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THE USE OF A SIMPLE, HIGHLY DIRECTIONAL ARRAY MICROPHONE FOR SOURCE LOCALIZATION IN PRACTICAL SITUATIONS

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ABSTRACT
Nowadays, interest increases for noise source localization with an array of microphones. Typically, array techniques are used with a large number of microphones and heavy digital data-acquisition systems with signal processing features. These imaging-techniques appear to be very capable but are not always cost-effective due to the high investment in equipment and time needed to prepare a set-up in the field. To this end two simple directional array microphones were developed with a practical size and simple signal processing. These array microphones were used for source localization on a tunnel-vent and to measure the noise level of a wastewater purification plant amidst other noise-sources. The use of the array microphones enabled a sufficient determination of the sound sources.

1 - INTRODUCTION
Acoustic source localization can be done with a directional microphone. Directional characteristics can be improved using a spatial distribution of microphones. A substantial directivity can only be obtained with a spatial distribution larger than the minimum relevant wavelength. Such techniques are used in many other fields like astronomy, sonar, radar and seismology. Array-processing techniques can be subdivided, depending on the application, in "real-time" techniques (sonar, radar, acoustic control and audio-applications) and "off-line" techniques (astronomy, seismology). However, all of them use a heavy digital data-acquisition system with additional signal processing features. These imaging-techniques appear to be very capable but are not always cost-effective and flexible to use in practical situations. The two developed array microphones have a practical size and signal processing done by analog circuitry. The whole array is battery-powered enabling flexible use in practice.

2 - FIXED ARRAY PROCESSING
In fixed array processing techniques, the transfer functions of the microphone signals of an array are kept constant to achieve a fixed directional pattern. The fixed directional pattern can be designed to have a narrow main beam or to give an optimum suppression of (diffuse) noise sources. In fixed processing, the signal of each microphone is processed according to a specific recipe involving e.g. filtering, amplitude weighting and time delay. The output signal is a summation of each processed signal and can be used as an input signal for a Sound Level Meter or other measurement apparatus with a read-out.
Now, we distinguish two important groups of linear arrays characterized by the position of the microphones and the main source angles.
In broadside arrays the microphones are placed along the x-axis and the main beam is perpendicular to the line of microphones (Fig. 1, left). The signal processing of this array is basically simple weighting of the microphone signals and summation. In endfire arrays the microphones are placed along the y-axis and the main beam is in the direction of the microphones (Fig. 1, right). The signal processing of this array consists of a time-delay to correct for the sound-velocity, weighting and summation.
The 3D-directivity patterns (here presented with arrays based on single cardioid microphones) show the difference between the array types. The broadside array has a very narrow beam in the x-y plane.

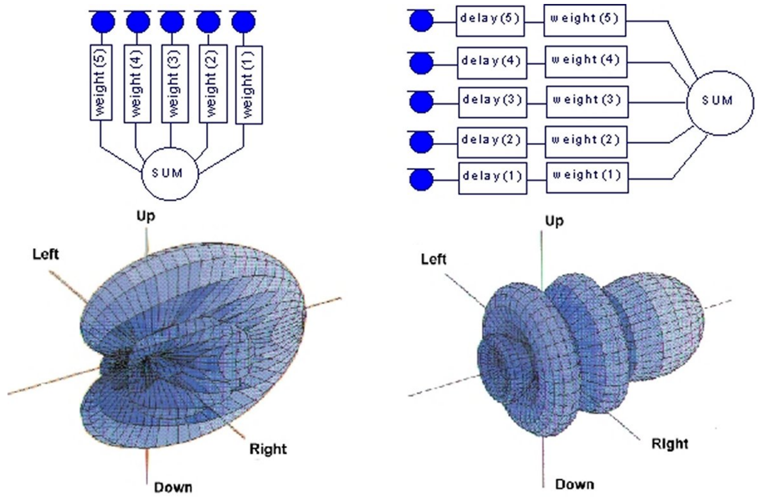

Figure 1: Basic processing and 3D polar diagram of broadside array (left) and endfire array (right).

However, no discrimination is possible in the z-plane. The endfire array has a wider beam in the x-y plane but can discriminate also sounds in the z-plane.

