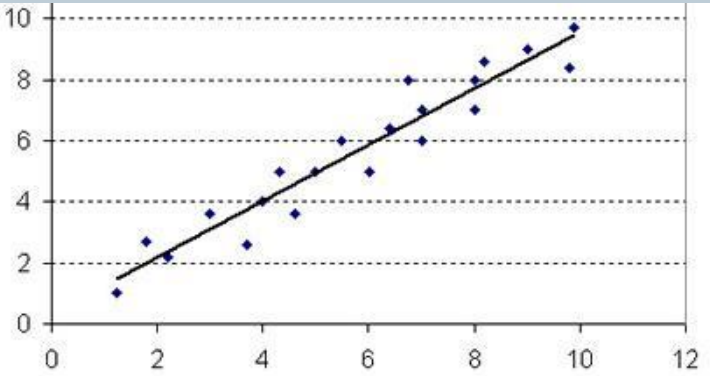
mathematical formulation that describes well the “average person” psychoacoustic perception of the noise



“average” person ?

How to find good metrics ?

Try to find OBJECTIVE functions (metric) that correlate well with the different SUBJECTIVE perceptions



From subjective to objective

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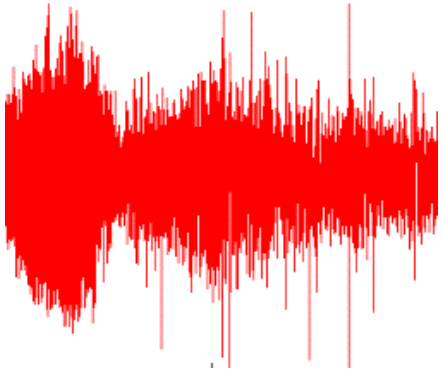
Sound recording
MEASURE



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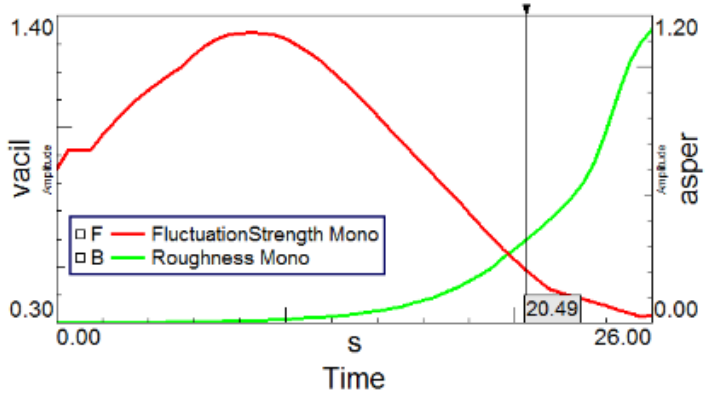
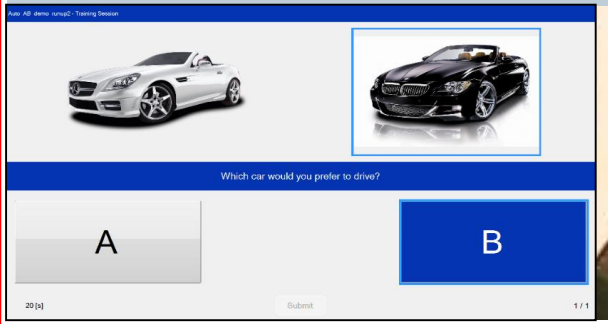
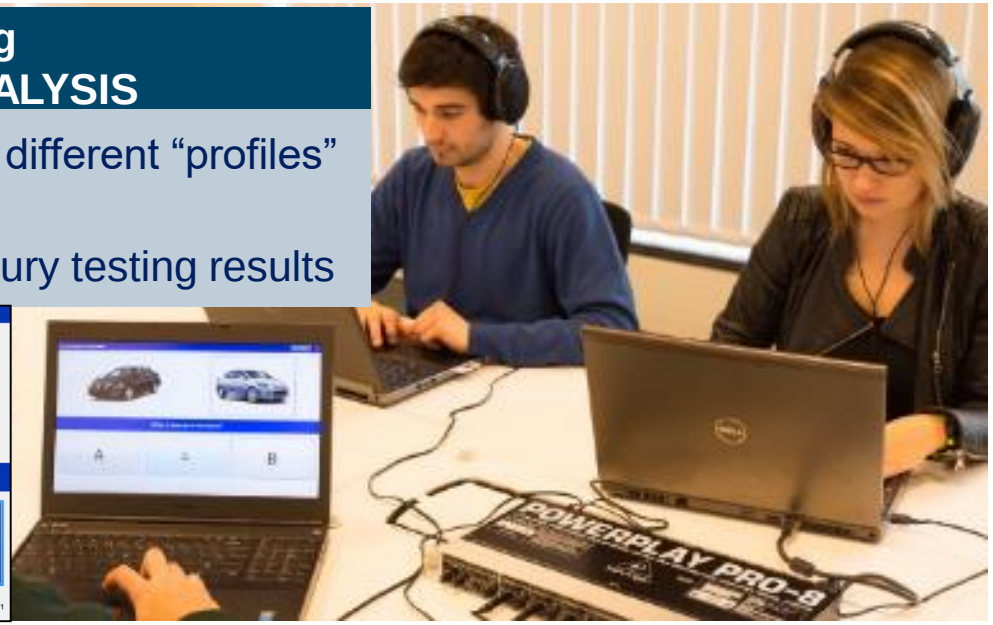


