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Work Package WP3	**Noise and vibration control at source – Acoustically green vehicles**
3.4	**Low noise DualQ tyre combined with electric vehicle**
Written by	**Oskar Lundberg**
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	Netherlands Organisation for Applied Scientific Research — TNO — NL
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Dissemination Level

PU	Public	✓
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restrictec to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for the members of the consortium (including the Commission Services)	

Nature of Deliverable

R	Report	✓
P	Prototype	
D	Demonstrator	
O	Other	

SEVENTH FRAMEWORK PROGRAMME

1 see List of Deliverables, DoW – Annex I to the contract, p.32 (document 233655_CITYHUSH_AnnexI_DoW_2010-01-31_Corrections.pdf - available on the ftp-server)

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0 EXECUTIVE SUMMARY

0.1 OBJECTIVE OF THE DELIVERABLE

Within the CityHush project, investigations with the aim to find noise reduction techniques for tyre/road noise have been performed. As a part of this, the objective of this study is to evaluate the reduction of emitted tyre/road noise by a new DualQ tyre design in relation to a standard tyre. Validation was performed for passenger cars with and without electric engine on low noise road as well as with single wheel trailer (QCity project).

0.2 DESCRIPTION OF THE WORK PERFORMED SINCE THE BEGINNING OF THE PROJECT

The objective of this study is to develop and test the DualQ tyre design as a method to reduce tyre/road noise from passenger cars. Four prototype tyres were developed and manufactured. Acoustic measurements where then performed with four prototype tyres mounted on a fuel passenger car and an electrically driven passenger car. The measurement procedure for exterior noise is in accordance with the ISO standard for pass-by noise measurements, ISO 362-2 with the exception that measurements were done for constant vehicle speeds. Additional tests were made concerning the interior noise and comfort vibrations in the car.

0.3 MAIN RESULTS ACHIEVED SO FAR

- Manufacturing of prototype tyres
- Tests on electrically driven car and gasoline driven car
- Low noise performance has been validated

0.4 EXPECTED FINAL RESULTS

In combination with low noise roads, the DualQ design is expected to ensure a traffic noise reduction (for an electric vehicle) of approximately 10 dB(A)-units at 40-60 kph (relative to standard car with standard tyres driving on a standard asphalt pavement).

0.5 POTENTIAL IMPACT AND USE[2]

Traffic noise reduction has two major benefits. First, citizens experiencing traffic noise as a disturbance and potential health risk can be provided with a much quieter and healthier traffic environment with less resident disturbances.

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2 *including the socio-economic impact and the wider societal implications of the project so far*

Secondly, areas, which are not populated due to traffic noise pollution, may be reconsidered as an appropriate area to build residential buildings once traffic noise reduction has been achieved.

0.6 PARTNERS INVOLVED AND THEIR CONTRIBUTION

Development of the DualQ prototype tyres was made by Acoustic Control (ACL). Sound pressure measurements by means of the Pass-by method were performed by Acoustic Control (ACL). Earlier work on the DualQ prototype development were performed in the QCity project, where sound pressure level measurements using "rough" and "smooth" road replicas, as well as measurements of hub forces were performed by Goodyear (GOOD) in their acoustical lab in Luxembourg. In the development phase of the DualQ prototype, various diagnostic acoustic tests regarding the horn effect of a DualQ tyre concept and the point mobility of different tyre models were performed by Acoustic Control (ACL).

0.7 CONCLUSIONS

Global warming and environmental issues is presently forcing the vehicle industry to produce more environmentally friendly vehicles. As a part of this work, electrically driven vehicles which have very silent drive-lines are becoming increasingly popular. In order to reduce vehicle noise in the future, it is therefore crucial to develop functional noise reducing measures for tyre/road noise, such as the DualQ concept which is validated in this report.

It has been found that the horn amplification effect is reduced compared to a standard car tyre. This effect has been found to be responsible for a major part of the total reduction. The DualQ tyre consists of two narrow tyres with small crown radius mounted on the same rim with a spatial separation between them. This spatial separation is preventing the two tyres to interact acoustically, which ensure that the horn amplification is not re-established. Measurements with the aim to evaluate the reduction potential from the DualQ tyre were performed by Acoustic Control (ACL) with the Pass-by method. For this, four DualQ low noise prototype tyres were manufactured and mounted on passenger cars. Further evaluation measurements of the interior noise and comfort vibrations were performed by Volvo Cars in cooperation with ACL staff. Earlier work performed in the QCity project also involved measurements with the CPX-method using a single wheel trailer for tyre/road noise measurements.

Results from Pass-by measurements and measurements with single wheel trailer reveal that the DualQ prototype reduces tyre/road noise by 4.1 – 8 dB(A)-units compared to a standard car tyre with similar dimensions. The DualQ design has previously proved to have highest noise reduction (compared to standard car tyres) for rough road surfaces (see results from QCITY project [1]). In Table 0.7.1, a summary of performed tests and corresponding noise reduction for the DualQ tyre prototypes compared to reference standard car tyres is presented.

Table 0.7.1 Summary of performed validation measurements and measured noise reduction [dB(A)-units] for DualQ prototype tyres.

Test number	Test vehicle	Asphalt pavement	Vehicle speed	Measurement site	Noise reduction [dB(A)-units]
1	Volvo C30 PEV	Very smooth	50	Volvo test track	4.7*
2	Volvo C30 T5	Very smooth	50	Volvo test track	4.1*
3	Volvo C30 PEV	Very smooth	80	Volvo test track	5.8*
4	Volvo C30 T5	Very smooth	80	Volvo test track	5.1*
5	Single wheel trailer	Smooth	50	Blackebergsvägen, Stockholm	6.3
6	Single wheel trailer	Rough	70	Arninge, Stockholm	8.0

* Correction for tread pattern tonal noise was made

In order to increase the already high noise reduction measured for the DualQ prototype compared to standard car tyres some adjustments should be made to the DualQ prototypes. Primarily, the sub-tyres should be replaced by tyres more suitable for passenger cars, supplied with low noise tread pattern. Moreover, the tyre belt mobility for DualQ sub-tyres should be in the same order of magnitude as mobilities of standard car tyres in the frequency region of importance for sound radiation.

1 INTRODUCTION

1.1 PURPOSE

The purpose of this study is to develop and validate the DualQ tyre design as a method to reduce tyre/road noise from passenger cars.

1.2 BACKGROUND

Global warming and environmental issues is presently forcing the vehicle industry to produce more environmentally friendly vehicles. As a part of this work, electrically driven vehicles which have very silent drive-lines are becoming more popular. Traffic noise is mainly the combination of tyre/road noise and driveline noise. In order to significantly reduce traffic noise for the whole speed range, mitigation measures concerning both tyre/road noise and driveline noise must be considered. In this deliverable, a method of reducing traffic noise by a combination of electric vehicles and the low noise tyre design DualQ is presented.

The prototype DualQ tyre was designed and developed by one of the partners in QCity and CityHush, Acoustic Control (ACL). The prototype tyre design consists of two narrow tyres (motorcycle tyre Dunlop 90/90-19 52H) mounted on a specially designed rim based on a normal car rim. The prototype comprises the same magnitude of gross diameter and width as a standard car tyre.

Similar tyre designs have previously been commercially available although the separation of the sub-tyres was not enough to create noise reduction. Previously developed twin-tyre designs aimed at improving handling in dry and wet conditions.

Figure 1.2.1.1 a) The DualQ tyre; b)JJD twin tyre system and c) Avon tyres

The DualQ concept as a method to reduce tyre/road noise was partly developed and investigated in the QCITY project. The aim was to specify an optimal geometry for the DualQ tyre prototype for maximum reduction of external tyre/road noise, yet exhibiting commercially realistic dimensions. The reduction of the horn amplification is highly dependent on the spacing between the two narrow sub-tyres forming the DualQ concept. In section 1.2.1, a short summary of the investigatory work concerning the horn effect is presented.

Narrow tyres presently available on the market had to be used for the DualQ prototype. A Harley Davidson (Dunlop) motorcycle front wheel tyre was selected as the most suitable tyre type for the DualQ prototype. It has the same outer diameter and a tread width small enough to give a substantial reduction of the horn amplification effect. The two sub-tyres forming the DualQ tyre has also the same load capacity as a normal standard passenger car tyre. However, the motorcycle tyre has much lower mechanical impedance than standard car tyres, which leads to higher vibration velocities for a given excitation and consequently also increased sound radiation. Diagnostic measurements of the tyre mechanical point impedance were performed in order to investigate the difference in point impedance for a standard car tyre and the motorcycle tyre. A short summary of this work is presented in section 1.2.2.

1.2.1 Horn amplification effect

The hornlike geometry formed by the tyre tread band and the road surface leads to an amplification of generated tyre/road noise. The sources of tyre/road noise are positioned very close to the leading and trailing edges of the contact patch which may cause amplifications of 5-15 dB-units [2]. In order to reduce the horn effect, narrow tyres should be preferred compared to wide tyres. It is found that a narrow tyre with small crown radius gives substantial reduction of the horn effect [4]. The DualQ tyre design consists of two narrow tyres with small crown radius. A big enough spacing between the two tyres will prevent the two tyres to interact acoustically. Diagnostic measurements were performed within QCity in order to find the optimal spacing between tyres in terms of horn effect reduction, yet achieving a commercially realistic total tyre width.

The horn effect reduction was measured as a function of tyre spacing for the DualQ tyre design by means of reciprocal transfer functions. The tyre mock-up and the omni-directional loudspeaker (acting as a constant volume-velocity source) are shown in Figure 1.2.1.1 [3]. In Figure 1.2.1.2 it is seen that the noise reduction as a function of tyre spacing reaches a plateau level when the distance between tyres is ≥ 50 mm.

