Das Messen in der Raum- und Bauakustik

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Modern measurement techniques in room and building acoustics

- Introduction
- Modern versus classical methods – a conflict ? (MLS, sweeps, …)
- New challenges in impact sound
- „Correct“ measurements? -> GUM
- Conclusions

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Modern vs classical methods

- Building Acoustics - what do we measure ?

- Sound levels (energy density)
- Reverberation times (1/3 octave bands)

- Sound intensity

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Classical methods in building acoustics

- ISO 140 (Sound insulation)
- ISO 354 (Sound absorption)
- ISO 10534 (Impedance tube)
- ISO 10484 (Flanking transmission)
- ....
- and ISO 3382 for room acoustics

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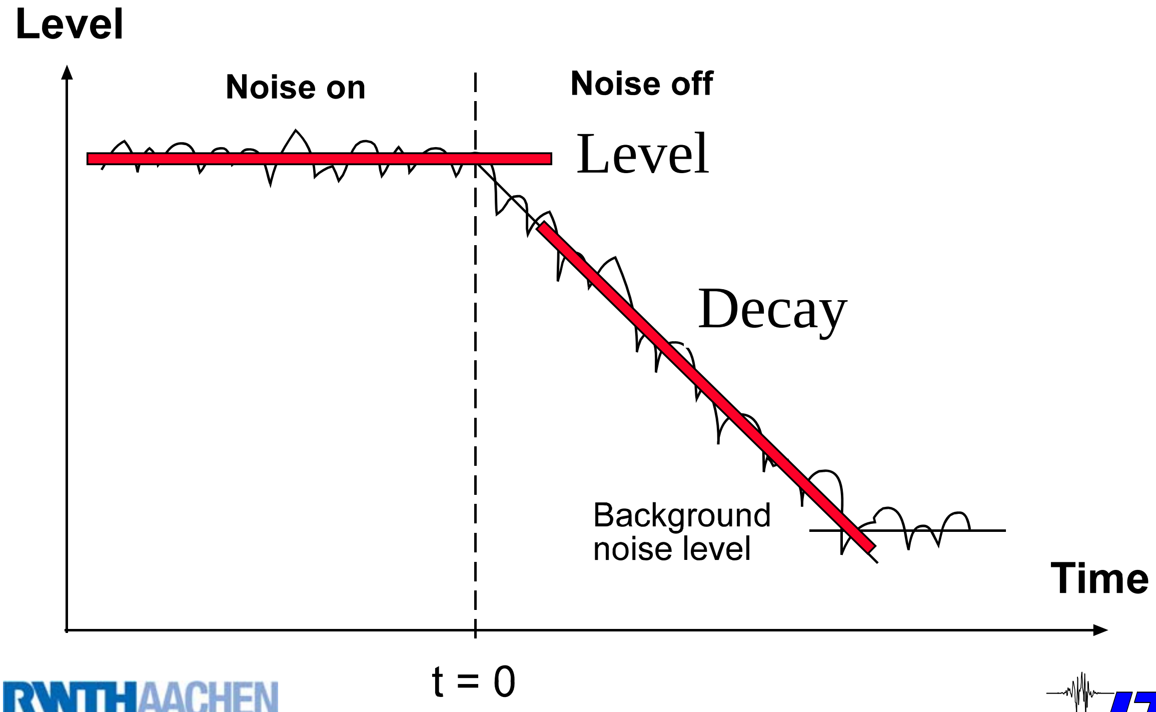
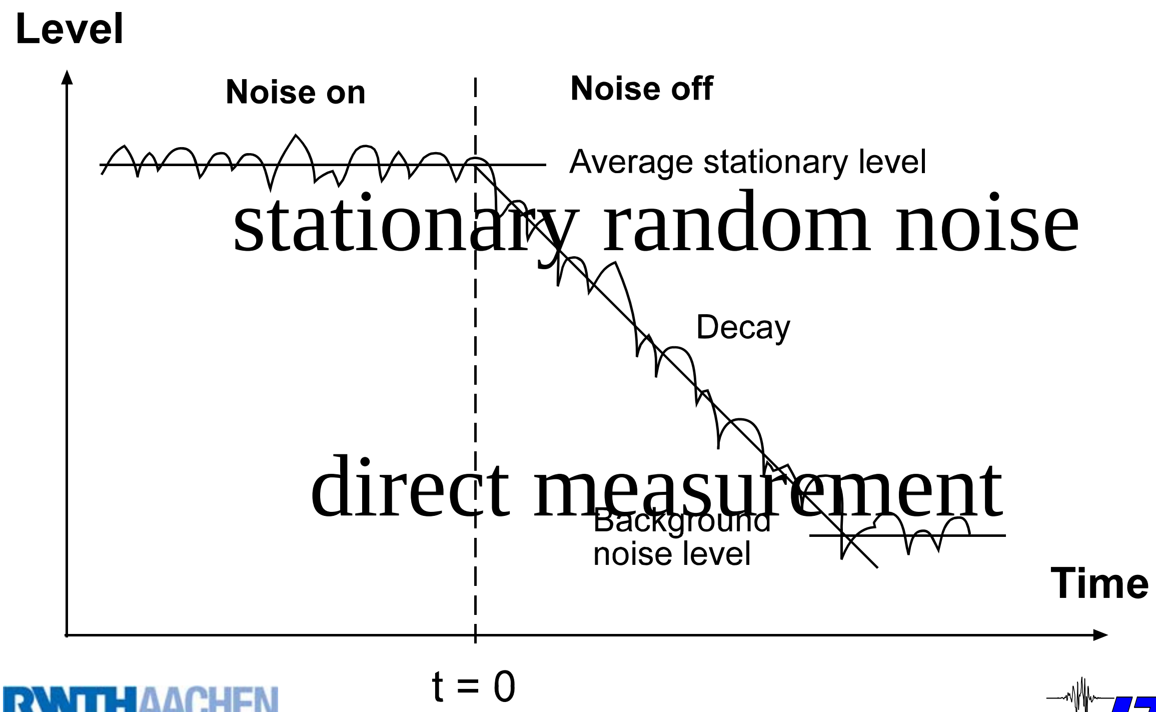
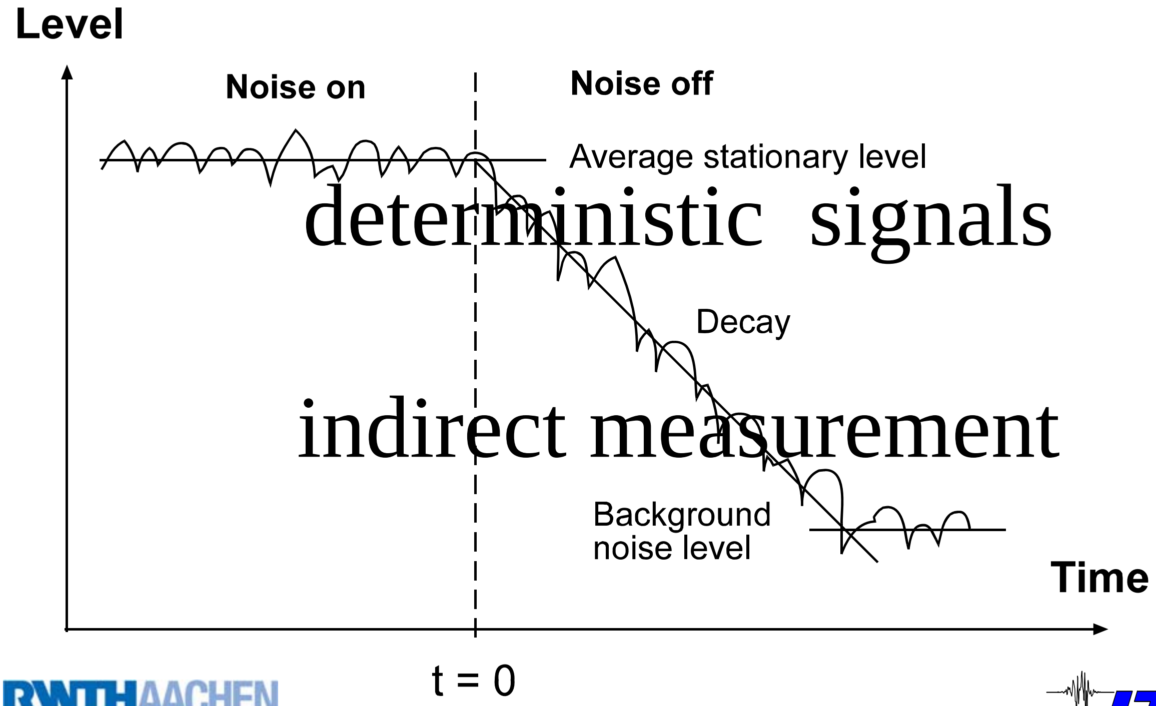
What do we measure ?



