Active Structural Acoustic Control in an Original A400M Aircraft Structure

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Abstract. Low frequency noise has always been a challenge in propeller driven aircraft. At low frequencies passive noise treatments are not as efficient as active noise reduction systems. The Helmut-Schmidt-University has built up a full-scale test rig with an original A400M aircraft structure. This provides a good opportunity to develop and test active noise reduction systems in a realistic environment. The currently installed system consists of mechanical actuators and acoustical sensors. The actuators are called TVAs (Tuneable Vibration Absorber) and contain two spring-mass systems whose natural frequencies are adjusted to the BPFs (Blade Passage Frequency) of the propellers. The TVAs are mounted to the frames and the force direction is normal to the skin. The sensors are condenser microphones which are attached to the primary structure of the airframe. The TVAs are equipped with signal processing devices. These components carry out Fourier transforms and signal amplification for the sensor data and actuator signals. The communication between the TVAs and the central control unit is implemented by the CAN Bus protocol and mainly consists of complex coefficients for the sensor and actuator data. This paper describes the basic structure of the system, the hardware set-up and function tests of the controller.

1. Introduction

The A400M (Figure 1) is a newly developed aircraft, powered by four turboprop engines. These engines face the challenge of a characteristic signature dominated by multiple pure tones which makes this aircraft particularly suitable for tests with active noise reduction systems for tonal low frequency disturbances.

Figure 1. A400M [1] © Airbus S.A.S

The Helmut-Schmidt-University was made available an A400M pre-series fuselage for test purposes. The fuselage was integrated in a test environment (Figure 2 and Figure 3) and first structural dynamic tests were successful ([1][3][4]).

Figure 2. Fuselage within the framework of the building

Figure 3. The complete test environment

The main purpose of the work described in this paper was to install an active noise cancellation system with mechanical actuators and acoustical sensors in an original full-scale aircraft structure. The idea was to make use of the unique opportunity of the available aircraft structure built by Airbus together with the perfectly matching sensors and smart actuators developed by Ultra Electronics. The latter so called Tuneable Vibration Absorbers (TVAs) come with a firmware and use the CAN bus protocol. The sensor and actuator allocation was derived from airbus documentation. Furthermore, the Rapid Control Prototyping (RCP) system from dSPACE is used as central control unit. The software implemented on the RCP like e.g. the CAN communication and the multiple input multiple output control algorithm was developed and implemented by HSU. Also power supply and wiring of the whole system was done by HSU. The communication with CAN bus is a considerable innovation. The consequential digital communication together with the distributed signal processing is advantageous for the weight and effort of the wiring harness for a high number of sensors and actuators.

2. System description

2.1. General aspects of active noise reduction

One important method for active noise reduction in aircraft cabins is using inertial shakers as secondary sources and microphones as error sensors. The principle of such systems is to control the radiated sound from vibrating structures. There are several references like [5], [6] and [7] which define these systems as Active Structural Acoustic Control (ASAC), although there are differences between the definitions. ASAC in this paper represents an active noise reduction system with mechanical actuators and acoustical error sensors which reduces the sound pressure level inside the aircraft cabin by changing the vibration of the primary structure. Figure 4 illustrates the main components and the principle of ASAC systems in aircrafts.