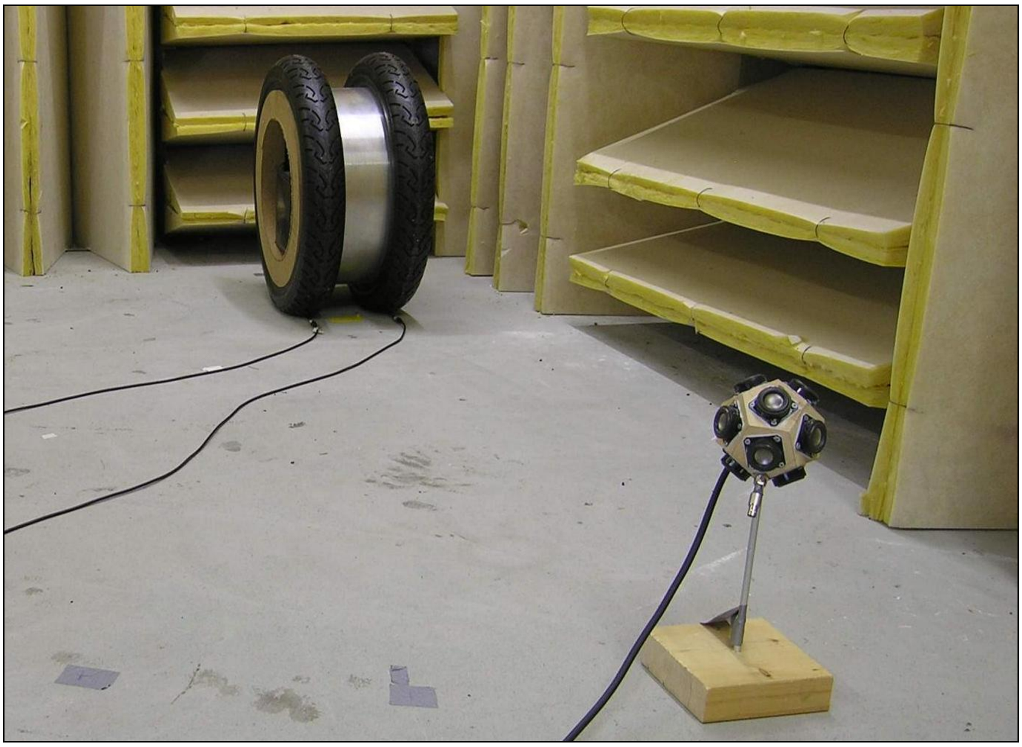


Figure 1.2.1.1 Measurement set-up used for transfer function measurements with the principle of reciprocity. Measurement results revealed the horn effect dependence on the spacing between narrow tyres [3].

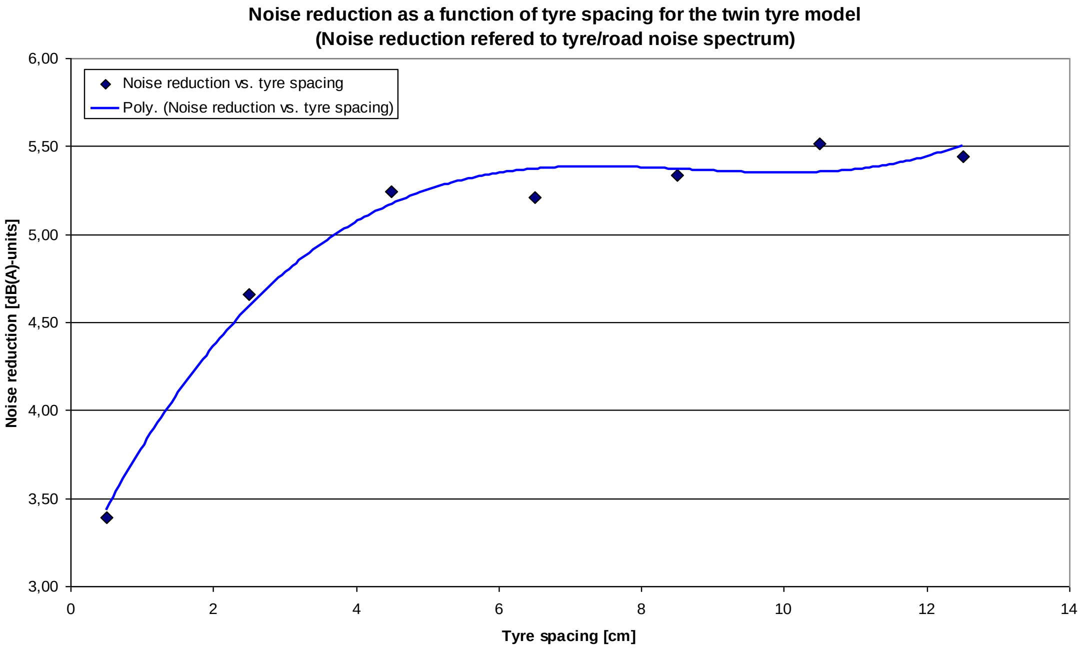


Figure 1.2.1.2 Noise reduction as a function of tyre spacing derived from transfer function measurements on mock-up [3].

1.2.2 Tyre point impedance

Both the exterior and certainly the interior tyre/road noise in a passenger car is highly related to the structural response to an excitation. The point impedance is one way of measuring the structural response to an excitation. Narrow motorcycle tyres have lower point impedance than standard car tyres. Measurements of the point impedance were performed with the side-by-side method according to the measurement set-up presented in Figure 1.2.2.1. In Figure 1.2.2.2, the point impedances for a standard car tyre (Goodyear Hydragrip 195/65 R15), a motorcycle tyre and a modified motorcycle tyre (rubber layer added) are shown. It is seen that a rubber strip added to the inside of a motorcycle tyre increases the point impedance substantially. However, for the prototype tyres which were mounted on passenger cars, no modifications were done to the motorcycle tyres.

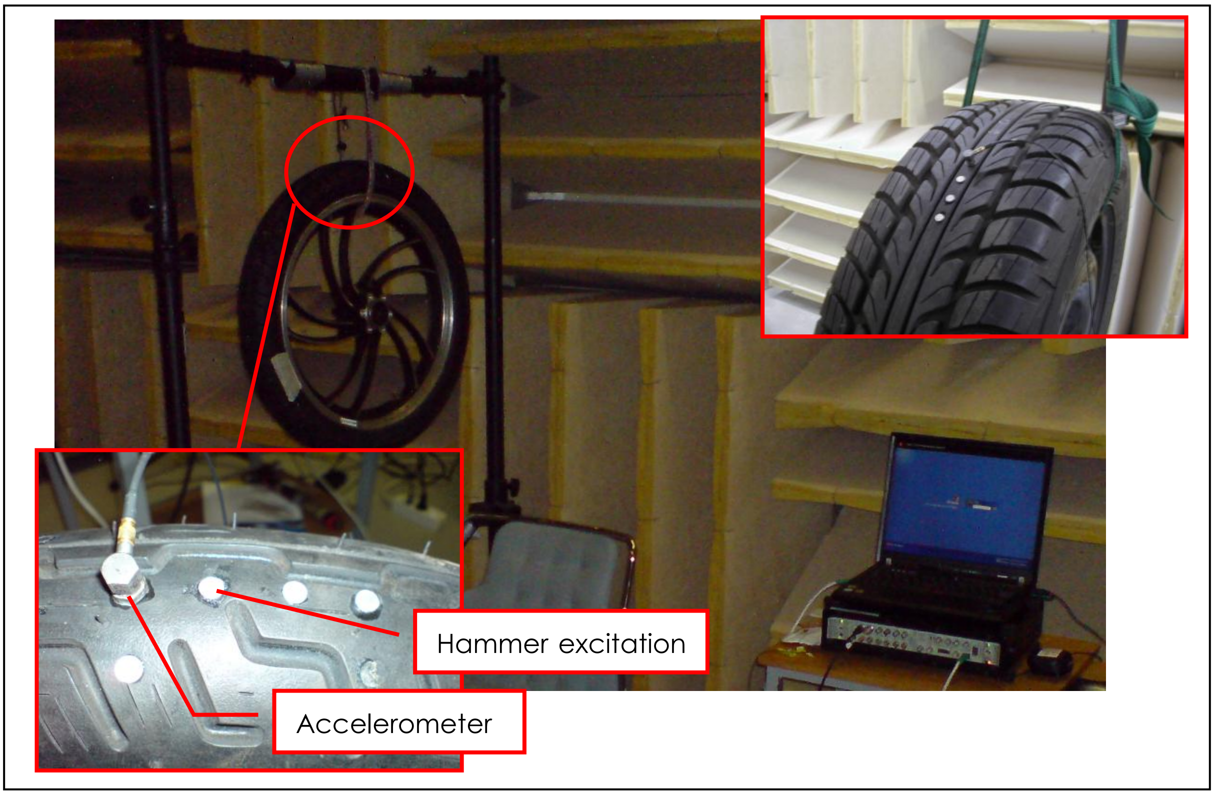


Figure 1.2.2.1 Measurement set-up for point impedance measurement on motorcycle tyres and car tyre [1].

