

# HIGH SPEED TRAIN NOISE - SOUND SOURCE LOCALIZATION AT FAST PASSING TRAINS

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## ABSTRACT

At high speeds of more than around 260 km/h the aerodynamic sound sources of trains are emitting the same or more sound energy as rolling noise. Such sources may be the pantographs, air flow exposed current connections or other sometimes unexpected sources. To identify and to localize the different noise sources of the German ICE 3 train at high speeds up to 350 km/h, the Deutsche Bahn AG used their 90-microphone-spiral-array with a diameter of 4 m. The results of measurements for the whole ICE 3, special points of interest and of other high speed trains, e.g. the ETR 500, are shown.

## INTRODUCTION

The most railway companies continually increase the speed of their trains on the main lines. The emitted noise is increased with higher speeds too, but while the rolling noise rises with a speed exponent of about 3, the sound emitted by aerodynamic sources rises with a speed exponent of about 6. As a matter of fact, the aerodynamic noise of a train becomes more important than the rolling noise at speeds between 250 km/h and 300 km/h, depending of the train type.

So the Deutsche Bahn AG (DB) developed a microphone array with 90 microphones on a spiral with 4 m diameter to investigate sound sources on railway vehicles. Of course the main object is to localize the sound sources on trains running with high speed.

## THE MICROPHONE ARRAY

The microphone array of the DB consists of 90 microphones. They are positioned on a spiral to get a stochastic and non-regular arrangement (figure 1). This form allows to get a good signal to noise ratio and to suppress side lobes. The diameter of 4 m is necessary to improve the resolution at low frequencies. Additionally the DB owns a spiral array with 2 m diameter to localize higher frequencies up to 5 kHz.

Measurement and signal processing are based on the theory of beamforming arrays, because the observation time at high speeds is short. The array receives all that sound from a source, which is radiated direct in its direction. Thus, all sources have to be monopoles to get a realistic sound source distribution of an object. As this is not the case on a train, some sources are over- or under-evaluated, depending on the characteristics of their radiation. Note for that reason, that's not possible to compare one by one the sound pressure levels given on the colormaps (calculated for a distance of 5 m) with levels measured by a normal single microphone.



figure 1: ICE 3 with microphone array

## THE ICE 3

The InterCity Express 3 (ICE 3), running in Germany, is one of the top modern high tech trains. It is designed for regular speeds of 330 km/h. It is a electro-multiple-unit with distributed drive components (figure 1). Figure 2 shows the sound source distribution of the whole train, measured by the array at 350 km/h (moving to the right), with an outline of the train.

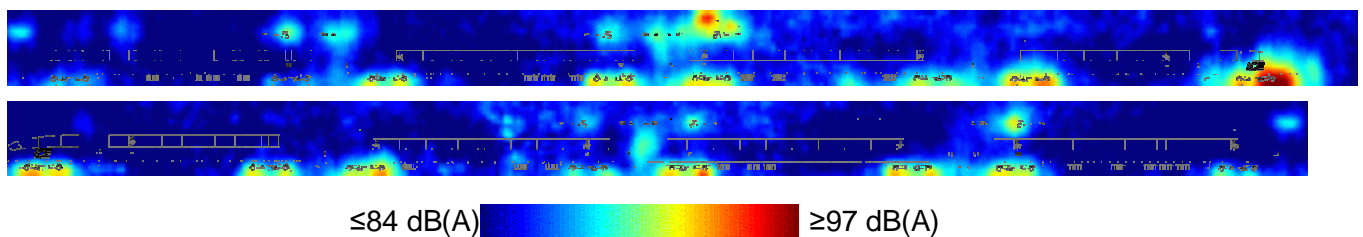
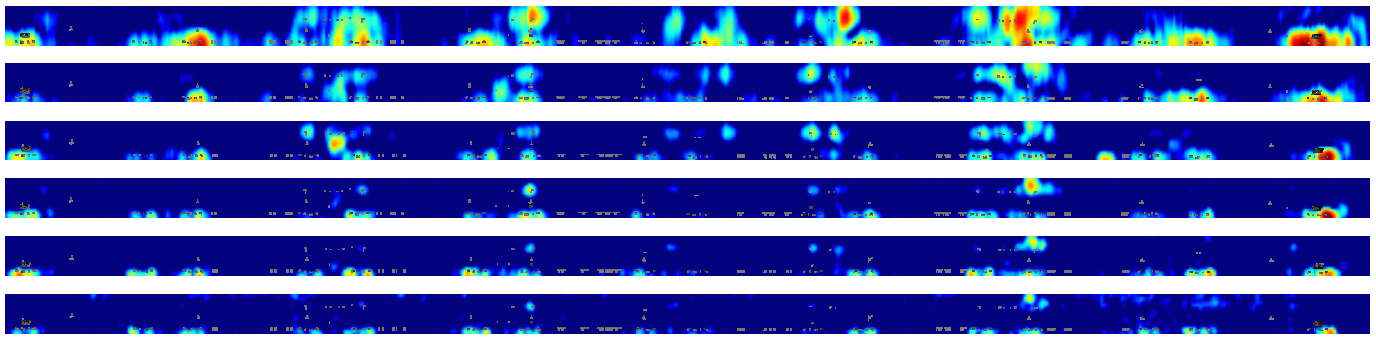


