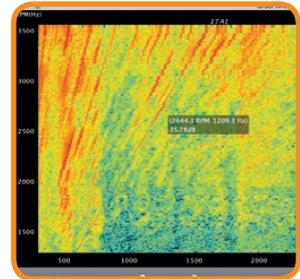
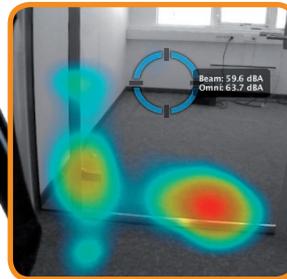


# Acoustic Camera



### A new modular design concept for acoustic arrays

Acoustic beamforming arrays, commonly known as acoustic cameras, enable the user to visualise different sound sources at different frequencies and source strengths. The resolution and ability to resolve sound sources spaced closely apart, and at lower frequencies, is mainly decided by overall size and number of microphones of the equipment being used. Although image manipulation and deconvolution techniques on the beamformed results might give added resolution, in practise the properties of the array still influence the results. This size versus resolution criteria is the crux of the acoustic camera market. Users want something that is small, light weight, and portable, while at the same time having excellent resolution, and the ability to go low in frequency. This has been an impossible demand for a single system - until now.

The Norsonic Hextile is a module based approach to acoustic camera that gives the user both portability and great resolution for a wide range of measurement situations. The array dish is based on a hexagon shape, given it both its name, and the ability to combine several tiles into larger systems.

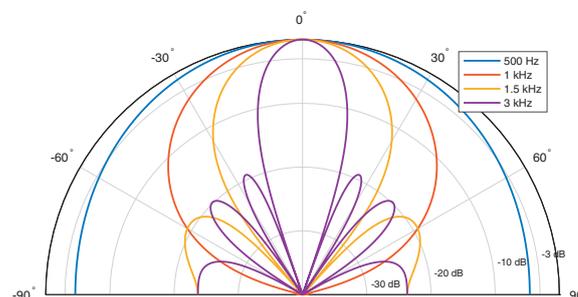
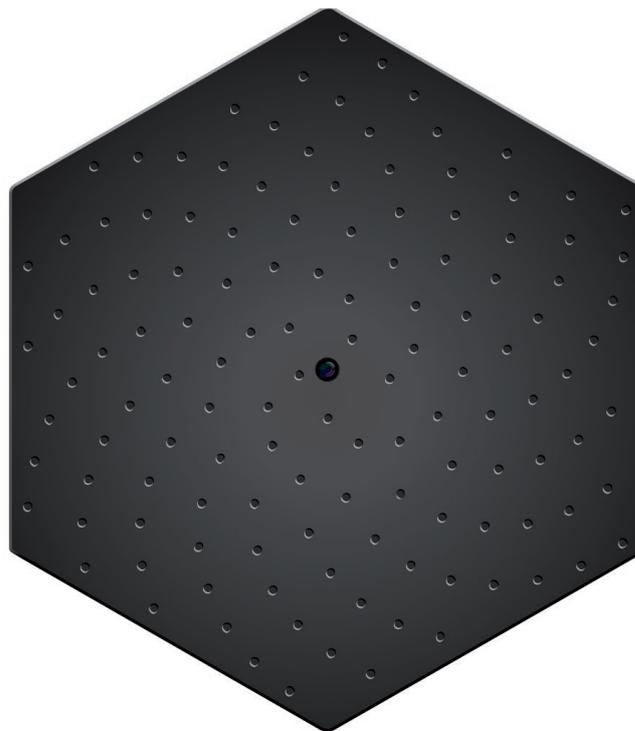
With a single Hextile, the user has a small, portable and lightweight acoustic camera that can be used for a wide range of measurement situations. The Hextile is a USB based acoustic camera, with a single USB cable for both power and data transfer - no extra battery cable needed. The array is made from robust and lightweight aluminium, has 128 MEMS microphones, weighs 3 kg while having a maximum diameter of 46 cm. The low frequency limit for the Hextile is 410 Hz.

For users that require better resolution both in lower frequencies and overall, three single Hextiles can be combined to a larger Multitile system, consisting of 384 microphones with a maximum diameter of 96 cm. The low frequency limit for the Multitile is 220 Hz.

For special low frequency applications below 1 kHz, it is also possible to utilise the Multitile in the low frequency configuration. By placing the individual Hextiles further away, the maximum diameter of the complete array system is increased to 1.46 m, making it ideal for low frequency measurements. The Multitile in LF mode is for low frequency measurements below 1 kHz, with a lowest frequency limit of 120 Hz.

