NOISE SOURCE IDENTIFICATION AT HIGH SPEED TRAINS USING ARRAY TECHNIQUE

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Abstract: *A 64 channel microphone array is used to localize the noise sources of an ICE-S train with speeds from 200 to 280 km/h. The aero acoustic noise sources play an increasing role in the total noise with increasing velocity. This is in contradiction to classical noise emission models that suppose the wheel-rail contact to be the dominating noise source. The aero acoustic sources are positioned at all heights, especially on the roof of the locomotive. The highest position is given with the pantograph. Normal noise barriers are lower than the height of the pantograph. The noise radiates without hindrance from this top position. The array technique will be used to separate the different sources and quantify their influence on the radiated noise. Sounds for the different beams of the array are synthesized. Sound examples give an impression of the characteristics of the different sound sources. A short time Fourier transformation (STFT) with a window size of 22 ms is unusual in technical applications but in good accordance with the perception. This type of short time Fourier transformation allows for a good resolution even at high speeds of the train. The results using this type of STFT are presented.*

Key words: microphone array, high speed train, noise source detection, beam forming

1. INTRODUCTION

The current model for noise sources assumes that the wheel rail contact is the dominating noise source. In accordance with this model the height of the sound source is set to *0.7 m* above the rail. This model is correct for trains with low speeds. But for high speed trains the aero-acoustic sources are of increasing importance. A modified model should include higher noise sources as well. With the current model sound barriers with limited height are an efficient measure to reduce radiation into the surrounding. This is not the case for sound sources in greater height. The highest aero-acoustic source is the pantograph. Only high barriers are able to reduce the radiation from this top position. A new model for the noise sources of high speed trains is needed that takes the height of the different noise sources into account.

A practical method for the detection of the height of sound sources is the microphone array technique. An advantage of the array technique compared with directional microphones is that the beam can be defined offline as long as all channels are recorded.

2. TEST ENVIRONMENT

The experimental ICE-S train was tested on the “Westbahn” in Austria between the stations Prinzerdorf and Ybbs with velocities from *200 km/h* up to *280 km/h*. A shorter version of the ICE-S train was previously tested up to *300 km/h*. The train was equipped with two pantographs. Both pantographs at the leading and trailing traction unit were raised.

The Acoustic Research Institute was allowed to do test measurements with a microphone array in *7.5 m* distance from the track. Additionally 8 microphones on two trusses in *7.5 m* and *25 m* distance were used to compare the array measurements with classical pass by measurements.

3. MICROPHONES ON TRUSSES

Microphones at four different heights were fixed on two trusses with a maximum height of *3.5 m* above the rail at two distances from the rail of *7.5 m* and *25 m*. The track was on top of an embankment so the 25 m point used a higher truss to compensate for the sloping terrain.

3.1 Equipment

Behringer ECM 8000 microphones were attached to the trusses. Conversion was done by one Behringer ADA 8000 Pro Digital 8 converter at a sample rate of *48 kHz*. A Laptop was connected using a RME Multiface adapter and a RME Cardbus interface card.
The results were computed using the S_Tools - ST^X Software package developed at the Acoustics Research Institute.

3.2 Measurement Results

A separation exclusively by height of the microphones was not possible. The discrimination in the direction of the movement is bad too.
Fig. 1 and Fig. 2 present the results of the highest microphones in *7.5 m* and *25 m* distance from the track for a train speed of *250 km/h*. the scale is in *dB* with a full scale of *0 dB*. The spectrogram uses a *22 msec* block size for the short time Fourier analysis with a Hanning window. The frequency range is presented in a linear scale from *0 Hz* to *15 kHz*.