figure 2: image of the sound source distribution of the ICE 3 as 'seen' by the array, A-weighted

Figure 2 and figure 3 presents clearly the most important sound sources. There are of course the wheels, which emit rolling noise. Aerodynamic sound sources are the pantographs and the gaps between the coaches, especially where the high voltage current lines are connected. Most surprising, the antennas on the roof emit a considerable aerodynamic sound. The head of the train is a region, where the sound comes from many different sources. Various cooling fans for the motors and drive assemblies or for the refrigerators of the restaurant car, situated in the lower parts of the coaches, are sound sources of secondary importance on the pass-by.

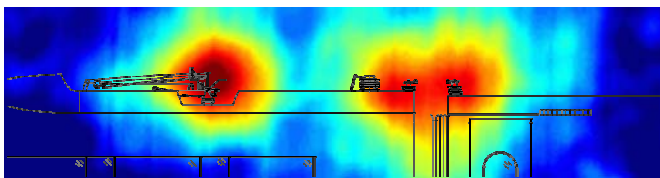


≤78 dB  ≥93 dB

figure 3: array image of the ICE 3, 1/3 octave bands 315 Hz, 400 Hz, 500 Hz, 630 Hz, 800 Hz and 1 kHz

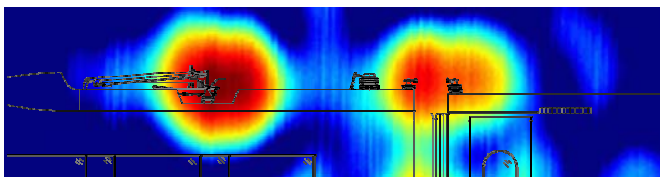
## SOUND SOURCES

### Pantographs and current connections

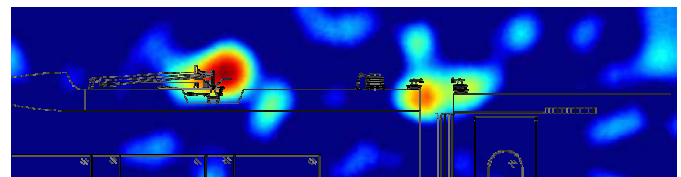


≤84 dB(A)  ≥91 dB(A)

figure 4: array image of the pantograph and the current connection wire (350 km/h), A-weighted



≤73 dB  ≥83 dB




≤76 dB  ≥82 dB

figure 5: array image of pantograph and the current connection wire, left 1/3 octave band 630 Hz, right 1/3 octave band 1,25 kHz

The measured train has six pantographs to be able to run in several countries in Europe (with different configurations for the contact wire). Each one has surrounding shrouds to improve the air flow (figure 6). Nevertheless they are still great sound sources also in down position, and similar pantographs emit different sound levels, what we couldn't explain yet satisfactory (figures 4 and 5).

