Microphone Array Measurements of Sound Radiation from Cars

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Introduction

The long term goal is to achieve an environmentally friendly transport system, by applying effective noise control measures. Since noise from motor vehicles is composed by radiation from tyres, driveline, and carbody, it would be most helpful if the different sources could be separated. Therefore, the Swedish National Road Administration decided to explore the potential of microphone array measurements. The paper reports some results of this investigation.

Figure 1: Acoustic camera consisting of about 100 microphones, held in positions by an aluminium stand. A passenger car in the background.

Figure 2: Passenger car passing the acoustic camera at a measurement distance of 5 m, while recording a sound image.

Delay-and-Sum Beamforming

Traditional delay-and-sum beamforming results in an acoustic image; sound signals are summed up, particularly accounting for the different propagation paths from the source and to the different microphones (Figure 3 and Equation (1)).

$$s_i(t) = \sum_{j=0}^{N-1} p_j(t + r_{ij}/c) \qquad (1)$$

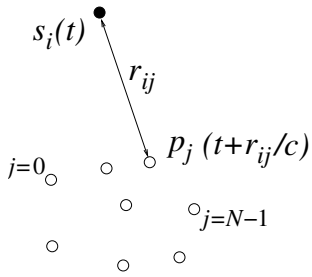

Figure 3: Sound source $s_i(t)$ at a distance r_{ij} from microphone no. j, with sound pressure signal $p_j(t + r_{ij})$. Total number of microphones, N.

Image quality above all depends on the number of microphones and their configuration. Using a great number of microphones is the safest way to guarantee high image quality.

In each image, a certain color represents a certain dB level. The colors are adjusted, so that locations of sound sources emerge as clearly as possible. Therefore, dynamic range and maximum dB level varies between the images. Dynamic range is the distance in dB between dark blue (silent) and dark red (noisy). It is generally 10 dB at high frequencies and 3–5 dB at low frequencies.

Results and Discussion

Excellent resolution is obtained, particularly at high frequencies (Figure 4). Tyres, the most important noise sources, dominate the A-weighted levels. Strangely enough, rear tyres are often, but not always, noisier than front tyres (Figure 5). Tyre radiation peaks around 800–1000 Hz for passenger cars, SUVs, and light trucks, but around 500–630 Hz for heavy trucks, realized by comparing A-weighted sound images with sound images at different third octave bands. If they resemble each other to a high degree, as they do in Figure 6, this third octave band must contribute significantly to the A-weighted level. Accordingly, sound power spectra always exhibit an increase where tyre radiation peaks (Figure 10).

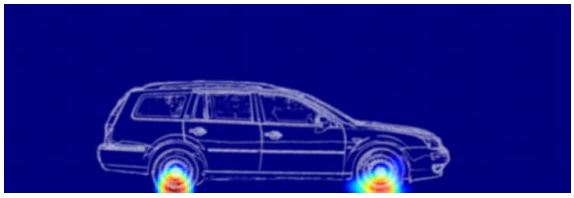

Figure 4: Sound image: passenger car, summer tyres, 120 km/h, 3150 Hz.

The vibrating tread radiates noise, possibly amplified by the horn effect and wheel house resonances (Figure 7).

Low frequency driveline noise radiate out from the space

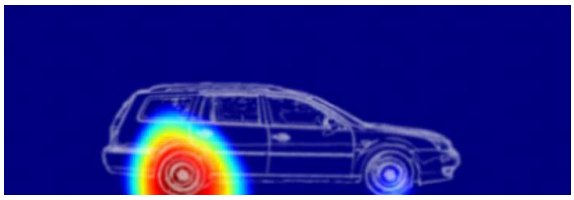

Figure 5: Sound image: passenger car, studded tyres, 120 km/h, 800 Hz.

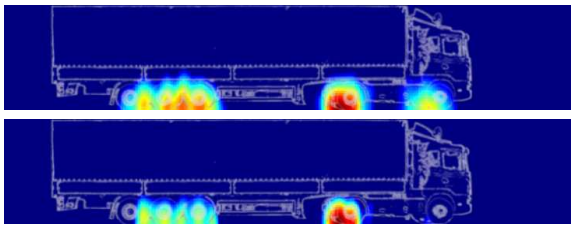

Figure 6: Sound images: heavy truck, 90 km/h: (*upper*) A-weighting, (*lower*) 630 Hz.

between the car bottom and the road surface (Figure 8). Possibly, source locations coincide with the positions of silencer chambers under the car.

