8th International Conference
on
Wind Turbine Noise
Lisbon – 12th to 14th June 2019

Noise Source Location in Wind Turbines

Pablo Alloza, gfai tech GmbH: alloza@gfaitech.de
Benjamin Vonrhein, gfai tech GmbH: vonrhein@gfaitech.de
Olaf Bölke, gfai tech GmbH: boelke@gfaitech.de

Summary

Sound source localization has a direct practical application on wind turbines. Thus offering a new point of view that provides novel solutions to several challenges from the wind turbines sector. With this acoustic measurement method it is easy to record, identify and localize sound sources in different parts on wind turbines, analyzing in time and frequency domain. In addition, the results can be showed in the wind turbine 3D model, acquired using a laser-scanner.

This publication presents the basic properties and functionalities of sound source localization using beamforming and the Acoustic Camera, it introduces the principle of operation and the different array typologies and concludes with several results in different scenarios.

1. Introduction

Wind energy is one of the renewable energies widely used around the world. The wind is a source available almost anytime not depending of other factors like temperature or sunlight. Sometimes the best locations for wind turbines are close to cities. Hence noise emissions from the wind turbines, can be a problem; especially in wind farms with a lot of units. The relation between the noise exposure and health is well know and been analysed in several publications. In outdoor noise emissions the wind strength and his orientation, temperature or humidity affect directly the noise propagation in the air. In addition, the sound footprint from a wind turbine has low frequency content, which increases the noise problems in the reception points.

The noise in and from wind turbines during operation is a complex equation because there are several potential noise sources: Blades, gearbox, generator, brakes, tower, etc. In addition aerodynamic noise can be present in the external part like blades or nacelle.

Be able to identify this sources separately is the key for analysing the contribution of each one in the global level and to take the right decisions about how to improve the noise reduction in a wind turbine. In addition, the noise localization provides a new point of view for maintenance purposes, visualizing where the specific noise like chirps, squeaks or screaks are coming from.

The Acoustic Camera system can provide this kind of results, using a special multichannel microphone array, a data recorder and a computer running the software, all this analysis in time and frequency domain can be done on site.

This method can be used in research & development for new prototypes, control and monitoring for installed ones or comparison between different models or different workflows. One of the main features of this system is that it is not necessary to install any sensor on the wind turbine, neither to stop in operation.

2. Principle of operation

There are different techniques for localising sound using microphone arrays; For near field measurements, Nearfield Acoustic Holography is the best method. When the target needs to be independent from background noise, to measure in very low frequencies and in close distances, Intensity is the best solution. Focusing in our aim, wind turbines are big objects and are usually far away from the point of evaluation, for this reasons Beamforming is the best technique for this application.

The basic algorithm running behind the processing software is named Delay-and-Sum-Beamforming, the most widely known sound localisation technique. It is based on the following principle: The sound of different noise sources travels using different ways so it takes different amounts of time to reach the array microphones. This means different run-times from the sound sources to the different microphones. By calculating this time differences between a sound event and each microphone of an array, direction and strength of sound sources are determined. The calculated sound pressure is then mapped on the optical picture or video of the measurement object. Figure 1 shows an easy example with two sensors; the human spatial hearing is a good and easy comparison.

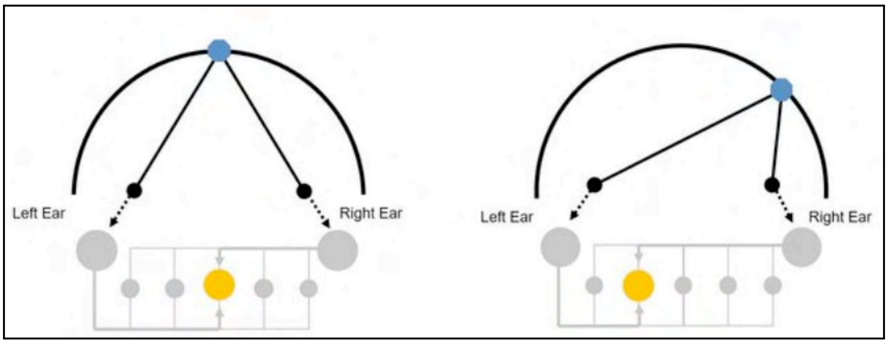


Figure 1. Run-time example using human earing.

