Acoustical Measurement of Sound System Equipment according IEC 60268-21

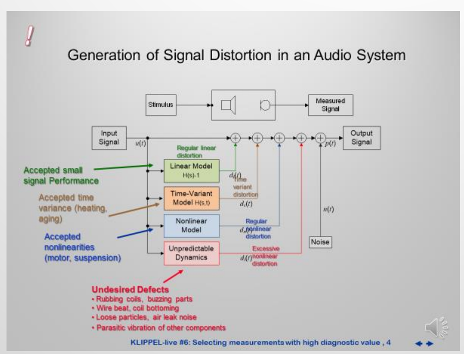
KLIPPEL LIVE

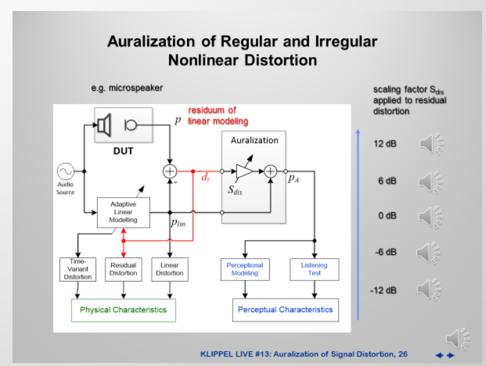
a series of webinars presented by

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 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 - rub&buzz, abnormal behavior, defects
11. Pitfalls in Testing Wireless Audio Devices
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





14th KLIPPEL LIVE:

设置有意义的信号失真公差

Setting meaningful tolerances for signal distortion

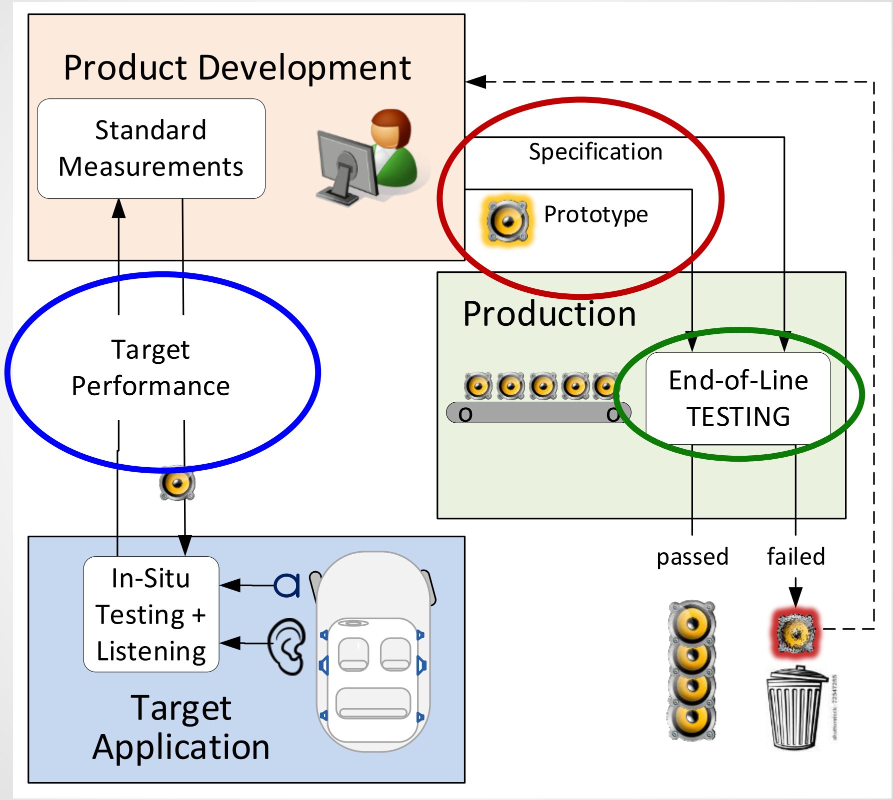
今日主题 Topics today:

- 对人耳处理进行建模 Modeling the processing in our ears
- 关键条件下的可听阈值 Audibility threshold under critical condition
- 用音乐测量的感知音质 Perceptual audio quality measured with music
- 大脑决定了音质 Our brain decides about the audio quality
- 最大化终端用户价值 Maximizing the end-user value

如何创建成功的音频产品?

How to create a successful audio product?

Life cycle



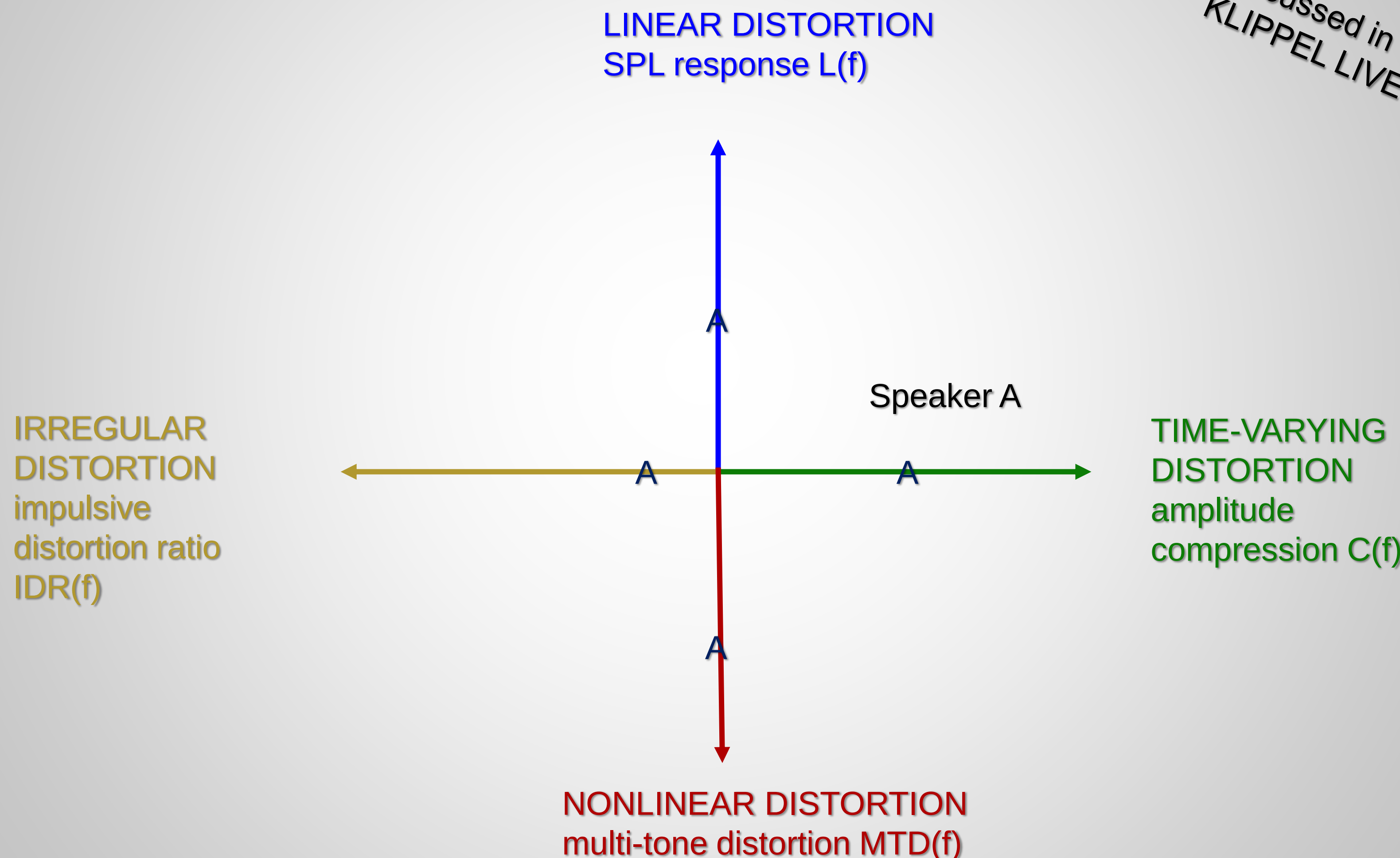
我们需要测量数据的目标值、界限值和公差!

We need target values, limits and tolerances for our measurment data !

IEC标准定义的基准测试的基本指标

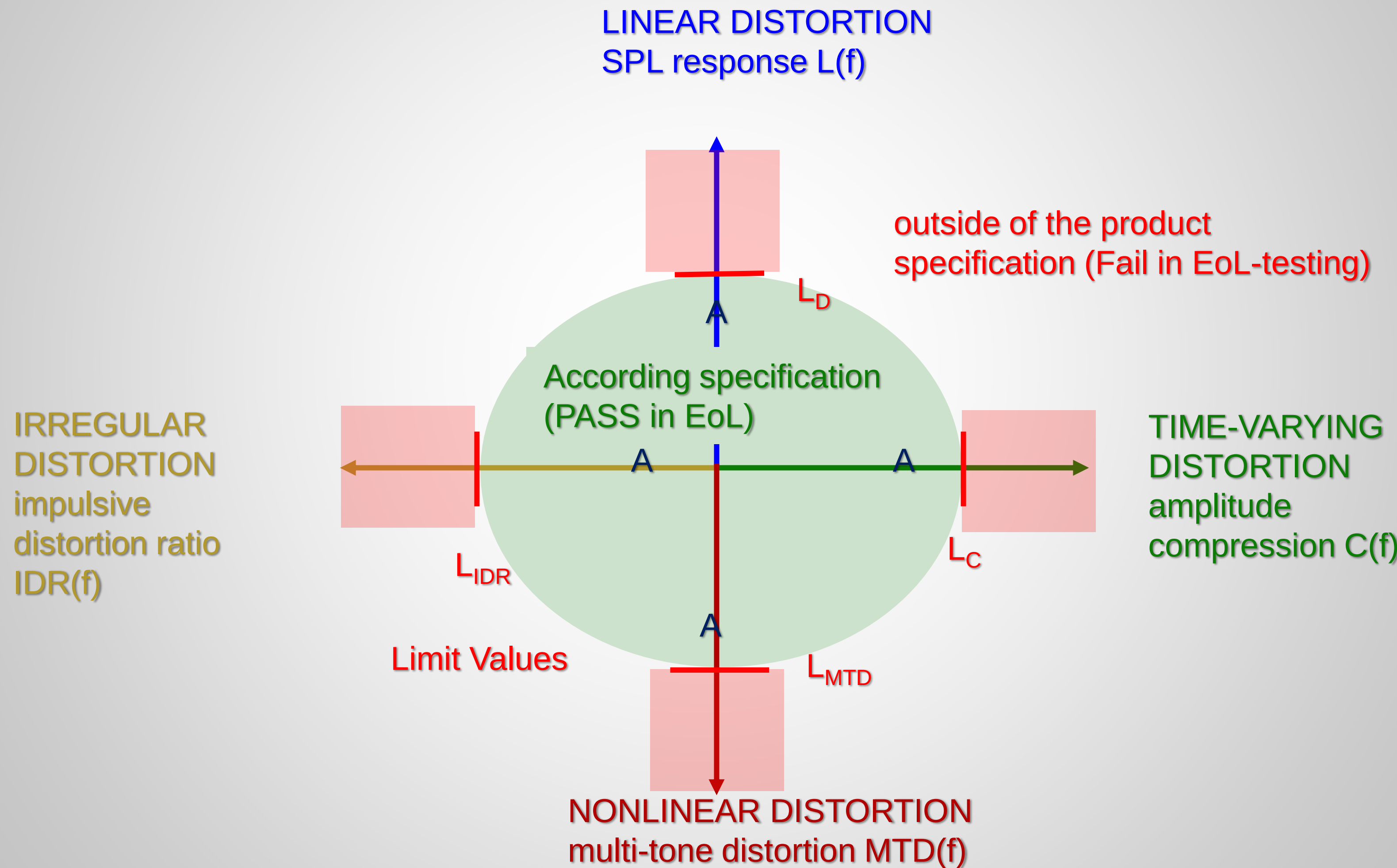
Essential Metrics for Benchmarking defined in IEC Standards

Discussed in KLIPPEL LIVE #12



对指标施加限制

Applying Limits to the Metrics



Poll:

您是如何为信号失真设定界限值的?
How would you set the limits for signal distortion ?

A. 达到界限值时，失真刚好可以被训练有素且经验丰富的听音者(金耳朵)在特定的关键条件下听到 At the limits, the distortion becomes just audible for a trained and experienced listener (GOLDEN EAR) under special critical conditions
B. 达到界限值时，失真可以被一般用户在典型条件下检测到 At the limits the distortion can be detected by a normal user under typical conditions
C. 在典型条件下，界限值对应的情况是，一般用户感知到的音质有小部分损失 The limits correspond to a small loss of perceptual audio quality as perceived by a normal user under typical conditions
D. 限制描述了失真不能被一些听音者接受 The limits describe distortion which are unacceptable for some listeners
E. 限制描述了信号失真为终端用户提供最佳性价比 The limits describe the signal distortion that generates the best benefit-cost ratio for end user
F. 其他 other

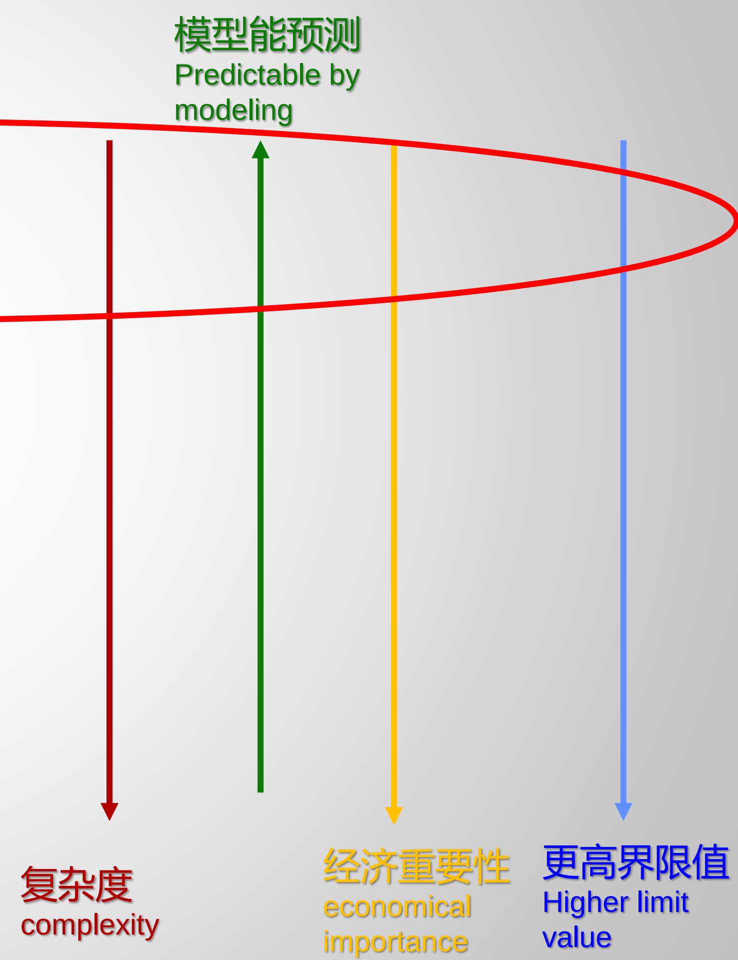
限制标准
Criteria for the Limits

最坏情况 Worst case scenario

I. 信号失真的可听阈值（灵敏的耳朵、关键测试条件） Audibility threshold of signal distortion (sensitive ear, critical test condition)

II. 一般终端用户在典型应用条件下所感知的音质下降不能被接受 Not acceptable degradation of audio quality as perceived by a normal end user under typical application condition

III. 终端用户看到的音频产品的价值大幅下降 A significant decrease of the value of the audio product as seen by the end-user



最坏情况 Worst Case Scenario

最关键条件下的可听度 Audibility under most critical condition

终端用户：经验丰富的听音者（比如，音响工程师、音乐家、发烧友）
End-user: Experienced listener (e.g. sound engineer, musician, audiophile)

最关键的程序素材：具有最佳幅值、频率设定和足够持续时间的双音信号
Most critical program material: two-tone signal with optimal amplitude, frequency setting and sufficient duration

声学环境：消声室（直达声主导、无环境噪声） Acoustical Environment: Anechoic room (dominant direct sound, no ambient noise)

测试方法：双盲AB测试找到刚好可检测差异 Test Methodology: Double Blind AB-Test to find a just detectable difference

界限：和可听阈值相同 Limit: Identical with audibility threshold

实用意义：高质量产品（例如监听音箱） Practical Relevance: High-quality products (e.g. Studio Monitor)

信号失真的可听度

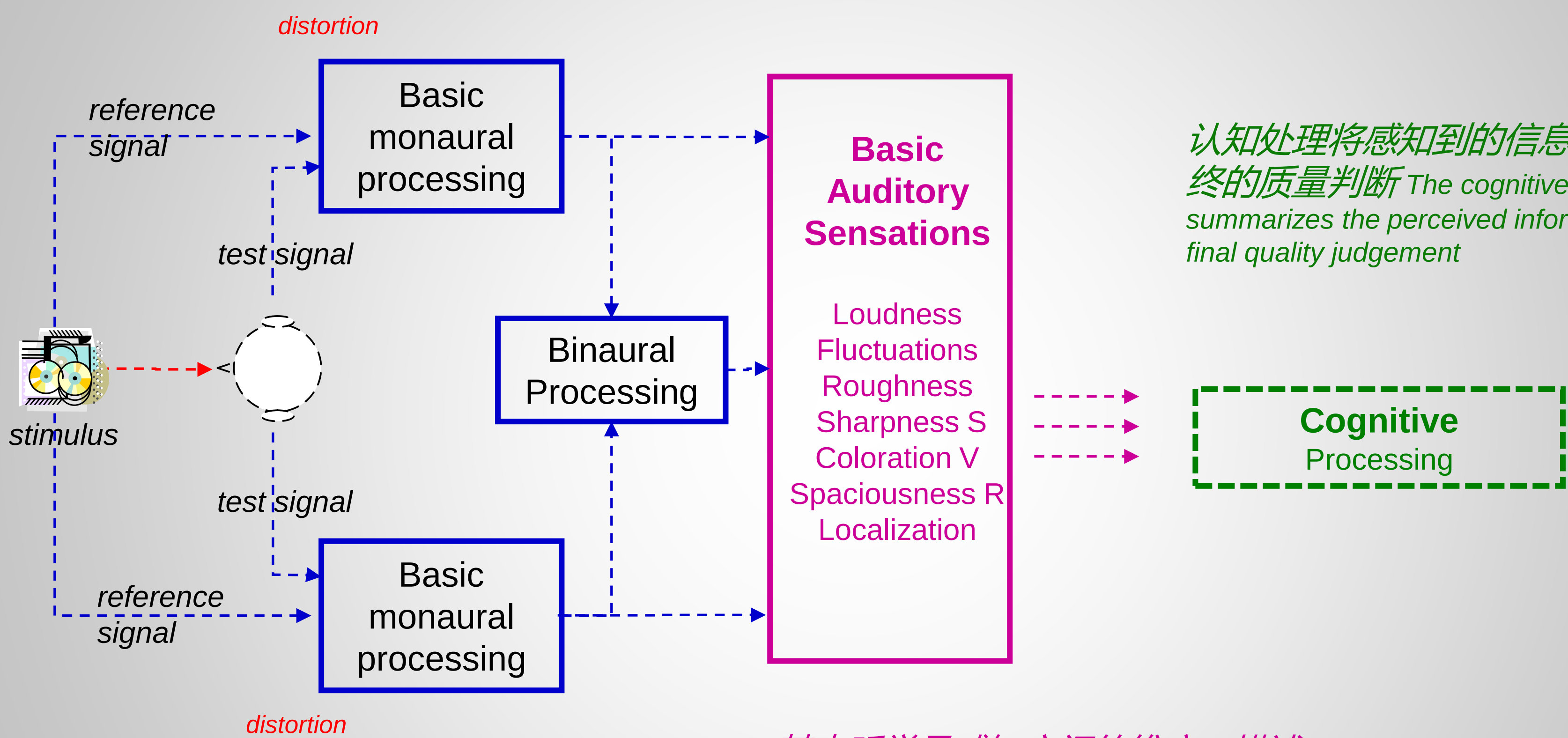
Audibility of Signal Distortion

评估方法 Methods for Assessments:

1. 基于基础研究对耳和脑的感知和认知过程进行建模 Modeling the perceptive and cognitive processing in ear and brain based on basic research
2. 聆听真实产品（选定参与者、程序材料、听音室、双盲AB测试、统计分析） Listening to real products (selected participants, program material, listing room, double blind AB test, statistical analysis)
3. 系统聆听修改后的声音输出（信号失真的可听化→ KLIPPEL live，＃13） Systematic listening to a modified sound output (Auralization of signal distortion → KLIPPEL live, #13)

基于感知建模的信号失真的评估

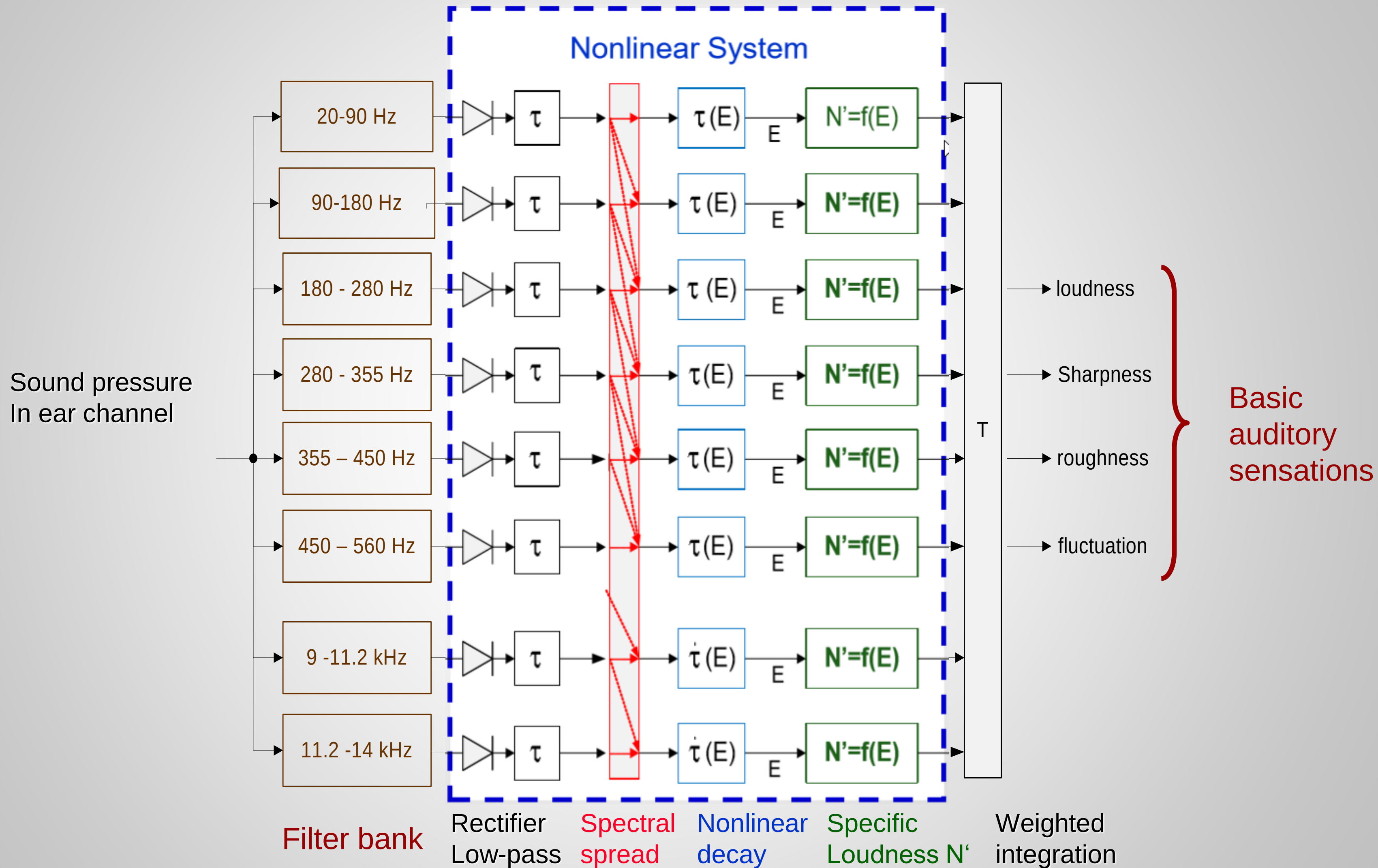
Evaluation of Signal Distortion based on Perceptual Modeling



认知处理将感知到的信息总结为最终的质量判断 The cognitive processing summarizes the perceived information to a final quality judgement

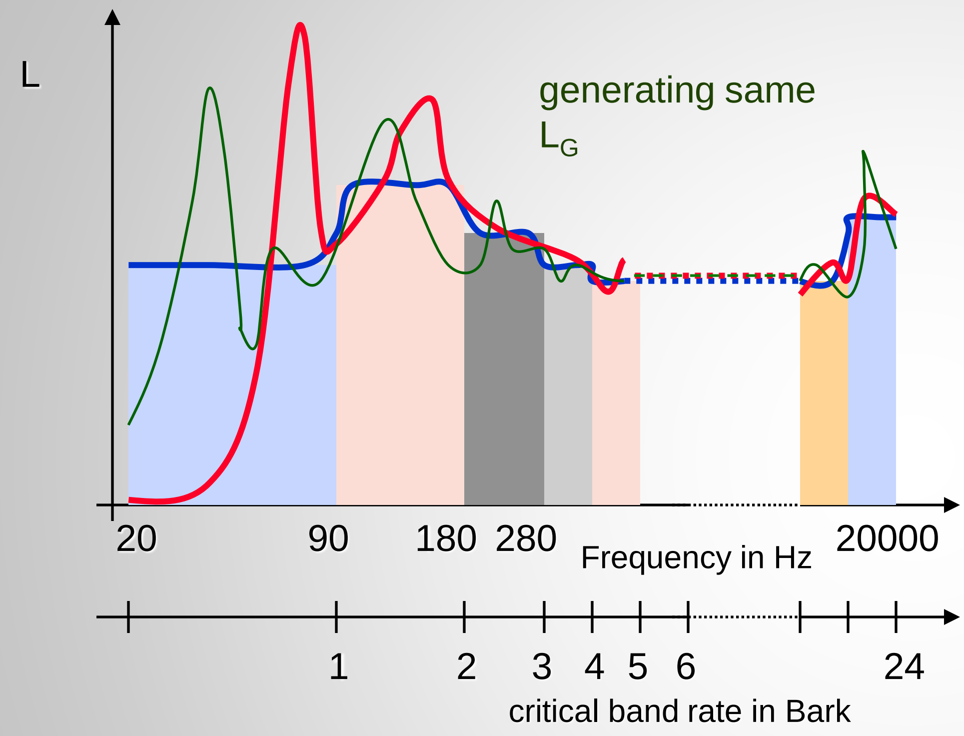
基本听觉是感知空间的维度，描述了失真的可听度 The basic auditory sensations are the dimensions of the perceptual space and describe the audibility of the distortion

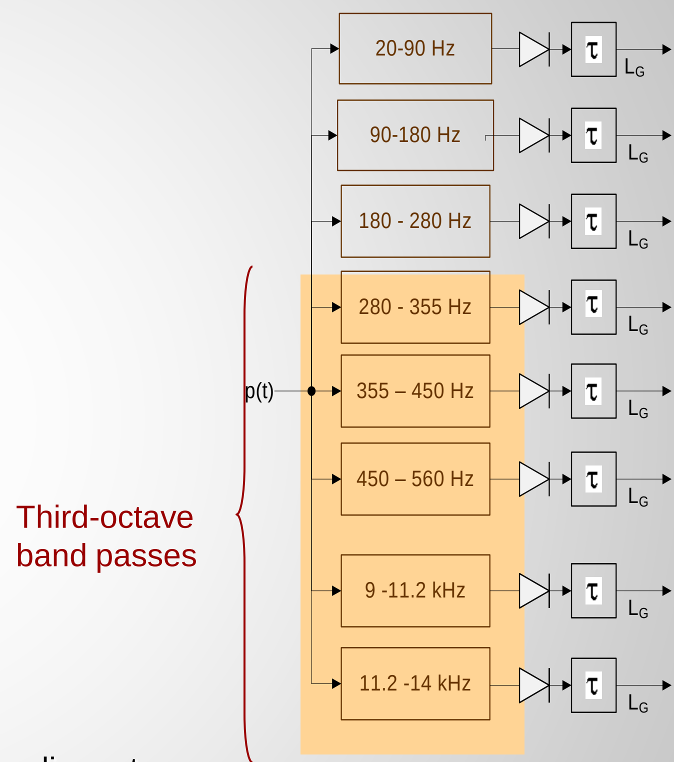
Basic Monaural Processing



Transformation

SPL Spectrum→ Critical Band Level L_G



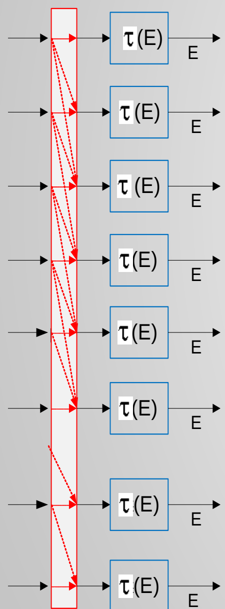


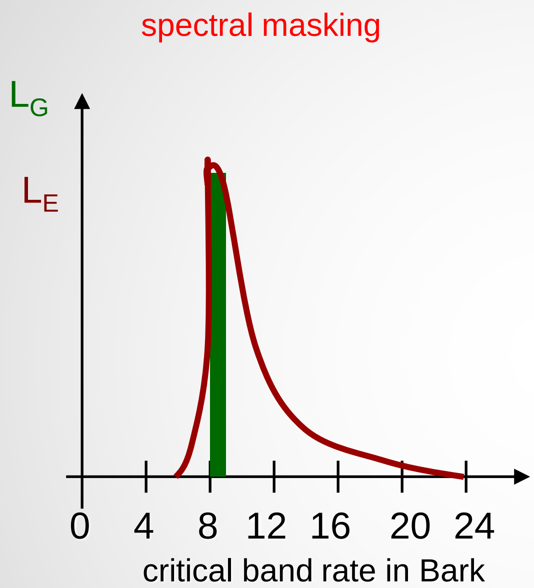
评估音响系统的结论： Consequences for the assessment of audio systems:

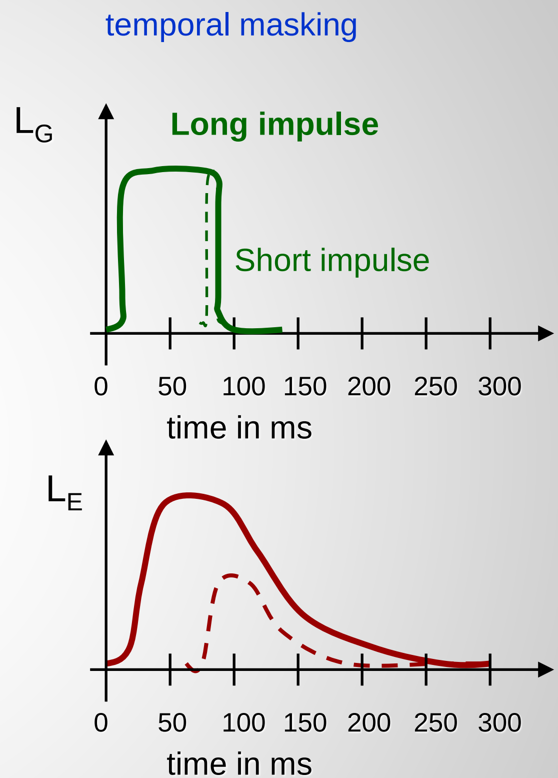
- 再现音频信号的1/3倍频程分析有助于解读音频链（激励-扬声器-房间-人耳）中的声染色 third-octave spectral analysis of reproduced audio signal is useful for interpretation of coloration in audio-chain (stimulus-speaker-room-ear)
- 可以通过增加临界频带中高频部分的电平级来增强低音感 bass sensations can be enhanced by increasing level of higher frequency components within the critical band
- 临界频带电平级的1dB变化可以被听到 1 dB variation of the critical band level becomes audible

Transformation

Critical Band Level L_G → Excitation Level L_E





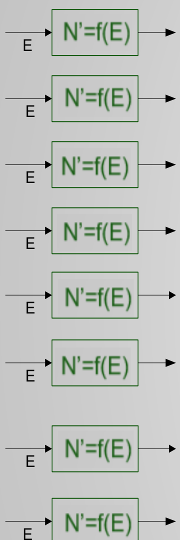


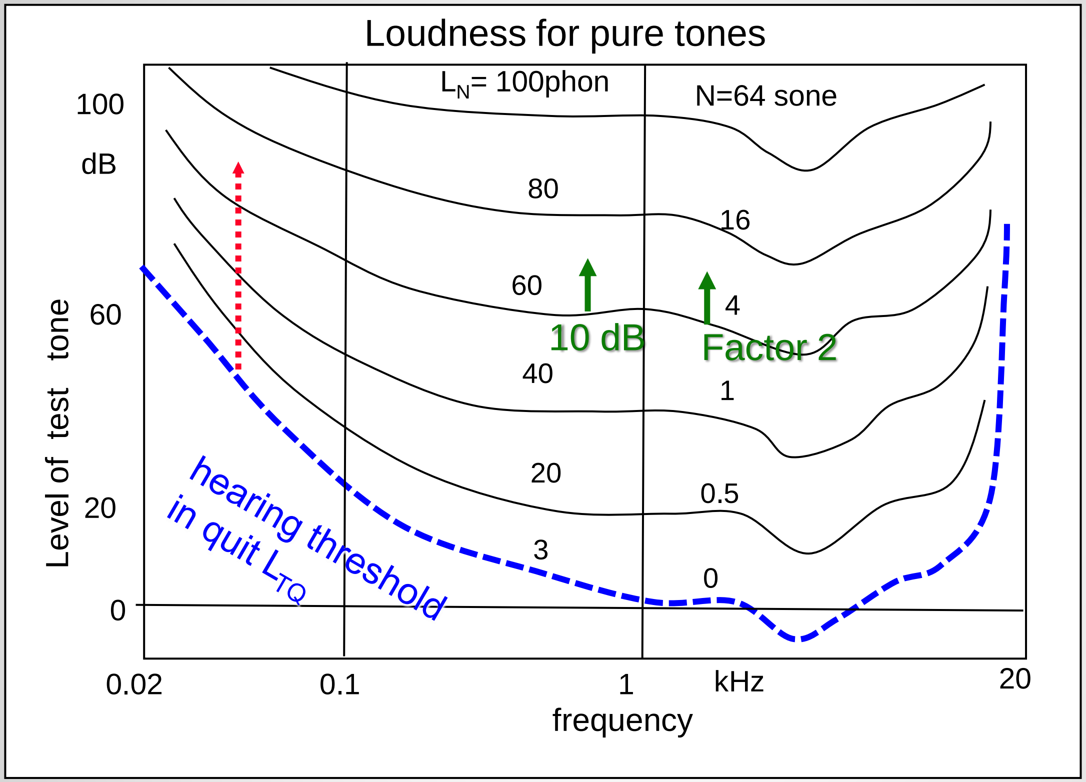
评估音响系统的结论： Consequences for assessment of audio systems:

- 幅值响应中的峰值比谷值更重要 Peaks are more critical than dips in amplitude response
- 非线性失真被基频分量掩蔽 Nonlinear distortion is masked by the fundamental component
- 包络的快速调制听不到 Fast modulation of the envelope is less audible

Transformation:

Excitation Level L_E → Specific Loudness N‘





1. Specific Loudness N‘=0 for $L_E < L_{TQ}$
2. Loudness doubles if excitation level rises by 10 dB for $L_E >> L_{TQ}$

评估音响系统的结论 Consequences for assessment of audio systems:

- 如果听音电平太低，则无法听到低音信号 Bass signals are not audible if the listening level is too low
- 传递响应的小差异可能导致低音感知的显著差异 Small differences in transfer response may cause significant differences in perceived bass sensation

Poll:

在最关键条件下，您将对总谐波失真THD应用哪种限制?
Which limit would you apply to Total Harmonic Distortion (THD) under most critical conditions ?

