Welcome to the LISTEN – G.R.A.S.
Headphone and Headset Measurement Seminar
The challenge of testing today’s headphones

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Presenter

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- Co-founder and owner of G.R.A.S. Sound & Vibration
- Live and work in Denmark
Agenda

• Definitions and abbreviations
  • The human body’s influence on the sound field
  • Types of headphones
  • Ear reference points
  • International standards

• Headphone & earphone testing
  • Basic tests
  • Other tests

• Next Generation Headphone Testing
  • High resolution ear simulator
  • Low noise ear simulator
Definitions and abbreviations
Ear Simulators and Manikins = Human Auditory System

- Acoustic **Diffraction**
  - People in the sound field
- Acoustic **Impedance**
  - Couplers, ear couplers, ear simulators
  - 318 and 711 down to the micron
- Great complement to subjective Golden Ear

- **The best test solution depend on the product you want to test**
Different types of headphones

- Circum-Aural headphones (CA)
- Supra-Aural headphones (SA)
- Earphones/Earbuds (EP)
- In-Ear headphones (IE)
Different ear reference points

- ERP = What enters the ear (CA + SA headphones)
- EEP = What enters the ear canal (Earphones)
- DRP = What you actually hear (IE phones)
Standards for Ear Simulators

EN 60318 is common standard for the acoustical test fixture
Headphone & Earphone testing
Designing and measuring Headphones/Earphones

Data that you **need** to capture:

- **Frequency Response**
  - Verify response across audible bandwidth 20Hz – 20kHz or higher
- **Distortion**
  - Produce a fundamental frequency with limited harmonics THD (a few %)
- **Quality?**
  - Rub’n’Buzz for loose, off-axis and/or grinding parts (high order harmonic distortion, very low levels)
- **Dynamic Range**
  - Destructive: at what SPL does the driver give in? (120dB or 95dB)
  - Non-destructive: min/max levels vs. distortion (80 dB range? 10%?) Design dependent.
- **Tracking/Wiring**
  - Right is right and left is left? balanced output? (4% disagreement)
- **Crosstalk**
  - Right to left and vice versa (< 50dB ?)
Challenge: Isolation of ambient noise

- EPA requirement for NRR!
  - “Products that are designed and sold on the basis of their ability to reduce the level of sound that may enter the ears... determine the performance... and properly label them with their effectiveness rating (Noise Reduction Rating, or NRR) for legal entry into U.S. commerce.”

Active Noise Cancelling test results
ANC Headsets tested on 45BB (Kemar)
Challenge: Isolation of headphone noise

• Leakage
  • Are you disturbing your environment? (library, office, public space)
  • How much noise do YOU make?

1) Measure ambient conditions using stand alone mic with all systems off.

2) Play pink noise through headphones at 90dB SPL

3) Measure ambient conditions with stand alone mic.

High Leakage score means you contribute to the acoustic pollution(!) in the world.
Challenges: Fit, placement and seal

- Head-related transfer function (HRTF) for each person
  - Uniquely shaped vs. KEMAR
  - High frequency (10+kHz) variations - in people and equipment
  - Small modal artifacts (room modes) arise when wearing headphones
- Move headphones around to achieve **spatial averaging**
  - Start with “ideal” fit
  - Then take 8 additional non ideal measurements
  - Finish with “ideal” fit, to have a total of 10 samples

Measuring your headphones
Measure “ideal” response and your many “bad” responses. Show variations on a single graph.
How do I find out if sealing is good?

• Headphone/Earphone positioning on Acoustic Test Fixture
  • **Pro-tip 1: Time Domain**
    • Play a 80 Hz square-wave as you mount the headphones to check for fit
  
  • **Pro-tip 2: Frequency Domain**
    • Play a pink noise signal and look for bass response
  
  • **Pro-tip 3: Human Domain**
    • Listen to the signal yourself
Solutions
Quality of test equipment vs quality of measurement

• Trust your tests
  • Your measurement isn’t better than the test equipment
  • Use international standardized equipment
  • Calibrate to ensure consistent measurements

• Avoid approving bad parts
• Avoid rejecting good parts
Next Generation Headphone Testing
Why a new generation of couplers and pinnae?

- Consumers demand more from their personal listening devices
- Increasing demand in high-end headphones
- Technological shifts in the audio business
- Multitude of form factors with no test capabilities
Goals for Next Generation Headphone Testing

- Better high frequency measurements
- Better low noise measurements (ANC, Bluetooth)
- Better repeatability
- Better low frequency measurements
- Solutions with backwards compatibility
- Solutions which are based on known standards
New high resolution (20kHz) ear simulator
Challenges in the market

- Consumers demand high definition sound experience

**New consumer expectations for wireless personal audio**

- **78%** Sound quality is the top ranking purchase driver for 78% of respondents
- **80%** of participants expect there to be **new features** included with each new release of wireless speaker or headphone product
- **50%** and **70%** Almost 70% of American and over 50% of British consumers surveyed rated **battery life** as “very important” (when choosing wireless speakers or headphones)
- **43%** 43% of those surveyed say having the ability to use voice to **control their audio devices** would make things easier

