DELIVERABLE D5.9

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	Part 3: In-field measurements of the influence of voestalpine VA71b rail on railway noise

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0 EXECUTIVE SUMMARY

0.1 OBJECTIVE OF THE DELIVERABLE

The objective of Part 3 was to determine the noise reduction potential of the new developed rail design VA71b from voestalpine.

0.2 STRATEGY USED AND/OR A DESCRIPTION OF THE METHODS (TECHNIQUES) USED WITH THE JUSTIFICATION THEREOF

To determine the noise reduction potential of the VA71b, railway noise measurements were performed on different test tracks. Because of the complexity of the superstructure and the strong influence of its parts on the noise behaviour of the whole system only real test site measurements deliver meaningful results.

0.3 BACKGROUND INFO AVAILABLE AND THE INNOVATIVE ELEMENTS WHICH WERE DEVELOPED

The EU research project 'Metarail' in the 2nd half of the 90s showed that a track constitutes a complex vibration system which makes it necessary to carefully align individual components in order to achieve a specific characteristic. Therefore, it is not possible to consider rails alone, but that only the interaction of rail and rail pad decides the amount of rolling noise a track radiates. A sound-optimised rail with the 'wrong' pads is therefore often 'louder' than a 60E1 or a 54E1-rail with the 'right' rail pads.

There was already an awareness of the importance of the (dynamic stiffness of) rail pads in connection with the noise emissions of rail tracks at the turn of the millennium. The problem that we still face today is to reproduce superstructures which are known to have low noise emission at a specific location and then to install the same superstructure with low noise emissions at a different location. A VA71b-superstructure was installed at the ÖBB test track near Dürnkrut after the first test with the VA71b-rail, where it produced very good results.

In the meantime, the use of rigid rail pads with high inner damping has become in theory the technology standard in order to obtain a quiet track, and it is now possible to define whether the requirements are fulfilled or not without having to resort to noise emission measurements. This check is possible with the track decay rate as described in the TSI-CR-NOI and TSI-HS-VEH. The check of the track decay rate regularly shows that nominally identical superstructures actually have a different dynamic behaviour and thus also different track decay rates. The explanation for this phenomenon lies in the contemporary description of the stiffness of rail pads, which does not take the dynamic behaviour into consideration. Thus, the rail pads of different producers are nominally the same, however, they have a different (dynamic) behaviour which results in tracks having different emission levels.

0.4 PROBLEMS ENCOUNTERED

Because of the complexity of the superstructure and the strong influence of its parts on the noise behaviour of the whole system it is not possible to make an overall fixed statement on the noise advantage due to the VA71b rail without testing the profile in track.

The resulting noise advantage - because of the use of the VA71b profile - can only be measured in an existing track tests.

0.5 PARTNERS INVOLVED AND THEIR CONTRIBUTION

During the Q-City project the potential of the VA71b profile concerning noise reduction was determined on two different test sites. One at Malmö/Tjörnarp (Sweden) and one at St.Egyden (Austria).

In Sweden the measurements were done by Banverket (BAN) and Acoustic Control (ACL). The Rails were delivered by voestalpine (VAS). In Austria the measurements were done by voestalpine (VAS) under the assistance of an external partner (psiA Consult, M Kalivoda).

0.6 CONCLUSIONS

While the VA71b rail showed always good results in comparison to the 60E1 rail profile, there was always some kind of inconsistency in the results for different train categories and pass-by speeds in comparison to the 60E1-rail.

Now for the first time, the test with a new Semperit caoutchouc rail pad (ZW700) has produced satisfactory results, i.e. a reduction of the noise level by 1.5 dB(A) by use of the VA71b rail profile for all train categories and pass-by speeds in comparison to the 60E1-rail at the noise test track by St. Egyden (Austria) in 2008 (see Figure 15, page 30). Now it should be possible to reproduce the noise level reduction by using this new rail pad together with the VA71 rail profile and checking it by measuring the track decay rate (see Figure 24, page 41).

0.7 RELATION WITH THE OTHER DELIVERABLES (INPUT/OUTPUT/TIMING)

There are no direct relations to other deliverables.

1 INITIAL SITUATION

At the end of the 90s, voestalpine Schienen GmbH started to develop the noise-optimised rail profile VA71b, a Vignol rail that with its reinforced web and rail base was supposed to radiate less noise and thus, in comparison with UIC rail profiles, constitute a noise reducing profile. The Austrian State Railways (ÖBB) installed a 500 metre test section with VA71b-rails on monoblock concrete sleepers on a track between Wiener Neustadt and St. Egyden. A pass-by noise level measurement, together with a comparison between a standard superstructure with concrete sleepers and UIC60-rails and the VA71b-superstructure only partially showed the anticipated reduction in noise level. Subsequently, model calculations to optimise the VA71b-superstructure were carried out, further VA71b-test tracks installed and additional pass-by noise level measurements taken.

This synthesis report aims at combining and assessing the results of the related series of measurements and investigations. Since individual measurements were taken over a longer period and not only took place under different surrounding conditions but also with different task definitions, the methodology is to a great extent comparable but (unfortunately) not entirely uniform. Between 1996 and 2000 the understanding of the generation and radiation of rolling noise as well as its measurement and assessment were significantly enhanced. These new findings were included in the investigations from 2002 onwards. From this point on, it has become standard procedure to determine rail roughness during noise level measurements in order to be able to assess the results more accurately.

Within the Q-city project two new measurements series took place on two different tests sites. One again at St.Egyden (Austria) and on at Malmö/Tjörnarp (Sweden).

To get an good and clear overview of the potential of the VA71b rail profile concerning its noise behaviour and its influence on the overall noise of the track all measurements (not only the Q-City measurements) are included in this report.

2 TEST SERIES

2.1 INVESTIGATION OF THE VA71B-SUPERSTRUCTURE, ST. EGYDEN, 1996

2.1.1 Objectives of the investigation

In 1996, the Austrian State Railways (ÖBB) replaced the conventional UIC60 rails by noise-optimised VA71b-rails on track 1 between Wiener Neustadt and St. Egyden at track km 54 over a 500 metre section.

The objective of this investigation was to identify the reduction of noise level when noise-optimised rails are used. The criteria used to answer this question were the 'classic noise criteria' such as the frequency distribution in the form of an FFT spectrum and the energy-based, averaged A-weighted sound pressure level $L_{A,m}$ as well as psycho-acoustic factors such as loudness and sharpness. The basis for the evaluation are digital recordings of the pass-by noise of a test train taken at four measuring points located next to both the conventional and the noise-optimised track.

2.1.2 Method of investigation

The objective of the measurements was to find the characteristic noise values and compare the system status for the following:

- Rail type VA71b (track 1)
- Rail type UIC60 (track 2)

at the four measuring points:

- Measuring point MP1L, at a distance of 0.87 metres from the track axis, in a sound-absorbing box at 0.1 metres under the top edge of the rail
- Measuring point MP2R, at a distance of 7.5 metres from the track axis at 1.2 metres above the top edge of the rail
- Measuring point MP3R, at a distance of 7.5 metres from the track axis at 3.5 metres above the top edge of the rail
- Measuring point MP4L, at a distance of 25 metres from the track axis at 3.5 metres above the top edge of the rail.

The following were used as relevant, characteristic noise values:

- The time-related noise level gradients, A-weighted L(t)A, un-weighted L(t)lin.
- The energy-based, averaged, one-third-octave spectrum for the whole pass-by time

- The frequency distribution in the form of a FFT spectrum of the measuring point MP1L at a distance of 0.87 metres from the track axis, in a sound-absorbing box 0.1 metres under the top edge of the rail
- The psycho-acoustic factors loudness, sharpness, tonality and roughness.

Of particular interest was the question to what extent the type of vehicle (passenger carriage, freight wagon, traction unit) and the type of brake (block brake, disc brake) would cause differences on the effect of the noise-optimised rail profile. Previous research has shown that by using measurement equipment with distance/time mapping in noise level measurements, it is possible, at measurement distances up to 25 metres, to analyse and isolate the effect of specific sections of a train with differing acoustic behaviour, and thus to minimise the number of pass-bys.

In the present investigation, a test train was used, consisting of a traction unit, five passenger carriages, four freight wagons and a further traction unit. The five passenger carriages were of modern construction with disc brakes, as used in high-level international traffic.

It was agreed between the voestalpine and the measurement team to measure the noise radiation also at a distance of 10cm from the rail web. These instructions presented various measurement-technology-related problems which had to be solved by using both a suitable method of measurement and an appropriate set-up.

It is important to point out that in this set-up, the 10cm distance between the microphone and the rail is so narrow that nearfield-conditions of a cut-off frequency of up to approx. 1,700 Hz prevail. This means that for frequencies below this value, phase differences between the sound particle velocity and the sound pressure level can be expected. In this particular case, the sound power or the transmitted sound energy does not proportionally correspond to the square of the sound pressure level. In extreme cases, it may even be possible that despite high fluctuations in the sound energy level, no energy transmission takes place in the nearfield. This implies that no conclusion can be drawn from the measured sound pressure level on the radiated sound power.

2.1.3 Findings

Average A-weighted pass-by noise level

The evaluation of the measurements showed that the pass-by speeds are scattered relatively strongly around the nominal value. In order to be able to compare both types of superstructure, a regression analysis was performed for each vehicle type and also for each measuring point and rail profile, then the dependence of the linear and A-weighted average noise level for the speeds was determined. These points and a sample of the regression curve, together with the 95% confidence interval, are shown in Figure 1 and Figure 2.

