LOCALIZATION OF NOISE SOURCES USING SOUND PROPAGATION THEORY

PACS: 43.50 Lj

Jonasson, Hans G.
SP Swedish National Testing and Research Institute
Box 857
SE-501 15 Borås
Sweden
Tel: +46 33 16 54 20
Fax: +46 33 13 83 81
E-mail: hans.jonasson@sp.se

ABSTRACT

The propagation of sound depends on the height of the source and the receiver and the acoustical impedance of the ground. The ground attenuation will vary with the heights and the distance. By measuring simultaneously in several microphone positions and compare the measured and calculated difference between the different positions it is possible to derive the location(s) of the noise source(s). The method is applied on cars and trains passing by in order to model the vehicles using point sources.

1. INTRODUCTION

Accurate sound propagation theories are based on point sources. In order to apply these theories on real noise sources such as road vehicles and trains it is necessary to describe these sources in terms of point sources. As the sound propagation depends strongly on the exact location of the sound source in relation to the ground the location of each source has to be known accurately. There are different ways to find out this location and each way has its advantages and disadvantages. The most direct way is to use microphone arrays. However, although the array technique works quite good, it is rather expensive and it is also subject to the physical limitation that small changes relative the wavelength cannot be detected. In this paper a simple method, which is sensitive to small variations in source height shall be presented.

2. PRINCIPLE

When sound propagates over ground at short distances the direct and reflected sound wave will interfere. The interference pattern depends on the location of the sound source and the receiver respectively, the distance between them and the ground impedance. Some examples:

With both a low source height and a low receiver the ground attenuation may be quite extreme at medium high and high frequencies if the ground is soft, and, with a constant receiver height, the magnitude of this attenuation will be very sensitive to changes in the source height. On the other hand, the excess attenuation will be very small with a high receiver whatever the height of the source. Thus by comparing the difference between simultaneously measured sound pressure levels at different heights with the theoretically calculated difference it is possible to draw conclusions of the source height. A theoretical example is shown in figure 1. The example has been calculated using exact analytical sound propagation theory using the one parameter model for the acoustic impedance of the ground. The implementation is that of the Nord 2000 project, [2].