## Hextile

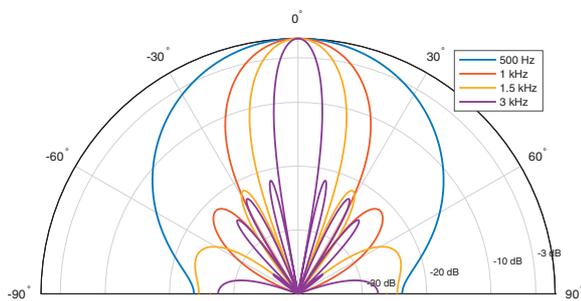
*Lightweight and portable*



*Array geometry and beam pattern for Hextile*

## Multitile

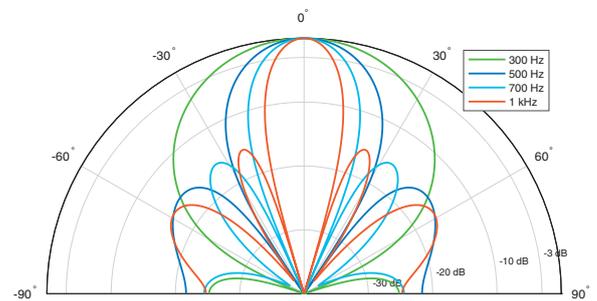
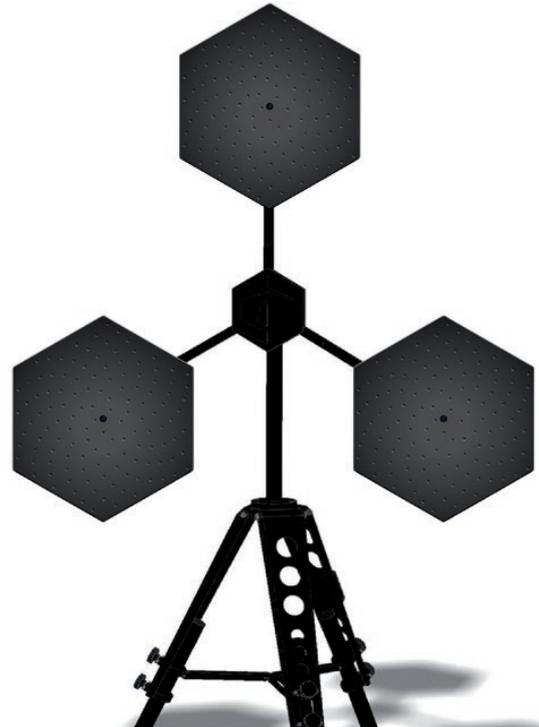
*Great resolution*



*Array geometry and beampattern for Multitile*

## Multitile (LF mode)

*Low frequency measurements*



*Array geometry and beampattern for Multitile (LF mode)*

# Array specifications

## Audio and video

Connection	USB
Microphones	128 MEMS microphones
Max sound level	120 dB
Min sound level (system)	9 dBA
SNR per microphone	65 dBA
SNR array (system)	82 dBA
Audio sampling rate	44.1 kHz
Camera resolution	2592 x 1944
Opening angle	105°
Frame rate	15 FPS
Operating temperature range	-40 to +85

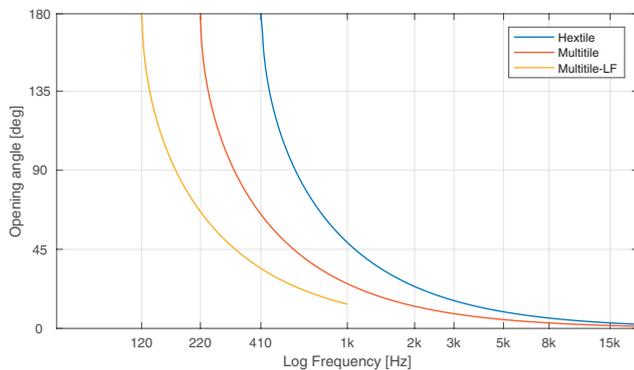
## Frequency response

Per microphone (flat)	100 Hz - 20 kHz
Per microphone	-26 +/-3dBFS/Pa @1 kHz 94 dB
Spatial sensitivity Hextile	410 Hz - 20 kHz
Spatial sensitivity Multitile	220 Hz - 20 kHz
Spatial sensitivity Multitile (LF mode)	120 Hz - 1 kHz

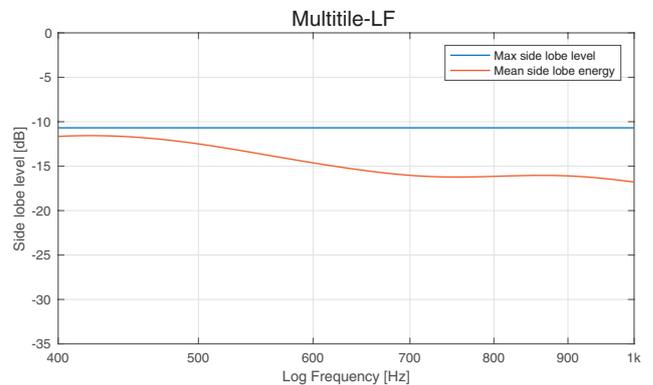
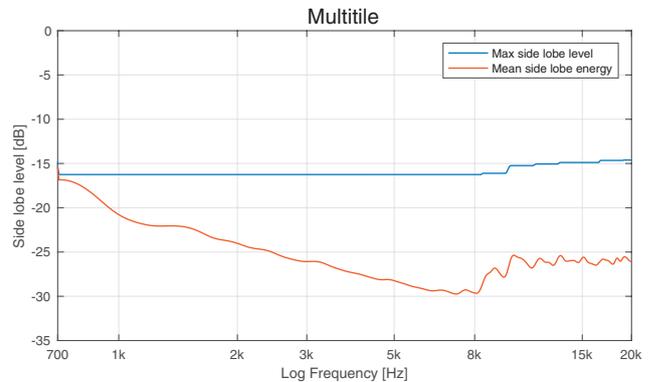
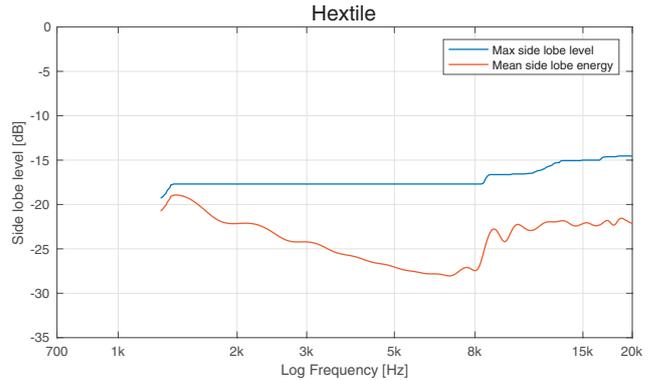
## Physical

Dimension Hextile	41 cm x 48 cm, Ø 48 cm
Dimension Multitile	83 cm x 84 cm, Ø 96 cm
Dimension Multitile (LF mode)	126 cm x 121 cm, Ø 146 cm
Weight Hextile	3 kg
Weight Multitile	< 10 kg
Material	Aluminium
Power consumption	< 3 W