A. More than 10 %
B. 10%
C. 1 %
D. 0.1 %
E. 0.01 %
F. Less than 0.01 %
G. I don’t know

关键条件下的可听阈值

Audibility Thresholds under Critical Conditions

Distortion	Metrics	Audibility Thresholds
Linear Distortion	Variation of SPL frequency response ΔL(f)	0.5 … 1 dB
Time-variant linear distortion	Amplitude Compression C	0.2 … 1 dB
Regular Nonlinear Distortion	$D_{THD}(f)$, $D_{2HD}(f)$, $D_{3HD}(f)$, $D_{2IMD}(f)$, $D_{3IMD}(f)$	0.3 … 3 %
Irregular Distortion (defects)	Impulsive distortion ratio IDR(f)	-60 … -40 dB

线性失真的可听度 Audibility of Linear Distortion
最关键条件 most critical condition

Just-noticeable Changes in Amplitude

Reference: E. Zwicker, H. Fastl, Psycho-acoustics, Facts and Models, 2nd edition Springer

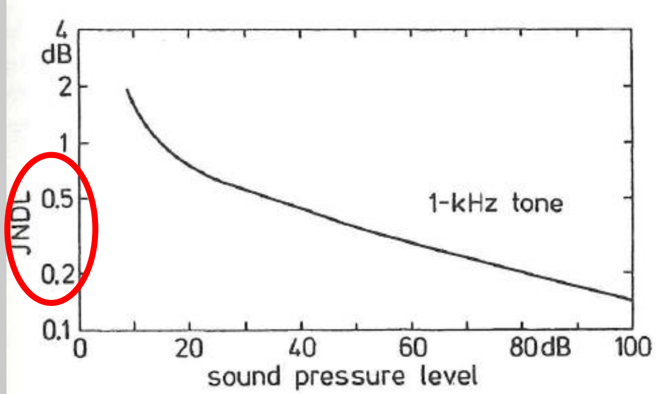


Fig. 7.5. Just-noticeable level difference of a 1-kHz tone as a function of sound pressure level

对音频测量的影响 Impact on Audio Measurements:

- SPL响应L(f) 与频率的变化
  Variation of SPL response L(f) versus frequency
- 幅值压缩C(t) 与时间的关系
  Amplitude Compression C(t) versus time

正弦激励阈值取决于：Threshold for sinusoidal stimulus depends

- 音调的频率和电平级 Frequency and level of the tone
- 音调的持续时间(至少0.5s) Duration of the tone (at least 0.5s)
- 音调之间的停顿(至少0.2s) Pause between the tones (at least 0.2 s)
- 其他因素 Other factors

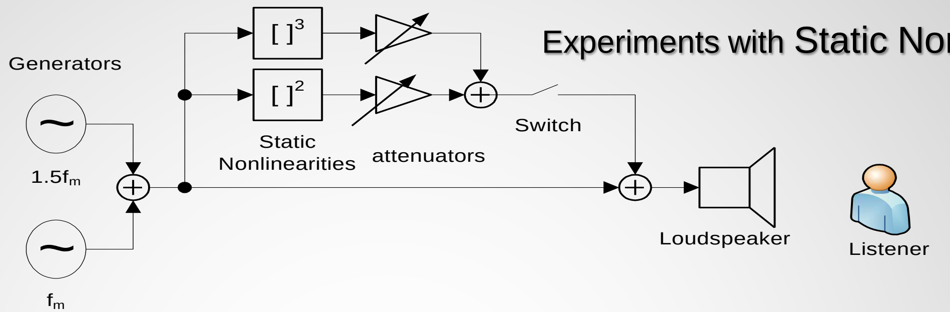
实践中的关键场景 Critical scenario in practice:

- 音乐中带稀疏频谱的滑音(连续滑奏)
  Glissando (continuous slide) in music with a sparse spectrum
- 声音事件定位中的刚好可察觉移动(偏侧化) Just noticeable shift in localization of the sound event (lateralization)

常规非线性失真的可听度

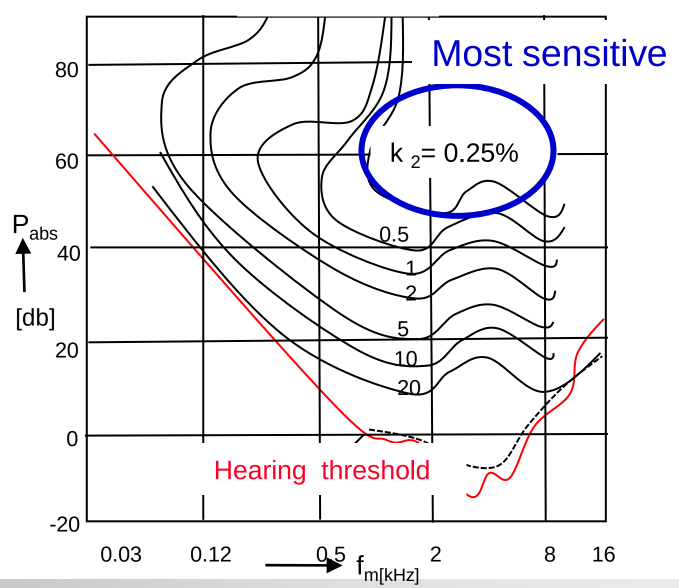
Audibility of Regular Nonlinear Distortion

Two tones
(fifth interval)

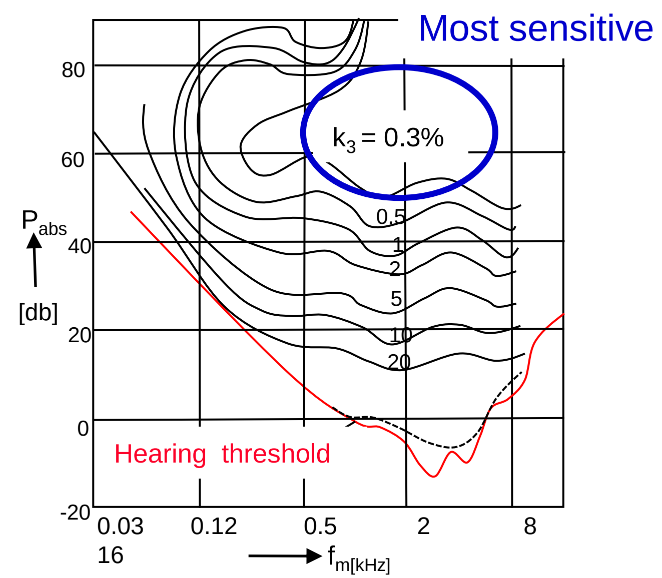


Experiments with Static Nonlinearities

Just- noticeable 2nd-order harmonic distortion



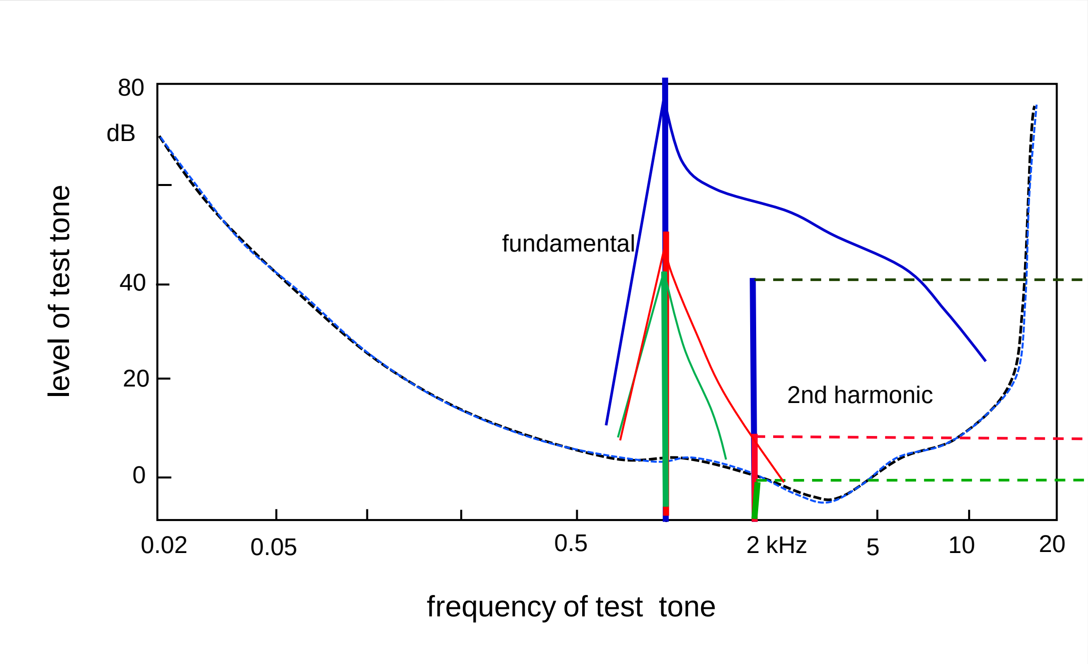
Just- noticeable 3rd-order harmonic distortion



Gäßler, G. Die Grenzen der Hörbarkeit nichtlinearer Verzerrungen bei der Übertragung von Instrumentenklängen. Frequenz 9, 15-25 (1955).

谐波失真的频谱掩蔽 Spectral Masking of the Harmonic Distortion

测试音电平被不同电平大小的1kHz音调掩蔽
Level of test tone masked by a tone at 1kHz of different levels



Reference: E. Zwicker, H. Fastl, Psycho-acoustics, Facts and Models, 2nd edition Springer

L_M= 80 dB and
1% of 2nd harmonic is not audible

L_M= 50 dB and
1% of 2nd harmonic is clearly audible

L_M= 40 dB and
1% of 2nd harmonic is not audible

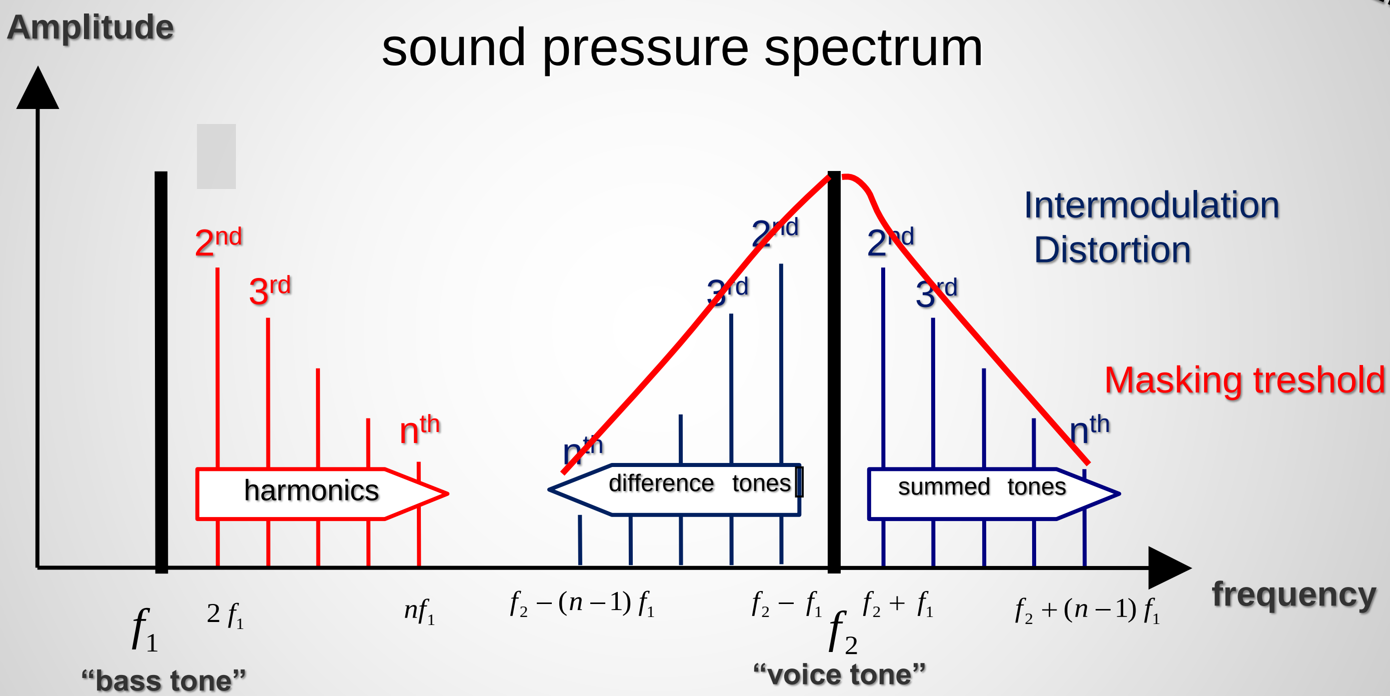
音频再现结论： Consequences for audio reproduction:

低SPL：安静时失真被听阈所掩蔽 Low SPL: Distortion are masked by hearing threshold in quiet
高SPL：失真被基波和人耳非线性所掩蔽 High SPL: Distortion are masked by the fundamental and ear nonlinearity

双音激励产生的互调失真

Intermodulation Distortion generated by Two-tone Stimulus

Discussed in KLIPPEL LIVE #9



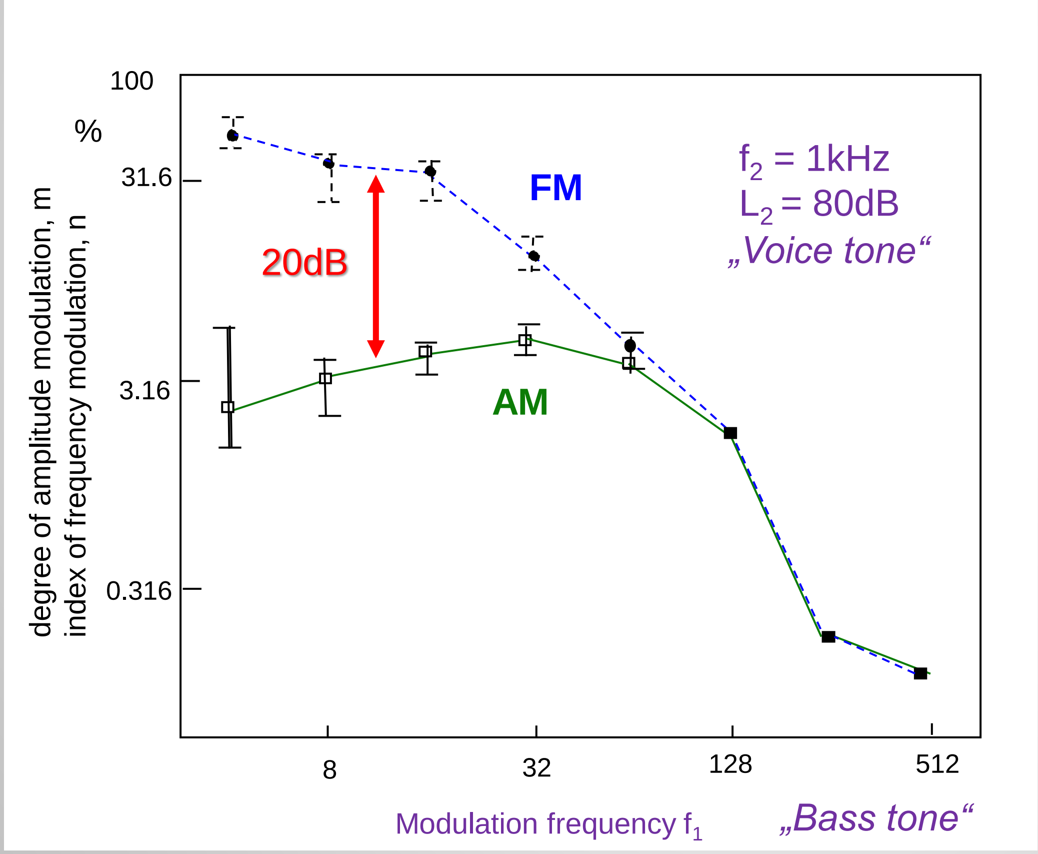
互调失真分量是否被基波所掩蔽？ Are the intermodulation distortion components masked by the fundamental ?

这取决于低音频率f_1！ It depends on the frequency of the bass tone f_1 !

互调失真的可听度

Audibility of Intermodulation Distortion

80dB SPL时，高频音f_2 = 1 kHz 的刚好可察觉调幅度和刚好可察觉调频指数，作为调制频率f_1的函数 Just-noticeable degree of amplitude modulation (AM) and just noticeable index of frequency modulation (FM) of a high-frequency tone f_2 = 1 kHz tone at 80 dB SPL, as a function of modulation frequency f_1



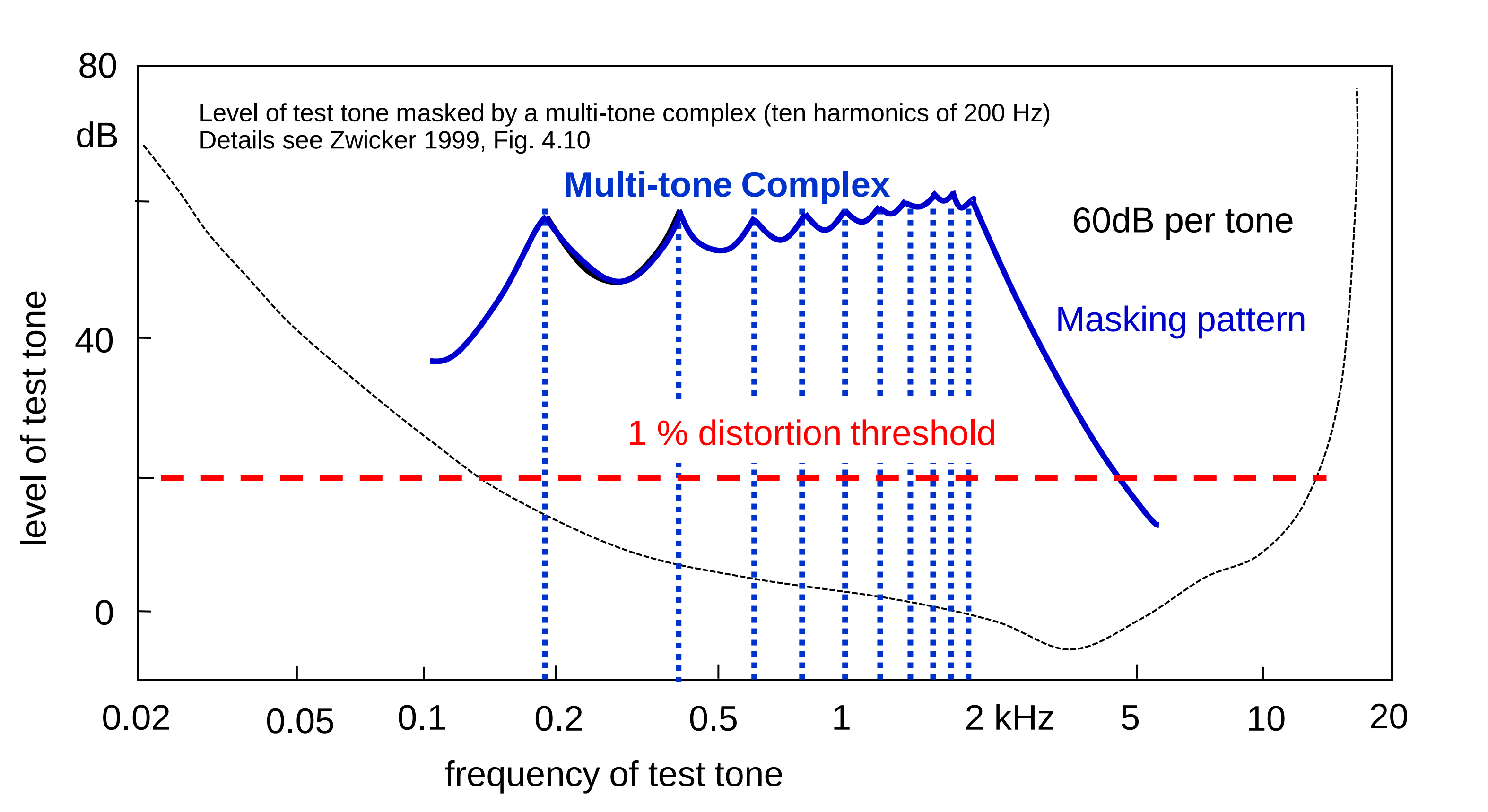
Zwicker, Fastl, 1999

结论 Conclusion:

- → 互调失真未被掩蔽(f_1 > 200Hz) the intermodulation distortion is not masked (f_1 > 200Hz)
- → **AM调制**(如力因数失真)达到3%时可闻并被感知为粗糙度和波动(f_1 < 100Hz) **AM modulation** (e.g. force factor distortion) is audible at 3% and perceived as roughness and fluctuation (f_1 < 100Hz)
- → **FM调制**阈值高于20dB (f_1 < 30Hz) Threshold of **FM modulation** is 20 dB higher (f_1 < 30Hz)
- → **多普勒**失真不重要 **Doppler** distortion is not critical

掩蔽阈值 Masking Threshold

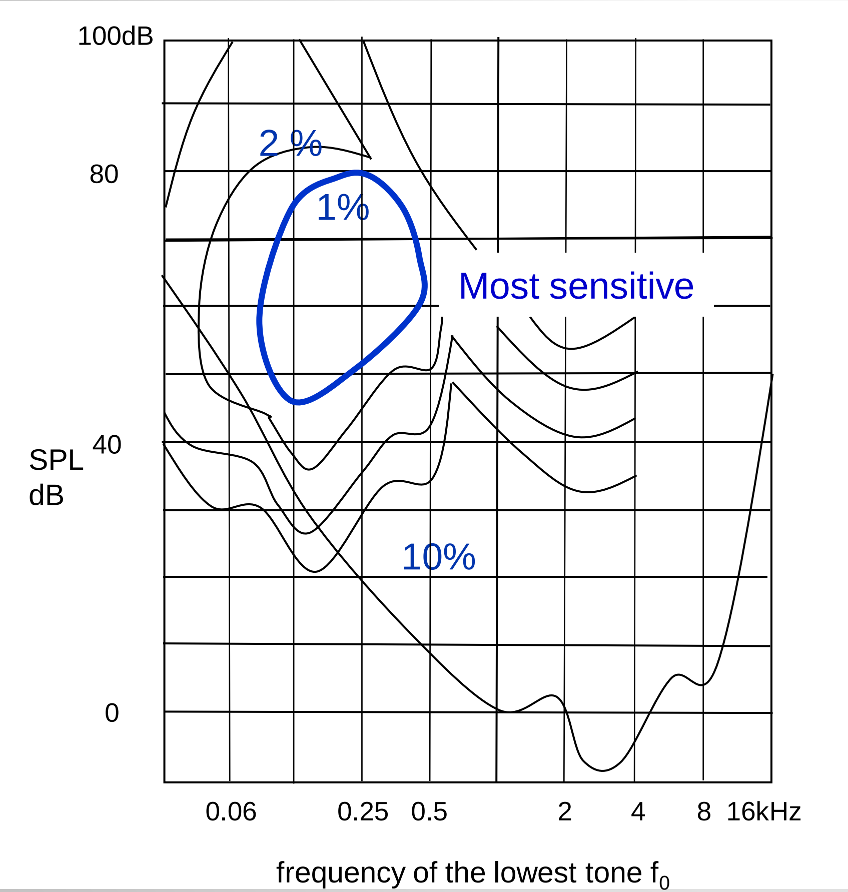
由带限多音激励产生 generated by a band-limed Multi-Tone Stimulus



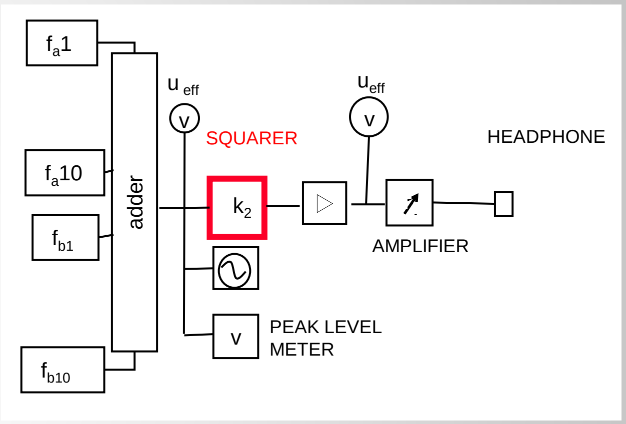
基频成分产生高掩蔽图 The fundamental components generate a high masking pattern.
高频处的失真可在1%阈值下检测到！ The distortion at higher frequencies can be detected at 1 % threshold !

互调的可听度 Audibility of Intermodulation

多音调复合音通过静态非线性 Multi-Tone complex via static nonlinearity



10 sinusoidal Generators at f_0 and harmonics

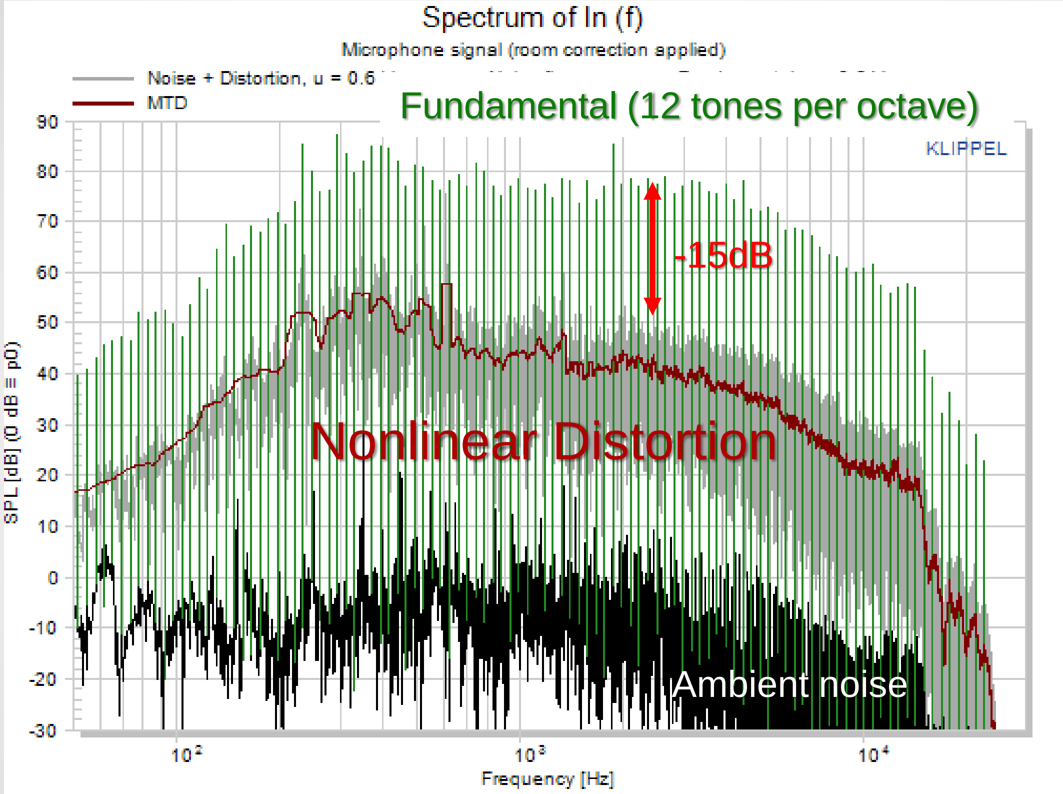


Gäßler, 1955

一个包含了基频和高达10阶谐波的失真多音调复合音的可听阈值

Threshold of audibility of a distorted multi-tone complex comprising fundamental f_0 and harmonics up the 10th order

密集谱中的非线性失真
Nonlinear Distortion in a Dense Spectrum



- 非线性失真被掩蔽在了响度和SPL频谱中！ Nonlinear Distortion are masked in the loudness and SPL spectrum !

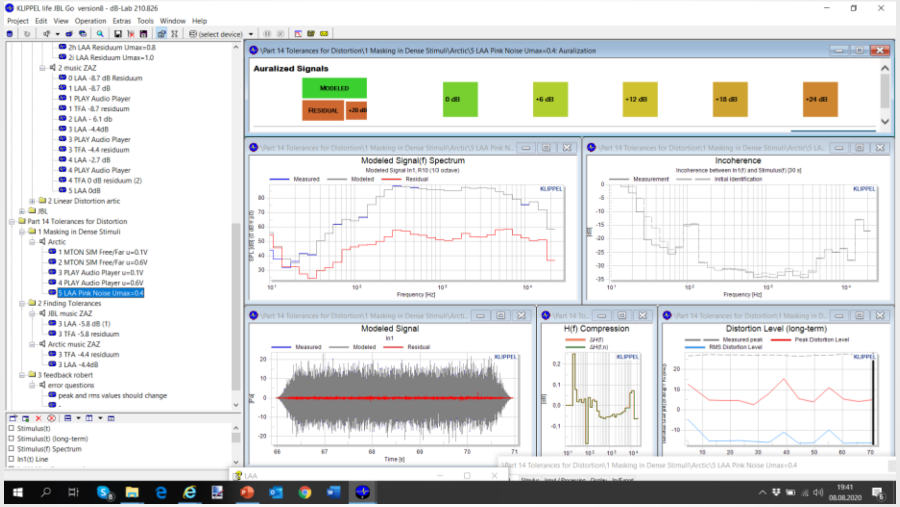
但是 BUT

- 非线性失真可在时域中被检测(为粗糙度和波动) Nonlinear Distortion can be detected in the time domain (as roughness and fluctuation)

Demo: Audibility of Amplitude Modulation

Tools: Using dedicated software modules of the KLIPPEL Analyzer

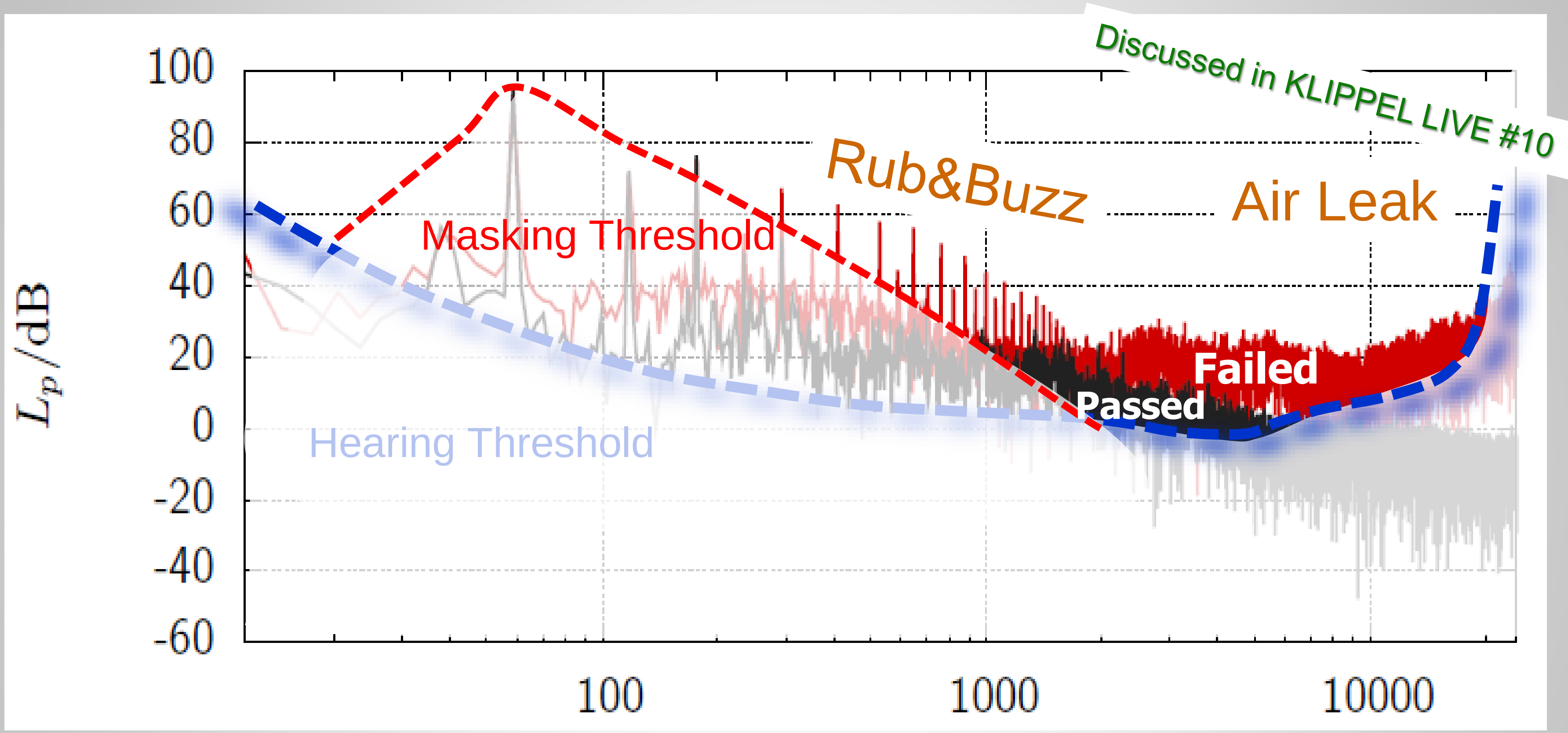
- LAA Live Audio Analyze
- MTONE Multi-tone Module



JBL Bluetooth Speaker (one channel)

Arctic Competitive Bluetooth Speaker (stereo, only left channel is used)

扬声器缺陷的掩蔽效应
Masking of Loudspeaker Defects

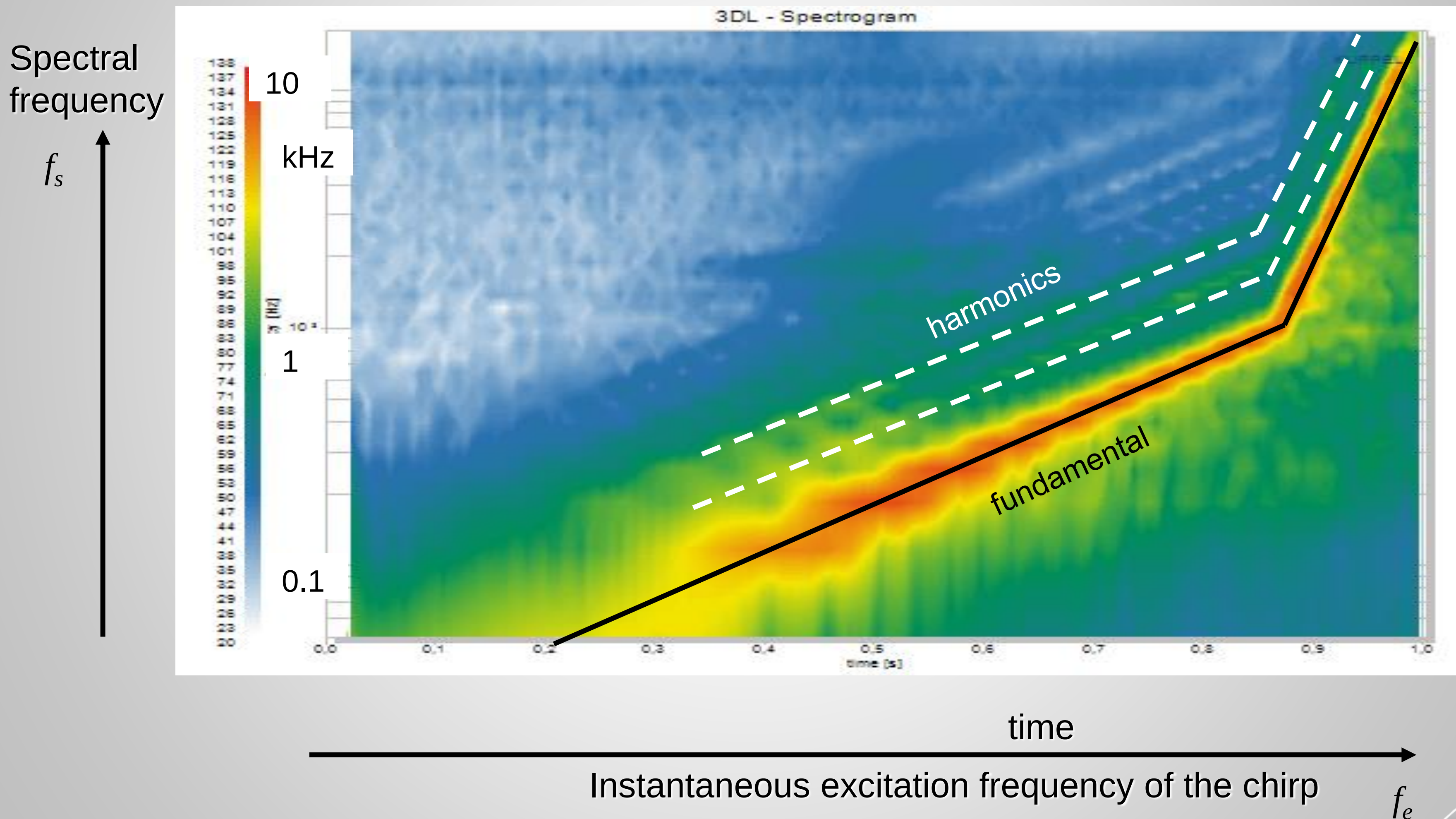


- 基频成分掩蔽了低次谐波 Fundamental component masks low-order harmonics
- 听阈也掩蔽了高频的非常规失真 Hearing threshold also masks irregular distortion at high frequency

问题：哪些感知指标能揭示扬声器缺陷？ Questions: Which perceptual metrics reveal the loudspeaker defects ?

