Seminar on:

- Measurement microphones
- Ear simulators
- Headphone testing
- Next generation headphone testing

Presenter:

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

Microphone Theory & Selection

ALMA 2017

We make microphones

Measurement microphones

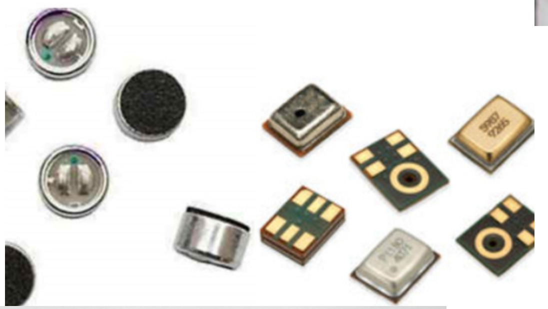
- Introduction
- The condenser microphone
- Design parameters
- The microphone in the sound field
- Dynamic range and sensitivity
- Frequency response
- Polarization
- Conclusion

Microphone types

- Studio microphones
  - Subjective impression
  - Design

- Communication microphones
  - Price
  - Failure rate

- Measurement microphones
  - Precision
  - Reliability
  - Robustness



Measurement Microphone

- Dynamic Pressure measurements in air
- Very accurate and stable
- Can be calibrated
- IEC standardadized

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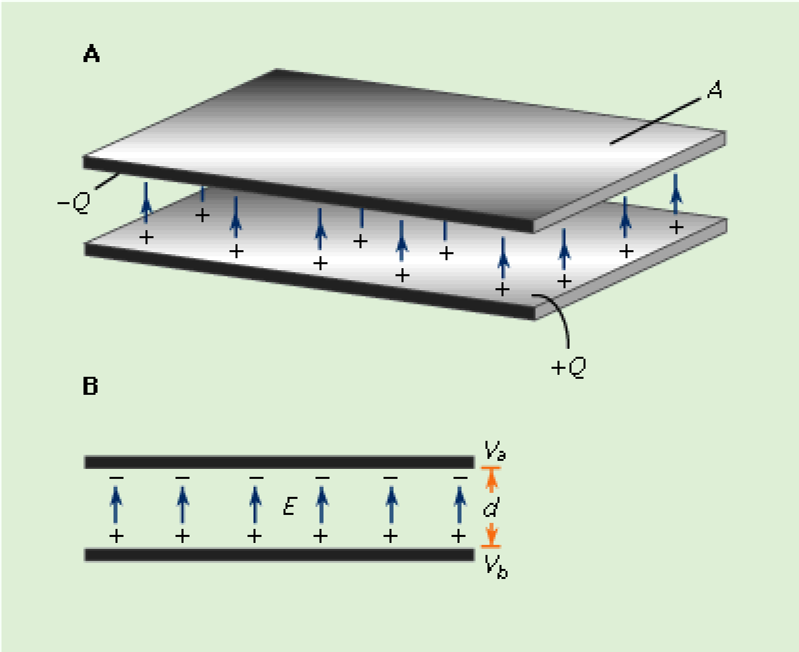
Plate capacitor

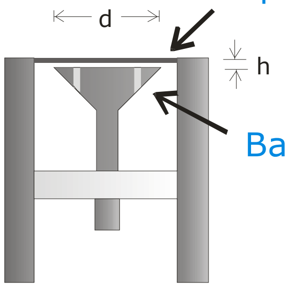


$$C = \frac{\varepsilon_0 A}{d}$$

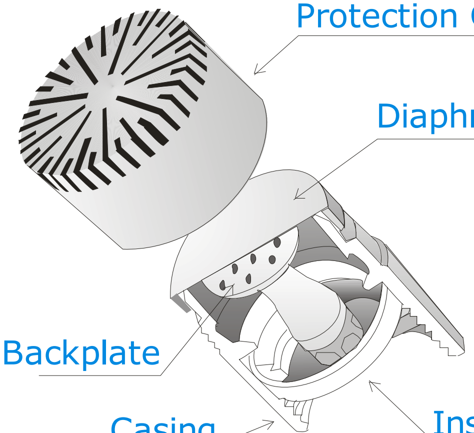
$$V = \frac{Q}{C}$$

Microphone Principle

- Microphone construction
- Condenser type



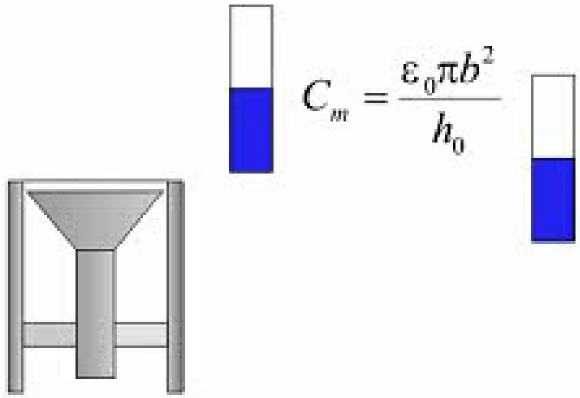
(A)



(B)

Microphone principle

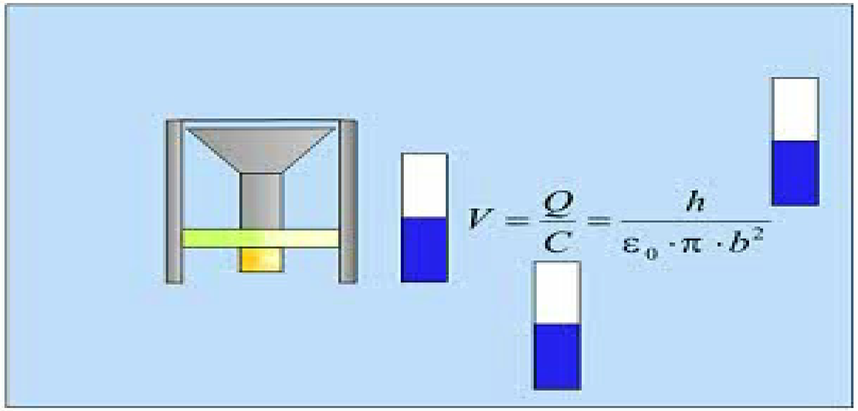
- Microphone capacity



$$C_m = \frac{\varepsilon_0 \pi b^2}{h_0}$$

Microphone Output

- Constant charge Q



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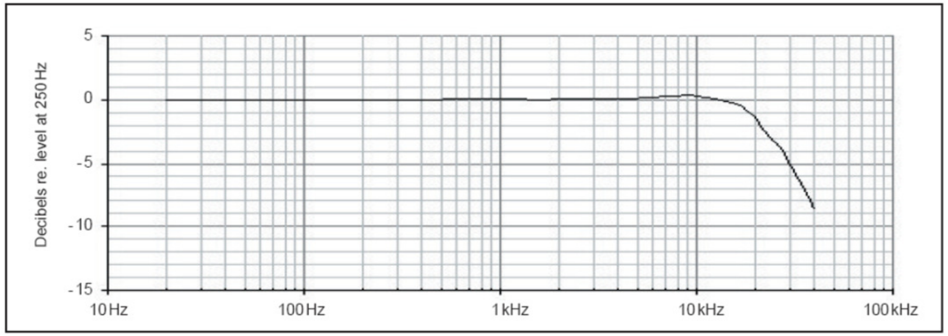
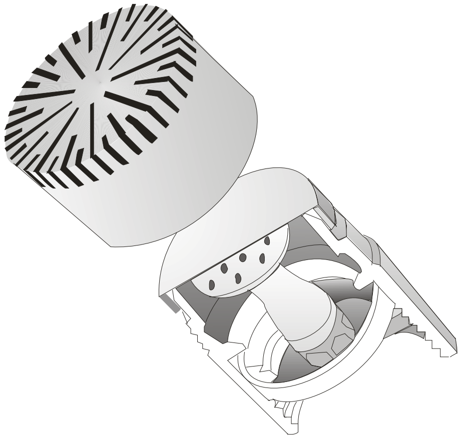
Design parameters

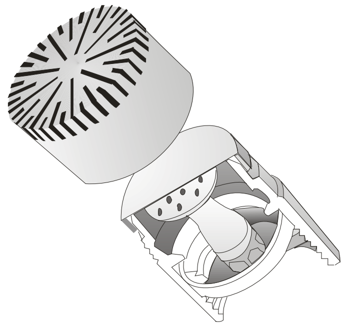
- Frequency range
- Frequency response
- Sensitivity
- Dynamic range



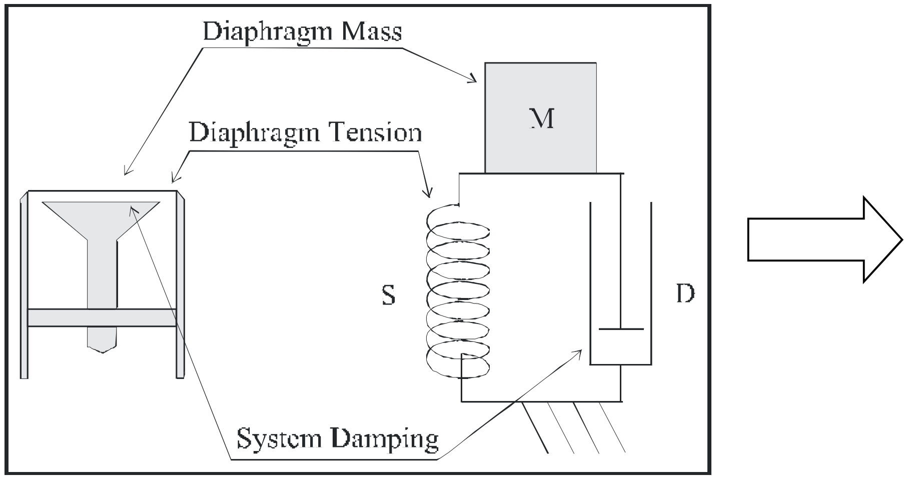


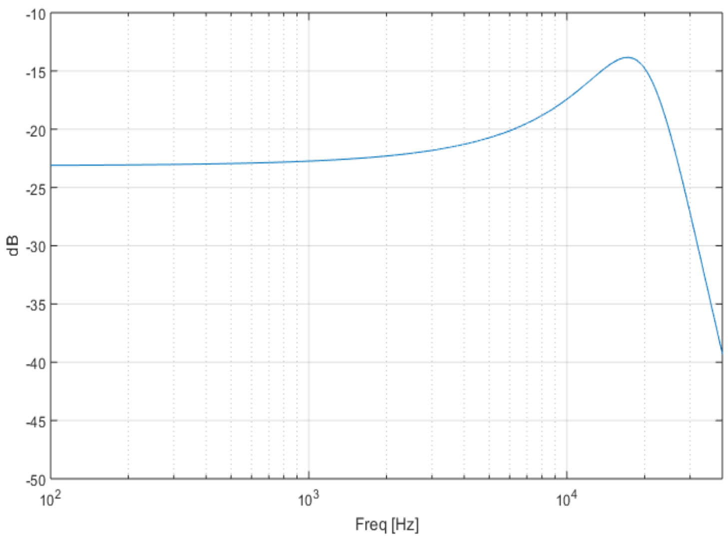
- Size
- Diaphragm
- Tension
- Distance to back plate
- Back plate hole pattern
- Internal Volume

Design parameters



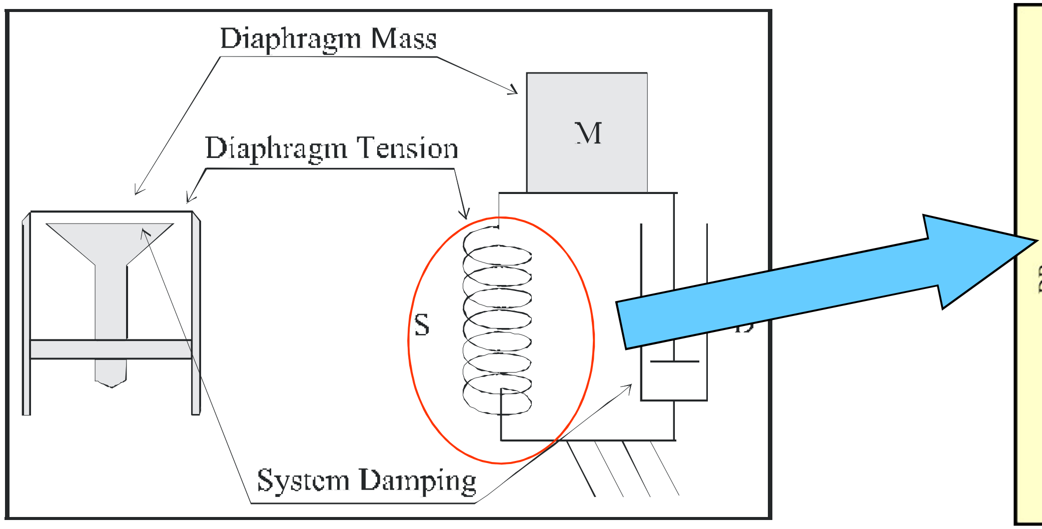
- Mechanical Equivalent
  - Mass = Size, Diaphragm
  - Spring = Tension
  - Damping = Distance to back plate, hole pattern and internal volume

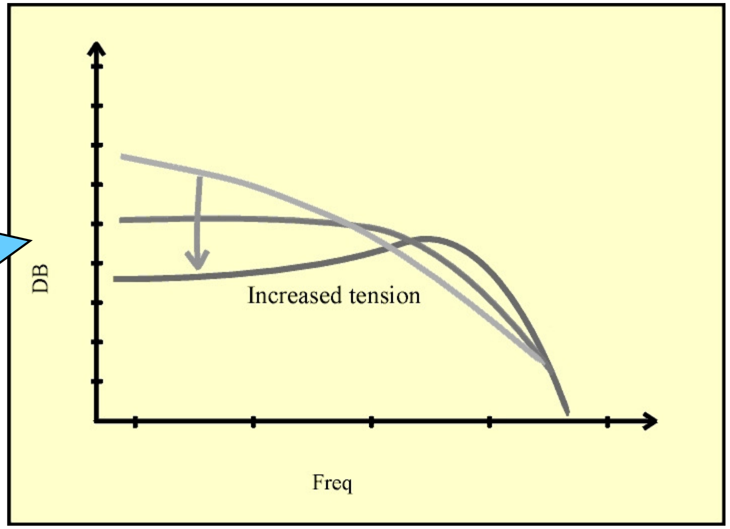




Design parameters

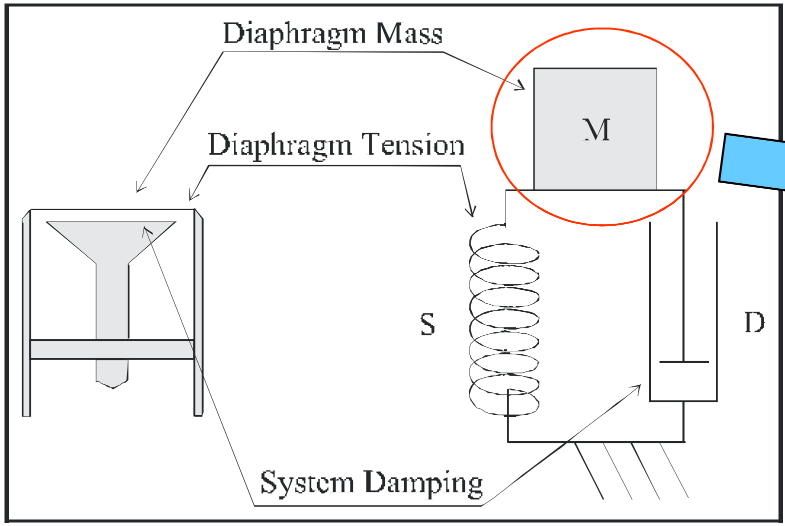
- Influence of diaphragm tension

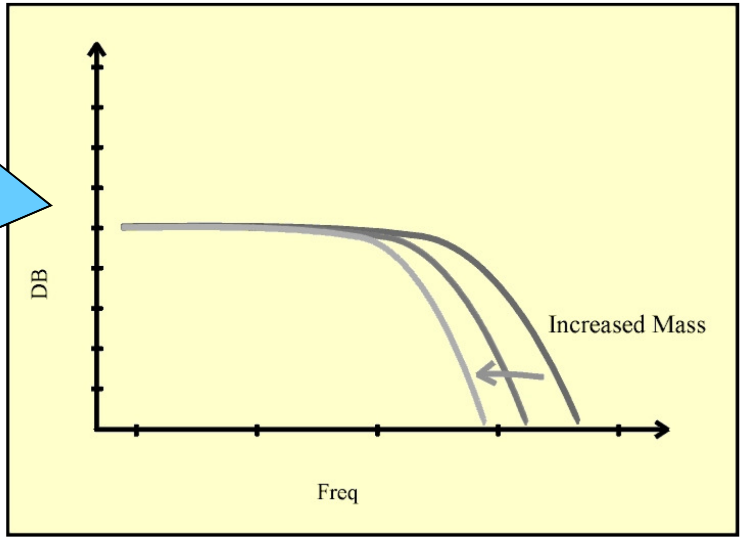




Design parameters

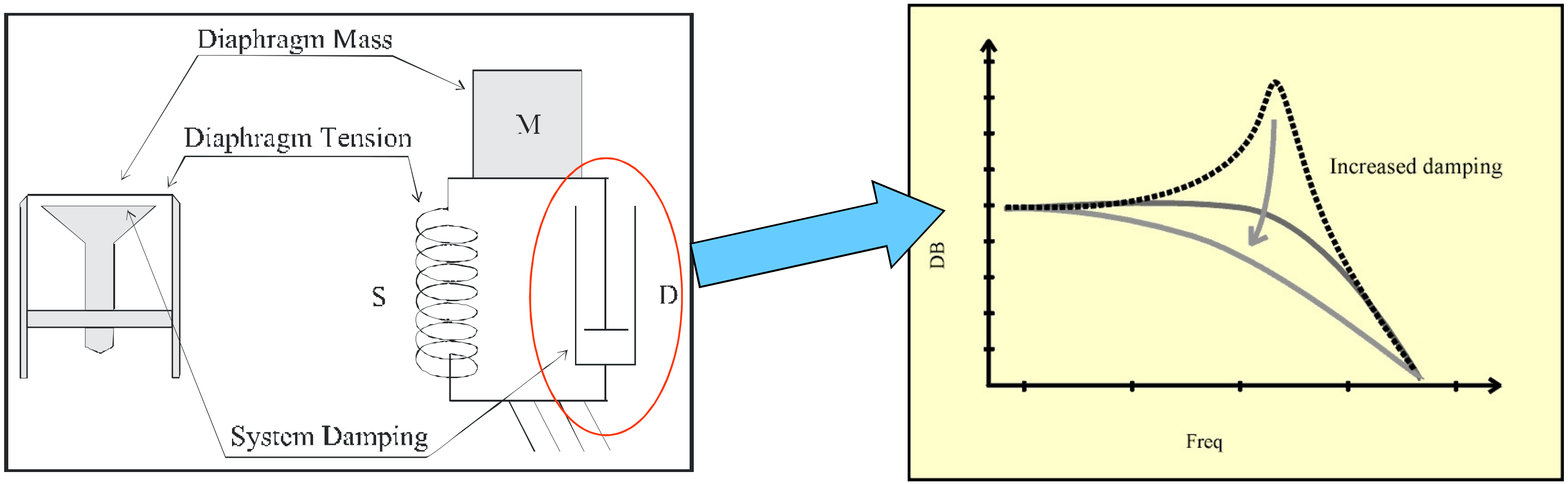
- Influence of diaphragm mass





Design parameters

- Influence of damping



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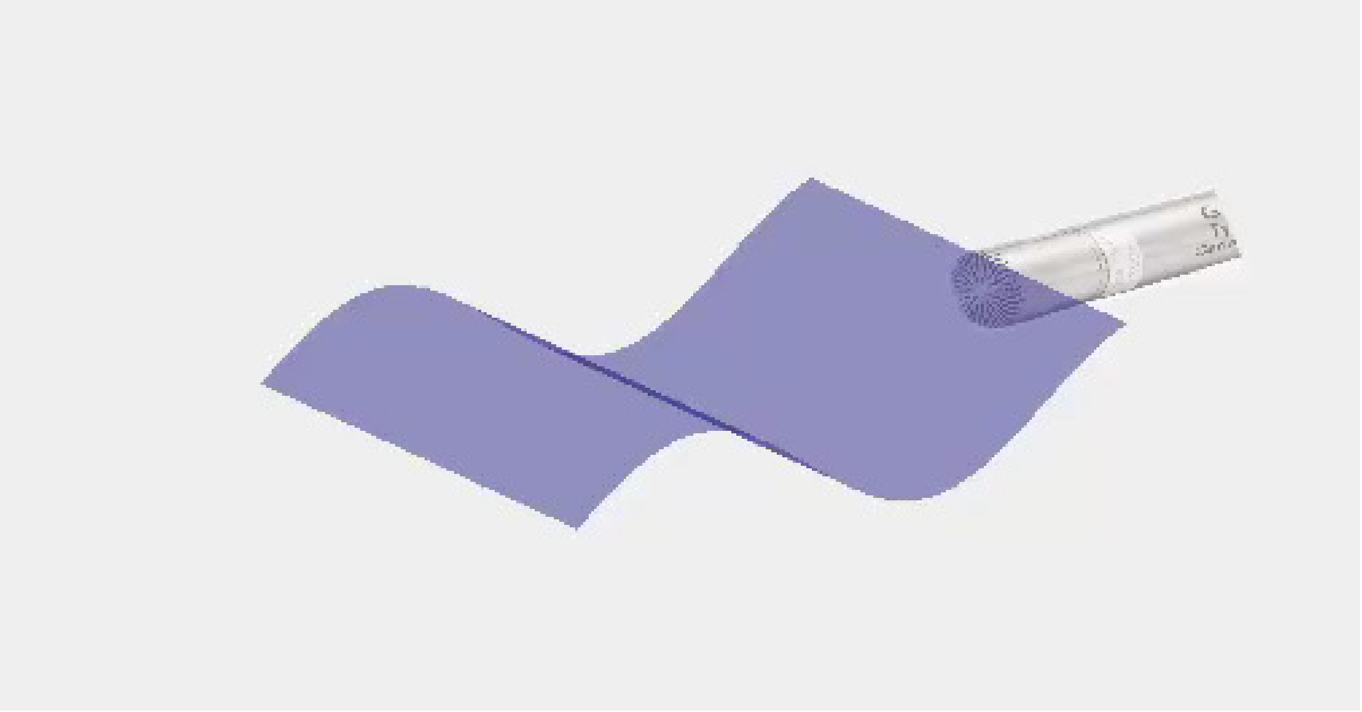
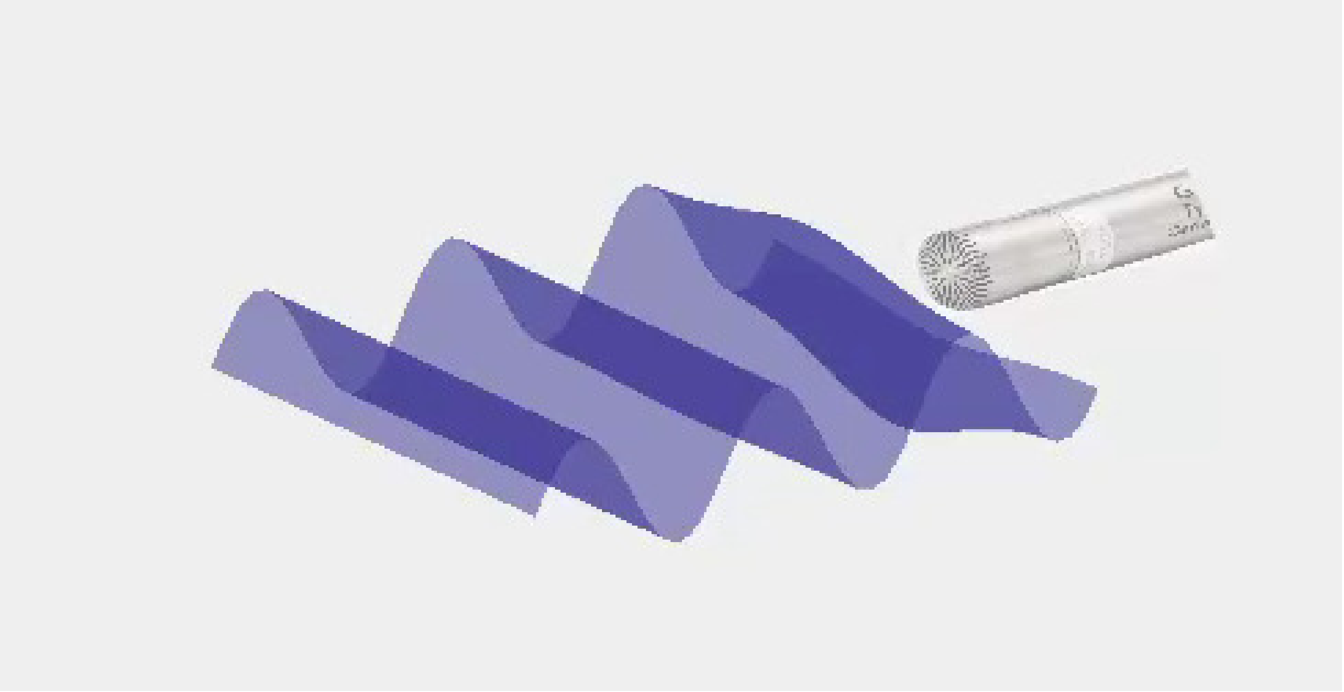
Microphone no diffraction

