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Report

Noise measurements of passenger car tyres at the Kloosterzande test track.

Noise ranking , frequency and texture analysis

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ABSTRACT

At the Kloosterzande test track in the Netherlands, noise measurements of 22 summer car tyres have been performed on 23 different road surfaces, including an ISO-surface.
All measurements have been performed with a CPX-trailer at 50 and 80 km/h. A frequency analysis of all combinations of tyres and road surfaces has been made. A ranking analysis of noise levels is included, where the ranking on the on the ISO-surface is compared to the ranking on the other 22 surfaces.
Furthermore, a relationship between different texture parameters and the noise levels has been studied.
Between the noisiest tyre on the noisiest road surface, and the quietest tyre on the quietest road surface, a difference of 17 dB was found. The difference in road surface noise performance is the most significant reason for this large number.

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Furthermore, we want to acknowledge M+P in the Netherlands for access to texture data and to tyre noise levels from their previous measurement campaign at Kloosterzande, as well as their assistance during our measurements.

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Summary

In 2009, SINTEF carried out noise measurements of 22 summer tyres on 23 road surfaces on the Kloosterzande test track in the Netherlands. The measurements were done with the Norwegian CPX-trailer (microphones close to the tyre). The road surfaces included an ISO-surface, dense surfaces, several thin layers, single and double porous surfaces and a new poroelastic surface (Rollpave PERS). Each of the road surfaces are approximately 80 m long, except for the PERS (40 m).

The measurements were carried out, using the CPX-trailer of the Norwegian Public Roads Administration at the two speeds of 50 and 80 km/h. The CPX-method is a method that measure the noise emitted by the tyre/road interaction, with two microphones mounted close to the tyre.

In addition to the maximum A-weighted noise level, LAcpx, dB, the average frequency spectra from 315 to 5 kHz was measured during runs over each surface.

The tyre dimensions were from 175/70 R14 to 225/60 R16. 4 identical Michelin Energy Saver, 2 identical SRTT tyres and 2 identical Avon AV4 tyres are included in the group of 22 tyres. The 4 latter tyres are proposed reference tyres of the CPX-standard.

On the ISO-surface, there is a range of levels of 6.5 dB at 80 km/h and 4.2 dB at 50 km/h between the most noisy and most quiet tyre. In general, the spread in levels are higher at 80 than at 50 km/h. No relationship between tyre widths and noise levels were found, for this batch of tyres.

The porous road surfaces clearly distinguish more between tyres (more sensitive to tread design) than the dense surfaces; a spread of 7-8 dB, compared to 3-4 dB on commonly used dense surfaces.

Between the noisiest tyre on the noisiest surface and the quietest tyre on the quietest surface, there is a difference of 17.4 dB (100.3 dB on SMA0/16 vs. 82.9 dB on PERS). Even between the SMA 0/16 and commonly used double layer surfaces, there is a difference of 14-15 dB.

A frequency analysis has been made for all tyres on the 23 road surfaces. The individual spectra show that some of the tyres have design related resonances, which are more or less independent on speed or type of surfaces. For the “normal” tyres, the peaks in the spectra depend on both speed and type of road surface. When looking at the average spectra for all of the tyres, there are clear differences in frequencies above 500 Hz, for the 4 groups of road surfaces; dense, single layer porous, double layer porous and poroelastic.

The noise ranking of tyres on all surfaces, compared to the ranking on the ISO-surface have been investigated. The purpose was to evaluate the efficiency of more stringent noise limits for tyres on other surfaces than the ISO. For this ranking analysis, 15 of the SINTEF tyres have been analysed, together with 10 tyres measured by M+P, using similar measurement equipment.

A linear regression between the ISO-surface and the 22 other surfaces has been made.

The slope is a good indicator on the efficiency of noise reduction on the ISO-surface and the correlation to other surfaces. The regression coefficient is also a good indicator on the ranking of tyres.

In general, road surfaces with smaller chipping sizes, like 4-6 mm rank tyres in an “ISO-way” better than surfaces with larger maximum chipping size.

On some of the normally used road surfaces, like SMA 0/11 or SMA 0/16, the ranking of the tyres is quite different from the ranking on the ISO-surface, for many of the tyres.

The results also show that there are tyres that are low-noise tyres, more or less independent on the type of road surface. Likewise, there are noisy tyres on the ISO-surface that are also noisy on the other types of surfaces.

An analysis of the relationship between the A-weighted noise levels, LAcpx (dB re 20 µPa), and texture levels (texture wavelength spectra, dB re 10^{-6} m) have been made. The results show that the noise levels have the highest correlation with the 80 mm wavelength octave band, where approximately 85 % of the variance in noise levels is explained by the Ltx80 for dense surfaces.

1 Background

A general reduction of road traffic noise in Norway by the means of source reduction, like tyre/road noise has a high priority by the Road Authorities in Norway.

One strategy is to investigate if different incentives can be used to motivate the usage of more low noise tyres on Norwegian roads. However, since tyres are type approved according to noise on an ISO-surface[1], it is important to study the noise ranking on other surfaces as well, since the ISO-surface is never used as a normal trafficked road pavement.
In addition, the noise labelling of tyres will be according to the noise level on an ISO-surface.

To investigate the external noise behaviour of different summer tyres of class C1 (passenger car tyres) on different road surfaces, SINTEF conducted extensive testing of such tyres at the Kloosterzande test area in 2009.

As part of the investigation, a special statistical approach has been introduced, to study the ranking of all the tyres on the different road surfaces, compared to the ranking on the ISO-surface. In the ranking study, 10 tyres measured by M+P[2] on the same surfaces have been included.

The texture of the different road surfaces clearly influences the noise levels. A texture/noise analysis has been conducted, based on available texture spectra, measured by M+P[3].

The results from the ISO-surface have previously been reported[4]. In the present report, the results from the remaining surfaces are included, as well as the frequency analysis from all combinations of tyres/road surfaces.

2 Measurement set-up

The measurements were performed at the test area in Kloosterzande, the Netherlands.

Measurements were performed on the 29th of September 2009. The weather was overcast, no rain and with air temperature of + 19 °C and road surface temperature of + 24 °C. The wind was moderate to calm and always below 5 m/s.

The CPX-trailer of the Norwegian Public Roads Administration, as shown in figure 1, was used for the measurements. The CPX-trailer was built by M+P in 2005.

Figure 1 *The Norwegian CPX-trailer*

The tyres were tested at two speeds; 50 and 80 km/h. At each speed, 2 runs were made and the results arithmetically averaged, with one run in each direction (except for tyres 19-22, which were measured in the North direction only).

The results were speed corrected to the reference speed, by the formula $35 \cdot \log(v/v_{ref})$.

Since the air temperature during measurements was close to the reference temperature (for tyre noise measurements) of 20 °C, no temperature correction has been implemented in the results.

3 Tyres

All tyres are passenger car summer tyres of class C1. The tyres where chosen among the most used tyres on the car fleet in Norway.

The tyres, with technical data are listed in table 1.

Table 1 *Tyres and technical data*

Tyre no	Name	Dimensions	Load/ Speed index	Prod. week/ year	Shore hardness – Tread Shore A
1	**Dayton D110**	**175/70 R14**	84 T'*)	1207	68
2	**Sportiva G70**	**175/70 R14**	84 T	0307	65
3	**Barum Brilliantis**	**185/65 R15**	88 T	1607	67
4	**Toyo 330**	**185/65 R15**	88 T	4705	70
5	**Goodyear Excellence**	**195/65 R15**	91 H	0206	69
6	**Conti Premium Contact 2**	**195/65 R15**	91 V	0307	70
7	**Toyo Proxes T1R**	**205/55 R16**	91 W	1407	69
8	**Nokian Hakka H**	**205/55 R16**	94 H	3407	69
9	**Michelin Pilot Primacy HP**	**215/55 R16**	93 H	0206	68
10	**Firestone Firehawk TZ200**	**215/55 R16**	97 H	1007	66
11	**Conti EcoContact 3**	**195/65 R15**	91 T	0706	71
12	**Yokohama AVS dBV500**	**185/65 R15**	92 H	1604	73
13	**Pirelli P7**	**205/65 R15**	94 V	0707	64
14	**Hankook Ventus Prime K105**	**205/65 R15**	95 W	5207	67
15	**Michelin Energy Saver**	**205/65 R15**	94 T	1508	70
16	**Michelin Energy Saver**	**205/65 R15**	94 T	1508	70
17	**Michelin Energy Saver**	**205/65 R15**	94 T	1709	68
18	**Michelin Energy Saver**	**205/65 R15**	94 T	1709	69
19	**Uniroyal Tigerpaw SRTT**	**225/60 R16**	97 S	4206	65
20	**Uniroyal Tigerpaw SRTT**	**225/60 R16**	97 S	4206	66
21	**Avon Supervan AV4**	**195/80 R14**	106/104N	0607	62
22	**Avon Supervan AV4**	**195/80 R14**	106/104N	0607	62

*) Speed codes: S=180, T=190, H=210, V=240, W=270 km/h.

Tyres 19 and 20 are the proposed new standard reference tyres representing light vehicles (P1) for the CPX-method[5].

Tyre 15 was also measured in a previous investigation[6] and since the noise levels were in the high range on several road surfaces, it was decided to include 3 more samples in this test. The intention was to compare these 4 tyres not only during CPX-measurements, but also to include controlled pass-by (CPB) measurements (a sort of "type approval test") with the tyres mounted on a vehicle. However, these measurements had to be skipped, due to rim problems.

Tyres 21 and 22 are also present candidates for new reference tyres (H1) for the CPX-standard, as representative for heavy duty truck tyre behaviour.

During the measurements, two tyres of similar dimensions were mounted on the CPX-trailer, and thus allowing two tyres to be measured at each run.

4 Road surfaces

The Kloosterzande test area is a former part of a normal road (N60) which was closed due to a re-routing of the road. In 2006, 41 different road sections were constructed, each section about 80 m long. The sections included an ISO-surface, thin layers, single and double layer porous surfaces, poroelastic surfaces, dense surfaces, including SMA, AC and surface dressing[7].

To reduce the amount of data, it was decided to include only the 23 first sections at Kloosterzande, as listed in table 2. During August 2009, the original surface 12 (a double layer surface) was replaced with a new poroelastic surface, named ROLLPAVE PERS, see figure 2. It was constructed as a continuous surface (40 m long) and not of glued tiles, as the other poroelastic surfaces at Kloosterzande. The thickness is 32 mm and the layer consists of small rubber granules (0/1 mm) and small aggregates (0/1 mm), bound with polyurethane.

Figure 2 *New Rollpave PERS surface at Kloosterzande*

Table 2 Road surfaces at Kloosterzande

Surface no	Top layer type, aggregate size	Thickness [mm]	Bottom layer type	Thickness [mm]
S1	ISO-surface (DAC 8)	30		
S2	Thin layered 2/4, 12%	25		
S3	Thin layered 2/6, 8%	25		
S4	Thin layered 2/6, 12%	25		
S5	Thin layered 4/8, 12%	25		
S6	Porous 0/11	50		
S7	Porous 0/16	50		
S8	Porous 4/8	50		
S9	Porous 4/8	25		
S10	Porous 4/8	25	Porous 11/16	65
S11	Porous 4/8	25	Porous 11/16	45
S12	Rollpave PERS	32		
S13	Porous 2/4	25	Porous 8/11	25
S14	Porous 2/6	25	Porous 8/11	25
S15	Porous 2/6	25		
S16	Porous 2/6	25	Porous 11/16	45
S17	Porous 2/6	25	Elastic Porous 0/16 (3m%)	45
S18	Porous 2/6	25	Elastic Porous 0/16 (10m%)	45
S19	SMA 0/6	20		
S20	SMA 0/8	25		
S21	SMA 0/11	30		
S22	SMA 0/16	40		
S23	DAC 0/16	40		

Detailed pictures of each road surface are given in Annex 2.

5 Measurement results

5.1 CPX-measurements

The measured A-weighted CPX-levels, LAcpx, dB, are presented for each of the 23 sections.

In addition to the CPX-level for each of the tyres, the average level and the difference between the highest (max) and lowest level (min) are also calculated.

5.1.1 Section 1: ISO-surface

Table 3 *Section 1: ISO-surface. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	85.4	93.5
2	Sportiva G70	87.9	95.8
3	Barum Brilliantis	88.5	95.0
4	Toyo 330	87.9	94.9
5	Goodyear Excellence	86.8	93.2
6	ContiPremiumContact2	86.4	93.6
7	Toyo Proxes T1R	86.1	93.0
8	Nokian Hakka H	85.4	92.5
9	Michelin Pilot Primacy	85.0	92.7
10	Firestone Firehawk	85.8	93.2
11	ContiEcoContact3	85.8	93.2
12	Yokohama AVS dBV500	84.8	91.3
13	Pirelli P7	88.5	96.0
14	Hankook Ventus Prime	86.0	93.0
15	Michelin Energy Saver	88.0	96.1
16	Michelin Energy Saver	87.9	96.7
17	Michelin Energy Saver	87.1	94.3
18	Michelin Energy Saver	86.6	94.8
19	Uniroyal SRTT	87.0	93.9
20	Uniroyal SRTT	87.1	96.4
21	Avon Supervan AV4	89.0	97.8
22	Avon Supervan AV4	88.8	95.5
	Average	**86.9**	**94.4**
	max-min	**4.2**	**6.5**
	Standard deviation	**1.28**	**1.48**

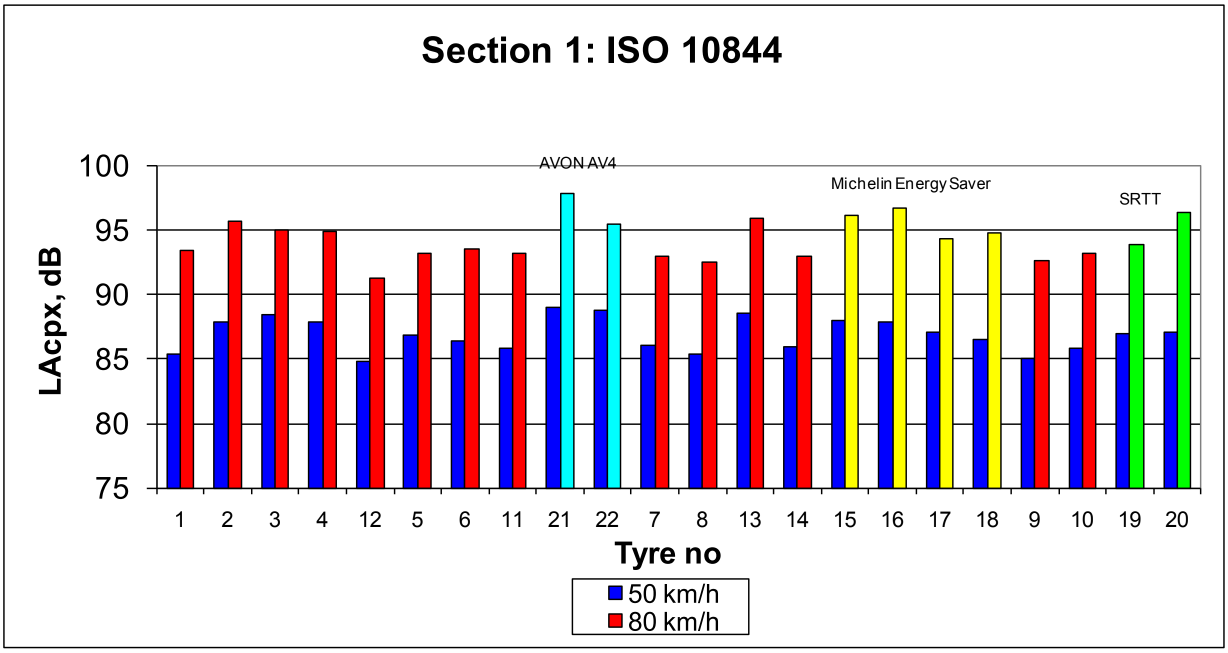

Figure 3 *Section 1: ISO-surface. CPX-results at 50 and 80 km/h*

In each of the figures (for all sections), the 4 Michelin Energy Saver -tyres have a yellow colour column, the two SRTT-tyres a green colour and the two Avon Supervan AV4-tyres a light blue colour for the results at 80 km/h. This is done to make comparison of noise levels of presumably identical tyres more easily.

In the figures, the tyres are sorted according to increasing tyre width; the narrowest tyres 1 and 2 (175 mm) to the left and the widest tyres 19 and 20 (225 mm) to the right.

As figure 3 shows, there is no significant correlation between the CPX-levels and tyre widths between 175 to 225 mm.

5.1.2 Section 2: Thin layer 2/4 (12%)

Table 4 *Section 2: Thin layer 2/4 (12%). LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	83.9	92.1
2	Sportiva G70	86.2	93.4
3	Barum Brilliantis	86.7	92.9
4	Toyo 330	86.3	92.7
5	Goodyear Excellence	84.0	90.2
6	ContiPremiumContact2	83.3	91.1
7	Toyo Proxes T1R	82.9	89.8
8	Nokian Hakka H	82.0	88.5
9	Michelin Pilot Primacy	81.8	89.5
10	Firestone Firehawk	83.1	90.2
11	ContiEcoContact3	82.9	90.3
12	Yokohama AVS dBV500	81.2	87.3
13	Pirelli P7	86.7	94.0
14	Hankook Ventus Prime	83.1	89.9
15	Michelin Energy Saver	85.6	93.6
16	Michelin Energy Saver	84.8	94.4
17	Michelin Energy Saver	84.4	91.4
18	Michelin Energy Saver	83.7	92.1
19	Uniroyal SRTT	84.7	91.2
20	Uniroyal SRTT	84.4	93.4
21	Avon Supervan AV4	87.3	96.3
22	Avon Supervan AV4	86.9	93.1
	Average	**84.3**	**91.7**
	max-min	**6.1**	**9.0**
	Standard deviation	**1.78**	**2.07**

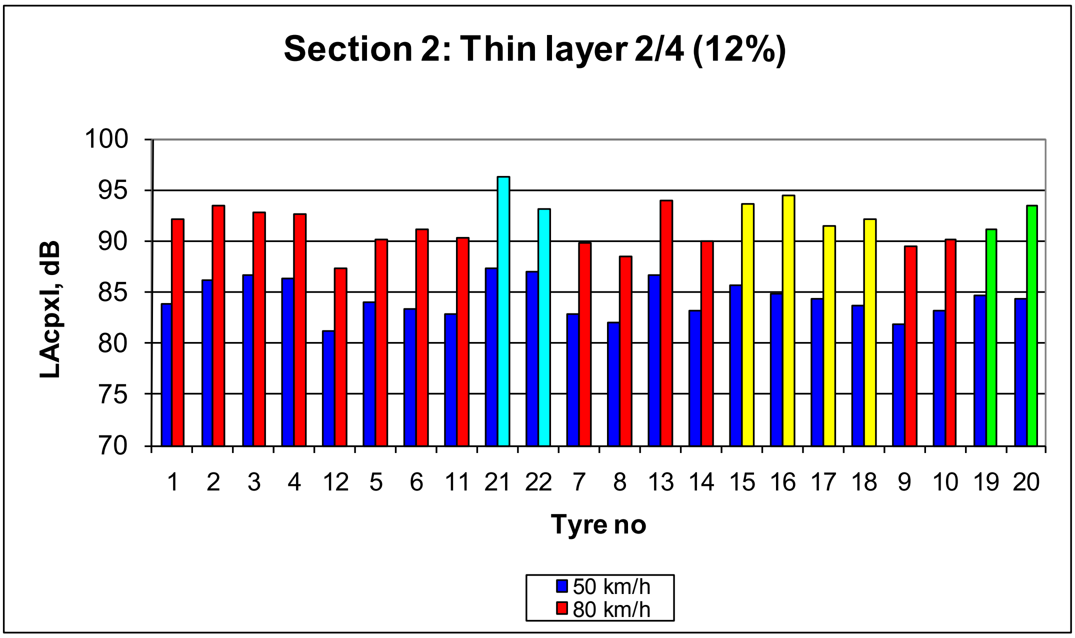

Figure 4 *Section 2: Thin layer 2/4 (12%)*

5.1.3 Section 3: Thin layer 2/6 (8%)

Table 5 *Section 3: Thin layer 2/6 (8%). LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	84.1	92.1
2	Sportiva G70	86.3	93.5
3	Barum Brilliantis	86.3	92.7
4	Toyo 330	86.0	91.7
5	Goodyear Excellence	84.3	90.5
6	ContiPremiumContact2	83.3	90.4
7	Toyo Proxes T1R	83.4	90.1
8	Nokian Hakka H	82.3	88.7
9	Michelin Pilot Primacy	82.4	89.4
10	Firestone Firehawk	82.6	89.4
11	ContiEcoContact3	83.5	90.3
12	Yokohama AVS dBV500	81.6	87.3
13	Pirelli P7	86.9	93.9
14	Hankook Ventus Prime	83.4	89.4
15	Michelin Energy Saver	86.0	93.0
16	Michelin Energy Saver	84.7	93.9
17	Michelin Energy Saver	84.8	91.4
18	Michelin Energy Saver	83.7	92.0
19	Uniroyal SRTT	83.8	91.0
20	Uniroyal SRTT	84.6	93.1
21	Avon Supervan AV4	86.8	94.8
22	Avon Supervan AV4	86.9	92.4
	Average	**84.4**	**91.4**
	max-min	**5.3**	**7.5**
	Standard deviation	**1.64**	**1.85**

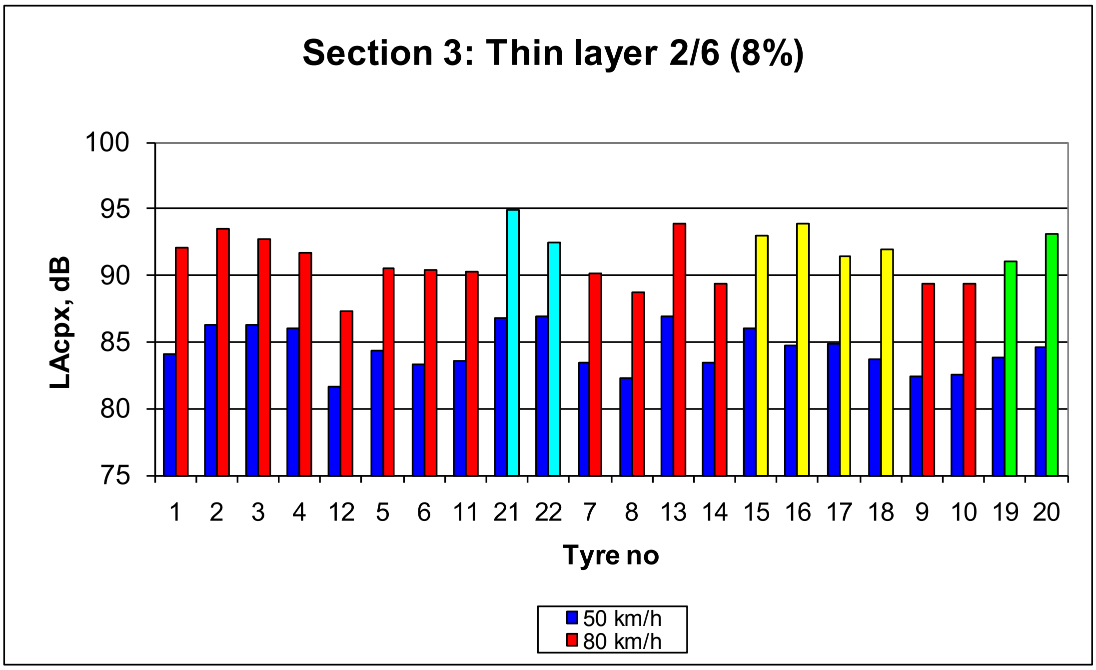

Figure 5 *Section 3: Thin layer 2/6 (8%)*

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5.1.4 Section 4: Thin layer 2/6 (12%)

Table 6 *Section 4: Thin layer 2/6 (12%).LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	84.6	93.4
2	Sportiva G70	85.9	93.7
3	Barum Brilliantis	85.4	92.5
4	Toyo 330	84.6	90.8
5	Goodyear Excellence	84.1	89.9
6	ContiPremiumContact2	83.8	90.1
7	Toyo Proxes T1R	83.1	89.7
8	Nokian Hakka H	82.6	87.9
9	Michelin Pilot Primacy	82.1	88.5
10	Firestone Firehawk	83.2	89.0
11	ContiEcoContact3	83.7	90.5
12	Yokohama AVS dBV500	82.0	87.1
13	Pirelli P7	87.3	94.7
14	Hankook Ventus Prime	84.0	89.8
15	Michelin Energy Saver	86.7	92.9
16	Michelin Energy Saver	85.4	94.4
17	Michelin Energy Saver	85.1	91.5
18	Michelin Energy Saver	84.0	92.3
19	Uniroyal SRTT	84.2	88.8
20	Uniroyal SRTT	84.7	91.7
21	Avon Supervan AV4	87.8	94.6
22	Avon Supervan AV4	87.3	91.6
	Average	**84.6**	**91.2**
	max-min	**5.8**	**7.6**
	Standard deviation	**1.56**	**2.13**

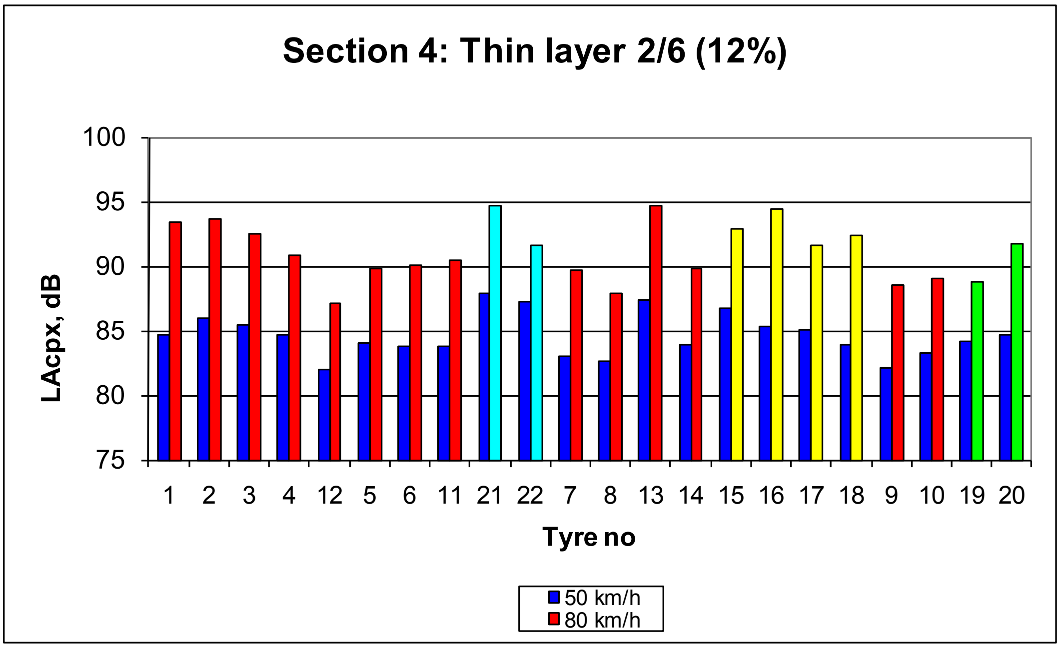

Figure 6 *Section 4: Thin layer 2/6 (12%)*

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5.1.5 Section 5: Thin layer 4/8 (12%)

***Table 7** Section 5: Thin layer 2/6 (12%).LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	86.1	93.8
2	Sportiva G70	87.4	94.4
3	Barum Brilliantis	87.1	93.3
4	Toyo 330	86.3	92.5
5	Goodyear Excellence	86.9	92.4
6	ContiPremiumContact2	85.8	92.3
7	Toyo Proxes T1R	86.2	92.4
8	Nokian Hakka H	84.8	91.1
9	Michelin Pilot Primacy	84.8	91.2
10	Firestone Firehawk	85.0	91.3
11	ContiEcoContact3	86.2	92.5
12	Yokohama AVS dBV500	84.4	90.2
13	Pirelli P7	88.7	95.4
14	Hankook Ventus Prime	86.2	92.1
15	Michelin Energy Saver	88.1	94.3
16	Michelin Energy Saver	87.4	95.3
17	Michelin Energy Saver	87.2	93.6
18	Michelin Energy Saver	86.4	93.8
19	Uniroyal SRTT	86.1	91.4
20	Uniroyal SRTT	86.2	92.7
21	Avon Supervan AV4	88.0	94.6
22	Avon Supervan AV4	87.1	92.6
	Average	**86.5**	**92.9**
	max-min	**4.3**	**5.2**
	Standard deviation	**1.29**	**1.46**

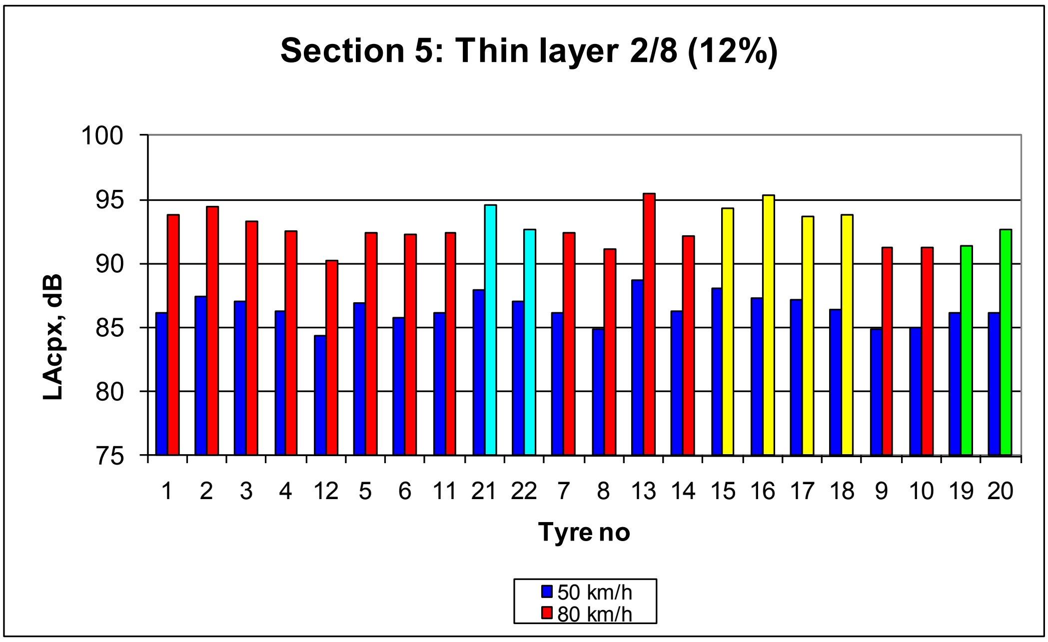

***Figure 7** Section 5: Thin layer 2/6 (12%)*

5.1.6 Section 6: Singe layer porous 0/11

Table 8 *Section 6: Single layer porous 0/11. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	89.0	95.8
2	Sportiva G70	88.6	95.2
3	Barum Brilliantis	88.9	95.1
4	Toyo 330	88.0	93.5
5	Goodyear Excellence	89.6	94.8
6	ContiPremiumContact2	89.5	94.9
7	Toyo Proxes T1R	88.8	94.8
8	Nokian Hakka H	88.5	93.8
9	Michelin Pilot Primacy	88.5	94.2
10	Firestone Firehawk	88.8	94.4
11	ContiEcoContact3	89.3	95.4
12	Yokohama AVS dBV500	88.2	93.4
13	Pirelli P7	90.8	97.0
14	Hankook Ventus Prime	89.4	94.8
15	Michelin Energy Saver	90.8	96.1
16	Michelin Energy Saver	90.5	96.7
17	Michelin Energy Saver	90.6	96.2
18	Michelin Energy Saver	90.2	96.3
19	Uniroyal SRTT	89.1	94.7
20	Uniroyal SRTT	88.4	93.5
21	Avon Supervan AV4	88.8	94.9
22	Avon Supervan AV4	87.6	92.6
	Average	**89.2**	**94.9**
	max-min	**2.6**	**4.4**
	Standard deviation	**0.83**	**0.92**

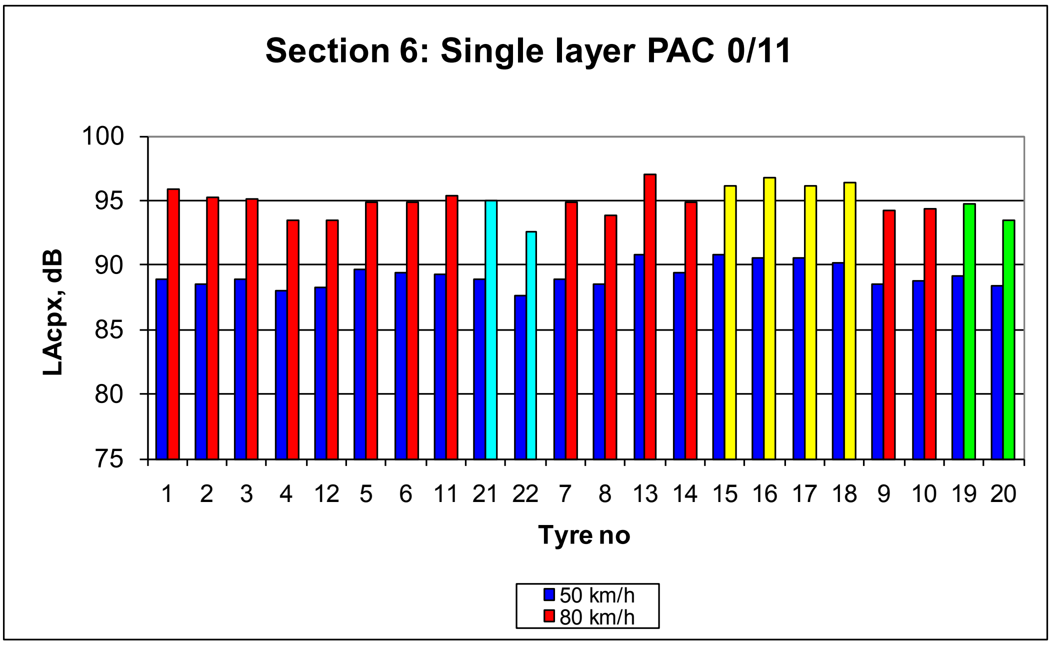

Figure 8 *Section 6: Single layer porous 0/11*

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5.1.7 Section 7: Single layer porous 0/16

Table 9 *Section 7: Single layer porous 0/16. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	87.7	94.1
2	Sportiva G70	88.6	95.3
3	Barum Brilliantis	88.1	94.1
4	Toyo 330	88.0	93.7
5	Goodyear Excellence	88.7	94.2
6	ContiPremiumContact2	88.5	94.3
7	Toyo Proxes T1R	88.1	94.2
8	Nokian Hakka H	87.3	93.3
9	Michelin Pilot Primacy	87.4	93.7
10	Firestone Firehawk	87.6	93.5
11	ContiEcoContact3	88.1	94.1
12	Yokohama AVS dBV500	86.7	92.5
13	Pirelli P7	89.9	95.5
14	Hankook Ventus Prime	88.1	93.6
15	Michelin Energy Saver	89.6	95.6
16	Michelin Energy Saver	89.2	95.7
17	Michelin Energy Saver	89.3	95.2
18	Michelin Energy Saver	89.0	95.3
19	Uniroyal SRTT	87.8	93.3
20	Uniroyal SRTT	88.2	92.8
21	Avon Supervan AV4	87.3	93.5
22	Avon Supervan AV4	86.7	92.1
	Average	**88.2**	**94.1**
	max-min	**3.2**	**3.6**
	Standard deviation	**0.92**	**1.00**

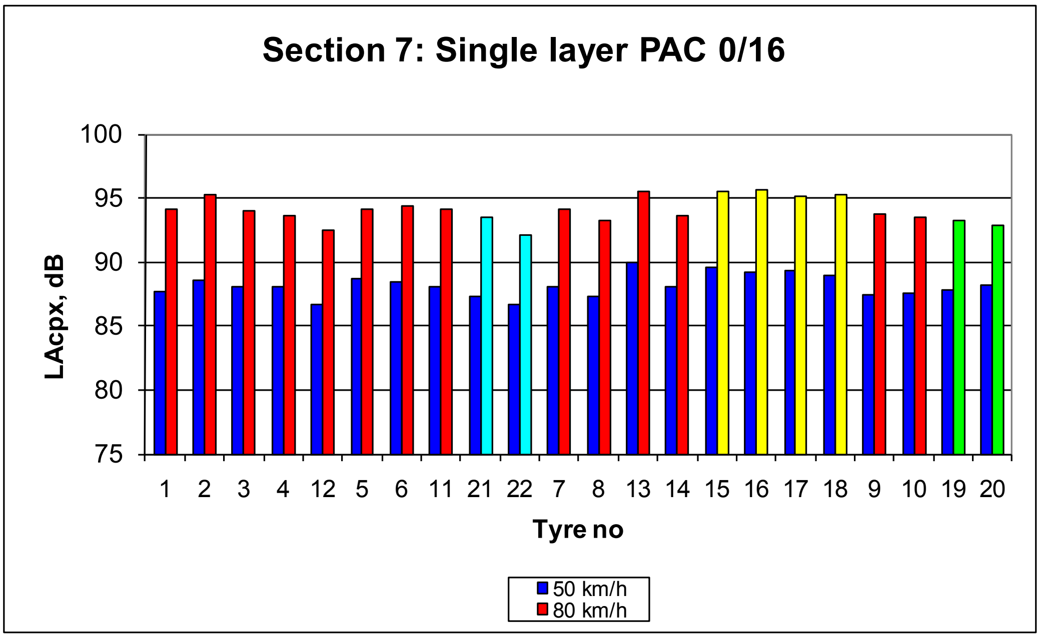

Figure 9 *Section 7: Single layer porous 0/16*

5.1.8 Section 8: Single layer porous 4/8

Table 10 *Section 8: Single layer porous 4/8. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	85.7	92.6
2	Sportiva G70	86.2	91.8
3	Barum Brilliantis	86.0	91.7
4	Toyo 330	85.6	90.7
5	Goodyear Excellence	86.0	91.3
6	ContiPremiumContact2	85.7	91.2
7	Toyo Proxes T1R	85.3	91.0
8	Nokian Hakka H	84.9	90.4
9	Michelin Pilot Primacy	84.8	90.7
10	Firestone Firehawk	85.2	90.7
11	ContiEcoContact3	85.2	91.0
12	Yokohama AVS dBV500	84.0	89.4
13	Pirelli P7	88.0	93.4
14	Hankook Ventus Prime	85.7	90.6
15	Michelin Energy Saver	87.7	92.2
16	Michelin Energy Saver	86.4	92.8
17	Michelin Energy Saver	87.0	91.9
18	Michelin Energy Saver	86.0	92.0
19	Uniroyal SRTT	85.7	90.3
20	Uniroyal SRTT	86.3	90.5
21	Avon Supervan AV4	86.3	92.3
22	Avon Supervan AV4	85.3	89.9
	Average	**85.9**	**91.3**
	max-min	**4.0**	**4.0**
	Standard deviation	**1.06**	**1.11**

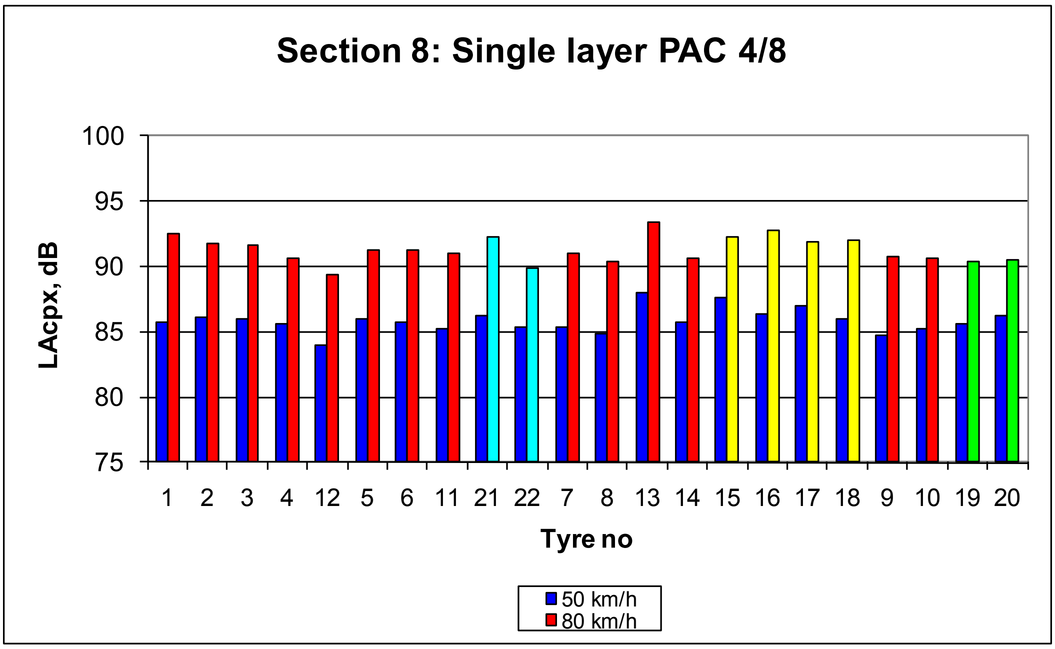

Figure 10 *Section 8: Single layer porous 4/8*

5.1.9 Section 9: Single layer porous 4/8

Table 11 *Section 9: Single layer porous 4/8. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	90.1	97.0
2	Sportiva G70	90.1	96.5
3	Barum Brilliantis	90.9	96.6
4	Toyo 330	88.9	94.6
5	Goodyear Excellence	90.1	94.8
6	ContiPremiumContact2	89.2	95.2
7	Toyo Proxes T1R	89.4	94.9
8	Nokian Hakka H	88.6	94.1
9	Michelin Pilot Primacy	88.8	94.6
10	Firestone Firehawk	88.6	94.4
11	ContiEcoContact3	89.8	95.5
12	Yokohama AVS dBV500	88.0	93.0
13	Pirelli P7	91.7	98.4
14	Hankook Ventus Prime	89.5	95.0
15	Michelin Energy Saver	91.1	96.9
16	Michelin Energy Saver	90.8	97.9
17	Michelin Energy Saver	90.7	96.2
18	Michelin Energy Saver	90.4	96.5
19	Uniroyal SRTT	89.9	94.8
20	Uniroyal SRTT	88.7	95.0
21	Avon Supervan AV4	90.6	97.0
22	Avon Supervan AV4	89.3	94.0
	Average	**89.8**	**95.6**
	max-min	**3.7**	**5.4**
	Standard deviation	**1.02**	**1.30**

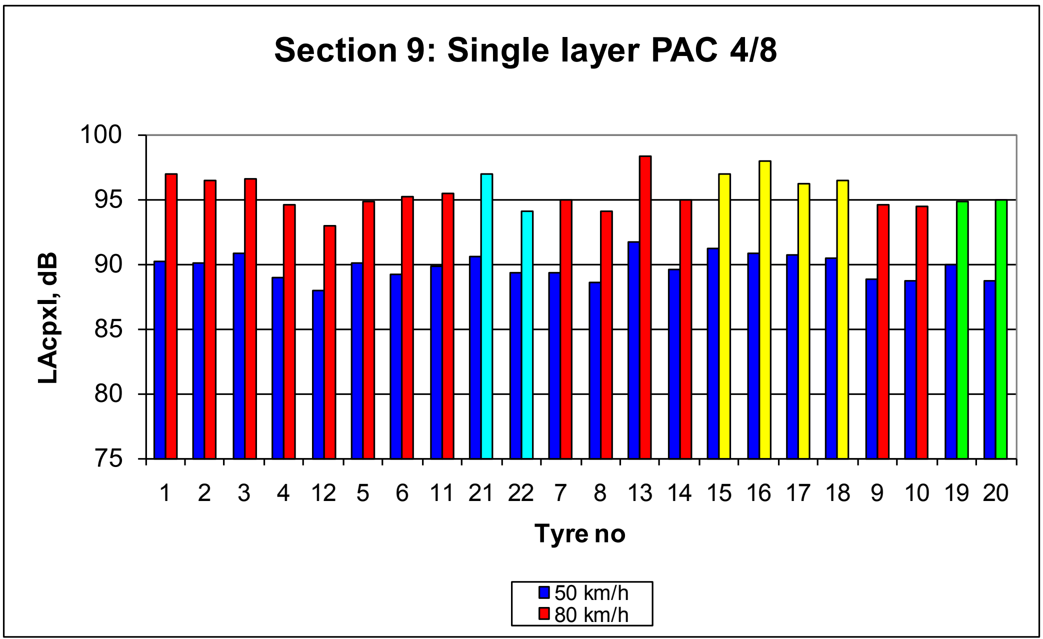

Figure 11 *Section 9: Single layer porous 4/8*

5.1.10 Section 10: Double layer porous 4/8 + 11/16

***Table 12** Section 10: Double layer porous 4/8 + 11/16 .LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	85.0	91.8
2	Sportiva G70	86.4	93.0
3	Barum Brilliantis	85.9	91.7
4	Toyo 330	85.3	91.1
5	Goodyear Excellence	85.8	90.8
6	ContiPremiumContact2	84.9	91.0
7	Toyo Proxes T1R	85.6	91.1
8	Nokian Hakka H	83.6	89.8
9	Michelin Pilot Primacy	84.0	90.4
10	Firestone Firehawk	83.6	90.0
11	ContiEcoContact3	85.1	91.0
12	Yokohama AVS dBV500	83.4	89.0
13	Pirelli P7	86.7	93.0
14	Hankook Ventus Prime	84.7	90.2
15	Michelin Energy Saver	86.8	92.4
16	Michelin Energy Saver	86.3	92.6
17	Michelin Energy Saver	86.0	91.8
18	Michelin Energy Saver	85.6	91.9
19	Uniroyal SRTT	84.2	90.0
20	Uniroyal SRTT	84.4	89.9
21	Avon Supervan AV4	85.1	92.1
22	Avon Supervan AV4	85.2	90.3
	Average	**85.2**	**91.1**
	max-min	**3.4**	**4.0**
	Standard deviation	**1.21**	**1.31**

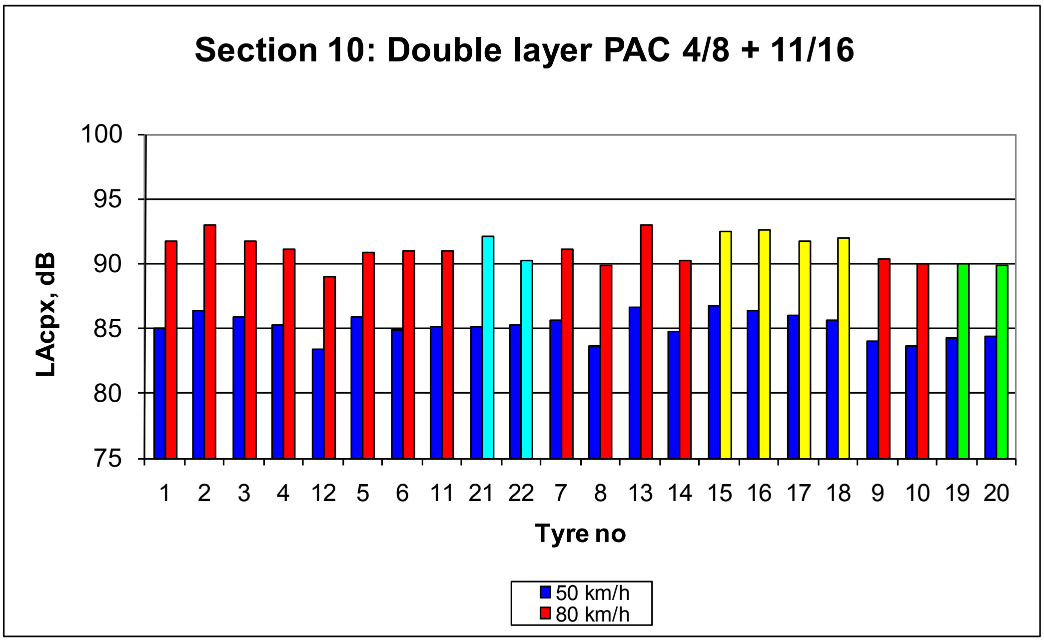

***Figure 12** Section10: Double layer porous 4/8+11/16*

5.1.11 Section 11: Double layer porous 4/8 + 11/16

Table 13 *Section 11: Double layer porous 4/8 + 11/16. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	85.5	91.2
2	Sportiva G70	86.1	92.3
3	Barum Brilliantis	85.1	90.5
4	Toyo 330	85.0	90.8
5	Goodyear Excellence	85.2	90.6
6	ContiPremiumContact2	85.3	90.9
7	Toyo Proxes T1R	84.9	90.5
8	Nokian Hakka H	84.1	90.0
9	Michelin Pilot Primacy	84.1	90.5
10	Firestone Firehawk	84.3	90.1
11	ContiEcoContact3	84.6	90.8
12	Yokohama AVS dBV500	83.2	88.7
13	Pirelli P7	87.0	92.5
14	Hankook Ventus Prime	84.7	90.0
15	Michelin Energy Saver	86.7	91.8
16	Michelin Energy Saver	86.1	92.2
17	Michelin Energy Saver	85.8	91.1
18	Michelin Energy Saver	85.3	91.5
19	Uniroyal SRTT	85.3	90.9
20	Uniroyal SRTT	84.8	90.6
21	Avon Supervan AV4	85.6	91.0
22	Avon Supervan AV4	84.8	89.9
	Average	**85.2**	**90.8**
	max-min	**3.8**	**3.8**
	Standard deviation	**1.10**	**1.11**

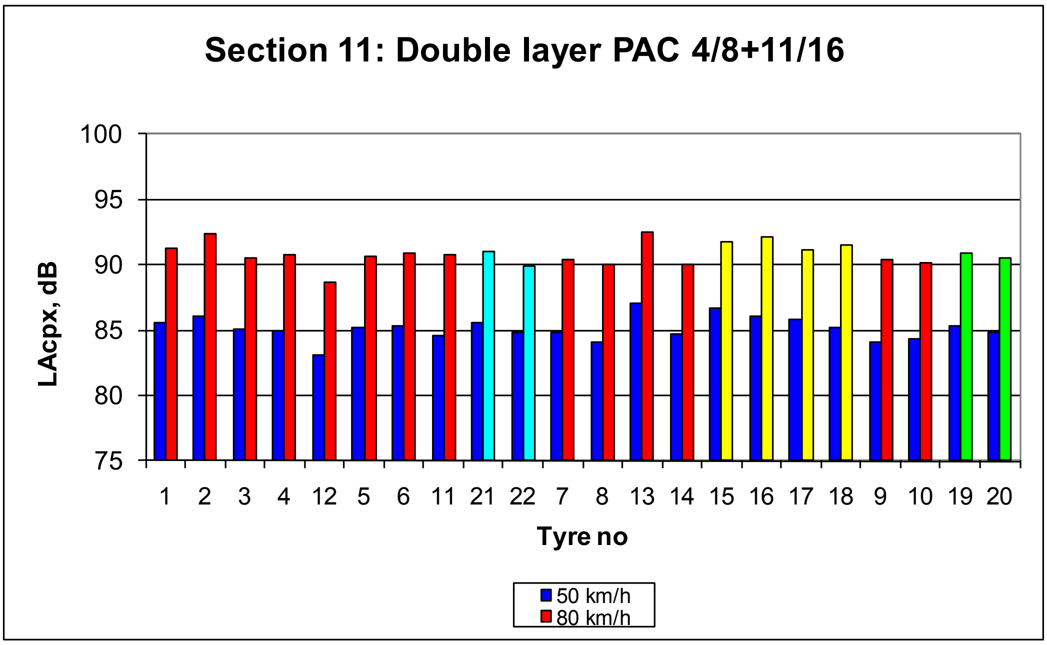

Figure 13 *Section11: Double layer porous 4/8+ 11/16*

5.1.12 Section 12: Rollpave PERS

Table 14 *Section 12: Rollpave PERS. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	80.3	88.6
2	Sportiva G70	82.0	90.6
3	Barum Brilliantis	81.9	88.1
4	Toyo 330	80.7	87.6
5	Goodyear Excellence	79.0	85.7
6	ContiPremiumContact2	79.2	86.5
7	Toyo Proxes T1R	78.2	86.0
8	Nokian Hakka H	77.1	84.3
9	Michelin Pilot Primacy	77.5	85.5
10	Firestone Firehawk	77.4	85.4
11	ContiEcoContact3	78.6	86.0
12	Yokohama AVS dBV500	76.4	82.9
13	Pirelli P7	82.1	89.5
14	Hankook Ventus Prime	79.7	86.2
15	Michelin Energy Saver	81.1	87.8
16	Michelin Energy Saver	79.8	89.0
17	Michelin Energy Saver	79.8	87.2
18	Michelin Energy Saver	78.6	88.1
19	Uniroyal SRTT	78.9	85.9
20	Uniroyal SRTT	80.0	86.2
21	Avon Supervan AV4	82.8	90.7
22	Avon Supervan AV4	82.6	89.3
	Average	**79.7**	**87.1**
	max-min	**6.4**	**7.8**
	Standard deviation	**1.89**	**1.98**

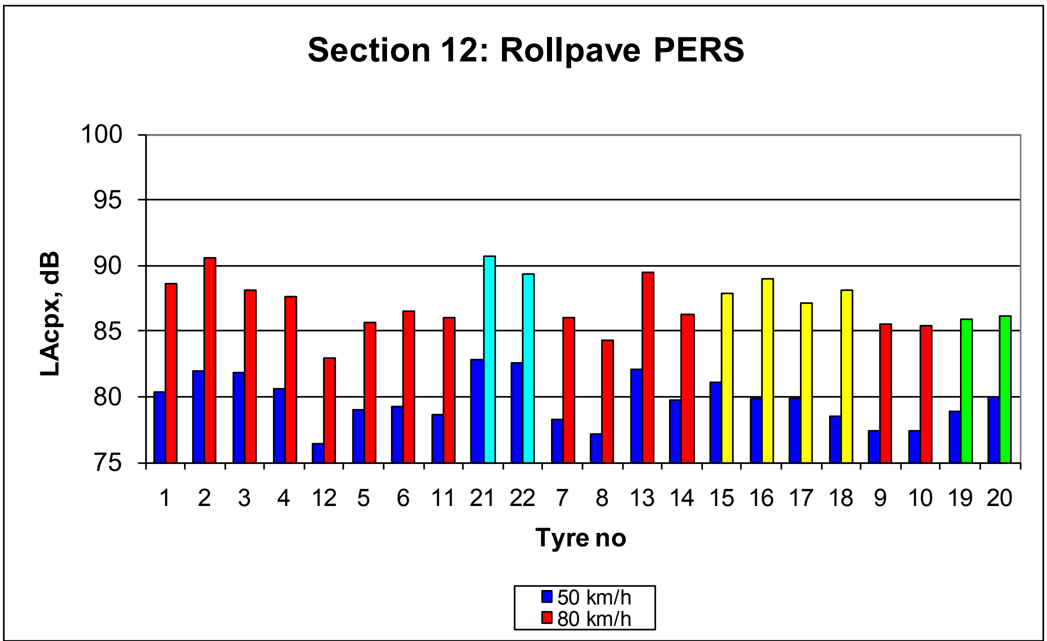

Figure 14 *Section12: Rollpave PERS*

5.1.13 Section 13: Double layer porous 2/4 + 8/11

Table 15 *Section 13: Double layer porous 2/4 + 8/11. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	82.4	89.9
2	Sportiva G70	83.5	89.9
3	Barum Brilliantis	83.1	89.2
4	Toyo 330	82.5	88.3
5	Goodyear Excellence	80.6	86.8
6	ContiPremiumContact2	81.4	87.9
7	Toyo Proxes T1R	79.5	86.4
8	Nokian Hakka H	79.8	85.3
9	Michelin Pilot Primacy	78.9	86.6
10	Firestone Firehawk	80.2	86.4
11	ContiEcoContact3	80.0	86.6
12	Yokohama AVS dBV500	78.2	83.8
13	Pirelli P7	84.9	90.6
14	Hankook Ventus Prime	80.9	86.2
15	Michelin Energy Saver	84.7	88.7
16	Michelin Energy Saver	81.5	90.5
17	Michelin Energy Saver	82.5	88.1
18	Michelin Energy Saver	80.2	88.6
19	Uniroyal SRTT	80.8	86.4
20	Uniroyal SRTT	83.0	87.7
21	Avon Supervan AV4	84.8	91.7
22	Avon Supervan AV4	84.5	89.1
	Average	**81.7**	**87.9**
	max-min	**6.7**	**7.9**
	Standard deviation	**1.95**	**1.93**

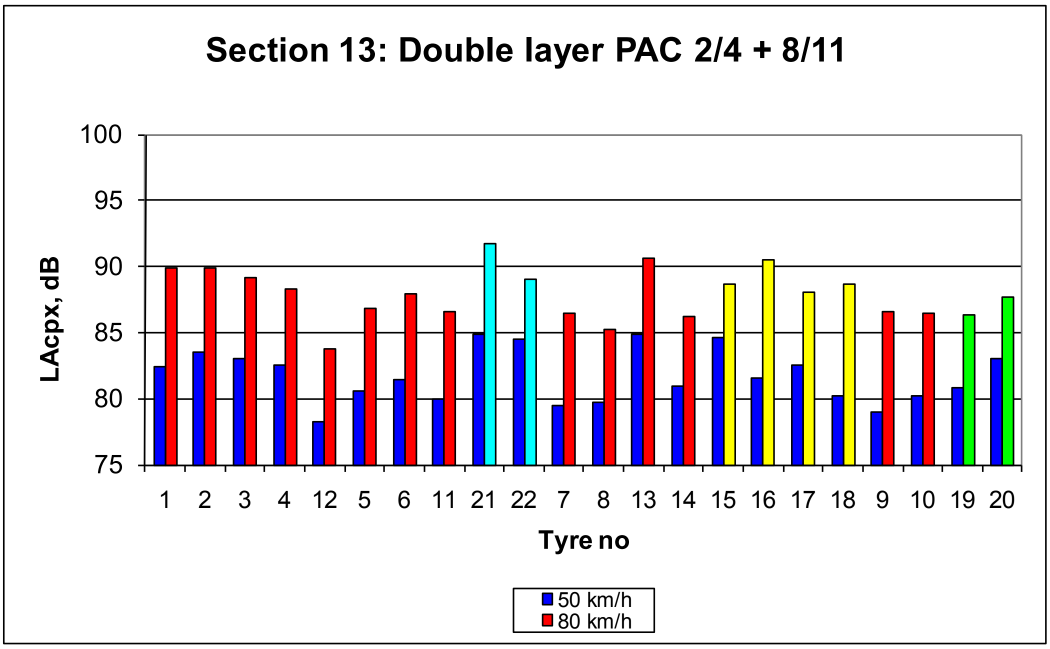

Figure 15 *Section13: Double layer porous 2/4 +8/ 11*

5.1.14 Section 14: Double layer porous 2/6 + 8/11

Table 16 *Section 14: Double layer porous 2/6 + 8/11. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	82.6	90.4
2	Sportiva G70	83.8	91.0
3	Barum Brilliantis	83.9	89.9
4	Toyo 330	83.2	89.1
5	Goodyear Excellence	81.9	87.5
6	ContiPremiumContact2	81.8	88.1
7	Toyo Proxes T1R	81.1	87.1
8	Nokian Hakka H	80.3	86.4
9	Michelin Pilot Primacy	79.8	87.1
10	Firestone Firehawk	80.7	87.2
11	ContiEcoContact3	81.3	87.6
12	Yokohama AVS dBV500	79.6	85.0
13	Pirelli P7	84.9	91.3
14	Hankook Ventus Prime	81.7	86.8
15	Michelin Energy Saver	84.4	89.6
16	Michelin Energy Saver	82.7	90.9
17	Michelin Energy Saver	82.8	88.6
18	Michelin Energy Saver	81.5	89.1
19	Uniroyal SRTT	81.7	87.4
20	Uniroyal SRTT	82.5	88.2
21	Avon Supervan AV4	84.8	92.0
22	Avon Supervan AV4	84.9	89.8
	Average	**82.4**	**88.6**
	max-min	**5.3**	**7.0**
	Standard deviation	**1.63**	**1.85**

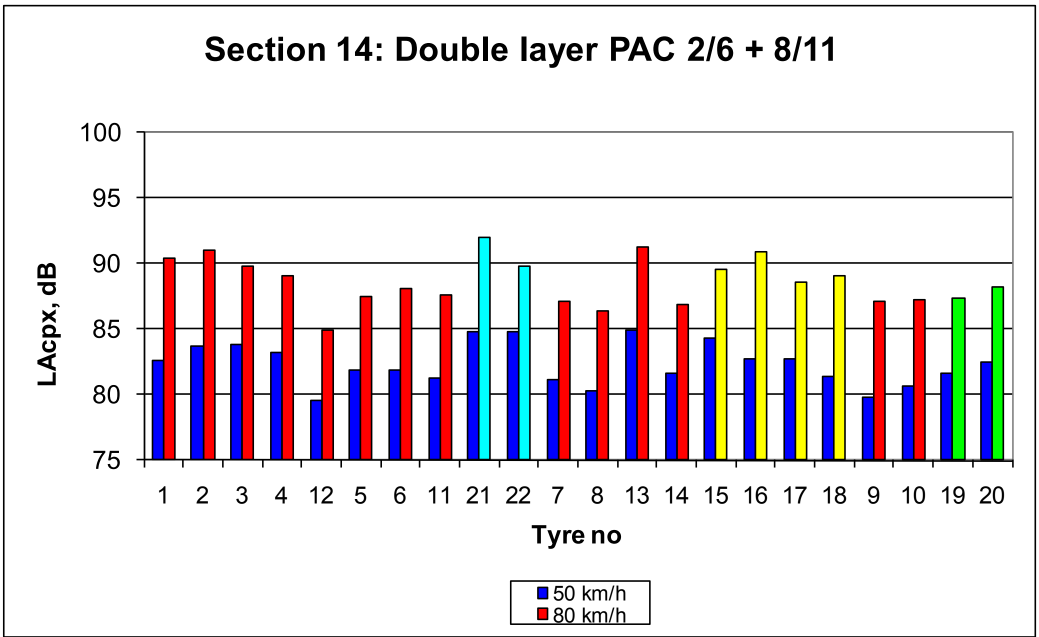

Figure 16 *Section14: Double layer porous 2/6 +8/ 11*

5.1.15 Section 15: Single layer porous 2/6

Table 17 *Section 15: Single layer porous 2/6. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	84.5	93.3
2	Sportiva G70	86.4	94.1
3	Barum Brilliantis	85.3	92.7
4	Toyo 330	85.5	91.1
5	Goodyear Excellence	84.3	89.9
6	ContiPremiumContact2	84.0	90.2
7	Toyo Proxes T1R	83.2	89.9
8	Nokian Hakka H	82.9	87.8
9	Michelin Pilot Primacy	82.8	88.7
10	Firestone Firehawk	83.5	89.2
11	ContiEcoContact3	83.7	90.4
12	Yokohama AVS dBV500	82.1	86.8
13	Pirelli P7	87.8	95.5
14	Hankook Ventus Prime	83.8	90.4
15	Michelin Energy Saver	86.9	93.1
16	Michelin Energy Saver	85.8	94.9
17	Michelin Energy Saver	85.6	91.8
18	Michelin Energy Saver	84.5	92.6
19	Uniroyal SRTT	83.6	88.6
20	Uniroyal SRTT	85.1	92.2
21	Avon Supervan AV4	88.0	95.0
22	Avon Supervan AV4	88.4	91.8
	Average	**84.9**	**91.4**
	max-min	**6.3**	**8.7**
	Standard deviation	**1.55**	**2.28**