How ?



Modern measurement techniques



deterministic signals

indirect measurement

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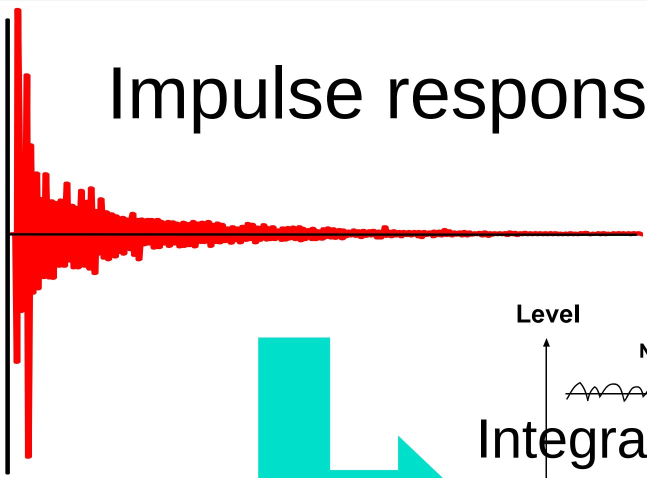
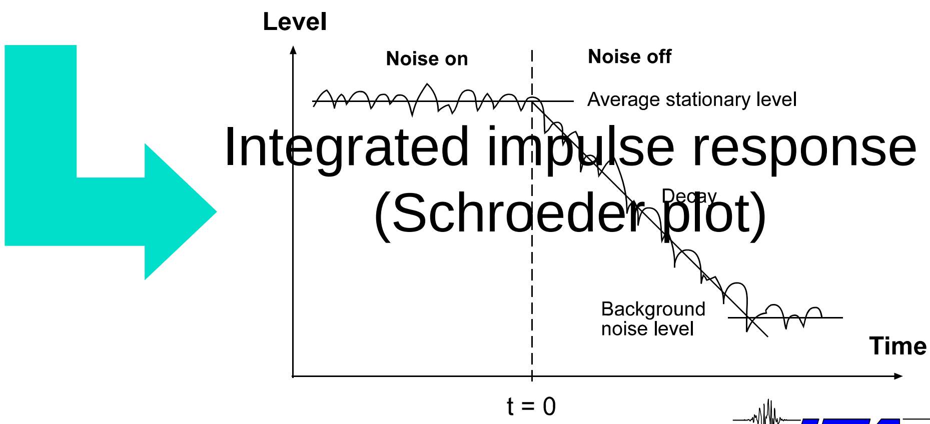
Modern measurement techniques – basic result

Impulse response





Integrated impulse response (Schroeder plot)

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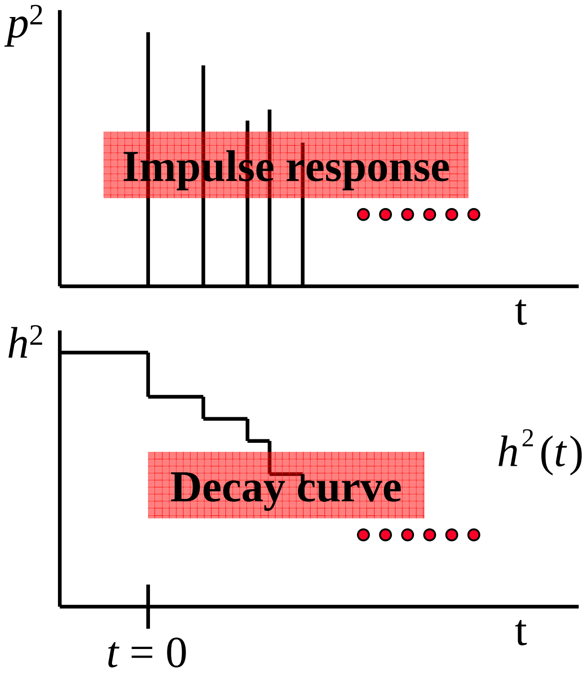
Integrated impulse response



Stationary case :

$$C = h^2(t<0) = N_0 \int_0^\infty p^2(\tau)\mathrm{d}\tau$$

Switch off :

$$h^2(t) = N_0\left[\int_0^\infty p^2(\tau)d\tau - \int_0^t p^2(\tau)d\tau\right]$$

$$= N_0 \int_t^\infty p^2(\tau)\mathrm{d}\tau$$

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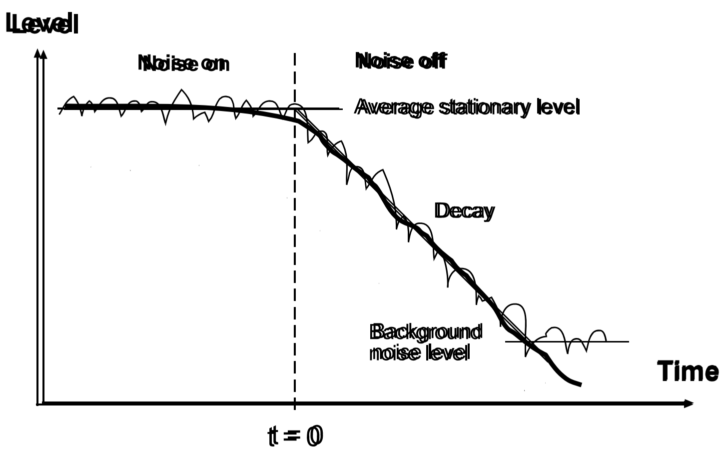
Integrated impulse response

Decay curve $h^2(t) = N_0 \int_t^\infty p^2(\tau)\mathrm{d}\tau$

Expected decay = average decay curve (infinite averages)
(smooth monotic curve)



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No !