## Half power beamwidth (HPBW)



## Max side lobe level, and mean side lobe energy



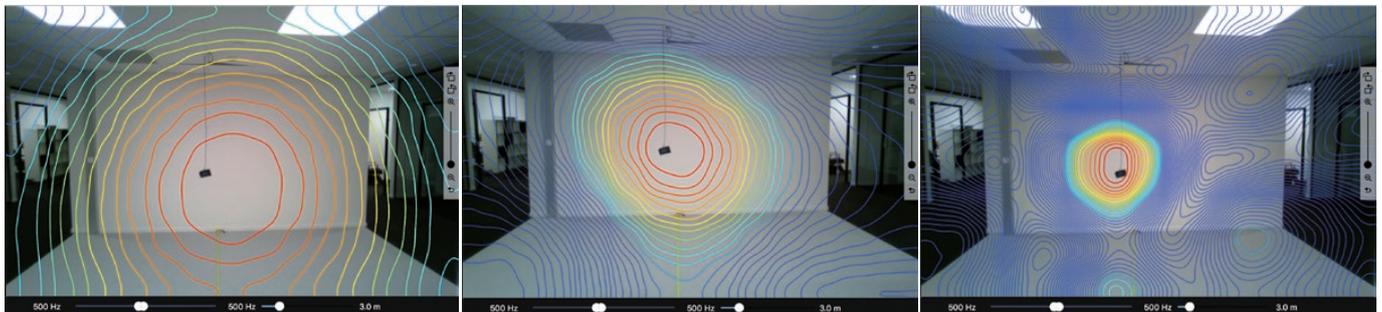
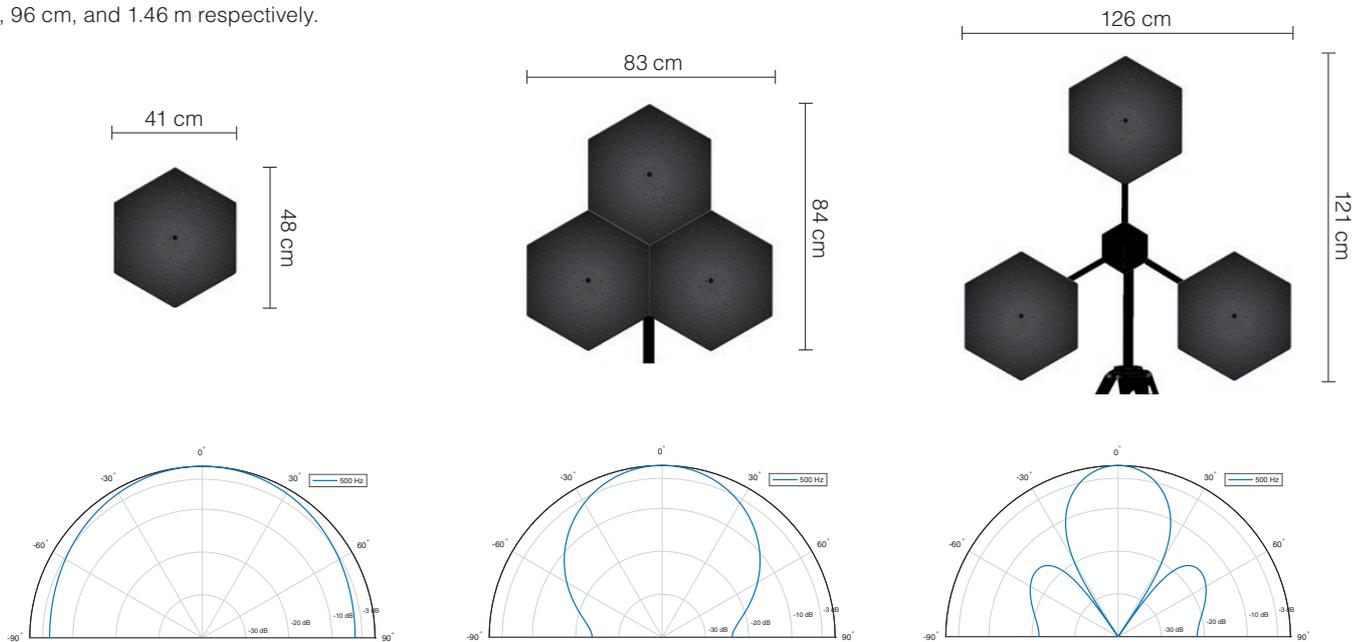
## Low frequency performance at 500 Hz

The biggest improvement when going from a single Hextile to the two different Multitile configurations is best demonstrated on a low frequency source. Seen below are the results from recordings on a single omnidirectional noise source emitting pink noise, with the colour plotting being done when the input signals are filtered at 500 Hz. This should give a direct comparison of the low frequency capability of the different arrays.

At the top are the different array configurations used for the recordings, with a 128 element Hextile, a 384 element Multitile, and a 384 element Multitile in LF mode. The diameters of the array configurations are 46 cm, 96 cm, and 1.46 m respectively.

The second rows show the beampattern for the different array configurations at 500 Hz and 3 dB dynamic range. As can be seen the beampattern gets more narrow, thus giving better resolution, as the overall array size increases.

Lastly the plotting results from the three different array configurations recorded on a real noise source are shown with 3 dB dynamic. The improvement in terms of resolution and pin-pointing the source is clearly visible when using bigger equipment.



Array geometry, beampattern at 500 Hz, and plotting results of pink noise source filtered at 500 Hz for Hextile, Multitile and Multitile (LF mode)

## Intuitive software design

The software design strategy has always had user friendliness and ease of use in mind. We want the user to be able to get results quickly, and start analysing recordings easily, thus spending time on the analysis, rather than the measurement set up or configuration of parameters. Live view of measurements combined with an intuitive software interface enables users without prior experience to make measurements within the first five minutes after powering the device.

