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Acoustic eraser used with the acoustic camera on disturbing sources

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1 Introduction

The "Acoustic Eraser" was presented by Dirk Döbler [2], from GFaI, Berlin at Inter Noise conference in Lisboa 2010, both theoretically and some practical examples were given. This paper describes how this and other new functionality works in reality in a laboratory when doing measurements with the Acoustic Camera from GFaI. The measurements have been carried out on a sound power reference source and a disturbing source. If the disturbing source is close, the measurement results will be influenced. By moving the disturbing source closer and closer to the reference source we can study its influence, and how accurate the "Acoustic Eraser" can calculate the sound power from the reference source with a disturbing source close by.

2 Acoustic Camera

2.1 Theory

The Acoustic Camera from GFaI is based on beam forming of a conventional delay-and-sum (DAS) beam former in the time domain. DAS beam forming can be performed in either the time or the frequency domain, whereby time domain DAS is done by separately delaying each microphone signal, making them align before summation and normalization. DAS in the frequency domain is different by that each microphone signal is first transferred into the frequency domain by FFT and then shifted, after that the signals are summarized and normalized. Hence in the time domain DAS have much faster processing speed. DAS beam forming requires knowledge of the positions of the array microphones and the distance to the focus plane. If the focus varies over the focus plane, there will be focus errors and they can also originate by the array geometry. Another parameter is the sampling of the microphone signals giving a higher spatial resolution the higher the sampling frequency is.

2.2 Measurements setup

In a laboratory [1] anechoic chamber two sound sources: BK 4204 reference sound source (Lw=90,7 dBA) and a disturbing sound source (a generic portable compressor pump), were positioned with different distances from each other. The noise from the reference sound source is omni-directional and has a stationary noise spectrum, but the disturbing compressor pump with characteristics of 2857 RPM has an unknown directivity pattern.

The sound waves were measured by a ring array microphone and sampled at high speed by the data acquisition system and stored to disc. In this case we used only 48kS/s due to the frequency range of the measurement and the relatively ideal environment in the laboratory anechoic chamber. When post-processing the microphone signals they were first A-weighted and then delayed due to their individual position relative the source position calculating an acoustic photo with a colour scale corresponding to the SPL value for every pixel in an image. All spectra are linear without A-weight.

Several cases were studied with / without disturbing source, four different distances in between the sources, changing places between the sources etc. Down below in figure 1 is a shown a typical acoustic photo of the sources:

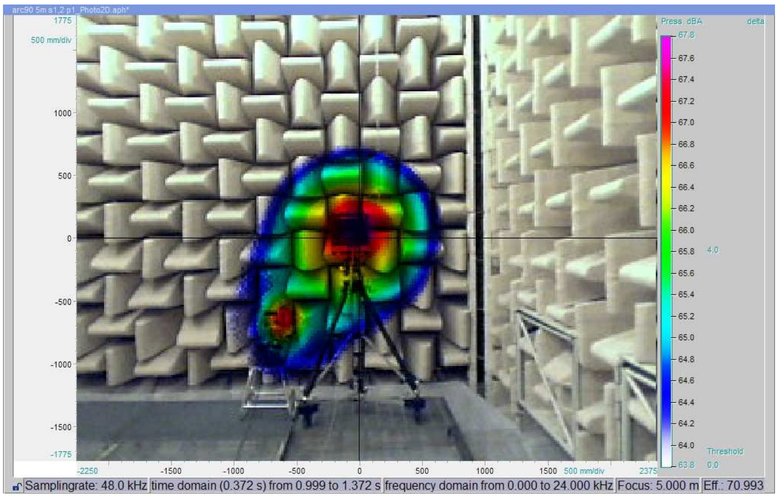

Figure 1: Acoustic photo (contrast 4dB) in a laboratory anechoic chamber, Royal Institute of Technology, Sweden

2.3 Contrast

The contrast is defined by the highest level and the noise floor in an acoustic photo and the typical dynamic range is normally from 5 to 15 dB. This low contrast from standard DAS beam forming can only be enhanced by increasing the number of microphones or changing the patterns of the array design, like spirals, rings, stars, spheres etc. or increase the sampling frequency. In real life measurements it would be very useful if high level masking sources could be deleted to find other relevant sources. Below is shown a typical acoustic photo of the sound power source and a disturbing source.