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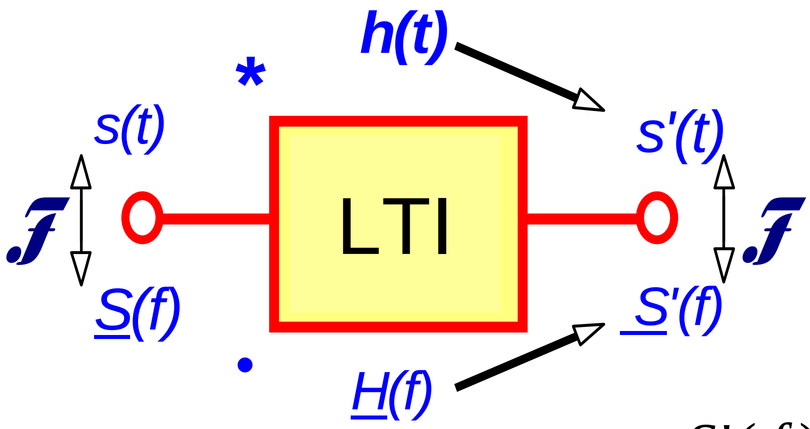
Measurement of impulse responses

$$s'(t) = s(t) * h(t) = \int_{-\infty}^{\infty} s(\tau)h(t-\tau)d\tau$$



$$\underline{S}'(f) = \underline{S}(f) \cdot \underline{H}(f)$$

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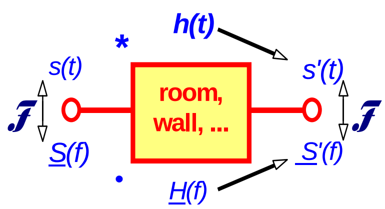
Measurement of impulse responses



Method 1: Spectrum division, inverse FFT

$$\underline{H}(f) = \frac{\underline{S}'(f)}{\underline{S}(f)} \qquad h(t) = \mathcal{F}^{-1}\{\underline{H}(f)\}$$

Important: $\underline{S}(f)$ broadband spectrum

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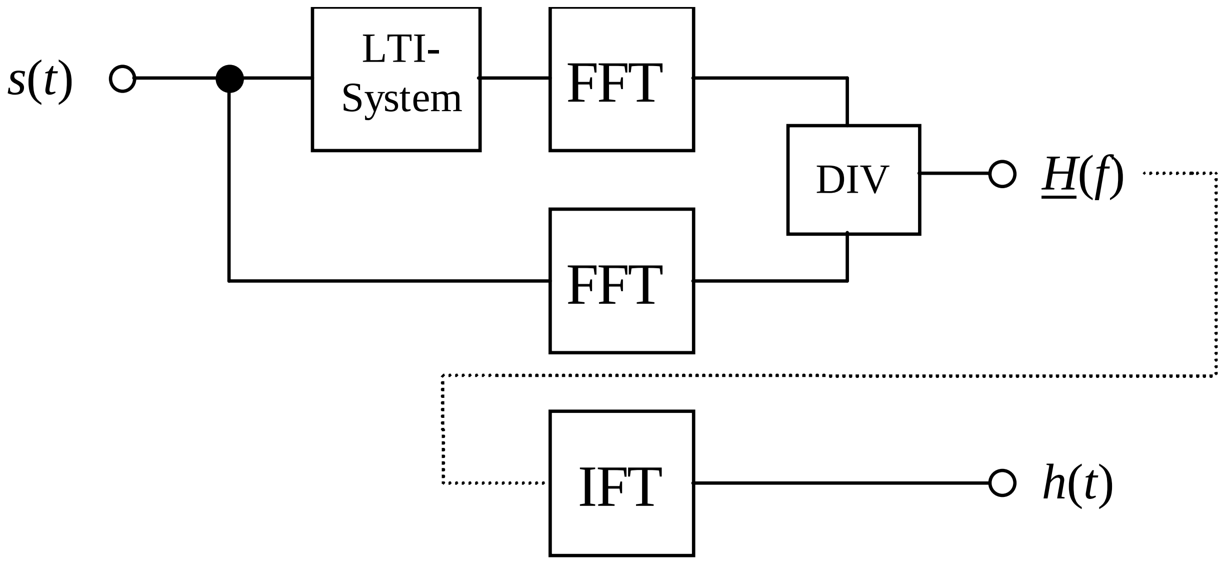
Example 1: 2-channel FFT technique



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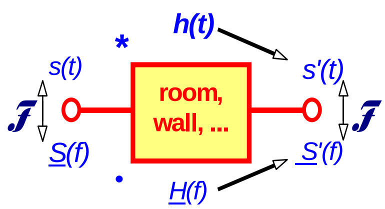
Measurement of impulse responses



Method 2: Deconvolution

$$h(t) = s'(t) * s^{-1}(t) \qquad s^{-1}(t) = \mathcal{F}^{-1}\left\{\frac{1}{\underline{S}(f)}\right\}$$

(matched filter, FIR filter)

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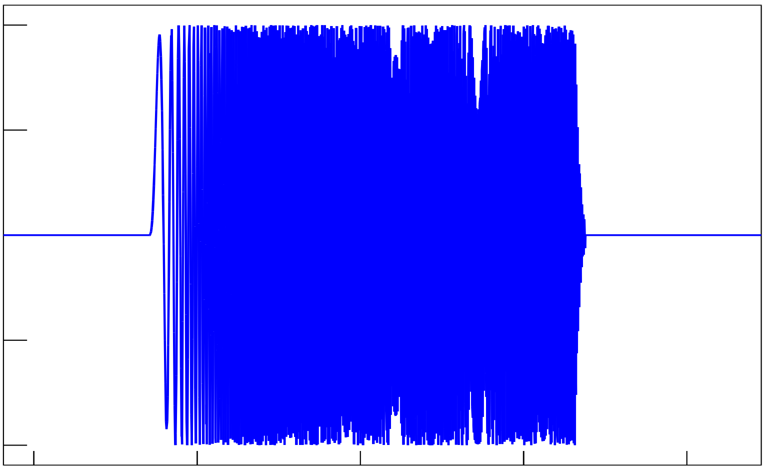
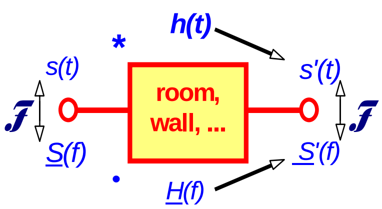
Example 2: “white” sinusoidal sweep



$$s^{-1}(t) = s(T_{\mathrm{Rep}} - t)$$

Measurement of impulse responses



Method 3: cross correlation

$$h(t) = s'(t) * s(-t) = s'(t) \otimes s(t) = \int_{-\infty}^{\infty} s'(\tau) s(t+\tau) d\tau$$

Important: *s*(*t*) „correlation signal“

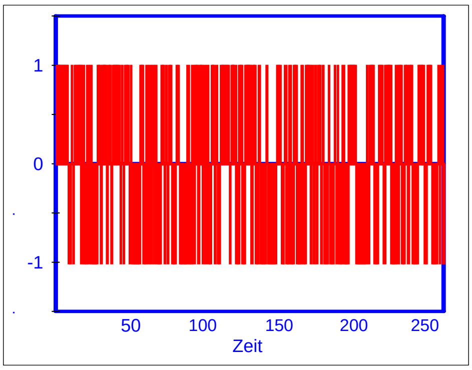
Example 3: MLS technique

$$s_{\mathrm{MLS}}(t) * h(t) * s_{\mathrm{MLS}}(-t) = s_{\mathrm{MLS}}(t) * s_{\mathrm{MLS}}(-t) * h(t)$$

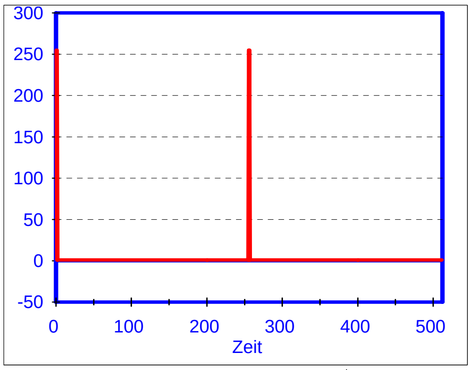
$$= \Phi_{ss}(t) * h(t)$$

measured

cross correlation



FHT



Modern measurement techniques

$$h(t) = \mathcal{F}^{-1}\left\{\frac{\underline{S}'(f)}{\underline{S}(f)}\right\}$$