### Virtual microphone

The one feature that really sets the software apart is the virtual microphone. The virtual microphone enables the capability to only get audio signals from the chosen listening point, and listen to sounds coming from specific directions of the video image, while suppressing noise and sounds emitting from other positions than what is selected. With this tool the user has the power of super hearing, and may gain more insight in addition to regular colour plotting of sources. Such super hearing may be especially useful in noisy and complex sound environments, where for instance different noise sources greatly impair the ability to distinguish which machinery is producing a faulty noise.

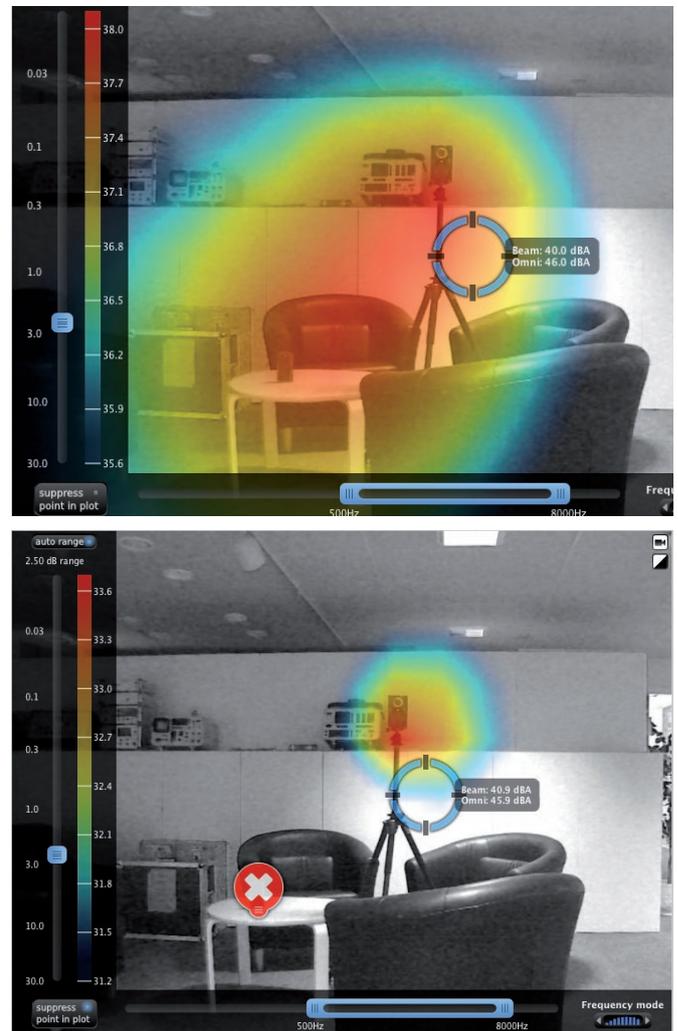
### Advanced post-processing audio analysis

In addition to live plotting and directive listening, it is also possible to record measurements and do the analysis at a later time. The raw signal from all microphones are then saved, and all parameters such as frequency selection, time selection and so on can be changed in post-processing. This means that a recording can be done without selecting the optimal parameters during the measurement, since these can be changed when analysing the recording. This also means that anybody can do the actual recordings themselves since it is then basically a matter of pointing the array roughly towards the area of interest and pressing record. All analysis and changes of parameters can be done in post-processing such as directive listening, graphical overlay of sources, spectrogram, FFT analysis and so on.

### Acoustic eraser

Sometimes sources may be closely spaced apart, or a strong noise source in the area of interest is interfering with the recording and impairing the image quality. Often this will be seen as either a single large source, or the source of interest will be completely shadowed by the stronger source. Seen in the image below is a situation where two equally strong sources are positioned close to one another, and

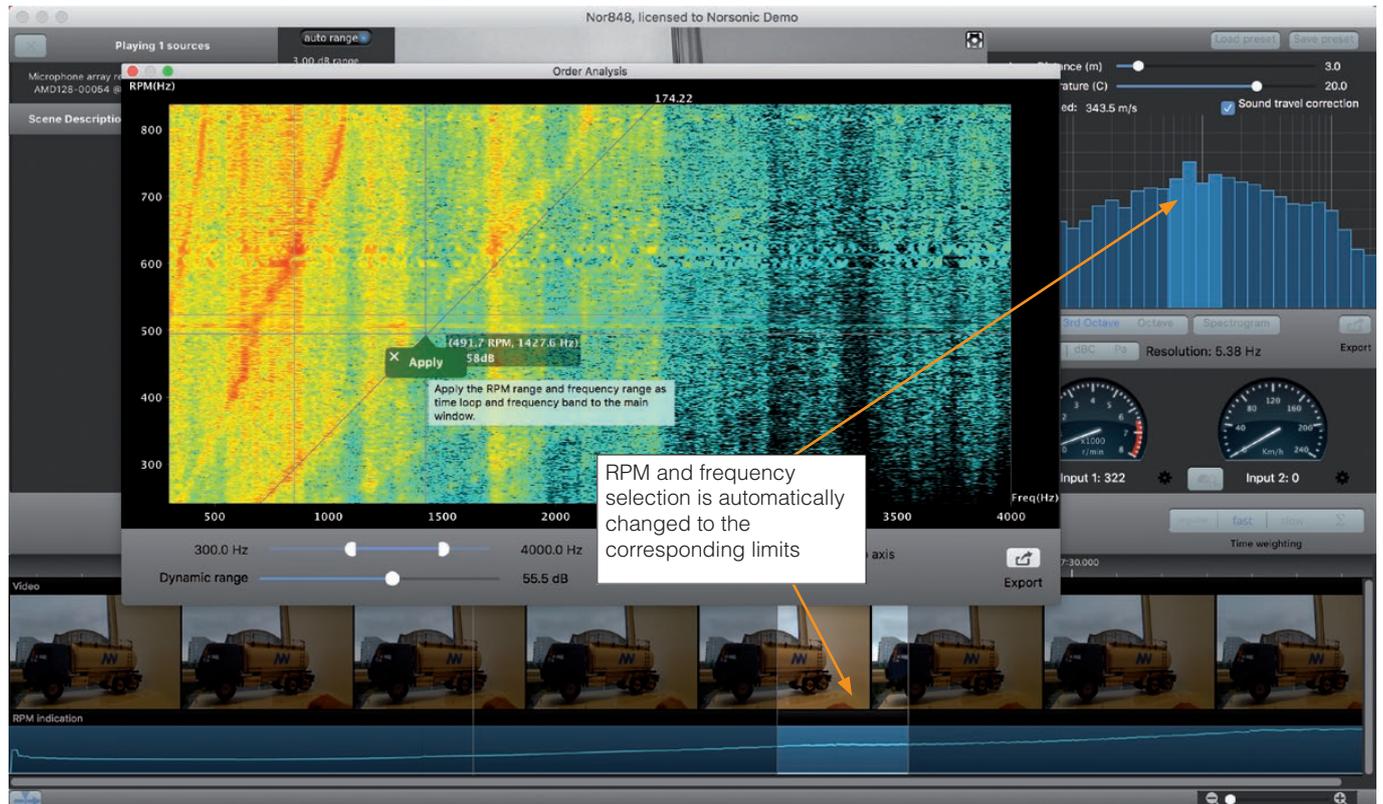
the resulting colour plot will display a single large source. In such situations the acoustic eraser feature may prove valuable. This function will add a red circle to the screen that can be dragged to any point, and remove the source from that point. This is highly effective when several noise sources are present. As seen on the pictures the acoustic eraser completely removes the source where the suppress point button is positioned. The virtual microphone can further be positioned on the source of interest.



