设计并生产小尺寸，大输出和高质量的扬声器
Designing and producing Loudspeakers With Small Size, Maximal Output And Good Quality

Wolfgang Klippel

KLIPPEL GmbH

Abstract

Professional and consumer applications in home, multi-media, automotive and telecommunication require small and lightweight transducers which produce the acoustical output with high sensitivity and good quality. To design such drivers and complete loudspeaker systems with the desired large signal performance a linear model based on T/S parameters and amplitude frequency response is not sufficient but an extended model and new measurement techniques are required. This seminar gives an overview on the new techniques and tools for speaker design, measurement, diagnostics and quality control in manufacturing.

扬声器应用
Loudspeakers are everywhere

- 车用 Cars
- 手机 Cellular phones
- 多媒体,电脑 Multimedia, Computers
- 助听 Hearing aids
- 家用再生音响 Home hifi reproduction
- 专业音响 Professional audio
- 噪音控制 Active noise control
- …





现代扬声器诉求
Requirements on Modern Loudspeakers

- 小体积 Small dimensions
- 轻重量 Low weight
- 少成本 Low cost
- 低失真大输出 High output at low distortion
- 最大效率 Maximal efficiency

→声再扬大一些 "Loud"speakers are required

研发 – 品管的循环 The R&D – QC life cycle

试听
Listener

扬声器系统
System
(音箱, 分音器, 聆听环境)

驱动器单元
Driver
(Re, fs, Q)

零件 Parts
(振膜, , 驱动部分 motor parts)

音质
Sound Quality

传递特性
Transfer Function

参数
Parameter

几何形状, 材料
Geometry, Material

产品目标
Product Target

模拟解决方案 Simulate Solution

生产测试
Production Test

原型样品的实现及测试 Realize & Testing the Prototype

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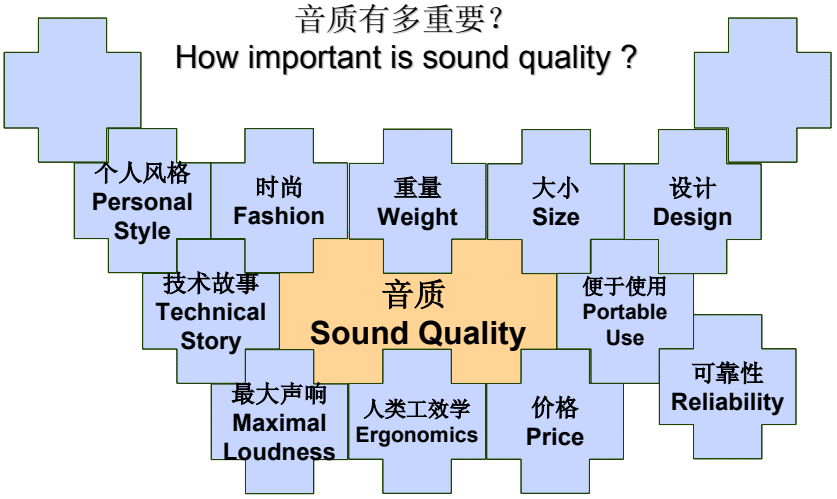
最终准则:偏好
Ultimate Criteria : Preference

音质有多重要？

How important is sound quality ?



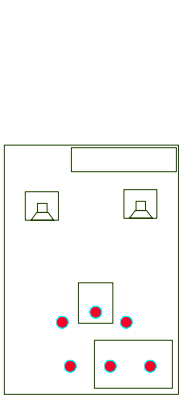
→ 什么是客户的整体利益? What`s the overall benefit for the customer ?

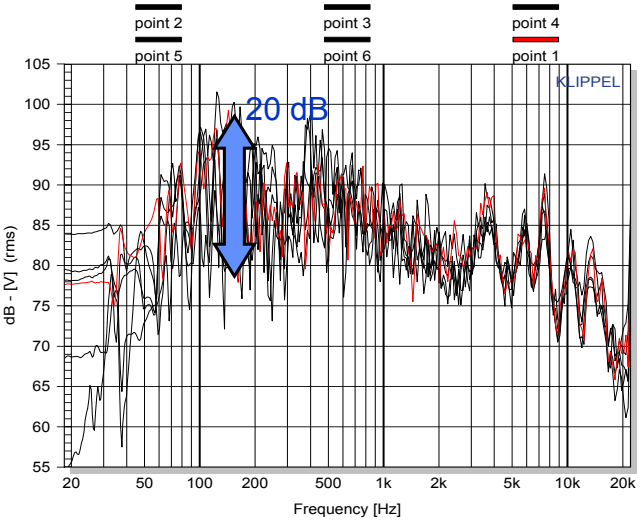
感知声质再现
Perceived Quality of Sound Reproduction

取决于 Depends on

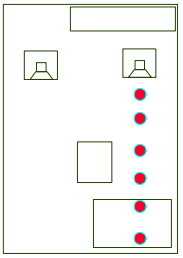
- 驱动信号 Stimulus (music, speech)
- 声学环境 acoustical environment (room)
- 听，训练，聆听者的期望 Hearing, training, expectation of the listener
- 电声学单体 Electro-acoustical transducer

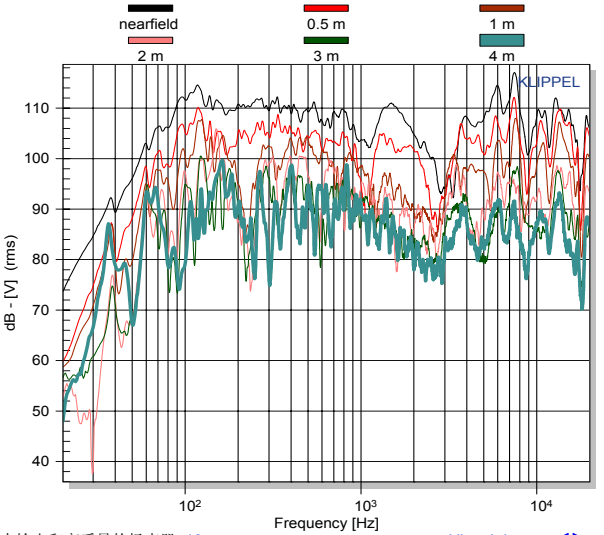
在住房中正常聆听范围内的声压级响应变化
Variation of SPL response within normal listening area in a living room



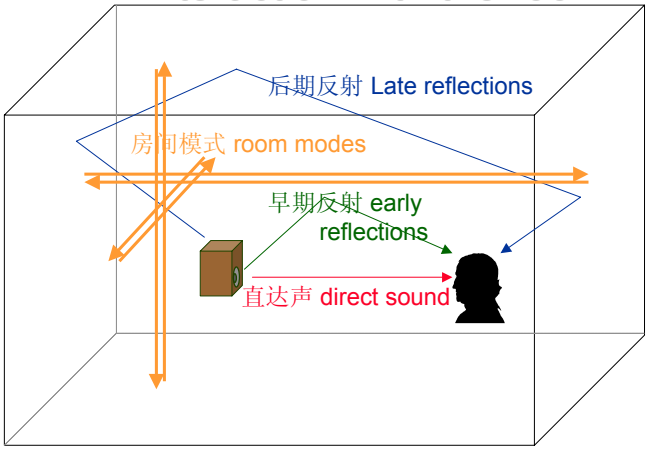


室内反应在声压级响应上扬声器和聆听位置之间距离的影响
Influence of distance between Loudspeaker and listening position on SPL response in room



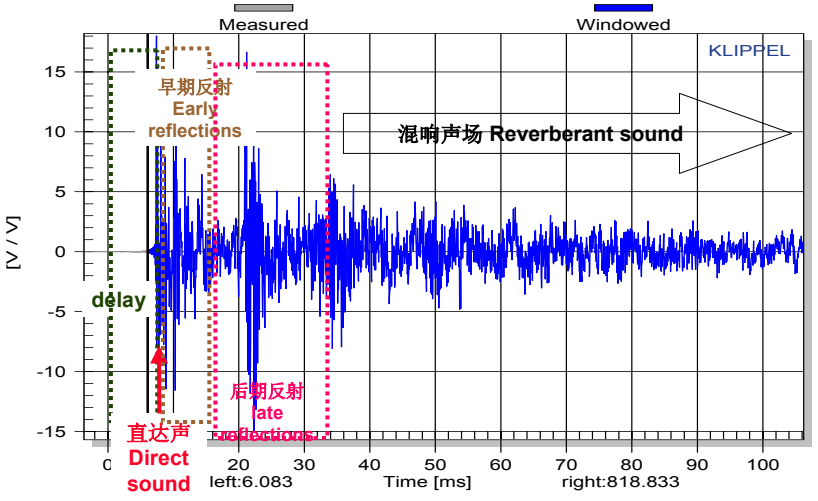


与房间的相互作用
Interaction with the room

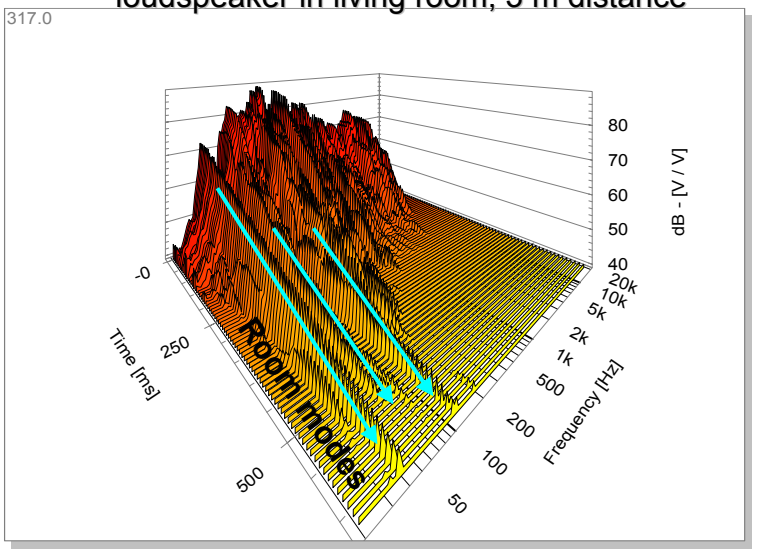


扬声器的哪些特性对此非常重要 Which loudspeaker properties are important for this ?

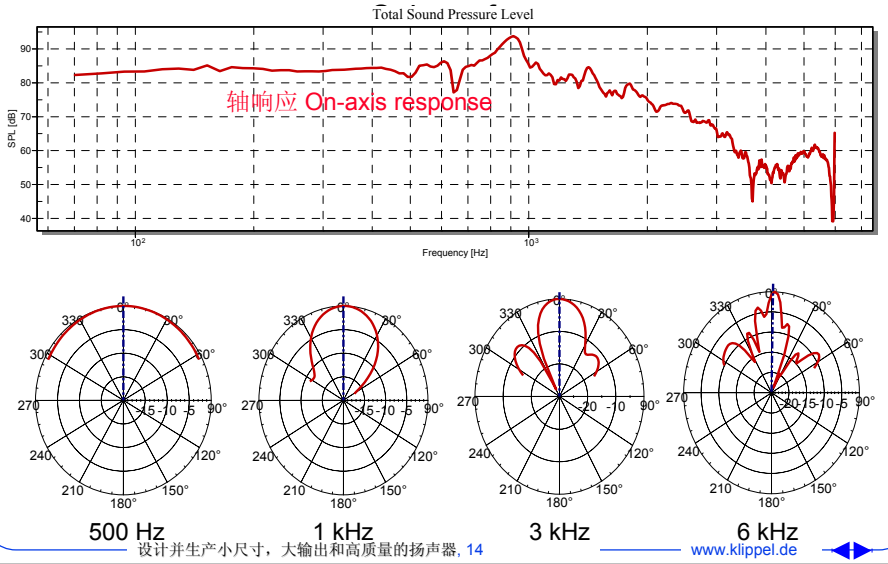
脉冲响应 Impulse Response
(扬声器在室内 loudspeaker in room)



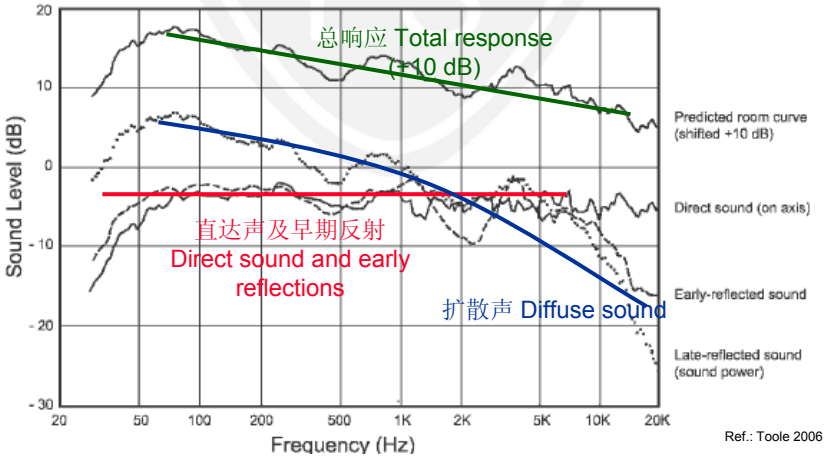
累积的频谱衰减
Cumulative Spectral Decay
loudspeaker in living room, 3 m distance



扬声器的指向性
Directivity of the Loudspeaker
以16英寸的超低音扬声器为例 for example 16“



在一个聆听点上声压级响应的预测
Prediction of SPL response at a listening point
例 example



Ref.: Toole 2006

扬声器的设计始于声学目标环境的定义
Loudspeaker design starts with the definition of the acoustical target environment !

- **扬声器可以被使用在特定环境下吗? Is Loudspeaker used in a particular room ?**
  → 带中间性能或特殊喇叭的通用扬声器 universal loudspeakers with neutral properties or special speaker
- **原声源的数量及位置 Number and position of original sound sources ?**
  → 单声道或多声道系统 Single-channel or multi-channel system
- **原声源的指向性 Directivity of original sound source ?**
  → 直达声源 (歌手) 或扩散声源 (乐团) directed source (singer) or diffuse source (orchestra)
- **扬声器在房间里的位置 Position of the loudspeaker in room ?**
  → 固定安装在最佳位置或便携式使用 fixed installation at optimal position or portable use
- **聆听距离 Listening distance**
  → 固定在车内,多媒体或可变像便利产品上 fixed as in cars, multi-media or variable as in convenience products

例样A: 通用扬声器
Example A: Universal loudspeaker

应用 Application:

- 便携式使用 portable use
- 环境特征不明 unknown room properties
- 距离的宽范围 wide range of distance
- 声源指向性不明 unknown source directivity

设计目标 Design Targets:

- 低指向性 Low directivity
- 轴响应平坦 Flat on-axis response
- 声功率响应平坦 Flat sound power response

例样 B: 特殊扬声器
Example B: Special loudspeaker

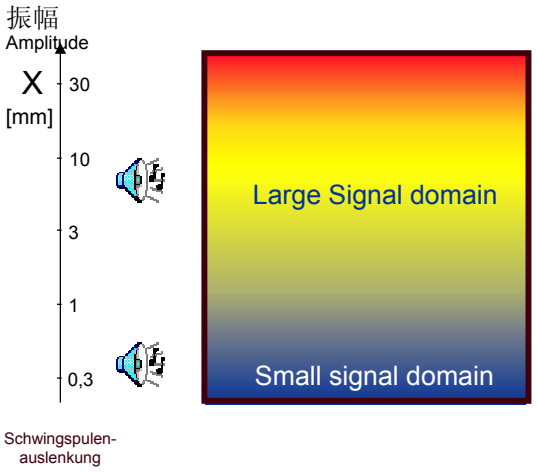
应用 Application:

- 不便携式使用 Non-portable use
- (声音)回响环境 Reverberant environment (e.g. church)
- 声源和耳朵之间距离大 large distance between source and ear
- 声源指向性不明 unknown source directivity

设计目标 Design Targets:

- 高指向性 High directivity
- 平坦的轴声压级响应 (重点在高频范围) Flat on-axis SPL response (emphasis at high frequencies)
- 平坦的声功率响应 (淡化低频范围) Flat sound power response (de-emphasize at low frequencies)