Low frequency:



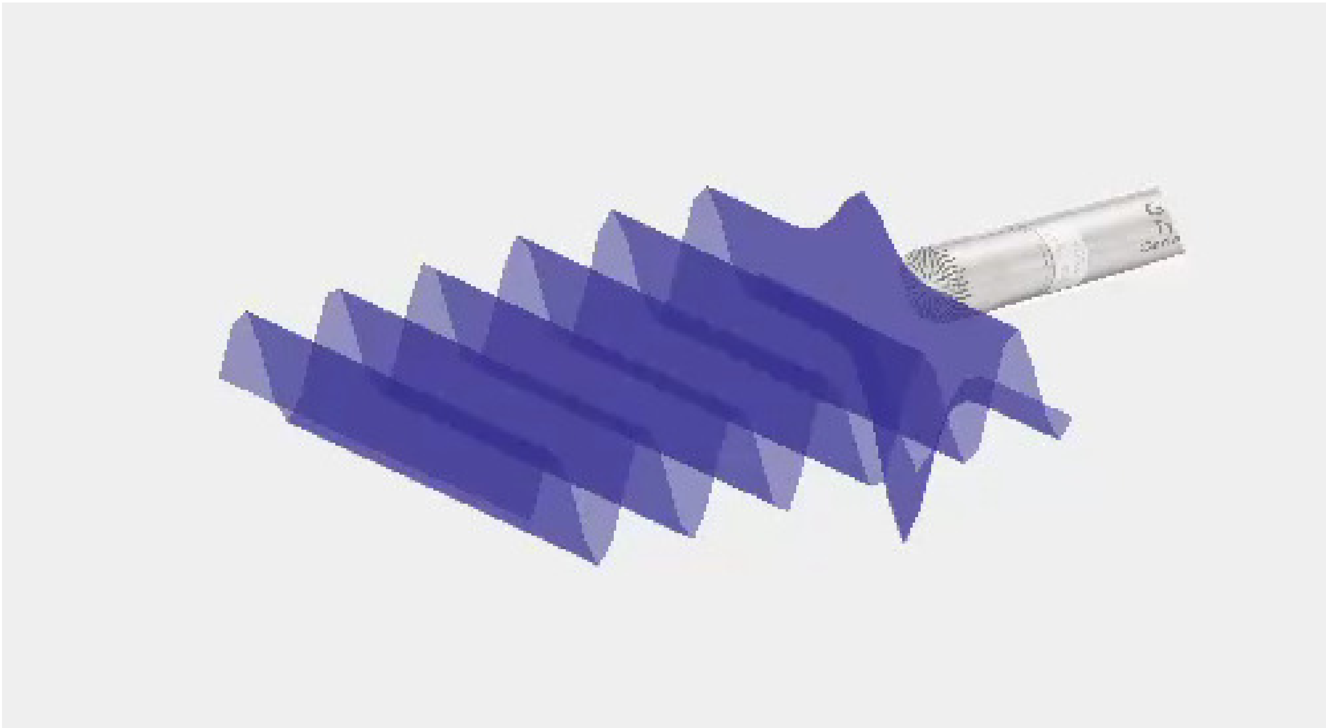
Microphone diffraction

Mid frequency:



Microphone diffraction

High frequency:



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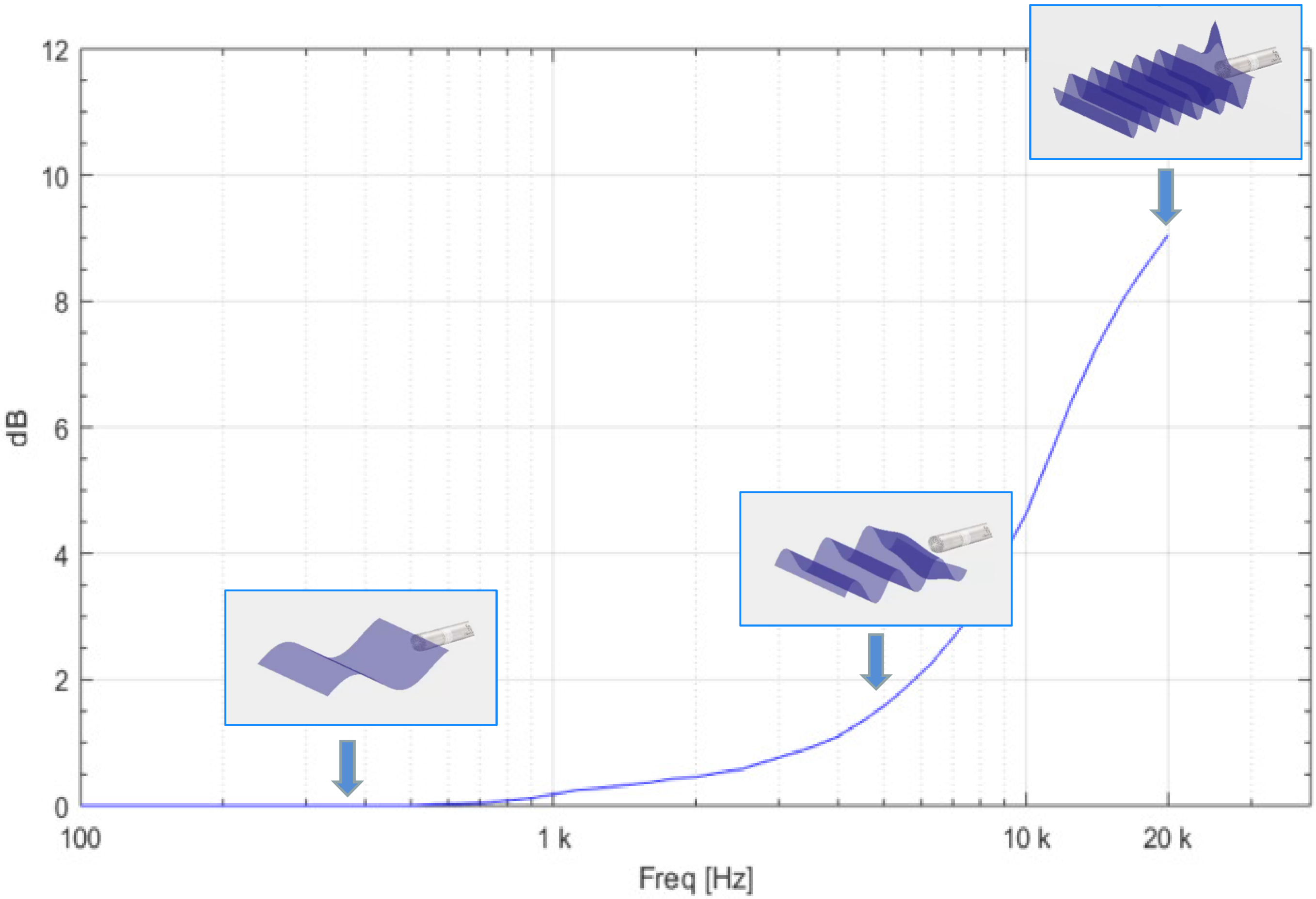
Pressure increase due to diffraction



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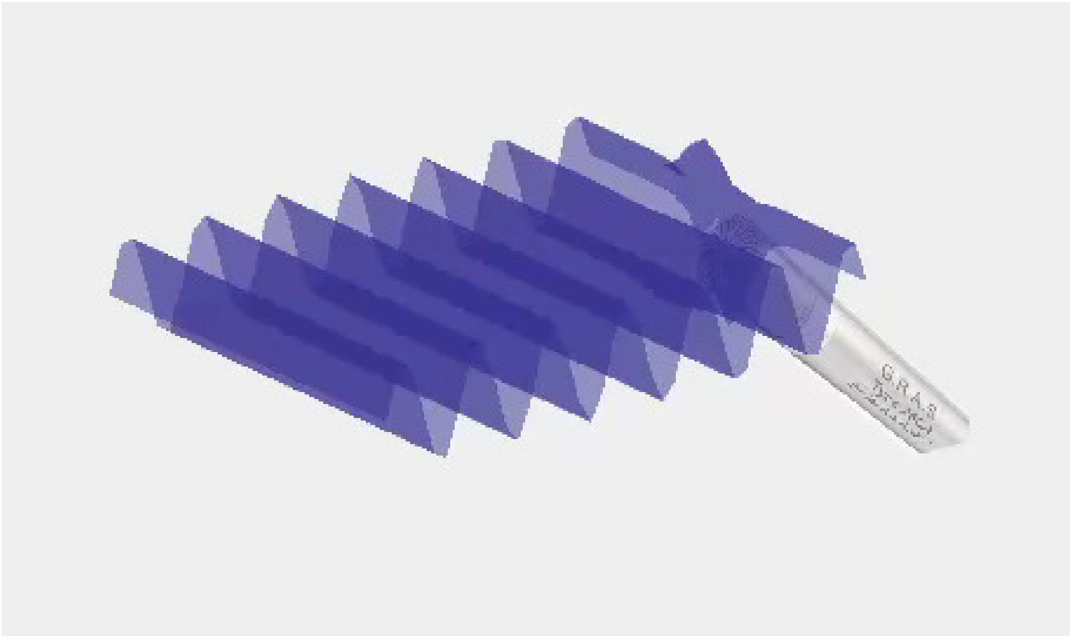
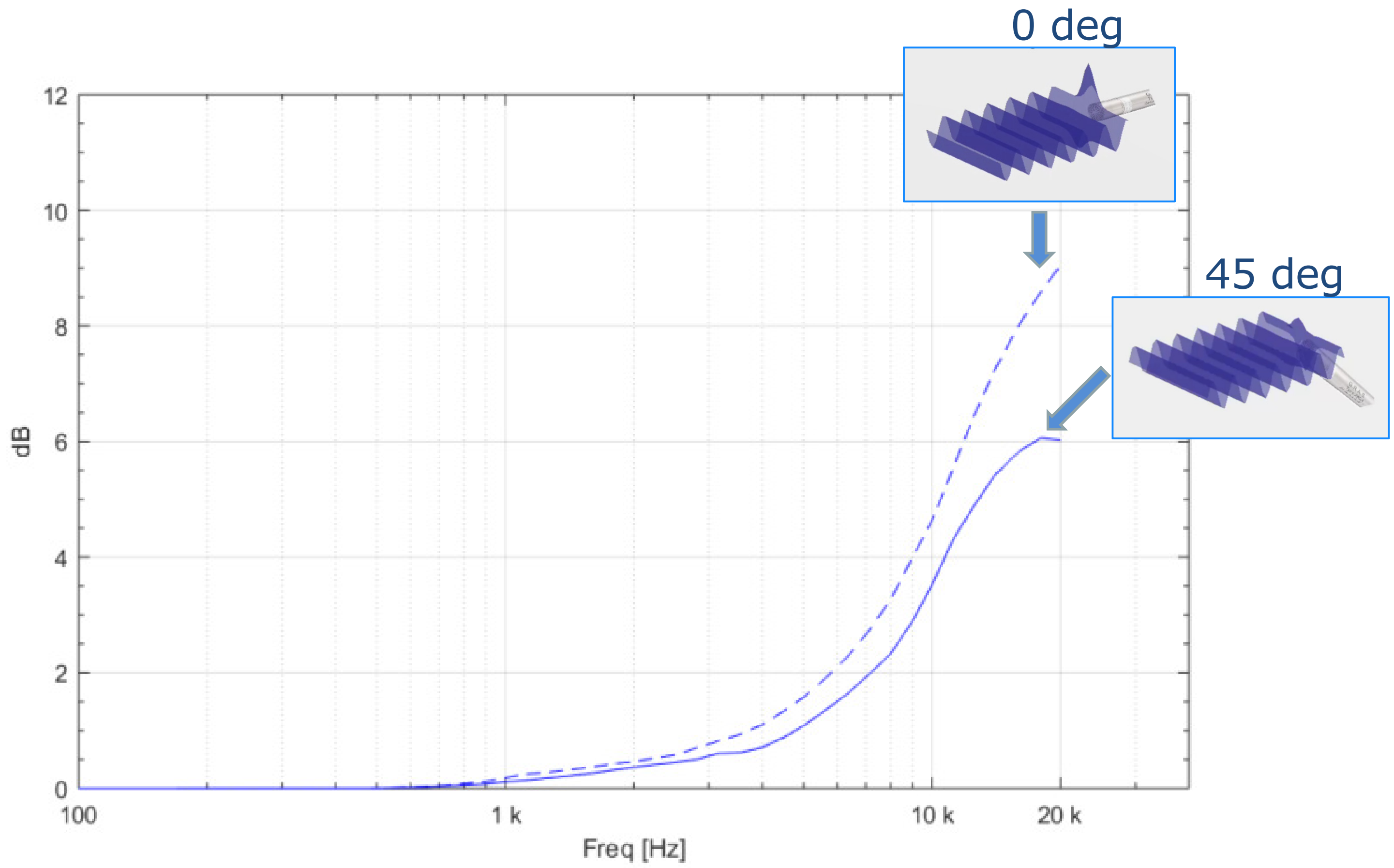
Microphone diffraction

High frequency, 45 deg incidence:

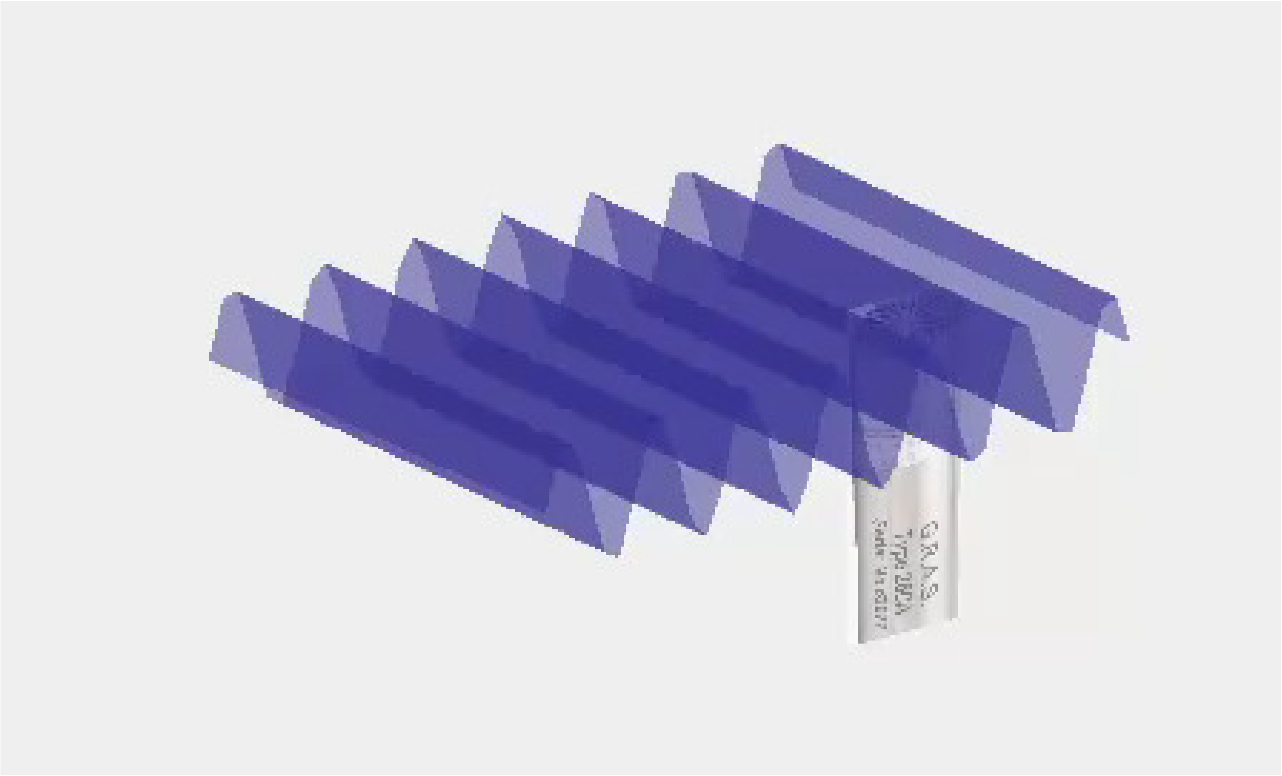


Pressure increase due to diffraction

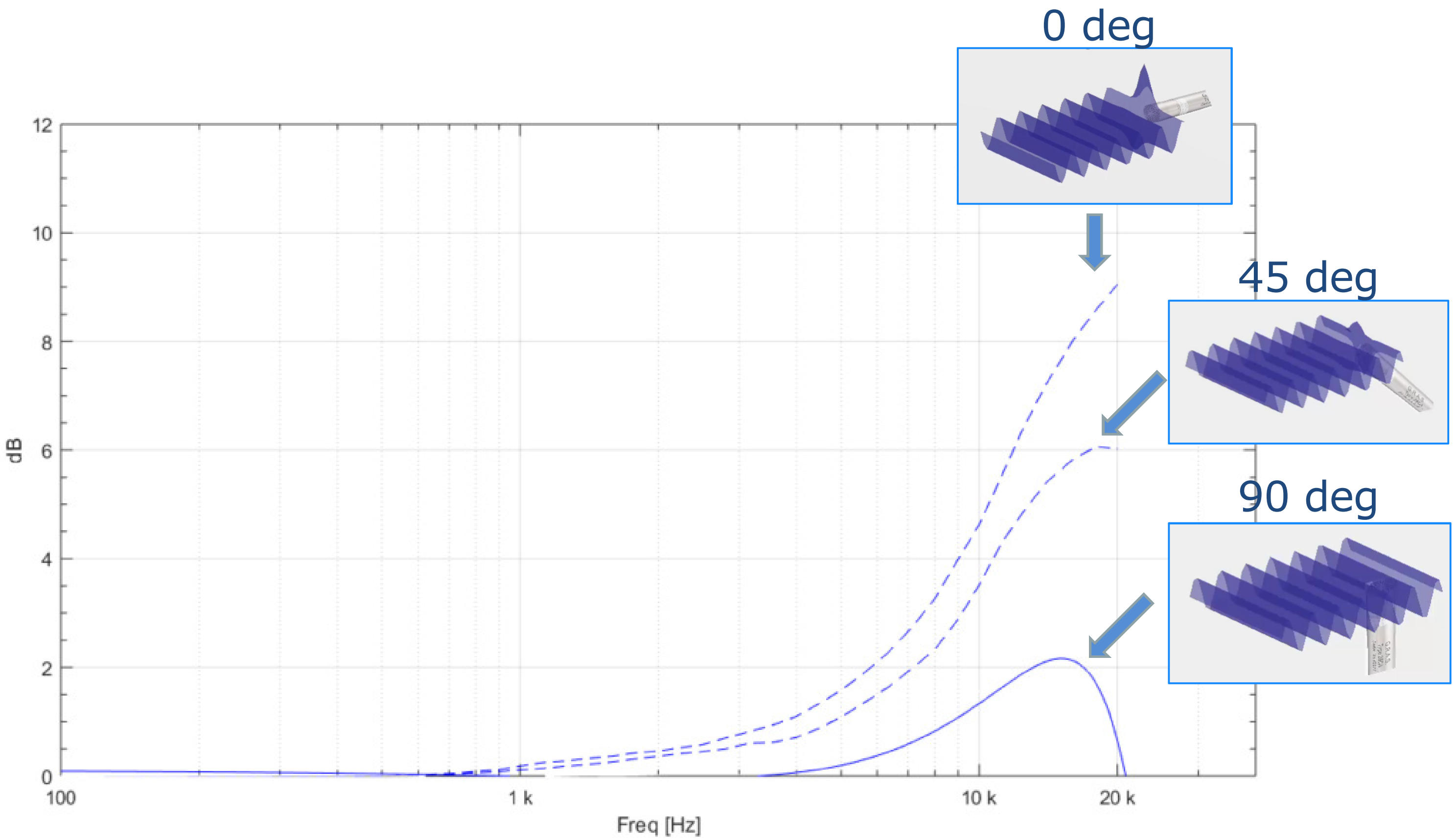


Microphone diffraction 90 deg

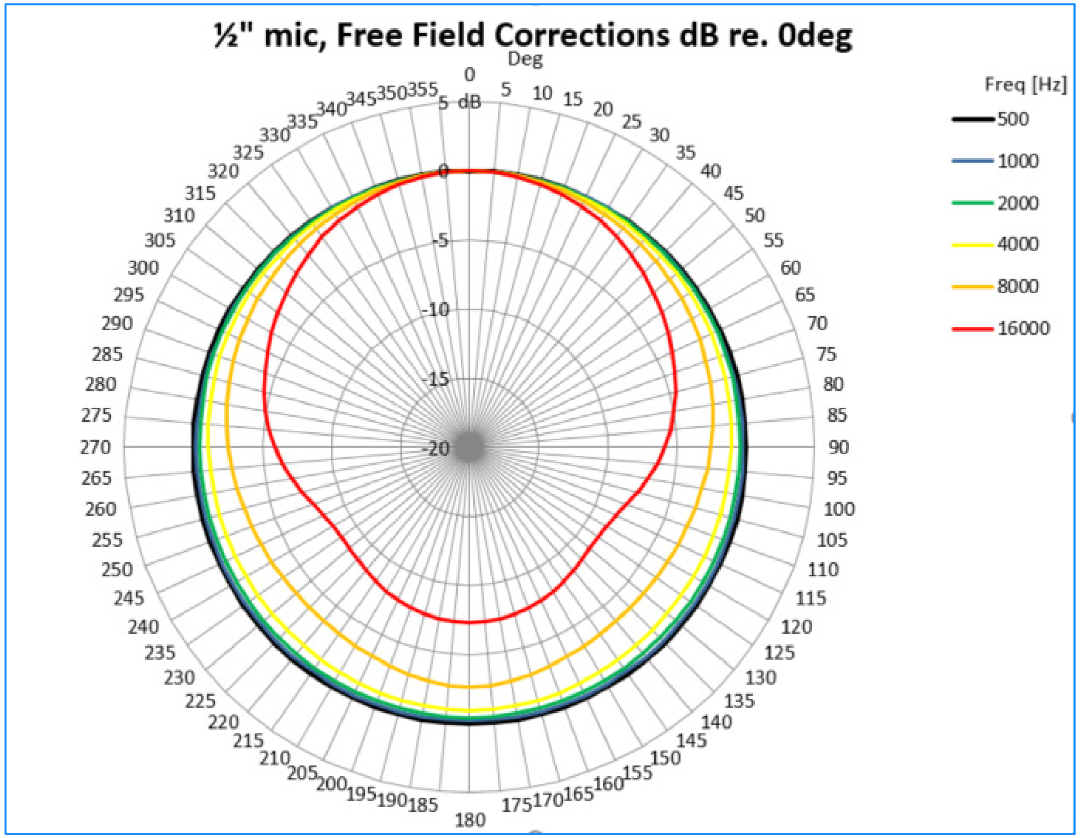
High frequency:



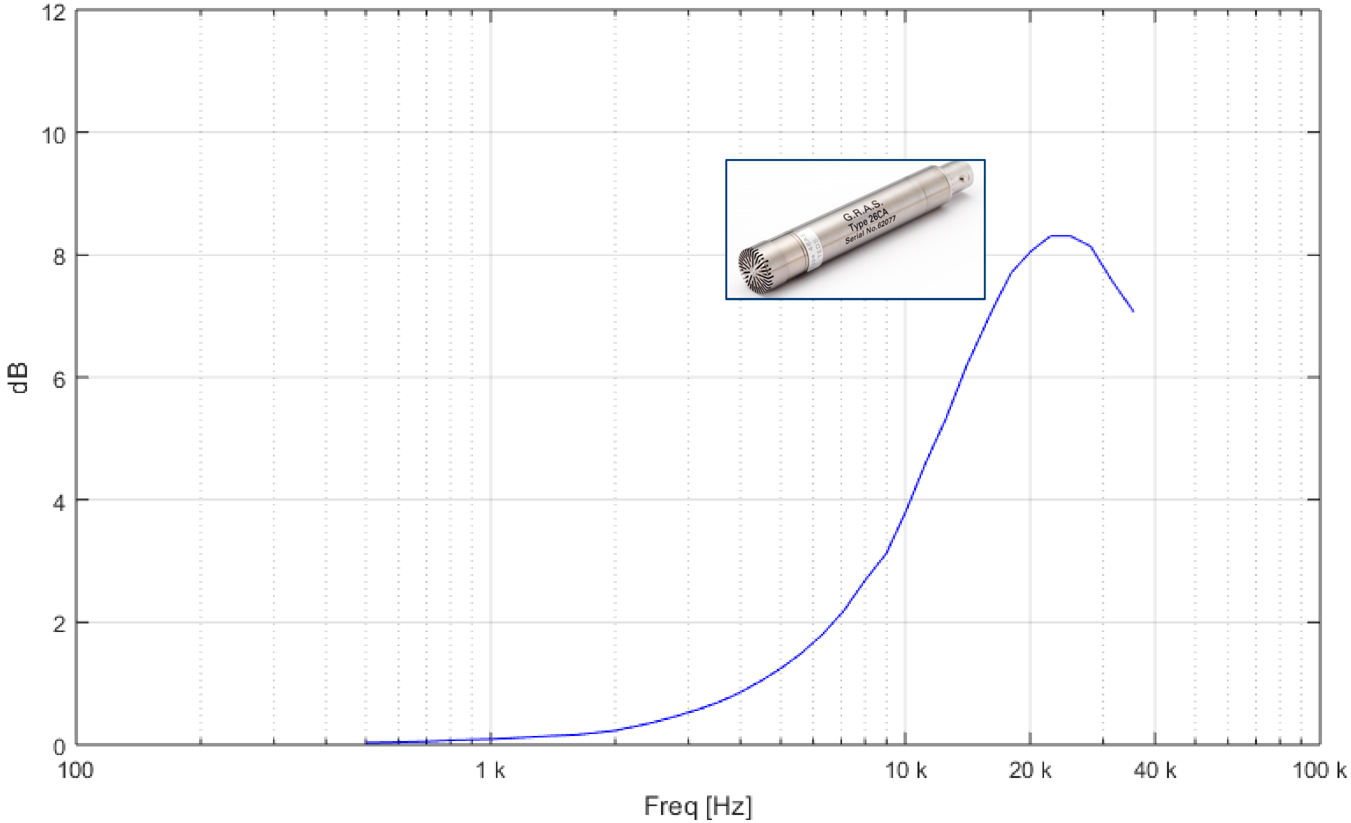
Pressure increase due to diffraction



Directionality



Diffraction for different sizes



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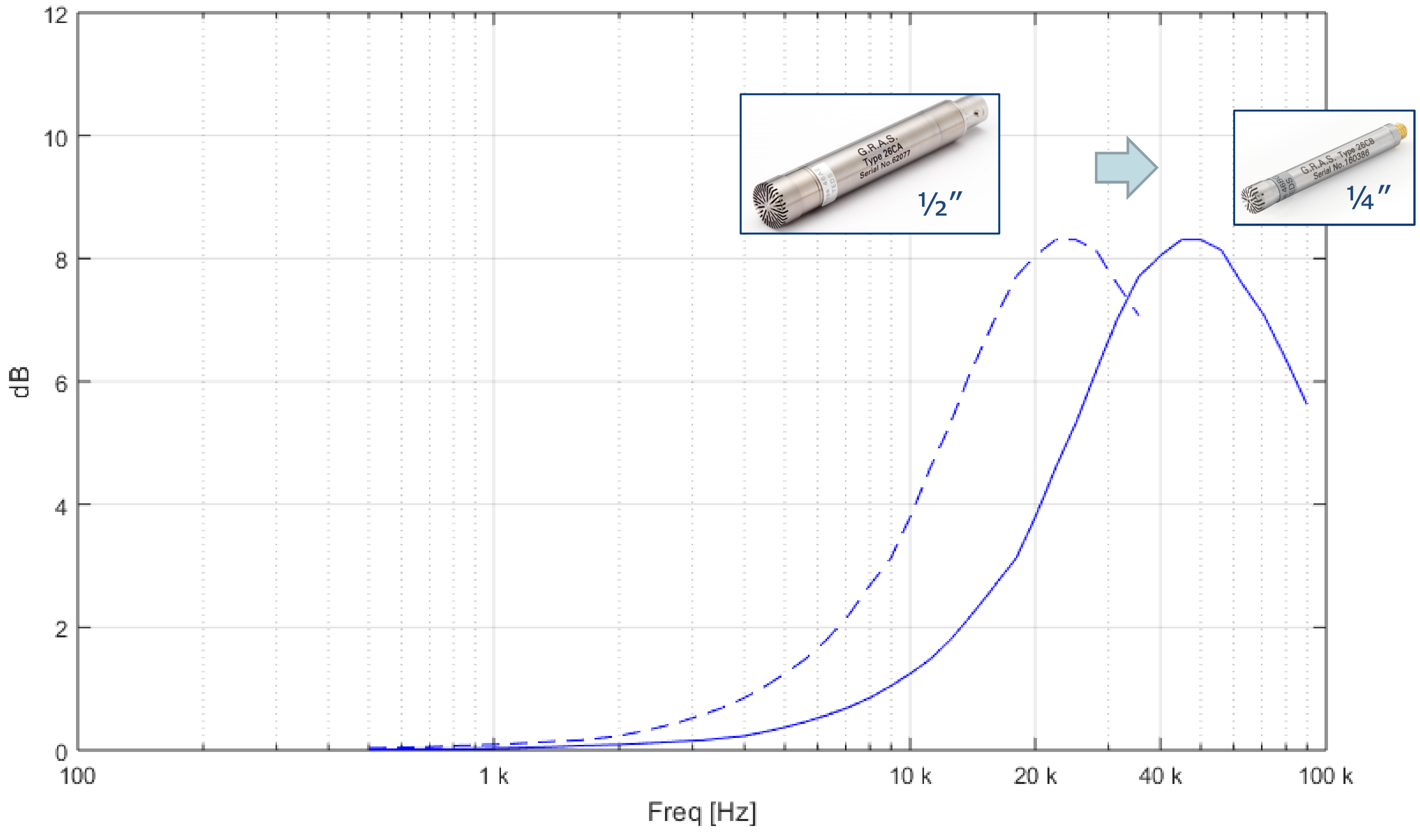
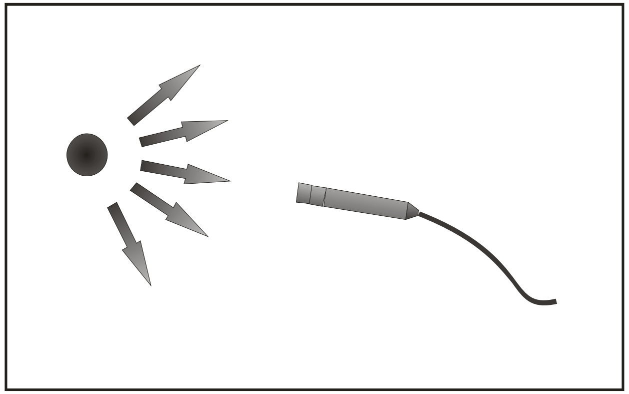
Diffraction for different sizes



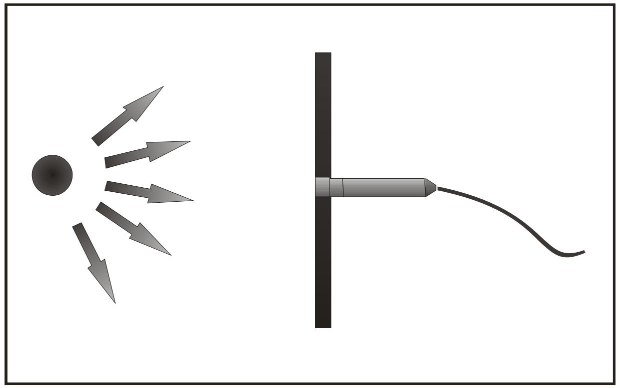
We make microphones

Types of Microphones

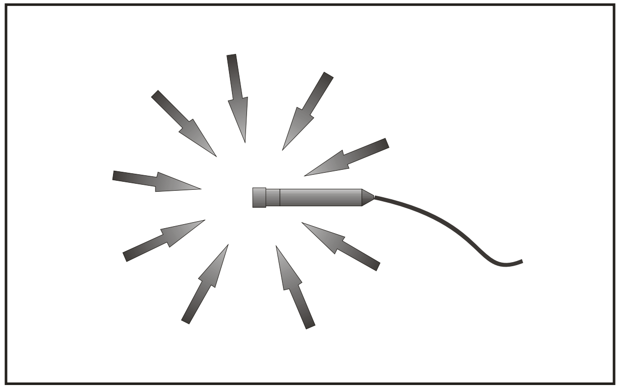
Free field microphone



Pressure microphone



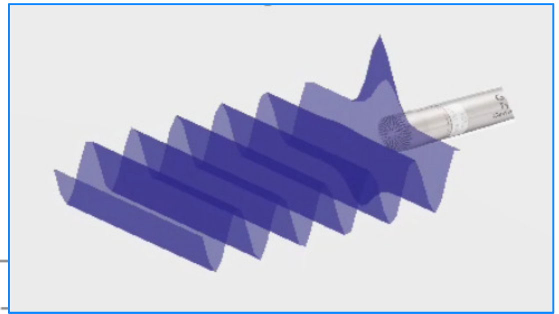
Random microphone

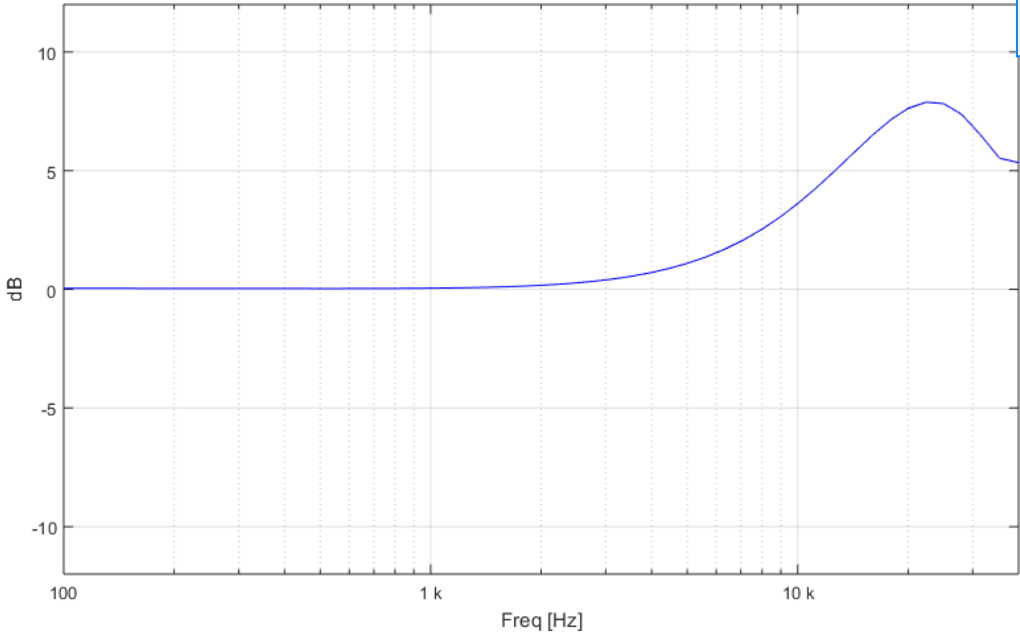


We make microphones

Frequency response of free field microphone

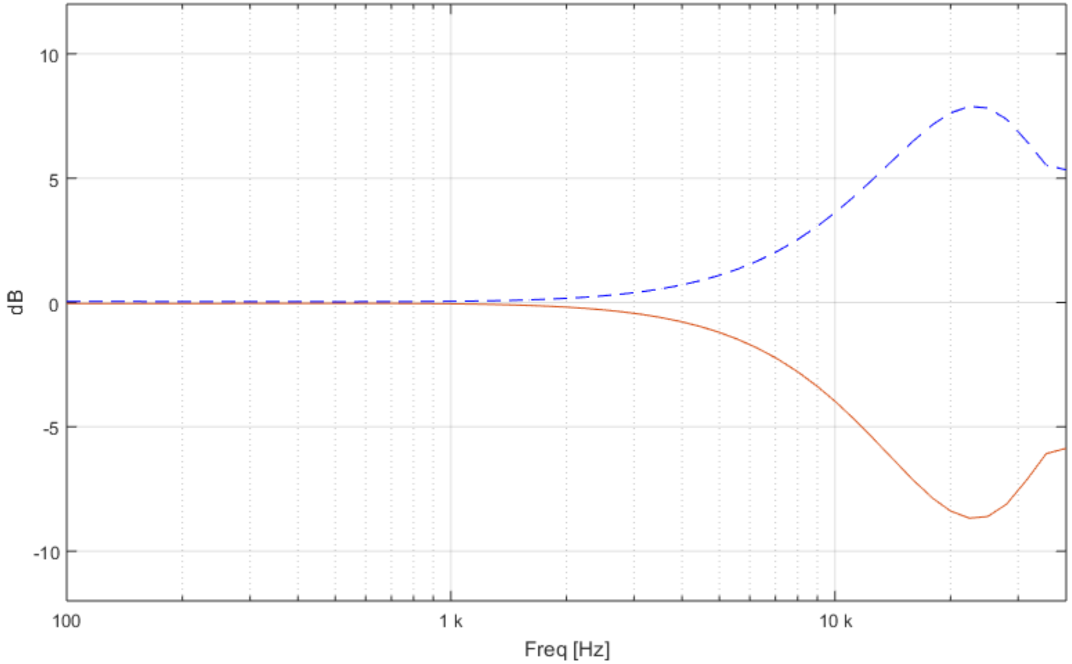
- Free-field diffraction pressure increase





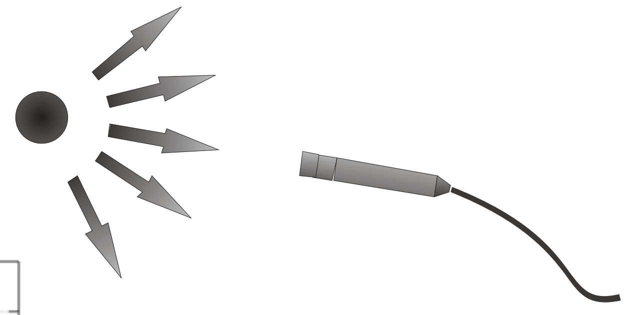
Frequency response of free field mic

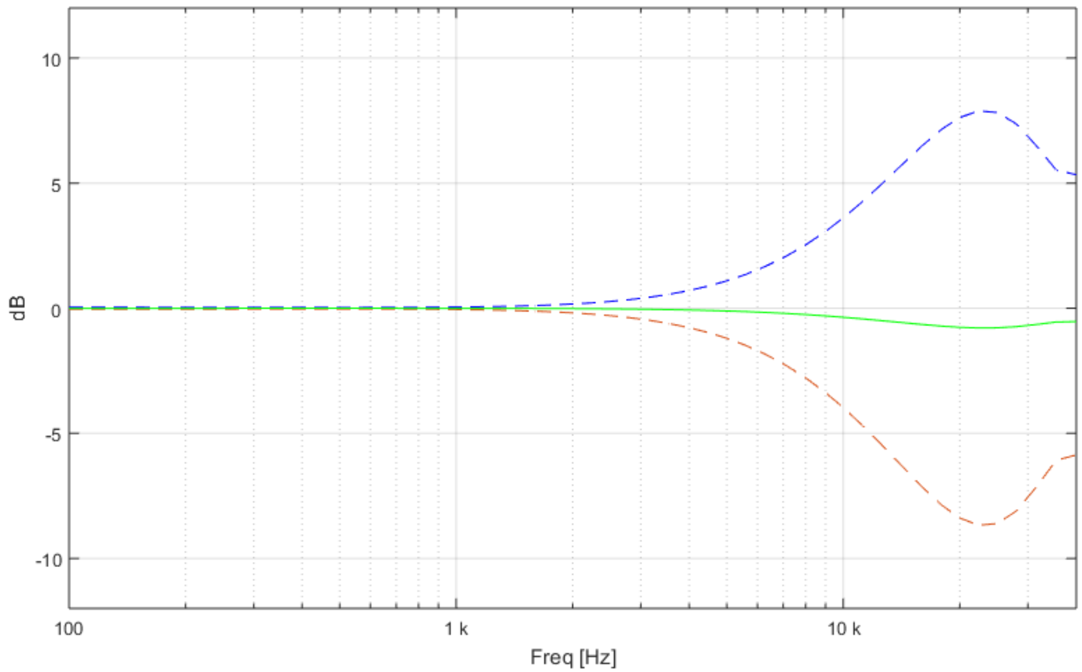
- Pressure response of microphone



Frequency response of free field mic

- Resulting free field response

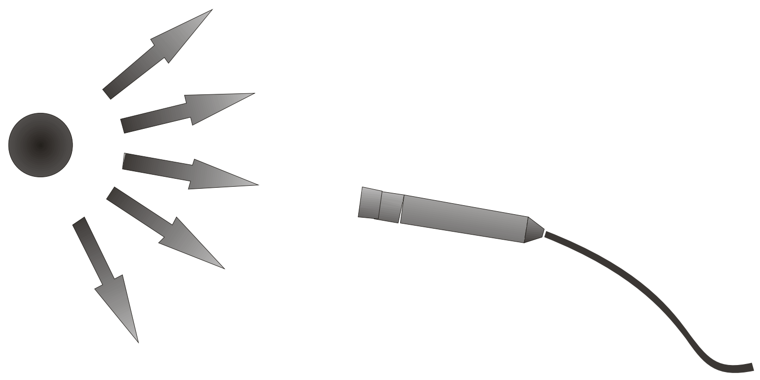




We make microphones

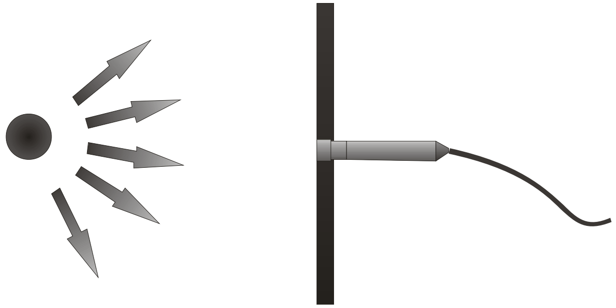
Free-Field Microphone

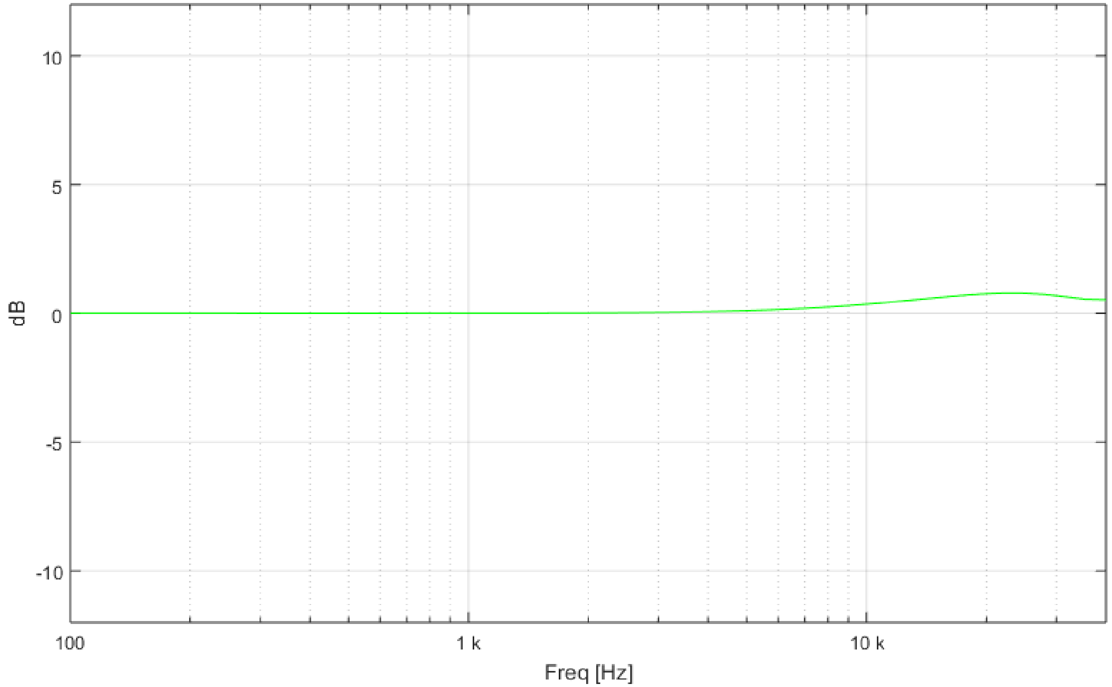
- Well defined noise source position
- ISO standards
- Sound level meters
- Sound power measurements
- Default type