2.4 Sound Power

The sound power level implemented in the Noise Image software for a point source in the far field at the distance r is expressed by equation (1), given standard values for ρ0 air density and c sound velocity the last term is constant.

$$L_w = L_p + 20*\log_{10}(r) + 10.697 \text{ dB} \qquad (1)$$

The sound power reference source have been tested at the official Swedish National Laboratory according to ISO 6926:1999 and ISO 3741:1999, with the exception for frequencies below 100Hz, where the measurement room is outside the standard. The reference source has also been measured by the acoustic camera and then the sound power levels have been calculated provided sound power algorithm. The results are given below in table 1:

Reference source certificate	Calc. Lw @ 1m	Calc. Lw @ 2m	Calc. Lw @ 3m	Calc. Lw @ 4m	Calc. Lw @ 5m
Lw = 90.7 dBA	89.8 dBA	91,2 dBA	91,3 dBA	91,7 dBA	91,7 dBA

Table 1: Comparison of a reference sound power source and measured levels by use of acoustic camera.

A more thorough investigation with frequency analysis in 1/3-octave bands have also been done, the differences as seen above are similar to the dBA-comparisons. As above the measurements have been compared with the certificate from the sound power source for 5 different distances. As can be seen below in figure 2 the main differences are for high frequencies above 3 kHz. This could be due to the width of the side lobe of the beam forming algorithm. This means that if being very close to the source, the width of the main lobe is not wide enough to measure all energy so that the spectra for longer distances get more in agreement to the spectra of the reference source certificate. The midrange and the low frequency region from above 250 Hz to 3000 Hz seem to be relatively equal to the reference source certificate, typically with in a range of +/- 2dB. The microphones used in this array are type 2 microphones but the frequency response of over the applicable frequency range 50 to 20 kHz is +/- 0,5 dB.

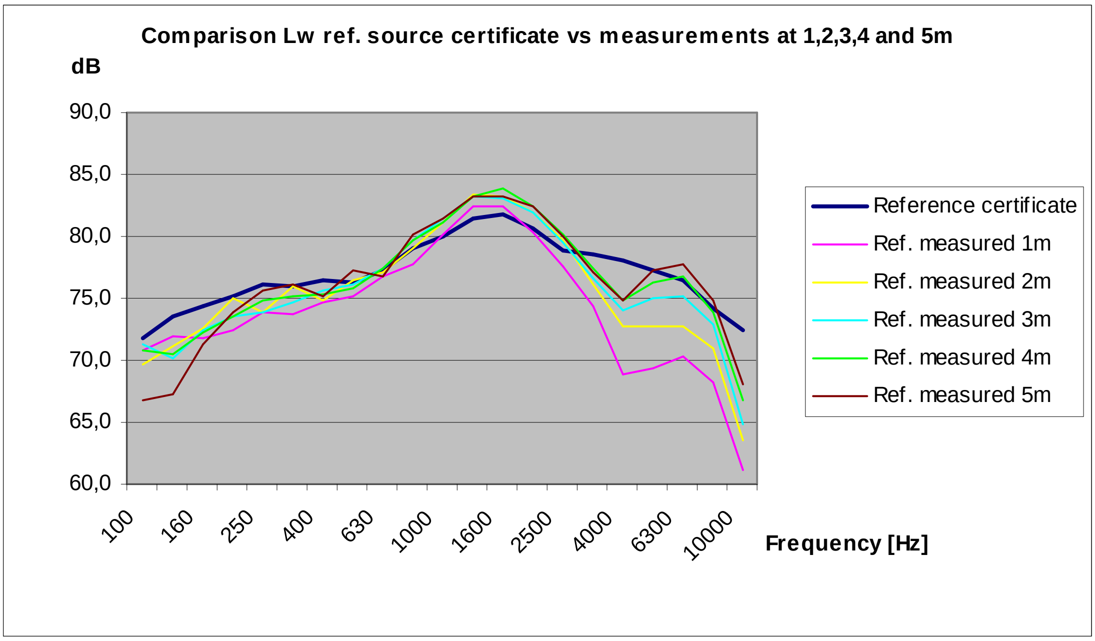

Figure 2: Comparison of Lw for a sound power source (official certificate) and acoustic camera measurements and calculated Lw values in 1/3-octave bands for 5 different distances 1,2,3,4 and 5m.

