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Wavebreaker - a new innovative interference sound damper for railway noise

Tony Johansson
Wavebreaker AB, Stamsjövägen 20A, SE-44339 Lerum, tony@wavebreakerab.se

Train noise is an increasing problem in society and actors are looking for better solutions. The reason for the increasing noise problem is due to intensified traffic, longer and faster trains and new residential buildings causing rising investments in more and higher noise screens. The problem is global. WHO reported in 2020 that 12.000 people in Europe die each year prematurely due to noise. Conclusions are that the problem is increasing, noise screens are getting more costly and higher and, up to now, no new technical solution has been available on the market. A new type of sound damper for urban train noise, that can be used for both new railway projects and existing noise problems, is under development. It uses acoustic interference technology, based on the well-known Quincke-effect, and is used and mounted as an additional product on top of the noise screens. The sound damper reduces the noise propagating over and above the noise screen and acts as if the screen is about 1-1.5 m higher. This effect means that noise barriers could be built lower or performance could be enhanced without making the screen as obtrusive as a higher screen. Also, non-reachable demands could be reached, both acoustically and economically. The use of Wavebreaker is forecasted to cost about 25-50% of an increased height of a standard screen. This paper presents the function of the interference sound damper, compares the analytical optimization studies made in Actran and full-size laboratory tests on a prototype. The results imply that an overall train noise reduction of up to 4-6 dB is obtainable tuning the sound damper to a general railway noise spectrum. Furthermore, as the sound damper is designed in a modular way, adapting the noise reduction spectrum is possible in the future by changing the acoustical insert. Further steps in the development process are a pilot study with field measurements, a ready-to-use documentation for acoustic planners and studies on the effect on road noise. All is made possible due to cooperation with SL, Trafikverket and financial support by InfraSweden2030, Almi and Vinnova.

1 Introduction

Today there is a lack of new solutions on the market for the increasing problem of traffic noise from trains and vehicles. Trafikverket noise specialists conclude e.g. that they do not know what will be the decisive noise situation from trains but they know that the traffic will increase, the trains will be longer and they will be faster causing rising investments in more and higher noise screens. Community noise and measures to reduce it tend often to be about noise screens and increasing the height of noise screens which many times result in negative landscape effects as “corridors” and shadow effects. The cost of noise reduction by higher screens increase exponentially with height due to the necessary foundations. Sometimes the costs for noise screen for a few houses are defined as non-defendable society cost leaving these residents without measures and with noise above regulated limits.

No new promising technologies have been available to counteract the trend of more noise, higher costs and higher noise barriers. In addition, with high-speed trains planned in Sweden, even higher noise levels and more challenges for noise screening are assumed to come. Based on these challenges, a development of a new interference sound damper for train noise started. The aim was to optimize the sound damper for a general train noise spectrum and reach insertion loss of 3-5 dB, equal to 1-1.5 m increased height of noise screen (depending on initial height).

Noise reduction through interference is well-known as the Quincke-effect since 1866. But only a few practical applications to free field propagation exist today. Looking back at the 80's there were promising investigations in Japan using interference as noise reduction for traffic noise. Some interesting reports using interference for traffic noise damping were published in the JSME bulletin [1] and former work. The authors investigated the use of an interference sound damper device, based on a pending patent, placed on top of noise screens, for all types of ground-borne traffic noise. A few field tests were made up to the early 90's, in Japan and in Europe, with field results showing around 2-4 dB reduction within 50-100 m from source, but the sound dampers and the results were soon forgotten. Reasons are unknown but perhaps the market conditions, costs and/or production challenges were not the right ones.

Stig Ingemansson, the founder of Ingemansson Ingenjörsbyrå, investigated the use of interference for fresh air ventilators in order to reduce low-frequency traffic noise in 1982 [2]. This is one of a few practical applications investigated in the Nordic area for traffic noise.

2 Development of an interference sound damper for train noise

2.1 Basic interference acoustics

The basic theory of interference is well-known as described in for instance [2]. In the simplest form, interference is created by adding another sound path L_2 (where L_1 is the shortest path) with a length which is an uneven multiple, n, of the half wavelength of the frequencies that are in focus.

$$f = n \times \frac{c}{2(L_2 - L_1)} \tag{1}$$

Adding more sound paths, the distribution of discrete frequencies can be organised in a way that a more broadband damping can be achieved [2].