Frequency response of Pressure microphone

- Pressure response

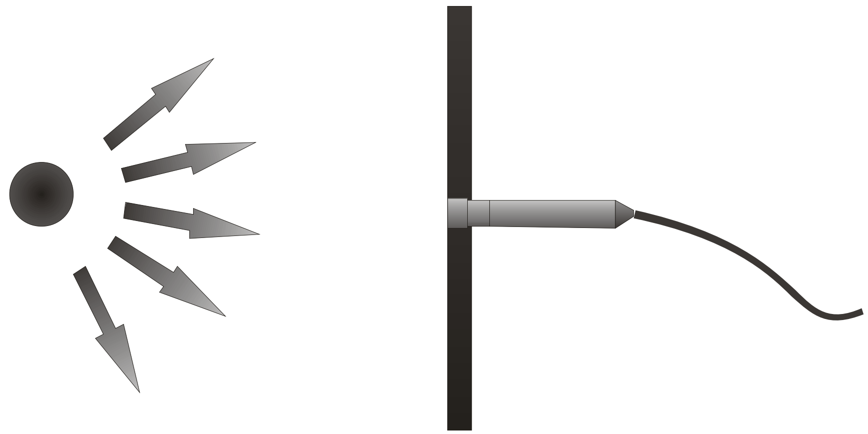




We make microphones

Pressure Microphone

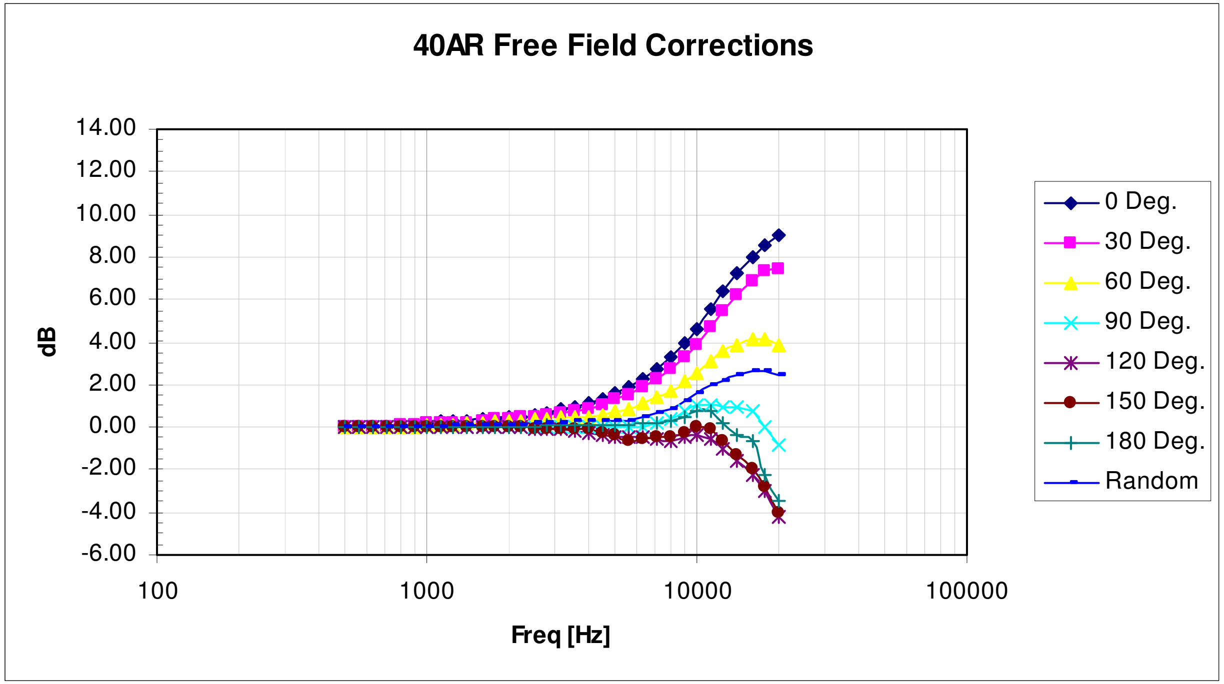
- Coupler measurements
- Binaural recording
- Surface or boundaries

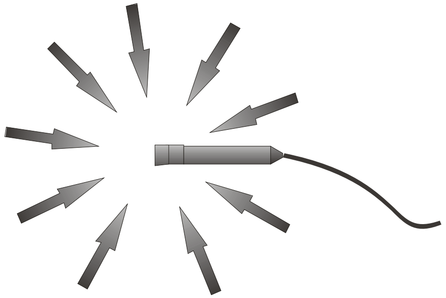


(a) APF LHS microphones

We make microphones

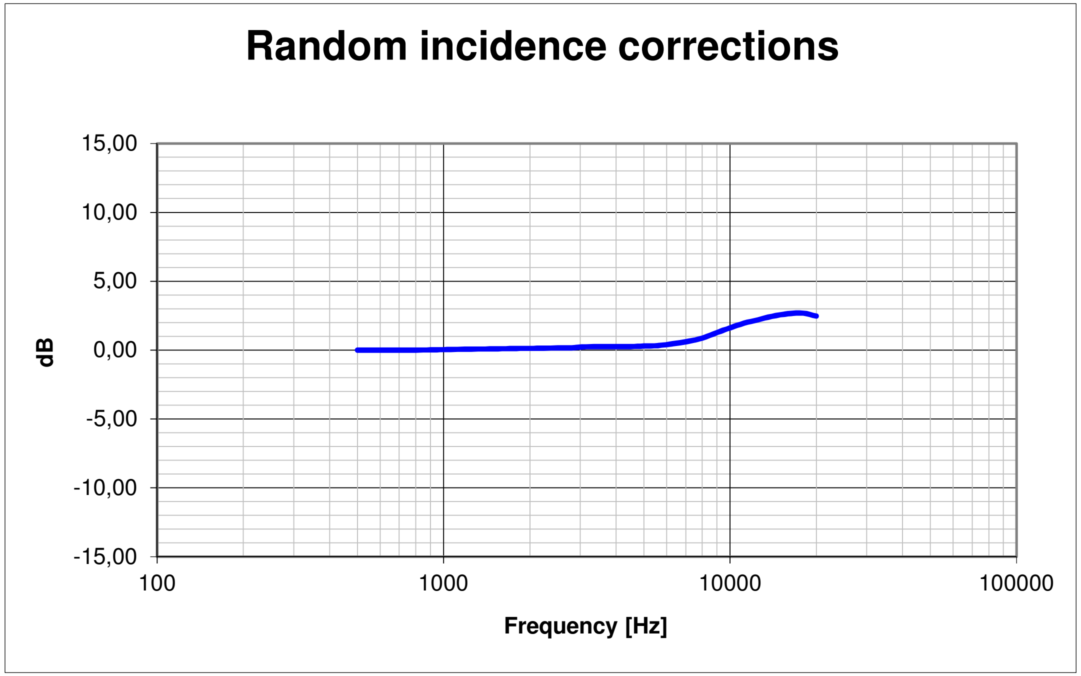
Frequency Response of Random Microphone

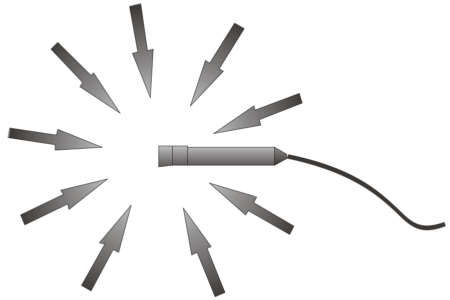




We make microphones

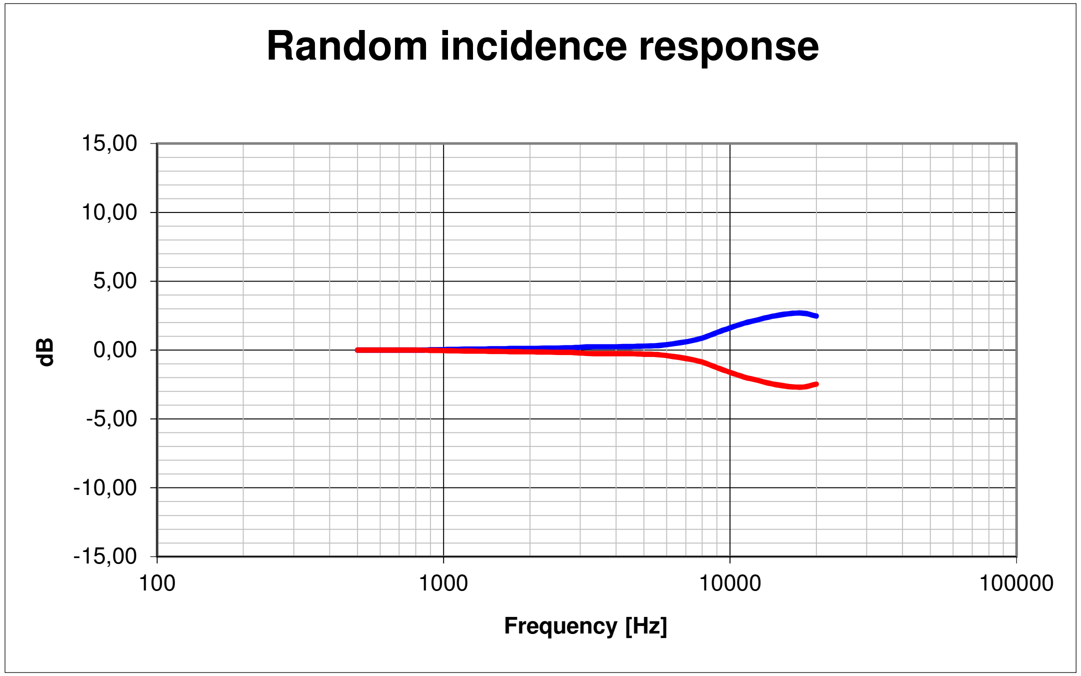
Frequency response of Random mic

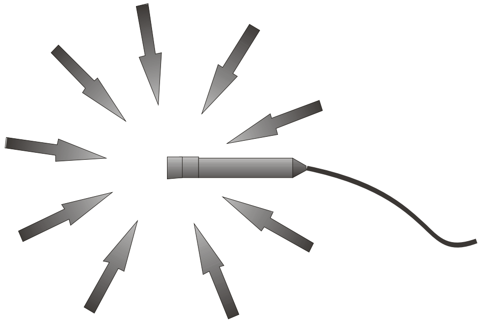




We make microphones

Frequency response of Random mic





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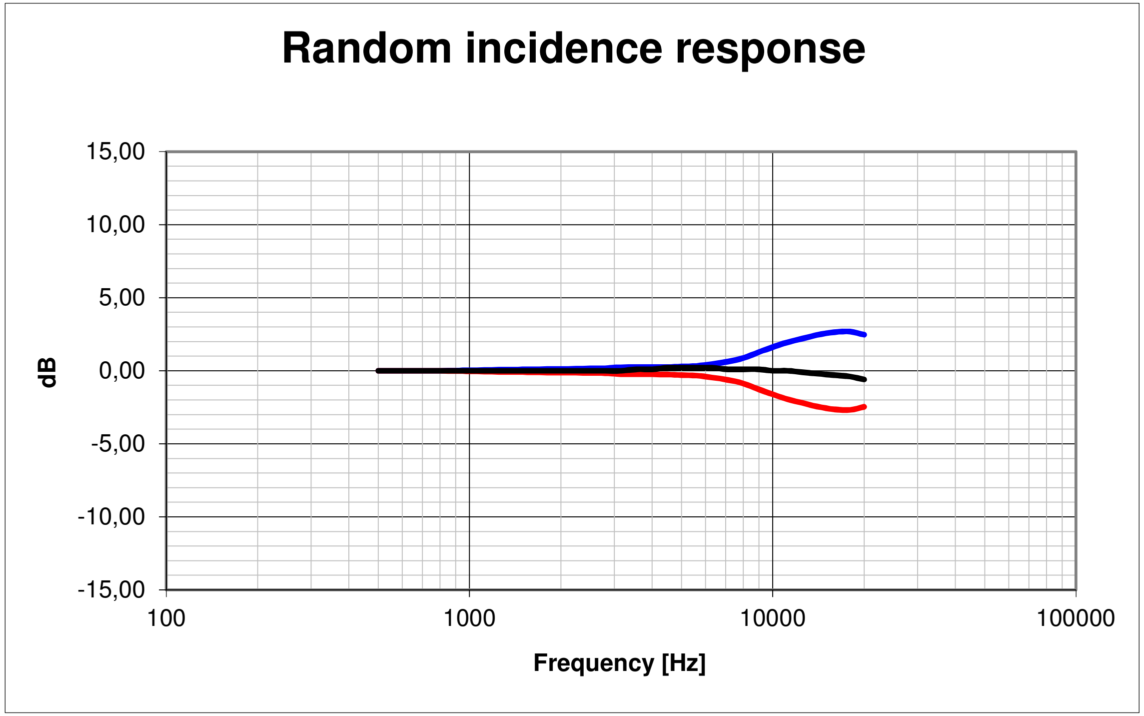
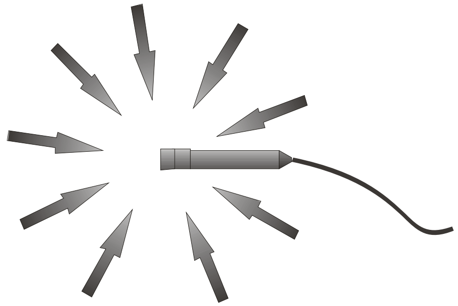
Frequency response of Random mic

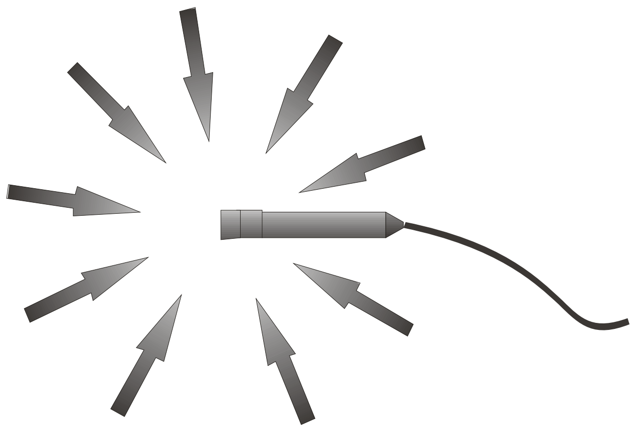




We make microphones

Random Incidence Microphone

- ANSI Standard
- Used where it is difficult to determine sound source
- Reverberant conditions



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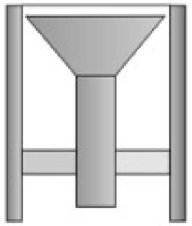
Dynamic Range for a Microphone

- Dynamic range:
  - The difference between the highest Sound Pressure Level SPL the microphone can measure and the internal self noise of the microphone

- The Dynamic range of a microphone is mainly determined by its sensitivity.
  - Sensitivity is determined by the size of the diaphragm, it’s tension and mass
  - Sensitivity is specified in mV/Pa
  - High sensitivity: Good for low SPL (but not large SPL)
  - Low sensitivity: Good for high SPL (but unable to register low SPL)

Dynamic range



- Upper level of the dynamic range:
  - Is determined by how much distortion is allowed (<3%) or
  - How much the diaphragm can move before it hits the back plate

- Lower level of the dynamic range:
  - The thermal movement of the air molecules will even in a completely silent environments excite the diaphragm and give an output.
  - Normally this limit is at 15dB ~ 4-5 μV for a ½" microphone.

Microphone sensitivity and dynamic range

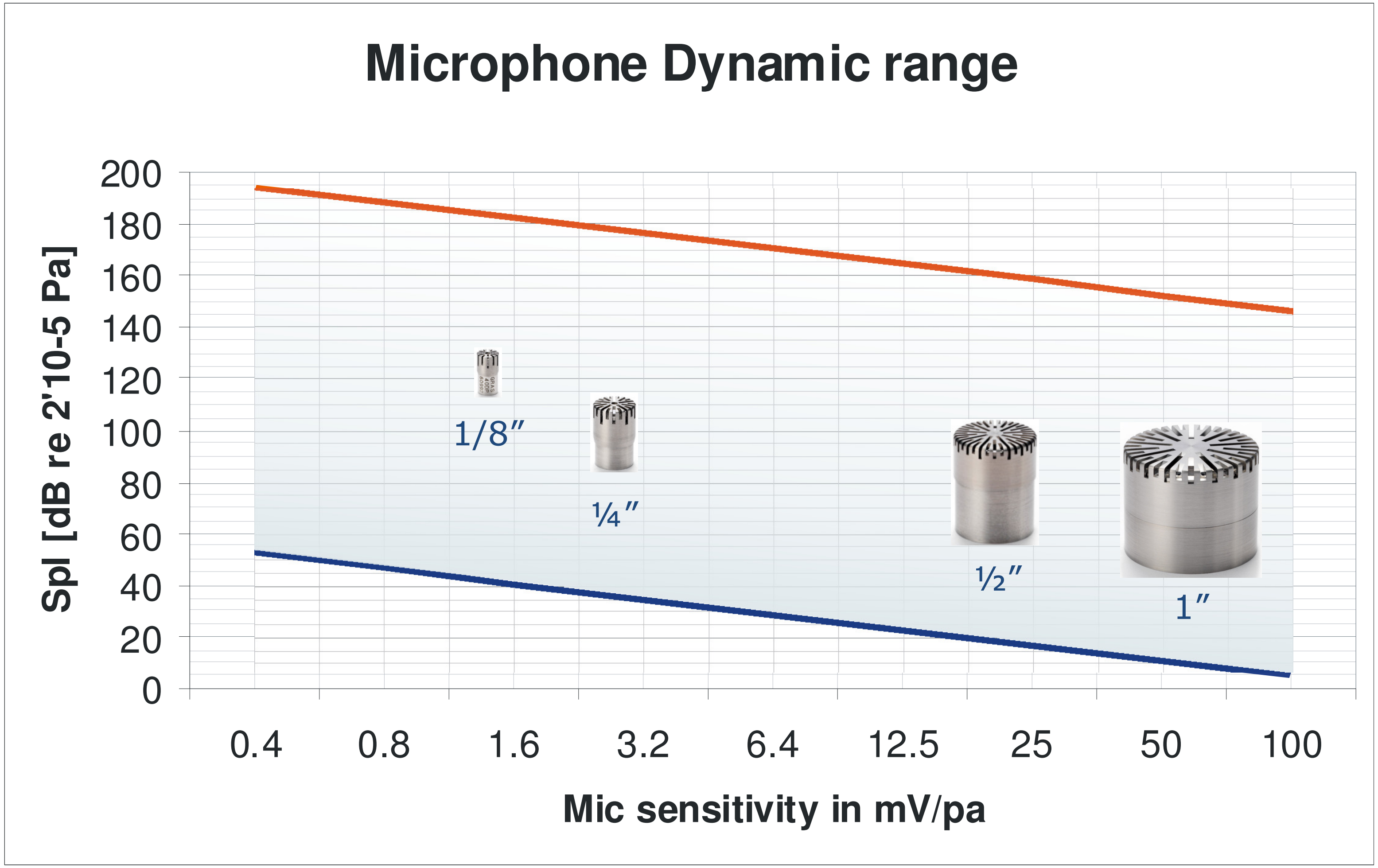
Microphone output signal

- Typical 1/8” microphone sensitivity: 1 mV/Pa
  - 1 Pa => 94 dB => 0.001 V mic output
  - 400 Pa => 146 dB => 0.4 V mic output
  - 40000 Pa => 186 dB => 40 V mic output

- Typical 1/2” microphone sensitivity: 50mV/Pa
  - 1 Pa => 94 dB=> 0.05 V mic output
  - 400 Pa => 146 dB => 20 V mic output
  - 4000 Pa => 166 dB => “200 V mic output”

- **Reference level is 20μPa (human hearing thresh hold)**

Dynamic range and sensitivity versus microphone size



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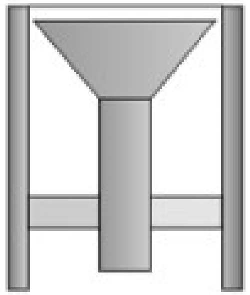
Frequency range of the microphone

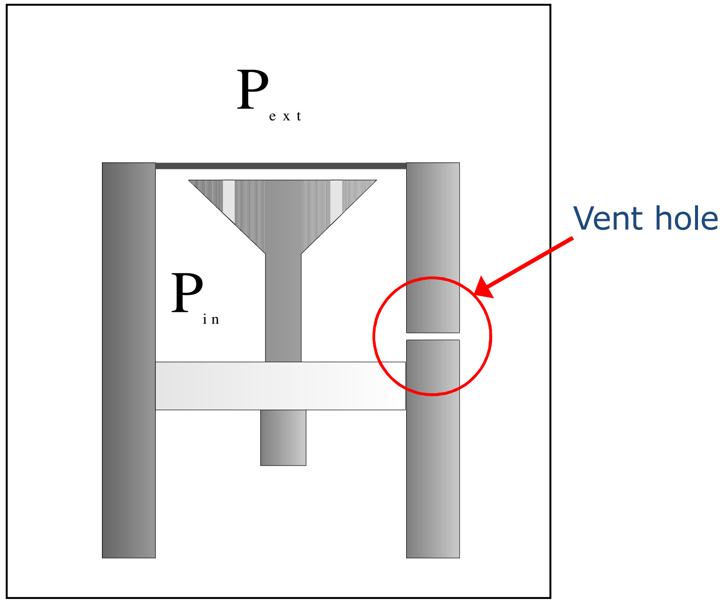
- Frequency range: The range between the lower and upper frequency limit. Defined by the roll off off either ±1dB or ±3dB
- Upper limits of the frequency range:
  The upper frequency is to a large extent defined by the size of the membrane (mass and damping)
- Lower limits of the frequency range:
  Is determined by the pressure equalization vent.