A high voltage current line goes between coach two and coach seven. On the gap between the coaches, there the cables are connected as a spiral wound wire mounted on insulators (figures 6). This sound source is as strong as the pantographs. Figure 5 shows the radiation of the wire and the upward insulators at different frequencies.



left: figure 6: pantograph with shroud and current wire; right: figure 7: roof antenna

## Roof antennas

Some antennas stand on the roof of the head cars and of the restaurant car. They have a height of about 40 cm and a diameter of 5 cm to 10 cm (figure 7). Because the antennas emit a lot of sound, it is to assume, that they reach outside the boundary layer. Also they follow the law of the vortex sound emission (STROUHAL-effect). The frequency of the main sound emission rises proportional to the increasing speed (shift from third octave bands 500 Hz and 630 Hz to 630 Hz and 800 Hz for a speed rise from 307 km/h to 350 km/h). On the restaurant car are two pairs of antennas, which are a little bit out of the train centreline. Thus the array is focused to the centreline, figure 8 shows the antennas radiating at different rates.

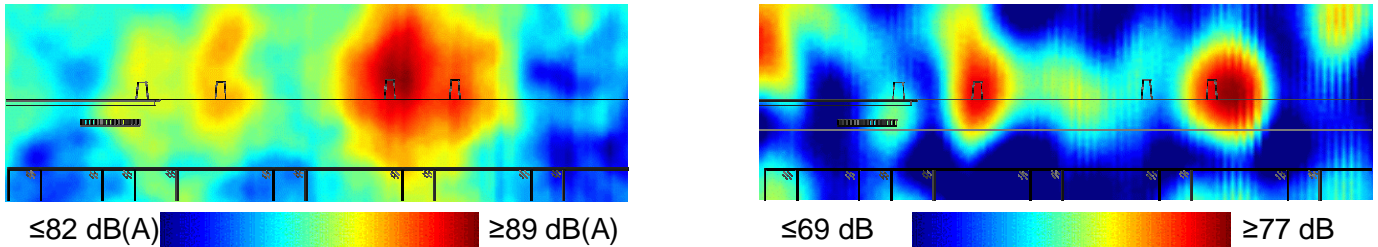


figure 8: array image of the antennas on the restaurant car (350 km/h), left A-weighted, right 1/3 octave band 800 Hz

## Head of the train

The strongest sound source of the whole train at speeds over 300 km/h is the area at the first bogie (figure 9). There the wheels generate rolling noise and the air flow together with some special equipment like train control antennas add aerodynamic noise. At the point of the most sound emission there is a rubber tube, starting from the first axle box, exposed to the laminar airflow of the front spoiler (figures 10 and 11). It fits the STROUHAL-effect too.

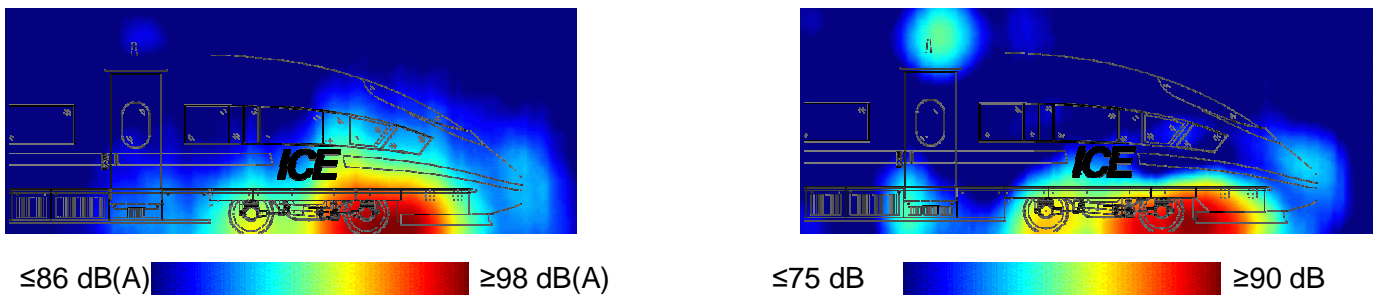


figure 9: array image of the train head (350 km/h), left A-weighted, right 1/3 octave band 800 Hz