2.5 Disturbing source

In addition there was measurement done with both the reference sound power source and the disturbing source (a generic portable compressor pump). In this case we only measured at 5m distance but for different distances between the ref. source and the disturbing source. The distances were: 0.80m, 1.45m, 1.93m and 2.5m. In diagram 3 below these measurements have been compared with the main position of the reference source (without the disturbing source).

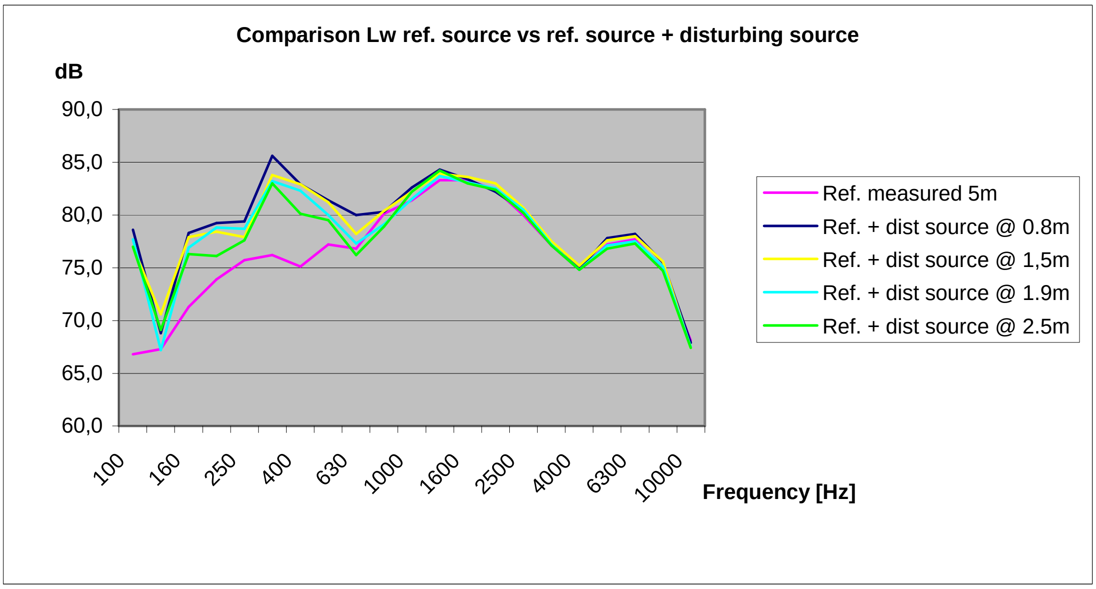

Figure 3: Frequency analysis of a comparison of measured and calculated Lw for a sound power source vs. the source and a disturbing source in 1/3-octave bands for 4 different distances between the ref source and disturbing source.

The overall values are shown in the table 2 below:

Reference source certificate	Calc. Lw @ 0.8m	Calc. Lw @ 1.45m	Calc. Lw @ 1.93m	Calc. Lw @ 2.5m
Lw = 90.7 dBA	92.6 dBA	92,5 dBA	92,1 dBA	92,0 dBA

Table 2: Comparison between the reference sound power source and calculated acoustic camera levels with a disturbing source at four different distances from the reference source.

