PRODUCT DATA

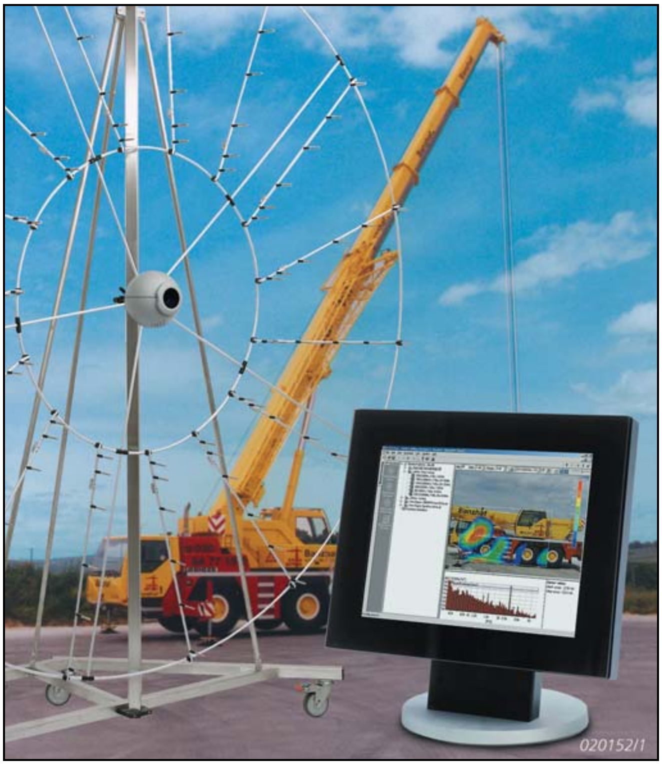
PULSE Array-based Noise Source Identification Solutions: Beamforming — Type 8608, Acoustic Holography — Type 8607, and Spherical Beamforming — Type 8606

Noise Source Identification (NSI) is an important method for optimising the noise emission from a wide range of products from vehicles, white goods, power tools and heavy machinery to components like engines, tyres, gear-boxes, exhausts, etc.

The goal of NSI is to identify the most important sub-sources on an object in terms of position, frequency content and sound power radiation. Ranking of sub-sources can be used to identify where design changes will most effectively improve the overall noise radiation.

Array-based methods provide both the fastest measurement process and the highest quality of the results. The combination of acoustical holography with phased array methods gives accurate, high-resolution maps in the full audible frequency range.

Time-domain methods can be used to study transients like impacts and run-ups or to get detailed understanding of stationary sources, for example, noise radiation versus crank angle on engines. For large, stationary sources, an automated microphone positioning system (robot) can be used to measure automatically.



Hardware and Software

Software

- Spherical Beamforming Type 8606, providing a full 360 degree sound field map without making any assumptions about the sound field
- Acoustic Holography Type 8607, a method for mathematically describing the sound field based on a set of measurements
- Beamforming Type 8608, a method of mapping noise sources by differentiating sound levels based the direction from which they originate
- All applications can post-process data

Arrays

- Grid arrays for scanned Spatial Transformation of Sound Fields (STSF)
- Patented arm wheel arrays, numerically optimised for acoustical performance in relation with beamforming
- Slice wheel arrays, numerically optimised for acoustical performance in relation with beamforming and STSF
- Hand-held array for real-time holography mapping, patch holography and conformal mapping
- Spherical array for beamforming even in confined environments

Brüel & Kjær

Brüel & Kjær's Selection of Arrays and Robots

Table 1 *Overview of Brüel & Kjær's selection of arrays and robots*

Spherical Array	Wheel Array (incl. camera)	Half-wheel Array	Grid Array
			
Applications: Vehicle and aircraft interior, building and industrial plants	**Applications:** General purpose (90-channel array typically used in automotive component applications)	**Applications:** Full vehicles including wind tunnel and pass-by testing	**Applications:** General purpose, stationary noise sources
NSI Method: Spherical Beamforming	**NSI Method:** Beamforming	**NSI Method:** Beamforming	**NSI Method:** STSF and NS-STSF
No. of Channels: 36 or 50	**No. of Channels:** 42 and over	**No. of Channels:** 42 and over	**No. of Channels:** 6 and over
Size: 0.20 cm diameter	**Size:** 0.65 m to 4.0 m diameter	**Size:** 1.5 m to 4.0 m diameter	**Size:** 0.125 m × 0.125 m and over (various spacing available)
Maximum Frequency: 8 kHz	**Maximum Frequency:** 20 kHz	**Maximum Frequency:** 10 kHz	**Maximum Frequency:** 6 kHz
Accessories: Tripod WQ-2691	**Accessories:** Tripod WQ-2691	**Accessories:** Carriage WA-0893	**Accessories:** Support Stand WA-0810 or Array Positioning System
Slice Wheel Array	**Hand-held Array (single or double-sided)**	**2D Robot**	
			
