Acoustic sources distribution reconstruction from non-synchronous sound pressure measurements

Sébastien BARRÉ [1]; Christof PUHLE[1]; Steffen Schmidt[1]

[1] GFaI e.v., Berlin, Germany

ABSTRACT

Acoustic holography arrays with high microphone density are often needed to enable high localization and frequency resolution of the reconstructed source distribution. Nevertheless, when investigating the properties of large objects with holography systems, one is confronted with the inherent limitation of the number of microphones and acquisition channels a system can have. To overcome these constraints, without compromising the quality of the resulting map, a measurement method has been developed in which multiple measurements are performed sequentially. The resulting pressure information is used to reconstruct the acoustic field over the entire object and particular attention is given to the distortion caused by sources outside the area covered by the array. This paper details the computational processing and the data collection of the method. The last section is devoted to present and discuss the results of an experimental validation.

Keywords: Acoustical Holography, HELS, SONAH, Microphone Array I-INCE Classification of Subjects Number(s): 74

1. INTRODUCTION

Planar near-field acoustic holography, introduced at the beginning of the 1980's (1), is now recognized as a powerful method for localizing sound sources and particularly adapted to analyze modes of a vibrating structure. Its only dependence on the emitted acoustic energy makes it a fully non-contact measurement procedure and has also the advantage of being rapid. Nevertheless, the discrete spatial Fourier transform (DSFT) on which it is based undergoes limitations: the spatial resolution of the measured pressure grid (i.e. the shortest distance between two microphones) must be finer than half the wavelength of the highest frequency of interest. Moreover, to avoid severe spacial windowing effects, it is necessary to use a measurement grid that is significantly larger than the radiating surface. Several methods that address the latter problem have since then been introduced, among them the Helmholtz Equation Least Squares method (HELS) introduced by Wu et al. (2, 3, 4), and the Statistically Optimal Near-field Acoustical Holography (SONAH) proposed by Steiner & Hald in (5) avoid the DSFT by doing a least square fit of the sound field at the emitting plane. The artifacts from the windowing of the DSFT being eliminated, it is now possible to perform measurements on surfaces that only partially cover the emitting area.

In a previous study (6), we presented measurements of a vibrating plate and compared the results of SONAH and HELS analysis to the one given by a laser vibrometer. The results from this reference are based on measurements performed with an array covering the overall area of the plate. In the present investigation, we performed measurement on the same plate using a smaller array with higher microphone density. The aim being to assess the spatial and the frequency resolution refinement obtained by using this method. The present paper is structured as follows: first a brief overview of the developments in patch NAH is given, then the measurement setup is presented, together with the holography analysis and the comparison with the results of the Laser Vibrometer. Particular attention is given to the spurious effect that may appear when the area covered by the array is placed close to high level sources without directly including them. Final conclusion and further studies are discussed.

[1]barre@gfai.de

2. PATCH NEAR-FIELD ACOUSTIC HOLOGRAPHY MEASUREMENT

Additionally to the HELS and SONAH methods mentioned previously in section [1] and also briefly presented in (6) several approaches have been examined to overcome the limitation of the NAH algorithm based on the DSFT. In the method of superposition, first suggested by Sarkissian (7), the field on, and close to the measurement surface is approximated by the field produced by an equivalent source distribution placed on a surface at the emitting structure. Boundary conditions on the measurement surface are then applied in order to evaluate the source strengths. In another method, the partially measured pressure field is extended into the exterior region of the array by using an iterative restoration algorithm (Lee et al. presented in (8)) or by using the method of superposition (9). The pressure map is then projected onto the source surface using conventional algorithm. A variant of this method has also been proposed: a one-step procedure using Tikhonov regularization with generalized cross validation (10). A comparison of SONAH and the regularized extension by iteration algorithms (11) ended up to the conclusion that both methods have similar results, with a slight advantage to SONAH that is most efficient in computing times.