*Source: Qualcomm 2017*
Standard IEC 60318-4 Ear simulator

- Also known as 711 coupler
- Designed almost 40 years ago
- Most complex ear simulator on the market
- Designed to mimic the transfer impedance of an average human ear
- Often used with pinna

- Built-in WS2P ½” microphone:
  - Sensitivity of 12.5 mV/Pa
  - **Frequency range 100Hz–10kHz (16kHz)**
  - Noise floor at 25 dB(A)
  - Maximum SPL ≈ 164 dB
Typical IEC 60318-4 (RA0045) Response

Specifications:

- IEC specified tolerances from 100 Hz -10 kHz
- IEC specified ½ wave resonance at 13.5 kHz +/- 1500 Hz
- GRAS RA0045 typically at 13 kHz +/- 500 Hz
Typical IEC 60318-4 (RA0045) Response

- Main Volume
- Side Volumes
- Microphone

Transfer impedance [dB re 500 Hz]

Frequency [Hz]

Reference plane

Main Volume ½ wave resonance
Resonance and Ear Canal

- Reference plane
- Ear Entrance point
- ½ wave resonance
- Full wave resonance

Transfer impedance [dB re 500 Hz]
Frequency [Hz]
Transfer Impedance with varying ear canal lengths, Standard 60318-4 Ear Simulator
Transfer Impedance with varying ear canal lengths, Standard 60318-4 Ear Simulator
Transfer Impedance with varying ear canal lengths, Standard 60318-4 Ear Simulator
Transfer Impedance with varying ear canal lengths, Standard 60318-4 Ear Simulator
Transfer Impedance with varying ear canal lengths, Standard 60318-4 Ear Simulator

![Graph showing transfer impedance with varying ear canal lengths. The x-axis represents frequency in Hz, ranging from 100 to 10000. The y-axis represents transfer impedance in dB re 500 Hz. Lines of different colors represent ear canals of varying lengths: 2 mm, 5 mm, 8 mm, and 11 mm. The graph illustrates the change in transfer impedance at different frequencies for each ear canal length.]
Transfer Impedance with varying ear canal lengths, Standard 60318-4 Ear Simulator
The new high resolution ear simulator

- Updated IEC 60318-4 (former 711) Ear Simulator
- Backwards Compatible, mechanically as well as impedance
- Improved High Frequency Response
- Improved repeatability
- Improved Measurement of THD, Rub’n’Buzz
New High Resolution Ear Simulator Response

![Graph showing typical response and IEC tolerance curves for transfer impedance vs. frequency.](image-url)
New High Resolution Ear Simulator Response

- Typical response
- High Resolution Ear Simulator
- IEC Tolerance

Transfer Impedance [dB re 500 Hz]

Frequency [Hz]
Typical High Resolution Ear Simulator Response
### New 10-20 kHz Tolerances

![Graph showing transfer impedance for different tolerances](image)

**Typical response**

**IEC Tolerance**

**GRAS Tolerance**

+/- 2.2 dB tolerance from 10-20 kHz

Same response below 10 kHz as standardized Ear Simulator
Transfer Impedance with Varying Ear Canal Lengths, Standard 60318-4 Ear Simulator
Transfer Impedance with Varying Ear Canal Lengths, High Definition Ear Simulator
In-Ear Headphone Response

![In-Ear Headphone Response Graph](image-url)

- Frequency [Hz]
- SPL [dB re 20μPa]

- Standard 711
In-Ear Headphone Response

![Graph showing In-Ear Headphone Response]

- **SPL (dB re 20μPa)**
- **Frequency [Hz]**
- **Ear Simulator Resonance**
- **Headphone Driver Resonance**
- **Standard 711**
- **HR 711**
Total Harmonic Distortion

\[ THD(\%) = \sqrt{\frac{V_2^2 + V_3^2 + V_4^2 \ldots}{V_1^2}} \times 100 \]

- Frequency [Hz]
- Transfer impedance [dB re 500 Hz]
In-Ear Total Harmonic Distortion

THD [dB re 100%]

Frequency [Hz]

THD Peaks due to Ear Simulator Resonance

- Standard 711
- HR 711
## Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Hz-10 kHz</td>
<td>Transfer Impedance According to IEC 60318-4</td>
</tr>
<tr>
<td>10-20 kHz</td>
<td>Dampened Resonance, with Peak @ 13.5 kHz, +/- 2.2 dB Test Tolerance.</td>
</tr>
<tr>
<td>Volume @500 Hz</td>
<td>1260 mm³, According to IEC 60318-4</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>12.5 mV/Pa</td>
</tr>
<tr>
<td>Form factor</td>
<td>Same as RA0045</td>
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</tbody>
</table>
Take home message