Jury testing
SUBJECTIVE ANALYSIS

Listening sessions, including different “profiles” of people.
Try to correlate metrics with jury testing results





Subjective analysis – Jury Testing

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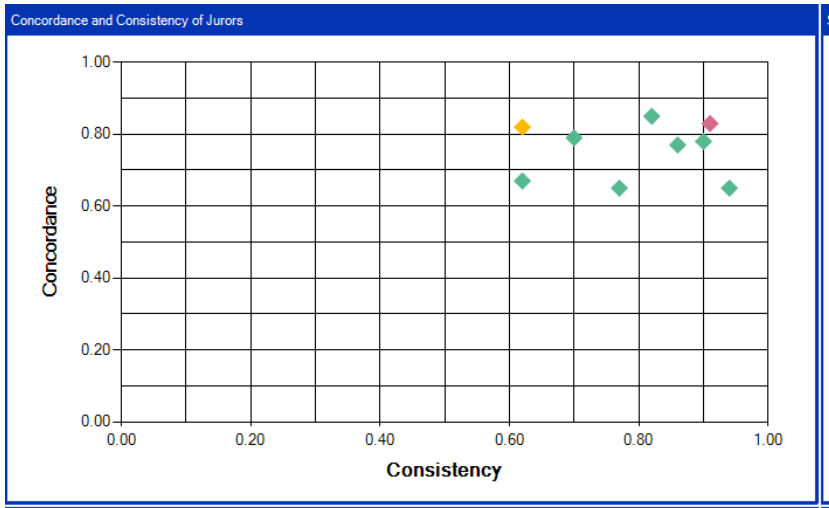
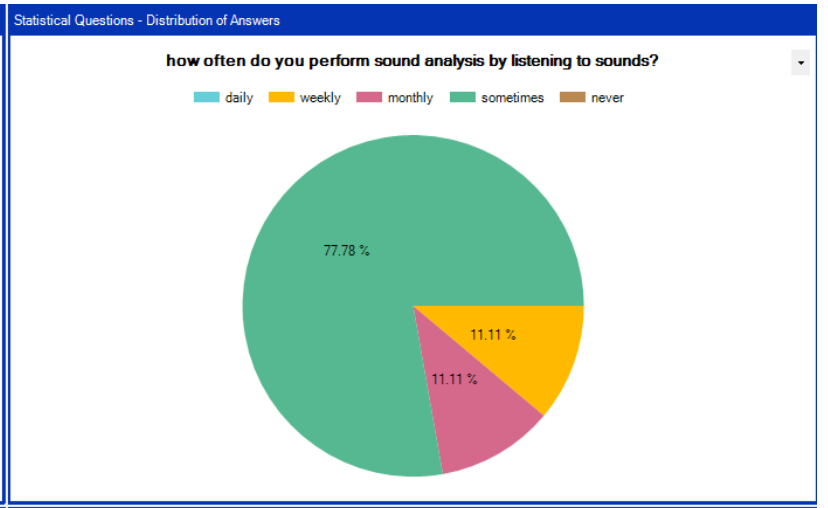
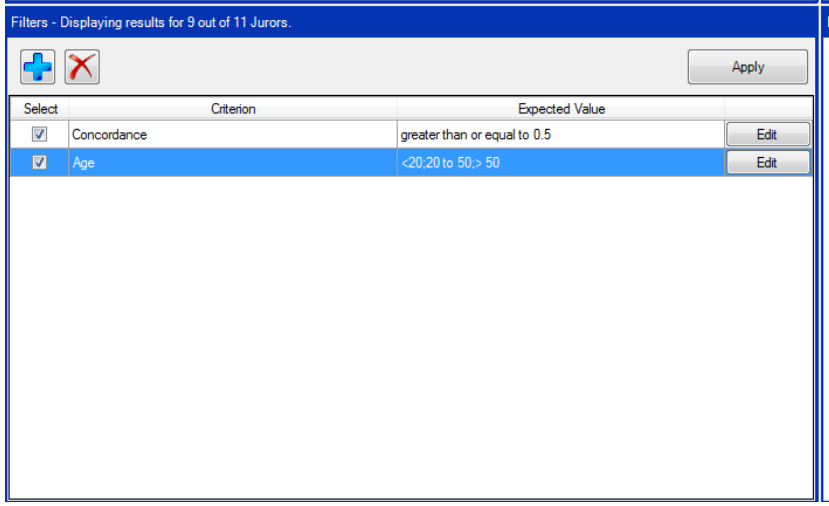
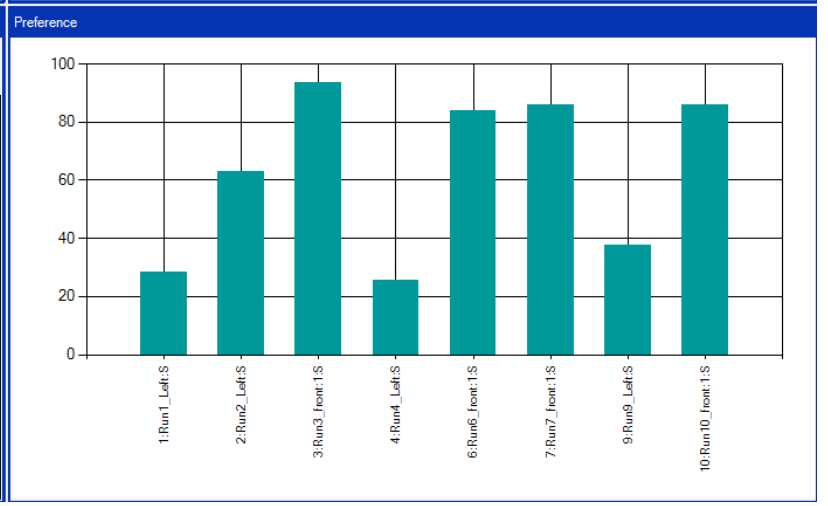
Understand what the customer thinks about the sound of your product

