

"Acoustic Camera" application in room and building acoustics

Dipl. Wi. Ing. Gunnar Heilmann



Who is the GFai



acoustic
camera



The GFai is a non-profit research association, founded and based 1990 in Berlin / Germany.

More than 120 employees work on scientific projects, R&D tasks and services.

GFai is engaged in the promotion and advancement of R&D in applied computer sciences and organizes the industrial joint research.



More than 100 companies and organizations are member* of the GFai.
The GFai has numerous successful co-operations.

* for list of members see www.gfai.de

Expertise / Departments:



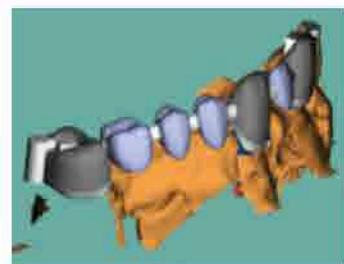
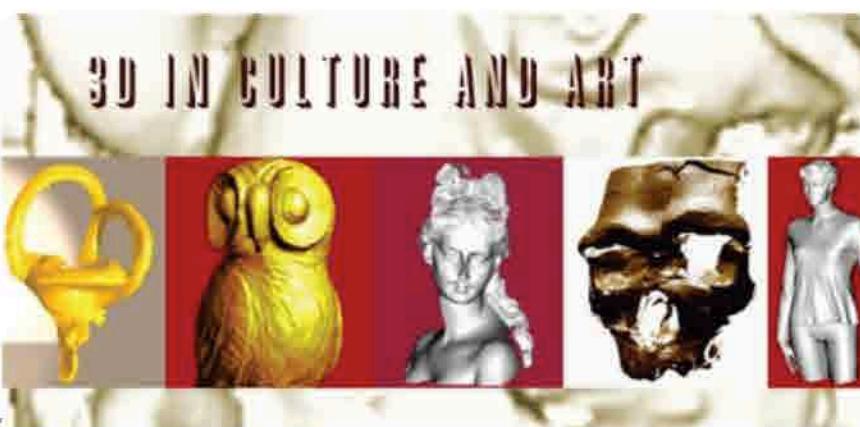
➤ Departments:

- Image Processing
- 3D Data Processing
- Graph Based Engineering Systems
- Computer Aided Facility Management
- **Signal Processing (Acoustic Camera)**



➤ Project groups:

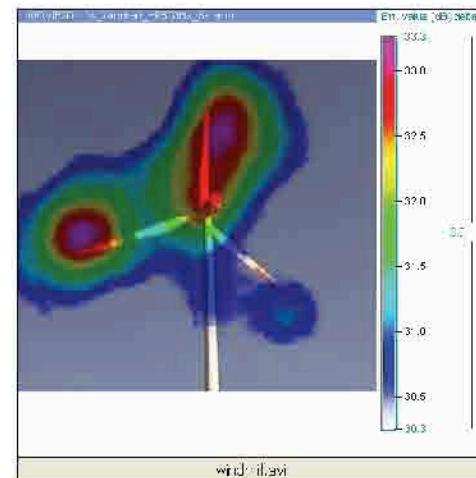
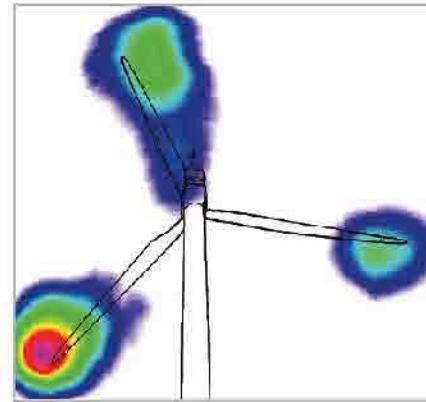
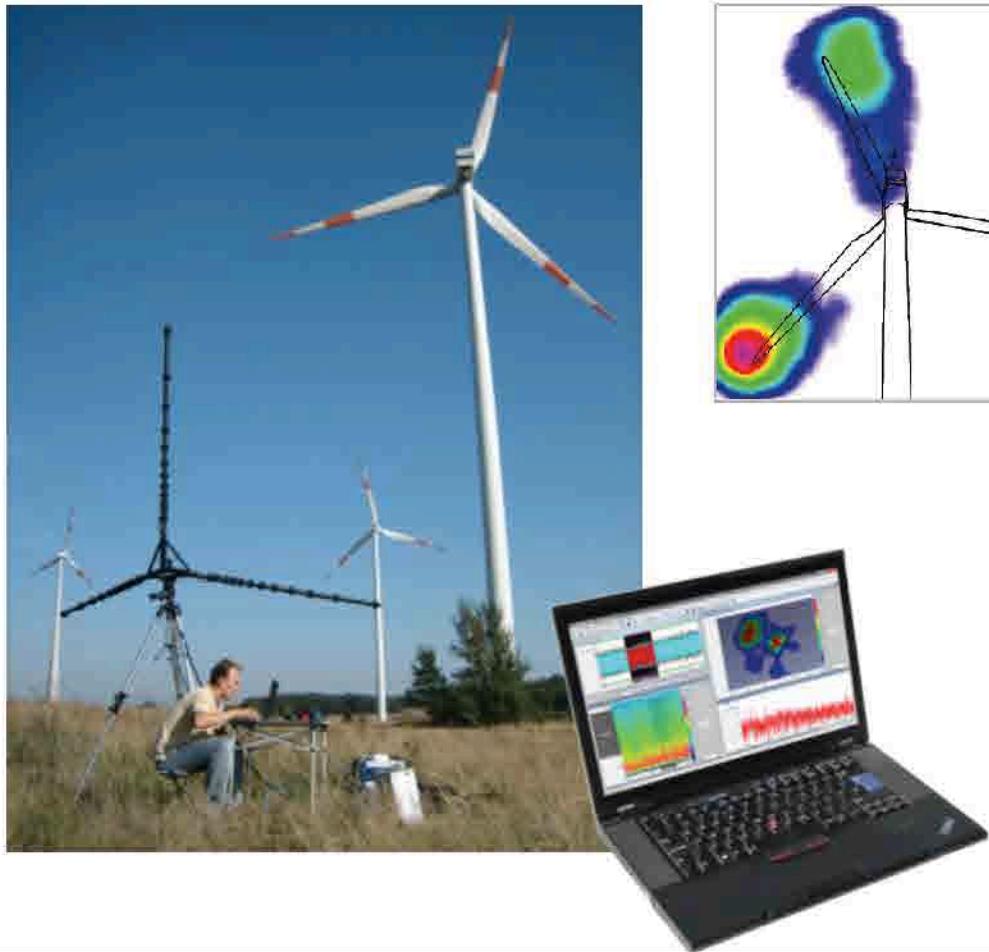
- Adaptive Modeling and Pattern Recognition
- Document Management
- Fuzzy Logic Applications
- Information Systems
- Multimedia
- Process Automation
- Robotics
- Sensors



The Acoustic Camera

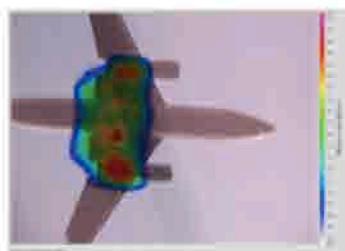


A revolutionary solution for sound localization

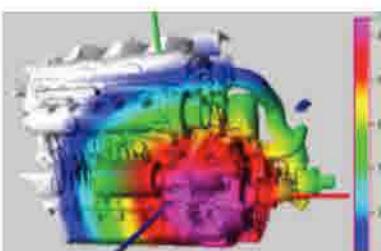


Acoustic Camera Application vary from A-Z

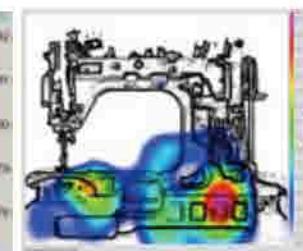
Airplane
Industry



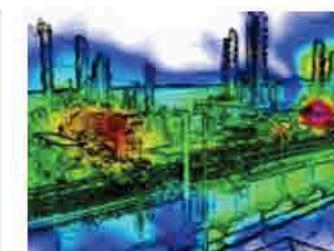
Automotive
Industry



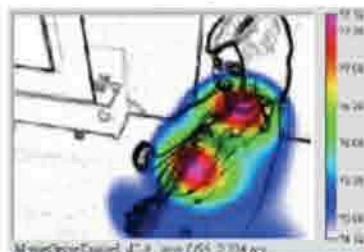
Consumer
Products



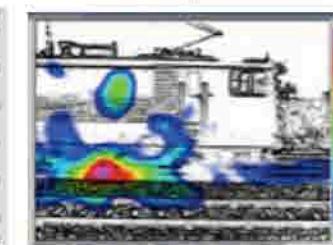
Environmental
Application



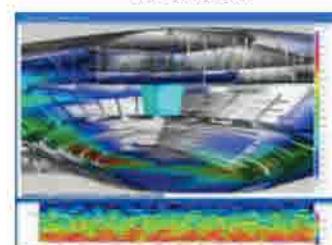
Music Instrument
Design



Railway
Industry



Room & Building
Acoustics



Zoological
Application



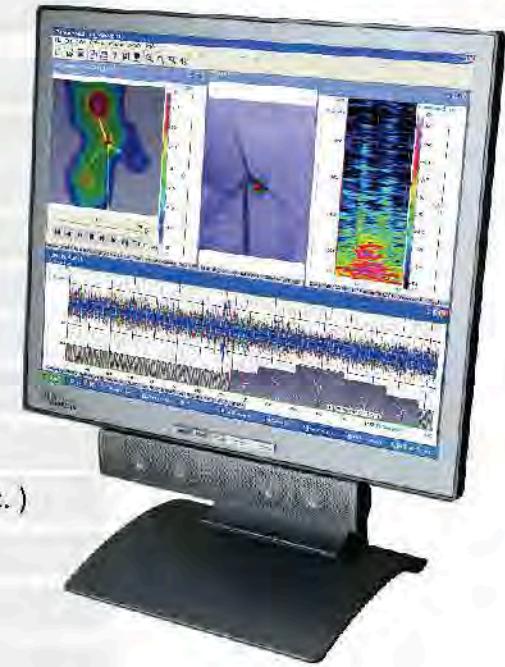
All audible sound can be recorded, mapped and analysed.
Products can be modified and optimised up on the focus
of Noise Reduction, Sound Design and Quality Management.

Acoustic Camera Concept



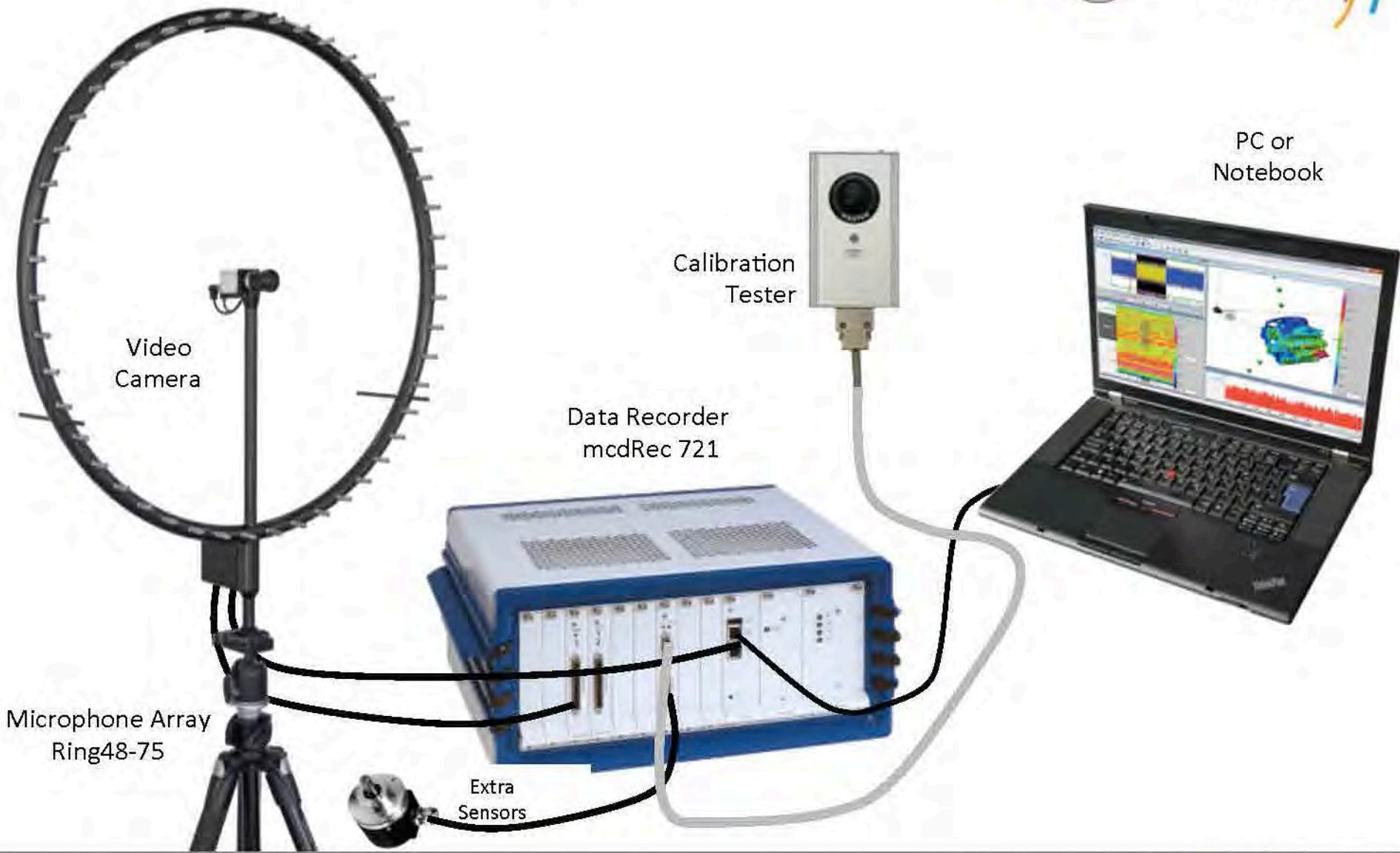
Important Acoustic Camera Specs:

- System Dynamic Range of 20-130dB (total 110dB) mapping from 100Hz -20kHz (70kHz)
- Single Map Dynamic of 6-15dB (with Deconvolution up to 60dB / dependent on array form)
- Spectral Photo Map Dynamic of at least 110dB
- Real Time Latency below 0.5µs (hardware trigger)
- Practical Time Resolution below 1µs for slow motion (through 192kHz sampling frequency)
- Average Acoustic Maps with 15.000 to 1.500.000 calculation Points per map
- Ring time buffer architecture of 173 Seconds Pre or Post Trigger (not to miss anything)
- Fully real time capability for standard 48 channel arrays (maps: with av. 5000 points)
- Advanced Algorithms implemented (HDR, Delete Auto Correlation, Zero Padding, Deconvolution etc.)
- 2D and 3D Measurement and Object planes (loading common CAD models)
- Shortest calculation times though multi processor support (eight core no problem)
- Practical Measurement distance from 0,40m to 600m
- System scalable up to 1200 channel – synchronization of 5 data recorders
- Acoustically transparent lightweight arrays – system fully mobile operate able by battery

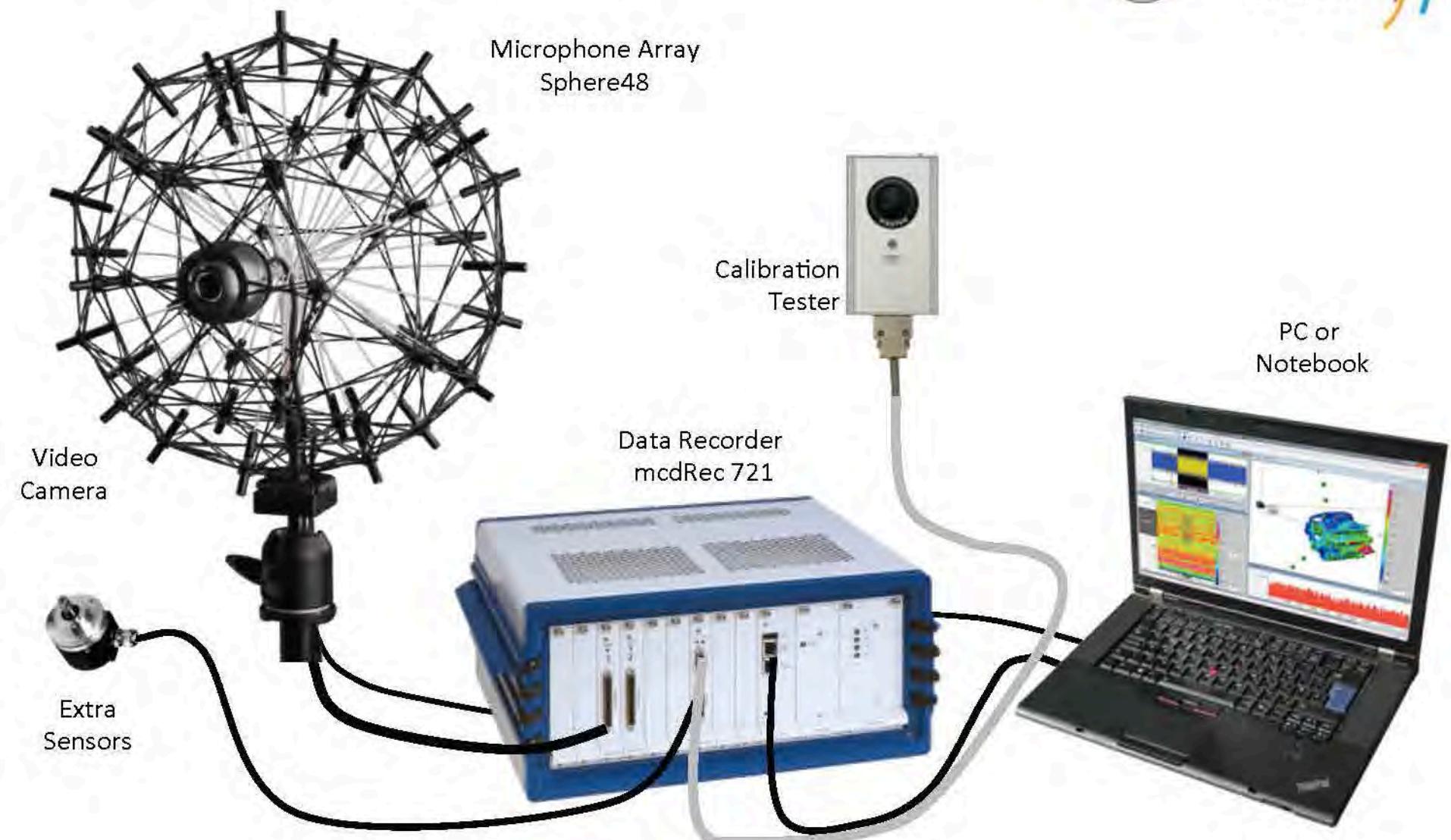


The GFai Acoustic Camera System was the first commercial Beamforming system available on the market. Launched in 1999 the development led to a *Product* designed by the influence of the customers focus on a practical solution. Fastest Set up time of all Beamforming systems, greatest flexibility and easiest user interface are a result of ongoing communication with our strongest customers. All critical hard and software components are specially designed and produced by the GFai to serve the purpose of handling many microphone channel as well as fast calculation of acoustic maps.