The disturbing source was as earlier mentioned a “generic portable compressor pump” and the pump have typically two quite different sources and the corresponding spectra’s are shown below in figure 4a and 4b. Figure 4c is a zoom of 4b:

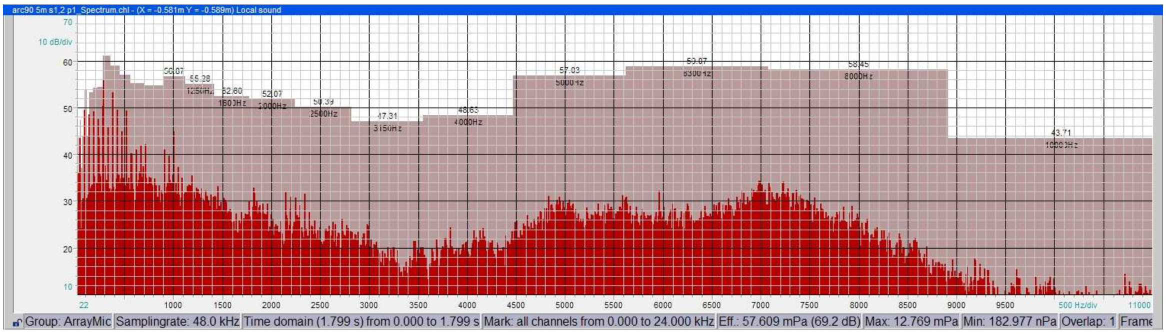

Figure 4a: Spectra from high frequency source of the disturbing source (a generic compressor)

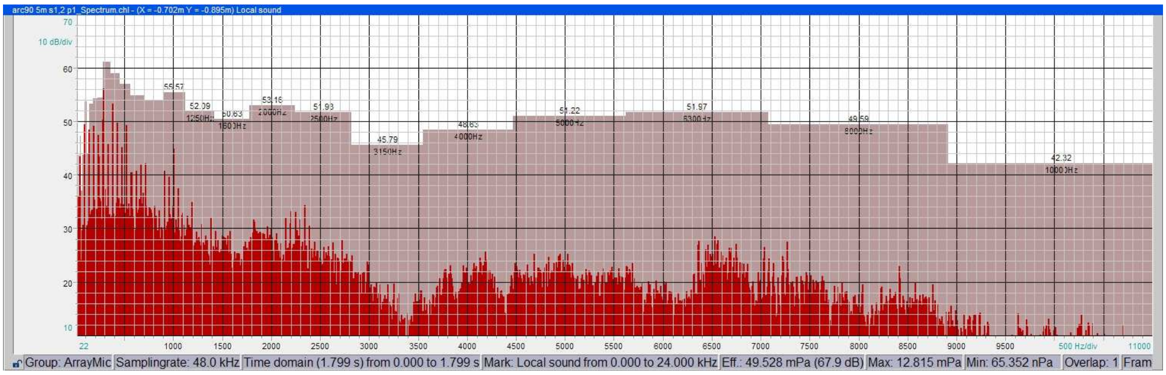

Figure 4b: Spectra from low frequency source of the disturbing source (a generic compressor)

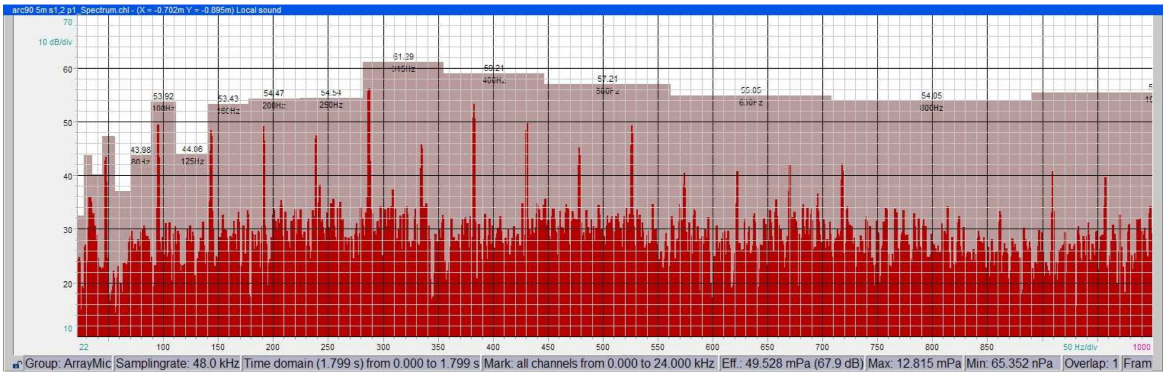

Figure 4c: Zoom of spectra 4b up to 1000Hz, 125Hz 1/3-octave is in between two tones

3 Acoustic Eraser / Extract

3.1 Eraser

By the "Acoustic Eraser" [2] it is possible to erase sources. The acoustic eraser can not improve the resolution of a beam forming system, it can only discover quiet sources and if we have a separation, improve sound separation. This function is enabled by moving the cursor over the point to be erased, hereby re-calculating the acoustic photo according to the algorithm.