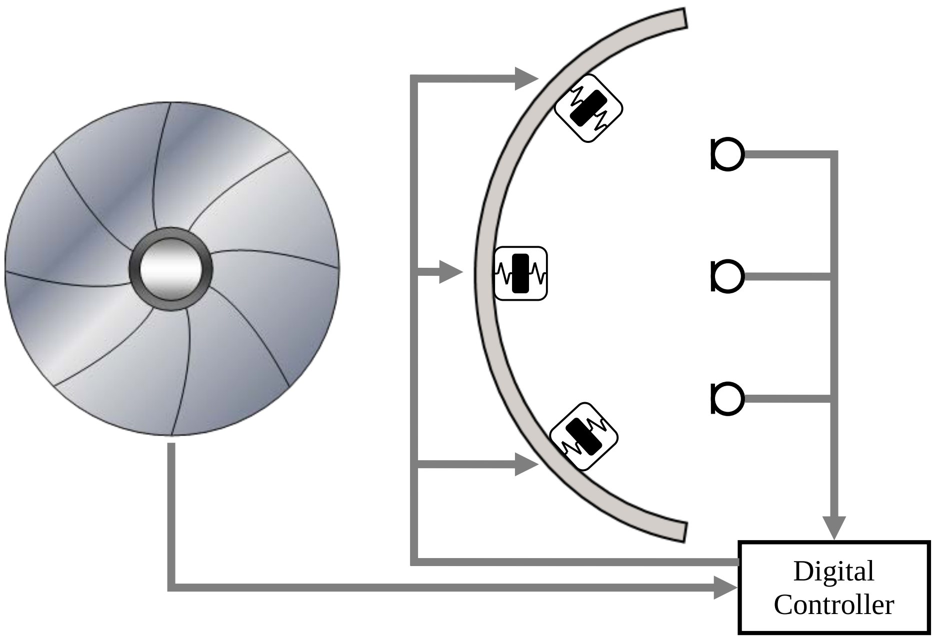

Figure 4. Active Structural Acoustic Control (ASAC) in Aircraft Cabins

The digital controller uses a reference signal from the engines and the error signals from the microphones to calculate the secondary signals. The calculation can be done by a Least Mean Square (LMS) algorithm which adjusts the coefficients of an adaptive filter. Figure 5 shows the corresponding block diagram for the Filtered Reference Least Mean Square (FxLMS) algorithm which can be derived from references like [8] and [9].

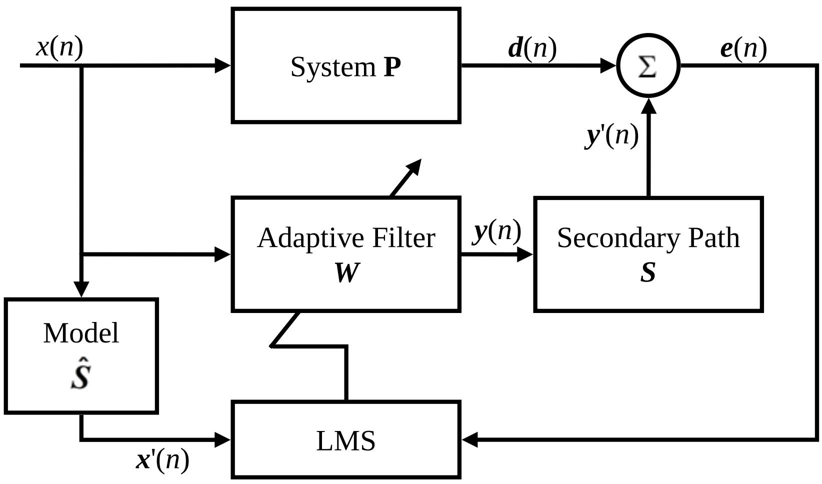

Figure 5. Filtered Reference Least Mean Square (FxLMS) block diagram with reference signal *x(n)*, disturbance signal *d(n)*, error signal *e(n)* and control signal *y(n)*

2.2. *Sensors and actuators*

The secondary sources used in the currently installed system are called Tuneable Vibration Absorber (TVA) (Figure 6) ([10][11]) and consist of two spring-mass systems whose natural frequencies are adjusted to the Blade Passage Frequencies (BPFs) of the propellers. The TVA housing contains a board with a DSP for signal processing and amplifying and three sensors: one accelerometer and one force sensor for each spring-mass system. Two condenser microphones (Figure 6) are connected to each TVA. The TVAs need a power supply of 70 V DC. The TVAs combined with the two error microphones each were designed by Ultra Electronics for A400M. Corresponding work on active noise reduction systems by Ultra Electronics can be found in [12], [13] and [14].The communication between the TVAs and the central control unit is implemented by the CAN bus protocol. There are only complex coefficients and frequency values which are transferred between the different components. The current frequency is given by the central control unit and is valid for sensor as well as actuator data. The analogue sensor signals are transformed into the frequency domain to obtain magnitude and phase information. The TVA board generates an analogue signal from the actuator coefficients for the voice coil which drives the spring-mass systems.