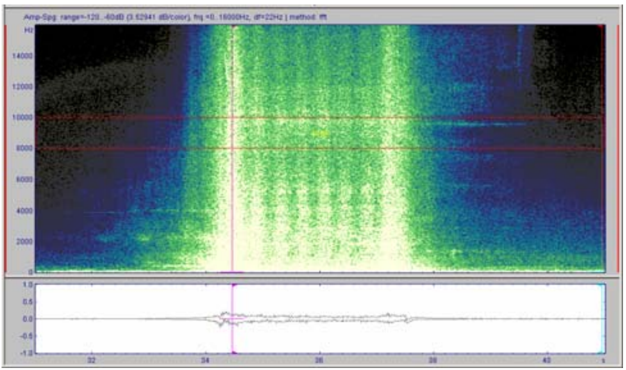

Fig.1. Spectrogram Microphone at *3.5 m* height and *7.5 m* distance from the track

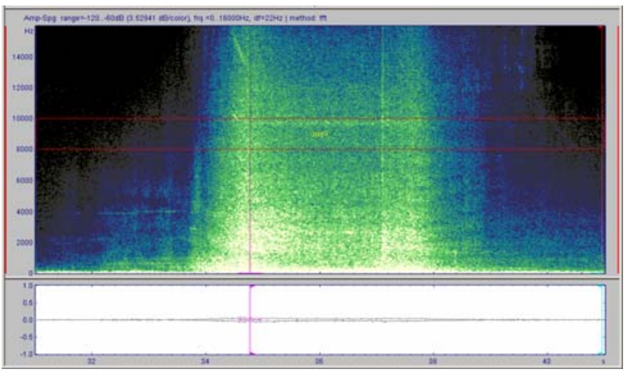

Fig.2. Spectrogram Microphone at *3.5 m* height and *25 m* distance from the track

4. MICROPHONE ARRAY

Higher levels are visible at the begining and the end of the train, but the signal does not separate the sources with respect to height. No remarkable differences are visible, if the microphones at different heights are compared with each other. The clustering of the 4 microphones on the truss at *7.5 m* distance into a simple array did not separate the signals with respect to the height of the different sources.
At *7.5 m* distance, the transition from one wagon to the next is visible, but the boogies belonging to the end of the leading wagon and the beginning of the trailing wagon are not separated in the signal.
To improve the situation a microphone array with 64 channels is used. The array is positioned at a distance of *7.5 m* from the track at a height of *2.0 m*. The 64 channels are arranged in 8 rows and 8 columns with a spacing of *6 cm*. The spacing with *6 cm* results in an interval of *40 m* between the main lobe and the first side lobe at a frequency of *1 kHz* or a *4 m* gap at a frequency of *10 kHz* in the chosen distance of *7.5 m*.

4.1 Equipment

The microphone array is build up using standardized components. 64 Behringer ECM 8000 microphones are used for data acquisition. The power supplies for the microphones and A/D converters are 8 Behringer ADA 8000 Pro-8 Digital devices. Sampling is done at a rate of *48 kHz*. The output are 8 ADAT streams. The streams are converted to 1 MADI stream using the RME ADI 648 converter. The data acquisition in a personal computer is done using the RME HDSP MADI interface card. The computer used for data acquisition is equipped with a SCSI raid and two Opteron processors. The array is built using a user defined aluminium structure.
A video camera synchronized with a trap was used to verify the correct moment of the pass by of the pantographs.

4.2. Analysis Parameters

Beam forming was done using a phase compensation for the different path lengths from the supposed source position in the time domain. The data is re-sampled. A simple linear interpolation of the sampled data in the time domain is used for this purpose.
Also the attenuation with the radiation assuming a monopole source is compensated for before the signals from the array microphones are summed up. The data is therefore multiplied by the inverse of the radial distance. The sum is divided by the number of channels. The result of the beam-forming is the signal at a distance of *1 m* from the assumed monopole source.
The processing is completely done in the time domain. The results are new time series stored in wave files. The sound can be played using the standard audio output of a computer. The acoustical impression for the different beams are more impressive than the corresponding spectrograms.
A high resolution in the direction of movement shall be achieved. Therefore a short time Fourier transformation

with a window length of *22 msec* is used. A weighting with a Hanning window is applied. Together with the focusing of the array along this axis a high resolution is possible. The boogies are clearly separated. The wheels themselves are sometimes separated in the spectrograms.
Also a high resolution in height was achieved using the beam forming method.
Tonal components in the wheel rail contact are suppressed, because the inclined transmissions of the sound of wheels excited at their resonances are eliminated.