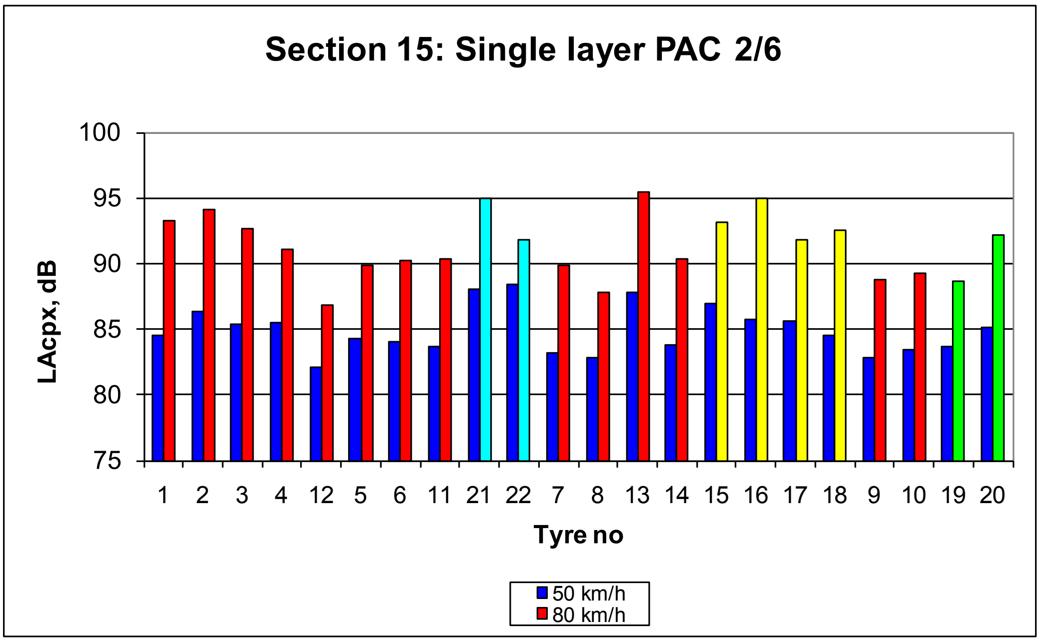

Figure 17 *Section15: Single layer porous 2/6*

5.1.16 Section 16: Double layer porous 2/6 + 11/16

Table 18 *Section 16: Double layer porous 2/6 + 11/16. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	82.2	89.7
2	Sportiva G70	84.1	91.5
3	Barum Brilliantis	84.0	89.2
4	Toyo 330	83.6	89.2
5	Goodyear Excellence	82.0	87.3
6	ContiPremiumContact2	81.5	88.0
7	Toyo Proxes T1R	81.5	87.4
8	Nokian Hakka H	79.9	86.2
9	Michelin Pilot Primacy	79.9	87.0
10	Firestone Firehawk	80.0	87.3
11	ContiEcoContact3	81.5	87.6
12	Yokohama AVS dBV500	79.7	84.8
13	Pirelli P7	84.3	91.4
14	Hankook Ventus Prime	81.3	86.6
15	Michelin Energy Saver	83.8	90.0
16	Michelin Energy Saver	83.0	91.1
17	Michelin Energy Saver	82.6	88.5
18	Michelin Energy Saver	81.6	89.2
19	Uniroyal SRTT	81.2	87.2
20	Uniroyal SRTT	81.7	88.2
21	Avon Supervan AV4	84.6	91.8
22	Avon Supervan AV4	85.2	90.0
	Average	**82.2**	**88.6**
	max-min	**5.5**	**7.0**
	Standard deviation	**1.63**	**1.89**

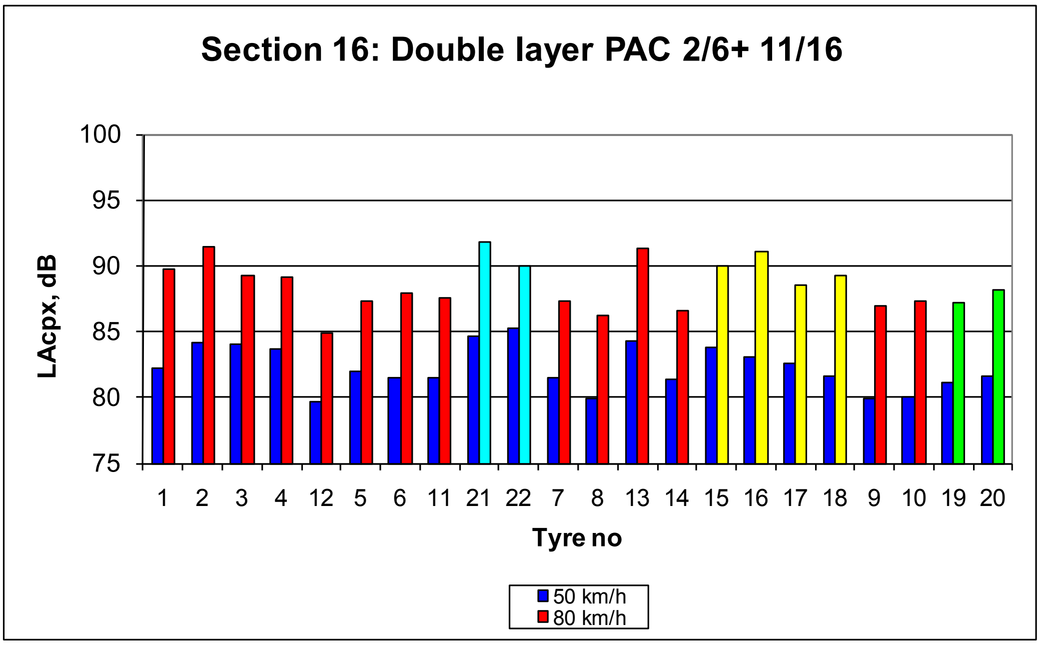

Figure 18 *Section16: Double layer porous 2/6+11/16*

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5.1.17 Section 17: Double layer porous 2/6 + elastic porous 0/16 (3m%)

Table 19 *Section 17: Double layer porous 2/6 + EPAC 0/16. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	82.5	89.2
2	Sportiva G70	83.4	90.7
3	Barum Brilliantis	83.2	88.8
4	Toyo 330	83.1	88.9
5	Goodyear Excellence	81.7	87.3
6	ContiPremiumContact2	81.8	88.3
7	Toyo Proxes T1R	81.2	87.3
8	Nokian Hakka H	80.2	86.7
9	Michelin Pilot Primacy	79.9	87.7
10	Firestone Firehawk	80.5	87.5
11	ContiEcoContact3	81.2	87.5
12	Yokohama AVS dBV500	79.4	85.4
13	Pirelli P7	84.2	90.6
14	Hankook Ventus Prime	81.3	87.4
15	Michelin Energy Saver	84.0	89.3
16	Michelin Energy Saver	82.4	90.2
17	Michelin Energy Saver	82.8	88.4
18	Michelin Energy Saver	81.6	89.1
19	Uniroyal SRTT	81.3	87.2
20	Uniroyal SRTT	82.3	87.9
21	Avon Supervan AV4	83.8	90.6
22	Avon Supervan AV4	84.1	89.5
	Average	**82.1**	**88.4**
	max-min	**4.8**	**5.2**
	Standard deviation	**1.51**	**1.53**

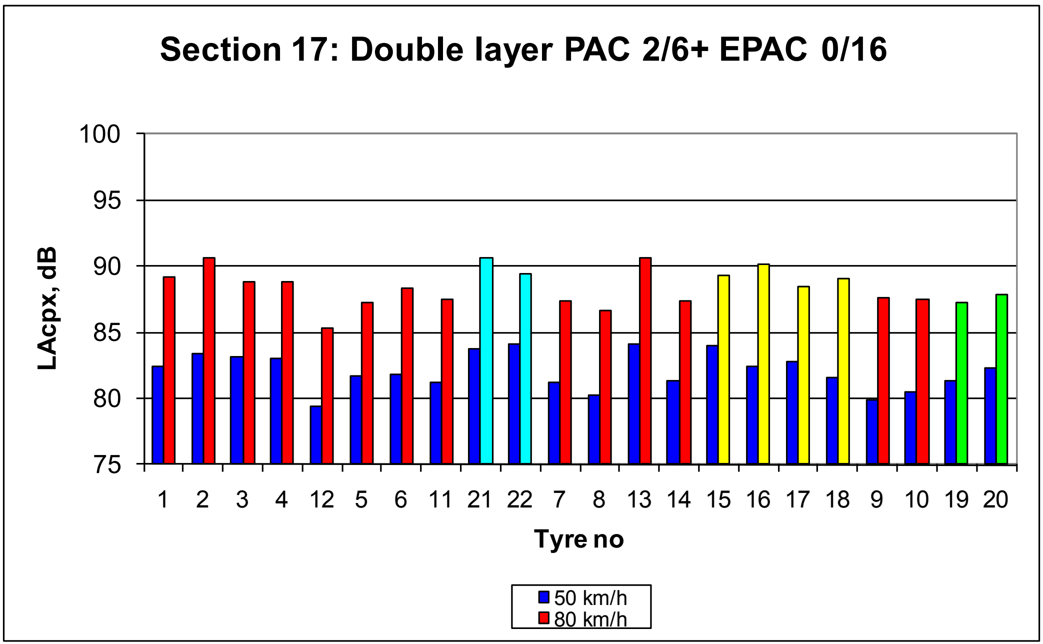

Figure 19 *Section17: Double layer porous 2/6+EPAC 0/16*

5.1.18 Section 18: Double layer porous 2/6 + elastic porous 0/16 (10m%)

Table 20 *Section 18: Double layer porous 2/6 + EPAC 0/16. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	82.2	89.3
2	Sportiva G70	84.0	91.6
3	Barum Brilliantis	83.0	88.7
4	Toyo 330	83.3	89.4
5	Goodyear Excellence	81.6	87.3
6	ContiPremiumContact2	81.5	88.4
7	Toyo Proxes T1R	80.9	87.3
8	Nokian Hakka H	80.6	87.4
9	Michelin Pilot Primacy	80.3	87.7
10	Firestone Firehawk	80.9	87.9
11	ContiEcoContact3	81.2	87.7
12	Yokohama AVS dBV500	79.9	86.1
13	Pirelli P7	83.6	90.3
14	Hankook Ventus Prime	81.6	87.8
15	Michelin Energy Saver	83.3	89.1
16	Michelin Energy Saver	82.7	90.3
17	Michelin Energy Saver	82.4	88.6
18	Michelin Energy Saver	82.0	89.6
19	Uniroyal SRTT	81.4	87.4
20	Uniroyal SRTT	82.1	88.2
21	Avon Supervan AV4	82.9	89.7
22	Avon Supervan AV4	83.4	89.7
	Average	**82.0**	**88.6**
	max-min	**4.1**	**5.5**
	Standard deviation	**1.35**	**1.37**

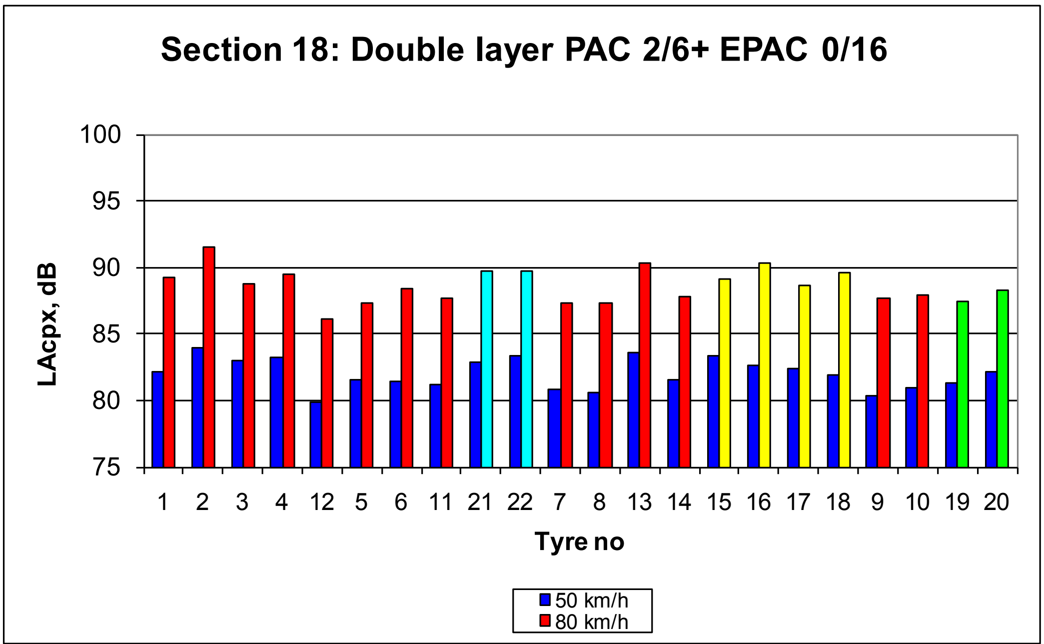

Figure 20 *Section18: Double layer porous 2/6+EPAC 0/16*

5.1.19 Section 19: SMA 0/6

Table 21 *Section 19: SMA 0/6, LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	85.7	93.4
2	Sportiva G70	87.9	95.3
3	Barum Brilliantis	88.3	94.9
4	Toyo 330	87.2	94.2
5	Goodyear Excellence	86.3	92.6
6	ContiPremiumContact2	85.8	93.2
7	Toyo Proxes T1R	85.7	92.2
8	Nokian Hakka H	85.0	91.9
9	Michelin Pilot Primacy	84.7	92.3
10	Firestone Firehawk	85.4	92.7
11	ContiEcoContact3	85.4	93.0
12	Yokohama AVS dBV500	84.6	90.8
13	Pirelli P7	88.4	95.9
14	Hankook Ventus Prime	85.6	92.4
15	Michelin Energy Saver	87.7	95.5
16	Michelin Energy Saver	87.7	96.6
17	Michelin Energy Saver	86.6	94.0
18	Michelin Energy Saver	85.9	94.7
19	Uniroyal SRTT	86.7	93.4
20	Uniroyal SRTT	86.8	95.7
21	Avon Supervan AV4	89.2	97.4
22	Avon Supervan AV4	88.2	94.9
Average		**86.6**	**94.0**
max-min		**4.6**	**6.6**
Standard deviation		**1.29**	**1.54**

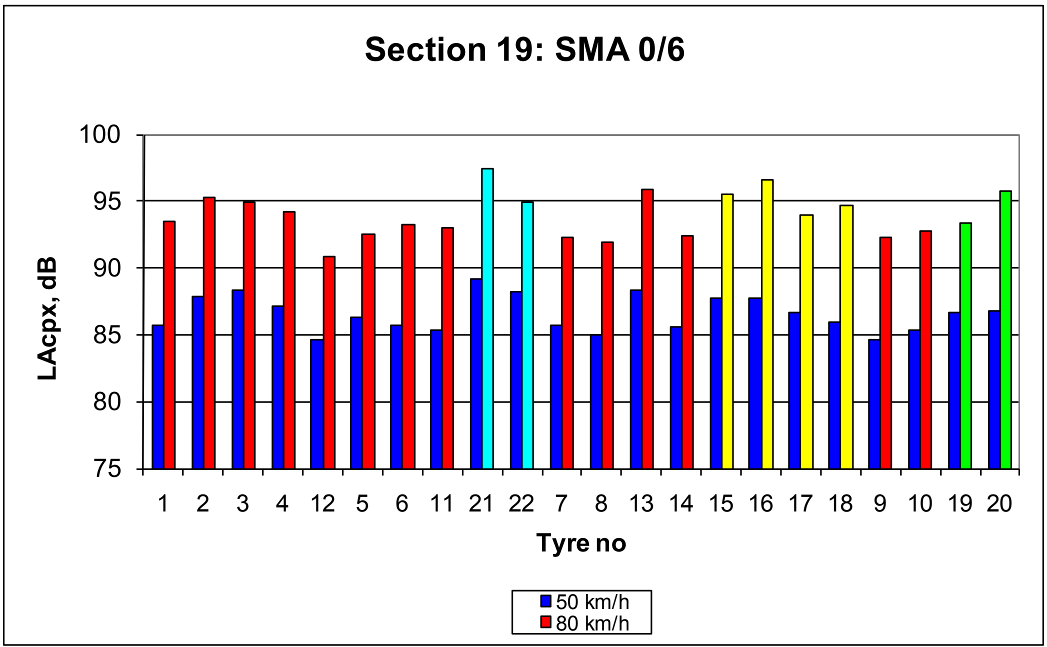

Figure 21 *Section19: SMA 0/6*

5.1.20 Section 20: SMA 0/8

Table 22 *Section 20: SMA 0/8. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	88.3	95.6
2	Sportiva G70	90.1	97.1
3	Barum Brilliantis	90.0	96.2
4	Toyo 330	89.4	96.0
5	Goodyear Excellence	89.8	95.8
6	ContiPremiumContact2	89.0	95.5
7	Toyo Proxes T1R	89.6	95.6
8	Nokian Hakka H	88.3	95.0
9	Michelin Pilot Primacy	88.2	95.3
10	Firestone Firehawk	88.4	95.2
11	ContiEcoContact3	88.8	95.5
12	Yokohama AVS dBV500	87.7	93.9
13	Pirelli P7	91.0	97.7
14	Hankook Ventus Prime	88.7	94.9
15	Michelin Energy Saver	90.6	97.6
16	Michelin Energy Saver	90.3	97.9
17	Michelin Energy Saver	90.0	96.5
18	Michelin Energy Saver	89.5	96.7
19	Uniroyal SRTT	89.2	95.5
20	Uniroyal SRTT	89.0	96.6
21	Avon Supervan AV4	89.9	97.3
22	Avon Supervan AV4	89.3	95.2
	Average	**89.3**	**96.0**
	max-min	**3.3**	**4.0**
	Standard deviation	**1.02**	**1.12**

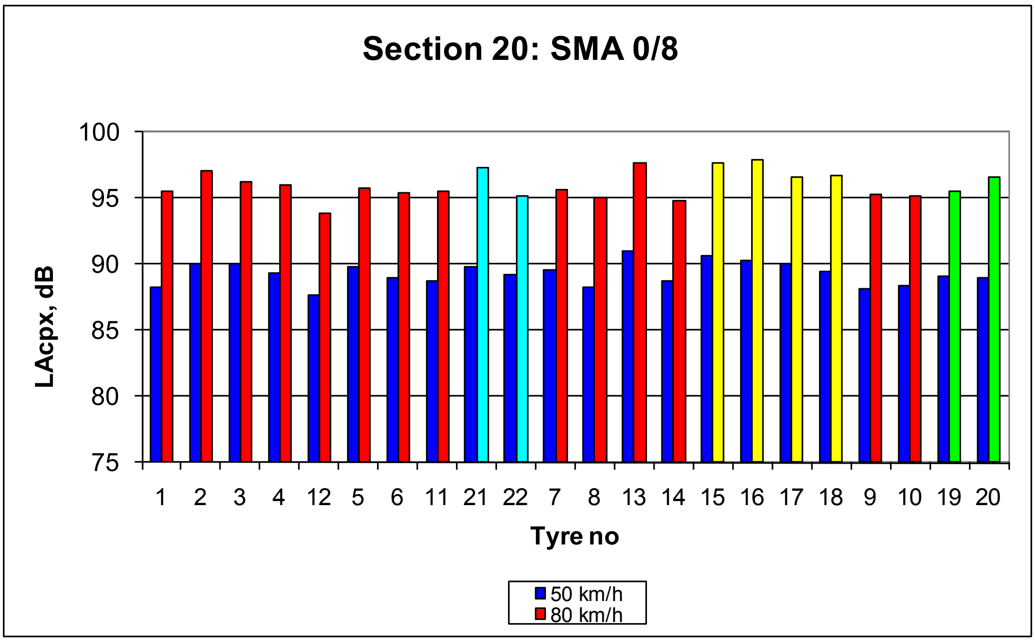

Figure 22 *Section 20: SMA 0/8*

5.1.21 Section 21: SMA 0/11

Table 23 *Section 21: SMA 0/11. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	89.7	97.0
2	Sportiva G70	91.4	98.3
3	Barum Brilliantis	90.9	97.6
4	Toyo 330	90.5	97.2
5	Goodyear Excellence	91.4	97.5
6	ContiPremiumContact2	90.7	97.2
7	Toyo Proxes T1R	91.3	97.7
8	Nokian Hakka H	89.9	96.7
9	Michelin Pilot Primacy	89.9	97.0
10	Firestone Firehawk	89.9	96.9
11	ContiEcoContact3	90.5	97.2
12	Yokohama AVS dBV500	89.3	95.7
13	Pirelli P7	92.4	98.9
14	Hankook Ventus Prime	90.5	96.5
15	Michelin Energy Saver	92.3	99.1
16	Michelin Energy Saver	92.1	99.2
17	Michelin Energy Saver	91.7	98.3
18	Michelin Energy Saver	91.5	98.4
19	Uniroyal SRTT	90.6	96.7
20	Uniroyal SRTT	90.1	97.2
21	Avon Supervan AV4	90.0	97.5
22	Avon Supervan AV4	89.6	95.6
	Average	**90.7**	**97.4**
	max-min	**3.1**	**3.6**
	Standard deviation	**0.98**	**1.00**

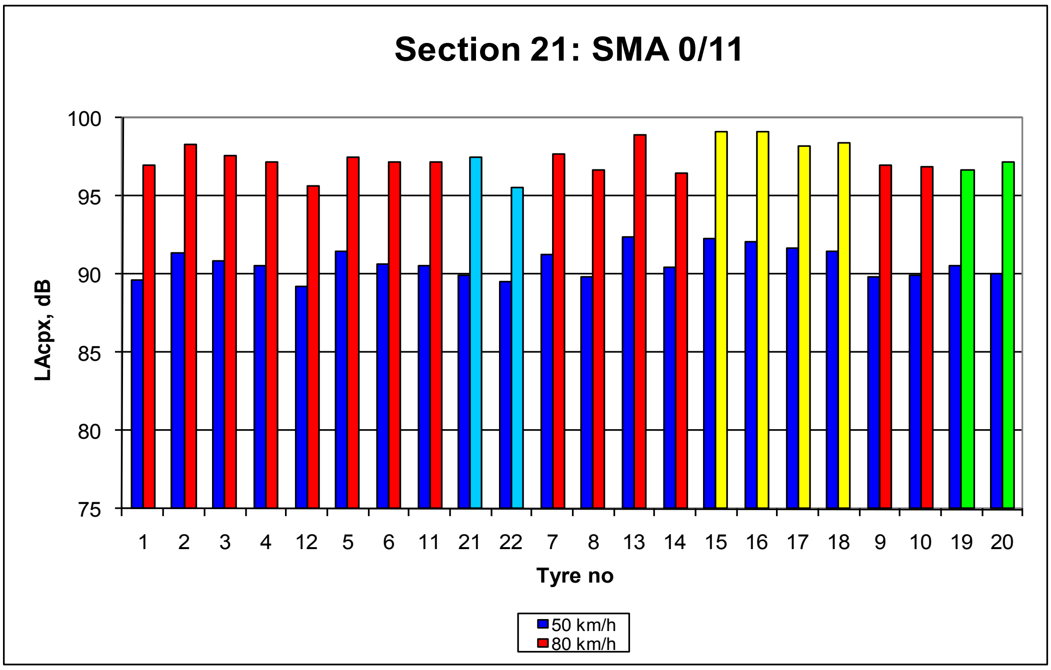

Figure 23 *Section 21: SMA 0/11*

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5.1.22 Section 22: SMA 0/16

Table 24 *Section 22: SMA 0/16. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	90.4	97.7
2	Sportiva G70	92.3	99.5
3	Barum Brilliantis	91.4	98.2
4	Toyo 330	91.7	98.6
5	Goodyear Excellence	92.3	98.8
6	ContiPremiumContact2	91.6	98.4
7	Toyo Proxes T1R	92.5	98.8
8	Nokian Hakka H	90.9	97.8
9	Michelin Pilot Primacy	91.0	98.4
10	Firestone Firehawk	90.9	98.0
11	ContiEcoContact3	91.5	98.4
12	Yokohama AVS dBV500	90.2	96.9
13	Pirelli P7	93.0	100.3
14	Hankook Ventus Prime	91.4	97.7
15	Michelin Energy Saver	93.3	100.2
16	Michelin Energy Saver	93.2	100.3
17	Michelin Energy Saver	92.9	99.5
18	Michelin Energy Saver	92.4	99.5
19	Uniroyal SRTT	91.1	97.7
20	Uniroyal SRTT	91.1	98.4
21	Avon Supervan AV4	90.4	97.5
22	Avon Supervan AV4	90.6	96.6
	Average	**91.6**	**98.5**
	max-min	**3.1**	**3.4**
	Standard deviation	**0.99**	**1.03**

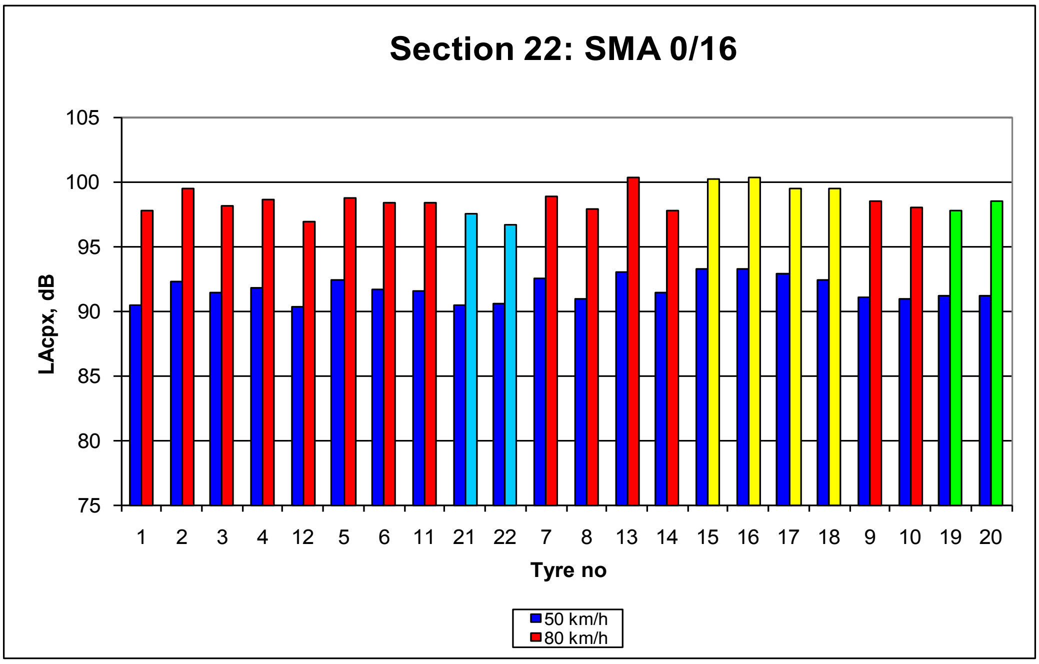

Figure 24 *Section 22: SMA 0/16*

5.1.23 Section 23: DAC 0/16

Table 25 *Section 23: DAC 0/16. LAcpx, dB*

Tyre no	Type	50 km/h LAcpx, dB	80 km/h LAcpx, dB
1	Dayton T110	86.6	94.8
2	Sportiva G70	89.3	96.9
3	Barum Brilliantis	88.9	96.1
4	Toyo 330	88.8	96.1
5	Goodyear Excellence	88.9	95.3
6	ContiPremiumContact2	88.1	95.7
7	Toyo Proxes T1R	88.2	95.3
8	Nokian Hakka H	86.7	94.8
9	Michelin Pilot Primacy	86.9	95.2
10	Firestone Firehawk	87.7	95.5
11	ContiEcoContact3	87.8	95.2
12	Yokohama AVS dBV500	86.4	93.5
13	Pirelli P7	90.0	97.4
14	Hankook Ventus Prime	87.5	95.2
15	Michelin Energy Saver	89.8	97.9
16	Michelin Energy Saver	89.6	98.1
17	Michelin Energy Saver	88.9	96.3
18	Michelin Energy Saver	88.9	96.5
19	Uniroyal SRTT	88.1	95.2
20	Uniroyal SRTT	88.5	97.2
21	Avon Supervan AV4	89.7	98.1
22	Avon Supervan AV4	89.7	97.1
	Average	**88.4**	**96.1**
	max-min	**3.6**	**4.6**
	Standard deviation	**1.22**	**1.28**

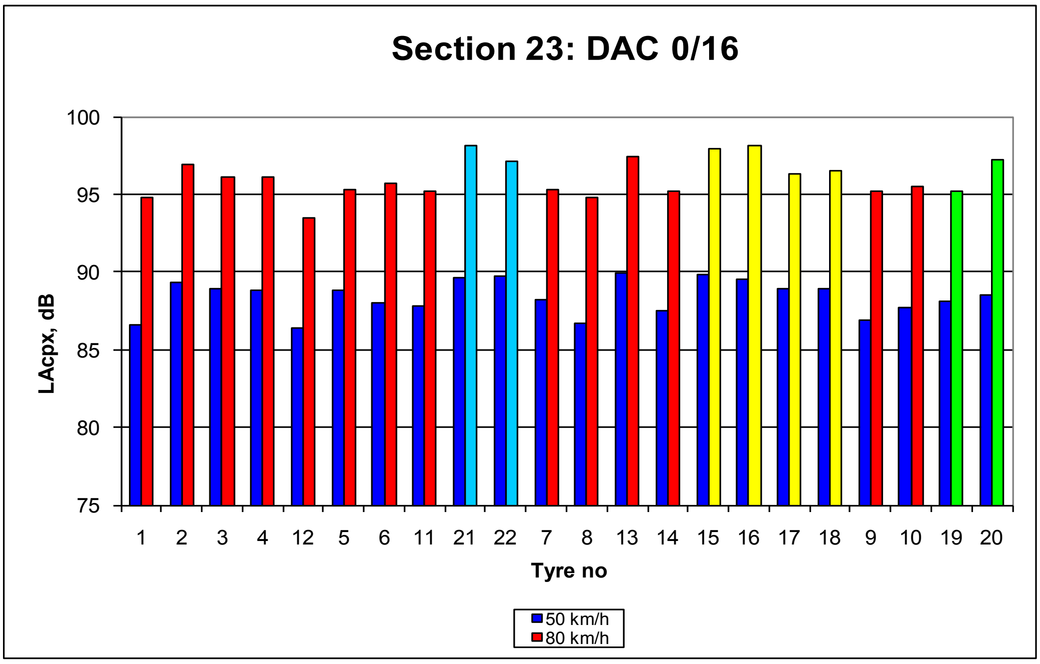

Figure 25 *Section 23: DAC 0/16*

Some conclusions can be made from these results:

- The spread in levels is generally higher at 80 km/h than at 50 km/h, with some exceptions (section 8/table10 and section 11/table10).
- The porous road surfaces clearly distinguish more between tyres (are more sensitive to tyre tread design) than the dense surfaces. As tables 15-17 show, there is a spread of 7-8 dB between the tyres on the porous surfaces, while only 3-4 dB on frequently used dense surfaces like SMA 0/8 – 0/16 (tables 22-24).
- There is a clear difference in noise levels between the 4 Michelin tyres on most of the surfaces. The two oldest tyres (no15/16) is in general 1-2 dB noisier than the newest tyres (no. 17/18). According to table 1, the Shore Hardness is about 2 units higher for the older tyres, but this small difference should not give such differences as measured. Reasons for this should be further investigated.
- Between the two samples of SRTT tyres, there is a clear difference (1-2 dB) in noise levels on most of the surfaces. However, on some of the surfaces, like section 15 (single layer PAC), the difference is even higher, 3.6 dB. Some of this difference may be related to differences in the wheel tracks on the surface. Tests with tyres running in both directions on this surface show that the *west* wheel track for many of the tyres give approximately 1 dB higher levels than the *east*.
- For the Avon Supervan AV4, the differences between the two tyres are consistent for almost all surfaces; the tyre mounted on the right side of the trailer (running on the east wheel track) is generally 2-3 dB more noise than the other tyre. Differences in texture levels cannot explain this.
- Between the noisiest tyre on the noisiest road surface (Tyre 16 Michelin Energy Saver on SMA 0/16) and the quietest tyre on the quietest road surface (Tyre 12 Yokohama on Rollpave PERS), there is a noise difference of approximately **17 dB** at both 50 and 80 km/h. Even between tyre 16 on the SMA 0/16 and tyre 12 on a more commonly used surface as the double layer PAC (section 16), there is a difference of **14-15 dB**.
- Tyre 12 (Yokohama AVS dB V500) is the quietest tyre, except on a couple of the singe layer surfaces.

A correlation and ranking analysis of the noise levels on the ISO-surface and the other surfaces is presented in chapter 7.

5.2 Average noise levels

To compare the different road surface types on the noise level, all the tyre results on each surface have been averaged. Since many of the tyres also have been measured on some typical Norwegian SMA11-surfaces (more than 1 year old), the average results on such a surface has been included for comparison in figure 26 and 27.

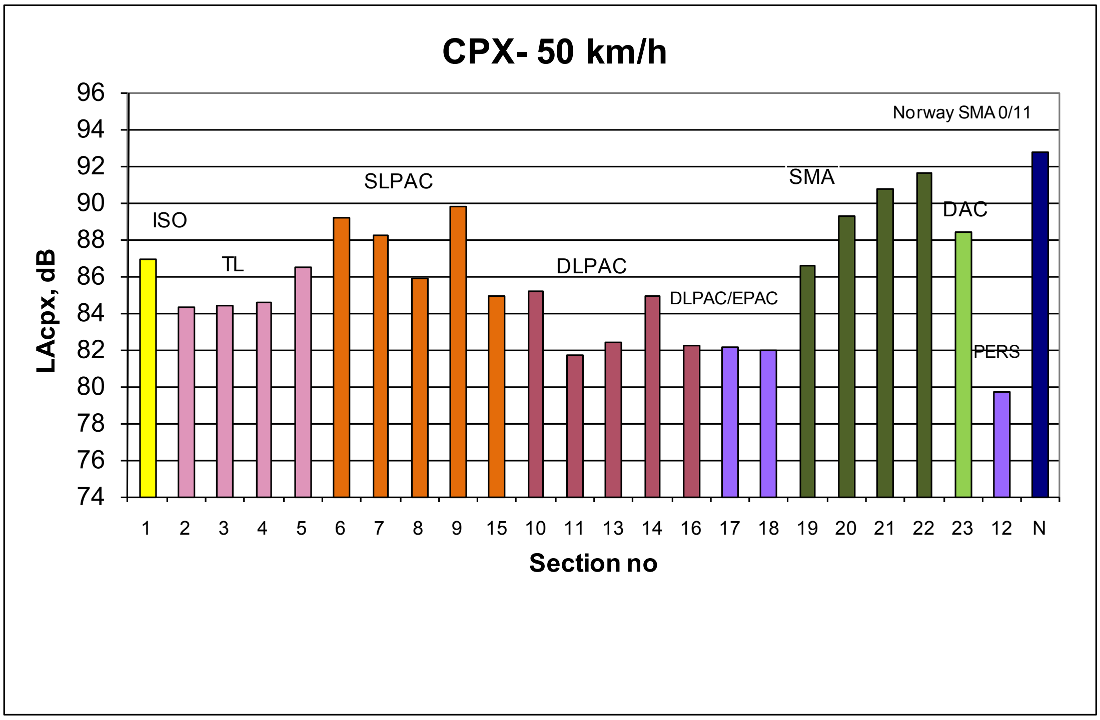

Figure 26 *Average LAcpx, dB, at 50 km/h for 22 tyres*

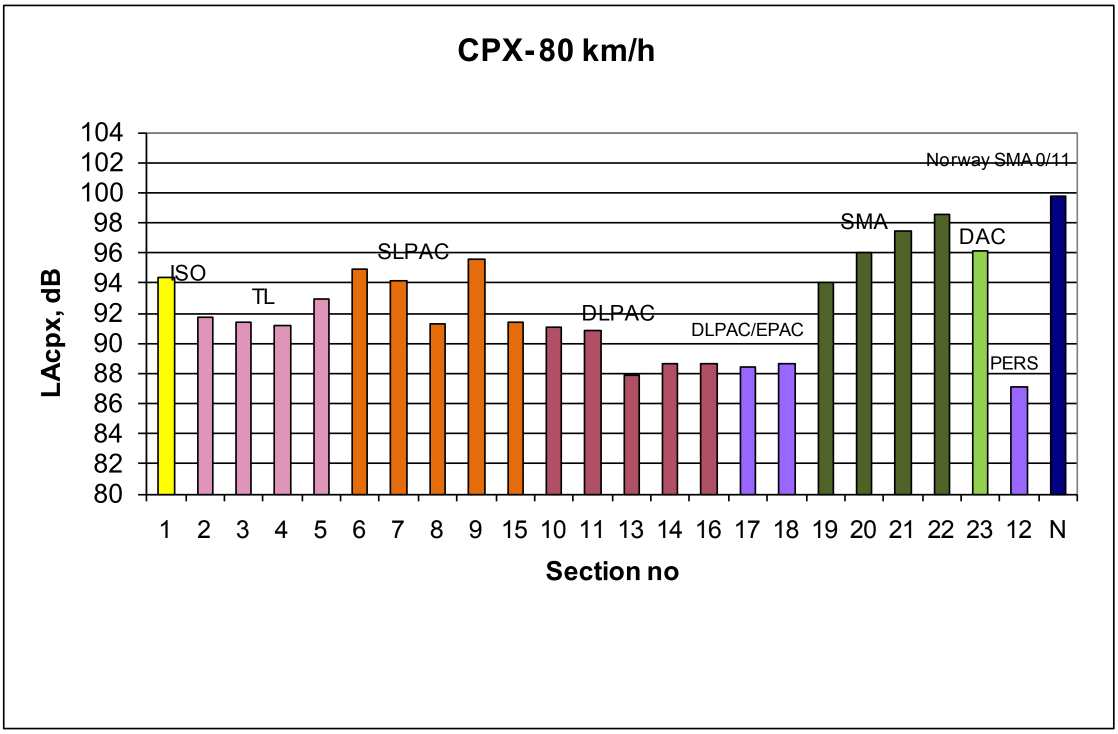

Figure 27 *Average LAcpx, dB, at 80 km/h for 22 tyres*

These results show that:

- The thin layers (TL) perform quite equally, with section 5 giving somewhat higher levels.
- There is a relatively large spread among the single layer porous surfaces (SLPAC) and the double layer surfaces (DLPAC), up to 3-4 dB in each category.
- There seems to be no benefit of the elastic sub layer (sections 17/18) compared to some of the other double layer porous sections.
- At 80 km/h, only about 1 dB difference was found between the poroelastic surface (section 12) and several of the double layers. One may have expected this difference to be higher.
- Comparing the 4 SMA-surfaces (sections 19-22) one clearly sees the influence of the aggregate size (from 6 to 16 mm).
- The Norwegian SMA 0/11-surface (section N) seems to give about 2 dB higher levels than a similar surface at Kloosterzande (section 21). This is consistent with similar results from other investigations.
- Between the Norwegian SMA 0/11-surface and the poroelastic surface, there is a difference of more than **12 dB**, based on average levels of the 22 tyres.

6 Frequency analysis

The PAKII-system (part of the CPX-trailer equipment) allows measurements of the A-weighted 1/3rd octave band frequency levels between 315 and 5000 Hz.

22 tyres measured at 23 road sections at two speeds, gives a total of 1012 individual frequency spectra. To reduce the amount of data in the presentations, the average spectra on 5 different categories of road surfaces has been calculated. The 5 categories are:

1. Dense surfaces, including the ISO-surface
2. Thin layers
3. Single layer porous surfaces
4. Double layer porous surfaces, including elastic sub layer
5. Poroelastic surface (Rollpave PERS)

In some of the figures, category 4 and 5 are grouped together.

For each of the categories, the spectra are shown at the two speeds, to see the speed dependence. Finally, the average spectra for each category of road surface has been compared and presented at the two speeds.

To study the behaviour of each individual tyre, compared to the “average” of all tyres, the total spectra for all tyres/road surface categories are presented first, figures 28-37. Then, the individual spectra for each tyre are presented (figures 38-105).

For the tyres Michelin Energy Saver, SRTT and Avon Supervan AV4, the frequency spectra are presented as the ***average*** of all the identical tyres.

Of special interest are the spectral levels on the ISO-surface compared to the other dense surfaces. The individual spectra for these types of surfaces are therefore included in the main presentation. The spectra on the other surfaces are presented in Annex 1.

6.1 Average spectra for all tyres

The average spectra for all the tyres are shown in figures 28 – 37. The spectra for each tyre can then be compared with these spectra, to see if there are some deviations from an “average” tyre. (Note: In figures 28 and 29, the levels on the ISO-surface are almost the same as for the SMA 0/6 surface).

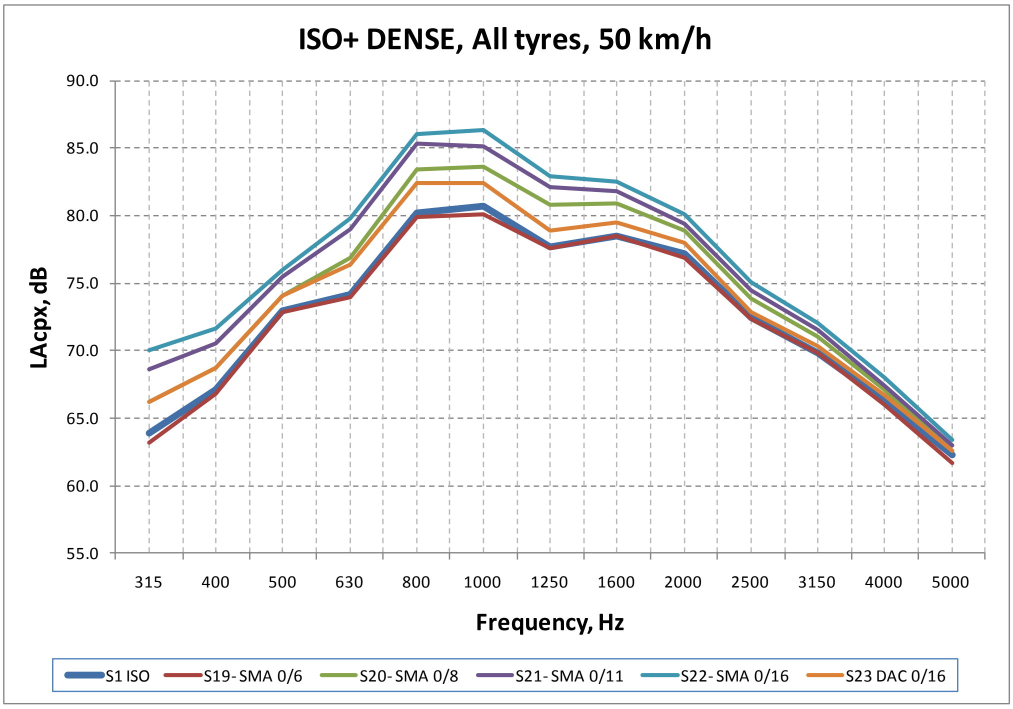

Figure 28 *Average frequency spectra for all 22 tyres, ISO and dense surfaces, 50 km/h*

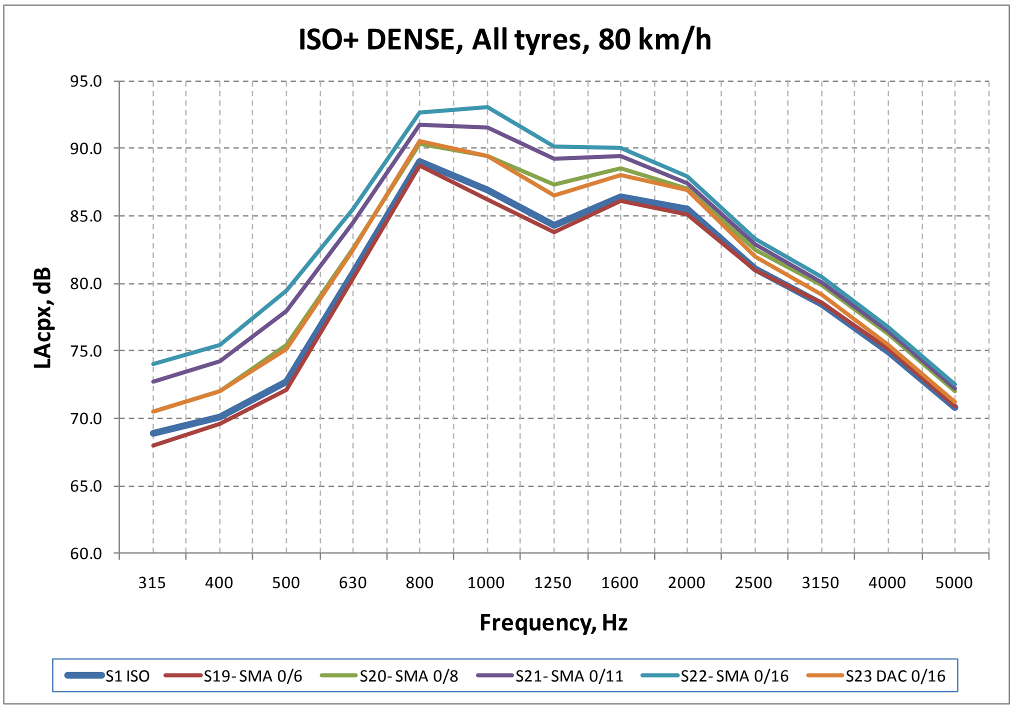

Figure 29 *Average frequency spectra for all 22 tyres, ISO and dense surfaces, 80 km/h*

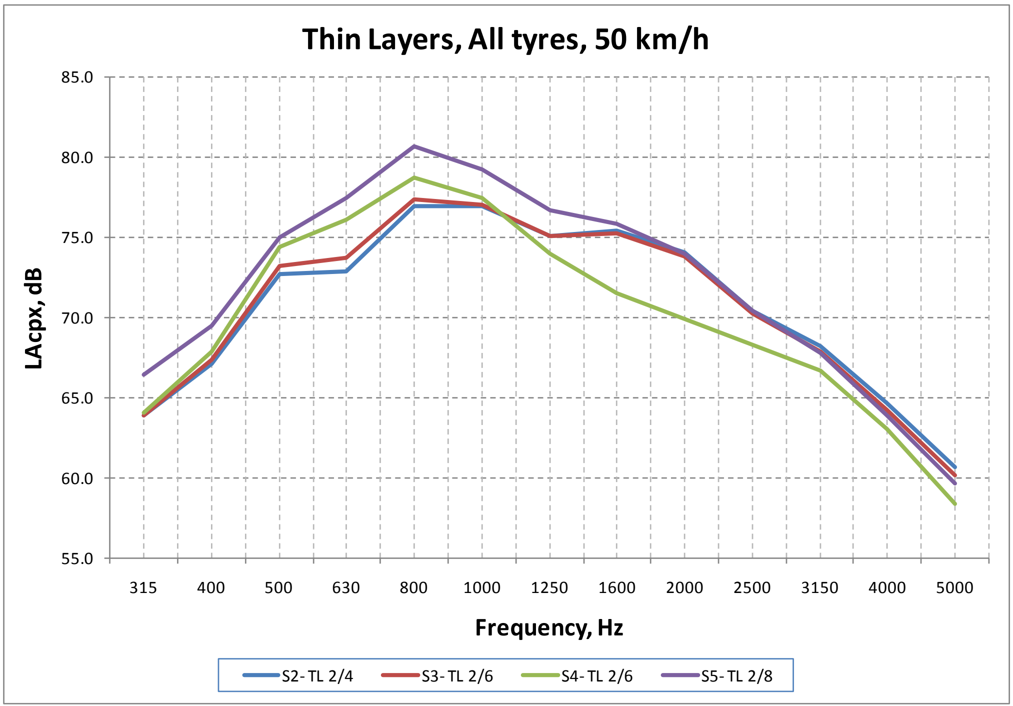

Figure 30 *Average frequency spectra for all 22 tyres. Thin layers, 50 km/h*

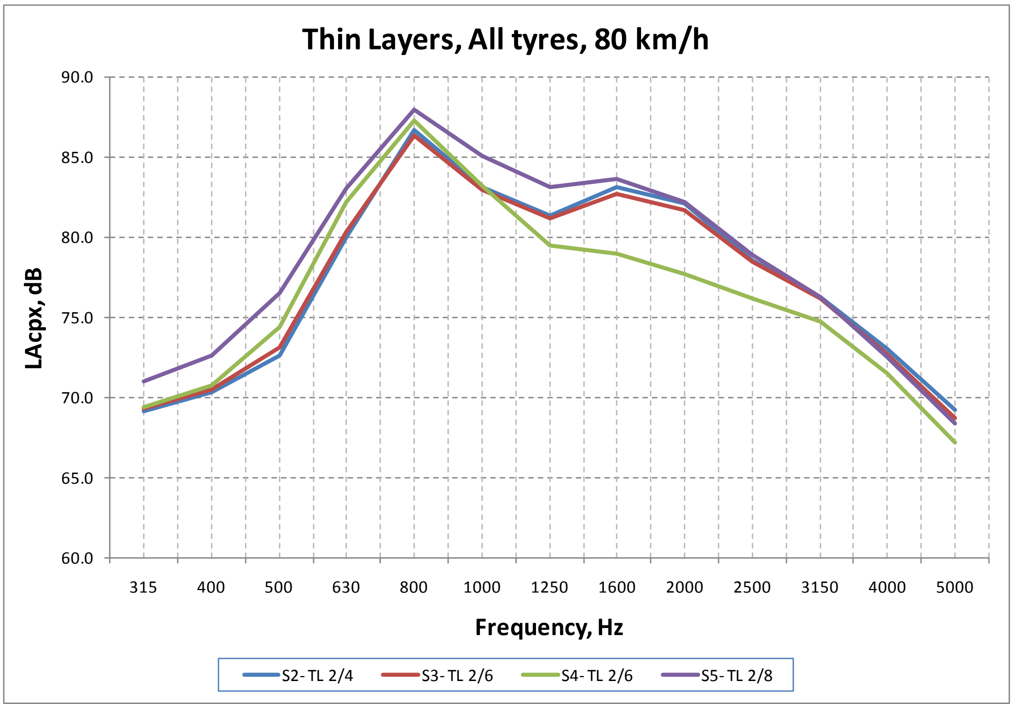

Figure 31 *Average frequency spectra for all 22 tyres. Thin layers, 80 km/h*

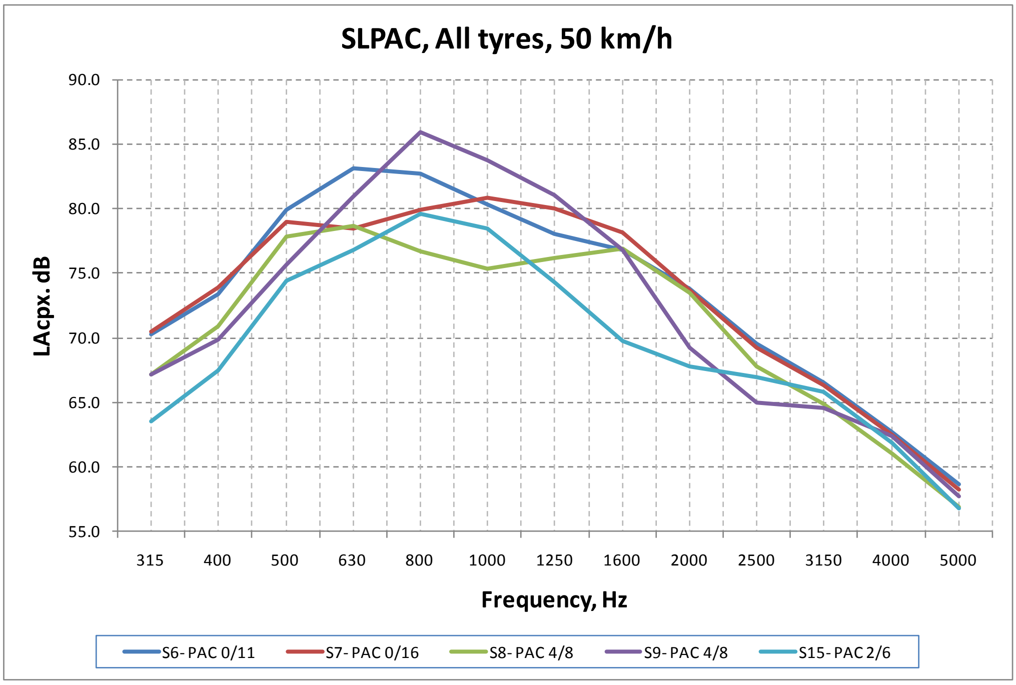

Figure 32 *Average frequency spectra for all 22 tyres. Single layer porous, 50 km/h*

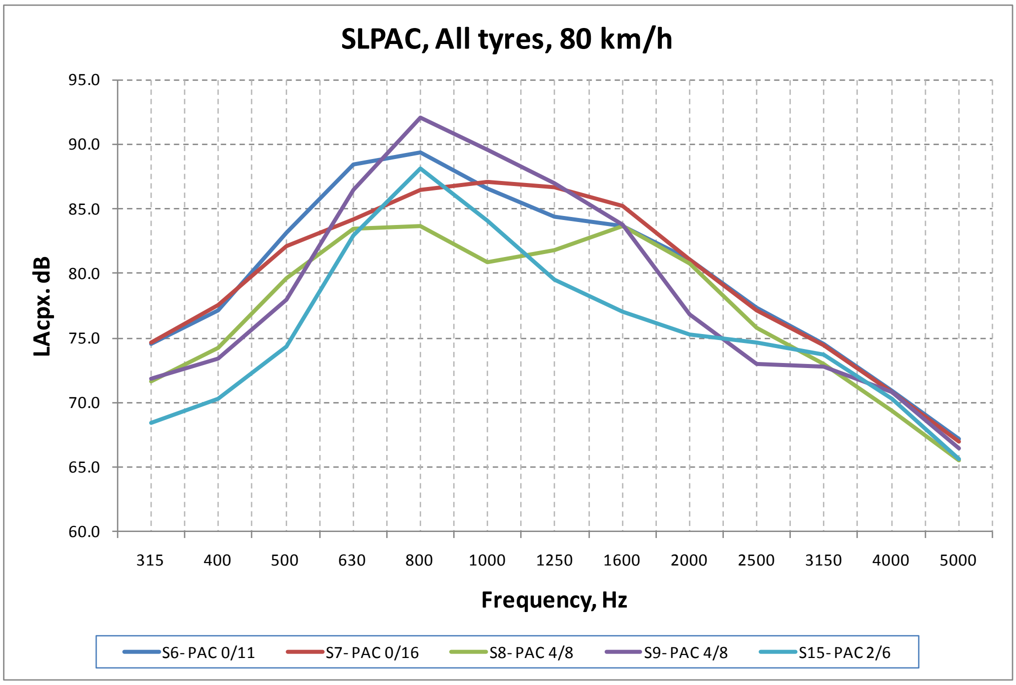

Figure 33 *Average frequency spectra for all 22 tyres. Single layer porous, 80 km/h*

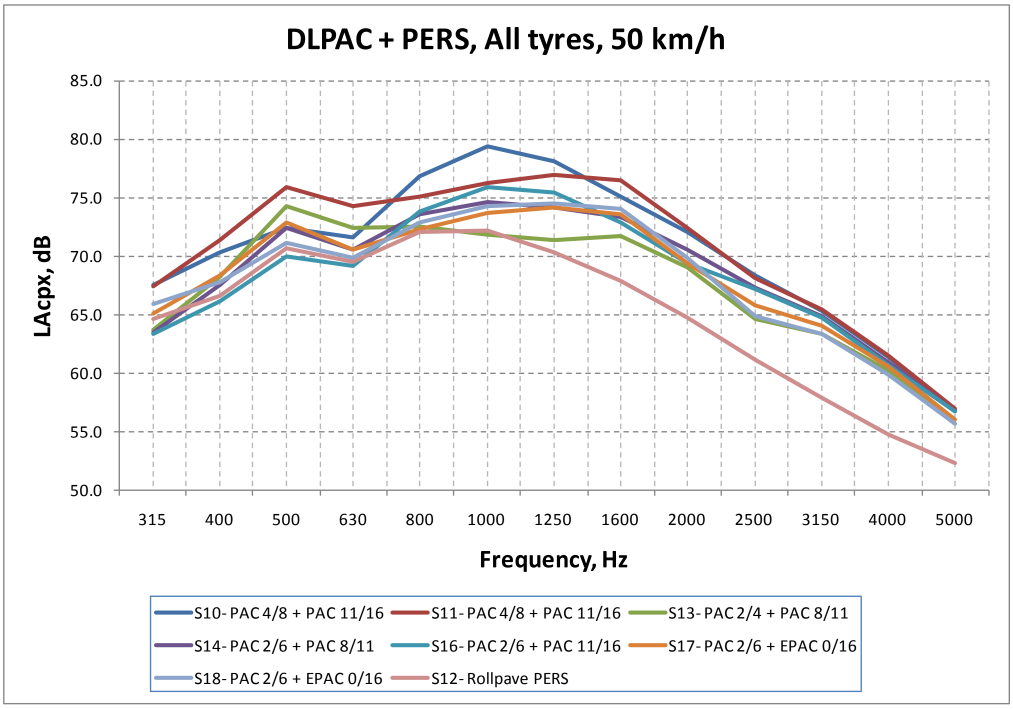

Figure 34 *Average frequency spectra for all 22 tyres. Double layer porous + PERS, 50 km/h*

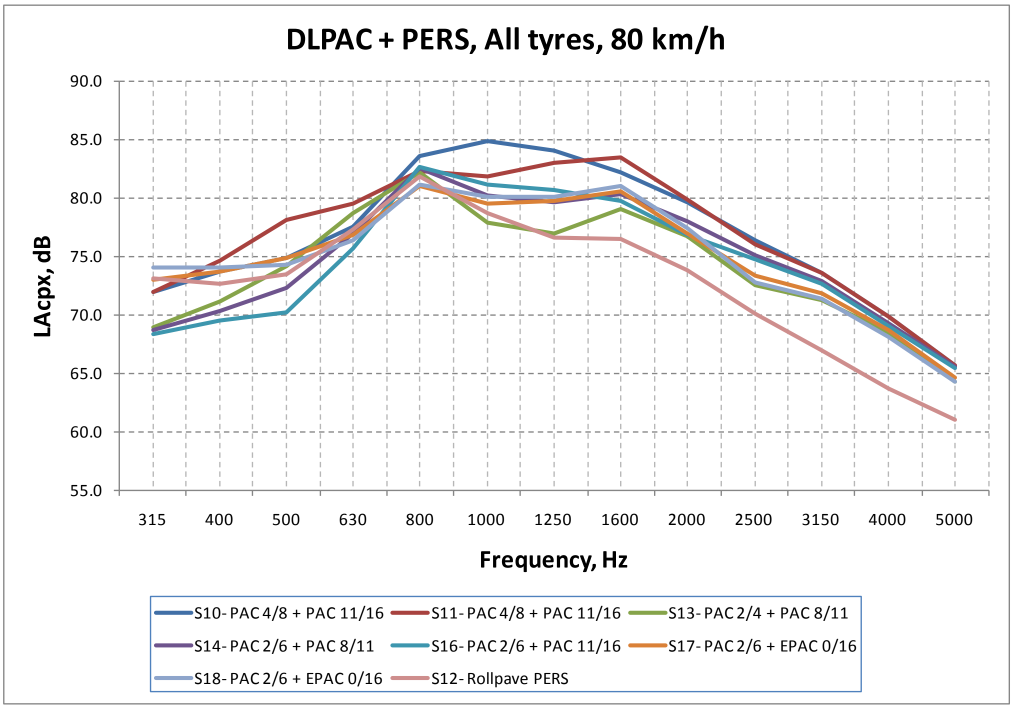

Figure 35 *Average frequency spectra for all 22 tyres. Double layer porous + PERS, 80 km/h*

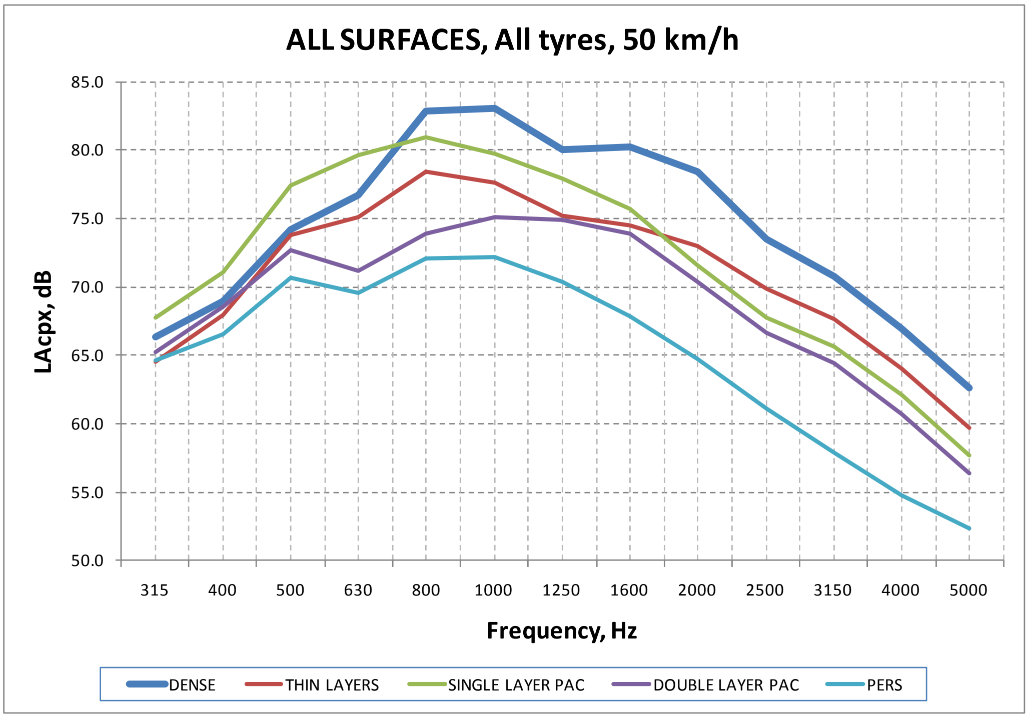

Figure 36 *Average spectra for all 5 categories of road surfaces, and all 22 tyres, 50 km/h*

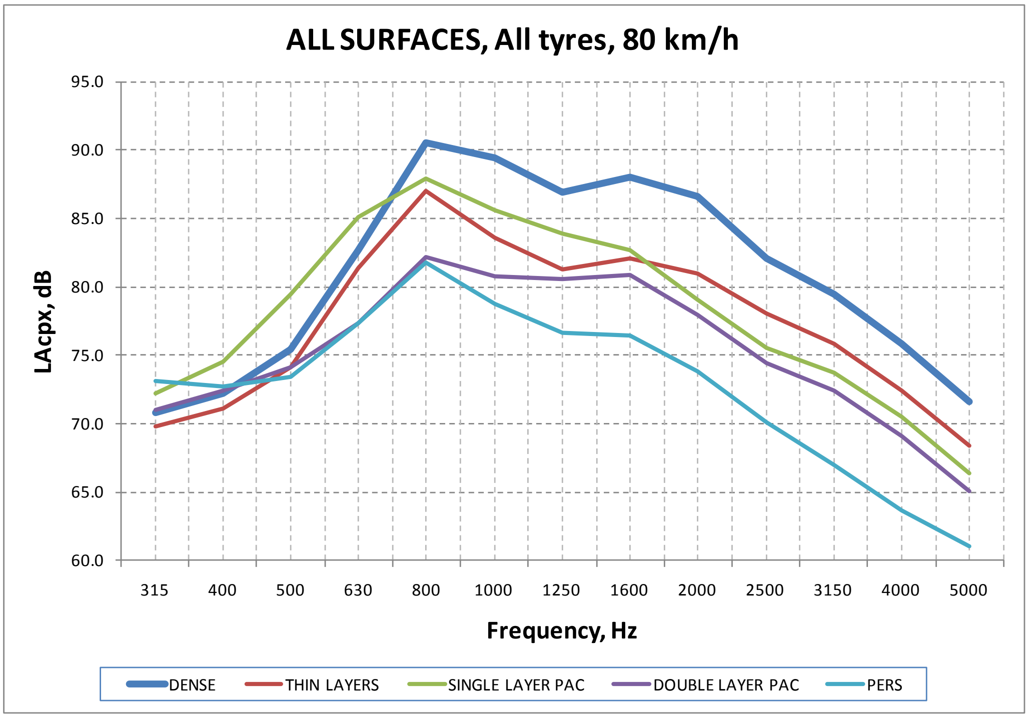

Figure 37 *Average spectra for all 5 categories of road surfaces, and all 22 tyres, 80 km/h*

Dense surfaces
As figures 28-29 show, there is a clear influence of the aggregate size on the spectra for the SMA-surfaces. Increasing the stone size gives an increase in the spectra below 2500 Hz. In the higher frequency range, there is no difference.
The ISO-surface is close to the spectra of the SMA 0/6-surface, even if the ISO-surface is a DAC 0/8- type of surface.
Surface S23, the DAC 0/16, has a similar spectrum as an SMA 0/8, especially at 80 km/h (figure 29).