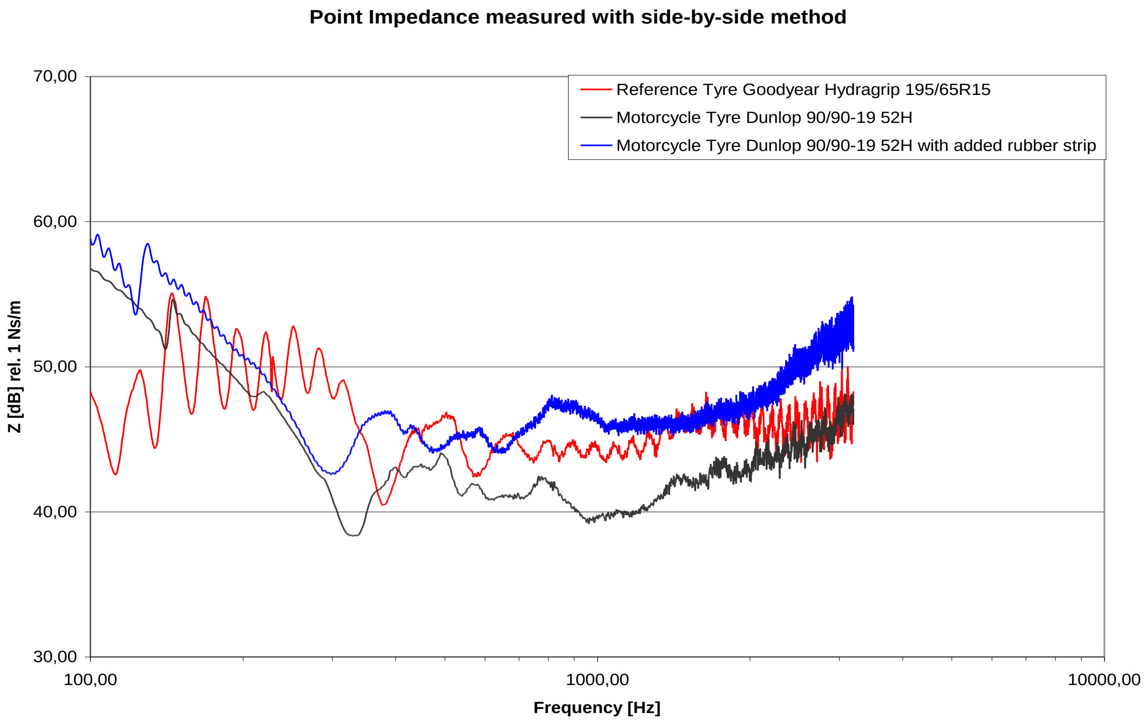


Figure 1.2.2.2 Point impedance for a standard passenger car tyre and two motorcycle tyres measured with the side-by-side method. One of the motorcycle tyres was modified to increase the point impedance [1].

1.3 WHAT THE REPORT COVERS

This report concentrates on validation of the DualQ design as a low noise tyre design for electrically driven and gasoline driven passenger cars. Measurement for DualQ prototypes mounted on passenger cars are presented and discussed. Moreover, to make this report comprehensive, results from measurements performed within the QCITY project with a single wheel trailer are summarized and discussed.

2 DEVELOPED PROTOTYPE TYRE DESIGN

The prototype tyres design is based on the background knowledge presented in chapter 1.2 and the outcome of the measurements performed within the QCity project (summarized in chapter 4). The design of the prototype tyre used for tests on passenger cars is presented in Figure 2.1. The rim was manufactured by welding two motorcycle rims on to a car rim which was previously cut. The two sub-tyres are motorcycle tyres, Dunlop 90/90-19 52H. They were selected due to the suitable width of 90 mm, the small crown radius and outer diameter (comparable to normal passenger car tyres). However, the motorcycle tyre model has some acoustic drawbacks. One of the disadvantages is the low mechanical impedance of the tread band compared to a standard car tyre, which results in higher vibration velocities thus increased sound radiation from the tyre structure. Another acoustic drawback is the tread block pattern, which leads to tonal noise, especially on smooth asphalt pavement.

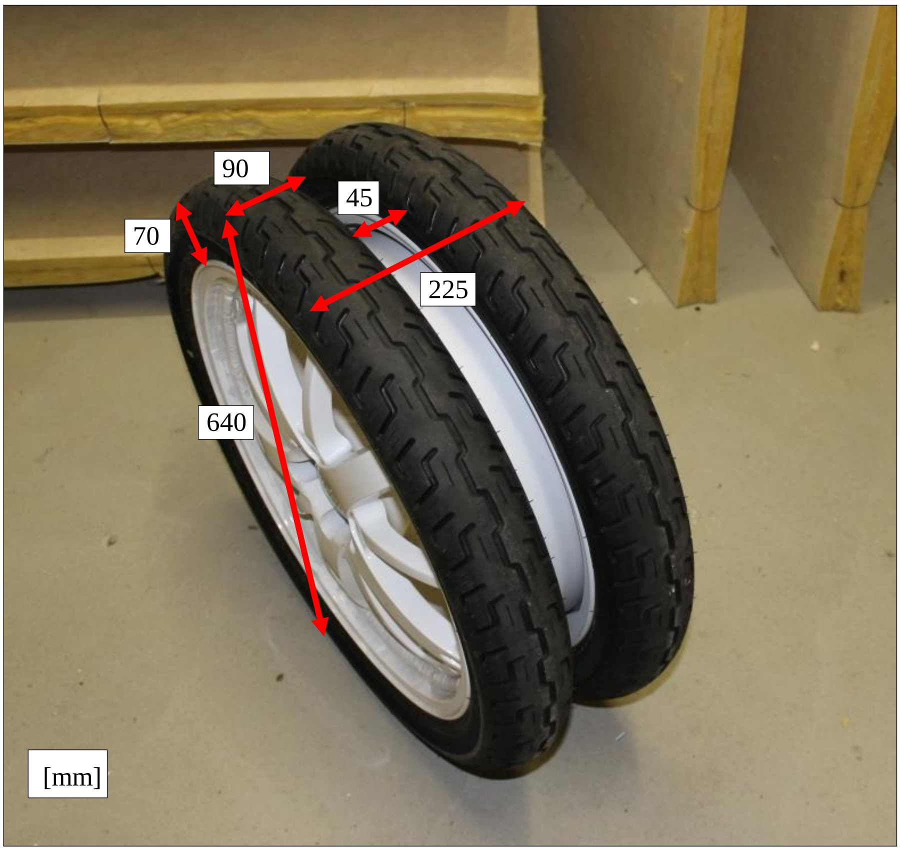
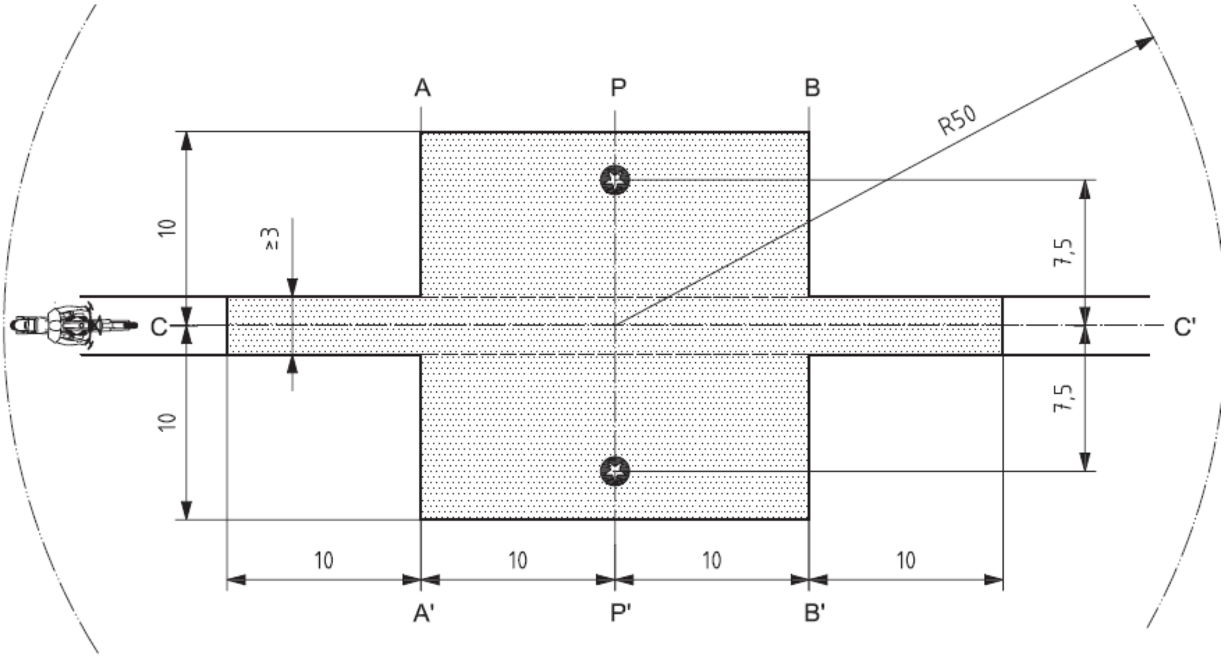


Figure 2.1 DualQ tyre design (dimensions in mm).

3 PROTOTYPE EVALUATION MEASUREMENTS ON PASSENGER CARS

3.1 PASS-BY MEASUREMENTS

Pass by measurements were performed on the Volvo Cars exterior noise test track in Gothenburg 2011-10-04 – 2011-10-05 by staff from ACL. The DualQ design validation was performed by mounting four prototype tyres on two vehicles, Volvo C30 Pure Electric Vehicle (PEV) and Volvo C30 T5 (gasoline). Pass by measurements were also made with reference car tyres (Continental SportContact2 205/50R17 93W XL) mounted on the same vehicles. Measurements were performed according to the standard ISO 362-2, with the exception that only passages with constant vehicle speeds were measured. In Figure 3.1.1, an extract from the measurement ISO standard shows the measurement site. The asphalt pavement at the test site was very smooth and in compliance with standard ISO 10844.



