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NOISE CONTROL FOR A BETTER ENVIRONMENT

Ultrasound localization using beamforming

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ABSTRACT

Sound source localization based on beamforming algorithms has a great variety of different applications. In industrial and environmental sectors this technology offers a precise solution to identify the main noise sources and their frequency range. In most cases that information is then used to reduce the emitted sound level. With the same set up beamforming systems can be used to localize ultrasound emissions to find gas leakages or to work on predictive maintenance tasks. This publication presents the results of a series of tests related to ultrasound localization. Different scenarios set ups have been tested to validate the accuracy of the system.

Keywords: beamforming, ultrasounds, localization.
I-INCE Classification of Subject Number: 71

1. INTRODUCTION

There are different noise localization techniques on the market, like beamforming, holography and intensity; depending on the application, one of them is more recommended. Intensity and holography are recommended for low frequency noise sources and measuring close to the sound field. Using beamforming we can localize noise sources with a wide range of frequencies from short to long distances. In this publication all the measurements are conducted with delay and sum beamforming algorithms in the frequency domain.

Noise localization is used in a wide variety of sectors, like environmental, industrial facilities, automotive sector, building and room acoustics, transport industry or zoological applications, but mainly in the human ear frequency range. This paper shows other points of view in the noise localization applications, identifying ultrasonic frequencies.

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Focusing in the industrial sector, several applications for noise source localization are being used since years with great success, like noise sources identifications for noise control and Safety & Health purposes, leakage localization in noise barriers and cabins or noise footprint localizations for predictive maintenance, locating faulty parts [1]. The localization of sources in the ultrasound range can provide another point of view in air and gas leakages localizations related with tubes and pumps failures and in predictive maintenance, locating and analysing ultrasound emissions related to machine failure. The use of the ultrasound analysis for predictive maintenance purposes is a well known topic in the industry. The ultrasonic emissions are directly related with the malfunction in several types of machines, rotating machines, gearboxes, and engines. There are several standards about this topics, like the standard *ISO 13374 on condition monitoring and diagnostics of machines*, that establishes general guidelines about data processing of machine condition monitoring and diagnostic information; or the standard *ISO 18436-8 on condition monitoring and diagnostics of machines, Part 8: Ultrasound,* that specifies the requirements for qualification of personnel who perform diagnostics using ultrasounds. Ultrasound analysis is a proved tool to acquire useful information for condition monitoring. The P-F curves, that describes the period between the Potential failure (Detectable state) and the Functional failure (Failed state) always set the ultrasounds close to the start of failure, therefore it represents a good time set for analysing and monitoring (Figure 1). Using this acoustic camera set up, we will go one step further in addition to measure ultrasounds; we will be able to visualize it.

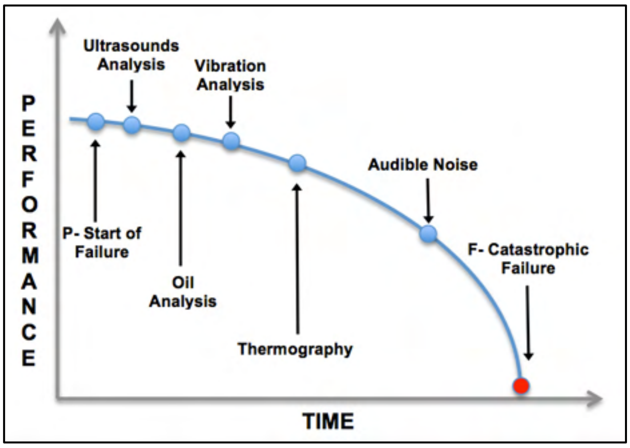

Figure 1 – P-F curve

2. MEASUREMENT PROCEDURE

2.1 Measuring System

The system used for these tests is a circular microphone array with 48 microphones (Figure 2, left). This microphone array design is optimized to provide the highest spatial resolution possible while providing a high depth of field to see all sources in one acoustic map [3]. The microphones from this array are able to measure frequencies up to 50 kHz. Although their frequency response is not perfectly flat above 20 kHz, for noise source localizations is not absolutely necessary.

About the data acquisition, a multichannel data recorder with high sampling frequencies (up to 192 KHz) was used in order to have good resolution in ultrasonic frequencies (Figure 2, right).