Applications: General purpose, engines, automotive components/ interior, etc.	**Applications:** Components, interiors, etc.	**Applications:** Large, stationary noise sources, engines, vehicles	
NSI Method: Beamforming and NS-STSF/SONAH	**NSI Method:** Real-time holography, patch mapping and Conformal SONAH	**NSI Method:** STSF	
No. of Channels: 36, 60 or 84	**No. of Channels:** min. 6 × 6 × 1, max. 8 × 8 × 2	**No. of Channels:** 6 to 96	
Size: 0.55 m to 2.0 m diameter	**Spacing:** 25, 30, 35, 40 and 50 mm (size dependent on channel count and spacing)	**Size:** 1 m × 1 m up to 10 m × 3 m	
Maximum Frequency: – Beamforming 36-ch.: 6.0 kHz; 60-ch.: 8.0 kHz – NS-STSF/SONAH 36-ch.: 1.5 kHz; 60-ch.: 1.2 kHz	**Maximum Frequency:** 6 kHz	**Maximum Frequency:** 5 kHz	
Accessories: Tripod WQ-2691	**Accessories:** 3D Creator Optical Sensor Positioning System 9712-W-D18	**Accessories:** Integral Connection Array WA-0806, Flexible Connection Array WA-0807 and Robot Controller WB-1477	

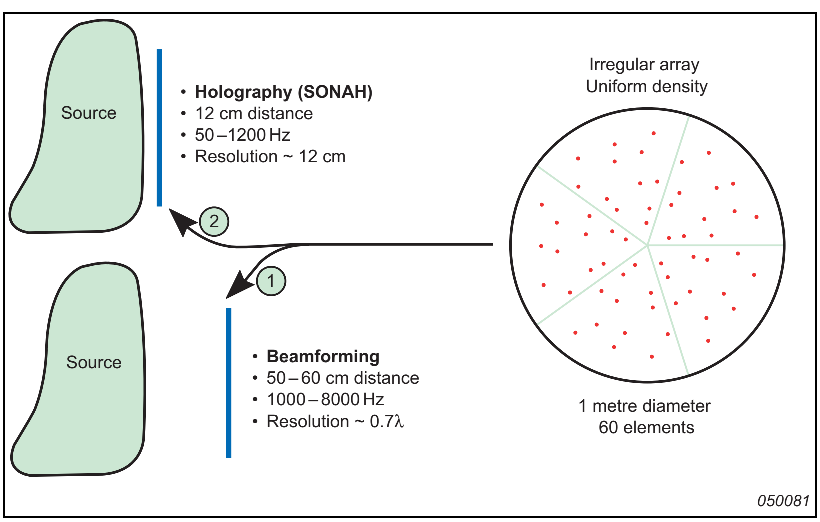
To improve overall noise levels, it is necessary to locate, quantify and rank the individual noise sources coming from a machine. This starts by identifying ‘hotspots’ – areas where the local sound radiation is significantly greater than that of the surrounding area. Knowing these hotspots, the dominating frequencies and relative sound power contributions enable the cause of the noise to be identified and its contribution to the overall noise level to be assessed.

Traditionally, this has been done by mapping the sound intensity directly at a number of points across the source measured with an intensity probe. With array-based techniques, this process can be significantly improved as many points are acquired simultaneously, making measurements much faster. Using modern calculation methods like Beamforming, Near-field Acoustic Holography (NAH) and Statistically Optimal Near-field Acoustic Holography (SONAH), maps can not only be rendered for the positions measured, but also in planes close to the source or even at the source surface itself. This not only makes the result much easier to understand, even for non-acousticians, but it also makes the sources better resolved and quantified.