Key

(shaded)	minimum area covered with test road surface, i.e. test area
✪	microphone positions (height 1,2 m)
AA′	test zone start
BB′	test zone end
CC′	line of vehicle travel through test zone
PP′	line perpendicular to vehicle travel between microphone locations
R50	radius of 50 m around the centre of the track

NOTE The shaded area (“test area”) is the minimum area to be covered with a surface complying with ISO 10844.

Figure 3.1.1 Description of measurement site. Extract from measurement standard ISO 362-2 [5].

Figure 3.1.2 DualQ prototype tyre mounted on test vehicle [6].

3.1.1 Results

Pass by measurements were performed for constant vehicle speeds 50 kph and 80 kph. It was expected and also proved that the motorcycle tyres used as sub-tyres forming the DualQ prototype has an acoustically poor tread pattern design. The tread pattern generates strong tonal noise which dominates the tyre/road noise, especially on a smooth asphalt pavement as the ISO standard implies. In order to evaluate the DualQ tyre design disregarding the acoustically poor tread pattern design (which is not of interest to investigate in this study), a correction is made by removing the tonal noise caused by the tread pattern. In Appendix 1, the tread pattern tonal noise and the correction is graphically presented.

In Table 3.1.1.1 and Figure 3.1.1.1 - Figure 3.1.1.4, the results from Pass by measurements with Volvo C30 Pure Electric Vehicle (PEV) and Volvo C30 T5 (gasoline) are presented.

Table 3.1.1.1 Pass by sound level, [dB(A)] measurement results.

Overall Sound Level [dB(A)]						
Speed [kph]	**DualQ PEV (with correction)**	**DualQ PEV**	**Continental PEV (reference tyre)**	**DualQ T5 (with correction)**	**DualQ T5**	**Continental T5 (reference tyre)**
80	**67.6**	**72.3**	**73.4**	**66.8**	**70.6**	**71.9**
50	**61.3**	**62.5**	**66.0**	**60.6**	**62.0**	**64.8**

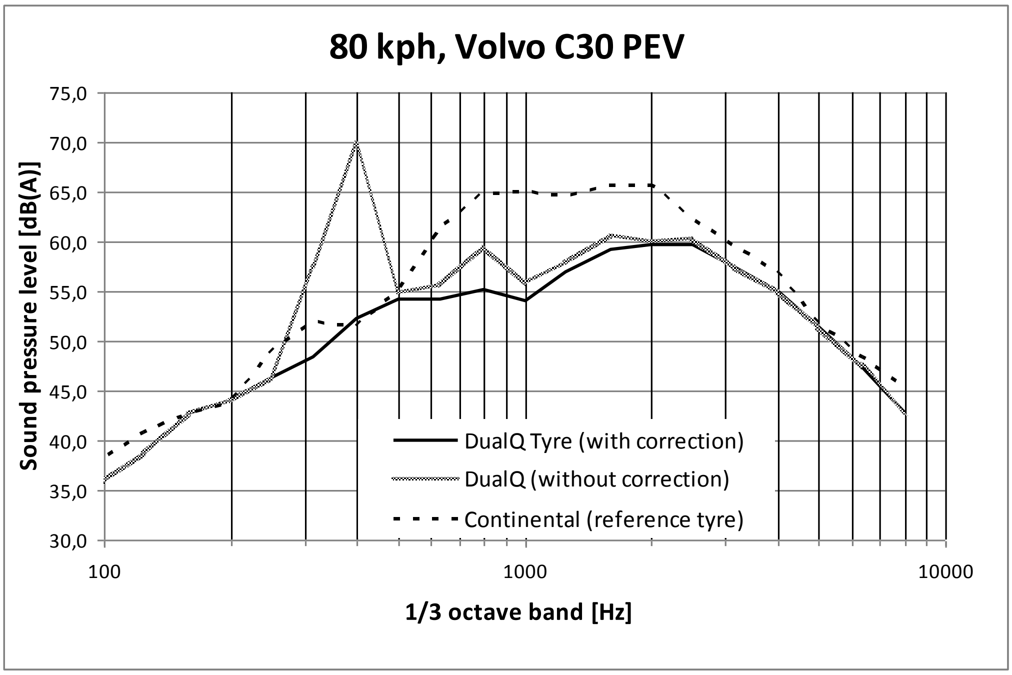


Figure 3.1.1.1 Pass by sound pressure levels [dB(A)] in 1/3rd octave band for Volvo C30 PEV at constant speed 80 kph.

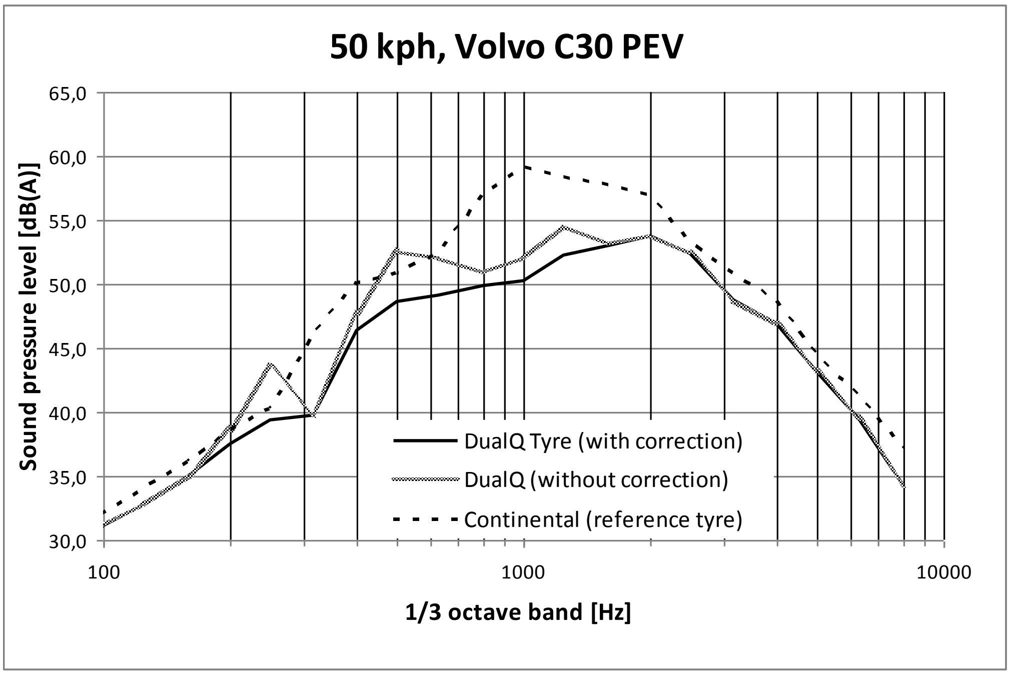


Figure 3.1.1.2 Pass by sound pressure levels [dB(A)] in 1/3rd octave band for Volvo C30 PEV at constant speed 50 kph.

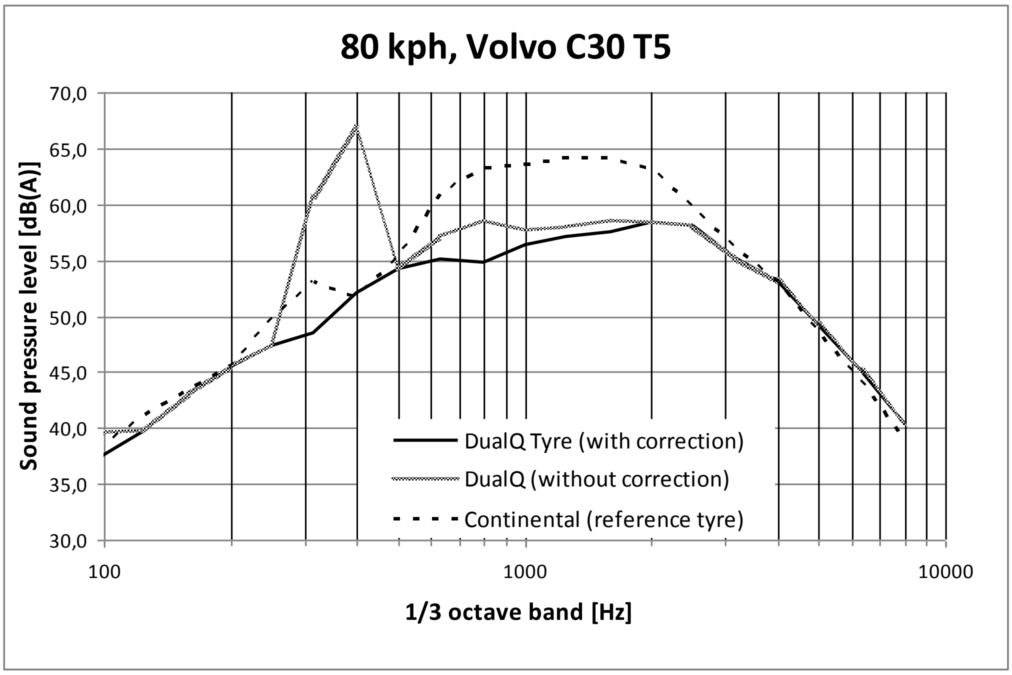


Figure 3.1.1.3 Pass by sound pressure levels [dB(A)] in 1/3rd octave band for Volvo C30 T5 at constant speed 80 kph.