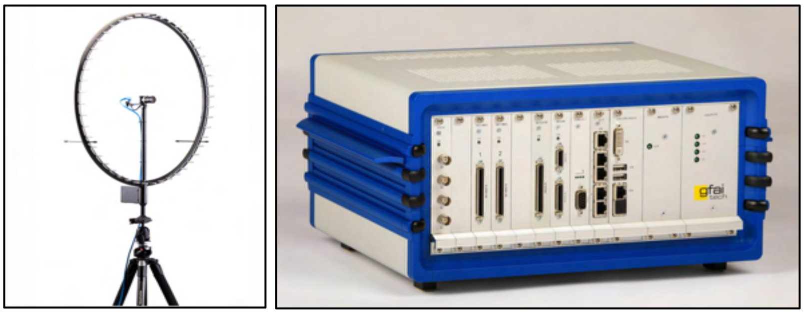

Figure 2 – Ring microphone array and data recorder used in the measurements.

2.2 Ultrasound emitters

Two piezo speakers (size: 30 mm x 13 mm) were installed in a metallic frame, 1 m distance between them. The metallic frame keep fixed the two piezo speakers in order to have the same source configuration for all the tests. The signal was generated by a module able to reproduce from 8 kHz to 48 kHz using a potentiometer.

Figure 3 – Ultrasonic piezo speakers used in the measurements

2.3 Beamforming algorithm

The Delay-And-Sum-Beamformer in frequency domain is based on a similar principle as in time domain [2]. This is the algorithm used in the data processing, which works the following way: The sound of each source travels to each microphone along different paths. This leads to delays and phases in the measured signals, which are both proportional to the travelled distances. The delays can be determined from the known distance (3, 6 or 30 meters in these tests) between the microphone array and the measurement plane in the piezo speakers set up and the speed of sound. After performing the Fourier transform of each microphone signal, the spectra are available as amplitude and phase. The phase of each individual microphone signal is shifted respect to the particular delay. The delay is carried out by the distance between each microphone and the considered point in an imaging plane (target plane). The resulting complex spectra are added up and the sum signal is normalized by the amount of microphones. If a source is present in the considered point of the imaging plane, the signals (Fourier transformed and phase shifted) of the individual microphones are interfering constructively. Without a source in the pixel, we get destructive interference. RMS and maximum values can be calculated from the sum spectrum and visualized in an acoustic map.

2.3 Measurement scenarios

Different scenarios were set in order to check from different distances and with additional noise sources:

- 1-A: Indoor. 3 meters between the microphone array and the metallic frame with the piezo speakers.
- 1-B: Indoor. 3 meters between the microphone array and the metallic frame with the piezo speakers. Air compressor with an air leakage working under the piezo speakers.
- 2-A: Indoor. 6 meters between the microphone array and the metallic frame with the piezo speakers.
- 2-B: Indoor. 6 meters between the microphone array and the metallic frame with the piezo speakers. Air compressor with an air leakage working under the piezo speakers.
- 3-A: Outdoor. 30 meters between the microphone array and the metallic frame with the piezo speakers.

3. RESULTS

For each scenario, the spectrogram is showed with the time signal on top. Then, spectral analysis selecting different frequencies ranges are used to calculate acoustic photos. In scenarios 1-A, 2-A and 3-A, only the ultrasonic range is selected. In scenarios 1-B and 2-B, different frequencies ranges are selected in order to localize the ultrasonic piezo speakers and the other noise sources (air compressor and air leakage).

In scenarios with only the ultrasound emitters, aliasing patterns appear (Figure 4). This is a common effect in ultrasonic sources, because the high directivity in very high frequencies. For this reason, the results have a threshold in order to focus the noise source localization.