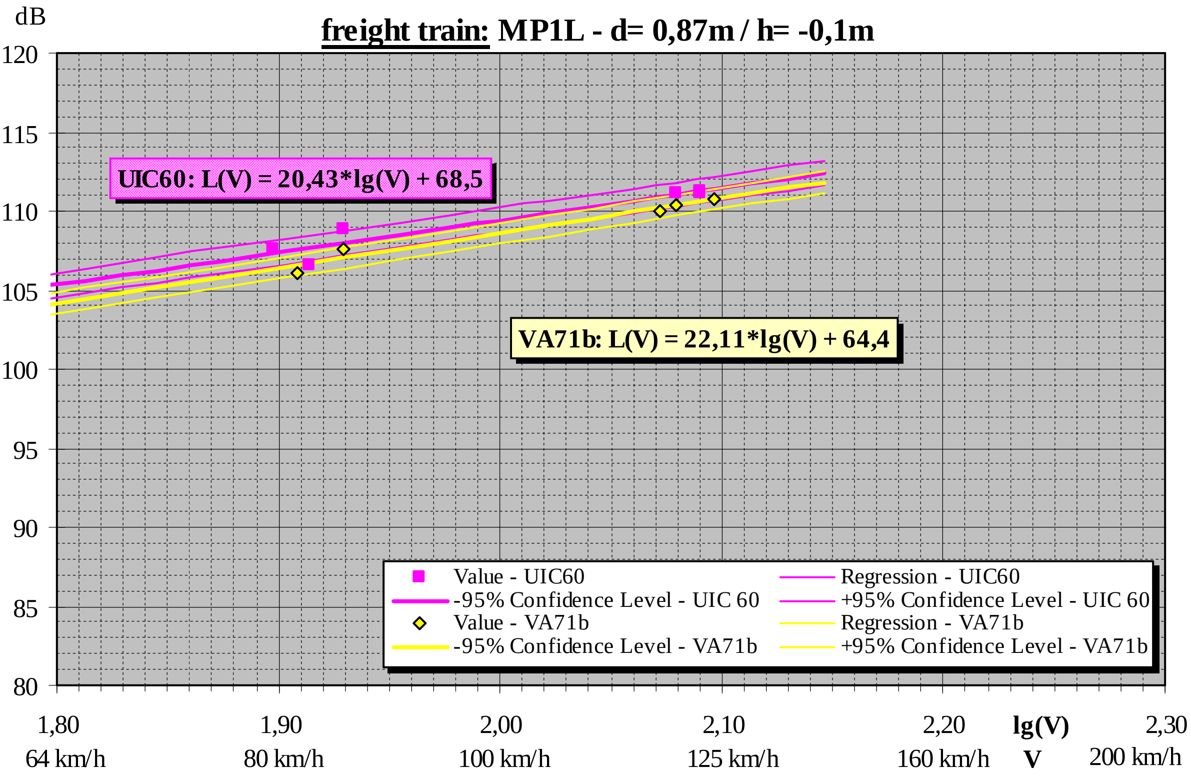


Figure 1: Speed-dependence of the average pass-by noise level, freight wagon

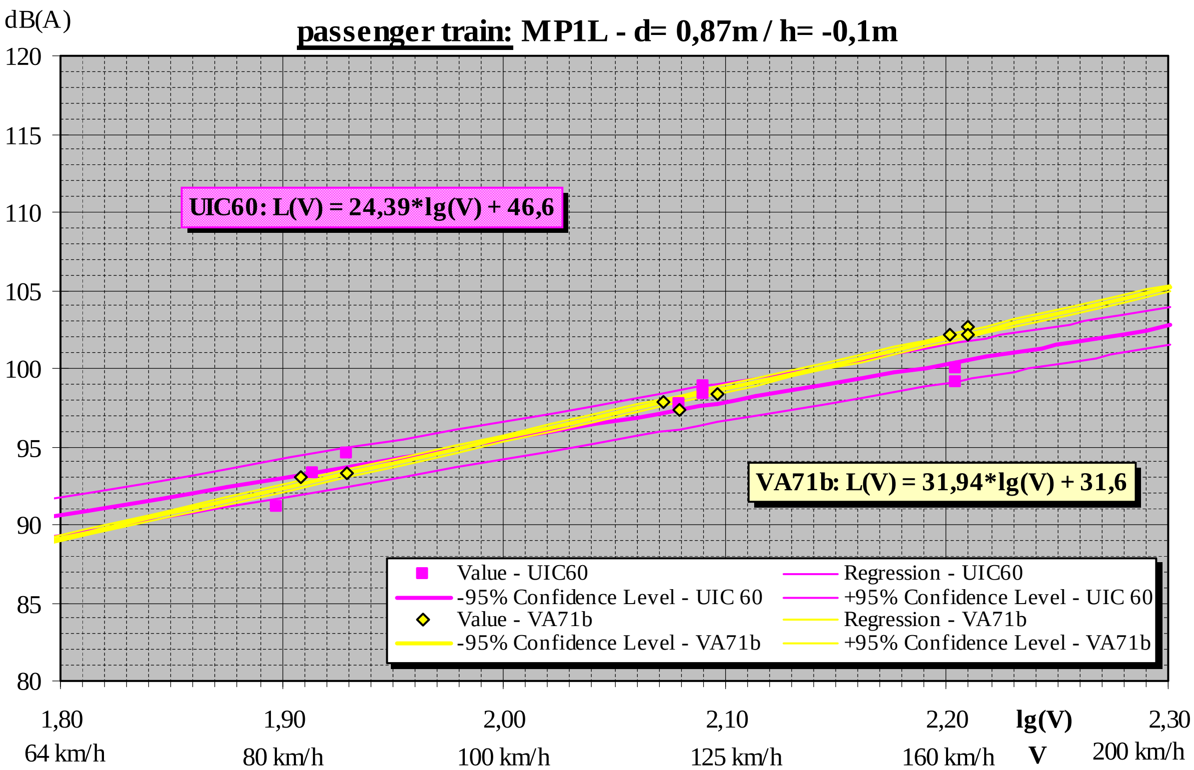


Figure 2: Speed-dependence of the average pass-by level, passenger carriage

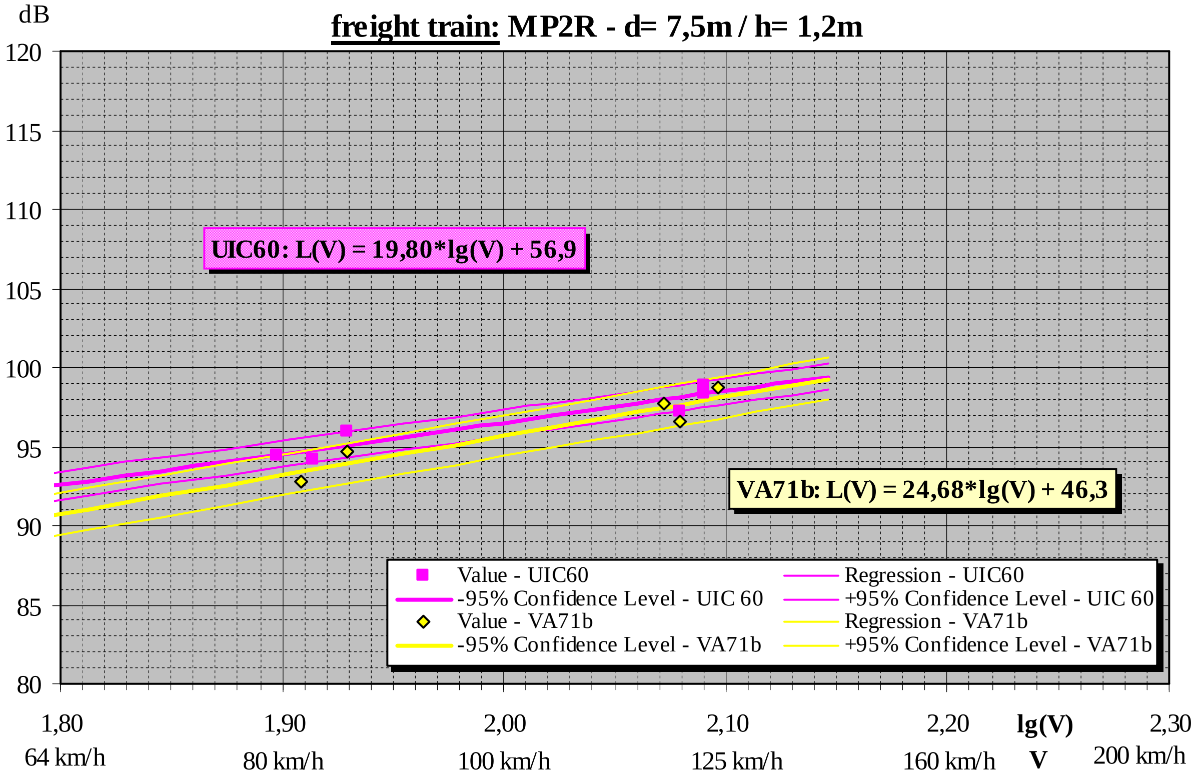


Figure 3: Speed-dependence of the average pass-by noise level, freight wagon

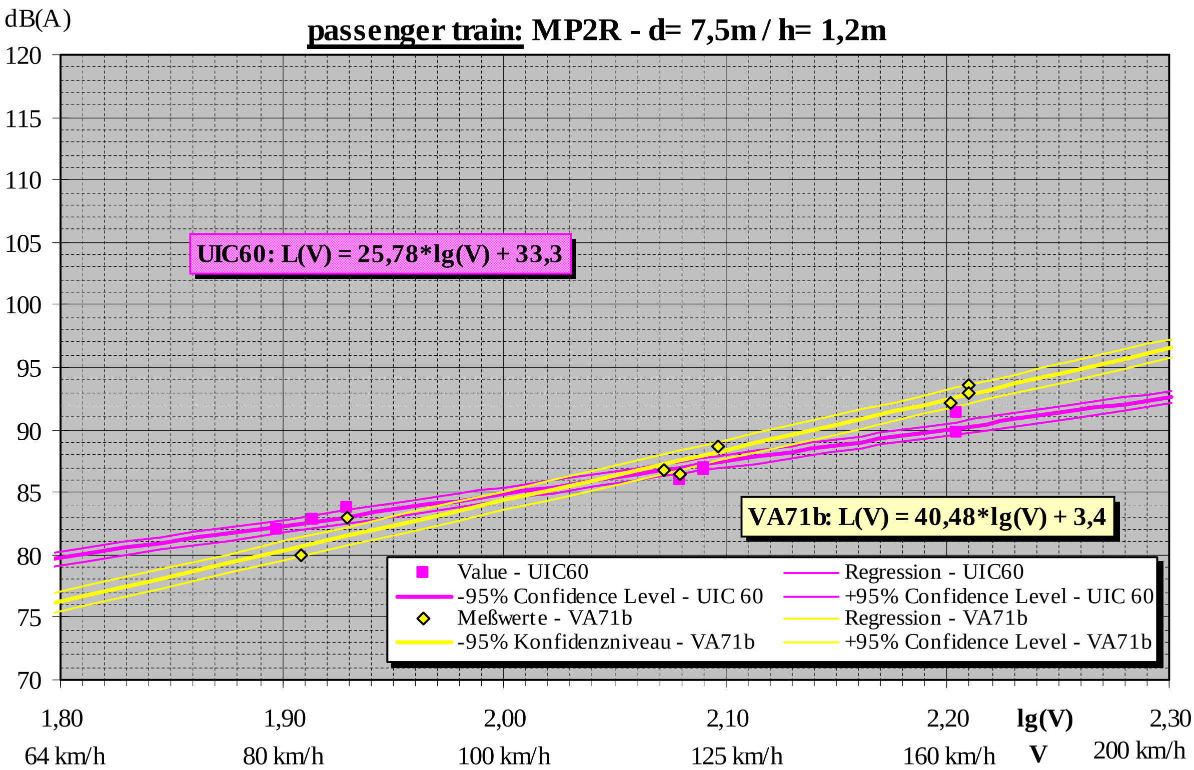


Figure 4: Speed-dependence of the average pass-by noise level, passenger carriage

This analysis shows that:

- The pass-by noise level tends to be lower on the VA71b-rail than on the UIC60-rail.
- The difference of the noise level between the VA71b and the UIC60-rail is higher at linear level than at A-weighted level. This effect is attributable to a shift in the noise level in frequency ranges in which the A-weighted assessment includes a noise level add-on (1 kHz - 5 kHz).
- The difference in the noise level between the VA71b and the UIC60-rail shows a tendency to diminish with increasing distance from the track. The highest value of 3 dB is found at the measuring point MP1 close to the track, and (MP4) at a distance of 25 metres from the track, it drops to only 1dB.
- The difference in noise level between the VA71b and the UIC60-rail shows a tendency to decrease when the speed increases. Whilst at 80 km/h the maximum drop in noise level close to the track is 3 dB, at speeds of 120 km/h at the measuring point MP1, the difference in noise level between the two types of rail reduces to approx. 0 dB. With passenger carriages travelling a speed of 160 km/h, the A-weighted pass-by noise level of the VA71b is 2 dB higher than that of the UIC60-rail.
- The difference in noise level between the VA71b and the UIC60-rail is at its highest with disc-braked wheels (passenger carriages) and lower speeds (80 km/h), when it can reach up to 3 dB.

FFT Spectrum

Figures 5 and 6 are examples of the average linear difference spectra for all vehicle types and pass-by speeds at the measuring point MP1 close to the track. The negative values correspond to a reduction in noise level at the VA71b-rail, the positive values correspond to an increase of noise level compared with the UIC60-rail.

The FTT analysis shows that:

- All types of wagons possess the same trends.
- As is the case with average pass-by noise levels, the difference in the noise level depends on the speed.
- With the VA71b-rail, the reduction of noise level diminishes with increasing speed. The figures clearly illustrate the shift of the whole spectrum towards the positive axis of noise level.
- When compared with the UIC60-rail, the strongest reduction of noise level of up to 15dB appears in the frequency ranges of approx. 1,200 – 1,400 Hz, 3,000 – 3,500 Hz and 5,000 – 6,000 Hz.
- With the VA71b-rail, three frequency ranges are discernable in which all types of vehicles and all speeds show a marked increase in noise level of up to 15dB.

- These frequencies are 2,000 – 2,700 Hz, 6,000 – 7,000 Hz and, at high speeds, 3,800 – 5,000 Hz.
- With the VA71b-rail, particularly clear peaks showing increases in noise level can be seen at 2,650 and 6,300 Hz.

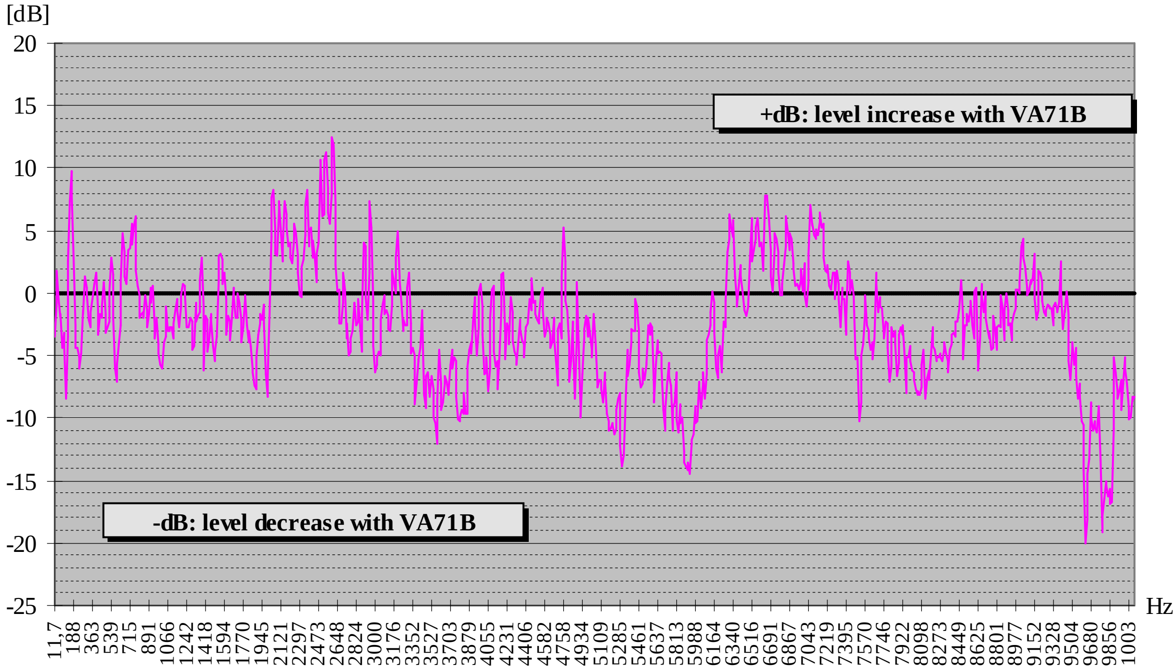


Figure 5: Freight wagon at 80 km/h for MP1

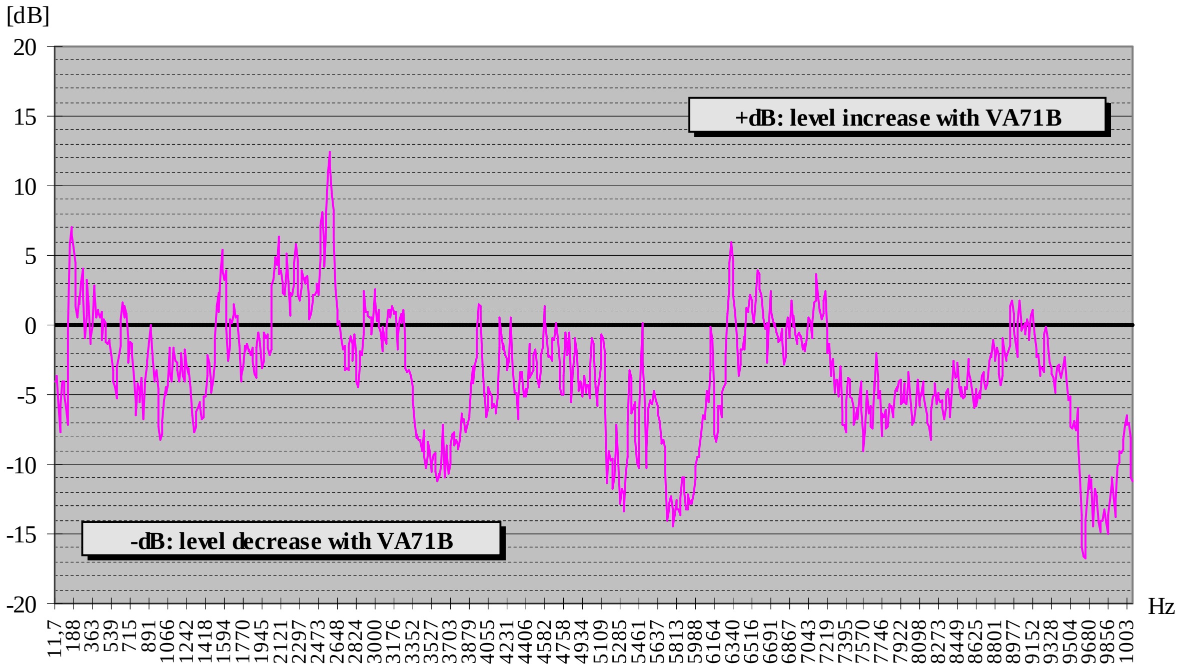


Figure 6: Passenger carriage at 80 km/h for MP1

Loudness

Loudness shows the same trend as the A-weighted pass-by noise level. At speeds of 80 km/h, the VA71b-rail is quieter than the UIC60-profile; at 120 km/h, both are more or less equal and at 160 km/h, the VA71b-rail is louder. The difference in loudness between the two rail profiles marginally drops when the measurement distance increases (0.87 metres – 7.5 metres – 25 metres).