A fundamentally different approach is to reconstruct the transfer matrix representing the propagation between the emitting structure and the consecutive positions, as if the measurements were done simultaneously. In such a method, the difficulty arise principally from the loss of the phase relationship between the consecutive positions. One strategy to solve this problem is to use reference microphones that continuously measure the acoustic field at judicious positions, and reconstruct the phase relationship in post-processing. However, the number of reference microphones must be at least as high as the number of uncorrelated sources in the emitting surface for the reconstruction to be successful. Antoni in Ref. (12) and Yu in Ref. (13) addressed the transfer matrix reconstruction from non simultaneous measurements without continuous reference data.

The aim of the measurements presented in the paper is to investigate the benefits of using an array of high microphone density in patch holography to increase the spatial resolution and the high frequency limit for the localization of acoustic sources. A simple reconstruction method based on SONAH algorithm has been selected and, after preliminary measurements with several size of overlap and contiguous regions, it has been decided to add an overlap extended over 3 microphone positions. The acoustic pressure map is then computed for each position over the overall emitting area, and simply combined together by averaging the results at each point.

3. EXPERIMENTAL SETUP

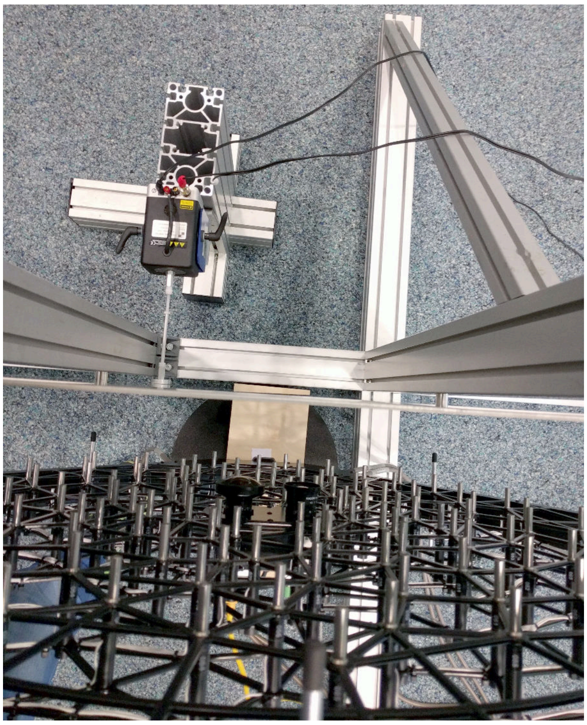
For the purpose of our assessment, a series of measurements has been performed *using two arrays* on a point-driven vibrating steel plate (a stainless steel plate of dimension 600 mm x 600 mm x 4 mm; fixed to an aluminum frame at each corner with bolts using a torque of 10 Nm). The results of a multi-patch measurement were compared to the one based on a single measurement performed with the Fibonacci 120 multipurpose array. Additionally, a laser vibrometer scan was performed on the 510 x 510 mm central area of the vibrating plate during an overnight measurement session. The data acquisition was completed using a Polytec PSV-500 Scanning vibrometer at 5 kHz using 1600 FFT lines and 66 % overlap.

The following devices were used during the measurement sessions:

- PCB SmartShaker™ with Integrated Power Amplifier, Model K2007E01
- An RME Fireface™ UCX external soundcard controlled from the measurement PC to output the excitation signal
- A white noise excitation signal
- AcousticCamera mcdRec721B data acquisition system, each measurement sampled at 192 kHz
- NoiseImage™ recording and analysis Software

The Polytec scanning presentation software was used for the Operating deflection shape analysis. Both measurement sessions took place in a quiet room at the GFaI offices in Berlin. The experimental setup for the acoustical holography measurement is presented Figure 1. The picture [1b] on the right depicts the setup with the vibrating plate, the shaker, and the AcousticCamera Fibonacci array (FA). The picture [1a] on the left is a front view with the multi-patch frame array. It is composed of a mesh of 10x10 microphones spaced each at a 25 mm interval. The mesh is fixed on a movable structure with a mechanical positioning system to ease the handling and the measurement process. The microphone arrays were placed 10 cm from the vibrating plate.