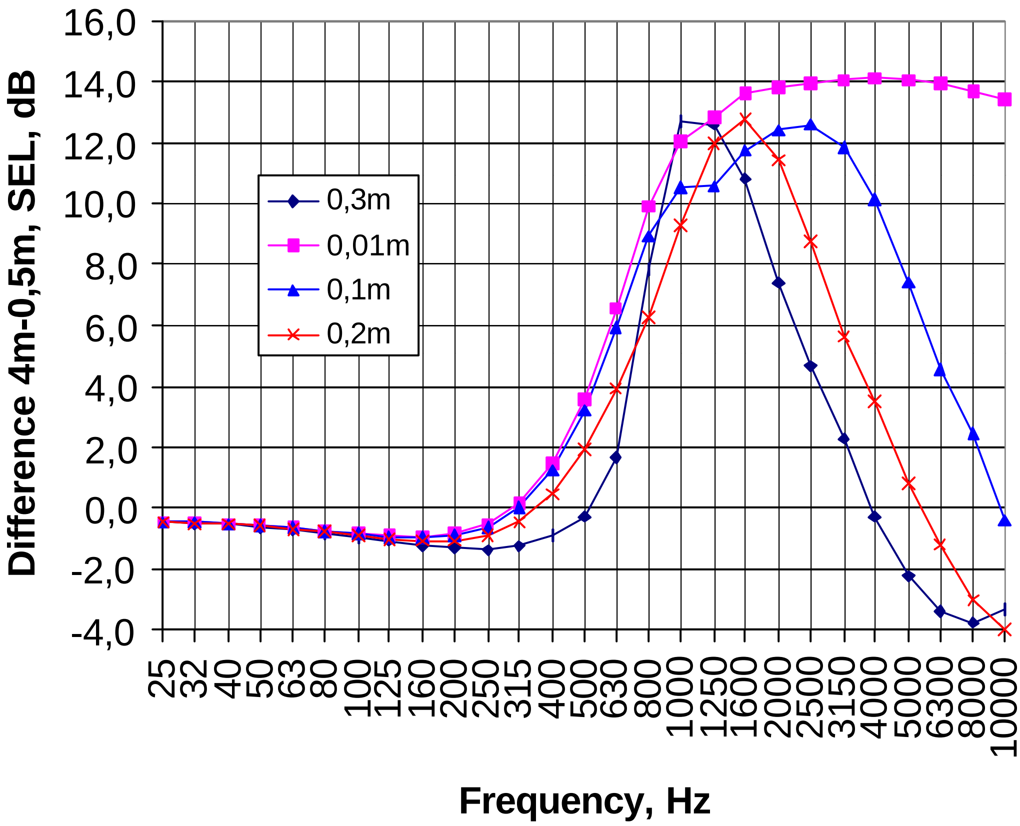

Fig. 1.- Calculated difference for different source heights between one microphone at 4 m and one at 0,5 m at a distance of 10 m and propagation over soft ground (Specific flow resistivity = 160 kRayls)

Figure 1 shows that it is possible to distinguish between different low sources with a resolution of 10 cm or better.

At low frequencies the excess ground attenuation will often be small. However, if the source height is large and its dimensions small it is always possible to find a receiver position where we will have an extreme dip in the propagation curve. Thus by selecting a suitable receiver position it is possible to find out the height of the low frequency source.

3. EXAMPLES WITH ROAD VEHICLES

The dominating sound source of road vehicles is the tyre/road. It has been shown by array measurements that the dominating source is close to the road surface. As was shown in the example in 2 it should be possible to determine the height of this source by studying the propagation pattern of noise from a passing car if the road is reasonably level with surrounding soft ground. Figure 2 shows the results of such a test. The nearest wheels of the passing cars are 2,6 m from the edge of the asphalt road which is 0,2 above the flat ground which is separated from the asphalt by a 6,1m wide 0,7 m deep ditch. Simultaneous measurements of the sound exposure level during pass-by were carried out at the two heights 0,5 m and 4 m at a distance of 18,45 m from the nearest wheels. The specific flow resistivity was measured using the method NT ACOU 104, [1], and the result was 160 kRayls. The calculations have been carried out according to the new Nord 2000 prediction method for environmental noise, [2]. The measurement results are from [3].