1. You CAN measure high frequency with repeatable results
2. Improved ability to measure total harmonic distortion, Rub’n’Buzz etc.
3. Lower deviation from coupler to coupler due to tighter tolerances
4. Minimized operator error & improved accuracy
5. Improved repeatability
6. Backwards compatible with IEC60318-4 measurements
New low noise ear simulator
Standard IEC 60318-4 Ear simulator

- Also known as 711 coupler
- Designed almost 40 years ago
- Most complex ear simulator on the market
- Designed to mimic the transfer impedance of an average human ear
- Often used with pinna

- Built-in WS2P ½” microphone:
  - Sensitivity of 12.5 mV/Pa
  - Frequency range 100Hz–10kHz (16kHz)
  - **Noise floor at 25 dB(A)**
  - Maximum SPL ≈ 164 dB

Designed in late 1970s by Gunnar Rasmussen
Better data for very low level testing

- The new ear coupler allow testing the “noise floor” of the headphone
  - Noise generated by electrical circuits
    - Active Noise Cancellation and Bluetooth headsets tend to have a “hiss” in quiet surroundings
    - This “hiss” can be detected via subjective testing
    - This phenomenon could not be measured in the past
  - Noise generated by the driver itself
    - Rub&Buzz measurements in mounted speaker units
Low noise ear simulator

- High sensitivity, low noise microphone plus ear simulator
  - 800 mV/Pa sensitivity
  - Noise floor at <10 dB(A)
  - Same impedance up to 10 kHz as IEC 60318-4
  - Maximum SPL ≈ 113 dB
Transfer impedance comparison

- Similar frequency response up to 10 kHz
- Differences above 10 kHz due to changed impedance of microphone diaphragm
Hearing threshold vs. noise floor of test equipment

- Standard 711 ear simulator
- “Sensitivity” of the human ear
- New ear simulator
Measurement example with low noise ear simulator

- Active Noise Cancellation headphones
  - Measured with new low noise ear coupler
  - Simulator mounted in KEMAR mannequin
  - Measurements conducted in anechoic room
Hearing threshold vs. noise floor of test equipment

Now we can measure what you can hear!
New Anthropometric Pinna and Ear Canal
Anthropometric Pinna and Ear Canal

- **Standard Pinna**
  - Cylindrical or conical ear canal
  - Developed for hearing aids

- **Anthropometric Pinna**
  - Based on 260 3D scans of human ear canals
  - Includes 1st bend and all the way to the 2nd bend of ear canal
  - Oval ear entrance point
  - Shaped to fit IEC60318-4 ear simulator
  - Realistic fit for in-ear as well as over and around the ear products.
Measurements with In-ear headphone

- Angle of IE headphone advantageous when mounted in human ear
- Difficult to mount in standard pinna gives poor repeatability
- New anthropometric pinna adapt to the angled IE headphones
Better repeatability

- Fewer and better measurements
- More reliable data
- Leaks destroy measurements below 1kHz
  - Better measurements on ANC circuits
    - ANC is predominantly active below 1 kHz
  - Better data on Rub & Buzz measurements
- Reduce cost and time spent on test
- Meets the need in the industry for realistic testing
IE headphone on Standard Pinna with conical ear canal

- Same IE headphone mounted repeatedly 20 times on same test setup
- Difficult to get repeatable seal resulting in leakage
- Spread at high frequencies due to difference in insertion depth
IE headphone measured on Antropometric Pinna

- Same IE headphone mounted repeatedly 20 times on same test setup
- Improved repeatability at low frequencies
- Smaller spread at high frequencies
Better low frequency results also for SA headphones

- Fewer and better measurements
- More reliable data
- Leaks destroy measurements below 1kHz
  - Better measurements on ANC circuits
  - ANC is predominantly active below 1 kHz
  - Better data on Rub & Buzz measurements
- Reduce cost and time spent on test
- Meets the need in the industry for realistic testing
Low Frequency response and leaks

• Supra-aural headphones tested on KEMAR

KB0065: Standard pinna, concha & canal

KB5000: New pinna, concha & canal
Summary

• High resolution Ear Simulator
  • Can measure high frequencies with repeatable results
  • Lower deviation from coupler to coupler due to tighter tolerances
  • Improved ability to measure total harmonic distortion
  • Frequency response within IEC 60318-4 limits

• Low Noise Ear Simulator
  • Can measure at or below human hearing threshold
  • Enable you to measure the noise of today's advanced headphones
  • Frequency response within IEC 60318-4 limits

• The Anthropometric Pinna
  • Has shown huge benefits in fit and seal for IE products
  • Has shown benefits in fit and seal for both SA and CA products
Solutions available

- Low noise Ear & Cheek simulator
- 45BB/45BC Full KEMAR Manikin solution
- Stand-alone Low noise Ear simulator system
- KB5000/KB5001 New Pinna
Take home message

• We will not tell you what your product should sound like
• These devices will not replace human ear

HOWEVER:
• They are the best tools available on the market
• They will speed up your R&D process
• They will give you more insight into the acoustic behavior of your device
• They will improve acoustic test correlation with subjective feedback
Questions?