(a)



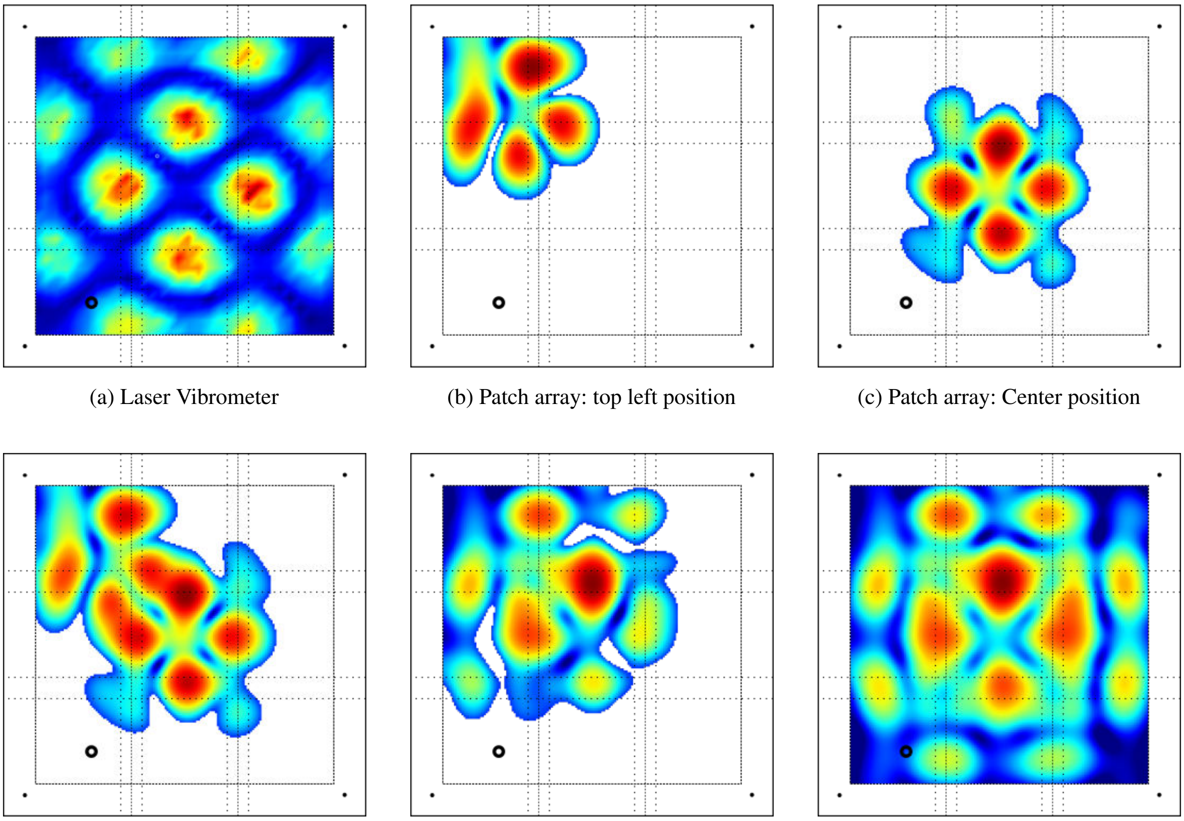
(b)

Figure 1 – Experimental setup with the microphone arrays: (a) front view with the multi-patch grid and (b) top view showing the shaker and the Fibonacci array.

4. RESULTS PARTIAL MEASUREMENTS

The pictures presented figure [2] give a schematic representation of the vibrating plate on which the partial results from single patch measurements at 817 Hz are depicted. The outer square of the schematic represents the vibrating plate, and the inner square is the 510 x 510 mm area scanned by the laser vibrometer. The positions of the microphone mesh are indicated by the horizontal and vertical dashed lines.