The noise level peaks found in the difference spectra of the FFT analysis can also be seen in the specific loudness of the VA71b-rail as peaks in the critical band rate of 10 Bark (frequency range 1,170 – 1,370 Hz) and 15 Bark (frequency range 2,500 – 2,900 Hz). The peaks of noise level thus noticeably influence the loudness pressure.

Sharpness

The average sharpness again shows a trend of dependence on speed. At 80 km/h, the sharpness of the VA71b-rail lies below that of the UIC60-rail.

With freight wagons travelling at 120km/h, the sharpness of the VA71b-rail still lies below that of the UIC60-rail. At a speed of 120 km/h, there is hardly any recognisable difference between the two rail profiles with both train and passenger carriages, and at 160 km/h, the VA71b-rail has a higher sharpness than the UIC60-rail.

This result shows, as was already the case in the spectral analyses, that with increasing speed the amount of high-frequency noise also increases with the VA71b-rail.

Roughness

Specifically at the measuring point MP1 close to the track, the roughness shows no uniform dependence on speed. However, the effect of wheel roughness on the amplitude modulation of the emitted noise can be clearly recognised. At all measuring points, the freight wagons with block brakes clearly show a greater roughness than the passenger carriages with disc brakes.

2.1.4 Summary assessment

The comparative measurements of two identical superstructures, apart from the rails, showed that:

- At 80 km/h, the use of the noise-optimised rail profile VA71b results in a reduction of the A-weighted noise pressure level when compared with the profile UIC60;
- This improvement disappears at 120 km/h;
- The noise level increases at 160 km/h
- A modification of the cross-section of the rail changed the frequency range of the emitted pass-by noise and at 1,200 - 1,400 Hz reduced the noise level, however, it increased it in the frequency range from 2,000 - 2,700 Hz.

- It has been shown that modifying the shape of the rail generally shows the desired effect and that further optimising the profile to reduce the noise level in the 2 kHz range and at speeds above 120 km/h is necessary and appears appropriate.

2.2 Investigation of LNT (low noise train) wagons on a VA71b superstructure, Dürnkrut 2002

2.2.1 Objectives of the investigation

The actual objective of the investigation was to find out, if the order specification the three freight wagons issued by ARGE LNT, i.e. an A-weighted pass-by noise level $L_{A,eq}$ at a distance of 7.5 metres from the track axis at 80 km/h not to exceed 81dB had been complied with.

The results of the LNT investigation have been included in this synthesis report because the measuring point at the Northern Line near Dürnkrut, which was used following the instructions of the Austrian State Railways (ÖBB), has a ballast superstructure with concrete sleepers, rigid rail pads and VA71b-rails.

2.2.2 The LNT freight wagon

The LNT freight wagons made by Ferriere Cattaneo SA are 4-axle container wagons of the type Sgnss, the wagon numbers being 83 85 457 3 000-7, 001-5 and 002-3. The wagon length from buffer to buffer is 14.2 metres, the deadweight 19 tons.

Figure 7: LNT (low noise train) container wagon 4573, type Sgnss

2.2.3 Method of investigation

The measuring point is located on the Northern Line at km 54.2, track 2, and corresponds to the specification prEN ISO 3095 [3] as well as that of ARGE LNT. Prior to taking the measurements of pass-by noise levels, the rail surface was conditioned by oscillating grinding on 6 June 2002. A control of the rail roughness made in July 2002 confirmed that the measuring point corresponded to the afore-mentioned specifications. Overall, the rail roughness was clearly below the ISO limit and entirely below the limit set for approval measurements by the Technical Specifications for Interoperability of High Speed Trains (TSI-HST) [2] .

The A-weighted average pass-by noise level LA,eq was determined at the following three measuring points:

- Measuring point MP1, at a distance of 7.5 metres from the track axis, at 1.2 metres above the top edge of the rail
- Measuring point MP3, at a distance of 7.5 metres from the track axis on the opposite side of the track, at 1.2 metres above the top edge of the rail
- Measuring point MP4, at a distance of 7.5 metres from the track axis, at 3.5 metres above the top edge of the rail

The test train consisted of the ÖBB traction vehicle 1016.032, a passenger carriage with disc brakes, the ÖBB test wagon (a 2-axle freight wagon with non-braked bogies), the three LNT freight wagons, two further passenger carriages with disc brakes and the ÖBB traction vehicle 1116.078.

2.2.4 Findings

Speed-dependent pass-by noise level

Figure 8 shows the A-weighted pass-by noise level $L_{A,eq}$ dependent on the pass-by speeds as well as the regression lines. The results at measuring points M1, M3 and M4 (each at a distance of 7.5 metres) are depicted together with the limits foreseen in the Ordinance on Noise Emission Limits for Rolling Stock (SchLV) [7] .

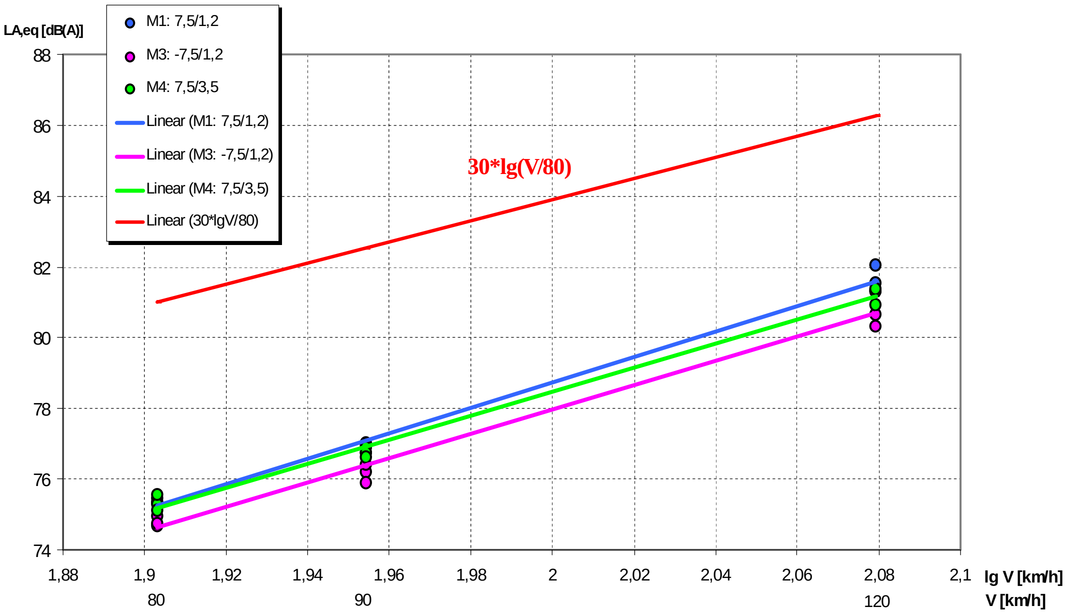


Figure 8: Speed-dependence of pass-by noise level of the LNT wagons at a distance of 7.5 metres

The linear equations for the speed-dependence of the A-weighted pass-by noise level at each measuring point are the following:

- M1(7.5/1.2): $L_{A,eq}(V)$ = 36.0 * lg(V) + 6.8
- M4(7.5/3.5): $L_{A,eq}(V)$ = 33.8 * lg(V) + 10.8
- M3(-7.5/1.2): $L_{A,eq}(V)$ = 34.4 * lg(V) + 9.1

This means that the speed-dependent increase of the pass-by noise level of 34-36 lg(V) of the LNT wagons is higher than the one usually found in relevant literature and above that of the 30 lg(V) allowed in the SchLV. The pass-by noise level of the LNT wagons augments more strongly with increasing velocity than the 30 lg(V) relationship would lead one to expect.

2.3 OPTIMISATION OF THE VA71B-SUPERSTRUCTURE, MARIA PLAIN 2003

2.3.1 Objectives of the investigation

After the first series of measurements of the acoustic effect of the VA71b-rails at the end of the 90s, the adjustment of the dynamic behaviour of the VA71b-rail and the rail pad was optimised by means of calculations. For reasons of noise protection, the ÖBB have installed an optimised VA71b-track on the Western Line in the area of Maria Plain next to the city of Salzburg.

2.3.2 Method of investigation

The investigation was carried out in two phases. The objective of the first investigation phase (1st series of measurements) was to determine the actual noise emission of the standard VA71b-rail (track 1) and compare it with the existing track with wooden sleepers and UIC54-rails / C-rails (track 2). In the second part of the investigation (2nd series of measurements), the noise emission of the track with standard VA71b-rails on concrete sleepers (track 1), and that of the track with concrete sleepers, VA71b-rails and sonically optimised pads was determined and then compared.

1st series of measurements: Comparison between the standard VA71b-track with concrete sleepers and the track with wooden sleepers

In the area of Maria Plain station (Salzburg), the Austrian State Railways selected a test track with a superstructure with wooden sleepers and two VA71b-superstructures, where it was possible to compare the different types of superstructures from a noise technology point of view. The cross section for the measurement of noise level was located at km 315.150 of the Western Line (Vienna – Salzburg) approx. 100 metres after the station, in the direction of Salzburg Main Station. The track with wooden sleepers and the UIC54-rail had a superstructure with ribbed plates, whereas the VA71b-std-rail with a K1 concrete sleeper used a Vossloh SKL fastening.

2nd series of measurements: Comparison between the standard and optimised VA71b-tracks with concrete sleepers

After the first series of measurements, the track with wooden sleepers (track 2) was exchanged for a VA71b-track with concrete sleepers and a sonically optimised pad (VA71b-opt). In addition, soled sleepers were installed on both tracks. The type of sleeper soling was identical on both tracks.

Measurement set-up

The measurement set-up for both series of measurements was identical and chosen in such a way as to correspond to the specifications of different regulations and methods. Since the Austrian State Railways are partners in the EU research project Stairrs, the latest measurement set-up of the Stairrs WP2 Data Collection Campaign according to the Noise & Vibration Protocol dated 11/04/2002 was taken into consideration. The measurement data collected and recorded in this way make it possible to analyse the contribution of vehicles and superstructure to the overall noise level in line with state-of-the-art measurement technology for rail noise according to the Stairrs method, which is currently being developed.

Owing to the location, it was unfortunately not possible to place a microphone at a distance of 7.5 metres from track 1. Instead of locating the microphone in line with the latest measurement set-up of the Stairrs WP2 Data Collection Campaign, a microphone was placed in the middle of the two tracks at a height of 0.5 metres above the top edge of the rail, i.e. at a distance of 2.35 metres from the track axle and 0.5 metres above the top edge of the rail. This made it possible to record both tracks with only one microphone.

In line with the norm, the second microphone, M2, was placed at a distance of 7.5 metres from track 2 (regular track Salzburg) at a height of 1.2 metres above the top edge of the rail. In order to be able to align the measurement of the pass-by noise level with the actual position of the train, inductive wheel sensors triggering the measurements were place next to the rail. The signals of the sensors were recorded on DAT simultaneously with the signals of the accelerometers and those of the microphones.

The accelerometers were placed in such a way that during the pass-by of the test train, the following vibrations were measured:

- V1 and V3, the horizontal vibrations on each rail
- V2 and V4, the vertical vibrations on each rail
- V5 and V6, the vibrations generated by the concrete or wooden sleepers

All scheduled trains were recorded during the measuring of the pass-by noise level. For the 2nd series of measurements, an additional test train with the LNT freight wagons was used, allowing a comparison with the VA71b-superstructure at Dürnkrut (see 2.2).

In addition to the noise level measurements, the acoustic rail roughness was recorded by direct method at the cross section of the measuring point, in line with the requirements of TSI-HST and the Stairrs measurement set-up. Rail roughness greatly influences the pitch of the pass-by noise level. This means that the rail roughness must be definitely checked when comparative measurements of two types of superstructure are performed, because only when both types of superstructure possess the same rail roughness, can the differences that occur be unambiguously assigned to the radiation behaviour and not to a difference in rail roughness.

2.3.3 Findings

Acoustic rail roughness

Figure 17 shows the rail roughness of the track with wooden sleepers (1st series of measurements, track 2), figure 18 shows the roughness spectrum of the VA71b-std-track (track 1) and figure 19, the rail roughness of the newly installed VA71b-opt-track (2nd series of measurements, track 2)

Both tracks with concrete sleepers, VA71b-std and VA71b-opt, had a comparable level of roughness, which only just corresponds to the TSI-HST limit for wave lengths below 5cms. At higher wavelengths, it was above the TSI-HST limit but in this range still below the limit of prEN ISO 3095. However, this limit was exceeded in the range of approx. 0.4 to 1.6cms wavelength by both tracks with concrete sleepers.

The track with wooden sleepers marginally exceeded both the ISO and the TSI-HST limit at wavelengths below 6.3 mm.

Pass-by noise level

The measurements of the noise level of the 1st series of measurements were carried out on km 310.150 of the Western Line near the Maria Plain station on 29 April 2003, and those of the 2nd series of measurements on 19 and 20 August 2003. For the pass-bys of trains, the signals mentioned below were digitally recorded on a multi-channel DAT recorder.

All scheduled trains were measured in both directions on both 29/04/2003 and 19/08/2003. In addition, a test train was available on 20/08/2003.

1st series of measurements: 29/04/2003

During the first series of measurements carried out on 29/04/2003, forty scheduled trains were measured. However, in the following analyses only 24 pass-bys were included because the remaining pass-bys related to trains either slowing down or driving off. Of the 24 pass-bys relevant to the analyses, 15 took place on track 1 (VA71b-std) and nine on track 2.

Table 1: Pass-bys; measurements taken in Maria Plain on 29/04/2003

	Track 1	Track 2	Sum
Passenger train	10	7	17
Freight train	5	2	7

Concerning passenger trains, the following brake systems were evaluated and assessed:

Table 2: Evaluated brake systems

Type of Waggon	RIC		Cityshuttle
Brake System	Disc	Cast Iron	Ceramic Composite

Of the measured pass-bys, the City Shuttle trains were exclusively braked by K-blocs, the RIC used wagons with both disc brakes and combined brakes (disc brakes with cast iron brake pads).