Thin layers
Surface S4 seems to behave somewhat like a porous surface in the frequency range 1250-3150 Hz (figures 30-31).
Surface S5, the thin layer with 2/8 mm aggregate size, is the "noisiest" surfaces in the frequency range between 500 and 1600 Hz, especially at 50 km/h (figure 30).
At 80 km/h, the thin layers seem to excite a resonance at 800 Hz, similar to the dense surfaces (figure 29).

Single layer porous surfaces
As figures 32 and 33 show, there is a big spread in the spectra for the different types of single layers.
Both surface S8 and S9 have similar aggregate sizes (4/8 mm), but behave quite different. S9 behaves more like a double layer porous surface and S8 more like a dense surfaces. The only difference is related to layer thickness; S8 is 50 mm and S9 is 25 mm. In chapter 8, the texture spectra are shown for comparison.

Double layer porous surfaces, including PERS
Except for some shifts in the peaks (may be related to differences inlayer thickness), the double layer pavements seems to perform quite similar, see figures 34 and 35. The elastic sub layer of sections S17 and S18 does not seem to influence the frequency spectra much.
The Rollpave PERS clearly reduces the noise in the frequency area above 1250 Hz, compared to the double layers. Below this frequency, there is no difference from some of the other double layers.

Comparing all surfaces
The average of all tyres on all the 5 categories of road surfaces are shown in figures 36 and 37.
There are clearly differences, depending on which frequency range one is analyzing. The differences seem to be speed dependent in some cases:
- Below 500 Hz: There is no variation between the different categories, except that the single PAC seems to give some higher levels.
- 500-800 Hz: At 50 km/h, there is a clear difference between the 5 categories. The single layer PAC still give higher levels than the dense surfaces, which could be related to texture differences. At 80 km/h, there is no difference between the PERS and the double PACs in this frequency range.
- 800-1250 Hz: Clear differences between all 5 categories. Again, the single PACs give higher levels than the thin and double layers.
- Above 1250 Hz. The dense surfaces clearly have the highest levels, while the PERS give the lowest. Minor differences between the other 3 categories.

6.2 Frequency spectra for individual tyres

Only the individual spectrum for dense surfaces and average spectra for the 5 categories of road surfaces are shown here for each tyre. A complete presentation for the other surfaces is shown in Annex 1.

Tyre 1: Dayton T110

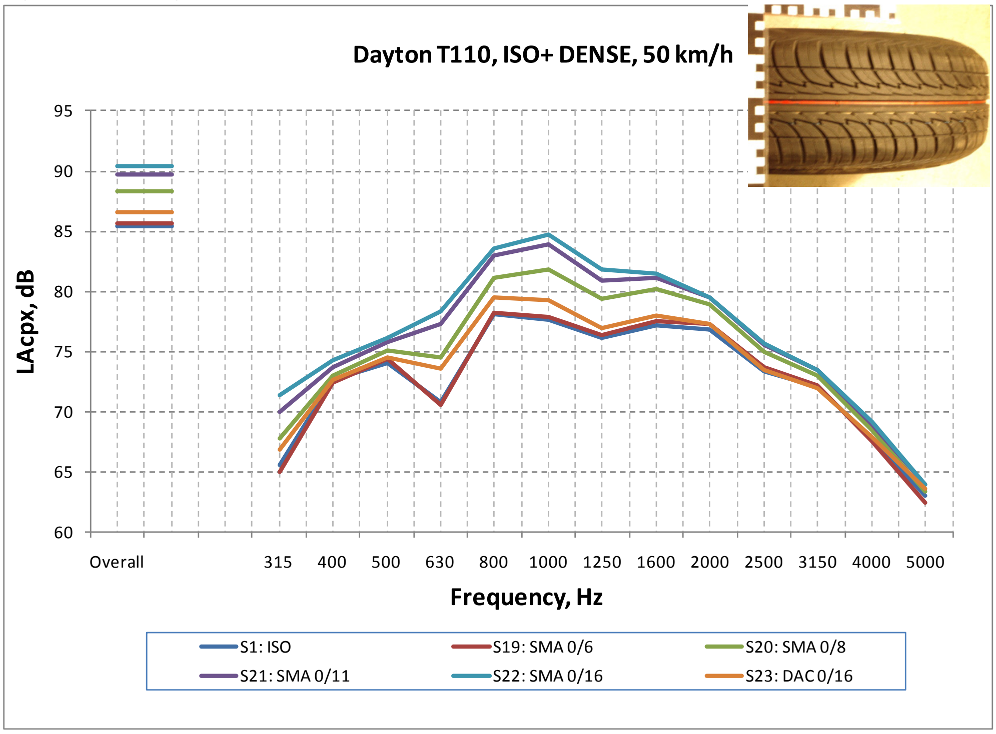

Figure 38 *Tyre 1: Dayton T11. Dense surfaces, 50 km/h*

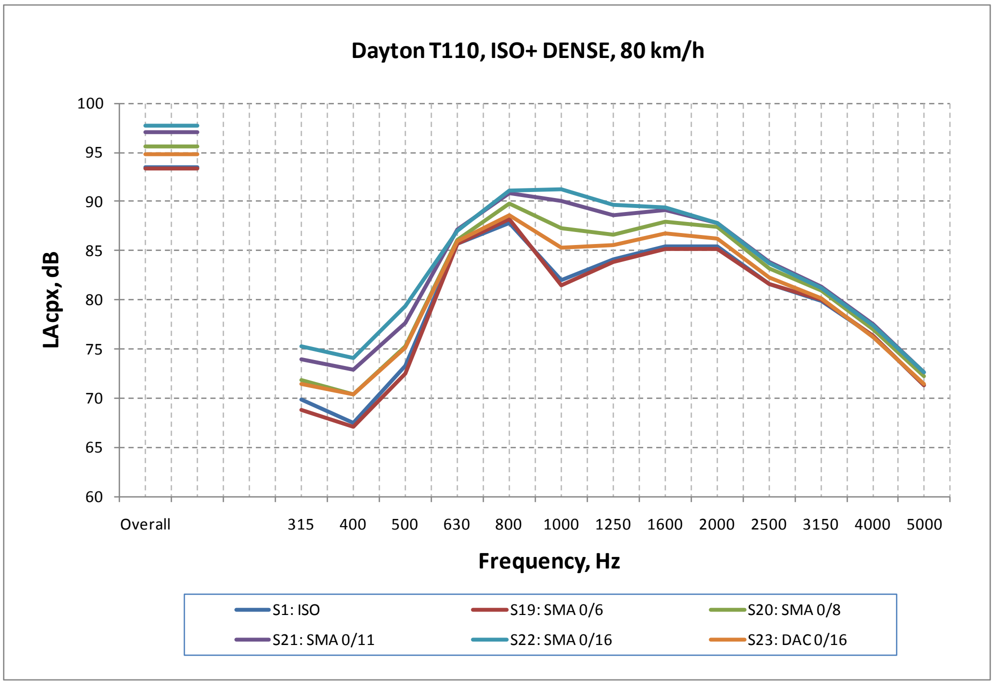

Figure 39 *Tyre 1: Dayton T110. Dense surfaces, 80 km/h*

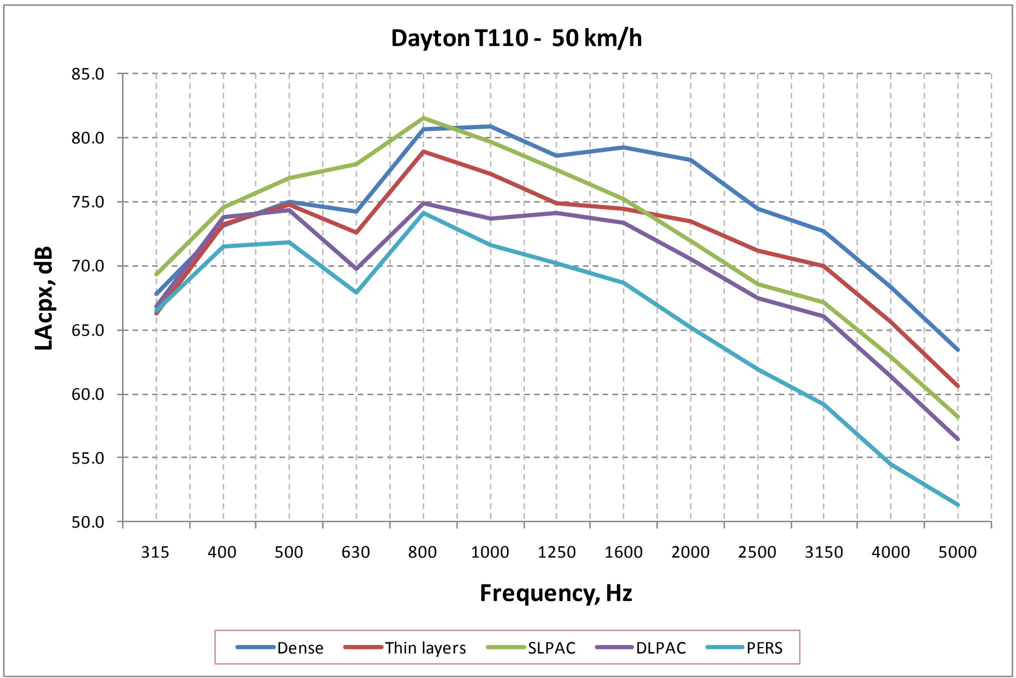

Figure 40 *Tyre 1: Dayton T110, average spectra for 5 categories of road surfaces, 50 km/h*

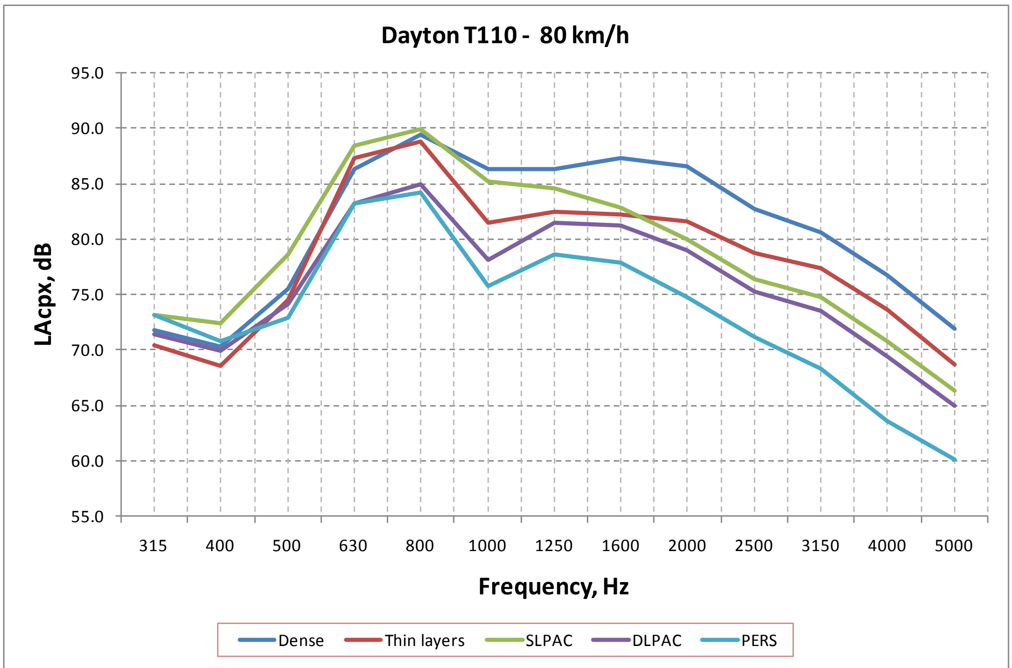

Figure 41 *Tyre 1: Dayton T110, average spectra for 5 categories of road surfaces, 80 km/h*

Tyre 2: Sportiva G70

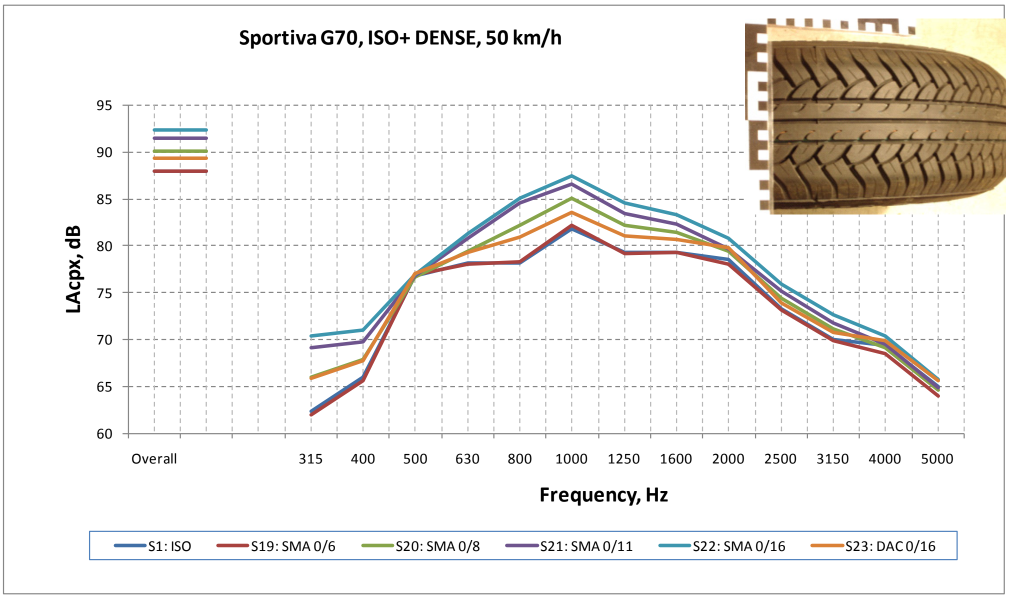

Figure 42 *Tyre 2: SportivaG70. Dense surfaces, 50 km/h*

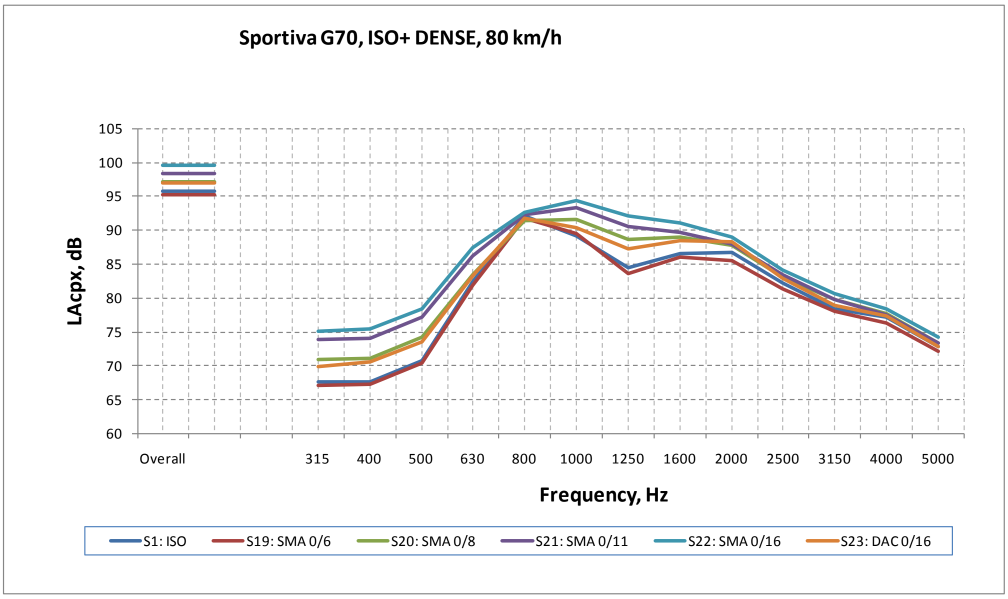

Figure 43 *Tyre 2: SportivaG70, Dense surfaces, 80 km/h*

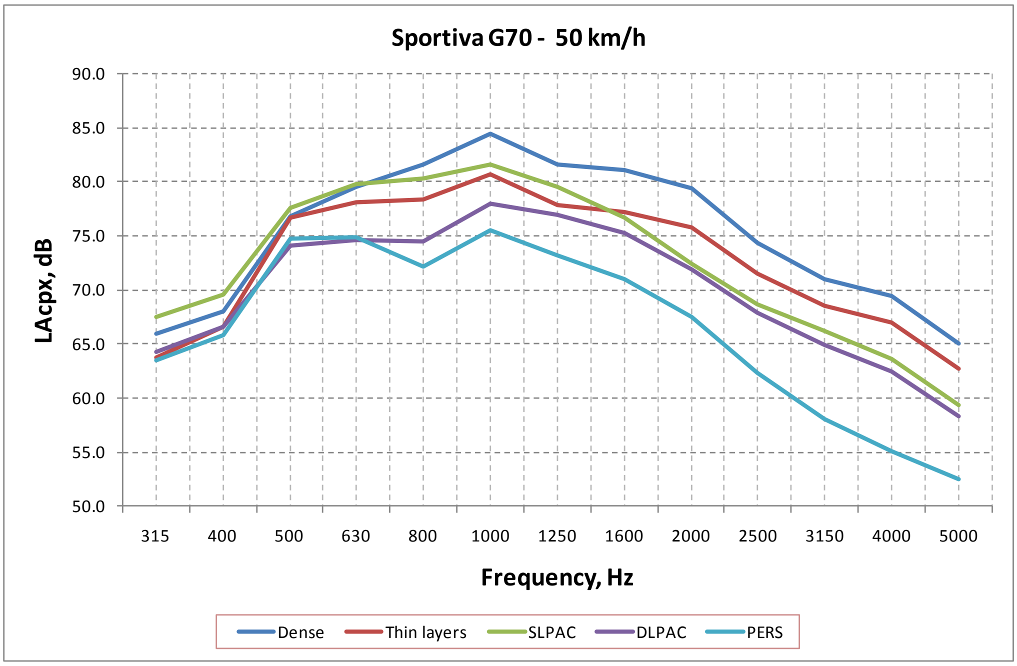

Figure 44 *Tyre 2: Sportiva G70, average spectra for 5 categoriess of road surfaces, 50 km/h*

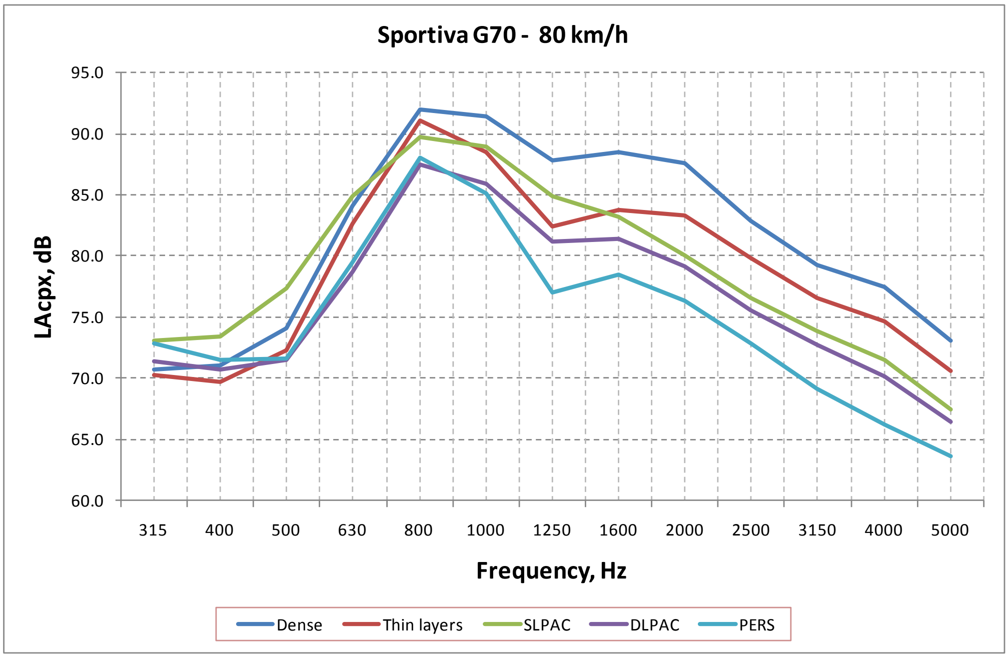

Figure 45 *Tyre 2: Sportiva G70, average spectra for 5 categories of road surfaces, 80 km/h*

Tyre 3: Barum Brilliantis

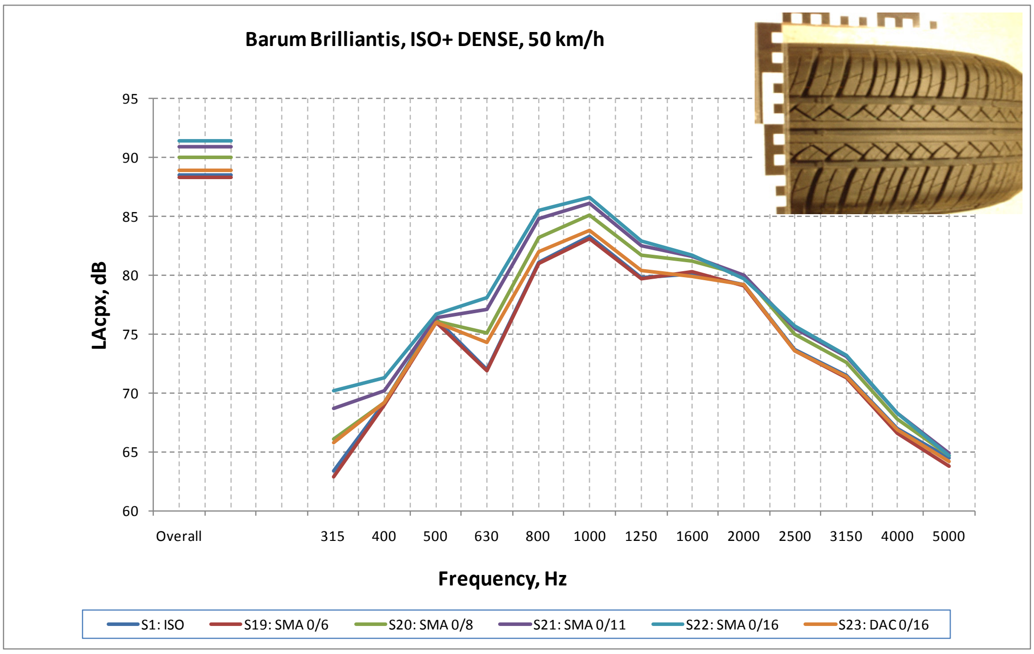

Figure 46 *Tyre 3: Barum Brillianti. Dense surfaces, 50 km/h*

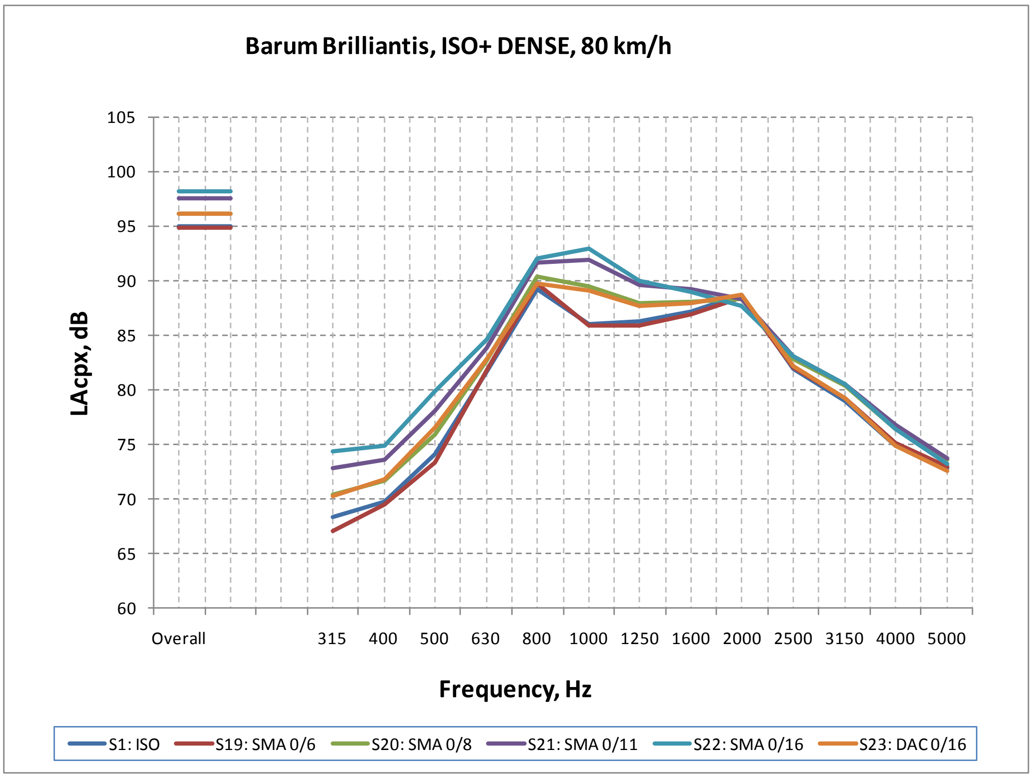

Figure 47 *Tyre 3: Barum Brilliants. Dense surfaces, 80 km/h*

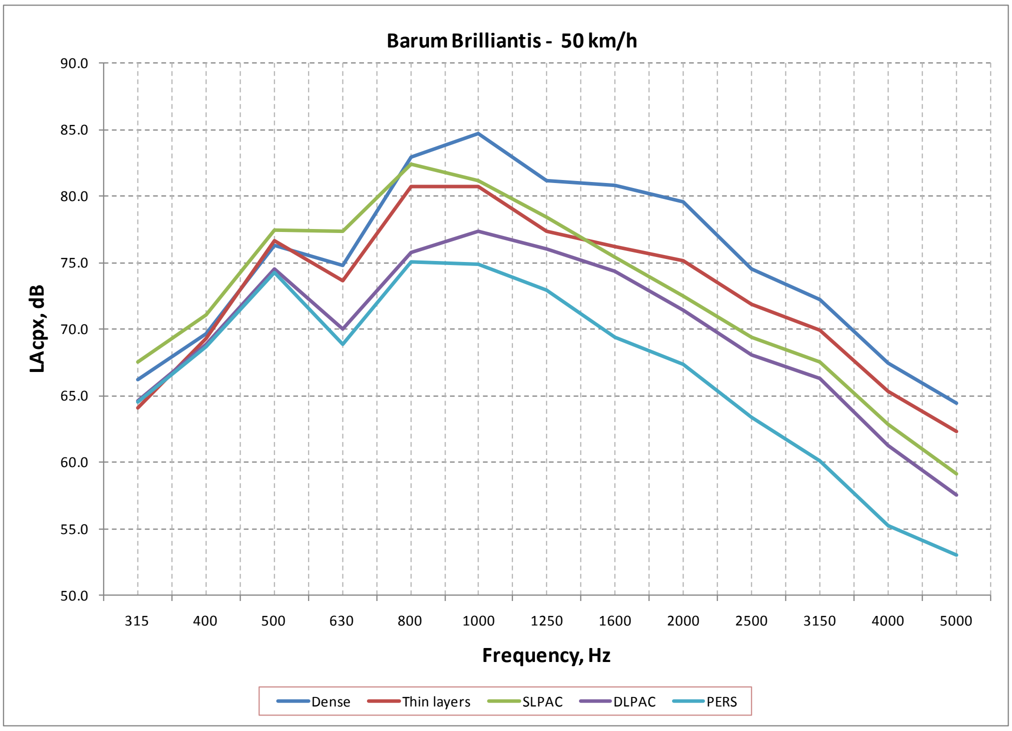

Figure 48 *Tyre 3: Barum Brilliantis, average spectra for 5 categories of road surfaces, 50 km/h*

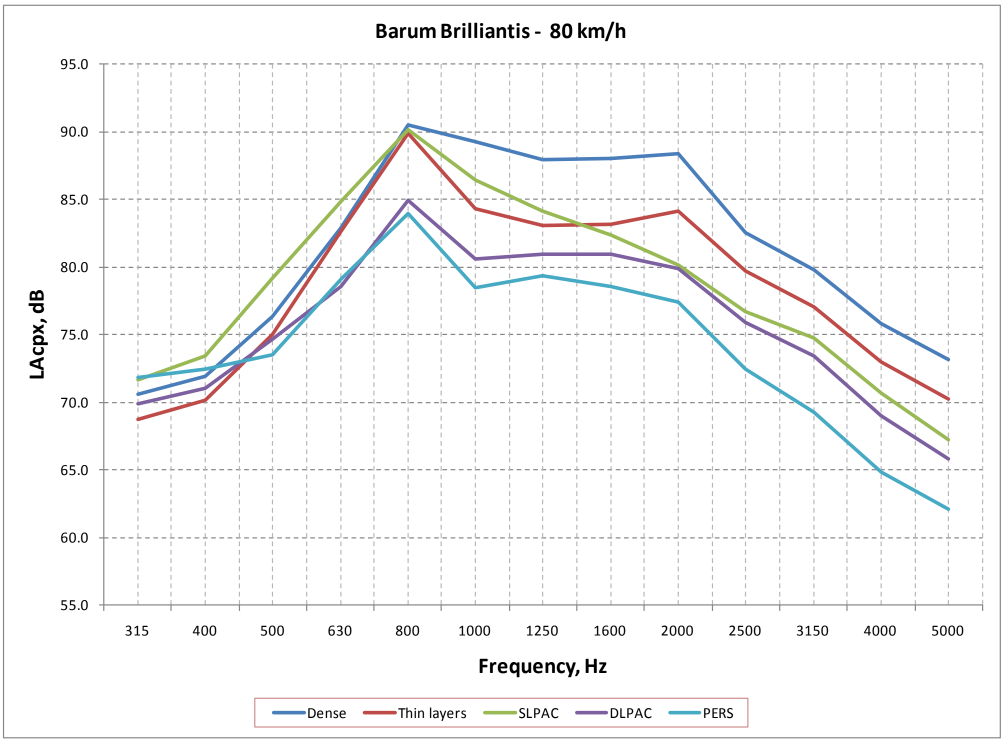

Figure 49 *Tyre 3: Barum Brilliantis, average spectra for 5 categories of road surfaces, 80 km/h*

Tyre 4: Toyo 330

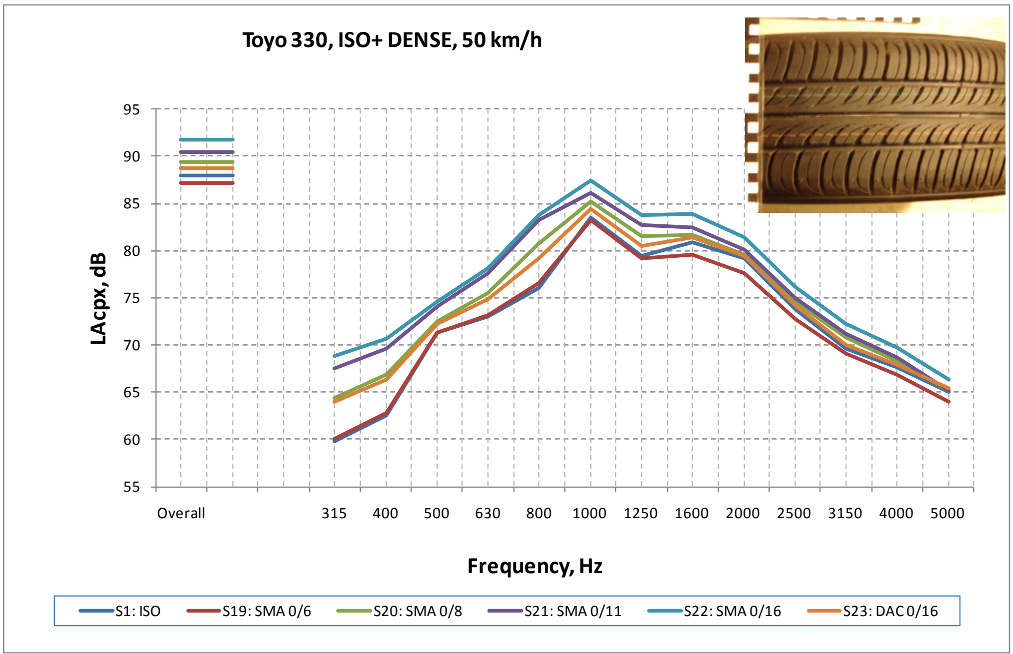

Figure 50 *Tyre 4: Toyo 330. Dense surfaces, 50 km/h*

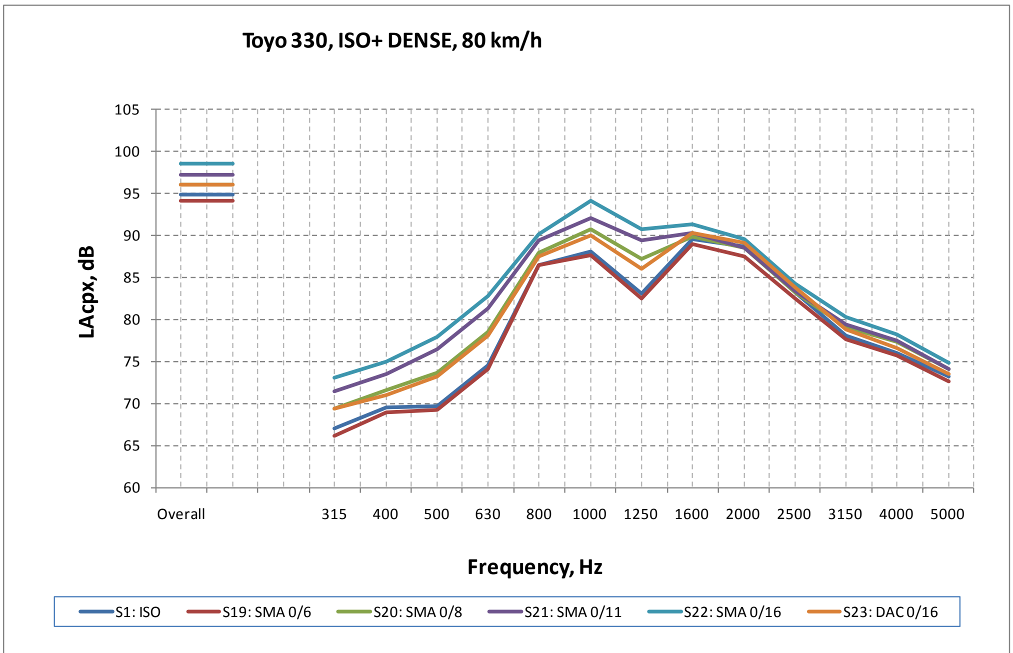

Figure 51 *Tyre 4: Toyo 330. Dense surfaces, 80 km/h*

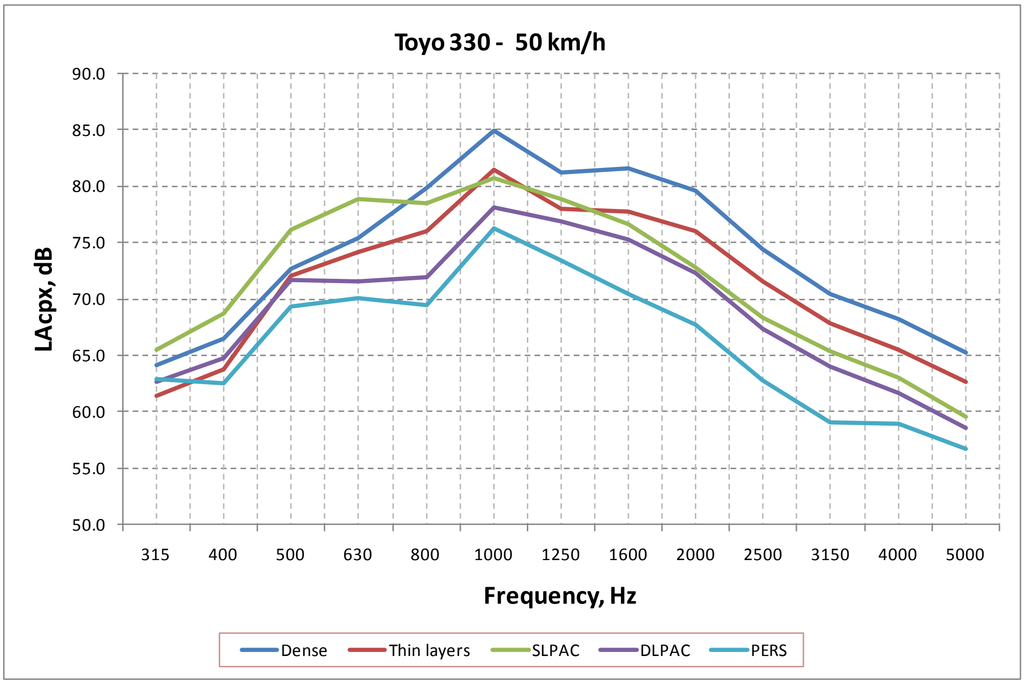

***Figure 52** Tyre 4: Toyo 330, average spectra for 5 categories of road surfaces, 50 km/h*

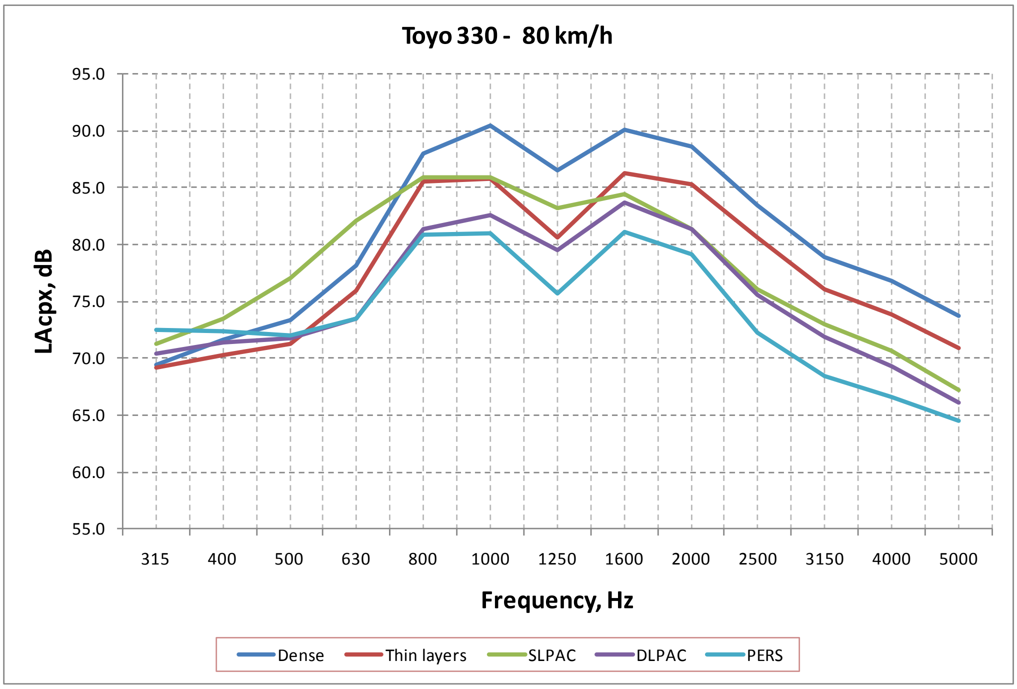

***Figure 53** Tyre 4: Toyo 330, average spectra for 5 categories of road surfaces, 80 km/h*

Tyre 5: Goodyear Excellence

The frequency spectrum for this tyre on a Norwegian SMA0/11-surface is included in figure 55, for comparison.

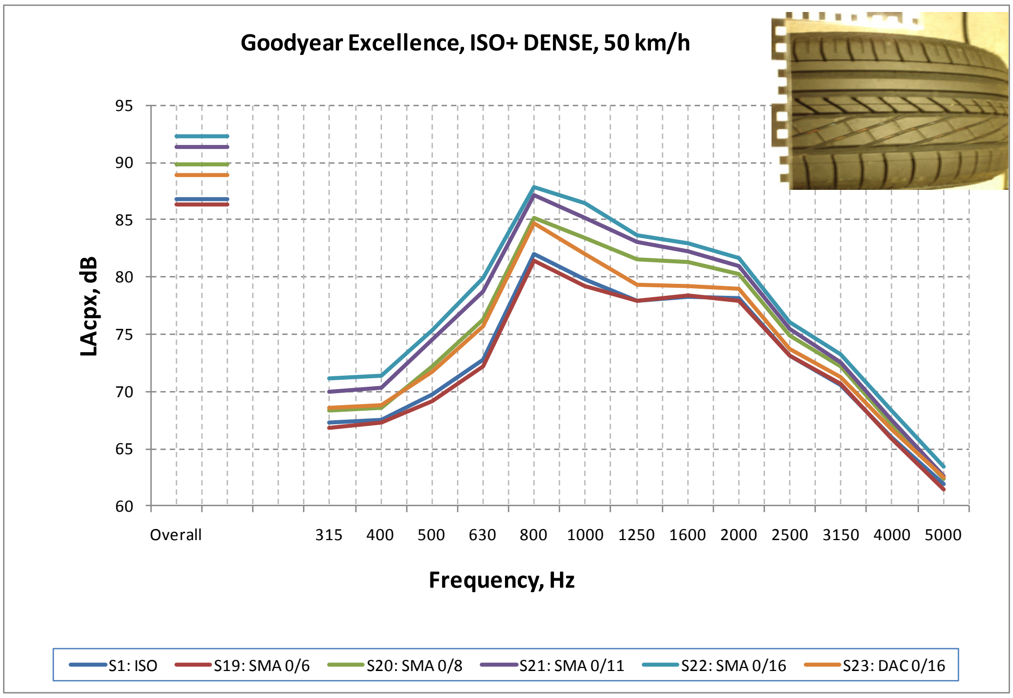

Figure 54 *Tyre 5: Goodyear Excellence. Dense surfaces, 50 km/h*

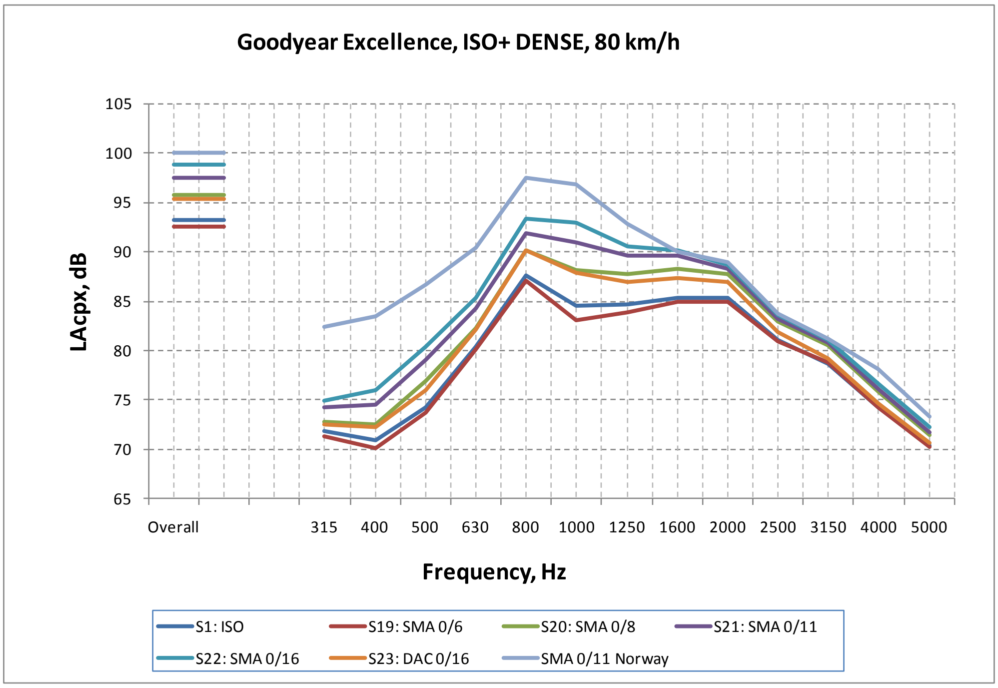

Figure 55 *Tyre 5: Goodyear Excellence. Dense surfaces, 80 km/h*

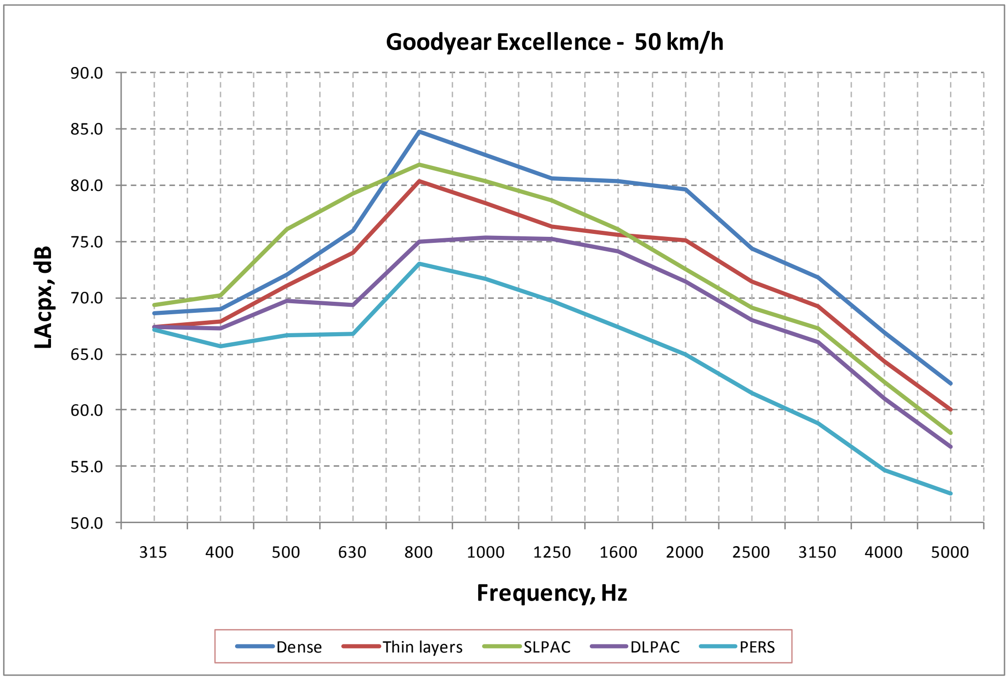

Figure 56 *Tyre 5: Goodyear Excellence, average spectra for 5 categories of road surfaces, 50 km/h*

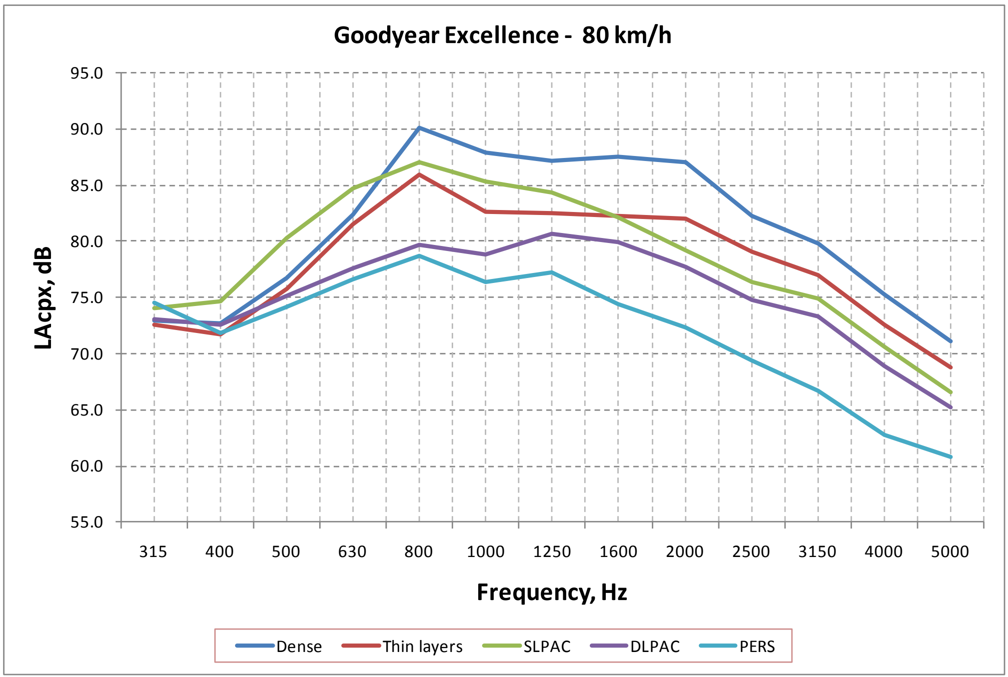

Figure 57 *Tyre 5: Goodyear Excellence, average spectra for 5 categories of road surfaces, 80 km/h*

Tyre 6: Conti Premium Contact2

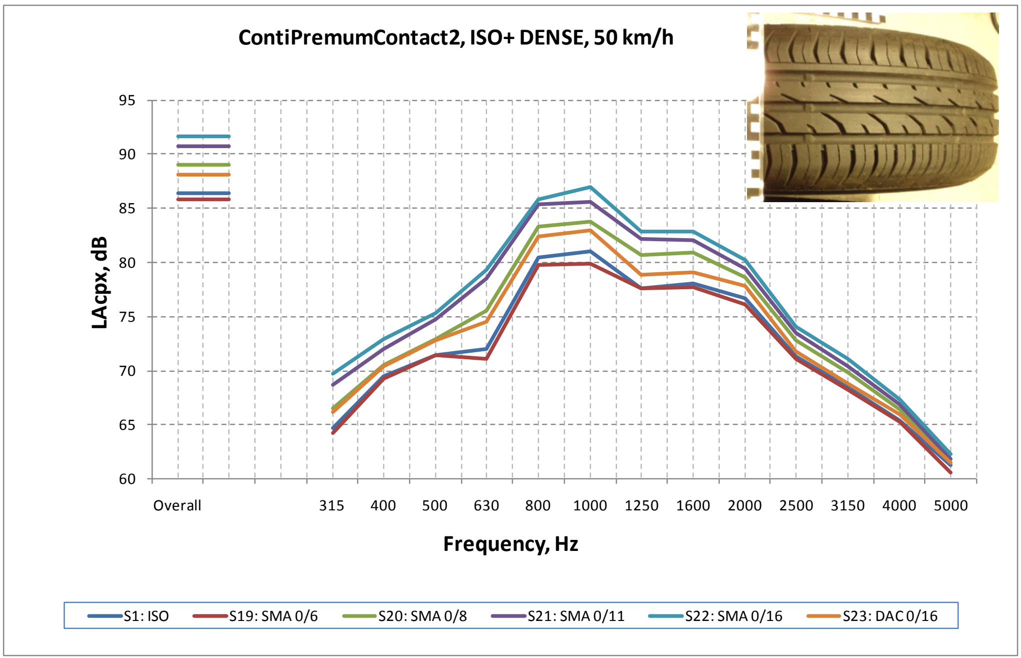

Figure 58 *Tyre 6: ContiPremuimContact2. Dense surfaces, 50 km/h*

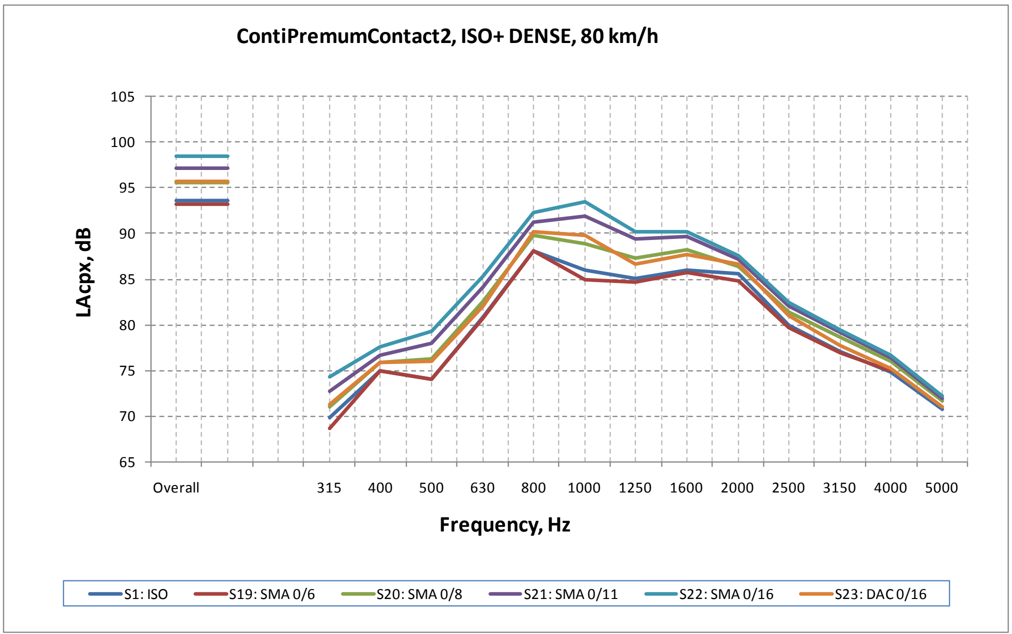

Figure 59 *Tyre 6: ContiPremuimContact2. Dense surfaces, 80 km/h*

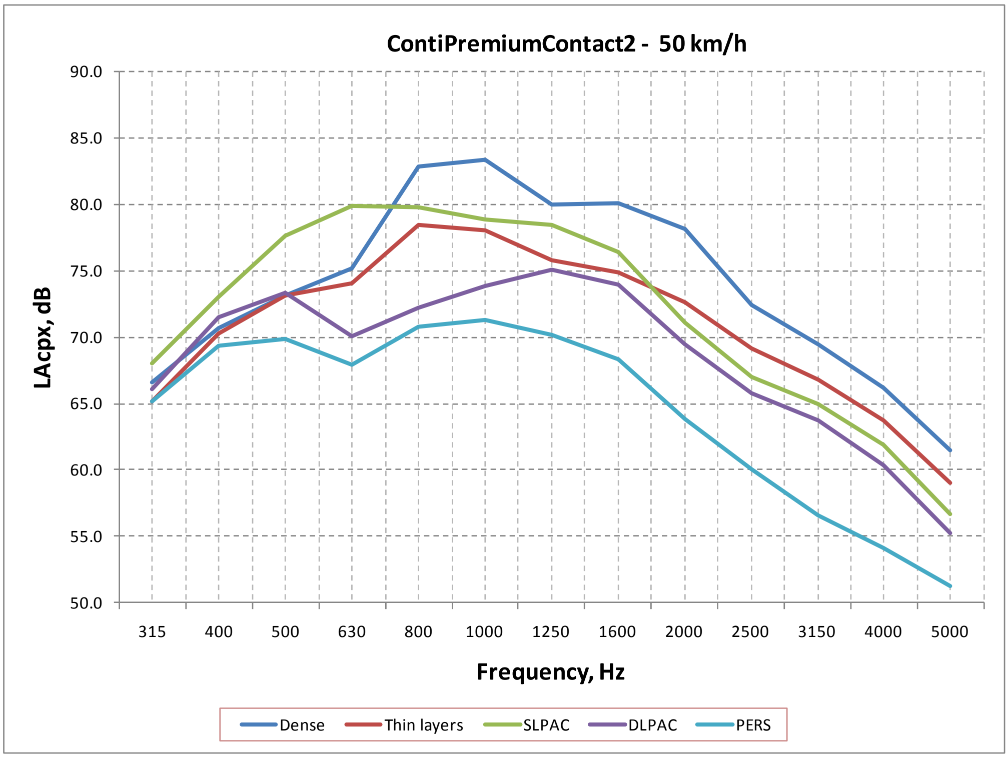

Figure 60 *Tyre 6: ContiPremiumContact2, average spectra for 5 categories of road surfaces, 50 km/h*

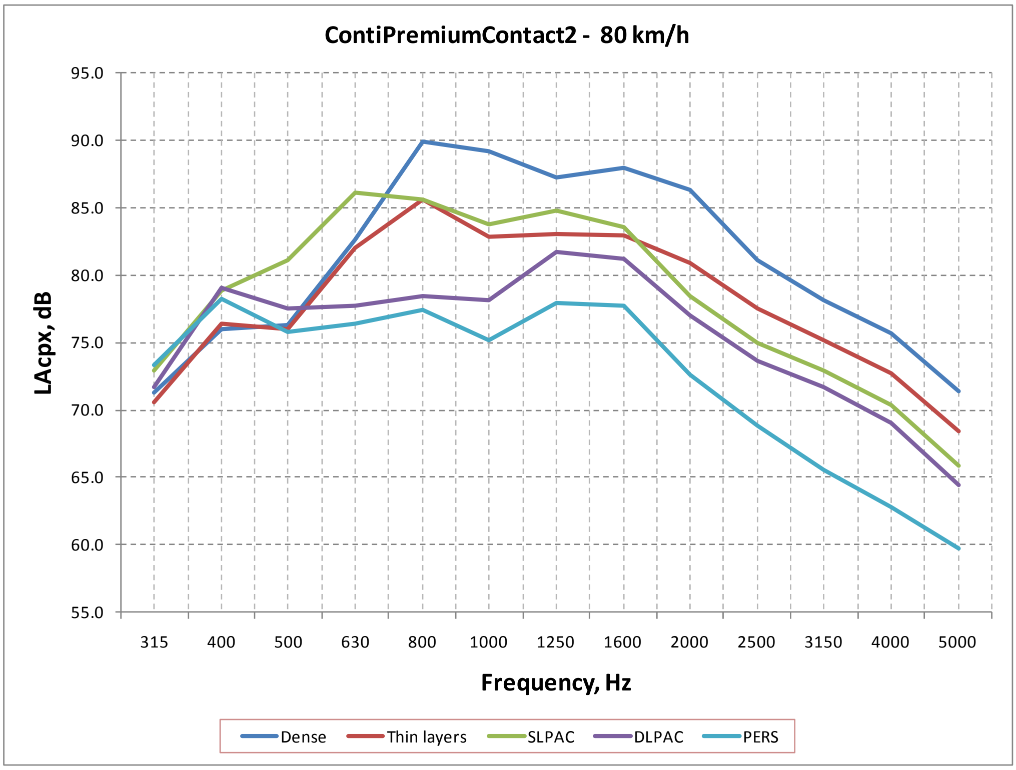

Figure 61 *Tyre 6: ContiPremiumContact2, average spectra for 5 categories of road surfaces, 80 km/h*