Low Frequency Response

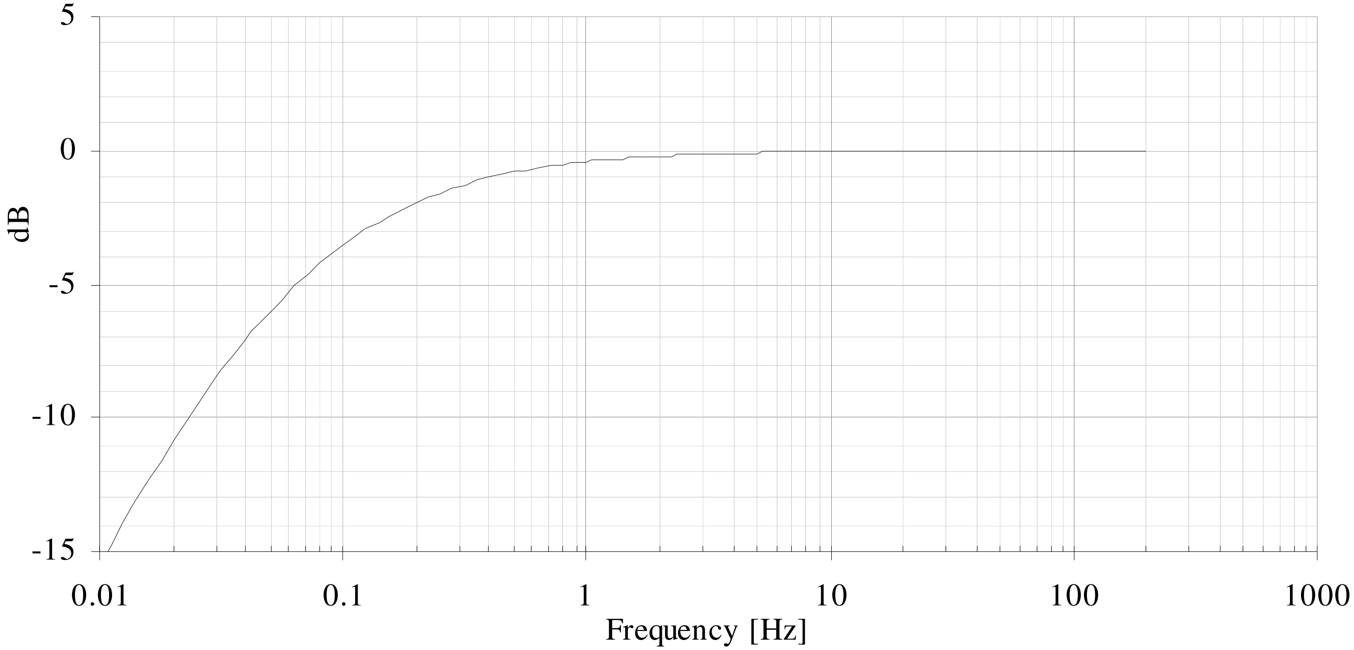
- Static pressure equalization
- Normal static pressure at sea level 1013 mBar = 101,300 Pa

1 m Height	= 0.12 mBar
	= 12 Pa
	= 106 dB



Low Frequency Response

- Microphone ventilation



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Microphone principle

- Externally polarized
- ”Traditional”
- ”Lemo type”

- Pre-polarized
- Electret
- ”CCP type” *

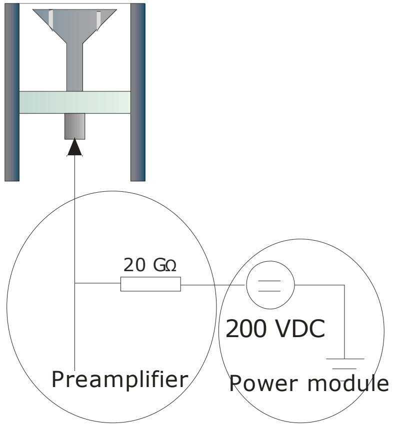
* Other names: CCLD, IEPE, Deltatron®, Isotron®, Acotron®, ICP

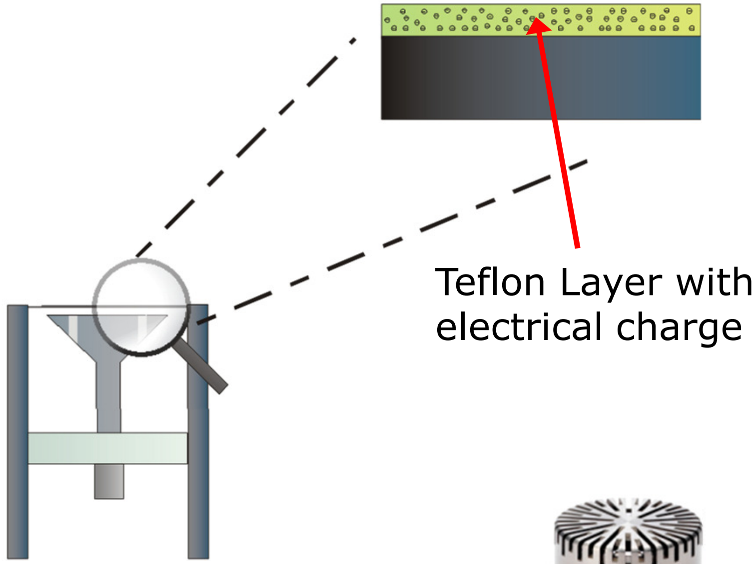
Polarization Voltage principles

External polarized

$$\boxed{Q = C_0 \cdot V_p}$$

Prepolarized





We make microphones

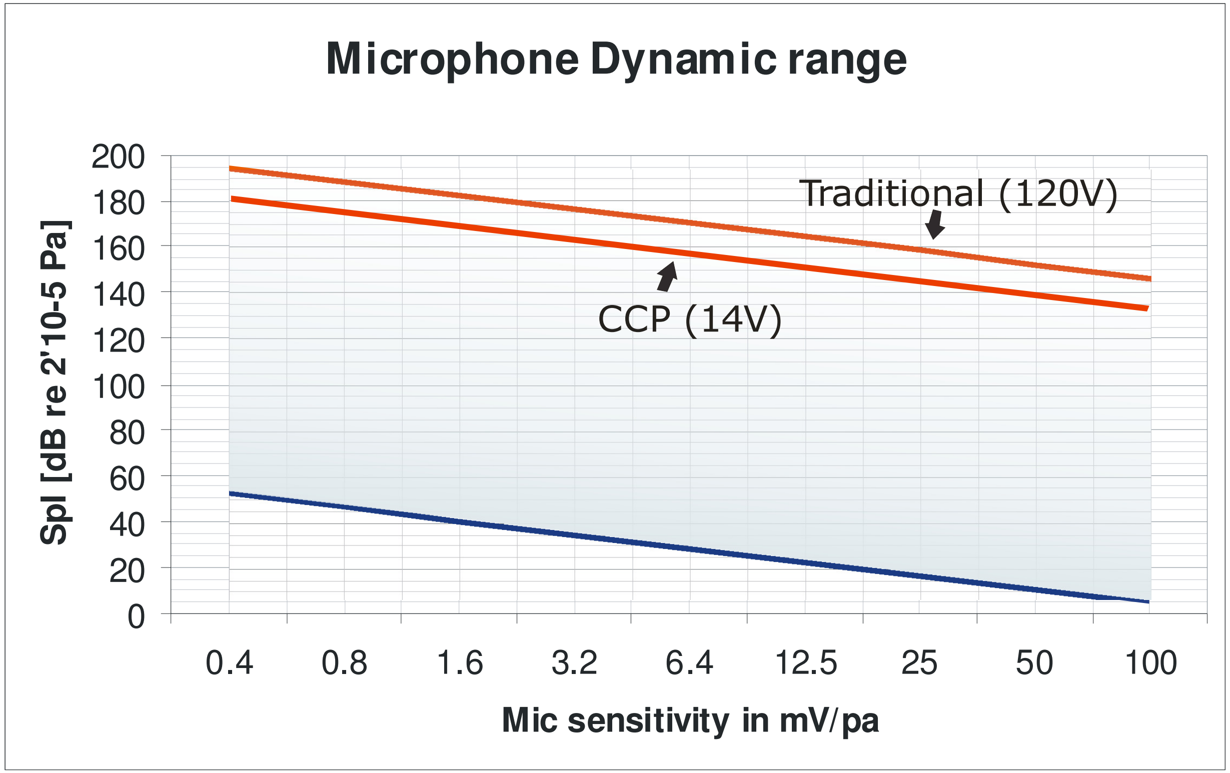
Traditional versus Prepolarized

- Externally polarized
  - 200 V polarization voltage
  - High temperatures
  - Long term stability (100 years?)
  - Negative output for positive pressure (180° phase shift)

- Prepolarized
  - Aproximately 200 V polarization voltage
  - Limited upper temperature range (Max 80 - 120 °C)
  - Less long term stability (10 years?)
  - Positive output for positive pressure (No phase shift)

Traditional versus CCP

- Dynamic range



Microphone Selection

The choice of the correct microphone is an evaluation of the following factors:

- Free Field / Pressure / Random incidence
- Dynamic range
- Frequency range
- Extern polarized / Pre Polarized

1” Microphone

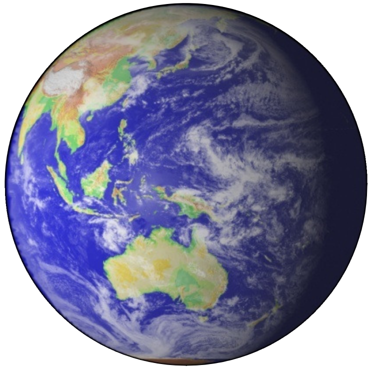
1/2” Microphone

1/4” Microphone

1/8” Microphone

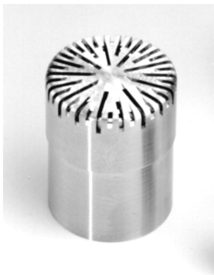
Microphone Dimensions

D= 12,500 Km



X 1,000,000,000

D= 12.3 mm

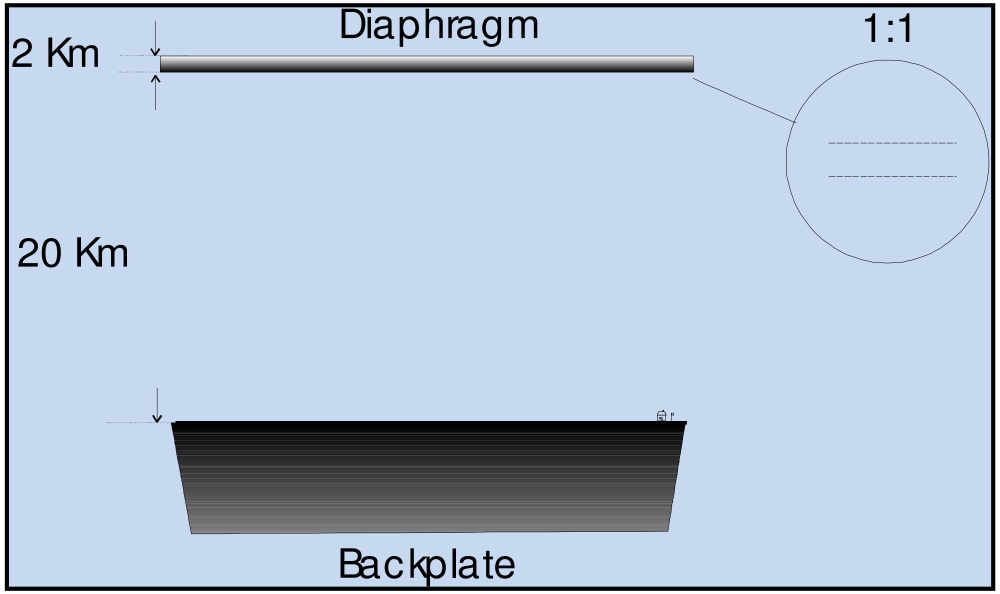


Diaphragm thickness: 2 km

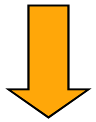
Distance between back plate and diaphragm : 20 km

Microphone Dimensions

- Diaphragm displacement



40 dB SPL



Diaphragm moves
10 mm or 0.4”

Microphone dimensions

40 dB SPL

Scale 1:1

Diaphragm movement
10^{-11} m

Diaphragm velocity:

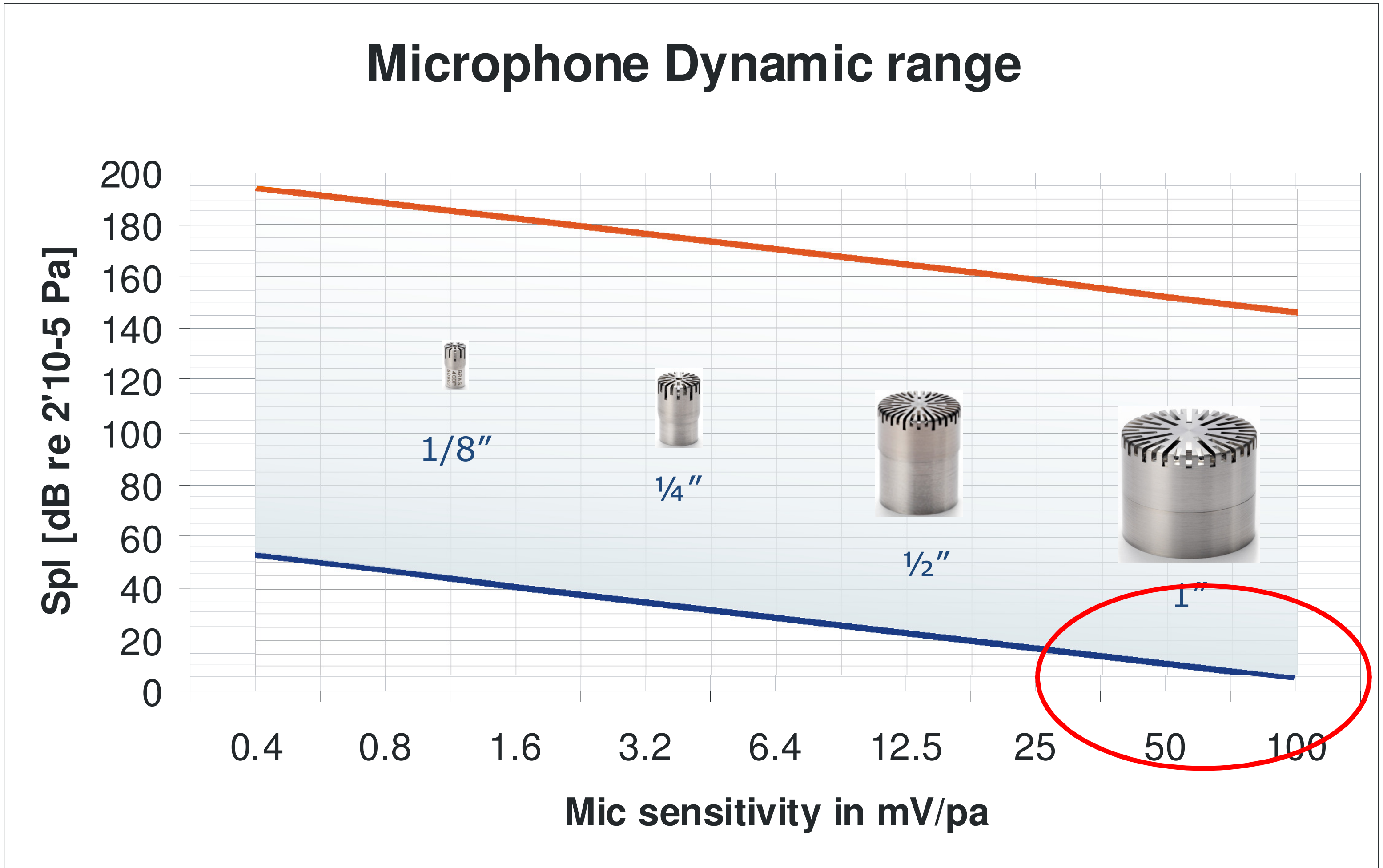
$$\boxed{v = 2 \cdot \pi \cdot x \cdot f}$$

