



PA system design under consideration of the room acoustics and noise levels using modern design and simulation tools

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Overview



PA system design

Basics

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Example

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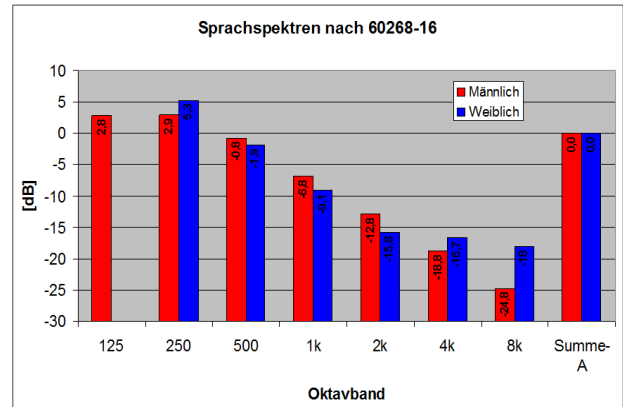
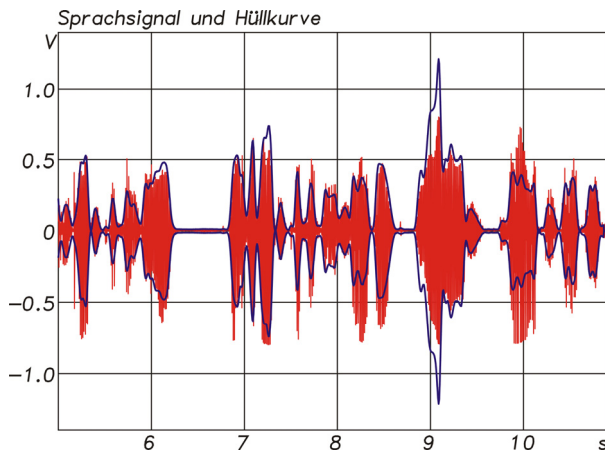
The PA System

- Only for information and entertainment
- Voice alarm (VA)
- Common minimum target:
Sufficient speech intelligibility
- Disturbing influences:
 - Noise (Signal/Noise)
 - Reverberation (Room Acoustics)
 - Insufficient level (Hearing threshold)
 - Too high levels (Masking effect)



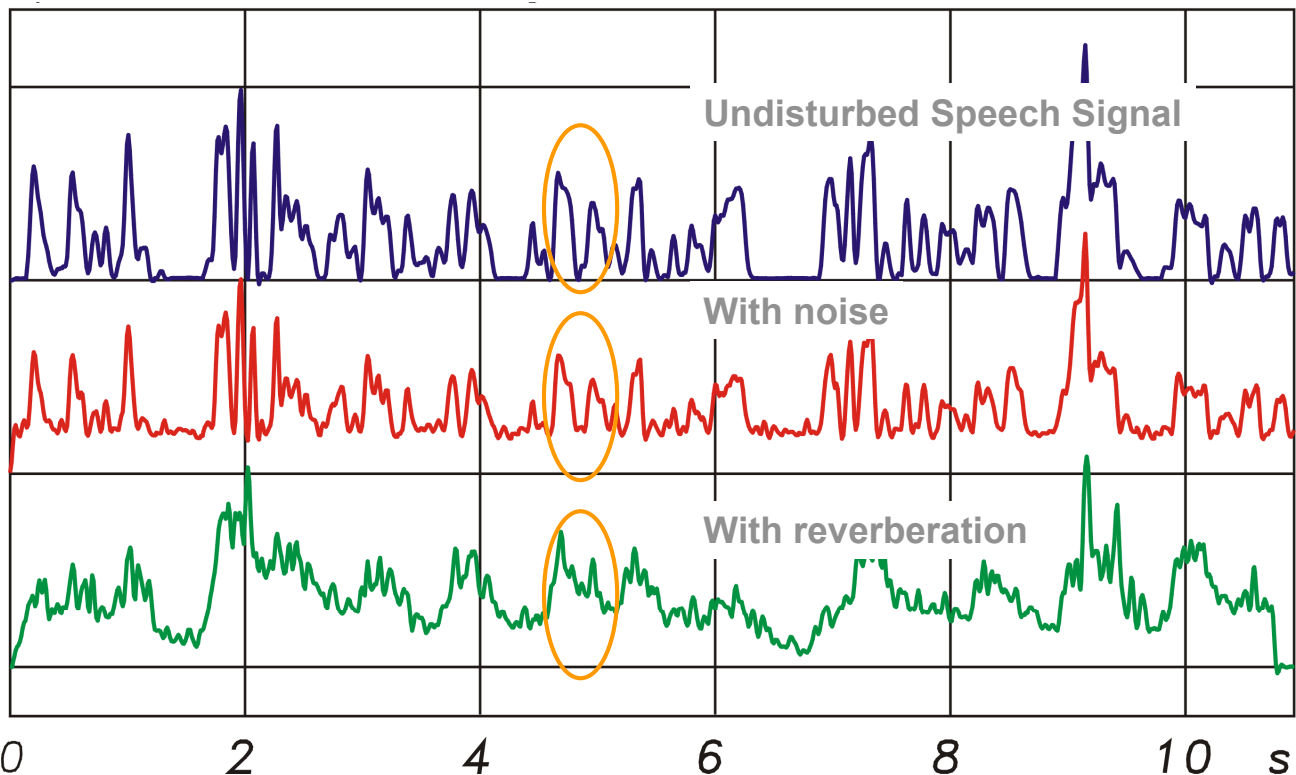
■ Speech is a modulated Signal

- ⇒ The information content is transported by the modulation
- ⇒ Reverberation, noise and band limiting lead to a loss of modulation in the signal and thus to a loss of information, that means it causes reduced speech intelligibility
- ⇒ Modulation frequencies up to 20 Hz
- ⇒ Spectral content in 7 octave bands from 125 Hz to 8 kHz



Modulation loss by reverberation and noise

Envelope of a speech signal



- Ambient noise is usually highly volatile concerning both time and spectral composition. Therefore it is difficult to define.
- Mostly only rough approximation: ... up to 65, 75, 85, ... dBA
- The decisive factor is not the noise considered alone, ...
- ... but rather the ratio between the signal level and the noise level
- Solution: sufficiently loud voice reproduction, but ...
 - Starting with a level of approximate 80 dBA the speech intelligibility goes down caused by the masking effect
 - Variable noise levels require an automatic ambient noise control and level adaptation
 - the cost of the sound system should remain reasonable
for example:
PA system at Cologne main station with 3 kW power for each platform