The top left picture [2a] depicts the analysis from the data collected with the laser vibrometer at 820 Hz. The top middle and top right pictures ([2b] and [2c]) represent the holography results from two partial measurements (SONAH algorithm with Particle Velocity). They give a well representative illustration of the spurious effect resulting from sources located outside the region covered by the microphone array: the two lower phantom sources appearing picture [2b] are projections of the higher level real sources situated outside, but very close to, the area covered by the array (sources which can be seen at [2c], the energy arising from these sources reaches the microphone of the array, and the reconstruction algorithm project the sources back on the emitting surface at an erroneous position). Figure [2d] depicts the mean of both analysis presented in [2b] and [2c]. The spurious effect is here particularly apparent because of the higher level and proximity of the sources. In the present study, no specific correction has been implemented to address for this distortion. Only an averaging will be applied over the 9 measurements to reconstruct the final acoustic pressure hologram. The results depicted figure [2e] and [2f] show that the averaging over multiple measurements partially correct for the distortion and the phantom sources.



(a) Laser Vibrometer (b) Patch array: top left position (c) Patch array: Center position

(d) Top Left and Center (e) Four Top Left Positions (f) Overall result 817 Hz

Figure 2 – Partial results of the vibrating plate: [a] results from the laser vibrometer at 820 Hz, [b] to [e] partial results at 817 Hz and [f] final result from multi-patch acoustic holography.

5. FINAL RESULTS AND DISCUSSION

For comparing the results of the laser vibrometer measurement and the acoustical holography methods, the results of the vibrometry method were confronted to the holography pressure maps obtained from the measurement with the patch array and the Fibonacci array. All plots that follow (Figure [3] to [10]) present the result from the laser vibrometer (left), the holography results with patch array (middle), and results with spiral array (right). For a better comparison, all plots show the same section of the plate, i.e. the section of dimension 510 x 510 mm that was scanned be the laser vibrometer. Since the acoustic measurements and the one from the laser Vibrometer were done at two separate sessions, light shifts between modes frequencies appeared (with an exception at 725 Hz).

Only SONAH results have been reproduced because HELS uses evanescent waves which have a short wavelength and decay exponentially with the distance to the source. The measurement distance of 10 cm clearly limited its performance. Since there are no microphones at the very center of the Fibonacci array (in order to place optical cameras), the acoustical holography results show tendencies to deviate in the center of the reconstruction area (see e.g. the reconstructed pressure map of Figure 7).

The results show that a higher spatial and frequency resolution could be reached using an array with higher microphone density and performing sequential measurements to cover larger emitting areas (see results at frequencies above 1000 Hz, Fig. [6] to [9]). The reconstruction method being rather simple, there is perspective for improvement by correcting for the spurious effect caused by neighboring sources using e.g. the method of expansion. This method could also be implemented to interpolate the data in the central region of the spiral array where pressure data are not available.

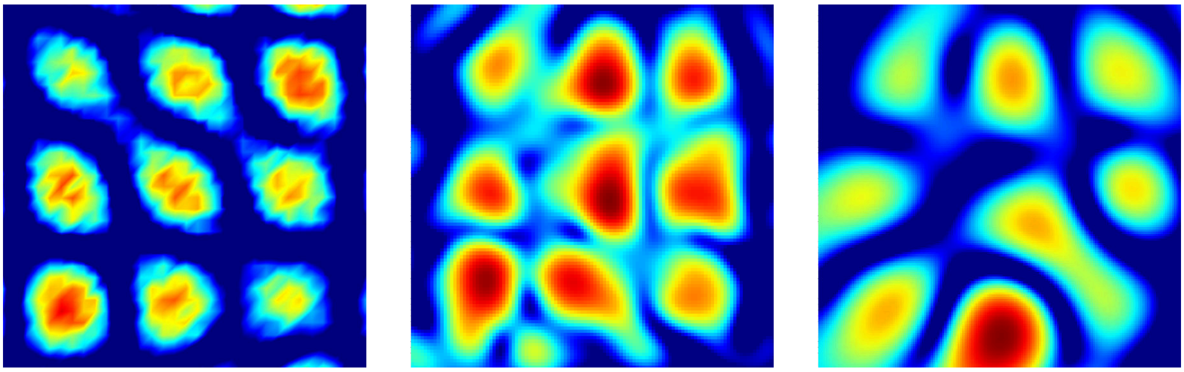


Figure 3 – Laser vibrometer at 725 Hz 14 dB dynamic (left), SONAH with patch (middle) and SONAH with FA (right) at 703 Hz