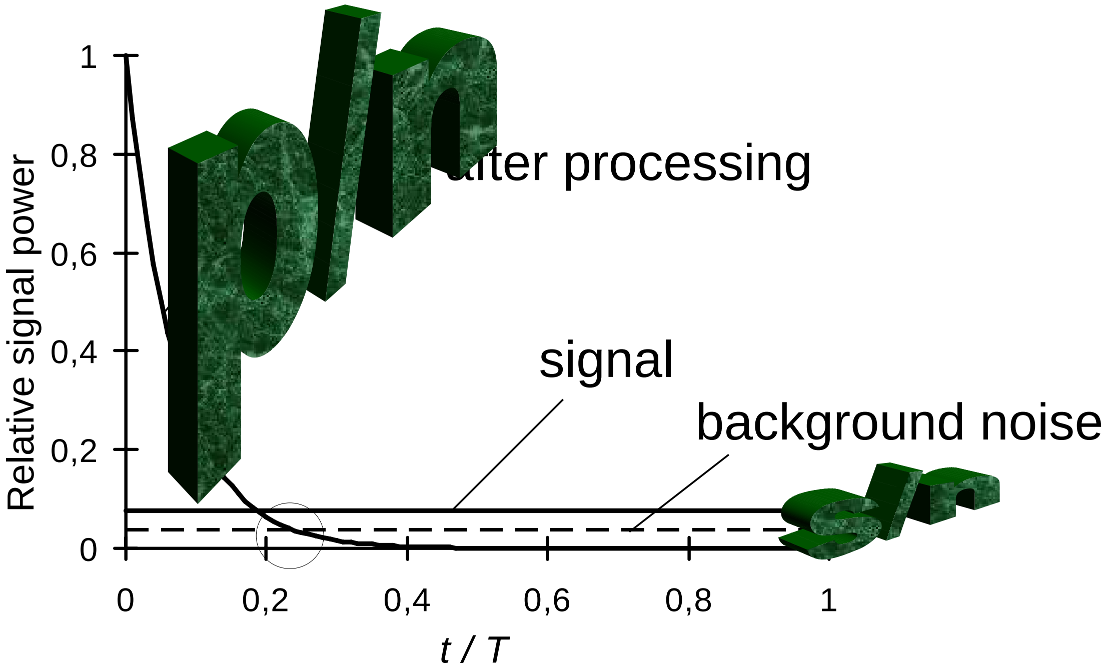
$$h(t) = s'(t) * s^{-1}(t)\ ; \quad s^{-1}(t) = \mathcal{F}^{-1}\left\{\frac{1}{\underline{S}(f)}\right\}$$

$$h(t) = s'(t) * s(-t) = s'(t) \otimes s(t)$$

- Formulations mathematically equivalent („white“ spectrum signals)
- Differences in crest factor (peak to rms), numerical precision, performance of A/D hardware, ...

Energy compression

by: - spectrum division
- deconvolution
- cross correlation



Impact into standardisation: ISO 18233

- Classical method vs. modern methods
- Impulse measurement technique
  (Excitation, spectral requirements, level and linearity, stability and time-invariance, integration limits, averaging, noise compensation, ...)
- Annex A: Example of MLS
- Annex B: Example of Swept-sine

Errors caused by nonlinearities

After Müller and Massarani (J. Audio Eng. Soc. 2001)

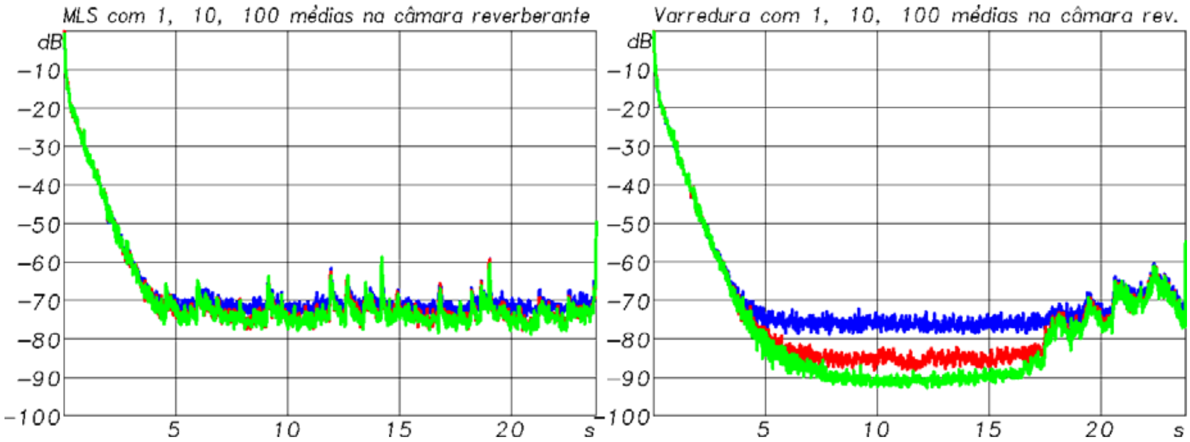


Fig. 10. Measurement of room impulse response in a reverberant chamber with 1, 10 and 100 synchronous averages. Left: with MLS, right: with sweep of identical coloration and energy. The curves are compressed to 1303 values, each of them representing the maximum of 805 consecutive samples.

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Modern measurement techniques in room and building acoustics

- we can measure as accurately as we want !

?

- yes, if LTI is fulfilled

- the remaining sources of errors are related to the acoustic field, to loudspeakers and to microphones, these errors are more or less systematic (-> GUM)

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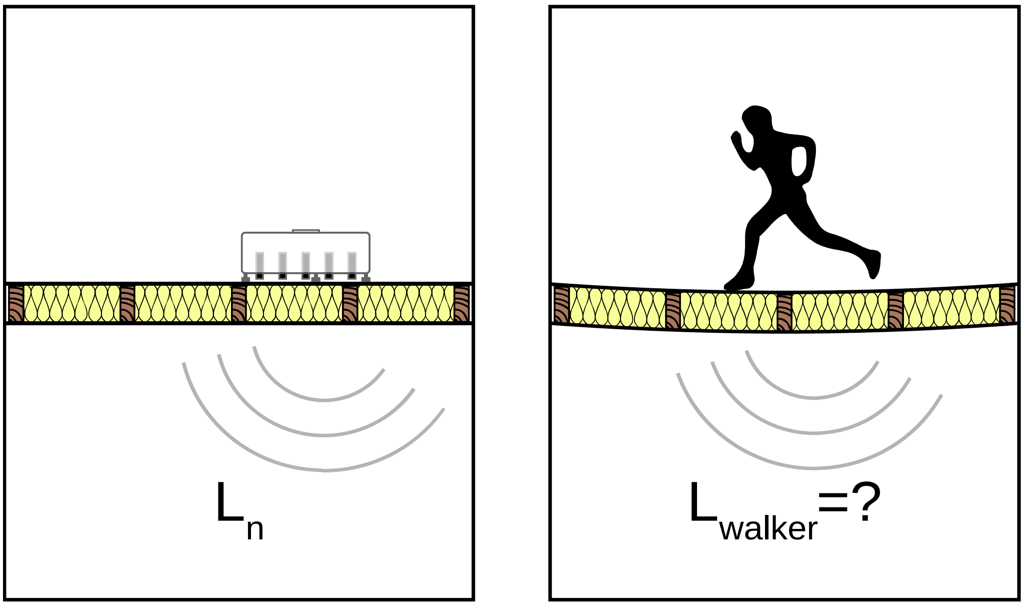
Impact sound level of a person walking