3 - BROADSIDE APPLICATION

The first model is based on broadside beamforming techniques and was developed for localization of noise sources around a tunnel ventilator with deflector blades to bend the air stream. The manufacturer of the ventilator was not yet satisfied with the overall sound power after application of a silencer and wanted to know the power level of the deflector blades. Based on earlier measurements it was felt necessary to develop an array with the ability to detect noise sources in the 500-3000 Hz frequency range with a detection angle of less than 5 degrees (being equivalent to a resolution of 6 cm at a distance of 100 cm). Based on simulations a choice was made for a broadside array of 7 microphones with an overall width of 80 cm. Figure 2 gives the resulting polar patterns, showing a very narrow beam for frequencies from 1000 Hz. The 500 Hz diagram shows a wider beam due to the limited size of the array (array length equals wavelength).

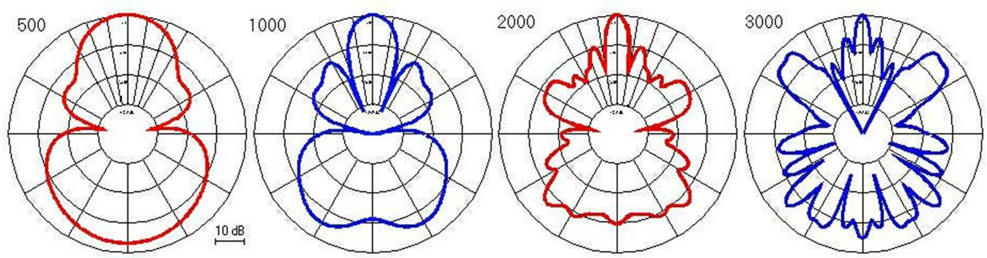

Figure 2: Polar patterns of broadside array of 7 microphones, total width 80 cm.

The measurements near the tunnel ventilator were done with a simple set-up consisting of the microphone array on a stand, the signal processing box running on a 9 V battery and a sound level meter (Rion NA27) enabling 1/3 octave frequency analysis. Set-up time took only one hour. Figure 3 gives a drawing of the measurement set-up and a graph with a typical result. The array microphone was put at a distance of 75 cm to the side of the ventilator. The Array Microphone was rotated around its axis to scan the area of interest. The measured results show that the maximum sound level was found at the end of the deflector blade and originates from turbulence of the airflow. Based on these measurements the manufacturer could start a program to improve the deflector blades.

4 - ENDFIRE ARRAY APPLICATION

The second model is based on endfire beamforming techniques and has a length of 10 cm only. The array microphone consists of 5 individual microphones. This model is based on an original design to suppress diffuse noise and/or a big number of noise sources at several angles of incidence (Soede et al, 1993). The

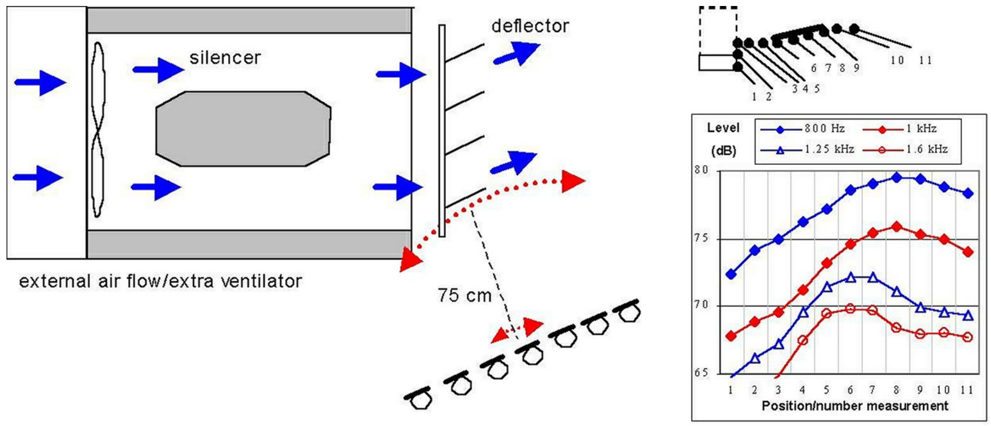

Figure 3: Set-up (left) and typical result of tunnel ventilator with deflector blades (right).

now used design was optimized to get extra directivity in the range from 500-1000 Hz. The resulting average detection-angle is 40-60 degrees (Fig. 4).
The need for the use of the microphone originated from the desire to determine the source strength of a water treatment unit without interrupting the industrial process of the company.