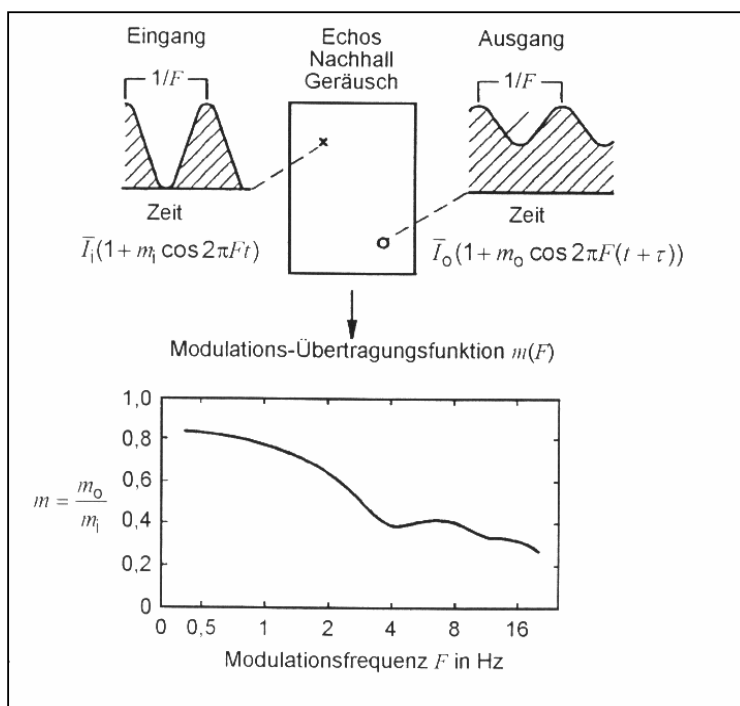
- Reverberation occurs in big halls with mostly reverberant surfaces (glass, concrete, stoneware, metal, ...)
- for 1,5 s and longer reverberation times special sound system concepts are required (highly directional radiation to the audience)
- The key is to transmit as much as possible direct sound from the speakers to the audience and to excite the reverberation as little as possible
- Solutions:
 - a few highly directional speakers
(good approach for big halls like churches, departure and arrival halls....)
 - many small speakers close to the audience
(good approach for subareas in big halls like platforms in railway stations)
 - Room acoustic optimizations are the best way, but not possible in most cases

- Long reverberation (**>1,5 s**)
 - High requirements for the speakers directivity
 - Churches and mosques 2 – 10 s
 - Road tunnels 10 – 30 s
 - Sport stadiums 2 – 6 s
 - Railway stations, airport lobbies 2 - 5 s

- Loud environment with high noise levels (**>70 dBA**)
 - High requirements on the maximum SPL (sound pressure level)
 - Railway stations 85 dBA ⇒ signal level for speech min. 95 dBA
 - Sport stadiums 95 dBA ⇒ signal level for speech min. 105 dBA

- Additional requirements on voice alarm systems (VA) :
 - Minimum values for speech intelligibility for standard- and error mode according to VA standards
 - Monitoring of the system, reliability,
 - All components certified according to standard **EN54-...** (EN54-4, EN54-16, EN54-24)

Modulation Transfer Function (MTF)



Objective rating of the speech intelligibility by the STI measurement (Speech Transmission Index)

The STI is calculated from the loss of modulation at 98 coefficients for different modulation frequencies from 0,63 Hz to 12,5 Hz and for the octave bands from 125 Hz to 8 kHz.

This takes into consideration:

- reverberation
- Signal to Noise
- Hearing Threshold
- Masking effects
- Various other effects ...

STI range from 0 to 1

Measured STI	Qualification category
0...0,3	bad
0,3..0,45	poor
0,45..0,6	fair
0,6..0,75	good
0,75..1	excellent

▪ **Minimum requirements:**

- For voice alarm systems: 0,5 considering the masking effect

▪ **Exceptions:**

- For a fixed group of people: 0,45 (example: factory side)
- In case of a system error: 0,45 for a single error
(only the STI criteria is relevant , the -3 dB criteria is no longer valid) VDE 0833-4 2014
- For critical acoustic environment (long reverberation, high noise level): 0,45

Relationship between STI and word and sentences scores

STI-value	CIS-value	Alcons in %	qualification EN 60268	Syllables score in %	Word score in %	Sentences score in %
0...0,3	0...0,48	100...36	Bad	0...32	0...37	0...75
0,3...0,45	0,48...0,65	36...17	Poor	32...61	37...68	75...93
<u>0,45...0,6</u>	0,65...0,78	17...8	Fair	<u>61...85</u>	<u>68...88</u>	<u>93...98</u>
0,6...0,75	0,78...0,87	8...3,6	Good	85...98	88...98	98...100
0,75...1	0,87...1	3,6...1	Excellent	98...100	98...100	100

Farrell-Becker-Equation:

$$CIS = 1 + \log(STI)$$

$$ALCons = 10^{\frac{1-STI}{0,45}}$$

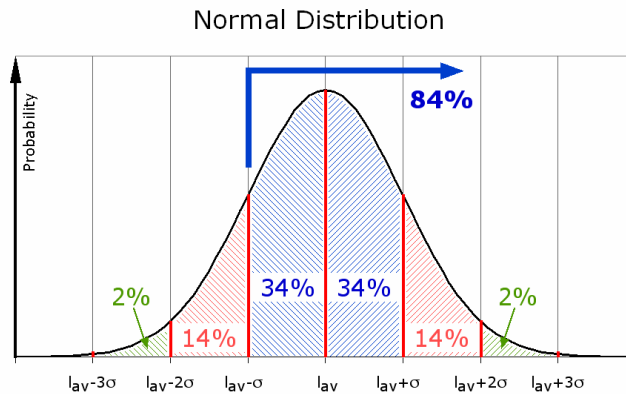
- arithmetic average – standard deviation $\geq 0,5$

- $I_{av} - \sigma \geq 0,5$

$$I_{av} = \frac{1}{n} (a_1 + a_2 + \dots + a_n)$$

$$\sigma = \sqrt{\frac{n \cdot \sum_1^n a^2 - \left(\sum_1^n a\right)^2}{n(n-1)}}$$

- Measurement point grid: 6 m (recommendation only)



STI requirements from EN 60268-16 standard 2011

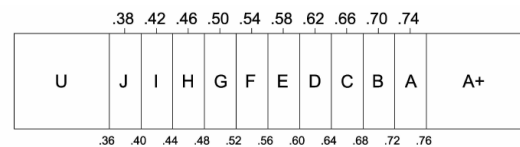
Examples of STI qualification bands and typical applications

The information in the Table G.1 is presented as an example of usage.