Table 3 shows the A-weighted pass-by noise level $L_{A,pb}$. The wagons with rough wheels (cast-iron brake pads) had an A-weighted pass-by noise level on the VA71b-std-track which was 2.1 dB lower compared with the track with wooden sleepers. The wagons with smooth wheels (disc brake) had an A-weighted pass-by noise level on the VA71b-std-track which was 1.6 dB higher compared with the track with wooden sleepers.

Table 3: Overall result of the 1st series of measurements

adjusted for 80km/h A-weighted pass-by level at d=2,35 / h=0,5 **L**pb,80 [dB(A)]		Area of Confidence		**average**	Area of Confidence	
		-95%	-90%		+90%	+95%
cast iron braked waggon	wodden sleeper track	102,3	102,5	**102,9**	103,3	103,4
	VA71b-std.-Track	100,2	100,3	**100,8**	101,3	101,4
	level difference VA71b-wooden sleeper			***-2,1 dB(A)***	*level decrease*	
disk-braked waggon	wodden sleeper track	87,5	87,7	**88,3**	88,8	89
	VA71b-std.-Track	89,2	89,3	**89,8**	90,3	90,5
	level difference VA71b-wooden sleeper			***+1,6 dB(A)***	*level increase*	

A statistical analysis of the data showed that the difference between the two types of superstructures are significant both at the 90% area of confidence as well as on the 95% level, which means that there is a 90% or 95% probability that the actual pass-by noise levels of both types of superstructures (from an indefinite number of measurements) will not have the same value.

2nd series of measurements: 19 – 20/08/2003

On the first day of measuring during the 2nd series, i.e. on 19/08/2003, 29 scheduled trains were measured, of which 21 pass-bys were useable for the evaluation. Of the 21 pass-bys relevant to the analyses, 8 took place on track 1 (VA71b-std) and thirteen on track 2 (VA71b-opt).

Table 4: 21 pass-bys; measurements taken in Maria Plain on 19/08/2003

	Track 1	Track 2	Sum
Passenger Train	6	11	17
Freight Train	2	2	4

On the second day of measuring, i.e. on 20/08/2003, 34 scheduled trains were measured, of which 33 pass-bys were useable for the evaluation. Of the 33 pass-bys relevant to the analyses, 15 took place on track 1 (VA71b-std) and 18 on track 2 (VA71b-opt).

Table 5: 33 pass-bys; measurements taken in Maria Plain on 20/08/2003

	Track 1	Track 2	Sum
Passenger Train	10	13	23
Freight Train	5	5	10

Concerning passenger trains, the following brake systems were evaluated and assessed:

Table 6: Evaluated brake systems

Type of Waggon	RIC		Cityshuttle
Brake System	Disc	Cast Iron	Ceramic Composite

On the 2nd day of the series of measurements, i.e. on 20/08/2003, in addition to the scheduled trains, a test train passed the measuring point, always on track 2 (VA71b-opt) and under exactly defined conditions with speeds of 70km/h, 80km/h and 95km/h.

A comparison between the two types of superstructure, VA71b-opt and VA71b-std is shown in figure 9. The noise level values were also adjusted to 80 km/h. The values shown as coloured bars illustrate the energy-based average values per vehicle category. In addition, the scattering of the results is shown by means of a black line. Table 7 contains the results of the analysis of the 2nd series of measurements. For wagons with K-blocs (City Shuttle), the A-weighted pass-by noise level on the VA71b-std-track is 2.0 dB lower than that on the VA71b-opt-track. The wagons with disc-braked wheels (RIC) had an A-weighted pass-by noise level on the VA71b-std-track which was 0.5 dB below that of the VA71b-opt-track. In contrast, the VA71b-std-track had a pass-by noise level that was 4.3 dB higher for wagons with cast iron brake pads (freight wagons), a pass-by level for passenger carriages with cast iron brake pads (ci-pass) that was 0.2 dB higher and for wagons of the ‘rolling highway) (ROLA), a level that was 1.1 dB higher than that of the VA71b-opt-track.

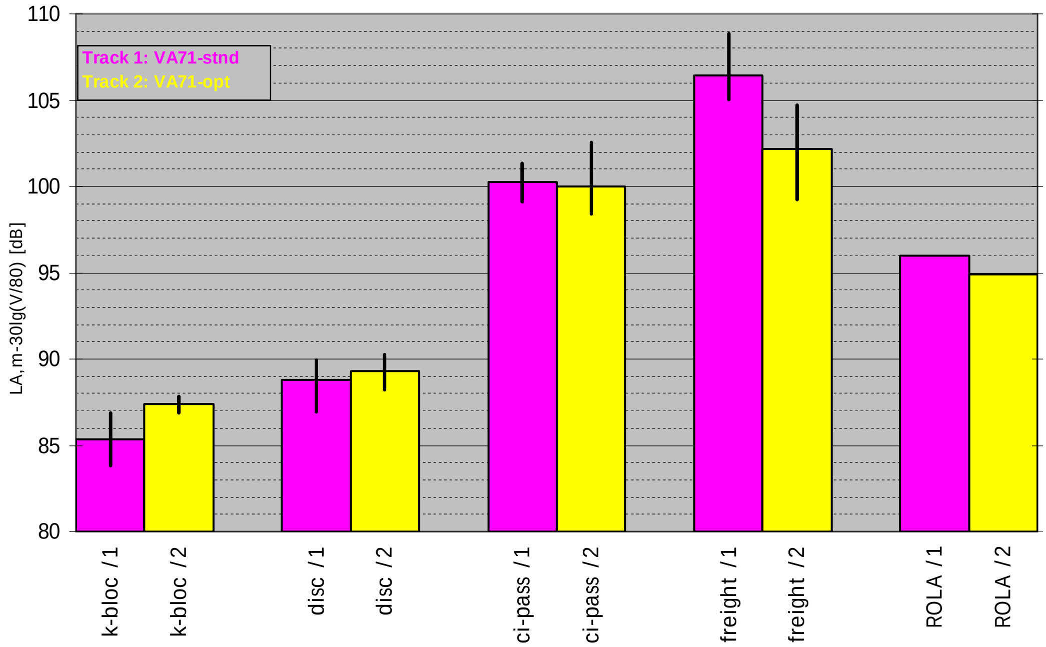


Figure 9: Comparison of the average values of VA71b-std und VA71-opt

Table 7: Overall result of the 2nd series of measurements

adjusted for 80km/h A-weighted pass-by level at d=2,35 / h=0,5 LA,m , 80 [dB]		minimum	**average**	maximum
K-Bloc	VA71b-opt.-Track	**86,9**	**87,4**	**87,9**
	VA71b-std.-Track	**83,8**	**85,3**	**86,9**
	level difference VA71b-opt - VA71b-std.		***+2,0 dB(A)***	
disc-braked waggon	VA71b-opt.-Track	**88,2**	**89,3**	**90,2**
	VA71b-std.-Track	**87,0**	**88,8**	**89,9**
	level difference VA71b-opt - VA71b-std.		***+0,5 dB(A)***	
Cast Iron braked waggon	VA71b-opt.-Track	**99,2**	**102,1**	**104,7**
	VA71b-std.-Track	**105,0**	**106,4**	**108,8**
	level difference VA71b-opt - VA71b-std.		***-4,3 dB(A)***	
RIC - Cast Iron-braked	VA71b-opt.-Track	**98,4**	**100,0**	**102,6**
	VA71b-std.-Track	**99,1**	**100,2**	**101,4**
	level difference VA71b-opt - VA71b-std.		***-0,2 dB(A)***	
ROLA	VA71b-opt.-Track		**94,9**	
	VA71b-std.-Track		**96,0**	
	level difference VA71b-opt - VA71b-std.		***-1,1 dB(A)***	

The results of the pass-by noise level of the test train are those taken at a distance of 7.5 metres. However, in this case, the measured noise level had not been adjusted to 80 km/h and the pass-by noise level for each wagon category is shown for the speeds 70, 80 and 95 km/h. The results for the individual wagon groups vary between 2 and 3 dB(A) with the exception of the fad type freight wagons with cast iron brakes which have a noise level of 10 to 15 dB(A) above that of the K-bloc braked vehicles.

Table 8: LA,eq test train at 7.5 metres

M2 (7,5/1,2)					
Test-Train		LA,eq [dB(A)]			LA,eq,average[(dB(A)]
pass-by		#39	#25	#13	
v = 70km/h	LNT	80,9	80,5	79,9	**80**
	Hbbills	79,2	78,5	78,7	**79**
	Tagnpps	81,9	81,5	81,5	**82**
	Hirrs	82,2	82,0	83,0	**82**
	Fads	93,6	93,6	93,7	**94**
pass-by		#02	#52		
v = 80km/h	LNT	81,4	82,8		**82**
	Hbbills	80,8	81,1		**81**
	Tagnpps	83,0	83,3		**83**
	Hirrs	81,8	83,1		**82**
	Fads	93,8	94,5		**94**
pass-by		#48	#33	#21	
v = 95km/h	LNT	84,8	84,7	83,3	**84**
	Hbbills	83,0	82,2	82,6	**83**
	Tagnpps	86,1	84,9	85,1	**85**
	Hirrs	84,6	85,1	85,1	**85**
	Fads	94,7	95,0	95,2	**95**

The A-weighted, one-third-octave noise levels of the pass-bys on the two VA71b-tracks in Maria Plain are analysed in the following section. Figure 10 shows the average one-third-octave spectrum of disc-braked (RIC disc), cast-iron pad-braked (RIC cast-iron) and K-bloc braked (CS_k-bloc) passenger carriages on the VA71b-opt and VA71b-std-tracks at a speed of 95 km/h and at a distance of 2.35 metres from the track-axis at a height of 0.5 metres above the top edge of the rail.

The sleeper contributes most of the noise up to 500 Hz, the rail contributes most to the overall noise level between 500 and 2,000 Hz, and above 2,000 Hz, the contribution of the wheel dominates. It is easy to see that the noise level of cast-iron pad-braked passenger carriages (RIC_cast-iron) clearly lies above the levels of wagons with disc or K-bloc brakes. In the frequency spectrum 500 to 2,000 Hz, the noise level varies up to 15 dB(A). The highest noise level is found exactly in this frequency segment and reaches values of up to 98 dB(A).

Above 500 Hz, the acoustic behaviour of both rails is very similar. However, between 125 and 400 Hz, the level scatters for both analysed types of superstructures. As, with the exception of the installed rail pads, the two configurations are identical, the difference is attributable to the rail pads. The noise level values for the analysed pass-bys on the VA71b-opt-track with the rigid K2a pads are noticeably higher than those on the VA71b-std-track with soft pads (ZW700/85). The differences in noise levels reach 8 to 10 dB between 200 and 500 Hz. This means that the sleepers of the VA71b-opt-track radiate more noise that those of the VA71b-std-track.

This fact impacts on the A-weighted overall noise level of individual pass-bys: For wagons with K-blocs (CS-k-bloc), the A-weighted pass-by noise level on the VA71b-std-track was 2.0 dB lower than on the VA71b-opt-track. The wagons with disc-braked wheels (RIC_disc) had an A-weighted pass-by noise level on the VA71b-std-track which was 0.5 dB below that of the VA71b-opt-track.

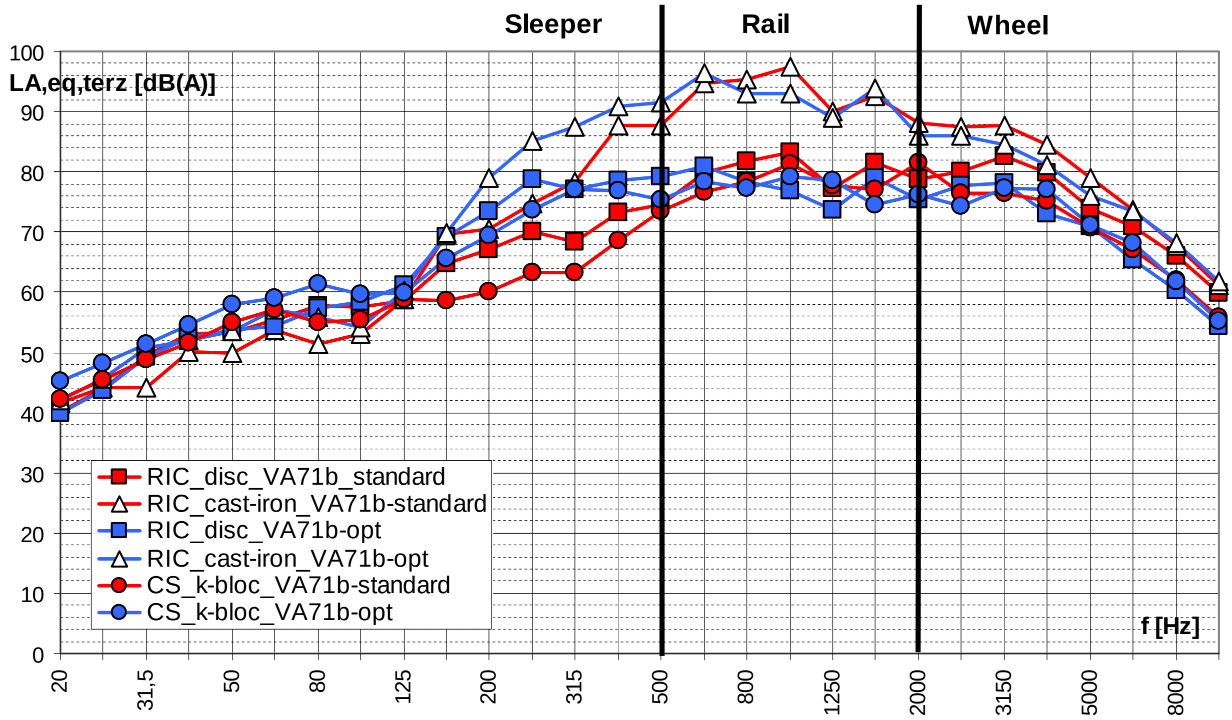


Figure 10: Average A-weighted pass-by noise level spectrum at a distance of 2.35 metres/0.5 metres at v=95 km/h

The effect on the emission levels of train traffic

Based on the calculation of noise emissions (length related sound power level Lw') according to ÖAL 30 or SchIV that Messrs. TAS-Schreiner made for the alteration project, a first assessment was made of the effects of the use of VA71b-rails on emission resp. immission levels (Table 9). The changes in noise level of the different train categories i.e. after modifying the track with VA71b-rails were considered in the calculations for the planning scenario (PLS), and were compared with standard track as stated in the norm. The emission level calculated for the planning scenario was increased by 1.6 dB in line with ÖAL 30/ONR 305011 for the (disc-braked) wagons with smooth wheels, the emission level for the (cast-iron pad-braked) wagons with rough wheels was reduced by 2.1 dB, and no adjustment to the level was made for engine-only trains.