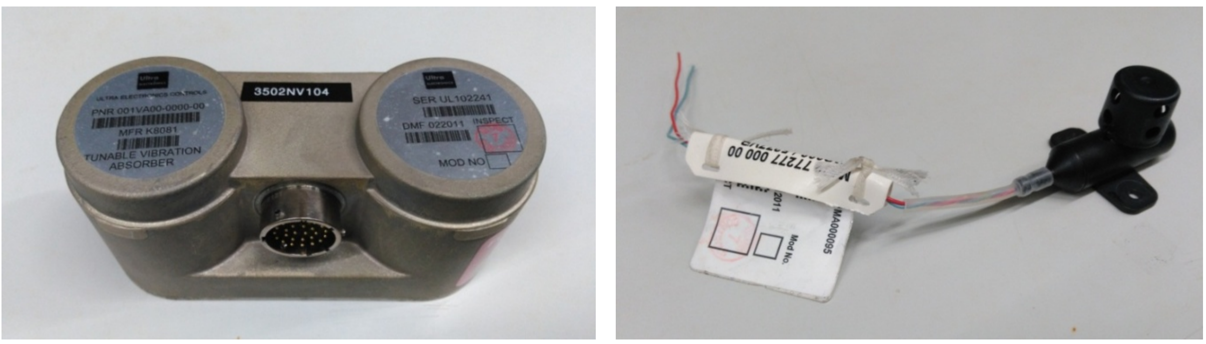

Figure 6. Tuneable Vibration Absorber (TVA) and error microphone

2.3. CAN communication

As mentioned in chapter 2.2., the data link between TVAs and control unit is implemented by CAN bus. CAN bus is a serial communication system which is here standardized by ISO 11898 with high speed medium access and extended identifier format.

Information on the bus is sent in frames (Figure 7) which are divided into different fields. The only interesting parts for the user are the identifier, which is part of the arbitration field, and the data field.

Start of frame	Arbitration field	Control field	Data field	CRC field	ACK field	End of frame

Figure 7. CAN frame structure [15]

The identifier contains information about the purpose of the message and the TVA number. The purpose might be to send actuator coefficients to a particular TVA. The data field then contains the value of the coefficients which are binary coded with a length of up to 64 bits. In this case a 64 bit data field can transmit four different coefficients which leads to a word length of 16 bits.

2.4. Control algorithm

The basic structure of the control algorithm could be derived from the FxLMS described in Section 2.1., but with the main difference of the digital communication by CAN bus. Figure 8 shows the block diagram of the full TVA system. The disturbance signal is generated within the Simulink model and put out by loudspeakers as primary sources. Because of the CAN communication with frequency domain values the adaptation is also done in the frequency domain. The coefficients derived by the LMS algorithm do not have to be multiplied by the reference signal, because the signal in the frequency domain is represented by a real constant. The frequency in the current version of the system is assumed to be known. There has to be some kind of reference signal with information about the current phase which is used to synchronize the whole system via CAN bus. The reference is obtained from an accelerometer mounted on the membrane of the primary source.

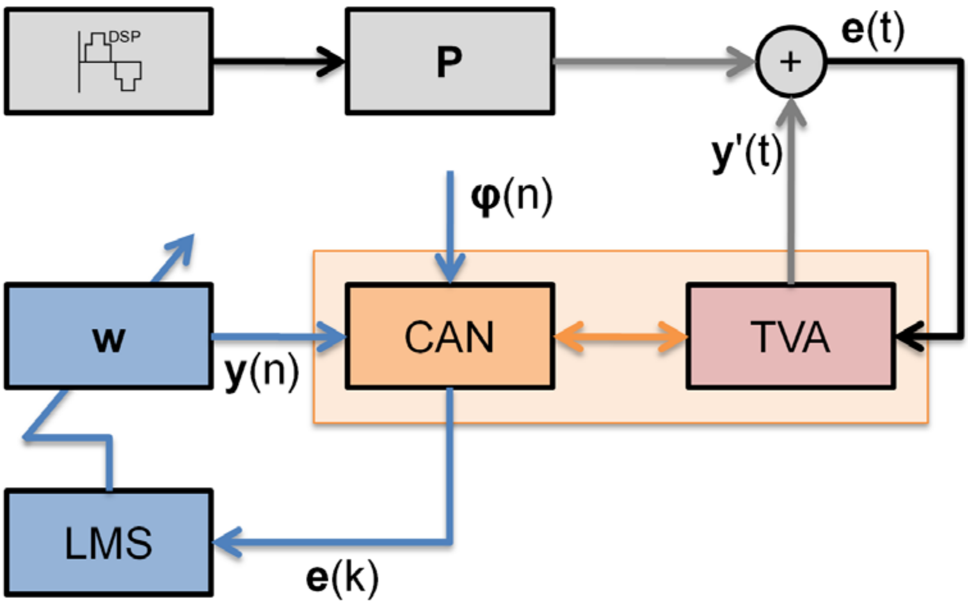

Figure 8. Block diagram of the TVA system. The current phase φ(n) is obtained from the reference signal

