

# ENVIRONMENTAL RAILWAY NOISE : A SOURCE SEPARATION MEASUREMENT METHOD FOR NOISE EMISSIONS OF VEHICLES AND TRACK

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## ABSTRACT

One of the main topics currently at stake in Railway acoustics is to be able to assess separately the contribution of the infrastructure and rolling stock from the total noise radiated in the environment.

Within the STAIRRS European project, SNCF has addressed this issue and proposed a method, exclusively based on pass-by measurements and which achieved promising results during a field test campaign. Hence, it is expected to be a useful tool for on going standard projects.

The key features of the method are described : principle, requirements and advanced data processing performed. Then examples of results obtained on different types of vehicles and tracks are compared and discussed. Last, conclusions are drawn, dealing with the limits of the method and the improvements foreseen.

## INTRODUCTION

Noise emitted by trains in the environment is a consequence of two major mechanisms: for speeds up to 250 kph, the rolling noise is the leading phenomenon producing noise, while for higher speeds the aerodynamic sources become more and more influent as the train runs faster.

If the train is responsible of the aerodynamic noise<sup>1</sup> (which excitation is mainly due to turbulences around the car body, the pantograph or the bogie... ), such a conclusion can not be applied to the rolling noise mechanism. It turns out to be proved that, at least for freight traffic, track contribution could be predominant in the total noise radiated. Moreover, as some types of trains are potentially/intrinsically noisier than others, infrastructure radiation efficiency may also vary according to some key track equipment parameter<sup>2</sup>(railpad stiffness, sleeper type, ballast/slab foundation...).Therefore it raises lots of questions from legislators, railway operators, infrastructure owners as well as from the whole railway industry. Some of them are listed hereafter [FOD01] :

- from the standardization side, does type testing efficiently assess the vehicule acoustic emission and does it enable us to compare different types of rolling stocks? What kind of variations do we have to expect on different track types ? How can we improve this test specification ?

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<sup>1</sup> Although aerodynamic sources could result from train, track and flow interaction too- See [POI02]

<sup>2</sup> one could add to this remark the wheel and rail roughnesses variations which causes another source of variations, but which is at the moment better taken into account and bounded.

- to limit the noise creation, should we develop low noise components and implement mitigation measures preferably on the track or on the vehicles, for a given configuration ? This issue is being addressed in the work package 2 of the European research program STAIRRS (Strategies and Tools to Assess and Implement noise Reducing measures for Railway Systems). Within the frame of this project, SNCF has developed and proposed an original source separation method for noise emissions of vehicles and track which is exclusively based on pass-by measurement data. This paper focuses on the description of this method and its achievements : its key theoretical features are provided first ; then an application is supplied, analysing results from a field test campaign in France; last, limits of this approach are listed and further improvements highlighted.

## THE SEPARATION METHODOLOGY

### Principle

To measure the pass-by noise emitted by railbound vehicles, the standard specifies the use of a microphone located at a distance of 7,5m or 25m from center line of the track.

The basic idea of the separation method is to assess the track contribution from noise measured on this standard microphone using supplementary captors : accelerometers to characterize the dynamic behavior of the track, a “near field” microphone to measure the acoustic radiation and a device to detect wheel passing and train speed.

Then the method relies on four fundamental steps :

1. assess the track transfer function between track vibrations and “near field” noise emitted midway between the bogies, assuming that the track is, at that time, the dominating source (this assumption has been checked –see Figure 4),

$$H_{track}^{between\ bogies} = P_{track}^{between\ bogies} \cdot [g_{track}^{between\ bogies}]^{-1}$$

2. derive the overall track contribution for a whole pass-by which is equal to the track transfer function times the track vibrations,

$$P_{track} = H_{track}^{between\ bogies} \cdot g_{track}^{whole\ pass-by}$$

3. infer the vehicle contribution from the difference between the total noise measured and the contribution of the track.

$$Lp_{vehicle} = Lp_{total} - Lp_{track} \quad \text{with } Lp = 20 \cdot \log\left(\frac{P^2}{2 \cdot 10^{-5}}\right)$$