Methods Engineered by Brüel & Kjær

- **SONAH:** Like traditional NAH methods, the SONAH calculation method introduced by Brüel & Kjær supports spatial FFT calculations and mapping at low frequencies. However, with SONAH, irregular arrays and arrays smaller than the source can be used to measure without severe spatial windowing effects. The algorithm is the basis of both the hand-held array and the Conformal Mapping solutions
- **Combined SONAH and Beamforming:** Often it is ideal to use NAH at low frequencies and Beamforming at high frequencies to obtain wideband results. While traditional NAH requires a regular grid array that completely covers the sound source, Beamforming provides optimal high-frequency performance with an irregular array that can be smaller than the sound source. However, repeated swapping between two different arrays is not practical. Fortunately, the SONAH technique for NAH calculations can operate with irregular arrays and it also allows for measurement with arrays smaller than the source, without severe spatial windowing effects

__Fig. 1__
Principle of the combined SONAH and Beamforming technique based on two measurements with the same array



Using two recordings taken with the same array at two distances (a near-field SONAH-based measurement and a Beamforming-based measurement at an intermediate distance), a high-resolution source map can be obtained over a very wide frequency range. Even though the measurement distance for Beamforming is only a bit larger than half the array diameter, with the irregular Slice Wheel Array shown in Fig. 1, Beamforming processing works well down to that distance.

NAH builds a mathematical model describing the sound field based on a set of sound pressure measurements typically taken in a plane fairly close to the source. From this description the parameters of the sound field sound pressure, sound intensity, particle velocity, etc., can be derived in target planes parallel to the measurement plane.

The model can also be used to calculate far-field responses, estimating the sound pressure distribution along a line in the far-field based on the Helmholtz Integral Equation (HIE). Further potential noise reduction scenarios can be applied to evaluate the impact of various source reduction possibilities.

The SONAH calculation method overcomes the limitations that traditional NAH calculation methods like STSF and NS-STSF have, namely:

- The measurement area must cover the full noise source plus some additional area to avoid spatial window effects
- The measurement grid must be regular rectangular to support spatial FFT calculations

SONAH can operate with irregular arrays and allows for measurements with arrays smaller than the source, without severe spatial windowing effects.

Measurement and Analysis

Stationary STSF measurements are typically made using a limited size grid array that is scanned over the source using a robot positioning system. To maintain an absolute phase reference between scan positions, a set of reference signals is simultaneously acquired.

Transient measurements are typically performed using large fixed arrays as all measurement positions must be acquired simultaneously.

Contribution Analysis

Contribution analysis is performed using sound power ranking of user-defined map subareas.

Performance

- **Resolution:** The resolution, defined as the shortest distance where two point sources can be separated, is approximately equal to:
  $R = min(L, \lambda/2)$
  where: L is the distance from array to source and λ is the wavelength
- **Frequency Range:** The frequency range is determined by:
  $f_{max} = c/2dx$ and $f_{min} = c/8D$
  where: c is the speed of sound, dx is the average spacing between measurement points and D is the diameter of the array

The use of STSF is, therefore, limited to high frequencies by the spacing between measurement points. Typically STSF can be used from 50 Hz to 3000 Hz

Features and Benefits

- Easy, high resolution mapping at low and mid frequencies
- Very low f_{min} using SONAH (applicable at low frequencies)
- Fully automated data acquisition including robot control using PULSE Acoustic Test Consultant Type 7761

Typical Applications

- Engines and powertrains
- Components
- Door seal leakage
- Office machinery
- White goods
- Heavy machinery

Application Examples

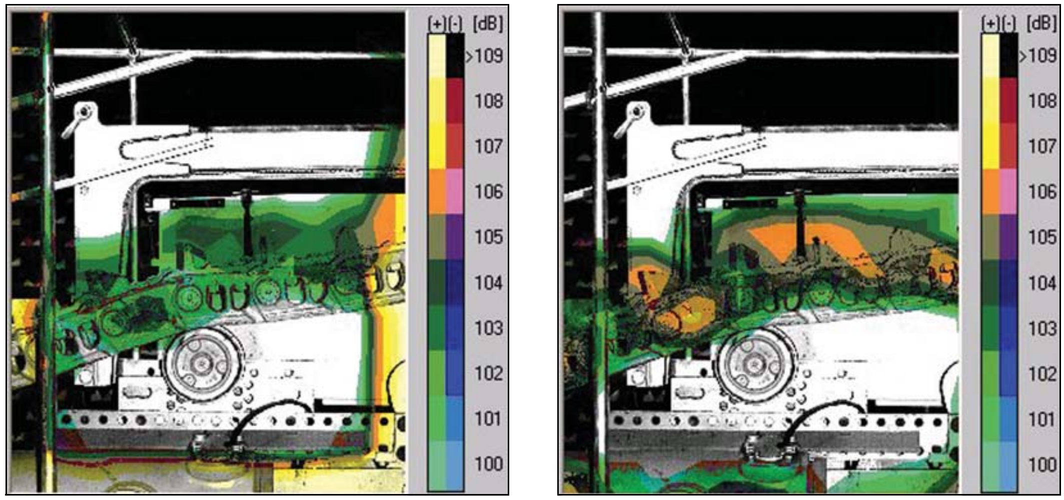


Fig. 2
Averaged particle velocity maps for the 1/12-octave bands 205–1454 Hz, A-weighted.
Left: *NAH,* ***Right:*** *SONAH*