3.2 Extract

By the "Extract"-function it is possible to reverse the acoustic erase functionality – meaning that after selecting a source – all other sources are deleted. The first study was to investigate how the eraser and extract functionality affects the previous sound power calculations with a disturbing source. Below are measurement shown for both cases of: erase of the disturbing source and extract of the reference source in table 3 and as acoustic photos in figure 5a/5b, contrast= 5dB.

Ref. source certificate	Calc. Lw @ 5m Ref. Source only	Calc. Lw @ 5m Ref. Source + dist. source	Calc. Lw @ 5m Ref. Source + disturbing source and erased dist. source	Calc. Lw @ 5m Ref source + disturbing source + extracted Ref source
Lw = 90.7 dBA	91.7 dBA	92,6 dBA	90,9 dBA	92,5 dBA

Table 3: Comparison of different measurements and calculations of the reference sound power source with the "Erase" and "Extract" functionality.

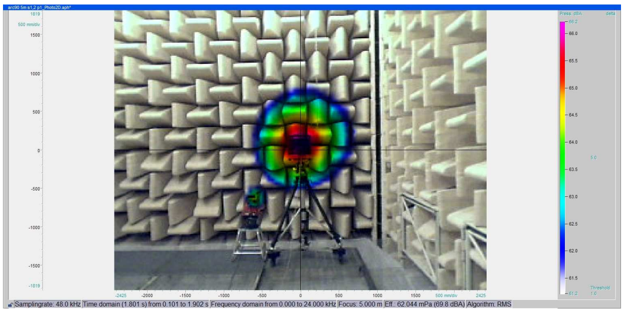

Figure5a: Acoustic Photo by Acoustic Eraser

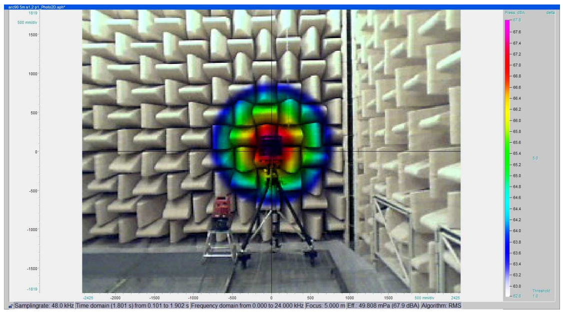

Figure5b:Acoustic Photo by Acoustic Extract

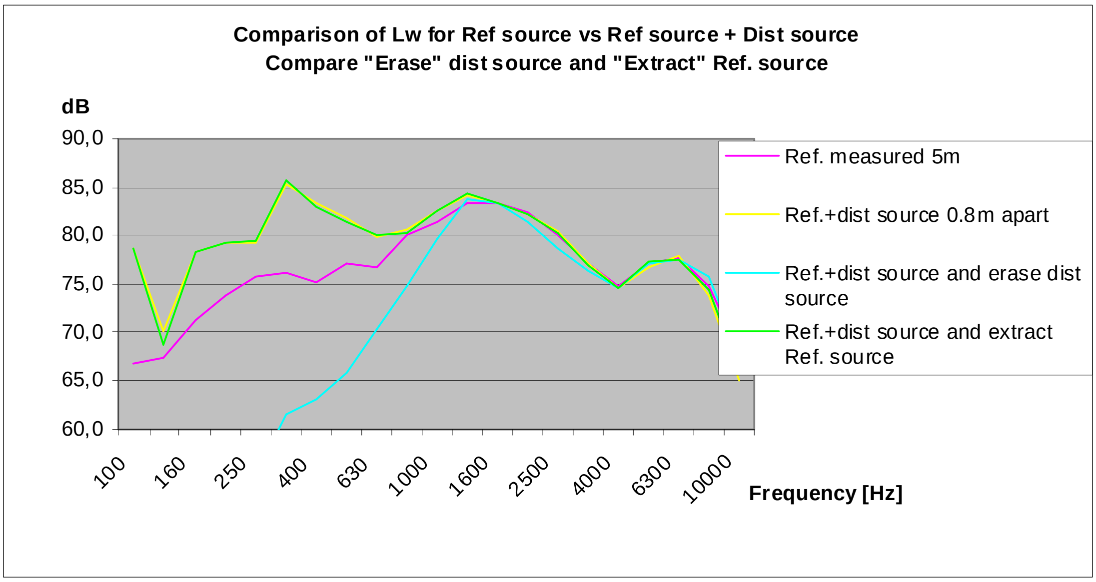

Figure 6: Frequency analysis of Lw for acoustic erase and acoustic extract function

3.3 High Dynamic Range

By the “HDR-function” (High Dynamic Range) it is possible to get extremely high dynamic range in an acoustic photo. HDR [3] is an advanced beam forming algorithm based on the acoustic eraser. The main lobes are successively extracted from the signal, the side lobes are suppressed and the extracted sources are combined in an image. In this way the available contrast of the acoustic photo is raised to 40dB. Thus, sources up to 40dB lower than the main sound source can also be localized und replayed via sound points. Furthermore, there is significantly better selectivity between the sources which is important for listening in to the acoustic map. However, the calculation time is considerably longer than for standard beam forming. The previously shown figure 1 with a actual contrast of approximately 3 dB have been re-calculated using the new HDR algorithm so that now the actual contrast in the acoustic photo have increased to approximately 30dB between the two sources. If using more iterations then sources then artefacts can occur, see figure 7 below which have been calculated using 8 iterations and given two artifacts.