3. Hardware set-up

The members of a CAN system are arranged by line topology and the number of nodes are, in this case, limited to 20. Since the installed system comprises 160 TVAs there are eight CAN channels with 20 TVAs each. Figure 9 shows the arrangement of the CAN channels schematically. Two error microphones are connected directly to each TVA, which leads to a total amount of 320 error sensors. The power supply is integrated into the cabling by a special switch box. All CAN channels are connected to the central control unit (CU1).

There are low-pass filters and an amplifier (LP+Amp) for the primary signal and for the reference signals. The reference from the accelerometer has already been described in Section 2.4. The signal from a microphone located outside the fuselage is used as a reference for the sound field mapping system (SFMS). The SFMS is used for measuring the noise reduction performance inside the fuselage, compare Section 4. There is another control unit (CU2) for the mapping system which enables fully automatic measurements. Both control units are operated by a standard PC. Figure 10 is a partial view of the TVA system inside the fuselage.

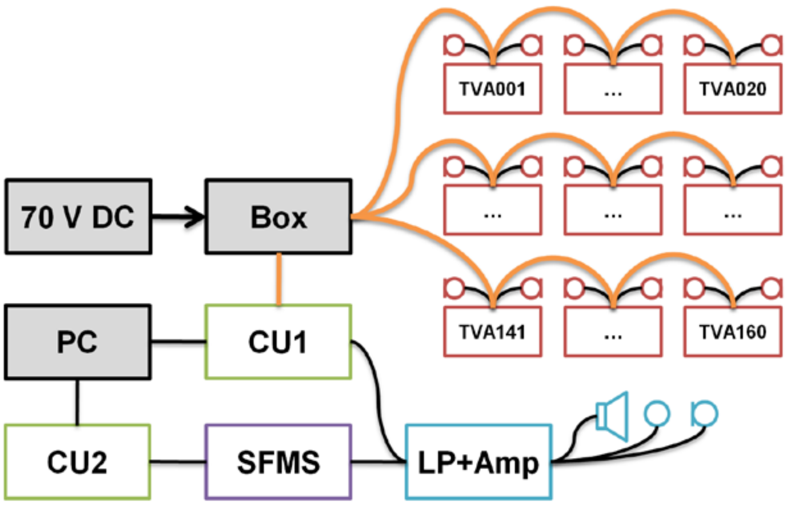

Figure 9. Hardware set-up of the TVA system

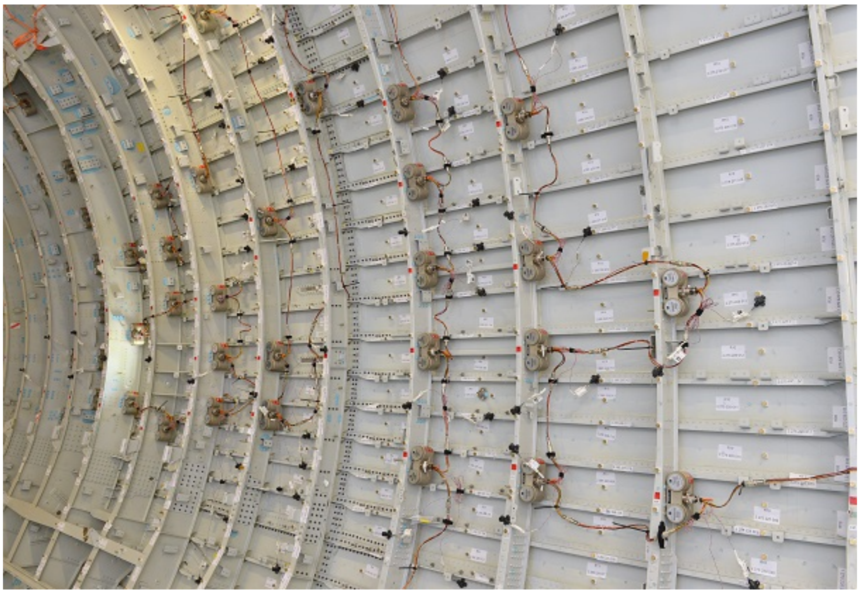

Figure 10. Fuselage section with mounted TVAs

Figure 11 (left) shows one TVA with an error microphone and the wiring harness in detail. The control unit (CU1) for the TVA system can be seen in Figure 11 (right), together with the switch box and the power supply. Finally, the primary source with reference sensors is depicted in Figure 12.