扬声器的工作效益
Performance of Loudspeakers

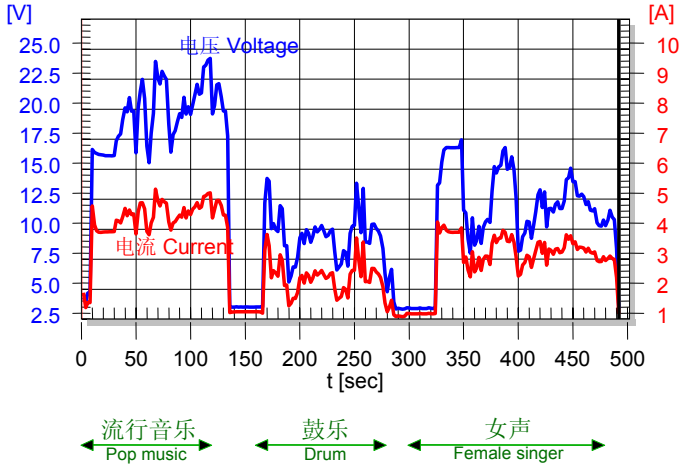


→毁损 Destruction

→ 非线性 nonlinear

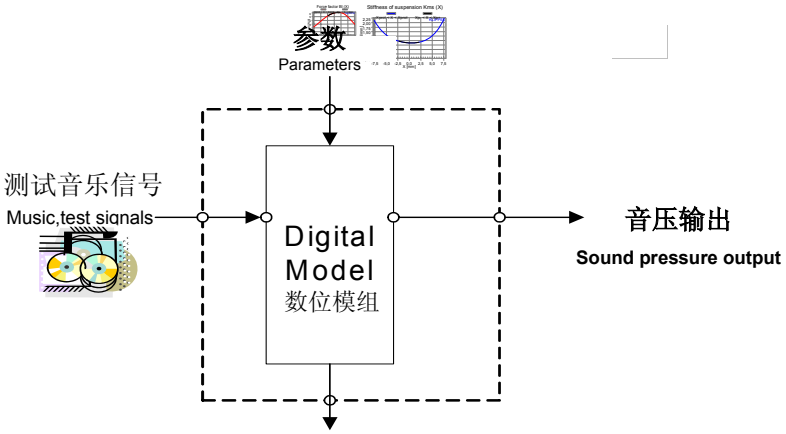
→ 接近线性 almost linear

电压及电流
Voltage and Current



模拟扬声器工作效益

Simulation of Loudspeaker Performance

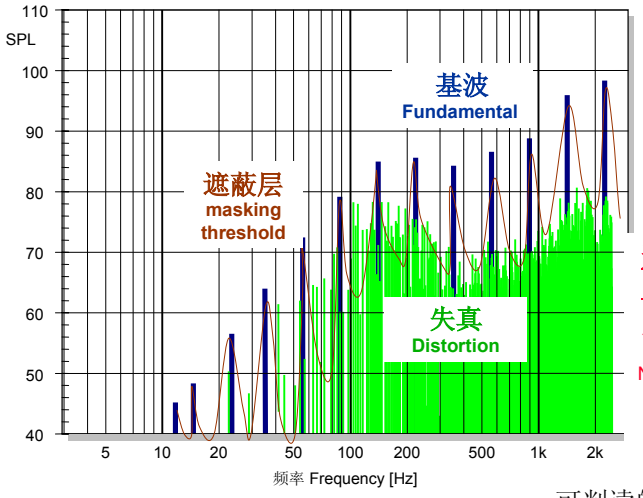


位移, 电流, 功率, 温度

Displacement, Current,Power, Temperature

低品质扬声器之输出

Output of an Low-Quality loudspeaker



无避免失真可闻的安全范围

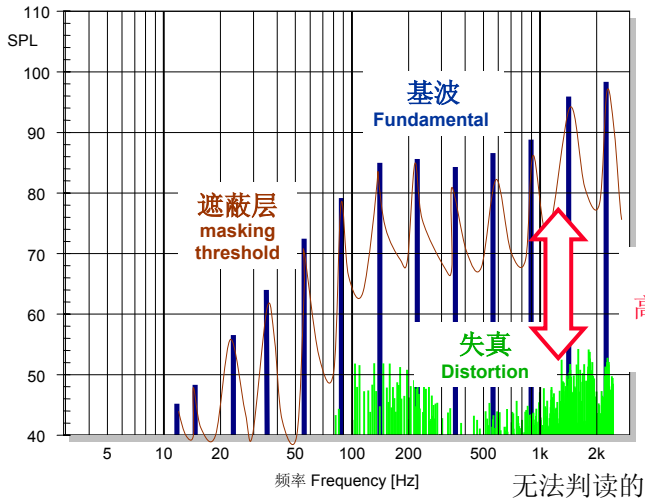
低输出比范围

No safety headroom

可判读的失真信号

高品质扬声器之输出

Output of a High-Quality loudspeaker



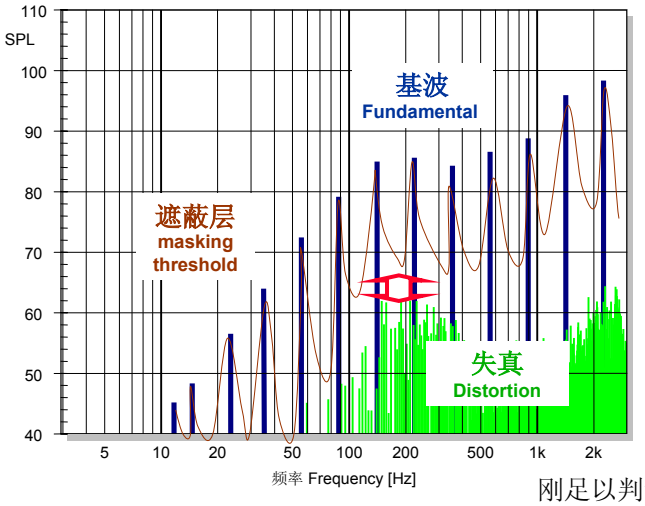
高输出比范围
High safety
headroom

无法判读的失真信号

l.de

顶级扬声器之输出

Output of an optimal Loudspeaker



足够的输出
比范围

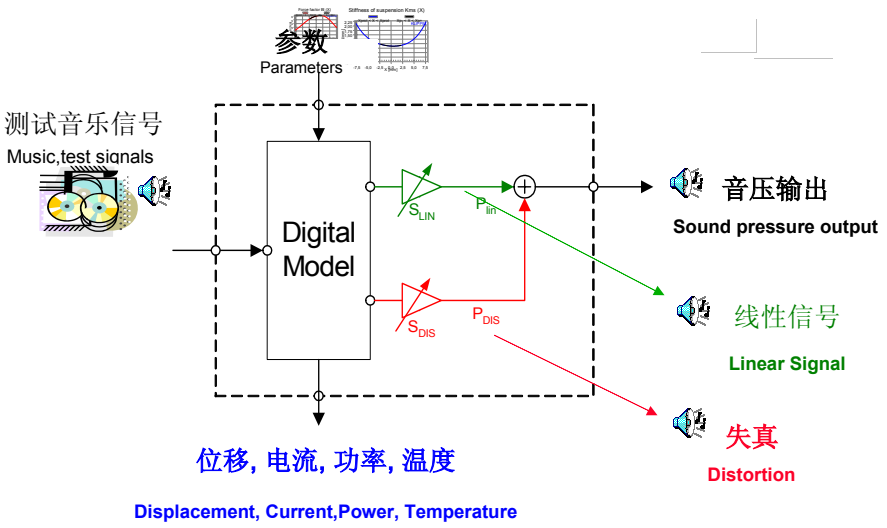
Sufficient safety
headroom

刚足以判读的失真信号

el.de

聆听分析失真信号

Listening into a Digital Model



输出范围

Measurement of Safety Headroom

	S_{lin}	S_{DIS}	Example
理想扬声器 Ideal Speaerk	0 dB	-100 dB	
	0 dB	-12 dB	
失真减少 Distortion decreased	0 dB	-9 dB	
	0 dB	-6 dB	
	0 dB	-3 dB	
实际扬声器 Real Speaker	0 dB	0 dB	
	0 dB	3 dB	
可判读层 threshold of audibility	0 dB	6 dB	
失真增大 Distortion increased	0 dB	9 dB	
	0 dB	12 dB	

输出范围相当于增大失真可判读比

Safety Headroom = Increase of S_{DIS} to make distortion audible

扬声器之主观及客观评价

Auralization in Loudspeaker Development

研发生产单位
Development
Manufacturing

市场营销单位
Marketing
Management

客观评价 Objective Evaluation

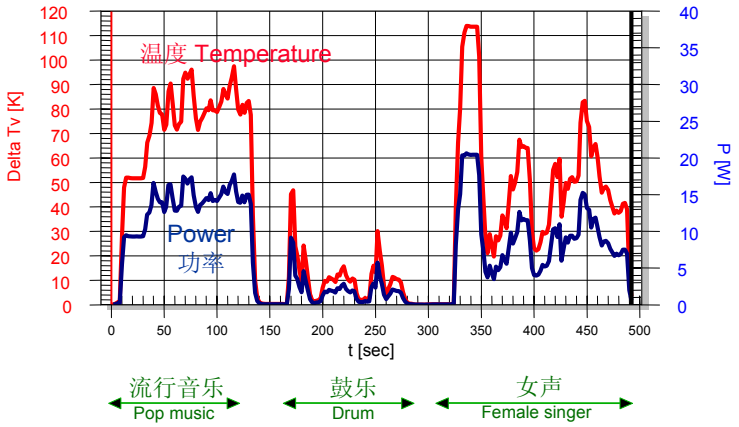
- 失真, 最大输出 Distortion, Maximal Output
- 振动模式, 温升模式 Displacement, Temperature
- 设计选择的评估 Evaluation of Design Choices
- 指出改进方向 Indications for Improvements

主观评价 Subjective Evaluation

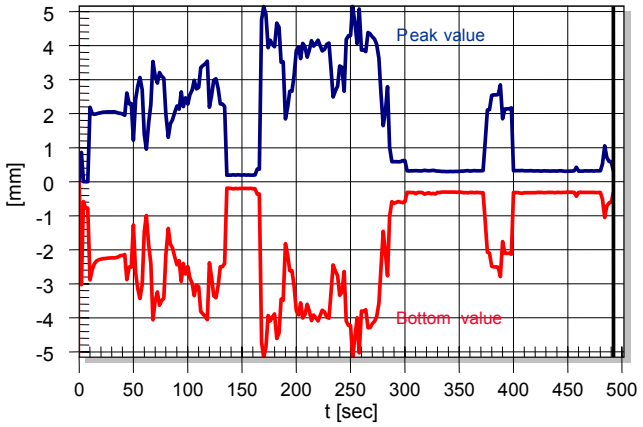
- 个人印象 Personal Impression
- 足够的音质 Sufficient Sound Quality
- 针对目标市场调适 Tuning to the target market
- 性价比(效益及成本比) Performance/Cost Ratio

热效应

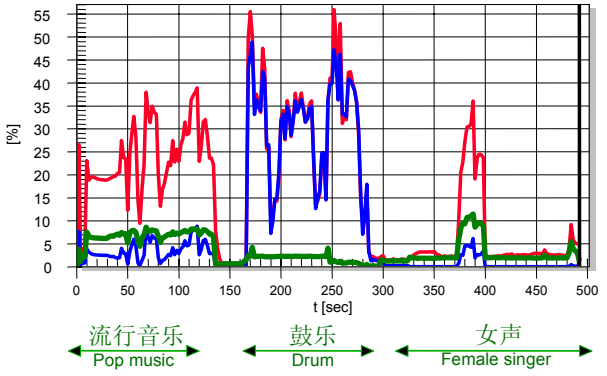
Thermal Performance



音圈位移
Voice Coil Displacement



失真分析
Distortion Analysis



磁力
Force Factor

柔顺
Compliance

感抗
Inductance

详述: 小信号性能
Specification: Small Signal Performance
扬声器系统 (无房间) Loudspeaker System (without room)

- 上限与下限的有效频率范围 Upper and lower limits of effective frequency range
  → $f_{highpass}$, $f_{lowpass}$ (IEC 60268-5 Sec. 21.2)
- 轴响应的平坦性 Flatness of on-axis response
  → 平均声压级的最大偏离 (无标准可用) maximal deviation from mean SPL (no standard available)
- 指向性 Directivity
  → 指向性因数$D_i(f)$或声功率响应$P_a(f)$ Directivity index $D_i(f)$ or sound power response $P_a(f)$ (IEC 60268-5 Sec. 22.1)
- 累积衰减频谱上的最大衰减时间 Maximal decay time in cumulative decay spectrum
  → 影响音质 (无标准可用) impact on sound quality ? (no standard available)

详述:大信号性能
Specification: Large Signal Performance
扬声器系统 (无房间) Loudspeaker System (without room)

1米处有最大轴声压级 $SPL_{max}(f)$ Maximal sound pressure level $SPL_{max}(f)$ at 1 m on axis

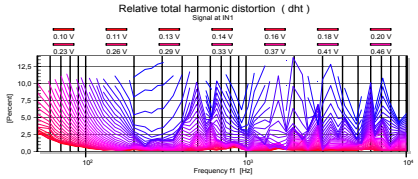
当 while

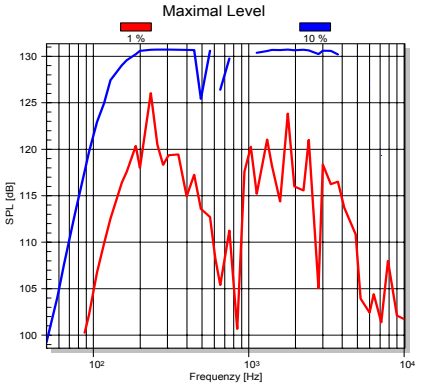
- 保证谐波失真和互调失真在允许限幅内 (例如: THD, IMD, MTD < 10 %) keeping harmonic and intermodulation distortion below allowed limit (e.g. THD, IMD, MTD < 10 %)
- 保证无由扬声器损毁导致的脉冲失真 having no impulsive distortion generated by loudspeaker defects (crest factor of harmonics < 10 dB)
- 保持音圈温度在允许范围内, 验证耐久性 (加速寿命实验) Keeping voice coil temperature in permissible range, durability verified (in accelerated life test)

在10%失真处的最大声压级
Maximal SPL at 10 % Distortion

DIS module
自动保护测量 Automatic measurement with protection

MAT module
后置处理 Post processing





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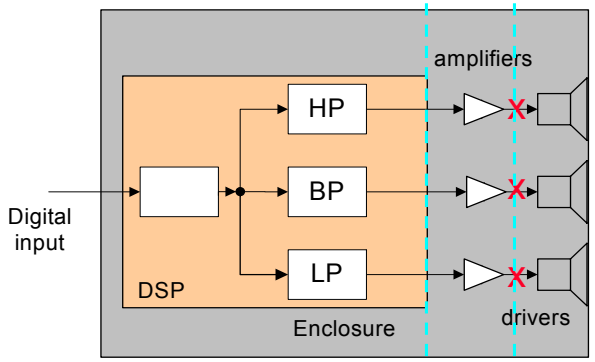
…我们如何支持你 - how we can support you?

指明界面系统组件
Specifying the interface between system components



新挑战: 致力于扬声器的放大+预处理
New challenges: Amplification + preprocessing dedicated to speakers ?

软件 software

电力电子技术 power electronics

单体 transducer

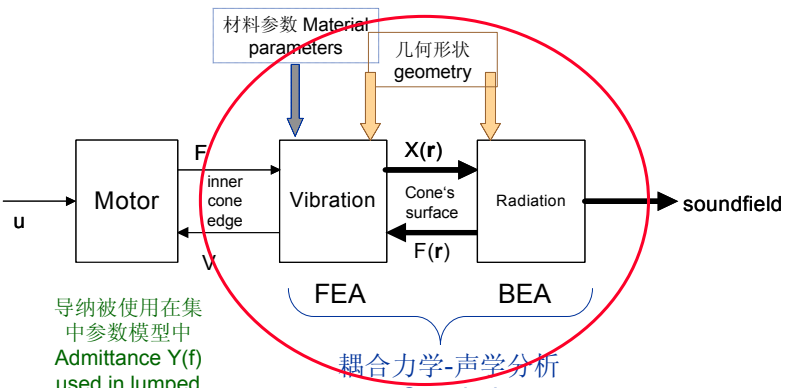
系统约束
System Constraints

- 系统里单体的数量 (低音，中音，高音扬声器) Number of drivers in the system (woofer, mid-range, tweeter)
- 最大功放电压峰值 Maximal amplifier peak voltage U_{peak}
- 最大功放输出功率 Maximal amplifier output power P_{max}
- 最大隔声罩尺寸 Maximal enclosure size
- 最优功放负载 Optimal amplifier load Z_{load} (Z_{min} → IEC 60268-5 Sec. 16.1)
- 低音扬声器振膜直径 Woofer cone diameter
- 价格，重量 Price, weight, ...