The data from all the microphones are used to calculate the sound pressure level for a certain position using the following formula:

$$\hat{f}(\mathbf{x},t) = \frac{1}{M}\sum_{i=1}^{M} w_i f_i(t-\Delta_i)$$

Figure 2. Delay and sum formula.

In the formula (Figure 2) the f corresponding sound pressure level for a given t time and a x position on a reference plane using $\mathcal{M}$ number of microphones; w_i could be used as optional spatial shading weights or set to unity if does not occur. Figure 3 shows the process in detail:

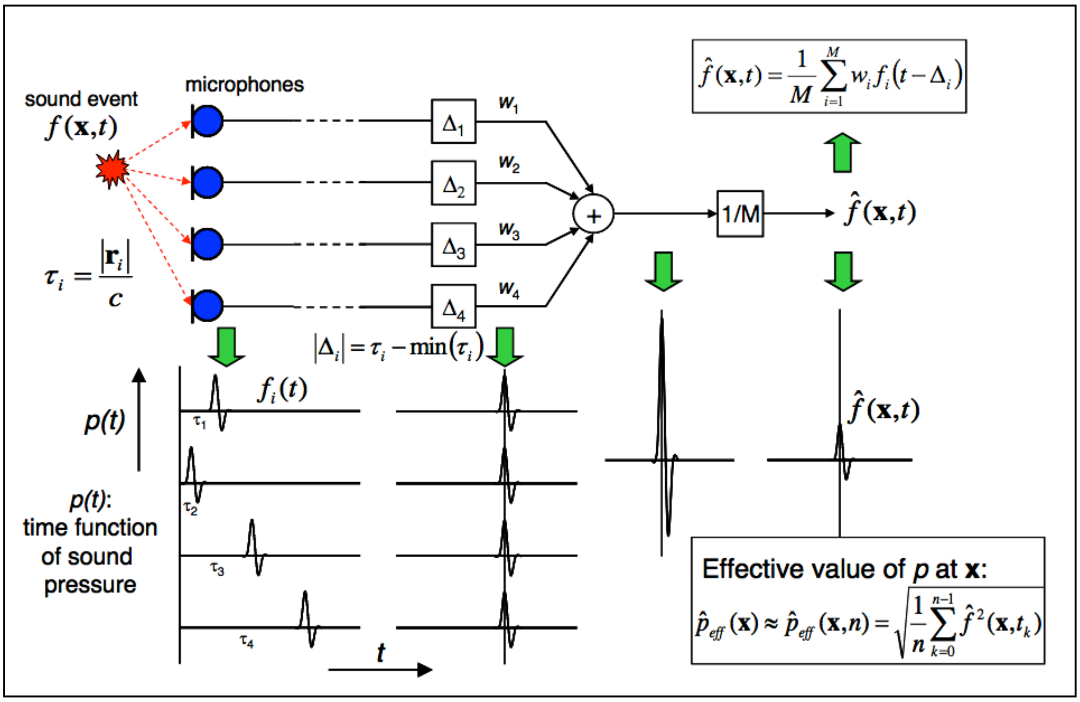


Figure 3. Time domain Beamforming operation principle.

Delay-And-Sum-Beamforming in the Frequency Domain allows acoustic evaluation via the frequency domain. The spectrum and the spectrogram show the different frequencies a signal is composed of. Using Fourier Transformation, a transition from time to frequency domain is possible and the spectrum and spectrogram can be calculated.

In the final step this process is applied to a number of picture points set by the user in a photo plane, in which the target is located. Figure 4 shows that to each picture point a corresponding set of distances r_i and run-time delays t_i can be calculated.

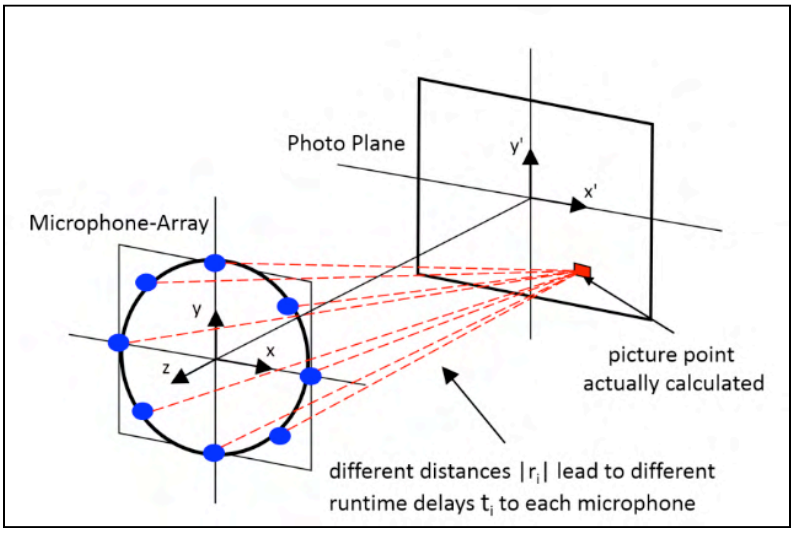


Figure 4. Picture points calculation.