Designing channels for the interference damper one should also relate to other basic formulas described in [1] and in the former reports of the authors. The operating frequency range is governed by geometrical design, where the channel length defines the lower frequency limit and the dimension of the channel cross section defines the upper frequency limit.

2.2 Analytical investigations

In 2018, FS Dynamics was tasked to perform numerical calculations to investigate the interference effect and, in a second task, to optimize the sound reduction effect with typical train spectra in focus [3]. The Actran software, using finite element formulations, were used and two CAE-models were created, with and without the interference sound damper. The basic 2D-model contained 130 000 elements to cover frequencies up to 4500 Hz. The source was of pressure type with a constant amplitude. Further, using infinite boundaries it was also possible to simulate the pressure at points outside the model.

The noise barrier was modeled as a 180 cm high and 13 cm thick wall. The interference model was placed on top of the noise barrier, raising it by 20 cm, hence the total height with the sound damper was 2,0 m. The source position was set to 0 m at 2 m distance from the wall and the microphones at 3 m from the wall. Once the interference effect was determined, the optimization process focused on the microphone at 2 m height, simulating 20 m distance from the wall (no.4).

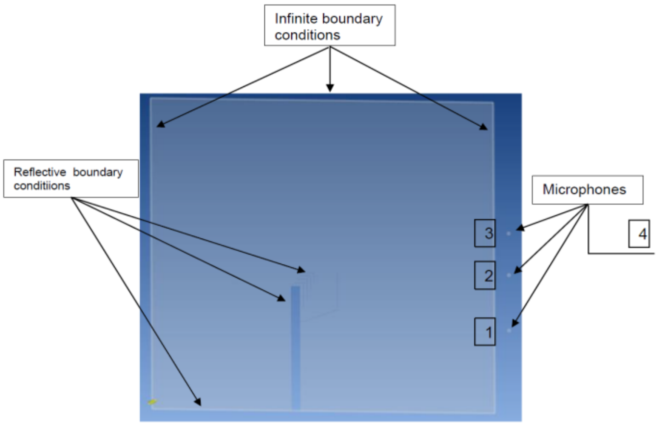

Figure 1: Basic model for the Actran simulations.

The simulations started with a basic interference sound damper design to investigate the effect, using channel dimensions based on the basic interference theory. A typical interference field could look like Figure 2.

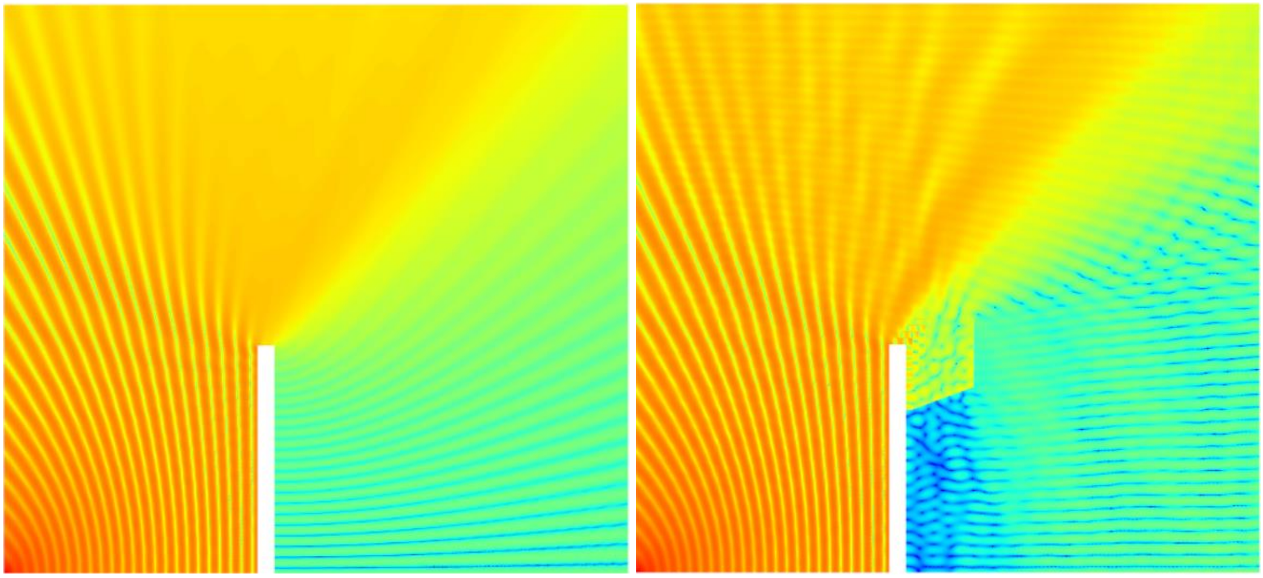

Figure 2: Sound field comparison without and with the interference sound damper at 2000 Hz.