All sources are located close to the road surface, even at 120 km/h, so wind generated noise must be considered to be negligible. However, some images display sources, which might be caused by the wind, e.g. Figure 9, with a source right behind the rear splashguard.

The sound power spectra in Figure 10 show total noise radiated out of sound images of passenger cars at different speeds. The spectra may be normalised, so as to display sound power ref. 10^{-12} W, but this delicate task still remains to be done. Sound images, consequently also spectra, depend not only on source strengths, but on many other parameters, such as measurement distance, microphone number, microphone configuration, and tracking length.

By the spectra in Figure 10, the speed exponent x may be calculated. It is defined by the relation $L \sim 10 \log v^x$, where v is vehicle speed and L noise level. The speed exponent $x = 3.5$, corresponding to 11 dB(A) / doubling of vehicle speed. Similarly, it may be concluded that studded tyres are about 4 dB(A) noisier than unstudded tyres. Passenger cars, SUVs, and light trucks are approximately equally noisy. Heavy trucks are about 7 dB(A) noisier than other vehicles.

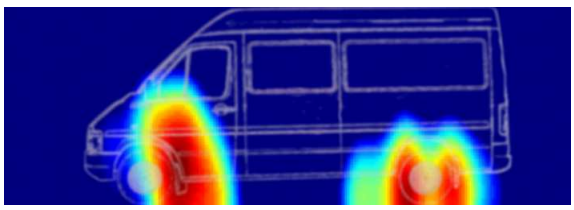

Figure 7: Sound image: light truck, 90 km/h, 500 Hz.

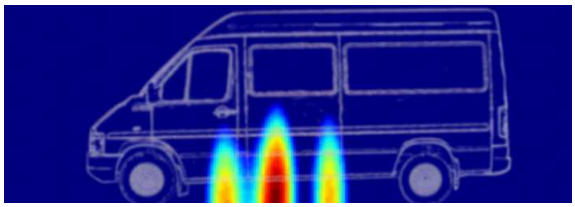

Figure 8: Sound image: light truck, 110km/h, 315 Hz.

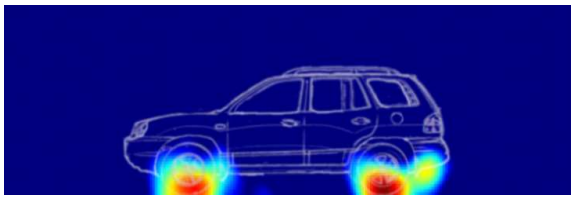

Figure 9: Sound image: SUV, studded tyres, 120 km/h, 2000 Hz.

Summary and Conclusions

It is possible to separate noise from tyres, drive line, and from wind. Tyres contribute most to the A-weighted levels. For cars, it has its maximum around 800–1000 Hz, and for heavy trucks around 500–630 Hz. The horn effect and wheel house resonances seem to be important. Low frequency driveline noise, around 250–400 Hz, radiate out from the space between the bottom of the car and the road. Wind generated noise is negligible at all speeds, at least up to 120 km/h. The speed exponent of noise radiation from cars, tyre/road noise, is approximately 3.5, corresponding to 11 dB(A) / doubling of speed. Studded tyres are about 4 dB(A) noisier than unstudded tyres. Passenger cars, SUVs, and light trucks are approximately equally noisy. Heavy trucks are about 7 dB(A) noisier than other vehicles.

Acknowledgements

Thanks are due to Kjell Strömmer, the Swedish National Road Administration.

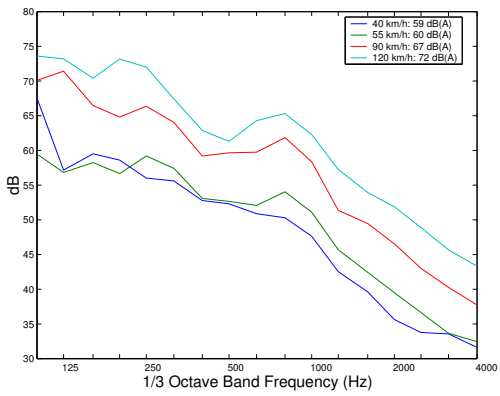

Figure 10: Sound power spectra of sound radiation from a passenger car at increasing speeds: 40 km/h, 55 km/h, 90 km/h, 120 km/h.