Thus, the sound pressure level can be determined for all the picture points using delay-and-sum-beamformer. To represent the sound pressure levels, a colour scale is used in the picture points with the optical reference photo, generating an acoustic picture.

2.1 Microphone array typologies

Depending on the beamforming applications, different microphone arrays, varying in geometry, size and number of microphones are used. Ring type arrays are suitable for several applications, inside and outside, depending on the array diameter. Sphere type arrays are designed for 3D applications, inside cabins or rooms. For the measurement campaigns in this publication, a star microphone array (STAR 48 AC PRO) with 48 channels and 3,4 meters was used. This microphone array (Figure 5, centre) is designed for outdoor applications and specialized for low frequency localization.

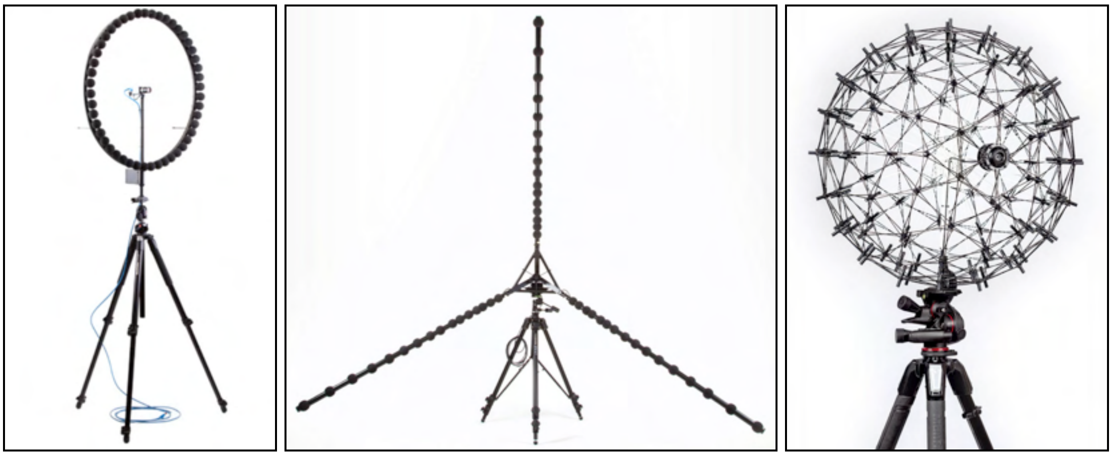


Figure 5. From left to right: Ring array with 48 microphones, Star array with 48 microphones and Sphere array with 120 microphones.

3. Measurement scenarios

The measurement tests were divided in 3 scenarios, in order to provide results from different locations and different wind turbine models (Figure 6).

- Scenario 1: Wind farm, several wind turbines in lines. Focus on the first one, the other ones are on the right.
- Scenario 2: Same point of view from scenario 2, focus on the right side.
- Scenario 3: Wind farm, several wind turbines inside a small forest. Point of evaluation in the middle of several wind turbines, focus on the right side.

Figure 6. From left to right: Evaluation points for scenarios 1, 2 and 3.

3.1 Scenario 1 results

In this measurement scenario, the Acoustic Camera is set 330 meters from the wind turbine selected as target. Other wind turbines are in the area, mainly on the right side. One first look to the spectrogram (Figure 7) provides us the possibility to identify continues frequencies in all the measurement or short time events.