## Order analysis

Especially in automotive applications RPM measurements may give vital information. The acoustic camera software has the possibility to display frequency content as a function of RPM by using the order analysis function.

In the spectrogram window, frequency as a function of RPM is plotted. It is further possible to select a square in the spectrogram window to isolate interesting events. By pressing the “apply” button on the selection, the RPM and frequency limits in the main view window automatically change to the limits set by the selection in the spectrogram. The user may then find and interesting sound event in the spectrogram, and automatically get the corresponding colour plotting of the event chosen.



Virtual microphone position selected by the cursor. Used for analysis and listening

Thumbnail of recordings

Select the colour range

Select plotting threshold

Enable the acoustic eraser

Playback control

Time axis

Video frames for quick navigation within recording

The screenshot displays a software interface for acoustic measurement. On the left, a live video feed shows a sound source with a color-coded beam pattern. Text overlay indicates: "Beam: 66.9 dBA" and "Omni: 82.6 dBA". The main panel features a bar chart of a spectrum with a y-axis from -24.0 to 84.0. Above the chart are sliders for "Array Distance (m)" at 15.0 and "Air Temperature (C)" at 22.7, with "Sound speed: 345.1 m/s" and a checked "Sound travel correction" option. Below the chart are buttons for "FFT", "3rd Oct", "Octave", and "Spectrogram", and a unit selector showing "dBA" selected. Two analog-style gauges labeled "Sensor Input 1" and "Sensor Input 2" are visible. At the bottom, there are controls for "Frequency mode" (5965Hz), "Band Filter", and "Time weighting" (impulse, fast, slow). A timeline at the bottom shows a video sequence with a blue bar representing sound level history.

Set the focal distance

Display spectrogram

Display the spectrum as FFT, 1/3 or 1/1 octave

A, C or flat frequency weighting selection

RPM and order tracking

Set the frequency range

Listen to broadband or selected frequency band

Sound level history

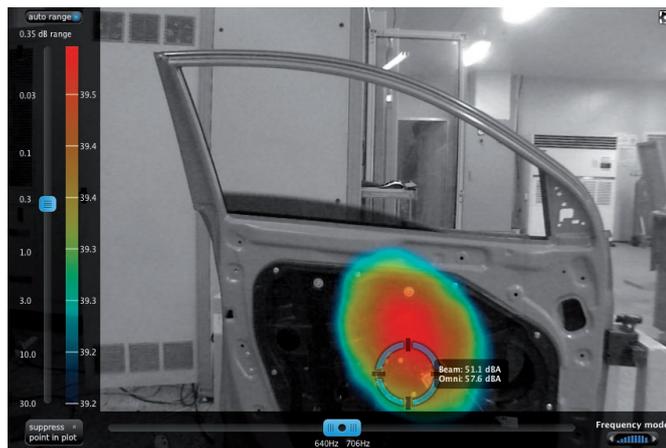
# Automotive

## Case study: Identifying Short Time High Pitch Squeak Noise from Electric Window in Car Door

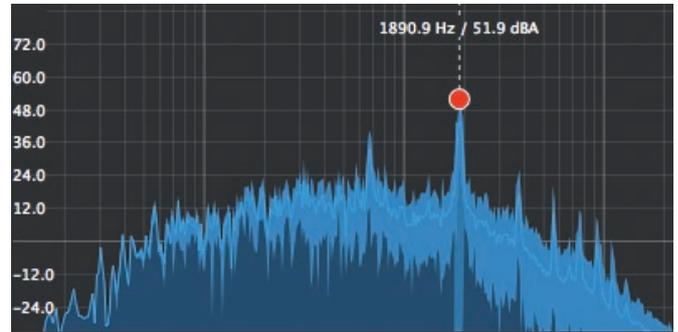
A well known car manufacturer in Korea are testing an automatic car door window intended for one of their new car models. The window is driven by an electric engine positioned in the middle of the car door that drives the window up and down. When the window was driven up by the electric motor, a short timed high pitch squeak noise could be heard. The squeak noise was obviously connected to the window and the car door, but the localisation of the source of the problem proved difficult.