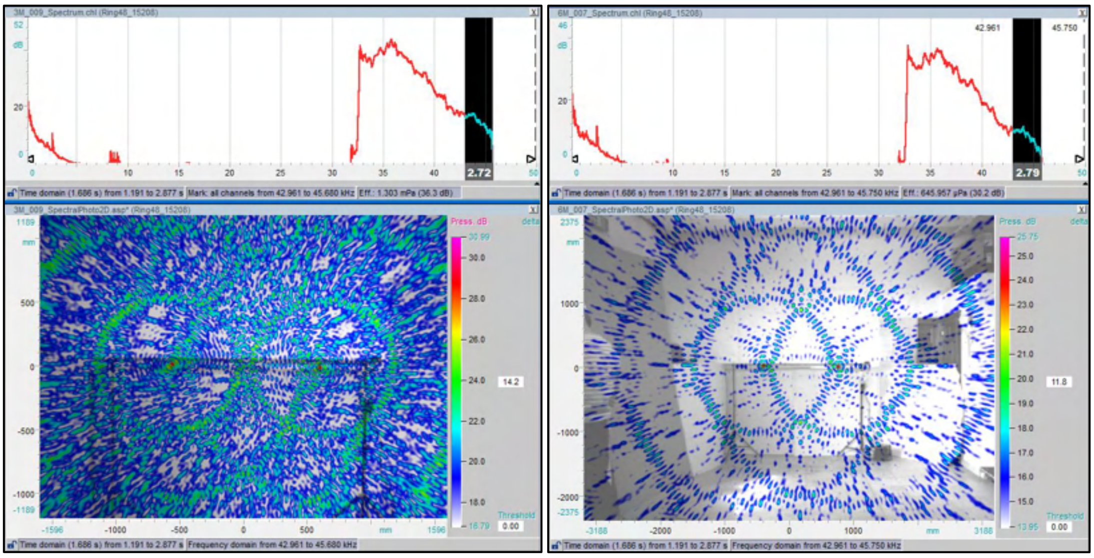

Figure 4 – Aliasing patterns in ultrasound sources

3.1 Scenario 1-A

Trough the spectrogram and the time signal, the frequency fluctuation between 32 kHz and 43 kHz is easily recognizable (Figure 5, above). Selecting the target frequency range, the acoustic photo shows a precise localization on the piezo speakers (Figure 5, below).

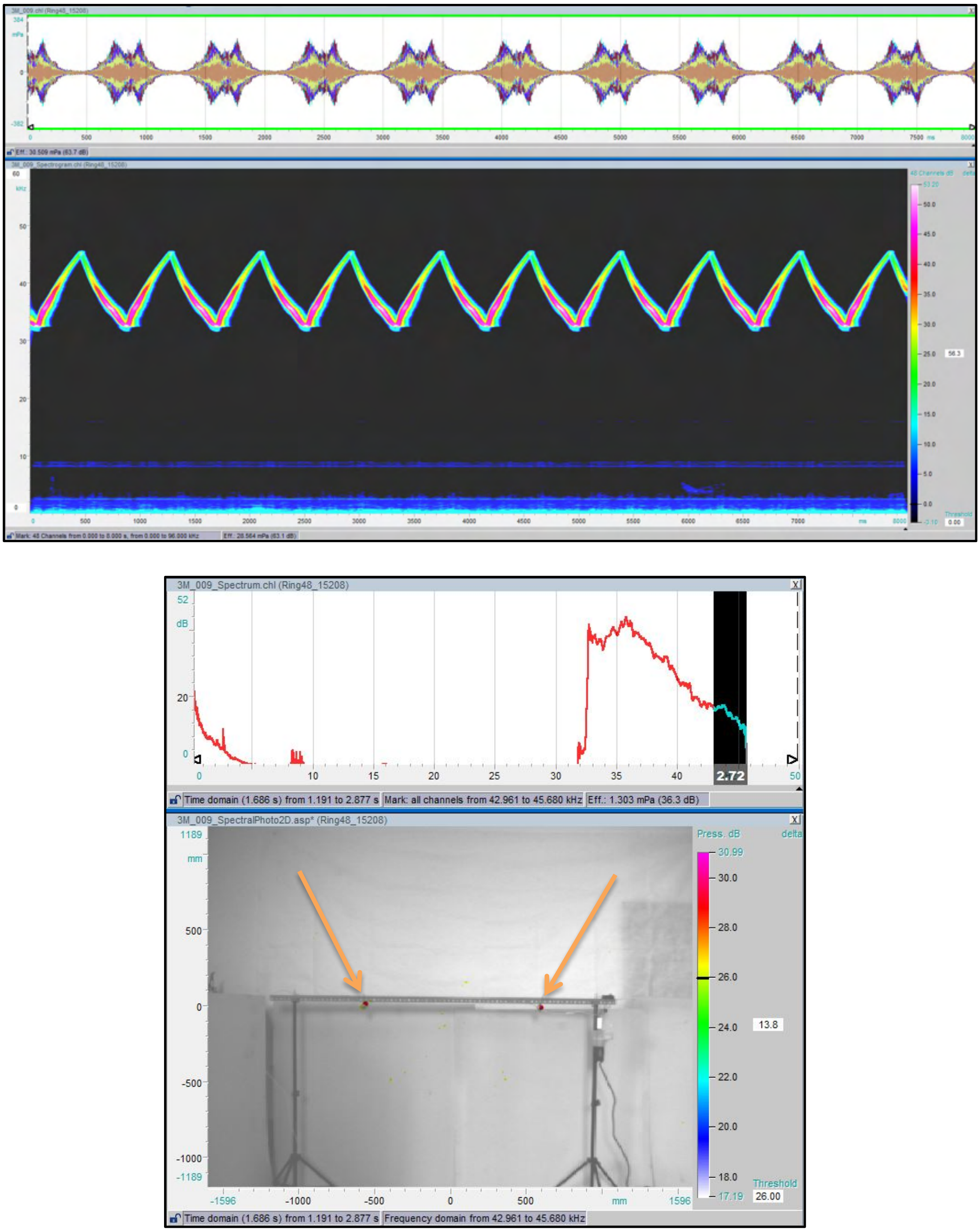

Figure 5 – Scenario 1-A results: 3 Meters

3.2 Scenario 1-B

Turning on the air compressor and the air leakage just above the piezo speakers, the ultrasonic emission is masked on the time signal but still recognizable in the spectrogram (Figure 6, above). Even selecting all the frequency range from 539 Hz to 4.6781 Hz, the piezo speakers are located (Figure 6, below). Using different frequency range selection, the different noise sources are located clearly and separately (Figure 7).