Spectrogram $L_{REF}(f_s,f_E)$
generated by an Auditory Filterbank

Discussed in KLIPPEL LIVE #10

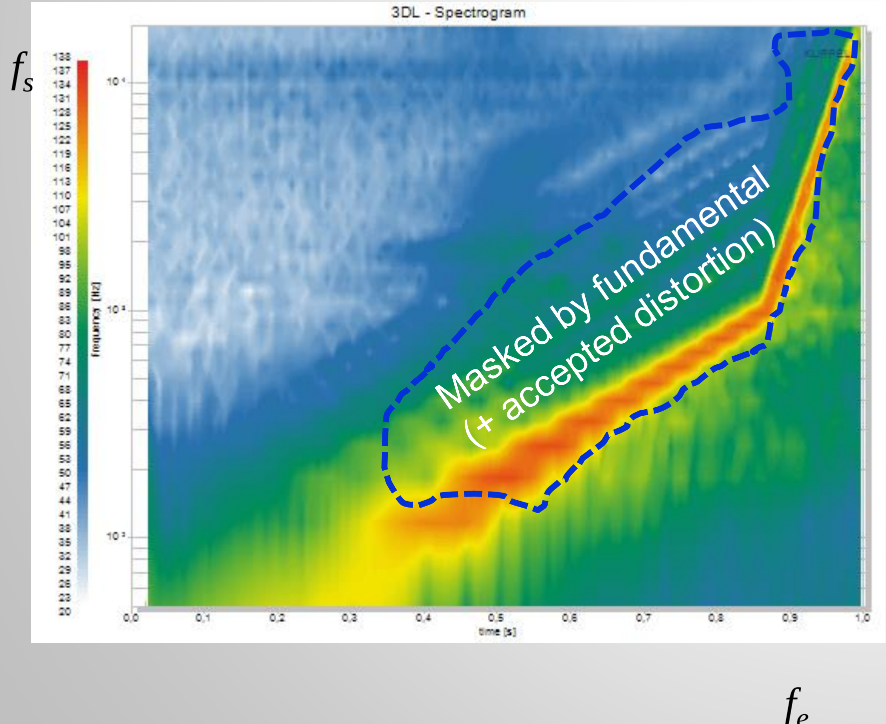


3D Disturbance to Mask Ratio

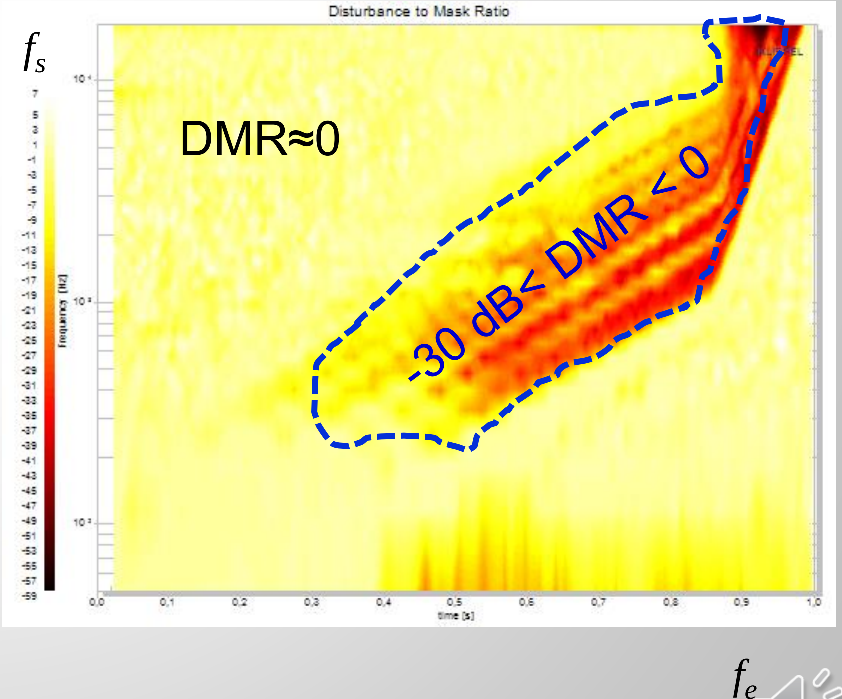
干扰掩蔽率显示了DUT频谱$L_{DUT}(f_s,f_E)$ 和黄金参考样的掩蔽阈值之间的差异!

Disturbance Mask Ratio shows the difference between the spectrum $L_{DUT}(f_s,f_E)$ of the DUT and the masking treshold generated by the Golden Reference Dut !

Spectrum $L_{REF}(f_s,f_E)$ of the Golden Reference DUT

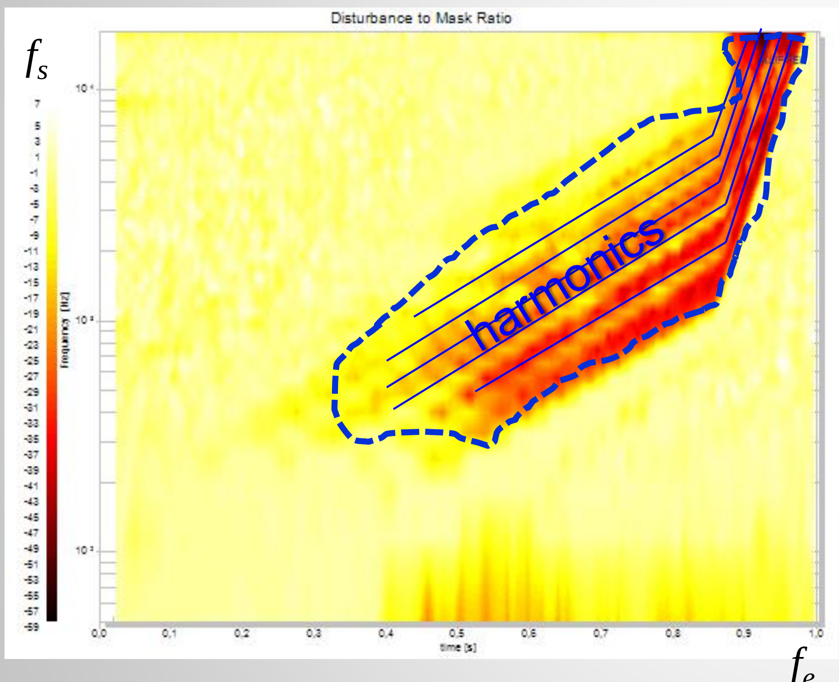


Disturbance Mask Ratio DMR(f,t) of the Golden Reference DUT



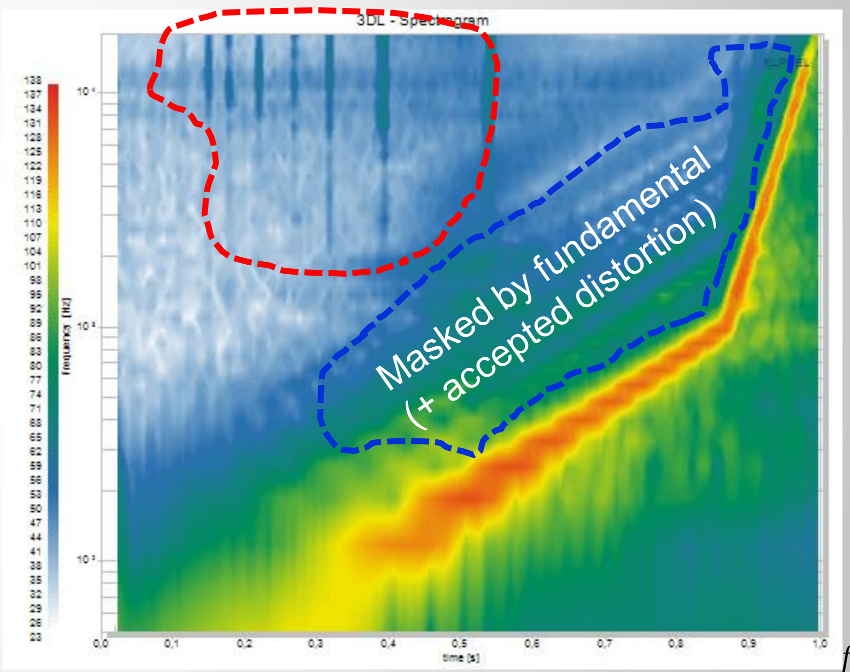
脉冲失真的轻度掩蔽
Low Masking of Impulsive Distortion !

黄金参考样的干扰掩蔽率DMR(f,t)
Disturbance Mask Ratio DMR(f,t) of the Golden Reference DUT



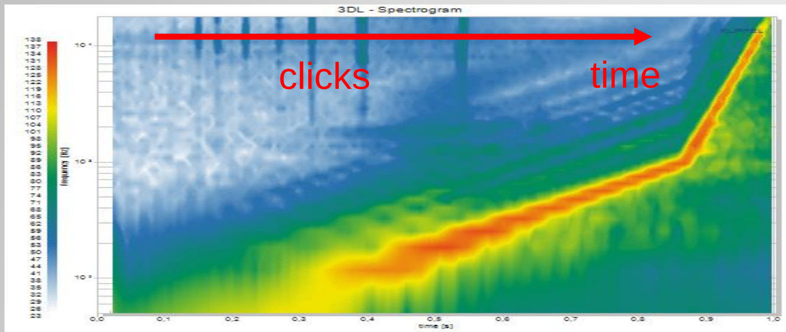
低次谐波失真(主导了THD)被基波和公认失真掩蔽 Low-order harmonic distortion (dominating THD) is masked by fundamental and accepted distortion

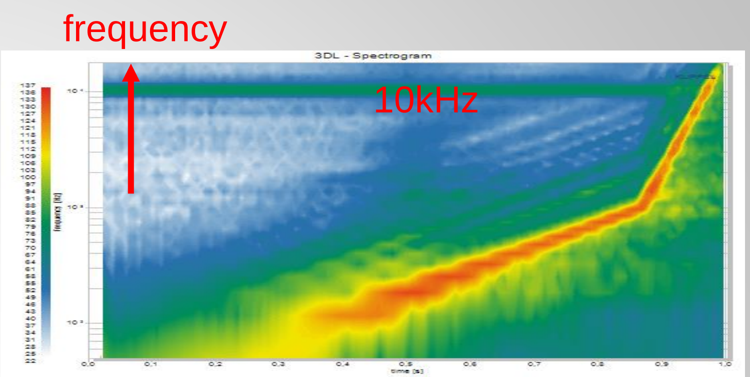
一款缺陷扬声器的3D频谱(一粒盐模拟的松散微粒) 3D Spectrum of a Defective Speaker (loose particles simulated by one grain of salt)



脉冲失真产生了高频成分，不能被基波掩蔽！ Impulsive Distortion generates high frequency components which are not masked by fundamental !

Basic Auditory Sensations





Temporal envelope variation
(e.g. amplitude modulation, transients)

↓

Increased Roughness

High-frequency distortion
(Increasing spectral power above 3 kHz)

↓

Increased Sharpness

Sensation: aggressive, unnatural, more noticeable

→ **Degradation of Sound Quality** ←

针对EoL测试的结论

Consequences for EoL-Testing

可听度是设置PASS/FAIL限制的可靠标准吗? Is audibility a reliable criteria for setting PASS/FAIL limits ?

- 不是，某些有缺陷的设备会产生略低于EoL的可听阈值的症状，但是**随着时间**故障会变得**越来越严重**，并导致以后的现场次品！ No, some defective units produce symptoms just below the audibility threshold at EoL but the failure becomes **worse over time** and cause a field reject later !
- 因此，传统EoL测试中聘请了训练有素且经验丰富的操作员来听音。 Thus, we have used **trained** and **experienced** operators for listening in traditional EoL testing.
- 如今，我们使用现代测试仪器，可以利用可用的物理信息，并在非常规缺陷（异常音）方面比人耳的**灵敏度和可靠性更高。** Today, we use modern test instruments that exploit available physical information and provide **more sensitivity and reliability** than the human ear for irregular defects (rub and buzz).

Questions, comments ?

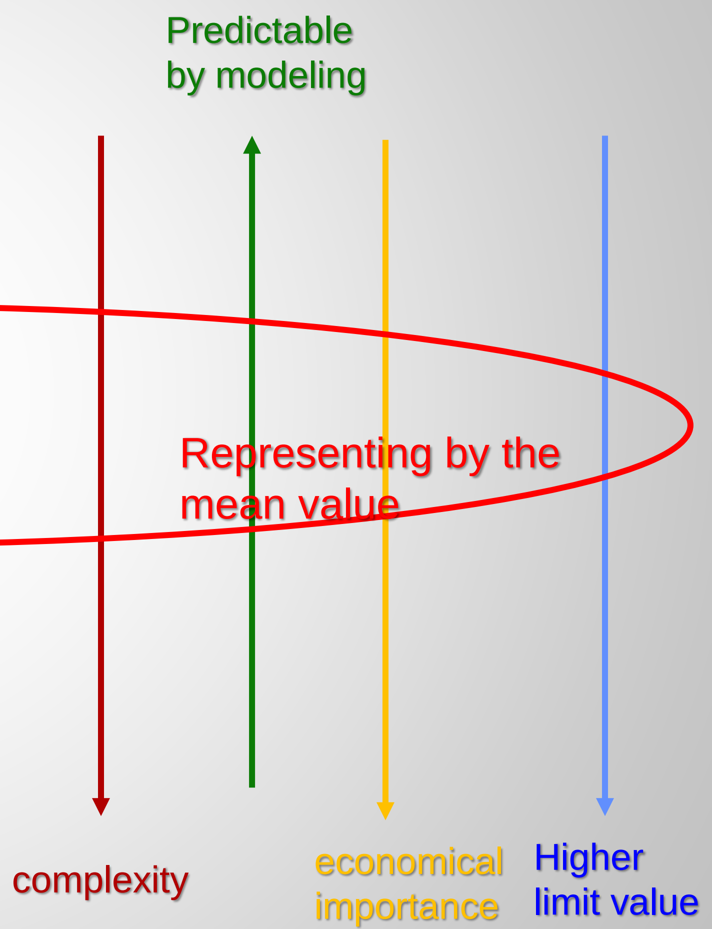
限制标准

Criteria for the Limits ?

I. 信号失真的可听阈值（灵敏的耳朵、关键测试条件） Audibility threshold of signal distortion (sensitive ear, critical test condition)

II. 一般终端用户在典型应用条件下所感知的音质下降不能被接受 Not acceptable degradation of audio quality as perceived by a normal end user under typical application condition

III. 终端用户看到的音频产品的价值大幅下降 A significant decrease of the value of the audio product as seen by the end-user



典型终端用户眼里的音质

Audio Quality as seen by the typical End-User

问题 Questions:

- 典型终端用户是什么? What is the typical end-user?
- 典型程序素材(音乐)是什么? What is the typical program material (music)?
- 典型的声学环境是什么? What is the typical acoustical environment?
- 如何简化音质的评估? How can we simplify the assessment of the audio quality?

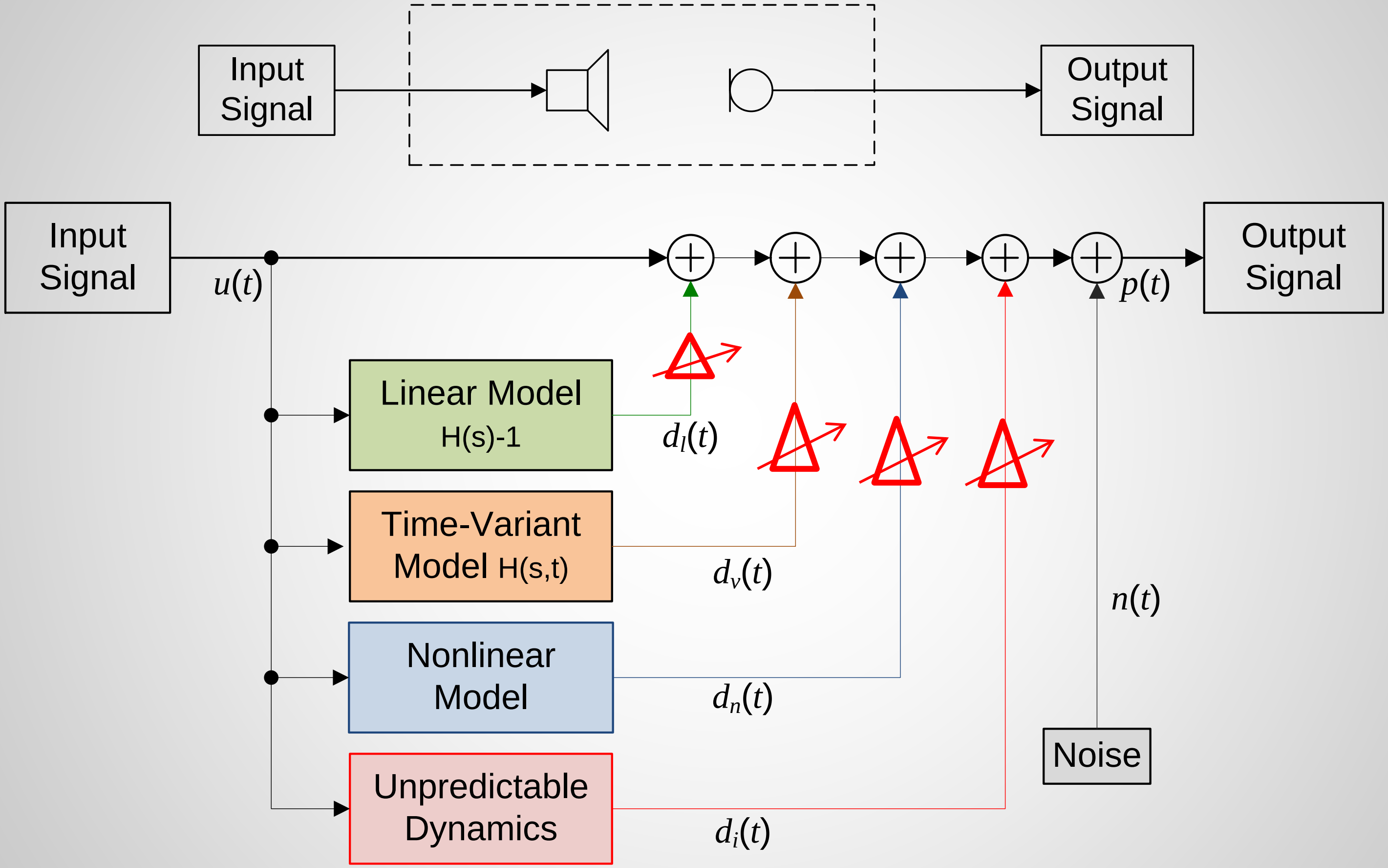
典型终端用户眼里的音质

Audio Quality as seen by the typical End-User

评估方法 Methods for Assessments:

1. 基于基础研究对耳和脑的感知和认知过程进行建模 Modeling the perceptive and cognitive processing in ear and brain based on basic research
2. 聆听真实产品（选定参与者、程序材料、听音室、双盲AB测试、统计分析） Listening to real products (selected participants, program material, listining room, double blind AB test, statistical analysis)
3. 系统聆听修改后的声音输出（信号失真的可听化→ KLIPPEL live，＃13） Systematic listening to a changed sound output (Auralization of signal distortion → KLIPPEL LIVE, #13