The acoustic camera was positioned at a distance of 2.0 m from the car door, with the front-end of the camera pointed straight at the door. The recording consisted of an event of the car window going up whilst being driven by the electric engine.

In addition to the high pitch squeak noise, sound from the electric engine could also be heard which was around 670 Hz. Since this sound was present during the entire recording, it could be easy to misinterpret the results and pinpoint the source of the high pitch noise to the wrong location without doing proper analysis. As seen in the image below, the location of the electric engine was in the middle of the door.



As opposed to the stationary sound from the electric engine, the high pitch squeak noise was only happening for a brief period of time, around 300 ms. By defining a scene in the sound level indicator



pane of the acoustic camera software, it was then possible to analyse events happening only within the time frame of the extent of the scene. The scene is made by simply dragging the cursor over the region of interest in the software.

Now by calculating the average spectral density over that part of the recording, it was easy to see that in addition to the noise from the electric motor around 670 Hz, a high pitch tonal noise with a fundamental frequency around 1890 Hz could also be seen in the frequency spectrum. In addition harmonics of the fundamental frequency up to the 7th harmonic was visible in the spectrum.

Now by filtering the frequency content of interest around the fundamental frequency, it was possible to get a clearer indication of the position of the source of the high pitch squeak noise as seen below. Due to the tonal nature of the noise it was possible to switch from the ordinary, robust wideband algorithm, to the adaptive algorithm for narrowband applications. This further helped in pinpointing the exact location of the problem. Higher resolution could also be achieved by zooming further in the image.



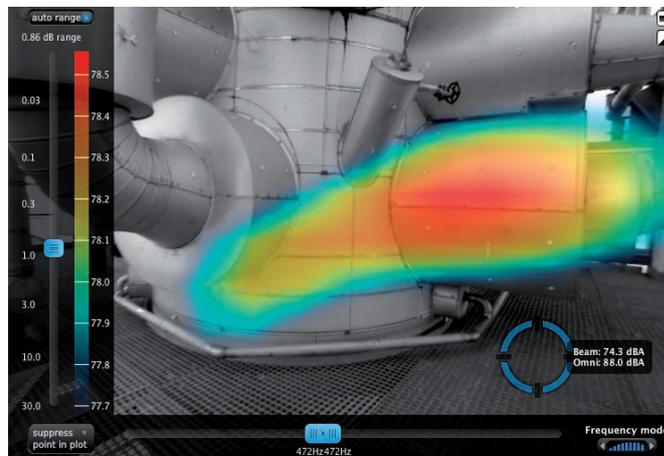
# Industry

## Case study: Identifying Low-Frequency Tonal Noise in Windy and Noisy Conditions

A large LNG gas facility (approximately 300 m x 150 m) producing 300 000 tons of LNG annually is situated in a terminal area with the nearest populated area at a distance of around 1 km. Within the gas production facility, a low-frequency tonal noise at around 500 Hz is generated causing complaints from nearby neighbors. The tone imposes a more stringent noise requirement on the facility, forcing noise reducing actions being made on the source.

In addition to the tonal noise, the entire LNG gas facility is rich in noise emitting sources, including lossing and loading of maritime vessels, which further complicates the source location of the single tonal noise source. Also the location of the facility at the coastal regions of the western part of Norway, ensures that windy conditions are frequent, with wind noise further impeding the quality of acoustic recordings.

Based on measurements with hand held sound level meters, the problem area was narrowed down to be a large pipe in the midst of the facility. However it could not be determined if the emitted tonal noise was from the entire pipe itself, or if it originated at a specific part of the pipe. There was also uncertainty whether there existed multiple sources within the pipe, for instance at both the base and top layer. In the worst case the noise insulation would have to be performed over the entire pipe length, which could have been a very expensive solution.



By positioning the center of the array towards the pipe and adjusting the frequency to display only coloring within the 500 Hz 1/3-band, the noise source was located within seconds, and the source producing the tonal part from the pipe was detected. Measurements from different measurement positions also confirmed the source location. By placing the virtual microphone on the localised source and using the spectrogram function, it was easy to verify the position of the source emitting a tone at 460 Hz.

Although the measurement location had quite windy conditions, the wind noise did not affect the measurement results at all. Wind noise can be viewed as spatially white, which means that wind noise sampled at different places in space, is not correlated from position to position. When many different signals from many microphones are added in the beamforming algorithm, the wind noise will be added out of phase and attenuated proportional with the number of microphones being used.

With the acoustic camera it was possible to detect the tonal sound of the most crucial parts of the turbine. This meant that the facility could focus on and implement noise reduction actions in the right places. After pin pointing the location of the noise source, further analysis could be made with measurements performed closer to the source of interest in order to further determine the position and cause of the generated tonal noise.

# Sound source identification

## Case study: Pinpointing Low Level Sanitary Noise in Apartment Building

A newly built apartment building consists of several floors with multiple apartments on each floor. One of the ground floor apartments is disturbed by sanitary noise from the apartment above, which is heard whenever the toilets in the top apartment are being flushed. The sanitary noise is heard in several rooms, and the level was measured to be around 30 to 35 dB, which is above the noise criteria set in the regulations. The culprit was thought to be embedded pipelines in one of the corners of the living room, and several measures were made on this area. Although increased insulation improved the noise dampening capabilities of the embedded pipelines, the noise was still heard. Also the improvements could not explain the fact that the noise was also heard in two bedrooms, one of which was not adjacent to the living room.

Given that the measured sound pressure levels were so low, it was very difficult to detect any real change in sound pressure level from different measurement positions. Also trying to locate the origin by hearing in different positions proved to be futile when trying to determine source position. In addition to hearing the noise in several rooms, it was also heard in the hallway and it was uncertainty whether there existed a single source location or several.