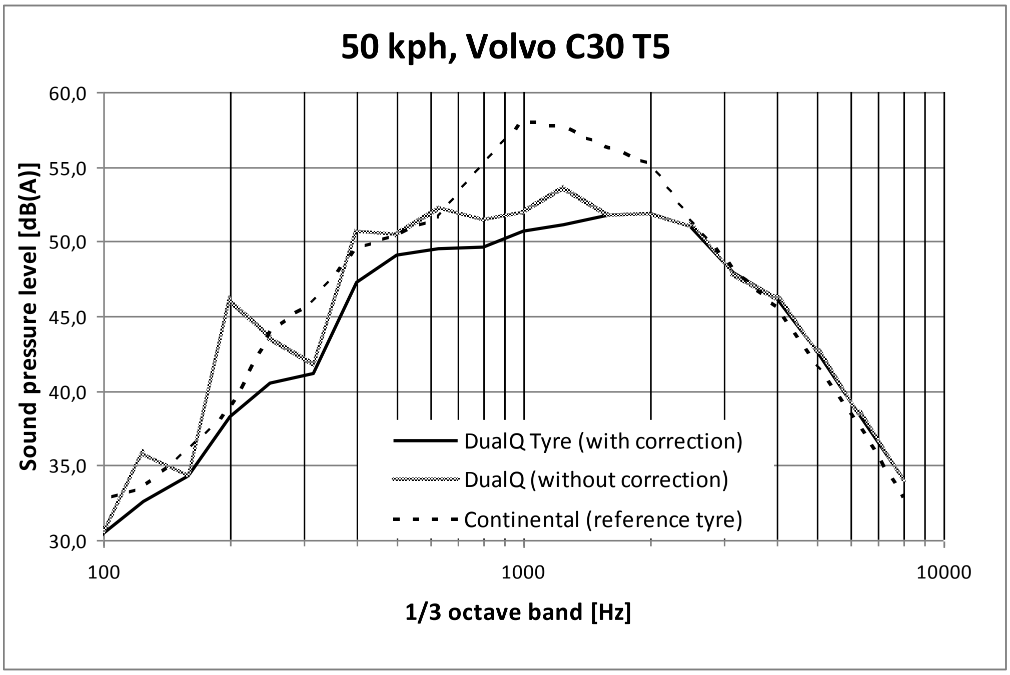


Figure 3.1.1.4 Pass by sound pressure levels [dB(A)] in 1/3rd octave band for Volvo C30 T5 at constant speed 50 kph.

3.2 INTERIOR NOISE & VIBRATION MEASUREMENTS

In order to evaluate the feasibility in using the DualQ tyres on passenger vehicles, other parameters than exterior noise must be tested. One parameter which is important for passenger cars is the passenger comfort in terms of interior noise and vibrations. Interior noise measurements as well as vibration measurements on steering wheel and seat were performed on the interior noise test track at Volvo Cars in Gothenburg, 2011-10-04. Test vehicle was a Volvo C30 T5 and tested tyres were the DualQ prototype and reference car tyre, Continental SportContact2 205/50R17 93W XL. In this report, measurements performed when running on a rough asphalt pavement denoted Glen Eagles at constant vehicle speed 80 kph are presented.

In Figure 3.2.1, the measurement positions for which results are presented in this report are shown.

Figure 3.2.1 Measurement positions; Left: microphone for rear passenger seat, Middle: Tri-axial accelerometer on steering wheel, Right: Tri-axial accelerometer for front passenger seat

3.2.1 Results

Interior noise measurement results showed similar overall sound pressure levels for the DualQ prototype and the reference car tyre. However, the so-called booming noise for frequencies below 200 Hz was clearly lower for the DualQ tyre than for the reference car tyre. In the frequency range 100-200 Hz, standard car tyres have several structural resonances which are usually well excited and consequently leads low mechanical impedance and booming noise problems. On the contrary, the DualQ sub-tyres have significantly higher mechanical impedance for frequencies below approximately 150 Hz, which can be seen in chapter 1.2.2 and especially Figure 1.2.2.2. The higher mechanical impedance for the DualQ tyre in this specific frequency range also leads to overall lower vibration levels on the steering wheel as well as on seat.

In Table 3.2.1.1 and Figure 3.2.1.1 – Figure 3.2.1.3 interior sound and vibration measurement results are presented.

Table 3.2.1.1 A-weighted overall sound level for interior noise in rear seat [6].

Overall Sound Level [dB(A)]		
Speed [kph]	**DualQ T5**	**Continental T5 (reference tyre)**
80	**74.4**	**75.2**

Figure 3.2.1.1 Sound pressure level spectra [dB(A)] for interior noise in rear seat; Red line: DualQ tyre, Green line: Reference tyre. Vehicle speed 80 kph [6].

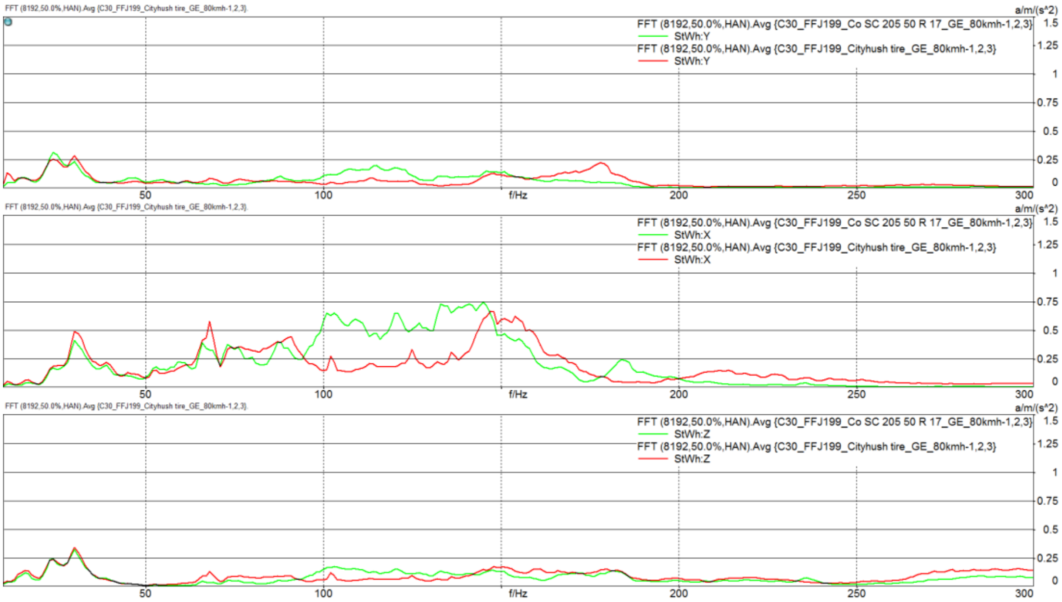


Figure 3.2.1.2 Vibration acceleration amplitude spectra [m/s²] on steering wheel in X,Y,Z directions; Red line: DualQ tyre, Green line: Reference tyre. Vehicle speed 80 kph [6].

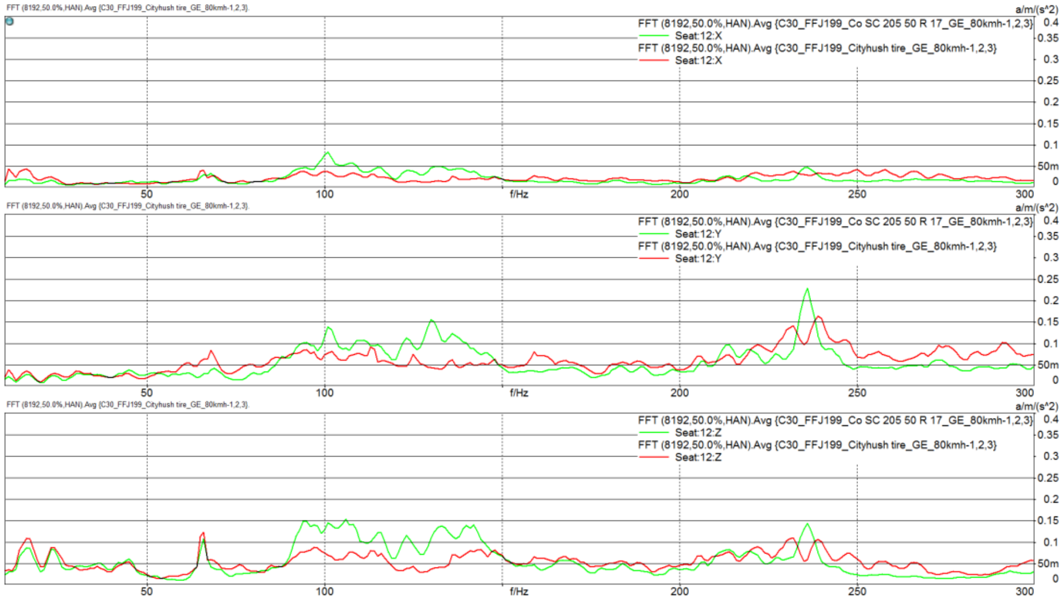


Figure 3.2.1.3 Vibration acceleration amplitude spectra [m/s²] on passenger seat in X,Y,Z directions; Red line: DualQ tyre, Green line: Reference tyre. Vehicle speed 80 kph [6].

4 PROTOTYPE EVALUATION MEASUREMENTS WITH SINGLE WHEEL TRAILER

In order to make this report a comprehensive presentation of the performed validation measurements with the DualQ design, the measurements performed with a single wheel trailer within he QCITY project are summarized here. For complete presentation of these measurements, see QCITY deliverable [1].

Tyre/road noise for two prototype tyre designs was measured with a single wheel trailer by Acoustic Control in the Stockholm area on November 2nd, 2007 and on August 19, 2008. The prototype tyre designs were as presented in chapter 2 with the following exceptions:

- **DualQ 1** Prototype with tyre spacing 45 mm having rubber strip of thickness 8.6 mm glued on to the inner side of the MC-tyres.
- **DualQ 2** Prototype with tyre spacing 60 mm having rubber strip of thickness 8.6 mm glued on to the inner side of the MC-tyres.