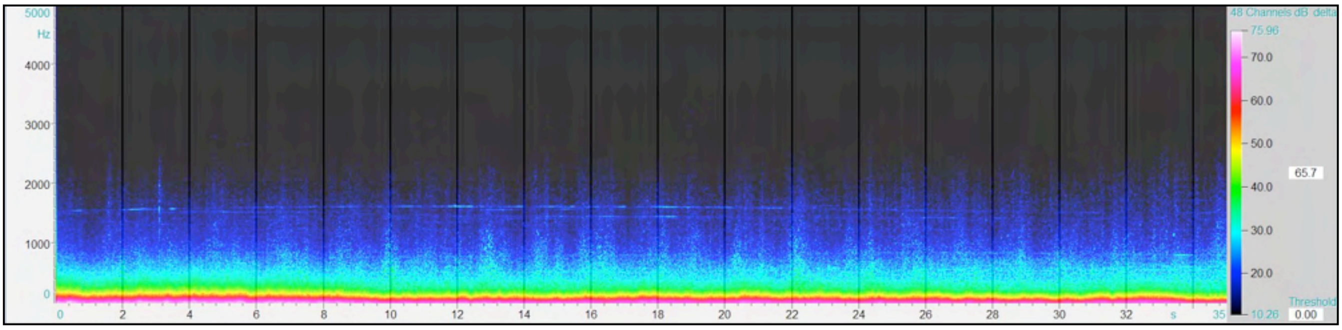


Figure 7. Spectrogram

Selecting when one blade is on the top, the 500 Hz third octave is always localized in the same position. The acoustic pictures are from different time selections. The blades on the right position are the noise source (Figure 8).

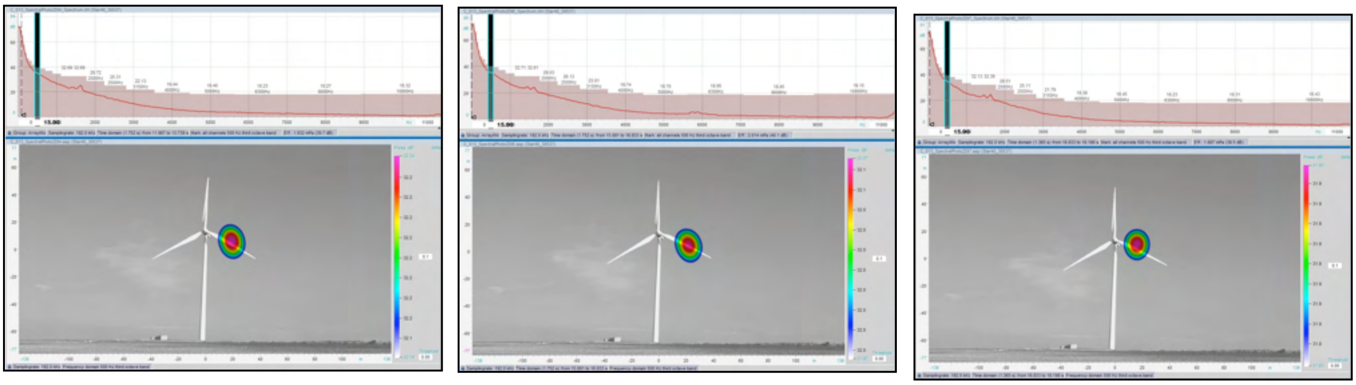


Figure 8. Acoustic pictures from different times selections, 500 Hz third octave

Going to the low frequency, 200 Hz third octave, the noise source is always localized on the wind turbine tower, no matter which blade is on the top position (Figure 9).