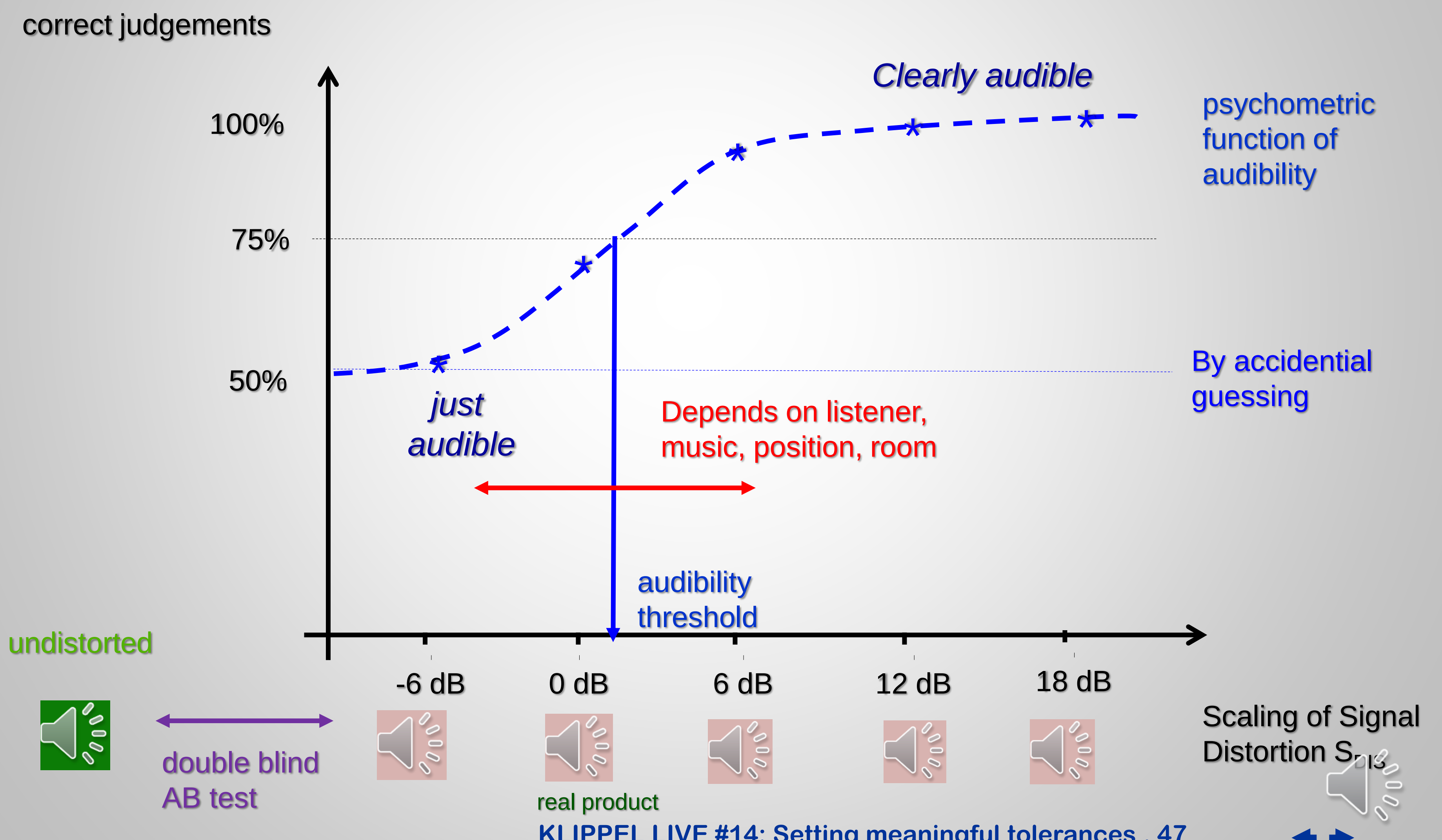
Assessing the Sensitivity of Signal Distortion



Virtual enhancement or attenuation of the distortion components (see KLIPPEL LIVE #13)

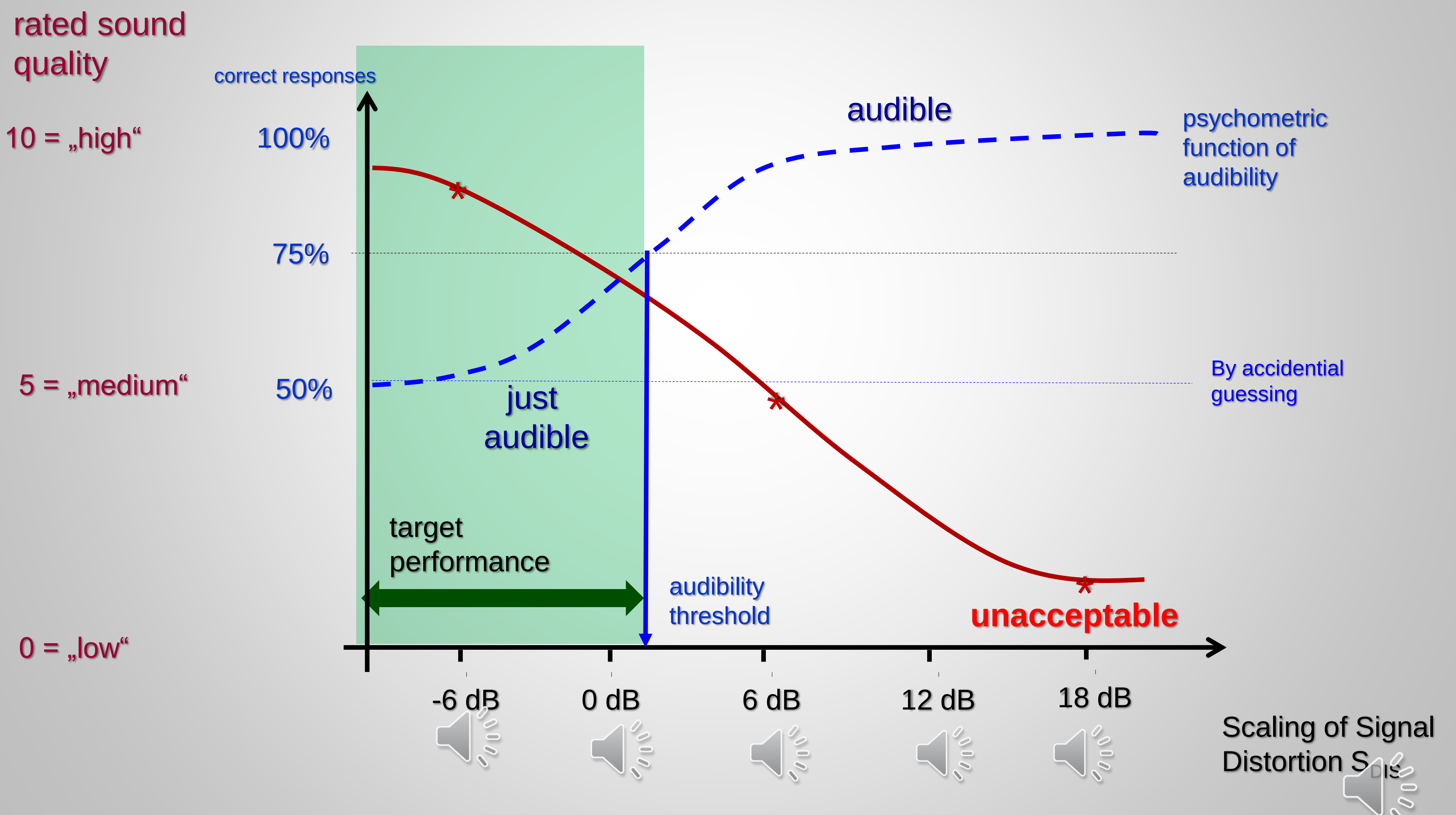
Measurement Audibility Threshold

Distortion generated by regular nonlinearity (force factor Bl(x))



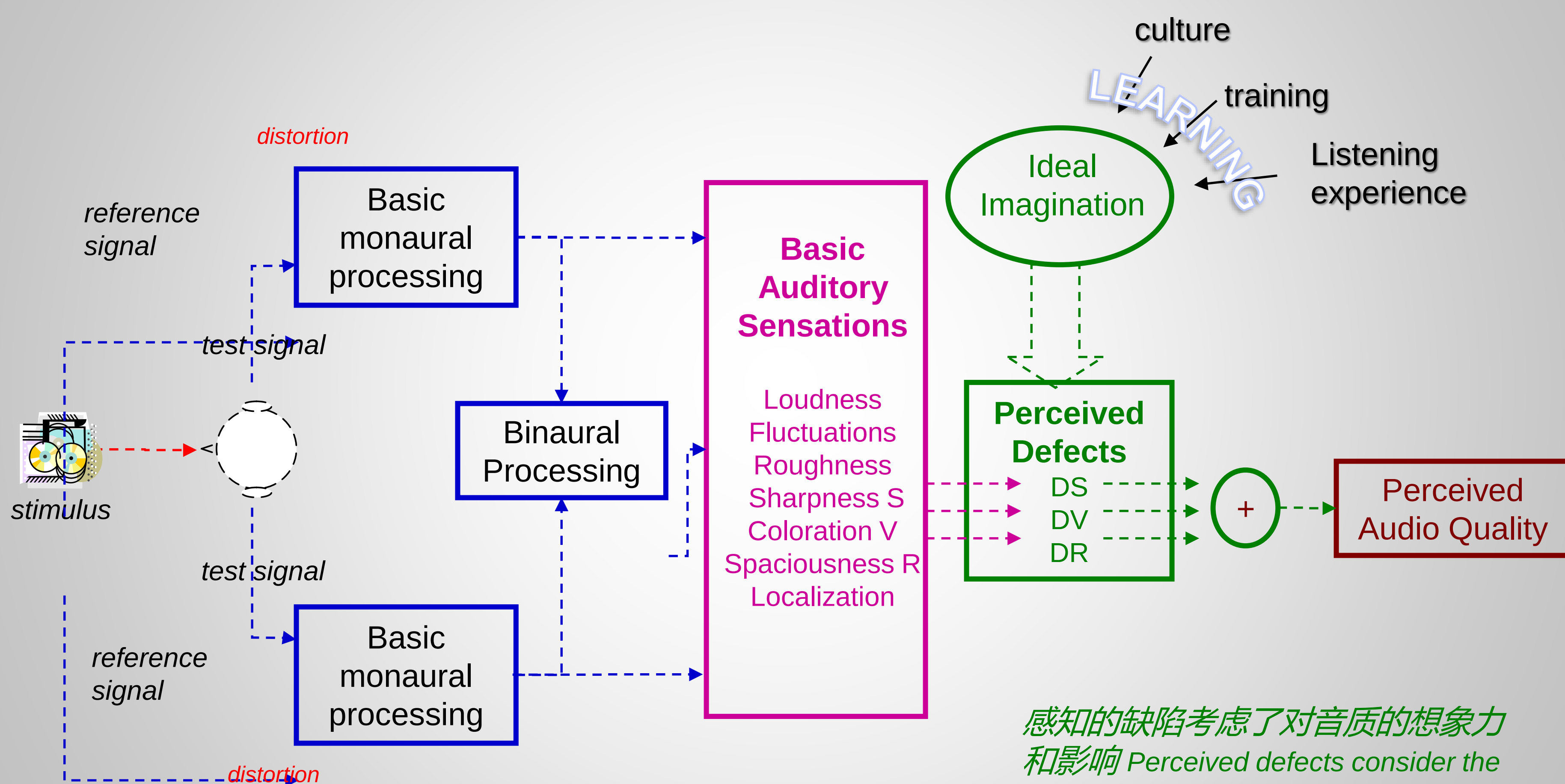
Audibility and Audio Quality

Distortion generated Regular Distortion (nonlinear force factor Bl(x))



评估信号失真 Evaluation of Signal Distortion

基于感知和**认知建模** based on Perceptual & **Cognitive Modeling**



感知的缺陷考虑了对音质的想象力和影响 Perceived defects consider the ideal imagination and the impact on audio quality

学习线性失真

Learning Linear Distortion

1 现场测试 Live Test

•每个房间有20个受试者使用3个程序评估3款扬声器 In each room 20 subjects evaluated 3 loudspeakers using 3 programs

•完成测试后移到下一个房间

After completing tests moving into the next room

结果 Results:

•扬声器之间有明显差异 Significant differences between loudspeakers

•房间没有明显影响 No significant influence of the room

2 双耳再现测试 Binaural Reproduction Test

•重复现场测试中的步骤 Repeating test in same order as Life Test

结果 Results:

•扬声器之间有明显差异 Significant differences between loudspeakers

•房间没有明显影响 No significant influence of the room

•与现场测试类似 Similar to Live test

3 随机次序测试 Random Order Test

双耳再现，但是房间、扬声器和程序随机 Binaural reproduction but presenting room, speaker and program in random order

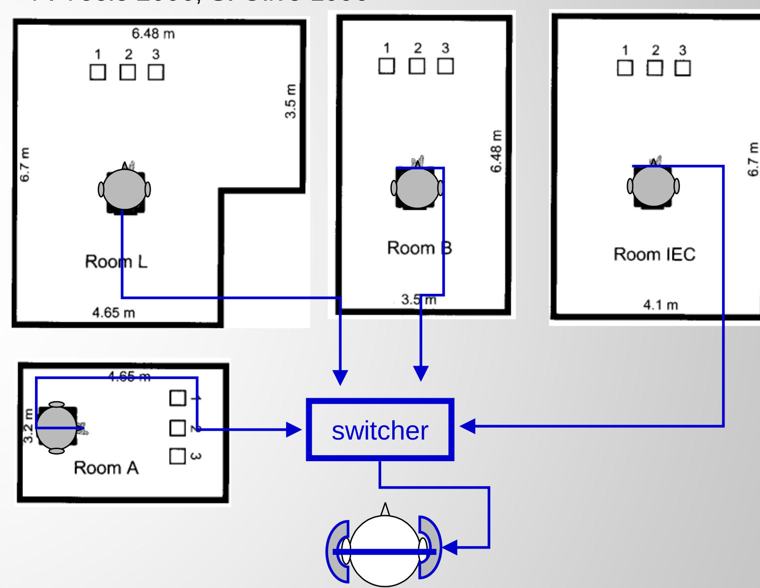
结果 Results:

房间之间有非常明显的差异 Highly significant differences between rooms

扬声器之间没有明显差异 No significant differences between loudspeakers

Reference: F. Toole, Sound Reproduction, loudspeakers and rooms, focal press

F. Toole 2006, S. Olive 1996



这就是适应性！ That is Adaptation !

有了很多问题，例如： Generates a lot of questions, for example:

如何进行有意义的听音测试？ How to perform meaningful listening tests ?

Poll:

您个人如何评价黑胶唱片中的典型噼啪声？ How do you (personally) assess the typical crackling sound found in vinyl records.

A. 从没听到过！ I never heard this!
B. 这种噼啪声只使耳朵不舒服，而不妨碍音质。 This crackling rather tickles the ear than obstructs the sound quality.
C. 我认为这是唱片中不能避免的东西。 I accept this as an unavoidable artifact in records.
D. 这是为什么我偏爱CD和其他数字存储媒介的原因之一。 This is one of the reason why I preferred CD and other digital storage media.
E. 这个声音立即引起我的注意，并且随着时间变得难以忍受。 It immediately attracts my attention and it becomes hardly bearable over time.

Poll:

您个人如何评价黑胶唱片中发现的但是由扬声器的松散颗粒产生的典型噼啪声？ How would you (personally) assess the typical crackling sound found in vinyl records but generated by loose particles in your loudspeaker ?

A. 从没听到过 I never heard this!
B. 这种噼啪声只使耳朵不舒服，而不妨碍音质。 This crackling rather tickles the ear than obstructs the sound quality.
C. 我认为这是一些扬声器的伪象。 I accept this as an artefact in some loudspeakers.
D. 这是我为什么买更好扬声器的原因之一。 This is one of the reason why I buy better speakers.
E. 这个声音立即引起我的注意，并且随着时间变得难以忍受。 It immediately attracts my attention and it becomes hardly bearable over some time.

感知信号失真的认知处理

Cognitive Processing of perceived signal distortion

感知信号失真的**认知评估**是一个**学习过程**！The **cognitive evaluation** of the perceived signal distortion is a **learning process**!

… 取决于时间 which depends on time …

评定取决于失真为听音者提供的信息。The rating depends on the information provided by the distortion to the listeners.

线性失真（幅值和相位响应）Linear distortion (amplitude and phase response)

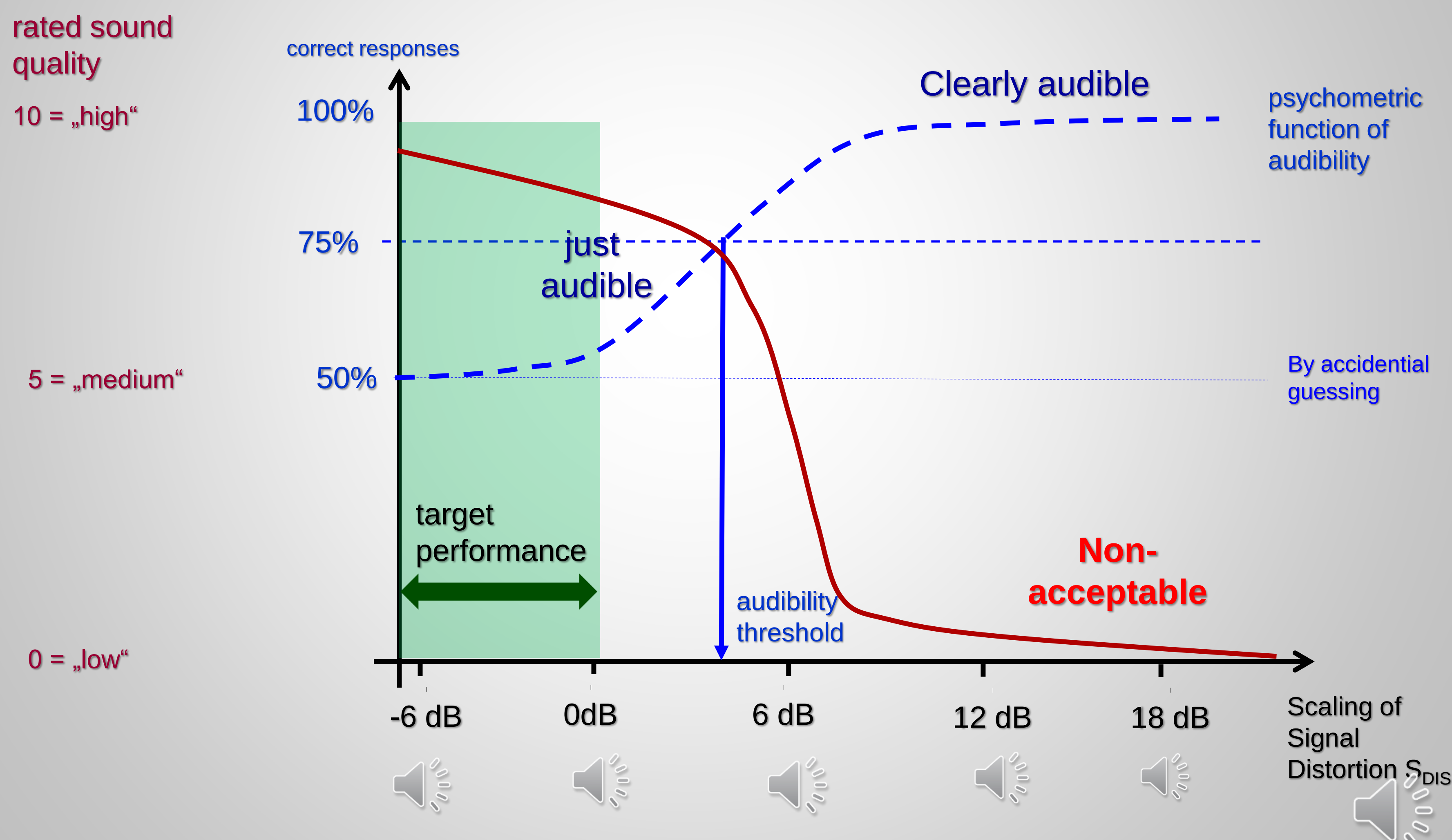
- 线性失真与激励相干 linear distortions are coherent to the stimulus
- 没有为听音者提供其他相关信息 provides no additional relevant information to the listeners
- 听音者习惯于它并会忽视它（适应、习惯）the listener gets accustomed to it and will ignore it (ADAPTATION, HABITUATION)

非线性和脉冲失真（异常音）Nonlinear and impulsive distortion (rub & buzz)

- 失真与激励不直接相关（非相干性）the distortion are not directly related to the stimulus (incoherent),
- 随着时间听音者把信号失真描述为刺耳 over time the listener describes the signal distortion as discordant
- 认知的提高使失真难以忍受（敏化）the rising awareness makes the distortion unbearable (SENSITIZATION)

Audibility and Audio Quality

Impulsive distortion generated by rub&buzz and other loudspeaker defects



Working with Average Values ?