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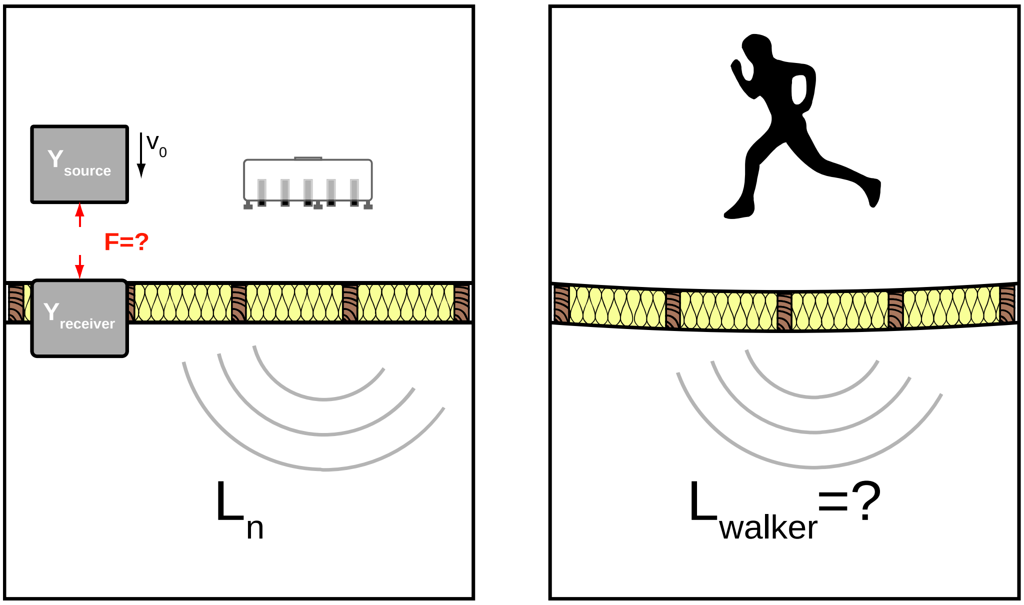
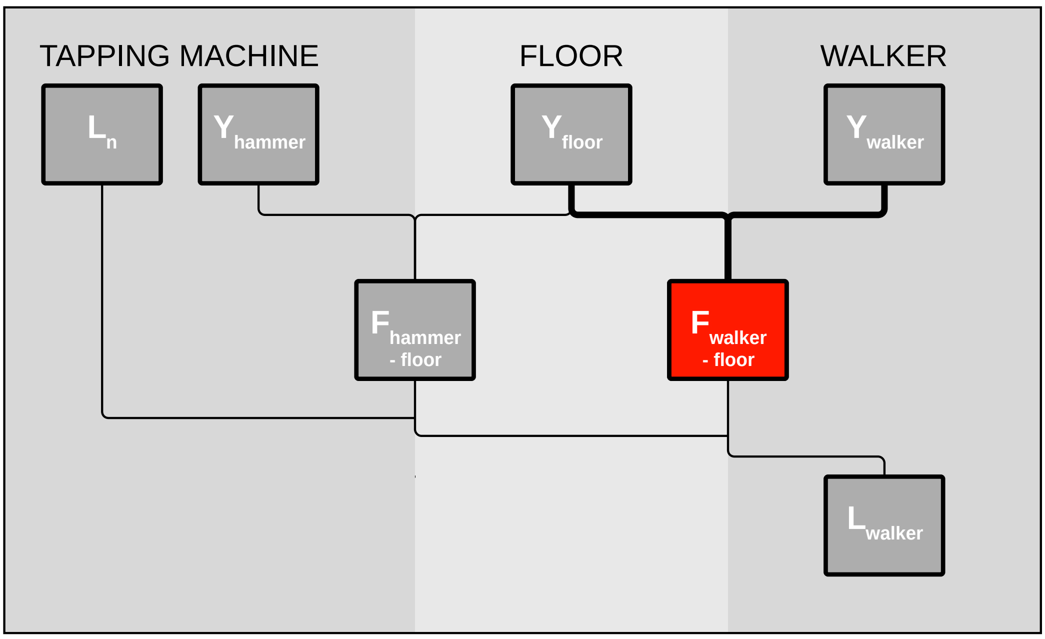
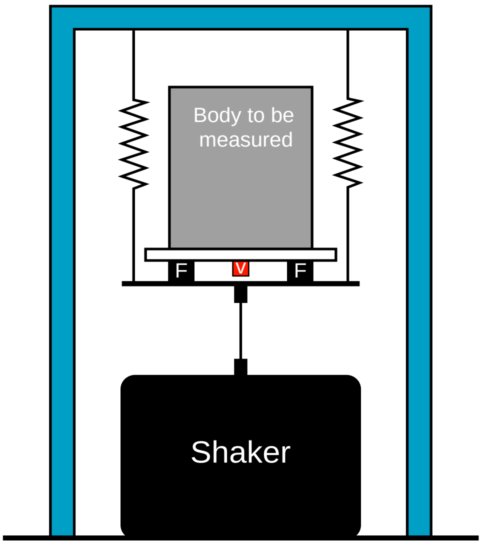
Interaction force

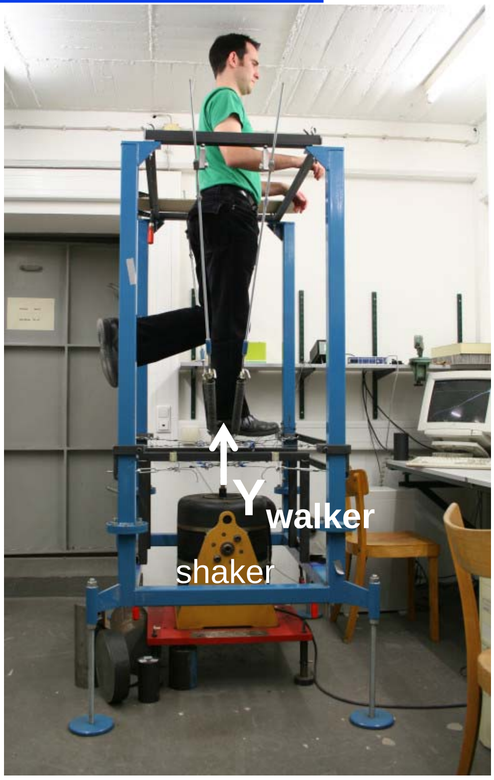


Calculating L_{walker}



Measurement setup





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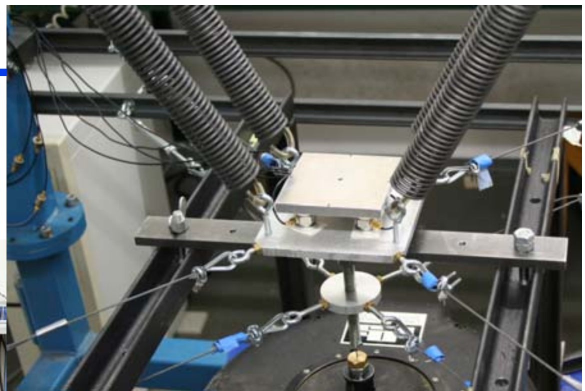
Measurement setup