Table G.1 – Examples between STI qualification bands and typical applications

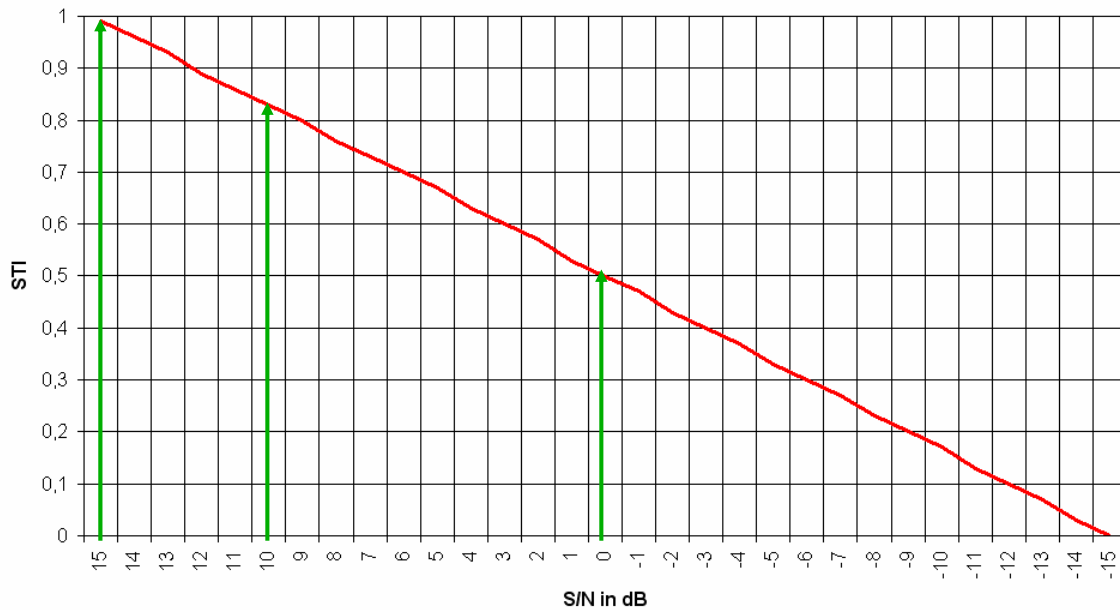
Category	Nominal STI value	Type of message information	Examples of typical uses (for natural or reproduced voice)	Comment
A+	>0,76		Recording studios	Excellent intelligibility but rarely achievable in most environments
A	0,74	Complex messages, unfamiliar words	Theatres, speech auditoria, parliaments, courts, Assistive Hearing Systems (AHS)	High speech intelligibility
B	0,7	Complex messages, unfamiliar words		
C	0,66	Complex messages, unfamiliar words	Theatres, speech auditoria, teleconferencing, parliaments, courts	High speech intelligibility
D	0,62	Complex messages, familiar words	Lecture theatres, classrooms, concert halls	Good speech intelligibility
E	0,58	Complex messages, familiar context	Concert halls, modern churches	High quality PA systems
F	0,54	Complex messages, familiar context	PA systems in shopping malls, public buildings offices, VA systems, cathedrals	Good quality PA systems
G	0,5	Complex messages, familiar context	Shopping malls, public buildings offices, VA systems	Target value for VA systems
H	0,46	Simple messages, familiar words	VA and PA systems in difficult acoustic environments	Normal lower limit for VA systems
I	0,42	Simple messages, familiar context	VA and PA systems in very difficult spaces	
J	0,38		Not suitable for PA systems	
U	<0,36		Not suitable for PA systems	

NOTE 1 These values should be regarded as minimum target values.
NOTE 2 Perceived intelligibility relating to each category will also depend on the frequency response at each listening position.
NOTE 3 The STI values refer to measured values in sample listening positions or as required by specific application standards.

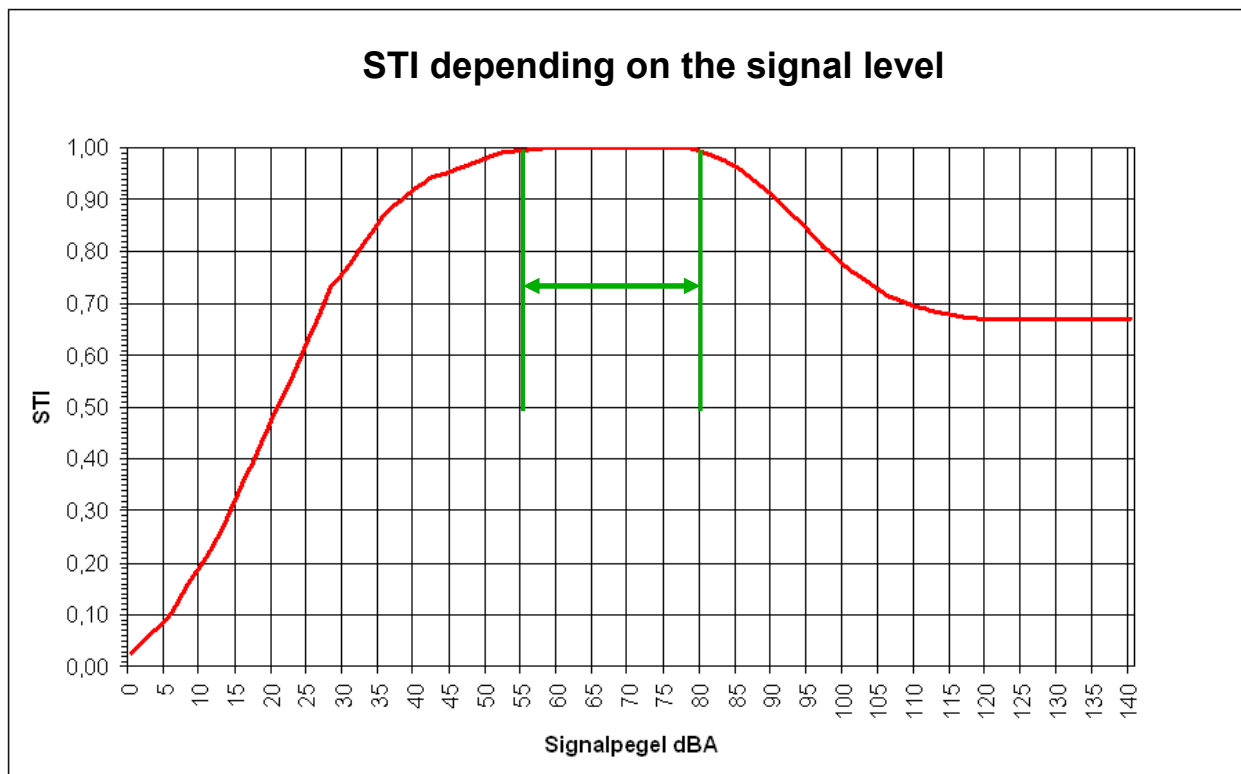


- STI qualification bands and typical applications (by Peter Mapp)
- All nominal STI values calculated as average value minus standard deviation
- Table only in the informative part of the standard only for orientation!