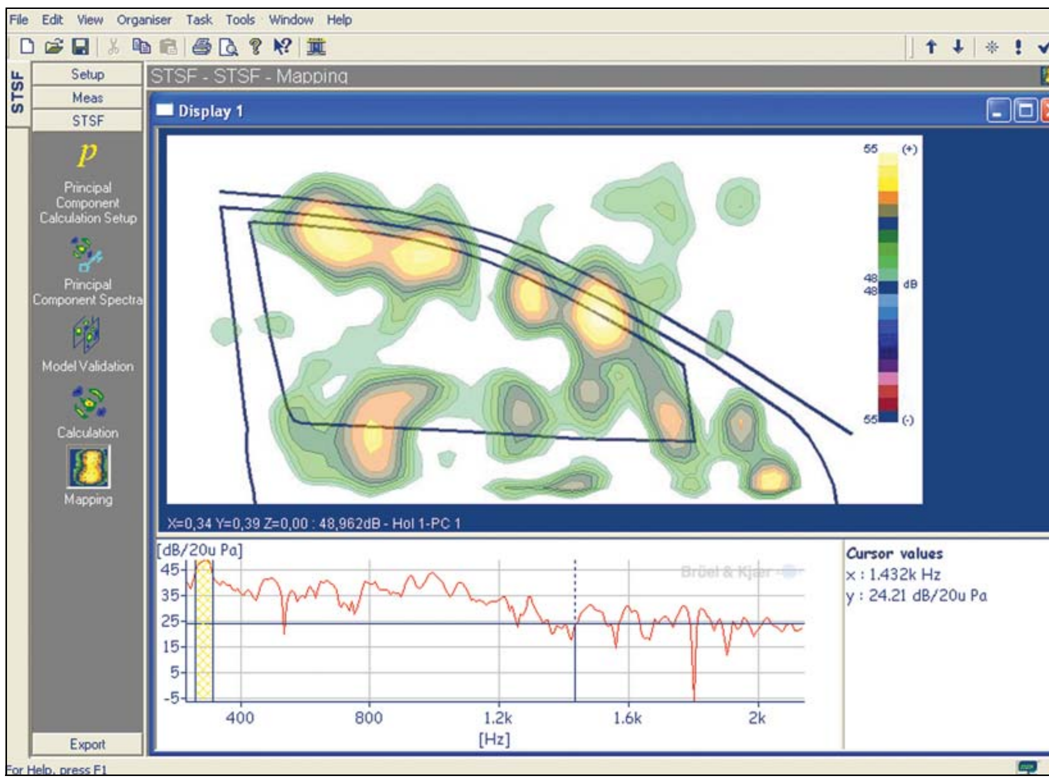


Fig. 3
STSF map of a door seal leakage. STSF/SONAH provides high-resolution mapping by calculating results in a plane close to the source surface

Beamforming is a method of mapping noise sources by differentiating sound levels based upon the direction from which they originate. The method is very quick, allowing a full map to be calculated from a single-shot measurement. It also works at high frequencies. Innovative Brüel & Kjær wheel arrays can be used with PULSE Beamforming to produce acoustically optimal results while maintaining maximum ease of use and handling.

Compared to other source location methods, the beamforming method is quick since all channels are measured simultaneously. This optimises the use of expensive measuring facilities such as anechoic chambers and wind tunnels, and takes away the tediousness and repetitiveness of many traditional methods.

Measurement and Analysis

The sound field radiating from the test object is measured at a number of microphone positions at some distance from the object. The microphones are arranged in a planar array facing towards the centre of the object.

By introducing a specific delay on each microphone signal and adding the result, it is possible to computationally create an acoustical antenna equivalent to a parabolic reflector with a main lobe of high sensitivity along a certain angle of incidence. By repeating the calculation process on the same set of measured data for a large number of angles, a full map of the relative sound-pressure contribution at the observation point can be generated. With Beamforming, results can be calculated to within an angle of up to 30° away from the centre axis so that even small arrays can map large objects. It is, for example, possible to map a full vehicle from just one measurement position.

Contribution Analysis

Contribution analysis can be performed using sound power ranking of user-defined subsections of the object model.

Array Design

The dynamic range (also known as the Maximum Side Lobe (MSL) level) of the maps will typically be between 8 and 15 dB depending on the design of the array. In general, irregular arrays outperform traditional regular array designs, but even irregular arrays with the same number of microphones may have very different performance depending on the exact position of the microphones. Brüel & Kjær uses a patented numerical optimisation method to design arrays with optimal performance for the frequency range and number of microphones.