Acoustic Camera – Set Up



Acoustic Camera – Set Up

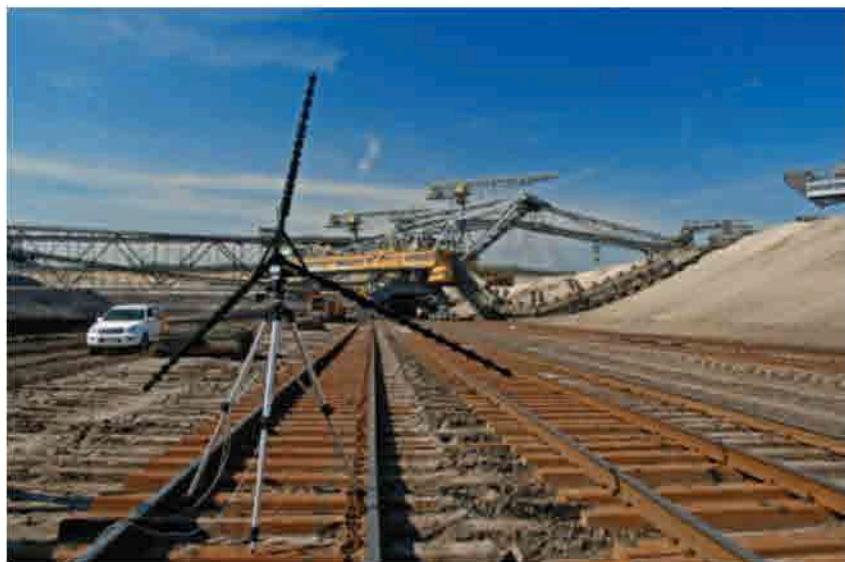




Star 48 / 36 Array

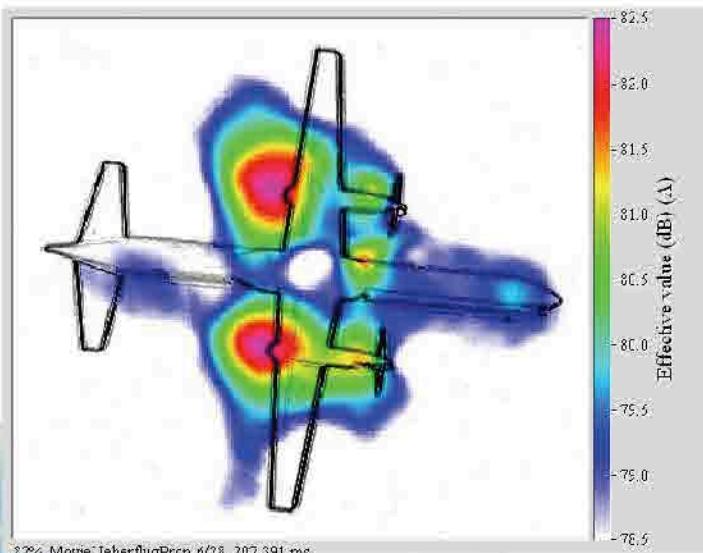


- Long distance, out door and free field
- Dynamic 35dB -130dB
- Recommended mapping frequency 100 Hz – 7 kHz
- Typ. single map dynamic ca. 6-7dB
- Typ. measurement distance 3- 300 m
- Video with 60 f/s (640 x 480)
- Foldable aluminum star structure

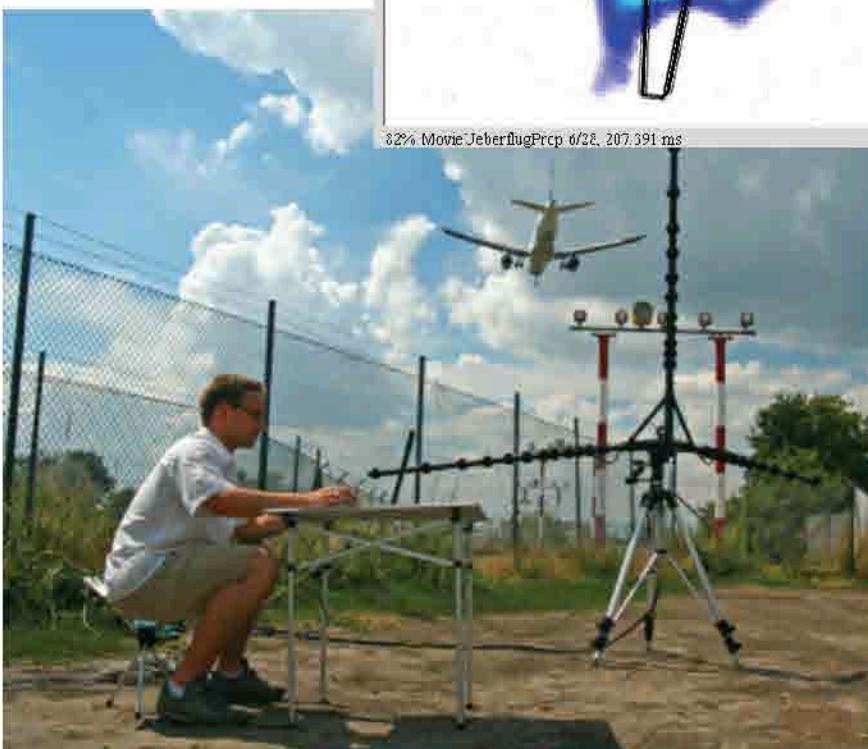
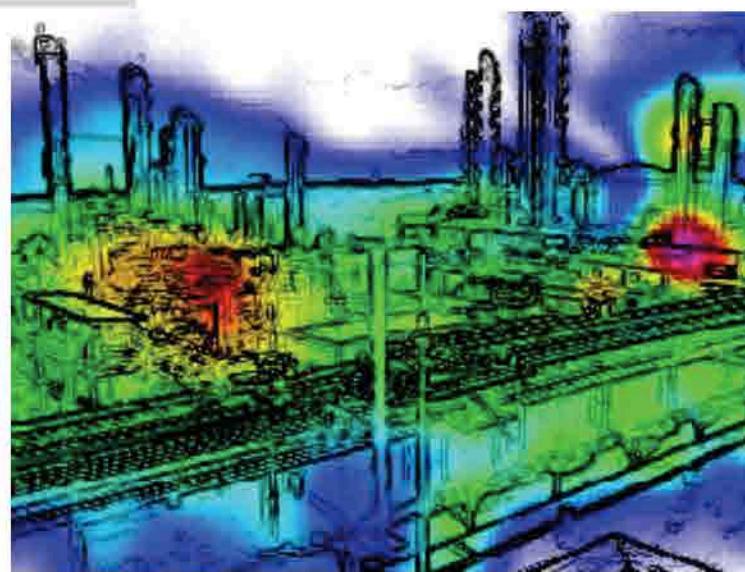




Star 48 / 36 Array



- Fly over
- Industrial Complex from 300 m distance

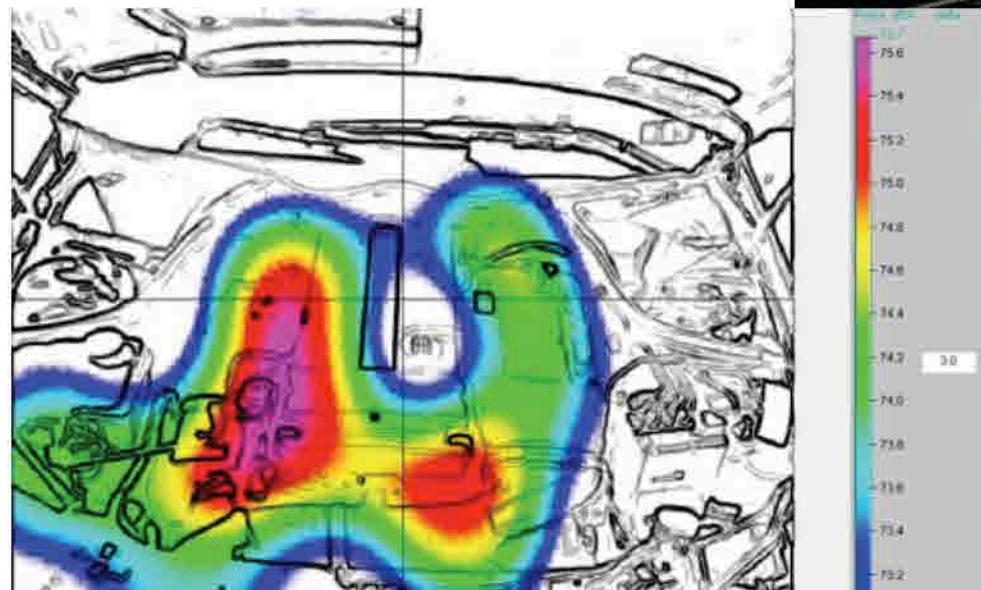


Sound becomes visible



How the sound becomes visible:

- fast
- simple



Localization Principle



Basis of the mapping in the space-time domain with Noiselman is:

$$P(t, \vec{r}) = \frac{1}{N} \sum_{i=1}^N p(t - \Delta_i(\vec{r}))$$

this formula is long known from
Delay-and-Sum Beamforming :

„Delay-and-sum Beamforming, the
oldest and simplest array signal
processing algorithm...“

Array Signal processing

Don H. Johnson, Dan E. Dudgeon

© 1993 by PTR Prentice-Hall, Inc.



WW 1 >> Jean Perrin – using one of the first "Acoustic Camera's"

Topofon profesora A. M. Mayera
usnadňuje navigaci lodí za mlhy
a špatné viditelnosti dle sluchových
vjemů.
(1880)



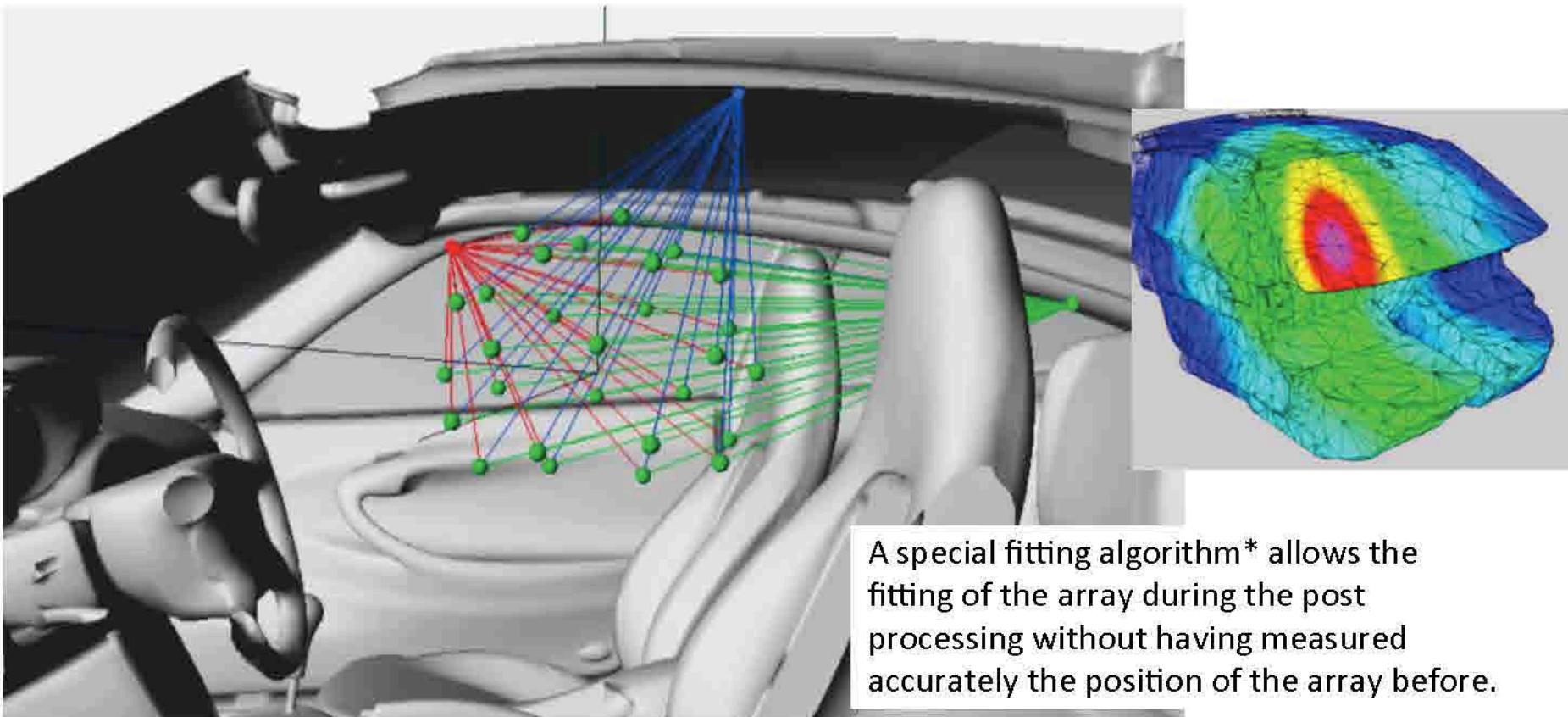
1880 the
first attempts



Localization Principle



With Noiselmage and our Sphere Arrays we offer
3D Mapping on common CAD models considering
the correct focal distances to all mesh / calculation points.



A special fitting algorithm* allows the fitting of the array during the post processing without having measured accurately the position of the array before.

*algorithm and methodical principle patented

Different Array Shapes

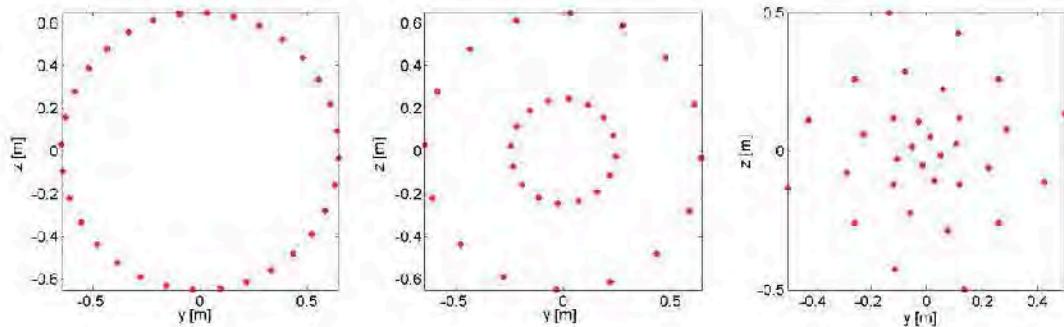


Abbildung 1: Optimierte Mikrofonanordnungen: EG, DG und SG.

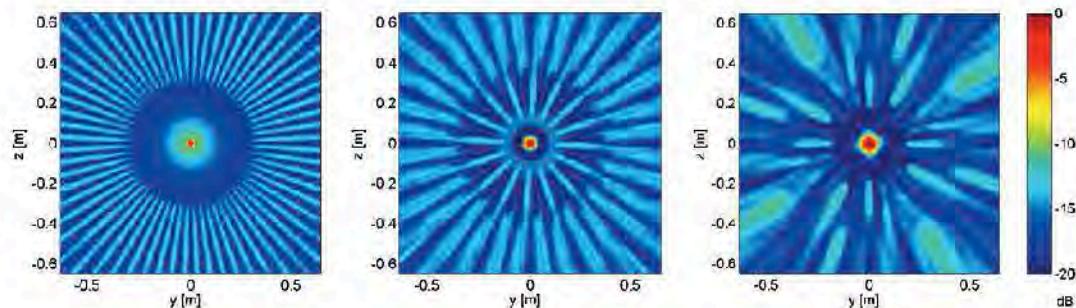


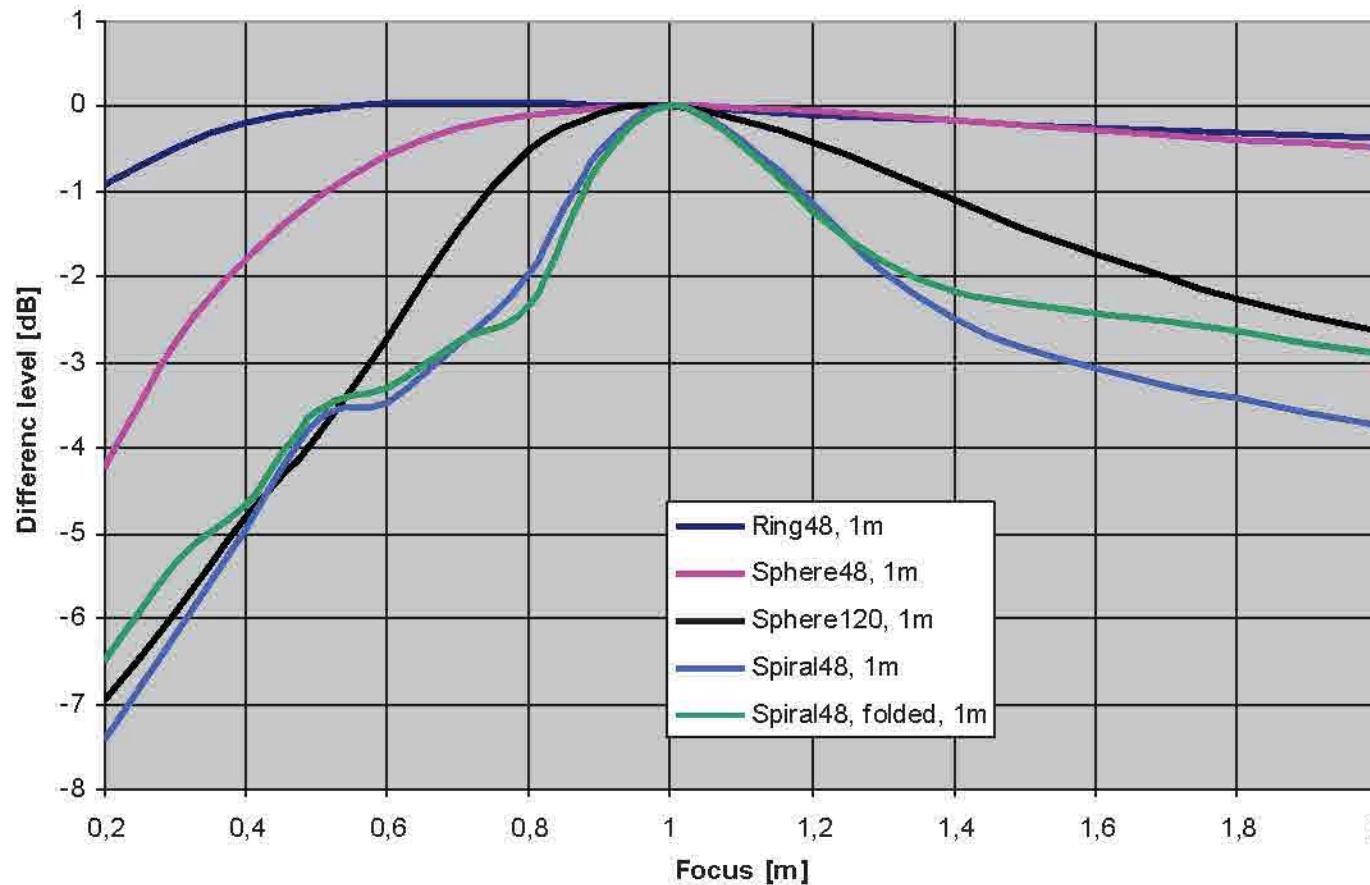
Abbildung 2: Arraypattern der drei optimierten Mikrofonanordnungen für das Oktavband von 8 kHz. Analyseabstand 1,0 m. Von links nach rechts: EG, DG, SG.

"Array Geometries" by
Christian Schulze, Ennes Sarradj,
Andreas Zeibig

Analysis by the Society for
Acoustic Research Dresden and
TU Dresden (Technical University
of Dresden, Inst. Of Acoustic and
Speech Communication)

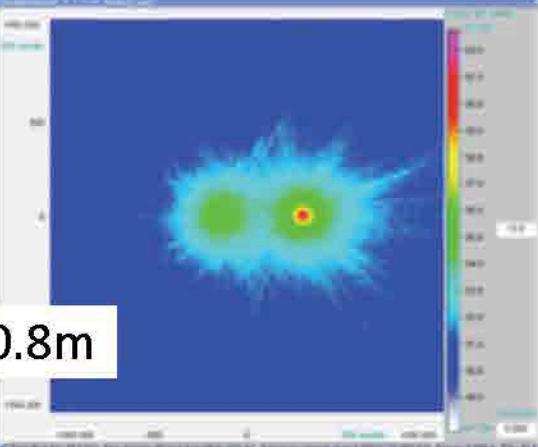
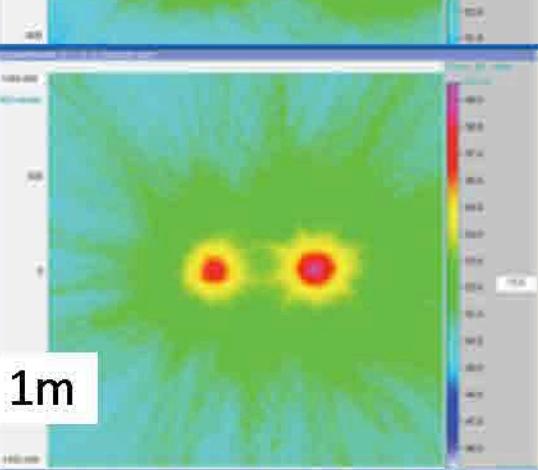
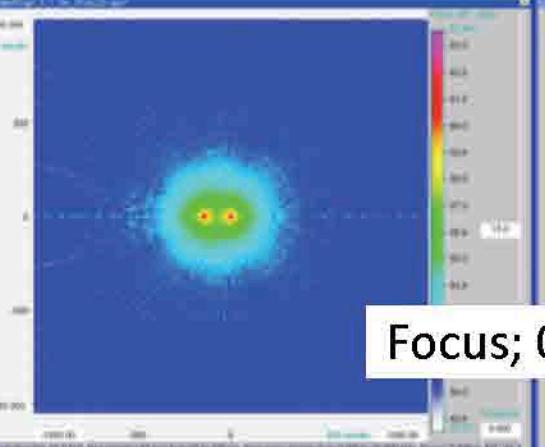
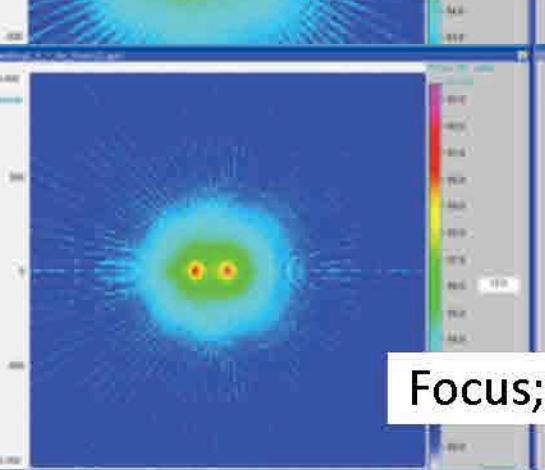
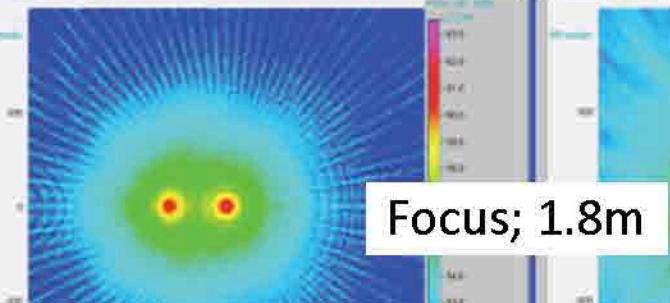
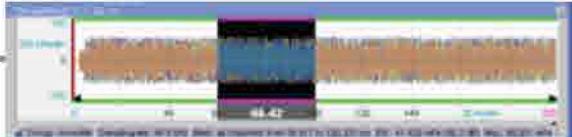
Published at the DAGA 2005

Difference in source level for the different arrays for white noise



If the source and the calculation plane is at 1m distance all arrays show the correct value (SPL) of the Source in the map. If the actual sound source (or a second source) is not at 1m distance this source will not show up in the acoustic map with the correct level. Most of the time the sound pressure is plotted in the map with a lower value, even when the source is closer than the focal Distance. This effect also varies by frequency and array form. Ring arrays show the least sensitivity to this effect!