STI depending on the S/N at 65 dBA signal level



STI depending on the signal level

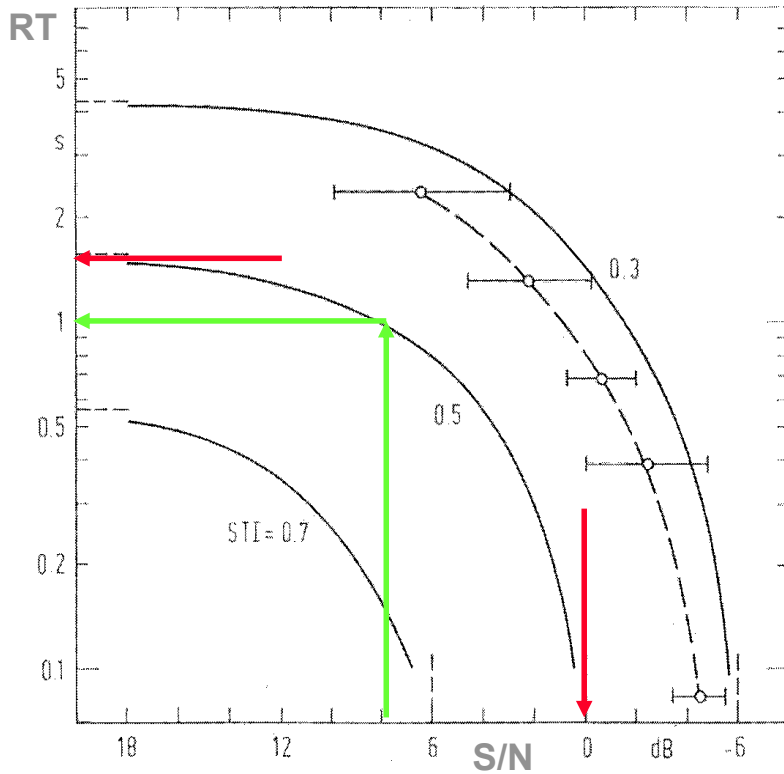


- IEC 60268-16 ; 2011
Sound System Equipment
Objective rating of speech intelligibility by the speech transmission index
- DIN EN 60849 ; 1999
Sound Systems for Emergency Purpose
- DIN EN 50849 ; expected 2017
Sound Systems for Emergency Purpose, which are not Part of Fire Detection Systems
- DIN VDE 0833-4 national application standard
largely corresponds to the standard EN TS 54-32 ; 2016
guidelines for the planning, design, installation, commissioning, use, maintenance and modification of voice alarm systems
- EN 54-xx requirements for all parts of fire alarm systems
Part 4: Power supply equipment
Part 16: Voice alarm control and indicating equipment
Part 24: Components of voice alarm systems - Loudspeakers

How to design a PA system ?

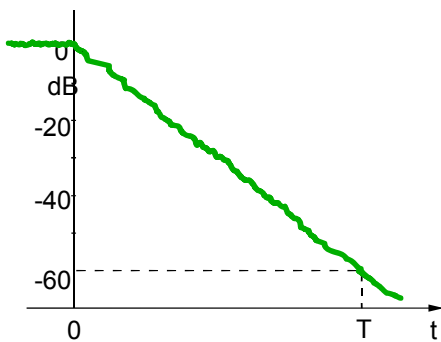


- Starting position:
 - Reverberation time in octave or 1/3 octave band (average values only for orientation)
 - Noise level in octave or 1/3 octave band (A-weighted total SPL only for orientation)
 - Timing of the noise level
 - Important standards
 - 60849 or 50849 for voice alarm systems
 - Further conditions
 - Conservation of historical buildings
 - Later modifications to the building
 - Disturbances of the environment
 - More questions
 - Which speaker positions are possible?
 - Are active speaker systems, like DSP controlled line sources, possible ?
 - Is the power supply and emergency supply sufficient ?

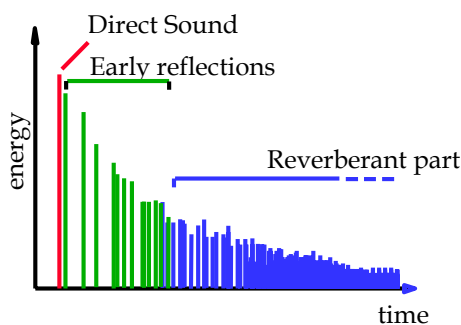
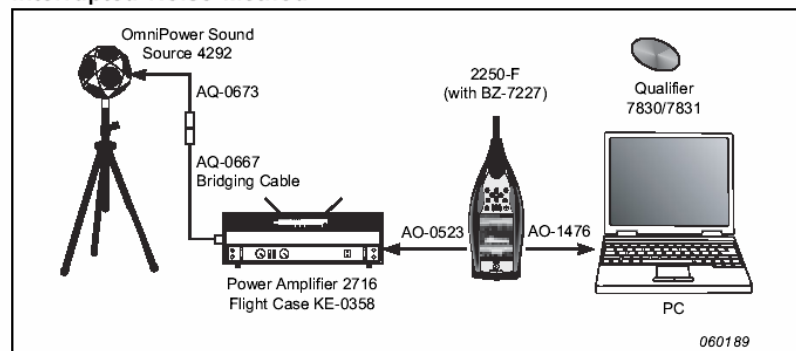


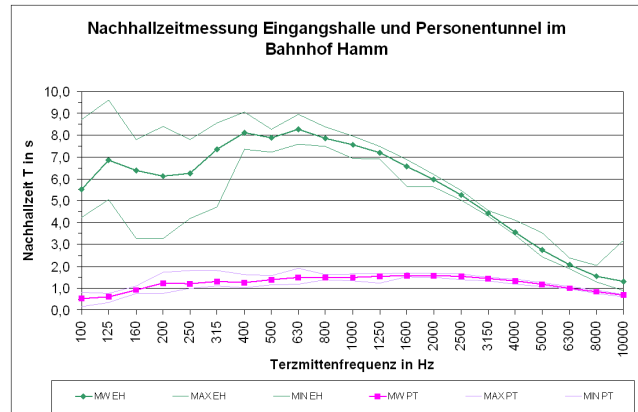
- Graphs for non directional sources like:
 - Small ceiling speakers
 - Simple fullrange systems
- For reverberation times of 1 s and more room acoustic improvements or highly directional speakers are required

Measurement of the Reverberation Time

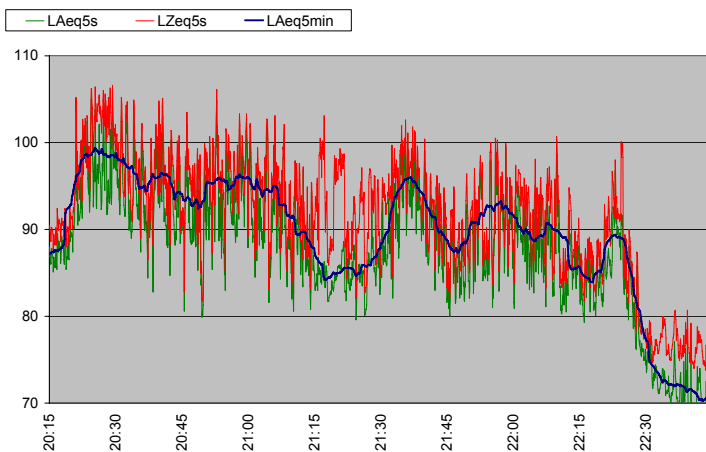


Interrupted Noise Method

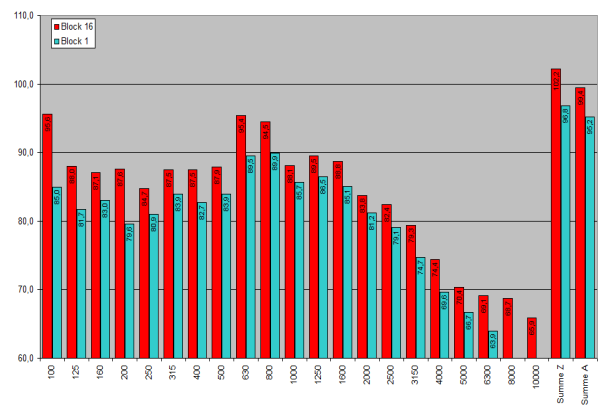
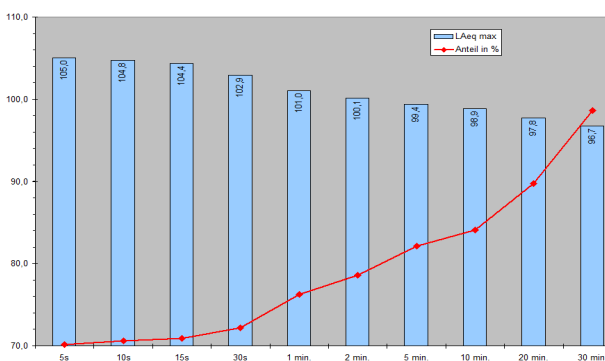