单体详述
Driver Specification

1. 多路系统的最佳交叉频率 Optimal crossover frequencies of a multi-way system
   → 单体的频率限幅 frequency limits of the driver
2. 频率限幅, 轴平坦性, 指向性 Frequency limits, flatness of on-axis, directivity
   → 振膜和隔声罩的几何形状, 辐射条件 Geometry of cone and enclosure, radiation conditions
3. f > fs处的最大声压级 maximal SPL at f > fs
   → 通带灵敏度,功率处理,热参数,力学和声学的非线性 Pass band sensitivity, power handling, thermal parameters, nonlinearities in mechanics and acoustics
4. f < fs 处的最大声压级 maximal SPL at f < fs
   →隔声罩种类, 最大位移, 驱动系统的非线性 Enclosure type, Xmax, motor nonlinearities

力学及声学设计
Mechanical and Acoustical Design



振膜设计的准则
Criteria in Cone Design

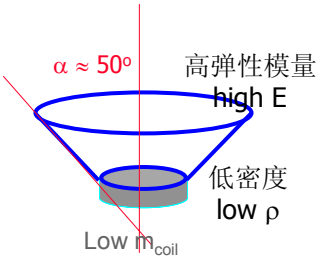
- 带宽 (下上限幅) **Bandwidth** (lower and upper limits)
- 敏感性 (有效) **Sensitivity** (efficiency)
- 声压级响应的平坦性 (轴上) **Flatness** of SPL response (on-axis)
- 指向性 (功率响应) **Directivity** (power response)

怎样得到大的带宽？
How to get large **Bandwidth ?**

音圈 Voice coil
- 轻的音圈质量,低电感值 low coil mass, low inductance

纸做的振膜 Paper Cone
- 高扬氏弹性模量 high Young's E modulus
- 低密度 Low density ρ
- 小顶点角度 small apex angle α

结果 Consequences:
- 通带上的峰值和谷值 Peak and dips in the pass band



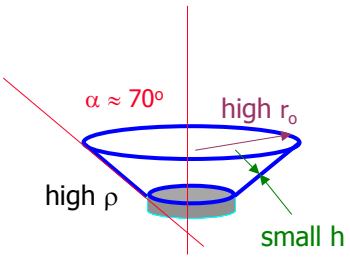
怎样得到一个平坦的响应
How to get a **Flat Response**

纸的振膜 Paper Cones:

- 最优顶点角度 Optimal apex angle α
- 大密度 high density ρ,
- 大的外半径 large outer radius r_o
- 最优内半径 Optimal inner radius r_i to have
- 低厚度 Low thickness h
- 大的内部损耗因子 High internal loss factor η
- 可展形态 developable shape

结果 Consequences:

- 小带宽, 低效益 small bandwidth, low efficiency



怎样得到高效率
How to get **High Efficiency**

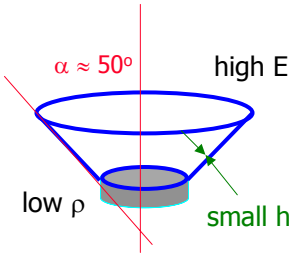
在振膜分裂运动之后 after cone break up ($f > f_{ra}$)

纸的振膜 PAPER CONE:

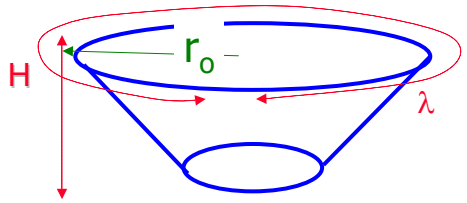
- 小的振膜重量 Low cone weight
- 小厚度 small thickness h,
- 低密度 low density ρ
- 小的顶点角度 Small apex angle α

结果 Consequences:

- 音圈质量起主导 Voice coil mass is dominant → 小带宽 small bandwidth

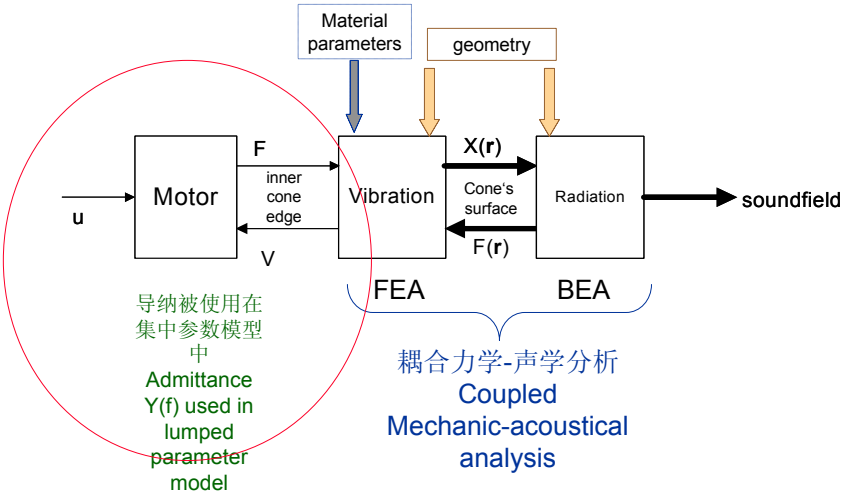


怎样得到固定的指向性
How to get **Constant Directivity**



- 对于辐射器使用振膜替代平坦的活塞 Use cone instead of flat piston for radiator
- 配合好振膜的高度和半径 Fit cone height H to cone radius r0
- 支持分裂模式 Support break-up modes
- 通过分裂模式减少有效半径 effective radius r should be reduced by break-up modes

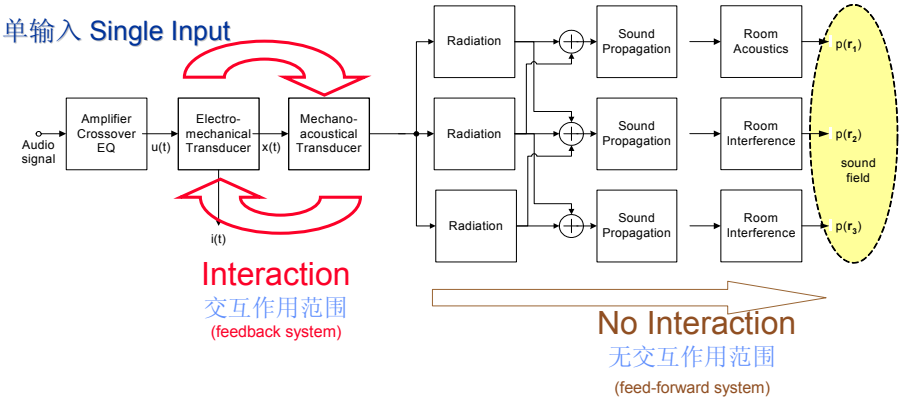
驱动系统及悬吊系统的设计
Motor and Suspension Design



基本扬声器模式
Basic Transducer Modeling

多输出 Multiple Outputs

单输入 Single Input



Interaction
交互作用范围
(feedback system)

No Interaction
无交互作用范围
(feed-forward system)

机电等效电路
Electro-mechanical Equivalent Circuit

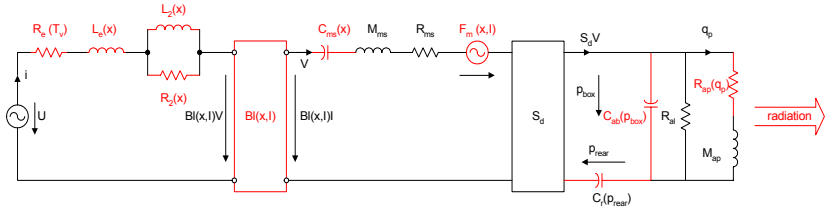
Nonlinear parameters are not constant
非线性参数不恒定

- Force factor Bl(x) 磁力强度
- Compliance $C_{MS}(x, t)$ 柔顺性
- inductance $L_E(x)$, $L_2(x)$ 电感量
- resistance $R_2(x)$ 电阻量
- DC-resistance $R_E(T_V)$ 直流电阻
- Reluctance force $F_M(x)$
- Compliance $C_r(p_{rear})$ of rear enclosure
- Compliance $C_{ab}(p_{box})$ of vented enclosure
- Losses in port $R_{ap}(q_p)$
- Time delay *t(x) due* to Doppler effect

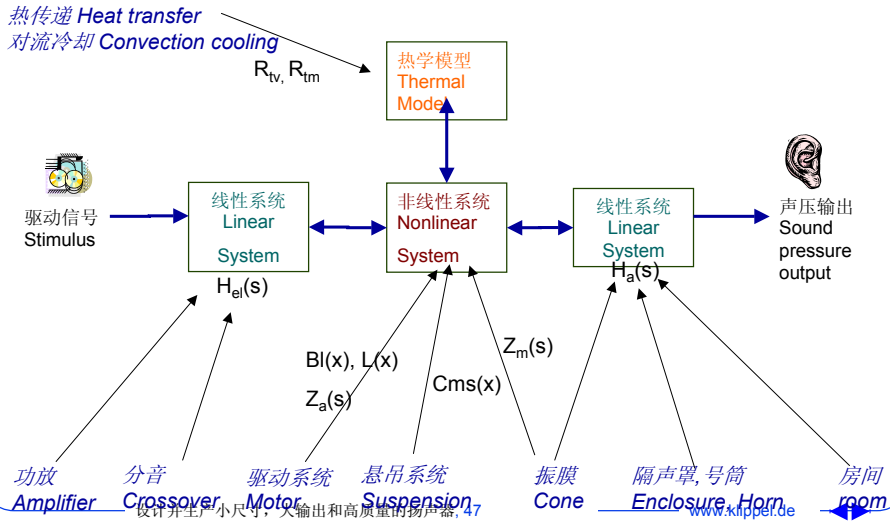
但取决于状态变量

But depend on state variables:

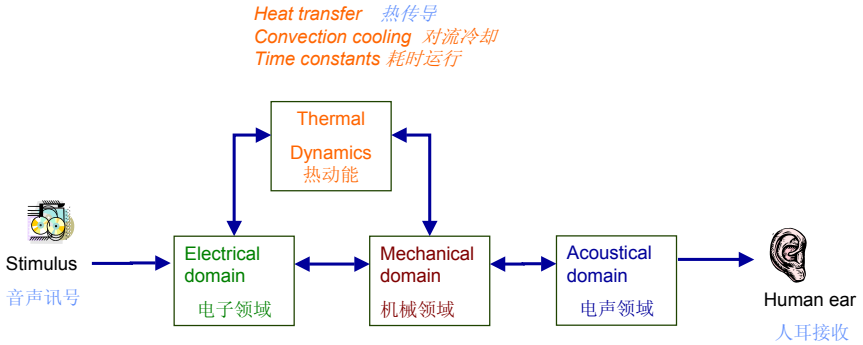
- Displacement x 位移
- Voice coil temperature T_V 音圈温度
- Time t due to ageing
- volume velocity q_p in port
- pressure p_{rear} rear enclosure
- pressure p_{box} in vented enclosure



集中参数分析
Lumped Parameter Analysis



连接不同领域的扬声器工作
Loudspeaker – Connecting Domains

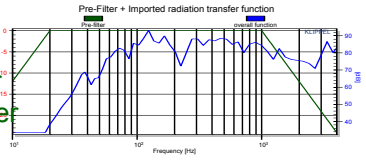


驱动系统和悬吊系统的详述
Specification of Motor and Suspension

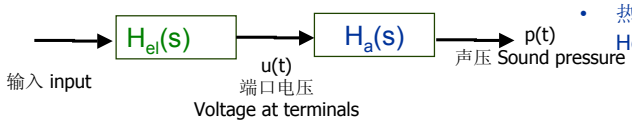
1. 设立目标性能 Define target performance
2. 执行小信号合成 Perform small signal synthesis
3. 模拟大信号性能 Simulate large signal performance
4. 找出非线性和热学参数 Find nonlinear and thermal parameters
5. 找寻最佳单体 (或设计) Search for optimal driver (or design it)

第一步: 小信号合成
1st Step: Small Signal Synthesis

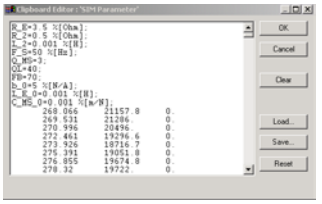
预过滤 Prefilter $H_{el}(s)$
- 分音 Crossover
- 均衡器 Equalizer
- 限幅器 Limiter



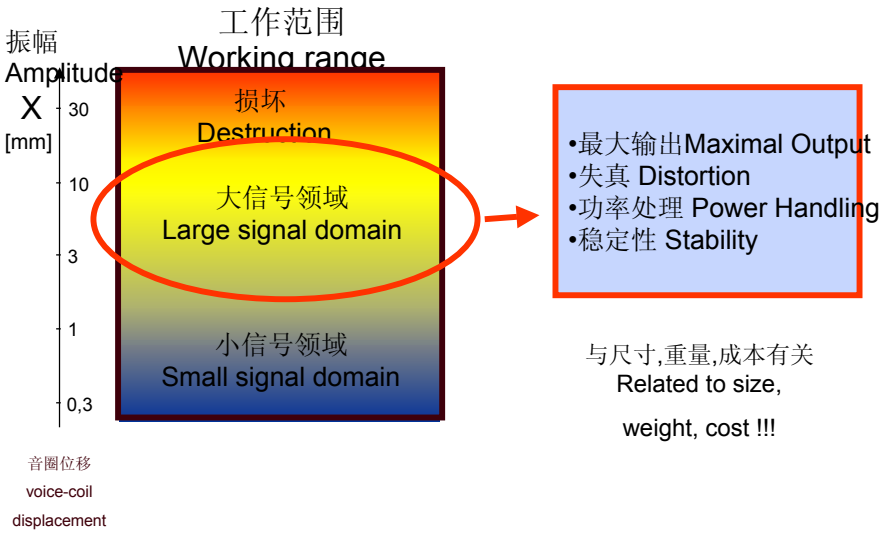
Post-Filter $H_a(s)$
- 音场辐射/传播 Radiation/Propagation
- 音场绕射 Diffraction
- 房间相互作用 Room-Interaction
- 热传递函数 Head Transfer Function



定义与通带敏感性有关的相关参数
Define parameters related to pass-band sensitivity
→ Re, Bl(x=0), Mms



大信号合成
Large Signal Synthesis



什么是非线性
Criteria for dominant Nonlinearities

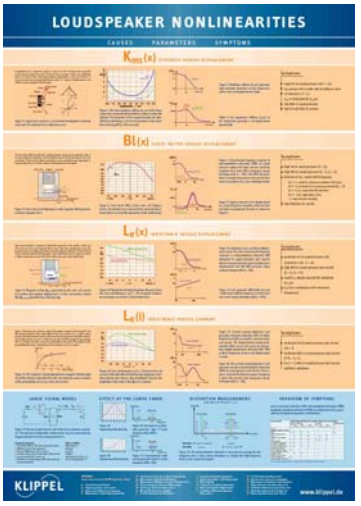
- 受限制的电声输出 limits acoustical output
- 产生可判听的失真 generates audible distortion
- 显示超出负载状况 indicates an overload situation
- 引起不稳定的行为 causes unstable behavior
- 影响成本重量及体积 related with cost, weight, volume
- 改变扬声器系统的配置 affects speaker system alignment
- 决定单体的效率 determines transducer efficiency

单体的非线性表
Ranking List of transducer Nonlinearities

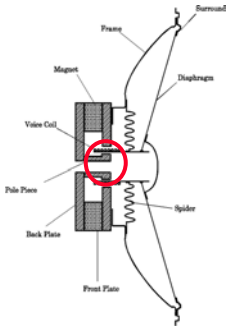
1. 磁力强度 Force Factor Bl(x)
2. 柔顺性 Compliance $C_{ms}(x)$ → 低音扬声器
3. 电感量 Inductance $L_e(x)$ → woofers
4. 非线性声音传播 Nonlinear Sound Propagation c(p) → 号筒扬声器
5. 电磁场模组 Flux Modulation $L_e(i)$ → horns
6. 多普勒失真 Doppler Distortion $\tau(x)$
7. 非线性振膜振动 Nonlinear Cone Vibration
8. 风管的非线性 Port Nonlinearity $R_A(v)$
9. 及其他 many others ...