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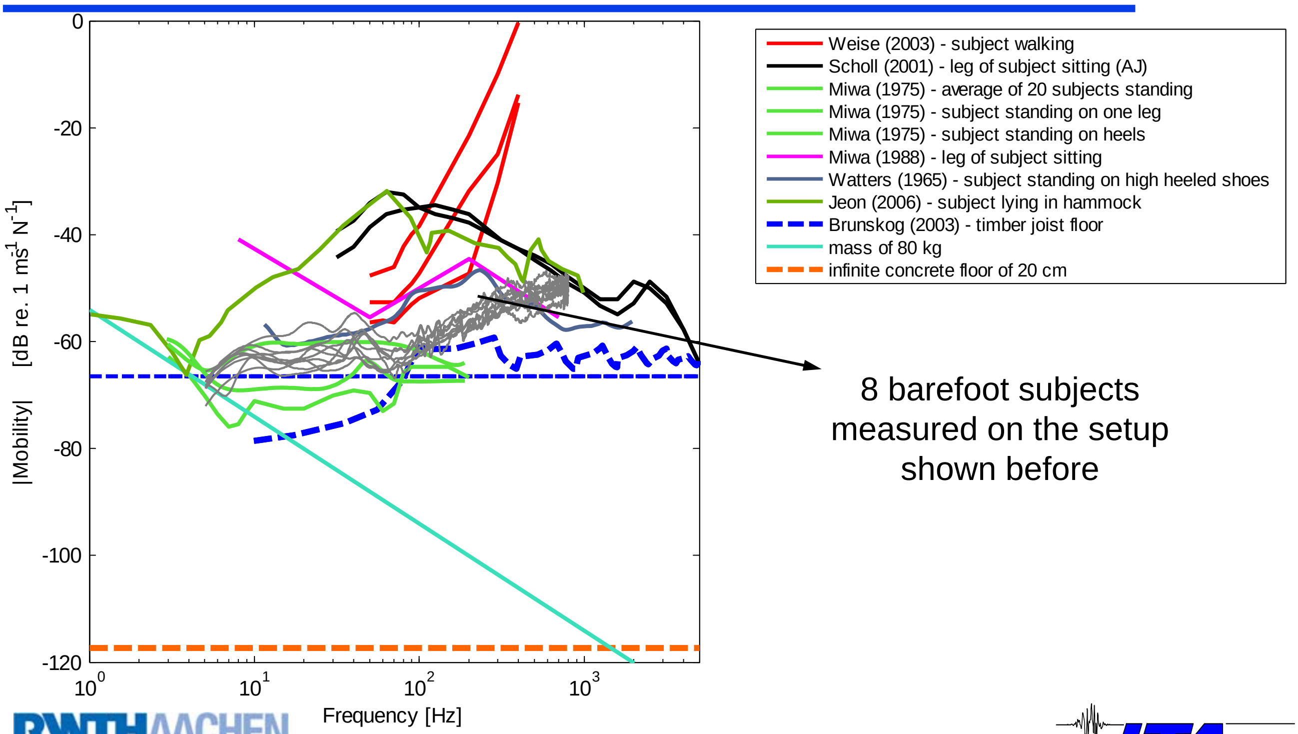
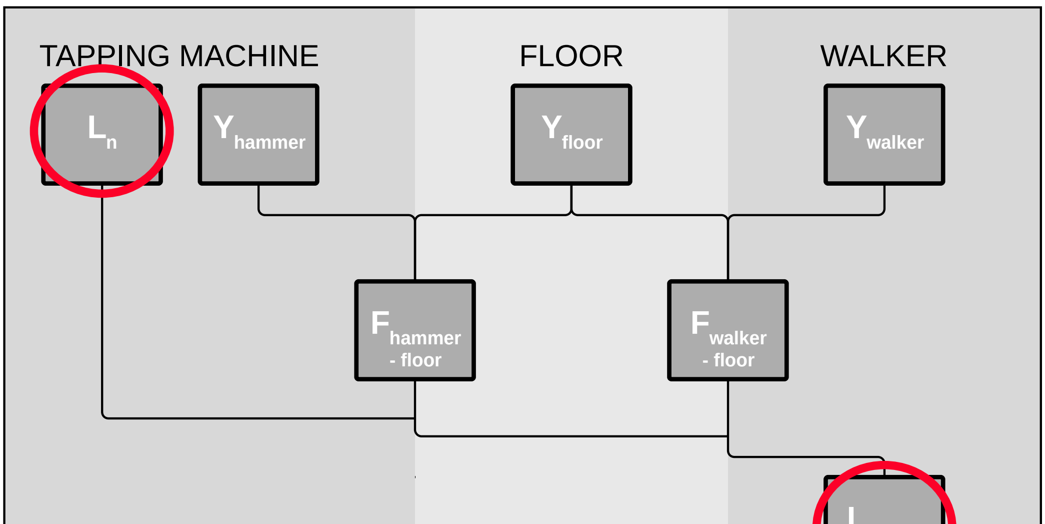
Walker and floor mobilities



L_n , L_{walker} , L_{ap} and all the others



New rating schemes?
Flexibility to characterise various sources?
(walking, jumping, housing equiment)

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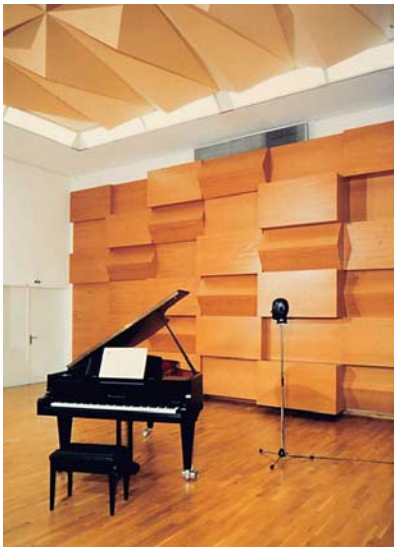
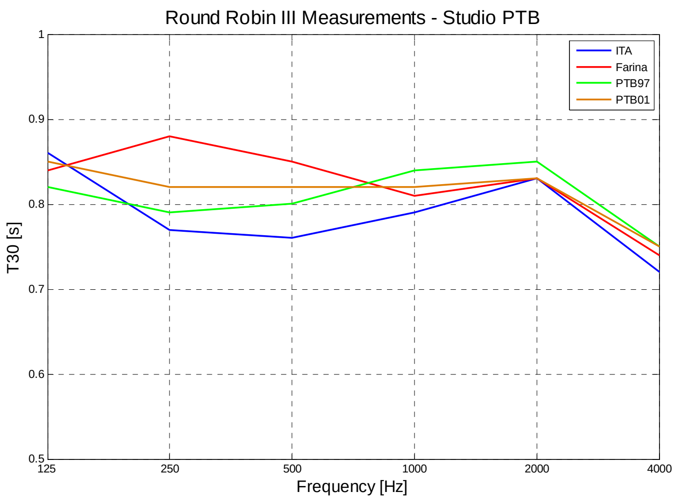
Why are uncertainties relevant?





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GUM

- Guide to the Expression of Uncertainty in Measurement
- Standardised methodology to treat uncertainties
- Guideline to develop uncertainty intervals
- Requirement in many measurement standards in acoustics

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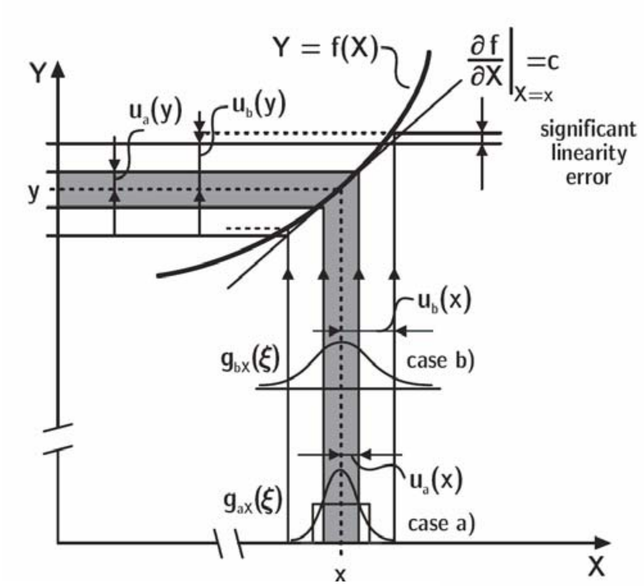
GUM procedure



A systematic approach to the modelling of measurements for uncertainty evaluation

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K D Sommer[1], A Weckenmann[2] and B R L Siebert[3] (2005)