Diaphragm velocity
(100 Hz)
$6.3*10^{-9}$ m/s

1000mm/m
2592000 s/month

16 mm/month

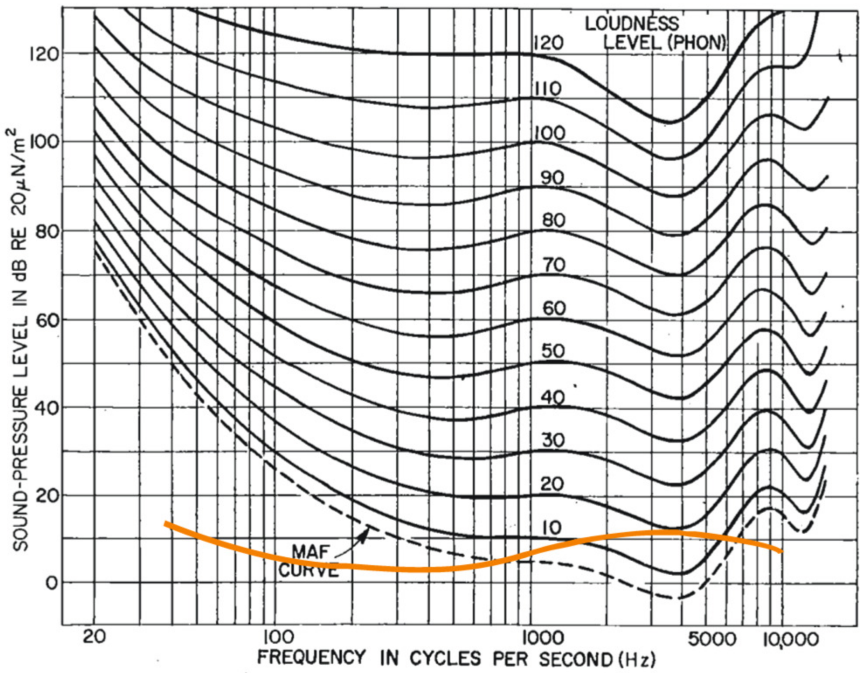
Very low level measurements



We make microphones

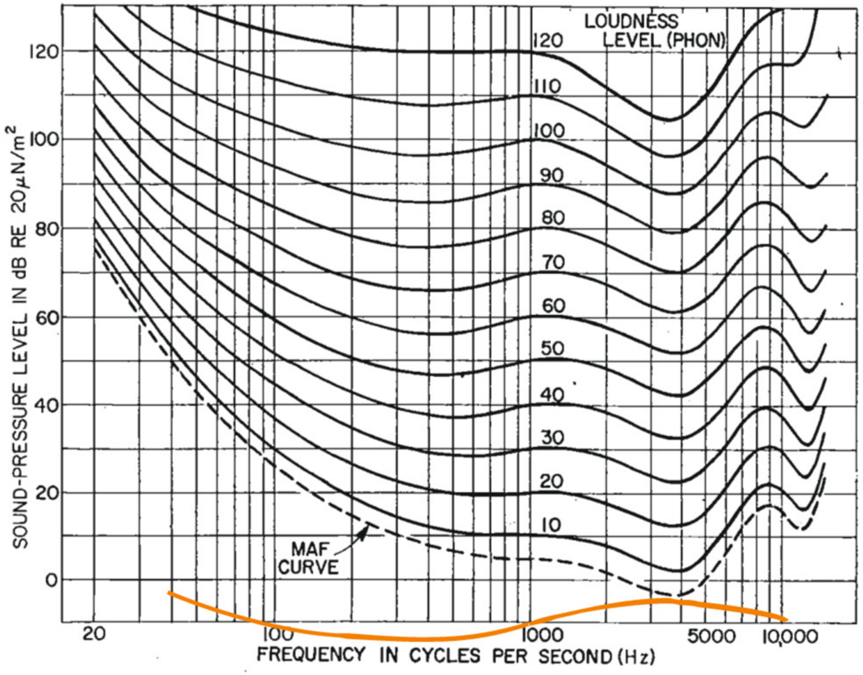
Normal measurement microphones

- Hearing threshold : 0 dB
- Normal microphone noise floor : 15-20 dB



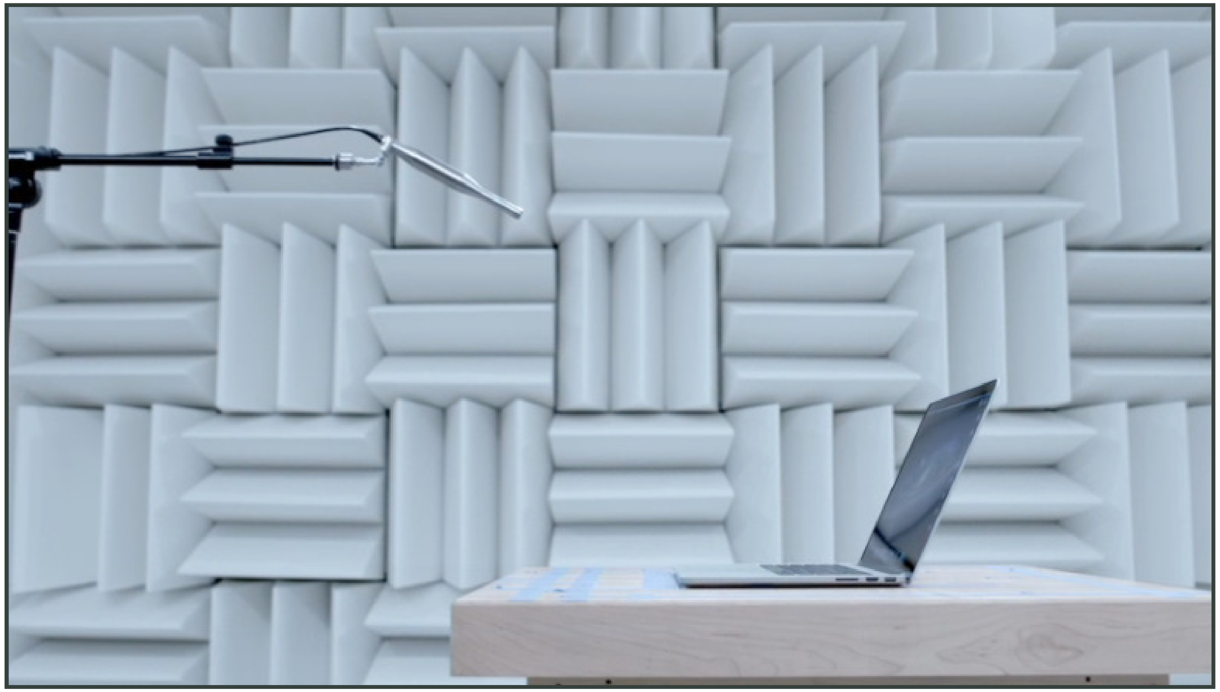
Low noise microphones

- Optimized for low level measurements
- Noise floor : Below 0 dB



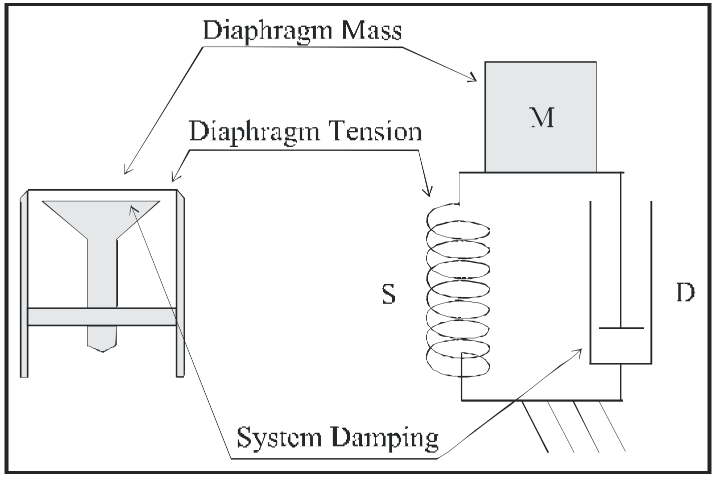
Increasing product demands

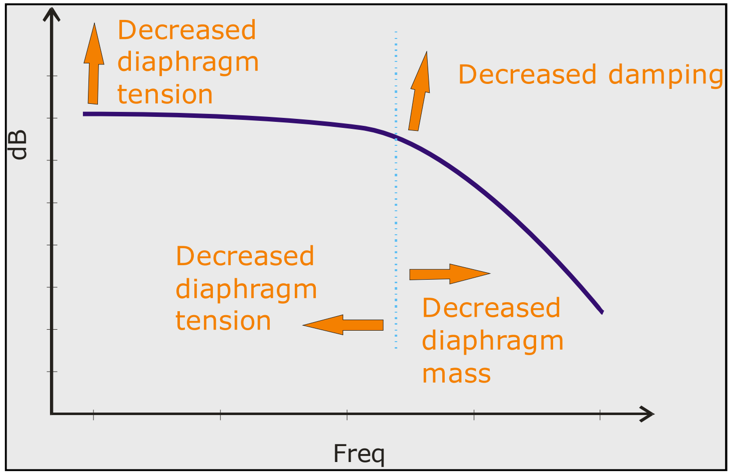
- Product noise as Key Selling Point



Design parameters

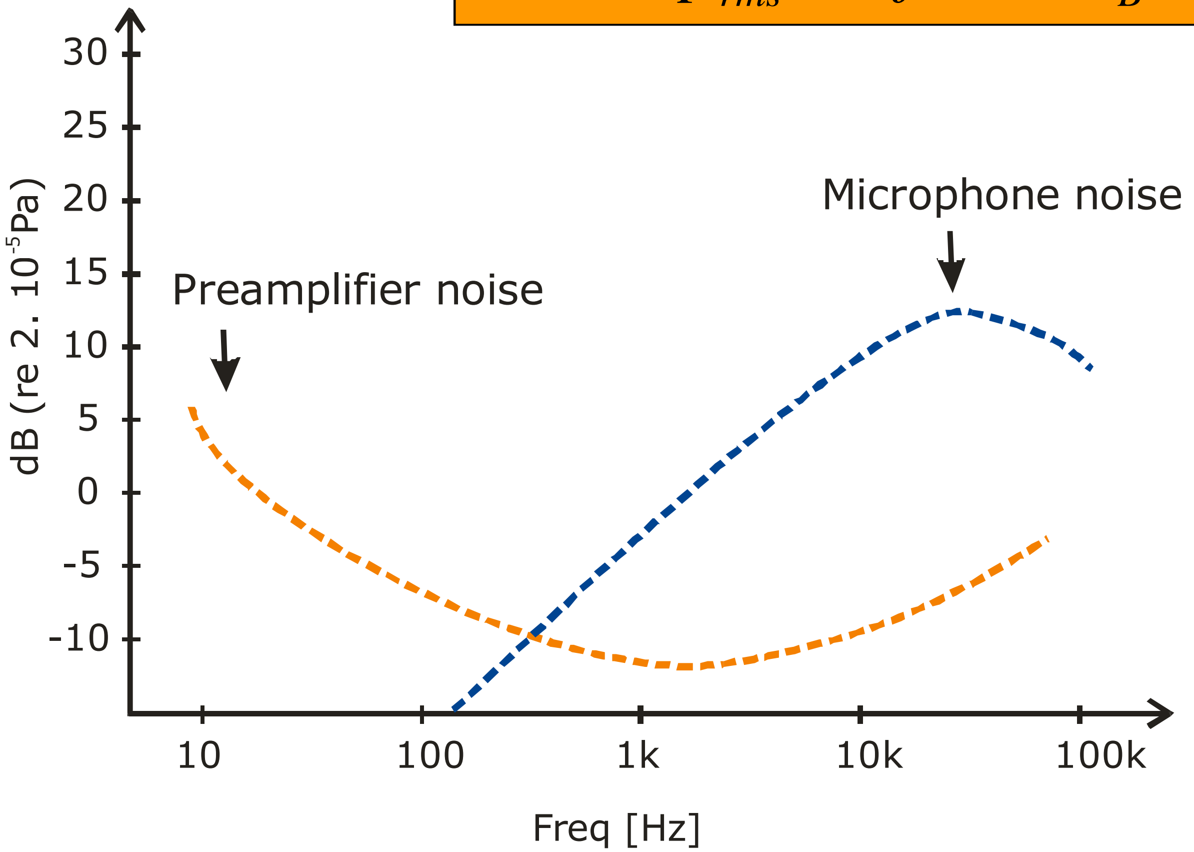
- Mechanical Equivalent





Noise floor optimization

$$PSD = p_{rms}^{\;2} / \Delta f = 4 \cdot k_B \cdot T \cdot R_A$$



Low noise example

Low noise microphone

- Questions

G.R.A.S.
SOUND & VIBRATION

Headphone & Earphone testing

ALMA 2017

We make microphones

Agenda

- Ear couplers
  - History
  - Theory
  - Different models
  - Which model to use
- Headphone testing
  - Challenges
  - Environmental impact
  - Test of ANC headphones
- Questions

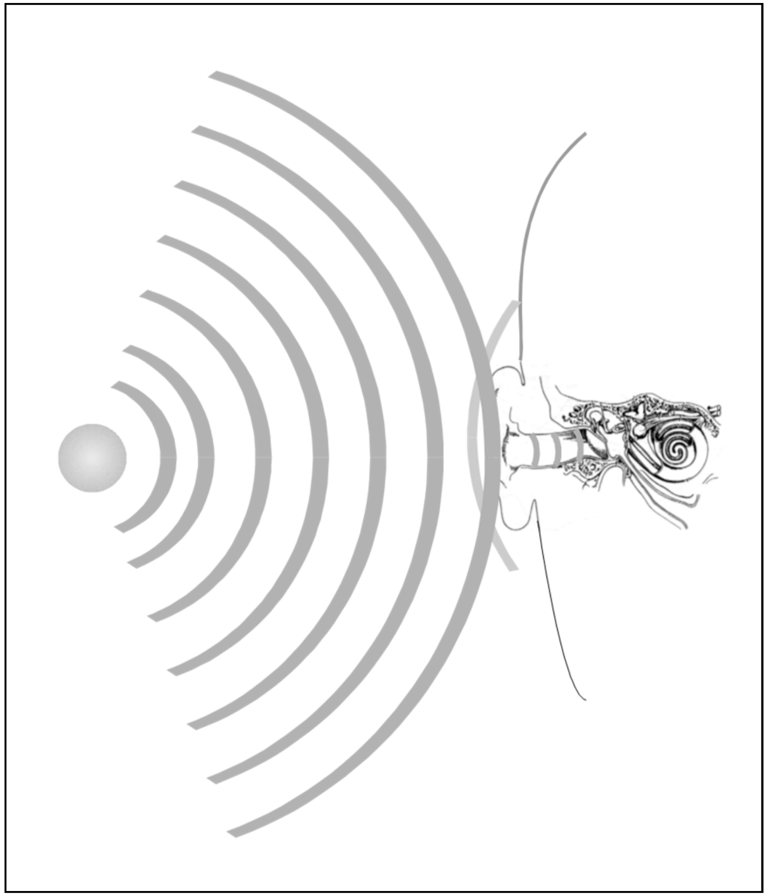
Ear Coupler History

- It all started with people doing listening test
- First known ear coupler was designed in the early 1920’s
- First standardized ear coupler was designed in the late 1940’s

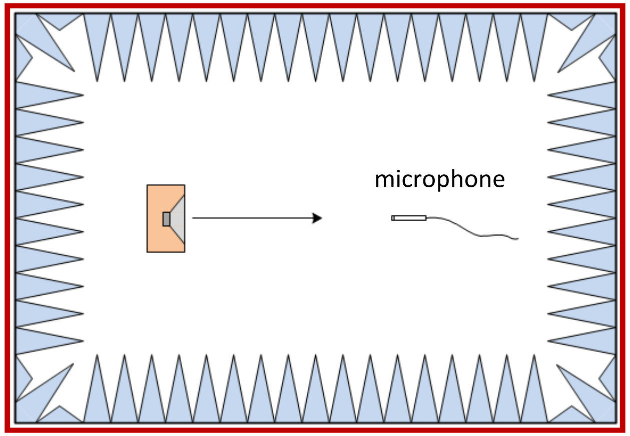
- But why do we need ear couplers?

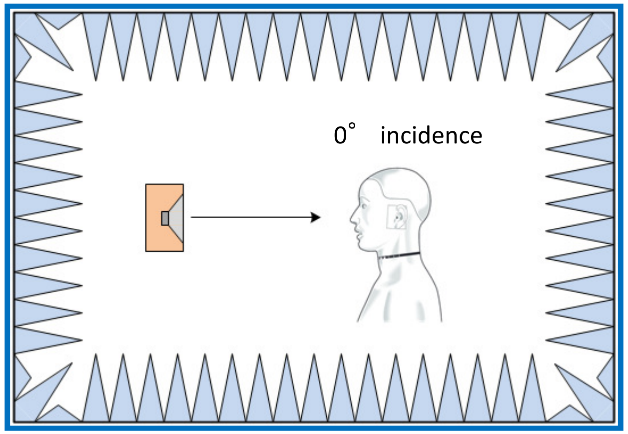
The human body’s influence on sound field

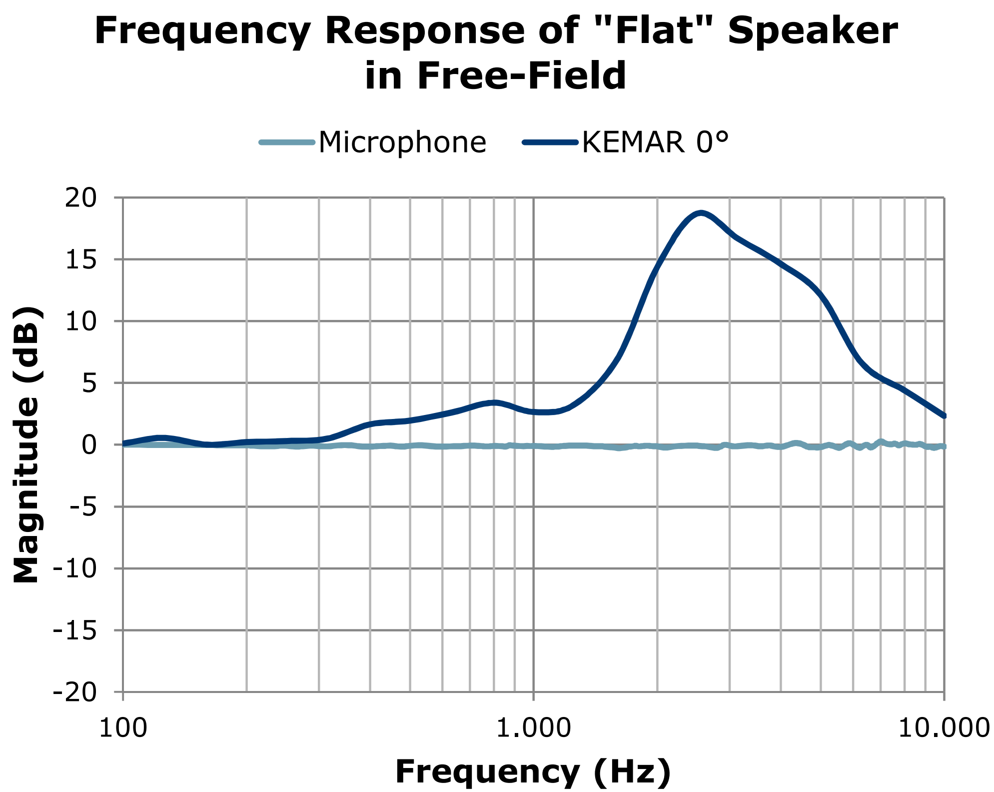
- Influence of human head and torso
- Influence of human head and ear on sound pressure at the eardrum



Head Related Transfer Function (HRTF)

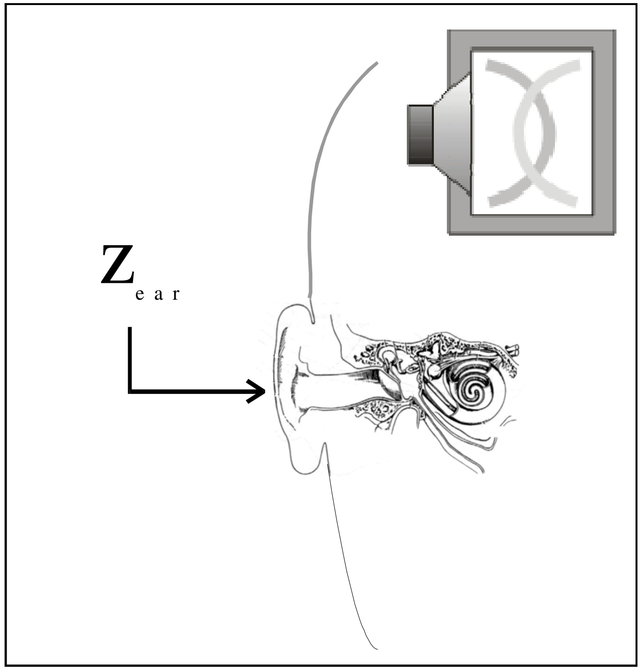


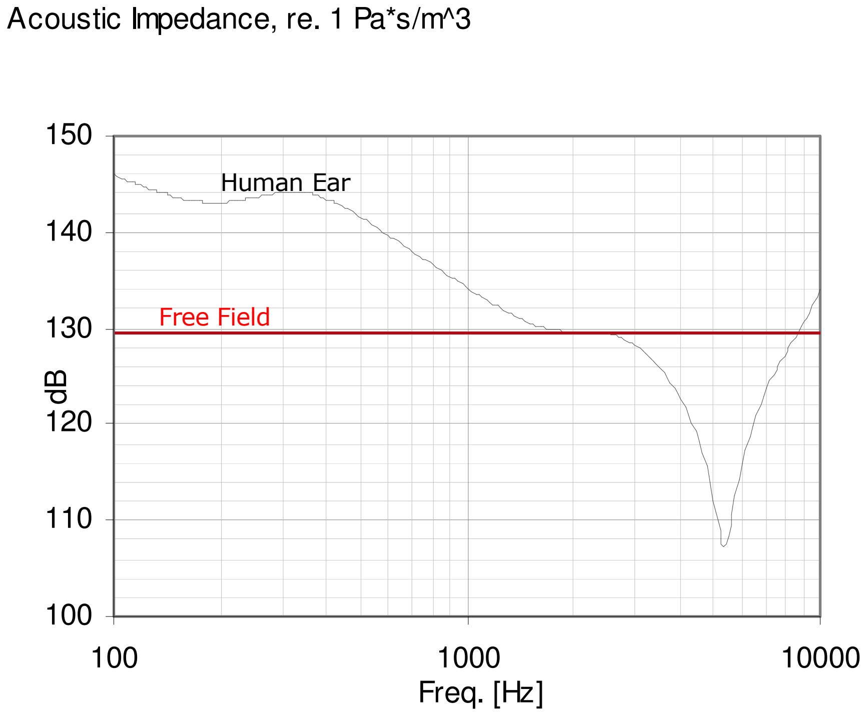




Human ear impedance

- Sound field is not looking into a free field
  - It is looking into a closed volume
  - Including: outer ear, ear canal, ear drum and inner ear





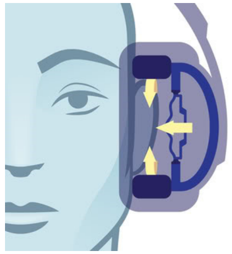
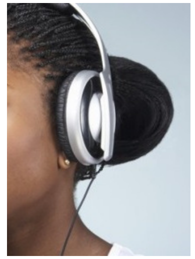
Simulation of ear impedance

Definitions and abbreviations

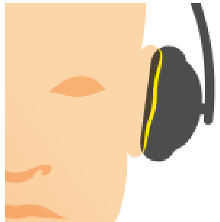
- Types of headphones
- Ear reference points
- International standards

Different types of headpones

- Circum-Aural headphones (CA)

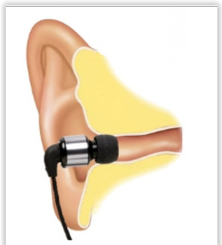



- Supra-Aural headphones (SA)




- Earphones/Earbuds (EP)


- In-Ear headphones (IE)

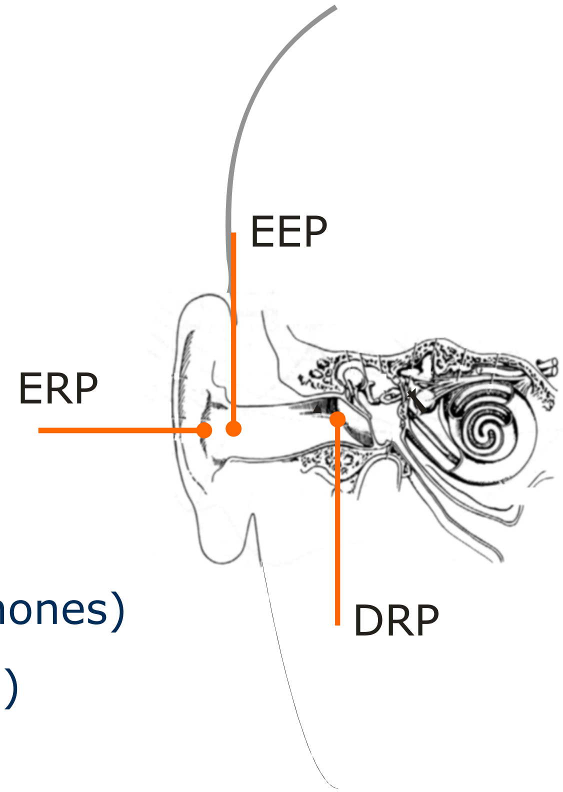



Different ear reference points

ERP: Ear Reference Point

EEP: Ear Entrance Point

DRP: Drum Reference Point



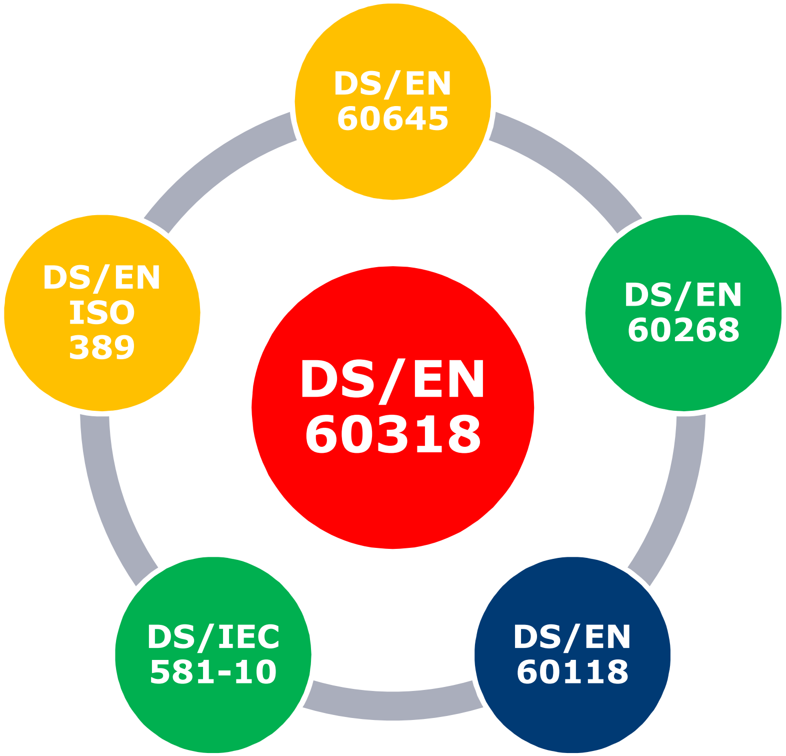
ERP = What enters the ear (CA + SA headphones)

EEP = What enters the ear canal (Earphones)

DRP = What you actually hear (IE phones)