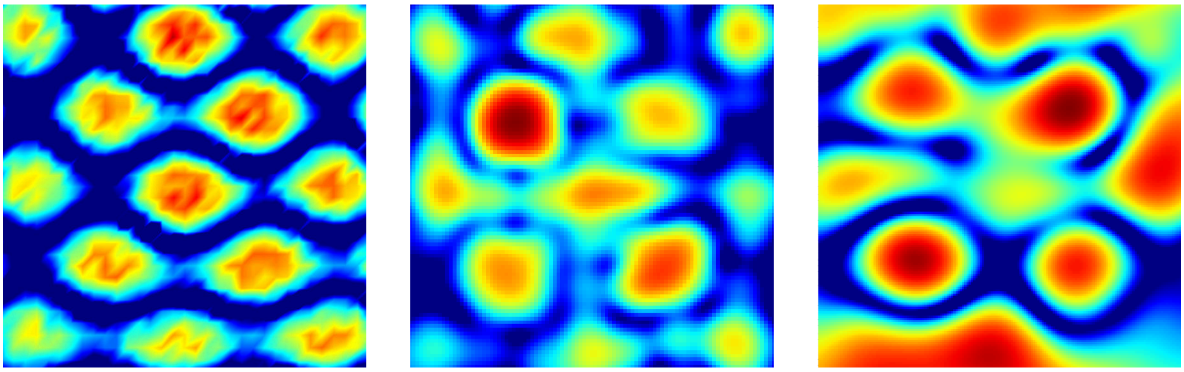


Figure 4 – Laser vibrometer at 802 Hz 17dB dynamic (left), SONAH with patch at 796 Hz (middle) and SONAH with FA at 806 Hz (right)

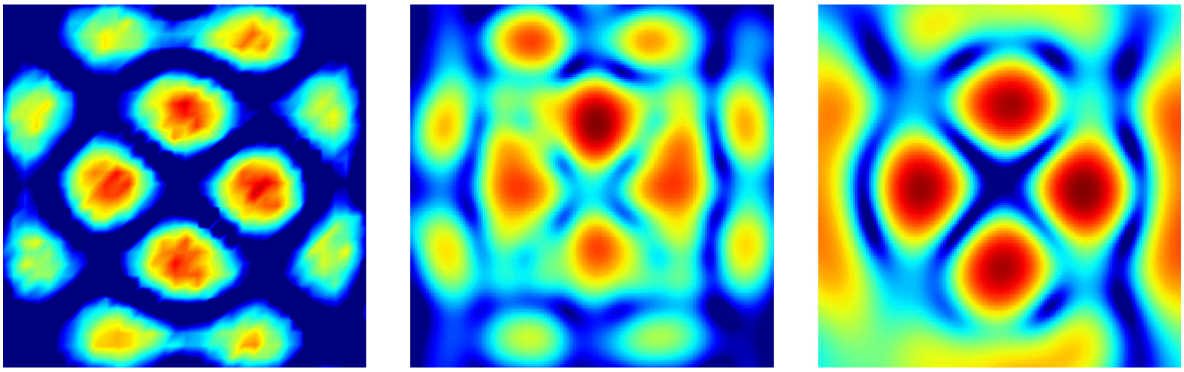


Figure 5 – Laser vibrometer at 820 Hz 17dB dynamic (left), SONAH with patch (middle) and SONAH with FA (right) at 817 Hz