4.3 Detection of source height

The effect of the pantograph being the highest aero-acoustic source is clearly separated from the wheel rail contact. The aero-acoustic sources dominate the higher frequency range for velocities from *240 km/h* to *280 km/h*.
The spectrogram for a velocity of *250 km/h* is presented in Fig. 3. The leading pantograph gives the highest noise signal. This effect does not depend on the direction of the trains. Therefore in the ongoing analysis only the leading pantograph is analysed.
It is already visible from the spectrograms that the wheel rail contact dominates the frequency range below *3 kHz*. Some boogies show higher amplitudes due to corrugation on the wheels.
A tonal component at the beginning and the end of the train increases in frequency and changes at once its position from *2.0 m* height to *3.8 m* and *5.3 m* height. This component should be the aero-acoustic noise of the train components on the roof and components of the pantograph.
A constant tonal component is visible in all spectra around *10 kHz*. This component is supposed to be an aero-acoustic component of the train, because the source height are equally distributed. The spectral characteristic changes only slightly with the height. At a *3.8 m* height additional lines are visible at *11 kHz* and *12 kHz*.

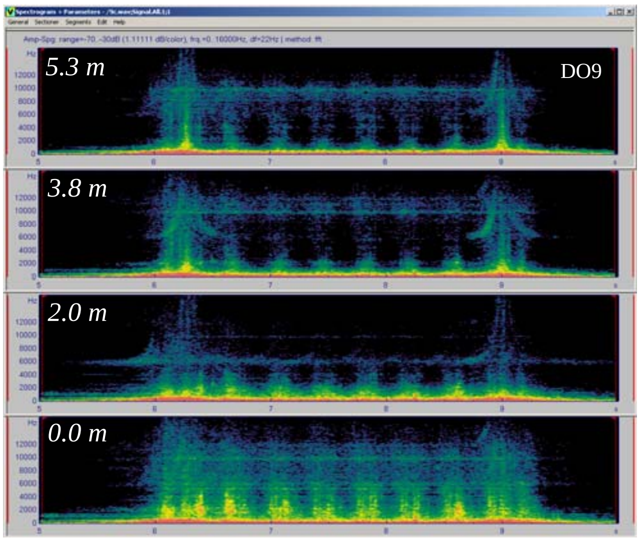

Fig.3. Spectrograms for a source height of *5.3 m*, *3.8 m*, *2.0 m* and *0.0 m* (*250 km/h*, DO 9)

At a *2.0 m* height a line at *6 kHz* dominates the signal. This line is also slightly visible at *0.0 m* height.
All these lines are not concentrated at the pass by of the boogies and also not concentrated at the power train. Therefore this lines are produced by aero-acoustic sources.

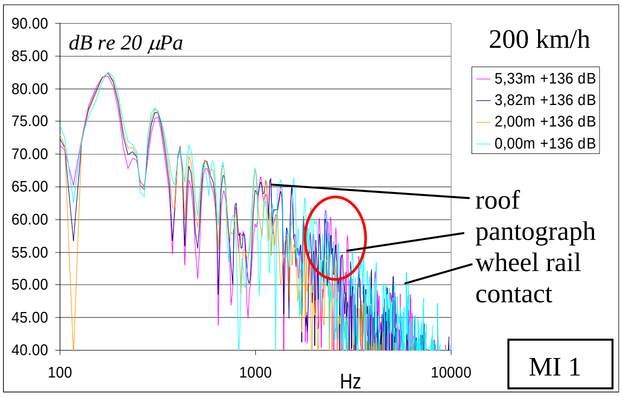

Fig.4. Spectrum at the moment of the pantograph pass by for source heights of *5.3 m*, *3.8 m*, *2.0 m* and *0.0 m*