Standards

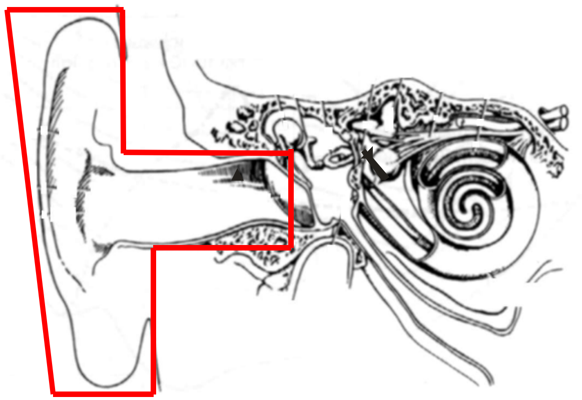
Standards for Ear Simulators

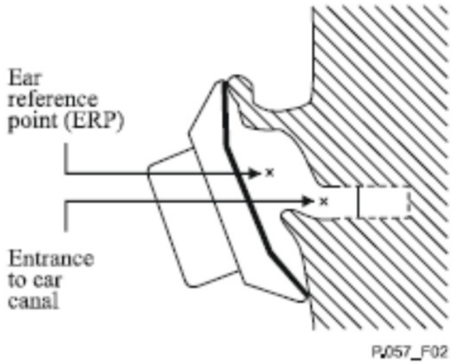


EN 60318 is common standard for the acoustical test fixture

6CC Coupler or NBS9A Coupler (IEC 60318-3)

- Frequency range from 20Hz – 6kHz
- Standardized calibration of audiometric SA headphones

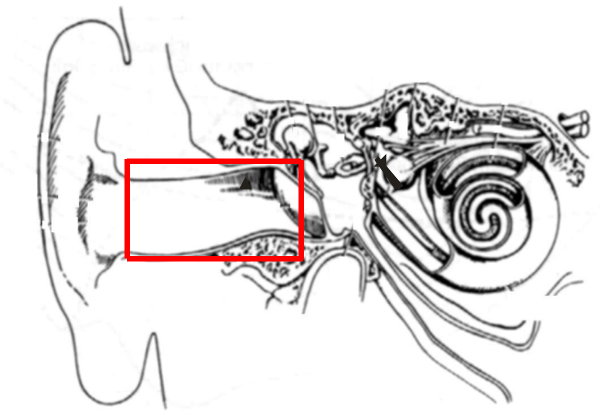




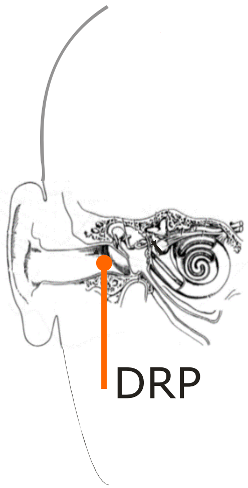
b) Supra-aural (closed)

2CC coupler (IEC 60318-5)

- Frequency range from 20Hz – 10kHz
- Measurements on hearing aids



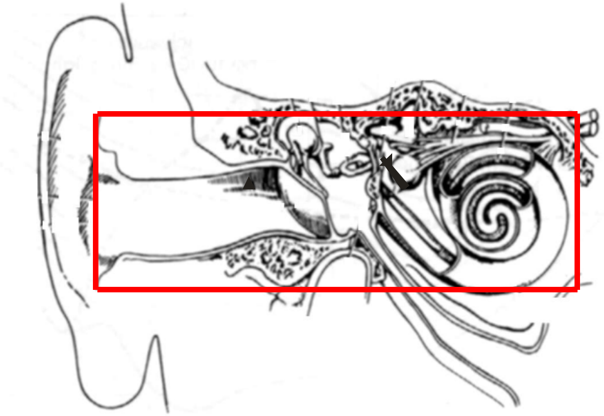
Simplified model of ear



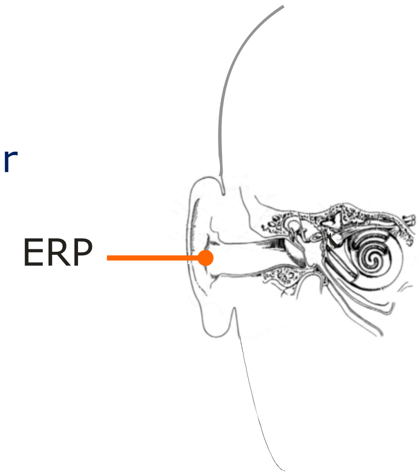
Simple volume coupler

318 Coupler (IEC 60318-1)

- Frequency range from 20Hz – 10kHz
- Test of headphones CA & SA and even EP with cutomized adapter
- Telephone handles and mobile phones



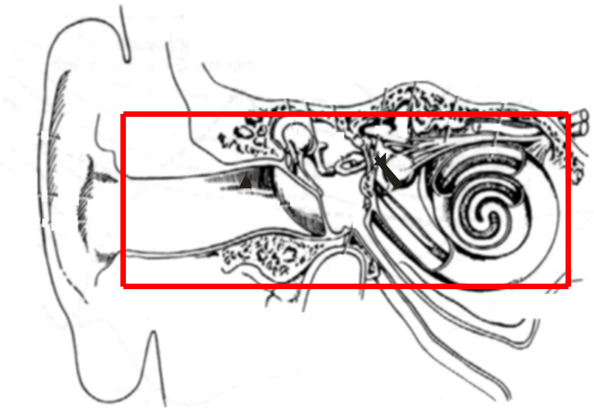
Model of middle and inner ear



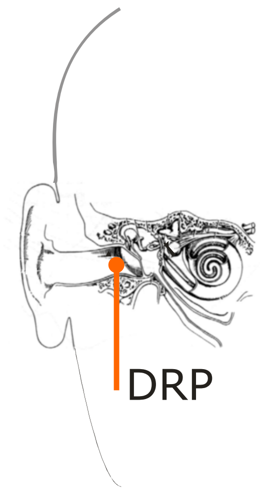
Advanced coupler ERP

711 coupler (IEC 60318-4)

- Frequency range from 20Hz – 10kHz (16kHz)
- IE headphones and hearing aids
- EP, SA and CA headphones when combined with a pinna
- Telephones and mobile phones when combined with a pinna



Model of middle and inner ear

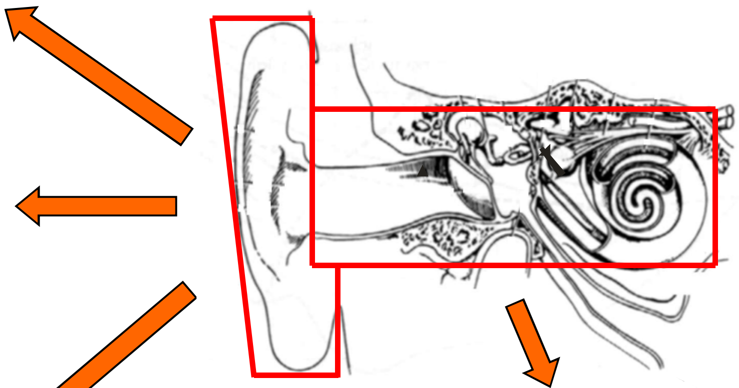


Advanced coupler DRP

Outer ear simulators (pinnae)

- Outer ear simulators or pinna simulators

ITU-T rec. P57 Type 3.2
Simplified Pinna Simulator
(High-leak)



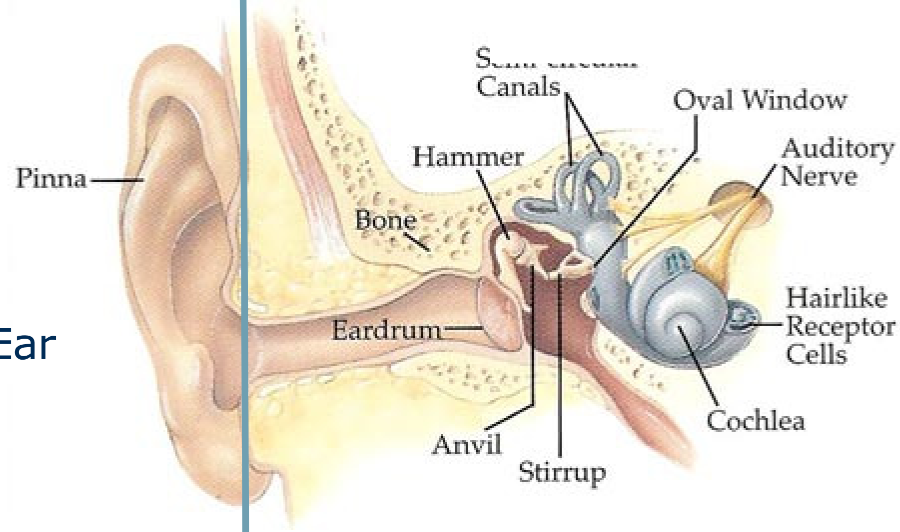
ITU-T rec. P57 Type 3.2
Simplified Pinna Simulator
(Low-leak)

ITU-T rec. P57 Type 3.3
Pinna Simulator

ITU-T rec. P57 Type 2
Artificial Ear = IEC 60318-4

Ear Simulators and Manikins = Human Auditory System

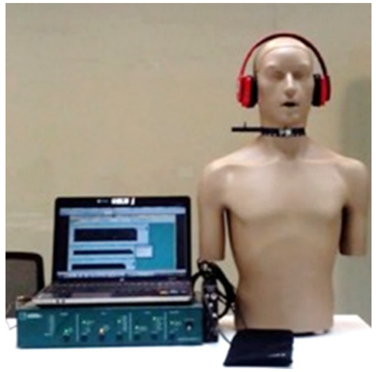
- Acoustic **Diffraction**
  - People in the sound field
- Acoustic **Impedance**
  - Couplers, ear couplers, ear simulators
  - 318 and 711 down to the micron
- Great complement to subjective Golden Ear
- **The best test solution depend on the product you want to test**



Diffraction

Impedance

Designing and measuring Headphones/Earphones



Data that you **need** to capture:

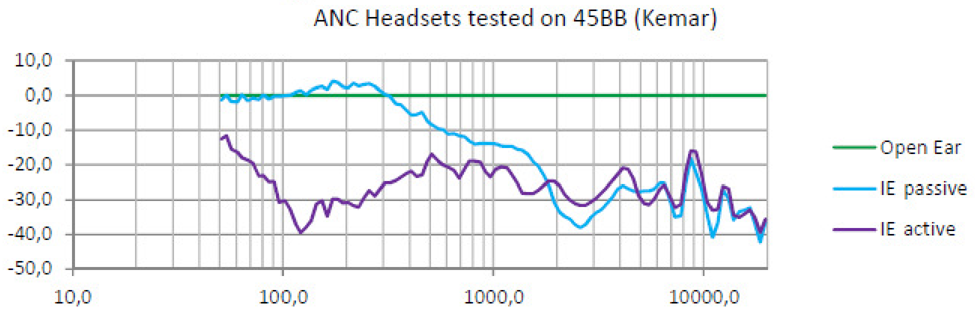
- Frequency Response
  - Verify response across audible bandwidth 20Hz – 20kHz or higher
- Distortion
  - Produce a fundamental frequency with limited harmonics (a few %)
- Dynamic Range
  - Destructive: at what SPL does the driver give in? (120 dB or 95 dB)
  - Non-destructive: min/max levels vs. distortion (60 dB range? 10%?) Design dependent.
- Quality?
  - Rub’n’Buzz for loose, off-axis and/or grinding parts
    (high order harmoni distortion, very low levels)
- Tracking/Wiring
  - Right is right and left is left? balanced output? (4% disagreement)
- Crosstalk
  - Right to left and vice versa (50 dB down?)

R&D

Challenge: Isolation of ambient noise

- Isolation
  - 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



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.

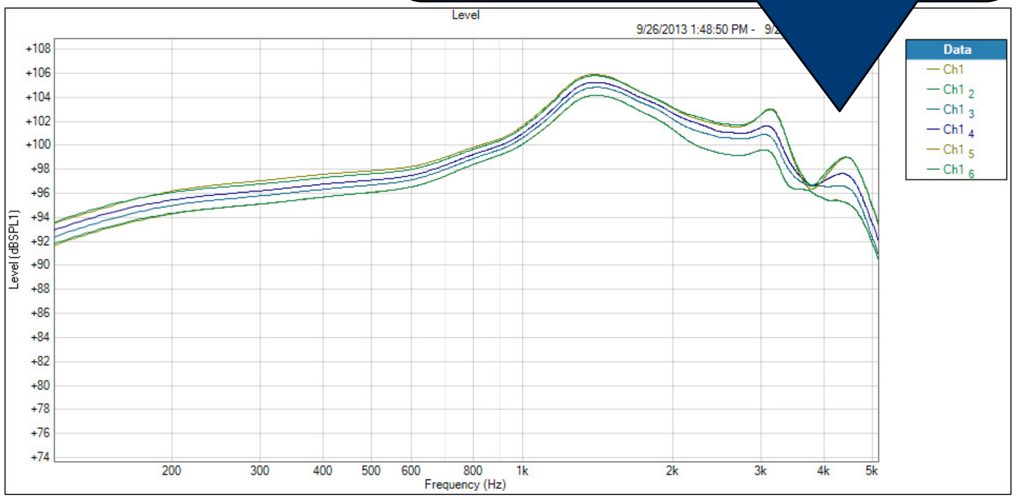
High Leakage score means you contribute to the acoustic pollution(!) in the world.

Challenges for headphones – 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**

Measuring your headphones
Measure "ideal" response and your many "bad" responses. Show variations on a single graph

- Start with "ideal" fit
- Then take 8 additional non-ideal measurements
- Finish with "ideal" fit, to have a total of 10 samples



How do I find out if sealing is good?

- Headphone/Earphone positioning
  - **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
  - **Pro-tip 3: Human Domain**
    - Listen to the signal yourself

Solutions

Quality of test equipment versus 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

Questions

?

Next Generation Headphone Testing

G.R.A.S. – Listen - Seminar 2016-10

We make microphones

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

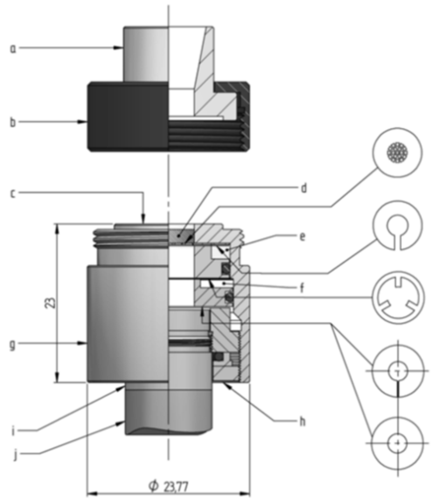
- Better low noise measurements (ANC, Bluetooth)
- Better repeatability
- Better low frequency measurements
- Better high frequency measurements
- Solutions with backwards compatibility
- Solutions which are based on known standards

New low noise ear simulator

We make microphones

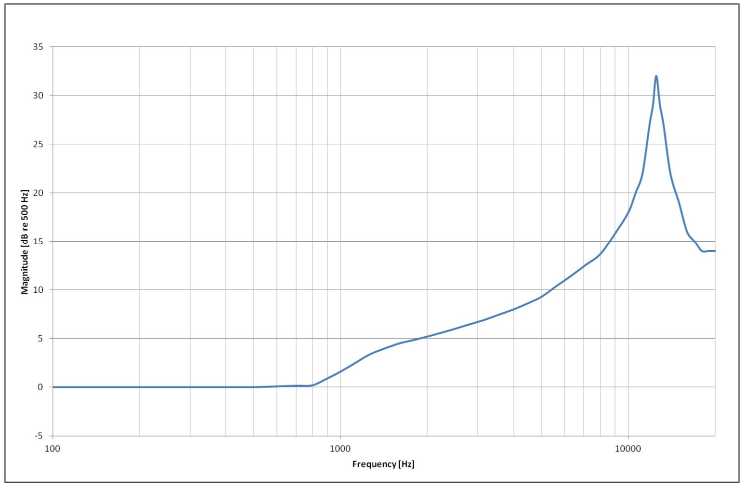
Standard IEC 60318-4 Ear simulator

- 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



Designed in late 1970s by
Gunnar Rasmussen

- Built-in WS2P ½" microphone:
  - Sensitivity of 12.5 mV/Pa
  - Noise floor at 25 dB(A)
  - Maximum SPL $\approx$ 164 dB



Better data for very low level testing

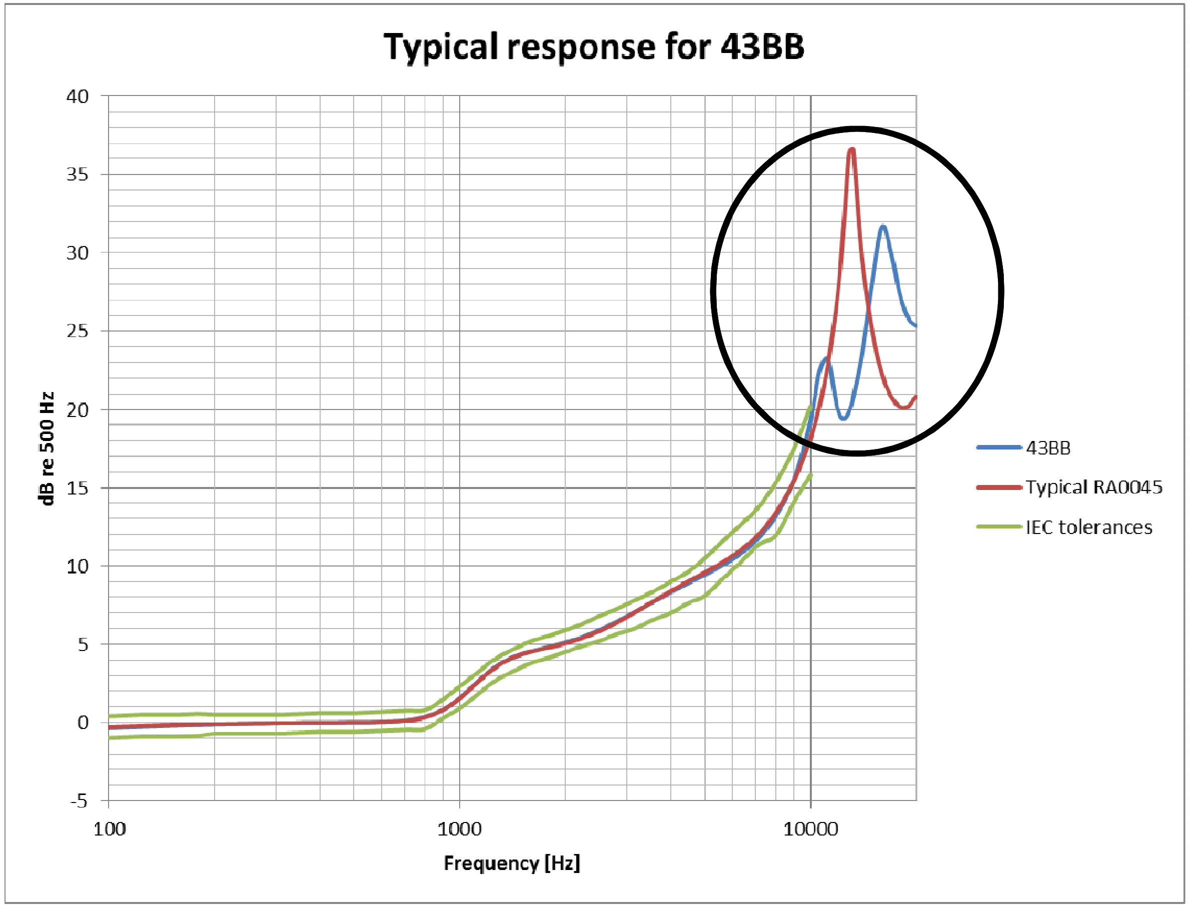
- The new ear coupler allow testing the noise floor of the headphone
  - Noise generated by electrical circuits
    - Active Noise Cancellation and Bluetooth headsets tend to have a “hiss” in quiet surroundings
    - This “hiss” can be detected via subjective testing
    - This phenomenon could not be 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)
  - Maximum SPL ≈ 113 dB
  - Same impedance up to 10 kHz

Transfer impedance comparison

- Similar frequency response up to 10 kHz
- Differences above 10 kHz due to changed impedance of microphone diaphragm



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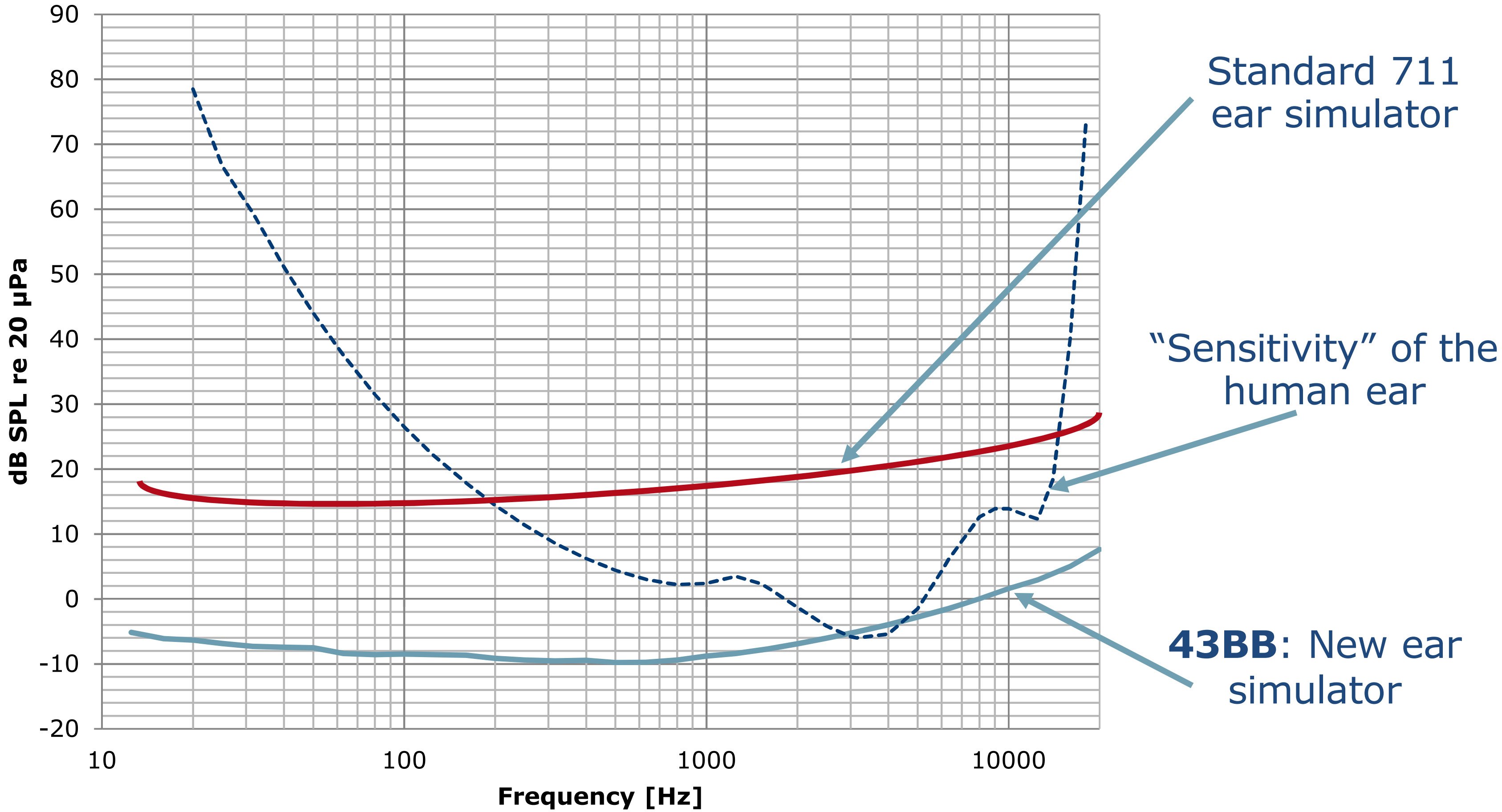
Hearing Threshold vs. Test equipment