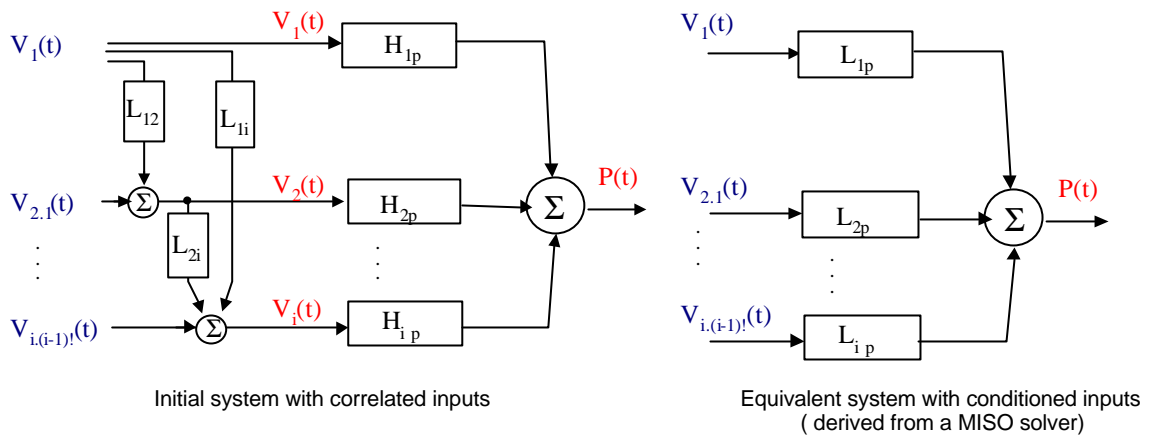
4. apply the same weight (ratio vehicle/track contribution) to the standard microphone

### Assessment of the Track transfer function

The number and the position of each accelerometer on the track as well as the distance and the height of the “near field” microphone are key parameters that are still being addressed. At least two accelerometers are necessary (vertical and lateral rail vibration located midspan).

Therefore, calculation of the track transfer function (step 1) requires a specific processing due to the partially correlated inputs (track accelerations). A complex system has to be solved, using the so-called MISO technics (Multiple Input Single Output technics – see [BEN86]).

The core of this technic is to transform the initial system into an equivalent uncorrelated system easier to solve.



- $V_i(t)$  : measured track vibration inputs. They are partially correlated.  
 $V_{i,(i-1)!}(t)$  : conditioned(uncorrelated) vibrations derived from MISO solver and used to assess the track transfer.  
 $P(t)$  : measured “near field” acoustic pressure  
 $H_{ip}$  : Transfer function between the vibration input  $i$  and its contribution to the output  $P(t)$   
 $L_{ij}$  : Transfer function representing the correlation between inputs  $i$  and  $j$   
 (part of the energy of the input  $n^o i$  comes from the inputs  $(i-1), \dots, 2, 1$ )  
 $L_{ip}$  : transfer function between the conditioned input  $i$  and its contribution to the output  $P(t)$

Starting from the Power Spectral Density functions (PSD) of the partially correlated measured accelerations  $V_i$ , the PSD of the uncorrelated (conditioned) inputs  $V_{i,(i-1)!}$  are recursively computed using the following equation :

$$G_{ij,r!} = G_{ij,(r-1)!} - L_{ij} \cdot G_{ir,(r-1)!} \quad \text{for any } j \geq i \text{ and any } r < j$$

$$\text{with } L_{rj} = \frac{G_{rj,(r-1)!}}{G_{rr,(r-1)!}} \quad \begin{array}{l} G_{ij} \quad : \text{ cross PSD of correlated inputs } i \text{ and } j \\ G_{ij,r!} \quad : \text{ cross PSD of inputs } i \text{ and } j \text{ conditioned} \\ \text{on the } r \text{ previous inputs } (r, r-1, r-2, \dots, 1) \end{array}$$

This yields to the transfer functions  $L_{ip}$  of the equivalent uncorrelated system :

$$L_{ip} = \frac{G_{ip,(i-1)!}}{G_{ii,(i-1)!}}$$

In a last step, track transfer functions of the initial system  $H_{ip}$  are derived, by working backwards :

$$H_{ip} = L_{ip} - \sum_{j=i+1}^q L_{ij} \cdot H_{jp} \quad ; q = \text{number of inputs}$$

This detailed process shows the real physical meaning of the energy transfer paths, but it could be sum up in a more compact matrix formulation as follows :

$$H_{xy} = [G_{xx}]^{-1} \cdot G_{xy} \quad \text{where} \quad \begin{array}{l} G_{xx} = \text{input spectral density matrix} \\ G_{xy} = \text{input/output cross-spectral density vector} \\ H_{xy} = \text{track transfer function vector} \end{array}$$

## APPLICATION OF THE METHOD

### Outlines of the validation field test campaign

A first application of this separation method has been performed using a set of data acquired during a field test campaign in France, in october 2001, and involving SNCF, TNO Institute of Applied Physics and AEA Technology.