The special slice wheel array design is optimised to perform with both beamforming and SONAH and can, therefore, be used with a combination of the methods to provide mapping of the full audible frequency range.

Performance

- **Resolution:** The resolution, defined as the shortest distance where two point sources can be separated, is approximately equal to:
  $R = L/D*\lambda$
  where: L is the distance from array to source, D is the size of the array, and λ is the wavelength

The use of Beamforming is, therefore, limited to low frequencies by resolution. Typically Beamforming can be used from 500 Hz to 20 kHz.

Features and Benefits

- Quick snapshot measurements
- Ideal for mid- and high-frequencies
- Covers large objects
- May, in combination with SONAH, cover the full audible frequency range

Typical Applications

- Full vehicles
- Machinery
- Construction equipment
- Wind tunnels
- Engines and powertrains
- Components
- Seals
- Vehicle interiors

Application Example

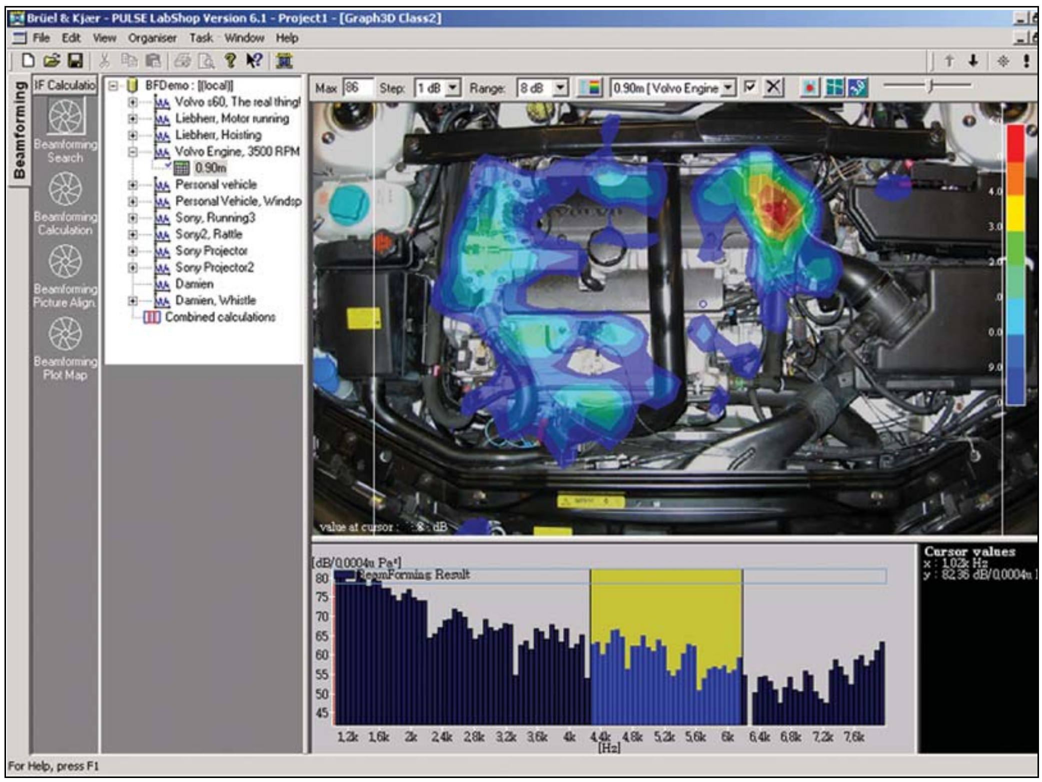


Fig. 4
Beamforming result on a car engine

Conformal Mapping using SONAH Method

Based on the unique capabilities of the SONAH algorithm, a completely conformal map is created based on a set of patch measurements at known positions and object geometry. The object geometry can either be imported from a number of standard formats or detected using the position detection system integrated in the Hand-held Array WA-1536.

Object Geometry

Replacing the microphone array with a pointer, the positioning system in the hand-held array's handle registers the 3D coordinates of the most significant points of the geometry. Meshing tools can, thereafter, be used to refine the object geometry to a suitable granularity depending on the resolution required. Alternatively, the object geometry can be imported from existing CAD or CAE models, in which case a reduction of the model is usually required in order to minimise the number of elements, and thereby the number of measurement points.

Measurement and Analysis

Measurements with the hand-held array are made at the most accessible places around the object, with 30 to 100 points typically measured simultaneously. Based on the integrated positioning system, the software keeps track of the actual positions measured. Typically the number of measurement points should correspond to the maximum frequency, as per STSF.