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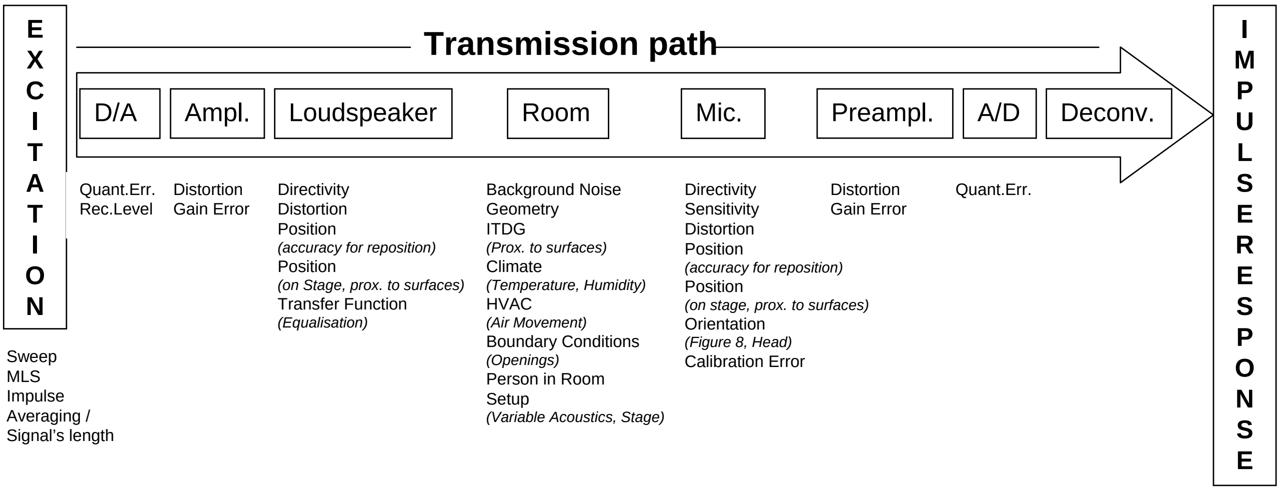
GUM procedure & application



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Applying GUM to room acoustics

- Identification of influence factors is challenging
- Influence factors not always directly measurable
- Complex mathematical operations (2Ch-FFT)
- RIR not a simple “in-between quantity”

- Search for a simple and practical model

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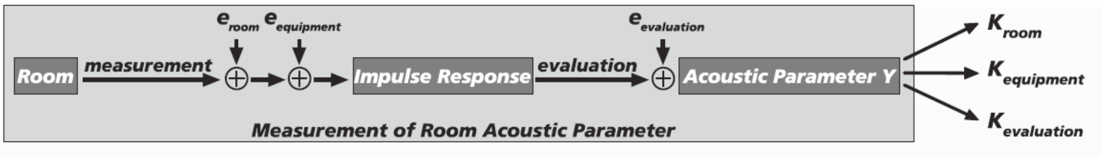
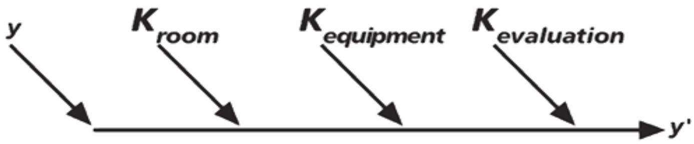
Room acoustical measurement model

- Linear model with sources of error



- Linear uncertainty dependence graph

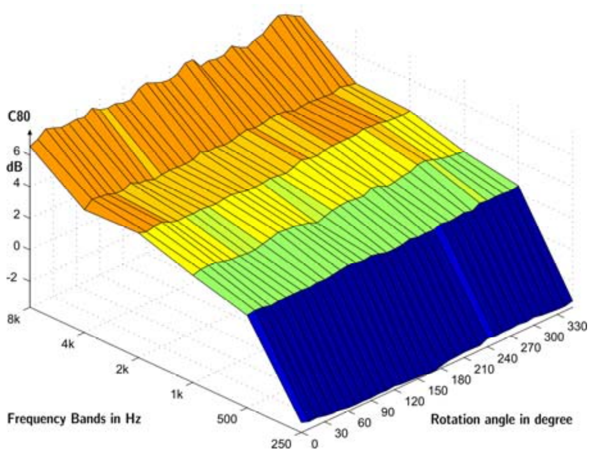


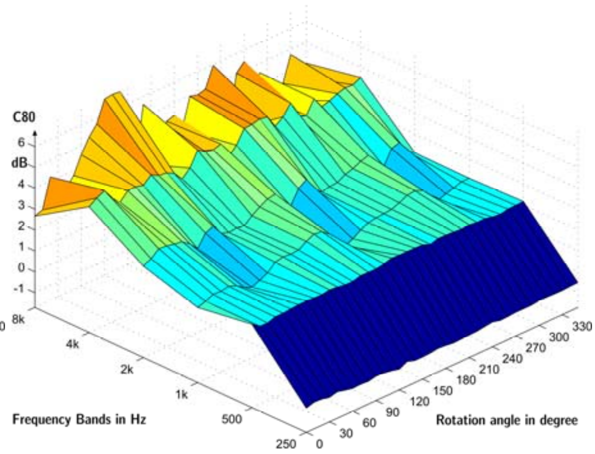
$$y = y' - K_{room} - K_{equipment} - K_{evaluation}$$

Experiments

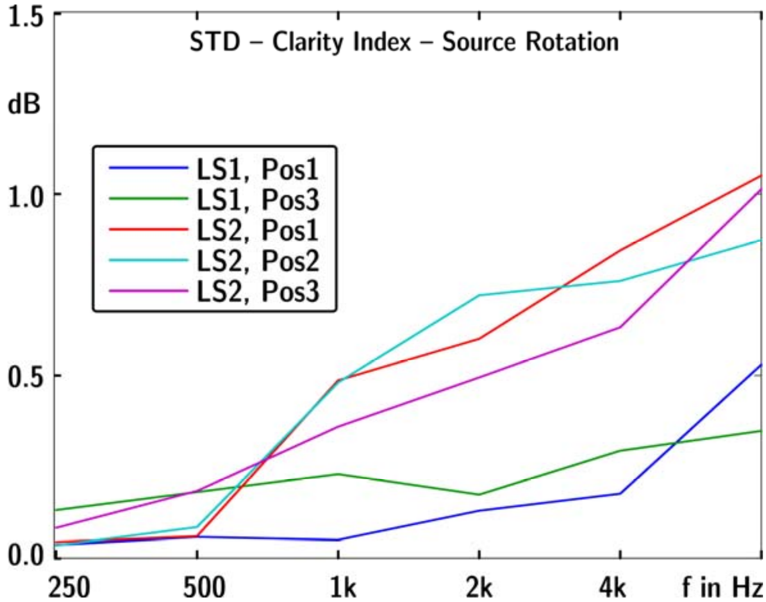
- Determining correction factors using special measurements
  - Turning the loudspeaker on a turntable
  - Displacement of the loudspeaker
  - Displacement of the microphones
  - Background noise
  - LTI-assumption correct?