The test surfaces were asphalt pavement of type SMA16 (2007-11-02) and a smooth asphalt pavement VIACOGRIP 8 (2008-08-19).

The single wheel trailer for measurement of tyre/road noise has the advantage of measuring the sound at very well defined locations relative to the test wheel. With the careful control of load, microphone positions, test surface, test tyre, test tyre pressure, temperature etc. this method enables comparison of measurements performed on different types of tyres run on the same reference surface without influence from other noise sources such as engine noise. The measurement set-up and testing methodology is, to applicable extent, performed according to the draft proposal to a new standard, ISO CD 11819-2. In Figure 4.1, the single wheel trailer and the standardized microphone positions are shown. The presented result is an energetic average of the measured sound pressure for the two mandatory microphone positions. The undisturbed average sound pressure level during constant speed was evaluated for each trailer passage. Several trailer passages with different constant speeds were registered for the test tyres. A least square curve fit was then performed in each 1/3-octave band which enables the presentation of the Sound Pressure Level (for each 1/3-octave band) at any given vehicle speed within the range of speeds measured.

The two test-sites are presented in Figure 4.2 and Figure 4.3.

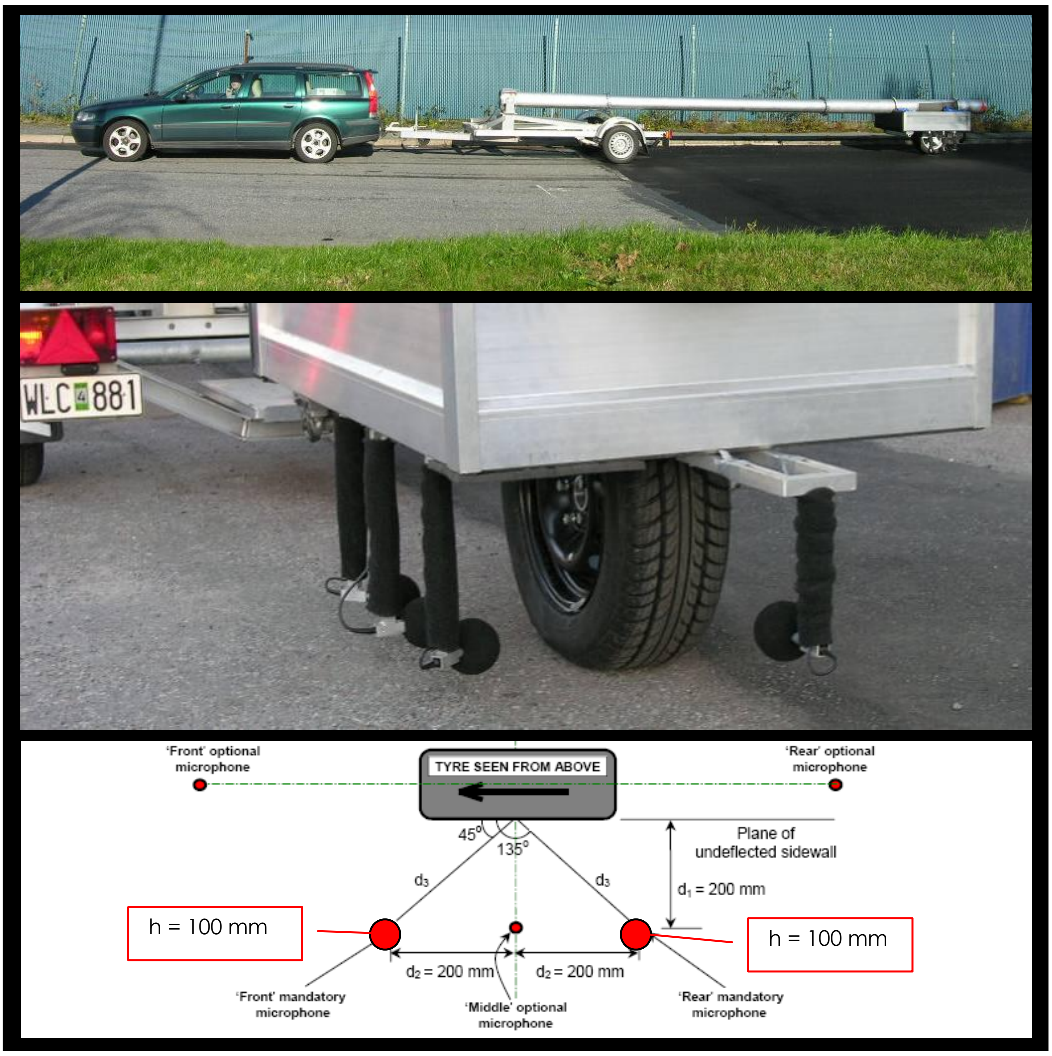


Figure 4.1 Microphone positions (extract from draft standard ISO/CD 11819-2) and the single wheel trailer for tyre/road noise measurements.

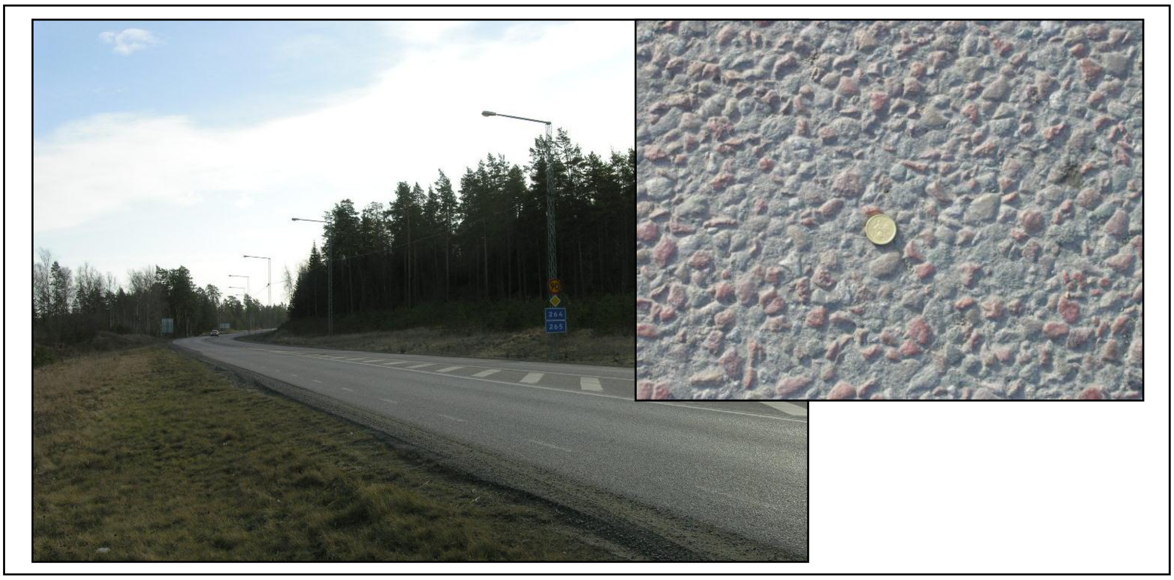


Figure 4.2 Test site at Arninge north of Stockholm. The test site is paved with asphalt SMA16, shown in a close-up photo with a Swedish 10 SEK coin as reference.

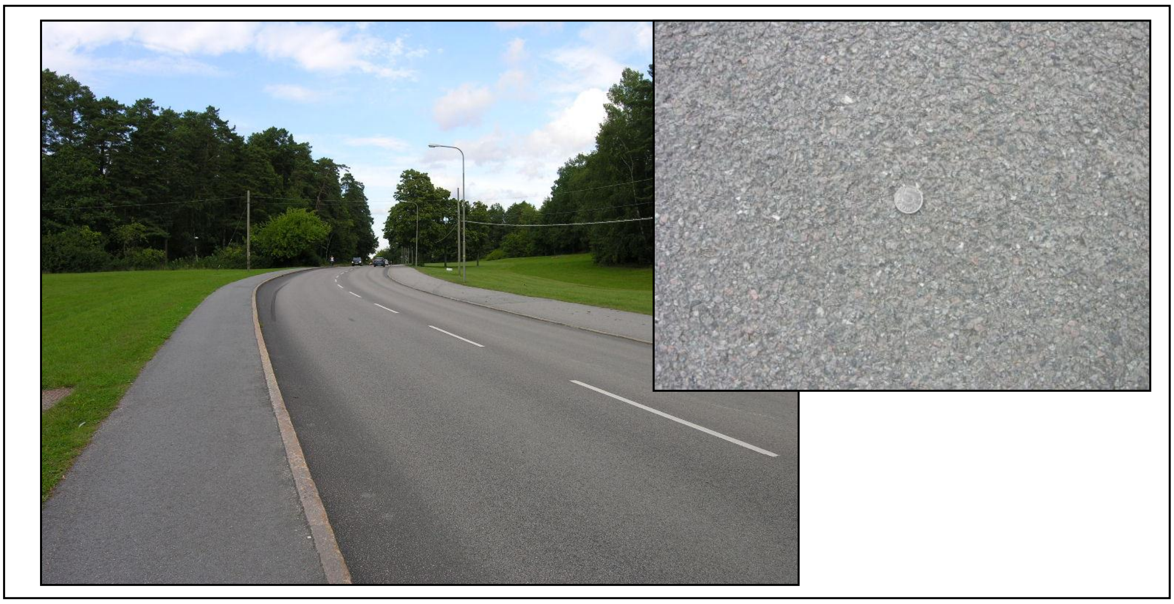


Figure 4.3 Blackebergsvägen test site. The test site is paved with asphalt VIACOGRIP 8, shown in a close-up photo with a Swedish 5 SEK coin as reference.