Contribution Analysis

Contribution analysis can be performed using sound power ranking of user-defined subsections of the object model.

Benefits

- Accurate mapping of non-planar objects
- High mapping resolution – even at low frequencies
- Measurements can be taken at the most accessible places
- No complicated array support structure needed
- No previous modelling required

Typical Applications

- Engines
- Components
- Subassemblies
- Seals
- Vehicle interiors

Application Example

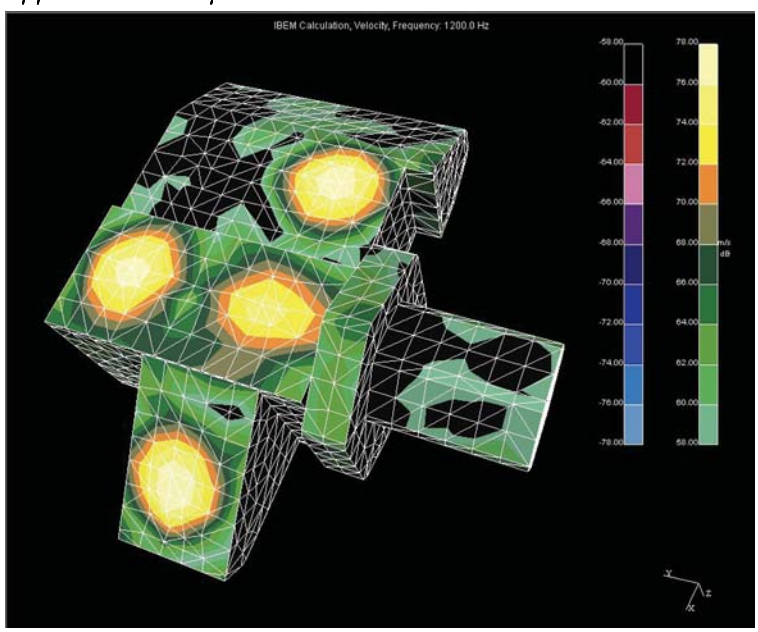


Fig. 5
Conformal map of a car engine at 828 Hz

Spherical Beamforming

Spherical Beamforming uses a spherical harmonics based algorithm called SHARP that provides a complete omnidirectional noise map in any acoustic environment based on one simple measurement. Unlike other methods that only map part of the surroundings, Spherical Beamforming uses a spherical array to map noise in all directions while 12 cameras mounted in the sphere automatically take pictures in all directions simultaneously. At display time, these images are used as background for the acoustic map.

In addition, Spherical Beamforming, does not make any assumptions about the nature of the acoustic environment and can, therefore, be used in both free-field and reverberant surroundings. For these reasons, Spherical Beamforming is commonly used to make overview maps in confined and semi-damped spaces like vehicle and aircraft cabins.

Measurement and Calculation

The measurement is performed using an array of microphones mounted on the surface of a hard sphere. The microphone positions on the sphere are numerically optimised to maximise the dynamic depth of the map. The sphere is usually placed at a typical impact position, for example, in the driver’s seat of a vehicle.

The calculation decomposes the observed sound field into its spherical harmonic components and then estimates the directional contributions by recombining these spherical harmonics.

Performance

The resolution (in radians) of Spherical Beamforming is approximated by: $\Theta \approx \frac{c}{(2 \cdot f \cdot a)}$

where c is the speed of sound, f is the frequency and a is the radius of the spherical array. This gives 48 degrees at 1 kHz (resolution at –3 dB). The error-free dynamic depth (Maximum Side Lobe (MSL) level) decreases with frequency, but for the 50-channel array, it is better than 6 dB up to 8 kHz, and for the 36-channel array, better than 6 dB up to 5 kHz. The bands of use of Spherical Beamforming are set, therefore, towards low frequencies by resolution and towards high frequencies by dynamic depth, with a range from 250 Hz to 8000 kHz.

In combination with Conformal SONAH, Spherical Beamforming can be used to cover a very wide frequency range.