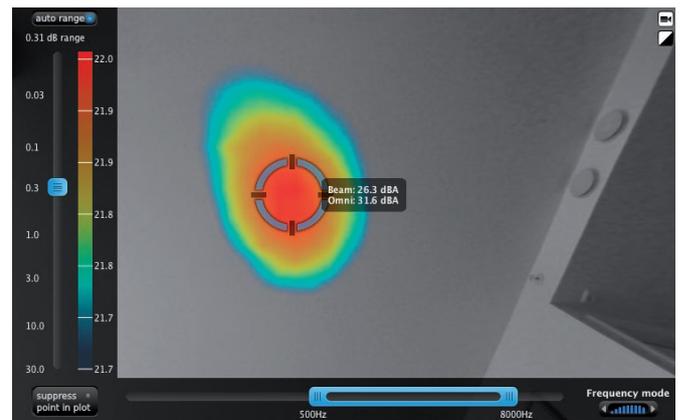
When filming at the location of the encased pipes in the corner of the living room, the acoustic camera did not pick up any energy at that position, but rather the colouring was upwards towards the roof and outside the field of view of the camera at that measurement position.



This was a very strong indication that the origin of the noise was in fact located somewhere else, and the camera was directed accordingly for the subsequent measurements.

When pointing the camera towards the ceiling it became apparent that the source was at this position. No other spots, either from the embedded pipes in the corner of the living room, or from the hallway, had any visible colouring, and could be excluded as the likely position of the origin of the source.

By using the virtual microphone, which enables the user to listen to a specific position in both real time and in a recording, one could clearly hear the sanitary noise from the recorded position at the roof. Also by enabling the bandpass filter one could further be able to filter out background noise and very clearly hear the sanitary noise from the piping. Based on these measurements one could deduce that the water pipes in were in fact not positioned as previously thought.



In addition to measurements in the living room subsequent measurements were also made in the two bedrooms. These measurements displayed the same result, the energy of the noise did not come from the walls, but were confined to the roof. All in all this was a very strong indication that the problem was piping located in separating floors between apartments.

# Sound leakage

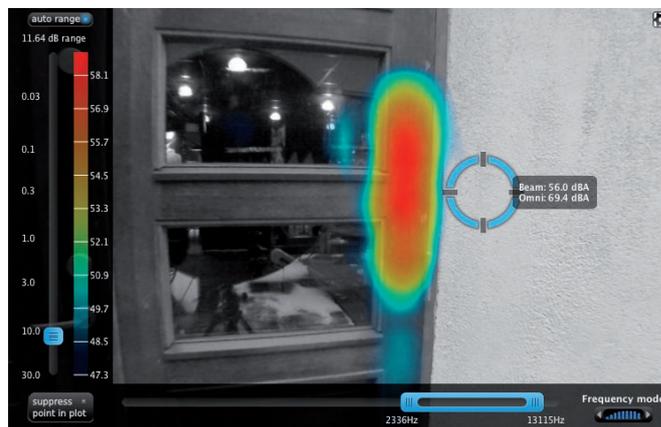
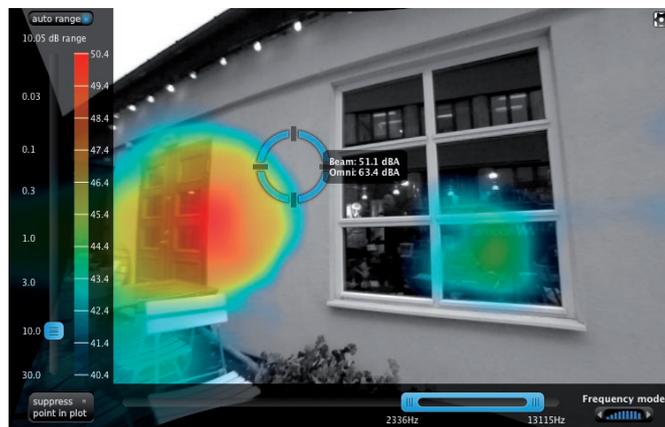
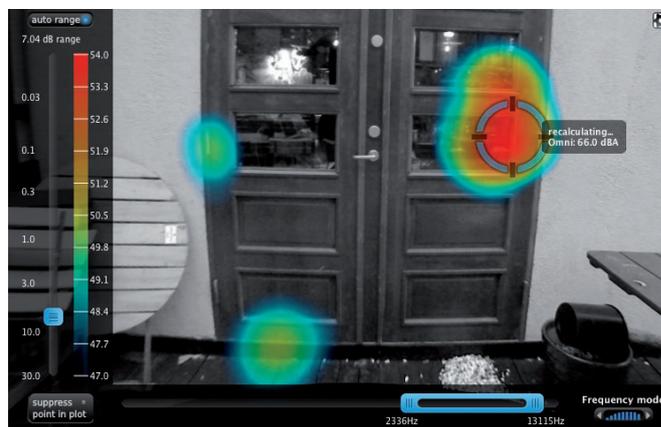
## Case study: Filming Breakout Noise from Café and Concert Venue

A combined bar, bistro and concert venue in the city center has been renovated with a great emphasis on acoustic noise dampening. Nevertheless, the venue is still getting complaints from neighbors close by due to breakout noise from the location, especially during late night concerts. The establishment consists of a bar and bistro on the ground floor, with the concert venue on the floor above. The concert venue has several windows facing the outside street and neighborhood buildings, and it was desirable to pin point any acoustic weaknesses in these windows. Also it was of interest to see if the wall itself needed additional measures, or if the main source contribution came from the windows alone.

For the recordings the acoustic camera was placed outside pointing at the facade of interest, with the audio system inside of the music venue playing white noise at volumes up to 100 dBA. The room inside would then act as a sending room, and the outside as the receiving room.

The wall between the café leading to the patio consists of both a door and several windows. The first step consisted in seeing what made the biggest noise contribution. As seen in the image below, where the dynamic range is set to 10 dB, the door had a noise contribution that was approximately 10 dB higher than the nearest window.