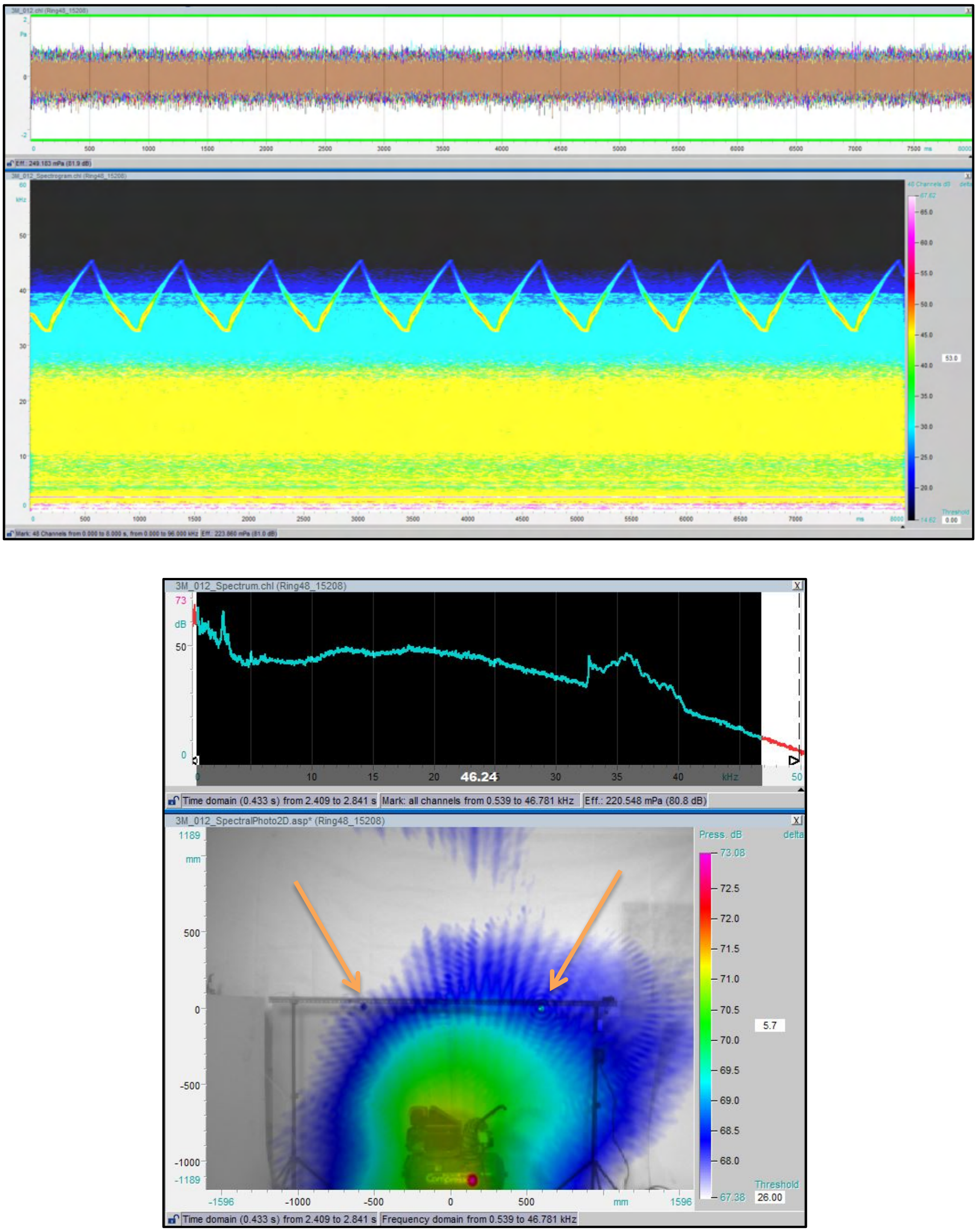

Figure 6 – Scenario 1-B results: 3 Meters, with air compressor

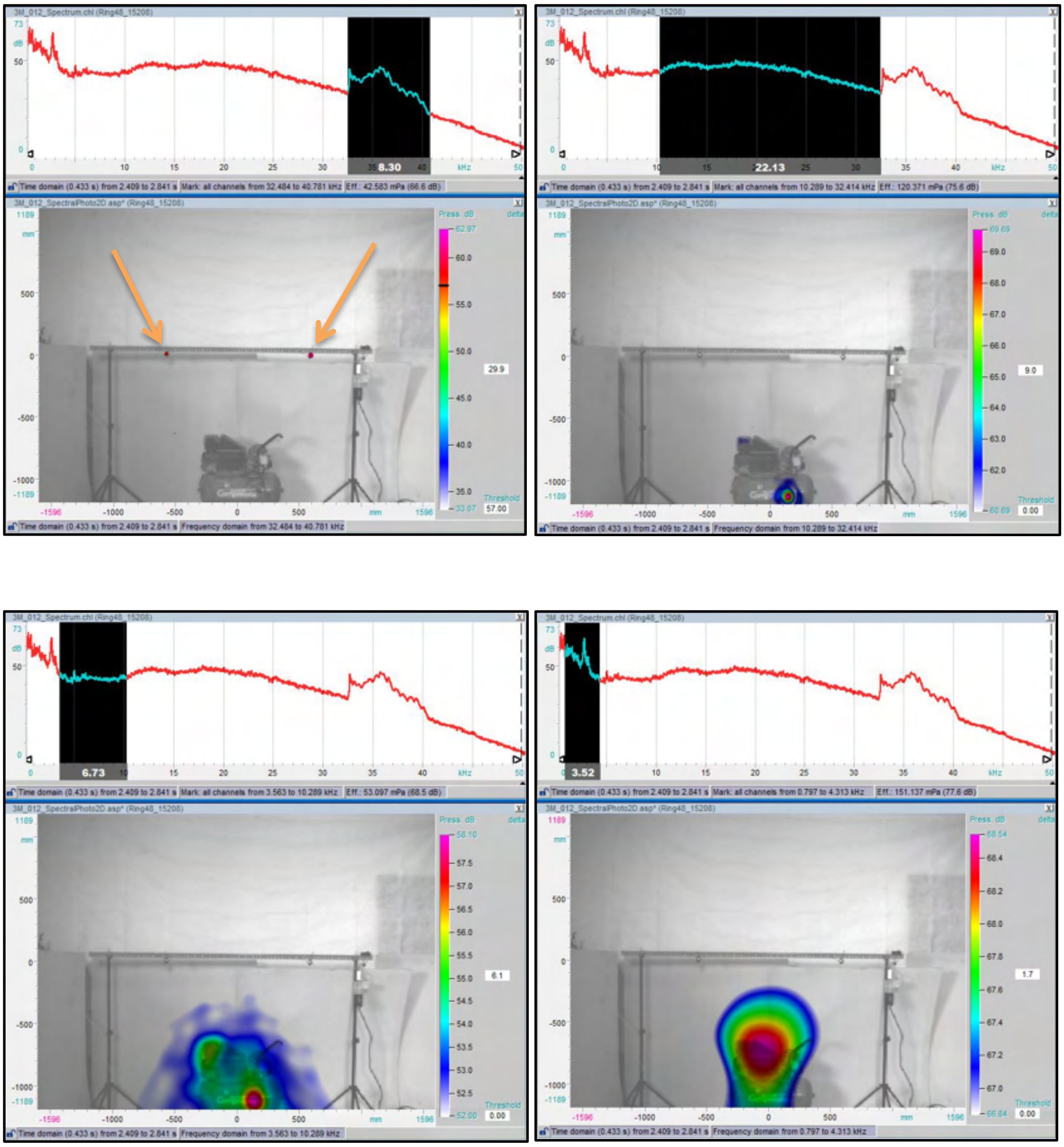

Figure 7 – Scenario 1-B results: 3 Meters, with air compressor by frequency ranges.

3.3 Scenario 2-A

Same conditions like in scenario 1-A, but 6 meters distance between the piezo speakers and the microphone array. Trough the spectrogram and the time signal the frequency fluctuation between 32 kHz and 43 kHz is still easily recognizable (Figure 8, above). Selecting the target frequency range, the acoustic photo shows a precise localization on the two piezo speakers (Figure 8, below).