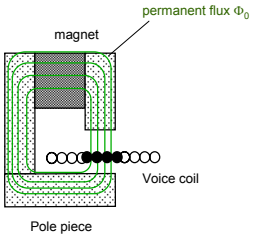
扬声器的非线性-成因,参数,征兆
Loudspeaker Nonlinearities – Causes, Parameters, Symptoms

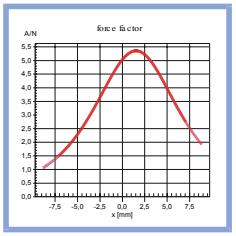
- Detailed discussion on practical examples in the Journal of Audio Eng. Soc., Oct. 2006.
- Tutorial at the next AES convention in New York
- Get a free poster for your workshop



磁力强度
Force Factor Bl(x)







磁力强度改变原因 Variation of Bl(x) caused by

- 磁场改变 Magnetic field
- 音圈高度 Height and overhang of the coil
- 最佳音圈位置 Optimal voice coil position

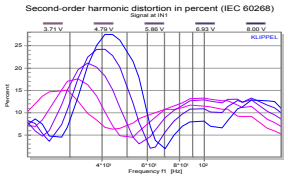
总揽Overview on
产生有意义征兆的测量 Measurements which provide meaningful symptoms

Nonlinearities	SYMPTOMS GENERATED IN MONITORED STATE VARIABLE							
	Sound Pressure				Current			Displacement
	HD	*IMD* (bass sweep)	*IMD* (voice sweep)	*AMD* (voice sweep)	*HD*	*IMD* (bass sweep)	*IMD* (voice sweep)	X_{dc}
$K_{ms}(x)$ suspension (spider +surround)	X							X*
Bl(x) **electro-dynamical motor**	X	X	X	X				X*
$L_e(x)$ position of coil in the gap		X	X	X		X*	X	
$L_e(i)$ "flux modulation"	X	X	X	X	X*	X*	X	
Variation of Geometry of Cone and suspension	X	X	X	X				
Young's-modulus $E(\varepsilon)$ of cone and suspension	X	X	X	X				
Flow resistance $R_A(v)$ in ports of vented enclosures	X							
Doppler Effect radiation of sound waves		X	X					
Wave Steepening sound propagation at high SPL	X		X					

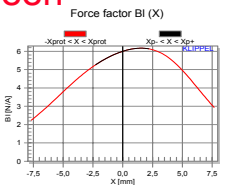
* provides unique symptoms which are sufficient for the identification of the nonlinearity.

SIM 模拟模块的结果 provides

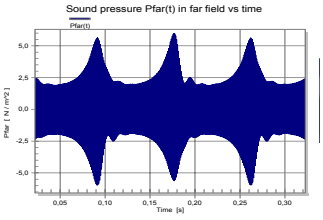
交互关系 Relationship between

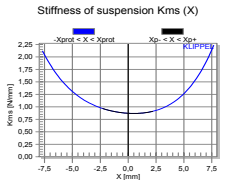


失真
Distortion and



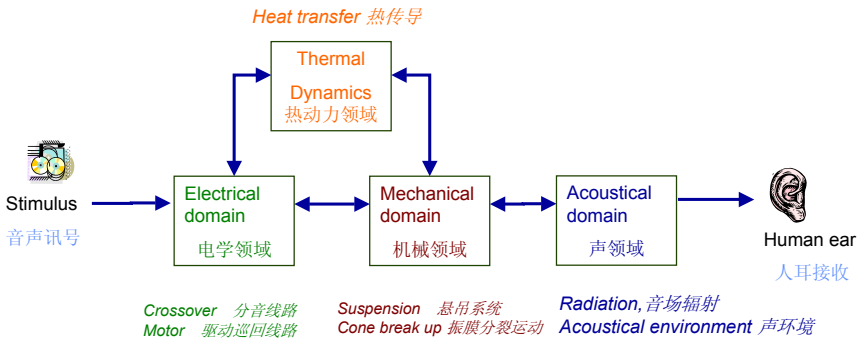
大信号参数
Large Signal
Parameters



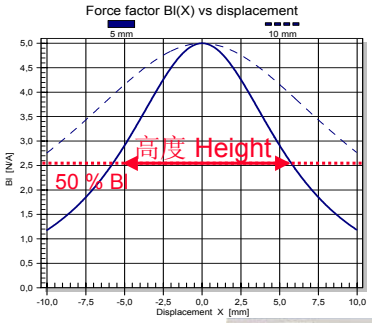


SIM – Connecting Domains

连接不同领域的扬声器工作

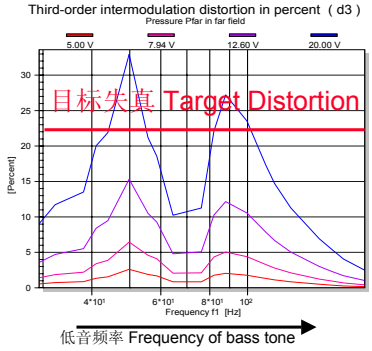


第二步:最佳音圈高度
2nd Step: Optimal Voice Coil Height

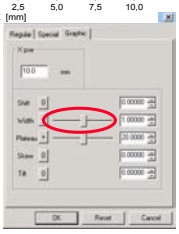


在X=Xmax处检查失真
Check Distortion at X=Xmax:

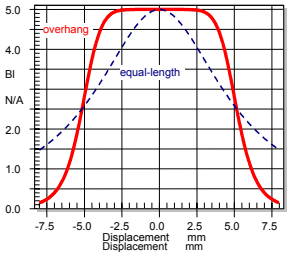
- 3次谐波失真或互调失真
  3rd order IMD for f >> fs
- 3次谐波失真 3rd HD for f < fs



将宽度转变为非线性曲线编辑 change WIDTH in nonlinear curve editor



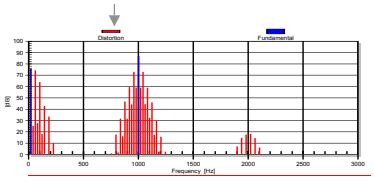
软限幅或硬限幅非线性?
Hard or soft limiting nonlinearity ?
对双音信号的影响 Impact on a two-tone signal



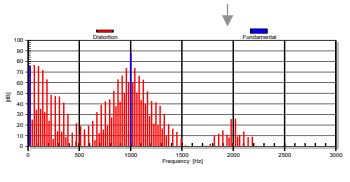
软限幅非线性
soft limiting nonlinearity

硬限幅非线性
hard limiting nonlinearity

声压信号频谱 Spectrum of sound pressure signal (two-tone stimulus):



high 2nd- and 3rd order distortion



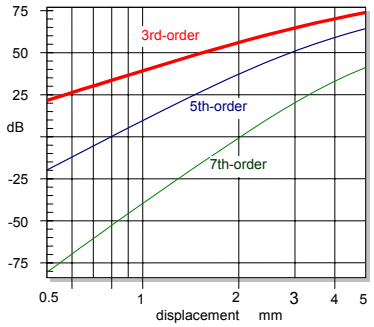
Large amplitude of all components

软限幅或硬限幅非线性?

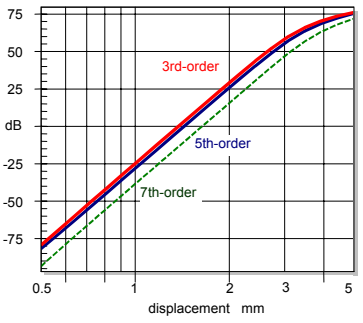
Hard or soft limiting nonlinearity ?

对失真分量的影响 Impact on distortion components

软限幅非线性
soft limiting nonlinearity

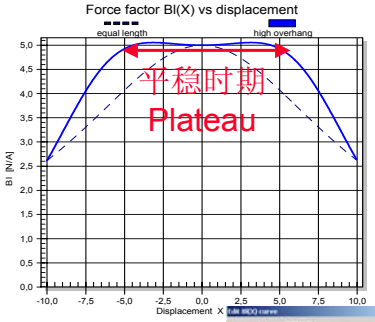


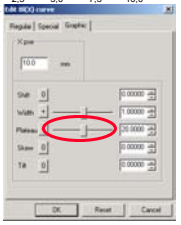
硬限幅非线性
hard limiting nonlinearity



第三步: 最佳长音圈

3rd Step: Optimal Voice Coil Overhang



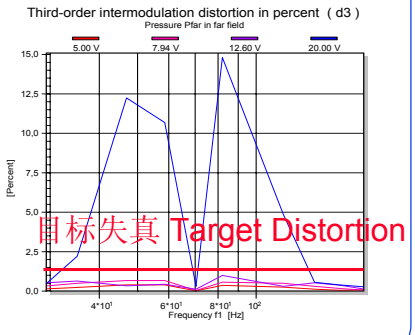


将平稳时期转变为非线性曲线编辑
change Plateau in nonlinear curve editor

在X=Xmax/2处检查失真

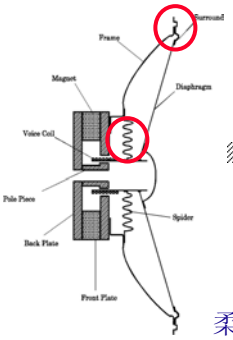
Check Distortion at X=Xmax/2:

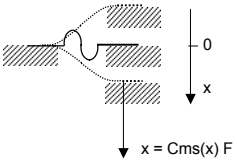
- 3rd order IMD for f >> fs
- 3rd HD for f < fs

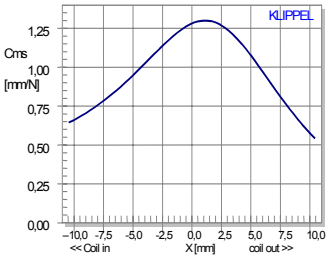


柔顺性

Compliance $C_{ms}(x)$





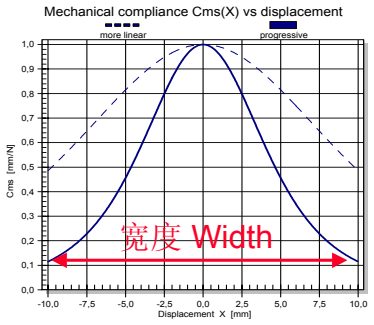


柔顺性改变原因 Variation of Cms(x)

- 定心支片和折环不对称 asymmetry caused by spider and surround
- 运动量, 最大机械负载 moving capabilities, maximal mechanical load
- 调整定心支片和折环 adjustment of spider and surround

第四步: 悬吊系统的自保

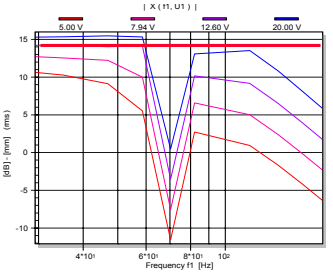
4th Step: Self-Protection of Suspension

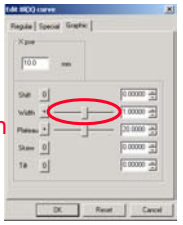


检查 Check:

- 峰值位移 Peak Displacement
- 基波的压缩 Compression of Fundamental for f < fs

最大位移 Maximal Displacement





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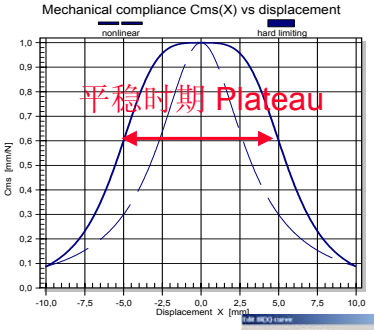
Bl(x) electro-dynamical motor	X	X	X	X				X*
$L_e(x)$ position of coil in the gap		X	X	X		X*	X	
$L_e(i)$ "flux modulation"	X	X	X	X	X*	X*	X	
Variation of Geometry of Cone and suspension	X	X	X	X				
Young's-modulus $E(\varepsilon)$ of cone and suspension	X	X	X	X				
Flow resistance $R_A(v)$ in ports of vented enclosures	X							
Doppler Effect radiation of sound waves		X	X					
Wave Steepening sound propagation at high SPL	X		X					

* provides unique symptoms which are sufficient for the identification of the nonlinearity.

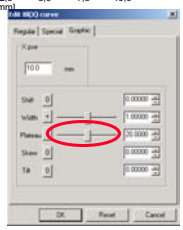
第五步: 柔顺性的失真

5th Step: Distortion of Compliance

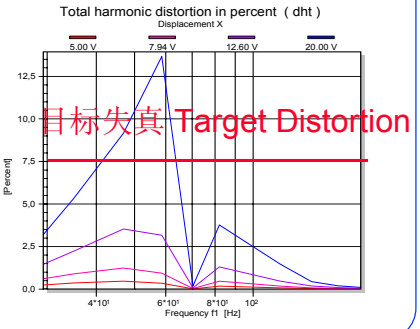


检查 Check:

- 3次谐波失真 3rd HD for f = fs



将平稳时期变为非线性曲线编辑 change Plateau in nonlinear curve editor



问题: 驱动系统的不稳定性
Problem: Instability of the Motor

实验 Experiment:

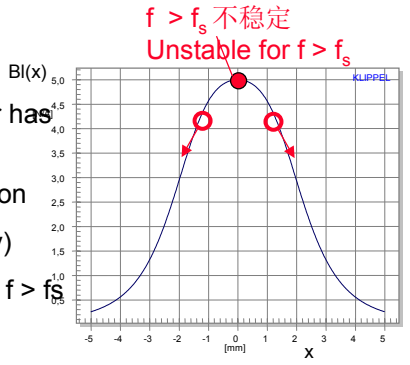
-单体具有较软线性悬吊系统 Driver has soft linear suspension

-等长结构 Equal-length configuration

(磁力强度非线性 Bl(x) nonlinearity)

-正弦驱动信号 Sinusoidal stimulus f > fs

bifurcation caused by motor.MOV

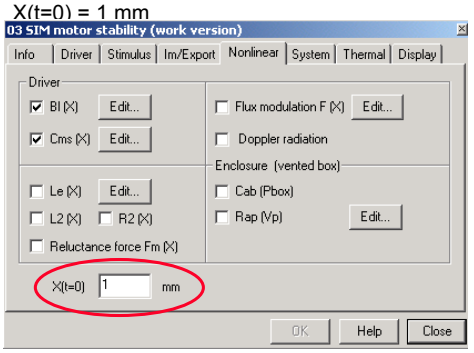


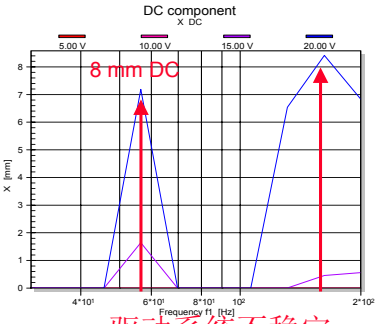
→分叉成两个稳定状态振动 Bifurcation into two stable states of vibration

第六步: 检查驱动系统的稳定性
6th Step: Checking Motor Stability

开始于初始位移 X(t=0) = 1 mm
Start with initial displacement X(t=0) = 1 mm

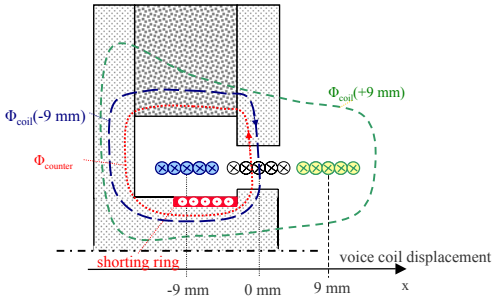
检查 Check
直流位移 DC displacement for fs < f < 2fs

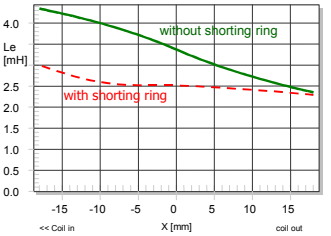




驱动系统不稳定
Motor unstable

音圈电感
Voice Coil Inductance $L_e(x)$

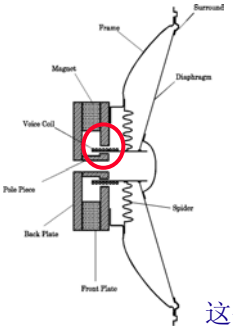


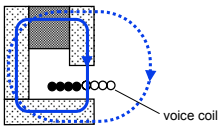


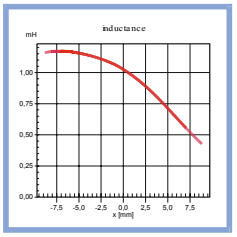
电感取决于 $L_e(x)$ determined by

- 音圈的几何形状,磁隙,磁体 geometry of coil, gap, magnet
- 短路环的最佳尺寸和位置 optimal size and position of short cut ring

音圈电感
Voice Coil Inductance $L_e(x)$







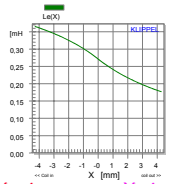
这个参数表示 This parameter shows

- 电感的对称性 asymmetry of inductance
- 最佳短路环形状与位置 optimal size and position of short cut ring

