



# Location of low frequency noise pollution areas.

Jan van Muijlwijk De Kompanjie, Veendam, The Netherlands Lola García Escribano Microflown Technologies, Arnhem, The Netherlands David Perez Cabo Microflown AVISA, Arnhem, The Netherlands Edwin Jansen Microflown AVISA, Arnhem, The Netherlands

#### Summary

Low frequency noise and infrasound noise are growing issues in the industrialized world. Such noises are mainly generated by the heavy industry, power plants, wind turbines etc. Being ever present in our everyday life, this phenomena is still heavily underestimated, and its long term impact on the human health and wellbeing is largely unknown.

Due to the nature of the noise sources under investigation, the problem of their localization becomes a cumbersome task. Traditionally the problem of localizing noise sources in the very low frequency range, could only be addressed by the employment of large sound pressure-based beamforming arrays. However, the limitations of such instrumentation renders it useless for low frequency applications. Currently the problem of noise assessment at very low frequencies was reduced to the determination of its sound pressure level.

In this paper, a new measurement system, based on a 2D particle velocity sensor along with a monitoring station, is presented. The combination of both particle velocity elements allows for successful localization of noise sources in the acoustic far field, without any frequency limitations. Furthermore, the system is able to monitor and visualize the behavior of a noise source, as well as highlight the temporal patterns and trends that it follows.

Results presented in this paper are an outcome of an investigation carried out, in cooperation with the city-hall of Veendam, on a real measurement case. The aim of the measurement was to locate the source of a 30 Hz noise problem, which was reported as "annoying" by the local community. **PACS no. 43.50.Jh 43.50.Yw** 

# 1. Introduction

Low frequency noise complaints are an increasing problem in today's life, not only in urbanized areas but also in rural environments due to the increasing presence of small industry, machinery, electrical plants, etc.

Typically these problems are only sensed by a limited amount of residents who experience a high level of distress. This distress is mostly increased by the feeling of being alone lead by the fact that the sensitivity of hearing threshold greatly varies from person to person, in this frequency region. Moreover, low frequency noise can appear as a very local effect, even focused or amplified at a certain position, for example inside a house.

Once a low frequency problem is acknowledged, authorities have to deal with a problem which is very difficult to assess due to its characteristics and currently available measurement tools.

First of all, the noise descriptors that are mostly used are based on "A" frequency weighing, which only masks the low frequency contributions, setting the sensitivity thresholds even higher than the data without the weighing.

Secondly, the low frequency noise annoyance is mostly caused by sources with complicated appearance patterns or masked periodically by other sources. This phenomena makes the planning of a measurement campaign a difficult process. A third factor relays on the low frequency noise nature and its capability to travel far distances without suffering a major attenuation.

The detection and assessment difficulties lead to a high percentage of unresolved cases, between 50 and 80 % [1], and leaves the residents with a single solution: learning how to live with the problem.

#### 2. Measurement techniques

#### 2.1. Traditional measurement techniques

Noise problems are mostly tackled by means of a pressure microphone and an analyzer, or by the usage sonometers. Mid-long term measurements are mostly needed in order to ensure the actual detection of the annoyance noise. This is performed by monitoring stations with a timespan log option. This feature allowing for the correlation between annoyance and measured noise.

These tools give the chance to assess the actual existence of the source, if the signal to noise ratio is sufficient for the equipment to detect it.

Typically all low frequency noise manuals and recommendations refer only to the noise assessment but this is, for actual troubleshooting, an insufficient approach. The actual noise source location is crucial for the proper solution proposal. Currently a handful of solutions allow not only for the assessment but also location of the noise source.

#### 2.2. Advanced LFN assessment: Localization

A more advanced approach to localize noise contributions is the utilization of microphone arrays. By means of signal processing, the signal arrived to each transducer at a different time moment are aligned, using the time differences to estimate where to focus the array and therefore where the noise is coming from.

These applications can and are in some cases combined with noise monitoring stations allowing for the assessment and location of the noise source. The biggest limitations for the usage of these systems for LFN problem assessment are the high price because of the number of sensors involved and, the usable frequency range which is restricted by the array size in the lower frequency region. Being in most cases not applicable for the low frequency noise problems that we have focused our attention on.

#### 2.3. Advanced LFN location: AVS system

The approach we propose is the determination of the direction of arrival (DOA) information by means of Acoustic Vector Sensors (AVS). A non-distributed 3 sensor probe which allows measurement and detection of acoustical contributions in 3D space. The AVSs are based on the Microflown MEMS particle velocity sensor. The Microflown utilizes the temperature difference in the cross section of two extremely sensitive platinum wires that are heated up to 200°C, in order to determine Acoustic Particle Velocity [2]. By assembling a sound pressure transducer and two orthogonally placed Microflown sensors in one single point, a very compact AVS is produced. Direction of sound arrival is the direct output of the sensor. Further algorithms and/or additional Acoustic Vector Sensors allow distance and other parameters to be determined [3].

One of the advantages of the usage of AVSs combined with noise monitoring devices is the reduced size of the sensing elements, not needing to distribute a network of sensors. A single measurement position is sufficient to obtain DOA. Secondly, the useable frequency range is not limited by the size of the sensor, being a single sensor capable of measuring the contribution and determining the direction of arrival of the noise for the whole frequency range.