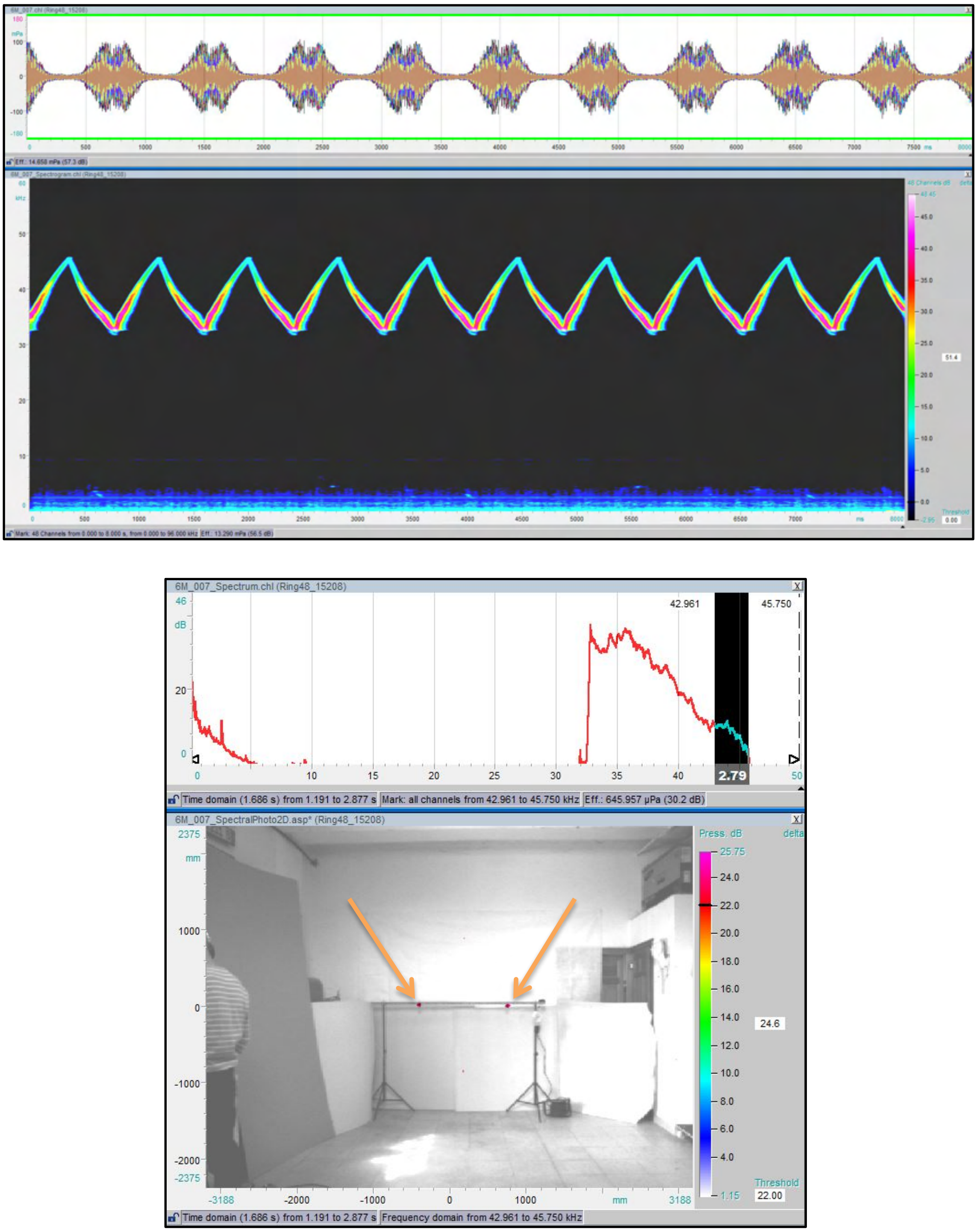

Figure 8 – Scenario 2-A results: 6 Meters.

3.4 Scenario 2-B

Turning on the air compressor and the air leakage in the same position like scenario 1-B, the ultrasonic emission is masked on the time signal but still recognizable in the spectrogram (Figure 9, above). From this position, some reflections on the floor and the roof appear (Figure 9, below). Using different frequency range selection, the different noise sources are located clearly and separately, with the mentioned reflections in the floor when the air leakage is the main source (Figure 10).