Old Wisdom:
„The pond was 50 cm deep on average, but nevertheless the cow drowned."

剩余问题 Remaining Question

我们可以忽略听觉、音乐和房间影响方面的变化吗？ Can we neglect the variance in hearing, music and room influence ?

不可以：关键条件下敏化还在继续!
No: The sensitization goes on under critical condition !

解决方案 Solutions:

1. 通过物理建模和可听化技术生成虚拟测试对象 Generating virtual test objects generated by physical modeling and auralization techniques
2. 通过感知和物理建模评估听音条件对音质的影响 Assessing the influence listening conditions on audio quality by perceptual and physical modeling
3. 网络上的自动听音测试，以更深入了解终端用户的认知过程 Automated listening tests on the web to get more insight into the cognitive processing of the end user

示例：钢琴音乐是检测由侧开口智能手机产生的失真的关键激励信号!
Example: Piano music is a critical stimulus for distortion generated by smartphones with side-fire ports!

一种典型音乐能检测所有信号失真?
One Typical Music for all Signal Distortion ?

不能，激励信号对感知音质有很大影响（物理生成、感知掩蔽、对音乐观念的干扰）！
No, the stimulus has a high impact (physical generation, perceptual masking, disturbance to musical idea) on perceived audio quality ！

音乐（平稳有平坦密集谱，例如放松的风噪）
→ 着色 music (stationary with dense flat spectrum, such as relaxing esoteric wind noise) → Coloration

LINEAR
DISTORTION
SPL response L(f)

强低音且高动态的音乐 Music with strong bass and high dynamics
→ 清晰度、粗糙度、非谐波成分
sharpness, roughness, nonharmonic content

TIME-VARYING
DISTORTION

IRREGULAR
DISTORTION
impulsive
distortion ratio
IDR(f)

由多通道再现、电平级系统变化的语音和音乐 Multi-channel reproduction of speech and music with systematic level variation
→ 响度、"抽动"、偏侧化中的移动
loudness,"pumping", shift in lateralization

NONLINEAR
DISTORTION

平稳低音(位移)+小提琴、歌手、长笛(稀疏高频频谱)的音乐 Music with stationary bass (displacement) + violin, singer, flute (sparse high frequency spectrum)
→ 粗糙度、非谐波成分、尖锐度 roughness, non-harmonic content, coloration, sharpness

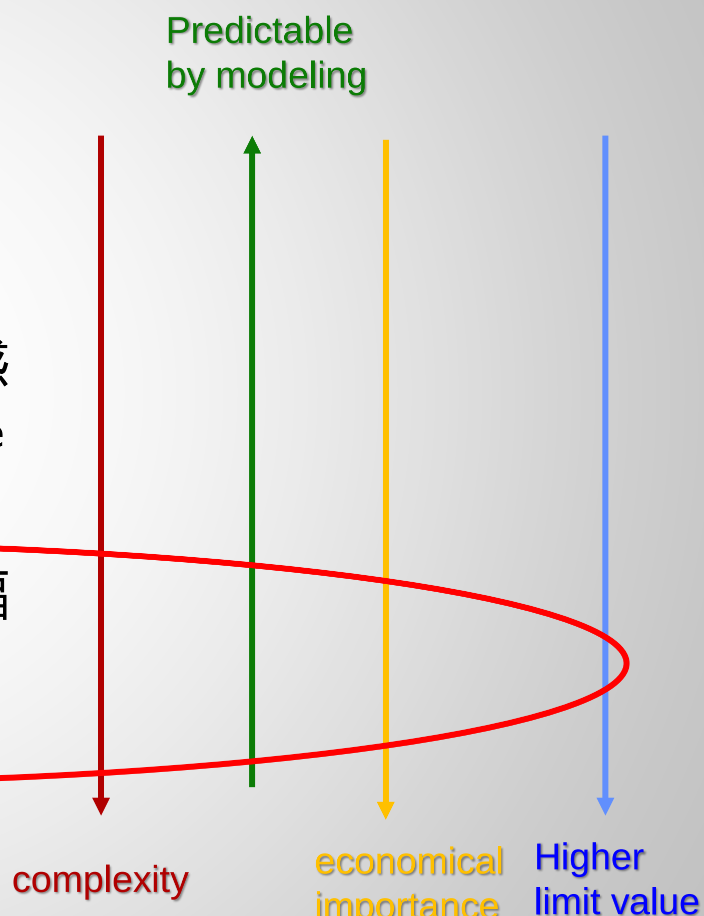
Questions, comments ?

Criteria for the Limits ?

I. 信号失真的可听阈值（灵敏的耳朵、关键测试条件 Audibility threshold of signal distortion (sensitive ear, critical test condition)

II. 一般终端用户在典型应用条件下所感知的音质下降不能被接受 Not acceptable degradation of audio quality as perceived by a normal end user under typical application condition

III. 终端用户看到的音频产品的价值大幅下降 A significant decrease of the value of the audio product as seen by the end-user



Poll:

您会妥协用音质换取其他好处吗?
Would you make a compromise and trade audio quality for other benefits ?

A. 绝不! Never !
B. 会，如果音频设备明显更小、更轻、更方便。Yes, if the audio device is significantly smaller, lighter and more convenient.
C. 会，如果电池供电设备的续航时间大大延长。Yes, if the operation time of a battery powered device is significantly extended.
D. 会，如果SPL输出显著提升。Yes, if the output SPL is significantly increased.
E. 会，其他理由。Yes, other reasons.

音频产品优点

Benefits of the Audio Device

性能空间范围：Dimensions of the performance space:

- 尺寸、体积、形状、重量 size, volume, shape, weight
- 最大输出(SPL$_{max}$, 功率$P_{a,max}$) maximum output (SPL$_{max}$, power $P_{a,max}$)
- 效率(功耗P_E、发热、电池供电设备的续航时间) efficiency (power consumption P_E, heating, mobile operation time in battery powered devices)

标准中明确定义
Well defined in standards

- 感知的音质(频谱和空间特性、失真) perceptual audio quality (spectral and spatial properties, distortion)
- 可靠性(故障概率) reliability (probability of failure)
- 外压（过载、环境）的耐久性 endurance of external stress (overload, environment)

音响工程的中心话题
A central topic in audio engineering

- 艺术产品设计和人体工程学artistic product design and ergonomics
- 技术故事 technical story
- 品牌声誉、用产品彰显个人身份 reputation of the brand, personal identification with the product
- 娱乐或享乐偏好 enjoyment or hedonistic preference

需要其他专家的更多研究
More research required by other experts

Value = Benefit Cost Ratio

Performance Sensitivity
$\mathbf{W}=\{w_1, \ldots, w_k, \ldots\}$

Benefit
(weighted performance)

performance features in
$\mathbf{P}=\{p_1, \ldots, p_k, \ldots\}$
(SPL_{max}, THD, …)

End User Value V
(acceptance, sales volume)

$$V(\mathbf{D}) = \frac{\sum_{\forall k} w_k p_k(\mathbf{D})}{\sum_{\forall j} C_j(\mathbf{D})}$$

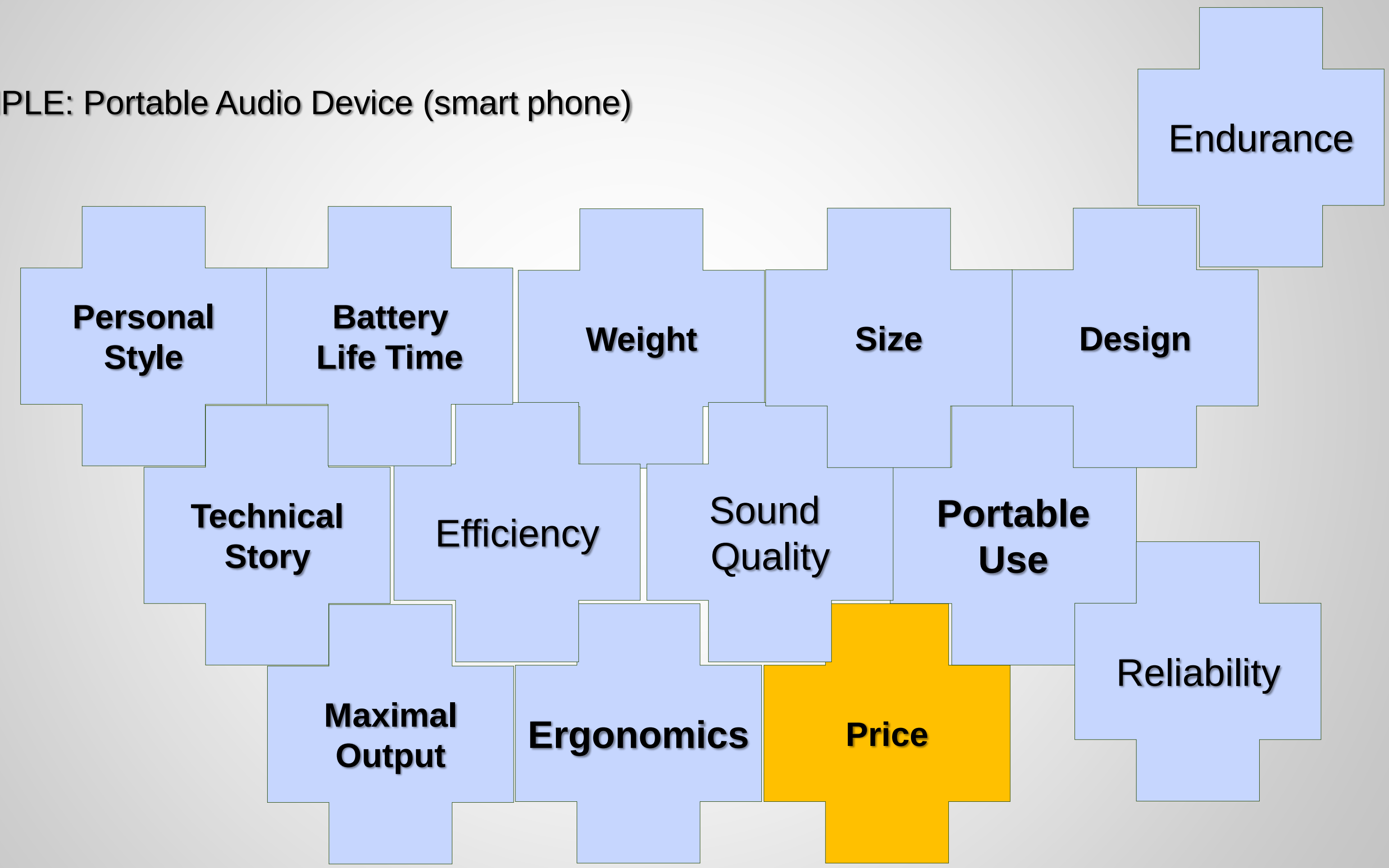
Design variables
$\mathbf{D}=\{d_1, \ldots, d_k, \ldots\}$

Cost structure

目标 Objective:
以最佳性能P和最低成本C_j最大化终端用户价值V
Maximizing the end user value V with the optimum performance **P** and minimum costs C_j

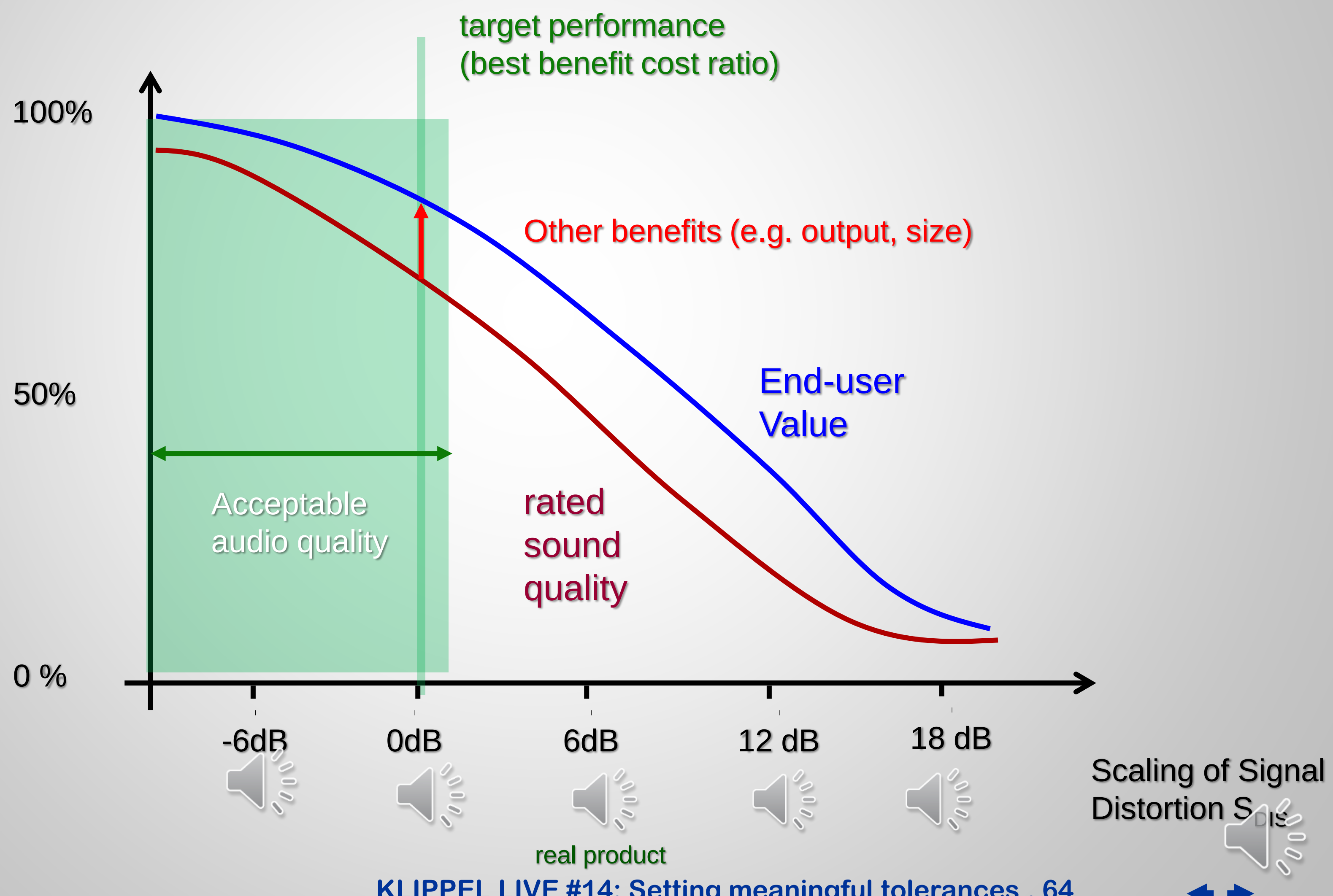
Performance Sensitivity w_k weights the Performance characteristics p_k

EXAMPLE: Portable Audio Device (smart phone)



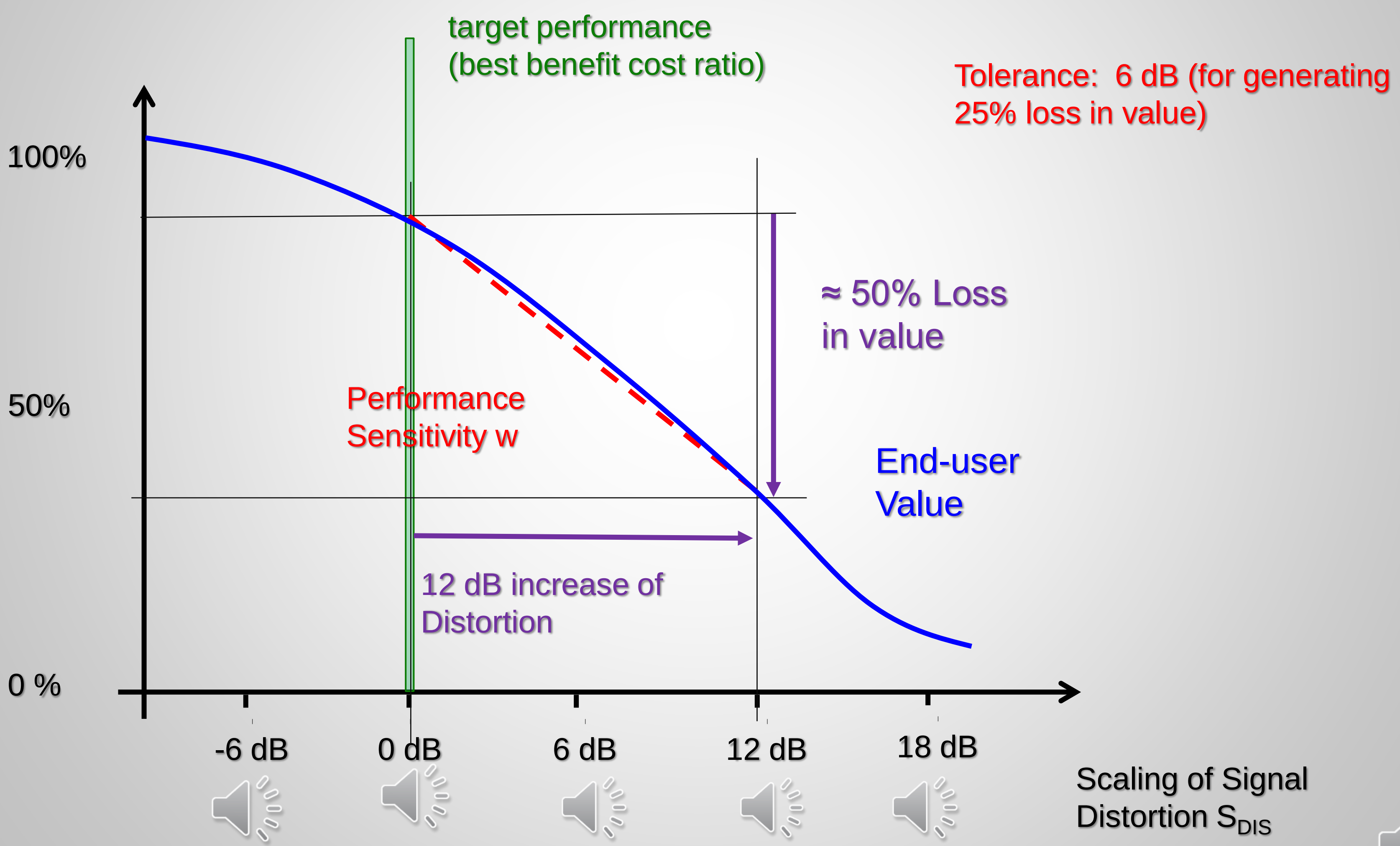
Audio Quality and End-User Value

Distortion generated by regular nonlinearity (force factor Bl(x))