Difference in source level for the different arrays for white noise



Ring48 results always on the left,
Sphere48 always on right

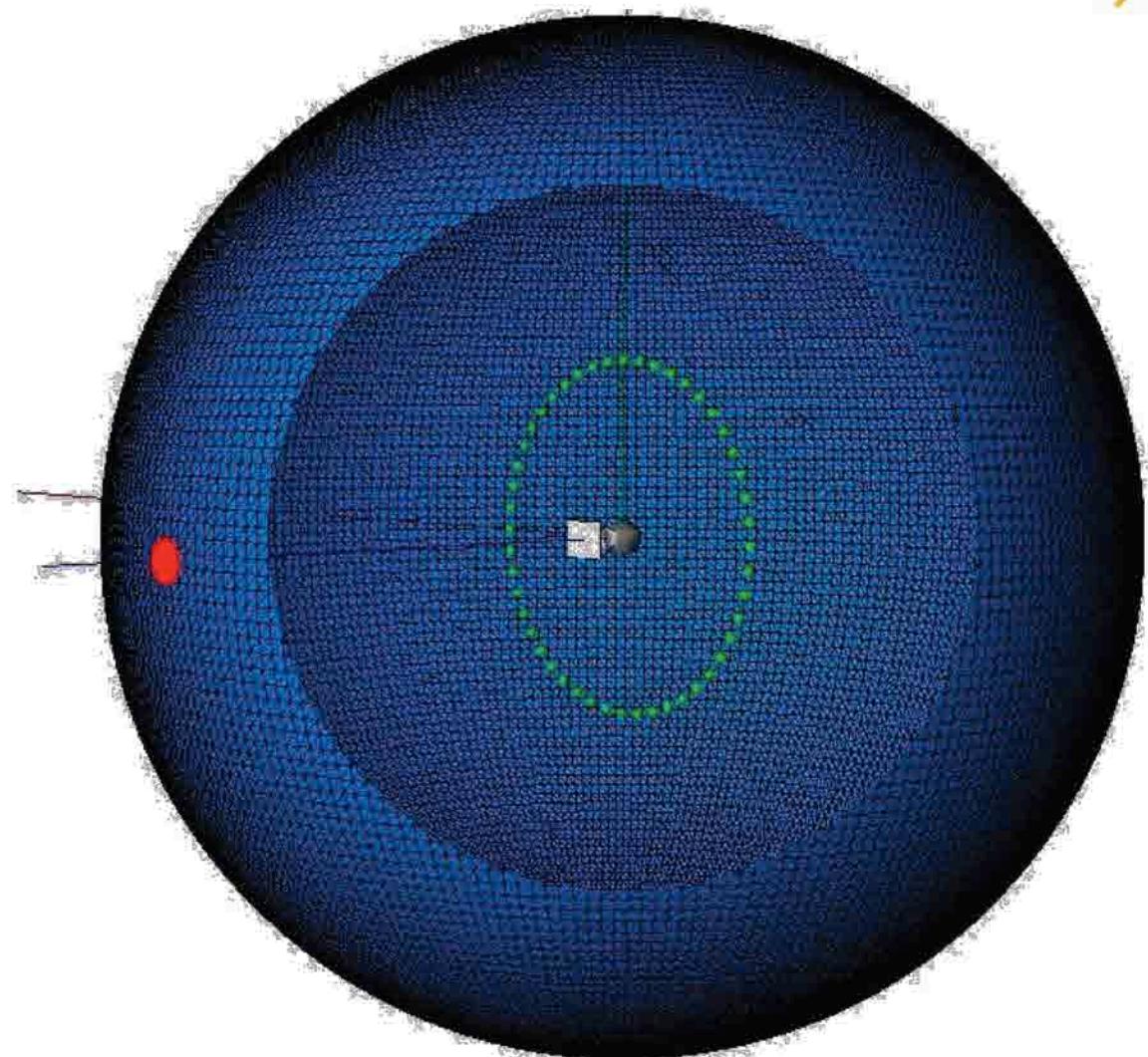
Two sources in distance of
0.8m and 1.8m from array

Array design for 3D - Interior Measurements



Simulation of a 3D-Szene:

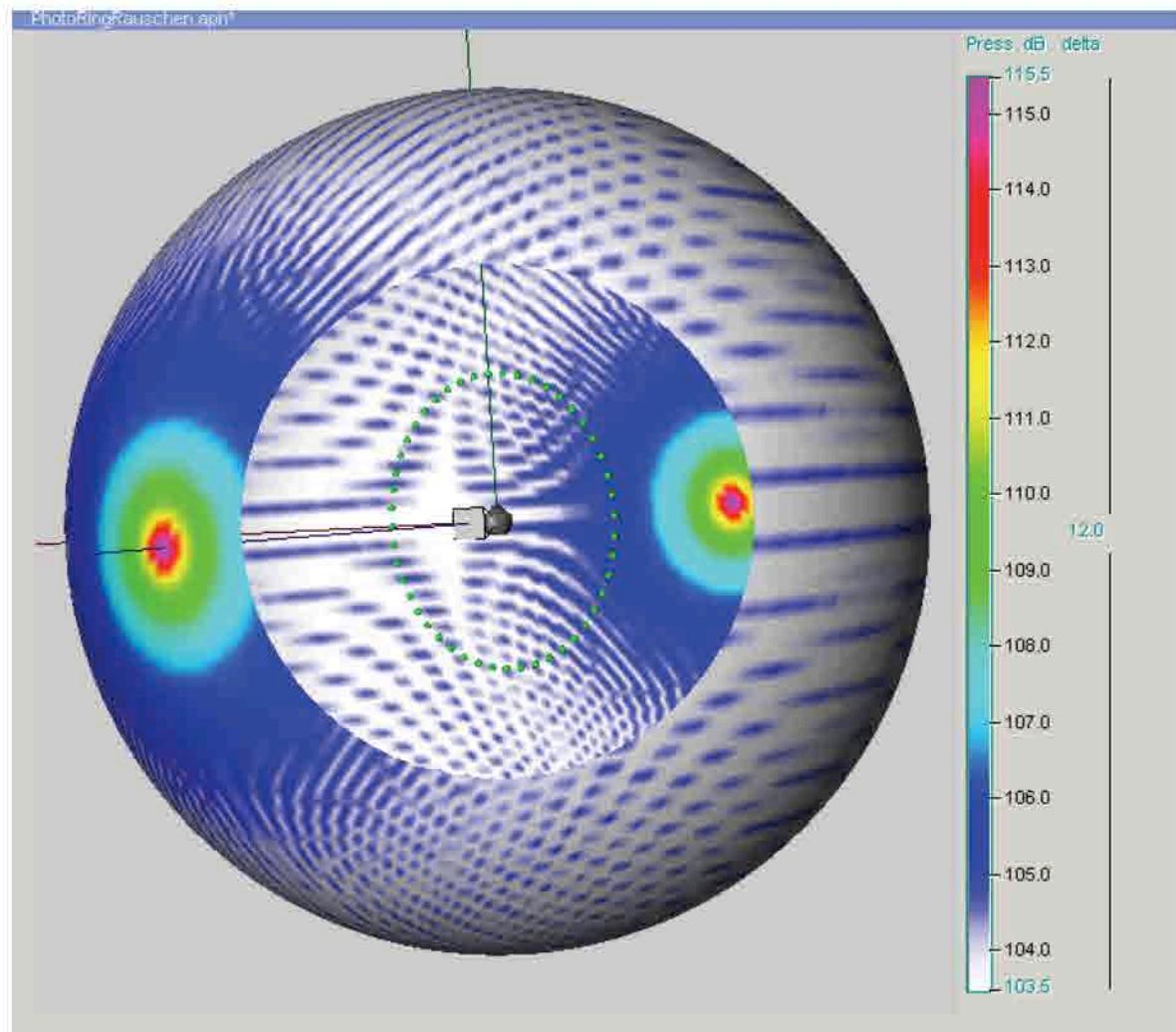
- Ring array 48 Channel,
- Diameter 0.7 m
- Dot like sound source with white noise (0-20 kHz) in 1m distance from Array
- Mapping onto a spherical projection plane with a radius of 1 m



Array design for 3D - Interior Measurements



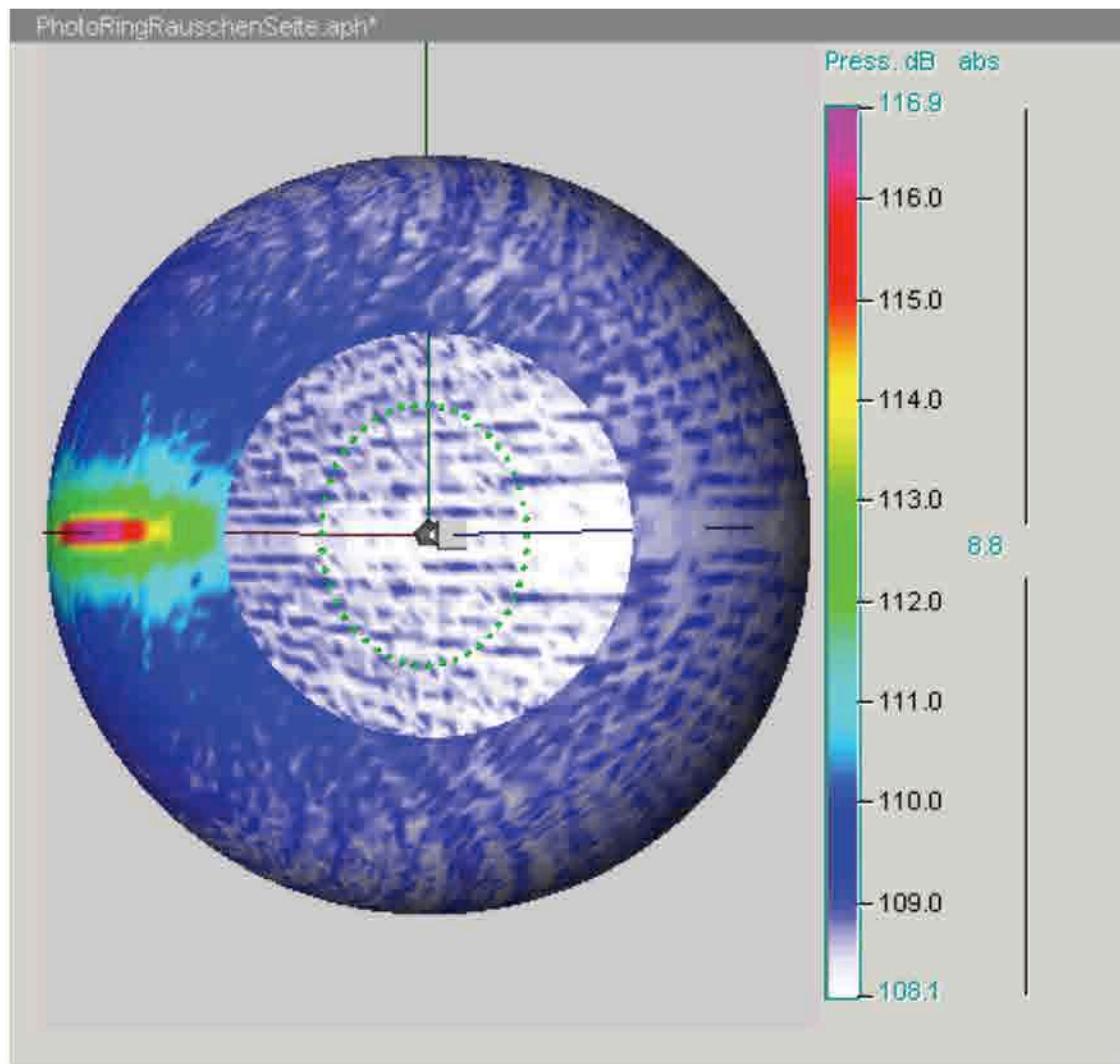
- Two dimensional arrays are not suited very well for 3D measurements
- All source will be mapped / mirrored in front and back of the Array



Array design for 3D - Interior Measurements



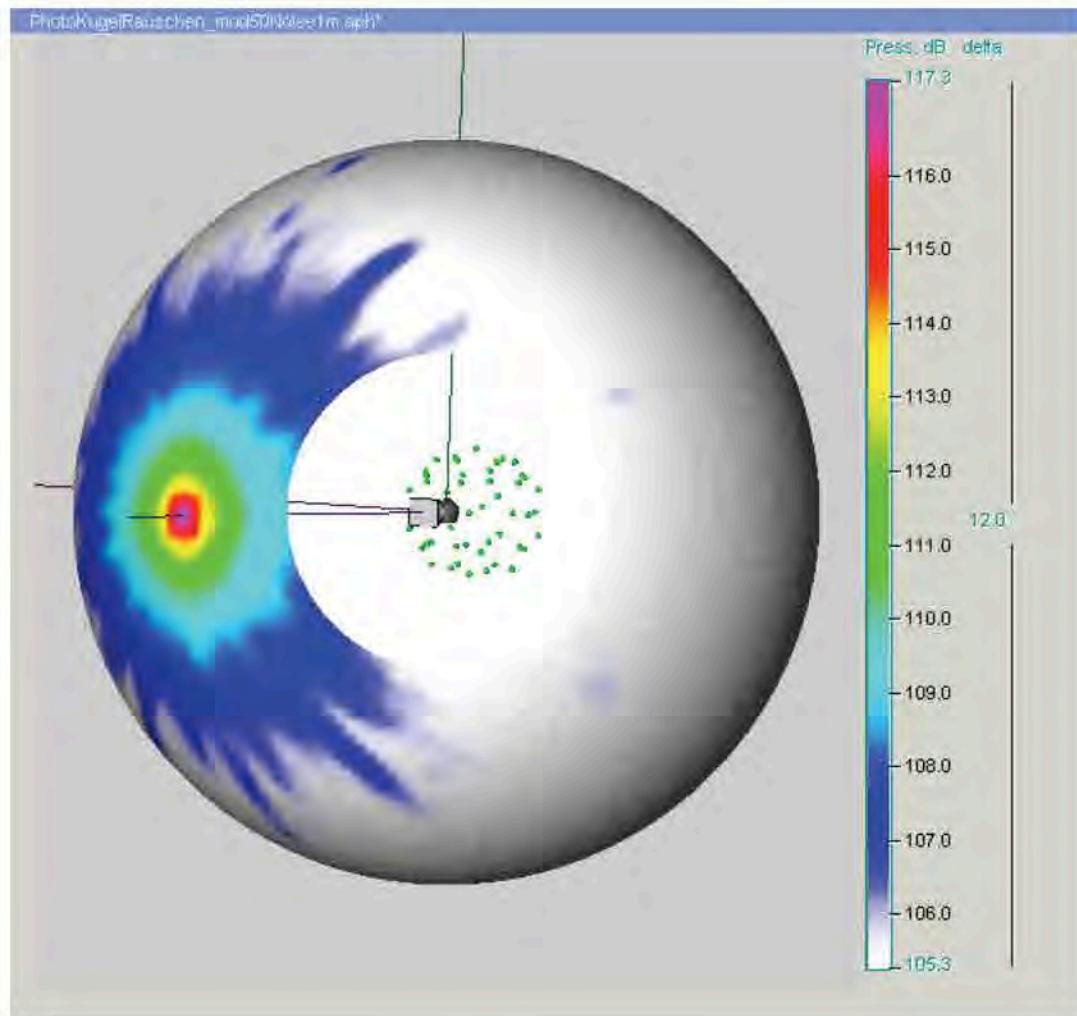
- 2D Arrays also have a dominating or favorite mapping direction
- These Arrays are **NOT** omnidirectional



Array design for 3D - Interior Measurements

Simulation of a 3D-Szene:

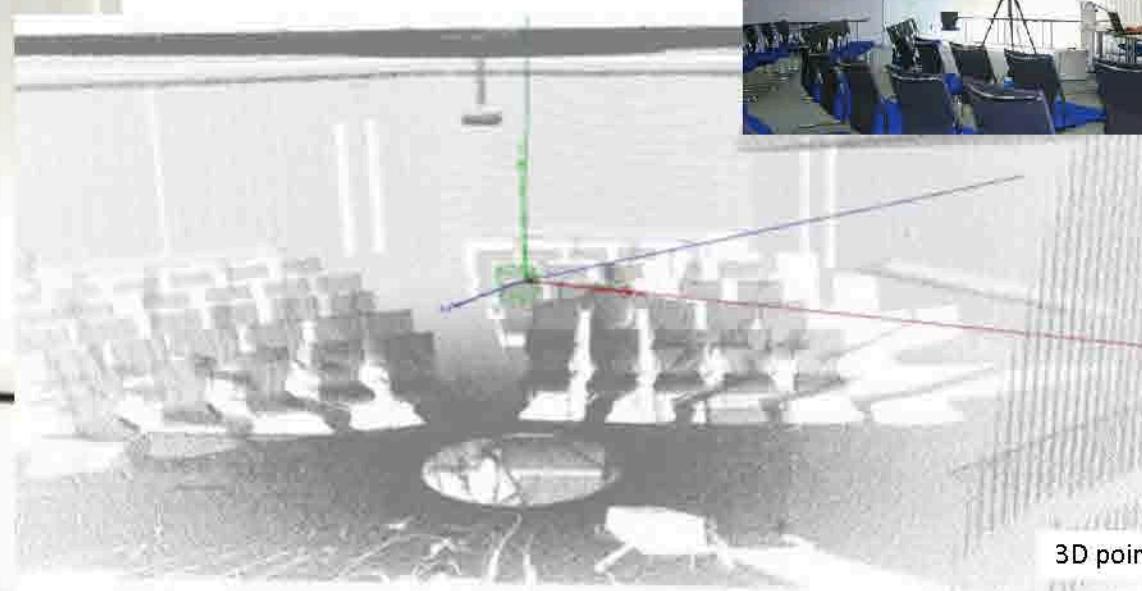
- Sphere array 48 Channel,
- 12 dB contrast
- Diameter 0.7 m
- Dot like sound source with white noise (0-20 kHz) in 1m distance from Array
- Mapping onto a spherical projection plane with a radius of 1 m



Leuze 3D Laser Scanner

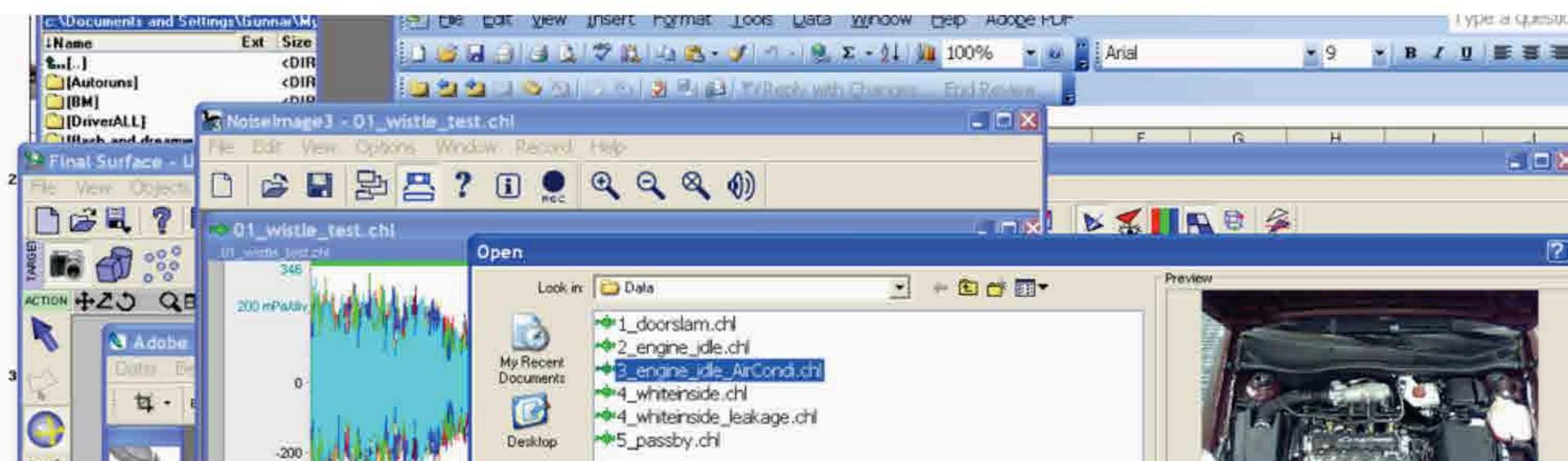


- ROTOSCAN ROD4plus
- Measurement distance 0-50m
- Radial resolution 5mm
- Lateral resolution 0.36 degree
- Operation temperature 0-50° Celsius
- Weight approx. 2kg
- Schunk PW70 robot arm