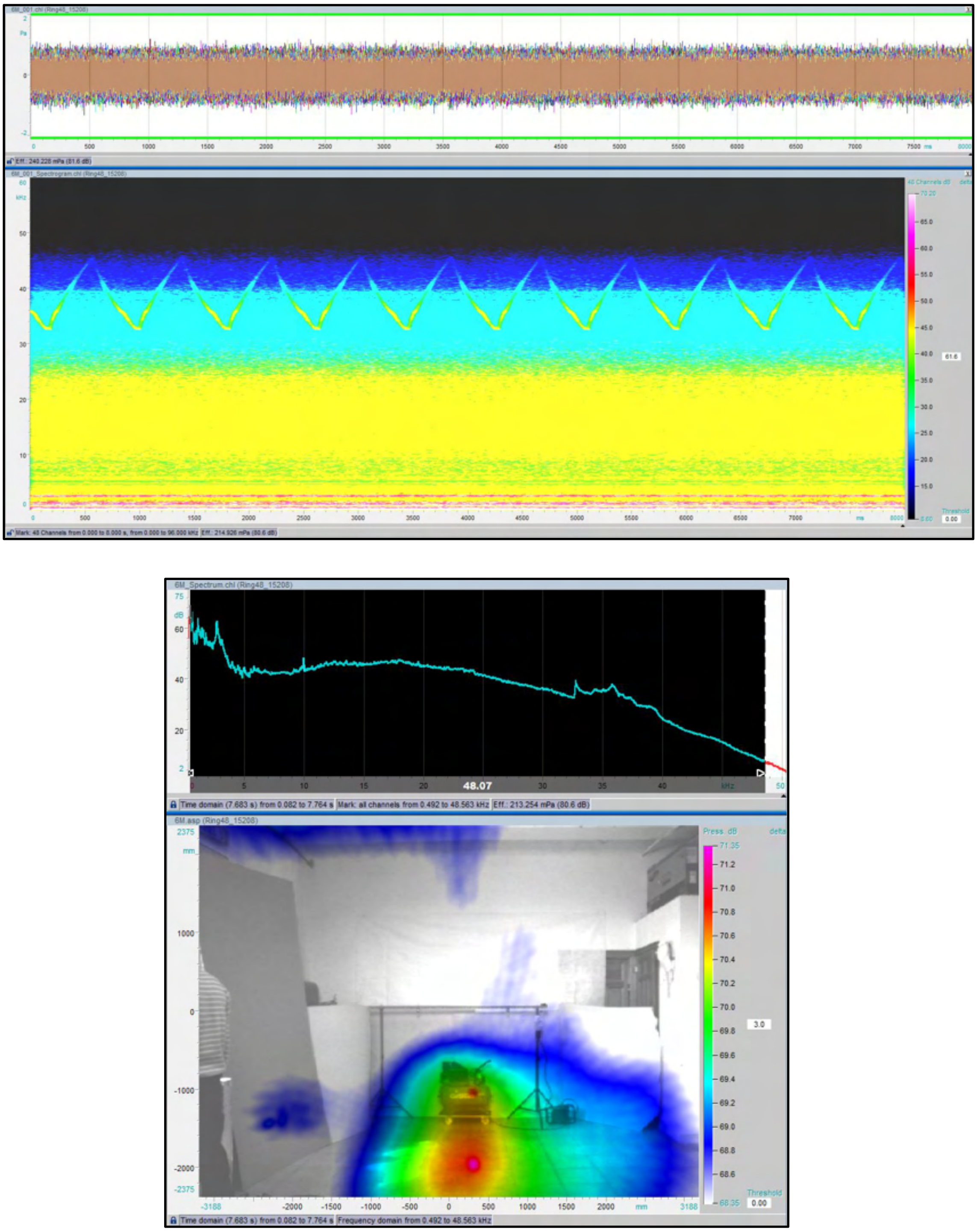

Figure 9 – Scenario 2-A results: 6 Meters, with air compressor

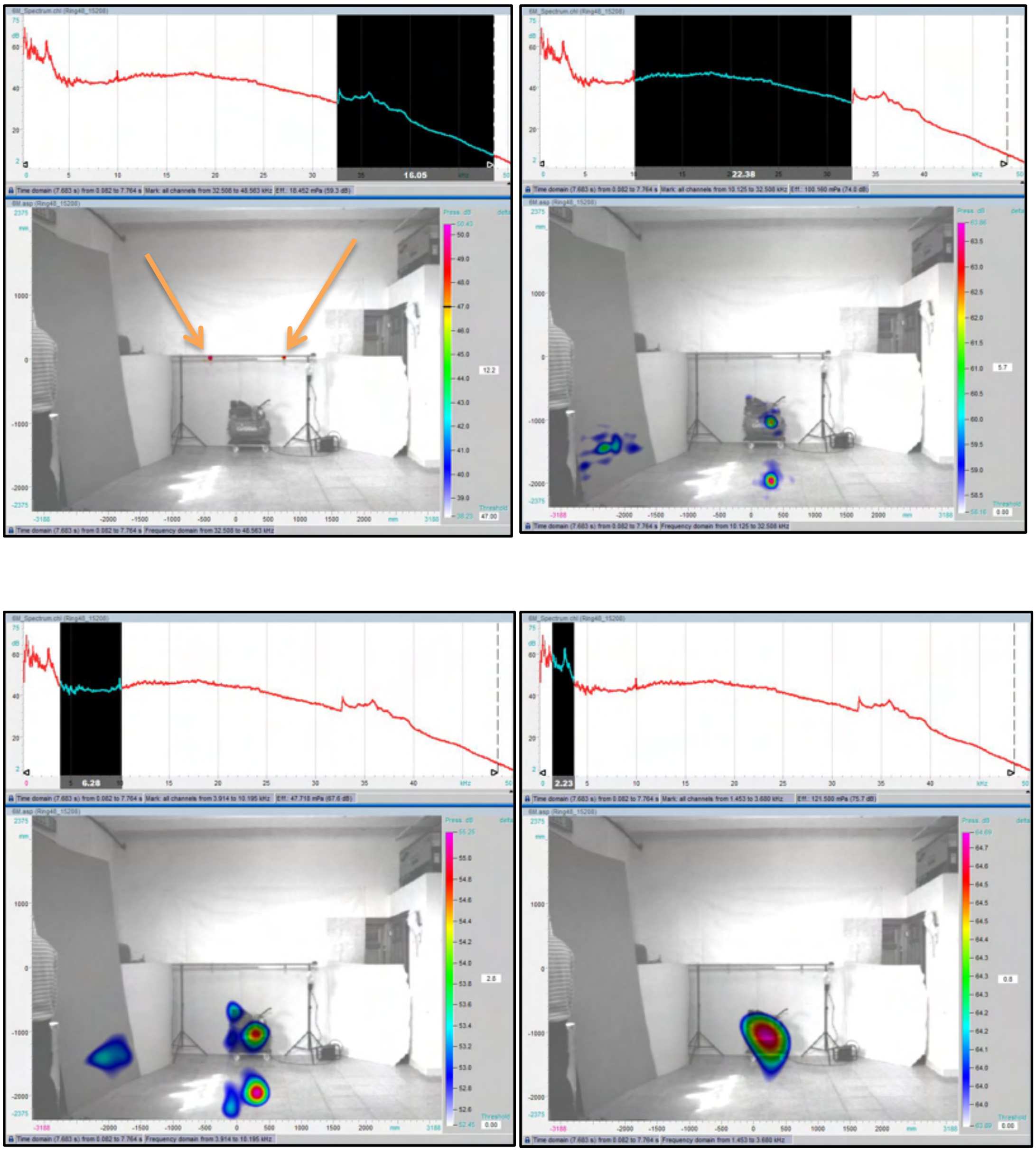

Figure 10 – Scenario 1-B results: 6 Meters, with air compressor by frequency ranges.

3.4 Scenario 3-A

With the piezo speakers 30 meters from the microphone array, outdoor, the two sources can still be located (Figure 11).

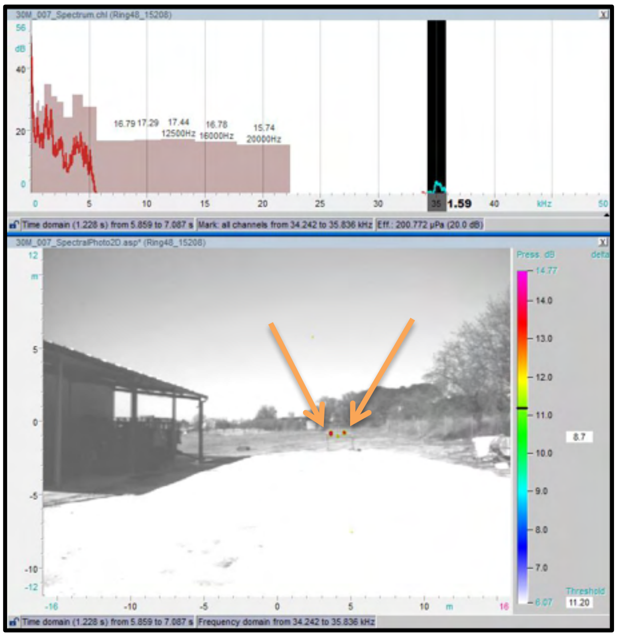

Figure 11 – Scenario 3-A results: 30 Meters.

4. CONCLUSIONS

The tests developed and shown in this publication provide reliable evidence that Beamforming can be applied in ultrasonic frequencies; this technology produces excellent results in the tested frequency range between 32 kHz and 45 kHz. This is a tool that can be used in industrial facilities to locate the ultrasound emissions and in other kind of scenarios too, like zoological applications.

In complex scenarios with several noise sources it is possible to locate and identify all the different noise sources with accuracy when processing the data in the frequency domain. In this way, the different contribution of each source or group of sources can be determinated.

The microphone array used in the tests is designed for the audible range, but still can be used to localize ultrasound sources. The aliasing pattern of the array is still known, which enables you to distinguish between aliasing artefacts and real sources. To minimize the aliasing, a ring array with a smaller diameter but the same amount of microphones could be developed. More tests in different scenarios using other microphone arrays geometry will be developed in future.

5. REFERENCES

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