Figure 11. Detail view of one TVA (left), TVA system controls inside the fuselage (right)

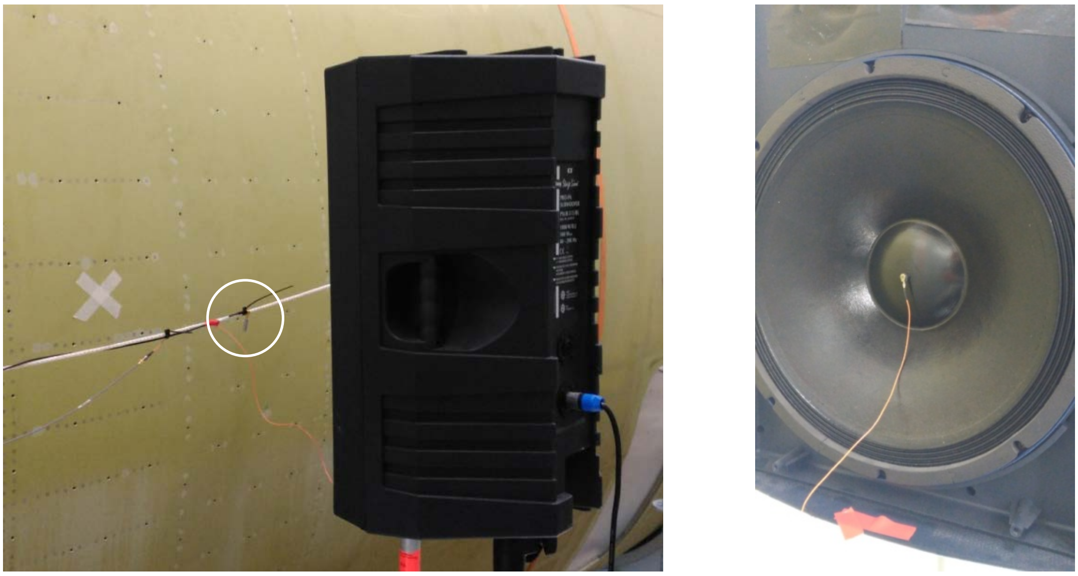

Figure 12. Primary source in the propeller plane outside the fuselage, with reference microphone (white circle) and accelerometer

4. Sound field mapping system

The performance of the noise control system is measured by a sound field mapping system. It consists of a microphone array shown in Figure 13 which can be automatically positioned along the longitudinal axis of the fuselage. There are 108 microphones in six rows and a grid of 270 mm in all dimensions.