Main Features

- Quick snapshot measurement
- Ideal for mid to high frequencies
- Omnidirectional coverage
- Independent of acoustic environment

Typical Applications

- Vehicle interior noise
- Aircraft cabins noise
- Rooms
- Industrial plant noise

Application Example

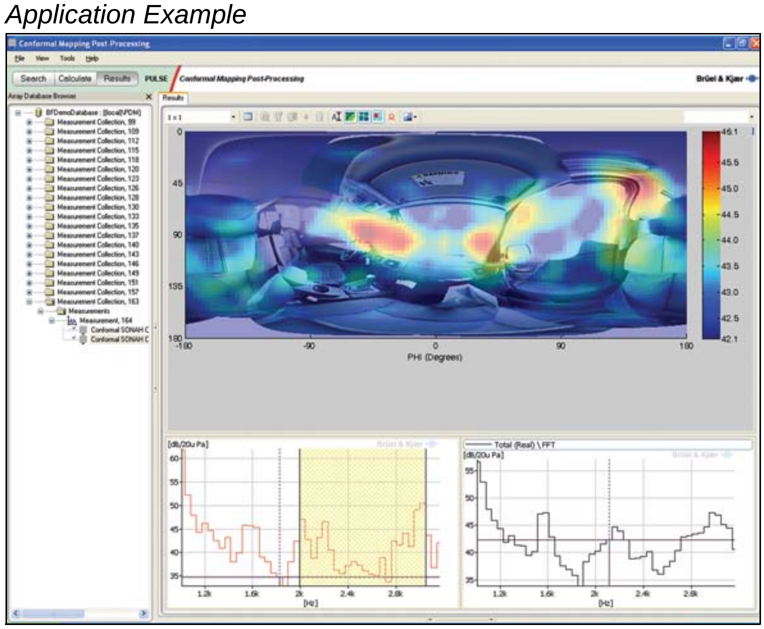


Fig. 6
Omnidirectional result from a road test using Spherical Beamforming.
The car interior at 80 mph: 2000–3000 Hz

Specifications – PULSE Acoustic Holography Type 8607, PULSE Beamforming Type 8608, and PULSE Spherical Beamforming Type 8606

Configuration

OPERATING SYSTEM REQUIREMENTS
Microsoft® Windows® XP, Windows Vista® or Windows 7

OTHER SOFTWARE REQUIREMENTS
Microsoft® Office 2003 or better and Microsoft® SQL Server® (a 2 GB server is included with the software)

COMPUTER CONFIGURATION
As required for PULSE

FRONT-END
Any PULSE-compatible front-end

COMPUTER CONFIGURATION/DATA ACQUISITION FRONT-ENDS
As for PULSE

PREREQUISITES
- PULSE 7700/7770/7771
- PULSE Noise Source Identification Type 7752
- PULSE Acoustic Test Consultant Type 7761
- PULSE Time Type 7789

	Acoustic Holography Type 8607	Beamforming Type 8608	Spherical Beamforming Type 8606
Measurement			
Monitor view	Yes	Yes	Yes (for single camera)
Data	Time or spectral	Time or spectral	Time or spectral
Process	Single, Patch or Scanned	Single	Single
Optical picture	N/A.	Take or reuse	Take or reuse
Automatic processing	Store automatically Calculate automatically Selectable calculation	Store automatically Calculate automatically Selectable calculation	Store automatically Calculate automatically Selectable calculation
Data Management			
Databases	Multiple simultaneous	Multiple simultaneous	Multiple simultaneous
Inspect metadata	Yes	Yes	Yes
Search on metadata	Yes	Yes	Yes
Change metadata	Yes	Yes	Yes
Calculation			
Multi core support	Yes	Yes	Yes
Target mesh type	Planar, Conformal	Planar	Spherical
References	Physical and Virtual	Physical	Physical
Methods	NAH, SONAH	Delay and Sum	SHARP
Filtering	Frequency, Order	Frequency, Order	Frequency, Order
Domains	Stationary Quasi-stationary Transient	Stationary Quasi-stationary Transient	Stationary Quasi-stationary Transient
Function	Pressure Intensity Reactive Intensity Particle Velocity	Pressure Contribution Pressure Intensity	Pressure Contribution Pressure Intensity
Index dimensions	Time, RPM, Angle	Time, RPM, Angle	Time, RPM, Angle
User interface			
User levels	Basic and Advanced User defined	Basic and Advanced User defined	Basic and Advanced User defined
Defaults	User defined	User defined	User defined
Contribution Analysis			
Sound Power	Area, Component	Area, Component	Area, Component
Map Displays			
Number of displays	1×1 to 4×4	1×1 to 4×4	1×1 to 4×4
Alignment of displays	Data, Frequency, Index, Colour scale	Data, Frequency, Index, Colour scale	Data, Frequency, Index, Colour scale
Playback	Measured and Calculated Points	Measured and Calculated Points	Measured and Calculated Points