Tyre 7: Toyo Proxes T1R

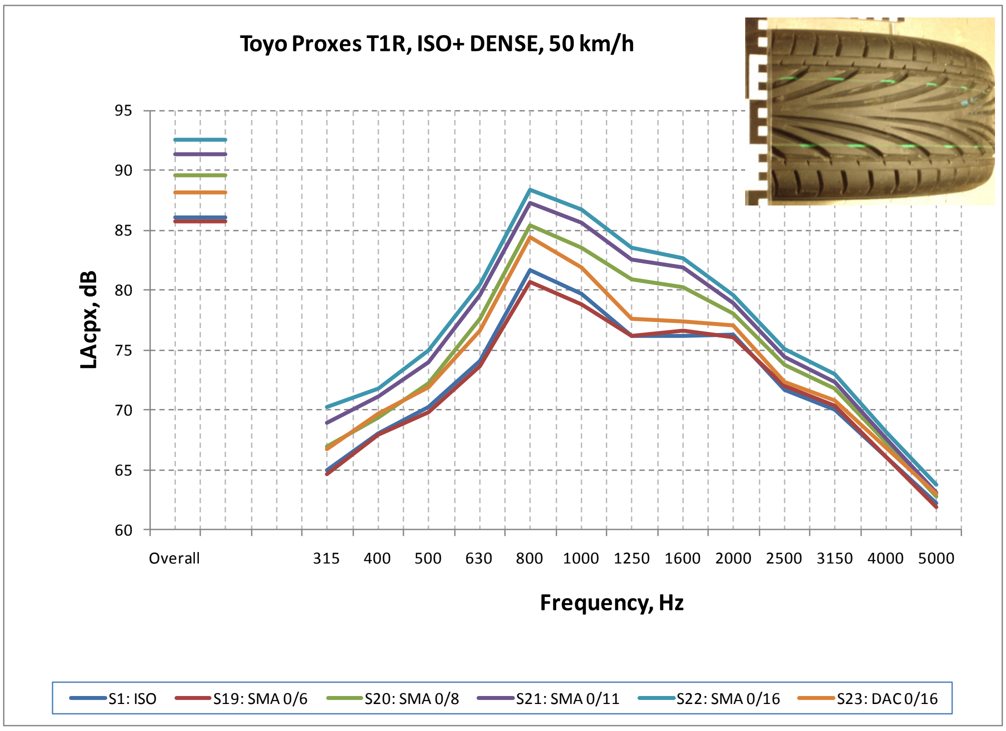

Figure 62 *Tyre 7: Toyo Proxes T1R. Dense surfaces, 50 km/h*

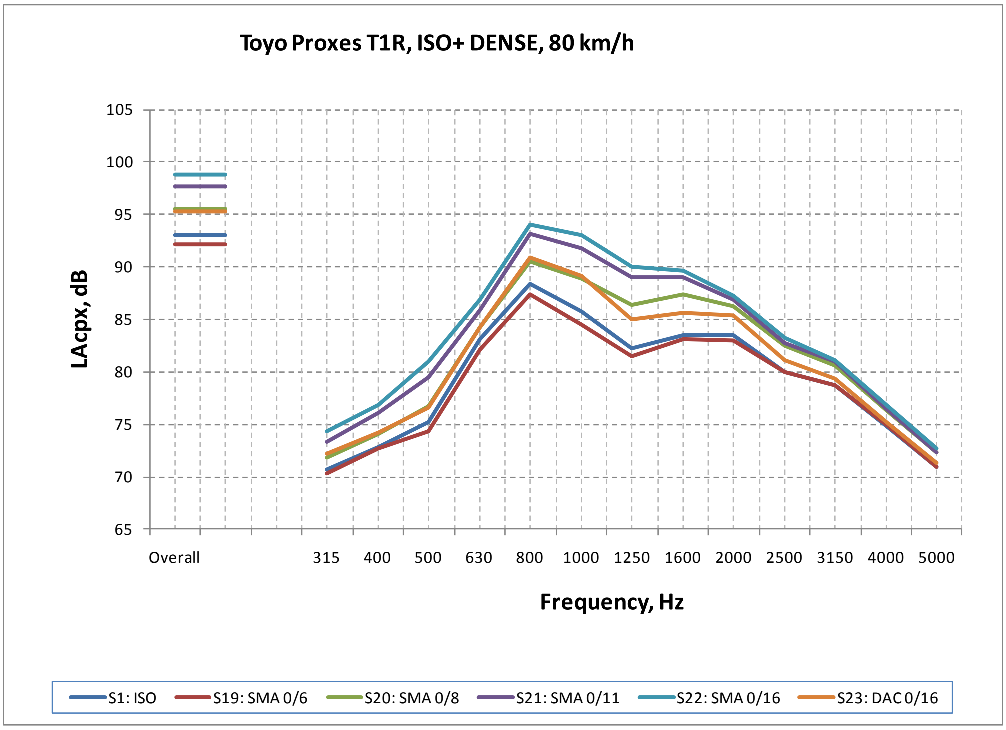

Figure 63 *Tyre 7: Toyo Proxes T1R. Dense surfaces, 80 km/h*

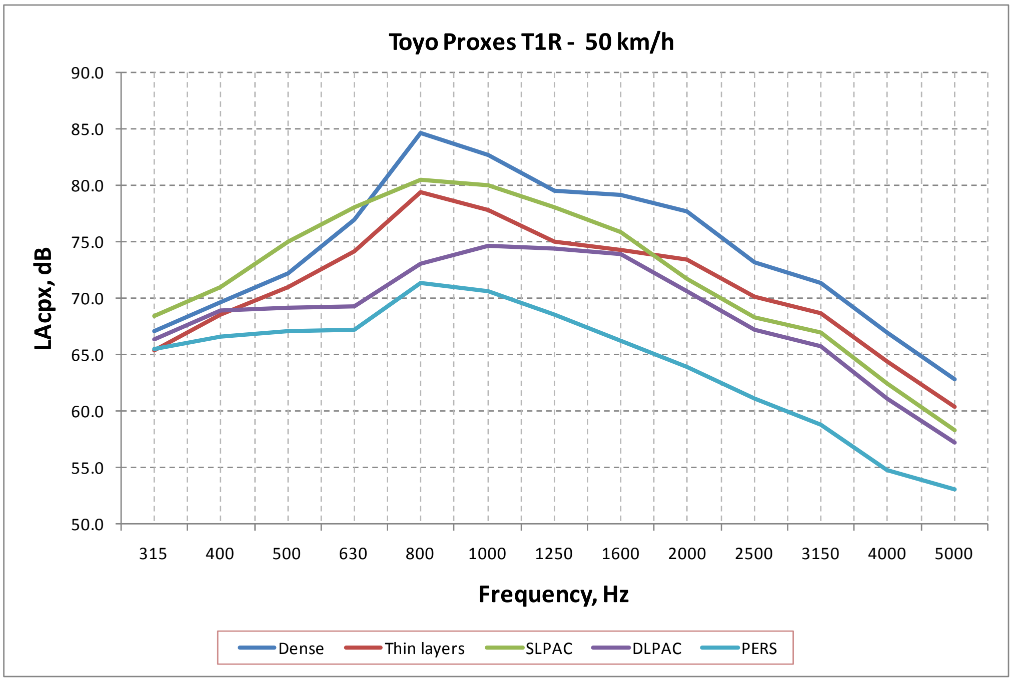

Figure 64 *Tyre 7: Toyo Proxes T1R, average spectra for 5 categories of road surfaces, 50 km/h*

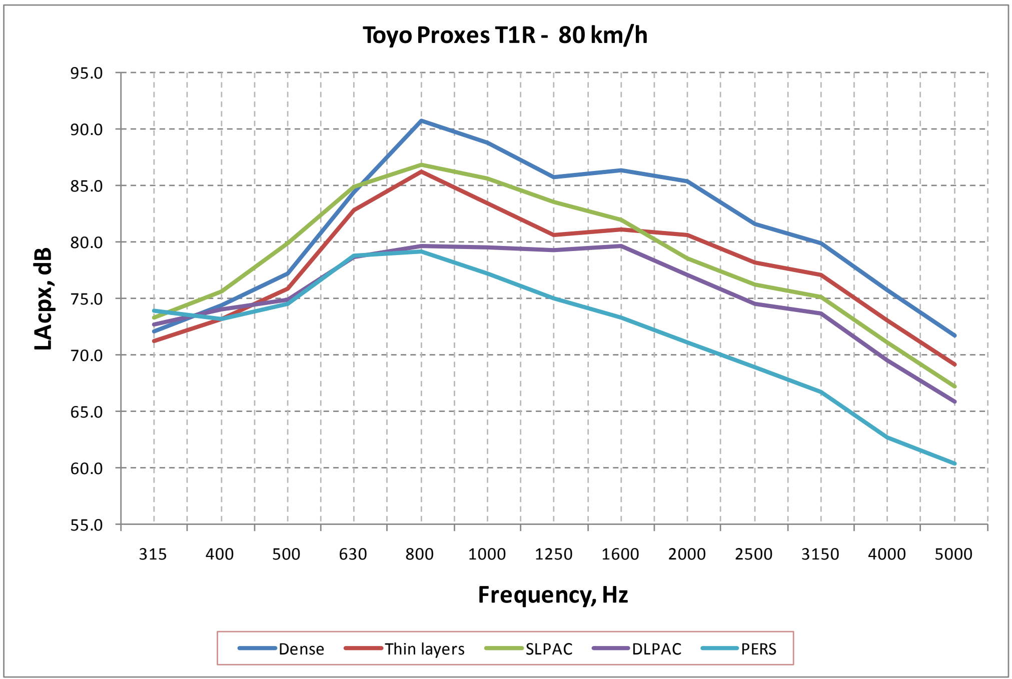

Figure 65 *Tyre 7: Toyo Proxes T1R, average spectra for 5 categories of road surfaces, 80 km/h*

Tyre 8: Nokian Hakka H

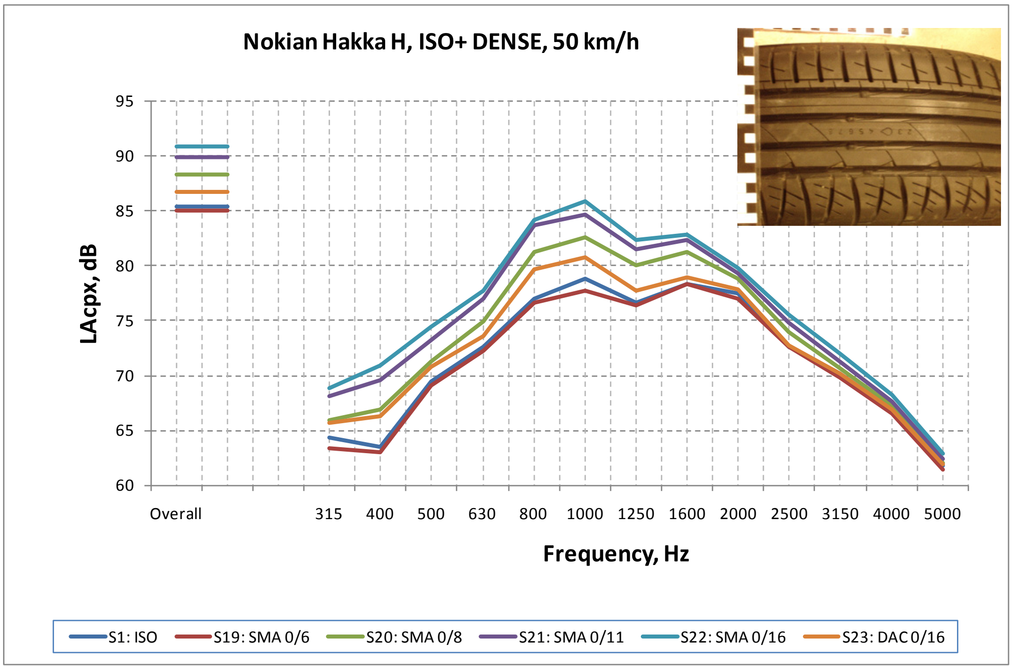

Figure 66 *Tyre 8: Nokian Hakka H. Dense surfaces, 50 km/h*

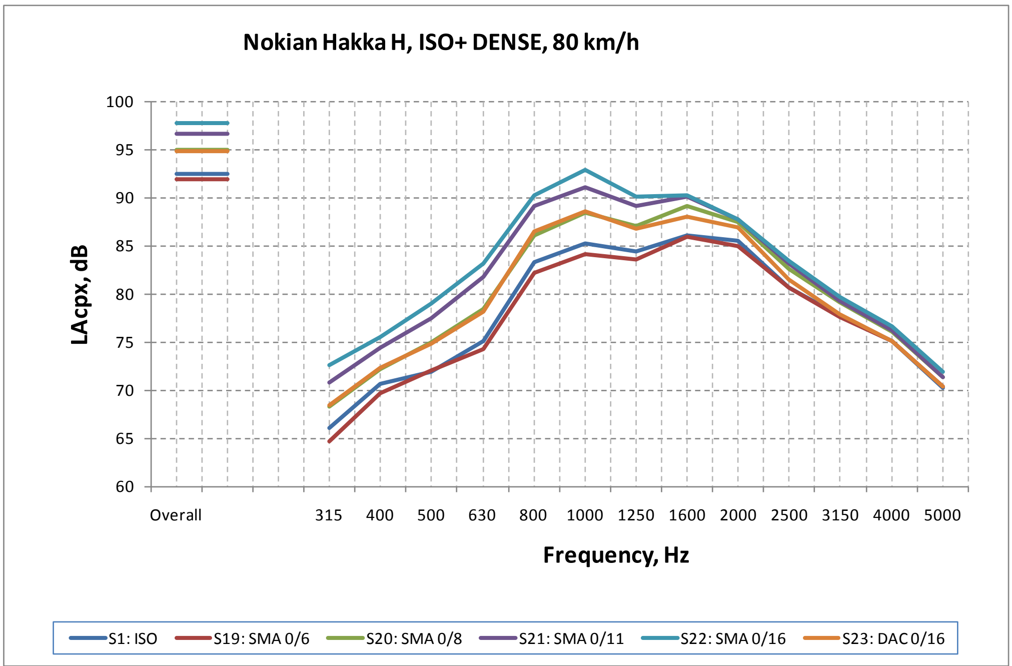

Figure 67 *Tyre 8: Nokian Hakka H. Dense surfaces, 80 km/h*

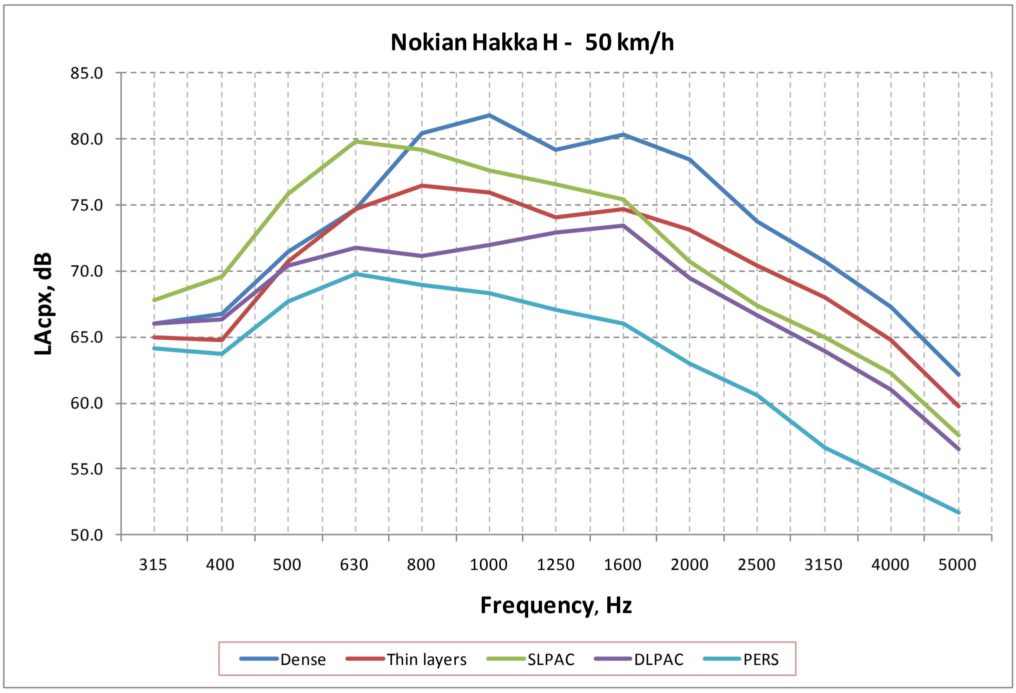

Figure 68 *Tyre 8: Nokian Hakka H, average spectra for 5 categories of road surfaces, 50 km/h*

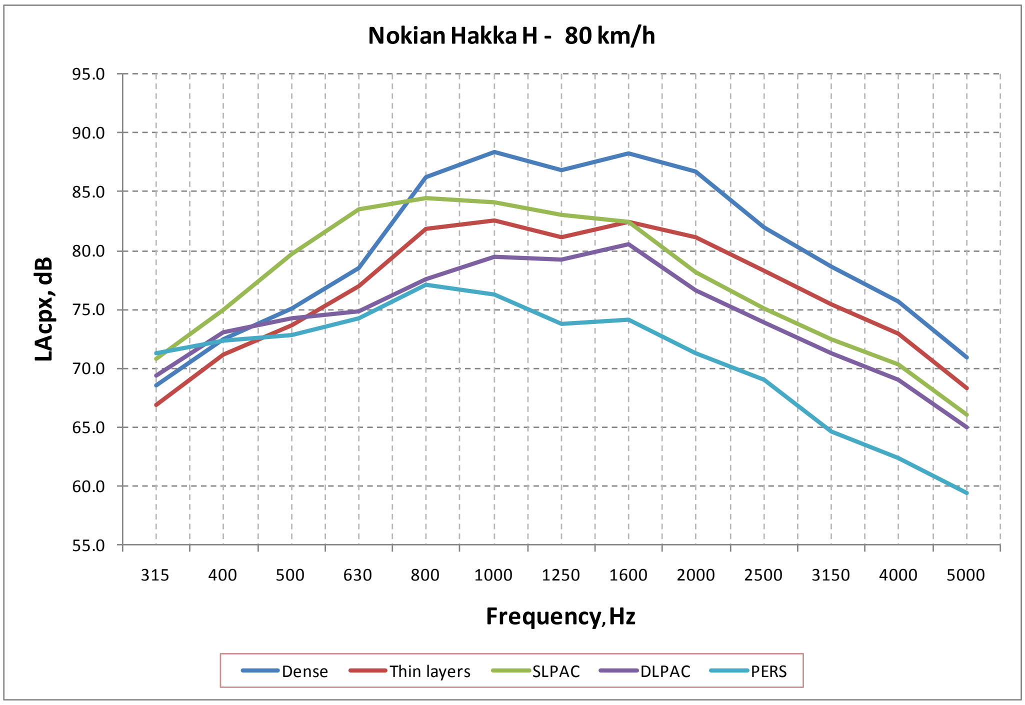

Figure 69 *Tyre 8: Nokian Hakka H, average spectra for 5 categories of road surfaces, 80 km/h*

Tyre 9: Michelin Pilot Primacy HP

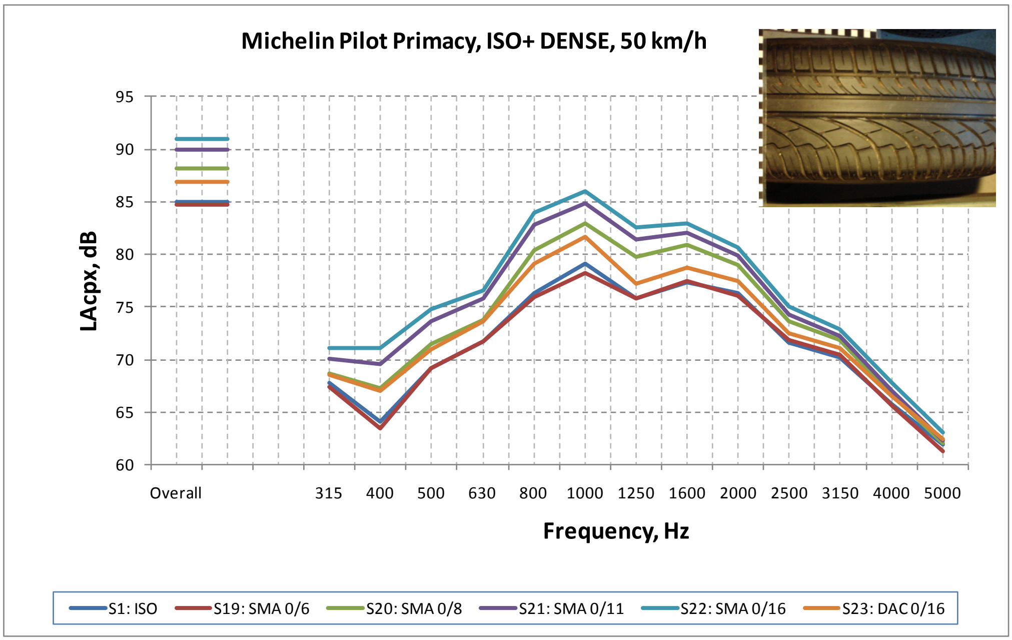

Figure 70 *Tyre 9: Michelin Pilot Primacy. Dense surfaces, 50 km/h*

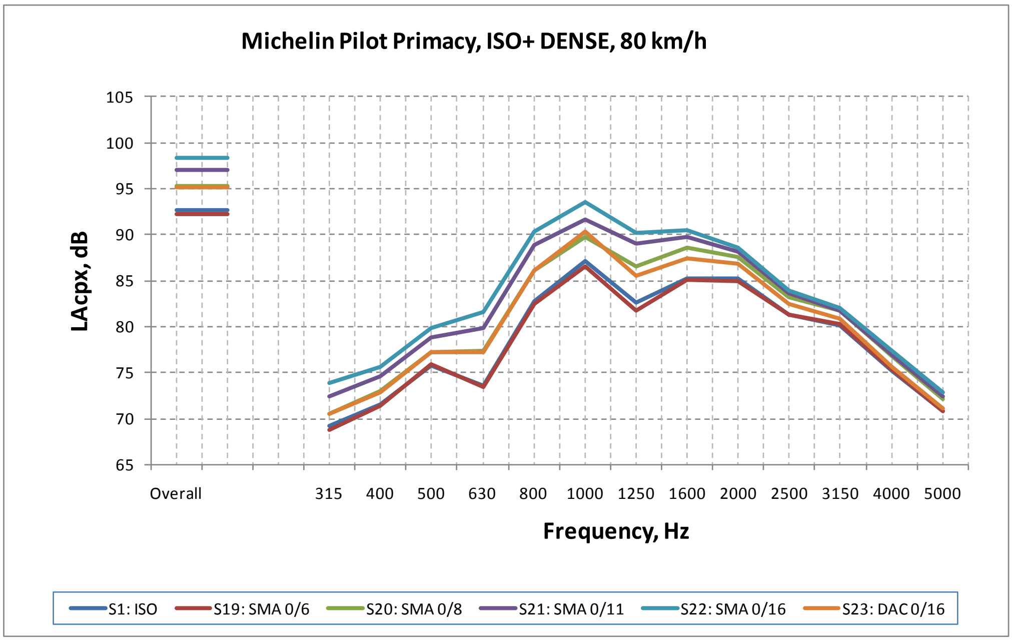

Figure 71 *Tyre 9: Michelin Pilot Primacy. Dense surfaces, 80 km/h*

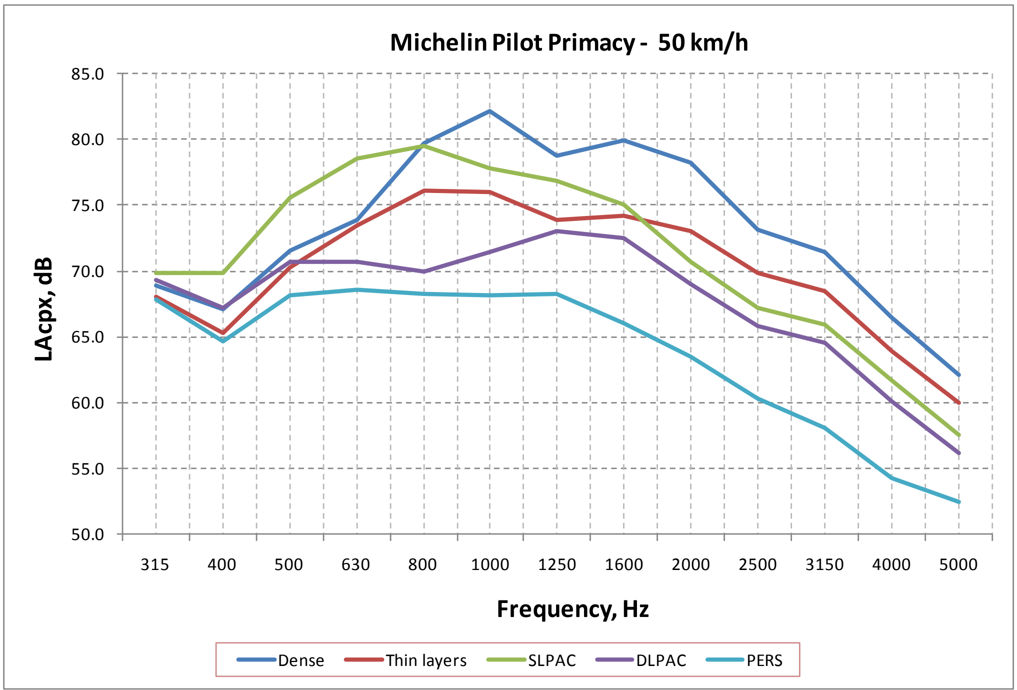

Figure 72 *Tyre 9: Michelin Pilot Primacy, average spectra for 5 categories of road surfaces, 50 km/h*

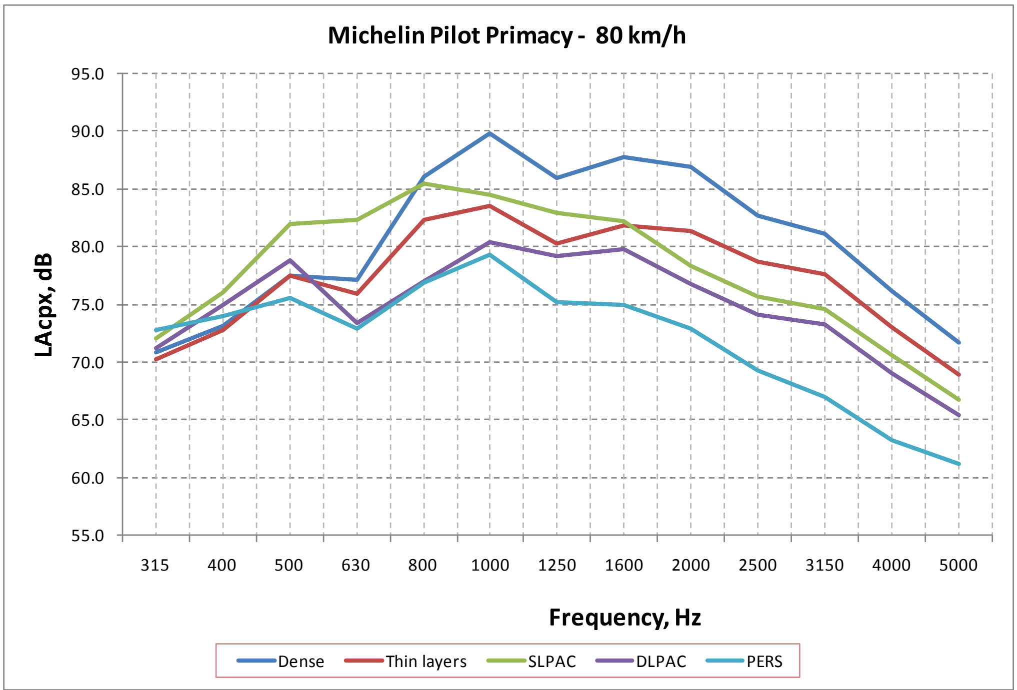

Figure 73 *Tyre 9: Michelin Pilot Primacy, average spectra for 5 categories of road surfaces, 80 km/h*

Tyre 10: Firestone Firehawk TZ200

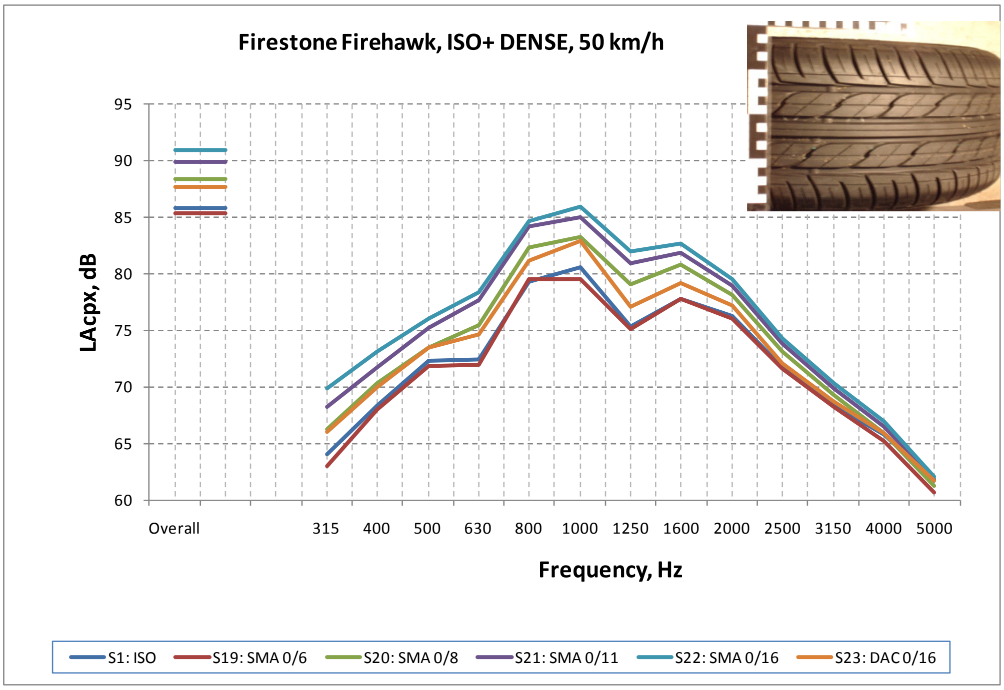

Figure 74 *Tyre 10: Firestone Firehawk TZ200. Dense surfaces, 50 km/h*

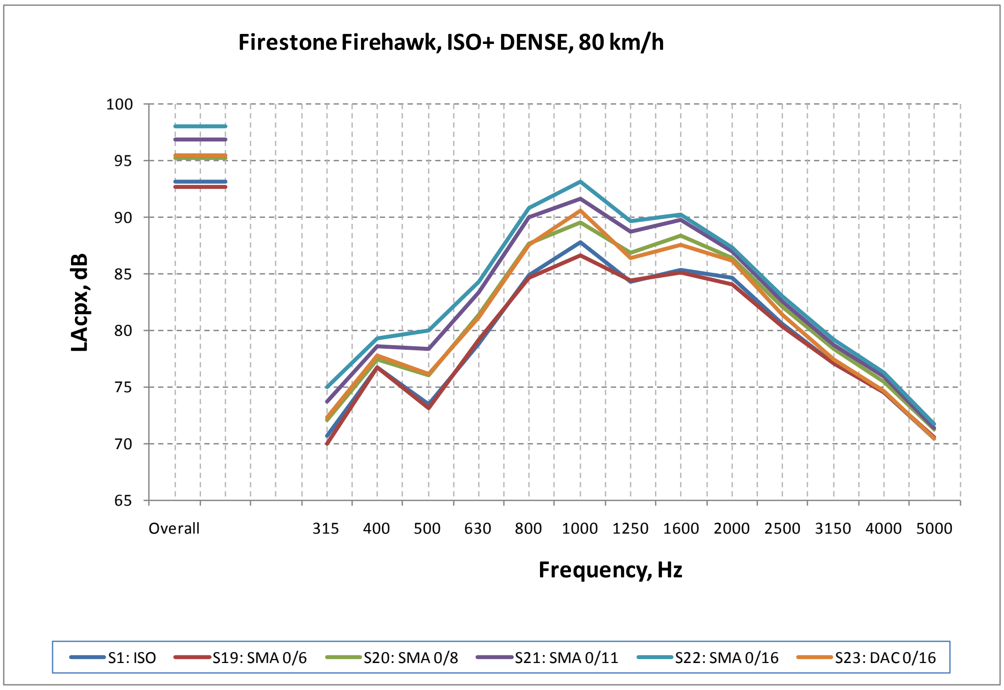

Figure 75 *Tyre 10: Firestone Firehawk TZ200. Dense surfaces, 80 km/h*

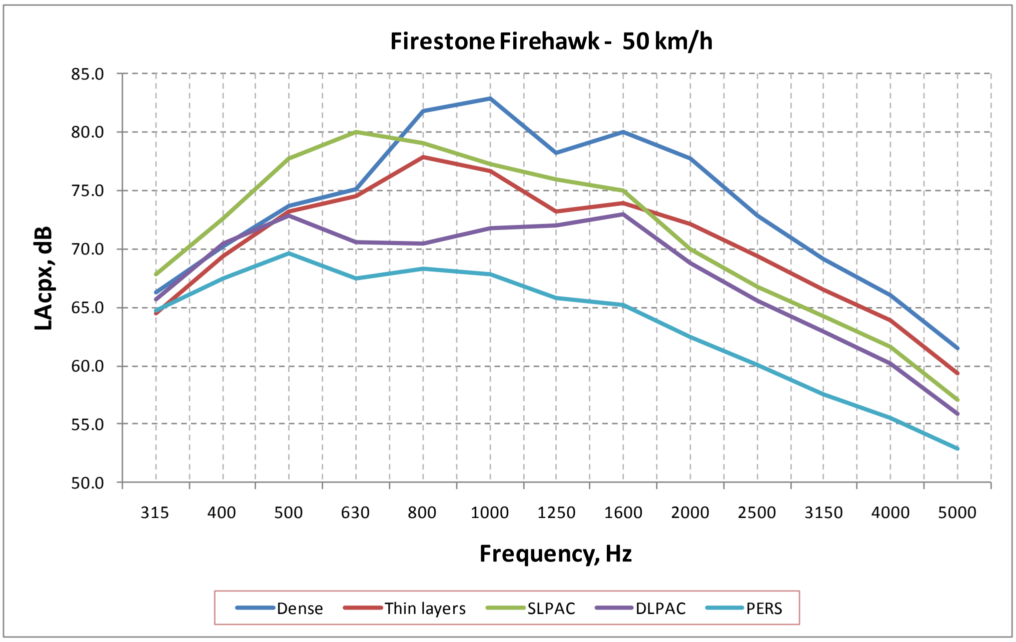

Figure 76 *Tyre 10: Firestone Firehawk TZ200, average spectra for 5 categories of road surfaces, 50 km/h*

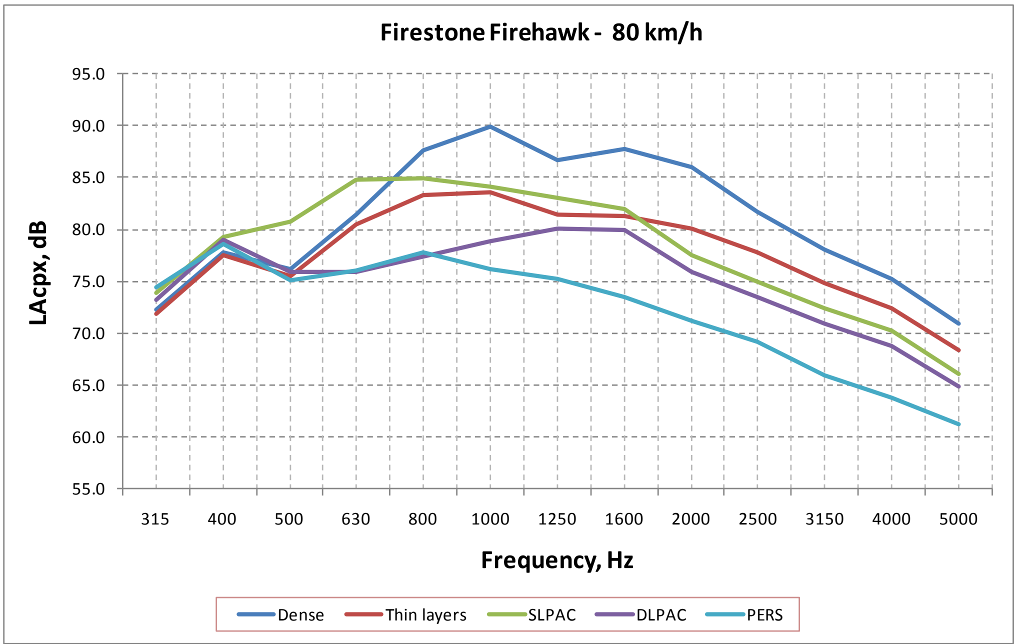

Figure 77 *Tyre 10: Firestone Firehawk TZ200, average spectra for 5 categories of road surfaces, 80 km/h*

Tyre 11: Conti Eco Contact3

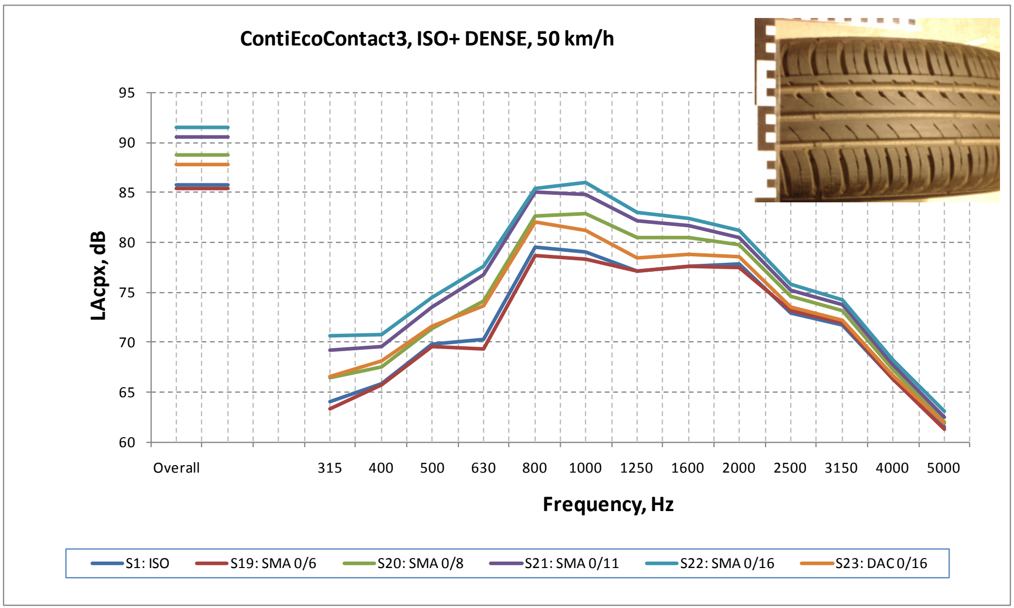

Figure 78 *Tyre 11: ContiEcoContact3, Dense surfaces, 50 km/h*

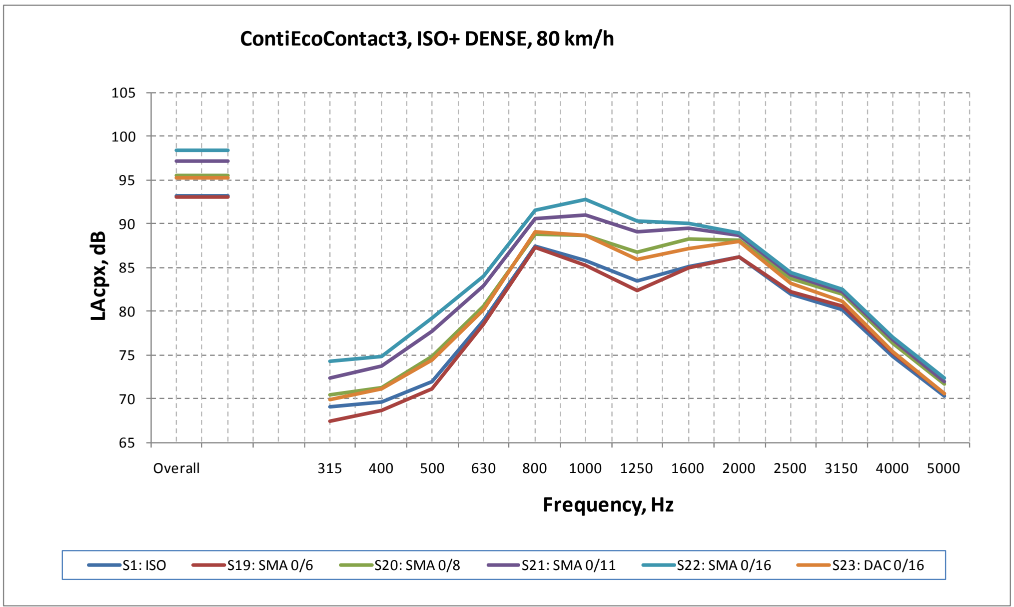

Figure 79 *Tyre 11: ContiEcoContact3. Dense surfaces, 80 km/h*

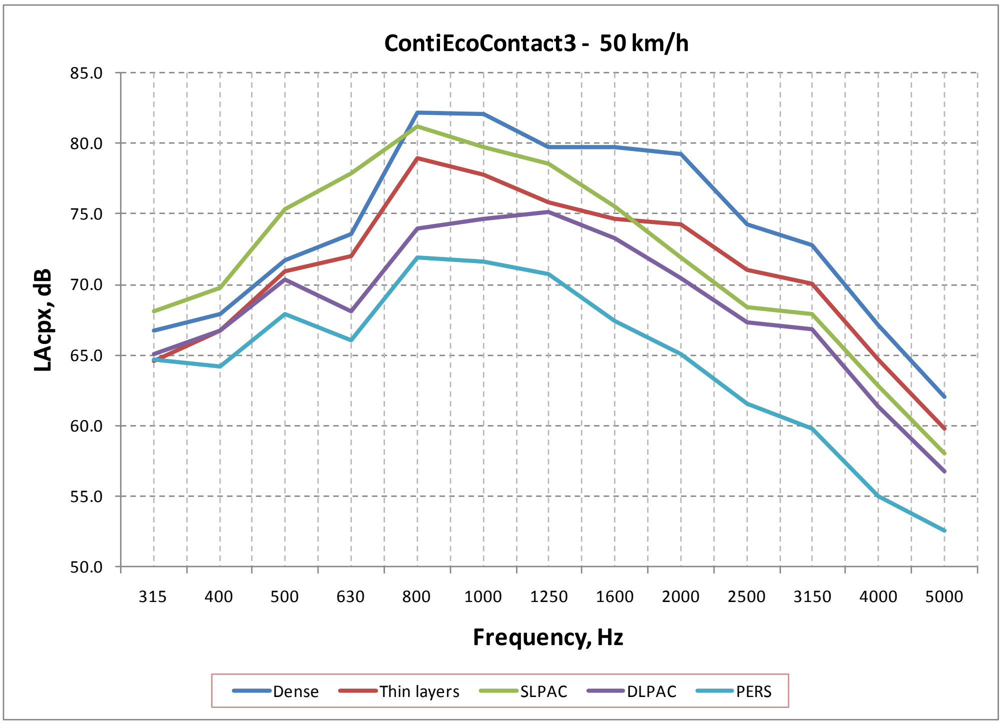

Figure 80 *Tyre 11: ContiEcoContact3, average spectra for 5 categories of road surfaces, 50 km/h*

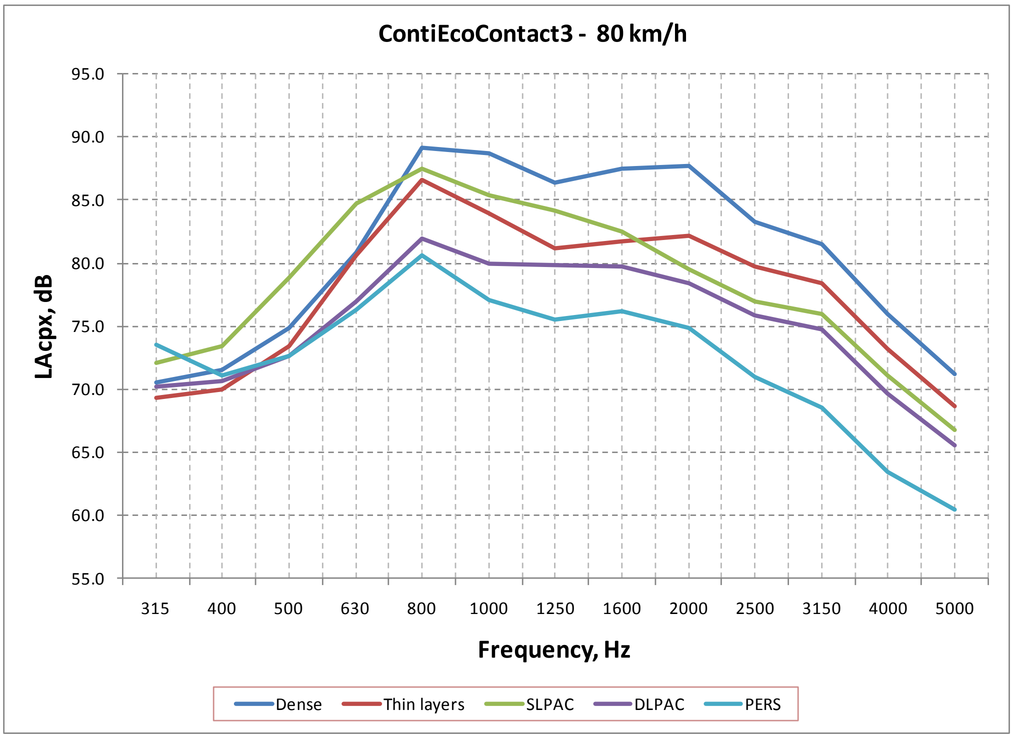

Figure 81 *Tyre 11: ContiEcoContact3, average spectra for 5 categories of road surfaces, 50 km/h*

SINTEF

Tyre 12: Yokohama AVS dB V500

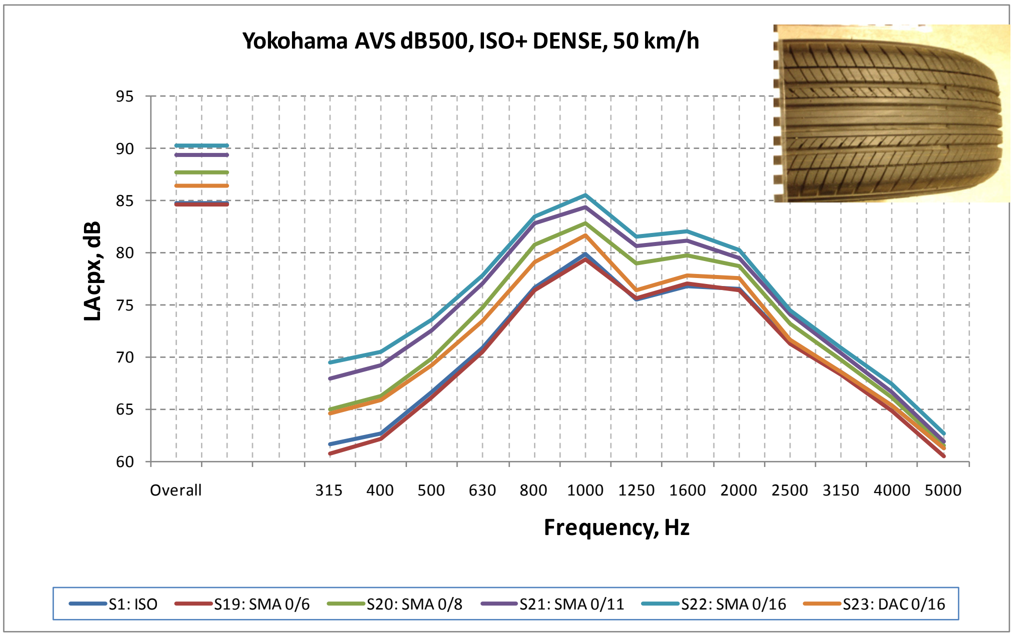

Figure 82 *Tyre 12: Yokohama AVS dB V500. Dense surfaces, 50 km/h*

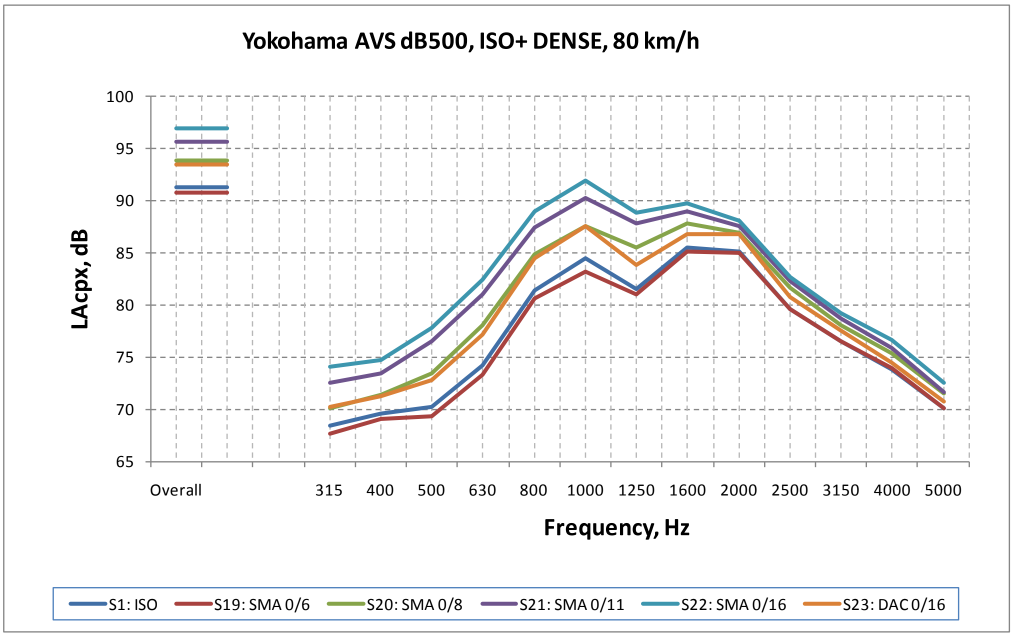

Figure 83 *Tyre 12: Yokohama AVS dB V500. Dense surfaces, 80 km/h*

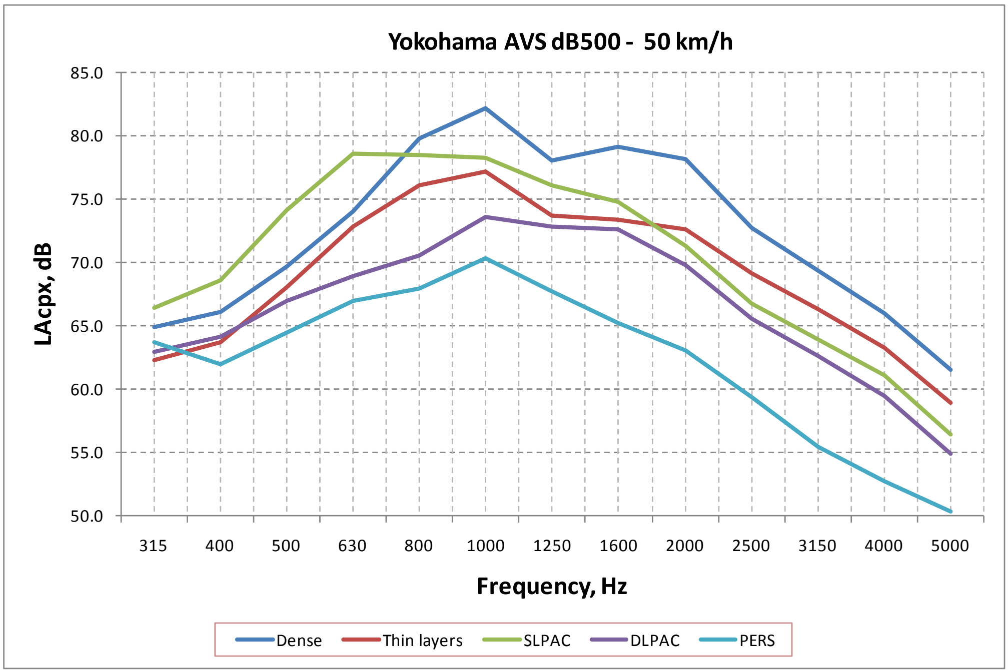

Figure 84 *Tyre 12: Yokohama AVS dB V500, average spectra for 5 categories of road surfaces, 50 km/h*

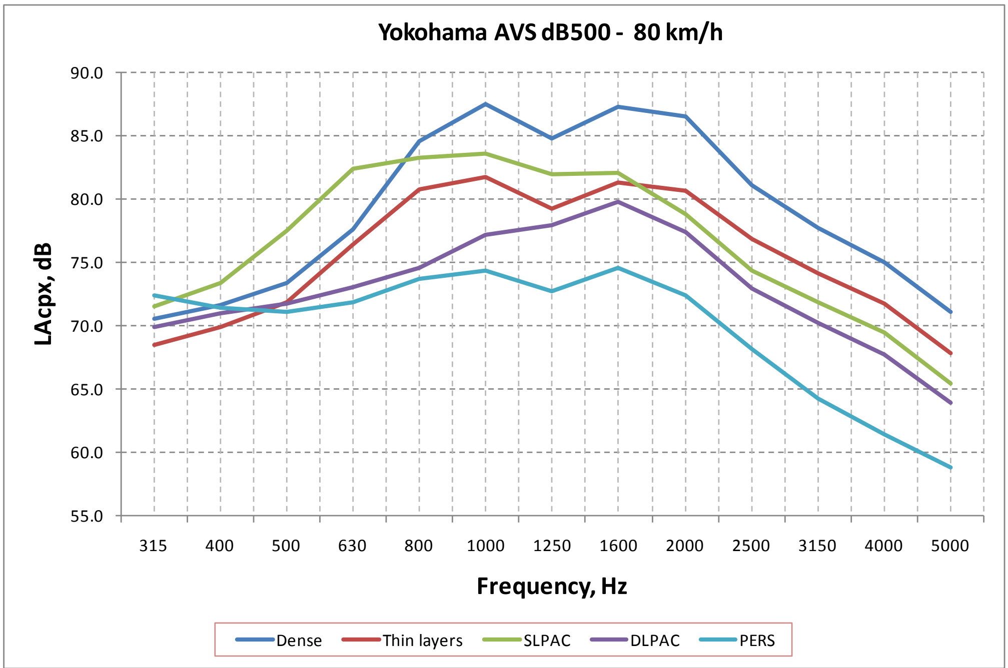

Figure 85 *Tyre 12: Yokohama AVS dB V500, average spectra for 5 categories of road surfaces, 80 km/h*

Tyre 13: Pirelli P7

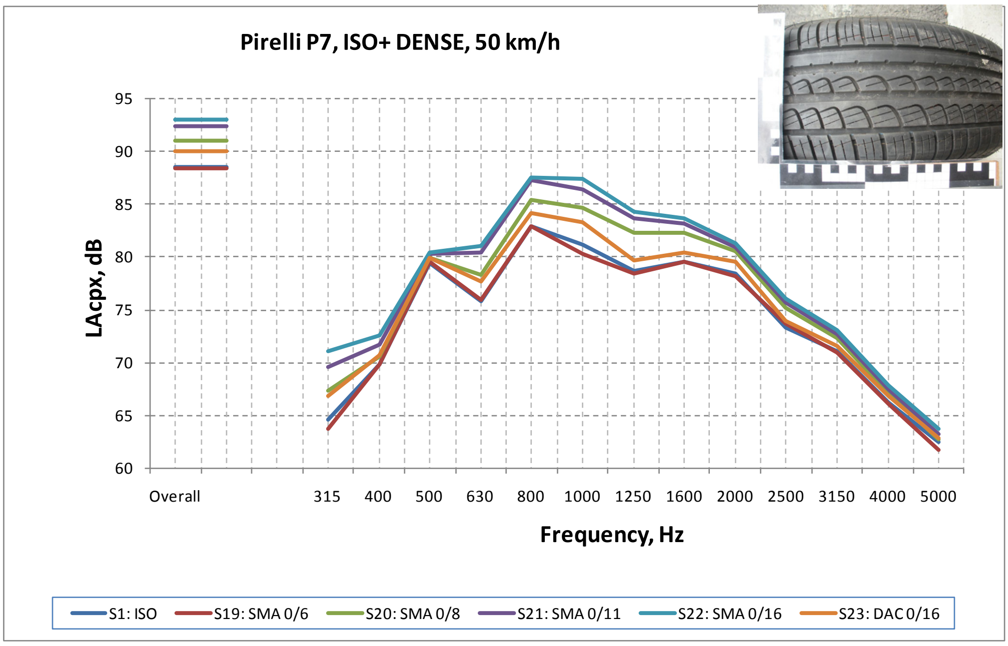

Figure 86 *Tyre 13: Pirelli P7. Dense surfaces, 50 km/h*

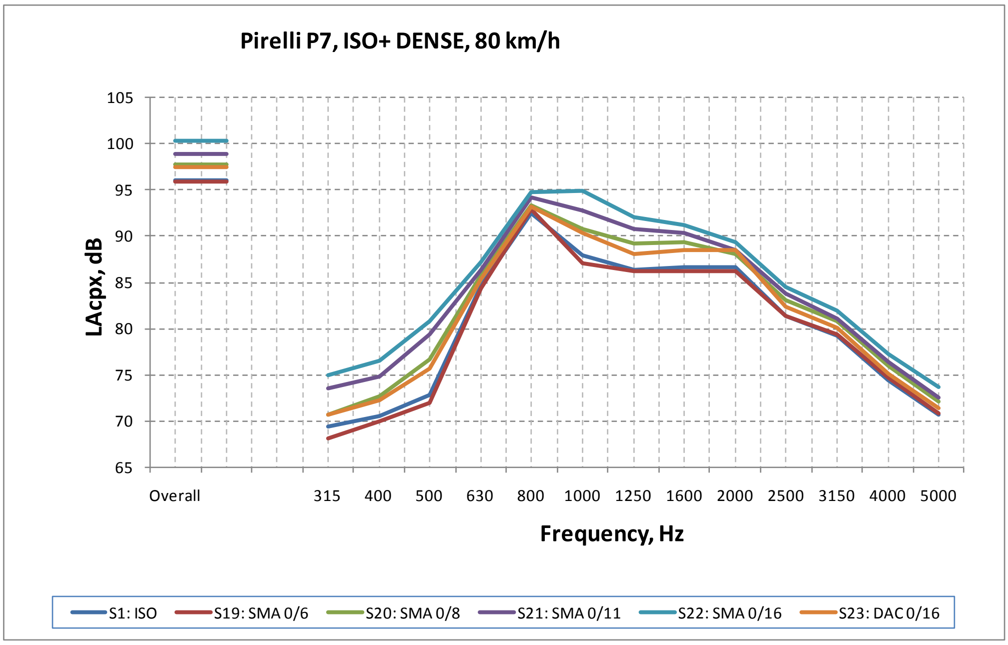

Figure 87 *Tyre 13: Pirelli P7. Dense surfaces, 80 km/h*

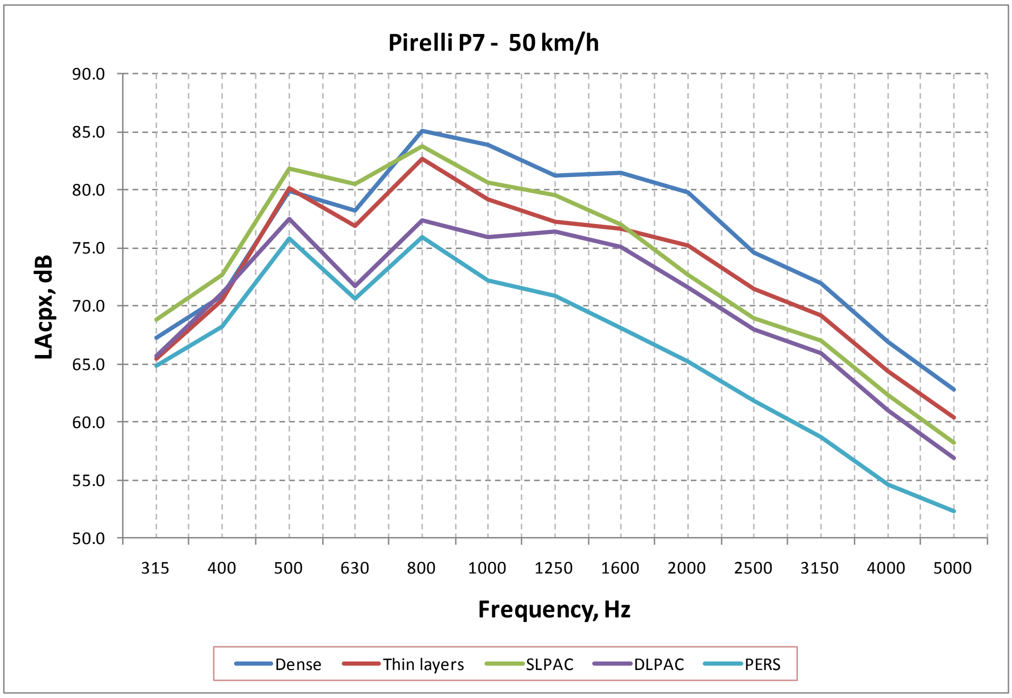

Figure 88 *Tyre 13: Pirelli P7, average spectra for 5 categories of road surfaces, 50 km/h*