The principle of this test was to run a test train composed of different kind of vehicles over several ballasted track types and to perform simultaneously on board and way-side measurements. Main characteristics of this field test are given hereafter :

- Composition of the test train :
  - 2 freight wagons G50 (Two wheels were equipped with accelerometers – see Figure 3),
  - 1 laboratory coach,

- 1 double flat container wagon with small wheels,
- 3 Corail Coaches with disk and composite block brakes
- Track types each equipped to perform pass-by vibroacoustic measurements (see the measurement protocol Figure 2) :
  - a reference track : UIC60 rail + 9mm grooved rubber railpad + bibloc concrete sleepers,
  - a silent track : reference track + rail dampers,
  - an alternative track : U50 rail + 4,5mm grooved rubber railpad + wooden sleepers.
- Runs at different speeds : [ 60 100 120 140 ] kph



Figure 1: *the test train*

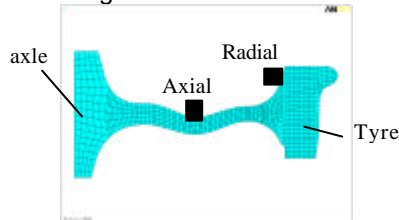
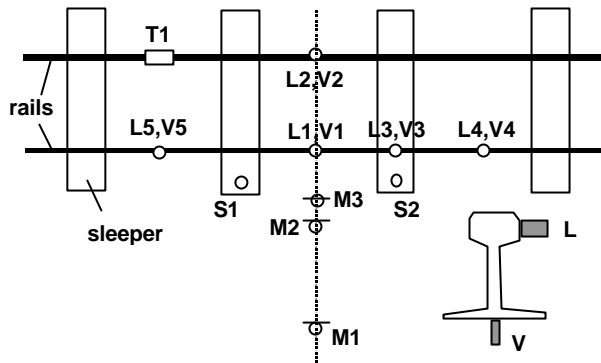


Figure 3 : *Positions of the accelerometers on the wheel (axisymmetric view)*



T : trigger device ( wheel passing detector)  
 V&L : Vertical and Lateral accelerometers  
 M : Microphones M1(7,5m /1,2m) and M2(1,75m /0m)  
 (distance from the centre of the track/ height above the railhead)

All signals are recorded using a common time base

Figure 2 : *captors position on the test section*

## Results

The following results concern the application of the separation method on the group of two G50 freight wagons passing the reference track at 60 kph (see Figure 1).

First of all, the validity of the basic assumption made in step 1 (i.e : wheel contribution can be neglected between bogies) is justified. In Figure 4 , the wheel dynamic behavior is mainly dominated by a few resonant eigenmodes at 1.8 kHz, 2.4 kHz and 3.2 kHz (see [THO93]). The radiation of these wheel modes are also clearly measured on the near field microphone. Moreover, the radiation has obviously a high directivity and does not influence anymore the microphone a few meters after the wheel has passed. Hence specific areas which are free of vehicle contribution can be defined on the train, by eliminating the bogies near side environment. These areas are used in the separation method to calculate accurately the track vibroacoustic transfer function.

In Figure 5, results issued from 2 different models of the separation method are provided. The first model consider only one input (the vertical accelerometer V1) whereas the second one takes into account both vertical and lateral accelerations (V1 & L1). A good estimation seems to be achieved in the low frequency range. Coherences are quite high and the derived track noise fits well the total noise. Sensible improvements are noticed in the second model for the coherence descriptor and at a lesser extent for the track contribution. This is particularly important in the frequency range [400 : 800 ] Hz for which the overestimation of the track contribution is smoothed. Nevertheless, even in that case, the multiple coherence is not completely satisfactory : it drops significantly above 1800 Hz, when the track is not dominant. This point will have to be adressed in a further step.