The simulation of the first model of the interference sound damper showed the following differences in total sound level in the frequency spectrum in focus.

Table 1: Total sound level difference in the Actran simulation.

Calculation	Source position	Microphone position		
		1: 1.2 m	2: 2.0 m	3: 2.6 m
3 m from wall	0 m	4.2 dBA	4.9 dBA	3.6 dBA

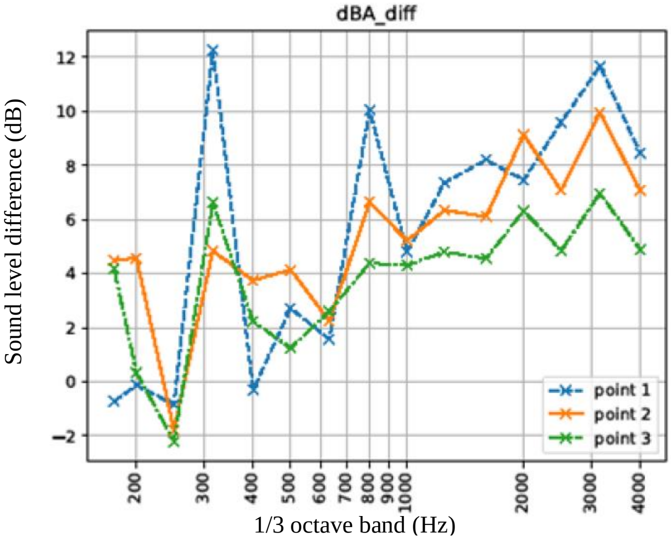

Figure 3: Sound level difference without and with the interference sound damper for the three receiving points.

As expected, frequency selectiveness of an interference sound damper and geometrical effects in the lower frequencies are noticeable. The “sharp” curves could to some extent be a result of low damping in the material parameters.

The next step was to fine-tune the design to distribute the damping frequencies and increase the insertion loss for a general train noise spectrum, focusing on 500-4000 Hz. The fine-tuning used the channel lengths and cross-sections in a parameter study which resulted in a further decrease of the total sound pressure level between 200 and 4000 Hz by 0.5-0.7 dB.

2.3 Laboratory tests

The first prototype version, similar to the fine-tuned version from the Actran analysis, of the interference sound damper, was measured in the semi-anechoic chamber at RISE, Borås in 2020 [3]. The aim was to verify the final design of the interference function based on the simulation performed in 2018.

The noise barrier was built as a double wall using 10 mm plywood with a gap of 75 mm, total thickness 95 mm. Height of the noise barrier was 2 m and the prototype interference sound damper increased the height by 25 cm. The screen was placed diagonal (about 7.2 m long) in the test chamber and 7 m of Wavebreaker on top of it.

The choice of measurement method was to correspond to standard EN 16727-4:2016 as close as possible. One major difference was that the microphone positions were kept at the same height throughout the measurements. A white noise was applied for 120 s and the total sound pressure level between 180 and 4500 Hz was evaluated, as well as the 1/3 octave bands 200 to 4000 Hz. By measuring without and with Wavebreaker, the difference of the sound pressure level due to the addition of the interference sound damper, could be interpreted as insertion loss.

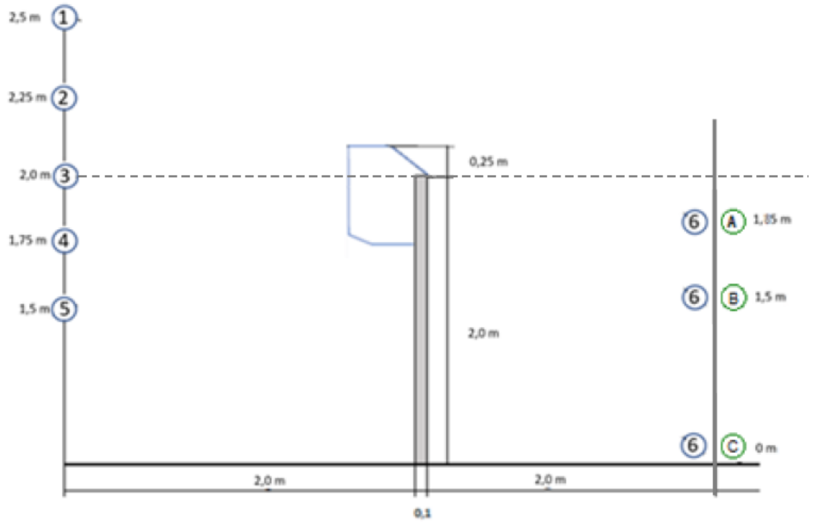

Figure 4: Test setup with three loudspeaker positions and five microphone positions on the receiver side.