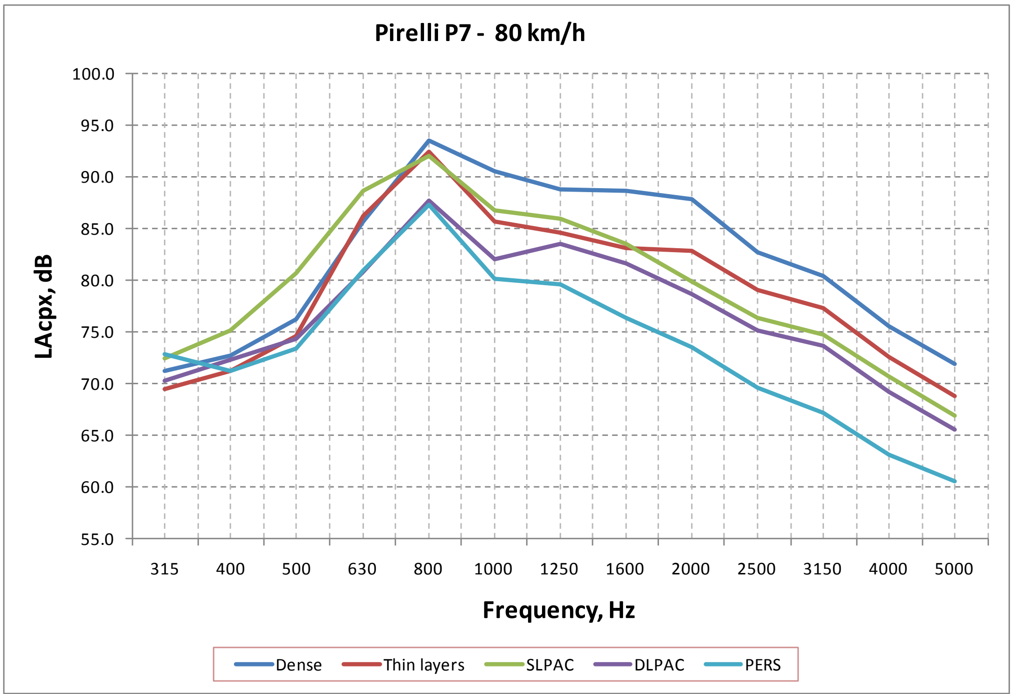

Figure 89 *Tyre 13: Pirelli P7, average spectra for 5 categories of road surfaces, 80 km/h*

Tyre 14: Hankook Ventus Prime K105

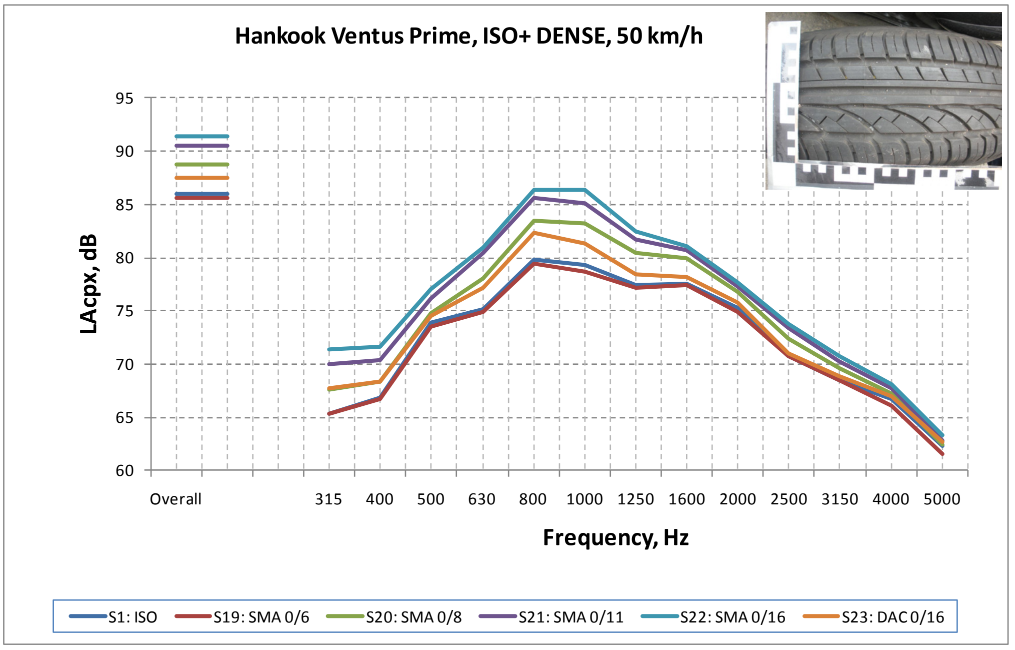

***Figure 90** Tyre 14: Hankook Ventus Prime K105. Dense surfaces, 50 km/h*

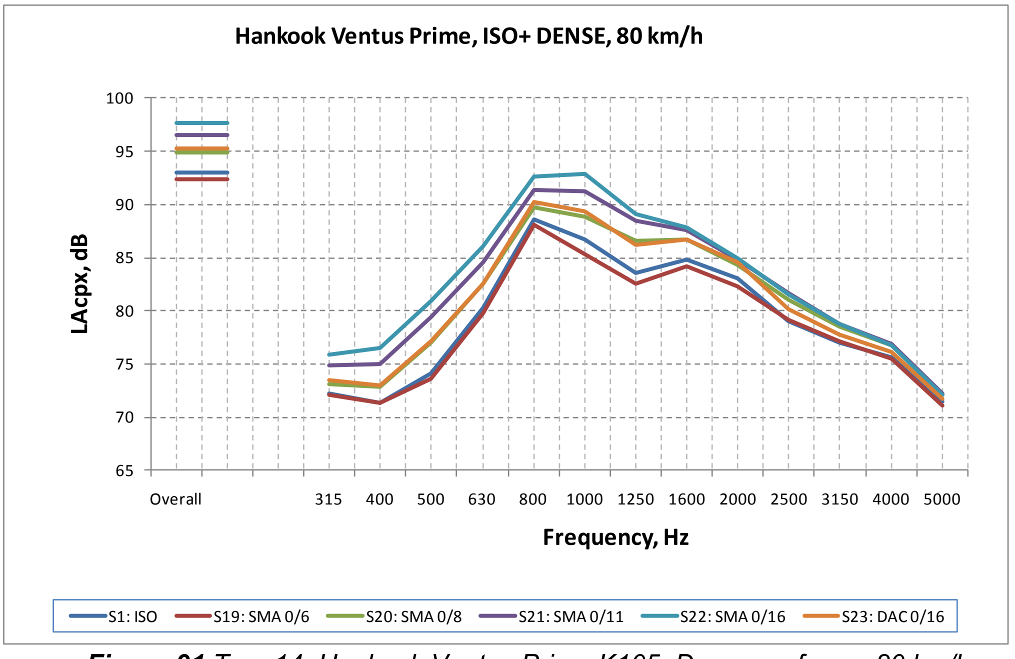

***Figure 91** Tyre 14: Hankook Ventus Prime K105. Dense surfaces, 80 km/h*

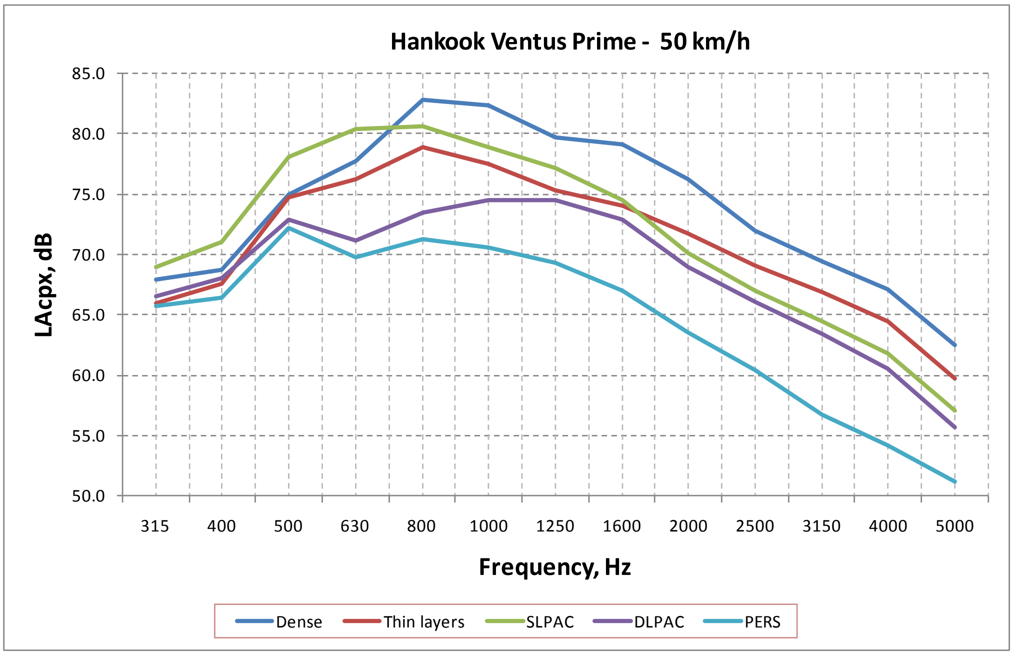

Figure 92 *Tyre 14: Hankook Ventus Prime K105, average spectra for 5 categories of road surfaces, 50 km/h*

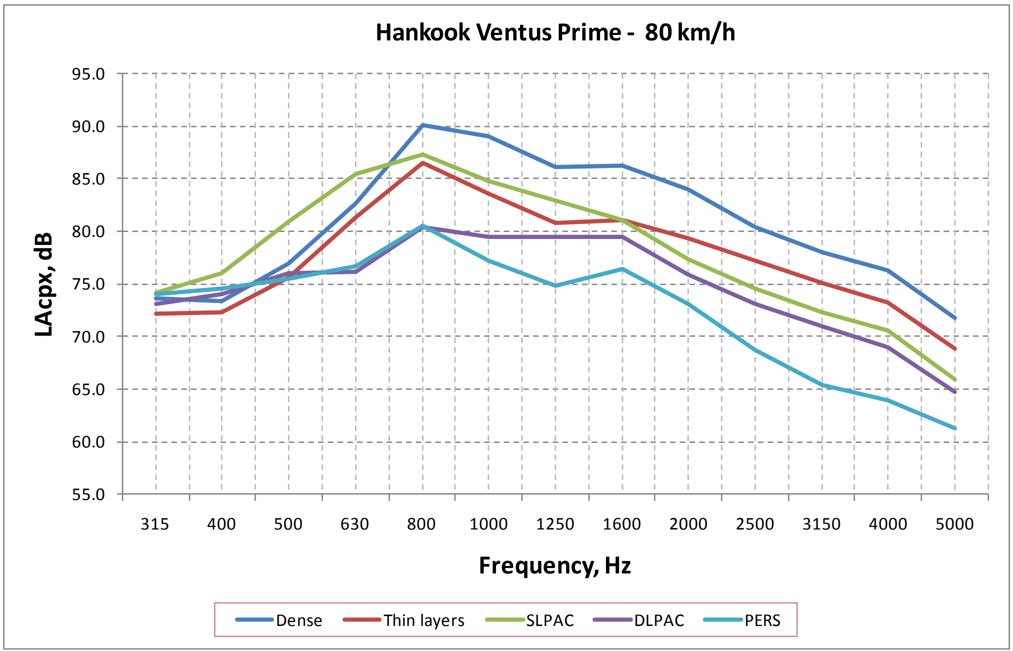

Figure 93 *Tyre 14: Hankook Ventus Prime K105, average spectra for 5 categories of road surfaces, 80 km/h*

Tyres 15-18: Michelin Energy Saver

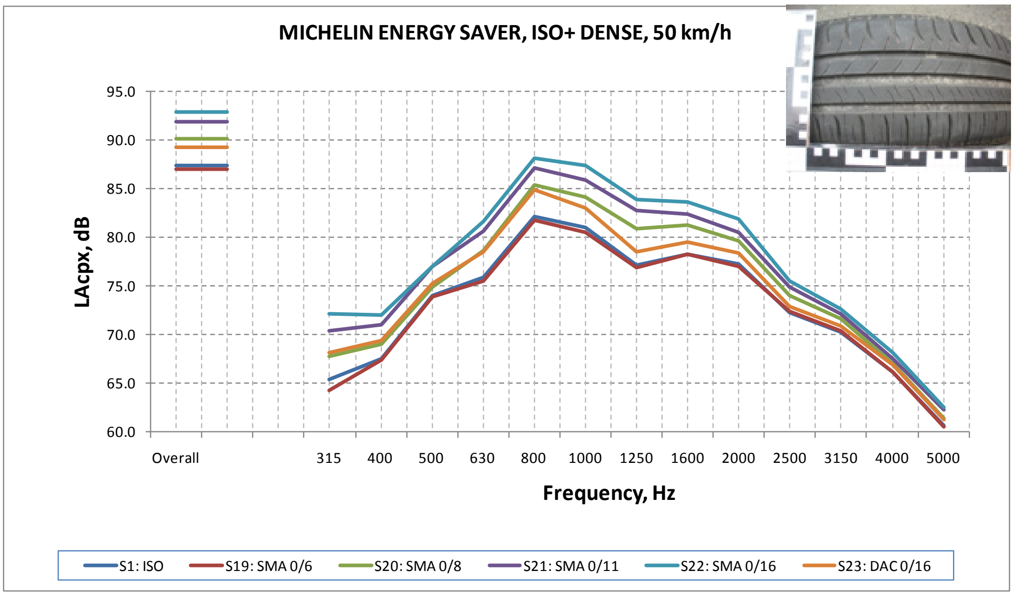

Figure 94 *Tyres 15-18: Michelin Energy Saver. Dense surfaces, 50 km/h*

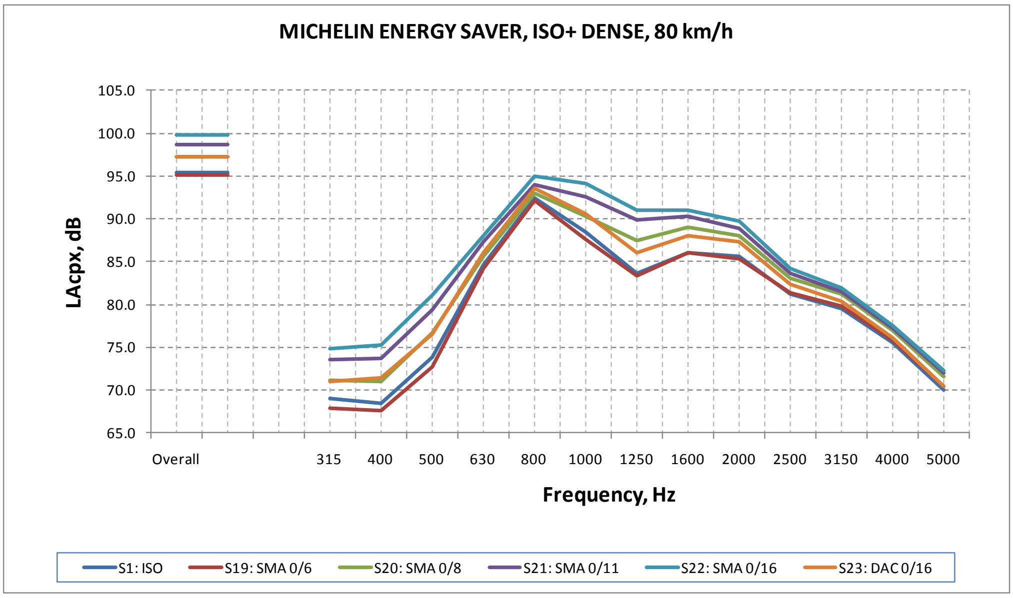

Figure 95 *Tyres 15-18: Michelin Energy Saver. Dense surfaces, 80 km/h*

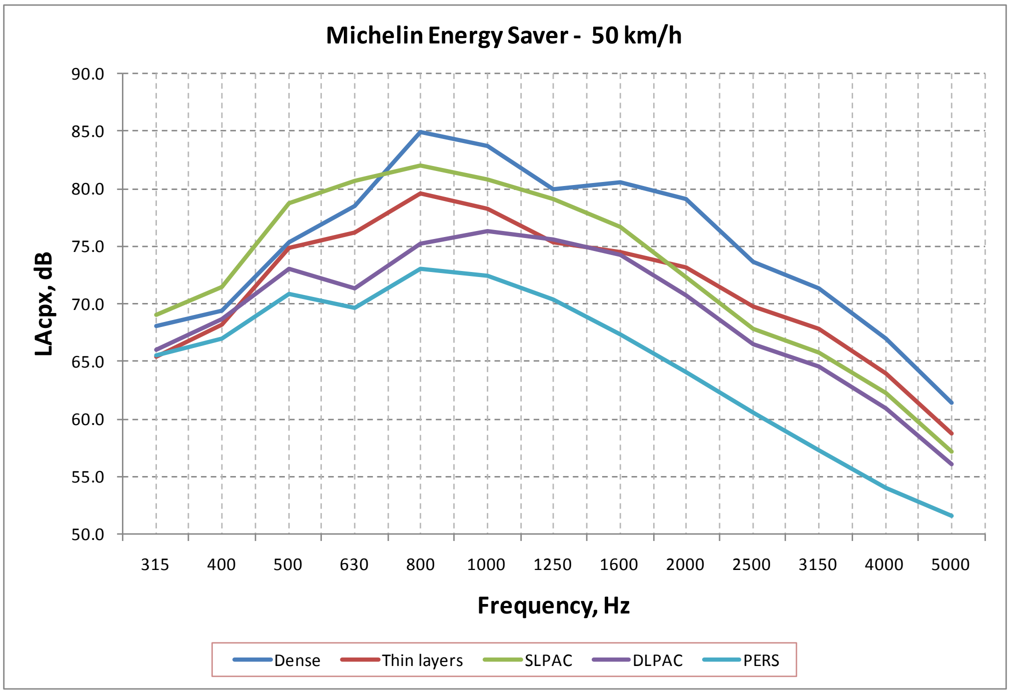

Figure 96 *Tyres 15-18: Michelin Energy Saver, average spectra for 5 categories of road surfaces, 50 km/h*

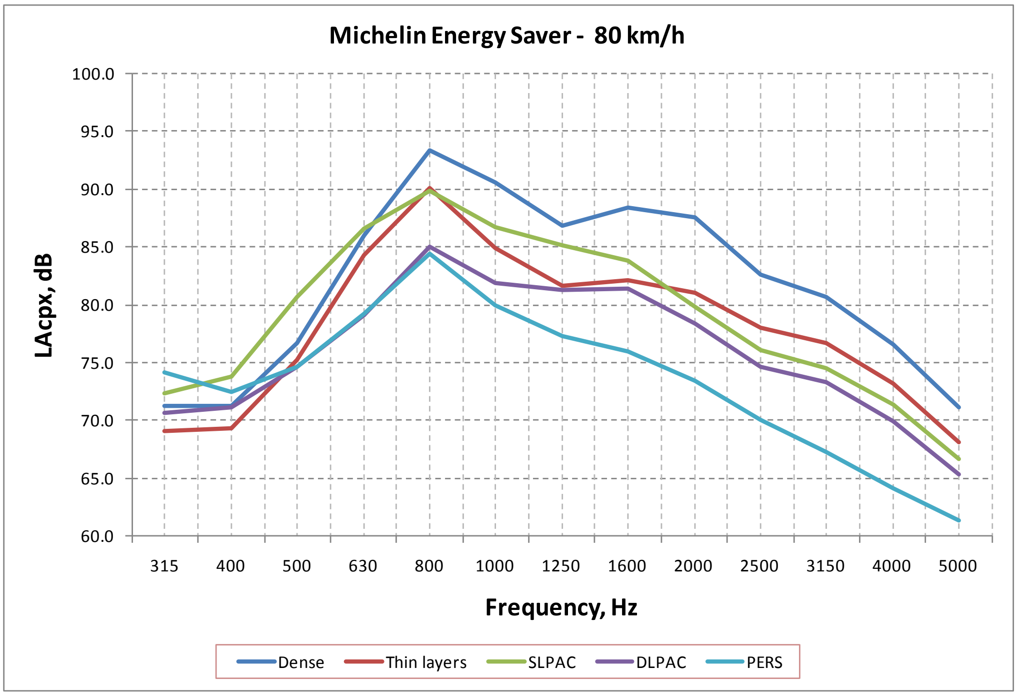

Figure 97 *Tyres 15-18: Michelin Energy Saver, average spectra for 5 categories of road surfaces, 80 km/h*

Tyres 19-20: Uniroyal Tigerpaw SRTT

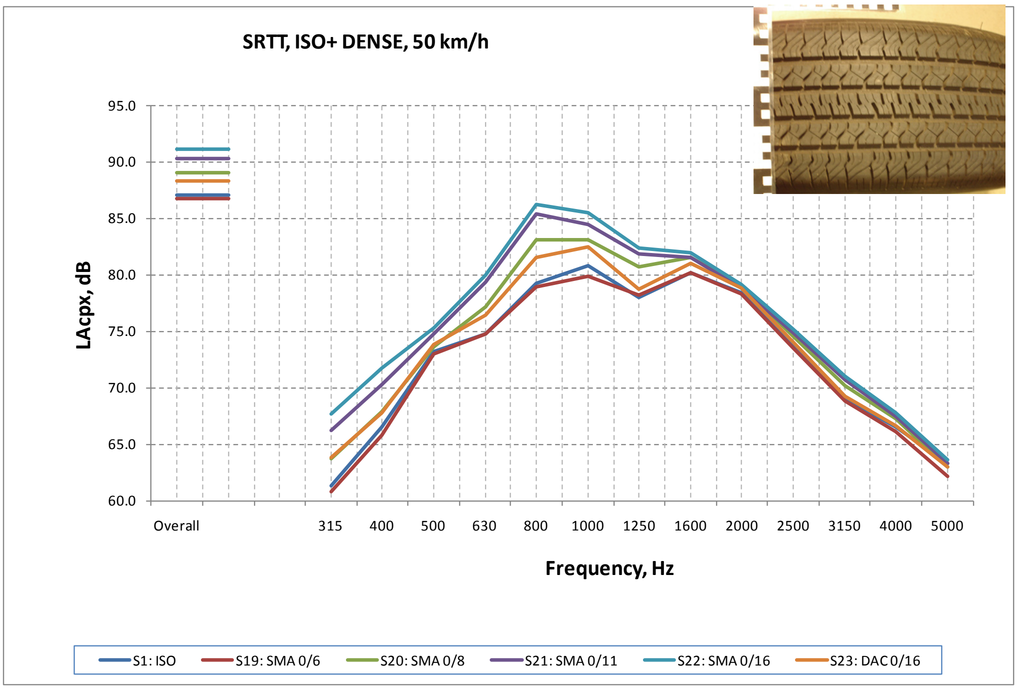

Figure 98 *Tyres 19-20: Uniroyal Tigerpaw SRTT. Dense surfaces, 50 km/h*

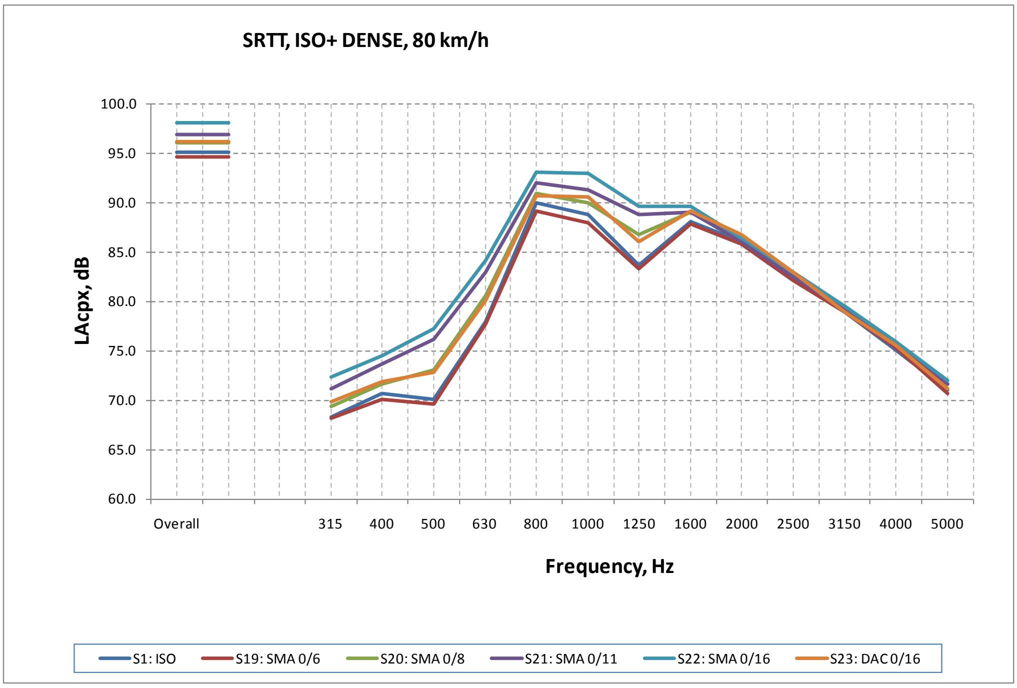

Figure 99 *Tyres 19-20: Uniroyal Tigerpaw SRTT. Dense surfaces, 80 km/h*

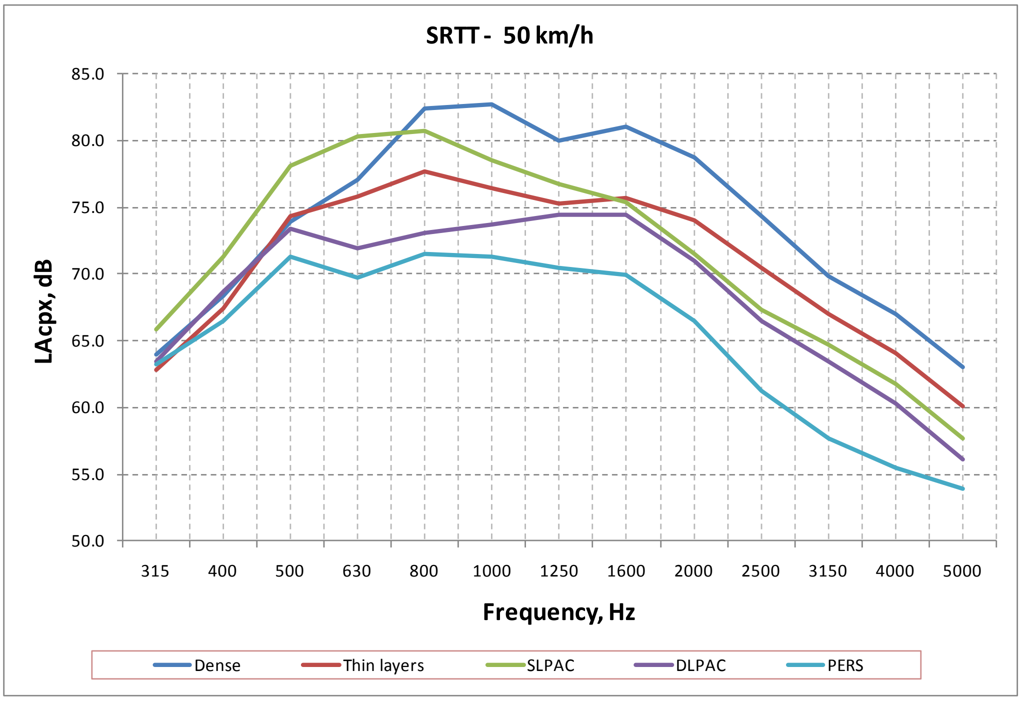

Figure 100 *Tyres 19-20: Uniroyal Tigerpaw SRTT, average spectra for 5 categories of road surfaces, 50 km/h*

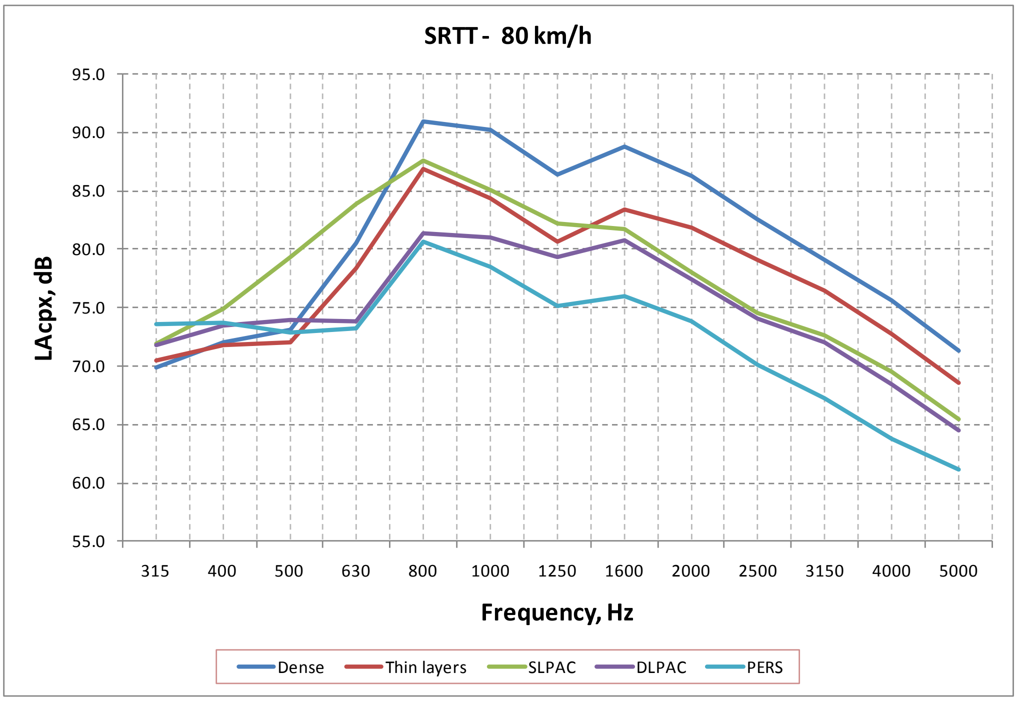

Figure 101 *Tyres 19-20: Uniroyal Tigerpaw SRTT, average spectra for 5 categories of road surfaces, 80 km/h*

Tyres 21-22: Avon Supervan AV4

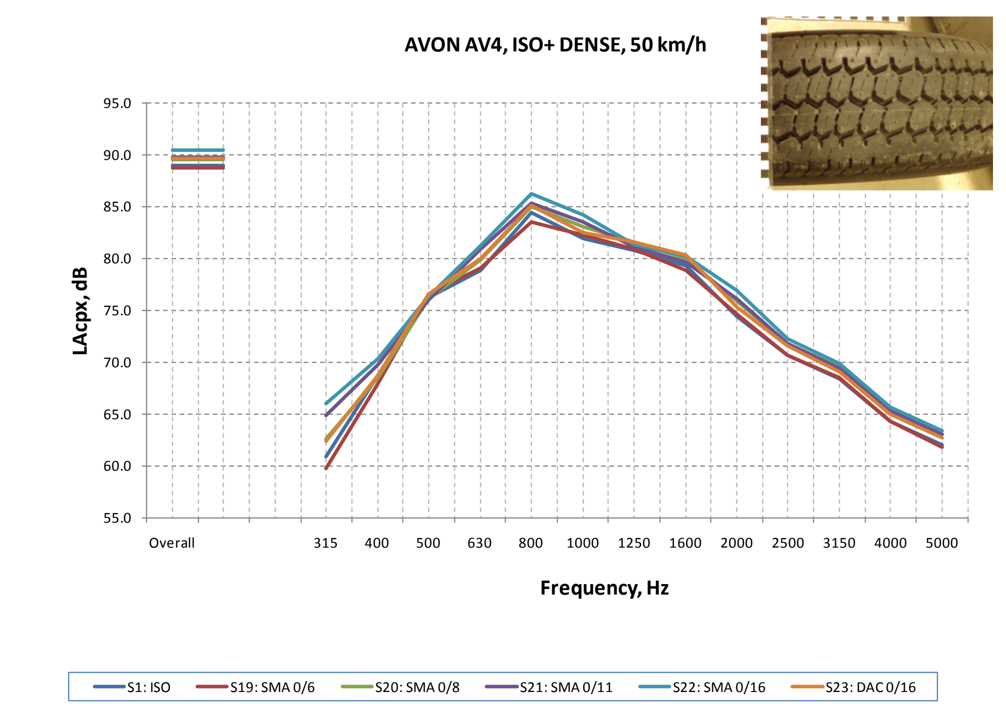

Figure 102 *Tyres 21-22: Avon Supervan AV4. Dense surfaces, 50 km/h*

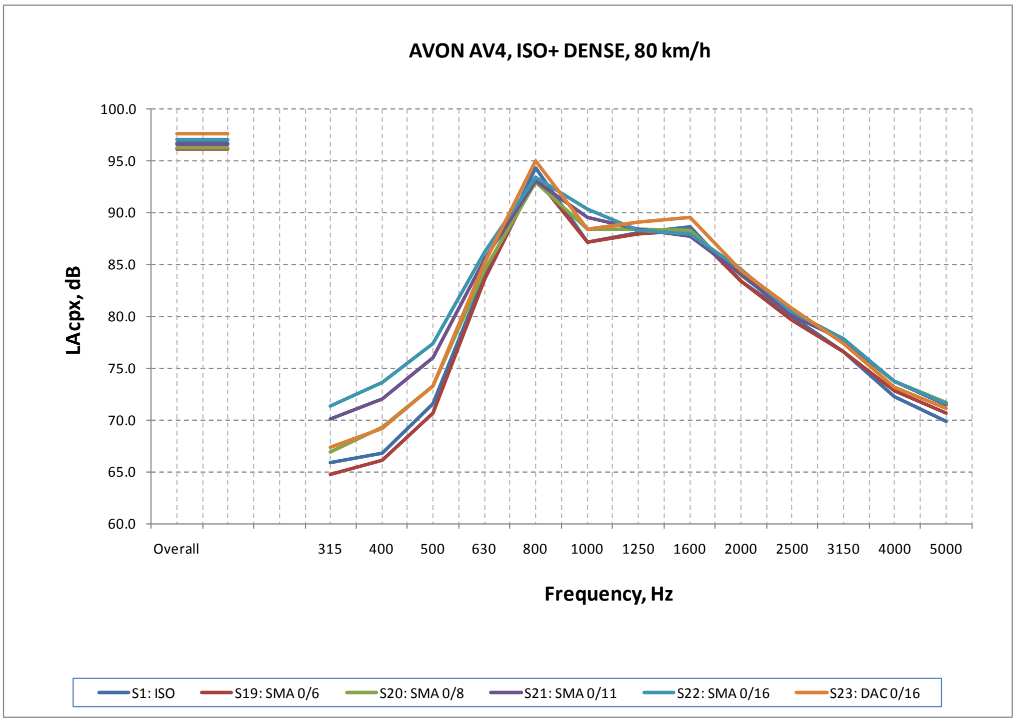

Figure 103 *Tyres 21-22: Avon Supervan AV4. Dense surfaces, 80 km/h*

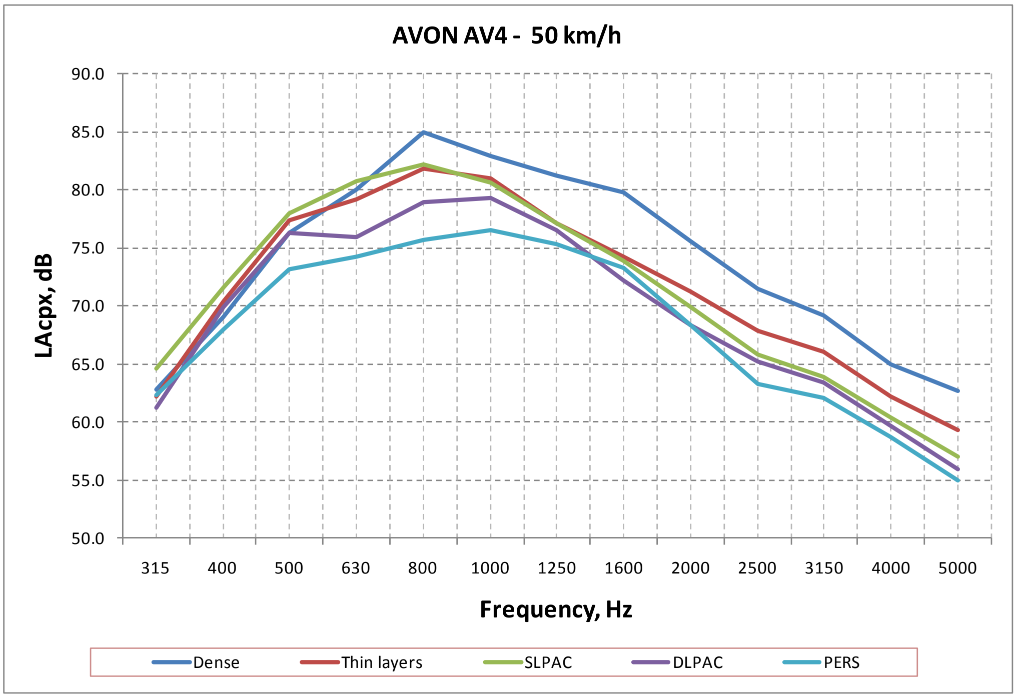

Figure 104 *Tyres 21-22: Avon Supervan AV4, average spectra for 5 categories of road surfaces, 50 km/h*

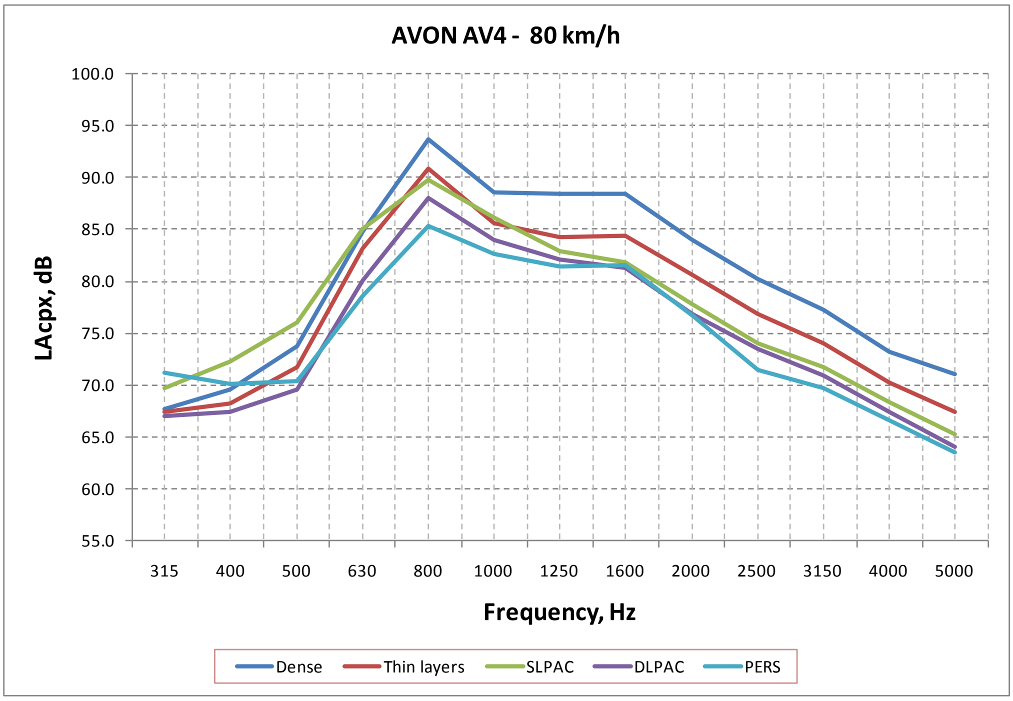

Figure 105 *Tyres 21-22: Avon Supervan AV4, average spectra for 5 categories of road surfaces, 80 km/h*

6.3 Comments to the results

Tyre 1 – Dayton T110:
This tyre has a speed dependent resonance at around 4-500 Hz at 50 km/h, which moves up to 800 Hz at 80 km/h. This resonance is dominating at all the different road surfaces.
Up to 800 Hz, there is no big difference between the dense surfaces, the thin layers and the single layer porous surfaces (see figure 41).

Tyre 2 – Sportiva G70:
The frequency spectra on the dense surfaces deviate from the average spectra see figures 42 and 43. There is resonance at about 1000 Hz (50 km/h), and at 80 km/h, there are smaller differences between the different surfaces, especially around 800 Hz, than the average.
The resonance at 800 Hz at 80 km/h is strong, independent of type of road surface (see figure A1_12 in Appendix 1).

Tyre 3 – Barum Brilliantis:
At 80 km/h, a strong resonance at all types of surfaces around 800 Hz. Overall ranking of surfaces is close to the average (figures 48-49).

Tyre 4 – Toyo 330:
The tyre has a resonance around 1000 Hz at 50 km/h, which seems to move up to around 1600 Hz at 80 km/h (figures 52 and 53).

Tyre 5 – Goodyear Excellence:
Figure 55 clearly demonstrates the difference in frequency spectra between the Norwegian SMA 0/11-surface and the dense surfaces at Kloosterzande. Above 1600 Hz, there is really no big difference, but in the low and mid frequency range, there is a difference of 5-8 dB. In general, this tyre performs close to the average off all tyres (figures 56-57).

Tyre 6 – Conti Premium Contact2:
This tyre performs as an average tyre.

Tyre 7 – Toyo Proxes T1R:
This tyre performs as an average tyre.

Tyre 8 – Nokian Hakka H:
This tyre performs as an average tyre.

Tyre 9 – Michelin Pilot Primacy HP:
This tyre has a resonance at around 1000 Hz, which seems to be independent of speed. And, except for some of the single layer porous surfaces (figures A1_51/52), the resonance seems also to be present, independent of surface type.

Tyre 10 – Firestone Firehawk TZ200:
Figure 77 show that there is a clear resonance at 400 Hz, which seems to be speed dependent. It is also present on the thin layers, and on the double layer porous surfaces (figures A1_59/60). Except for this resonance, the tyre performs as the average.

Tyre 11 – Conti EcoContact3:
This tyre performs as an average tyre.

Tyre 12 – Yokohama AVS dB V500:
This is the quietest tyre on most of the surfaces. According to figures 84 and 85, the spectra are as the average, but the tyre separates better between the types of surfaces, at frequencies below 5-600 Hz.
As figures A1_71 and A1_72 show, there are no clear resonances on the double layer porous surfaces, which certainly contribute to the overall low noise performance of this tyre.

Tyre 13 – Pirelli P7:
This tyre is in the noisy range, according to the results shown in chapter 5. The frequency analysis show that this is generally caused by speed dependent resonances, around 500 HZ at 50 km/h, which moves up to around 800 Hz at 80 km/h, see figures 88 and 89.

Tyre 14 – Hankook Ventus Prime K105:
This tyre performs as an average tyre.

Tyres 15 –18 Michelin Energy Saver:
Even if this tyre is ranked among the more noisy tyre (chapter 5), there are no special resonances explaining this, see figures 96 and 97. The spectral shapes are in general as the average tyre, but with 3-4 dB **_higher_** levels.

Tyres 19 –20 Uniroyal Tigerpaw SRTT:
This tyre has been chosen in the CPX-method to be a tyre giving tyre/road noise levels representative of light vehicles. Figures 100 and 101 show that the frequency spectra of this tyre are very close to the average of the tyres in this test.

Tyres 21 –22 Avon Supervan AV4:
Normally, truck tyres are much less sensitive to the texture and porosity of the road surface, than tyres for light vehicles. The frequency analysis of this tyre confirms that it has a performance close to a truck tyre. As figures 102 and 103 show, there is negligible influence of the stone size. In addition, this tyre has a very distinct resonance at 800 Hz.

7 Correlation and preliminary ranking analysis

7.1 Correlation analysis

One important part of this investigation is to study the ranking order of tyres on the different road surfaces, compared to the ISO-surface. To improve the basis for the data analysis, a set of data from tyre measurements performed by M+P in 2009[2] is included. The measurement made by M+P has been made with similar CPX-trailer, instrumentation and test conditions (speed, etc.) as our measurements, and therefore should be well suitable for comparison.

In addition to the inclusion of the 10 M+P tyres, the following tyres were removed from the analysis:

- The 2 SRTT-tyres. These tyres are normally not fitted on cars (and not yet type approved in Europe)
- The 2 Avon Supervan AV4 tyres. These tyres has a different behaviour than normal passenger cars and therefore not suited for this analysis
- Michelin Energy Saver tyres 16, 17 and 18 (table 1). Only tyre 15 is included.

Table 26 gives a complete list and numbering of the tyres included in the statistical analysis.

***Table 26** Tyres included in the statistical analysis*

Tyre no	Name	Dimensions	Source	Shore hardness
1	**Dayton D110**	**175/70 R14**	SINTEF	68
2	**Sportiva G70**	**175/70 R14**	SINTEF	65
3	**Barum Brilliantis**	**185/65 R15**	SINTEF	67
4	**Toyo 330**	**185/65 R15**	SINTEF	70
5	**Goodyear Excellence**	**195/65 R15**	SINTEF	69
6	**Conti Premium Contact2**	**195/65 R15**	SINTEF	70
7	**Toyo Proxes T1R**	**205/55 R16**	SINTEF	69
8	**Nokian Hakka H**	**205/55 R16**	SINTEF	69
9	**Michelin Pilot Primacy HP**	**215/55 R16**	SINTEF	68
10	**Firestone Firehawk TZ200**	**215/55 R16**	SINTEF	66
11	**Conti EcoContact3**	**195/65 R15**	SINTEF	71
12	**Yokohama AVS dBV500**	**185/65 R15**	SINTEF	73
13	**Pirelli P7**	**205/65 R15**	SINTEF	64
14	**Hankook Ventus Prime K105**	**205/65 R15**	SINTEF	67
15	**Michelin Energy Saver**	**205/65 R15**	SINTEF	70
16	**Vredestein Hi-Trac**	**205/55 R15**	M+P	68
17	**Goodyear Optigrip**	**205/55 R15**	M+P	67
18	**Pirelli Cinturato P6**	**205/55 R15**	M+P	65
19	**Interstate Sport IXT-1**	**205/55 R15**	M+P	68
20	**Yokohama AVS dBV500**	**185/60 R14**	M+P	68
21	**Dunlop SP Sport Maxx**	**205/55 R15**	M+P	71
22	**Conti EcoContact3**	**195/65 R15**	M+P	65
23	**Brigdestone B-250**	**195/65 R15**	M+P	68
24	**Conti Premium Contact2**	**195/65 R15**	M+P	67
25	**Goodyear GT3**	**195/65 R15**	M+P	67

Tyres 6 and 24 (Conti Premium Contact2), and tyres 11 and 22 (Conti EcoContact3) have identical rims, sizes and tread pattern. Tyres 12 and 20 (Yokohama AVS dB V500) have identical width and tread pattern, but different rim size and profile.

In table 27, all the measured CPX-levels on the ISO-surface are given for the 25 tyres at the two speeds.

Table 27 *Measured LAcpx-levels, ISO-surface*

Tyre no	Name	Measured by	50 km/h LAcpx dB	80 km/h LAcpx dB
1	**Dayton D110**	SINTEF	85.4	93.5
2	**Sportiva G70**	SINTEF	87.9	95.8
3	**Barum Brilliantis**	SINTEF	88.5	95.0
4	**Toyo 330**	SINTEF	87.9	94.9
5	**Goodyear Excellence**	SINTEF	86.8	93.2
6	**Conti Premium Contact2**	SINTEF	86.4	93.6
7	**Toyo Proxes T1R**	SINTEF	86.1	93.0
8	**Nokian Hakka H**	SINTEF	85.4	92.5
9	**Michelin Pilot Primacy HP**	SINTEF	85.0	92.7
10	**Firestone Firehawk TZ200**	SINTEF	85.8	93.2
11	**Conti EcoContact3**	SINTEF	85.8	93.2
12	**Yokohama AVS dBV500**	SINTEF	84.8	91.3
13	**Pirelli P7**	SINTEF	88.5	96.0
14	**Hankook Ventus Prime K105**	SINTEF	86.0	93.0
15	**Michelin Energy Saver**	SINTEF	88.0	96.1
16	**Vredestein Hi-Trac**	M+P	87.7	95.6
17	**Goodyear Optigrip**	M+P	86.8	93.5
18	**Pirelli Cinturato P6**	M+P	85.4	92.8
19	**Interstate Sport IXT-1**	M+P	83.7	90.8
20	**Yokohama AVS dBV500**	M+P	84.2	90.7
21	**Dunlop SP Sport Maxx**	M+P	86.5	91.9
22	**Conti EcoContact3**	M+P	86.7	93.0
23	**Brigdestone B-250**	M+P	86.1	93.8
24	**Conti Premium Contact2**	M+P	86.5	93.0
25	**Goodyear GT3**	M+P	85.5	92.7
Average			**86.3**	**93.4**
Max-min			**4.8**	**5.4**
Standard deviation			**1.28**	**1.48**

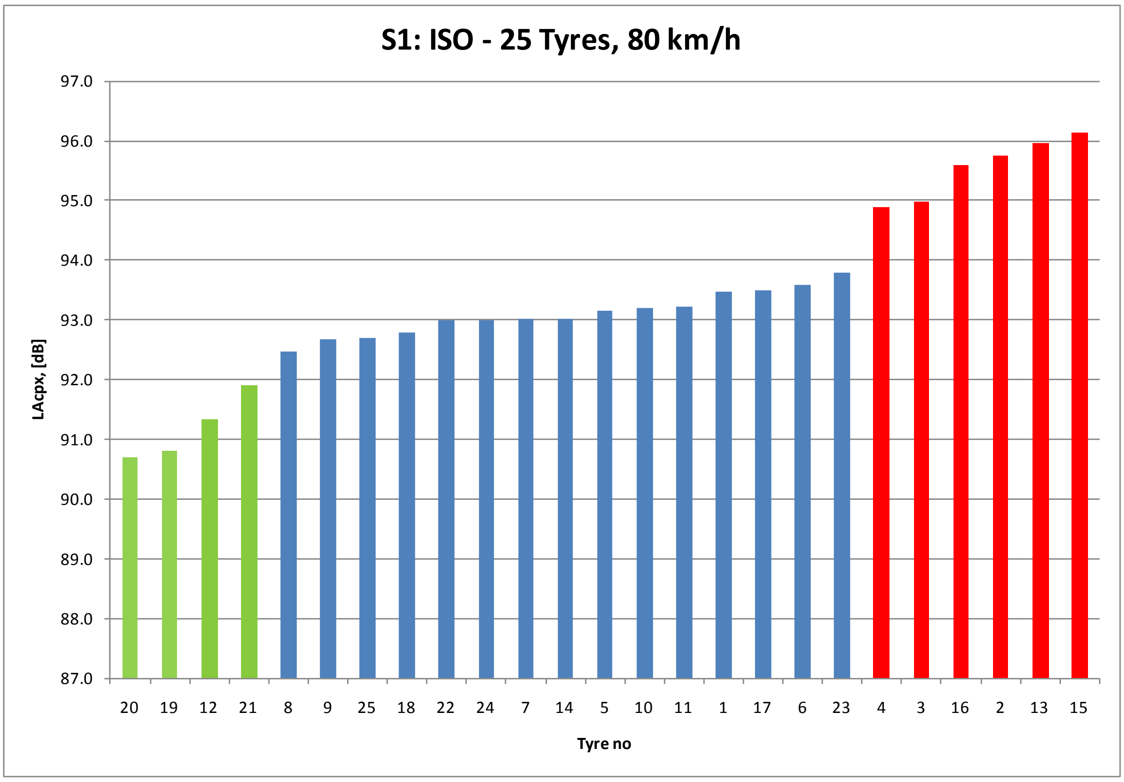

Figure 106 *Noise levels, LAcpx, on the ISO-surface at 80 km/h*

Based on the results at 80 km/h, the tyres have been classified into 3 categories, as shown in table 28 and figure 106. The ‘quiet’ tyres are marked green, the ‘average’ tyres blue and ‘noisy’ tyres are marked red.

Table 28 *Classification of tyres*

Category	Level range, LAcpx, dB	Tyre no
“Quiet” (green)	90 – 92	12,19, 20, 21
“Average” (blue)	92.1 – 94	1, 5, 6, 7, 8, 9,10,11,14,17,18, 22 , 23, 24, 25
“Noisy” (red)	94.1 - 96	2,3,4,13,15,16

If the classification is based on the results at 50 km/h, the only difference is that tyre 21 is shifted from the ‘quiet’ to the ‘average’ class.

In order to investigate the efficiency of the tyre directive based on measurements on an ISO-surface, a linear regression analysis between the noise levels on the ISO-surface (LAcpx, dB) and the corresponding levels on the other road surfaces have been made.

The equation for a linear correlation is given on the format of

$$L_A(y) = a + b \cdot L_B(x) \quad (1)$$

Where
$L_A(y)$: the noise level on surface A
$L_B(x)$: the noise level on surface B
a: interception at $L_B(x)=0$
b: slope

The slope shows in average how much a reduction of the ISO-level will give on the other surface. As an example, if the slope of the regression is 0.8, it means that a reduction of 1.0 dB on the ISO-surface gives a reduction of 0.8 dB on the other surface.
This would be the most important parameter for evaluating the efficiency of the EU-directive for noise reduction (type approval and labelling)[8].
The regression coefficient R^2 gives the explained variance of the relation. It is then a measure on the quality of the relation. A high correlation means that low noise tyres also will perform as low noise tyres on the other surface. A perfect linear correlation would also show that the relationship between the noise levels of the tyres on the two compared road surfaces is explained by the overall A-weighted level (LAcpx) only.
The results for the slopes and the regression coefficients are shown in table 29. Note that for surface 12, the Rollpave PERS, only the 15 SINTEF tyres are included in the analysis, since this pavement was constructed in 2009, after the measurements by M+P were done.

In the table, a blue highlighting has been made for the surface within each class, which has the best correlation with the ISO-surface.

Table 29 *Regression analysis*

Section no	Surface type	50 km/h		80 km/h	
		Slope, b	R^2	Slope, b	R^2
2	TL 2/4	1.34	0.93	1.36	0.95
3	TL 2/6	1.23	0.92	1.20	0.92
4	TL 2/6	1.11	0.83	1.31	0.83
5	TL 4/8	0.90	0.79	0.90	0.84
6	SLPAC 0/11	0.52	0.24	0.40	0.42
7	SLPAC 0/16	0.60	0.70	0.58	0.74
8	SLPAC 4/8	0.70	0.72	0.62	0.69
9	SLPAC 4/8	0.64	0.64	0.74	0.71
10	DLPAC 4/8+11/16	0.82	0.74	0.80	0.82
11	DLPAC 4/8+11/16	0.72	0.69	0.65	0.76
12	Rollpave PERS	1.28	0.76	1.24	0.78
13	DLPAC 2/4+8/11	1.34	0.77	1.18	0.83
14	DLPAC 2/6+8/11	1.19	0.87	1.16	0.85
15	SLPAC 2/6	1.11	0.84	1.41	0.84
16	DLPAC 2/4+11/16	1.20	0.89	1.20	0.89
17	DLPAC 2/6 + EPAC 0/16	1.07	0.82	0.95	0.85
18	DLPAC 2/6 + EPAC 0/16	0.97	0.84	0.83	0.81
19	SMA 0/6	0.99	0.97	1.04	0.99
20	SMA 0/8	0.74	0.86	0.72	0.90
21	SMA 0/11	0.66	0.73	0.59	0.72
22	SMA 0/16	0.63	0.66	0.58	0.69
23	DAC 0/16	0.91	0.91	0.83	0.92

Table 29 shows that the slope and regression coefficient R^2 for most of the surfaces are a little higher at the speed of 80 km/h than at 50 km/h. 80 km/h is therefore chosen in the presentation of the regression and ranking analysis.

In the previous study by M+P[7], the slope and regression coefficient were calculated based on the 10 tyres.
A comparison of the M+P results (10 tyres) for the 22 surfaces (excluding the Rollpave PERS) and the new group of 25 tyres has been made. In figures 107 and 108, the slope and regression coefficient are shown for the two tyre groups. For each road surface, the column to the left is based on the 10 M+P tyres and the column to the right is the 15 SINTEF tyres + the10 M+P tyres. As the figures show, the overall trends are the same for the two groups. Increasing the number of tyres in general increases the slopes somewhat, but the correlation is a little bit reduced. An exception from this is the SMA-surfaces (figure 108).

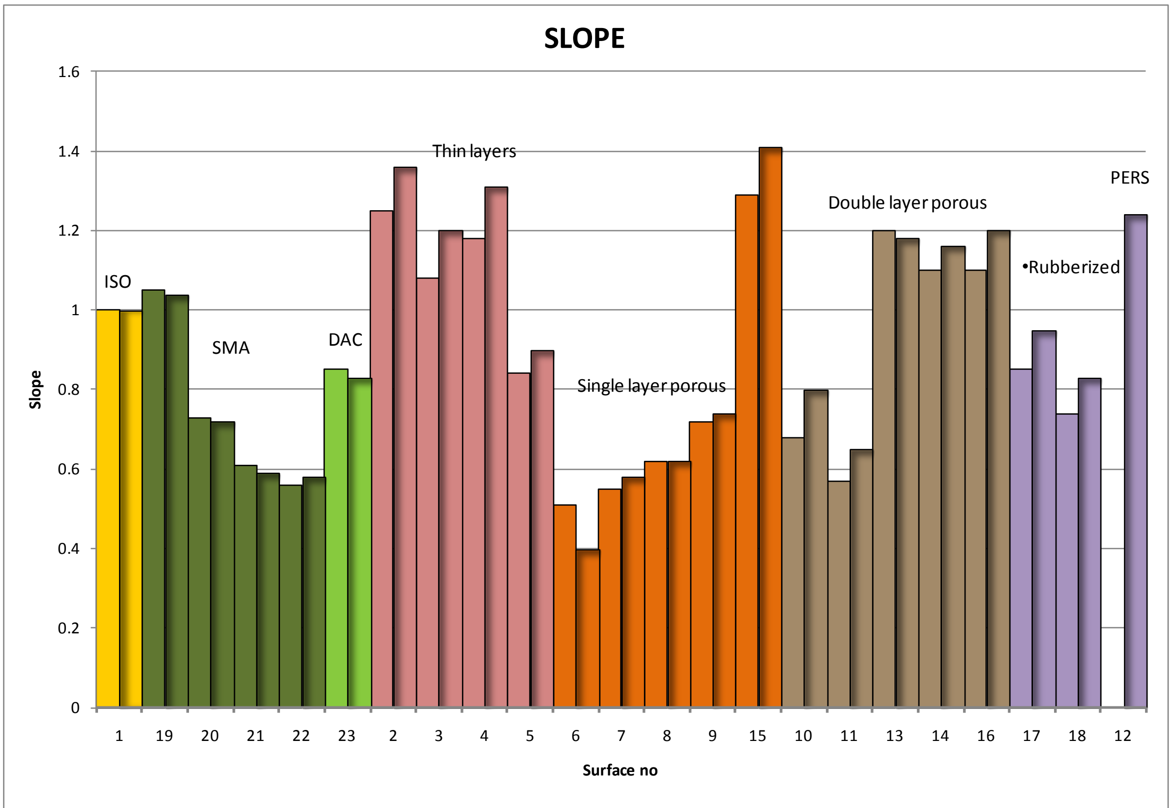

Figure 107 *The slope calculated for two sets of tyre: Left column: M+P tyres. Right column (shadow); SINTEF and M+P tyres. Reference surface: ISO. Speed: 80 km/h.*

Figure 108 *The regression coefficient calculated for two sets of tyre. Left column: M+P tyres, Right column (shadow): SINTEF and M+P tyres. Reference surface: ISO. Speed: 80 km/h.*

To further study the influence of the tyre selected for the correlation analysis, we have separated the SINTEF group of tyres and the M+P group. In table 30, this comparison for the slope and R^2 are shown for 80 km/h.

Table 30 *Comparison of SINTEF and M+P group of tyres, 80 km/h*

Section no	Surface type	SINTEF		M+P	
		Slope, b	R^2	Slope, b	R^2
2	TL 2/4	1.36	0.94	1.25	0.96
3	TL 2/6	1.28	0.90	1.08	0.97
4	TL 2/6	1.41	0.77	1.18	0.95
5	TL 4/8	0.89	0.79	0.84	0.86
6	SLPAC 0/11	0.43	0.41	0.51	0.62
7	SLPAC 0/16	0.51	0.74	0.55	0.68
8	SLPAC 4/8	0.53	0.59	0.62	0.75
9	SLPAC 4/8	0.80	0.66	0.72	0.81
10	DLPAC 4/8+11/16	0.74	0.69	0.68	0.85
11	DLPAC 4/8+11/16	0.54	0.75	0.57	0.74
12	Rollpave PERS	1.24	0.78	-	-
13	DLPAC 2/4+8/11	1.17	0.75	1.20	0.92
14	DLPAC 2/6+8/11	1.16	0.79	1.10	0.92
15	SLPAC 2/6	1.53	0.79	1.29	0.93
16	DLPAC 2/4+11/16	1.24	0.86	1.10	0.92
17	DLPAC 2/6 + EPAC 0/16	0.93	0.84	0.85	0.87
18	DLPAC 2/6 + EPAC 0/16	0.85	0.76	0.95	0.85
19	SMA 0/6	1.04	0.98	1.06	0.99
20	SMA 0/8	0.70	0.91	0.73	0.86
21	SMA 0/11	0.56	0.79	0.61	0.70
22	SMA 0/16	0.54	0.69	0.56	0.60
23	DAC 0/16	0.75	0.92	0.83	0.94

Together with figures 107 and 108, table 30 shows that the two groups do not differ significantly concerning the correlation between ISO and the other surfaces. The tendency is somewhat higher correlation for the M+P group of tyres.

A high number of the slope means a high “efficiency” in relationship with the ISO-surface. It is also advantageous if the spread in the noise levels is high. This mean that the surface is able to discriminate between different tyres, relating to tyre design parameters like tread design, rubber material properties, etc. An indicator of this is the standard deviation. In tables 4-25, the standard deviation is given for all surfaces S2-S23. In figure 109, a regression analysis of the slope and the standard deviation is shown for 80 km/h.
The correlation is high, proving there is a strong relationship between road properties like the texture, stone size and tyre related parameters. The influence of the texture is further analysed in chapter 8.