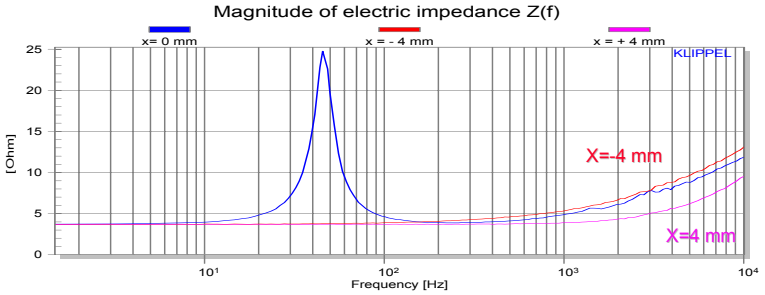
非线性电感的效应
Effect of nonlinear inductance

电感非线性引起 Le(x) nonlinearity causes

- 输入电阻抗的变化 variation of electrical input impedance
- 低音和人声之间的互调 intermodulation between bass tone and voice tone



X=-4 mm X=4 mm



总揽 Overview on

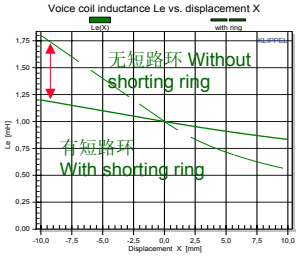
产生有意义征兆的测量 Measurements which provide meaningful symptoms

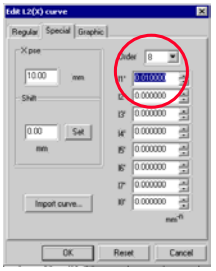
Nonlinearities	SYMPTOMS GENERATED IN MONITORED STATE VARIABLE							
	Sound Pressure				Current			Displacement
	HD	*IMD* (bass sweep)	*IMD* (voice sweep)	*AMD* (voice sweep)	*HD*	*IMD* (bass sweep)	*IMD* (voice sweep)	X_{dc}
$K_{ms}(x)$ suspension (spider +surround)	X							X*
Bl(x) **electro-dynamical motor**	X	X	X	X				X*
$L_e(x)$ position of coil in the gap		X	X	X		X*	X	
$L_e(i)$ "flux modulation"	X	X	X	X	X*	X*	X	
Variation of Geometry of Cone and suspension	X	X	X	X				
Young's-modulus *E(ε)* of cone and suspension	X	X	X	X				
Flow resistance $R_A(v)$ in ports of vented enclosures	X							
Doppler Effect radiation of sound waves		X	X					
Wave Steepening sound propagation at high SPL	X		X					

* provides unique symptoms which are sufficient for the identification of the nonlinearity.

第七步: 短路材料的需求?
7th Step: Shorting Material required ?

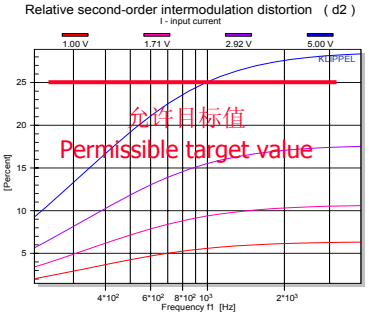
非线性电感的影响 Impact of nonlinear inductance L(x)



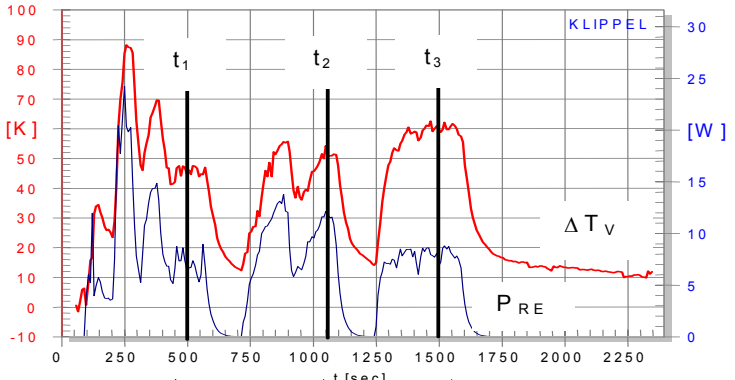


检查2次谐波失真和互调失真

Check 2rd-order IMD in e.g. current voice tone sweep



问题:功率处理
Problem: Power Handling

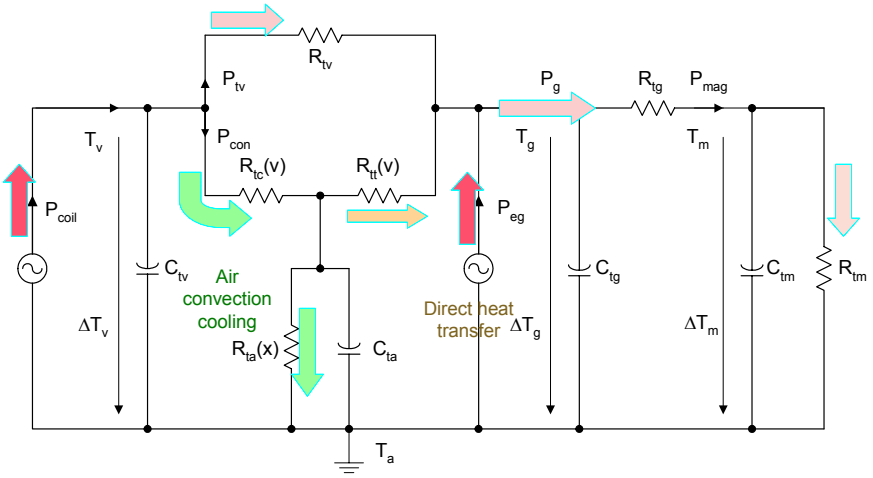


音乐Music: 古典乐 Classic 流行乐 Pop 声乐 Vocal

$\Delta T_v/P_{re}$= 6,8 K/W 4,6 K/W 7,5 K/W

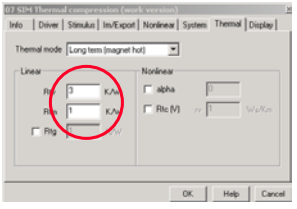
热力电阻不是常数
Thermal resistance is not constant !!

非线性热力模型
Nonlinear Thermal Model



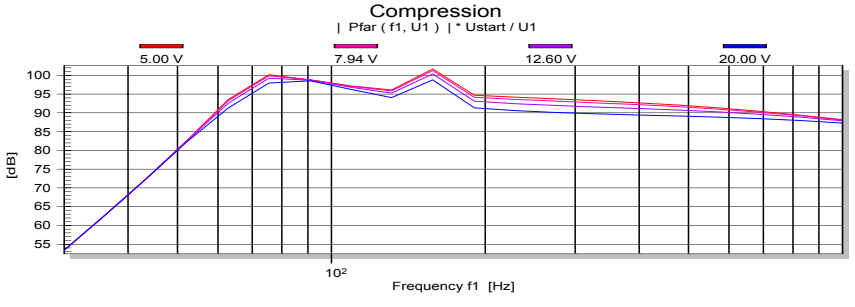
第8步: 热力压缩
8th Step: Thermal Power Compression

将热参数转变为非线性曲线编辑 Change Thermal parameters in nonlinear curve editor



检查 Check:

- 最大音圈温度 Maximal Voice Coil Temperature
- 基波的压缩 Compression of Fundamental



研发 – 品管的循环 The R&D – QC life cycle

试听
Listener

扬声器系统
System
(音箱, 分音器, 聆听环境)

驱动器单元
Driver
(Re, fs, Q)

零件 Parts
(振膜,折环,磁回)

音质
Sound Quality

传递特性
Transfer Function

参数
Parameter

几何形状,
材料
Geometry,
Material

产品目标
Product Target

模拟结果 Simulate Solution

生产测试
Production
Test

原型样品的实现及测试 Realize & Testing the Prototype

参数→← 几何形状，材料
Parameters ←→ Geometry, Material

Geometry

驱动系统
Motor

悬吊系统
Suspension

振膜
Cone

电磁学 Electro-
Magnetical
FEA

热学Thermal
FEA

机械学 Mechanical
FEA

耦合力学及声学
Coupled
mechanical
acoustical
FEA/BEA

Bl(x), Le(x),
Re, ...

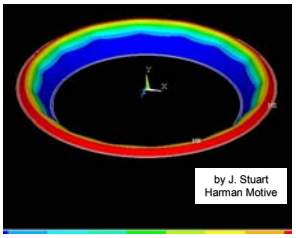
Rtv, Rtm, ...

K(x)

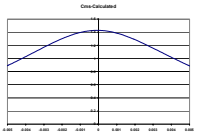
集中参数模型
Lumped
Parameter
Model

声压级传递函数
Transfer function SPL(f)
导纳
Admittance Y(f)
振膜振动
Cone Vibration X(φ,R,f)

机械有限元分析分析输出
Output of mechanical FEA (finite element analysis)

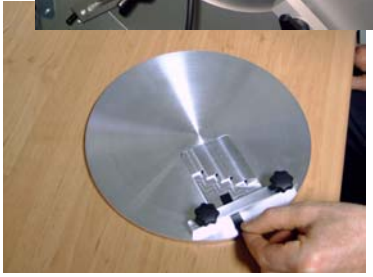


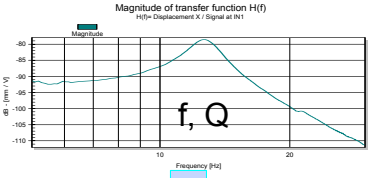
结果 Results:



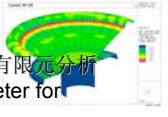
非线性柔顺性
Nonlinear
compliance Cms(x)

材料本身的参数测量
Measurement of Material Parameters





Young's E modulus
Loss factor η
测得扬式模量, 损耗因数



输入参数的机械有限元分析
Input parameter for
FEA

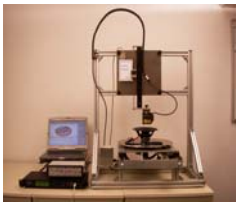
材料本身的参数测量
Measurement of Material Parameters

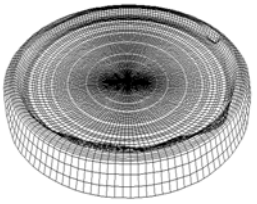
Parameter Measurement of
Loudspeaker Materials

测量几何形状
Measurement of Geometry

- 高精确性 High Precision
  < 10 μm for 0 < z< 300 mm
  < 2.5 μm for –5 mm < z < 5 mm
- 双有关联测量 Dual Measurement with correlation
- 自动检测光学误差 Automatic detection of optical errors
- 报告以常见格式输出 Export in common formats
  (如 such as *.txt, *.dxf)

扬声器扫描仪
Loudspeaker
Scanner





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Production Test

原型样品的实现及测试 Realize & Testing the Prototype

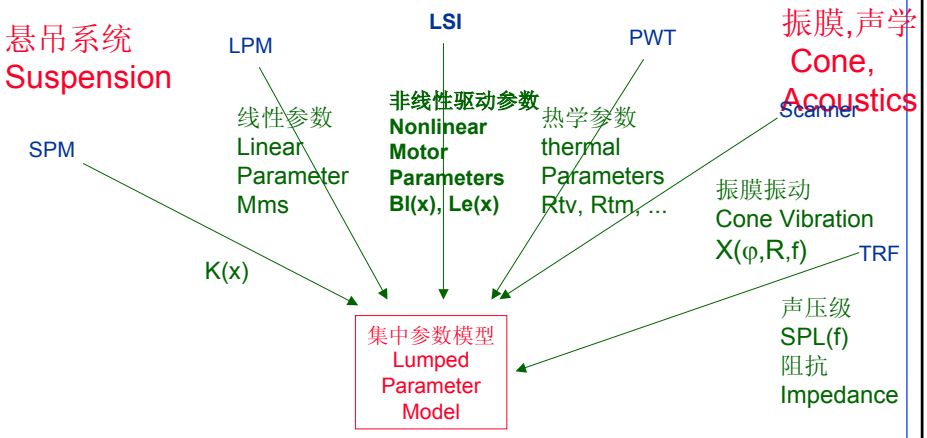
…我们如何支持你 - how we can support you?

原型样品的评价
Evaluation of the Prototype

1. 参数基于 (模型要求) Parameter based (model required)
   - 线性传递函数 Linear transfer functions
   - 小信号参数 Small signal parameter T/S
   - 大信号参数 (热学的, 非线性的)Large signal parameters (thermal, nonlinear)

2. 性能基于 (取决于驱动信号) Performance-based (depend on stimulus)
   - 非线性征兆 Nonlinear symptoms (THD, IMD, XDC)
   - 音圈温度,压缩,最大功率 Coil temperature, compression, Pmax

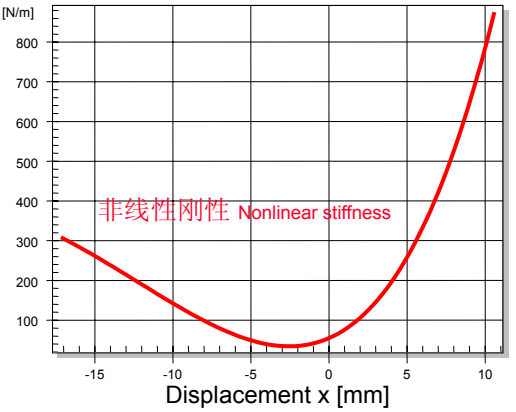
测量中的参数
Parameters from Measurement



扫描仪
SCANNER

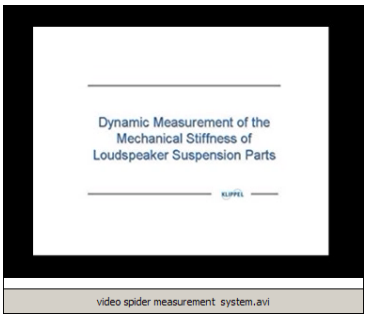
动态测量悬吊部件的机械刚性

Dynamic Measurement of the Mechanical Stiffness of Suspension Parts



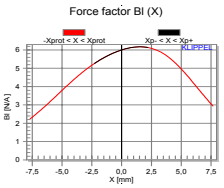
悬吊系统机械刚性动态测量

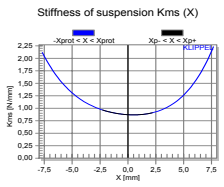
Dynamic Measurement of the Mechanical Stiffness of Suspension Parts

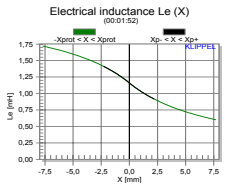


大信号参数测量 LSI

Large Signal Identification







结果 Results:

- 非线性参数
  Nonlinear Paramter
- 最大振幅极限
  Displacement Limits
- 热学参数
  Thermal Parameter

动态参数测量模组总览

Overview on Modules

for Dynamical Parameter Measurement

LPM
线性参数测量
Linear parameters

LSI
大信号鉴定
Nondestructive,
Full protection
Linear, nonlinear and thermal

PWT
功率测试
Power test
with any signal (music !!)
No protection
Linear, nonlinear

LSI Woofer 低音
Fs < 600 Hz

LSI Tweeter高音
Fs < 4kHz

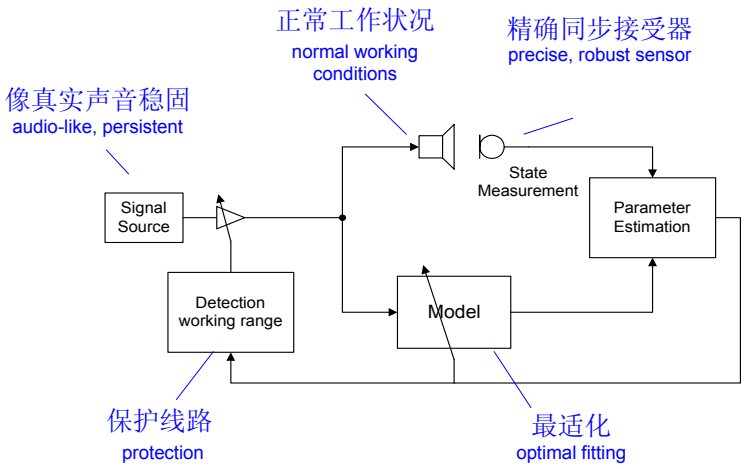
LSI Box音箱系统
Fs < 600 Hz
Driver
+ enclosure