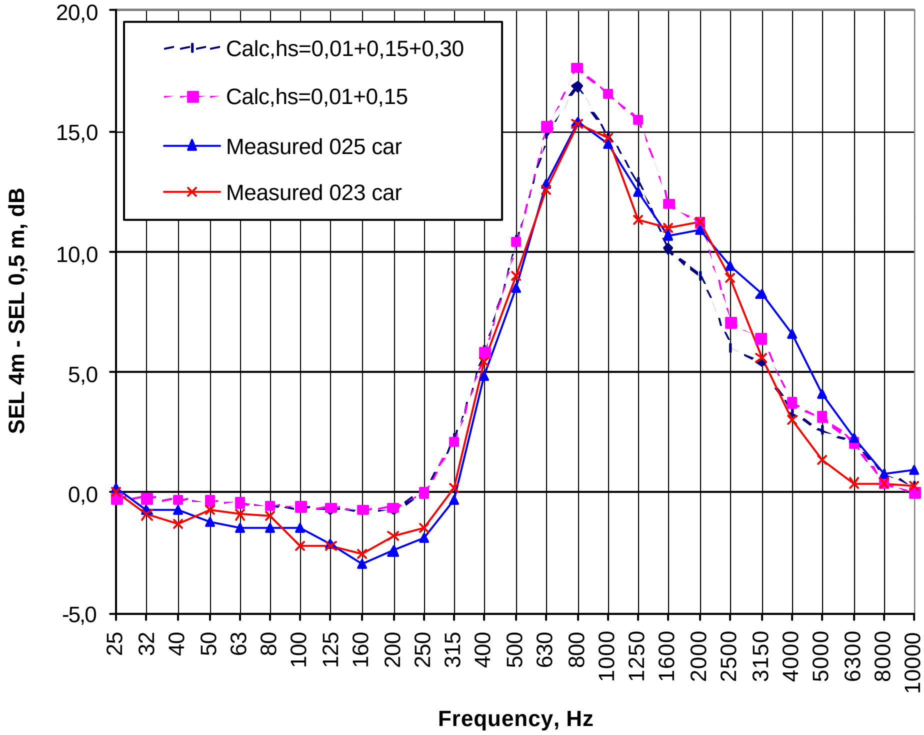

Fig. 2.- Calculated and measured difference for different source heights between one microphone at 4 m and one at 0,5 m at a distance of 18,45 m and propagation over soft ground (Specific flow resistivity = 160 kRayls).The measurements refer to two passing passenger cars.

Figure 2 shows that a source model using three equally strong sources at the heights 0,01 m, 0,15m and 0,3 m respectively yields a reasonable agreement with actual measurements on passenger cars.

Normally it is not possible to distinguish between exhaust and engine noise by using simple pass-by measurements. However, there is one exception and that is when the exhaust is on top of the vehicle. Measurements and calculations were carried out on a heavy vehicle with a high exhaust at the height 3,5 m above the surface of the road. Figure 3 and 4 indicate that there is a qualitative agreement between predicted and measured behaviour.

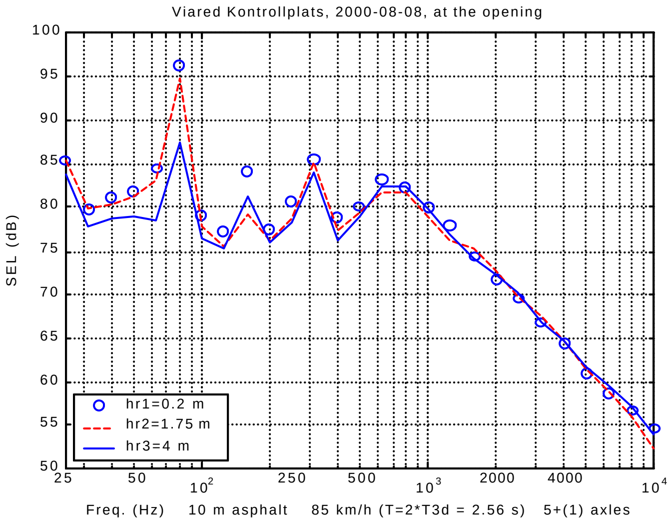

Fig. 3 - High exhaust. Measured SEL-values at 3 heights(hr).

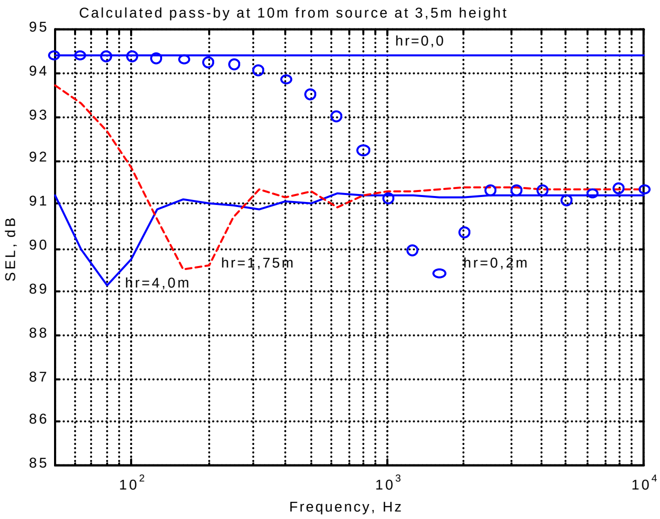

Fig. 4 – Calculated pass-by SEL-values at different heights from a point source at 3,5 m.

Figure 3 shows about 7 dB higher SEL-value at 1,75 m than at 4 m. The only possible explanation for this is destructive interference between the direct and reflected sound at the 4 m position. The calculations in figure 4 show a qualitative agreement by yielding a difference of 4 dB. Uncertainties due to the interaction of the body of the vehicle may explain that the agreement is not even better.