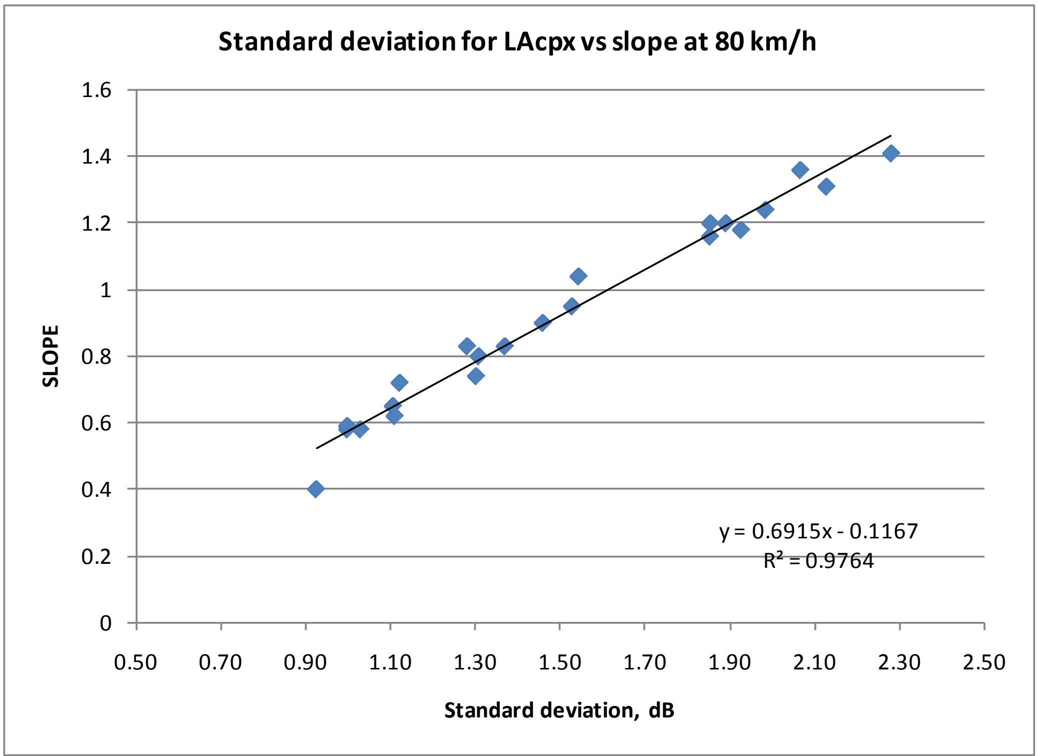

Figure 109 *Regression analysis of standard deviation for LAcpx and the slope*

7.2 Ranking analysis

In figures 110-153, the linear regression analysis and the ranking are shown for all 22 surfaces, related to the ISO-surface.
In the ranking figures, the X-axis show the ranking on the ISO-surface at the reference speed of 80 km/h, while the corresponding ranking on the other surface is shown on the y-axis. If there is a perfect match in ranking, the actual ranking curve will follow the blue diagonal curve (ref. rank). On each of the figures with the ranking analysis, it is possible to identify which of the tyre(s) that deviates much compared to the ISO ranking.