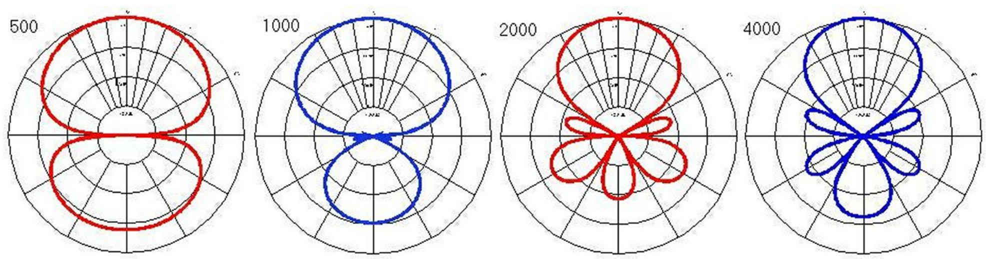

Figure 4: Polar patterns of endfire array of 5 microphones, total length 10 cm.

From measurements with a standard Sound Level Meter (SLM) it was not possible to determine the sound power of the water treatment unit with enough reliability. Therefore, the array was used to measure the noise level amidst numerous other noise-sources as given in Fig. 5. The graphs give the measurements with the Endfire Array directed towards 0, 45, 90, 135, 180 degrees and the sum over all angles (0-180). For comparison, the sound level measured with the SLM is added. The SLM cannot distinguish any direction.
The maximum is at 90 degrees with a significant contribution between 1000 and 2000 Hz. The last graph shows the sum over the five angles. The sum is nearly equal to the sound level measured with the SLM. From these measurements it could be concluded that the sound power of the water treatment unit is best described by the measurement at 90 degrees.

5 - CONCLUSION

Based on these designs and measurements in practical situations it can be concluded that a lot of practical questions for source localization can be solved with simple highly directional array microphones and that no specific digital array processing is needed.

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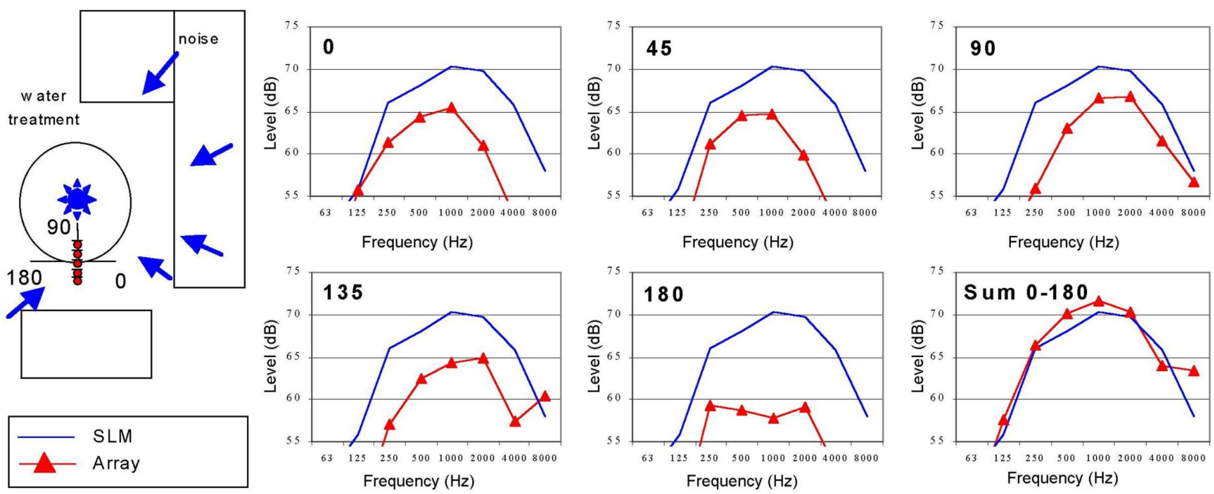

Figure 5: Location of water treatment plant (left) and measurement results (right).