- Lobby of a railway station with very long reverberation times up to 8 s
 - Installation with two 5m long DSP controlled line sources (STI very close above 0,5)
- Platform entrance with reverberation times of approximate 1,5 s
 - Installation with distributed line sources with small full range speakers (STI very close above 0,5)



- Long time sampling for L_{eq} values of defined time periods dt
- Statistical evaluation
- Spectral analysis of the noise
- Relation to the signal spectrum calculated as L_{eq} values for octave bands from 125 Hz to 8k



- Noise Measurements (long-term recordings)
- Reverberation Time (with noise or with impulse source)
- STI measurement and analysis
- Impedance measurements and speaker tests

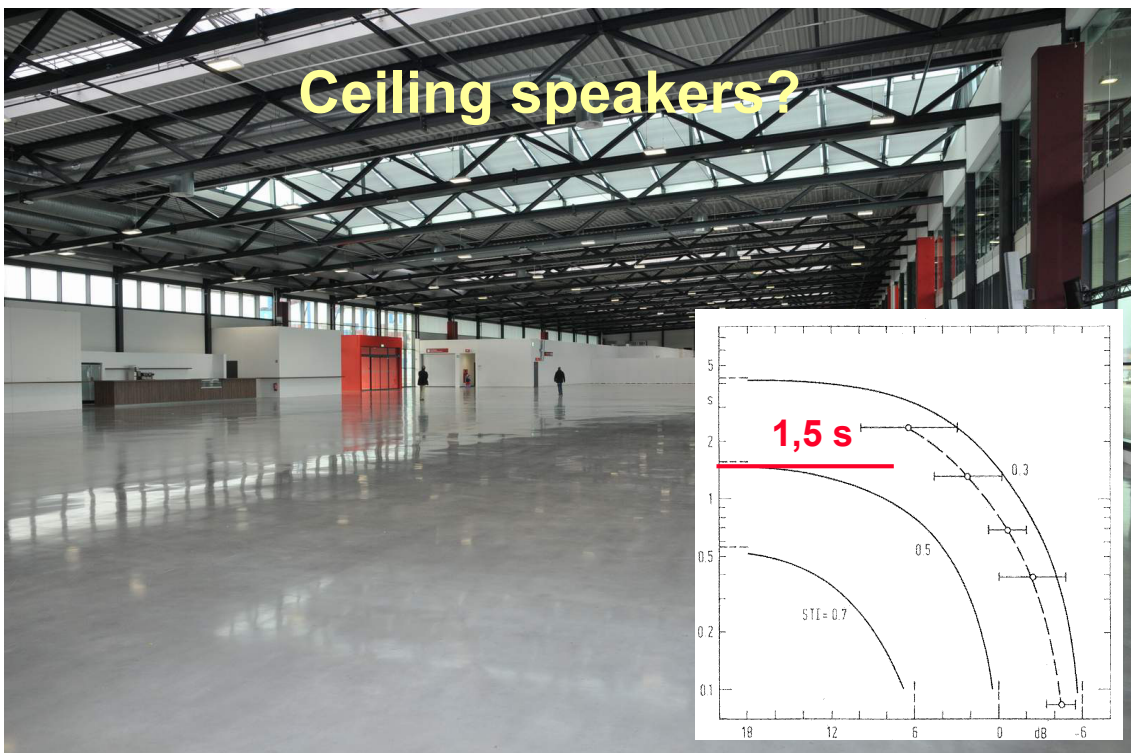


Crest factor, the critical point ?

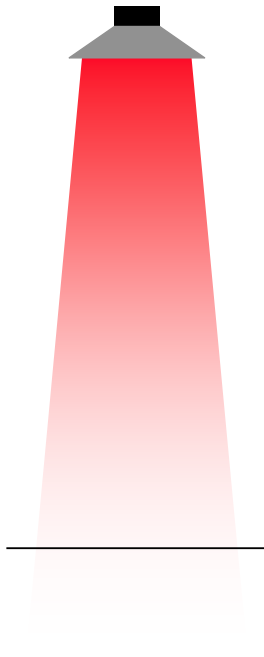
- Simulations are calculated with average power values of the speakers
(2h average power according to AES)
- On the acoustical side, there is the L_{eq} SPL value
(equivalent to the total Sound Energy over a given period of time)
- Example Speaker (400W/8Ω AES 2h)
average sensitivity of 94 dB 1W/1m
calculated SPL for 400 W is approximate 120 dB at 1 m
- The question is:
How to reach an average power of 400 W with a typical test signal like the STI-PA noise? That is not possible!
- Crest factor (CF):
Relation of the signal peak level to the RMS value
(RMS = root mean square)
- Crest factor examples:
 - Sinus signal: 3 dB
 - Speech: 12 - 20 dB
 - STIPA Test signal: 12 - 14 dB
 - Music: 9 - 20 dB
 - Rectangle: 0 dB
- Example 400W speaker
 - amplifier 80 V_{pk} max. and 56 V_{RMS}
 - CF 3 dB: LS power 400 W_{avg.}
 - CF 12 dB: LS power 50 W_{avg.}
 - Level loss for the L_{eq} of 9 dB compared to the 400 W calculated value of 120 dB



Departure Hall



- Colour intensity = level
- Contrast to the environment = modulation = speech intelligibility