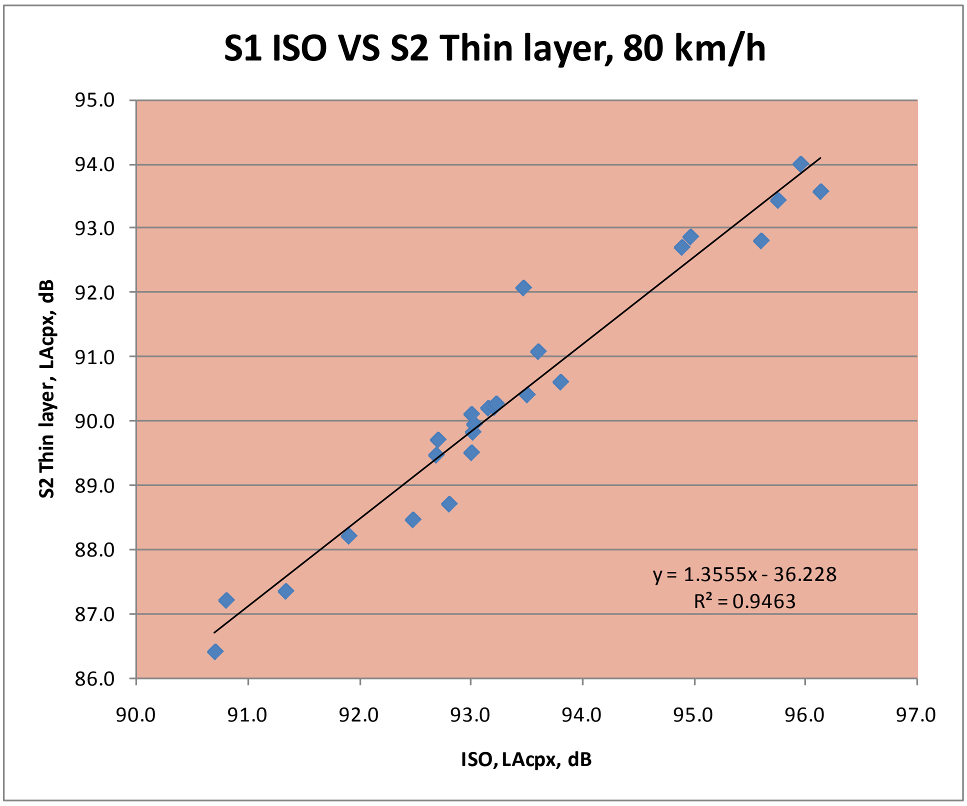

Figure 110 *Linear regression, S1/S2*

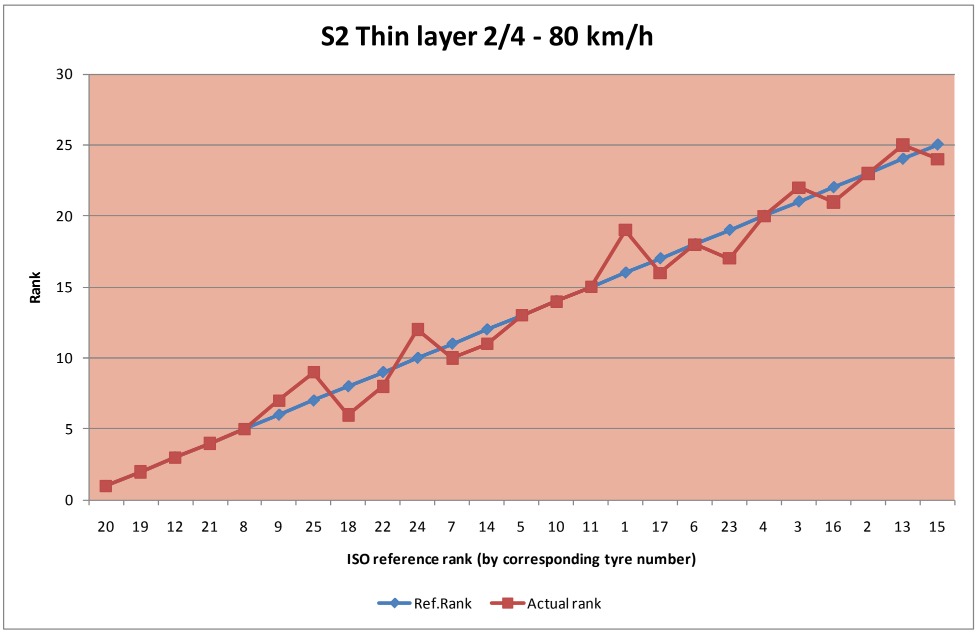

Figure 111 *Ranking analysis, S1/S2*

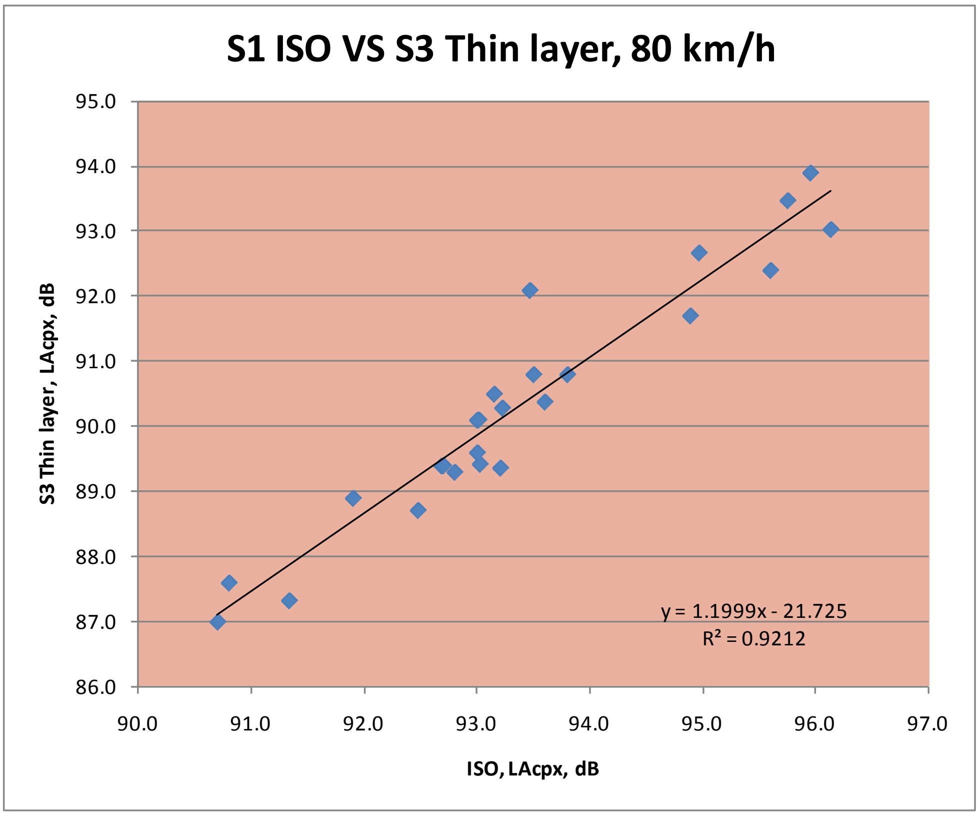

Figure 112 *Linear regression, S1/S3*

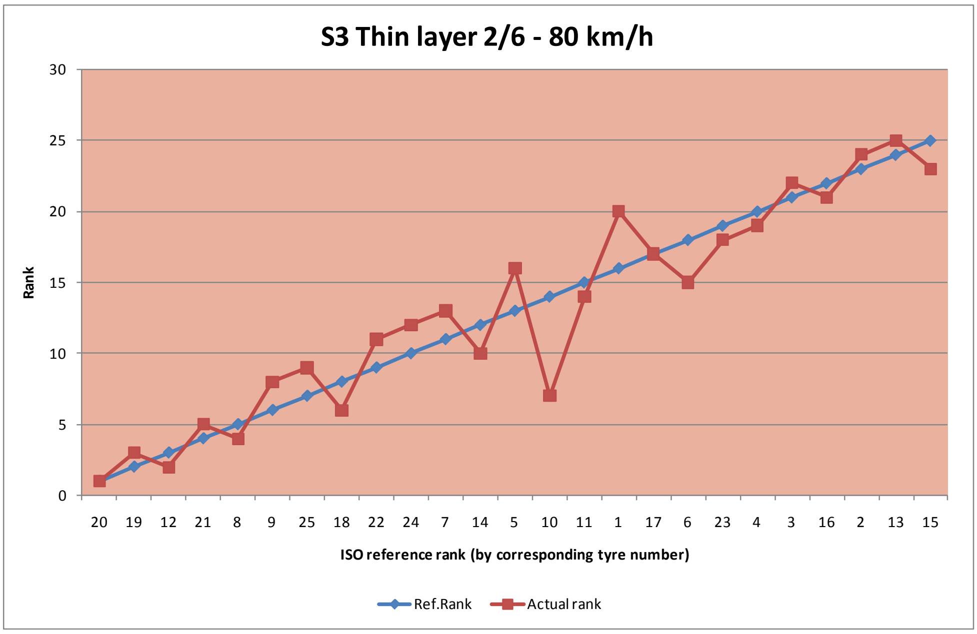

Figure 113 *Ranking analysis, S1/S3*

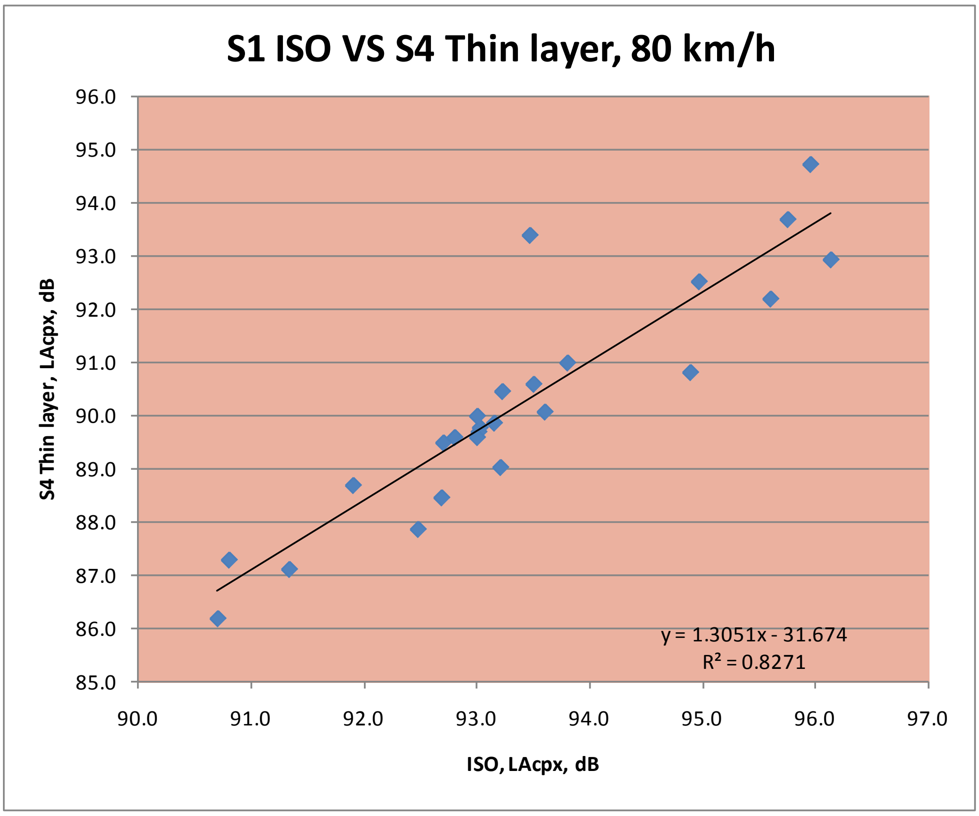

Figure 114 *Linear regression, S1/S4*

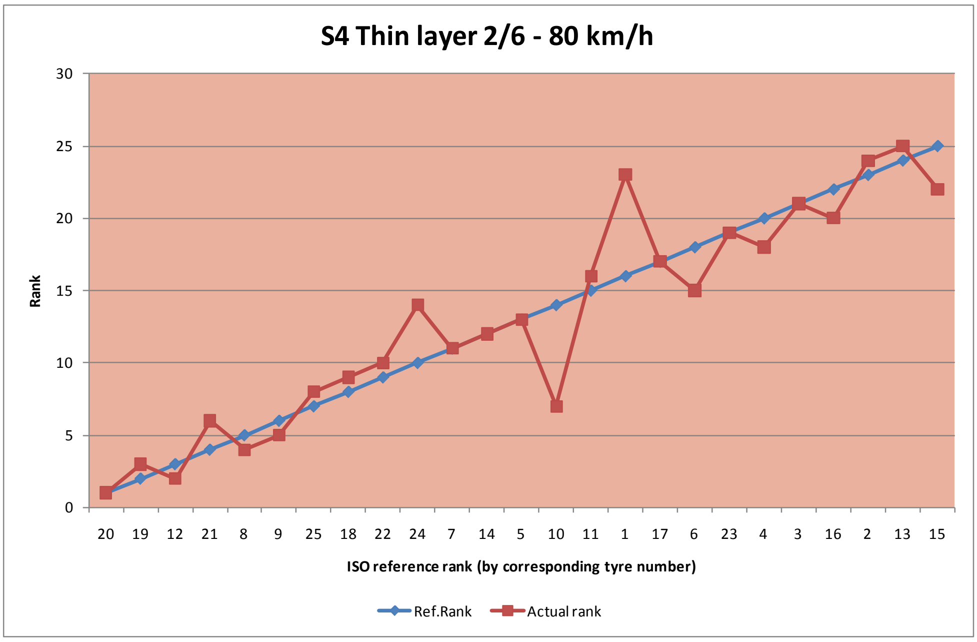

Figure 115 *Ranking analysis, S1/S4*

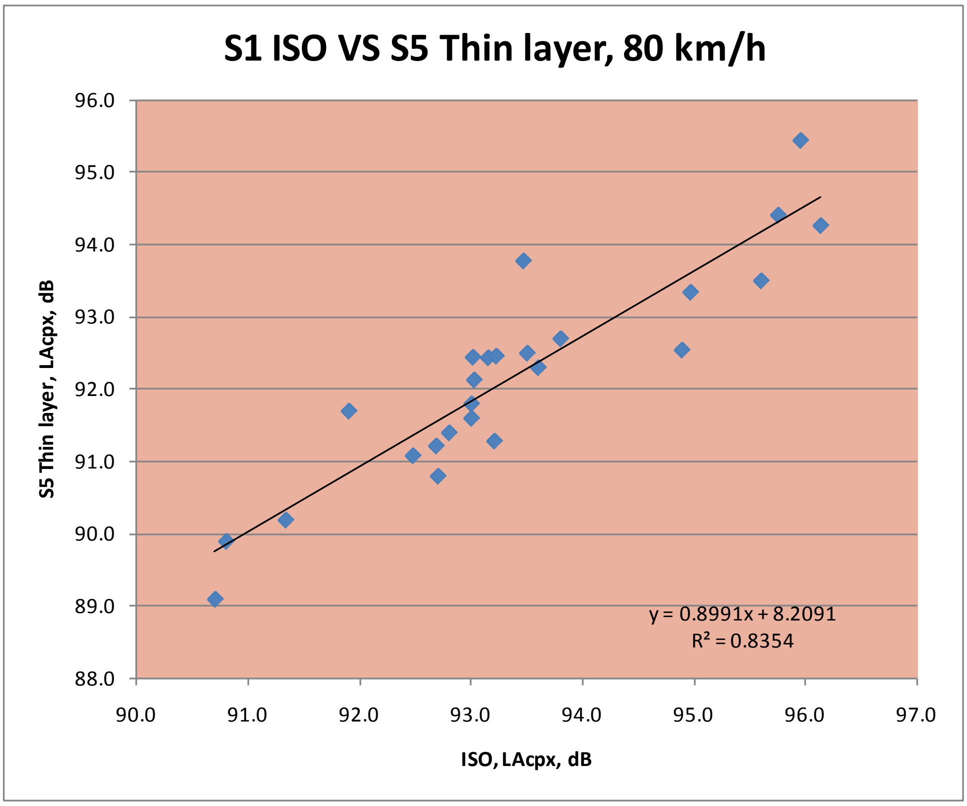

Figure 116 *Linear regression, S1/S5*

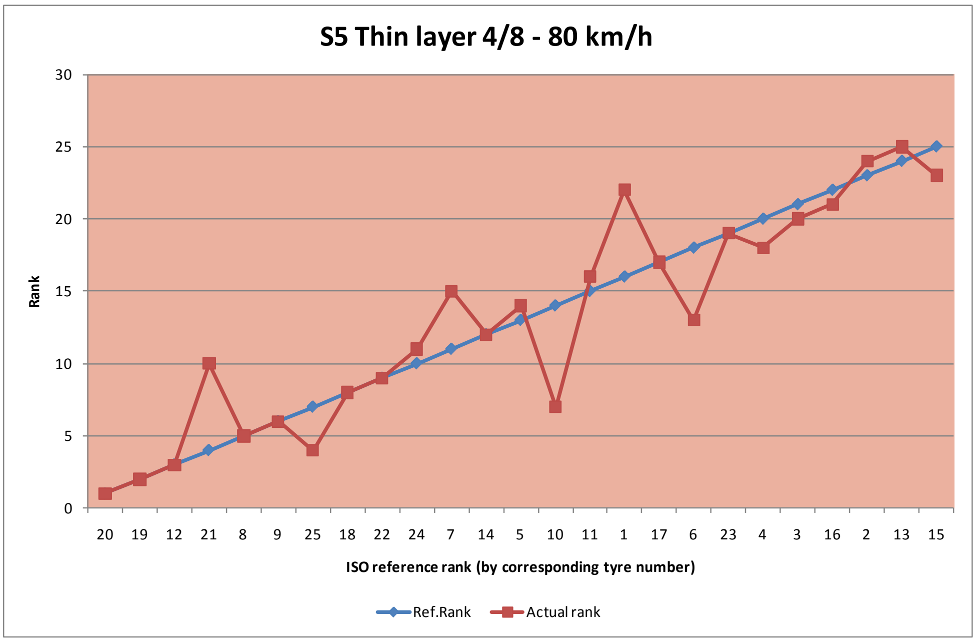

Figure 117 *Ranking analysis, S1/S5*

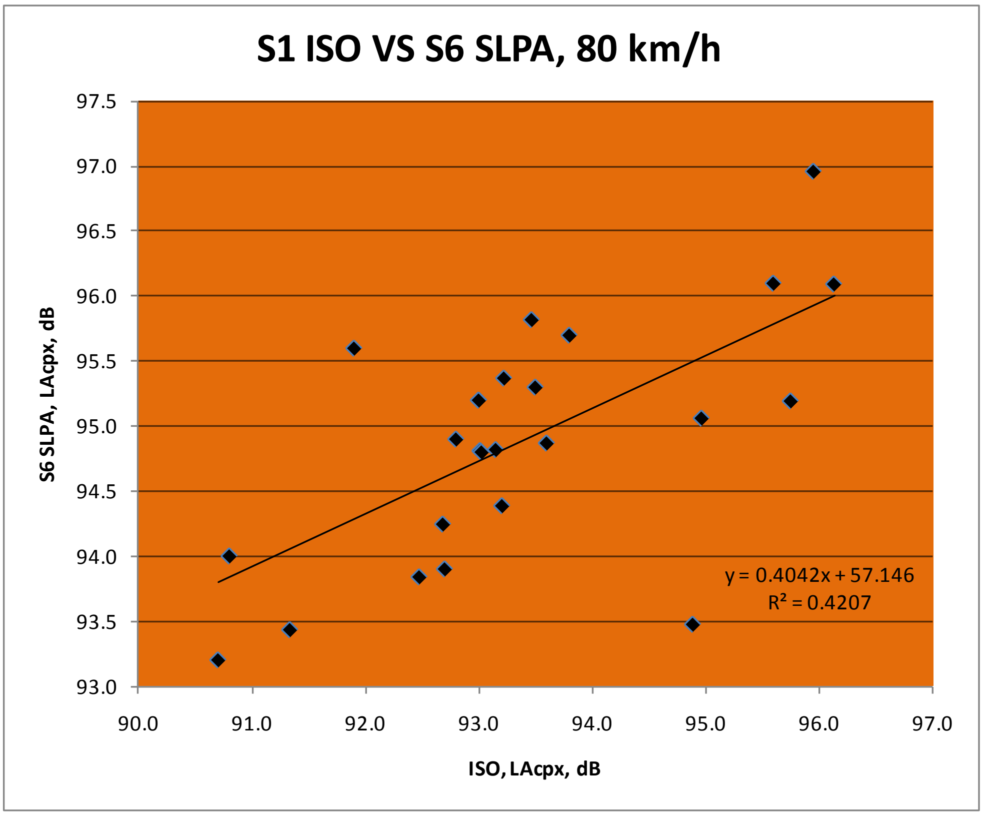

Figure 118 *Linear regression, S1/S6*

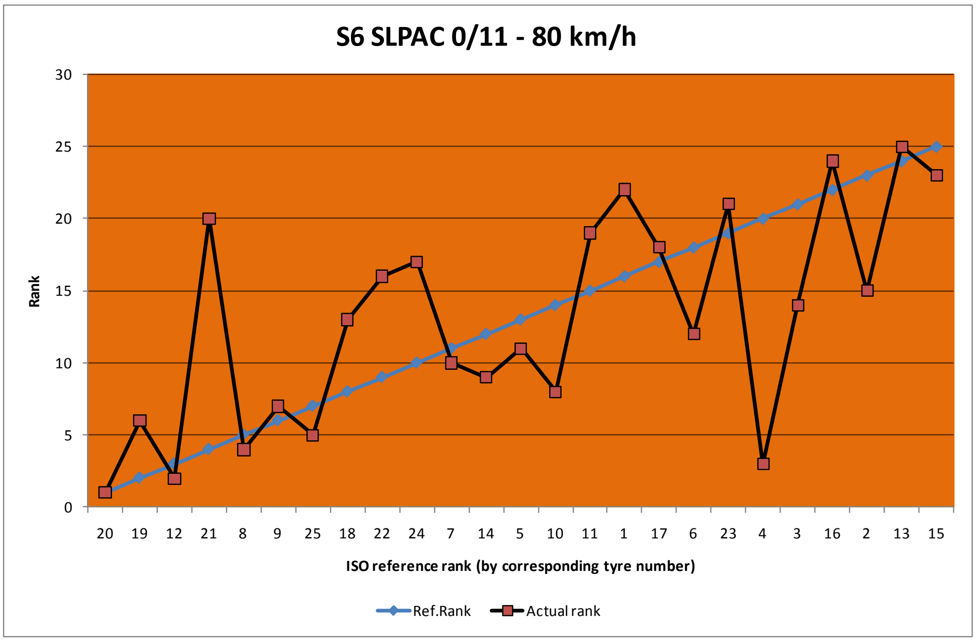

Figure 119 *Ranking analysis, S1/S6*

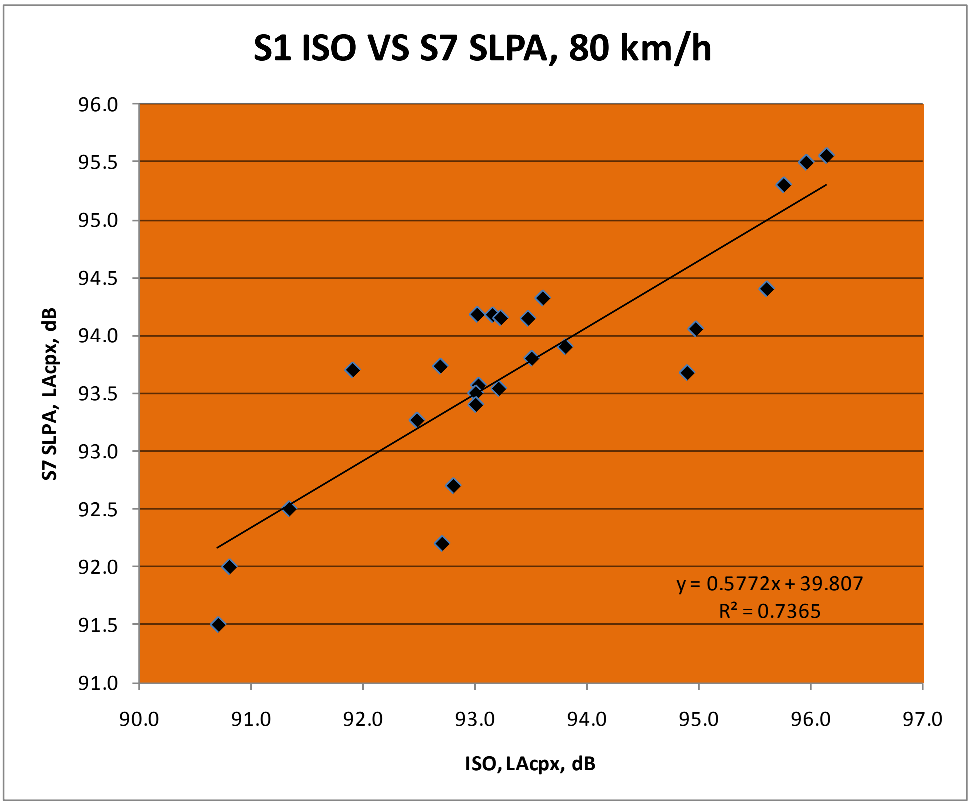

***Figure 120** Linear regression, S1/S7*

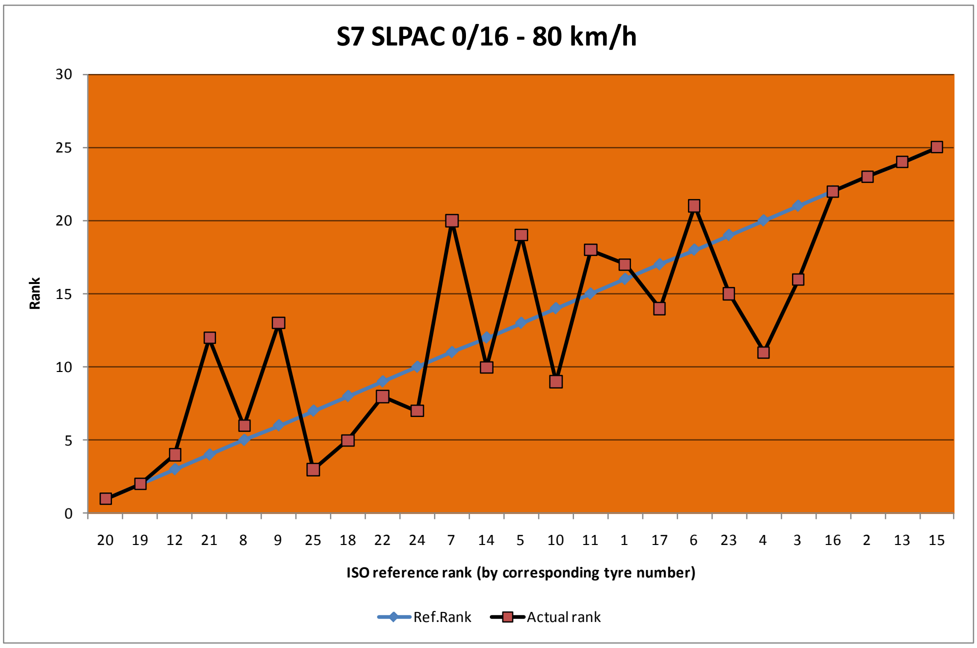

***Figure 121** Ranking analysis, S1/S7*

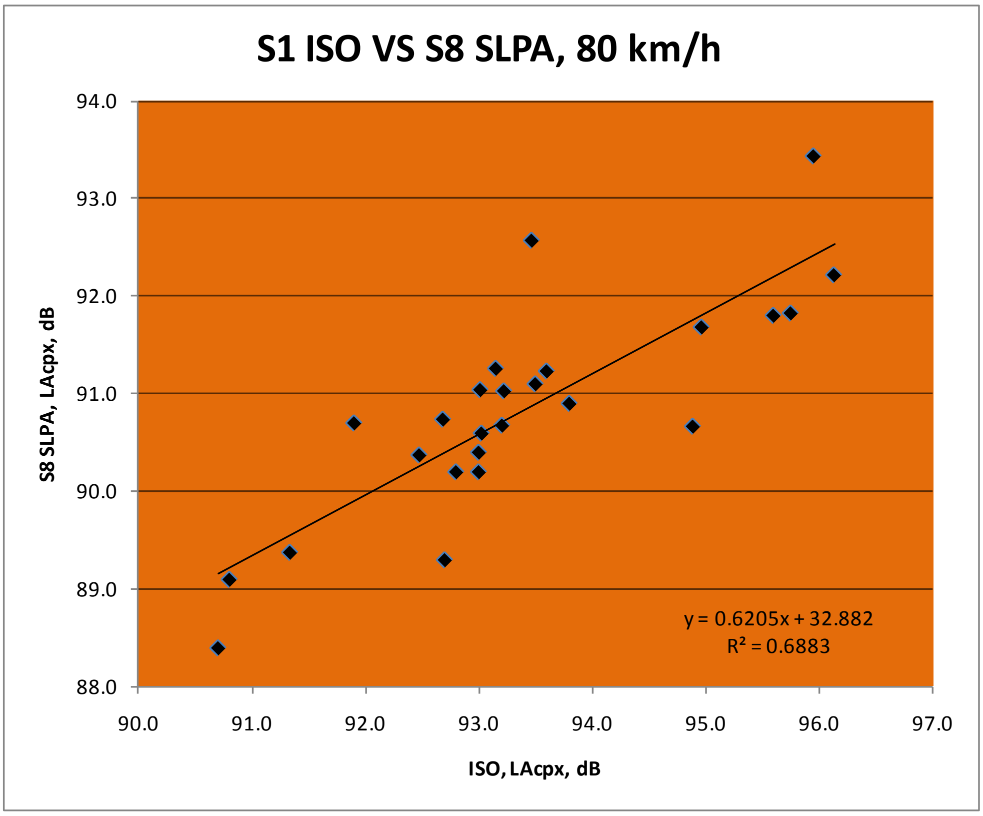

Figure 122 *Linear regression, S1/S8*

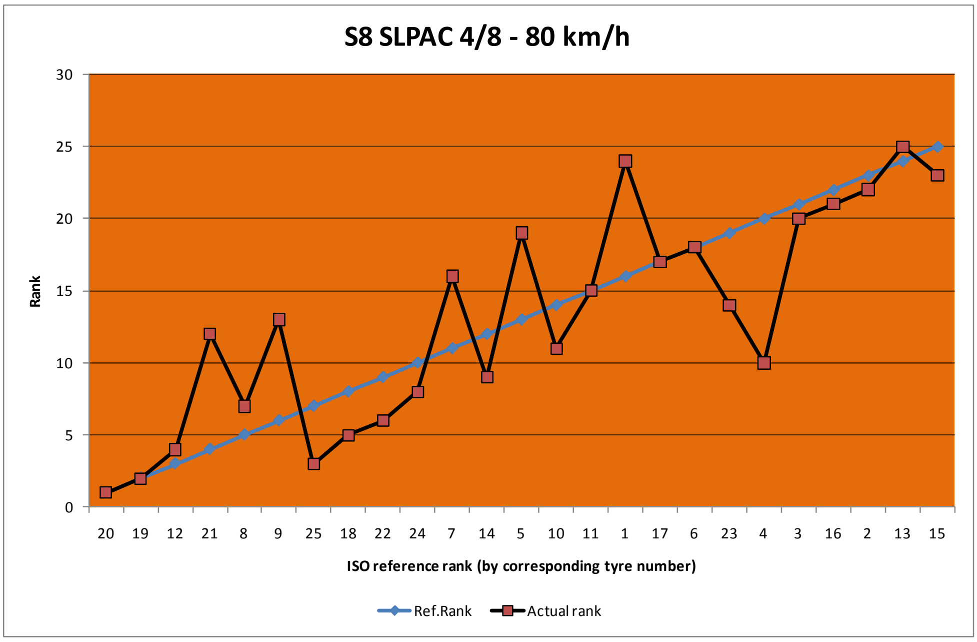

Figure 123 *Ranking analysis, S1/S8*

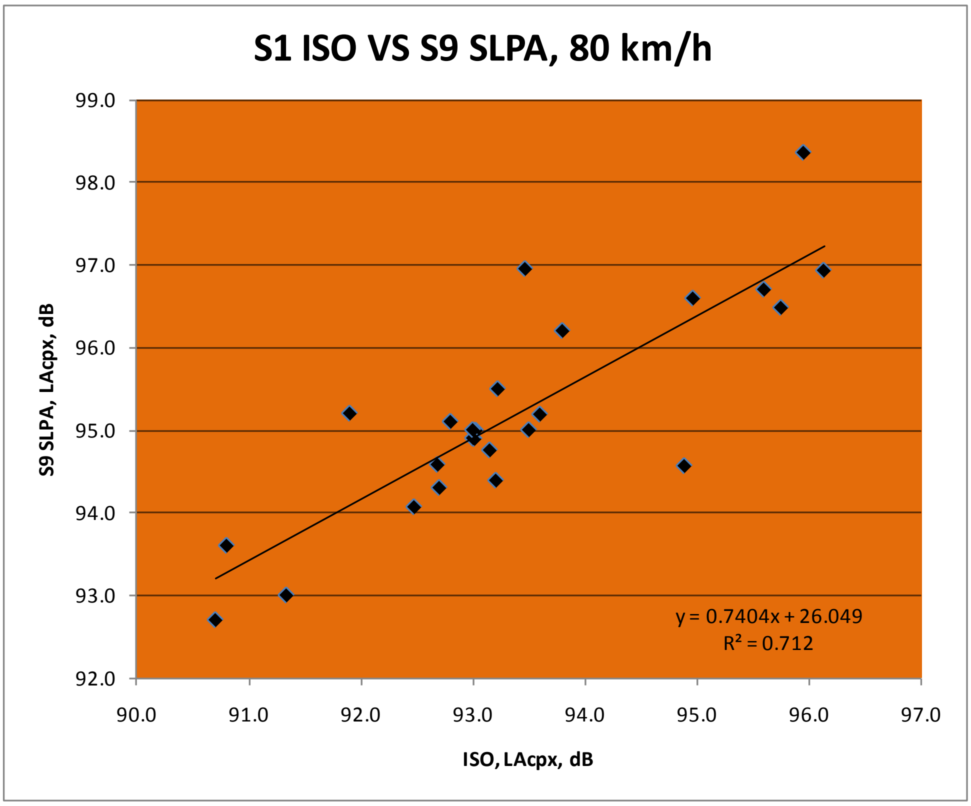

Figure 124 *Linear regression, S1/S9*

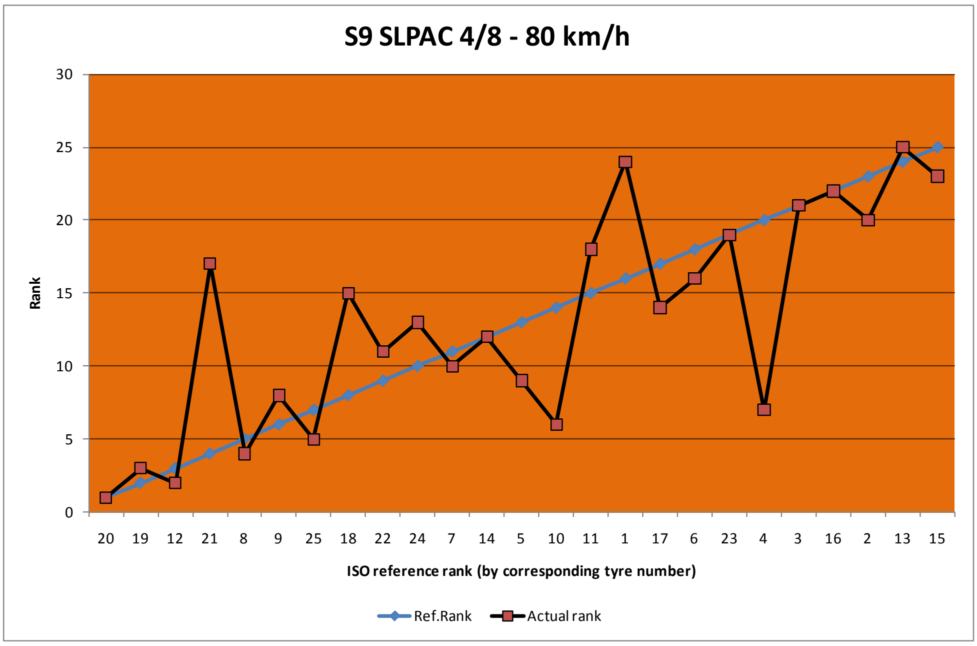

Figure 125 *Ranking analysis, S1/S9*

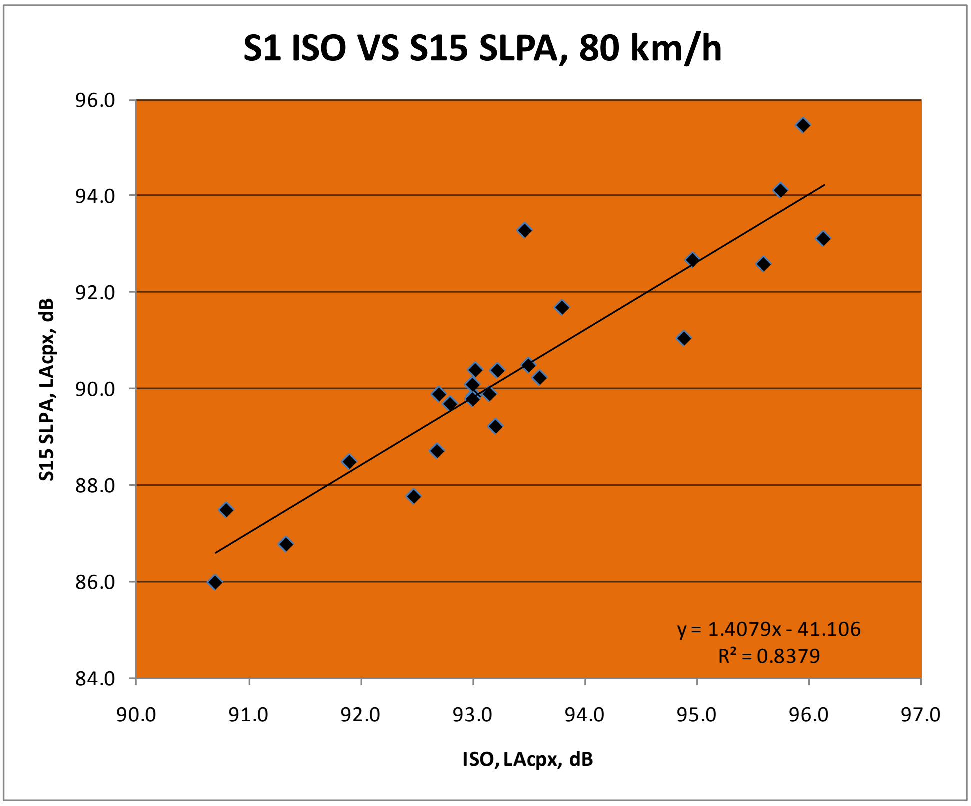

Figure 126 *Linear regression, S1/S15*

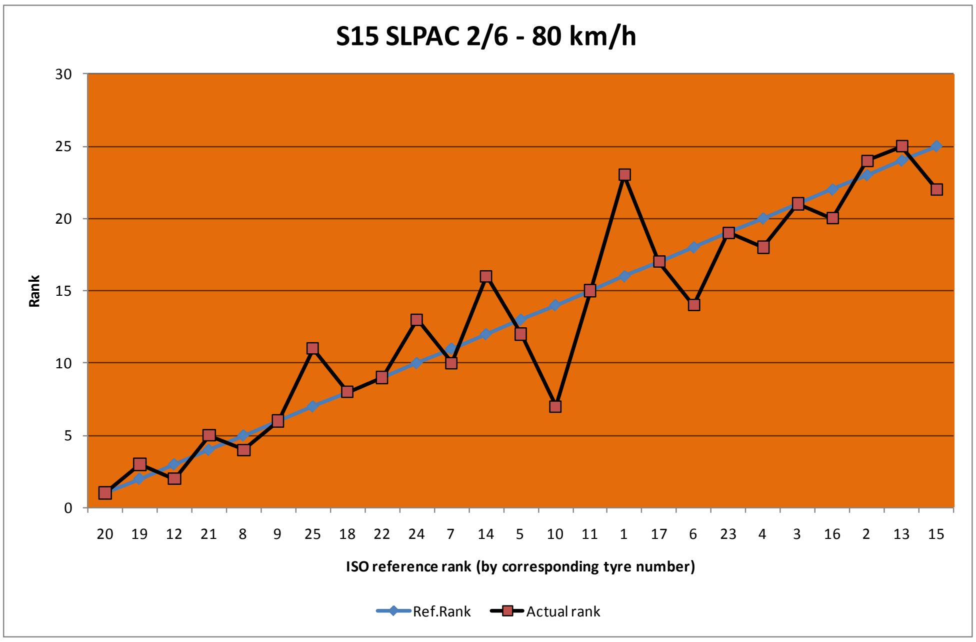

Figure 127 *Ranking analysis, S1/S15*

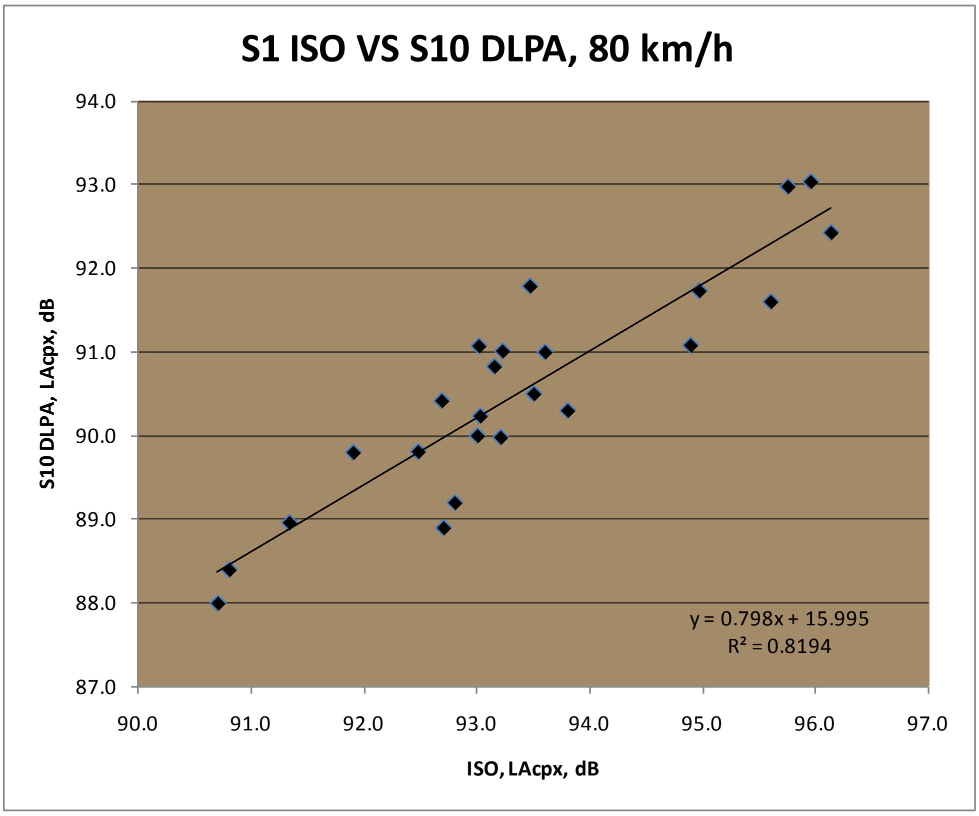

Figure 128 *Linear regression, S1/S10*

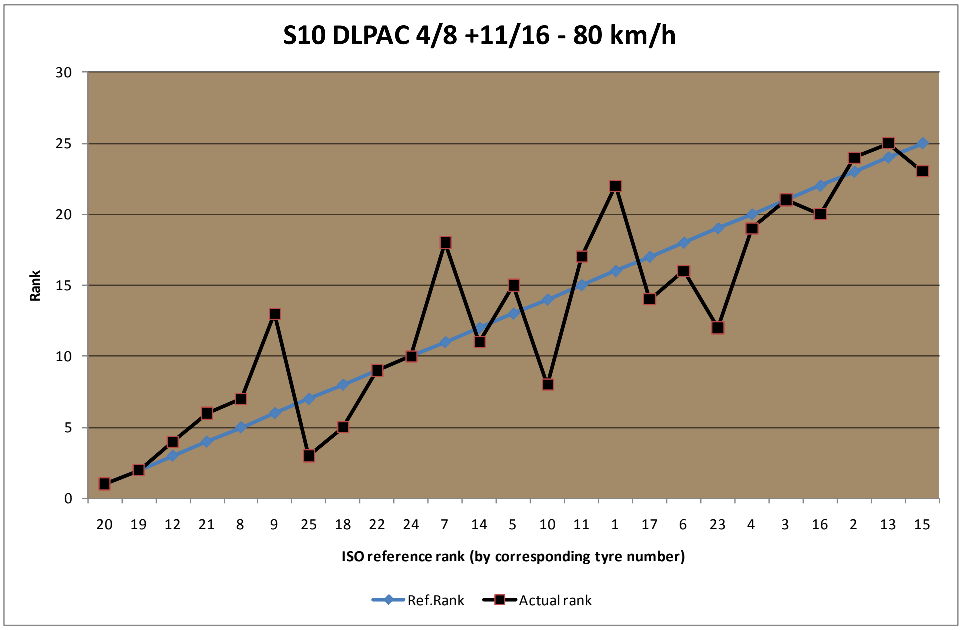

Figure 129 *Ranking analysis, S1/S10*

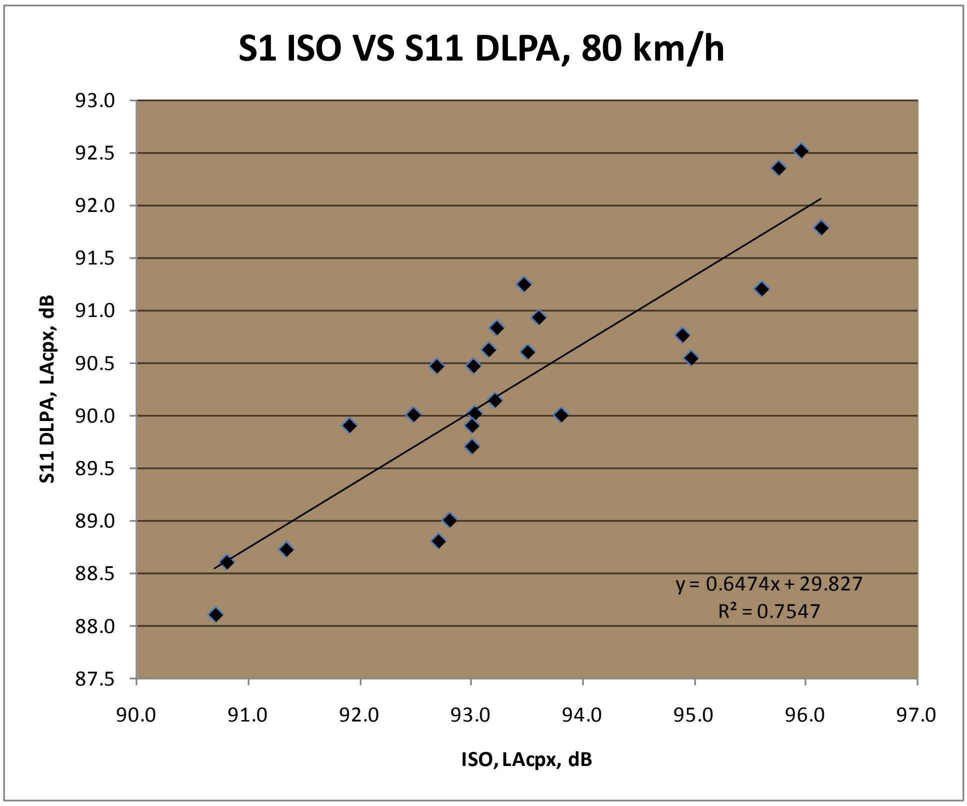

Figure 130 *Linear regression, S1/S11*

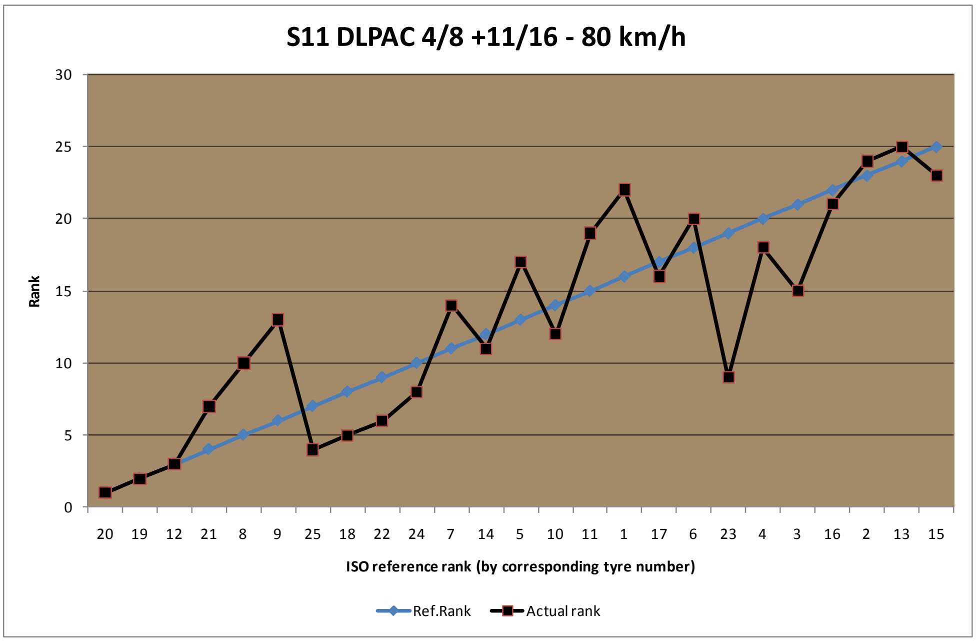

Figure 131 *Ranking analysis, S1/S11*

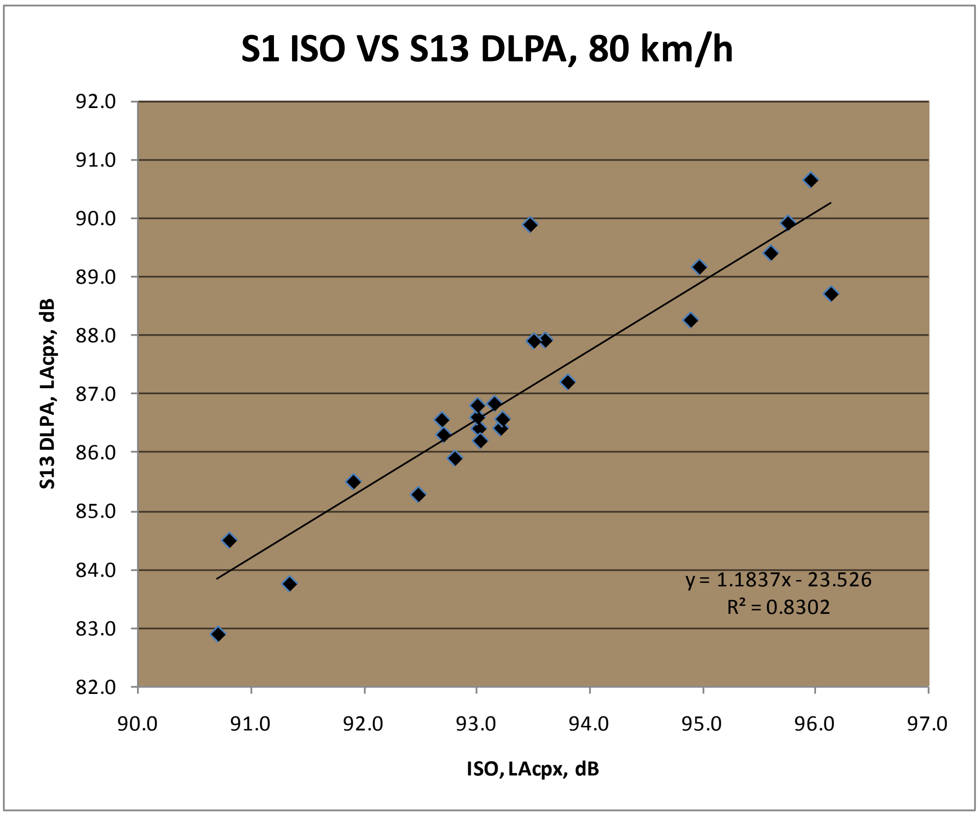

***Figure 132** Linear regression, S1/S13*

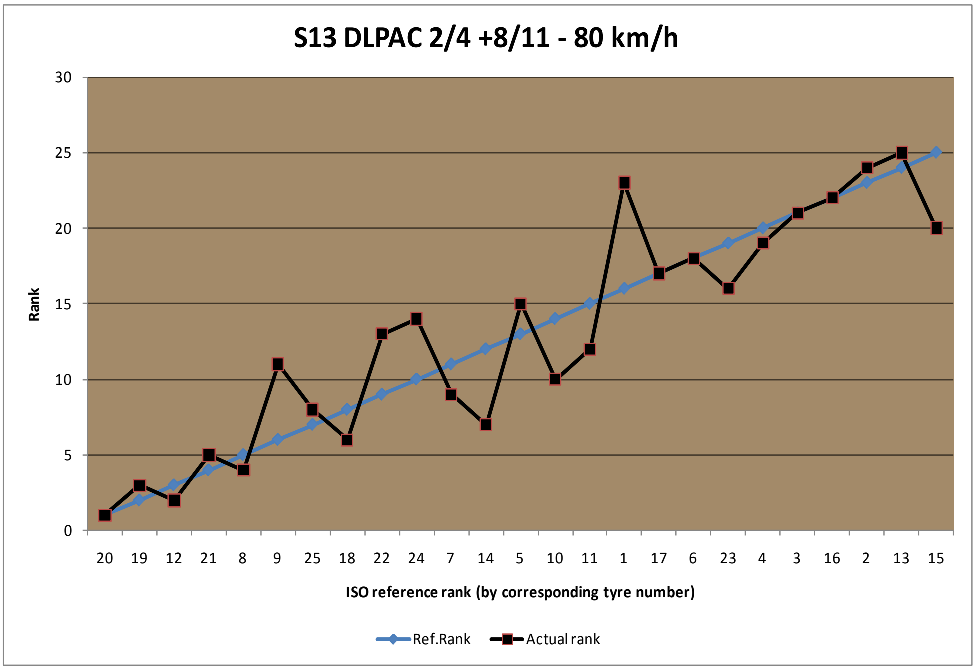

***Figure 133** Ranking analysis, S1/S13*

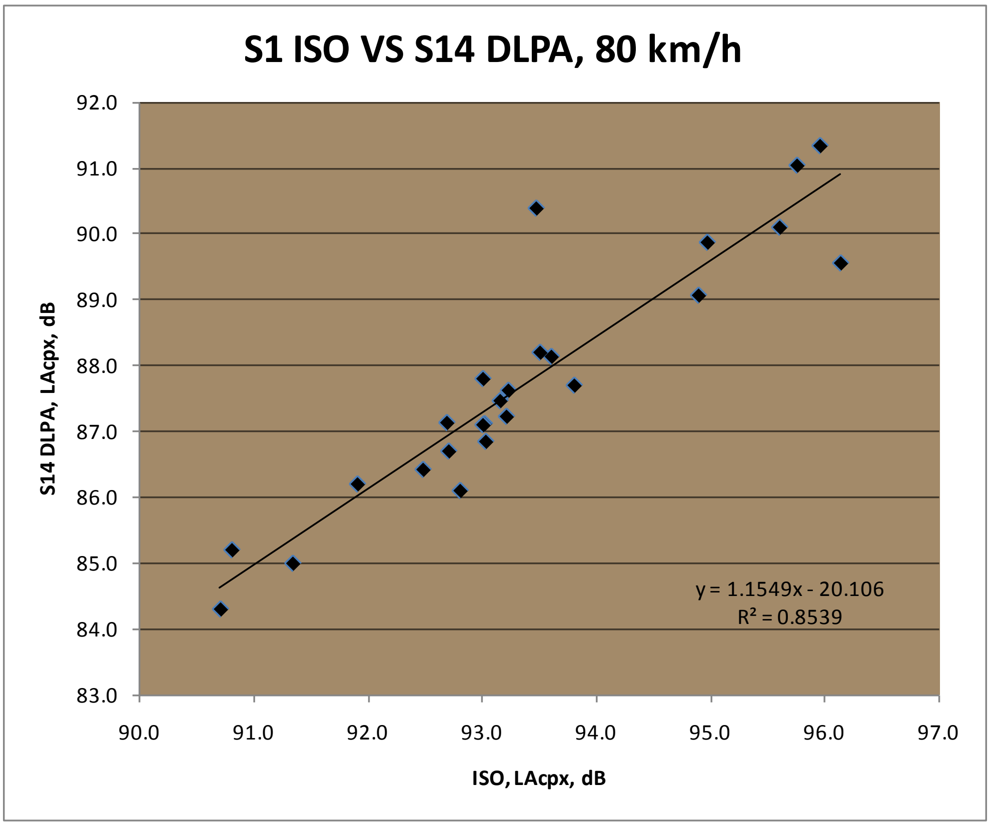

***Figure 134** Linear regression, S1/S14*

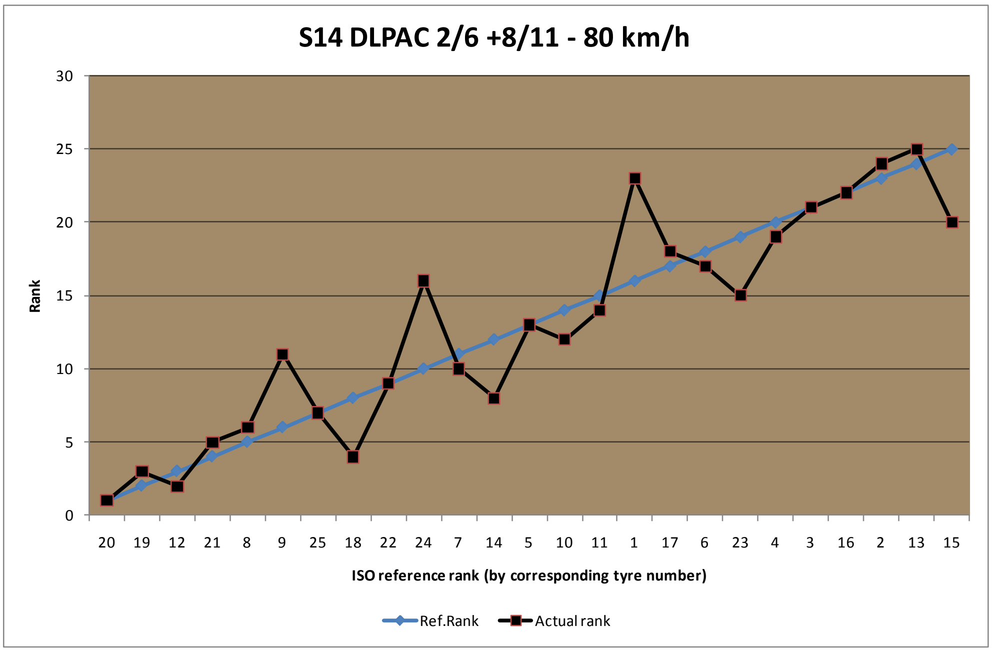

***Figure 135** Ranking analysis, S1/S14*

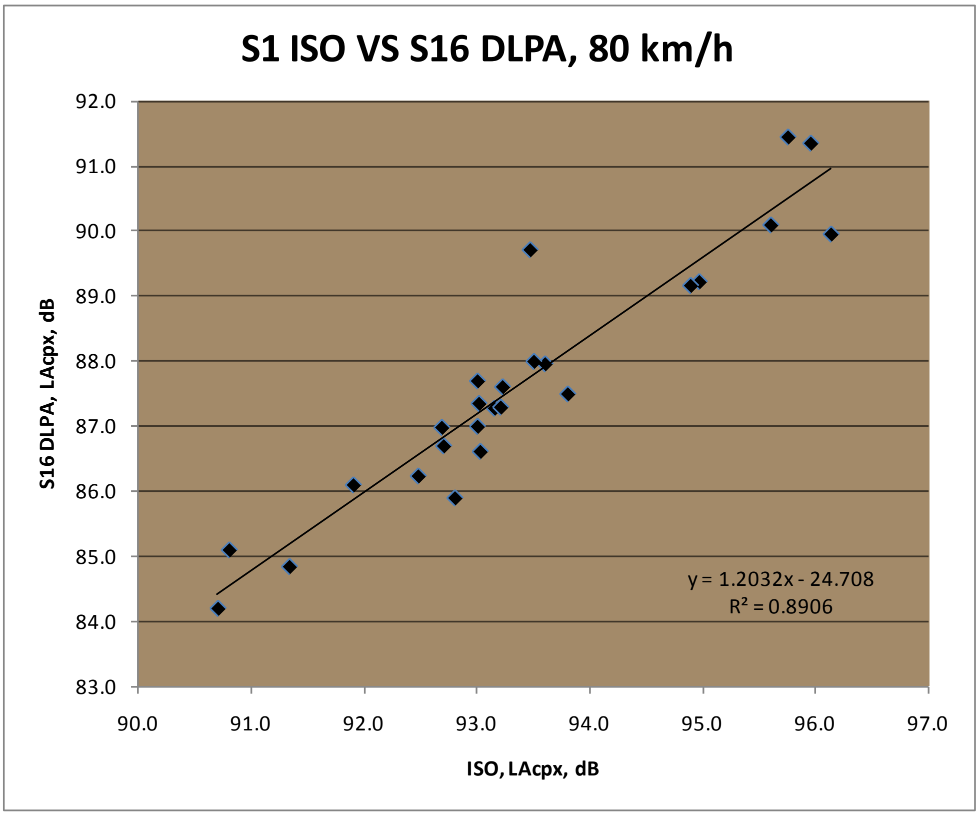

Figure 136 *Linear regression, S1/S16*

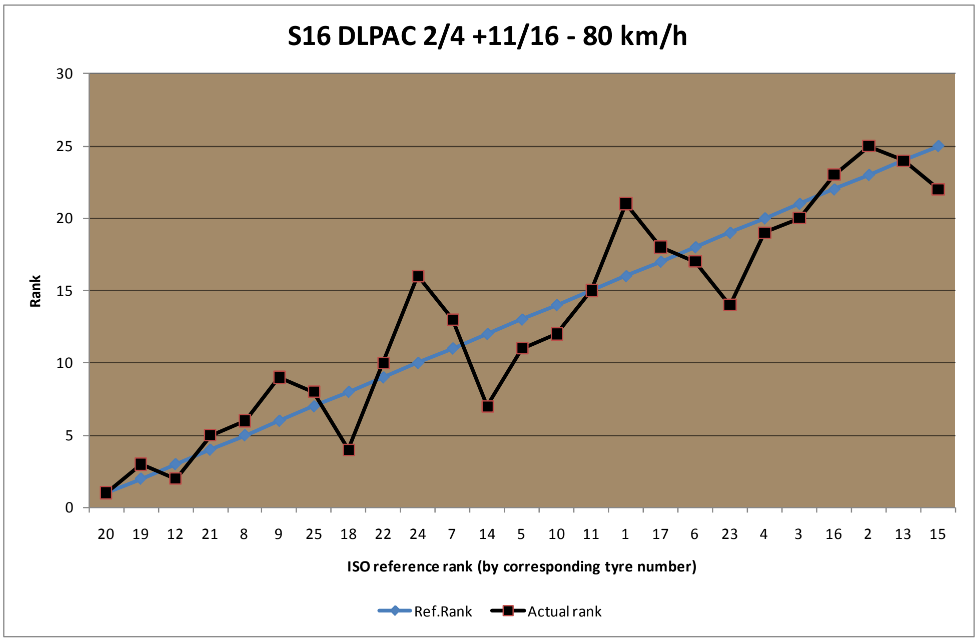

Figure 137 *Ranking analysis, S1/S16*

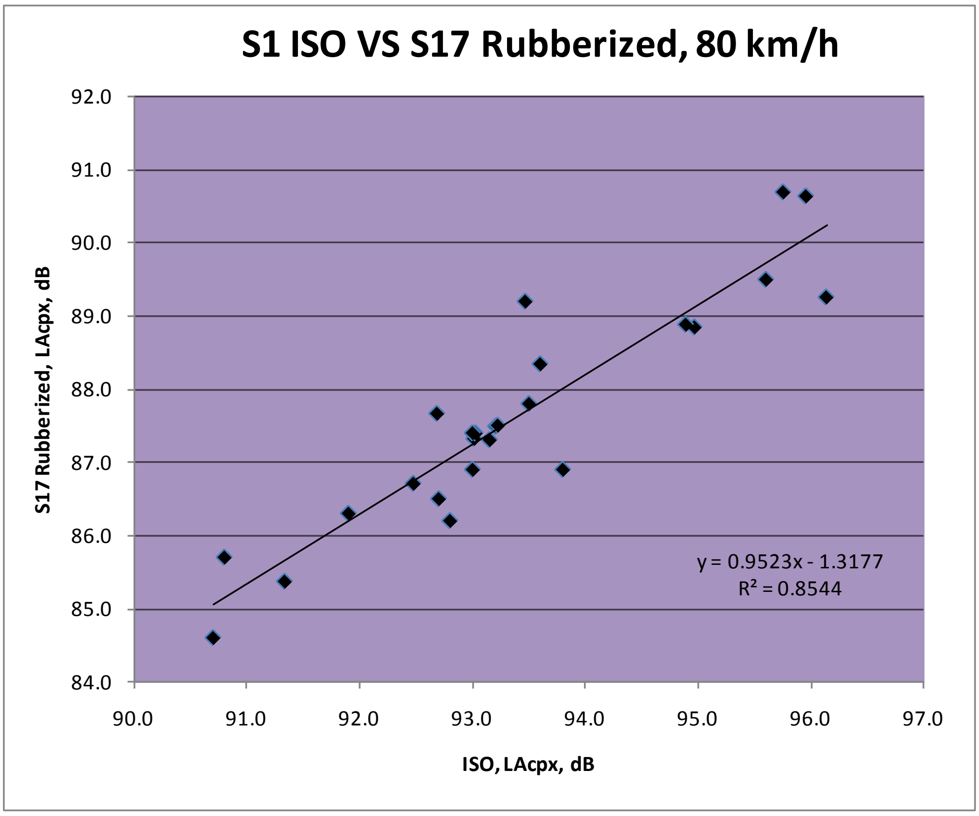

***Figure 138** Linear regression, S1/S17*

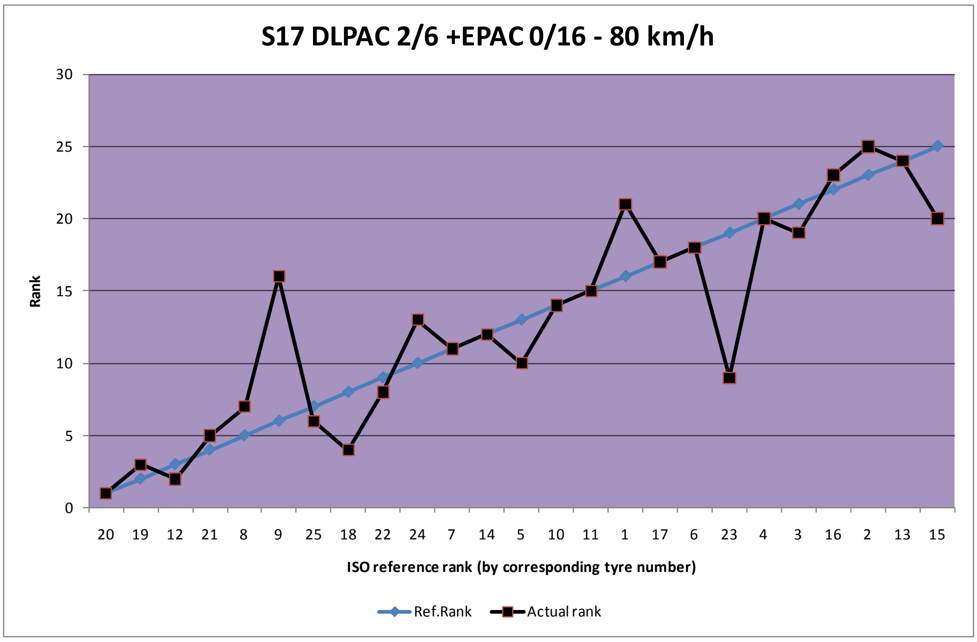

***Figure 139** Ranking analysis, S1/S17*

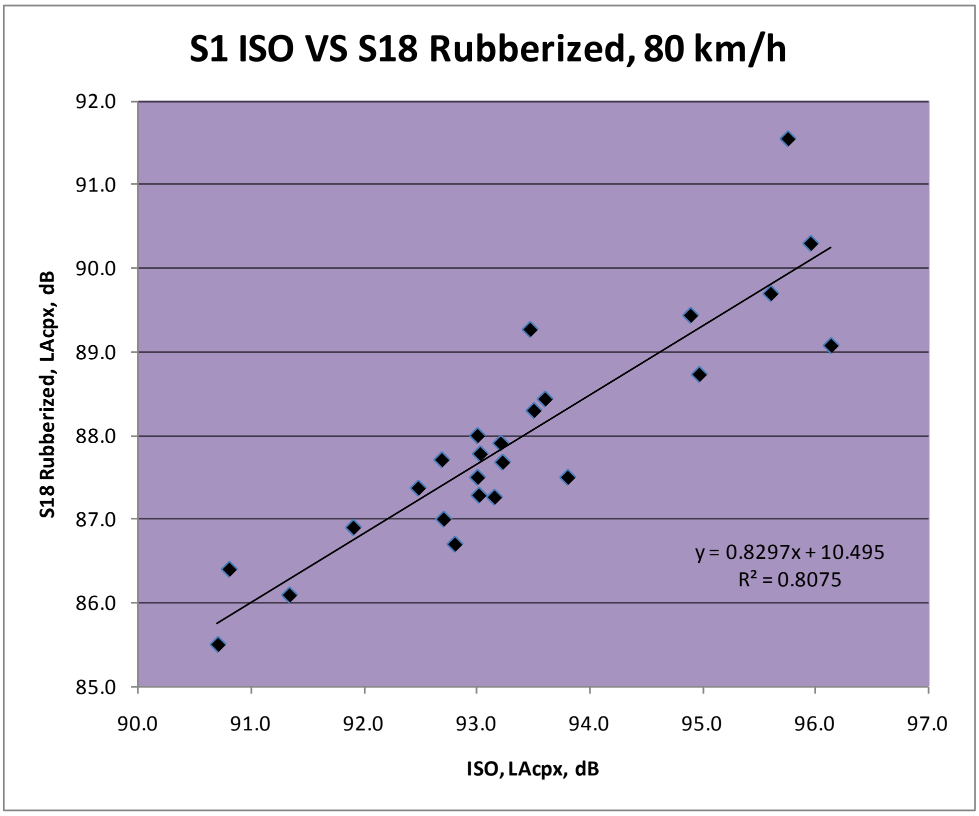

Figure 140 *Linear regression, S1/S18*

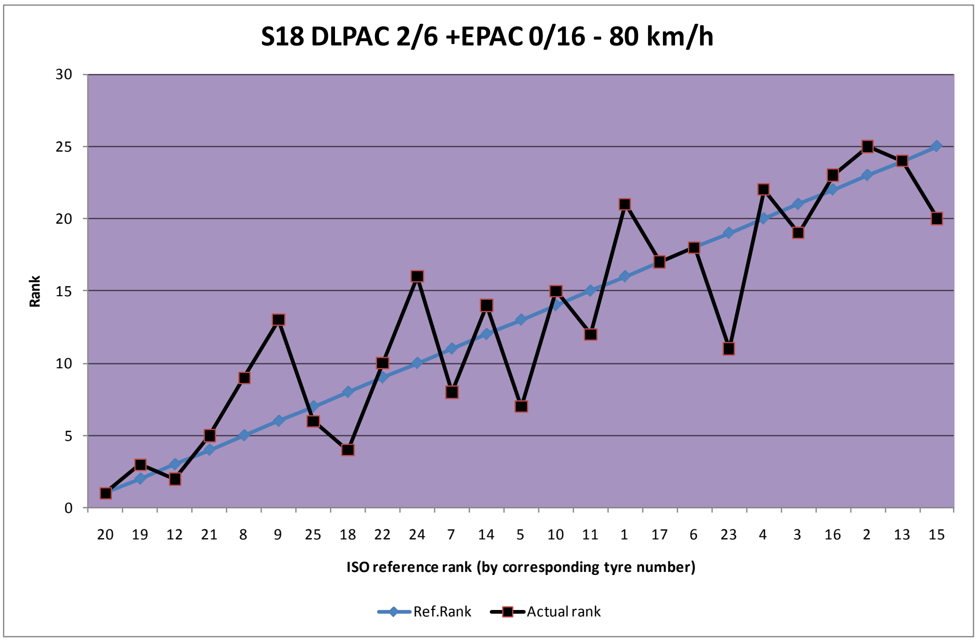

Figure 141 *Ranking analysis, S1/S18*

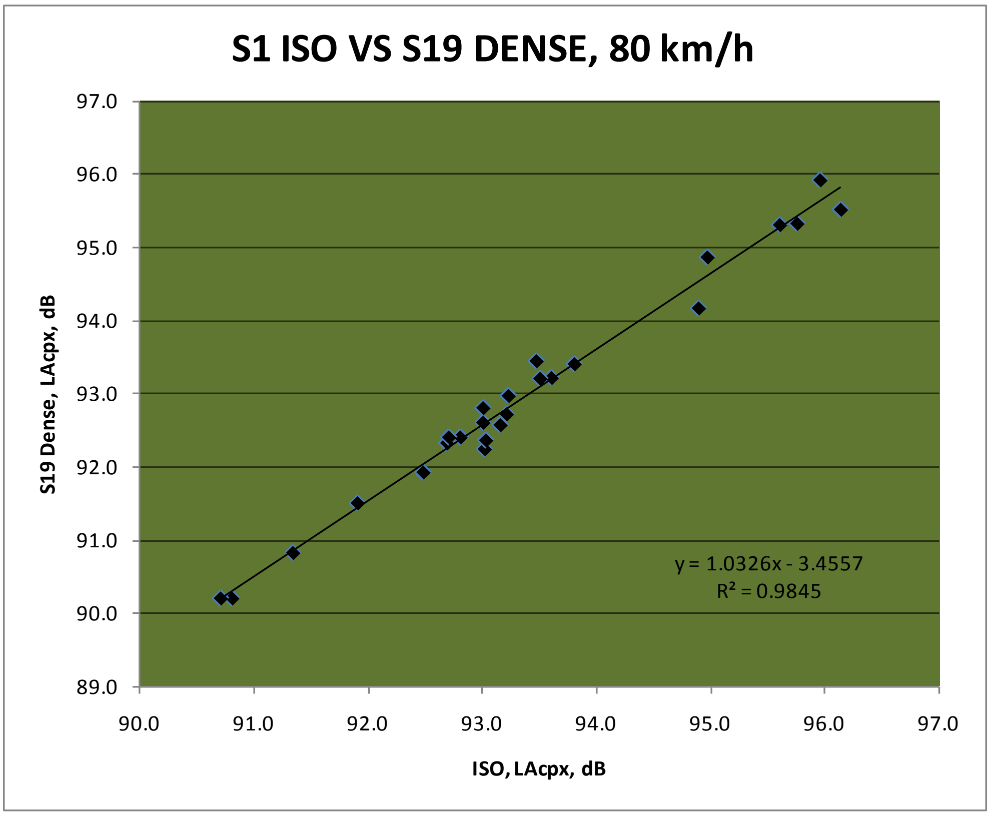

Figure 142 *Linear regression S1/S19*

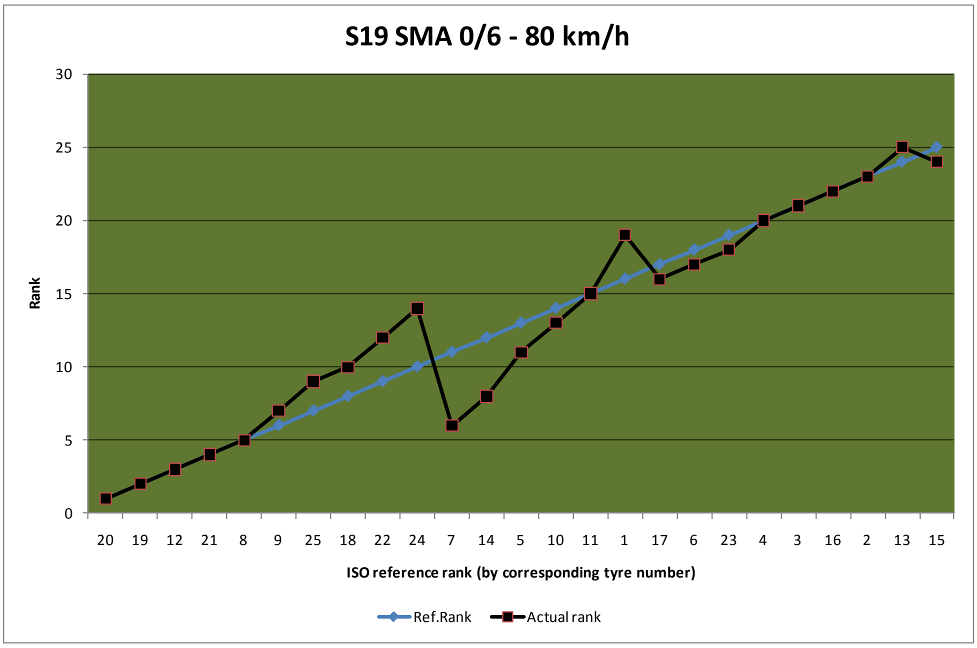

Figure 143 *Ranking analysis, S1/S19*

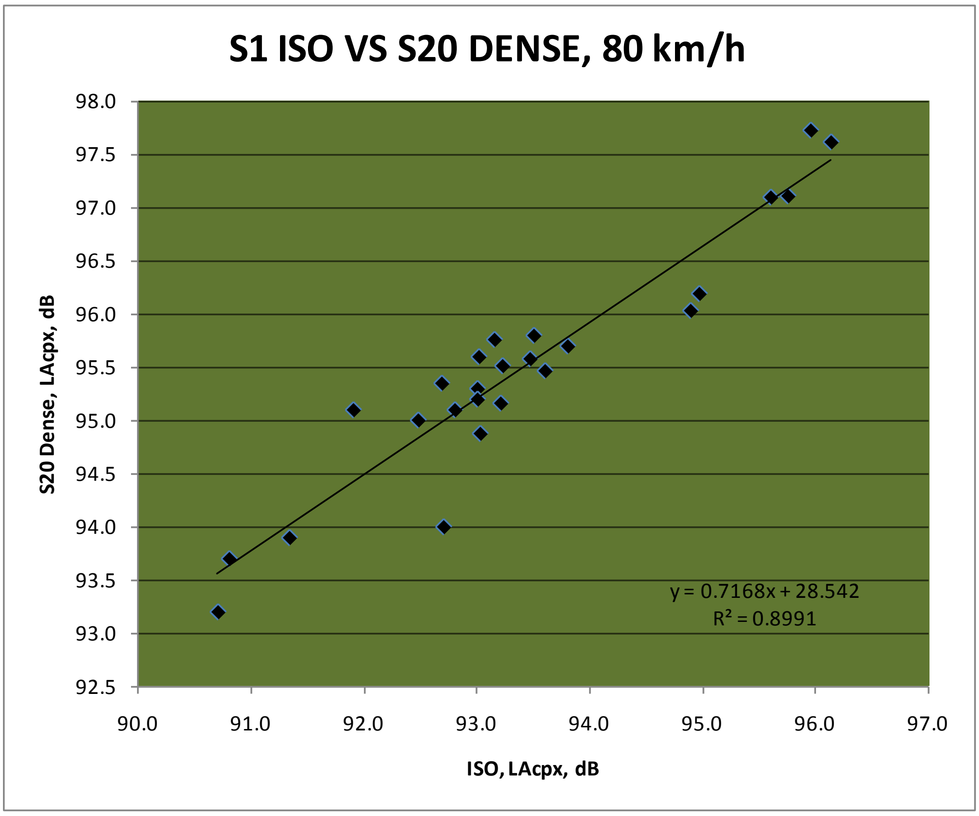

Figure 144 *Linear regression, S1/S20*

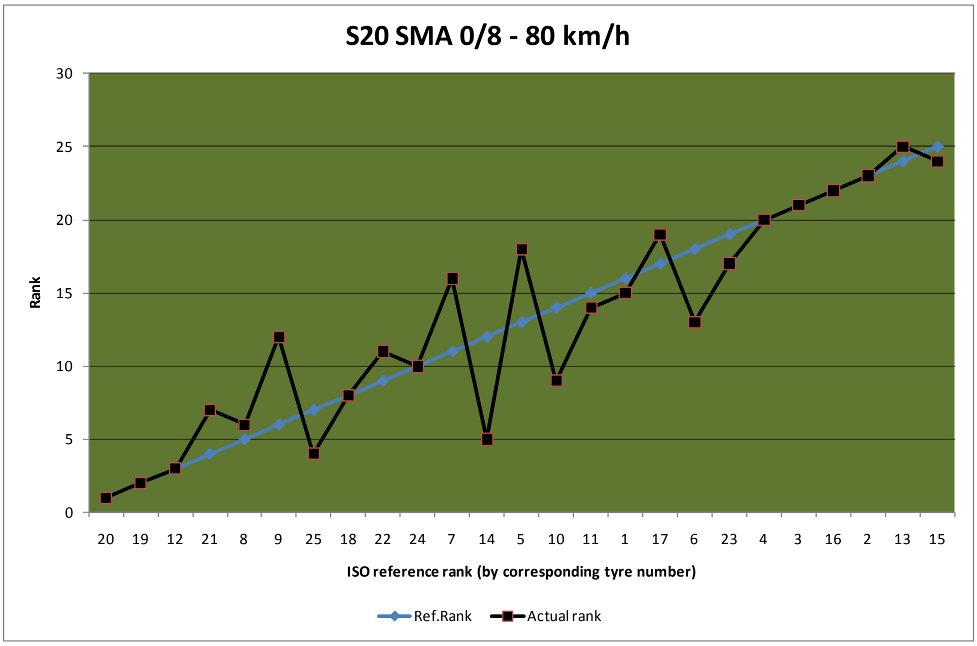

Figure 145 *Ranking analysis, S1/S20*

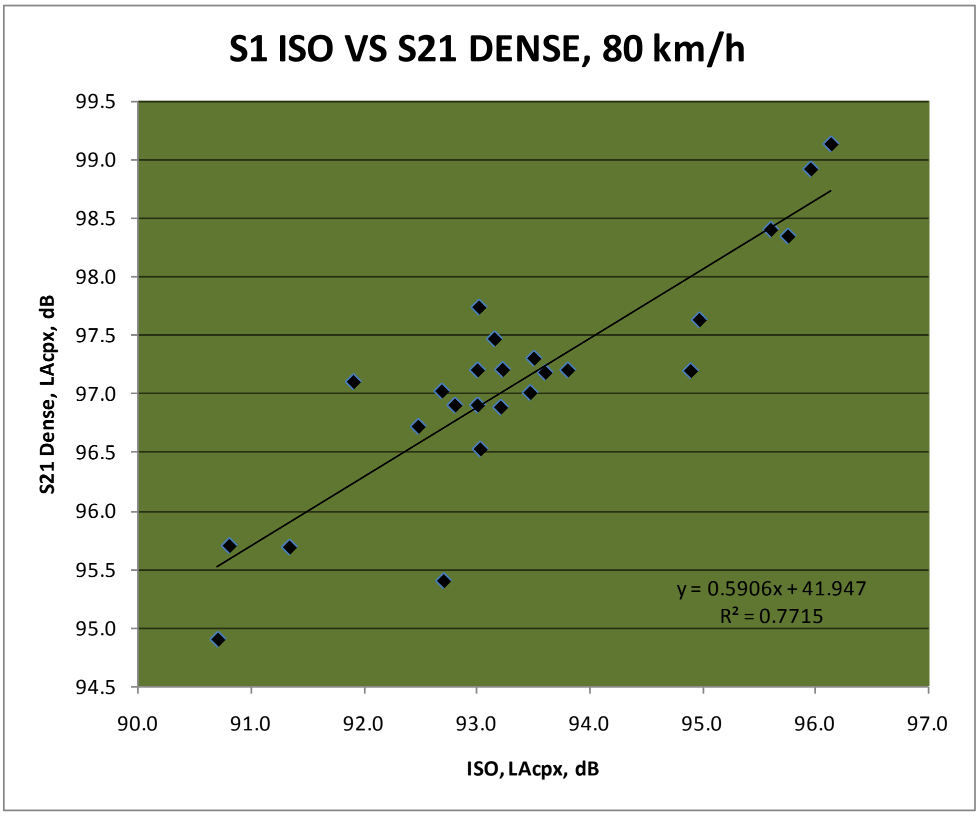

Figure 146 *Linear regression, S1/S21*

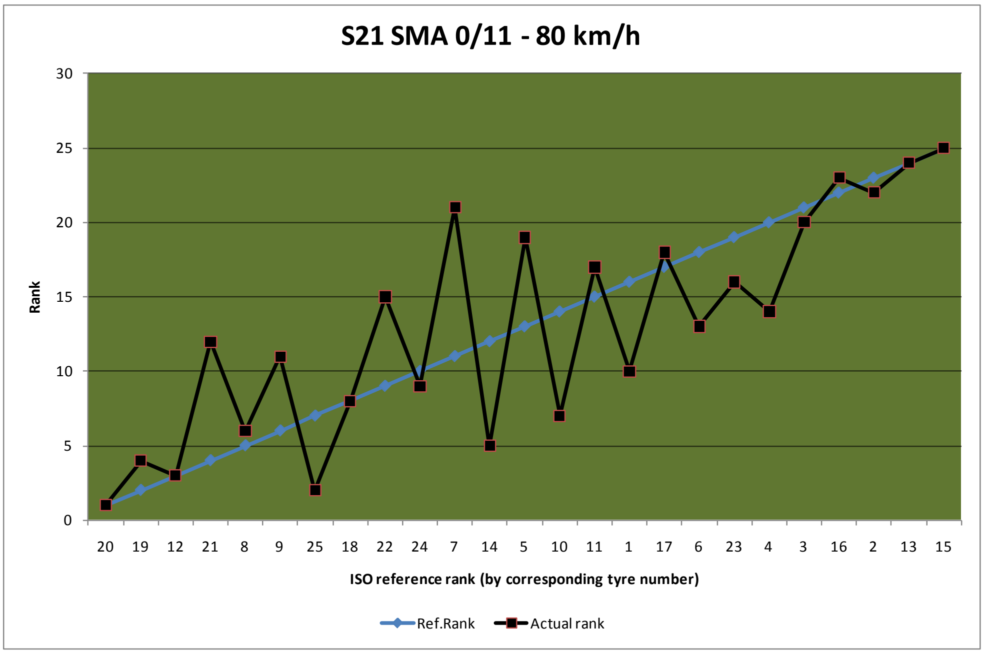

Figure 147 *Ranking analysis, S1/S21*

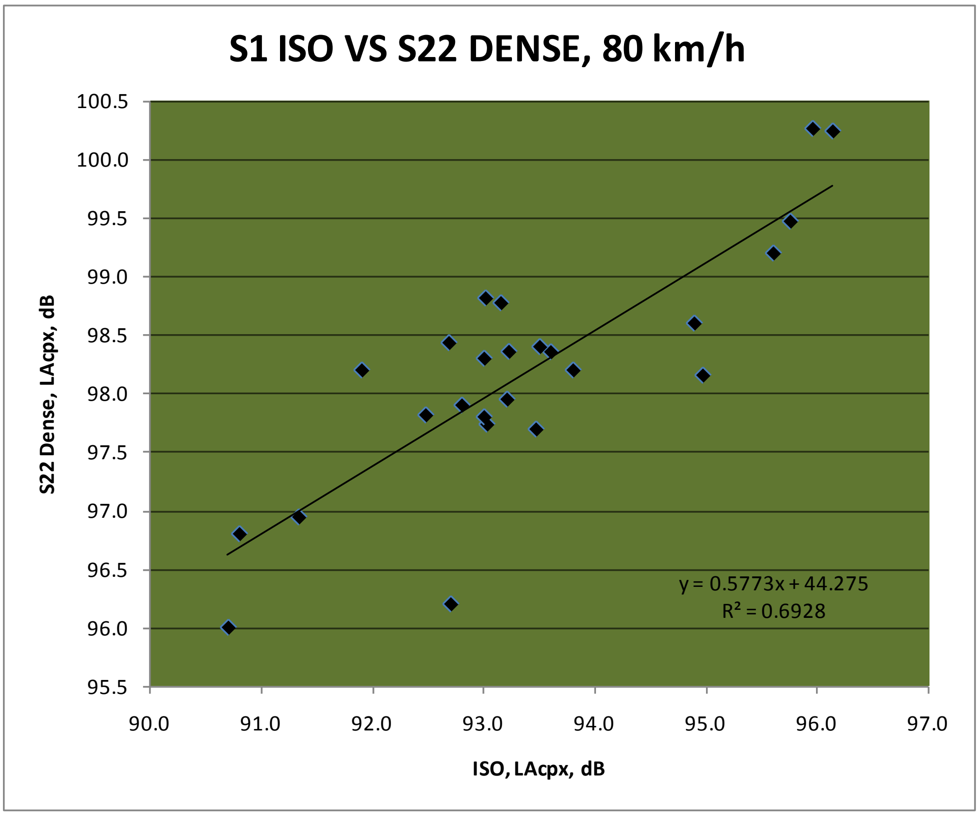

Figure 148 *Linear regression, S1/S22*

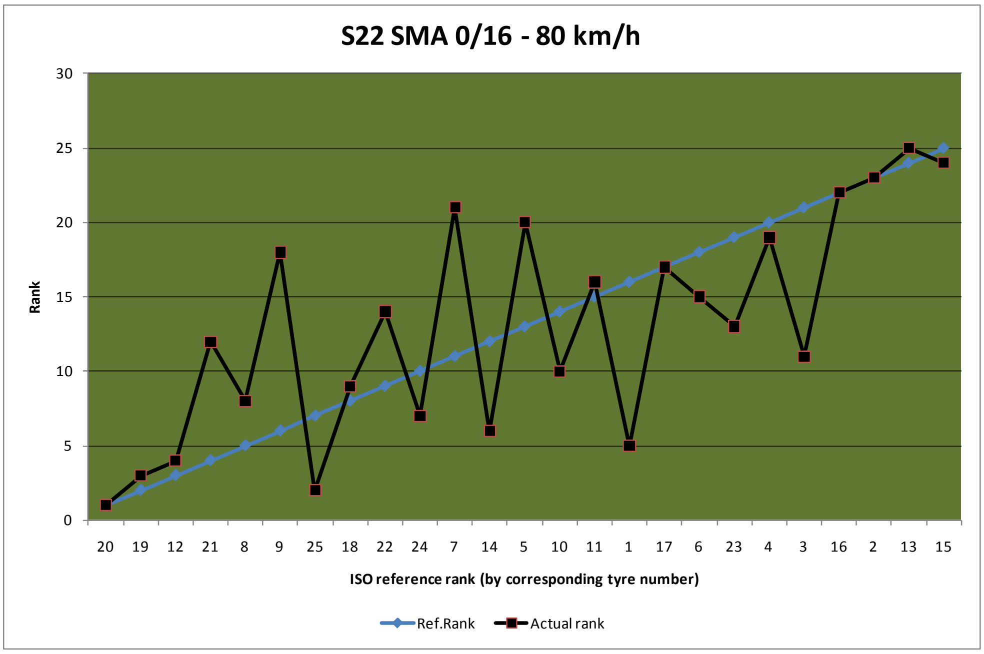

Figure 149 *Ranking analysis, S1/S22*

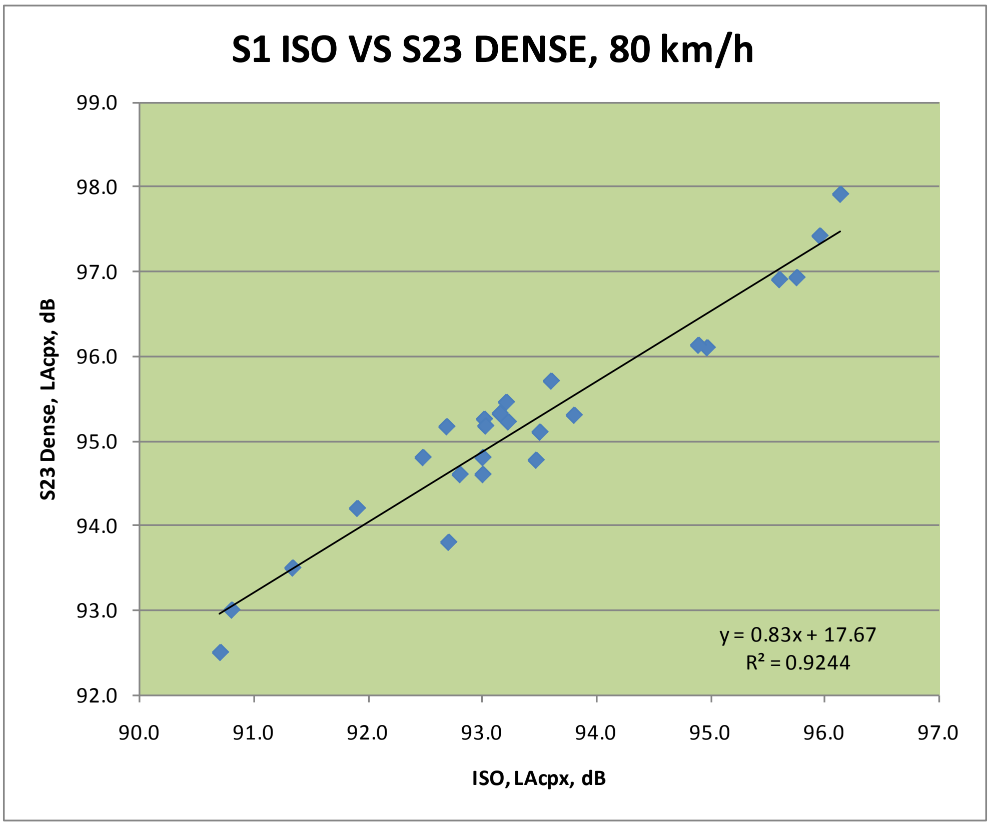

Figure 150 *Linear regression, S1/S23*

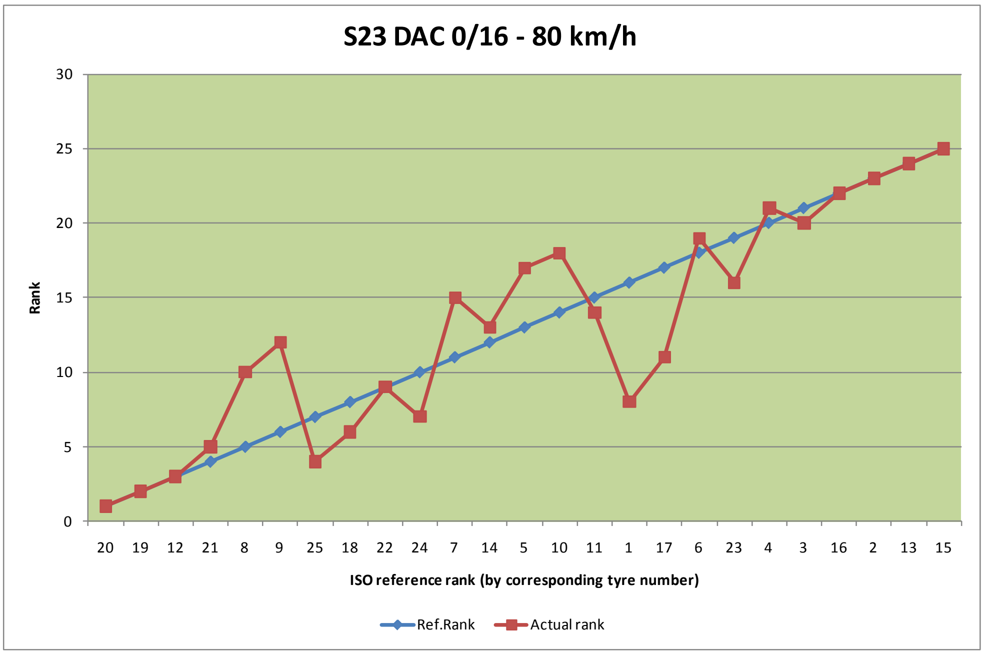

Figure 151 *Ranking analysis, S1/S23*

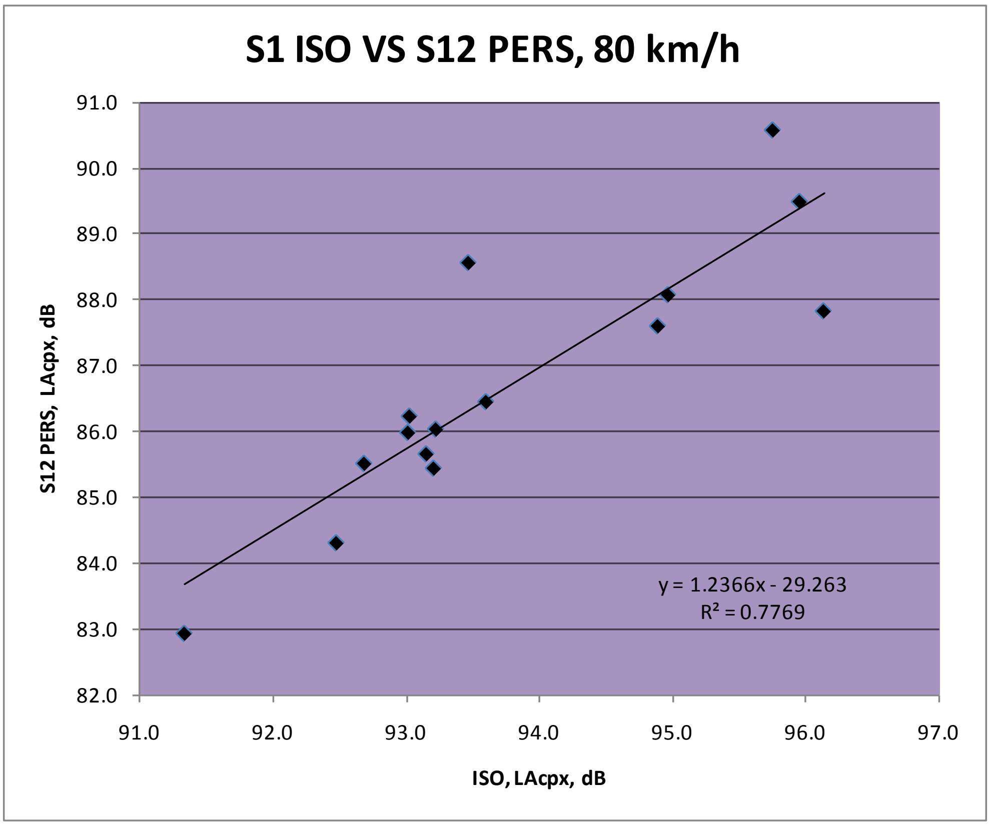

Figure 152 *Linear regression, S1/S12*

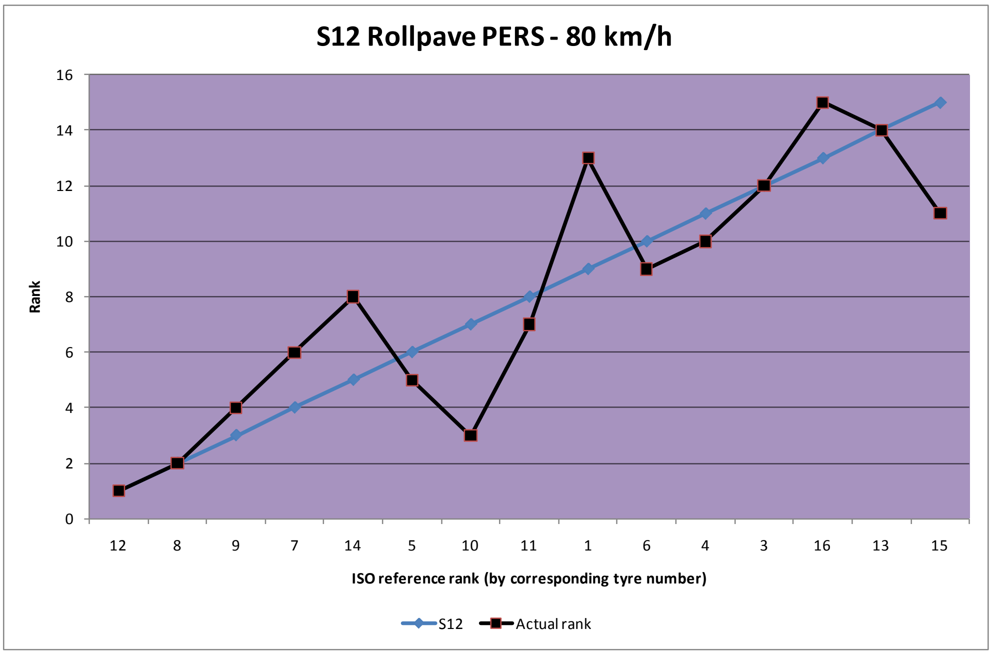

Figure 153 *Ranking analysis, S1/S12*

Several alternative ranking analyses, like Pearson or Spearman have been tested on the datasets. It was concluded that the regression coefficient, R^2 (Pearson), is a good indicator for the different surfaces ability to rank tyres in an “ISO-way”.

This analysis shows that two of the surfaces clearly have a high correlation with the ISO-surface and rank the tyres almost as the ISO. These surfaces are S2 (Thin layer 2/6 – figures 110/111) and S19 (SMA 0/6 – figures 142/143).

A shift in the ranking position can be based on very small differences; less than 0.5 dB, and then within the uncertainty of the measuring method. To evaluate “ability” of the different road surfaces to rank the tyres in an “ISO- way”, we have analyzed all tyres that shift 4 or more places from the ISO-surface (up or down). Those tyres are marked with red square in table 31. From this table, we can evaluate which tyres that rank most different from the ISO-surface, and on which surfaces. The table can be used to both as an indicator to the performance of the individual tyre and of the individual road surface.

***Table 31** Ranking analysis. Combinations of road surface and tyre which shifts more than 4 places are marked with red*

		Surface																						
No	Tyre	S2	S3	S4	S5	S6	S7	S8	S9	S15	S10	S11	S13	S14	S16	S17	S18	S19	S20	S21	S22	S23	S12	Σ Number
1	Dayton T110		X	X	X	X		X	X	X	X	X	X	X	X	X	X			X	X	X	X	18
2	Sportiva G70					X																		1
3	Barum Brilliantis					X	X					X									X			4
4	Toyo 330					X	X	X												X				4
5	Goodyear Excellence						X	X	X			X					X		X	X	X	X		9
6	ContiPremiumContact2				X	X				X									X	X				5
7	Toyo Proxes T1R				X			X			X							X	X	X	X	X		8
8	Nokian Hakka H						X										X					X		3
9	Michelin Pilot Primacy						X	X			X	X	X	X		X	X		X	X	X	X		12
10	Firestone Firehawk		X	X	X	X	X		X	X	X		X	X					X	X	X	X	X	15
11	ContiEcoContact3					X						X												2
12	Yokohama AVS dBV500																							0
13	Pirelli P7																							0
14	Hankook Ventus Prime									X			X					X	X	X	X			6
15	Michelin Energy Saver_1(T1029)												X	X	X	X	X						X	6
16	Vredestein Hi-Trac																							0
17	Goodyear Optigrip																					X		2
18	Pirelli Cinturato P6					X			X						X	X	X							5
19	Interstate Sport IXT-1					X																		1
20	Yokohama AVS dBV500																							0
21	Dunlop SP Sport Maxx				X	X	X	X	X											X	X			7
22	ContiEcoContact3					X							X	X	X					X	X			6
23	Brigdestone B-250						X	X			X	X			X	X	X				X			8
24	ContiPremiumContact2			X		X							X	X			X	X						6
25	Goodyear GT3						X	X		X	X	X								X	X			7
	Σ Number	0	2	3	5	12	9	8	5	5	6	7	7	6	5	5	8	3	6	11	11	7	3	

Note: Tyres 16-25 not measured on S12 (grey area)

Tyre ranking:

Based in the results in table 31, we can categorize the tyres into 3 classes:

Class 1: Shifts ranking 4 or more places on 0 – 3 road surfaces
Class 2: Shifts ranking 4 or more places on 4 – 7 road surfaces
Class 3: Shifts ranking 4 or more places on more than 8 surfaces

This classification indicates that tyres in class 1 are the tyres with quite similar ranking on the ISO-surface and on the others. Class 3 then, ranks quite different on many of the road surfaces compared to ISO. One “bad” tyre is tyre 1, which ranks significantly different on 18 of 22 surfaces.

The categorization of tyres according to this system is shown in table 32.

Table 32 *Ranking - classes of tyres*

Class 1	Class 2	Class 3
Tyre 2 Sportiva G70	Tyre 3 Barum Brilliatis	Tyre 1 Dayton T110
Tyre 8 Nokian Hakka H	Tyre 4 Toyo 330	Tyre 5 Goodyear Excellence
Tyre 11 ContiEcoContatct3	Tyre 6 ContiPremiumContact2	Tyre 7 Toyo Proxes T1R
Tyre 12 Yokohama AVS dB V500	Tyre 14 Hankook Ventus Prime	Tyre 9 Goodyear Excellence
Tyre 13 Pirelli P7	Tyre 15 Michelin Energy Saver	Tyre 10 Firestone Firehawk
Tyre 16 Vredestein Hi-trac	Tyre 21 Dunlop SP Sport Maxx	Tyre 23 Bridgestone B-250
Tyre 17 Goodyear Optigrip	Tyre 22 ContiEcoContact3	
Tyre 19 Interstate IXT-1	Tyre 24 ContiPremiumContact2	
Tyre 20 Yokohama AVS dB V500	Tyre 25 Goodyear GT3	

As table 32 shows, the most silent tyres; 12 and 20 are found in class 1, as well as some of the noisiest tyres like 2, 13 and 16. This is a positive result, as the ISO-surface then seems to be representative for the noise behaviour of these tyres.
However, it is still an open question if there are some common features of these tyres, which cause similar behaviour on the ISO-surface, as on the other types of surfaces. This should be further investigated.

Road surface ranking:
Another way to interpret the results in table 31 is to look at which of the road surfaces do rank the tyres most like the ISO-surface. In table 33, the surfaces are also separated into 3 classes (surface 12 is not included since fewer tyres were measured on this surface):

Class 1: Shifts ranking of 0-4 tyres ≥ 4 places
Class 2: Shifts ranking of 5-8 tyres ≥ 4 places
Class 3: Shifts ranking of 9-12 tyres ≥ 4 places

The road surfaces in class 1 is then road surfaces which ranks tyres most like the ISO.

Table 33 *Ranking - classes of road surfaces*

Class 1	Class 2	Class 3
S2: TL 2/6	S5: TL 4/8	S6: SLPAC 0/11
S3: TL 2/4	S8: SLPAC 4/8	S7: SLPAC 0/16
S4: TL 2/6	S9: SLPAC 4/8	S21: SMA 0/11
S15: SLPAC 0/6	S10: DLPAC 4/8+11/16	S22: SMA 0/16
S19: SMA 0/6	S11: DLPAC 4/8+11/16	
	S13: DLPAC 2/4+8/11	
	S14: DLPAC 2/6+8/11	
	S16. DLPAC 2/6+11/16	
	S17: DLPAC 2/6+EPAC 0/16	
	S18: DLPAC 2/6+EPAC 0/16	
	S20: SMA0/8	
	S23: DAC 0/16	

A similar test was done on a shift of 2 places, but then the results are not statistically significant. Increasing the number to more than 6 places, did not improve/change the classification.

As table 33 indicates, it is the thin layers with 4-6 mm aggregate sizes, as well as the SMA 0/6, who ranks tyres in an “ISO-way”. This is also reflected in the correlation results shown in table 29. The road surfaces with the lowest correlation with ISO seem to be surfaces with 11-16 mm aggregate sizes.

To investigate this in more detail, a regression analysis was made on the relationship between the ranking and the aggregate size at the speed of 80 km/h.

In this analysis, all differences between the ranking on the ISO-surface and the corresponding surfaces are included and added up. If only one tyre shifts one place, this number will be 1. If two tyres shifts 3 places, this number will be 6, etc. Low number (20-40) means a good fit with the ISO, and high numbers (> 80) means poor fit.

In figure 154, the correlation between this ranking factor and the aggregate size are shown for all the surfaces together.

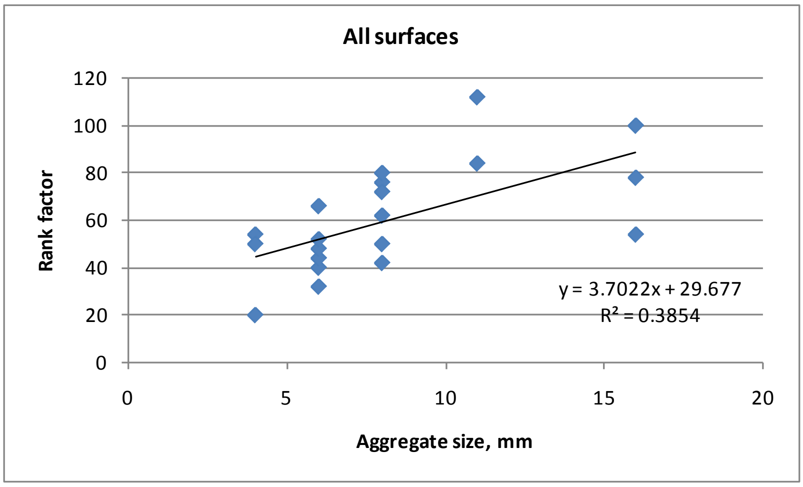

***Figure 154** Regression analysis of aggregate size and ranking factor, all surfaces*

Figure 154 shows that about 38 % of the different road surfaces ability to rank tyres in an “ISO-way” can be explained by the aggregate size.
A higher correlation seems to be achieved for aggregate sizes 4-8 mm. A similar analysis was done individually for each category of road surface, but due to few samples in each category, no statistically significant correlation was found.
The regression coefficient seems to be a good indicator on the ranking behaviour. In figure 155, a linear regression between R^2 –values (table 29) and the number of tyres shifted more than 4 places (see numbers at the bottom of table 31) is presented. This confirms that there is a reasonable good correlation between the traditional regression analysis, and this ranking method.

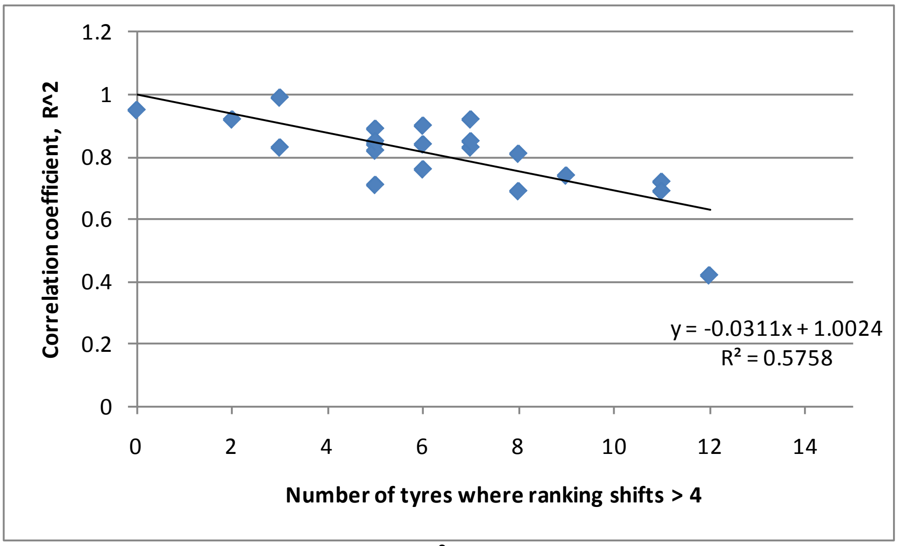

Figure 155 *Correlation between R^2 and the number of tyres where the ranking shifts more than 4 places*

As a conclusion, based on this analysis, it is found that, the best effect of reducing the type approval limits for tyres could be achieved if normal roads have aggregate sizes in the range of 4-8 mm.

8 Road surface influence

All texture data at Kloosterzande was measured by M+P[3], using their stationary laser profilometer. The texture was measured by moving the laser along a beam. With this stationary set-up, the texture was measured at a length of 3 m. The texture profile is measured by sampling the laser signal every 0.2 mm. At each 3 m long road section, the laser was moved 10 mm in transversal direction, measuring at total of 20 parallel profiles. This set-up then gives a quasi 3D plot of the texture. The texture was measured on a total of 6 positions at each road sections, 3 in each of the wheel tracks.

The texture data has cordially been made available to SINTEF for this analysis, by M+P.

8.1 Texture spectra

In figures 156-159, the texture spectra (average of west and east wheel track) at the 23 road sections are shown.

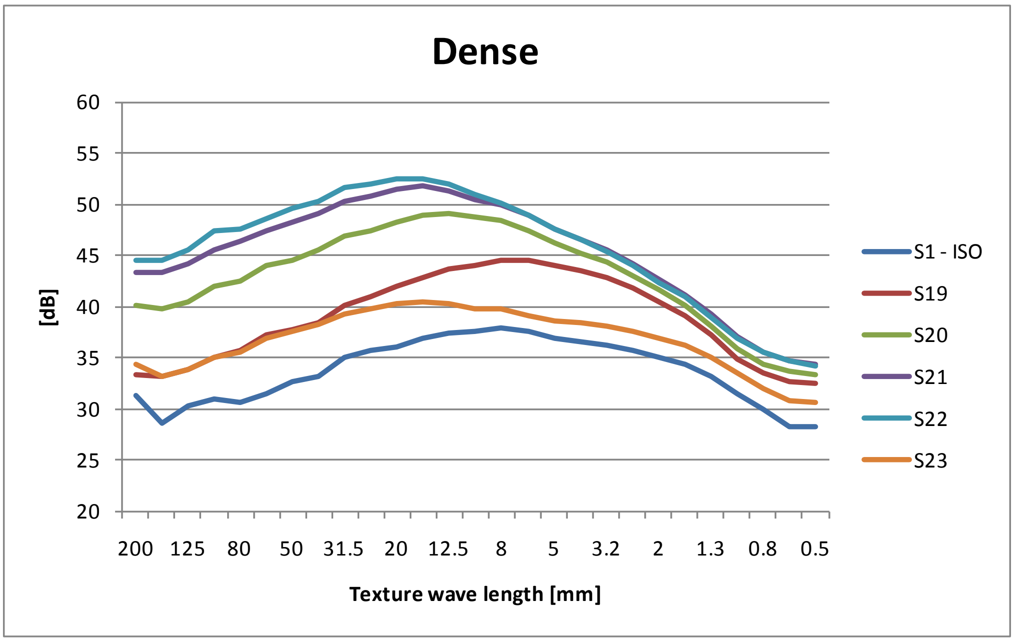

Figure 156 *Texture spectra for the dense surfaces*

From a noise perspective, it is favorable to have low texture levels at longer wave lengths (from 20 mm and above – left side in the figures) and a higher texture levels at the shorter wave lengths. However, the texture levels in the longer wave length are of higher importance for noise generation, than the shorter.

Figure 156 show a clear dependence of the aggregate sizes for the SMA-surfaces (S19 - S22). The texture spectra for the DAC16 (S23) is significant different from the SMA16 (S22) and reflects the difference in noise levels as well (figures 26 and 27).

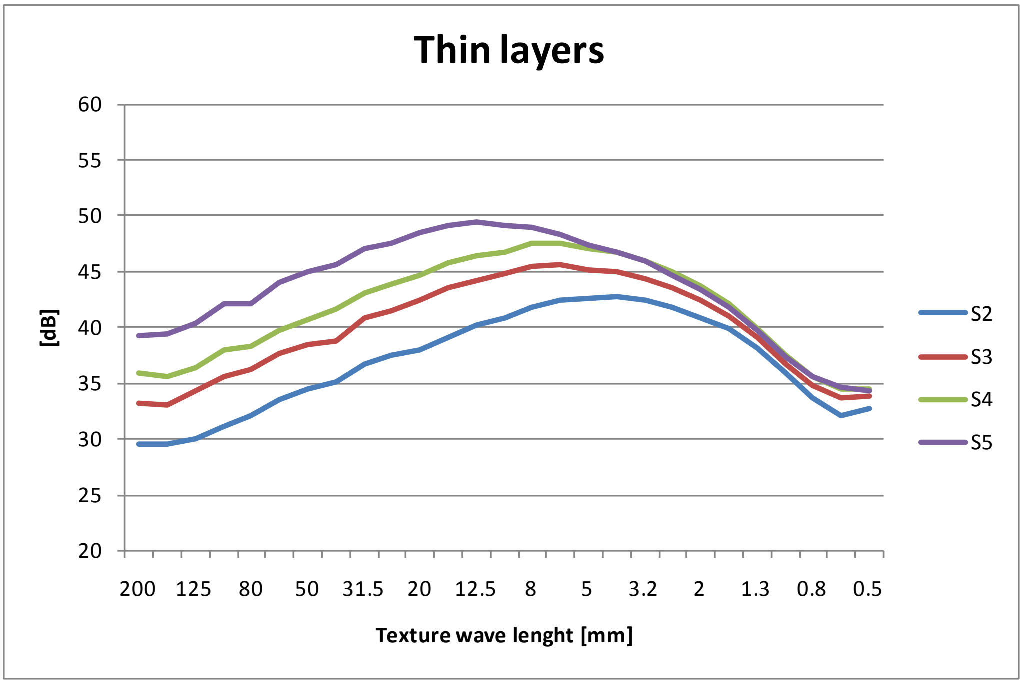

Figure 157 *Texture spectra for the thin layers*

As for the dense surfaces, the spectra for the thin layers in figure 157 also show a dependence of aggregate size. S2 has a 2/4 mm surface (lowest texture levels in the longer wave lengths). S3 and S4 both have 2/6 mm, while S5 (highest levels) has a 4/8 mm. For the shorter wave lengths, there is no difference.

The single layer porous surfaces, figure 158, can be grouped into 3 for texture wave lengths above 5-8 mm:

- S15 (2/6 mm) has the lowest levels
- S8 and S9 (both 4/8 mm) have medium levels
- S6 and S7 (11 and 16 mm) have the highest texture levels

Again, there seems to be a relationship with aggregate size.

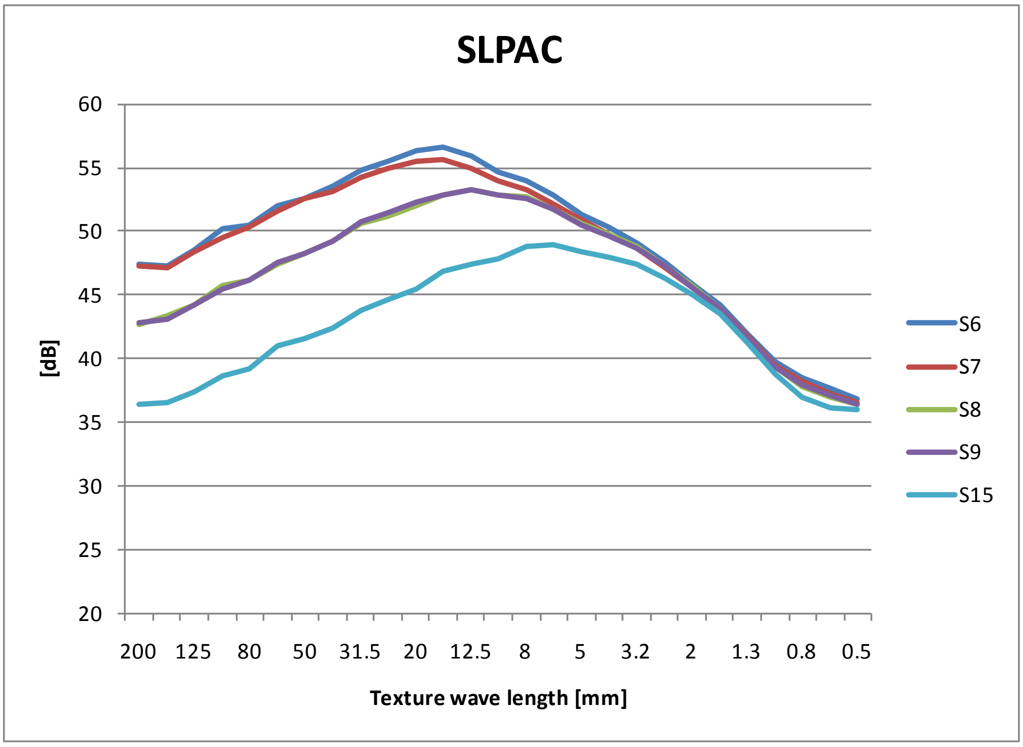

Figure 158 *Texture spectra for the single layer porous*

The double layers in figure 159 can be grouped into 4:

- S12 (Rollpave PERS) with the lowest level
- S13 (2/4+11/16) as the 2^{nd} lowest
- S14, S16, S17 and S18 in the middle range
- S10 and S11 (4/8 + 11/16) having the highest texture levels.

As for the other types of surfaces, the highest texture levels are found for those surfaces with the largest aggregate sizes.