One example: Source rotation

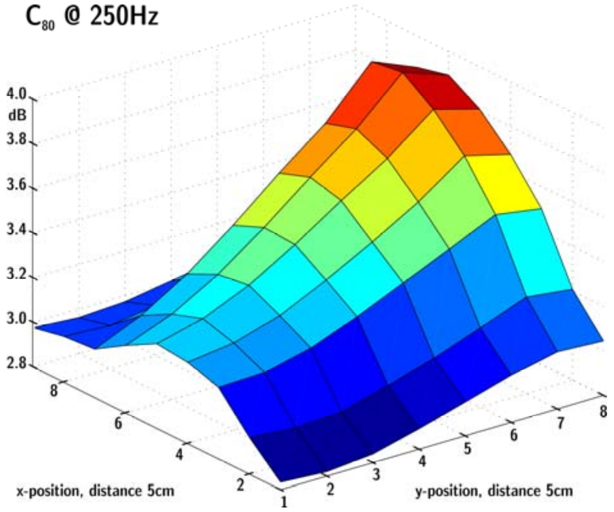


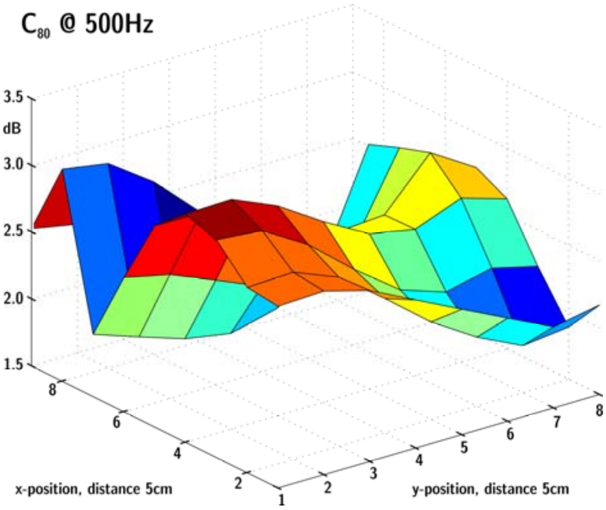


Source rotation



Another example: Receiver position





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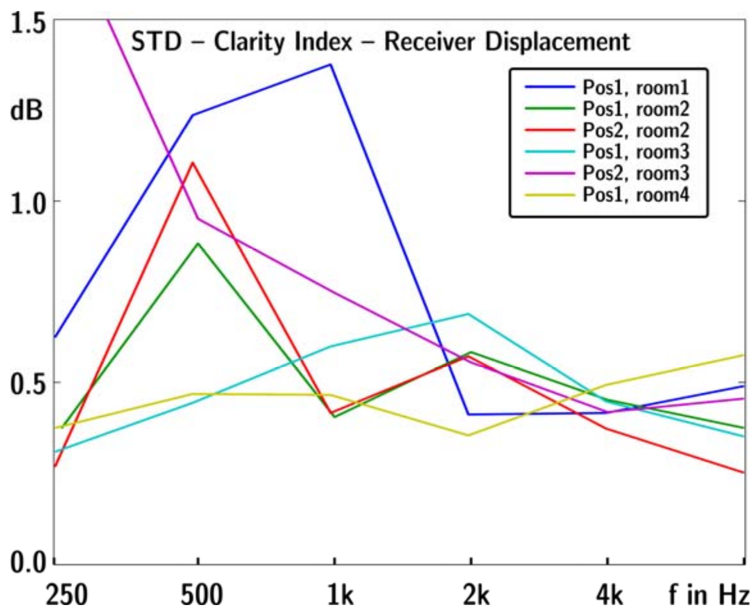
Receiver position



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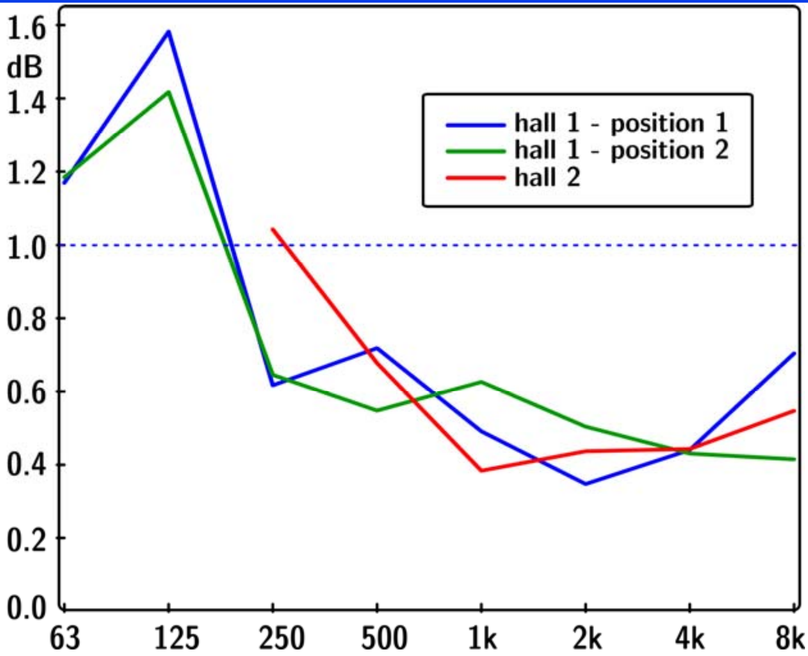
Source position



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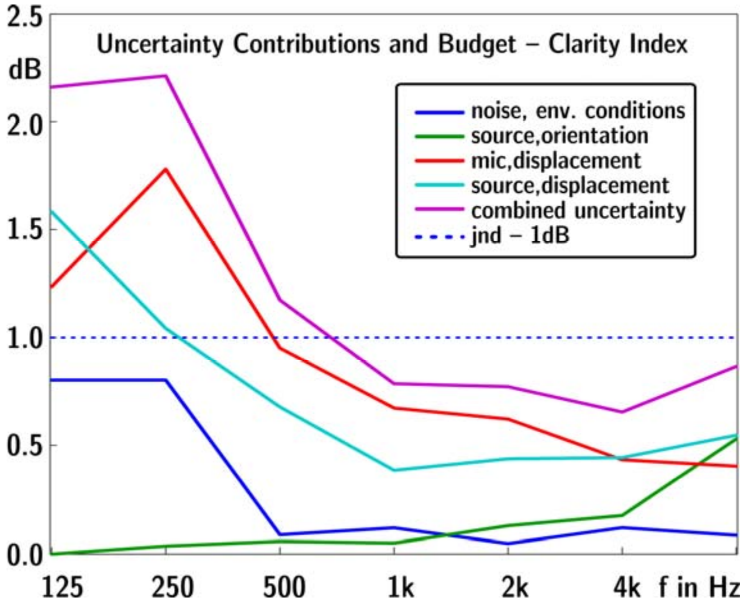
Uncertainty budget of a single measurement



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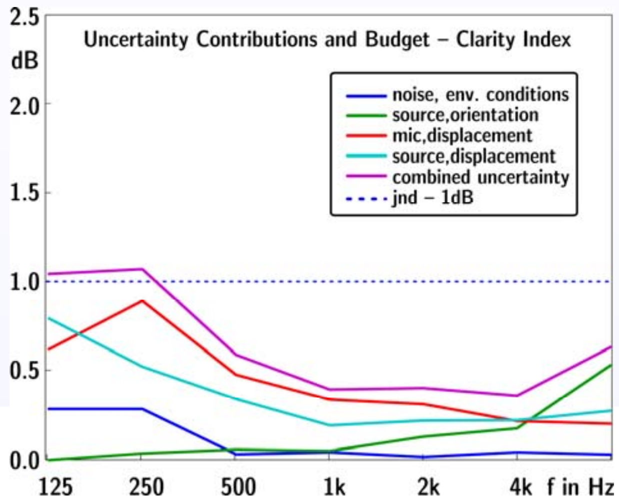
Reduced uncertainty budget due to averaging

$$u_c = \sqrt{\sum_{i=1}^{N} u^2(K_i')} \qquad u^2(K_i') = \frac{u^2(K_i)}{n}$$



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Conclusion

- New methods are powerful (ISO)
- Coming soon: New approaches in impact and structure-borne sound in buildings
- GUM – Strategy to reduce uncertainty
- GUM in sound insulation (Wittstock, PTB)

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