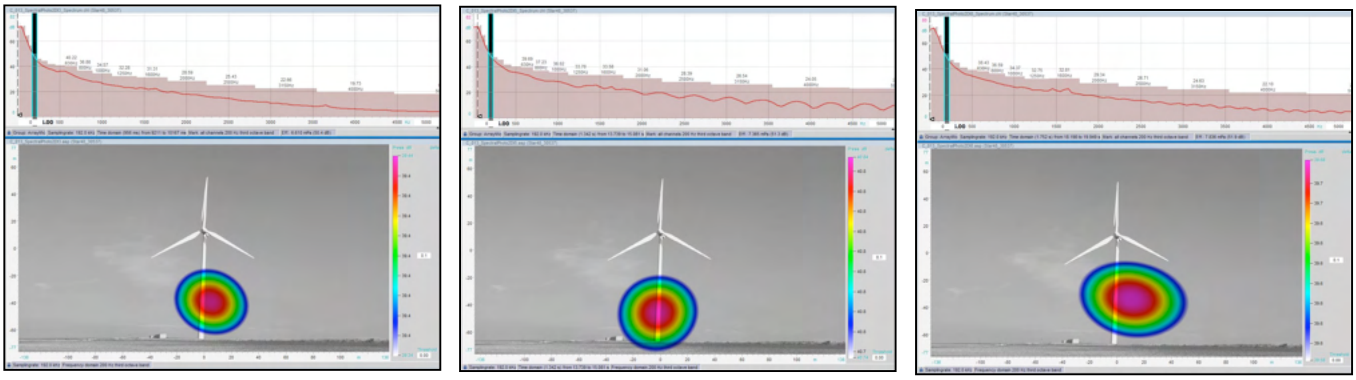


Figure 9. Acoustic pictures from different times selections, 200 Hz third octave

3.2 Scenario 2 results

From the same evaluation position as scenario 1, just rotating to the left of the microphone array. In this position the microphone array is not parallel aligned in front of the noise sources. Now the first wind turbine is located in 400 meters distance. In this measurement two wind turbines are in the view, 120 meters distance between them (Figure 10). The striking frequency peak on 1.594 Hz is localized on the blade.

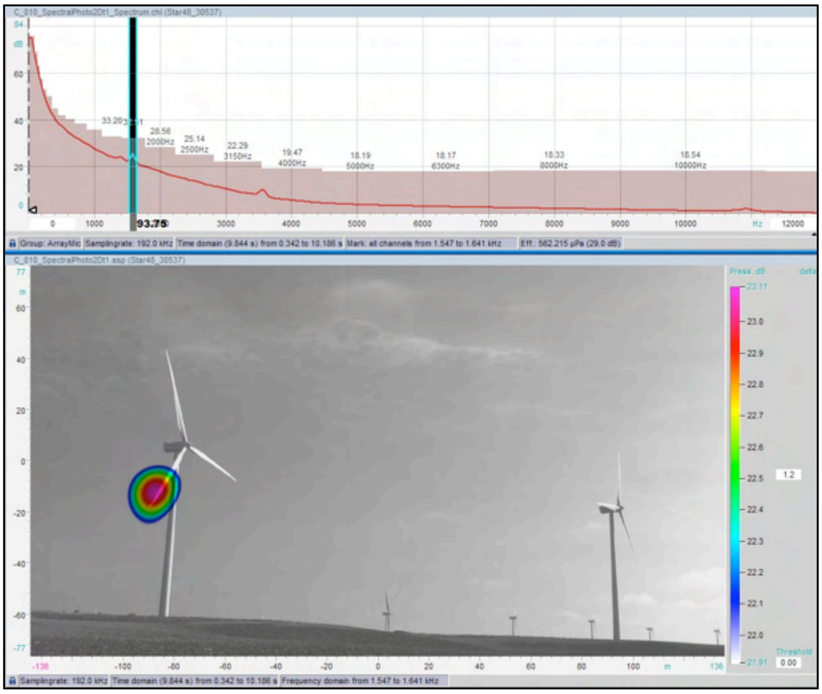


Figure 10. Acoustic picture focused on the frequency peak on 1.594 Hz

The 2.000 Hz third octave is localized on the first wind turbine tower, but increasing the dynamic range (Figure 11, right), the same third octave is localized on the second wind turbine tower too.