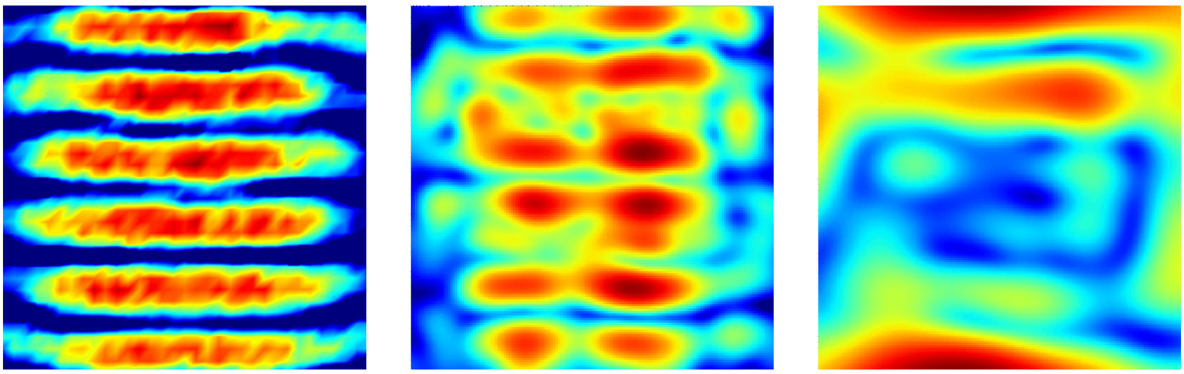


Figure 6 – Laser vibrometer at 1130 Hz 17dB dynamic (left), SONAH with patch (middle) and SONAH with FA (right) at 1131 Hz

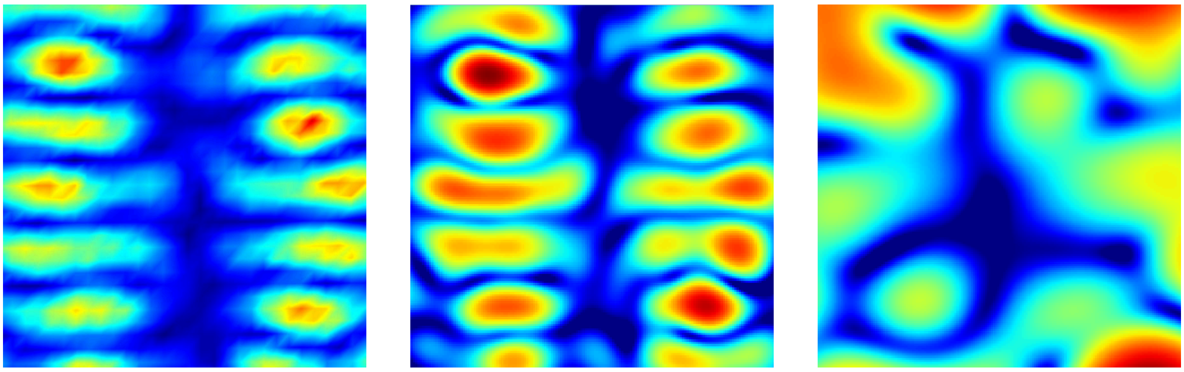


Figure 7 – Laser vibrometer at 1570 Hz (left), SONAH with patch (middle) and SONAH with FA (right) at 1559 Hz 17dB