3D point cloud

Acoustic Camera Software – Noiselmanage4





Noiselmanage4:



Modular Plug In Concept > **fully real time capability**

Channel data viewer

AC Photo Functionality 2D / 3D

AC Spectral Functionality 2D / 3D

AC Movie Functionality 2D / 3D

AC Order Analysis / Mapping 2D / 3D

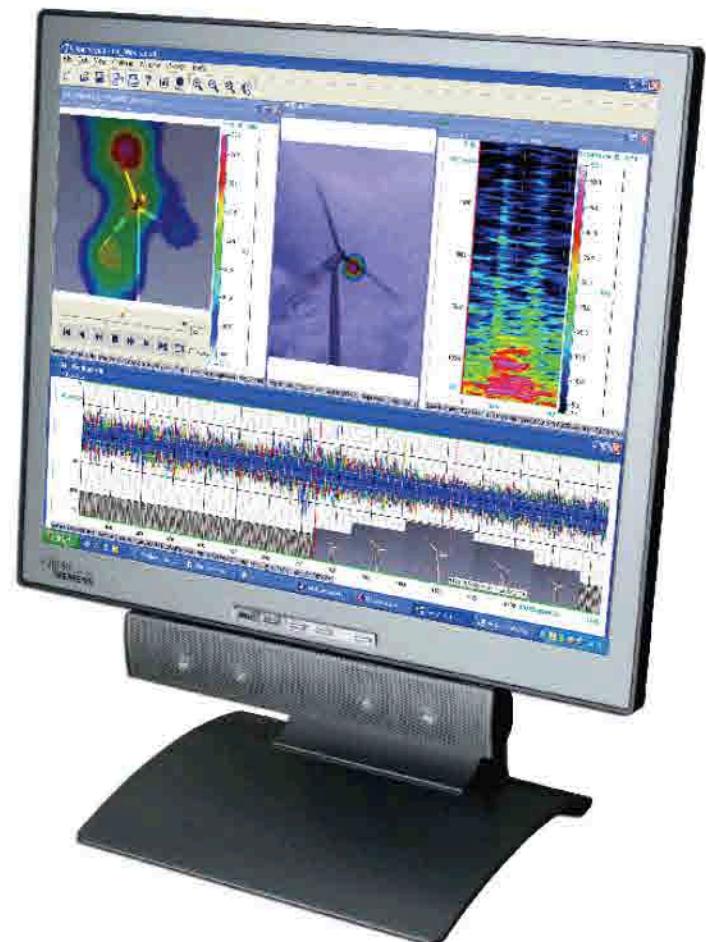
AC Extended Analysis modules

(Acoustic Eraser, HDR, Zeropadding, RMS vs. MAX method,
Delete Autocorrelation and several Deconvolution methods;
DAMAS, CLEAN SC)

AC Near Field Methods **NEW**

Live View module 2D / 3D for all modules

Project Management and Lay Outs for all modules



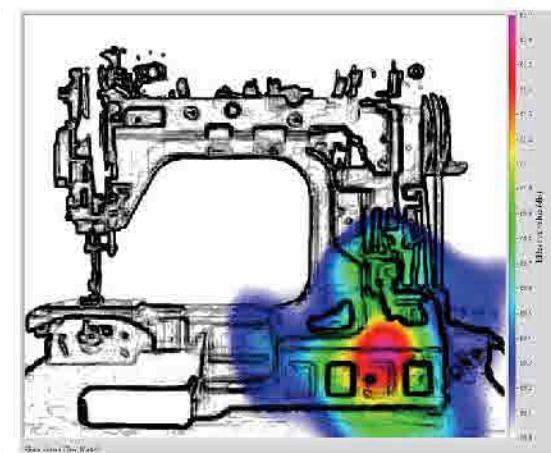
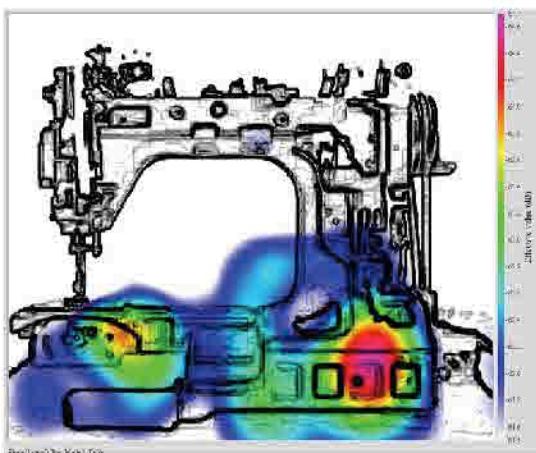
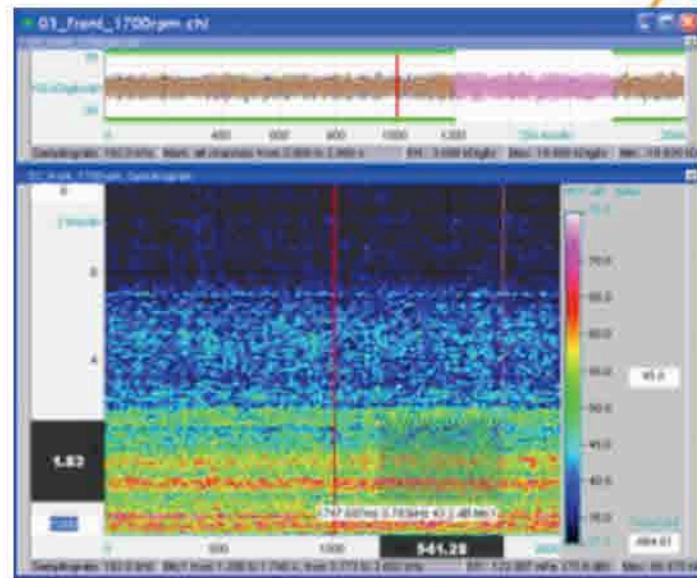


Software Features: Acoustic Photo 2D

acoustic
camera

AC Photo 2D

- Creating an acoustic photo by integrating a sound emission over selected time and or frequency interval
- Mainly used for comparing stationary noise sources comparing two development stages (before and after)



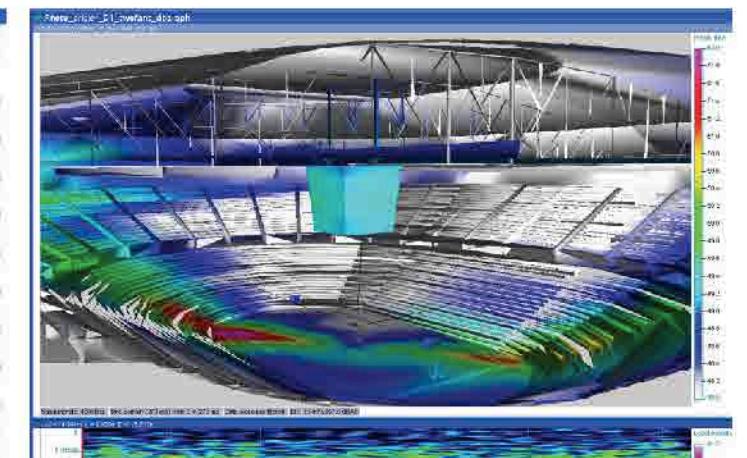
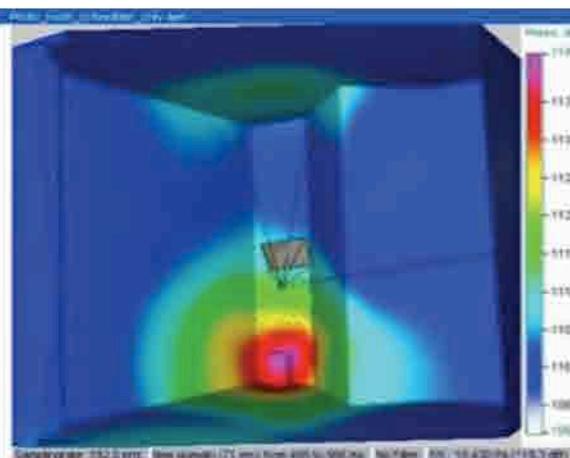
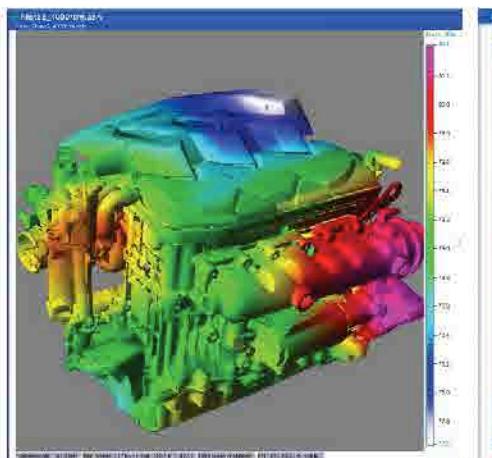
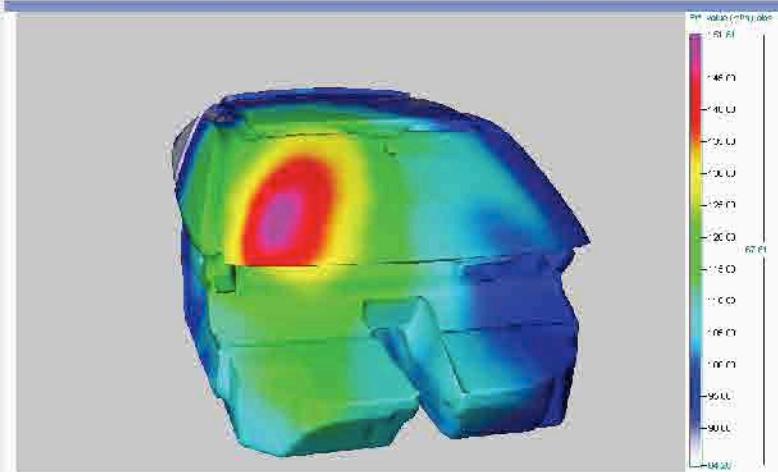


Software Features: Acoustic Photo 3D



AC Photo 3D

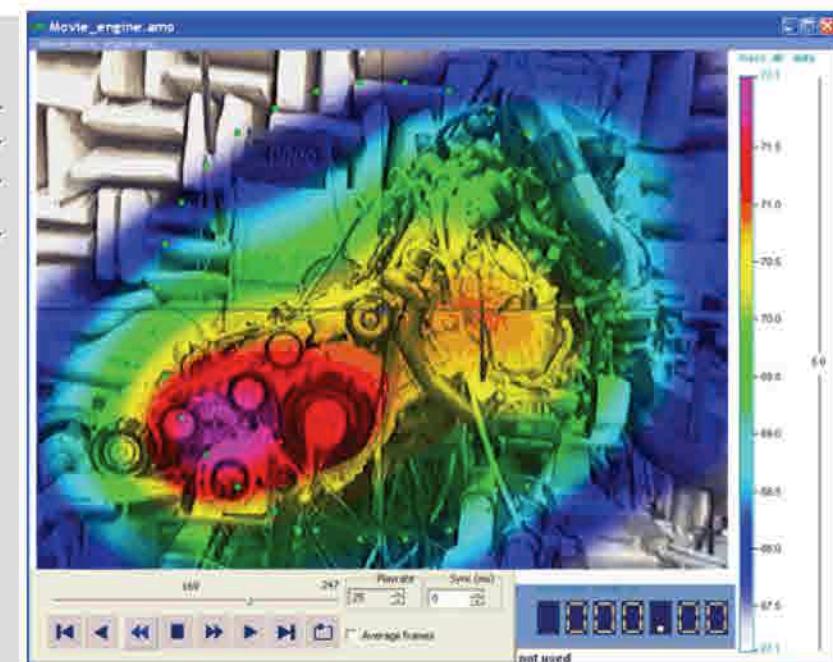
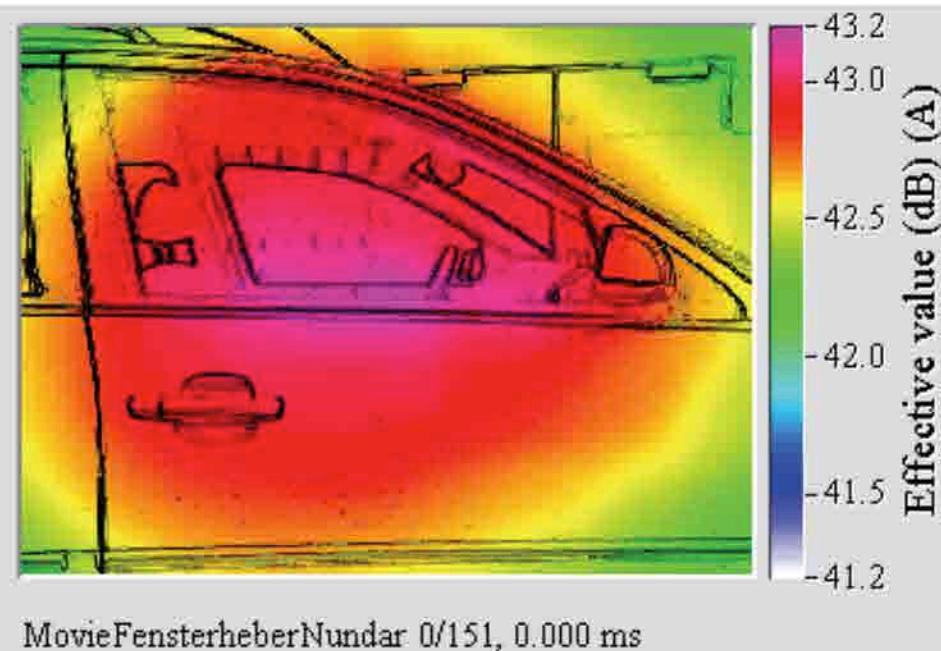
- Creating an acoustic photo by integrating a sound emission over selected time and or frequency interval and mapping it onto a common interior or exterior CAD model
- Used for comparing stationary and non stationary noise sources comparing two development stages (before and after)





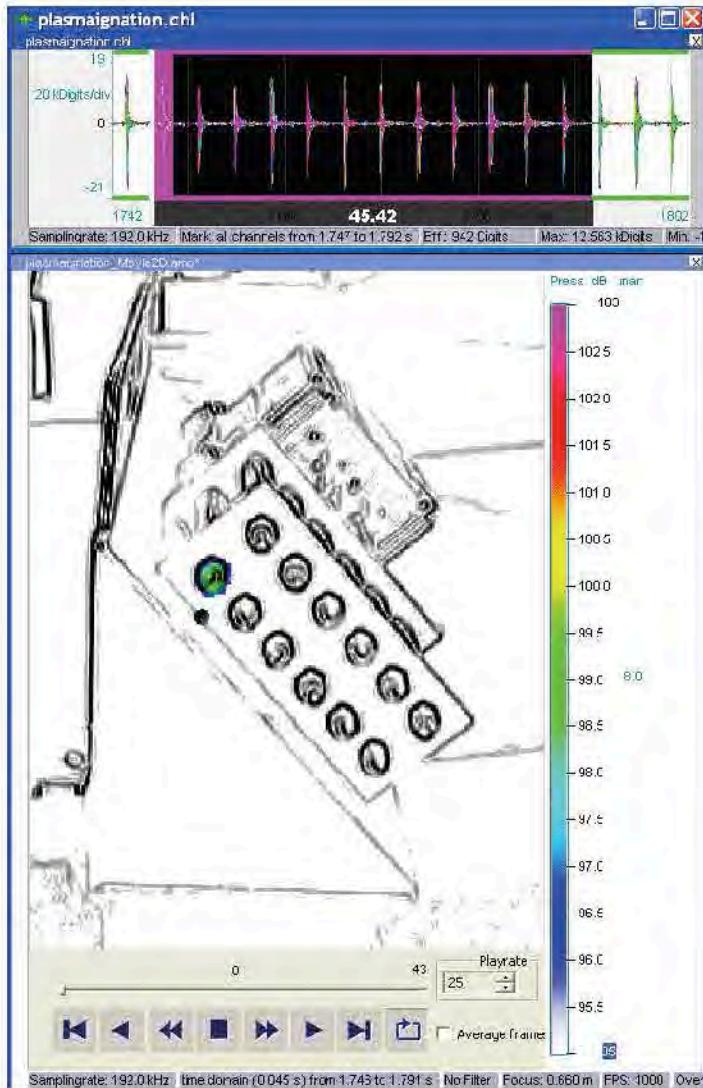
AC Movie 2D

- Creating a series of acoustic photos by integrating a sound emission over selected time and or frequency interval and showing it as acoustic movie with up to 192000 pictures/second
- Mainly used for analyzing non-stationary noise sources to visualize the changes over time





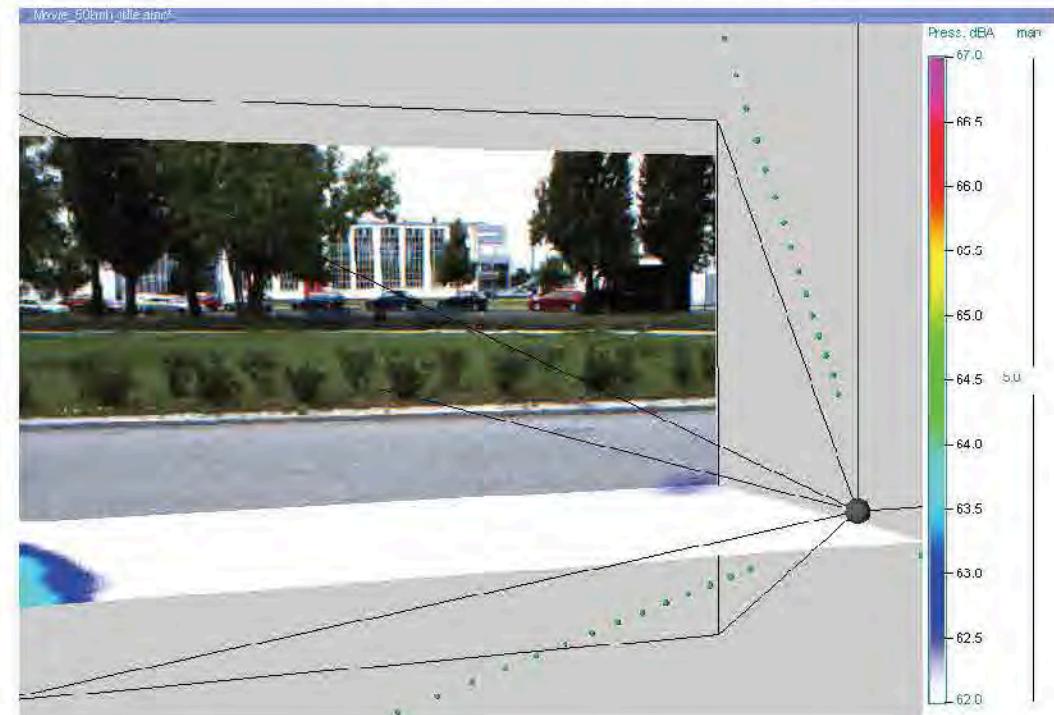
Software Features: Acoustic Movie 2D/3D



Plasma ignition
field at 1000 f/s

Pass By Measurement as MoM
(Movie on Movie)

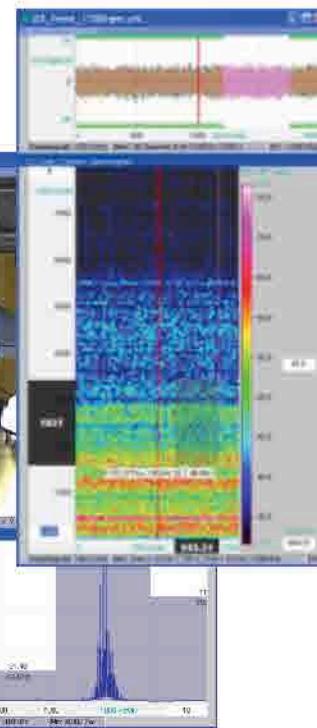
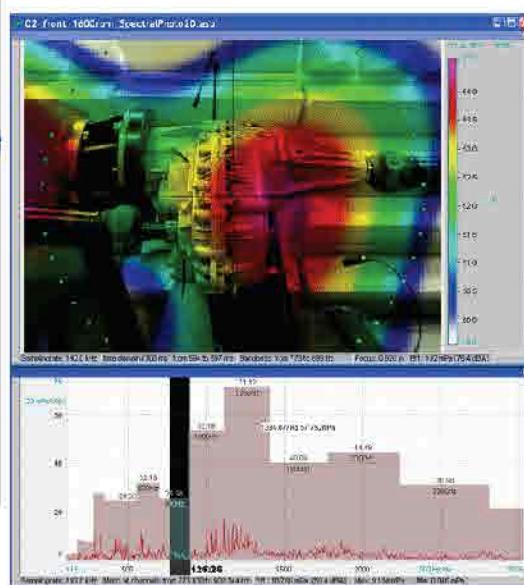
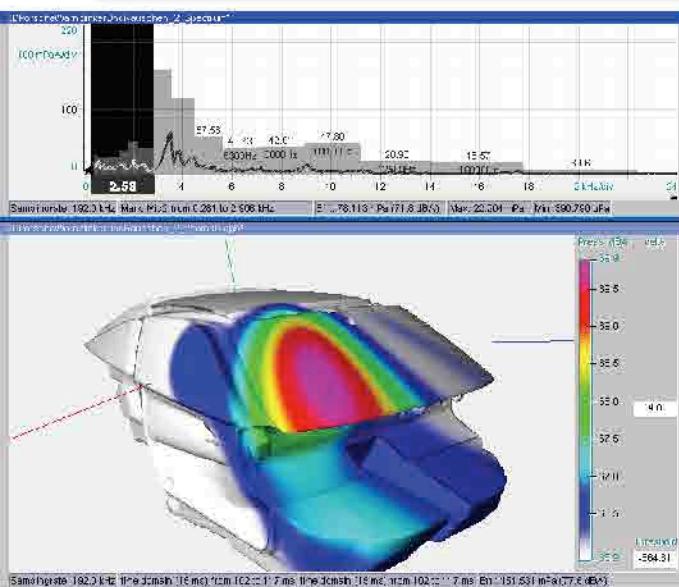
Here a Mercedes C-Class
In cruise-by at 50 km/h (tire noise)