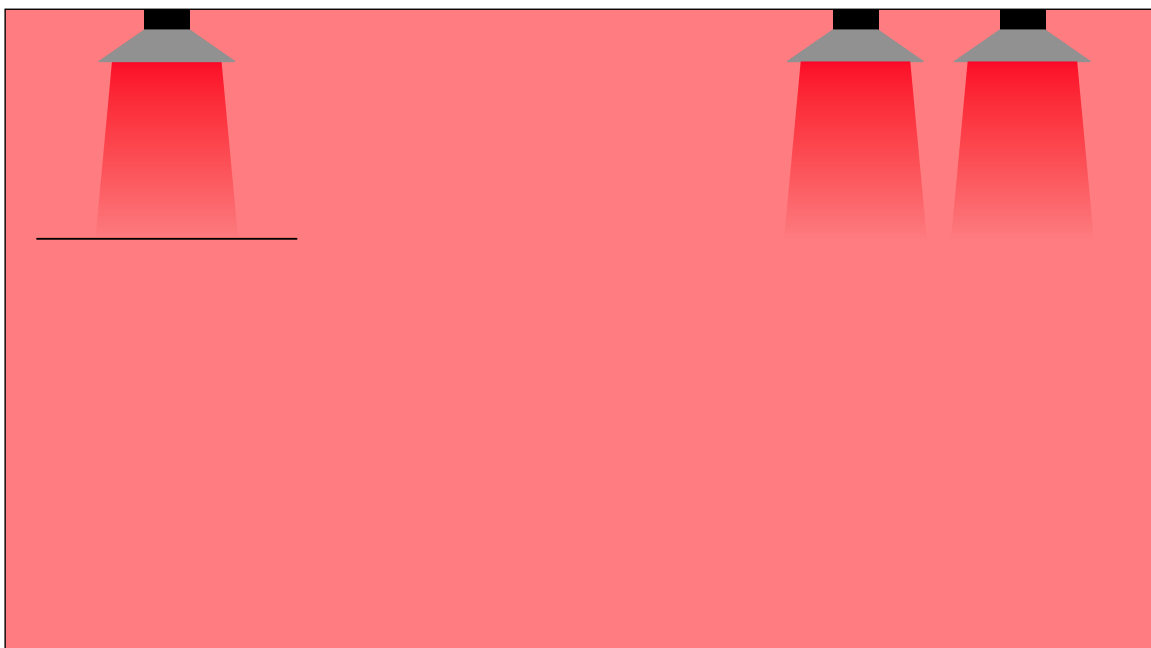
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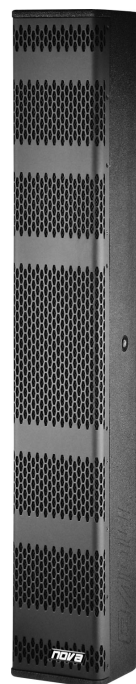


- Colour intensity = level
- Contrast to the environment = modulation = speech intelligibility

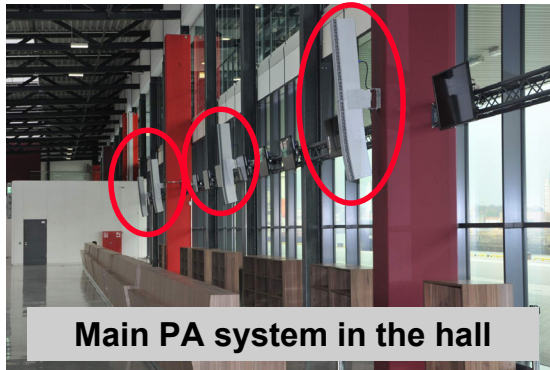


Selection of the loudspeakers

- Target:
 - highly directional sound radiation to the audience
 - As little as possible radiation into the remaining space
 - All listeners are on the ground level
 - Line source speakers
 - horizontal wide coverage
 - and vertical narrow coverage
 - Active DSP controlled line sources ?
 - Power supply ?
 - Emergency power supply ?
 - EN54 components ?
 - Passive line source speakers
 - Stairs and Skywalk separately considered



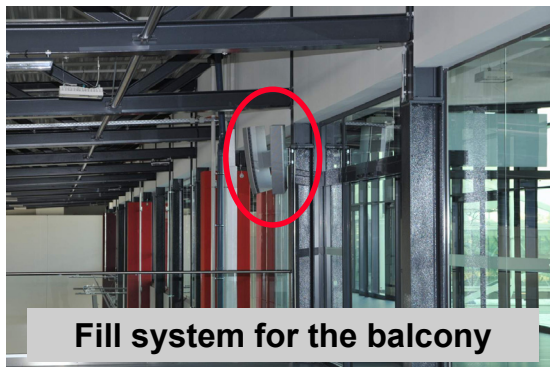
Basic concept of the PA system



Main PA system in the hall



Fill system for the stairs



Fill system for the balcony



Distributed line for the skywalk

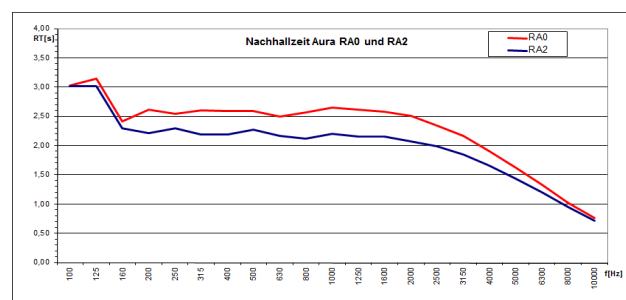
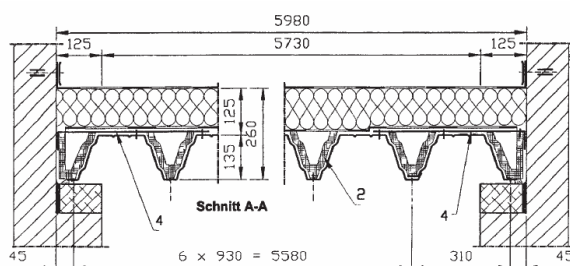
Room acoustic improvements



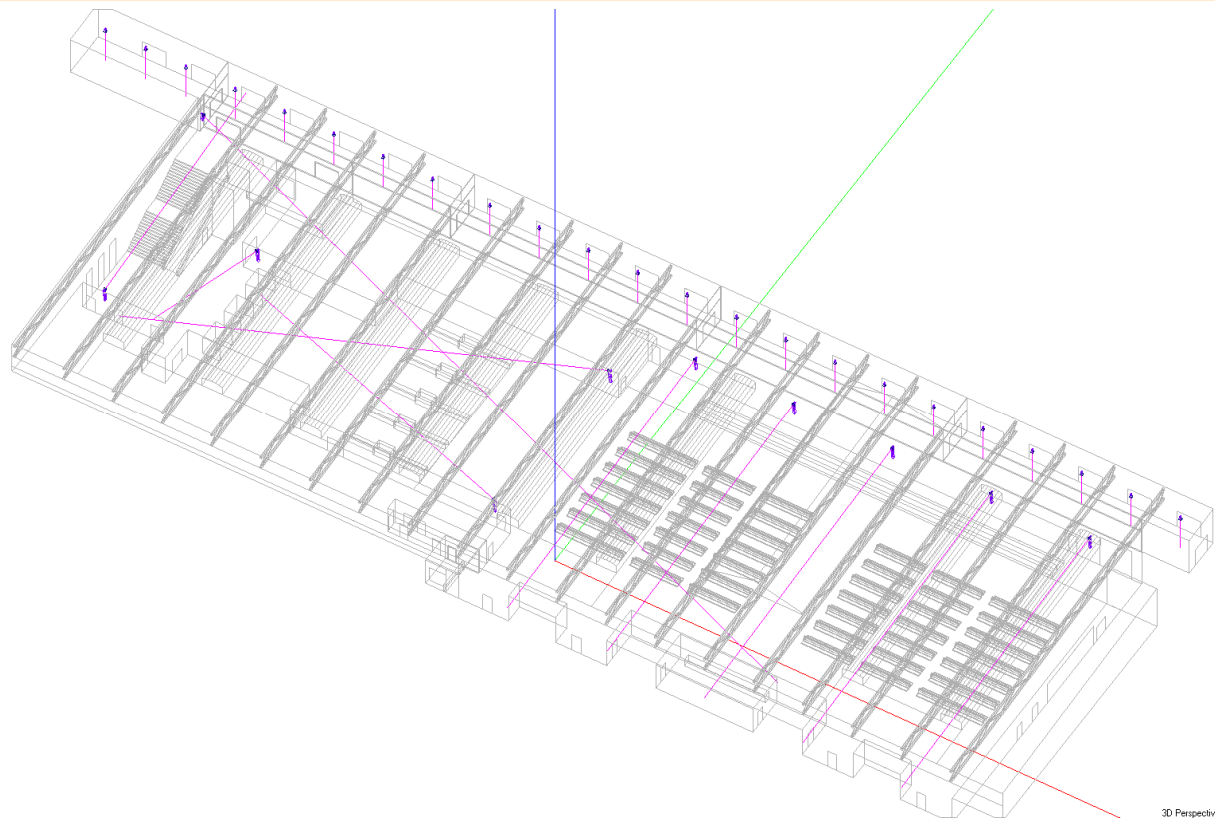
Departure hall with appr. 4.100 m² perforated trapeze sheet at the ceiling