The results of the tests, presented as insertion loss, are shown in the table below. In general, approximately 6 to 9 dB insertion loss could be seen. The added screening effect by the increased height (2 to 2.25) m is assumed to be about 2 dB, which means that the interference effect alone was about 4-7 dB.

Table 2: Total sound level difference = insertion loss of the screen with the interference sound damper in the frequency range 180-4500 Hz.

Microphone position	**1**	**2**	**3**	**4**	**5**
Sound source at 0 m	6.2	7.2	7.8	7.4	7.6
Sound source at 1.50 m	6.6	7.2	7.7	7.6	5.8
Sound source at 1.85 m	6.7	8.3	9.0	8.7	7.5
	dB	dB	dB	dB	dB

The one third octave band evaluations verified that the design met the goal to optimize the noise reduction effect between 500-4000 Hz.

Figure 5: Sound level difference comparison in 1/3 octave bands.

Based on the results achieved, the insertion loss for different train noise spectra was predicted as an indication on the use of the interference sound damping with Wavebreaker on top of a noise barrier. The results from the measurements with the sound source B and microphone position 3 were used. (It is not shown that the average sound pressure level integrated over all angles of outgoing sound from the noise barrier top (or at all distances from the noise barrier) would give the same result at the receiving side.)

Table 3: Predicted sound level difference for different train noise spectra (Nord2000/SS 25267:2004), based on positions B and 3. (High speed train spectrum = predicted values from SP Rapport 2015:42)

Train noise spectrum	**EN 16727-3-1**	**Pass train RC 160 km/h**	**Freight train RC 4a-80 km/h**	**Pass train RC 120 km/h**	**X2000 200 km/h**	**X2000 80 km/h**	**High speed train 320 km/h**
Predicted ins. loss, dBA	6.3	6.1	7.1	6.0	6.8	6.7	4.9

The predicted values should be seen as indications that the intended work of fine-tuning the interference sound damper towards general train noise was effective enough to meet the target of 3-5 dB insertion loss.

2.4 Comparisons calculations and tests

An interesting comparison was to lay the insertion loss results of the Actran FEM calculations, (the optimized sound damper at 20 m distance from the wall) – over the laboratory measurements. Although the small differences in the setup, as presented above, the tendencies of the behavior are well forecasted in the FEM calculations, or even underestimated.

Table 4: Total sound level difference using white noise comparing Actran and laboratory measurements.

Total sound level difference - Calculation vs measurement	Mic height position	Sound source height position		
		0 m	1,5 m	1,85 m
Actran, 20 m from wall	2 m	4,2 dB		
Measurement, 2m from wall	1,85 m	7,8 dB	7,7 dB	9,0 dB

Using FEM to do parameter studies seem to have its advantages of being able to analyse and fine-tune acoustic design without exaggerated results. In this comparison it seems to be a good tool in the mid and higher frequencies.