4.1 RESULTS

4.1.1 Arninge test site

In Figure 4.1.1.1, the measured data and the evaluated data (from the least square curve fit functions) are presented as A-weighted total sound level as a function of trailer speed. The total A-weighted sound level for the speed 70 kph was found to be 102 dB(A) for the reference tyre and 94 dB(A) for the DualQ 2 prototype. The DualQ 2 was found to reduce the A-weighted sound level with 8 dB(A)-units compared to the standard car tyre for the whole measurement speed range (60-80 kph). In Figure 4.1.1.2 the 1/3 octave band spectra at trailer speed 70 kph are shown.

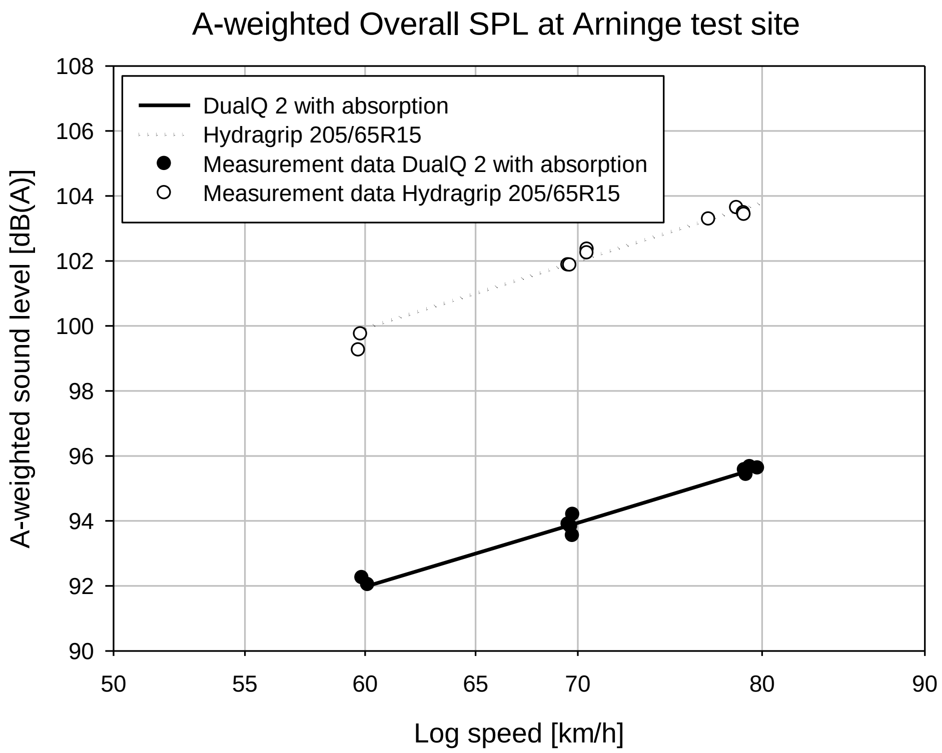


Figure 4.1.1.1 Arninge test site. A-weighted total sound level as a function of trailer speed. Both measured data and curve fit data is presented.

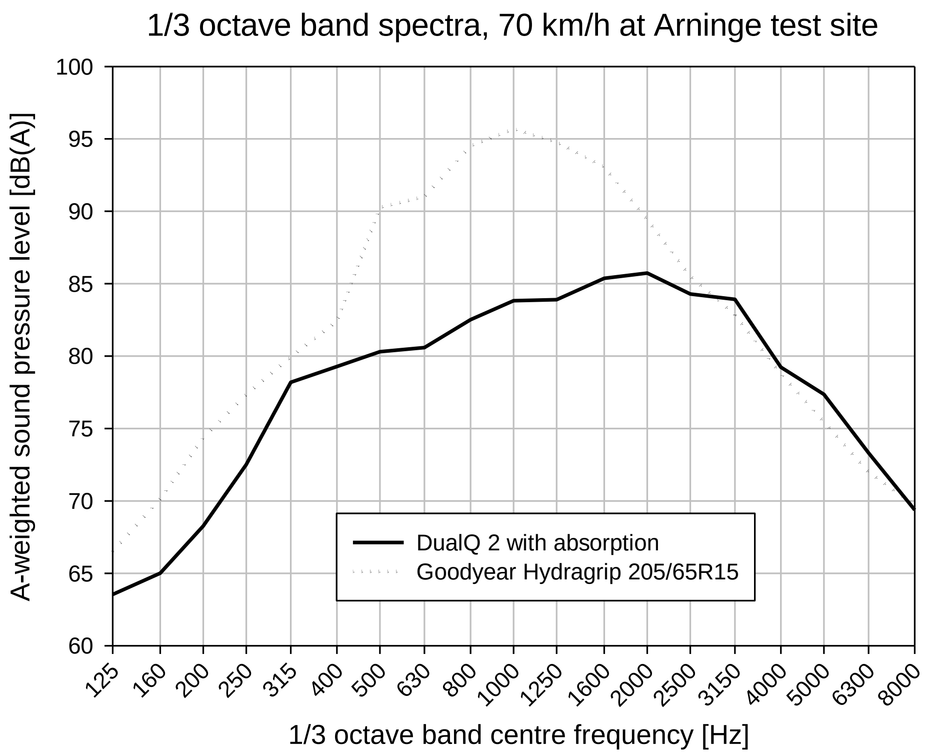


Figure 4.1.1.2 A-weighted sound pressure level in 1/3 octave band for the DualQ 2 and the reference car tyre at speed 70 kph, Arninge test site.

4.1.2 Blackebergsvägen test site

In Figure 4.1.2.1, the measured data and the evaluated data (from the least square curve fit functions) are presented as A-weighted total sound level as a function of trailer speed. The total A-weighted sound level for the speed 50 kph was found to be 91.2 dB(A) for the reference tyre, 84.9 dB(A) for the DualQ 1 and 85.5 dB(A) for DualQ 2. The DualQ 1 was found to reduce the A-weighted sound level with 6.3 dB(A)-units compared to the standard car tyre for the whole measurement speed range (40-60 kph). In Figure 4.1.1.2 the 1/3 octave band spectra at trailer speed 50 kph are shown.

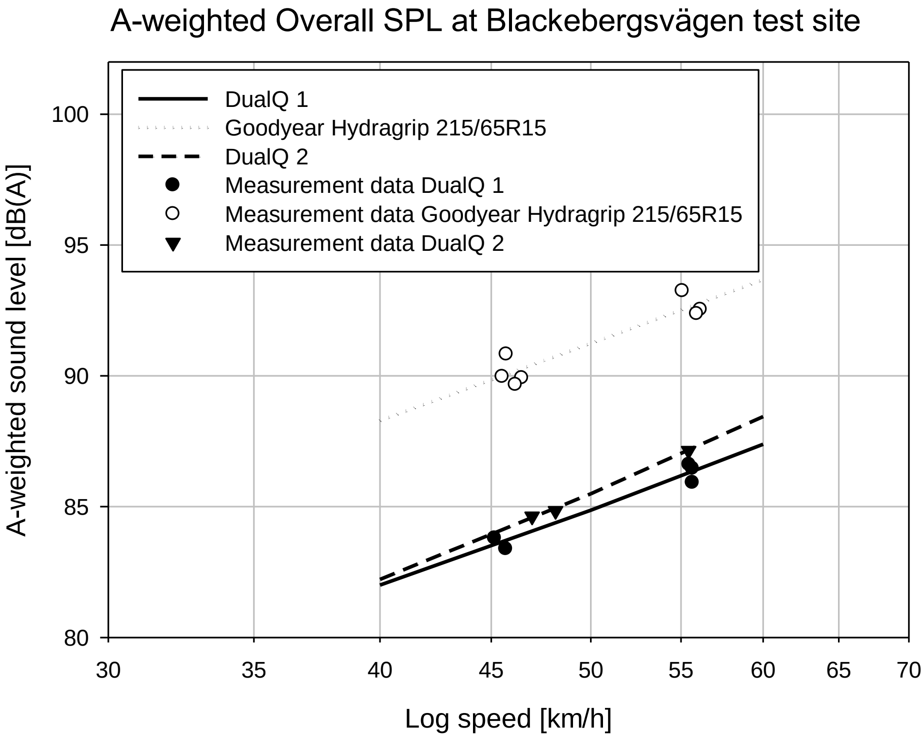


Figure 4.1.2.1 A-weighted total sound level as a function of trailer speed at Blackebergsvägen. Both measured data and curve fit data is presented.

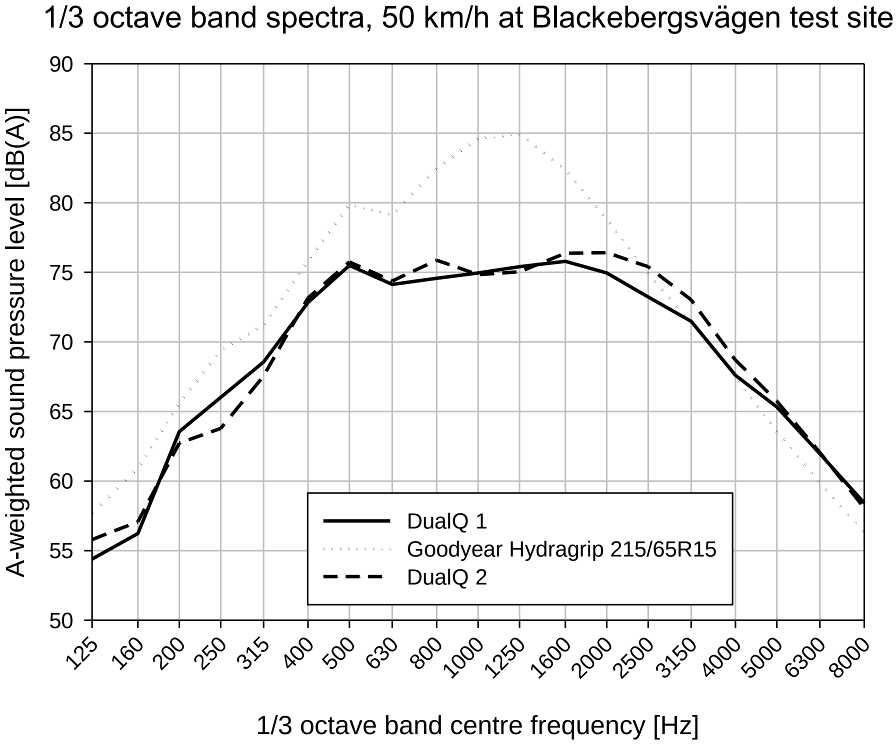


Figure 4.1.2.2 A-weighted sound pressure level in 1/3 octave band for the DualQ prototypes and the reference car tyre at speed 50 kph, Blackebergsvägen.