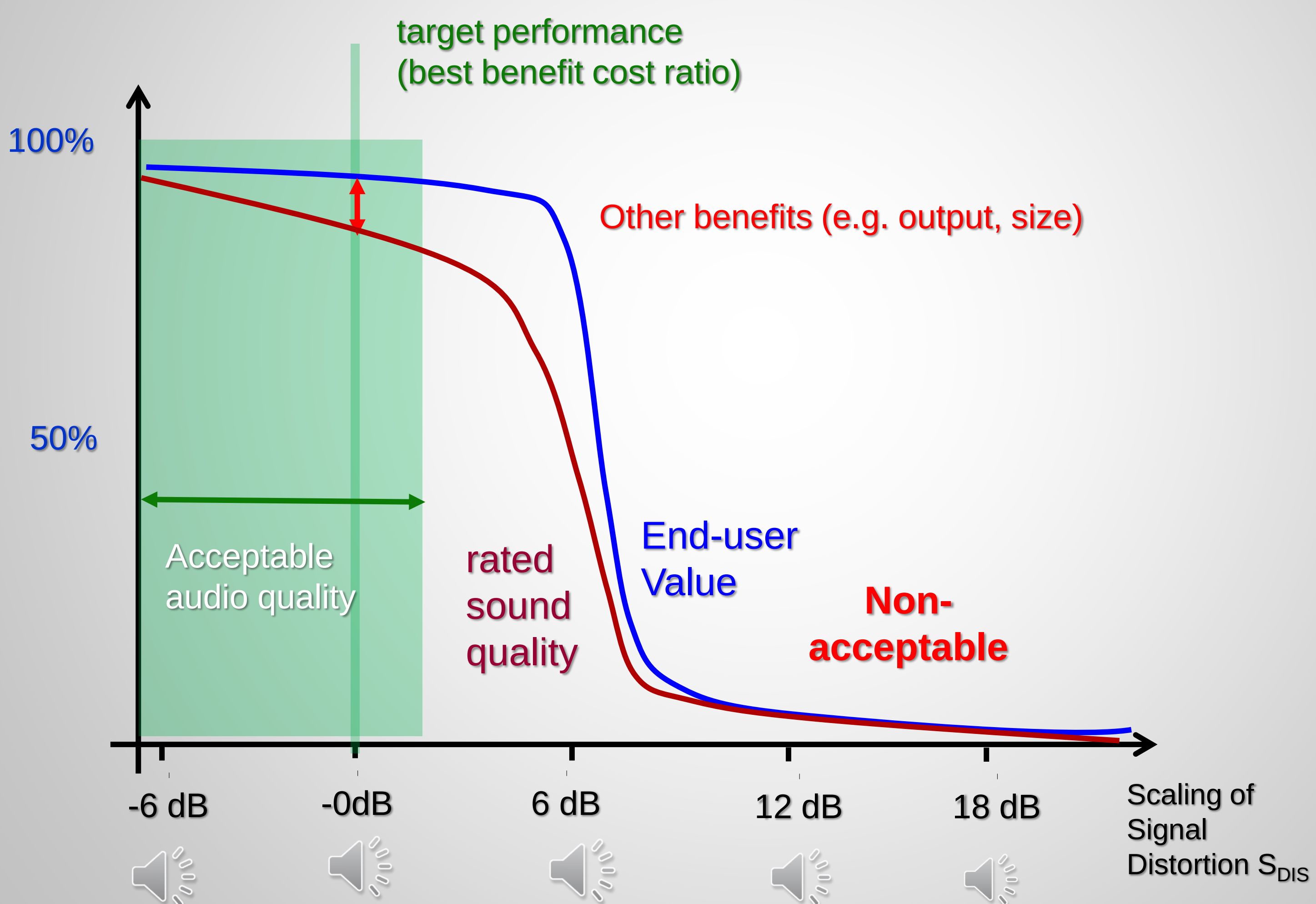
Performance Sensitivity

Distortion generated regular nonlinearities (force factor Bl(x))



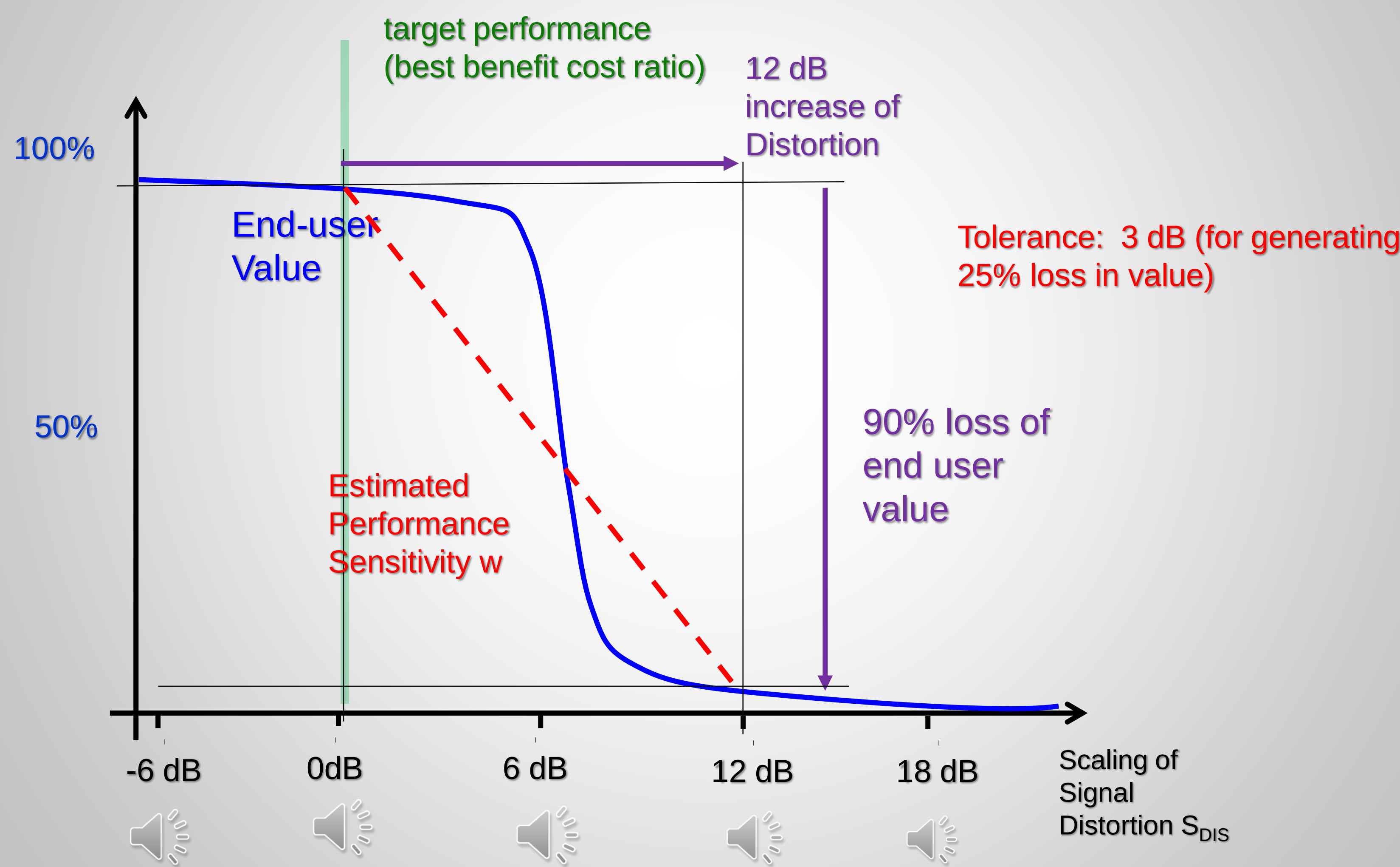
Audibility and Audio Quality

Impulsive distortion generated by rub&buzz and other loudspeaker defects



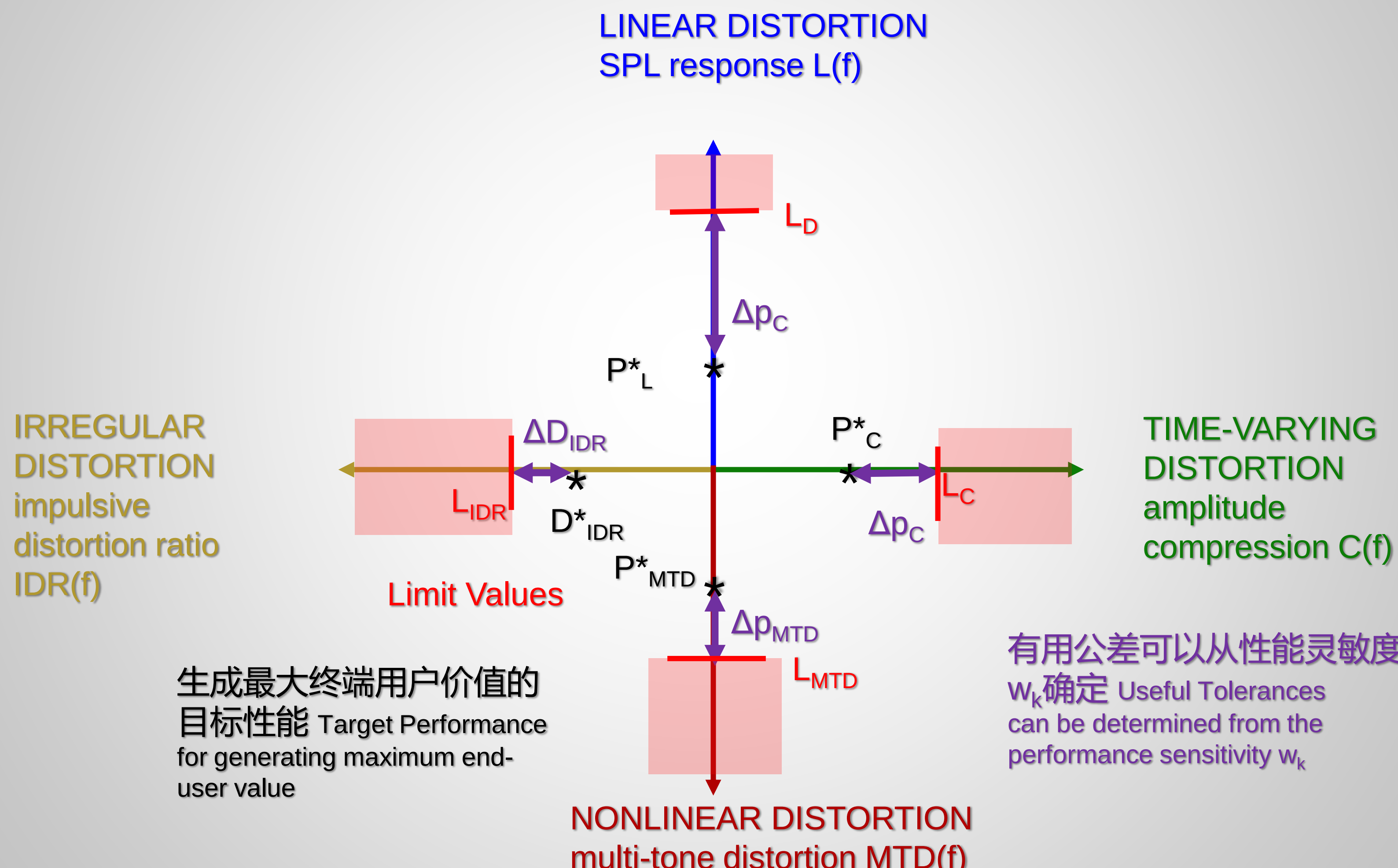
Performance Sensitivity

Impulsive distortion generated by rub&buzz and other loudspeaker defects



信号失真的目标值和公差

Target Values and Tolerances of Signal Distortion



生成最大终端用户价值的目标性能 Target Performance for generating maximum end-user value

有用公差可以从性能灵敏度 w_k确定 Useful Tolerances can be determined from the performance sensitivity w_k

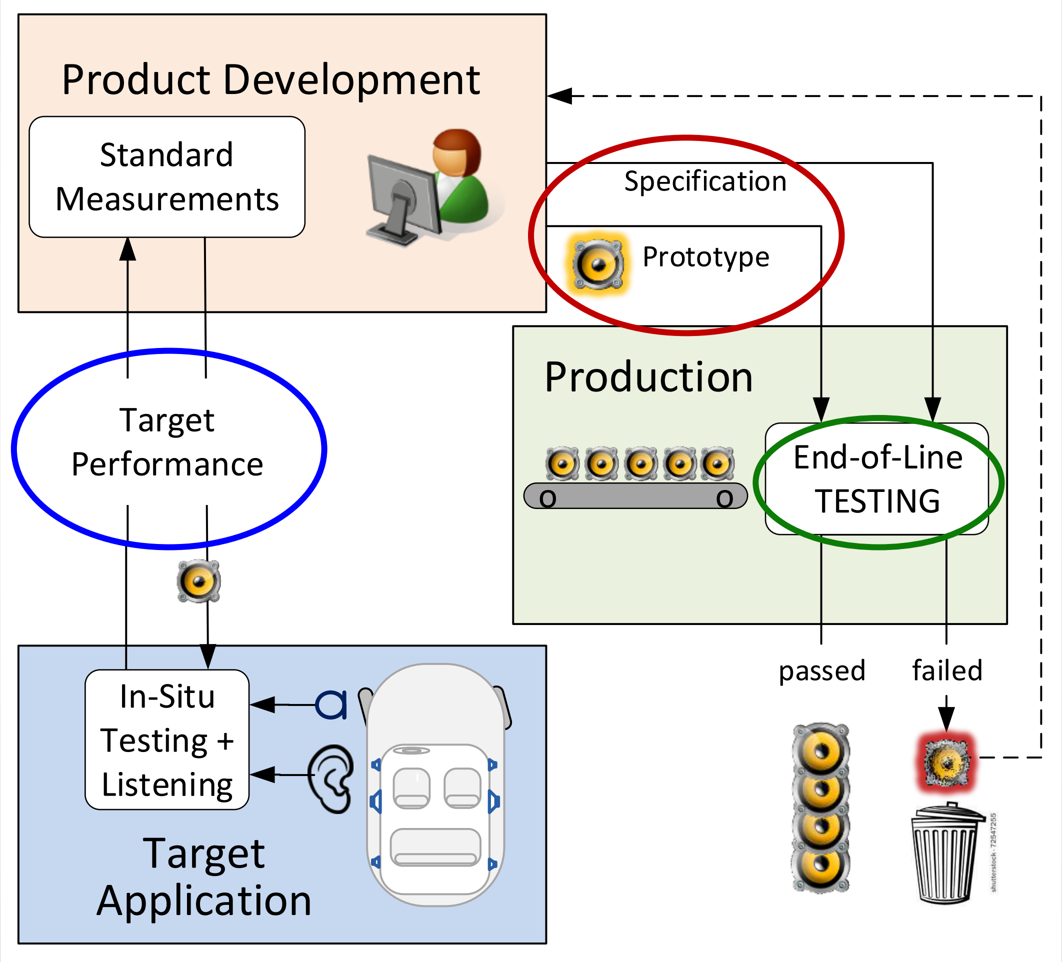
Life Cycle of an Audio Device

Target values

Performance
Sensitivity

Audio Quality

End-User Value



Typical values, tolerances in specifications

Pass-Fail Limits with risk management

More about this topic

Webinar presented at the Virtual ALTI-EXPO 2020

Klippel, "Linking Cost, Performance, End-User Satisfaction by Physical and Perceptual Assessment",

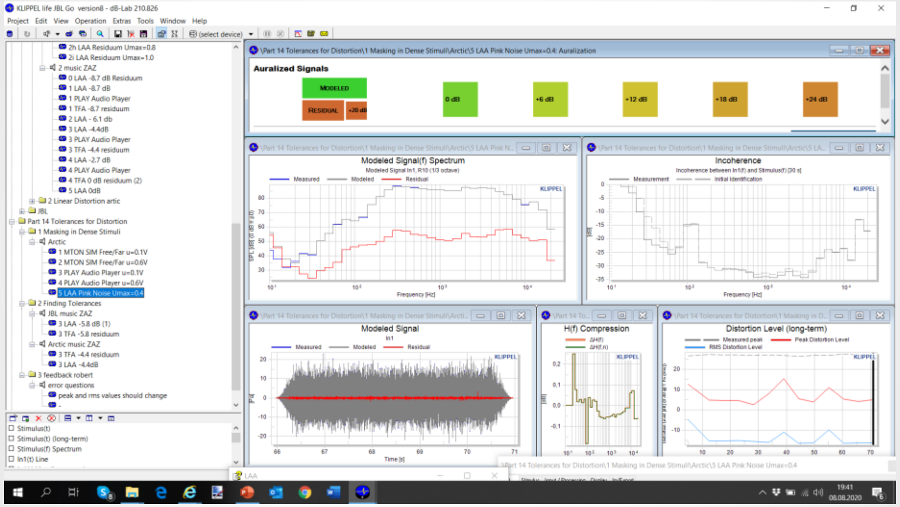
AES Paper:

W.Klippel, Creating Audio Products With Maximum End-User Value, J. Audio Eng. Soc. Vol. 68, No. 7, 2020 July (open access, freely available online)

Demo: Finding Tolerances

Tools: Using dedicated software modules of the KLIPPEL Analyzer

- LAA Live Audio Analyzer



JBL Bluetooth Speaker (one channel)

Arctic Competitive Bluetooth Speaker (stereo, only left channel is used)

Discussion

Summary

- 关键条件下，人耳对信号失真非常灵敏 The human ear is very sensitive for signal distortion under critical conditions
- 音质远不止信号失真的可听度 Audio quality is more than audibility of signal distortion
- 最大化终端用户价值需要在所有性能标准和成本之间做出折衷 Maximizing the end-user value requires a compromise between all performance criteria and cost
- 目标值取决于特定应用（终端用户、环境、激励） Target values depend on the particular application (end user, environment, stimulus)
- 性能灵敏度是定义有意义公差的有力基础 Performance sensitivity is a powerful basis for defining meaningful tolerances
- 通过/失败限制不仅要考虑已批准原型的性能，还需考虑将有缺陷的产品交付给客户的风险 Pass/Fail limits consider not only the properties of the approved prototype but also the risk of delivering a defective product to the customer

Open Questions

我们讨论了为评估音质设定限制的复杂性。如何运用该信息来评估最大输出？ We have now discussed the complexity of the setting limits for assessing audio quality. How can we apply this information for assessing the maximum output?

第15期KLIPPEL网络研讨会主题 The last 15th KLIPPEL LIVE webinar titled
产品最大SPL值的评定 Rating the maximum SPL value for product
将讨论will address the points:

- 评定最大SPL的最佳实践 Best practice for rating maxSPL
- 利用来自设计和目标应用的背景信息 Exploiting background information from design and target application
- 使用预设极限的自动搜索方法 Automatic search methods with predefined limits
- 将IEC60268-21和其他标准及方法联系起来 Linking IEC 60268-21 with other standards and methods
- 网络研讨会的最终结论 Final conclusion of the webinar series

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 - rub&buzz, abnormal behavior, defects
11. Pitfalls in Testing Wireless Audio Devices
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