Since the high emission levels of the loud train categories (passenger trains with combined brakes and freight trains) can be reduced by using VA71b-rails, the overall emission level of train traffic is reduced both day and night. During the day, when passenger train traffic (wagons with smooth wheels) is at its greatest, the reduction of the A-weighted, length-related sound power level of the distance Lw' equals 1.2 dB, and at night, when the freight traffic)wagons with rough wheels) dominates, the reduction of the Lw' is 1.6 dB in comparison with the superstructure with wooden sleepers and Vmax=90 km/h.

Table 9: A-weighted, length-related sound power level of the distance Lw' for train traffic

Day	**Calculation (ÖAL30)**		**in regard of VA 71b**	
	exsistence	PLF	Change of level compared to ÖAL30 with VA71b	PLF
design speed	90km/h	95km/h		95 km/ h
passenger train disc-braked (300m)	77,4	77,9	+1,6	97,5
passenger train disc-braked (150m)	72,2	72,6	+1,6	74,2
passenger train combinded brake (150m)	81,6	82,2	-2,1	80,1
freight train	90,1	90,6	-2,1	88,5
locomotive	65,6	69,9	+0,0	69,9
emission level of railway-traffic	90,9	91,5		89,7
change of emission level	**ÖAL30**	**+0,5 dB(A)**	**with PLF compared to ÖAL30**	**-1,8 dB(A)**
Night	**Calculation (ÖAL30)**		**in regard of VA 71b**	
	exsistence	PLF	Change of level compared to ÖAL30 with VA71b	PLF
design speed	90km/h	95km/h		95 km/ h
passenger train disc-braked (300m)	74,6	75,1	+1,6	76,7
passenger train disc-braked (150m)	67,9	68,4	+1,6	70,0
passenger train combinded brake (150m)	78,8	79,5	-2,1	77,4
freight train	93,9	94,3	-2,1	92,2
locomotive	68,6	69,0	+0,0	69,0
emission level of railway-traffic	94,1	94,5		92,5
change of emission level	**ÖAL30**	**+0,4 dB(A)**	**with PLF compared to ÖAL30**	**-2,0 dB(A)**

If one only relates the changes to the planned scenario, i.e., if one compares the calculated emission level after adaptation according to ONR 305011 and the actual effect of the VA71b-rail, the A-weighted, length-related sound power level of the distance Lw' is reduced by 1.8 dB during the day and by 2.0 dB at night in the planned scenario. In good approximation, these noise level reductions can also be deducted from the A-weighted emission levels of the planned scenario, because the spectral differences between the ONR 305011 emissions and those when VA71b-rails are used are not so great that they would result in a substantial change to the propagation loss.

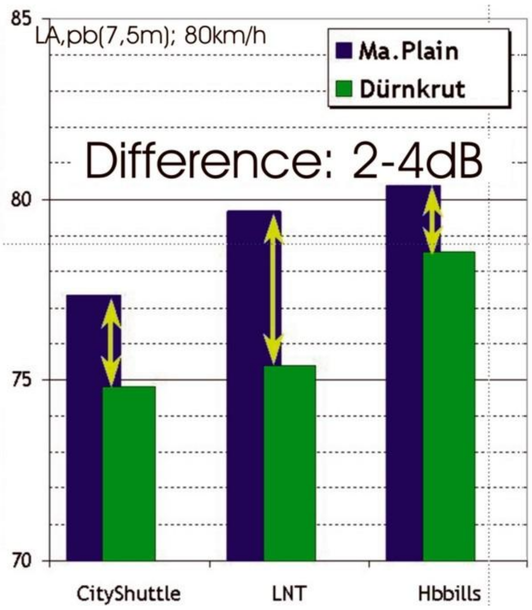
2.3.4 Summary assessment

The measurements at Dürnkrut on a VA71b-superstructure on 25/09/02 were additionally included in the assessment for reference purposes. In addition, the same LNT wagons and SBB wagons were available for the test train at Dürnkrut.

With exception of the soled sleepers, the VA71b-opt-track in Maria Plain should correspond exactly to the superstructure of the noise level test track in Dürnkrut. In contrast to Maria Plain, where both sleepers were soled, no soled sleepers were used in Dürnkrut.

Figure 11 depicts the pass-by noise levels at Maria Plain, Dürnkrut and the test track in Switzerland at a speed of 80 km/h, at a distance of 7.5 metres and at 1.2 metres height. The LNT wagons measured in Dürnkrut and Maria Plain were the same, but nevertheless differences can be seen in the pass-by noise level at 80 km/h. The quiet LNT wagons reached 79 – 80 dB(A), i.e. they were louder by up to 4 dB(A) on the VA71b-opt-track at Maria Plain than they were at the measuring point at Dürnkrut. The results are similar with the k–bloc braked City Shuttles, where the pass-by levels of 77 dB(A) are higher by 2 – 3 dB(A) at Maria Plain than at Dürnkrut. The difference for the Swiss Hbbills wagons measured by ÖBB in Dürnkrut comes to approx. 2 dB. Also in this case, the track at Maria Plain is clearly louder.

Figure 11: Pass-by noise levels at Maria Plain at a distance of 7.5 metres and the Dürnkrut comparison-track



To sum up, the following can be said:

- Substituting a track with wooden sleepers by a superstructure with concrete sleepers, VA71b-rails and standard rail pads reduced the high emission levels of the 'loud' train categories (passenger trains with combined brakes and freight trains with cast-iron pad brakes) by 2.1 dB(A).
- The rail roughness measured for the track with wooden sleepers in the frequency range relevant for the A-weighted assessment level of 500 to 4,000 Hz was somewhat lower than on the track with concrete sleepers and VA71b-rails. The identified improvement of 2 dB(A), in comparison with the superstructure with wooden sleepers, for the train categories 1 (passenger train with bloc or combined brakes) and 6 (freight wagon) according to ONR 30501, is a marginal improvement that can definitely be attributed to the superstructure with VA71b-rails.
- The A-weighted, length-related sound pressure level $L_{W',A}$ on the track assessed in the area of Maria Plain station is thus reduced by 1.8 dB during day and by 2.0 dB at night.
- The reduction of the A-weighted pass-by noise level expected from the VA71b-superstructure with optimised (= hard) rail pads on track 2 (VA71b-opt) in comparison with the VA71b-superstructure with standard rail pads on track 1

(VA71-std) was only apparent with the cast-iron block-braked freight wagons. The reduction of noise level for this train category reached approx. 4 dB(A). In the case of k-bloc-braked passenger carriages, the A-weighted pass-by noise level on the VA71b-opt-track even increased by 2 dB, whereas no significant difference of noise level between the two types of VA71b superstructures was discernable with the other categories, i.e. passenger carriages with disc-brakes or combined brakes, or the 'rolling highway'.

- Although the rail roughness of the two VA71b-tracks at Maria Plain only just fulfilled the TSI-HST requirements, it was, however, approx. 5 dB higher than at the comparable test tracks. The reason for the rougher rail surface is that at Maria Plain, head-hardened rails are used. However, the grinding was carried out in the usual way, i.e. as with non-head-hardened rails, which means that too little material was removed from the rail surface.
- Research in connection with this project has shown that on the ÖBB noise level test track on the Northern Line at Dürnkrut, the built-in superstructure is almost identical to that of the VA71b-superstructure with optimised rail pads. The nominal rigidity of the rail pads is identical. However, the concrete sleepers at Maria Plain are soled, whereas at Dürnkrut unsoled sleepers are used. Owing to the higher rail roughness at Maria Plain, the pass-by noise levels on the VA71b-opt-track were noticeably higher at Maria Plain than on the VA71b-superstructure at Dürnkrut.
- If for nothing else because of the difference in rail roughness between Dürnkrut and Maria Plain, the individual groups of wagons were louder by 2 – 4 dB(A) on the VA71b-opt-track at Maria Plain at a speed of 80 km/h than on the TSI-HST-track in Dürnkrut.

2.4 Optimisation of the VA71b-superstructure at St. Egyden, 2005-2008

2.4.1 Objectives of the investigation

At the request of voestalpine-Schienen GmbH, the vibration properties of the VA71b-superstructure (rigidity of the rail pads, track decay rate) on the original test track at St. Egyden were altered while carrying out additional optimisation and tuning work on the VA71b-superstructure and the effect on noise emissions were investigated. In this instance, a Semperit caoutchouc rail-pad (ZW700) with improved sound-emission behaviour was incorporated.

The objective of the investigation was to find out if the use of caoutchouc rail-pads would avoid the original increase in noise level at the VA71b-superstructure and whether this rail pad could produce a sound-optimised VA71b-track.

2.4.2 Method of investigation

As in 1996, a standard UIC60-superstructure was compared with the VA71b-track. In order to be certain that both test tracks had the same acoustic rail roughness and would thus be comparable, the rail roughness was also measured when the investigation of noise generation took place.

An additional indicator developed during recent years, which was included in the TSI-CR-Noise [1] and helps with assessing the dynamic behaviour of a track section, is the so-called Track Decay Rate, which indicates the reduction of rail vibrations per metre of track [dB/m] in individual one-third-octave bands. This means that the higher the track decay rate is, the less a track unit vibrates along the length of the rail, which offers information on the acoustic condition of the rail. At the same time the acoustic measurements were made, both the vertical and the horizontal track decay rate were also defined.

The measurement set-up was the same for all measurements carried out. At both measurement cross-sections, i.e. at the reference cross-section of the UIC60-rail and the investigated cross-section of the VA71-b rail, the following signals were recorded for each measuring point together with the pass-by speed of the trains, and analysed with the help of an 8-channel analysis system.

- Channel 1: M1 (Micro): Measuring point at a distance of 7.5 metres and at a height of 1.2 metres
- Channel 2: M2 (Micro): Measuring point at a distance of 7.5 metres and at a height of 3.5 metres
- Channel 3: V1 (Vrv): Vertical accelerometer at the rail
- Channel 4: V2 (Hrv): Horizontal accelerometer at the rail
- Channel 5: V3 (Vsv): Vertical accelerometer on the sleeper
- Channel 6: T1 (Trigger): Inductive wheel sensor

The following types of superstructures were investigated according to EN ISO 3095 or TSI-High Speed in three series of measurements of pass-by noise levels:

- 1st series of measurements (2005): VA71b-superstructure with SSL-pads / UIC60 reference superstructure.
- 2nd series of measurements (2006): VA71b-superstructure with Semperit caoutchouc pads (ZW700) / UIC60 reference superstructure.
- 3rd series of measurements (2008): Repeat of the measurements of the VA71b-superstructure with Semperit caoutchouc pads (ZW700) / UIC60 reference superstructure.

2.4.3 Findings

Acoustic rail roughness

The acoustic rail roughness of both measurement cross-sections did not differ significantly. This means that as far as the rail roughness is concerned, the pass-by noise levels are comparable.

Pass-by noise level

The following diagrams show the differences in noise level between the VA71b and the UIC60-superstructures for double-decker regional trains, EC/IC passenger trains and freight trains as well as with two different rail pads in the VA71b-track. SSL-pads were installed on the VA71b-superstructure in 2005. After taking the measurements, the pads were exchanged for Semperit caoutchouc pads (ZW700), therefore, the values in 2006 represent the optimised VA71b-superstructure.

In addition to the average value of the noise level difference (white point), the diagram also shows the 95% confidence interval. This means that with a probability of 95%, the actual differences of noise level will be found in this area. Increases in the pass-by noise level on the VA71b-superstructure compared with the UIC60-track show positive values, reductions in noise level on the VA71b-track show negative values.

Figure 12 shows the results for the double-decker regional trains, i.e. wagons with smooth wheels. It is easy to see that the A-weighted pass-by noise levels on the VA71b-superstructure with SSL-pads (2005) were higher by 0.5 to 1.5 dB at both measuring points ((M1: 7.5/1.2 metres, M2: 7.5/3.5 metres) than those on the UIC60-track. With double-decker trains, the VA71b-superstructure (2006), after the pads had been exchanged, was quieter by approx. 1 – 1.5 dB , in comparison to the UIC60-superstructure. The 95% confidence interval is also narrower, i.e. the difference in noise level is more reliable.

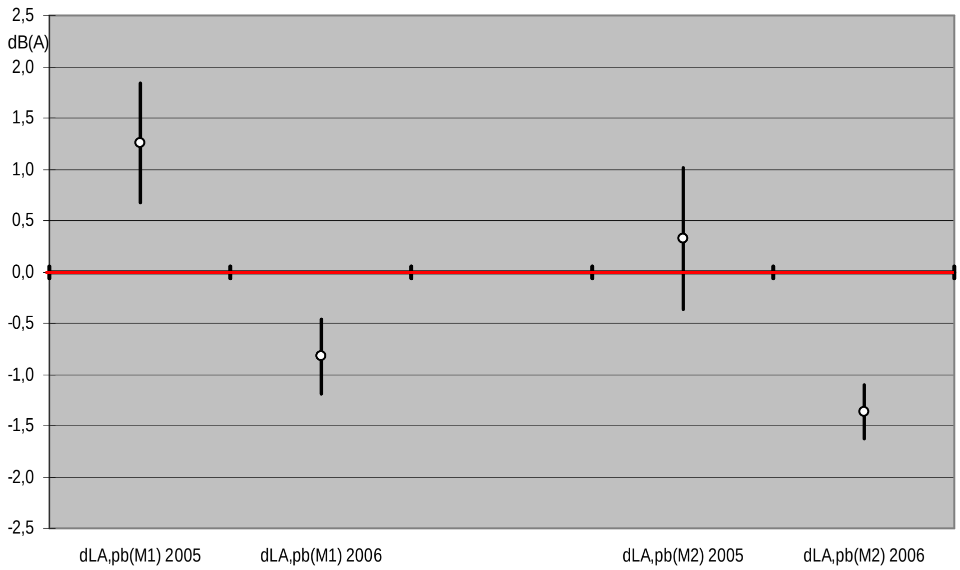


Figure 12: Average noise level differences between the VA71b and UIC60-tracks for double-decker regional trains

In figure 13, the same comparison is made for EC/IC passenger trains. This category of trains represents rail vehicles with rough wheels. Even with the SSL-pads (2205), the VA71b-superstructure was, on average, equally as loud or only 0.5 dB(A) quieter than the UIC60-track. After the pads had been changed (2006), the difference in noise level was 0.8 to 1.2 dB in favour of the VA71b-track.