figure 10: rubber tube

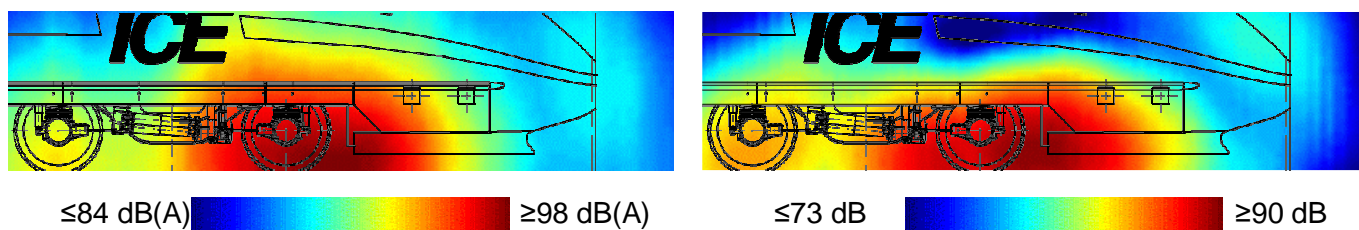


figure 11: zoom to this region of the rubber tube, left A-weighted, right 1/3 octave band 800 Hz

Another source just behind the first bogie is a step leading to the first door. It does not follow the STROUHAL-effect, probably because of its complicated geometry.. Above the door there is an antenna with a behaviour as described above. The train nose is a sound source of second importance (figure 9).

## OTHER HIGH SPEED TRAINS

The DB measured the Italian high speed train ETR 500 with the large array within the project trilateral cooperation DB-FS-SNCF at speeds up to 300 km/h (figure 12). On this train, the main source is the first bogie too. Additional, a strong sound source appears at the steps and the handles of the driver cabin, when the speed rises.

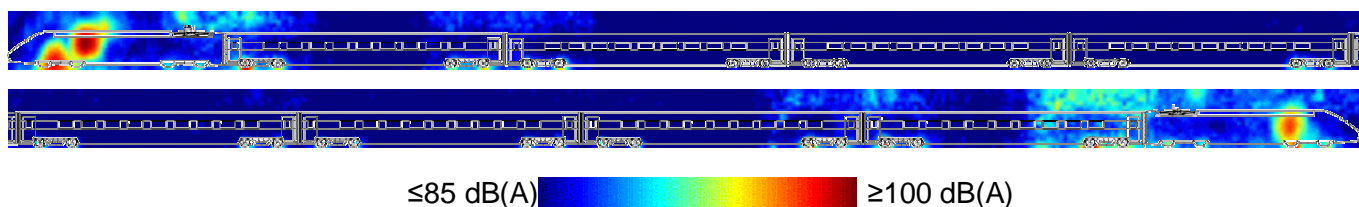


figure 12: array image of the ETR 500 (291 km/h, moving to the left)

Some trains ICE 1 and ICE 2 are measured at their regular speed of 250 km/h. Also on these trains at this speed the head of the train is a considerable sound source (figure 13).

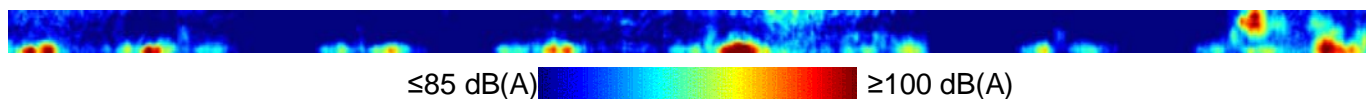


figure 13: array image of the ICE 2 (semi train, 250 km/h, moving to the right)

## **CONCLUSIONS**

European high speed trains were measured by the Deutsche Bahn AG with a large microphone array at speeds between 250 km/h and 350 km/h. A lot of aerodynamic sound sources of the ICE 3 are distributed on the roof along the whole train. The area at the head of the train is also a strong aerodynamic source, that's the fact for all trains. So in the development of future high speed trains, e. g. the High speed Train Europe (HTE), the train heads have to be improved. On the other hand, any assemblies not essential necessary on the roof, have to be avoided.

## **ACKNOWLEDGEMENTS**

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