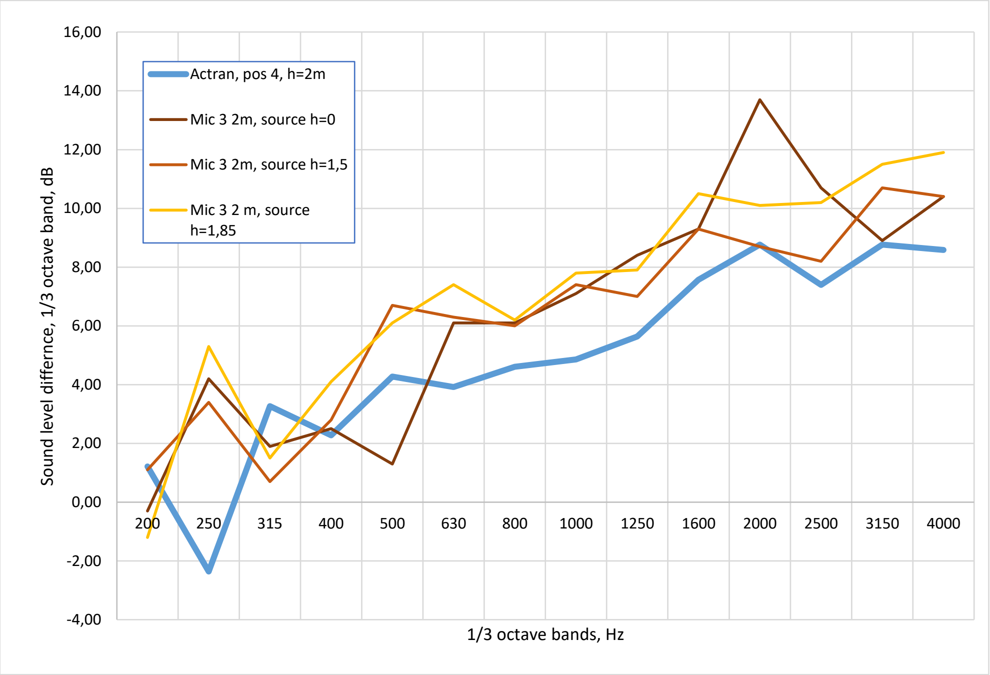

Figure 6: Sound level difference comparison using white noise. Actran calculations (20 m from wall, h=2,0 m) vs laboratory measurements (2 m from wall, h=1,85 m, different source heights).

Wavebreaker was designed for an optimum damping function in the frequency spectrum 500-4000 Hz. The effect in the lower frequencies cannot therefor be related to the acoustic design of the interference function. Taking into account for the approximately 2 dB screening effect of the 25 cm raise, the effect below 500 Hz is considered low. The difference in total sound level difference is influenced by the 6 dB difference at 250 Hz, but can also be related to the different differences in parameters, for instance the difference in height (25 cm) and the different distances to the wall (2 and 20 m).

2.5 Further work

A pilot project with field measurements is planned to be realised in the summer of 2021 with the first serial production version of the product. Wavebreaker is assumed to be working within 50-100 m range from the noise screen, whereas longer distances are more dependent on weather conditions. Field measurements of train noise at different distances from the track and different heights is planned for. The aim of the pilot project is to validate the interference sound damper in cooperation with end clients. As a result of all data collected, a complete documentation with instructions for acoustic planners on how to implement an interference sound damper into existing noise calculation tools will be summarized.

Other technical demands like durability for wind loads and shock wave from high-speed trains have been investigated but there is further need of field experience to clarify different practical issues. The pilot project is one step further to learn more. Future work also includes investigating the potential of using Wavebreaker for vehicle traffic noise and noise with a more dominant low-frequency part like high-speed trains and city traffic. Since the product is made in a modular design, there are possibilities to adapt the interference sound damper for other spectra.

3 Summary

Train noise is a major problem in society and actors are looking for better solutions. Trafikverket (Swedish Transport Administration) noise specialists conclude e.g. that they themselves do not know what will be the decisive noise situation from trains, but they know that the traffic will increase. The trains will be longer and faster causing rising investments in more and higher noise screens. A new type of noise silencer for urban train noise, that can be used for both new railway projects and existing noise problems, is under development. It uses interference technology and is used and mounted as an additional device on top of the noise screens, with the result as if the walls were about 1-1.5 m higher. This effect means that noise screens could be built lower or performance could be enhanced without making the screen as obtrusive as a higher screen. Also, non-reachable demands could be reached, both acoustically and economically. The use of Wavebreaker is predicted to cost about 25-50% of an increased height of 1-1.5 m of a standard screen.

Through analytical studies the interference sound damper has been optimized to reduce different typical train noise spectra by at least 3-5 dB which has been verified by different actors in the field to be an approved target. This has been verified by laboratory tests in a semi-anechoic chamber. Using the insertion loss spectrum on top of some typical train spectra to simulate the effect for different train situations resulted in 4-6 dBA insertion loss (calculated between 180-4500 Hz from a single source to a single receiver). This indicates that the product seems to meet expectations on insertion loss.

The well-known interference sound damping effect has so far had very few practical applications but the development of a new sound damper to enhance noise screening effects, designed especially for community noise from trains, could very well benefit from this acoustic technology. Road traffic noise solutions could also be developed in the future.

(Notes: Wavebreaker is a registered trademark and the product has a global patent pending.)

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