5 SUMMARY OF RESULTS & DISCUSSION

Several validation measurements for the low noise DualQ tyre design have been performed within the CityHush project as well as during the QCity project. In Table below, a summary of the measured noise reduction [dB(A)-units] for each validation measurement is presented.

Table 5.1 Summary of performed validation measurements and measured noise reduction [dB(A)-units] for DualQ prototype tyres.

Test number	Test vehicle	Asphalt pavement	Vehicle speed	Measurement site	Noise reduction [dB(A)-units]
1	**Volvo C30 PEV**	**Very smooth**	**50**	**Volvo test track**	**4.7***
2	**Volvo C30 T5**	**Very smooth**	**50**	**Volvo test track**	**4.1***
3	**Volvo C30 PEV**	**Very smooth**	**80**	**Volvo test track**	**5.8***
4	**Volvo C30 T5**	**Very smooth**	**80**	**Volvo test track**	**5.1***
5	**Single wheel trailer**	**Smooth**	**50**	**Blackebergsvägen, Stockholm**	**6.3**
6	**Single wheel trailer**	**Rough**	**70**	**Arninge, Stockholm**	**8.0**

*** Correction for tread pattern tonal noise was made by removing tonal components (See Appendix 1)**

Measured noise reduction is in the range 4.1 – 8 dB(A)-units. This shows that the overall noise reduction for the combination DualQ tyres/low noise asphalt pavement is likely to be at least 10 dB(A)-units relative to the combination standard car tyres/standard asphalt pavement. This is one of the expected results for the CityHush project.

The DualQ tyre design seems to have higher exterior noise reduction the rougher the road surface is and the higher the vehicle speed is relative to standard car tyres.

Vehicle interior noise and vibrations in steering wheel and seat were evaluated. It was seen from measurement results that the DualQ design leads to somewhat lower vibration levels. Overall interior sound level was similar for the DualQ prototype and the standard reference car tyre. However, the DualQ design was seen to reduce the so-called booming noise (sound below 200 Hz inside the car).

In order to increase the already high exterior noise reduction measured for the DualQ prototype some adjustments should be made. Primarily, the sub-tyres should be replaced by tyres more suitable for passenger cars, supplied with low noise tread pattern. Moreover, the tyre belt mobility for DualQ sub-tyres should be in the same order of magnitude as mobilities of standard car tyres in the frequency region of importance for sound radiation.

The development process of the DualQ design should proceed by further evaluating and developing other important parameters (besides exterior noise, interior noise and comfort vibrations) such as handling in dry and wet conditions, rolling resistance, tyre wear etc.

6 REFERENCES

[1] Lundberg, O., Nilsson, N-Å.: *Acoustical performance of implemented quiet tyres - Evaluation of the low noise DualQ tyre prototype,* QCITY deliverable D5.11 & D5.15 (2008)

[2] N-Å. Nilsson. High and narrow tyres – possible noise reduction mechanisms. Q-City - Work Package 3.5 (July 2005)

[3] Höjer M. Use of reciprocity technique for the study of the tyre/road horn effect and sound absorption properties of road surfaces, M.Sc. Thesis, Department of Aeronautical and Vehicle Engineering, Royal Institute of Technology, Stockholm (2006)

[4] O'Boy, D.J. Tyre / road interaction noise : Variation in the radiated sound pressure due to changes in the geometry of a car tyre. Q-City – Work Package 3.4, (August 2006)

[5] ISO 362-2:2011 Measurement of noise emitted by accelerating road vehicles – Engineering method – Part 2: L category, Measurement standard, (2011)

[6] Galehie, R., *Cityhush project C30 Road noise, NVH-center*, Summary of interior noise measurements at Volvo test track, PowerPoint document, (2011)

Appendix 1: Tread pattern tonal noise

In Figure A.1.1, a contour plot is shown for a vehicle (Volvo PEV) passage with DualQ prototype tyres at constant speed 80 kph. The tonal noise due to the prototype tread pattern design is clearly dominating the exterior noise. In Figure A.1.2, an A-weighted Sound pressure level spectrum averaged over the vehicle passage time is shown with and without correction.

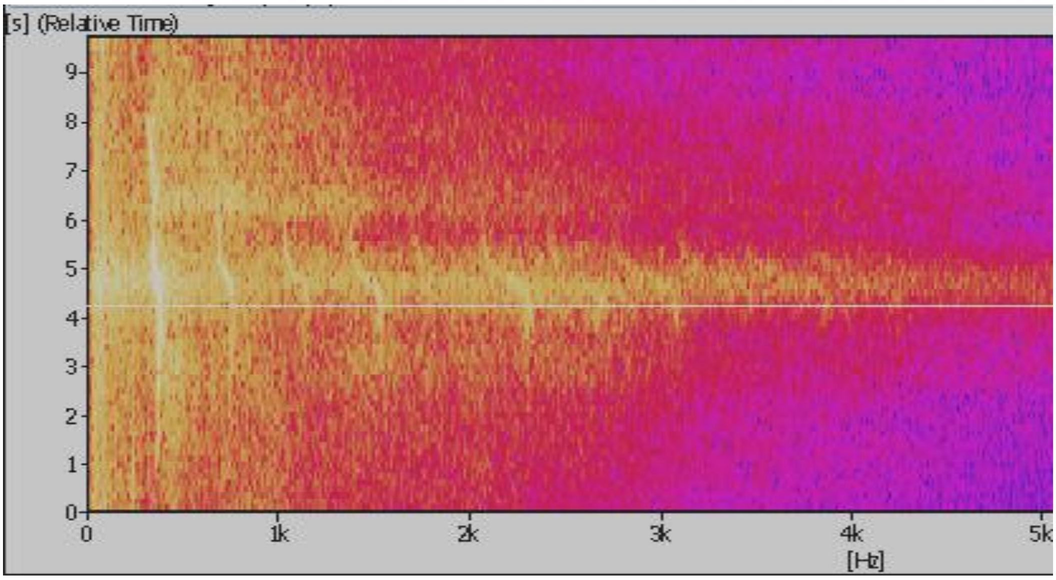


Figure A.1.1 Sound pressure level contour plot for Pass by with DualQ tyres at constant speed 80 kph, Volvo PEV.

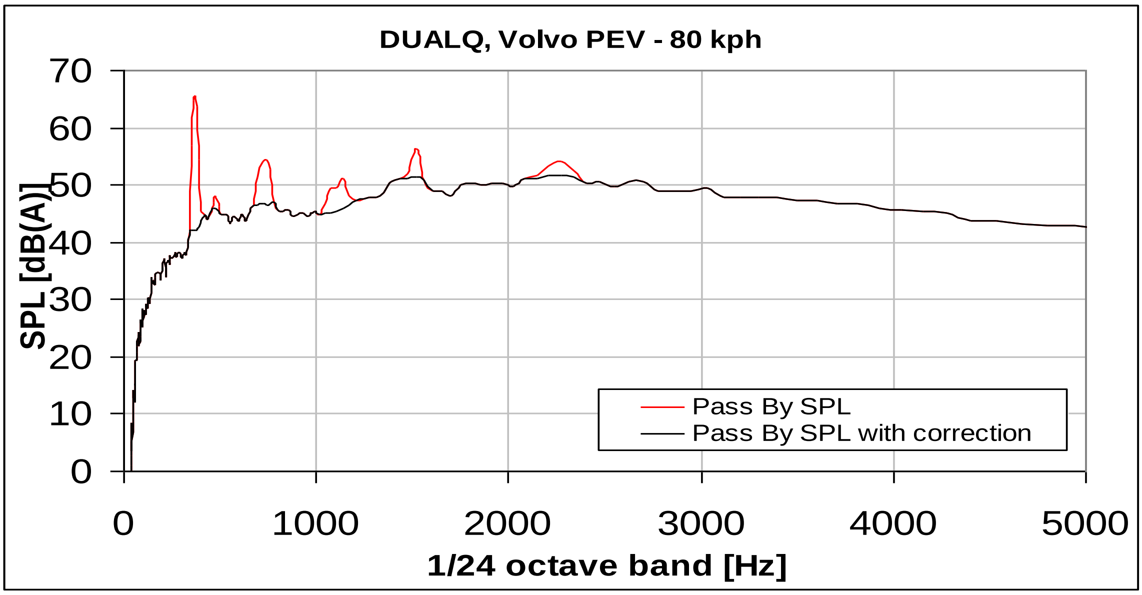


Figure A.1.2 A-weighted SPL spectrum with and without correction for tonal tread pattern noise. Pass-by with DualQ tyres at constant speed 80 kph, Volvo PEV.