4. EXAMPLES WITH TRAINS

It is well known that there are several different sources on trains. The most important source for trains at moderate speeds is wheel/rail and numerous investigations have shown that the wheel primarily radiates noise above about 1000 Hz and that the rail with rail bed, sleepers and rail also radiate low frequencies. For some trains traction noise may become important. Many Swedish trains have cooling fans radiating noise within the frequency range 200-500 Hz. The openings for these fans are 2,5 – 3 m above the top of the rail, see example in figure 5. High speed trains also have aerodynamic noise sources around the body of the cars. The task is to find a source model, which, when combining the different sources yield the correct sound propagation behaviour.


Fig. 5 – Train with high low frequency sources

In figure 6 two measurements at 25 m are shown together with the calculated difference between the two microphone heights 4m and 2m respectively using different source combinations. Each source height shown in the legend has been allocated the same sound power level. Thus 0,01/0,01/0,56 means that 2/3 of the sound power radiates from 0,01 m above the rail bed and 1/3 from 0,56 m. The following observations can be made:

- It is obvious that the peak at 315 Hz cannot be explained by a low source only.
- Using only one high low frequency source will yield both a high peak at 315 Hz and a low trough at 160 Hz. As this is not consistent with the measurements this source description is most likely too simple.
- By combining a very low low frequency source which could represent rail, sleeper and rail bed radiation a good agreement can be achieved up to at least 1600 Hz. Below 250 Hz the best fit is obtained by distributing the sound power 50/50% between the sources. At 315 Hz a better agreement is obtained by assigning 2/3 of the sound power to the high source.
- It is more difficult to draw firm conclusions at high frequencies although it is obvious that one low source at 0,01 m gives a very bad fit at 4000 Hz. By distributing the sources across the wheel a better agreement is achieved.

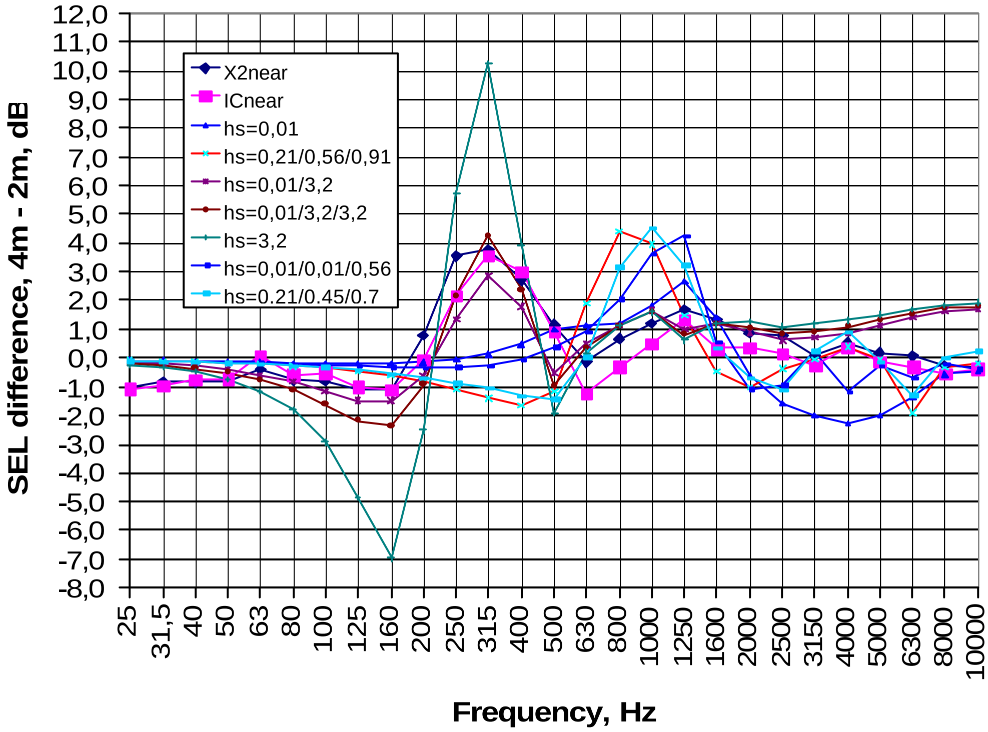

Fig. 6 - The average of a few X2 and IC pass-bys at the Alingsås site together with calculated values for different source combinations, from [4].