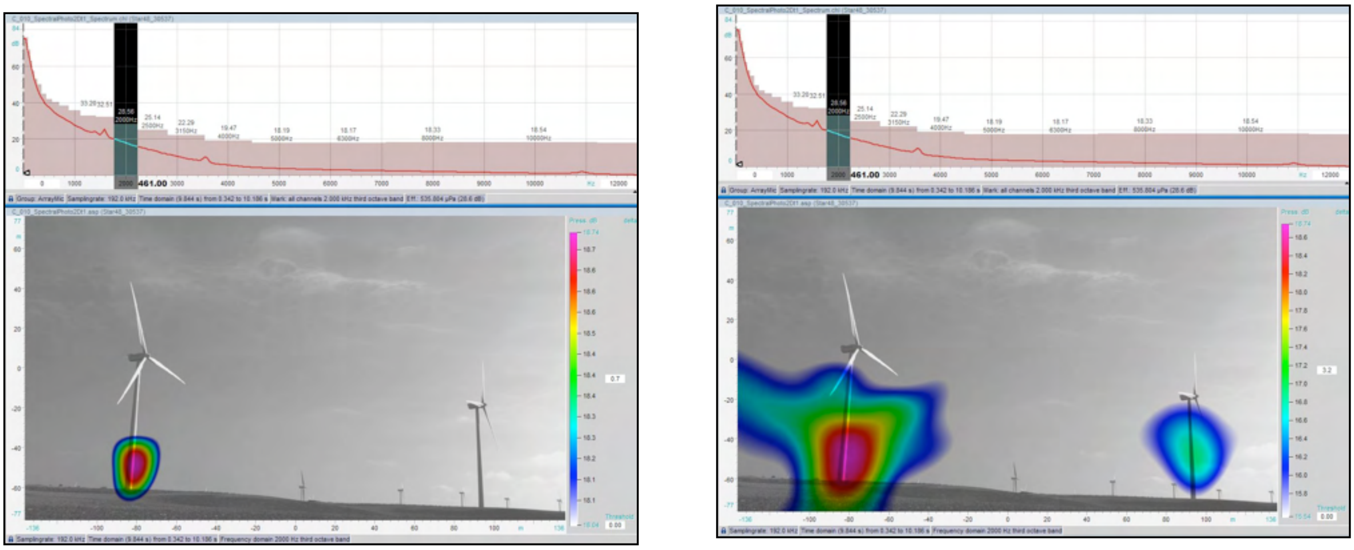


Figure 11. Acoustic pictures with different dynamic range, 2.000 Hz third octave

Looking in the low frequencies, 400 Hz third octave is localized in the bottom of the first wind turbine and again, increasing the dynamic range (Figure 12, right), the second noise source in the same frequency but less level appears in the second wind turbine tower.

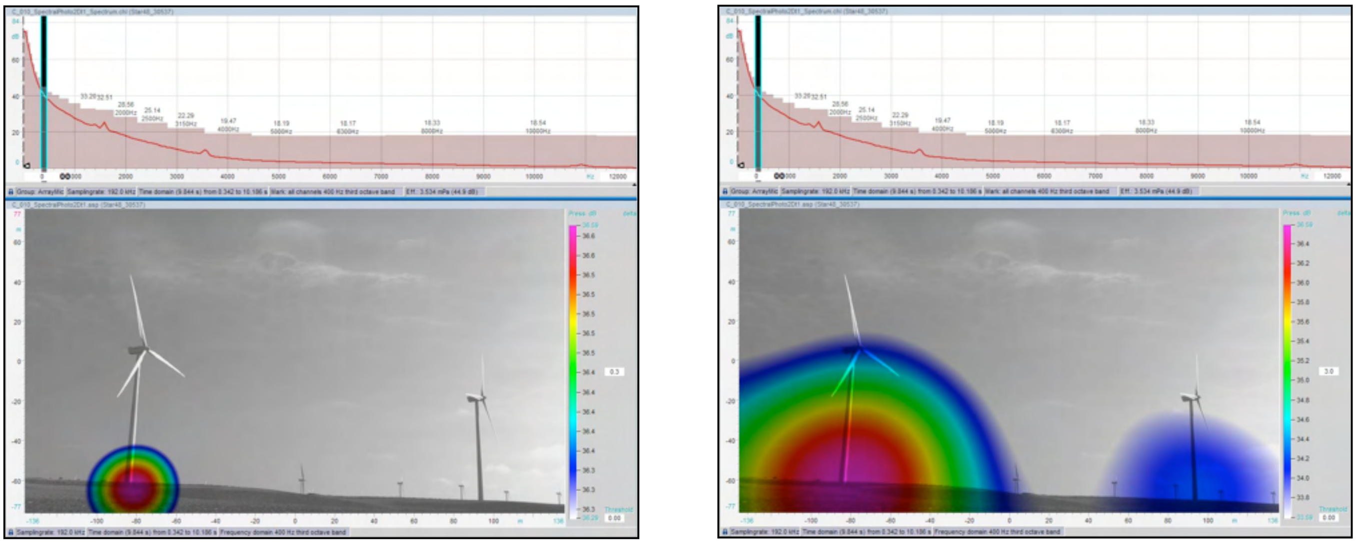


Figure 12. Acoustic pictures with different dynamic range, 400 Hz third octave

3.3 Scenario 3 results

The area for this test is a small forest on a mountain with several wind turbines around in the high part. The point of evaluation is in front of three wind turbines more or less aligned. The microphone array is 350 meters from the first one. In the spectrogram some fluctuations are showed between 2.000 Hz and 3.000 Hz. Selecting this fluctuations directly in the spectrogram (Figure 13), the noise source is pointed on the top blade.