AC Spectral Analysis 2D/ 3D

- Creating a series of pre-calculated acoustic photos/movies for all frequencies within the selected interval and showing it in a connected frame to be able to choose freely frequency band and see the acoustic sources location to it
 - Narrow band analysis, 1/3 octave analysis, spectrum, listening of sources



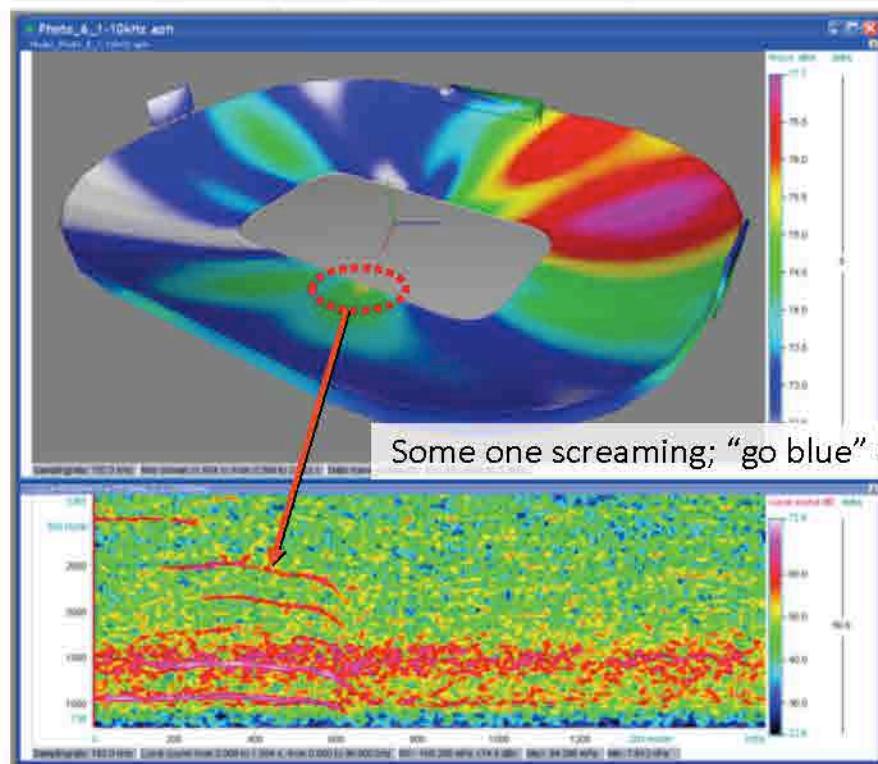


Standard Software Features

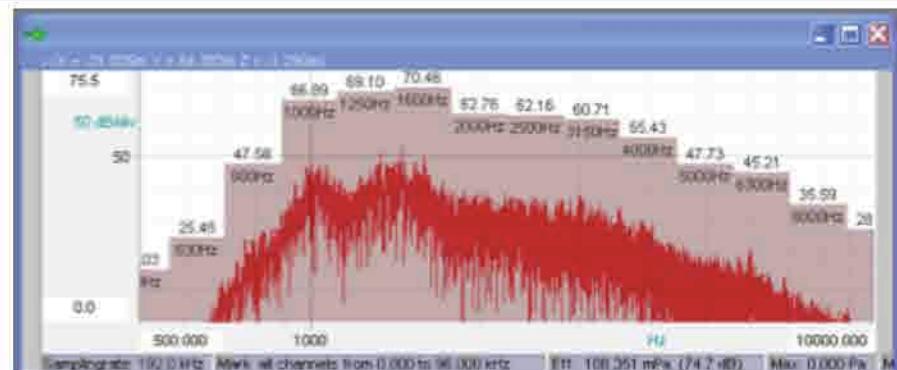


Standard Features: Spectrum, Spectrogram, Virtual Sound Studio

- Every acoustic map offers the ability to extract the spectrum, spectrogram and-or listen to the sound of every given calculated point in the acoustic map
- Export into standard file formats like *.txt, *.jpg, *.bmp, *.png, *.wav, *.avi, and into other acoustic tools like Matlab or AtemiS,



Some one screaming; "go blue" at position x,y,z



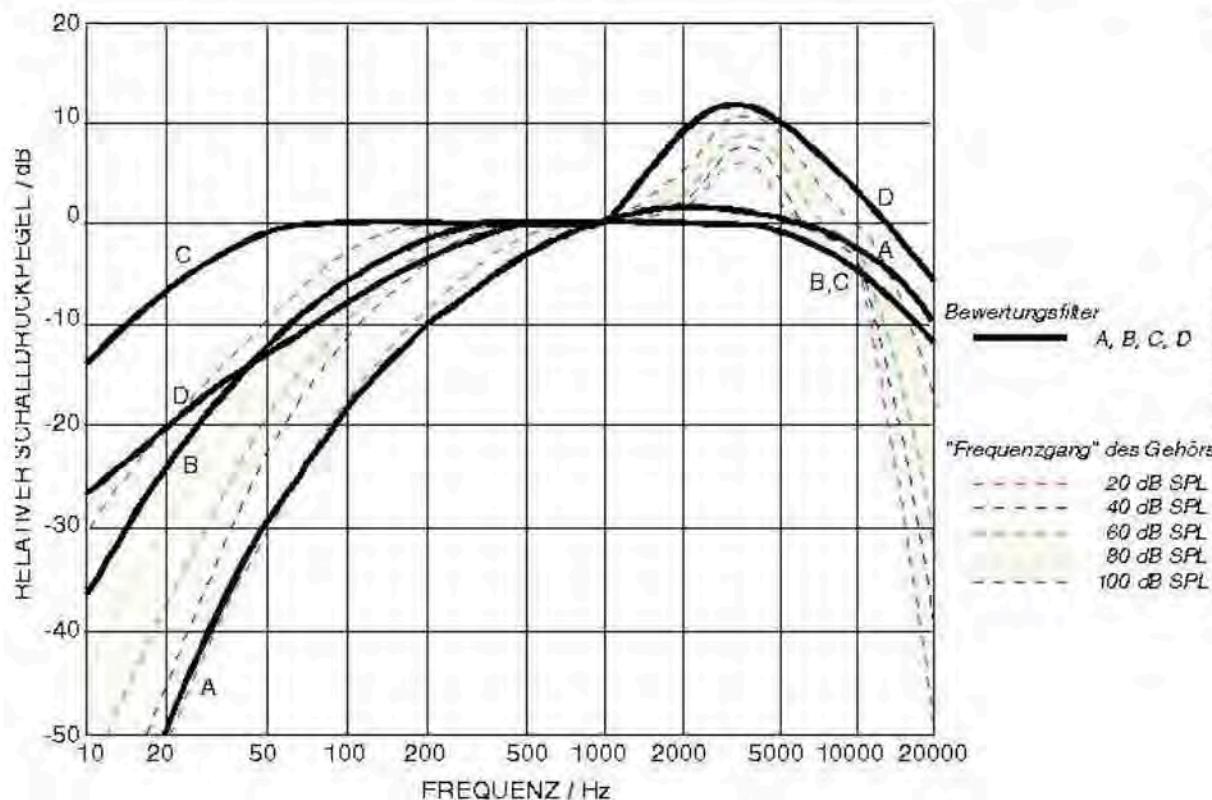


Head-Related Transfer Function (HRTF)

HRTF for acoustic images in 2D and 3D
considering the actual 3-dimensional
Head-Related Transfer Functions for the acoustic imaging



- The microphone does not „hear“ like the human so there are different filters
- Most common filter is the A-Weighting (B,C,D – are for other levels)
- The problem is that the A-Weighting only considers the frequency response of the human ear but does not consider the direction of sources origin





- Head-Related Transfer Function – describes the filter function of the human ear, head and torso to one or more sound sources
- Several common measurement tools / artificial heads for binaural recording are available
Head acoustics GmbH (1), Brüel & Kjaer (2), G.R.A.S. (3), Georg Neumann GmbH (4)



(1) HMS IV



(2) "Kunstkopf" 4100



(3) KEMAR Manikin



(4) KU 100



HRTF - Introduction



The key idea = combine Acoustic Camera with directional filtering (3D HRTF).

- In cooperation with the University of Michigan an extensive new empiric study of representative number persons was performed to evaluate the physical shapes of ears and torso >> creating an average persons ear etc. and then an average HRTF for each direction and frequency (5° raster)
- The results in an applicable basis for directivity selective filters for the Noiselmanage Acoustic Photo2D/3D modules



with permission from : Prof. Mojtaba Navvab
(University of Michigan)



With Permission from : CIPIC Interface Laboratory,
University of California at Davis, Davis, CA 95616

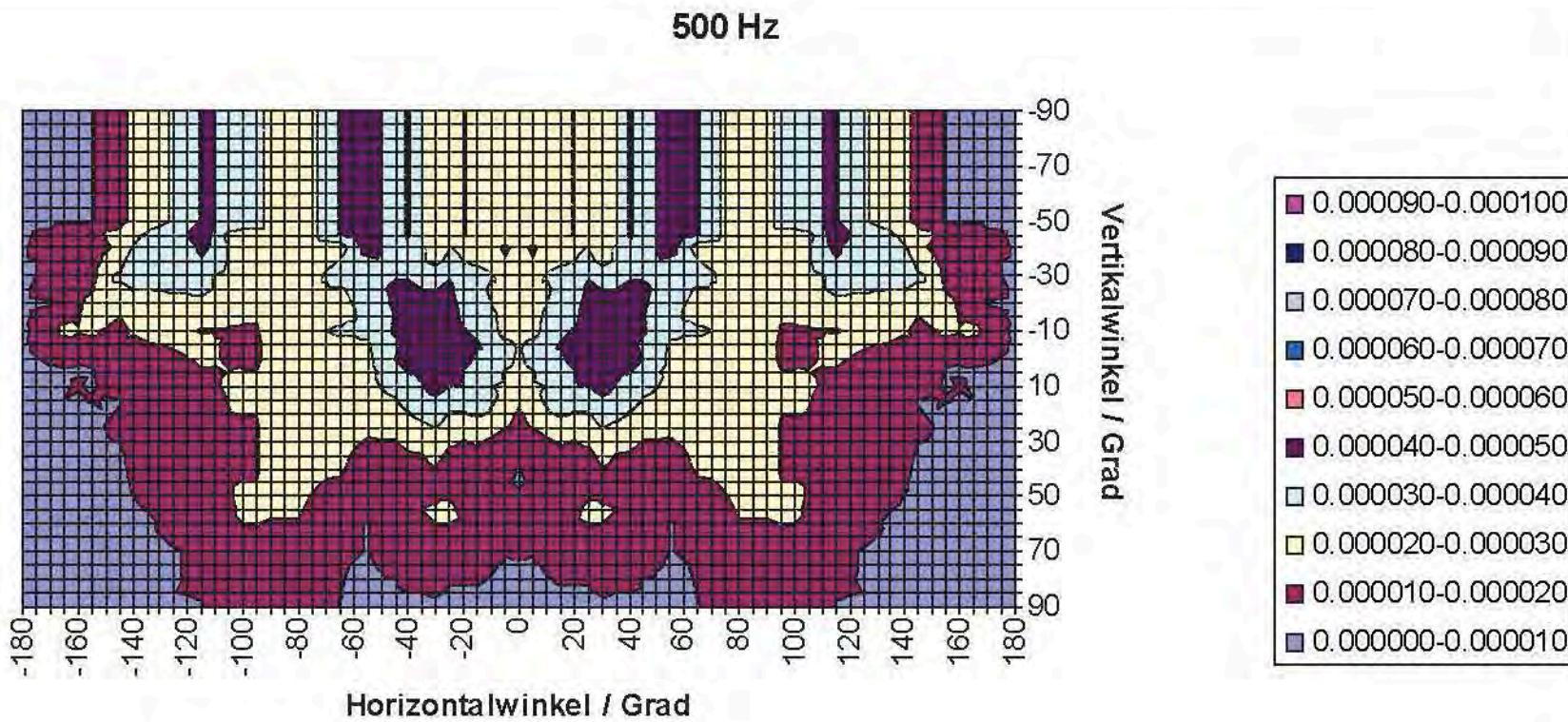


- Sources (Sinus in different frequencies) moving in a 5 degree raster (-180 to 180 degree in horizontal and 90 bis -90 Grad in vertical direction) positioned around the artificial ear
- Calculation of a correction factor (k in Pa) dependend on frequency (f) and the space vector (h, v) => $k_N = F(h_N, v_N, f)$

500 HZ	-180	-175	-170	-165
90	0,000004	0,000005	0,000006	0,000006
85	0,000004	0,000004	0,000005	0,000005
80	0,000003	0,000004	0,000004	0,000005
75	0,000003	0,000003	0,000004	0,000005
70	0,000003	0,000003	0,000004	0,000005
65	0,000003	0,000005	0,000006	0,000004
60	0,000003	0,000004	0,000005	0,000004
55	0,000004	0,000004	0,000005	0,000006
50	0,000004	0,000004	0,000005	0,000007
45	0,000003	0,000006	0,000005	0,000006
40	0,000003	0,000004	0,000004	0,000006



HRTF - Results - 500 Hz



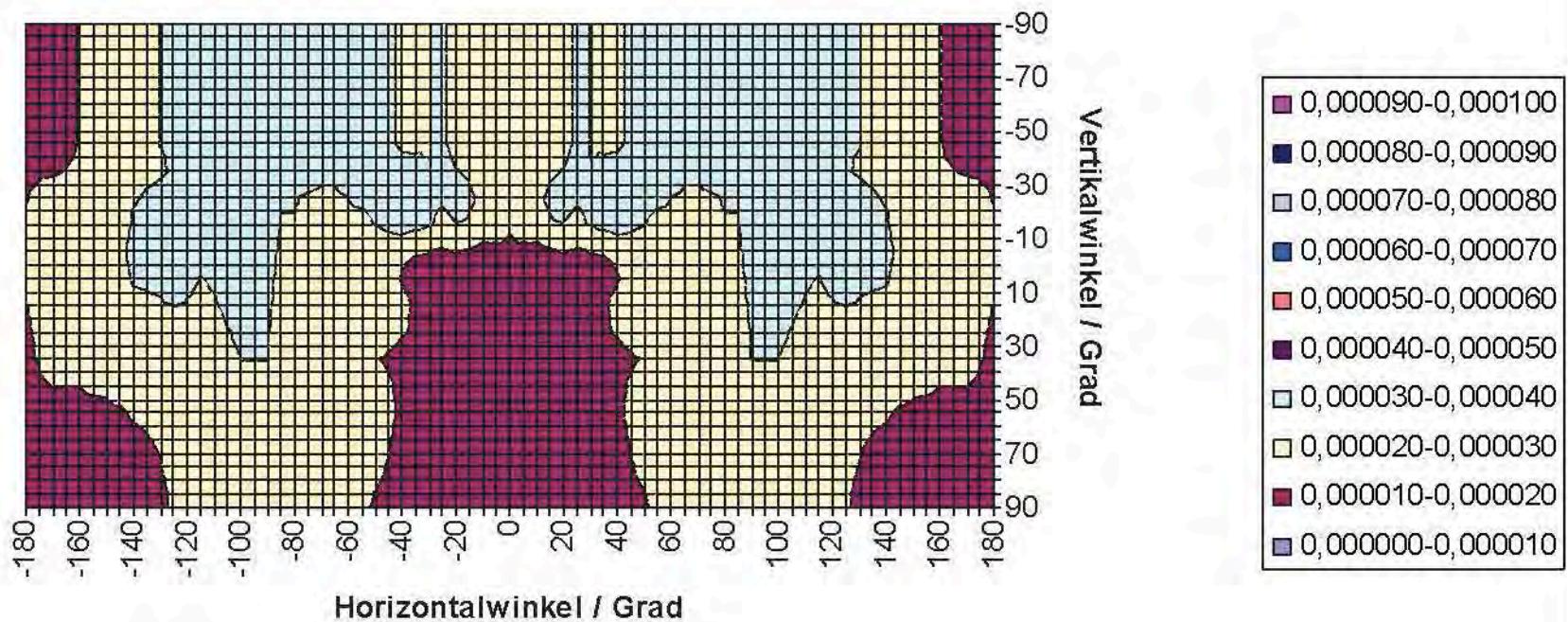
with permission from : Prof. Mojtaba Navvab (University of Michigan)



HRTF - Results - 1000 Hz



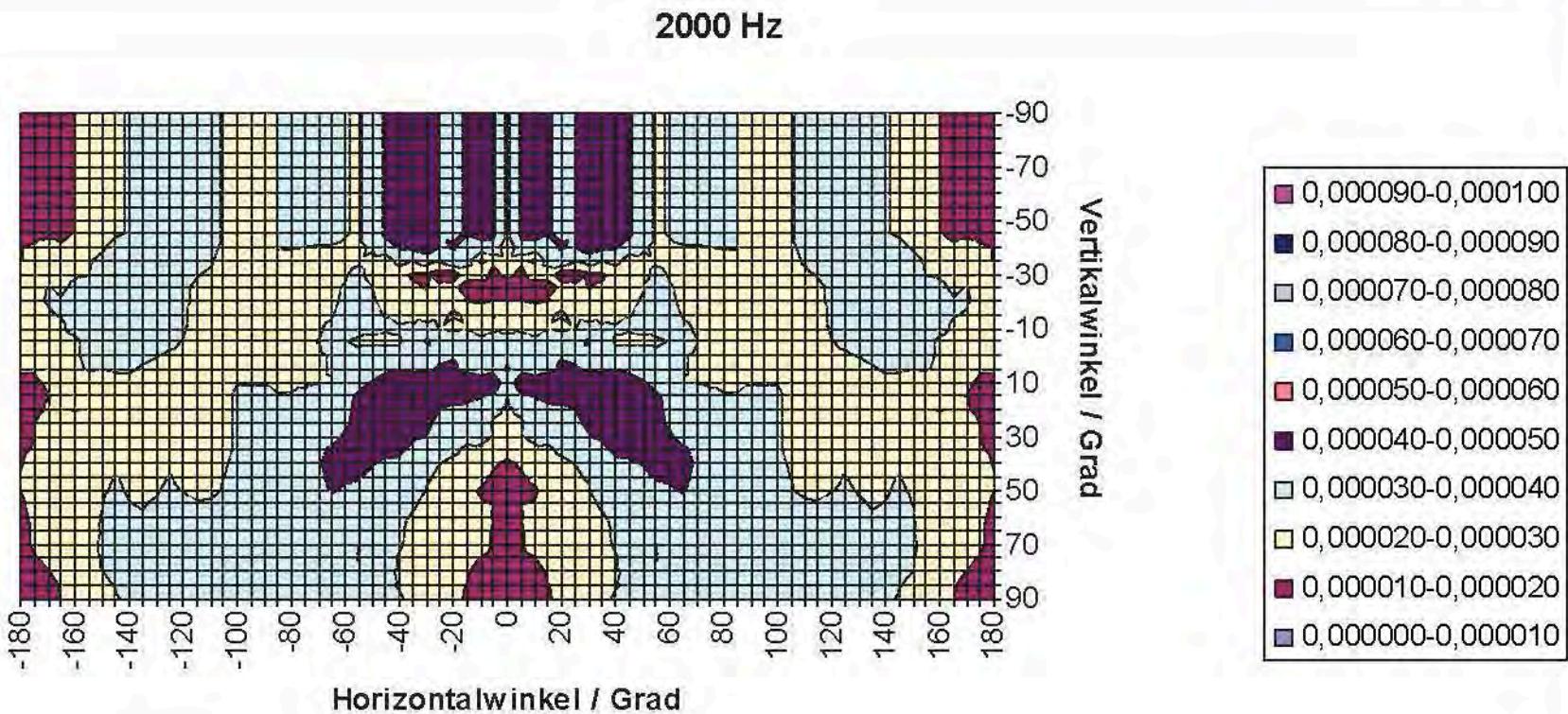
1000 Hz



with permission from : Prof. Mojtaba Navvab (University of Michigan)