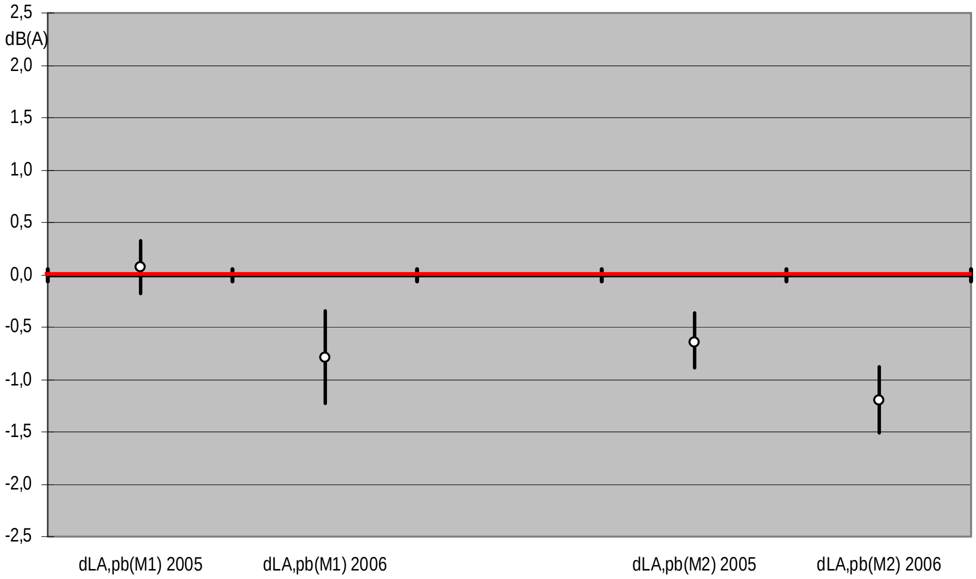


Figure 13: Average noise level differences between the VA71b and UIC60-tracks for EC/IC passenger trains

For freight trains, i.e. vehicles with very rough wheels, the differences in noise level between the superstructures before and after changing the pads was, on average, less than 0.3 dB(A) at both microphone locations (Figure 14). The 95% confidence interval is very wide, which means that the average values are not very reliable due to the limited sample of 2005,

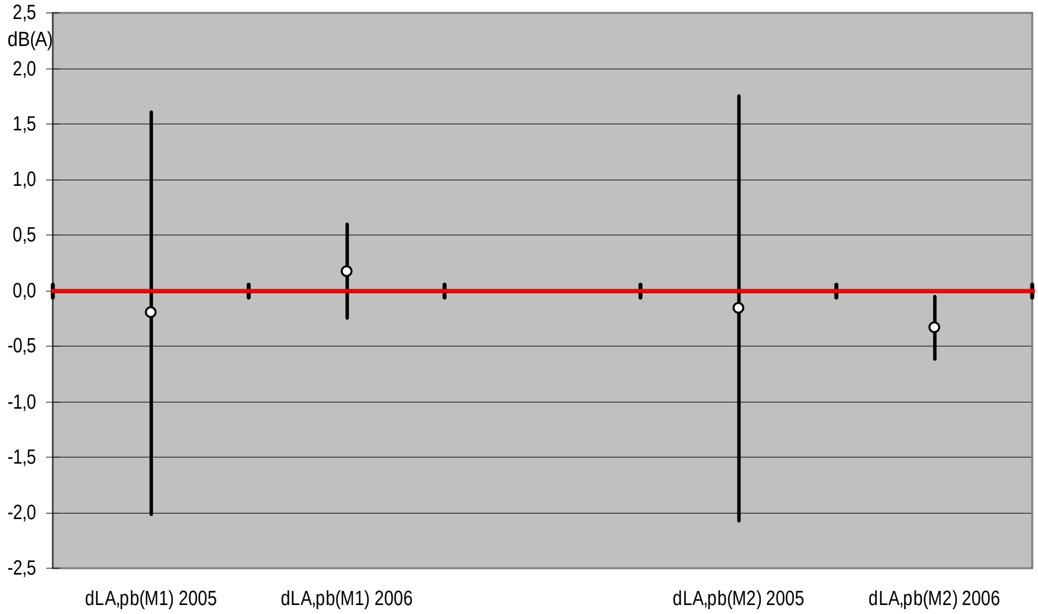


Figure 14: Average noise level differences between the VA71b and UIC60-tracks for freight trains

A further series of measurements was undertaken on 28 and 29/05/2008 due to the fact that the pass-by noise levels that were measured in 2006 were widely scattered.

Figure 15 compares the recorded A-weighted pass-by noise level $L_{A,pb}$ between the VA71b-superstructure and the reference section with UIC60-rails for all trains passing during this series of measurements. In the diagram, each point represents one train, whereby the $L_{A,pb}$ on the VA71b-superstructure is shown on the abscissa and the $L_{A,pb}$ on the UIC60-superstructure is shown on the ordinate. It can clearly be seen that the A-weighted pass-by noise level for all train categories is approx. 1.5 dB(A) lower on the VA71b-superstructure, with a sound-optimised Semperit-pad, than on the UIC60-superstructure. Freight trains, i.e. trains with very rough wheels and high noise emission are represented by yellow triangles in the diagram. The suburban train (4020, blue diamond) and the passenger trains (EC/IC, purple diamond) represent rail vehicles with rough wheels, and the double-decker regional trains (80-33, red circles) stand for disc-braked wagons with smooth wheels.

One can see that the trend lines for the different categories (of roughness) and the level of noise emission are in line with the regression line of all trains (green line).

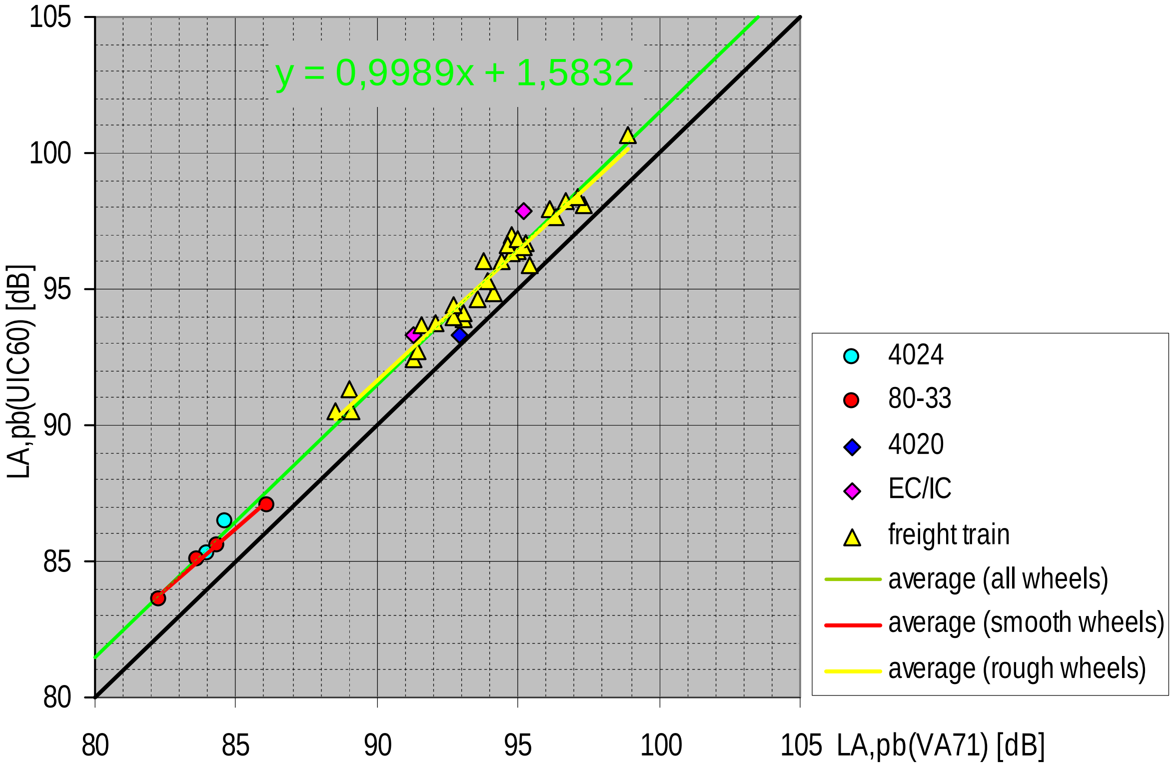


Figure 15: Comparison of VA71b and UIC60 (rail pads of the same static stiffness for both tracks) at a distance of 7.5 metres – St. Egyden 2008

2.5 MEASUREMENTS ON THE VA71B-SUPERSTRUCTURE AT MALMÖ/TJÖRNARP 2007

The details of this measurements are take out of the Q-City WP5.9 technical report from 2007-08-12 written by Henrik Malker/ACL and Nicolas Renard/BAN.

Sound and measurements were performed in May 2007. the weather conditions during the sound measurements were monitored and are included in the technical report.

More than 50 train passages during day time were recorded.

Four different train categories were measured. For the Öresund train type (21 records) X2 (15 records) train type a noise reduction of about 1dB(A) because of the use of the VA71b rail was measured. For the Inter City trains (3 records) equal noise levels compared to the reference rail were measured. For the freight trains (15 records) an increase of the noise level of about 1 dB(A) was observed. The details of all measurements can be found in the technical report.

The measurements were done by ACL and BAN and were classified as uncertain. The reason for this classification were perceived problems with the quality of the substructure ballast at the track site.

Nevertheless the measured results show once more the important influence of the substructure on the total noise level of the track.

3 SUMMARY

As we mentioned in the introduction, the measurements compiled in this report were made over a period of 10 years and, in addition, had different objectives, which is the reason why the methodological approach is not uniform. However, since all investigations applied rather comparable methods, it is still possible to offer an overall assessment. The fact that both the first and the last series of measurements were made on the same superstructures and that in both cases the same reference was included, greatly facilitated our work. Table 10 lists the most important measurement parameters and shows which of them were applied in which investigation.

Table 10: Overview of the most important parameters recorded in each investigation

Location	Year	Rail Roughness	TSI Limit achieved	Decay Rate	TSI Limit achieved	MP (7,5m/1,2m)
Dürnkrut	2002	Yes	Yes	No	-	Yes
Maria Plain	2003	No	-	No	-	Yes
Maria Plain	2003	Yes	No	No	-	No
St. Egyden	1996	No	-	No	-	Yes
St. Egyden	2005	No	-	Yes	No	No
St. Egyden	2006	Yes	No	Yes	No	Yes
St. Egyden	2008	Yes	No	No	-	Yes

VA71b-superstructure, St. Egyden, 1996

The comparative measurements between the standard UIC60-superstructure and the VA71b-superstructure gave the results mentioned below. Apart from the rail in use, both superstructures were identical:

- The A-weighted pass-by noise levels at 80 km/h were lower on the track with the VA71b-rail profile than those on the UIC60-track.
- This improvement disappears at a speed of 120 km/h and the noise level even increases at 160 km/h.
- A modification of the cross-section of the VA71b-rail changed the frequency range of the emitted pass-by noise and reduced the noise level at 1,200 - 1,400 Hz, however, it increased it in the frequency range from 2,000 - 2,700 Hz.
- The results led to the conclusion that the approach of modifying the shape of the rail generally shows the desired effect and that further optimising the profile to reduce the noise level in the 2 kHz range and at speeds above 120 km/h is necessary.

Investigation of LNT wagons, Dürnkrut 2002

Despite these limitations, ÖBB subsequently installed the VA71b on the section of the Northern Line near Dürnkrut used for pass-by noise level measurements in accordance with SchLV. The measurements for the approval of the LNT freight wagons took place on this superstructure in 2002.

The LNT wagons have an A-weighted pass-by noise level LA,pb of 75.4 dB, at a distance of 7.5 metres from the track, at 1.2 metres height from the top edge of the rail and at 80 km/h, and are thus 5.6 dB quieter than the limit of 81 dB set by ARGE LNT.

These results caused great excitement. Since no additional comparative measurements for the LNT wagons on a UIC60-superstructure are available, it was impossible to state which part of the noise reduction was attributable to the construction of the vehicles and which to the VA71b-superstructure. However, the results of the measurements at Dürnkrut were subsequently used for reference purposes when assessing other VA71b-test tracks.

Optimisation of the VA71b-superstructure, Maria Plain 2003

After the termination of the EU research project ‘Metarail’ in 2000, it was clear that only a careful alignment of the dynamic behaviour of rails, in particular the adaptation of the dynamic rigidity of the pad to the rail profile, would make a track ‘quiet’. It was possible to show that from an acoustic point of view, a track with concrete sleepers generally causes less noise emission than one with wooden sleepers, just as a heavy/rigid rail is generally more favourable from an acoustic point of view than a light/flexible rail. However, only the right choice of pads will lead to success because with the wrong, e.g. too soft, pads even a concrete sleeper may give off a higher pass-by noise level than a wooden sleeper.

In light of these findings, the existing superstructure with wooden sleepers was replaced on both tracks with a superstructure with concrete sleepers and VA71b-rails during a renewal of the superstructure in the Maria Plain section in 2003. On track 1, a standard pad type ZW700/85 (VA71b-std-track) and on track 2, a rigid pad type K2a (VA71b-opt-track) were incorporated. Then, the A-weighted pass-by noise level of scheduled trains was measured on the track with wooden sleepers and on both VA71b-tracks. In a second phase of the investigation, a test train with the LNT-freight wagons was measured on the VA71b-opt-track. The results are the following:

- By substituting the track with wooden sleepers with a superstructure with concrete sleepers, VA71b-rails and standard rail pads reduced the high emission levels of the ‘loud’ train categories (passenger trains with combined brakes and freight trains with cast-iron pad brakes) by 2.1 dB(A).
- The rail roughness measured on the track with wooden sleepers in the frequency range of 500 to 4,000 Hz relevant for the A-weighted assessment level, was somewhat lower than that on the track with concrete sleepers and VA71b-rails. The identified improvement of 2 dB(A) in comparison with the superstructure with wooden sleepers for the train categories 1 (passenger train with bloc or combined brakes) and 6 (freight wagon) according to ONR 30501, is a marginal improvement that can definitely be attributed to the superstructure with VA71b-rails.
- The reduction of the A-weighted pass-by noise level expected from the VA71b-superstructure with optimised (= hard) rail pads on track 2 (VA71b-opt) in comparison with the VA71b-superstructure with standard rail pads on track 1 (VA71-std) was only apparent with the cast-iron block-braked freight wagons.