SPM
悬吊系统测试
Suspenion part

大信号辨识系统

Large Signal Identification of Transducers

LSI Module of the KLIPPEL-System

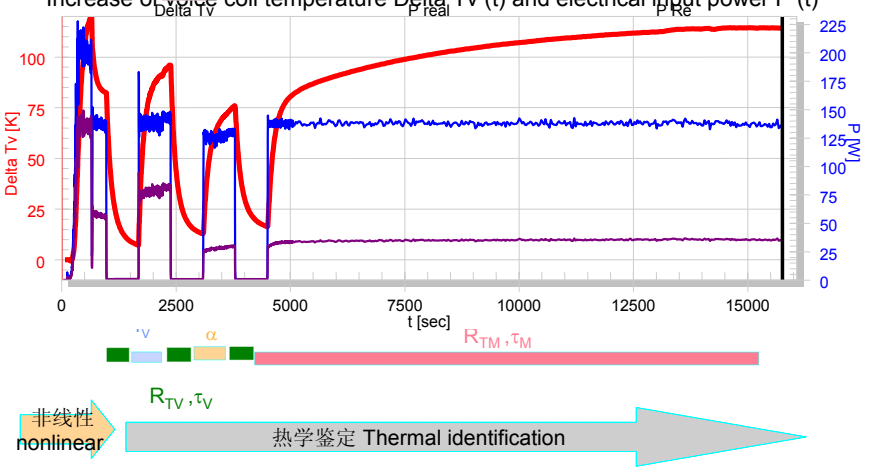


热学参数的测量

Measurement of thermal Parameters

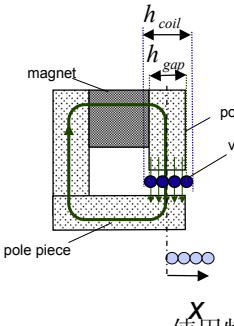
观察音圈温度及输入功率增加的关系

Increase of Voice coil temperature Delta Tv (t) and electrical input power P (t)



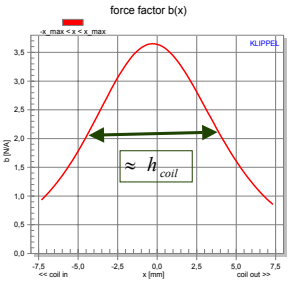
等长磁回系统

Motor with Equal-length Configuration



卷宽 ≈ 磁间隙高

Coil height h_{coil} ≈ gap height h_{gap}



使用特性 Properties:

坏 BAD

- 对音圈偏移敏感 Sensitive to offset in rest position
- 高于 Fo 的频率范围运作不稳定 Sensitive to instabilities f>f_s

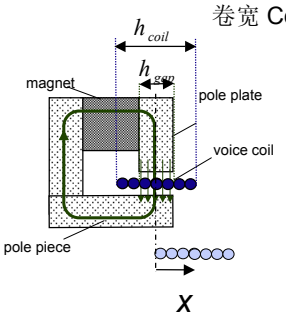
好 GOOD

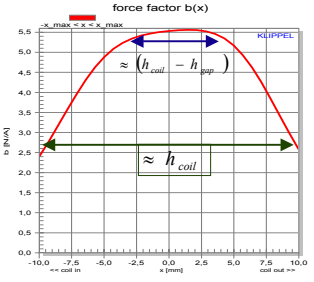
- 小振幅时低阶失真输出 Low order distortion at low amplitudes
- 低电感及磁场调变 low inductance and flux modulation

长音圈的磁回系统

Motor with Overhang Coil

卷宽 Coil height h_{coil} >磁间隙高 gap height h_{gap}





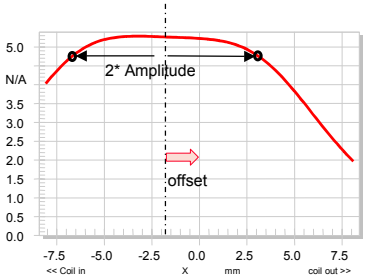
好 GOOD

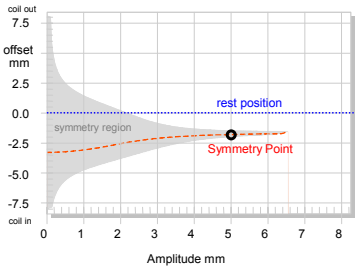
- 对音圈偏移较不敏感 Insensitive to offset in rest position
- $x < (h_{coil}-h_{gap})$ 时低失真 Low distortion for $x < (h_{coil}-h_{gap})$
- $x > (h_{coil}-h_{gap})$ 时高阶失真 High order distortion for $x > (h_{coil}-h_{gap})$

坏 BAD

- 高音圈电感 High voice coil inductance
- 对磁场调变敏感 Sensitive to flux modulation

分析磁力强度的不对称曲线
Assessing the Asymmetry of the Bl(x)-curve

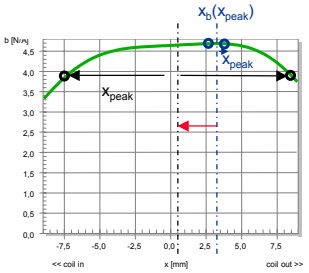


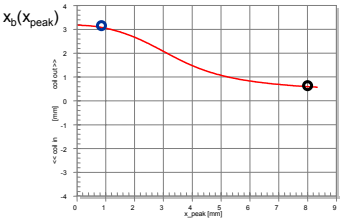


Target 设计目标 :
Keep rest position in symmetry region ! 保持静止位置在对称的范围内 !

Remedy 修正方法 :
If symmetry point is independent of amplitude then offset can be compensated by a voice coil shift ! 调整音圈的位置至振幅的对称点 !

找到磁力强度对称点
Find symmetry point in Bl(x)

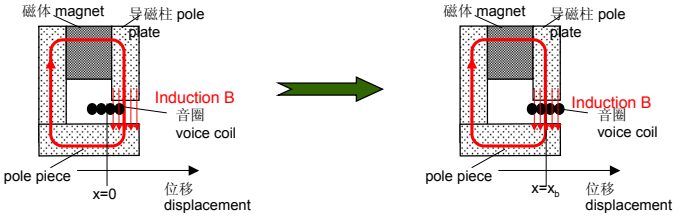


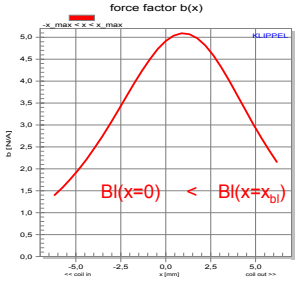


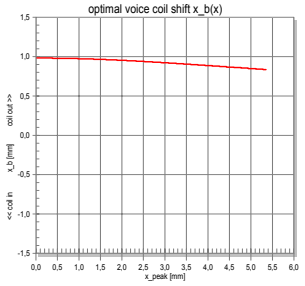
$$Bl\left(x_{Bl}(x)+x\right) = Bl\left(x_{Bl}(x)-x\right)$$

对称点可看出 Symmetry point shows
- 磁力强度曲线的最大值 maximum of Bl(x) curve
- 磁场相对于振幅是否对称 dependence on displacement amplitude

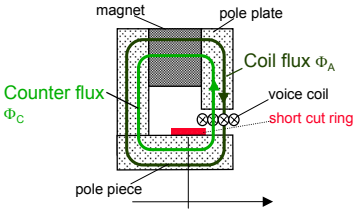
调整音圈的位置
Adjusting voice coil position

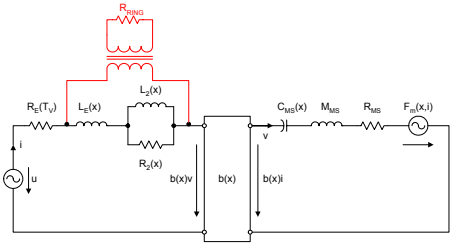




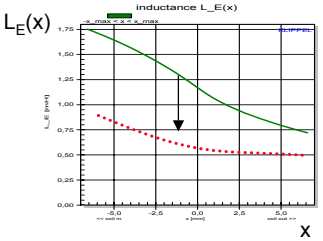


维持电感线性
Linearizing Inductance





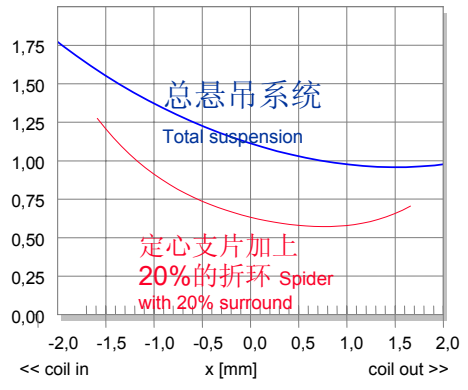
电机等效电路 Electro-mechanical Equivalent Circuit

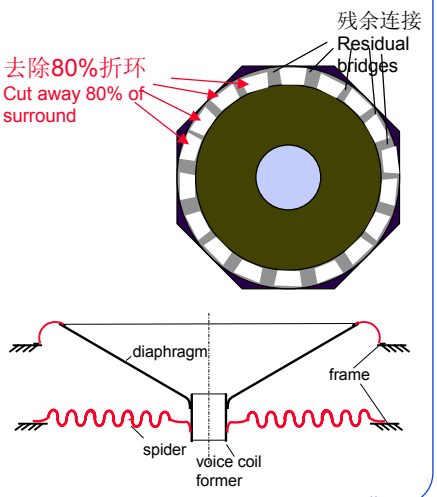


优化设计 Optimal Design:

- 几何形状 Geometry (环或杯 Ring or Cap)
- 材质 Material (铝或铜 Aluminum or Copper)
- 尺寸及位置 Size and position

定心支片和折环的分离刚性
Separate Stiffness of spider and surround





研发 – 品管的循环 The R&D – QC life cycle

试听
Listener

扬声器系统
System
(音箱, 分音器, 聆听环境)

驱动器单元
Driver
(Re, fs, Q)

零件 Parts
(振膜, 折环,磁回)

音质
Sound Quality

传递函数
Transfer Function

参数
Parameter

几何形状, 材料
Geometry, Material

产品目标
Product Target

模拟结果 Simulate Solution

生产测试
Production Test

原型样品的实现及测试 Realize & Testing the Prototype

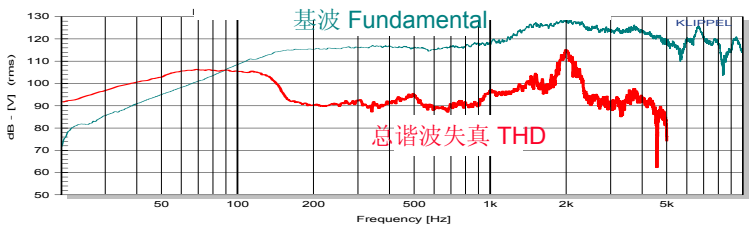
…我们如何支持你 - how we can support you?

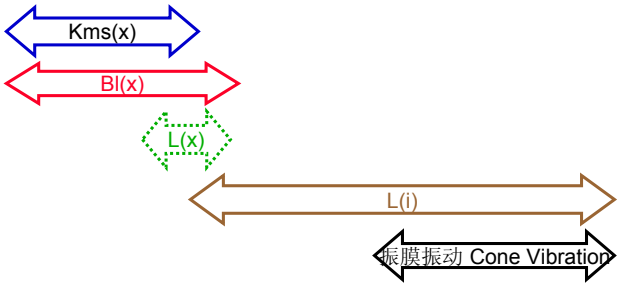
原型样品的评价
Evaluation of the Prototype

1. 参数基于(模型要求) Parameter based (model required)
   - 线性传递函数 Linear transfer functions
   - 小信号参数 T/S Small signal parameter T/S
   - 大信号参数 (热学的，非线性的) Large signal parameters (thermal, nonlinear)

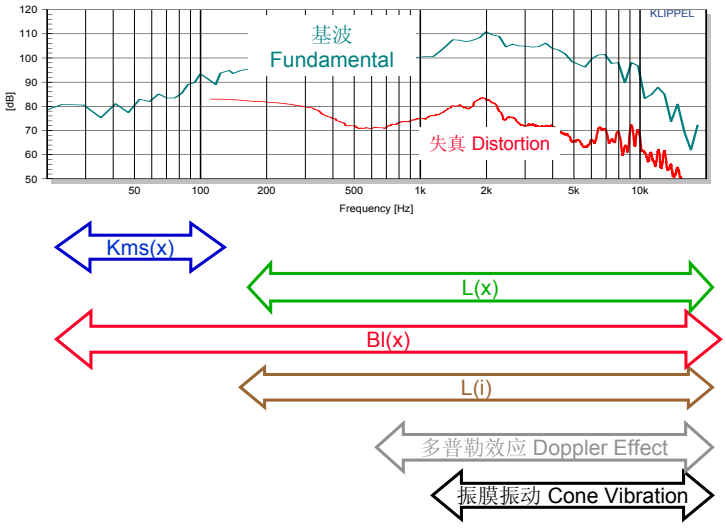
2. Performance-based (depend on stimulus)
   - 非线性征兆 Nonlinear symptoms (THD, IMD, XDC)
   - 音圈温度,压缩,最大功率 Coil temperature, compression, Pmax

解释声压级的总谐波失真
Interpretation of THD in SPL

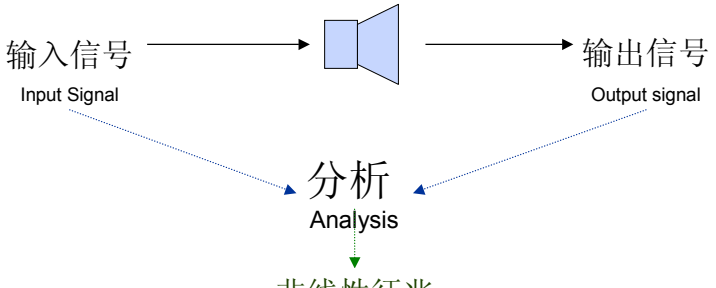




解释多频音失真
Interpretation of Multi-tone Distortion



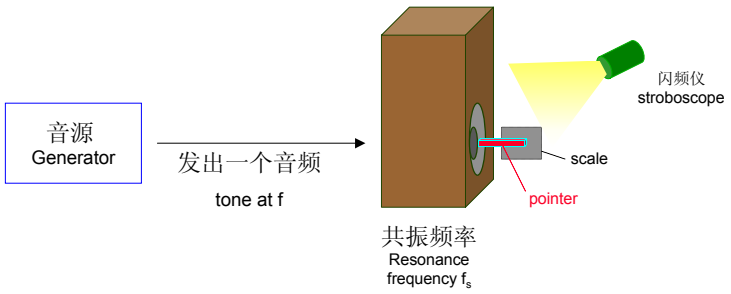
特性评估
Assessing Symptoms



1. 有哪些征兆? What are the symptoms ?
2. 激励信号的影响 Influence of the Stimulus
3. 分析的方法 Methods for analysis

由闪频仪来观看振动模式

Stroboscopic View on the Vibration Behavior



观察频率小于共振频率点	观察频率相当于共振频率点	观察频率大于共振频率点
1. Experiment	2. Experiment	3. Experiment
$f < f_s$	$f \approx f_s$	$f > f_s$

振动行为

Nonlinear Effects in the Vibration of Loudspeakers

video nonlinear behavior.m1v

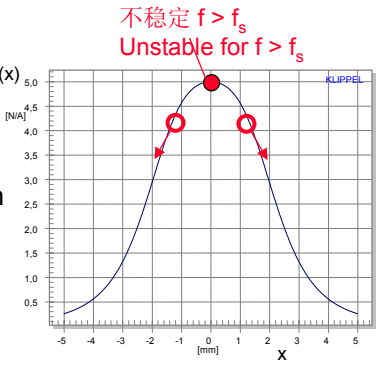
驱动系统的不稳定
Motor Instabilities

发生于单体具有 Occurs in drivers having

- 较软的线性悬吊系统 soft linear suspension
- 等常磁回结构 Equal-length configuration

  (磁力强度非线性 Bl(x) nonlinearity)
- 正弦驱动 Sinusoidal stimulus f > fs

bifurcation caused by motor.MOV



→ 分叉成两个稳定状态振动 Bifurcation into two stable states of vibration

非线性征兆
Nonlinear Symptoms

- 只显示出结果而非原因
  Symptoms show only effects not the cause
- 无法完整表现在大信号下的振动模式
  can not describe the large signal behavior completely
- 取决于是否有合适的驱动信号
  depend on properties of the stimulus (music, test signal)
- 取决于单体的非线性特征
  depend on driver nonlinearity

例：总谐波失真只是其中一个特定征兆
For example: Total harmonic distortion is only one special symptom

什么征兆是我们应该要测量的?
What kinds of Symptoms should we measure ?