HRTF - Results - 2000 Hz



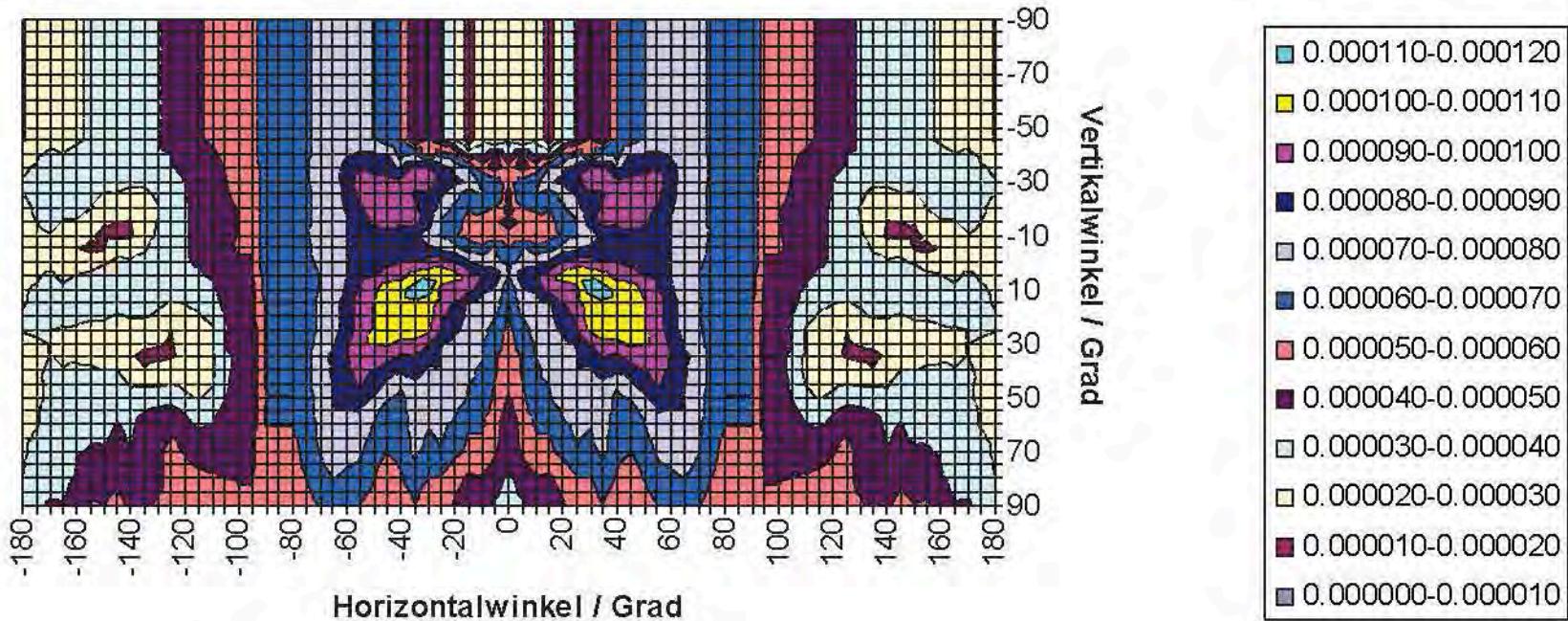
with permission from : Prof. Mojtaba Navvab (University of Michigan)



HRTF - Results - 4000 Hz



4000 Hz



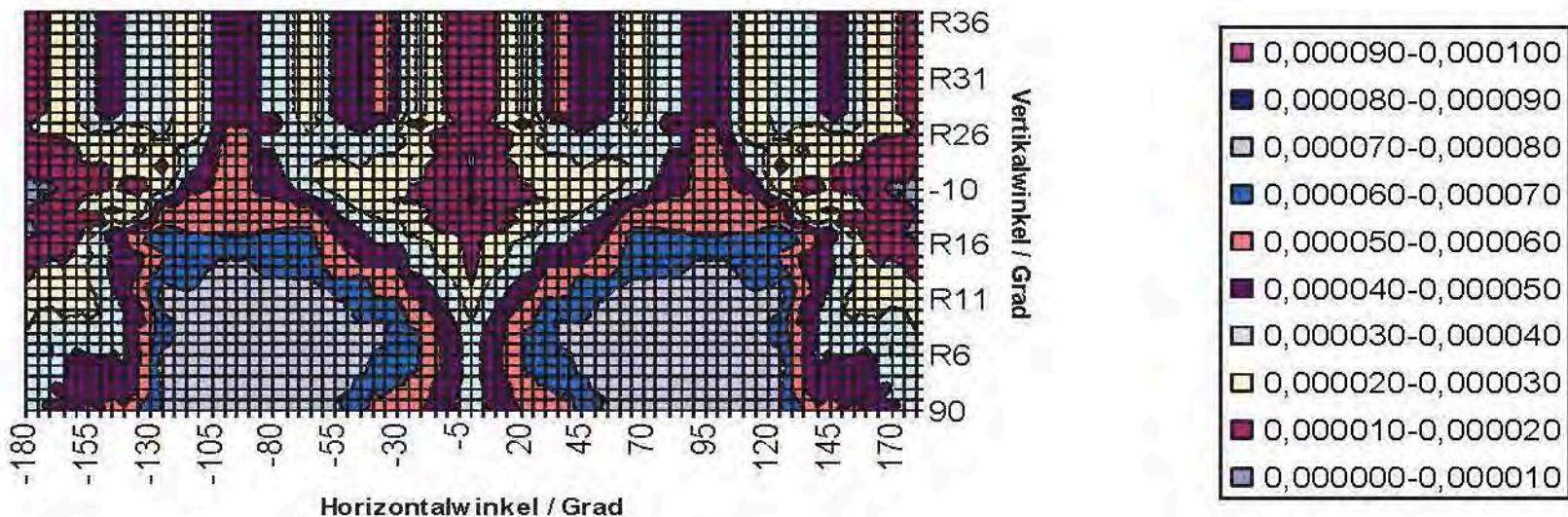
with permission from : Prof. Mojtaba Navvab (University of Michigan)



HRTF - Results - 8000 Hz



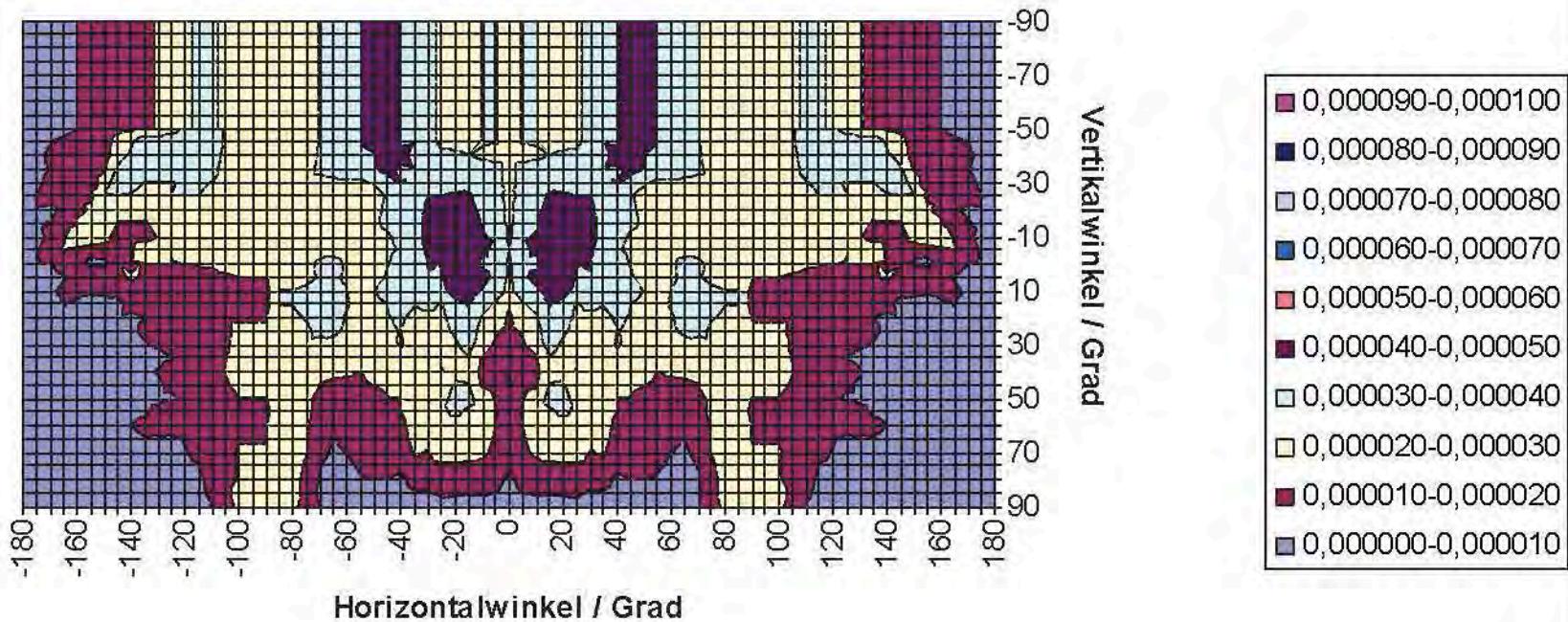
8000 Hz



with permission from : Prof. Mojtaba Navvab (University of Michigan)



16000 Hz



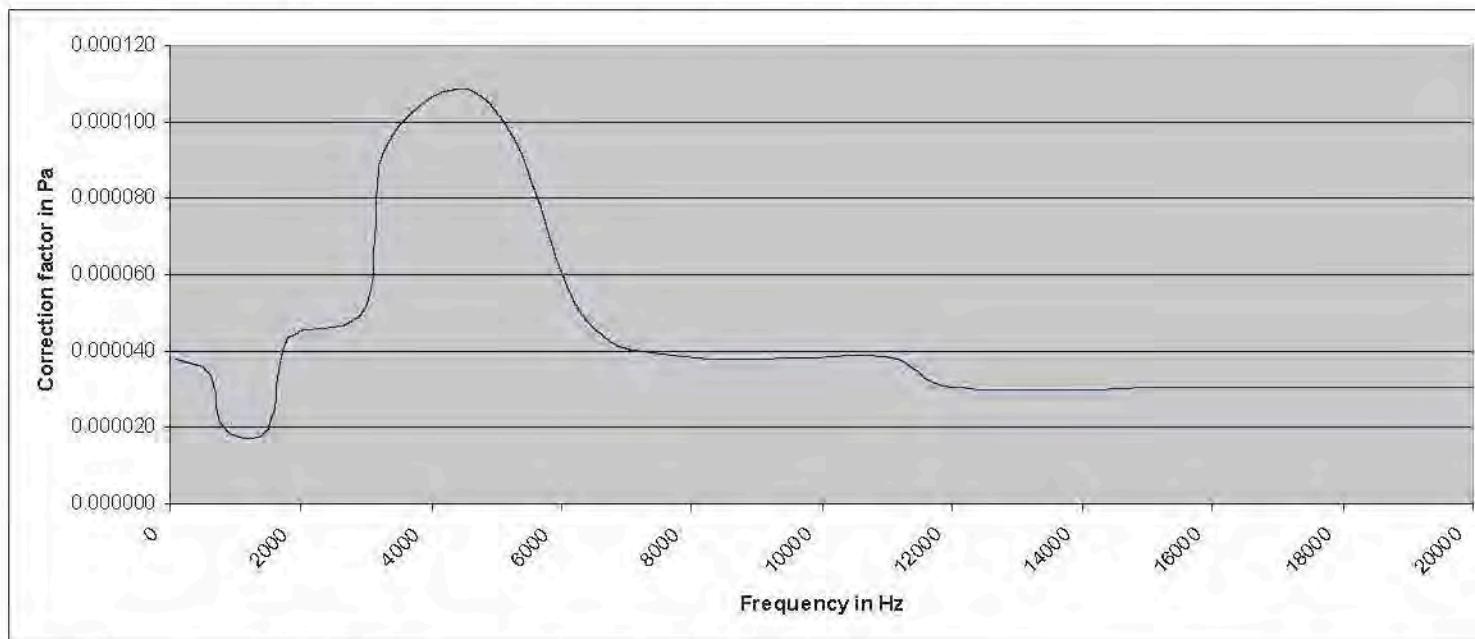
with permission from : Prof. Mojtaba Navvab (University of Michigan)



HRTF – Noiselmanage4 Implementation



- The empiric HRTF values for the frequencies from 500 Hz to 16000 Hz have been obtained by the University of Michigan, Prof. Mojtaba Navvab
- These values determine the transfer function HRTF, plotted in an Excel sheet and loaded in Noiselmanage4
- Therefore the implementation of any (one's) HRTF through an external Excel sheet is possible and is open for further investigation



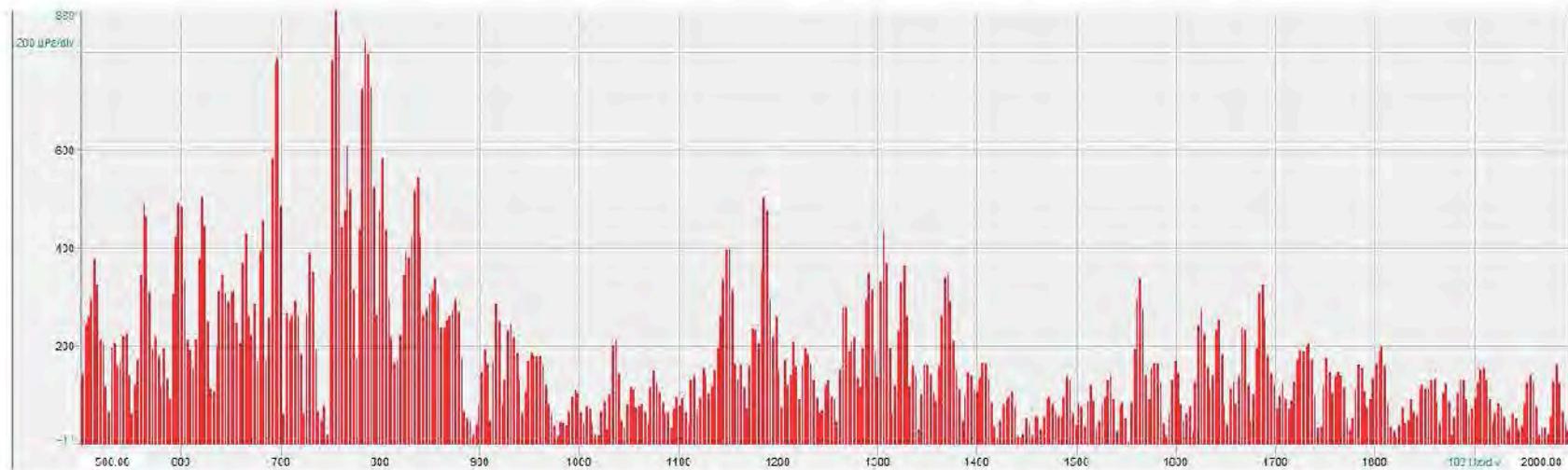
Transferfunction for a single point : $P(h,v,f) = (-35 \text{ degree}, 15 \text{ degree})$



HRTF – Noiselman4 Implementation



- Taking the spectrum of a given beamfomer result at point $P[x,y,z]$ over a chosen frequency intervall (f_1-f_2)
- Calculation of Sphere coordinates $P[h,v] = F(P[x,y,z])$
- Running the 3D HRTF filter over the point's spectrum
- Resulting in a change of the points value / colour in the acoustic map

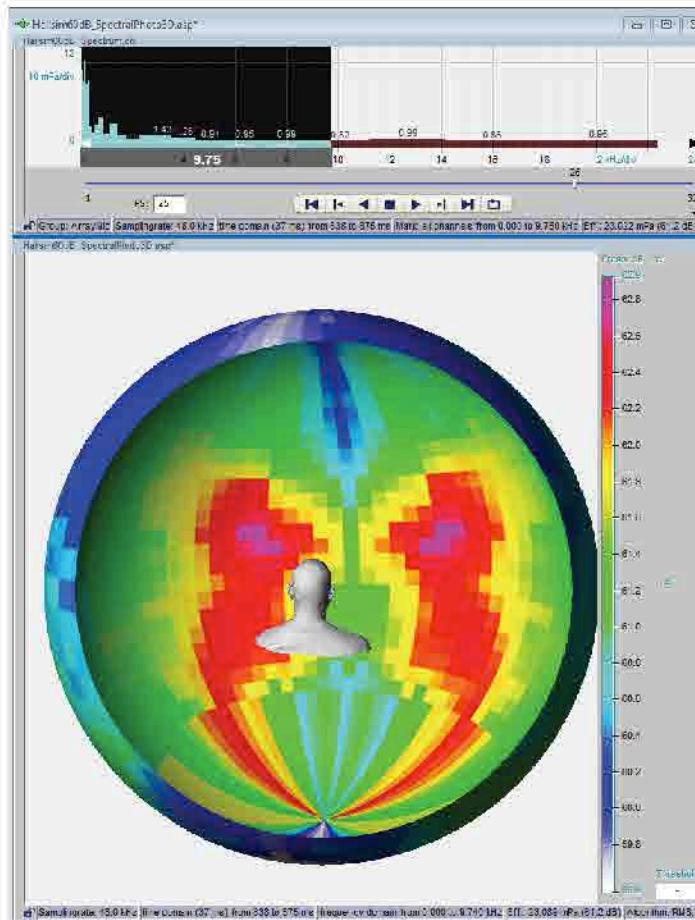


example: result at point (x=1.223m, y=3.327m, z=1.942m) at the frequency 500 -2000 Hz

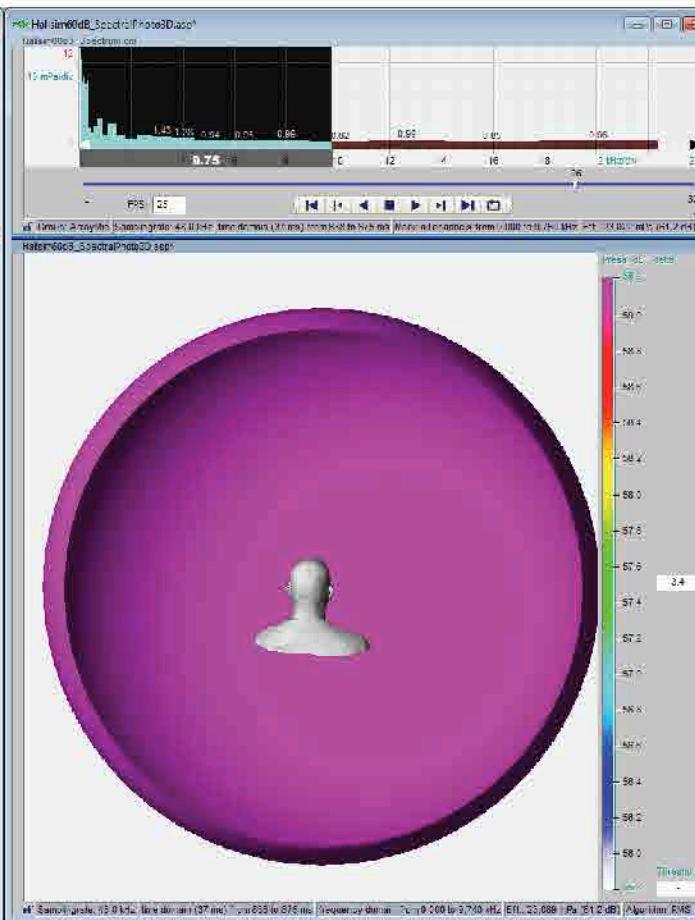


- Simulated echoic chamber with 50.000 equal white noise sources
- Calculated 20ms from 0-24000 Hz – shown 0-10kHz