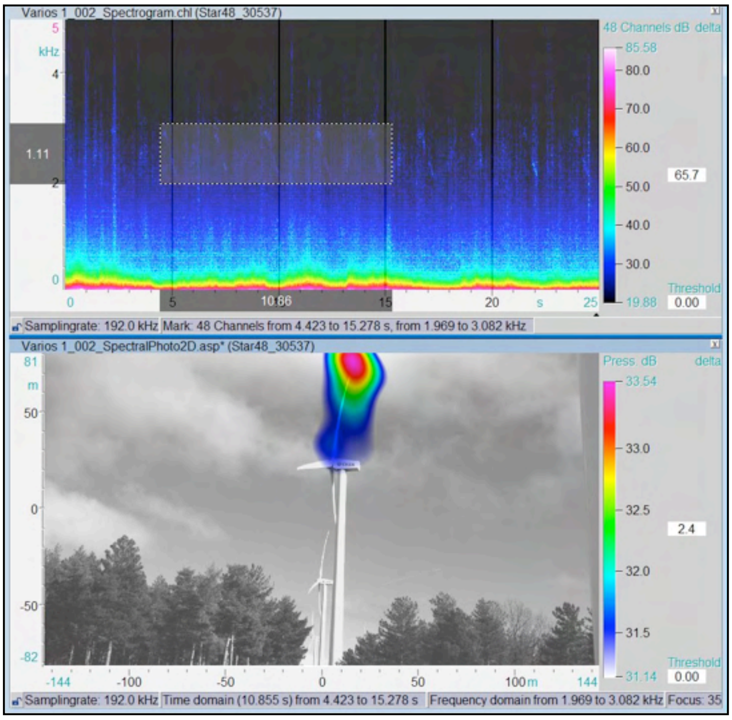
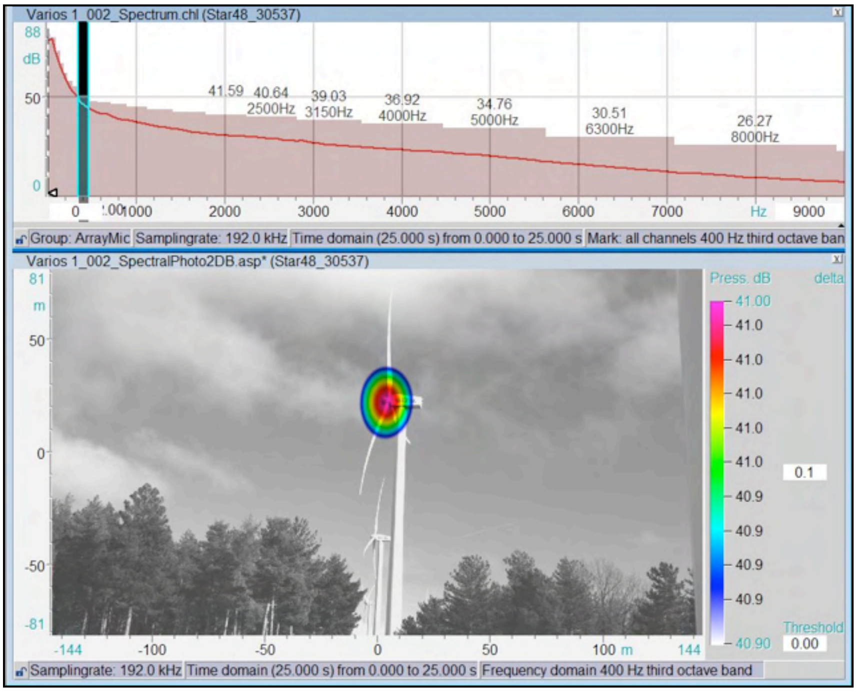


Figure 13. Spectrogram and acoustic picture from the selected area.

The 400 Hz octave band can be focused on the rotor from the first wind turbine. Independently of the blades position, during the whole workflow the noise source remains.