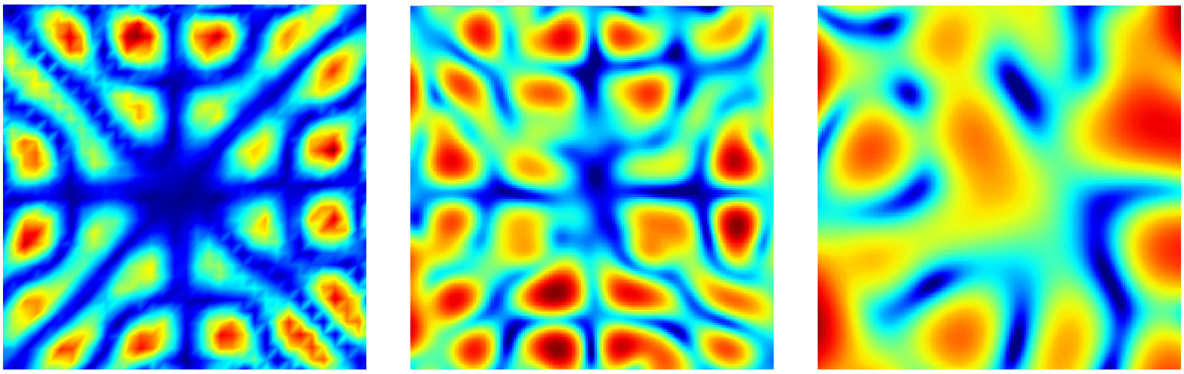


Figure 8 – Laser vibrometer at 1770 Hz (left), SONAH with patch (middle) and SONAH with FA (right) at 1767 Hz

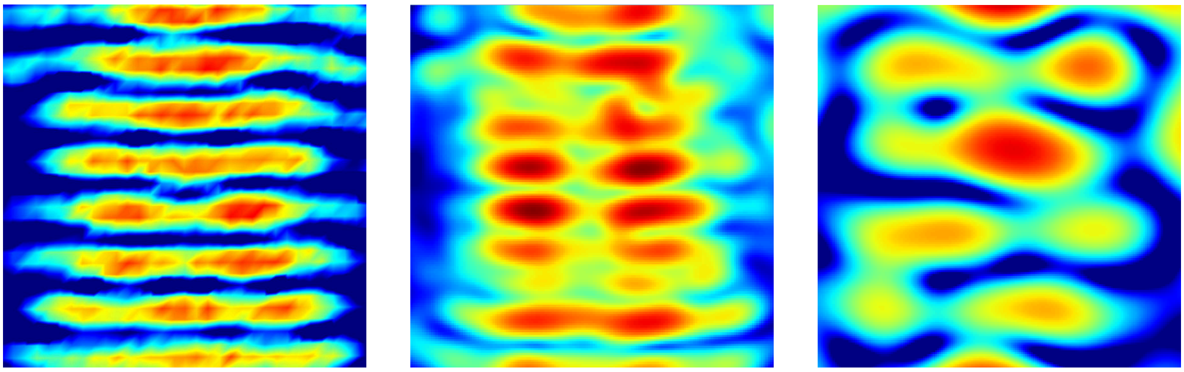


Figure 9 – Laser vibrometer at 1900 Hz (left), SONAH with patch at 1901 Hz (middle) and SONAH with FA at 1898 Hz (right)

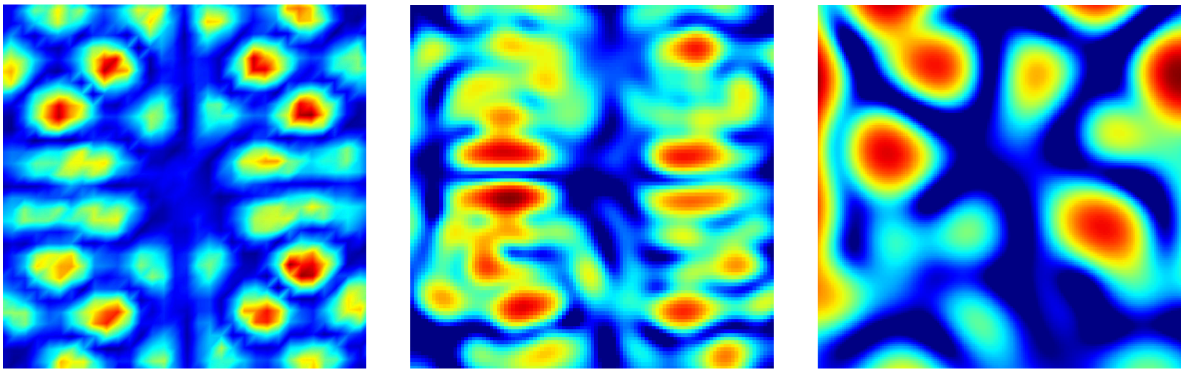


Figure 10 – Laser vibrometer at 1980 Hz (left), SONAH with patch at 1978 Hz (middle) and SONAH with FA from 1972 to 1986 Hz (right)

6. ACKNOWLEDGMENT

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