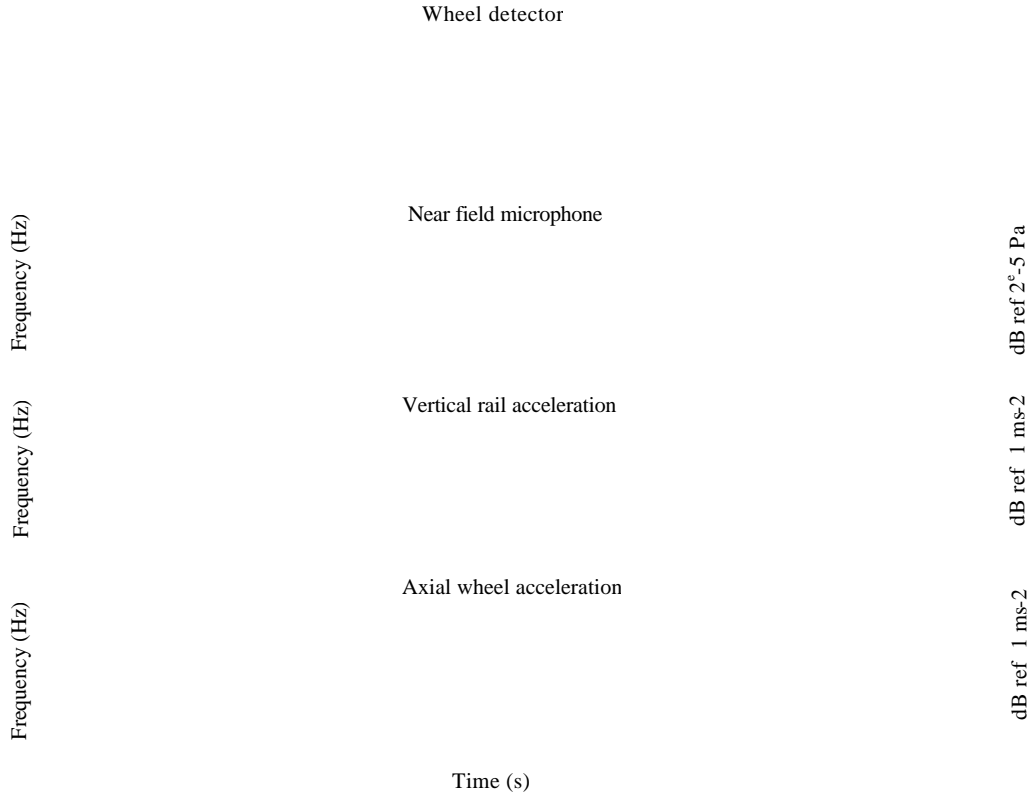


Figure 4 : *Spatial location of the acoustic wheel contribution on the near field microphone M2 (Pseudo-smoothed Wigner-Ville distribution)*