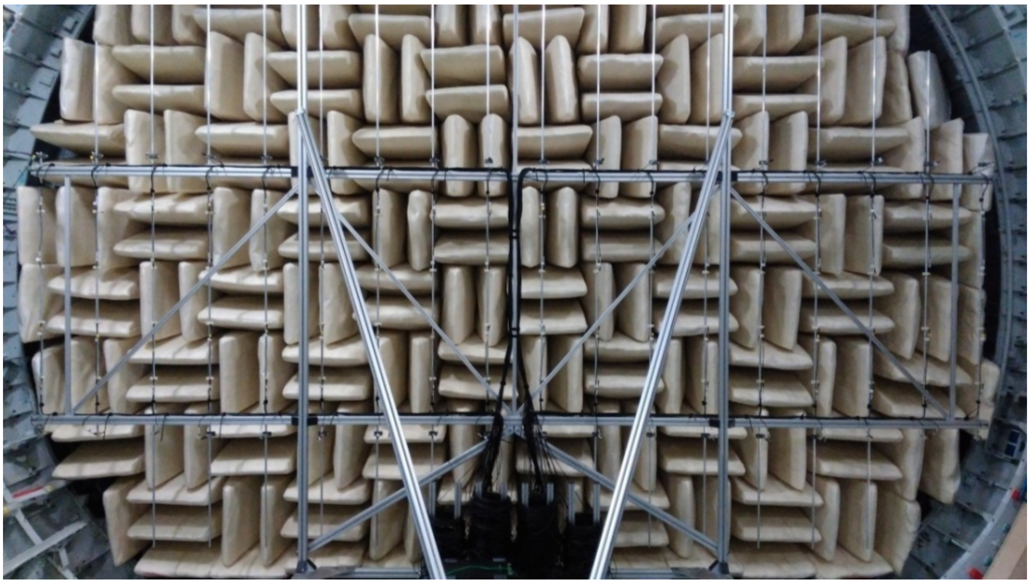

Figure 13. Microphone array of the sound field mapping system

5. Performance tests

Since the TVA system was designed for control of tonal disturbances, some interesting frequencies were chosen in the range of the first two BPFs. For each frequency the sound field measurement was taken for the primary field and for the controlled field.

The noise attenuation was determined in three different ways, which are plotted in Figure 14. The first one was the overall reduction at the error microphones. These values only show a tendency because the microphones were just roughly calibrated. In addition, the reduction in the whole mapping area was calculated. The values of the measuring system are reliable because calibrated measuring microphones were used. Finally, a so-called TVA area was defined which represents the mapping area in which the TVAs are installed. The last noise reduction values were calculated for this area.

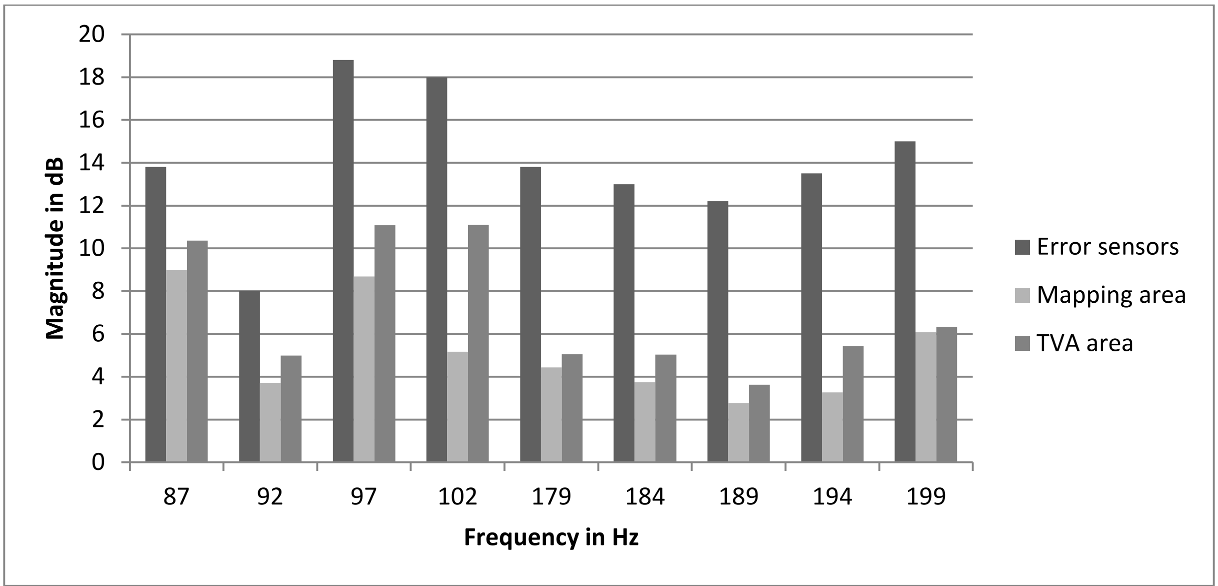

Figure 14. Noise reduction values

One example of the sound field mapping results is shown in Figure 15. The six frames of the plots belong to the six microphone rows of the mapping system where the top frame corresponds to the lowest microphone row. The frames represent the top view of the measuring planes and the left edge equals to the front side of the fuselage.