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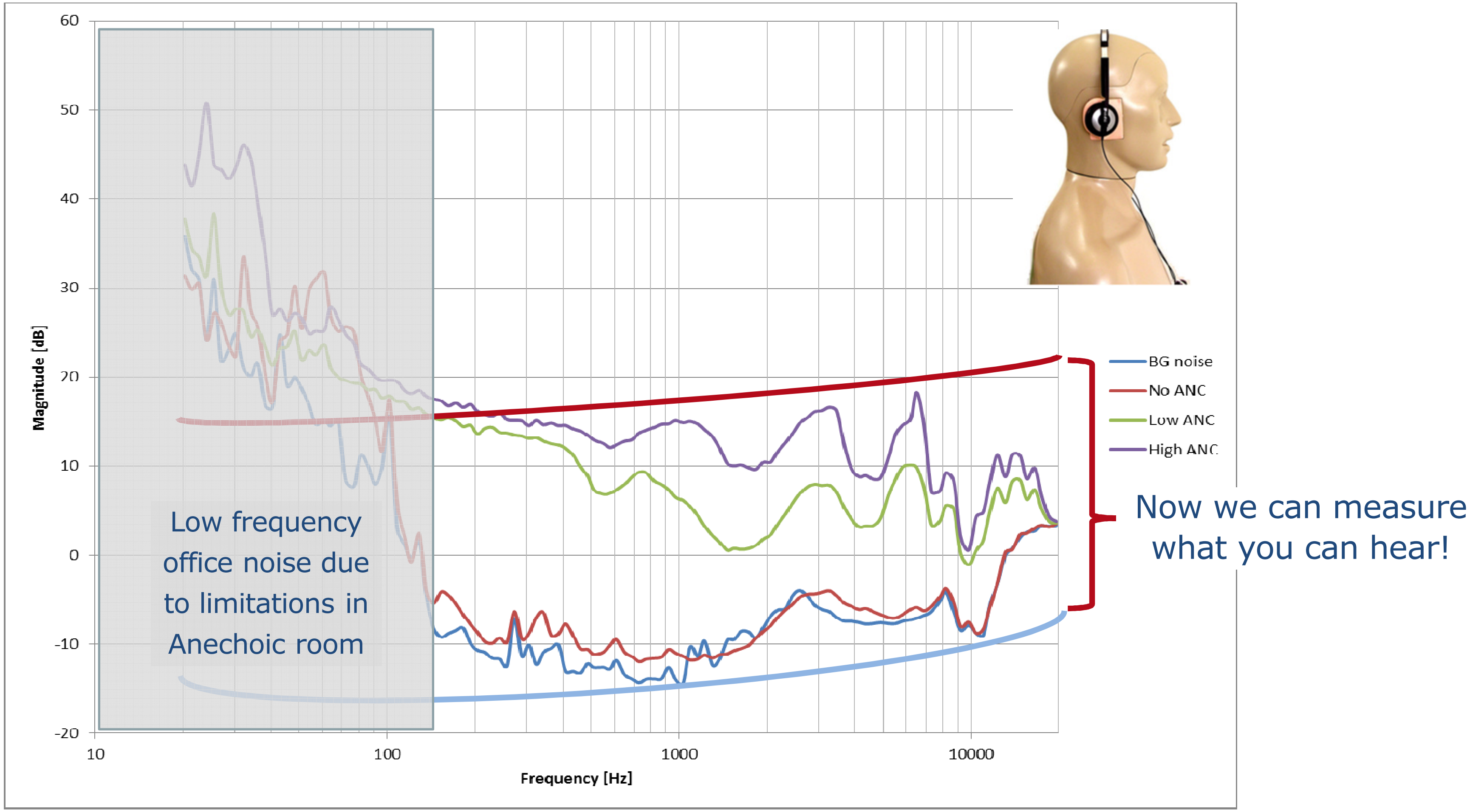
Measurement example with low noise ear simulator

- Active Noise Cancellation headphones
  - Measured with new low noise ear coupler
  - Simulator mounted in KEMAR mannequin
  - Measurements conducted in anechoic room

Hearing Threshold vs. Test equipment



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New Anthropometric Pinna and Ear Canal

We make microphones

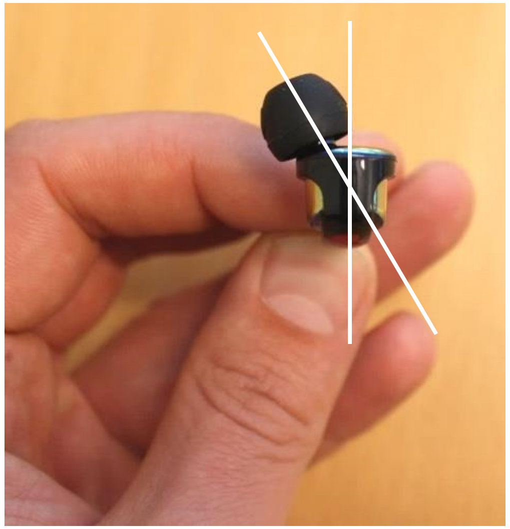
Anthropometric Pinna and Ear Canal

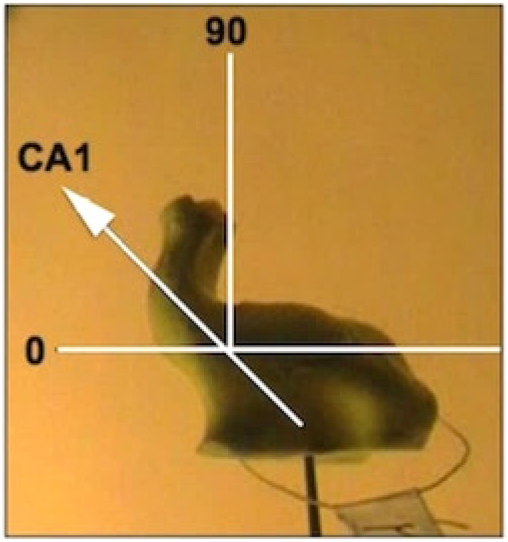
- **Standard Pinna**
  - Cylindrical or conical ear canal
  - Developed for hearing aids

- **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

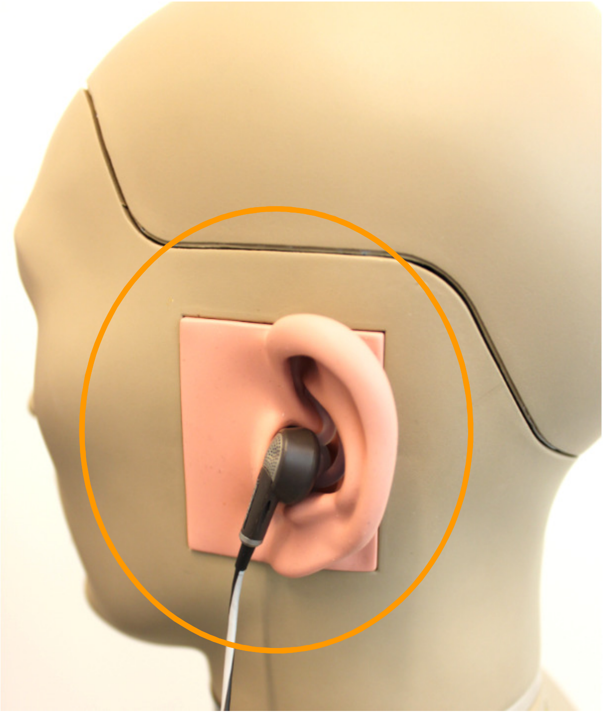




Axial View (from below)

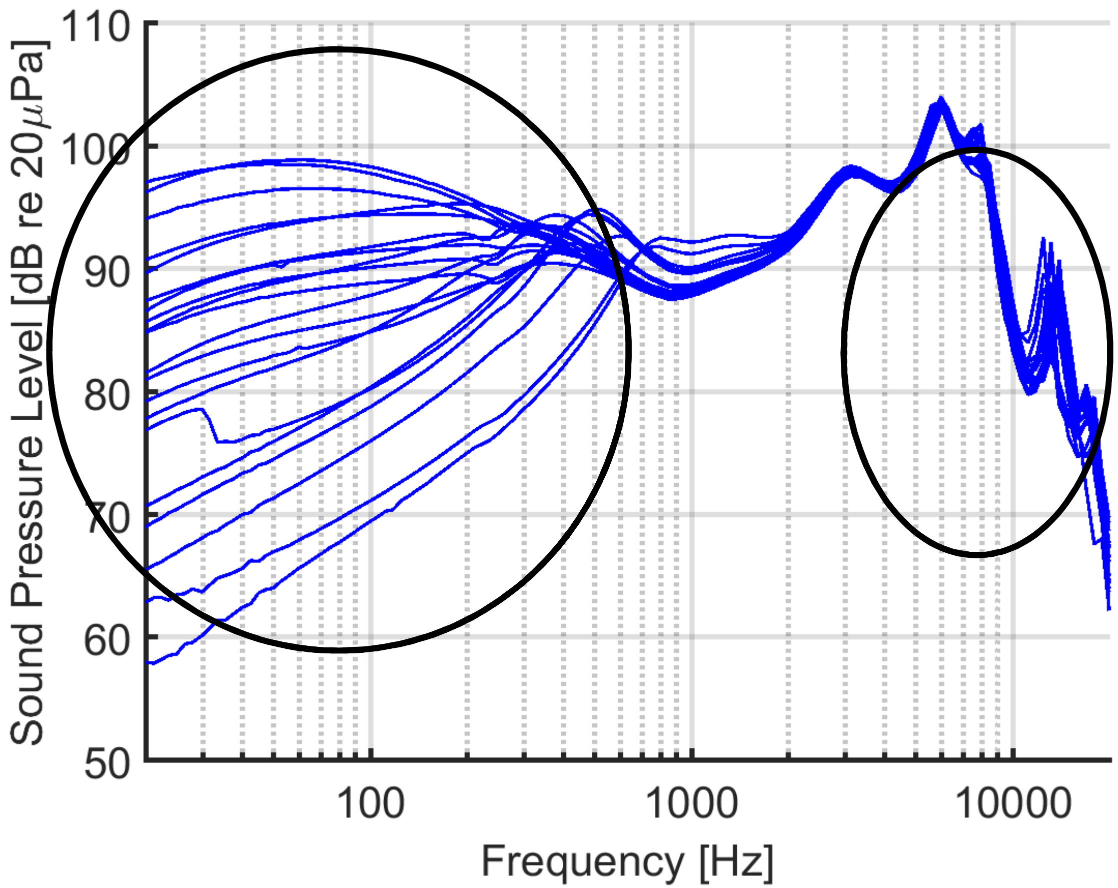
Better repeatability

- Fewer and better measurements
- More reliable data
- Reduce cost and time spent on test
- Meets the need in the industry for realistic testing



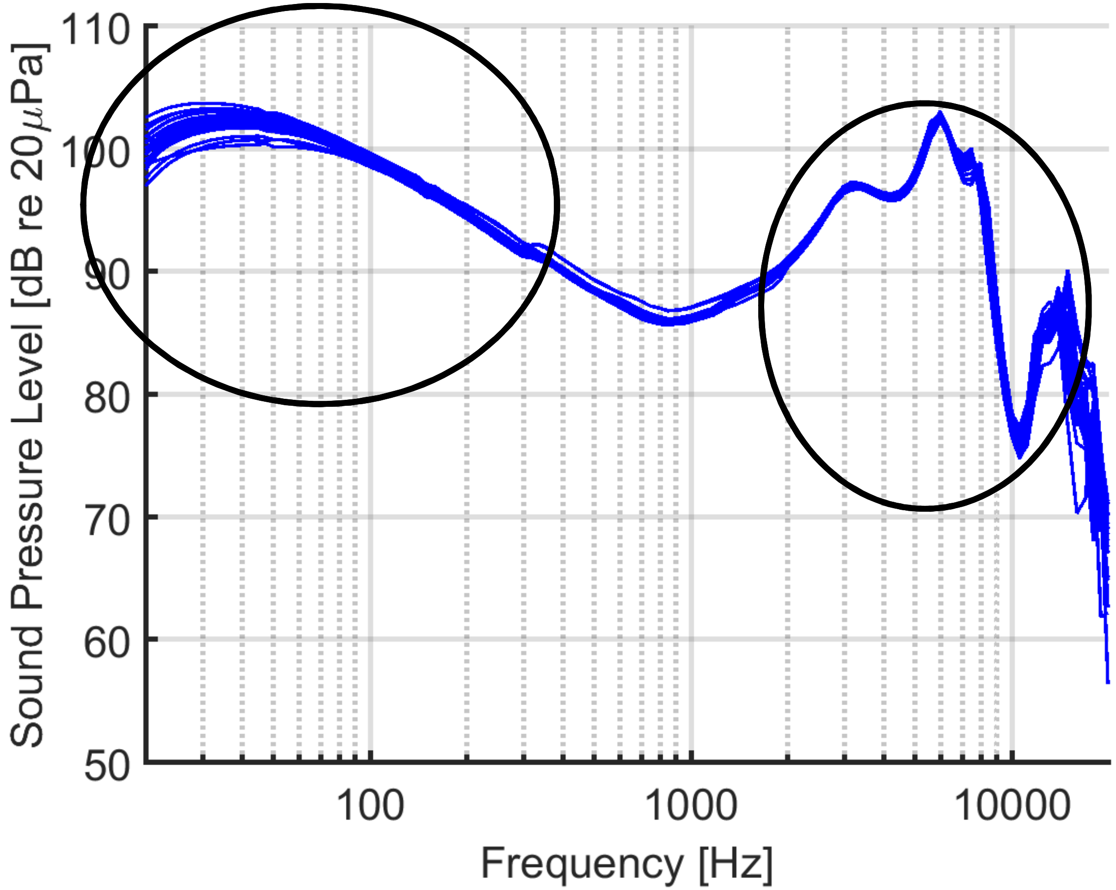
IE headphone on Standard Pinna with conical ear canal

- Headphone mounted repatedly 20 times on same test setup
- Difficult to get repeatable seal resulting in leakeage
- Spread at high frequencies due to difference in insertion depth



In-Ear headphone measured on Antropometric Pinna

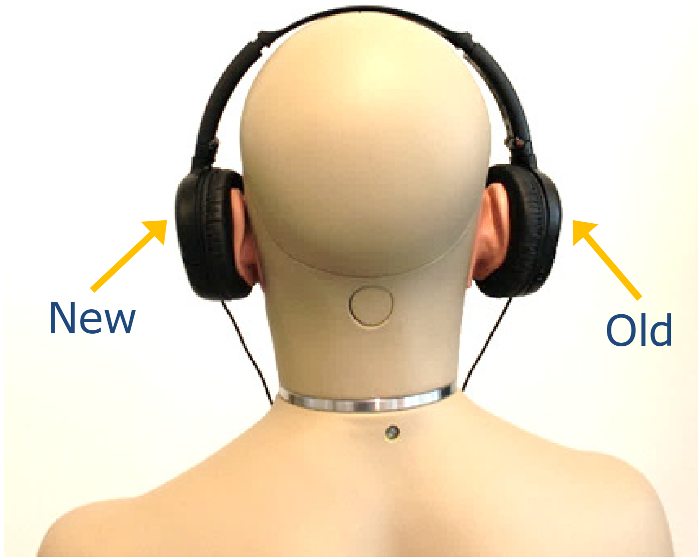
- Headphone mounted repatedly 20 times on same test setup
- Better repeatability at low frequencies
- Smaller spread at high frequencies



We make microphones

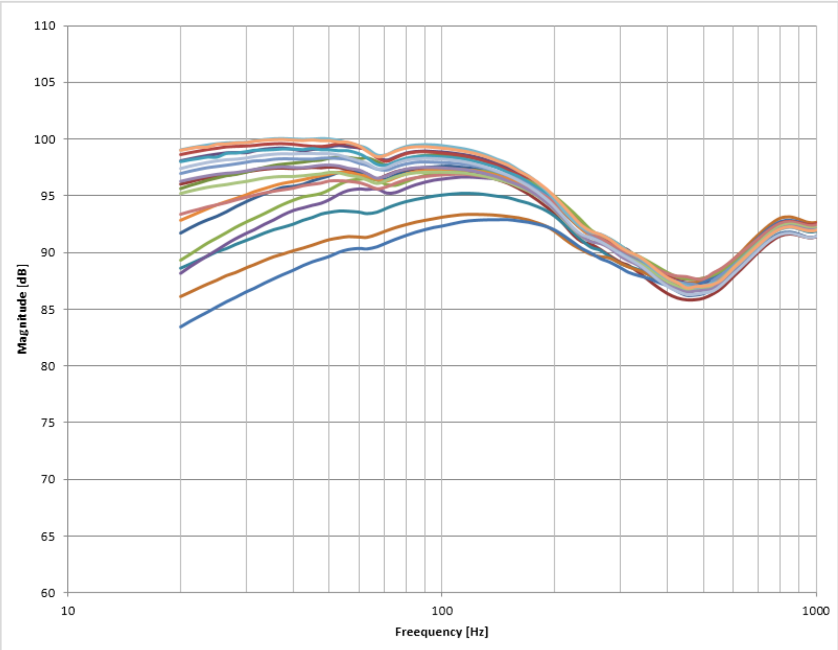
Better low frequency results for supra aural headphones

- More reliable data
- Fewer and better measurements
- Leaks destroy measurements below 1kHz
  - Better measurements on ANC circuits
    - Active Noise Cancellation is predominantly active below 1 kHz
  - Better data on Rub & Buzz measurements

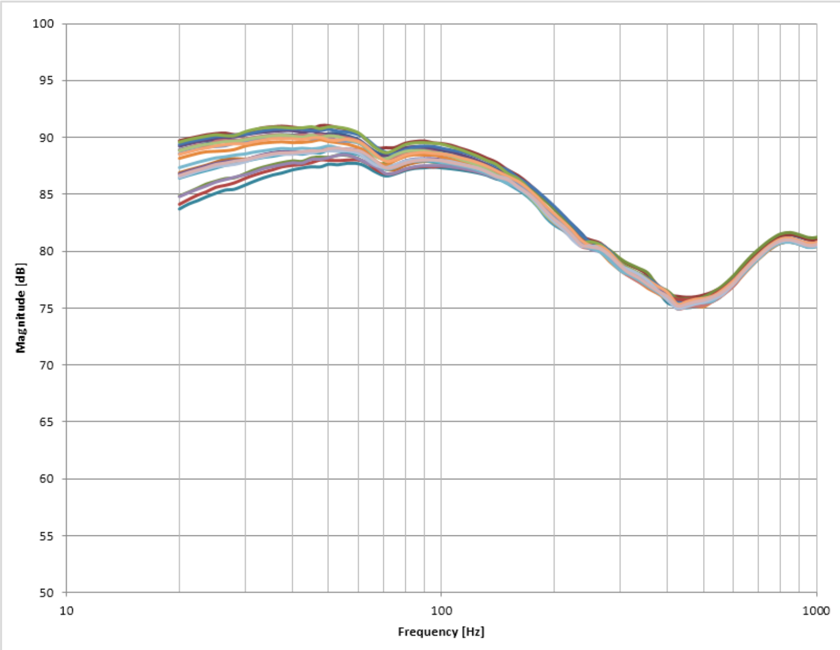


Low Frequency response and leaks

- Supra-aural headphones tested on KEMAR



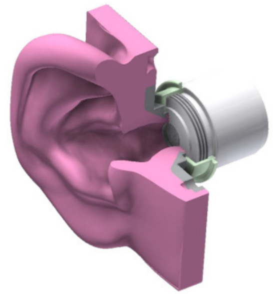
KB0065: Standard pinna, concha & canal



KB5000: New pinna, concha & canal

Summary

- Low Noise Ear Simulator
  - Can measure at or below human hearing threshold
  - Frequency response within IEC 60318-4 limits



- The Anthropometric Pinna
  - Has shown huge benifits in fit and seal for In-Ear products
  - Has shown benifits in fit and seal for both SA and CA products

Solutions available

Full KEMAR Manikin solution

KB5000/KB5001 New Pinnae

Low noise Ear & Cheek simulator

Stand-alone Low noise
Ear simulator system

Take home message

- We will not tell you what your product should sound like
- This will not replace human ear

HOWEVER:

- This is the best tool available on the market
- This will speed up your R&D process
- This will give you more insight into the acoustic behavior of your device
- This will improve acoustic test correlation with subjective feedback

Questions?

Questions can also be directed to the following emails:

contact_us@gras.us

gras@gras.dk

Check also our webpage

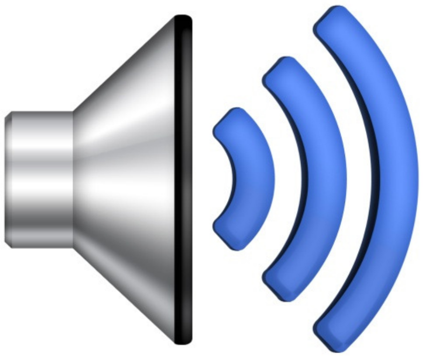
gras.us

gras.dk

We make microphones

Thank-you for attending today's presentation.

For more information about ALMA and for more education content, please go to www.almainternational.org
or email info@almainternational.org
or call 602-388-8669



Mission Statement:

ALMA is the source of standards, networking, and education for technical and business professionals in the acoustics, audio, and loudspeaker industry

Association of Loudspeaker Manufacturing & Acoustics International