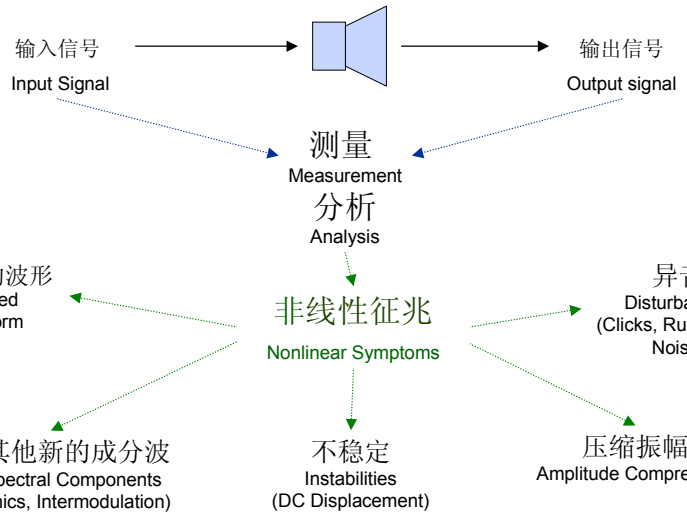
所使用的方法应该是 Use Methods which

- 可取的单体在最临界的状态
  assess transducer under most critical condition
- 可以重复取得的
  allow quantitative assessment
- 可提供具判断性的结果
  give results that are interpretable
- 可显示非线性特征
  reveal nonlinearity
- 根据聆听测试可使用的驱动信号
  Based on stimulus usable in listening tests

驱动信号的影响
Influence of the Stimulus

1. 单音调 Single Tone (TRF Module)
   → 影响基波及谐波 Fundamental, Harmonics only
2. 双音调 Two-tone Signal (DIS Module)
   →影响基波,谐波和互调 Fund., Harm., Intermodulation only
3. 多复合音调 Multitone Complex (LPM Module)
   → 影响稳态特征 steady-state symptoms only
4. 音乐信号 Music (AUR Module)
   → 影响所有特征 all symptoms

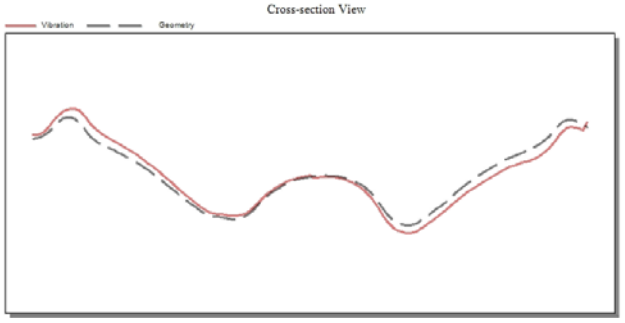
评估大信号振动状况
Assessing the Large Signal Behavior



物理学的一个不规则缺损
Physics of a Irregular Defect
第一个例子:音圈摩擦

1st Example: voice coil rubbing

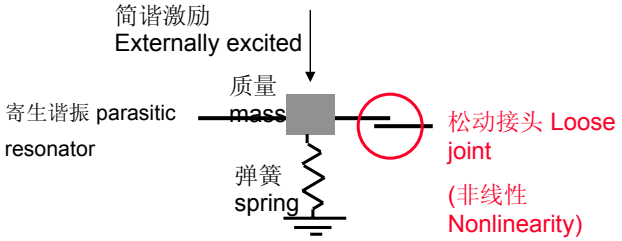
328 Hz



→ 摇摆模式可能导致音圈摩擦 Rocking mode may cause voice coil rubbing

物理学的一个不规则缺损
Physics of a Irregular Defect

第二个例子: 粘胶问题 *2nd Example: Glue problem*

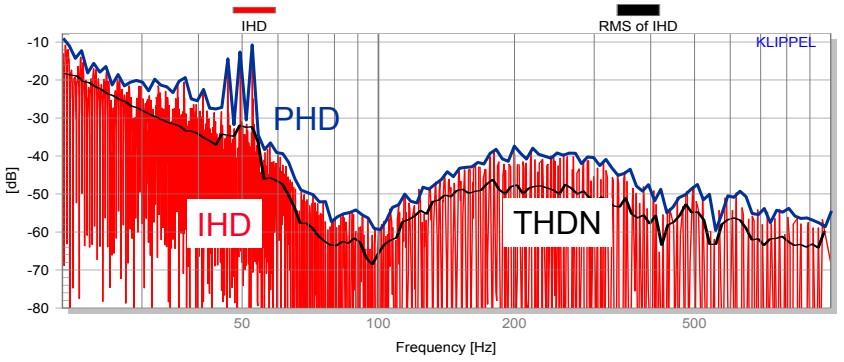


大多数缺陷表现为非线性弹簧振子 Most defects behave as a **nonlinear oscillator**

- 在临界振幅以上运动 active above a critical amplitude
- 振动新模式 new mode of vibration
- 驱动和同步由驱动信号完成 powered and synchronized by stimulus
- 输出功率稳定 constant output power

谐波失真
Harmonic Distortion

驱动信号: 正弦扫频 Stimulus: Sinusoidal sweep



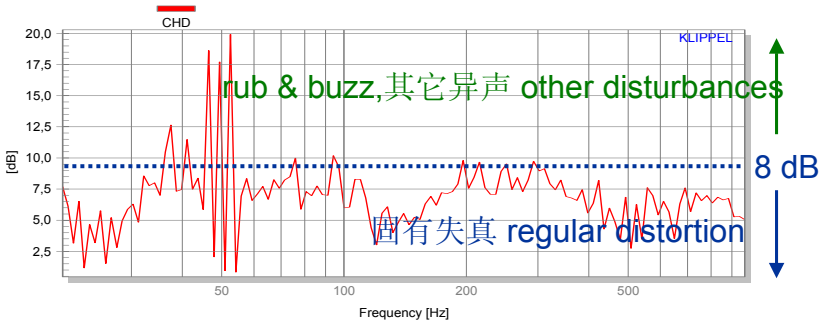
瞬时谐波失真 Instantaneous harmonic distortion

谐波失真的平均值 Mean value of harmonic distortion

峰值谐波失真 Peak harmonic distortion

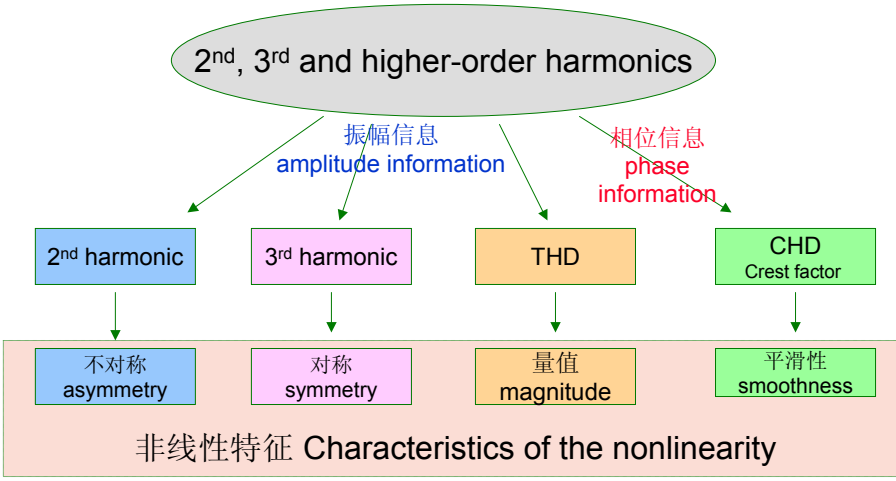
谐波失真的峰值因子
Crest factor of harmonic distortion (CHD)

驱动信号: 正弦扫频 Stimulus: Sinusoidal sweep



谐波失真峰值因子可以在绝对标度上被解释！
CHD can be interpreted on an absolute scale ！

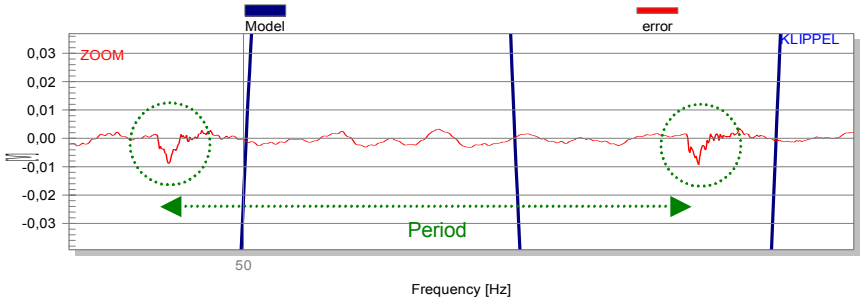
谐波失真测量的结果
Results of the Harmonic Distortion Measurement



时域信号失真的细节

Detail of the distortion time signal

案例 A:Case A: „beating wire of a defect driver“



- 固有失真具有高能级 Regular distortion have high energy
- 异声具有低能级 Disturbances have low energy
- 异声是集中在一小部分周期里的 Disturbances are concentrated at a fraction of a period

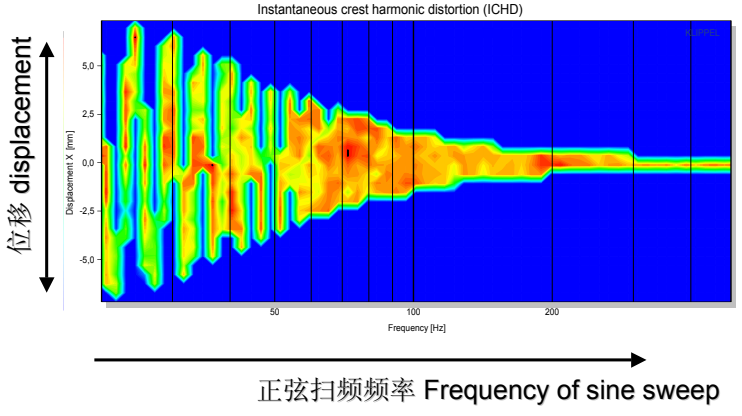
→ 峰值失真 (大峰值因子) peaky distortion (high crest factor)

→ 有源补偿是有益的 Active compensation is useful

检查: 谐波失真的峰值因子

Check: crest factor of harmonic distortion

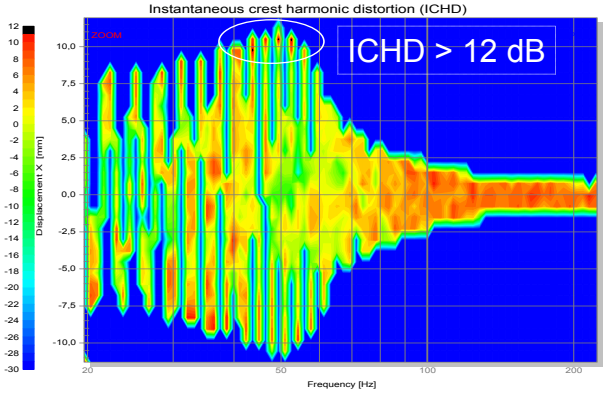
谐波失真的峰值因子 Crest factor of harmonic distortion



正弦扫频频率 Frequency of sine sweep

瞬时峰值谐波失真
Instantaneous crest harmonic distortion ICHD(f,x)

案例A: 毁损单体接线敲打 Case A: „beating wire of a defect driver“

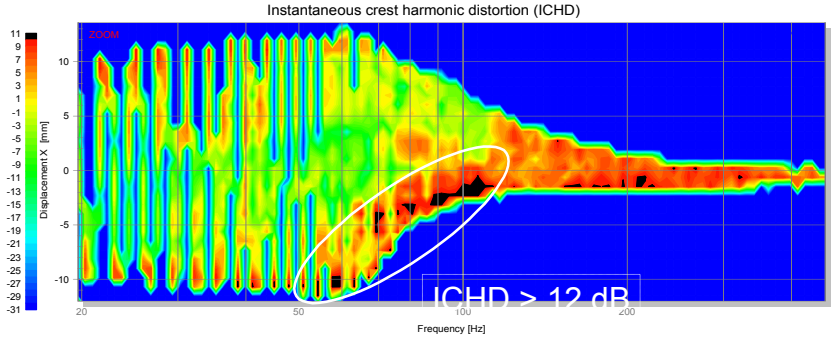


毁损出现在50赫兹 + 10 mm 位移处

Defect occurs at + 10 mm displacement at 50 Hz

瞬时峰值谐波失真
Instantaneous crest harmonic distortion ICHD(f,x)

案例B: 毁损单体音圈摩擦 Case B: „rubbing voice coil of a defect driver“



初始摩擦条件 Conditions initiating rubbing:

- 负转折点的音圈偏移
  Negative turning point of voice coil excursion
- 共振频率之上 (质量主导) → 音圈倾斜
  Above resonance frequency (mass dominant) → Tilting of voice coil former

需求
Requirements

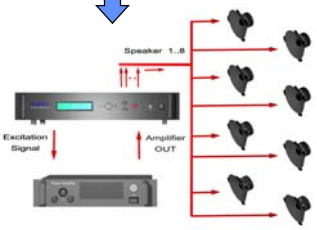
软件 Software:

- dB-Lab (frame)
- PWT (module)
- SPY

USB

硬件 Hardware:

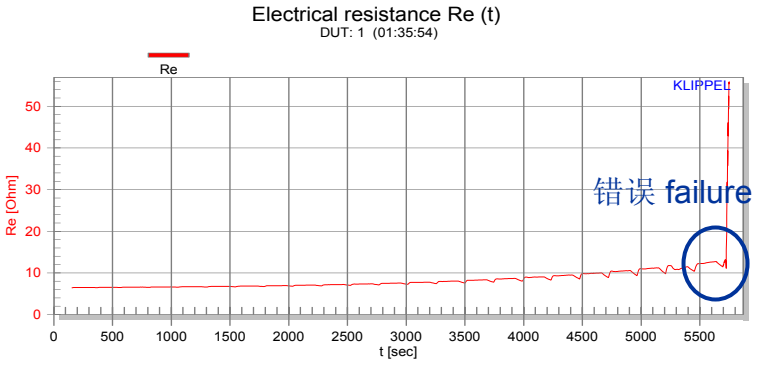
- Power Monitor 8
- Power Amplifier



1 ... 8 DUTs

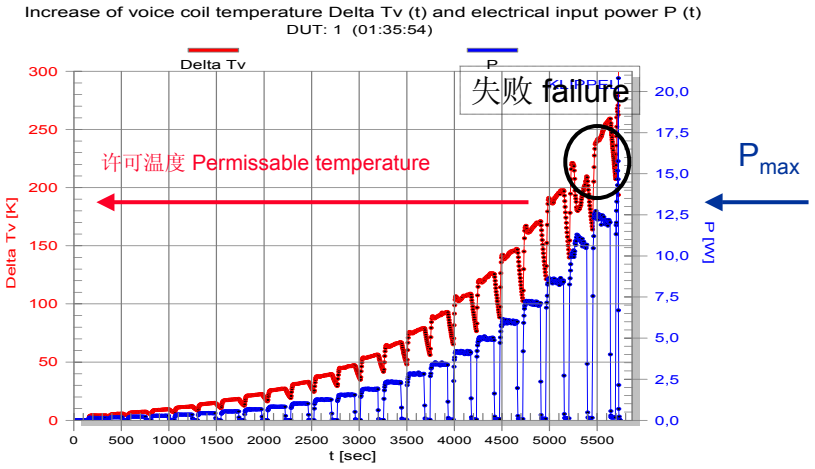
检查耐久性
Durability Check

Power handling test according to AES2
Accelerated life test according to EIA-426B
Tests according IEC to 60268



评估可承受功率 PWT

Assessing Power Handling

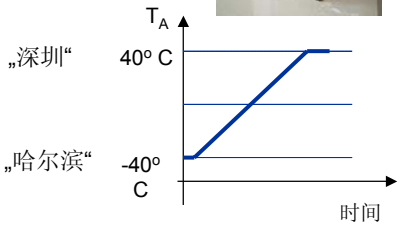


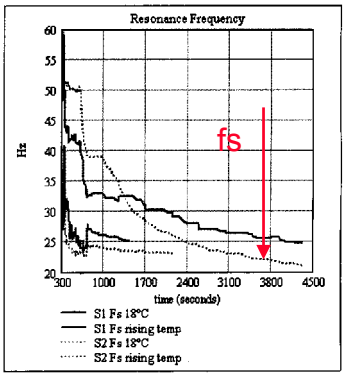
参数变化 Parameter Variation - PWT

研究环境温湿度变化对参数的影响

Investigate the Influence of Ambience Conditions

恒温恒湿箱
chamber





→ S. Hutt: Ambient Temperature Influences on OEM Automotive Loudspeakers, AES preprint 5507

研发 – 品管的循环 The R&D – QC life cycle

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Listener

扬声器系统
System
(音箱, 分音器, 聆聽環境)

驱动器单元
Driver
(Re, fs, Q)

零件 Parts
(振膜, 定心支片, 驱动部分)

音质
Sound Quality

传递函数
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几何形状, 材料
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产品目标
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生产测试
Production Test

原型样品的实现及测试 Realize & Testing the Prototype

…我们如何支持你 - how we can support you?