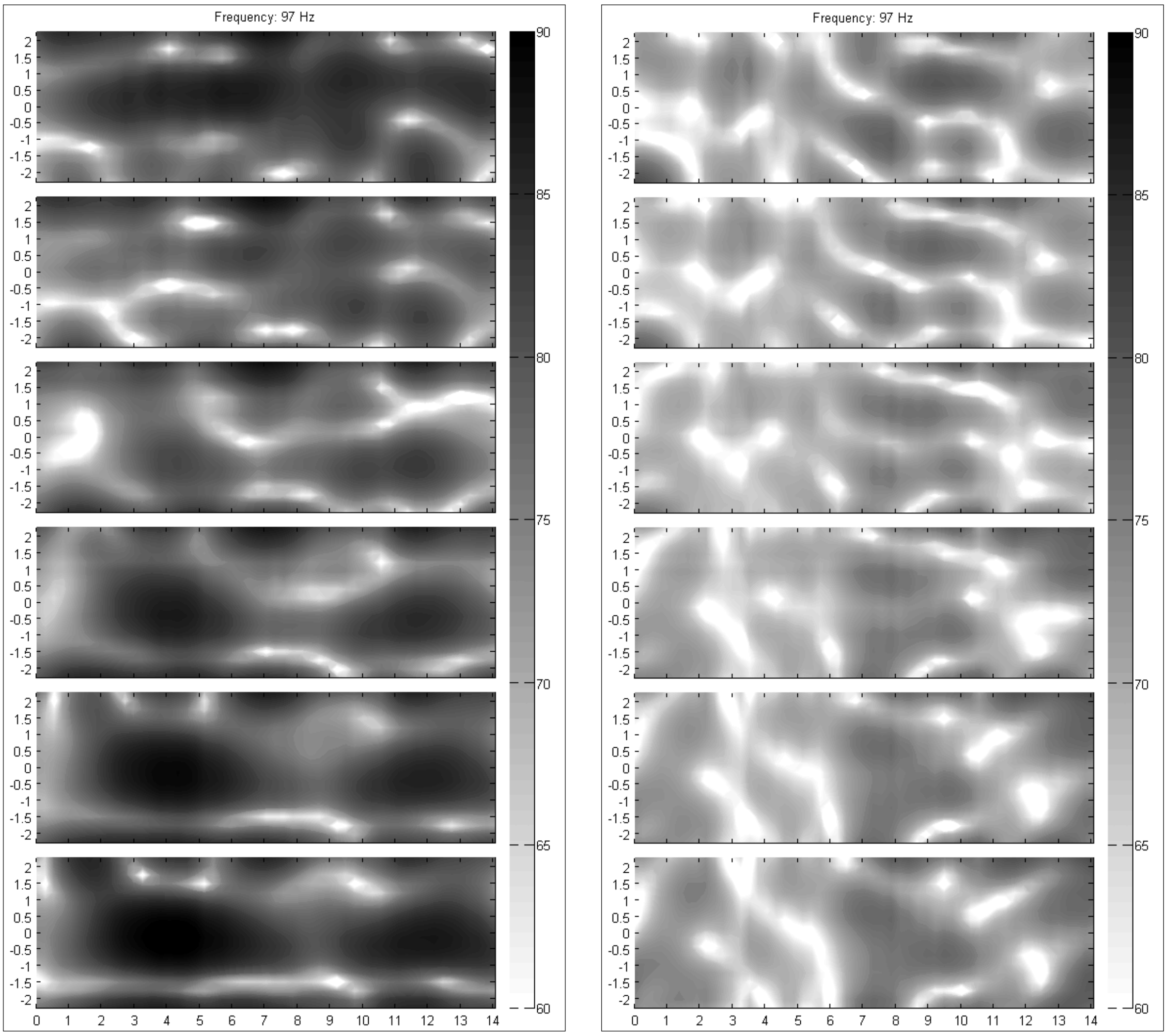

Figure 15. Sound field mapping results, ASAC off (left) and ASAC on (right)

Journal of Physics: Conference Series **744** (2016) 012185 doi:10.1088/1742-6596/744/1/012185

6. Conclusion and outlook

The work up to now comprises the first implementation which shows the operability of the system. A remarkable global noise reduction could be successfully demonstrated for several interesting frequencies. There are several changes and enhancements which can be implemented in future, for example a higher update rate for the LMS algorithm or weighting matrices for the error signals and the control effort. This can also lead to a more robust controller. The performance is expected to be increased by improvements of the algorithm and sensor and actuator allocation.

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