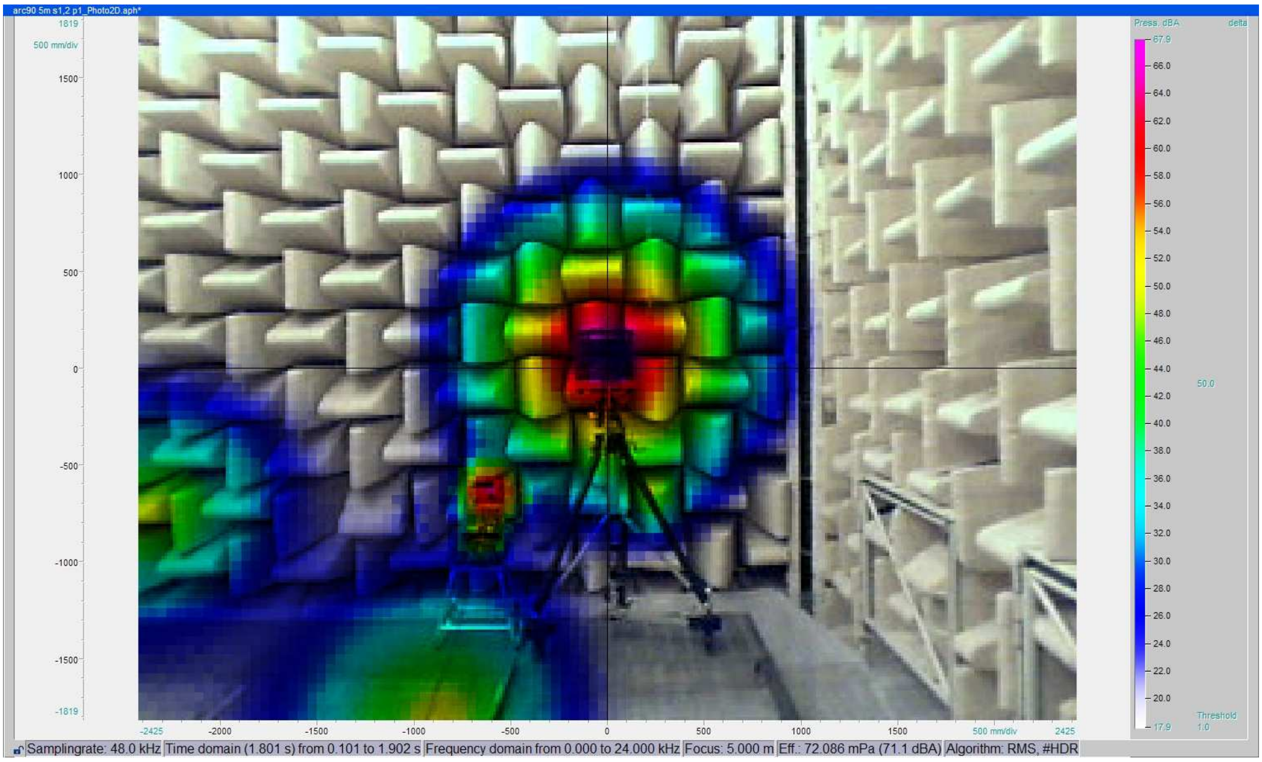

Figure 7: HDR-function with a suppression of 8 times and a maximum of 8 iterations and given two artifacts.

3.4 Discussion

When applying the new functions “acoustic eraser” and “acoustic extract” on an acoustic photo, it will show much better separation of sources. Secondly the new HDR algorithm gives increased contrast of up to 40 dB. The outcome of this new functionality is however greatly depending on the frequency of the dominating sources and/or the distance between sources. In our case the acoustic eraser can not extract the signal parts correctly, due to that the disturbing source have a dominating frequency range between 100 – 1 kHz and is rather close to the reference source 0.5m. All frequencies of both sources lower then 1 kHz are therefore extracted giving the same frequency spectra and equally the acoustic eraser will delete both sources low frequency parts up to 1 kHz.

Therefore the comparison with between a sound power reference source and erased / extracted source in the frequency domain must be used for the frequency region where it is applicable. When erasing it is also depending how (moving the cursor) one actually erases a source when it is not exactly a point source. However for the erase function the overall dBA-values will actually show better agreement due to that in our case the mid frequency range is dominating and that the measurement system already from beginning measure 1 dB too high. For the extract function applied on these two sources a better setup would be to separate the sources further apart. The wavelength of the noise will decide the low frequency limits. Another test to do would be using the HDR-calculation and to compare the overall A-weighted Lw and 1/3-octave spectra from the reference sound power source but this is yet not available.

4 Summary