Varios 1_002_Spectrum.chl (Star48_30537)

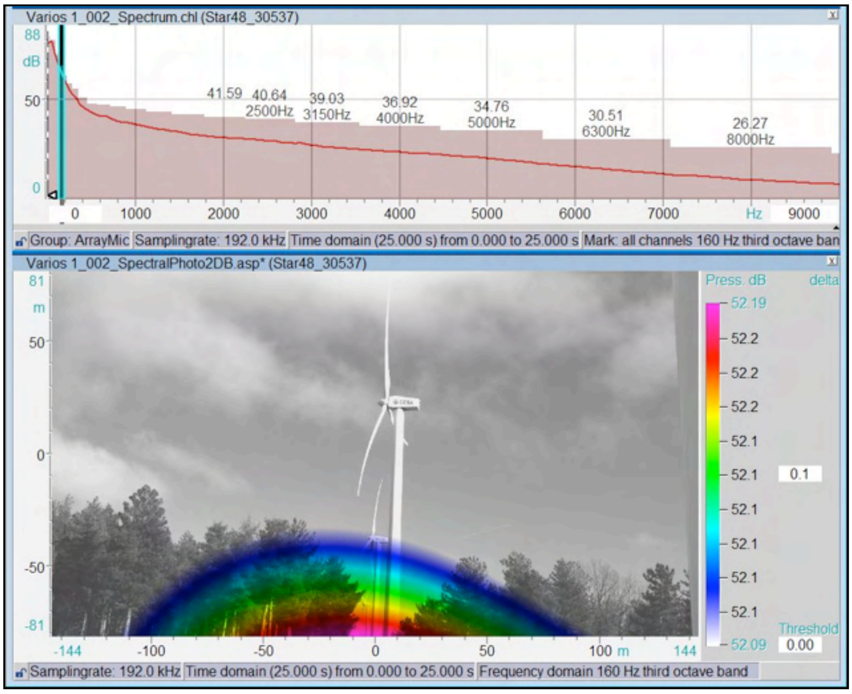
Group: ArrayMic Samplingrate: 192.0 kHz Time domain (25.000 s) from 0.000 to 25.000 s Mark: all channels 400 Hz third octave ban

Varios 1_002_SpectralPhoto2DB.asp* (Star48_30537)

Samplingrate: 192.0 kHz Time domain (25.000 s) from 0.000 to 25.000 s Frequency domain 400 Hz third octave band

Figure 14. Acoustic picture, 400 Hz third octave

The low frequencies, like the 160 Hz third octave band showed, can be focused near to the ground (Figure 15).



Varios 1_002_Spectrum.chl (Star48_30537)

Group: ArrayMic Samplingrate: 192.0 kHz Time domain (25.000 s) from 0.000 to 25.000 s Mark: all channels 160 Hz third octave ban

Varios 1_002_SpectralPhoto2DB.asp* (Star48_30537)

Samplingrate: 192.0 kHz Time domain (25.000 s) from 0.000 to 25.000 s Frequency domain 160 Hz third octave band

Figure 15. Acoustic picture, 160 Hz third octave

4. Conclusions

A lot of data has been generated in these measurement tests, but only the more interesting are showed on this publication. The results from the different scenarios show the different kind of data that can be used as basis for analysing, regardless if the wind turbine target is close to others. This data can be used as reference for comparing it with other workflow conditions, like different wind speeds or wind directions. Repeating the same points of evaluation in the same units and same conditions after a known number of working hours can provide useful information comparing the noise emissions regarding level and point or area of emission. Without stopping the wind turbine and without installing any sensors on it, noise results related with maintenance and malfunction can be acquired and processed on site.

The acoustic pictures can be used for validating predictive noise models, focusing on the noise emission from each part of the wind turbine or using global values for predictive noise propagation softwares, feeding them with real data from installed and working wind turbines.

References

Stuart Bradley, Michael Kerscher, Torben Mikkelsen (2017) *Use of the Acoustic Camera to accurately localise wind turbine noise sources and determine their Doppler shift.* Wind Turbine Noise

Michael Kerscher, Benjamin Vonrhein, Prof. Dr. Friedrich Ueberle, Dr. Dagmar Rokita (2016) *How Acoustic Camera Measurements can help to increase the Acceptance of Wind Turbines.* Wind Europe Submit.

Ofelia Jianu, Marc A. Rosen, Greg Naterer (2011) *Noise Pollution Prevention in Wind Turbines: Status and recent advances*

Oerlemans, S, Sijtsma, P and Méndez López B (2007) *Location and quantification of noise sources on a wind turbine*. J Sound Vibration 299, 869-883.

Zhang X-Z, Bi C-X, Zhang Y-B and Xu L (2017). *A time-domain inverse technique for the localization and quantification of rotating sound sources*. Mech Systems Sig Proc 90,15–29

www.acoustic-camera.com (2019)