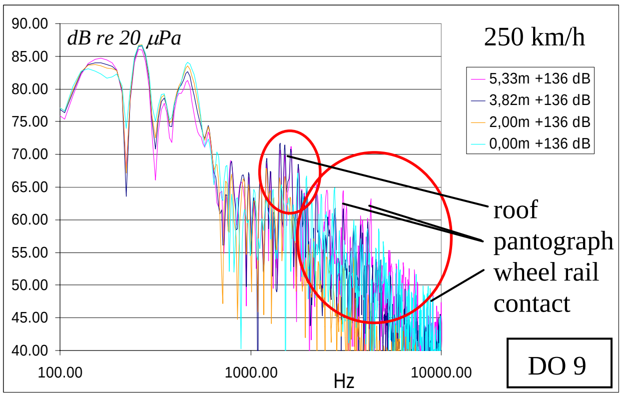

Fig.5. Spectrum at the moment of the pantograph pass by for source heights of *5.3 m*, *3.8 m*, *2.0 m* and *0.0 m*

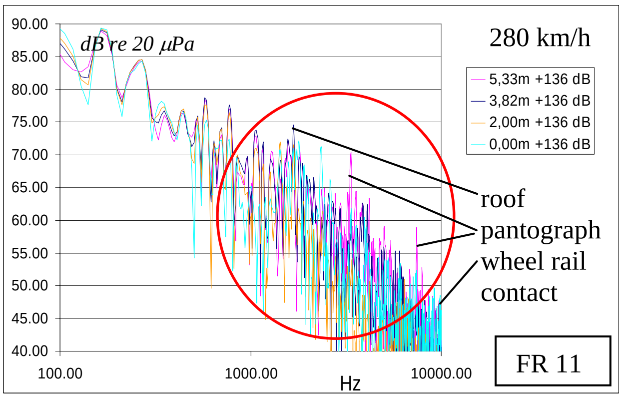

Fig.6. Spectrum at the moment of the pantograph pass by for source heights of *5.3 m*, *3.8 m*, *2.0 m* and *0.0 m*

4.4 Comparison of different noise sources

Fig. 4 to 6 present cuts through the spectrograms in *dB re 20 μPa* at the moment of the pass by of the first pantograph at different speeds. The correct time of the pantograph was proven using the video film.