Moreover comparing the response, in terms of resolution and location estimation error, of several existing array configurations with the response of a simple single AVS. Applying the most beamforming algorithm, Delay and Sum (DAS), one can see the advantages that AVSs provide [4]. Figure 1 compares the response of one AVS with other beamforming solutions in terms of spatial resolution; defined as the ability to distinguish two closely spaced noise sources. Typically represented by the -3dB width of the main lobe; and the localization accuracy, expressed in degrees of error in the estimation of the position of the noise source.

Number of	Array geometry	Array size
sensors		
3	AVS	0.01
32	Sphere	0.35
48	Star	3.4
90	Wheel	2.43
128	Circle	0.8

Table I. Data used for Figure 1. Existing commercial array configuration features.



Figure 1. DAS beamformer on array configurations of table I

# 3. Measurement scenario: Veendam LFN problems

For many years there were LFN complaints in the center area of the Dutch village of Veendam. Affected population were visited by the local authorities and after some measurements performed with a microphone and a FFT analyzer, a 30 Hz noise was detected, measured and correlated with the disturbance that the residents reported.

Further measurement campaigns were taken outside the houses, but the reduced SNR and masking effects of other present noise sources made it impossible to establish the actual location of the source of the problem. As a result the problem was left unattended for some years.

After a few years the same problem appeared in a different area of the city where the residents pointed to a nearby factory of being the source of the problem but one more time the available tools allowed for the noise assessment, but not localization. By means of a 2 microphone system. Placing the sensors 60 meters apart and using a color coding for the phase variations a sense of direction was determined, pointing to the suspected conflict area. Obtaining an estimation of the possible area of the noise source location.

#### 3.1. Measurement campaign

To locate the noise source with the objective of a solution proposal for the residents, the local authorities of Veendam contacted Microflown Technologies. The aim was to effectively locate the origin of the 30 Hz noise.

The measurements were taken in one day. The same monitoring station was 5 times re-positioned for this trial measurement. Positions can be visualize in Figure 2.

Currently a network of measuring stations, named NoiseLoc, can be deployed and synchronized via GPS clock, obtaining a more accurate triangulation in the measurement results.



Figure 2. Left: Measurement positions deployed in Veendam; Right: NoiseLoc system deployed for measurement

#### 3.2. Common coordinate system

To be able to use a common coordinate system for all measurement positions, each of them are referred to a reference position. The installation process is as follows:

- 1. Selection of a visual reference
- 2. Installation of the measurement station. Pointing the (0,0) position of the NoiseLoc to each reference position by means of an orientation tool.



Figure 3. Orientation tool

3. Registration of the coordinates of reference and measurement position and insertion in NoiseLoc as input data.

# 3.1. Data processing

All 5 positions detected the tonal component at 30Hz, with a clear constant tonal contribution in all

channels. This is visualized in the spectrogram generated from each measurement channel at one of the locations:

A so called "Tone- Tracker" algorithm was used in order to detect and monitor non-moving noise sources. The idea behind it is being able to detect tonal components and follow their life process, by registering:



Figure 4. Problem assessment: 30 Hz tonal component detection.

- Tone life span
- Tone time status
- Tonal component variation during life span
- DOA of tone at each measurement location.

The DOA can be obtained by direct calculation of the intensity vector and/or refined by the application of beamforming techniques, as presented in Figure 1. Besides, time delay information and/or DOA triangulation can be applied to calculate the distance to the noise source.

Applying the above mentioned algorithm along with averaging factors, the triangulated noise

position is obtained. Figure 5 represents the noise source location.

# 4. Current problem status

Results pointed to a cooling tower on the factory premises. Gratefully, the factory management was open for cooperation and problem solution and collaborated during and after the measurements.

The first approach to eliminate the low frequency annoyance was to reduce the rotation speed of the cooling system, aiming to move the low frequency radiation to an even lower band in which humans become less sensitive. This solution proved to work well in the context of noise reduction. Not only the noise moved to the lower frequency region but also the intensity radiated was reduced. However, in practice, this new working regime crippled the capability of the cooling tower to serve its purpose.

In the end the, factory management has decided to accelerate the renewal process of their plant, by fitting it with a new cooling tower.

Hopefully this solution will allow residents to enjoy a low-frequency-free environment.

# 5. Conclusions

LFN investigations were, till now, only performed until the noise assessment phase. Annoyance and noise detection were correlated, in the few cases that this was possible.

My means of the AVS- based system, NoiseLoc. Low frequency noise source location is made possible. The system provides information about the specific location of the source allowing the operator working on its mitigation by direct action on it.

This initial test has proven NoiseLoc as a very useful tool for low frequency noise location. The system capabilities in terms of accuracy, dynamic range, frequency resolution, etc. Will be further studied to fully define and understand the limitations and applicability of the solution for LFN assessment and localization.

# Acknowledgements

Special acknowledgments to Nedmag, for their active participation and cooperation in the measurement campaign and problem solving.

#### References

- [1] Dr. Moorhouse, Dr. Waddington, Dr. Adams: Procedure for the assessment of low frequency noise complaints. Salford University.
- [2] H-E. de Bree, Peter Leussink, Twan Korthorst, Henri Jansen, Theo S.J. Lammerink, Miko Elwenspoek: The Miroflown - a novel device for measuring acoustic flowns. Published at Sensors and Actuators 1996.
- [3] T. Basten, H-E de Bree, S. Sadasivan. Acoustic eyes, a novel sound source localization and monitoring technique with 3D sound. Published at the ISMA 2008.
- [4] Wen-Qian Jing, D. Fernandez Comesana, D. Perez Cabo. Sound source localisation using a single acoustic vector sensor. Internoise 2014.



Figure 5. Noise source location in the factory plant