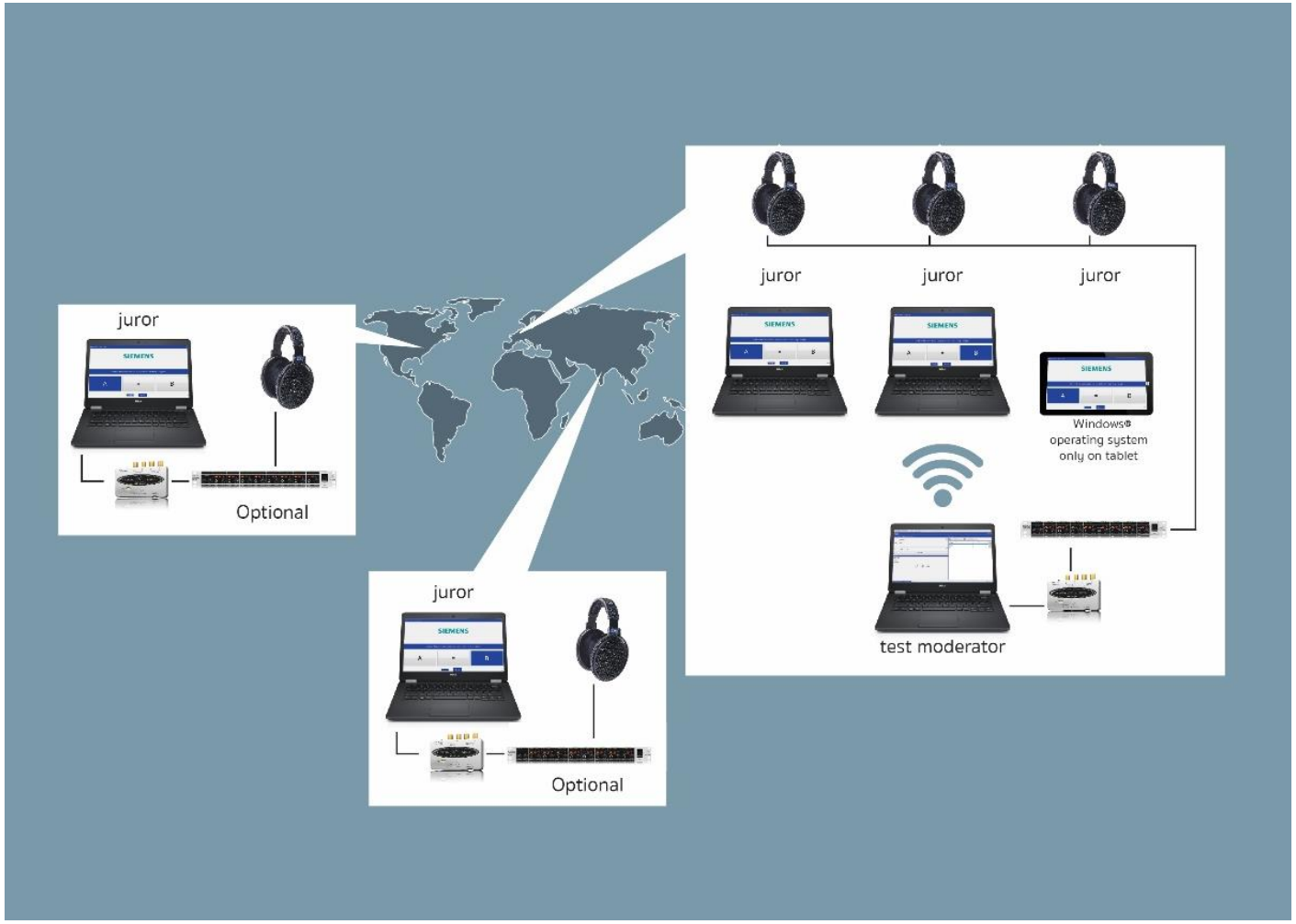








Test procedure



Group Mode

Group of Jurors participates in the test at the same location and time. Answers are sent through wireless or cable connection.

Individual Mode

One Juror at a time sits in front of the computer and participates in the test.

All decentralized results can be analyzed together.

Jury Testing

SIEMENS
Ingenuity for life

Use sounds measured with Testlab or imported from an external source

Support for A/B comparison, Semantic Differential and Category Judgement with statistical questions and reference answers

Connect to an unlimited number of Jurors and watch their answers in real time

Improve result quality with automatic checks on concordance and consistency
1-click export to Excel to further analysis

Thank you!

Stefanie Fabian
PreSales Consultant
Testing Solutions

phone: +49 (40) 23720534
mobile: +49 (1520) 3464954
email: Stefanie.Fabian@siemens.com

https://www.plm.automation.siemens.com/de/products/lms/testing/