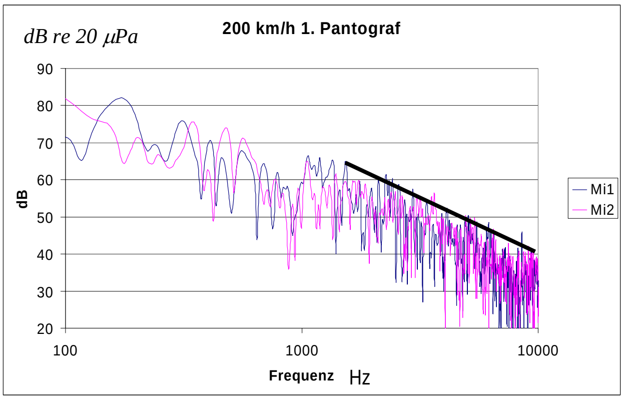

Fig.7. Spectra of pantograph (*5.3 m* height) at *200 km/h*

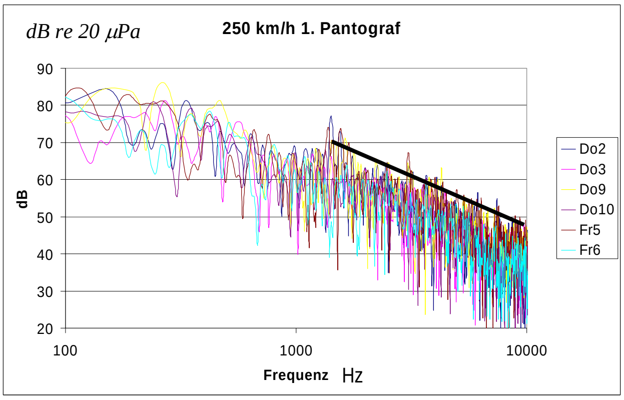

Fig.8. Spectra of pantograph (*5.3 m* height) at *250 km/h*

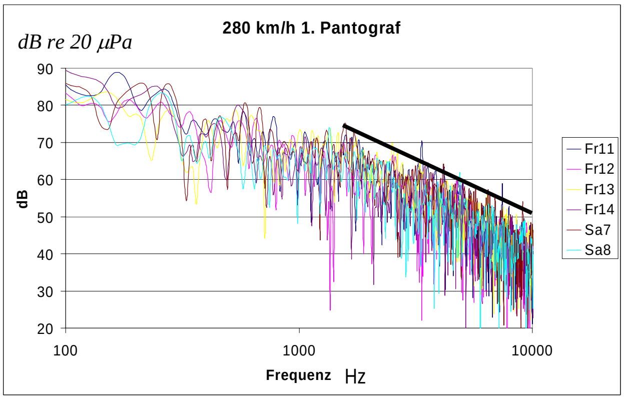

Fig.9. Spectra of pantograph (*5.3 m* height) at *280 km/h*

Fig. 4 presents a typical short time Fourier spectrum at *200 km/h*. Only some spectral lines of the pantograph (*5.3 m* height) and the roof (*3.8 m* height) are visible in the spectrum. At a height of 2 m, the lowest amplitudes are measured. This assures that the sources at and above the roof are clearly separated from the wheel rail contact. Also the sounds at the different heights are completely different.

Fig. 5 presents a typical spectrum at *250 km/h*. A tonal component is visible at *1.5 kHz*. The tonal component is typical for the ICE-S. It is assumed that this component radiates from measurement devices near by the pantograph.

In the higher frequency range from *2 kHz* to *8 kHz* the pantograph dominates the spectrum. The signal is wide banded and the acoustic impression is noise.

Fig. 6 presents the same data for a speed of *280 km/h*. The wide band spectrum has increased in amplitude. The tonal component has not increased and vanishes in the wide band noise.

4.5 Noise level of pantograph

In the next step, spectra for the different runs at the same speed are evaluated for the pantograph height of *5.3 m*.

At 200 km/h (Fig. 7) the level decreases from *65 dB* at *1.5 kHz* down to *40 dB* at *10 kHz*.

At *250 km/h* the level increases by *5 dB* neglecting the tonal component (Fig. 8).

Another 5 dB increase is visible from *250 km/h* to *280 km/h* (Fig. 9).

The absolute levels of the short time Fourier analysis used do not allow the direct evaluation of a standard pass by level or sound intensity. A comparison with sound intensity measurements is needed for scaling.

5. CONCLUSION

Using standardized components reduces the cost of the microphone array by a factor of 10.

A two dimensional array is an appropriate measure to localize the sound sources of high speed trains. The resolution allows the separation of the different noise sources. Such arrays can be used to build up a new model for the radiation of sound from high speed trains that implies the different heights of the sound sources.

A short time Fourier analysis with a time constant of *22 msec* that is in accordance with human perception gives a high resolution along the moving direction of the train even at high velocities. But this type of analysis does not allow for the direct definition of the sound intensity.

A combination of this type of analysis with an ordinary octave analysis of the *7.5 m* pass by level can be used to split the total noise level into the noise sources due to their importance for every octave or third octave.

It was found that for speeds higher than *240 km/h* the pantograph is a source that dominates the higher frequency range from *1.5 kHz* to *8 kHz*. Standard sound barriers with a height less than the height of the pantograph do not prohibit the radiation of this noise source into the environment. Therefore this noise source is of great importance.

The array can also be used to design new noise optimized pantographs.