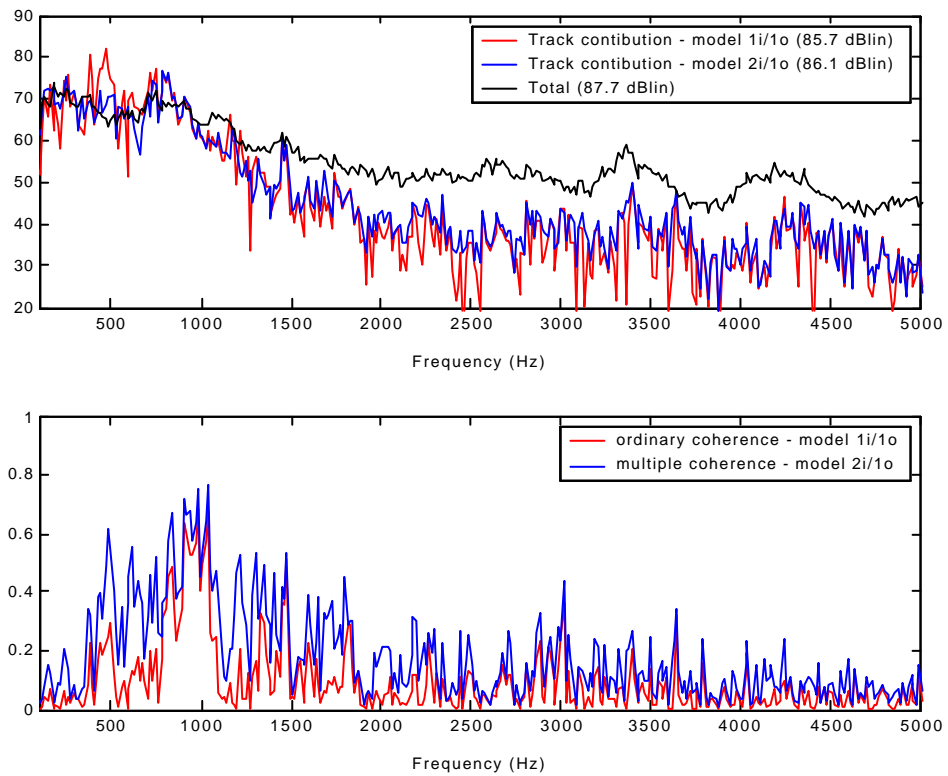


Figure 5 : *Measured noise emitted by the group of G50 wagons (Microphone M2)*

In red : model using 1 input : vertical accelerometer V1 and 1 output : micro M2

In blue : model using 2 inputs : vertical & lateral accelerometers (V1& L1) and 1 output : micro M2

Regarding the validity of the track contribution assessment, one can be satisfied by the global trends of the curves (see third octave results Figure 6) . As expected, the track is the main source of noise : 2dB(A) higher than the vehicles. Moreover, the analysis of the spectra confirm the background knowledge, i.e. that the track contribution is dominant below 1,25KHz while the vehicles become the main source of noise above 1,25KHz.

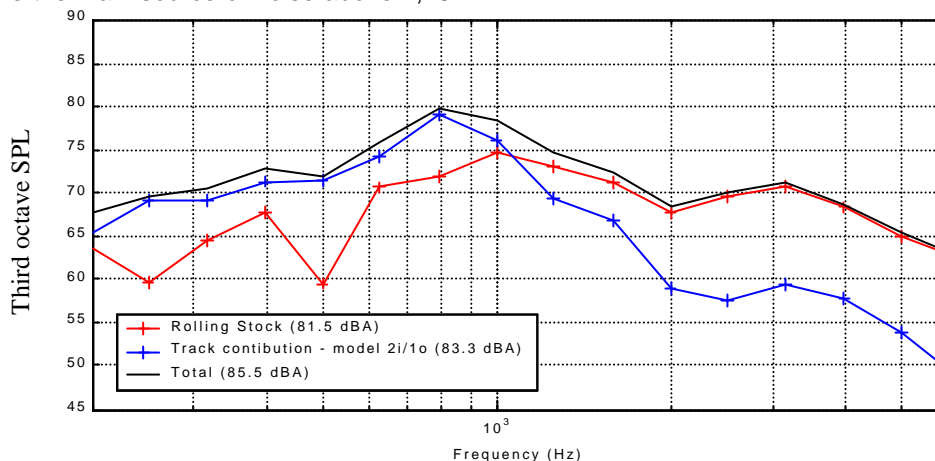


Figure 6 : Third octave band integration of the G50 group pass-by noise level (Microphone M2)  
(model using both vertical and lateral accelerations as inputs)

## LIMITS AND FURTHER IMPROVEMENTS

The core of the separation method is based on the use of cross-spectra and partial coherences between an acoustic pressure and accelerations. These quantities, which are computed using signals phase relationships, are very sensitive to measurement problems like background noise or perturbations generated by the blast in the front train (aerodynamic effect).

Therefore, it is crucial to optimize all parameters that could improve this phase relationship assessment : besides the use of a low pass filter which is recommended, more accelerometers describing the dynamic behaviour of the track could improve the multiple coherence (captors on the inner rail and on the sleepers). The optimization of the position of all captors and specifically the near field microphone (height and distance) could also help, as well as the choice of an improved dynamic range for the acquisition system (use of a 24 bits D/A converter) or the correction of the time delay due to the propagation.

## CONCLUSIONS

The separation method developed by the SNCF demonstrated good preliminary results with a field test campaign data. Its main feature is to be completely based on vibroacoustics pass-by measurements. This method has been recently implemented in a userfriendly matlab tool which is going to be used for the data collection of the STAIRRS project. The underlying model takes into account at the moment 2 inputs (vertical and lateral rail vibration of the outer rail) but a further issue, more complete is in progress. More extensive and severe tests are presently performed on the method to check its robustness and to assess its accuracy.

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