By focusing on the door only it was further possible to locate the exact position of, and zoom in on, those weaknesses as seen in the images below.



# Environmental noise

## Case study: Measuring Impact of Traffic Noise in Apartment Living Room

An apartment on the ground floor of a two story house in the city lies close to a busy road. The living room in the apartment is facing the road, and the inhabitants are bothered by traffic noise, especially in the morning and the afternoon, when the traffic is the heaviest. Traffic noise could be clearly heard when standing in the living room. The facade facing the city street consists of a large window and a porch door. It was thought that the main contribution of noise came from these two parts, but it was difficult to verify if those assumptions were true, or exactly where any weaknesses in the structure might be located.

For the recordings the acoustic camera was placed inside the living room pointing at the facade facing the street. The living room would hence act as the receiving room, and the outside as the sending room, much in the same sense as the procedure for sound insulation measurements. Weaknesses in the facade would then be possible to be seen as small noise sources in the structure. It was possible to use regular traffic as sound source, regardless whether the traffic was steady, or just a single vehicle from time to time.

In addition to using traffic as noise source, measurements were made by placing an omnidirectional loudspeaker emitting white noise on the outside of the facade. This created a more stationary sound field on the outside of the structure, and made detection of small cracks and gaps in the structure even easier.



Initial recordings when using traffic as noise source displayed a single strongest facade weakness at the top left of the living room wall. This strongest source position was also confirmed when using the omnidirectional loudspeaker as noise source. At this position a ventilation valve was installed, and most of the traffic noise came from this location.

Having determined that the intake valve was the main noise contributor, this spot was covered up with a pillow to remove it from the overall noise field, and try to locate secondary sources. By filtering on a relatively high frequency band around 3 - 4 kHz, it was possible to filter out only the noise being emitted by small gaps and cracks. This produced two new possible weaknesses, one on the porch door, and another on the air valve above the window.



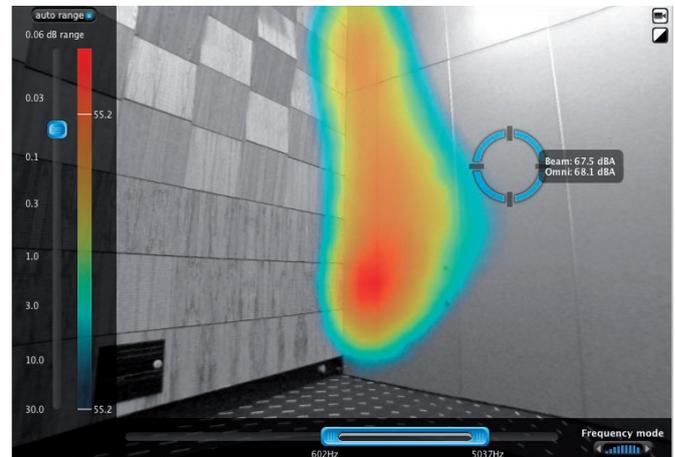
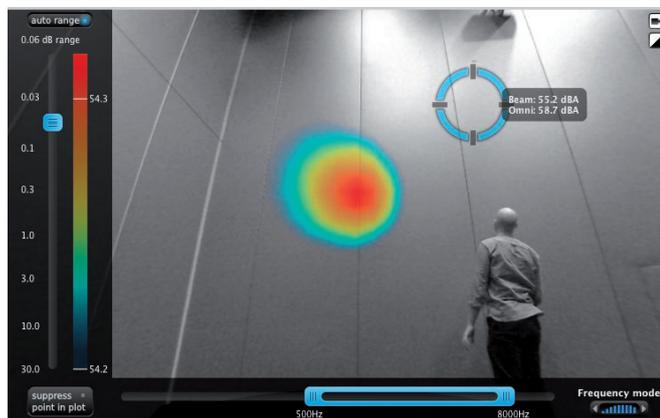
# Building acoustics

## Case study: Finding Acoustical Weak Points in Room Dividing Modular Walls

A conference hotel is using modular walls to divide large halls into several smaller conference rooms. The rooms are divided by modular walls that provide several different opportunities for subdivision and multipurpose use of the large area spaces.

When measuring the sound insulation between adjacent rooms through the modular walls, the resulting value was found to be too low, and noise from one conference room could possibly disturb listeners at adjacent rooms. The dividing modular walls cover large areas, and are as high as 7 meters from bottom to top, which makes intensity measurements with hand held sound level meters difficult. The room dividers could have several weak points, which were not easily identifiable. It was thought that identifying and fixing the weak points in the individual modular walls would help increase the overall sound insulation capabilities of the entire wall element.

The acoustic camera was plugged into an external battery pack for easy transportation and mobility. The measurement procedure consisted of choosing two adjacent rooms divided by a modular wall of interest. One of the rooms was chosen to act as receiving room, where the acoustic camera was positioned. A noise source and omnidirectional loudspeaker generating white noise at high volume was positioned in the source room. The speaker was placed in one of the corners of the room furthest away from the dividing wall, in order to achieve as diffuse source noise field as possible.



Due to the large size of the modular walls, the camera was pointed to different areas of the walls, and several measurements were made. The individual measurements could then be examined further in post-processing analysis. Due to the source being used at high volume in the sending room, cracks and gaps in the modular walls would appear as small noise sources at specific location on the walls when recording with the acoustic camera in the receiving room. The acoustic camera was able to locate several weak spots on the walls, even though the range where differences could be discovered were for certain areas below 0.05 dB.

The measurement system's virtual microphone feature was also very helpful during live measurements. With this function you can scan and listen to the desired spots in the image, and also filter the listening function to desired frequency range. This made it possible to scan along edges and hear differences in frequency from different points. A change in frequency may indicate a sound leakage. Also by using the spectrogram function to get a visual representation of the spectrum of frequencies as they varied with time, one could further indicate a leakage at various parts of the walls.



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