Additional acoustically absorbing perforated walls with appr. 600 m²



Simulation model in EASE with loudspeakers



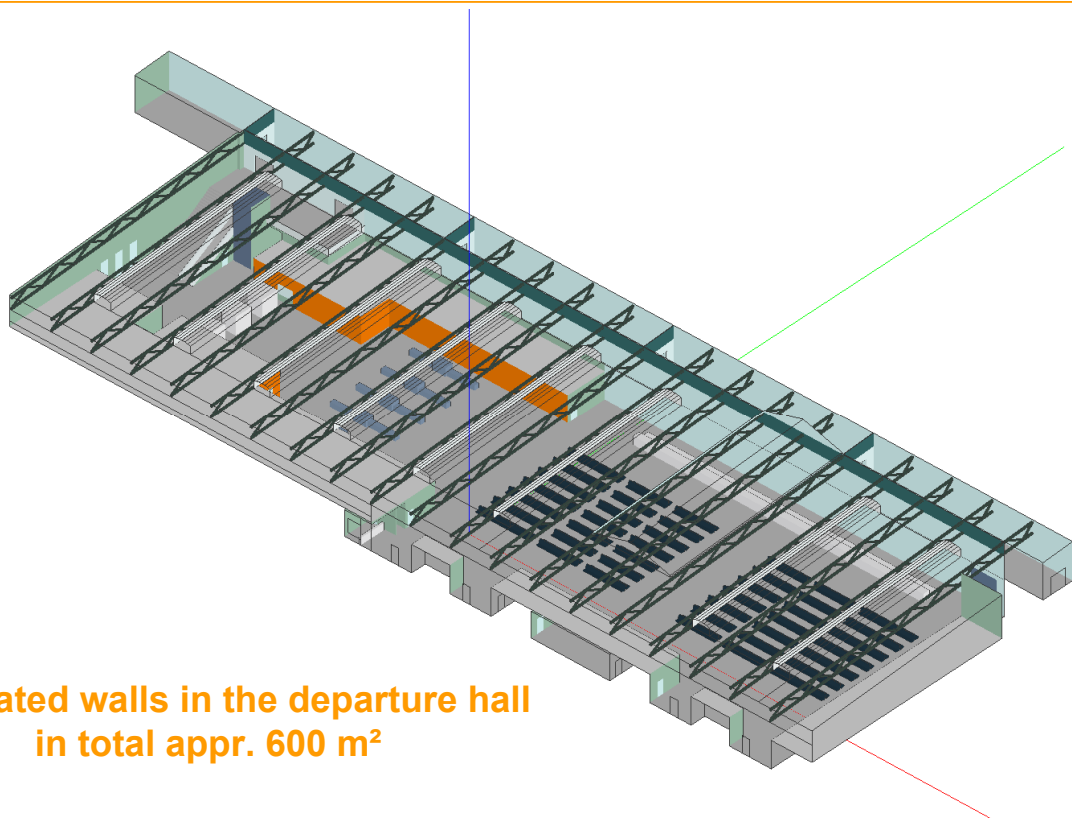
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V2017_2
Folie 35