	Acoustic Holography Type 8607	Beamforming Type 8608	Spherical Beamforming Type 8606
Reporting			
Cut and Paste	One view, All views	One view, All views	One view, All views
Movie file generation	Animation driven Audio driven	Animation driven Audio driven	Animation driven Audio driven
Microsoft® Word report generator	Across frequencies Across indices	Across frequencies Across indices	Across frequencies Across indices
Capacity			
Measurement	Frequency Data: • Set by PULSE FFT analyzer (Type 3560-B/C/D/E with Type 7700 or 7770) • 2000 measurement points • 6 references • 400 line FFT Time Data: • 64 s at 12.8 kHz • Set by data recorder (Data Recorder Type 7701 or Time Data Recorder Type 7708)	Time Data: • 64 s at 12.8 kHz • Set by data recorder (Data Recorder Type 7701 or Time Data Recorder Type 7708)	Time Data: • 64 s at 12.8 kHz • Set by data recorder (Data Recorder Type 7701 or Time Data Recorder Type 7708)
Calculation[a]	Stationary: • 2000 measurement points • 2000 target points • 6 references • 400 line FFT	Stationary: • 64 s at 12.8 kHz • 60 measurement points • 8000 target points • 400 line FFT (or equivalent)	Stationary: • 64 s at 6.4 kHz, • 400 lines FFT • 2592 target points (spacing 5° in azimuth and elevation)
	Transient: • 64 s at 6.4 kHz • 128 s at 3.2 kHz • 256 s at 1.6 kHz (or equivalent)	Transient: • 64 s at 12.8 kHz • 60 measurement points • 400 target points • 200 frames (or equivalent)	Transient: • 64 s at 12.8 kHz • 400 target points • 200 frames (or equivalent)

a. For one parameter at a time (for example, sound pressure, sound intensity)

Ordering Information

Type/Part No.	Name	Holography	Beamforming	Spherical Beamforming
8607-X[a]	PULSE Array Acoustics Acoustic Holography	Necessary	–	–
8608-X[a]	PULSE Array Acoustics Beamforming	–	Necessary	–
8606-X[a]	PULSE Array Acoustics Spherical Beamforming	–	–	Necessary
BZ-5635-X[a]	PULSE Array Acoustics Quasi-stationary Calculations	Option	Option	Option
BZ-5636-X[a]	PULSE Array Acoustics Transient Calculations	Option	Option	Option
BZ-5637-X[a]	PULSE Array Acoustics Conformal Calculations	Option	–	–
BZ-5370	PULSE ATC Robot Option	Option	–	–
BZ-5611	PULSE ATC Positioning Option	Option	–	–
7752-X[a]	PULSE Noise Source Identification	Prerequisite	Prerequisite	Prerequisite
7761-X[a]	PULSE Acoustic Test Consultant	Prerequisite	Prerequisite	Prerequisite
7700/7770/7771-Xy[a,b]	PULSE FFT & CPB/FFT/CPB	Prerequisite	Prerequisite	Prerequisite

a. X indicates the license model, either N: Node Locked or F: Floating
b. y is the number of channels supported by the license, between 2 and 16. A 16-channel license supports an unlimited number of channels

SOFTWARE OPTIONS

Type 7707-X[a]	Analysis Engine
BZ-5496-X[a]	PULSE Moving Source Option for Beamforming
BZ-5370-X[a]	Robot Option for ATC Type 7761

ACCESSORIES

Type 9665	Array Positioning System (Robot)
WA-0810	Support Stand for Grid Array
WA-0806	Integral Connection Array
WA-0807	Flexible Connection Array
WB-1477	Robot Controller

The 5D Robot is a customised order only. Please contact Brüel & Kjær

9712-W-D18	3D Creator Optical Sensor Positioning System
WA-1565-W-003	Spherical Array for 36 Channels
WA-1565-W-004	Spherical Array for 50 Channels
WA-1647-W-001	Car Seat Fixture for Spherical Array
WA-0728-W-004	Single-channel Pistonphone Adaptor, stethoscope, for Spherical Array with Microphones Type 4959
WA-0728-W-003	Adaptor for 6-Channel Pistonphone, short version for all Array Microphones
WA-0890	Circular/Half-circular Beamforming Array
WA-1558	Slice Wheel Array
WQ-2691	Tripod
WA-0893	Carriage for half wheel array
WA-1536	Hand-held Array

Type 4957	10 kHz Array Microphone
Type 4958	20 kHz Precision Array Microphone
Type 4959	10 kHz Very Short Array Microphone

a. X indicates the license model, either N: Node Locked or F: Floating

SOFTWARE MAINTENANCE AND SUPPORT

Available for all software packages

See the PULSE Software Maintenance and Support Agreement Product Data (BP 1800) for further details

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Local representatives and service organisations worldwide

Brüel & Kjær

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