The reduction of noise level for this train category reached approx. 4 dB(A). In the case of k-bloc-braked passenger carriages, the A-weighted pass-by noise level on the VA71b-opt-track even increased by 2 dB, whereas no significant difference of noise level between the two types of VA71b superstructures was discernable with the other categories, i.e. passenger carriages with disc-brakes or combined brakes, or the 'rolling highway'.

- Although the rail roughness of the two VA71b-tracks at Maria Plain only just fulfilled the TSI-HST requirements, it was, however, approx. 5 dB higher than at the comparable test tracks. The reason for the rougher rail surface is that in Maria Plain head-hardened rails are used. However, the grinding was carried out in the usual way, i.e. as with non-head-hardened rails, which means that too little material was removed from the rail surface.
- Research in connection with the project in Maria Plain showed that on ÖBB's noise level test track on the Northern Line at Dürnkrut, the installed superstructure is almost identical with the VA71b-superstructure because the stated rigidity of the rail pads is the same. The concrete sleepers at Maria Plain are soled, whereas in Dürnkrut unsoled sleepers had been incorporated. Due to the higher rail roughness at Maria Plain, the pass-by noise levels on the VA71b-opt-track were noticeably higher at Maria Plain than on the VA71b-superstructure at Dürnkrut.

Owing to the fact that at the test in Maria Plain some parameters which substantially influence the noise emissions, such as the rail roughness or the soling of the sleepers, were not adhered to, a final assessment of the optimisation of rail pads was unfortunately not possible.

Optimisation of the VA71b- superstructure, St. Egyden 2005-08

Subsequently, an additional series of tests with different pads was carried out at the original VA71b- measuring track near St. Egyden. In 2005, in a first step, the VA71b-track with SSL-pads was compared with the UIC60-superstructure, both of which had been left unchanged since 1996. On the VA71b-track, the A-weighted pass-by noise level of trains with rough wheels was slightly lower than or equal to that on the UIC60-track, and the A-weighted pass-by level of rail vehicles with smooth wheels was higher by 1.2 dB.

After changing the pads of the VA71b-track for a sound-optimised version of caoutchouc, the difference of the A-weighted pass-by noise level of all categories of trains was approx. 1.5 dB, which means that this VA71b-superstructure is now generally 1.5 dB quieter than the UIC60-superstructure in St. Egyden.

Overall assessment

At the beginning of the development of a sound-optimised rail profile in the 90s when the knowledge of the mechanisms of rolling noise and radiation generation was rather limited and it was hoped that it would be possible to produce a highly noise-optimised, conventional rail profile.

The disillusion was great when after the first practice tests it became apparent that a reduction in noise level could not be measured for all train and speed categories with the VA71b-rail in comparison to the UIC60-rail. The ‘problem’ of the VA71b-rail was that it was considerably quieter when a train approached but that during the pass-by of a train, the maximum frequency of the VA71b-rail shifted from approx. 1.2 kHz to 2.5 kHz. The first effect does not influence the pass-by noise level, whereas the frequency shift leads to a noise level shift which impacts negatively on the A-valuation. The conclusion was that the rail had to be optimised.

The EU research project ‘Metarail’ in the 2nd half of the 90s showed that a track constitutes a complex vibration system which makes it necessary to carefully align individual components in order to achieve a specific characteristic. Therefore, it is not possible to consider rails alone, but that only the interaction of rail and rail pad decides the amount of rolling noise a track radiates. A sound-optimised rail with the ‘wrong’ pads is therefore ‘louder’ than a UIC60 or UIC54-rail with the ‘right’ rail pads.

There was already an awareness of the importance of the (rigidity of) rail pads in connection with the noise emissions of rail tracks at the turn of the millennium. The problem that we still face today is to reproduce superstructures which are known to have low noise emission at a specific location and then to install the same superstructure with low noise emissions at a different location. A VA71b-superstructure was installed at the ÖBB test track near Dürnkrut after the first test with the VA71b-rail, where it produced very good results.

In the meantime, the use of rigid rail pads with high inner dampening has become in theory the technology standard in order to obtain a quiet track, and it is now possible to define whether the requirements are fulfilled or not without having to resort to noise emission measurements. This check is possible with the track decay rate as described in the TSI-CR-NOI and TSI-HS-VEH. The check of the rail decay rate regularly shows that nominally identical superstructures actually have a different dynamic behaviour and thus also different track decay rates. The explanation for this phenomenon lies in the contemporary description of the rigidity of rail pads, which does not take the dynamic behaviour into consideration. Thus, the rail pads of different producers are nominally the same, however, they have a different (dynamic) behaviour which results in tracks having different emission levels.

For the first time, the test with the Semperit caoutchouc rail pad (ZW700) has produced satisfactory results, i.e. a reduction of the noise level by 1.5 dB(A) for all train categories and pass-by speeds in comparison to the UIC60-rail (see Figure 15, page 30). It should be possible to reproduce the noise level reduction by using this rail pad and checking it by measuring the track decay rate (see Figure 24, page 41).

4 LITERATURE & DOCUMENTS

[1] TSI-CR-NOI: Commission Decision of 23 December 2005 concerning the technical specification for interoperability (TSI) relating to the subsystem rolling stock — noise of the trans-European conventional rail system (Com 2006/66/EC)

[2] TSI-HS-VEH: Commission Decision of 21st February 2008 concerning a technical specification for interoperability relating to the 'rolling stock' sub-system of the trans-European high-speed rail system (Com 2008/232/EC)

[3] prEN ISO 3095:2001: Railway applications - Acoustics - Measurement of noise emitted by railbound vehicles, draft document 01/03/2001

[4] prEN 15461:2007: Railway applications Noise emission Characterisation of the dynamic properties of track sections for pass by noise measurements; Final draft, September 2007

[5] ON EN ISO 3095:2005: Railway applications - Acoustics - Measurement of noise emitted by railbound vehicles; Document 01/11/2005

[6] ON EN ISO 3381:2005: Railway applications - Acoustics - Measurement of noise inside railbound vehicles; Document 01/11/2005

[7] SchLV: Schienenfahrzeug-Lärmzulässigkeitsverordnung. [Ordinance on Noise Emission Limits for Rolling Stock] Bundesgesetzblatt der Republik Österreich [Austrian Federal Law Gazette], *BGBl*. Nr. 414/1993

5 REFERENCE

The measurements and calculations in this report (except the measurements in Malmö/ Tjörnarp) were done by psiA-Consult (Umweltforschung und Engineering GmbH, Manfred T.Kalivoda, Austria)

6 ANNEXES

Figure 16: Roughness spectra acc. to prEN ISO 3095 – Dürnkrut 2002

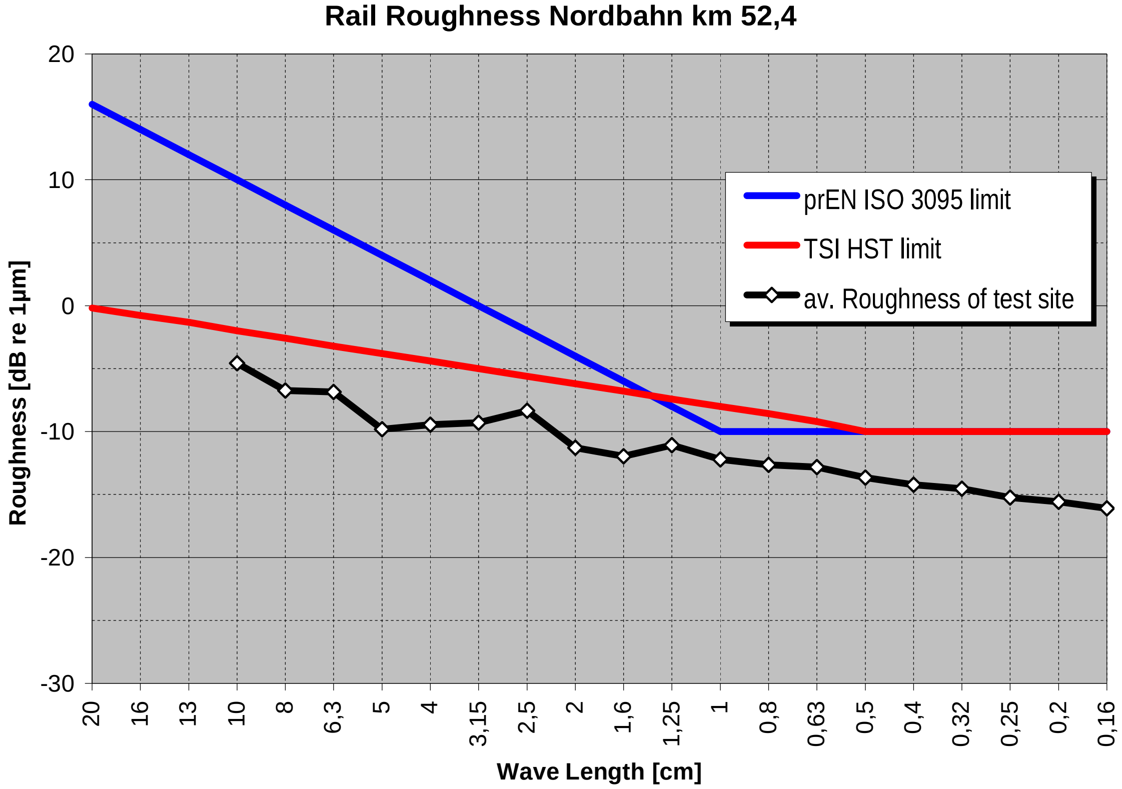


Figure 17: Roughness spectra acc. to prEN ISO 3095 of the track with wooden sleepers – Maria Plain

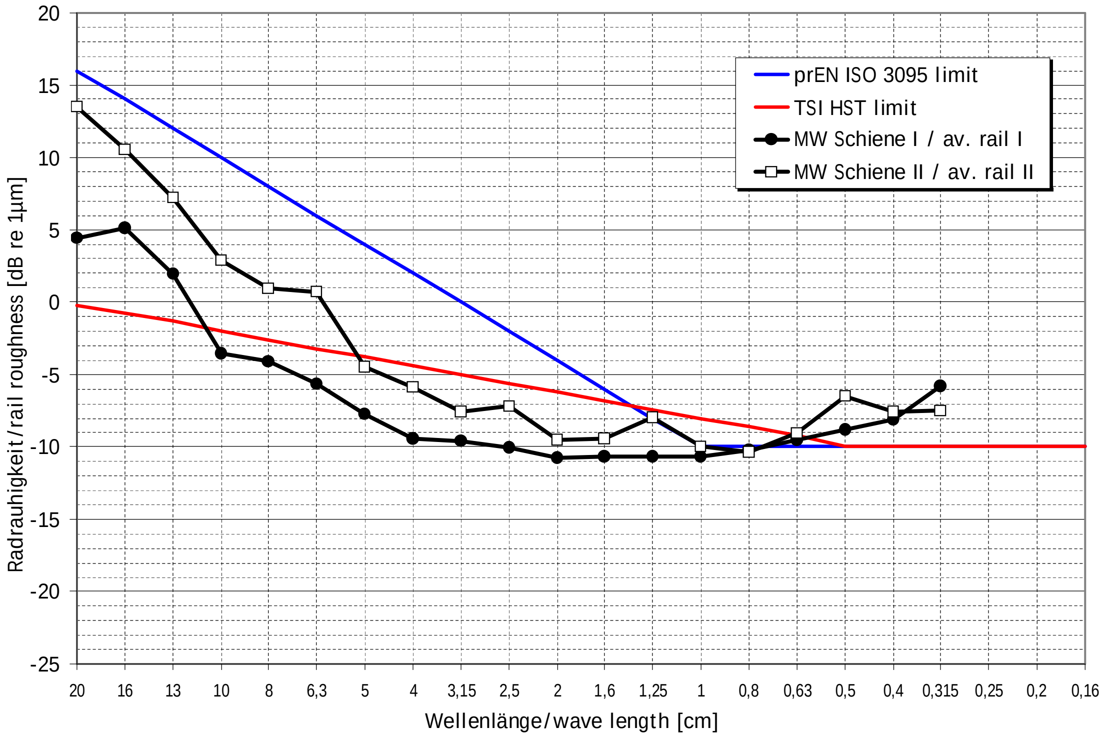


Figure 18: Roughness spectra acc. to prEN ISO 3095 of the VA71b-std-track – Maria Plain

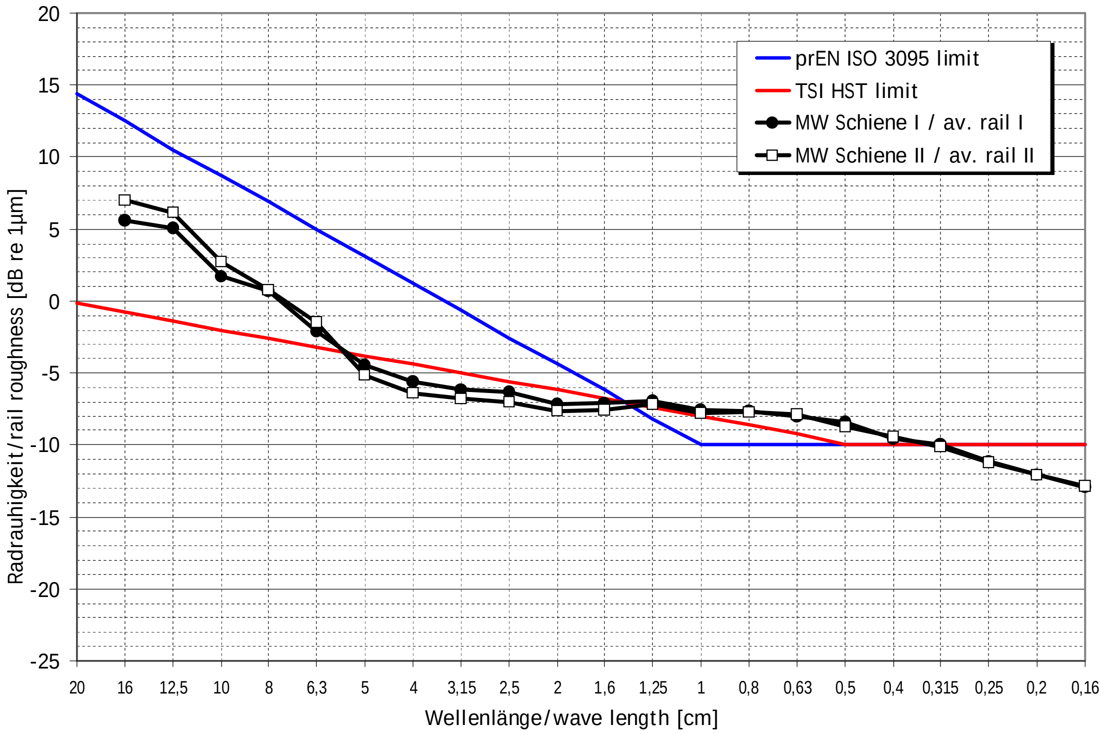


Figure 19: Roughness spectra acc. to prEN ISO 3095 of the VA71b-opt-track – Maria Plain