Simulation model in EASE



Ver: 36° Hor: 138°
Project: CC3AB V2 RA2@asic
Dye: Material Colors
Freq: 1000 Hz

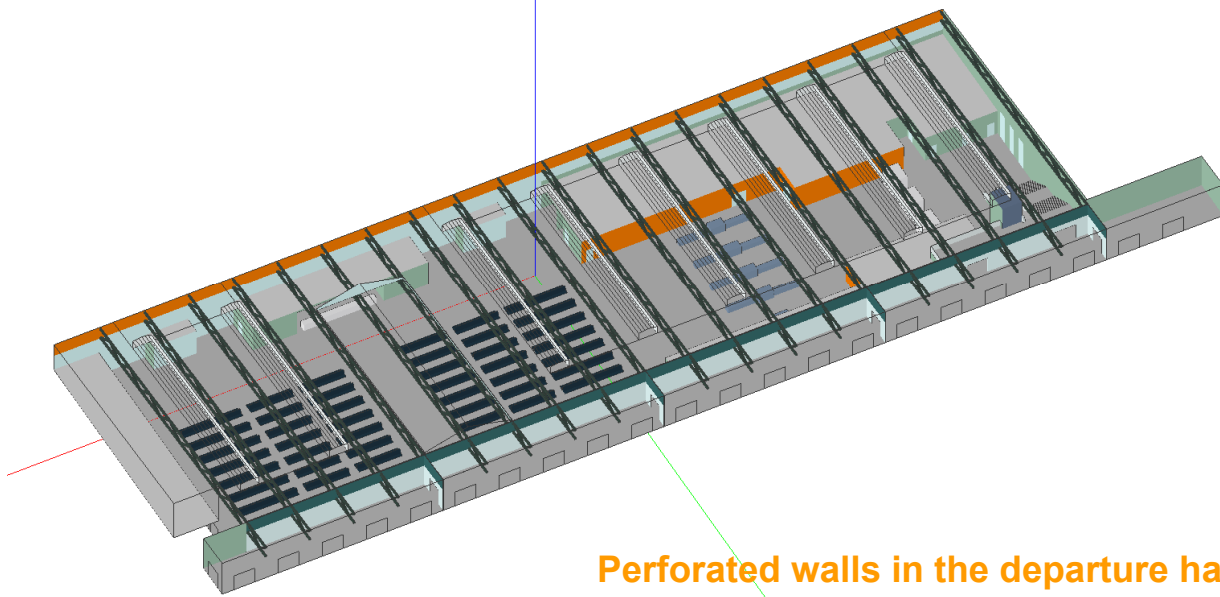


**Perforated walls in the departure hall
in total appr. 600 m²**

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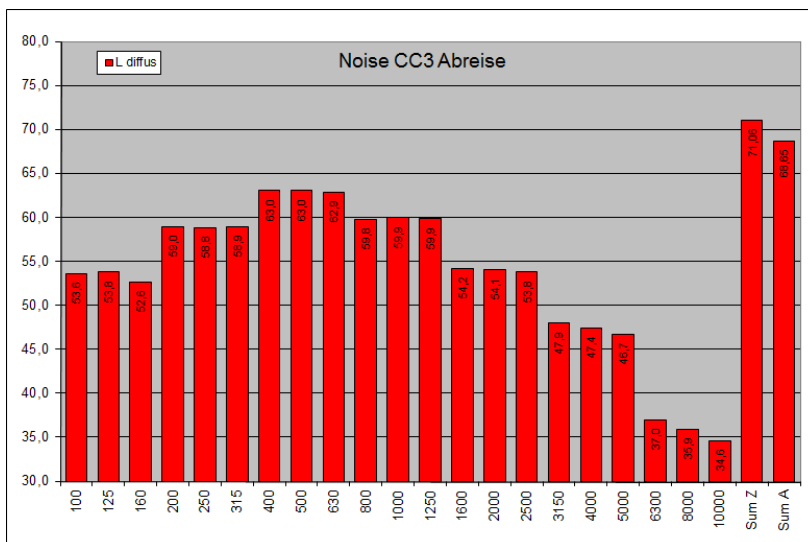
Ver: 47° Hor: 28°
 Project: CC3AB V2-RA2@basic
 Dye: Material Colors
 Freq: 1000 Hz



**Perforated walls in the departure hall
 in total appr. 600 m²**

Noise level approximation

- 500 persons talking with normal level $L_w = 70 \text{ dBA} + 10 \cdot \log(500) = 97 \text{ dBA}$
- Sound power level per person $L_{WAeq} = 70 \text{ dB}$ (corresponds to appr. 65 dBA DSPL)
- Volume of the room appr. 43.500 m³
- Average reverberation time appr. 2,5 s $L = L_w - 10 \cdot \lg\left(\frac{V/m^3}{T/s}\right) + 13,88 \text{ dB}$



**Noise level:
 71,1 dBZ
 68,6 dBA**

Direct SPL only. Mapping and Distribution



CC3-Terminal-Adresse
 Used:
 Lsp: H01 SR-S4(2S), H02 SR-S4(2S), H03 SR-S4(2S), H04 SR-S4(2S), H05 SR-S4(2S), K01 SR-S4(2S), K02 SR-S4(2S), Z01 SR-S4(2S), Z02 SR-S4(2S), G01 SR-S4(S), VG01 F-1000, VG02 F-1000, VG03 F-1000, VG03 F-1005, VG03 F-1004, VG03 F-1003, VG03 F-1002, VG03 F-1001, VG04 F-1000, VG05 F-1000, VG06 F-1000
 Map: Direct SPL (Z)
 Freq: 4000 Hz
 (3/1 Octaves Sum)
 Energy: 2 * Epot
 (1/3rd Octave)

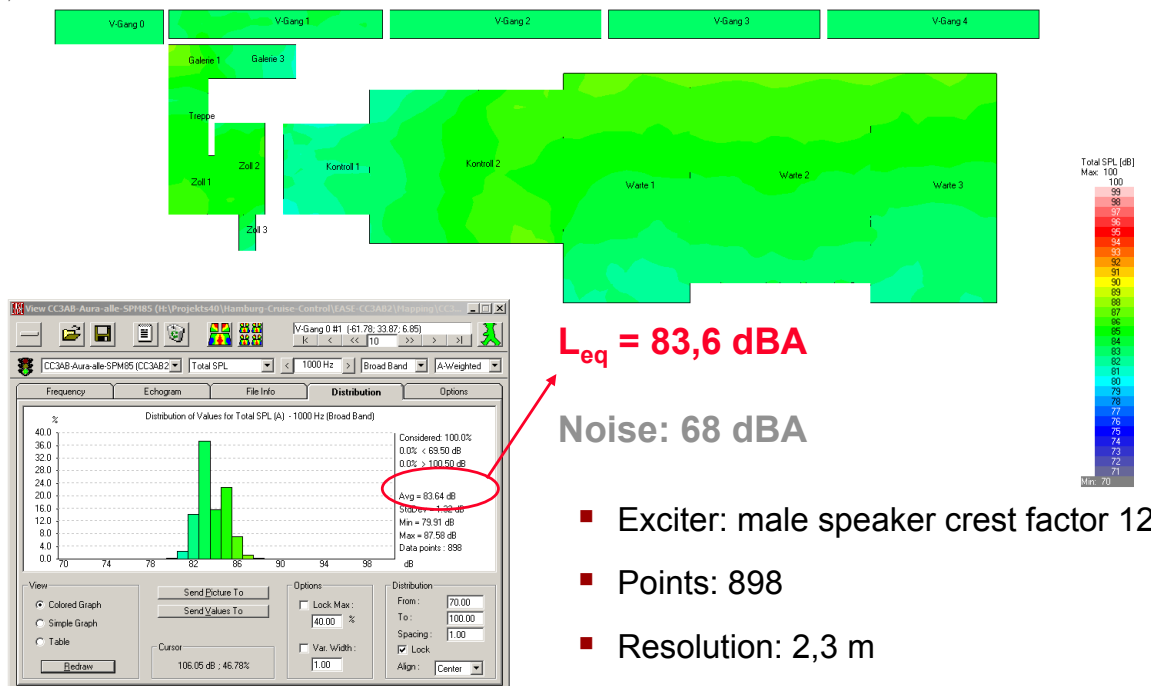


- Exciter: Pinknoise
- Points: 1136
- Resolution: 2 m
- Freq. Range: oct. bands: 2, 4, 8 kHz

Total SPL mapping and distribution



CC3-Terminal-Adresse
 Used:
 Lsp: H01 SR-S4(2S), H02 SR-S4(2S), H03 SR-S4(2S), H04 SR-S4(2S), H05 SR-S4(2S), K01 SR-S4(2S), K02 SR-S4(2S), Z01 SR-S4(2S), Z02 SR-S4(2S), G01 SR-S4(S), VG01 F-1000, VG02 F-1000, VG03 F-1000, VG03 F-1005, VG03 F-1004, VG03 F-1003, VG03 F-1002, VG03 F-1001, VG04 F-1000, VG05 F-1000, VG06 F-1000
 Map: Total SPL (A)
 Freq: 1000 Hz
 (Broad Band Sum)
 Energy: 2 * Epot
 (1/3rd Octave)



$L_{eq} = 83,6 \text{ dBA}$
 Noise: 68 dBA

- Exciter: male speaker crest factor 12 dB
- Points: 898
- Resolution: 2,3 m
- TSPL: broad band sum A-weighted

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Manuscript to this presentation with text and graphics as PDF file