For the purpose to improve the acoustic photo and the ability of better separation of disturbing sources, the functions "acoustic eraser" and "acoustic extract" gives good possibilities to better find masked sources and to study relevant sources. Also the new HDR algorithm gives an excellent contrast in the acoustic photo, which was previously pretty poor, typically 5 – 15 dB, now increased up to 40 dB.

Using these new mathematical algorithms on measurements with the acoustic camera and the calculation of sound power levels from an acoustic photo have been compared with measurements of a traditional sound power reference source done in a laboratory. The results shows that it is possible to use the acoustic camera for sound power measurements and if there are disturbing sources close by it is possible to erase these or extract the relevant source. For the sound power calculations of the overall A-weighted level and with an erased disturbing source the results shows agreement with traditional sound power measurements in labs and the error is less then 1 dB. However if doing frequency analysis then one must consider the width of the microphone array lobes and the distance between sources, when using the erase and extract functionality, due to that the calculation of the low frequency parts will be based on both sources. With the erase / extract function it is very easy to separate each of the relevant sources and to find masked sources and along with HDR it gives new tools for analysis of acoustic photos from the acoustic camera.

References

[1] M. Carré, Sound power estimation with an acoustic camera, *Master Thesis, Luleå University of Technology*, Luleå, 2010.

[2] D. Döbler, R. Schröder, G. Heilmann, Successive deletion of main sources in acoustics maps working in the time domain, *Inter-Noise 2010*.

[3] GFaI, Manual for Noise Image 4, *Chapter 9 Calculation option*, Berlin, 2011