In figure 7 a corresponding figure for another train, the Arlanda train, is given. The data has been taken from [5] and the measurement situation is very similar to that of figure 6. In this case we do not find any low frequency peak. This is quite logical as the Arlanda train has all traction equipment located below the car body while the other trains studied in figure 6 have locomotives with high fan noise sources. The fit is quite good for the low source up to about 2000 Hz while the distributed wheel sources give a much better agreement around 2500 Hz.

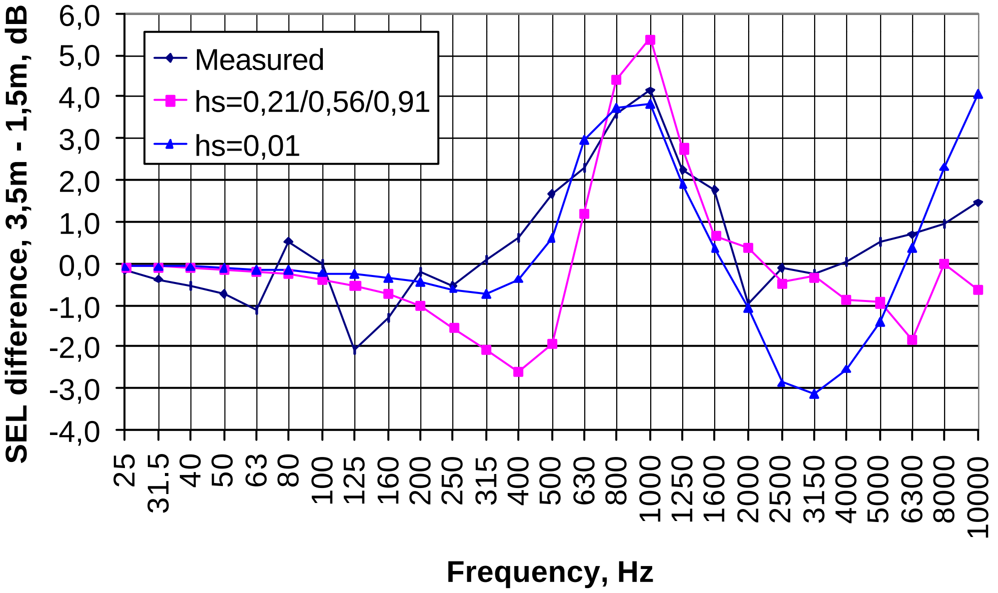

Fig. 7 - The Arlanda train. Difference in SEL at 25 m between 3,5 m and 1,5 m above the ground.

5. CONCLUSIONS

By studying the sound propagation pattern of a sound source it is in many cases possible to determine the height of the source provided that the measurement conditions are appropriate. For low sound sources and medium to high frequencies absorbing ground and one high and one very low position, less than 0,5 m, should be selected. For high sources and low frequencies measurement distances and microphone heights should be matched to yield one maximum and one minimum level.

BIBLIOGRAPHICAL REFERENCES

[1] Nordtest method NT ACOU 104 , Ground surfaces: Determination of the acoustic impedance

[2] Birger Plovsing, Nord 2000. Comprehensive outdoor sound propagation model. Part 1: Propagation in an atmosphere without significant refraction.

[3] Hans G.Jonasson, Measurement and modelling of noise emission of road vehicles for use in prediction models, SP Report 1999:35

[4] Hans G. Jonasson & Xuetao Zhang, Modelling of Railway Noise Sources with Applications on Swedish Trains, SP Report 2001:40

[5] Xuetao Zhang, Hans G. Jonasson and Kjell Holmberg, Source Modelling of Train Noise – Literature Review and some Initial Measurements, SP REPORT 2000:36