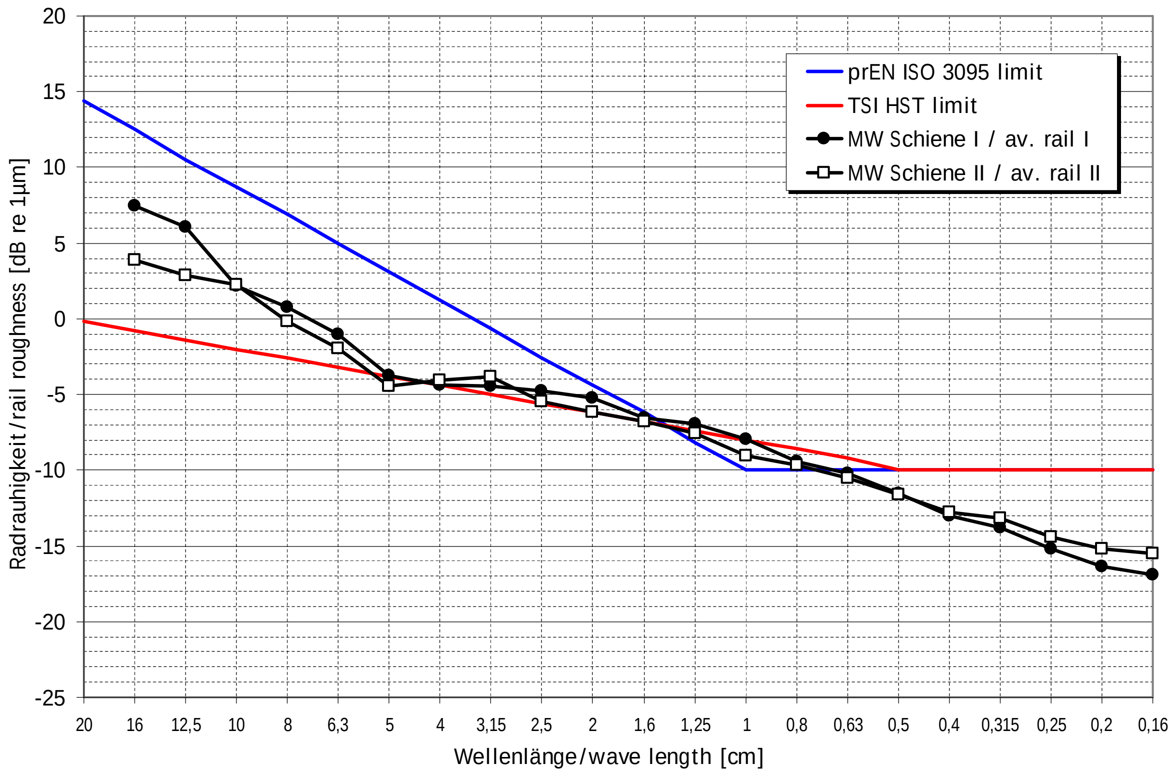


Figure 20: Roughness vs. wave lengths, St. Egyden - UIC60 both tracks

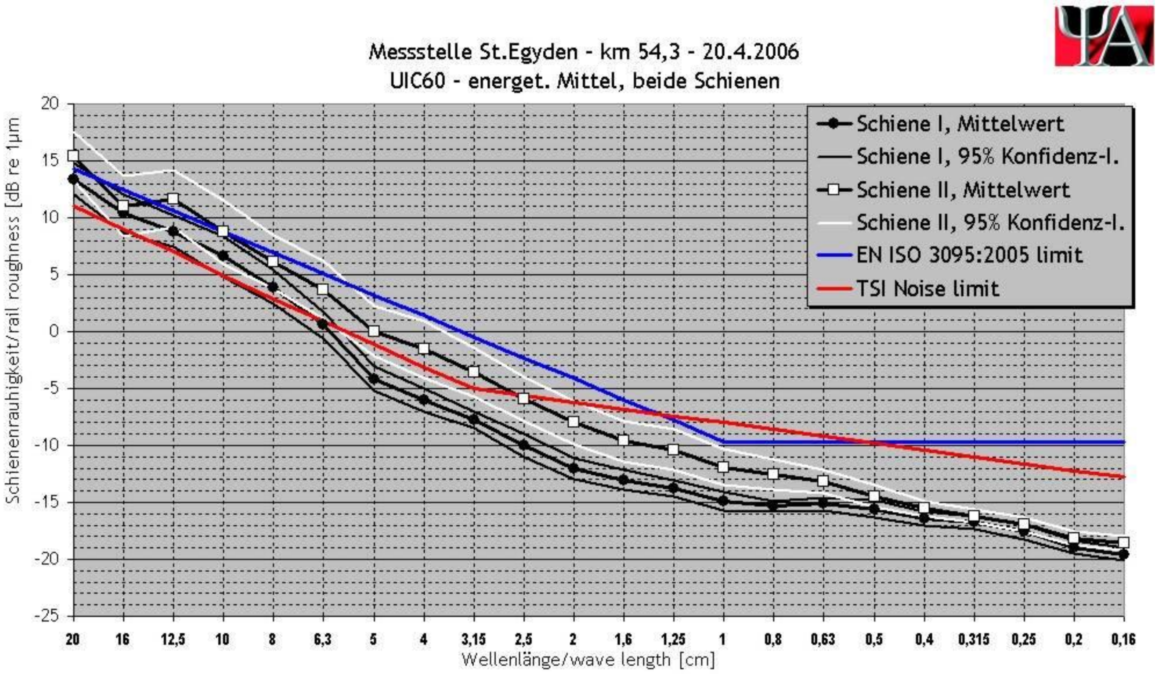


Figure 21: Roughness vs. wave lengths, St. Egyden - VA71b both tracks

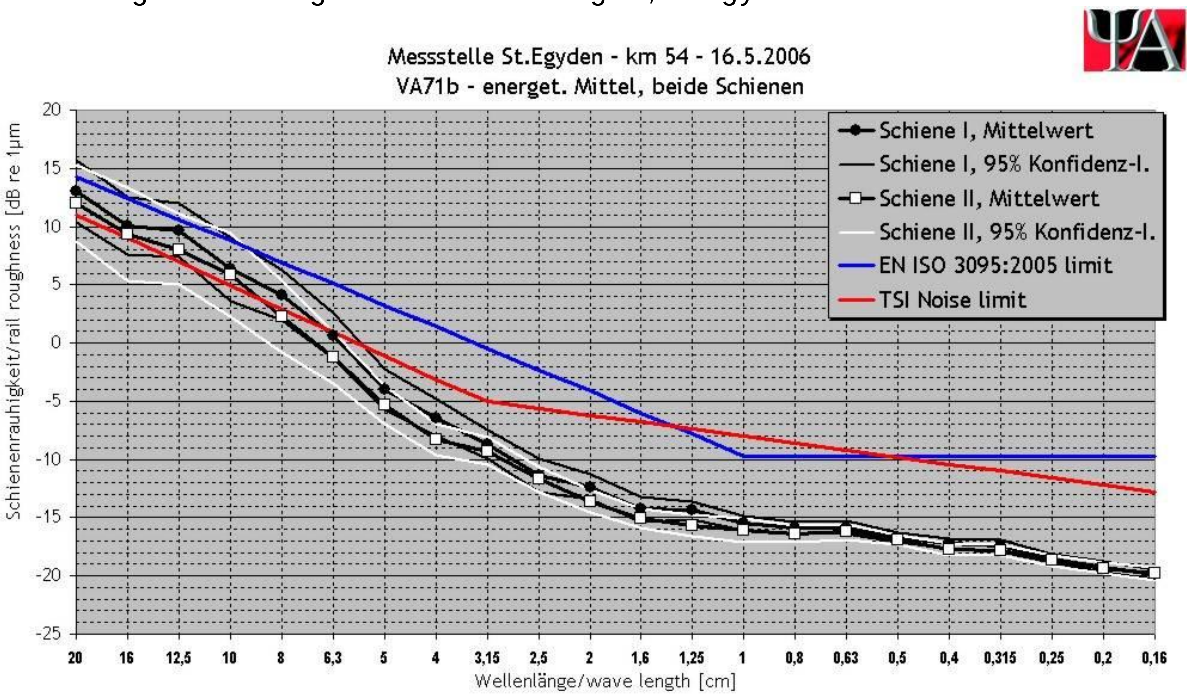


Figure 22: Roughness vs. wave lengths, St. Egyden - UIC60 both tracks

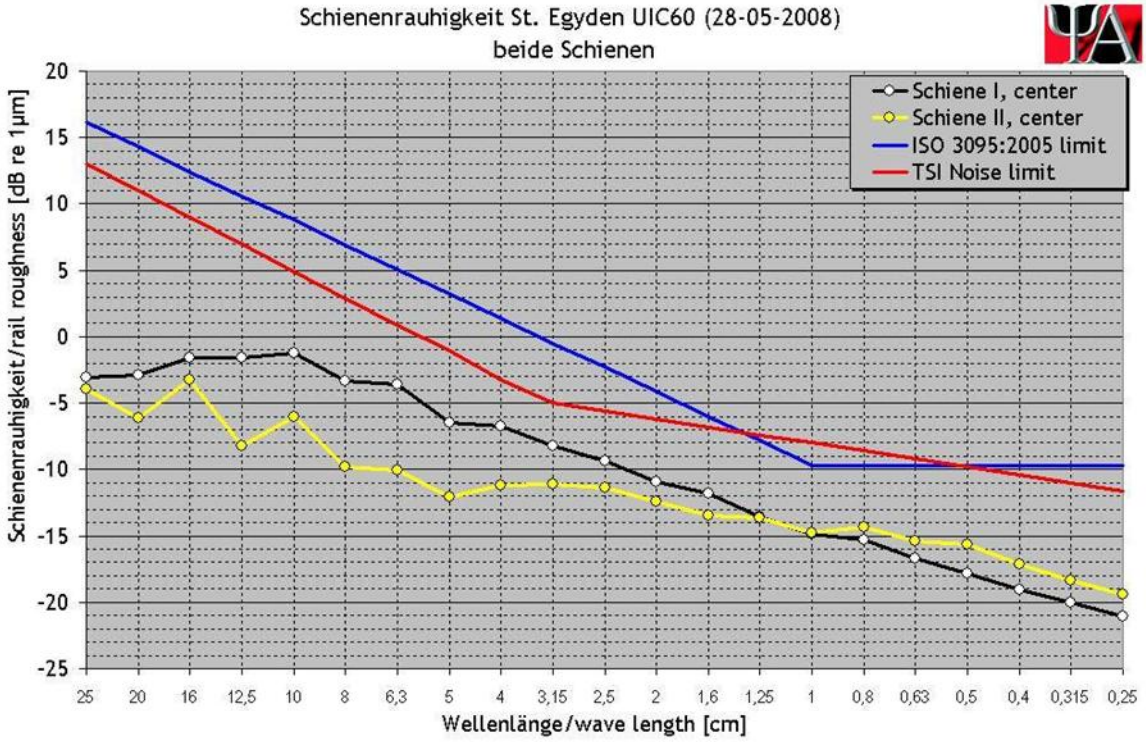


Figure 23: Roughness vs. wave lengths, St. Egyden - VA71b both tracks

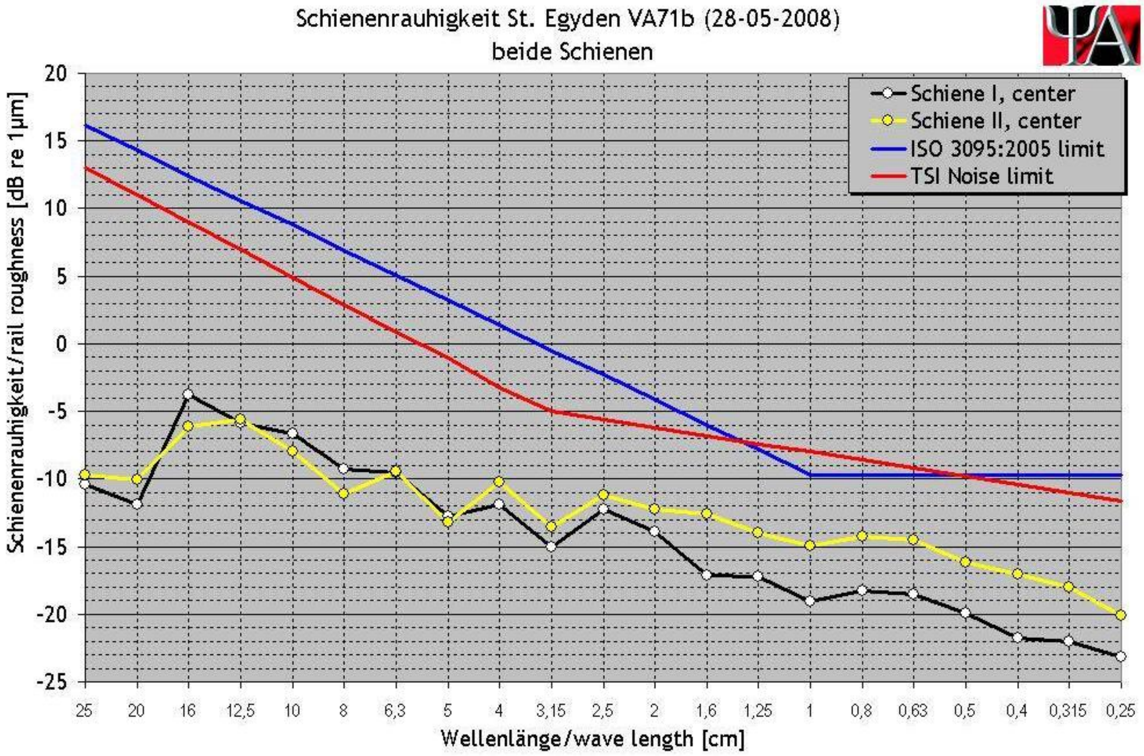


Figure 24: Decay Rate comparison / VA71b track with different rail pads and UIC 60 track