With HRTF



Without HRTF

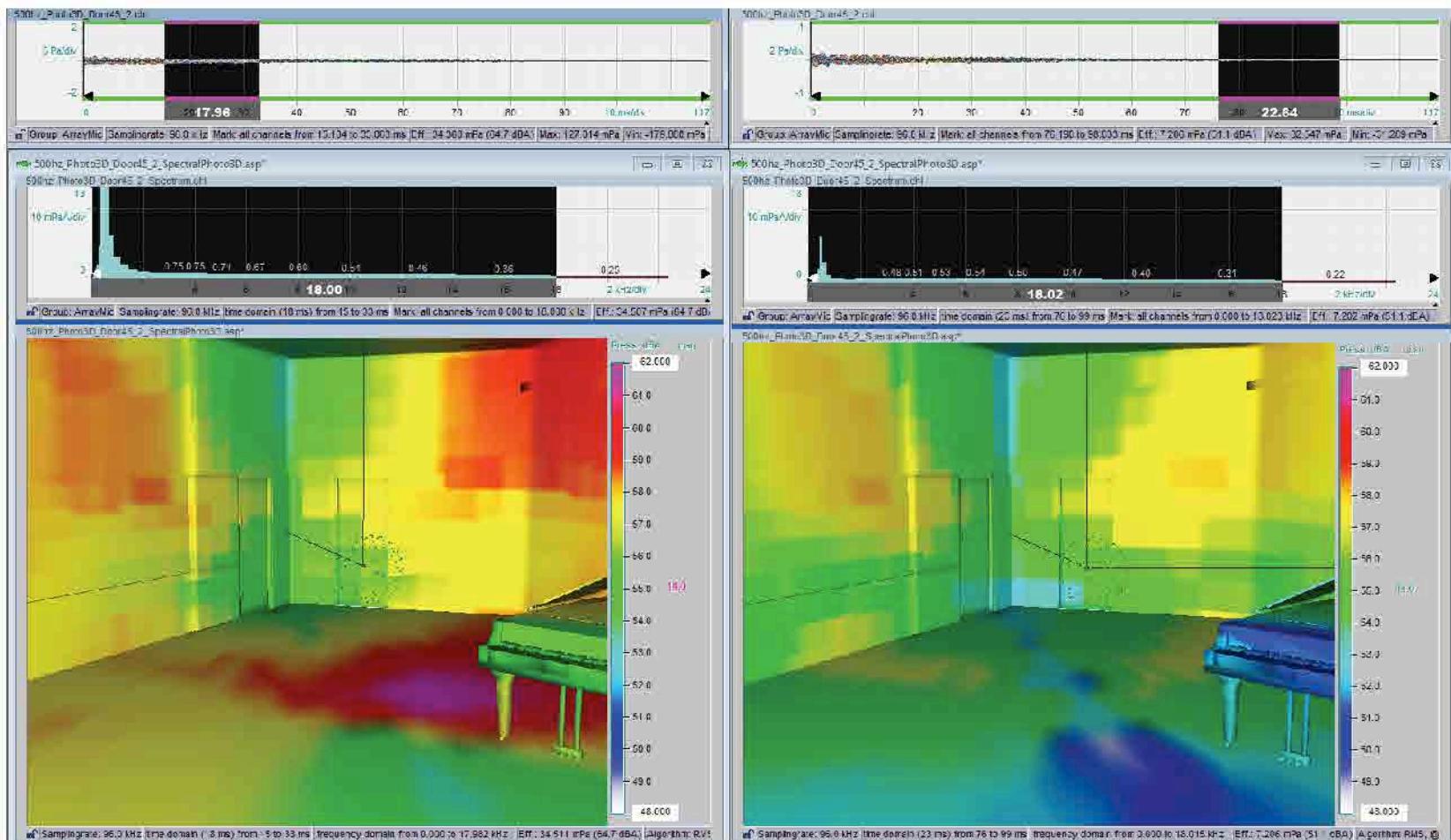




Acoustic Photo 3D with HRTF – Example

acoustic
camera

Direct comparision of direct (left) and reflective (right) component of source in a small practice music studio using the HRTF filtering





Scanner Module

Scanner module – connecting to a 3D scanner device and load a 3D mesh or point cloud directly into the Acoustic photo 3D module, Finalsurface extension to edit or create your own scans or 3D meshes

Leuze 3D Laser Scanner



- ROTOSCAN ROD4plus
- Measurement distance 0-50m
- Radial resolution 5mm
- Lateral resolution 0.36 degree
- Operation temperature 0-50° Celsius
- Weight aprox. 2kg
- Schunk PW70 robot arm

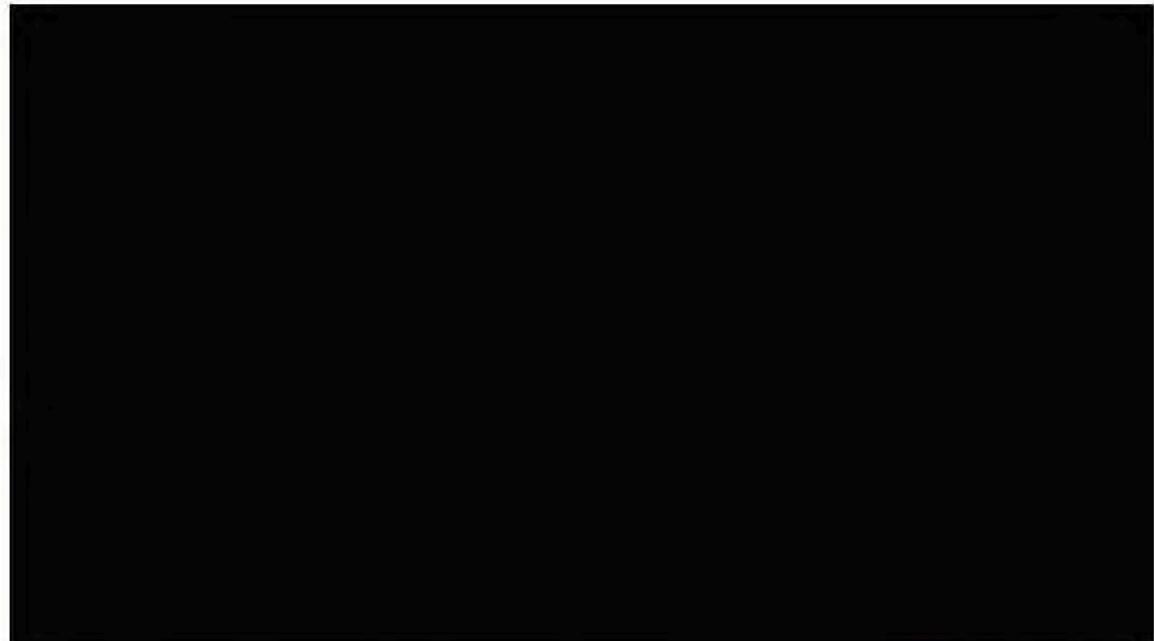




Leuze 3D Laser Scanner

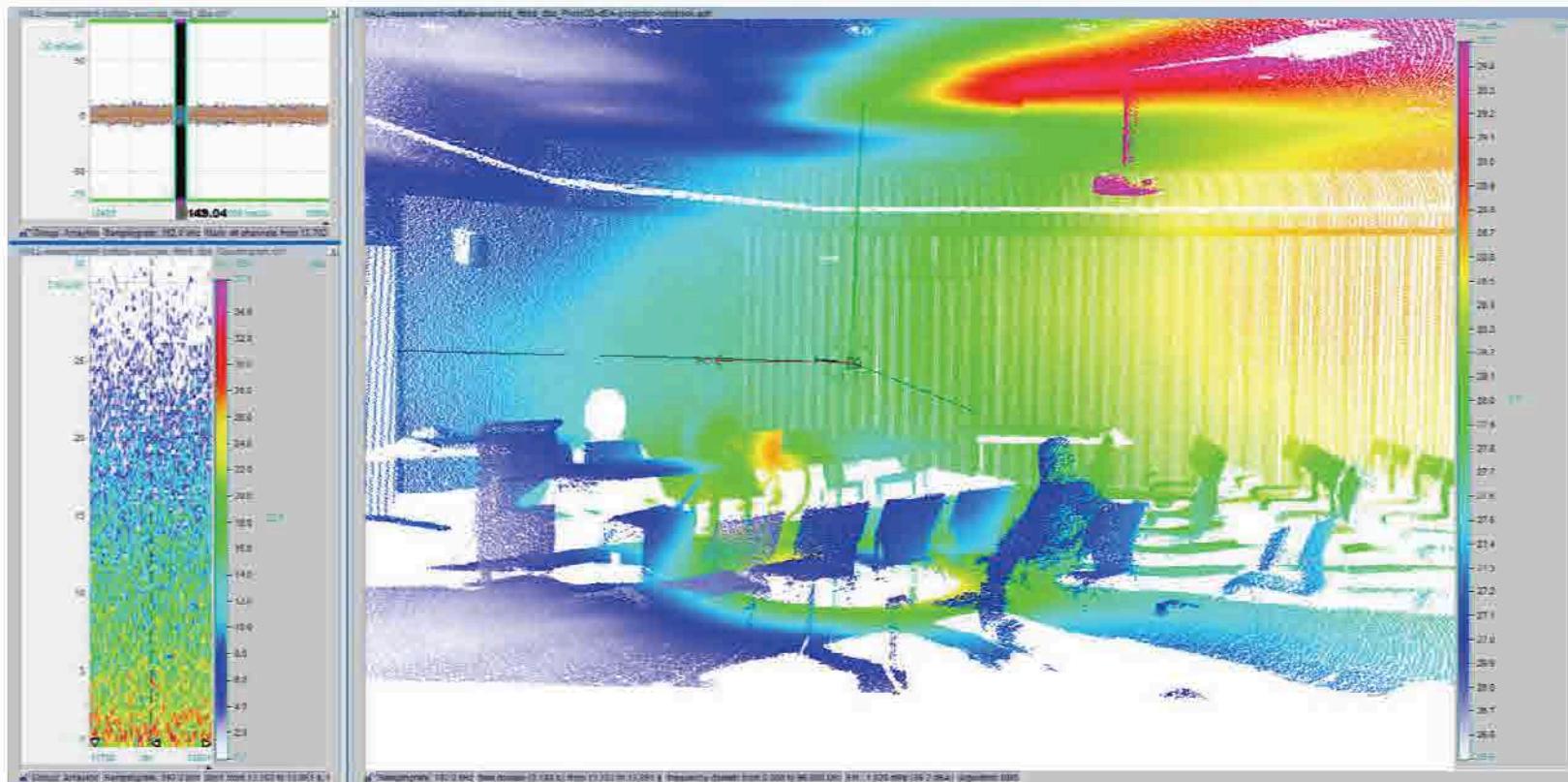


- ROTOSCAN ROD4plus
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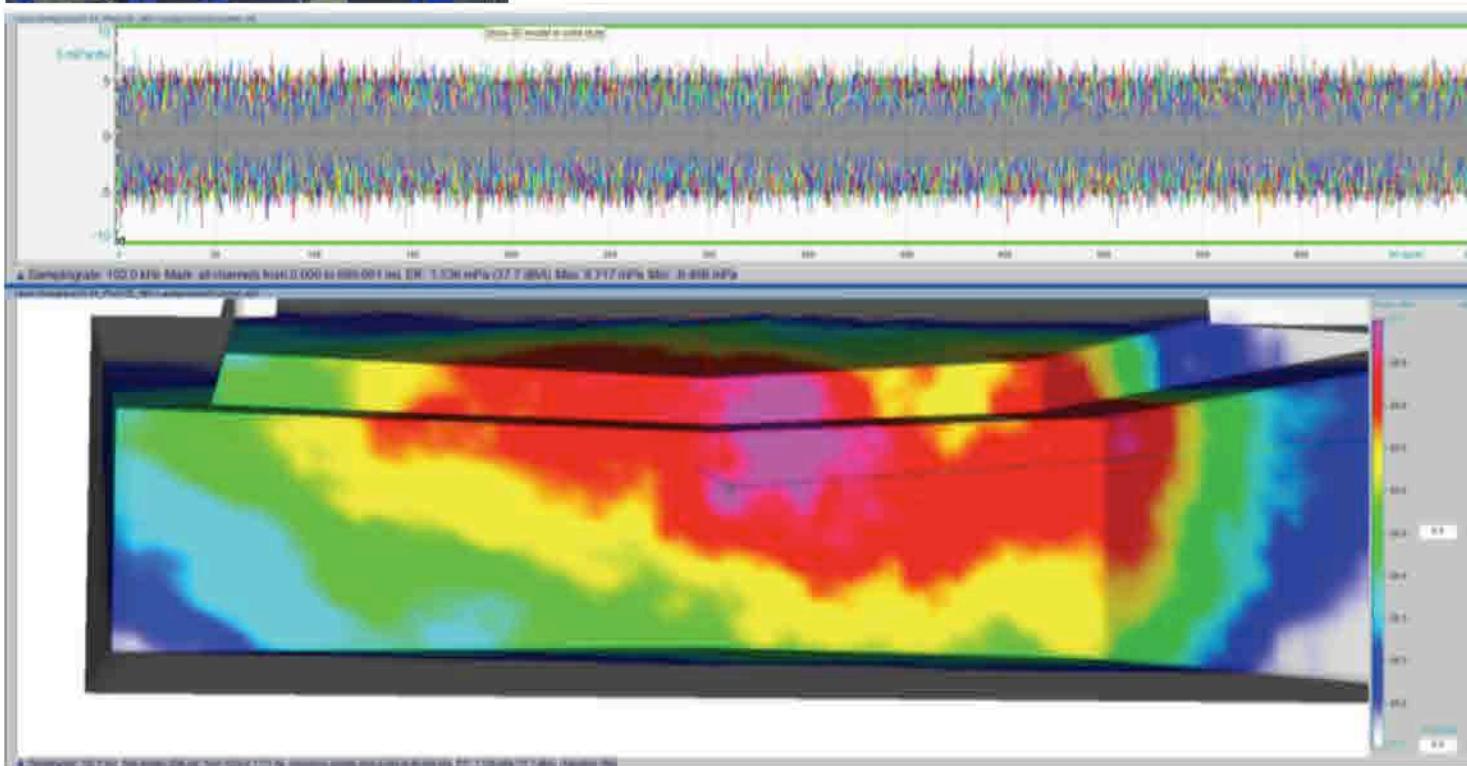


First two noise sources identified:
The projector and the notebook on the table
peak level at 29.5 dBA



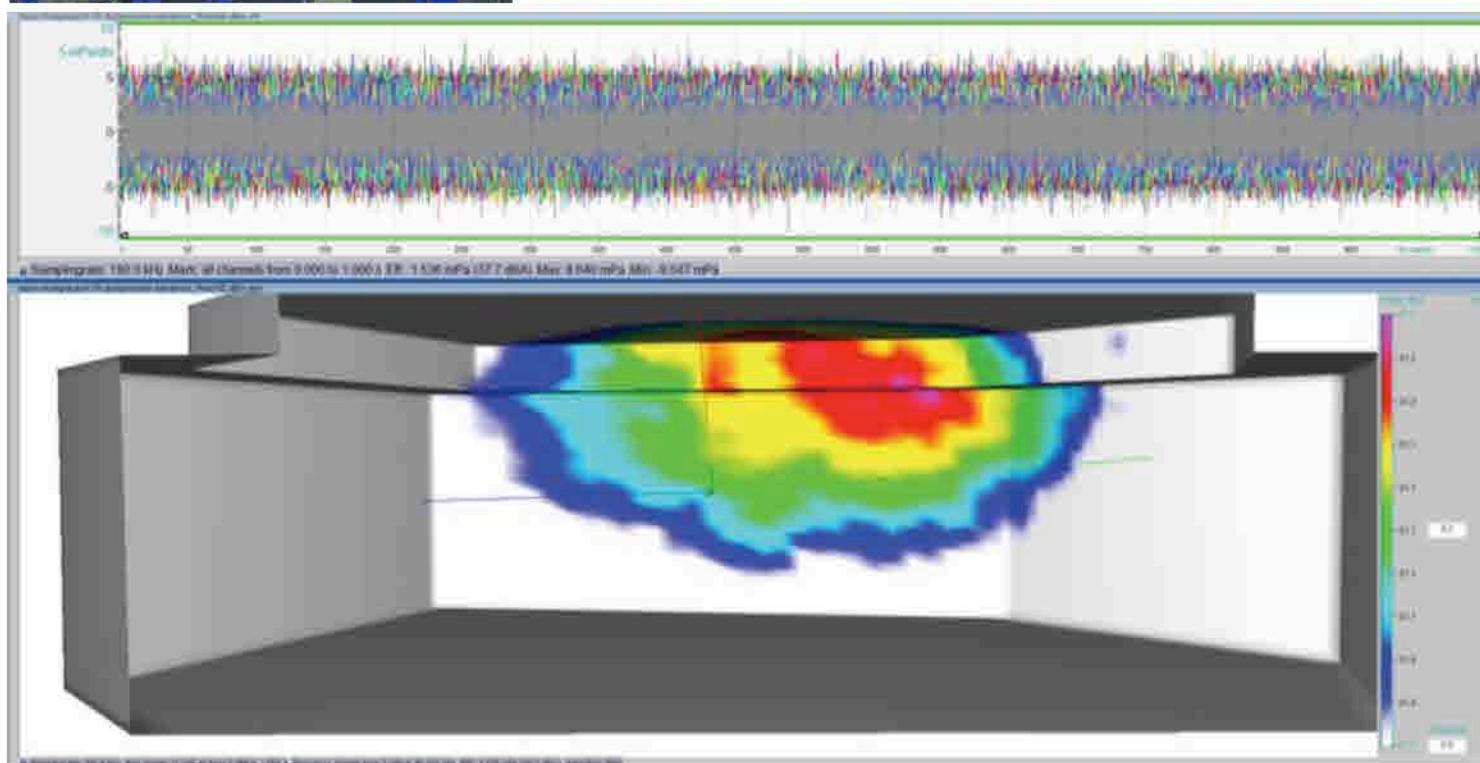


next noise sources identified:
The loud speaker on the wall – ground loop noise
peak level at 21 dBA





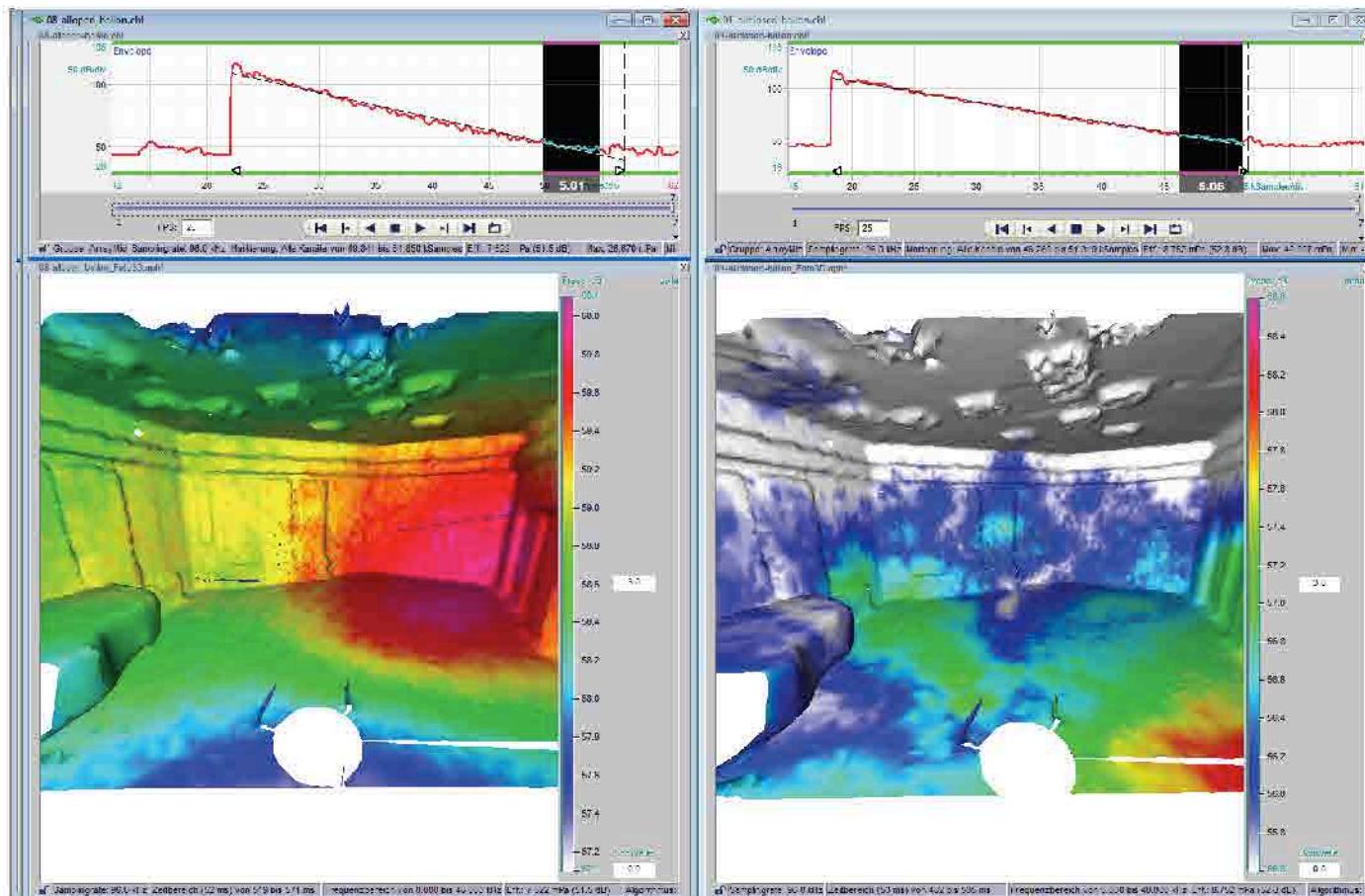
After cutting off the speakers
last noise sources identified:
the air conditioning duct – at full power mode
peak level at 20.9 dBA





Reverberation time T0-60 of a UofM Recording Studio (USA):