线上测试需求
Requirements for
100 % end-of-line testing

1. 可信赖的不良品检测 reliable detection of defect units
2. 自动环境噪声修正 robustness against ambient noise
3. 快速执行 high speed
4. 灵活的客制化设计 flexibility for customer‘s needs
5. 操作简易 simple use
6. 经济实惠 cost effective solutions
7. *未来可作线上诊断 In future → on line diagnostics ?*

目标:可信赖的测试

Target: Reliable Testing

问题: 测量环境 Problem: Measurement Condition

声学环境 Acoustical environment
- 空气 Free air, panel
- 箱子 box
- 平面波管 plane wave tube
- 人造耳 artificial ear

天气条件 Climate conditions
- 温度 temperature
- 湿度 humidity

激励 Excitation
- 功放的输出电阻
  Output impedance of amplifier
- 分流或不分流 Shunt or not

扬声器位置 Speaker position
- 垂直/水平
  vertical/horizontal
- 到麦克风的距离
  Distance to microphone

测量结果应该 Measurements results should be
- 可再生和可重复 reproducible and repeatable
- 对定义条件有效 valid for defined condition

目标: 可信赖的测试

Target: Reliable Testing

解决方法: 致力于QC的硬件

Solution: Hardware dedicated for QC

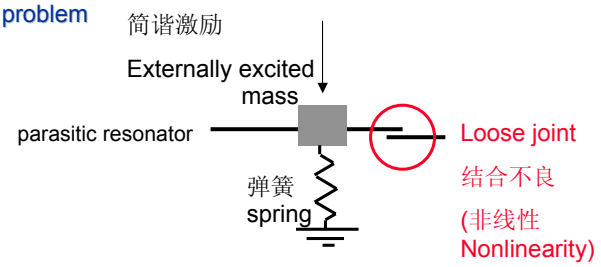
- 2x Line inputs (100 dB SNR)
- 2x Microphones + ICP Power
- 2x XLR outputs
- 2x speaker impedance

  电压传感器 voltage sensors (200 V)

  电流传感器 Current sensors (50 A)
- GPI/GPO digital control interface
- 温度和湿度传感器 temperature & humidity sensor

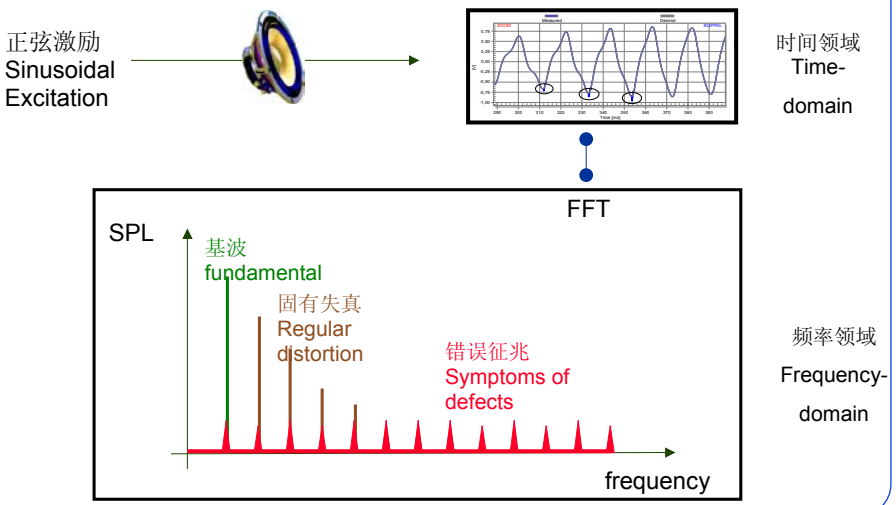
不良扬声器的物理现象
Physics of a Loudspeaker Defect

Example: glue problem
例: 粘胶问题



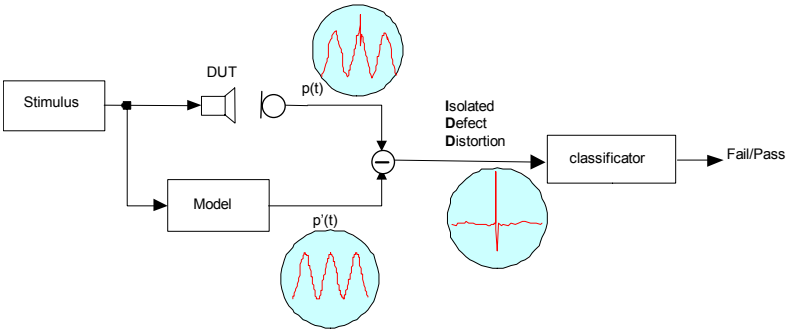
不良的非线性行为模式 Most defects behave as a **nonlinear oscillator**
- 超出限定放大范围–限压 active above a critical amplitude
- 产生新的振动模式 new mode of vibration
- 驱动和同步由驱动信号完成 powered and synchronized by stimulus

分解征兆
Separation of the Symptoms



可检测人耳难分辨得缺陷

Detecting Defect Units with inaudible symptoms

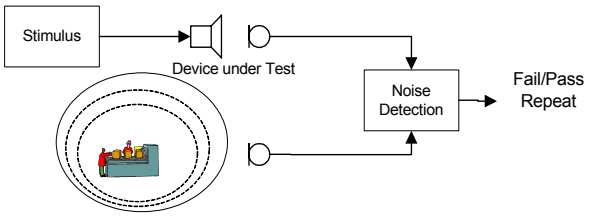


Meta-Hearing Technology

- 固有失真可预测 Regular distortion are predictable
- 模拟固有失真 Modeling of regular distortion (adaptive learning)
- 遮掩固有失真可主动滤除 Masking by regular distortion can be removed actively

在吵杂的生产环境作可靠性高的测试

Reliable Measurement in a noisy production environment



Solution:

→ 第二支麦克风测远场噪音 Second microphone in the far field

→ 预测在待测物的噪音 Predict noise at DUT

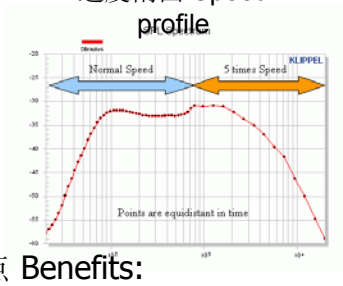
→ 有效得知测量是否被环境噪声干扰 Detects corrupted measurements reliably

→ 自动重复测试 Repeats measurement automatically

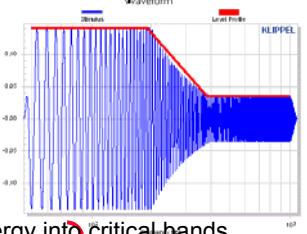
使用非常短的测试信号 (<0.5s)
Using very short test signals (<0.5s)

高速度性能High Speed Performance

速度剖面 Speed profile



水平剖面
Level profile

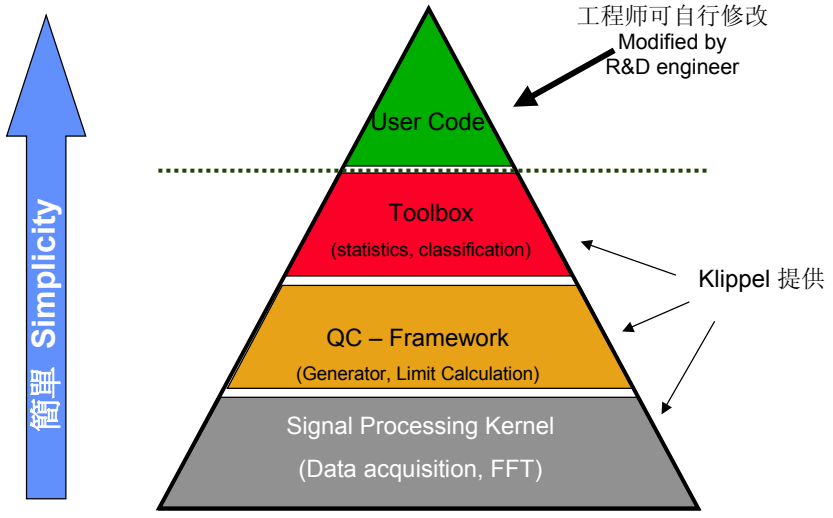


优点 Benefits:

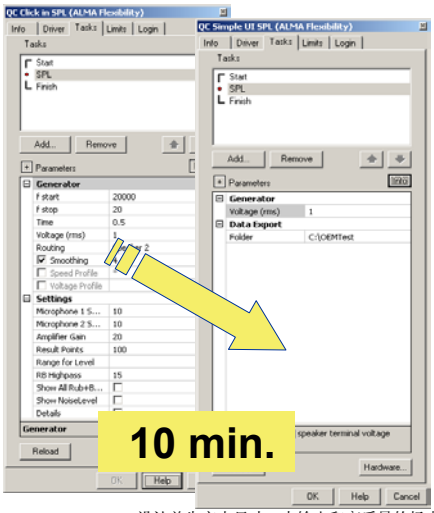
- 提供足够的能量进入临界带 Provide sufficient energy into critical bands
- 给予足够的时间来建立临界振动 Give sufficient time to establish critical vibration
- 在低频处保护单体 Protect driver at low frequencies
- 在高频处保护操作者 Protect operator at high frequencies

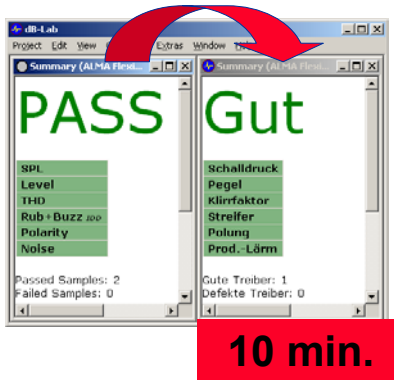
节约时间
Save time

保持程序简单
Keep Programming simple

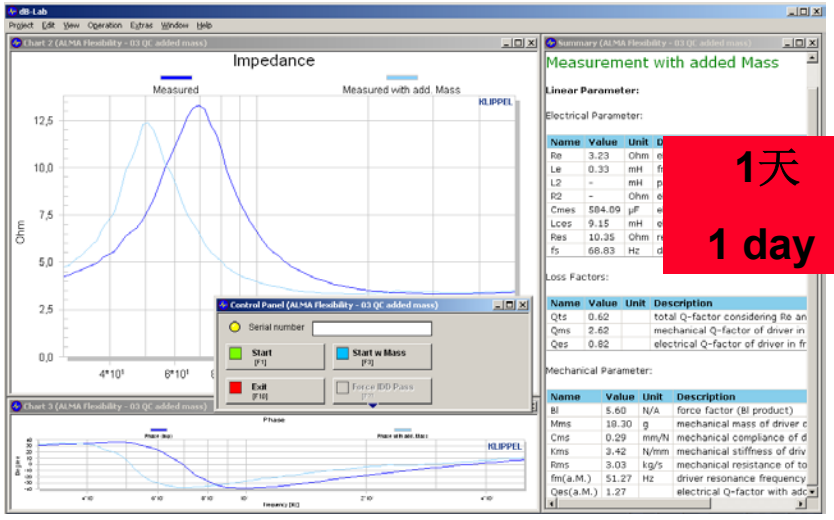


可调整使用者界面, 可汉化
User-Interface can be adjusted



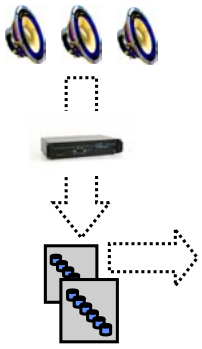


实现客户特制测试程序
Implement specific algorithms



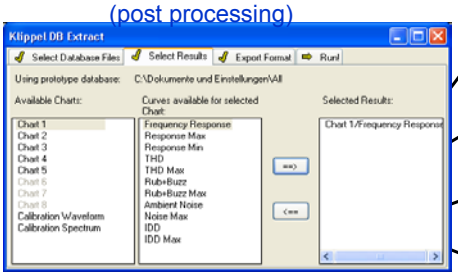
→ 密码被保护 Code can be protected

目标: 灵活性 + 简易操作
Target: Flexibility + Simple Use
解决: 获取所有数据 Solution: Access to all data



独立的数据库
对每个DUT
Separate
database for
each DUT

提取工具 (后置处理)
Extraction tool
(post processing)



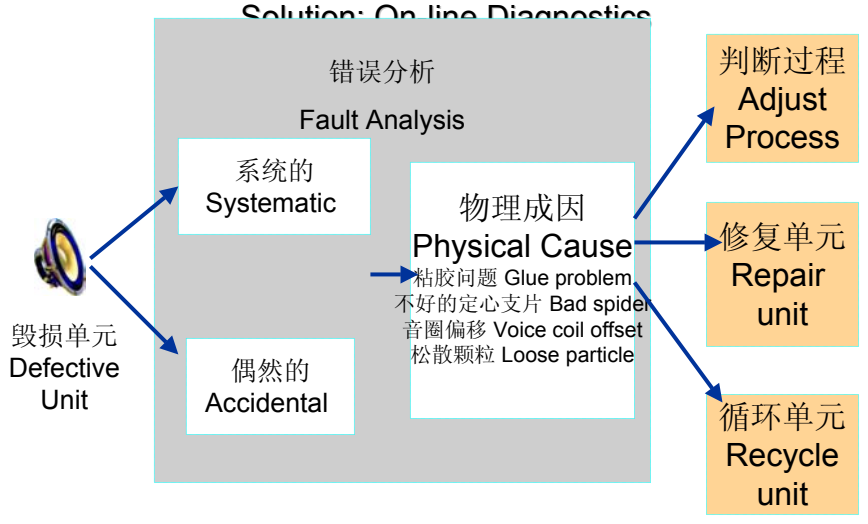
过程控制
Process
control

诊断
Diagnostics

长期统计
Long term
statistics

顾客报告
Report
for customer

目标: 过程控制信息
Target: Information for Process Control
解决: 线上诊断
Solution: On-line Diagnostics



目标: 过程控制的信息

Target: Information for Process Control

解决:驱动系统和悬吊系统的检查

Solution: Motor and Suspension Check

失败 Fail

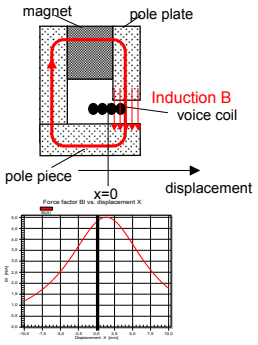
X_{offset}=1.5 mm

in QC

1 s

成功 Pass

X_{offset}=0.2 mm

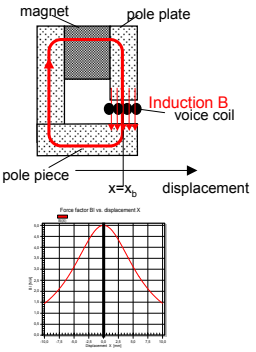


确保最佳音圈位置

Ensure optimal coil position !

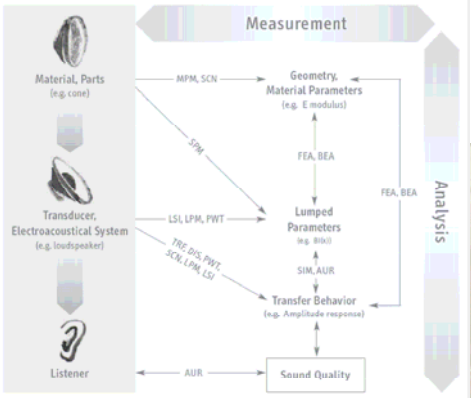
LSI

(5 minutes)

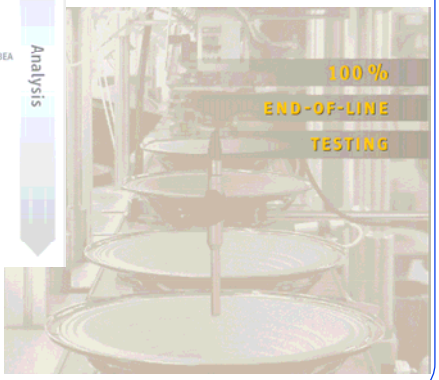


KLIPPEL Analyzer System

工具对于开发Tools for development



和制造and manufacturing



联系方式
Contact

www.klippel.de 中国代表意富公司
or
info@klippel.de

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- Discuss Solutions (email or phone)　电邮电话联系
- Get Training (workshops)　详情请联络后方展位