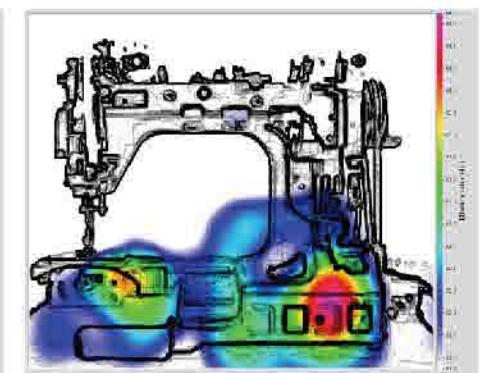
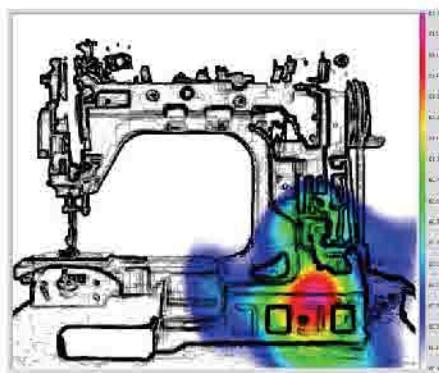
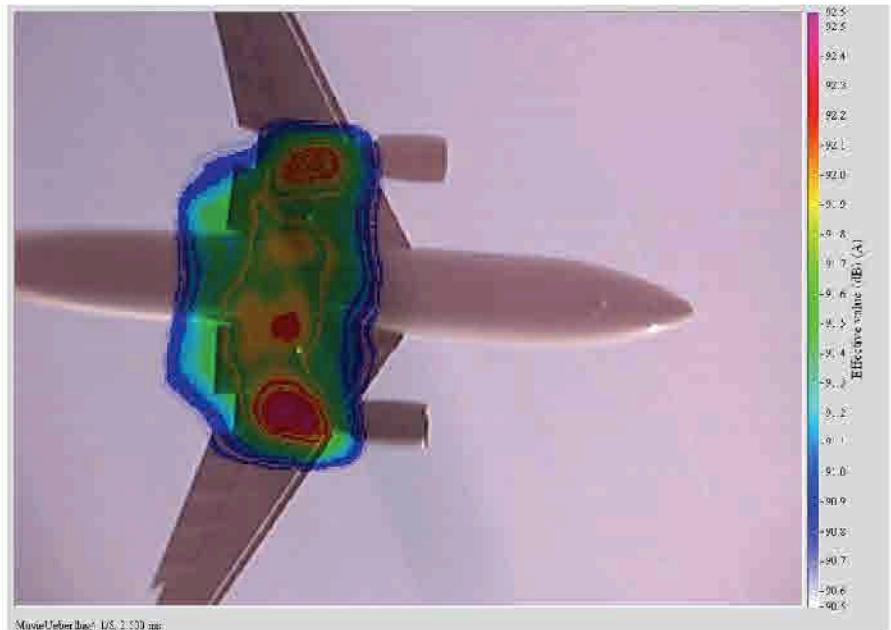
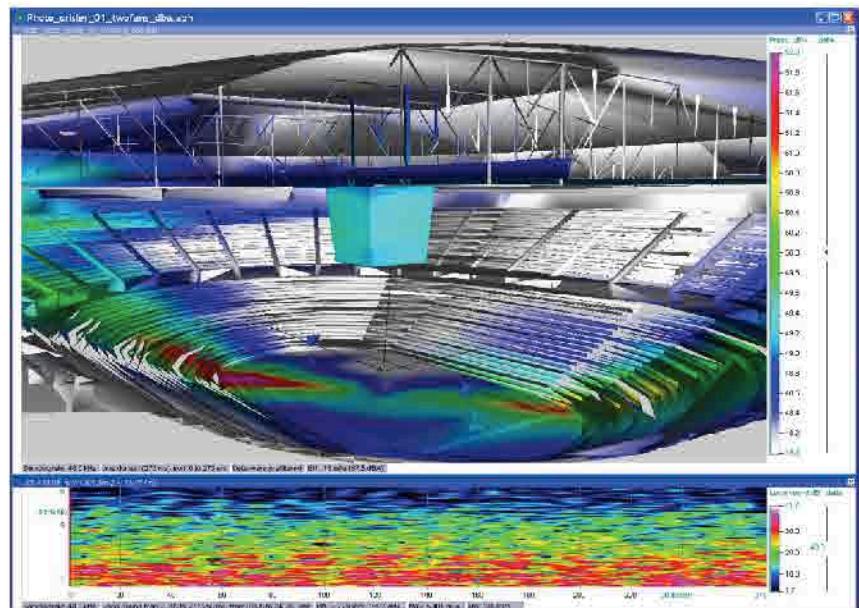
- A) with absorbing panels on left walls (left images) and
- B) with hard reflecting panels (right images)



Acoustic Camera - A New Solution

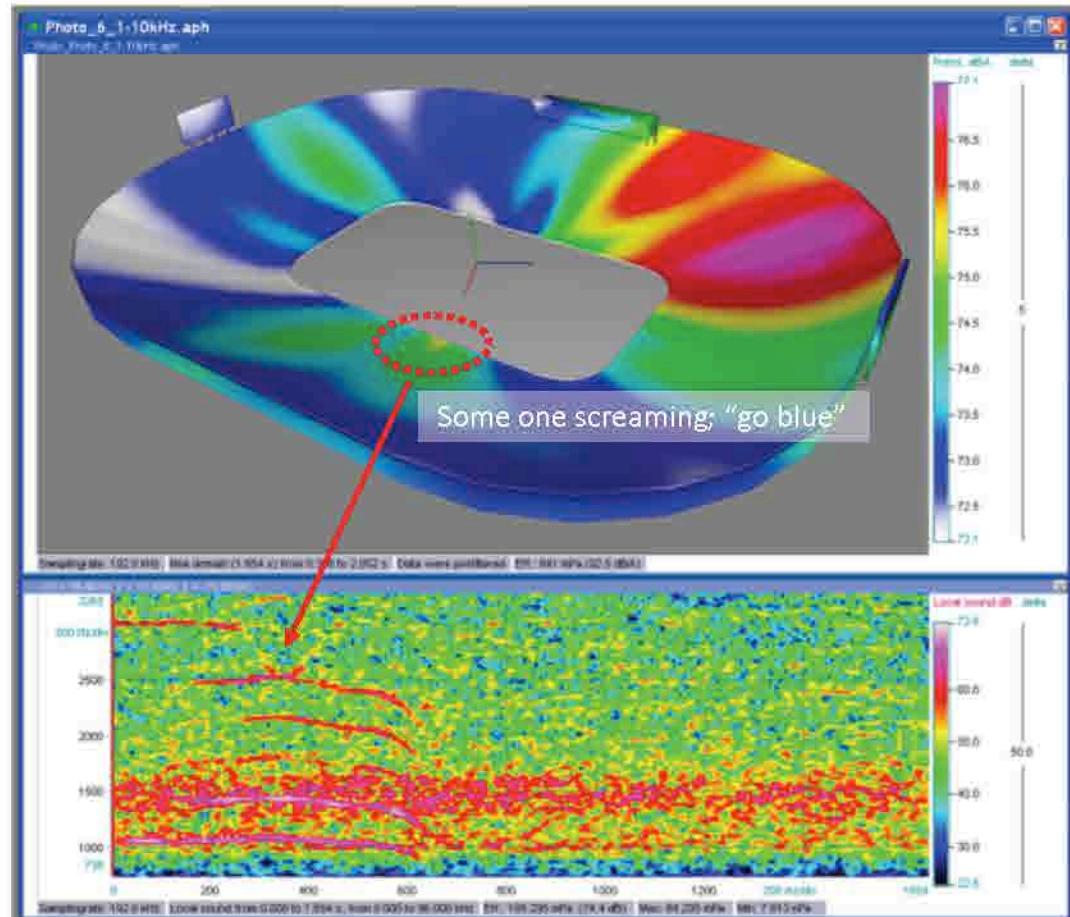
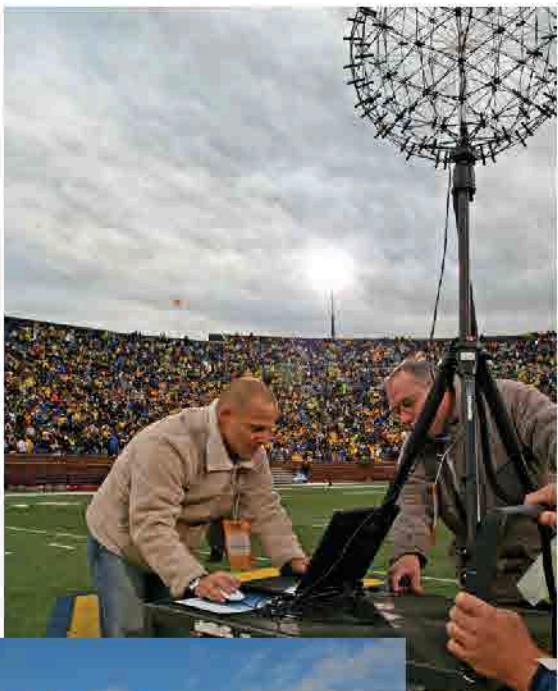
acoustic
camera

- Noise reduction
- Quality Management
- Sound Analysis / Sound Design



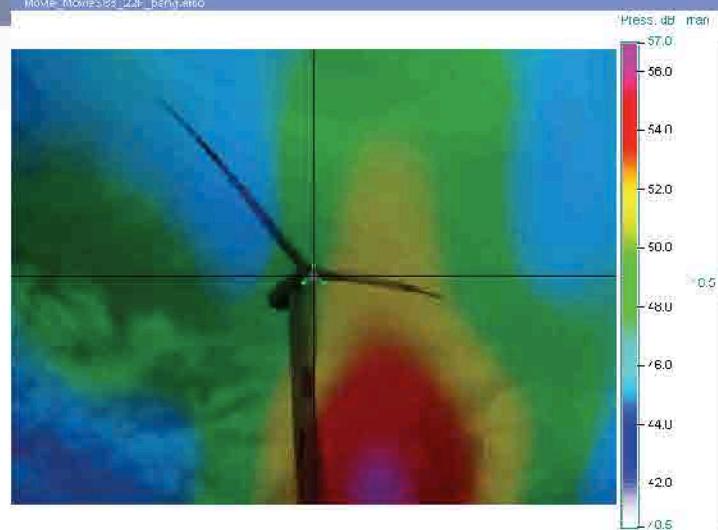
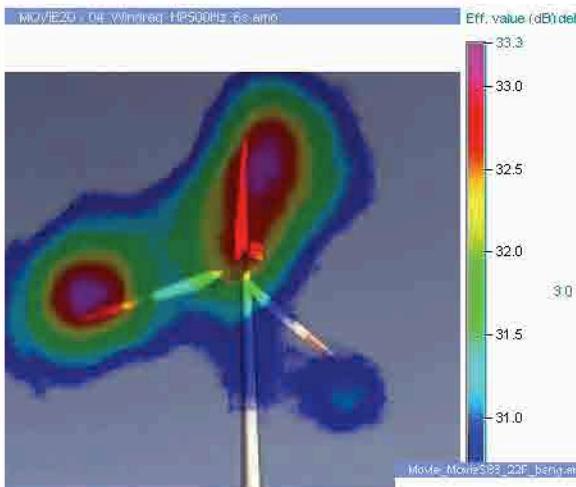
Typical Application

Measurements in Michigan Stadium



More than 100 000 people cheering during the Halftime break
of the game Michigan vs. Minnesota (28th Oct. 2007)
> Loudest is the clearly the student section

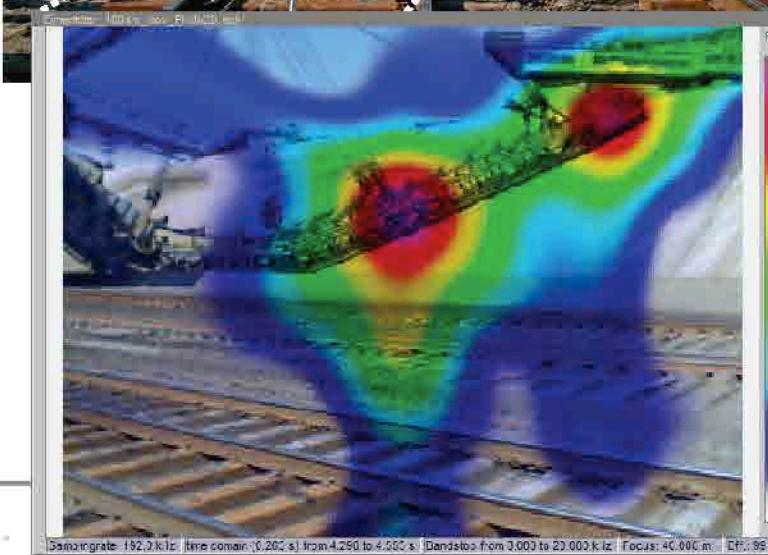
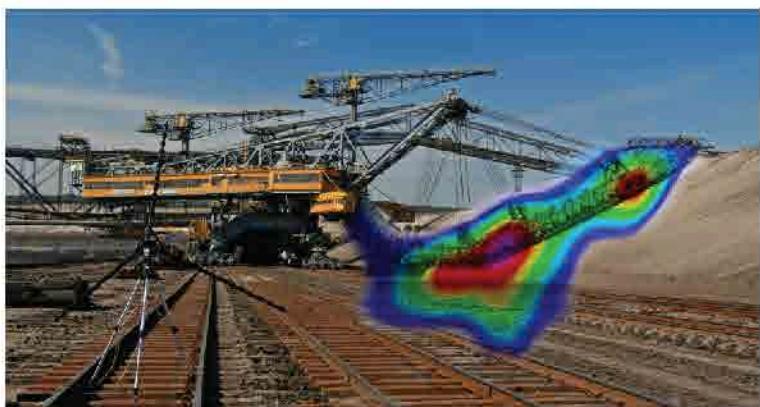
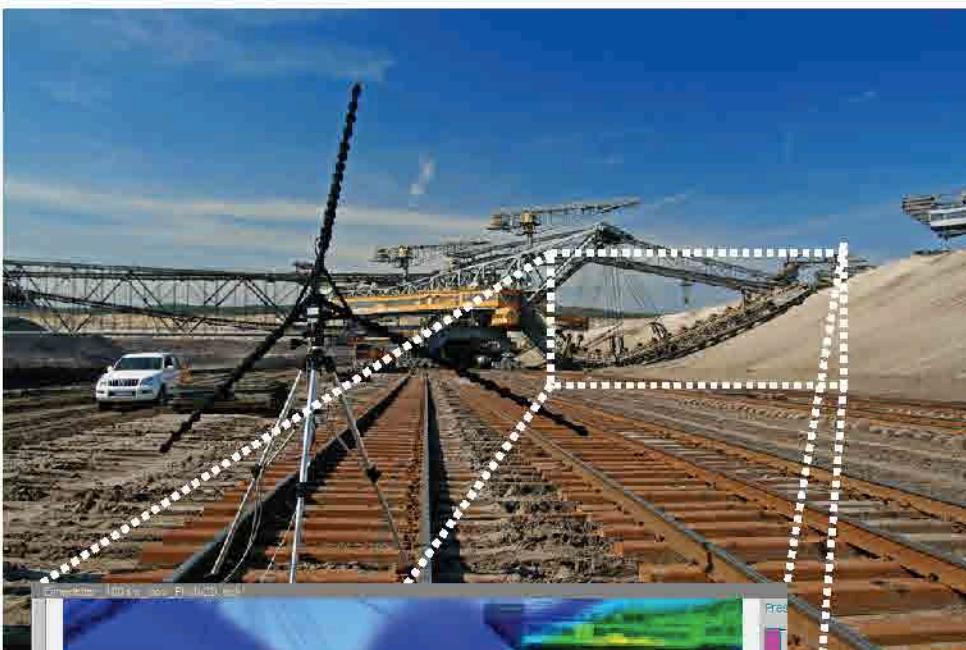
Typical Application



Measurements on wind turbines are possible in 2d and 3D

Typical Application

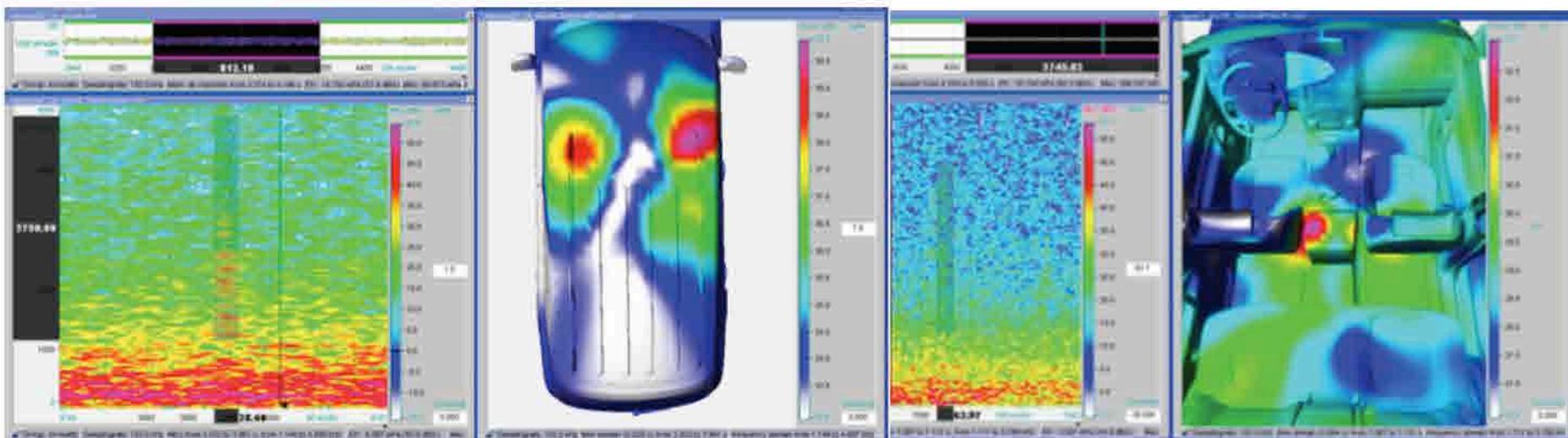
Mining bridge in action - Welzow / Germany



Typical Application

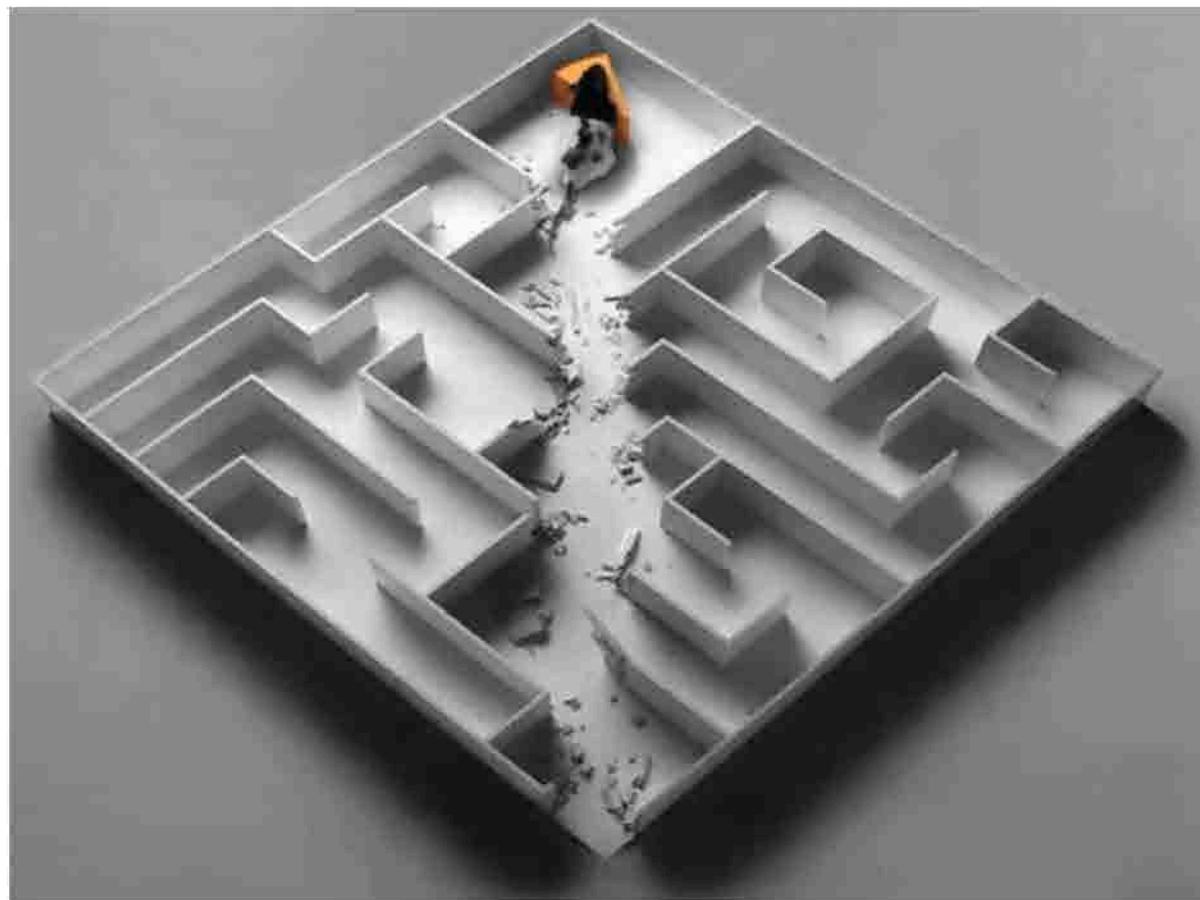
BSR – Buzz, Squeak and Rattle

Car refinement and QM on VW Tiguan



Sun roof - rattle

Under seat - Buzz



The Acoustic Camera:
With a Short cut
to Your answers.

Thank you for your attention.
Feel free to ask any question.

Gunnar Heilmann

GFAI

gfai
tech