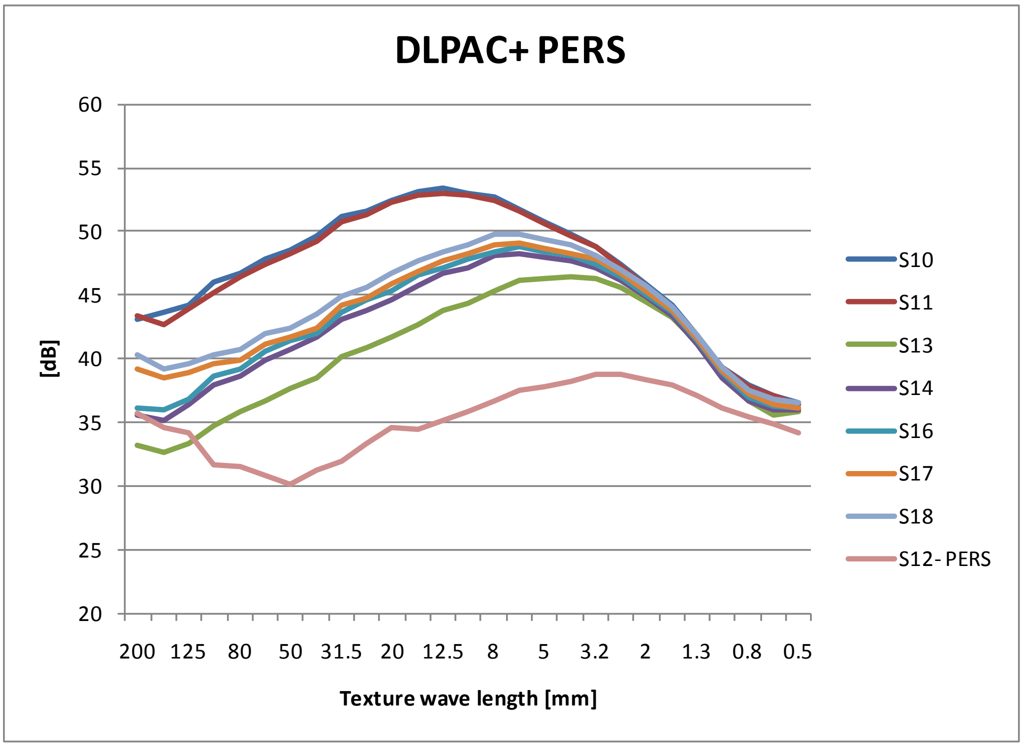

Figure 159 *Texture spectra for the double layer porous+ PERS*

The surfaces at the Kloosterzande are not exposed to normal traffic or winter conditions (with studded tyres) as the road surfaces in Norway are. From previous projects[9] we know that the texture is changed considerable during the exposure of traffic during winter time. A large number of texture measurements have been made in Norway, but with somewhat different measurement equipment (laser mounted on vehicle and measurement of single profiles at 40 km/h). Due to limitations in the signal processing equipment on the moving vehicle, it is not relevant to present texture levels with wave length shorter than 5 mm.

In figure 160, a comparison has been made between the texture spectra for the dense surfaces S1 (ISO) and the dense surfaces S19 - S23 at Kloosterzande and some typical texture levels for SMA11-surfaces in Norway. In figure 161, the texture spectra for an SMA11-surface in Norway after 1 year and after 5 years of traffic are shown, compared to the SMA11 at Kloosterzande.

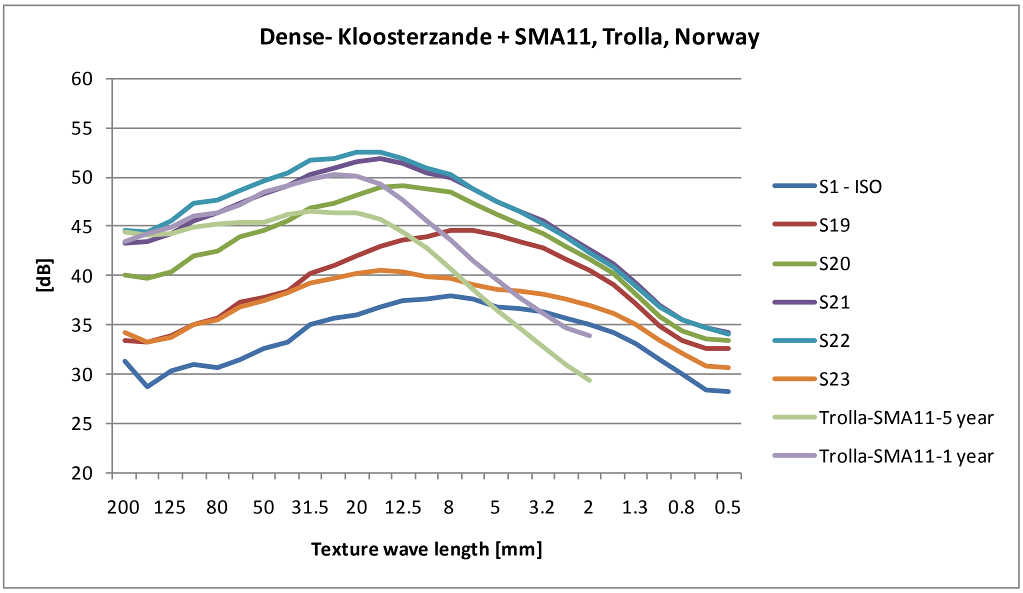

Figure 160 *Texture spectra for S1+ S19-S23, compared to SMA11-surfaces in Norway*

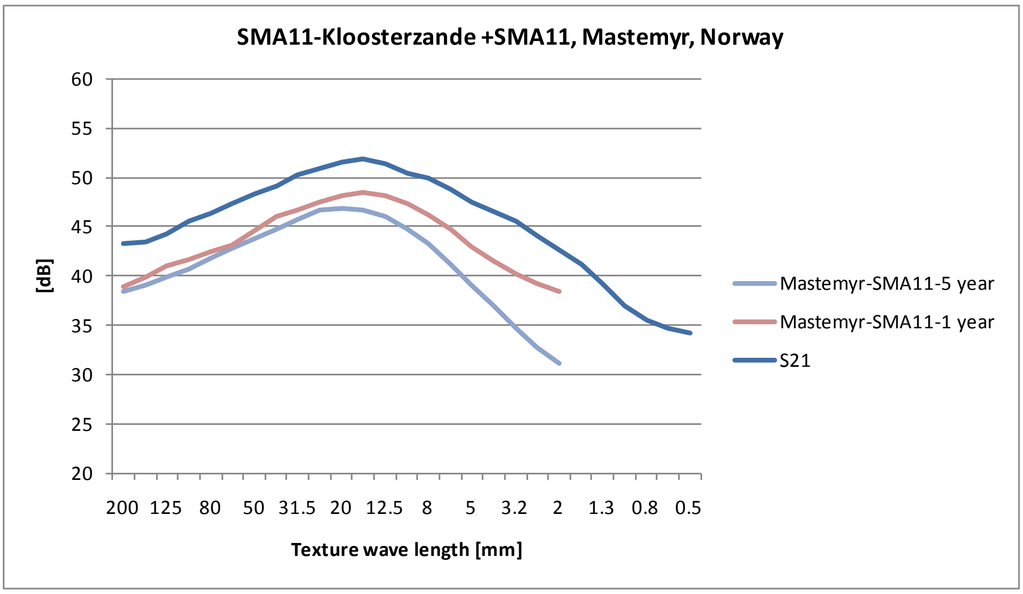

Figure 161 *Texture spectra for S21 (SMA11, compared to SMA11-surfaces in Norway*

As figure 161 shows, the texture spectrum of the 1 year old SMA11-surface is closer to the texture spectrum of the SMA11-surface at Kloosterzande, than the other Norwegian surfaces.

8.2 Texture and noise level analysis

To investigate the most important relationship between texture and measured noise levels, a correlation analysis has been made between some of the texture spectral levels and LAcpx (80 km/h).

In figure 162, the texture spectrum in 1/3rd octave wavelength bands for the ISO-surface is shown. The octave band chosen for the correlation analysis are marked with different color than blue. These bands are:

$$L_{tx160}, L_{tx80}, L_{tx40}, L_{tx8} \text{ and } L_{tx5}$$

(for the L_{tx8} *and* L_{tx5}-octave bands, there is an overlap of the 6.15 mm band)

The bands have been selected based on previous investigations.

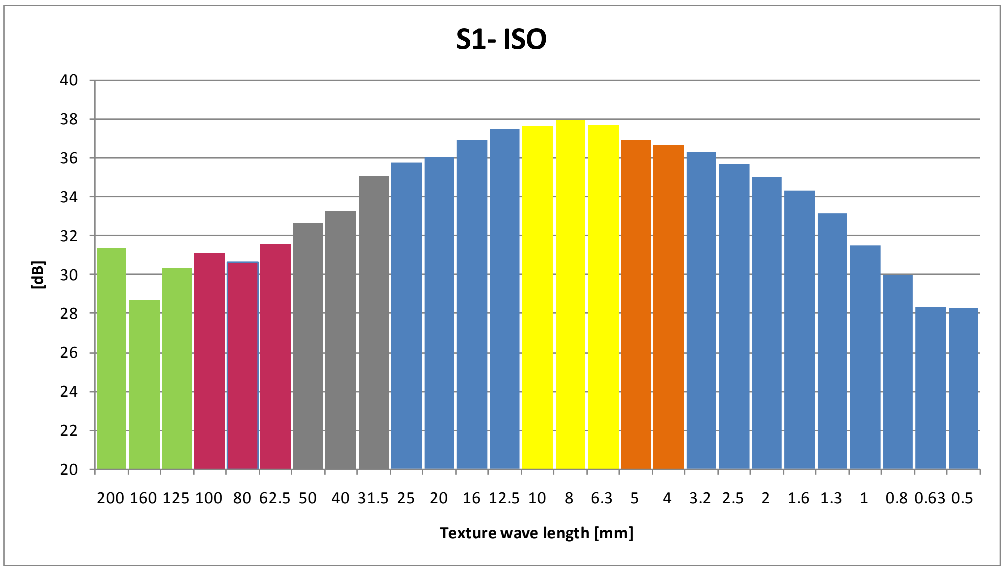

***Figure 162** Texture spectrum for the ISO-surface*

The analysis showed some differences in the correlation, if one included S12 (Rollpave PERS) or not.
The best correlation was found when S12 was excluded from the analysis.
The following results were found between the texture levels chosen (based on 22 road sections) and the average LAcpx-level (of 25 tyres) on the different surfaces:

L_{tx160}: *Very weak correlation with LAcpx*
L_{tx80} : *Significant correlation with LAcpx*
L_{tx40} : *Significant correlation with LAcpx*
L_{tx8} : *No significant correlation with LAcpx*
L_{tx5}: *No significant correlation with LAcpx*

Based on these results the texture levels of L_{tx80} was chosen as being the most important octave band for further analysis. Figure 163 show the regression between the texture levels of L_{tx80} and the measured LAcpx-levels (average of 25 tyres).

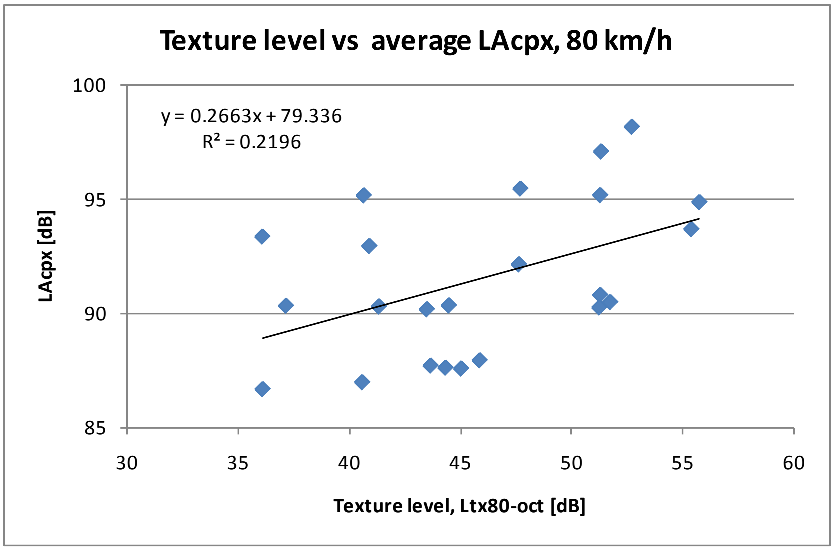

Figure 163 *Regression analysis of Ltx80 and LAcpx, all surfaces*

Even though the correlation was proved to be significant, the spread in the results are rather large, when all categories of surfaces are included in the analysis.

The correlation depending on category of surface has also been analyzed. In figure 164, the correlation for the dense surfaces is shown, and is quite strong, as 85 % of the level variation is explained by the texture octave band L_{tx80}.

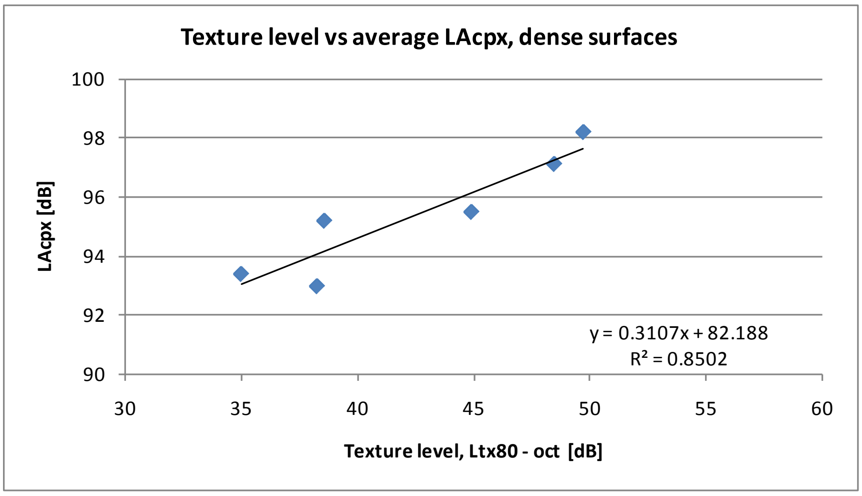

Figure 164 *Regression analysis of Ltx80 and LAcpx for dense surfaces*

In figure 165, the similar relationship is shown for all the porous surfaces (except S12).

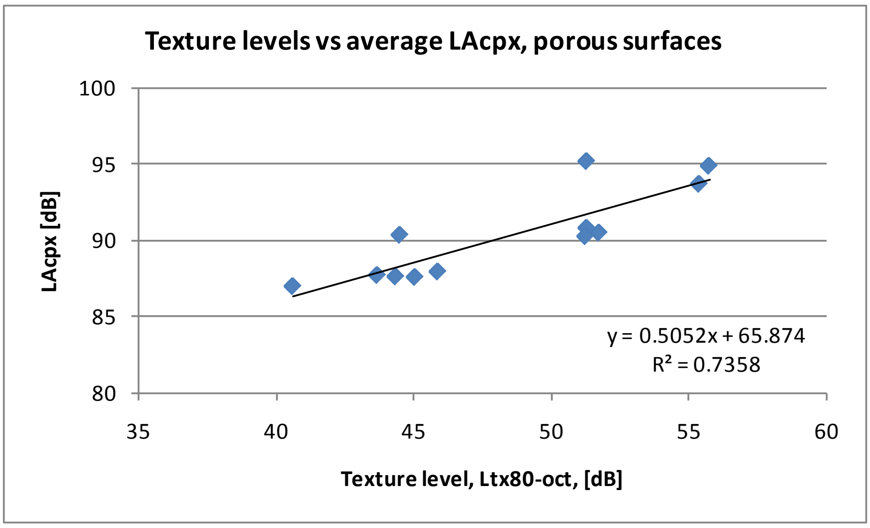

Figure 165 *Regression analysis of Ltx80 and LAcpx for porous surfaces*

As shown in figure 109, there is a high correlation between the slope and the standard deviation for average LAcpx-levels on the individual road surfaces. Figure 166 show that there is a similar relationship between the standard deviation and Ltx80 octave band levels. ***Decreasing*** the texture level means that the standard deviation ***increases***, which again means a larger spread of the tyre noise levels.

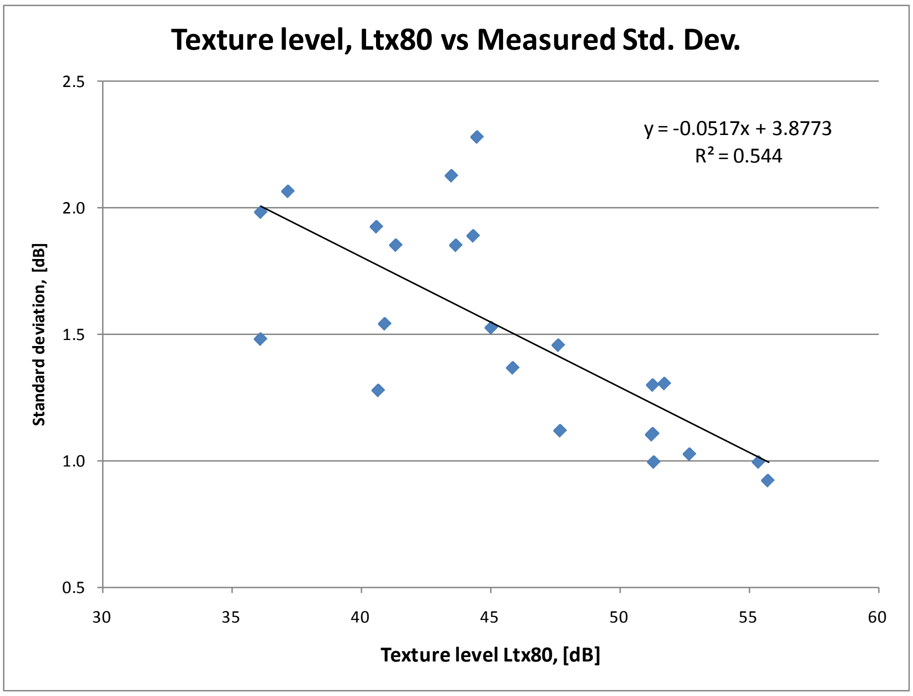

Figure 166 *Regression analysis of Ltx80 and the standard deviation for LAcpx-levels, 80 km/h*

This analysis shows indirectly the strong link between the slope and the texture of the road surface.

8.3 Correlation between noise levels and MPD

The mean profile depth (MPD) has also been measured by M+P[7].
A regression analysis of the relations between the MPD and the measured LAcpx-levels for the 25 tyres at 50 and 80 km/h has been made.

In figures 167 and 168, the results of the regression analysis are shown. Only for 50 km/h, the regression is statistically significant. The analysis shows that the MPD is not a good descriptor for the noise behaviour of road surfaces.

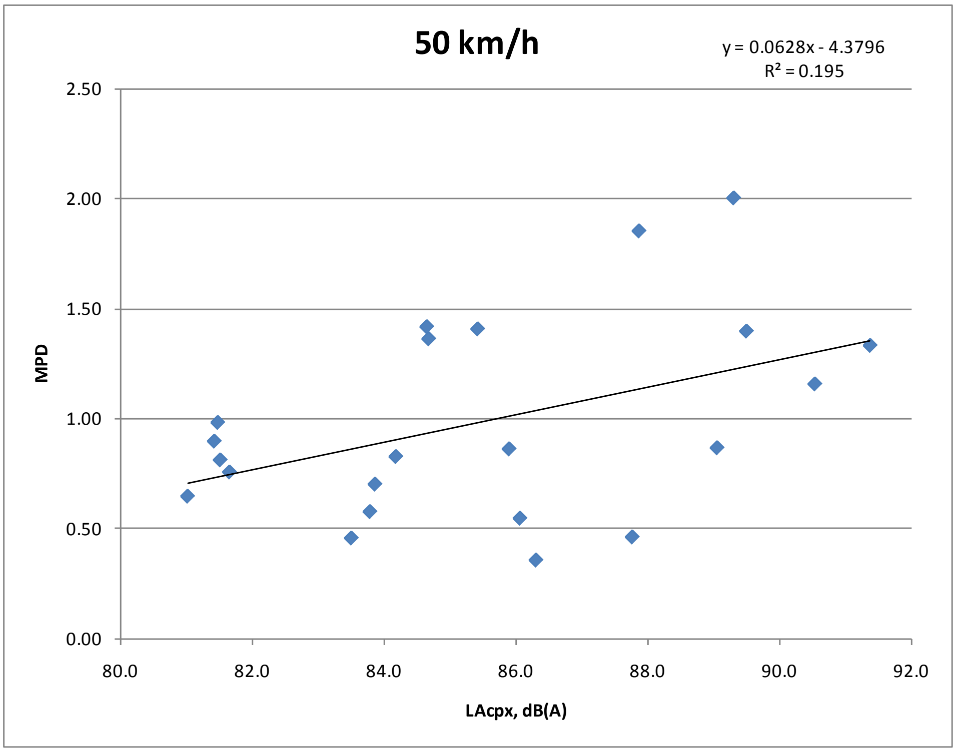

Figure 167 *Regression analysis of MPD and LAcpx, 50 km/h.*

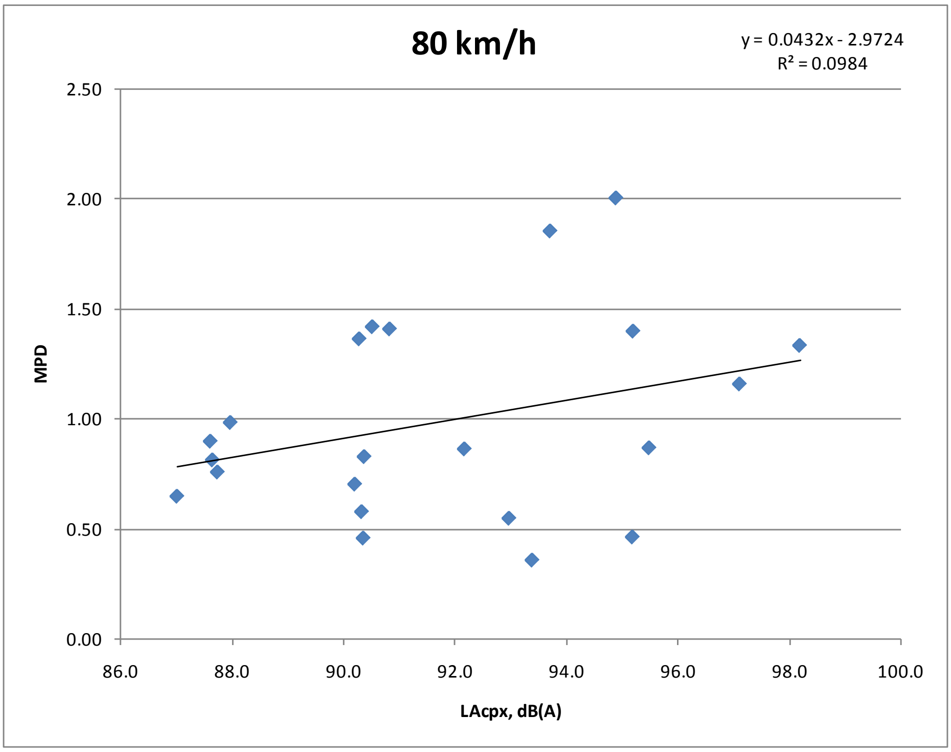

Figure 168 *Regression analysis of MPD and LAcpx, 80 km/h.*

9 References

[1] ISO 10844 – Acoustics - Specification of test tracks for the purpose of measuring noise emitted by road vehicles and their tyres. ISO, Geneva, Switzerland, 2011.

[2] G.van Blokland, H.M. van Leeuwen: Geluidtechnische eigenschappen van 10 banden uit de stille banden lijst op verschillende wegdekken. M+P Rapportnummer M+P.DVS.09.10.1. 10 oktober 2009.

[3] G.van Blokland, M+P: Texture spectra/Private communication, 2010.

[4] T. Berge, F. Haukland; Tyre/road noise modelling; Measurement of passenger car tyres on an ISO track and frequency analysis of results. SINTEF Report A14882, February 2010.

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A Appendix

A.1 Individual frequency spectra

Tyre 1: Dayton T110

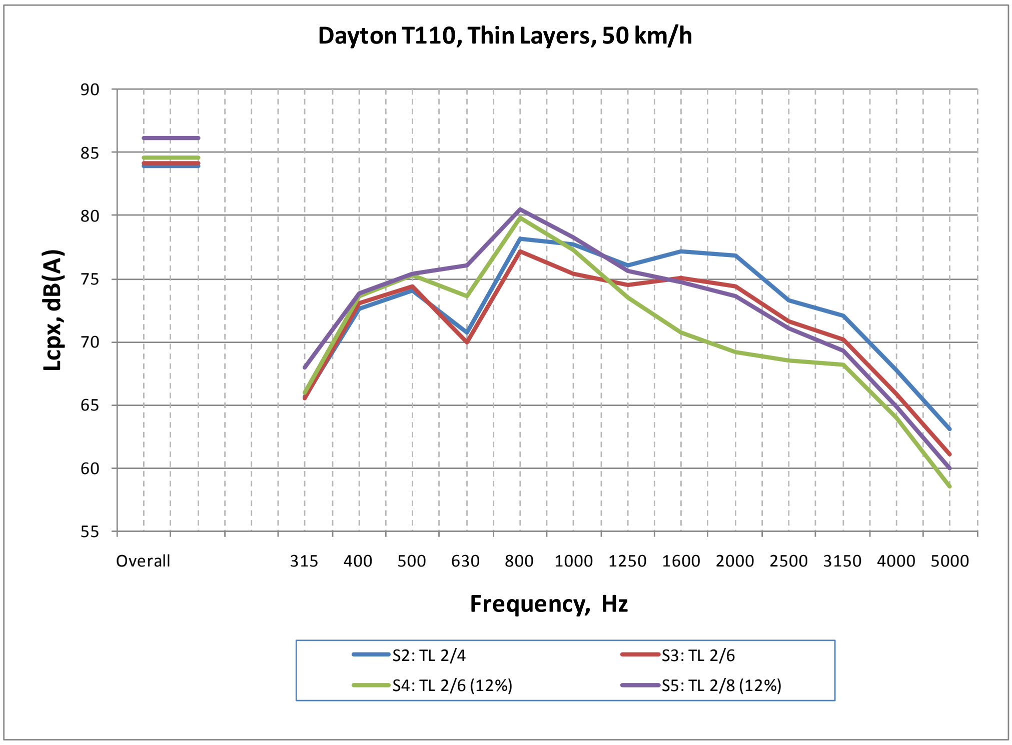

Figure A1_1 *Tyre 1: Dayton T110, Thin layers, 50 km/h*

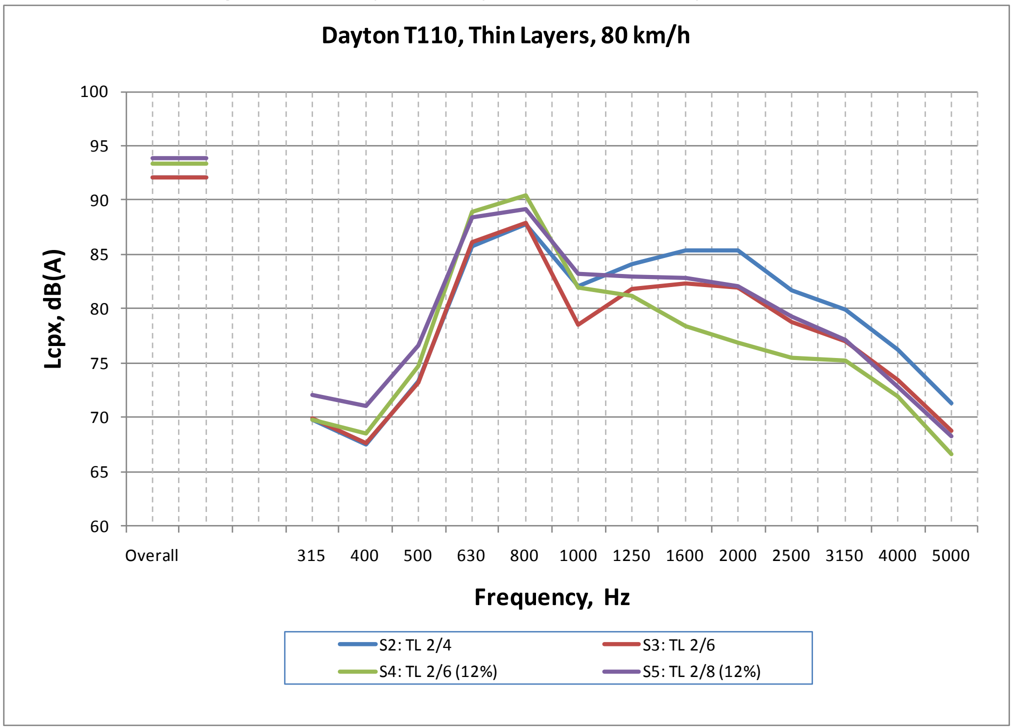

Figure A1_2 *Tyre 1: Dayton T110, Thin layers, 80 km/h*

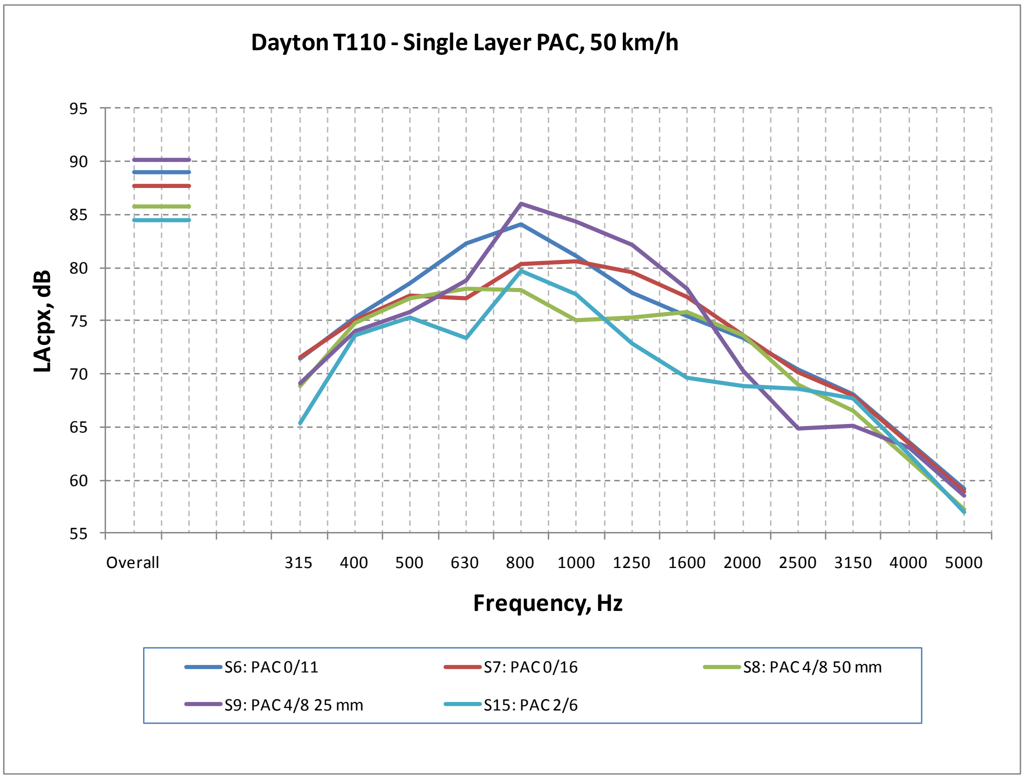

Figure A1_3 *Tyre 1: Dayton T110, Single layer porous, 50 km/h*

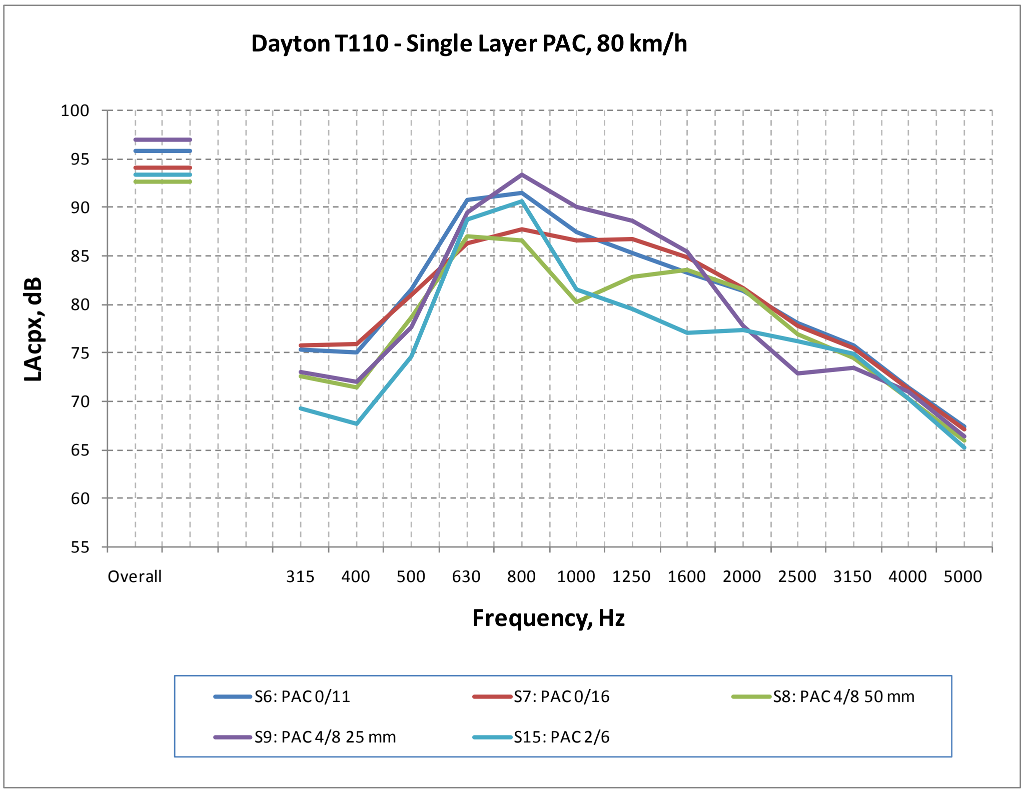

Figure A1_4 *Tyre 1: Dayton T110, Single layer porous, 80 km/h*

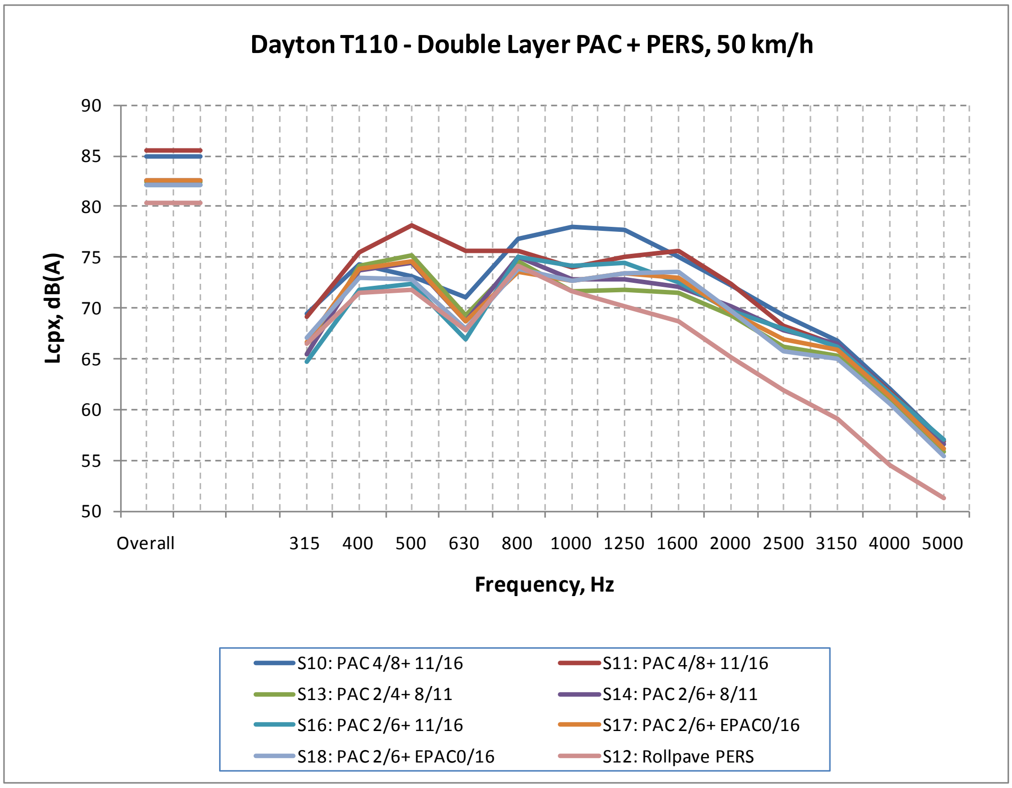

Figure A1_5 *Tyre 1: Dayton T110, Double layer porous + PERS, 50 km/h*

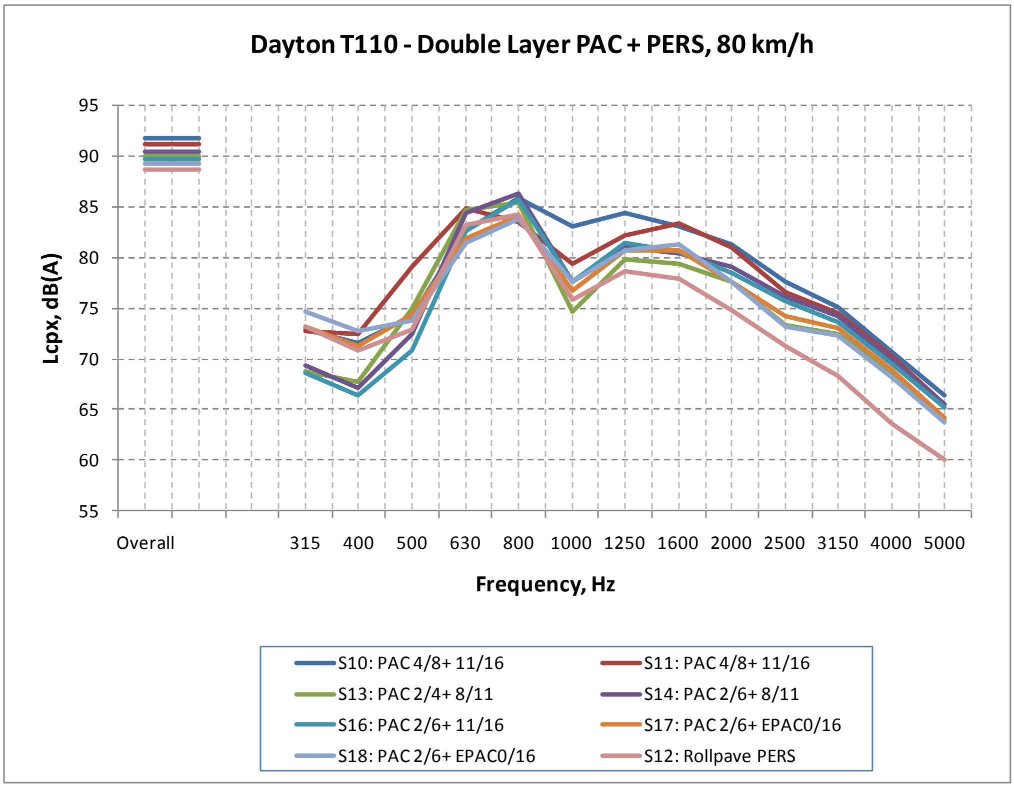

Figure A1_6 *Tyre 1: Dayton T110, Double layer porous + PERS, 80 km/h*

Tyre 2: Sportiva G70

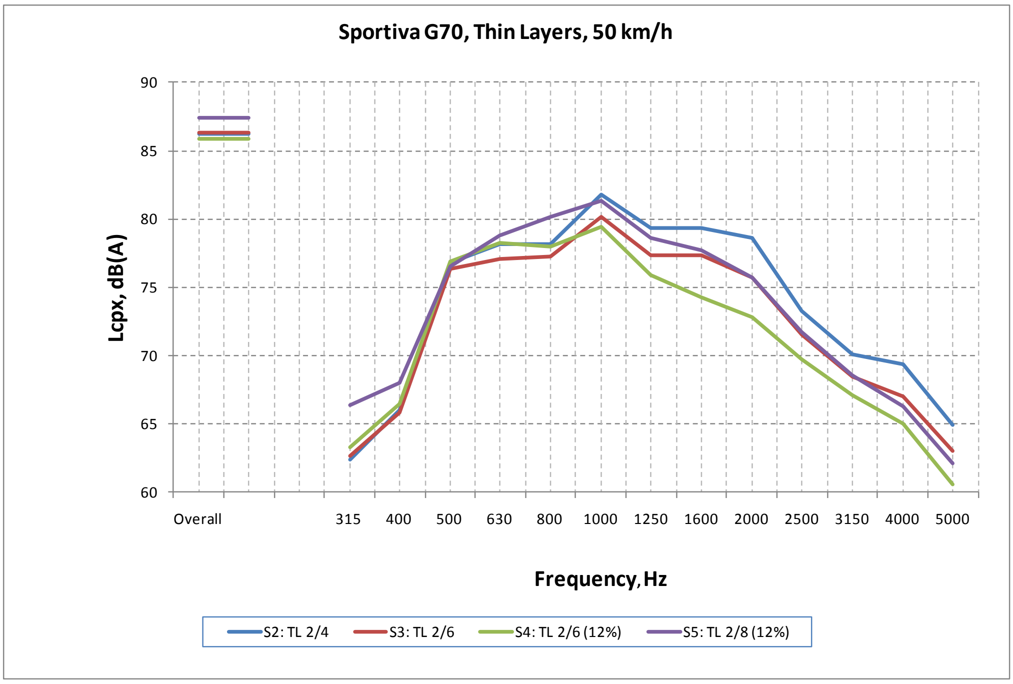

Figure A1_7 *Tyre 2: SportivaG70, Thin layers, 50 km/h*

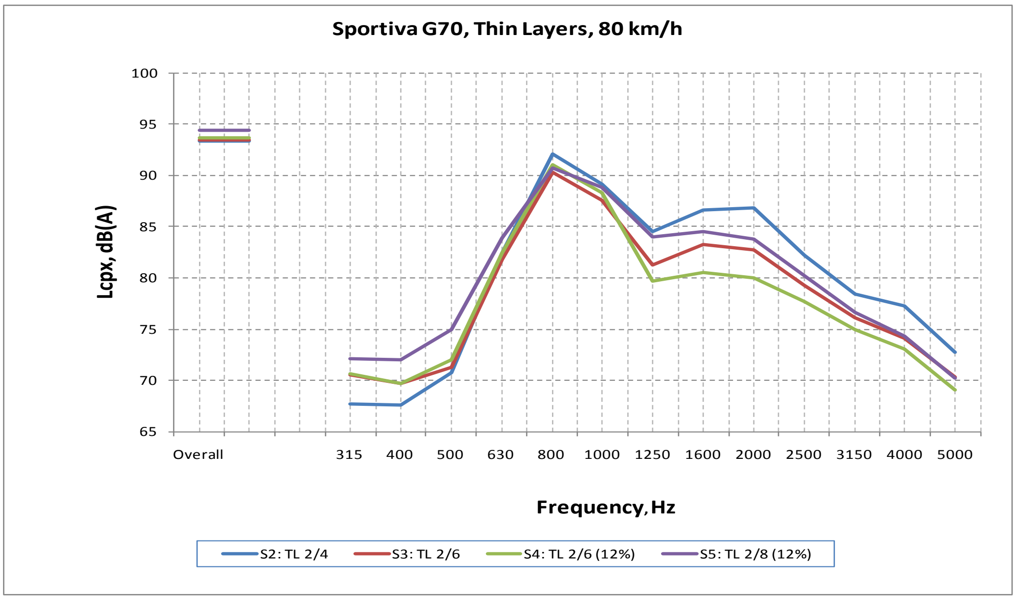

Figure A1_8 *Tyre 2: SportivaG70, Thin layers, 80 km/h*

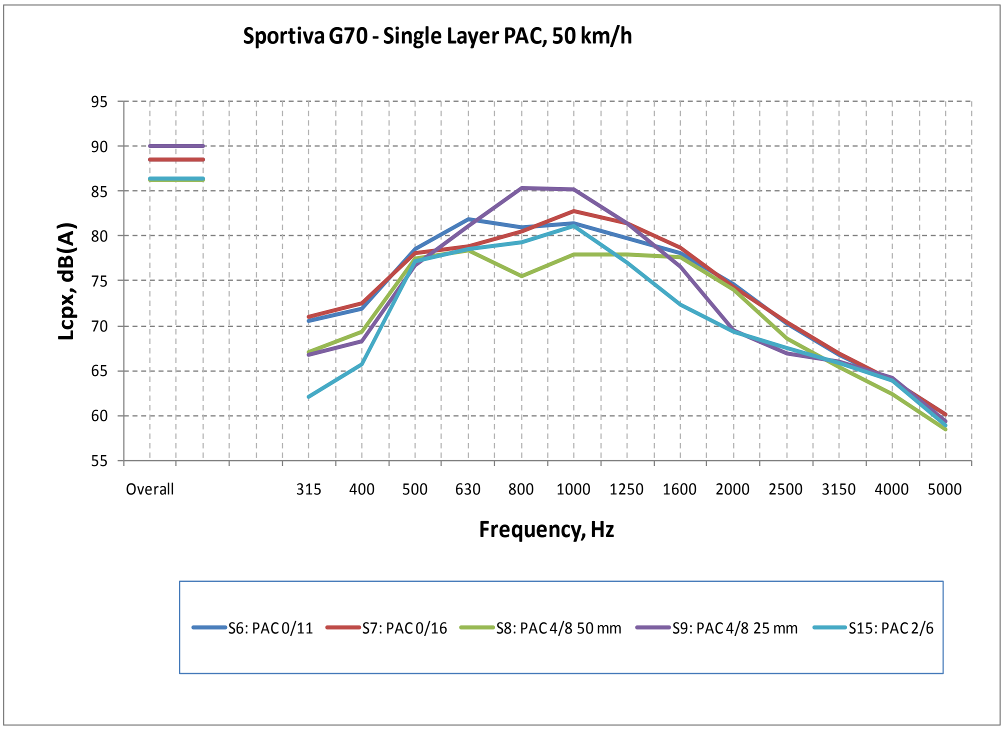

Figure A1_9 *Tyre 2: SportivaG70, Single layer porous, 50 km/h*

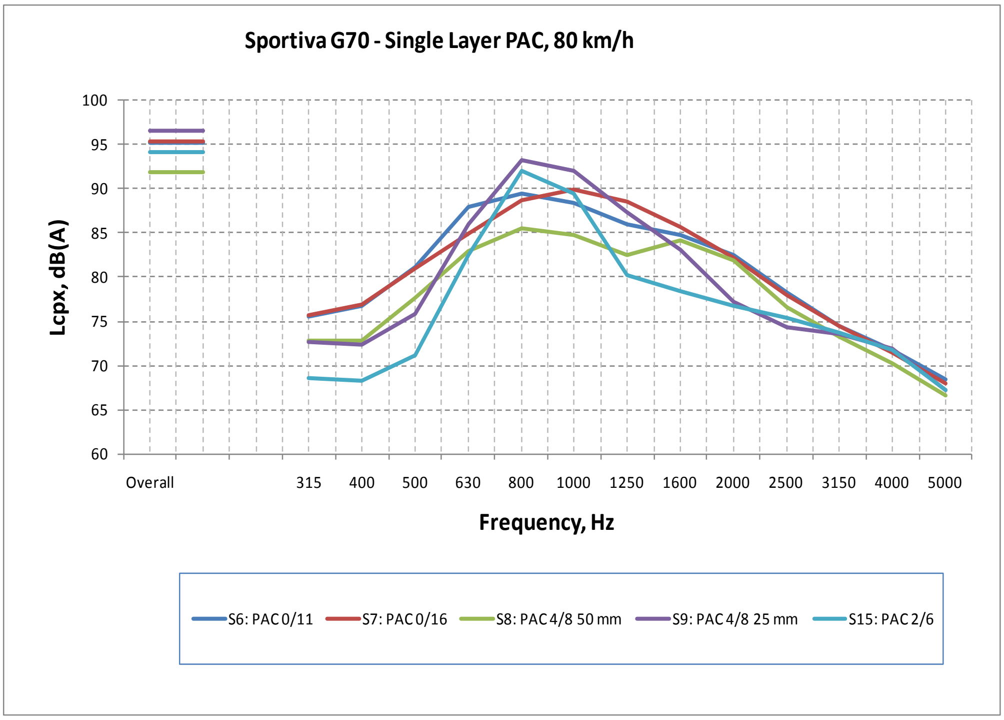

Figure A1_10 *Tyre 2: SportivaG70, Single layer porous, 80 km/h*

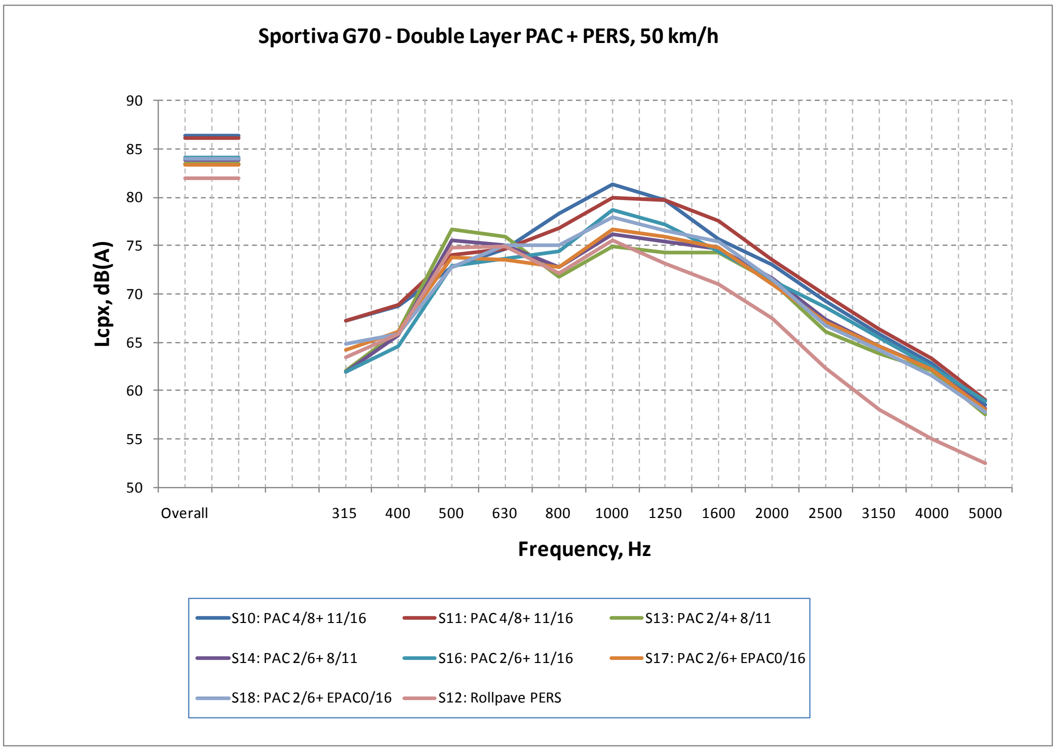

Figure A1_11 *Tyre 2: SportivaG70, Double layer porous + PERS, 50 km/h*

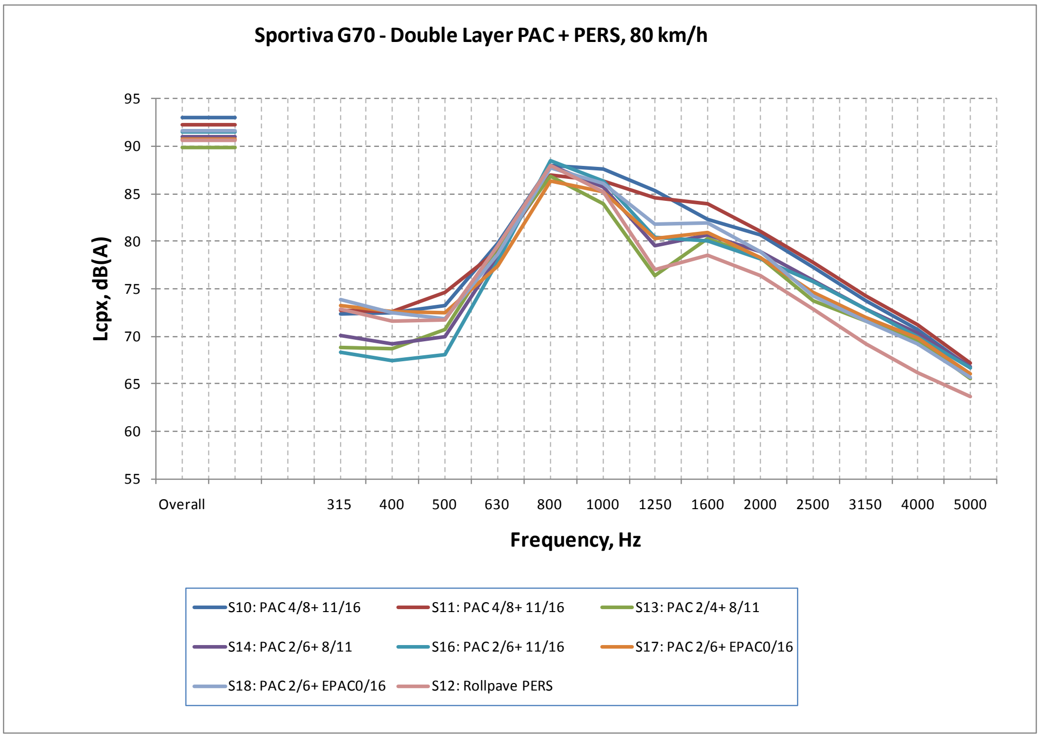

Figure A1_12 *Tyre 2: SportivaG70, Double layer porous + PERS, 80 km/h*

Tyre 3: Barum Brilliantis

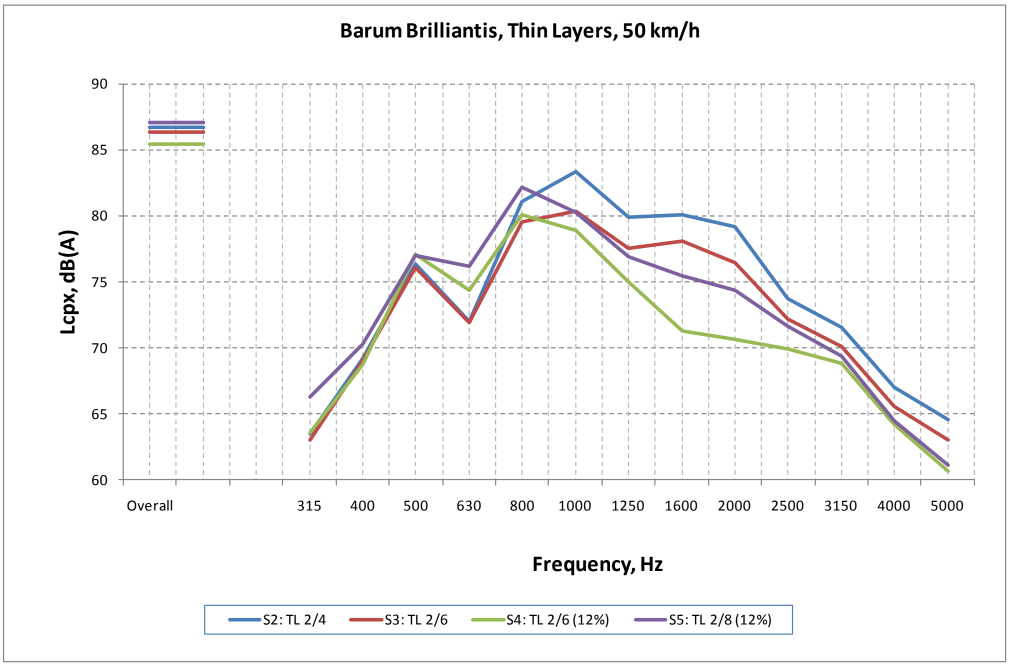

Figure A1_13 *Tyre 3: Barum Brilliantis, Thin layers, 50 km/h*

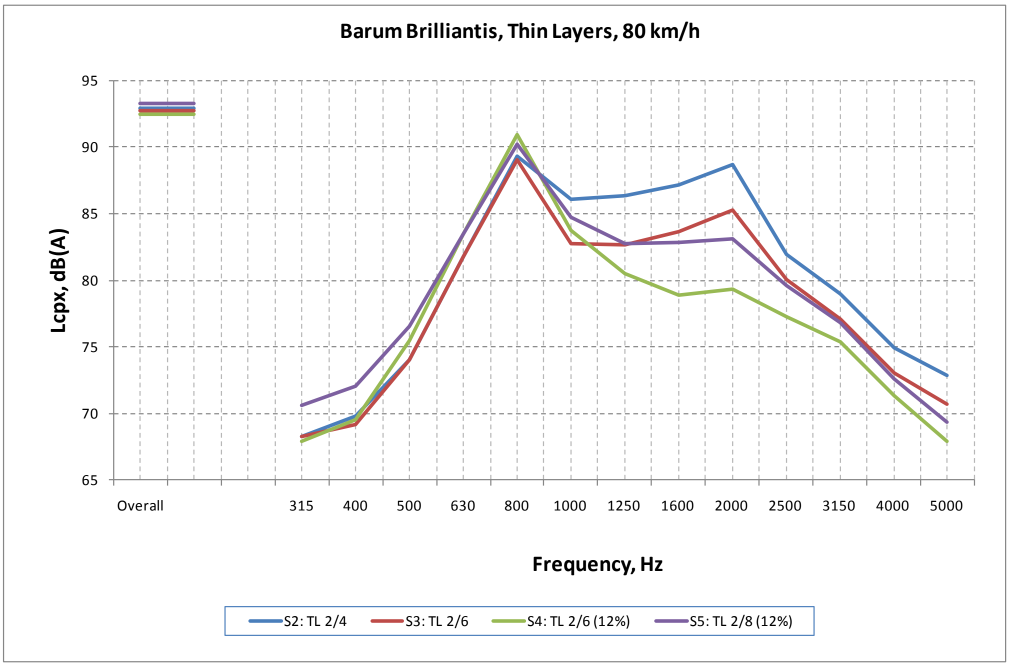

Figure A1_14 *Tyre 3: Barum Brilliantis, Thin layers, 80 km/h*

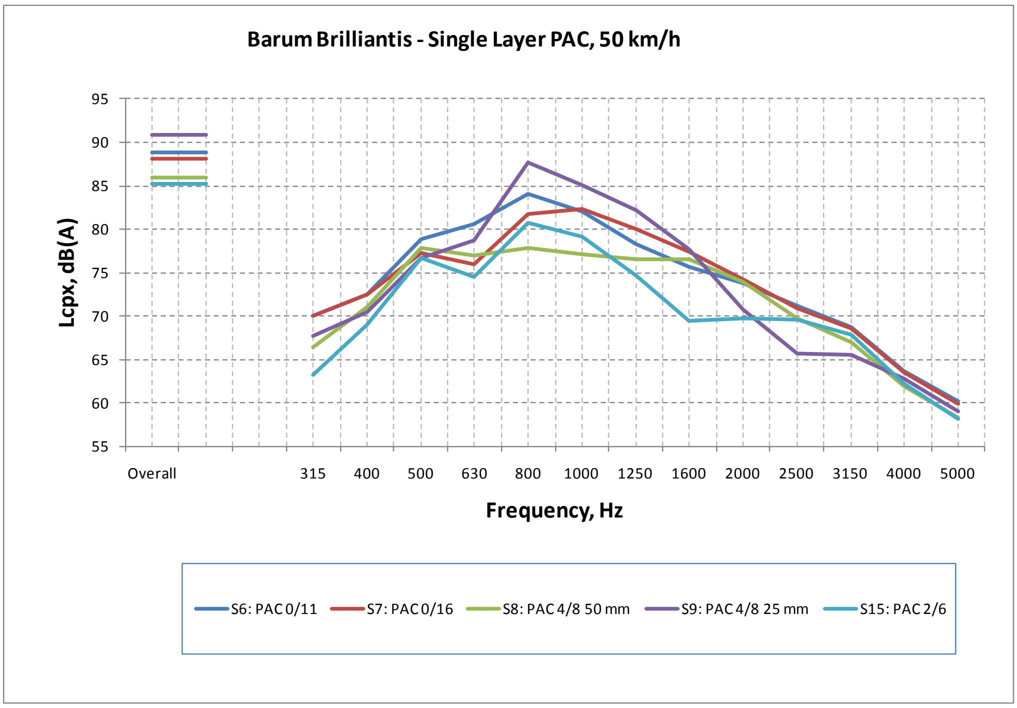

Figure A1_15 *Tyre 3: Barum Brilliantis, Single layer porous, 50 km/h*

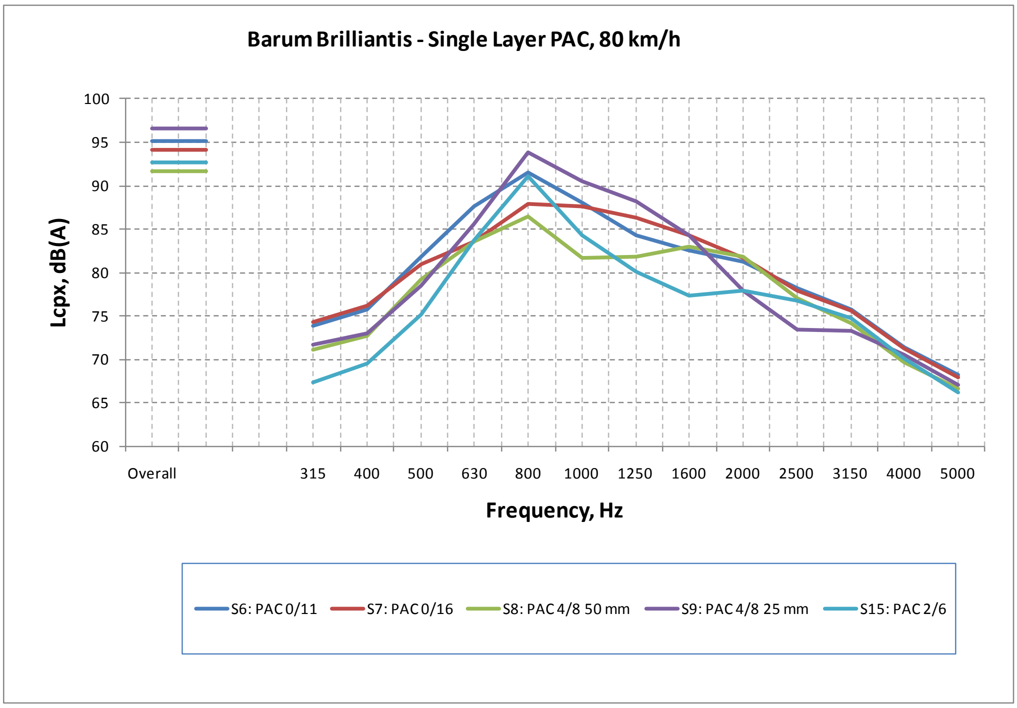

Figure A1_16 *Tyre 3: Barum Brilliantis, Single layer porous, 80 km/h*

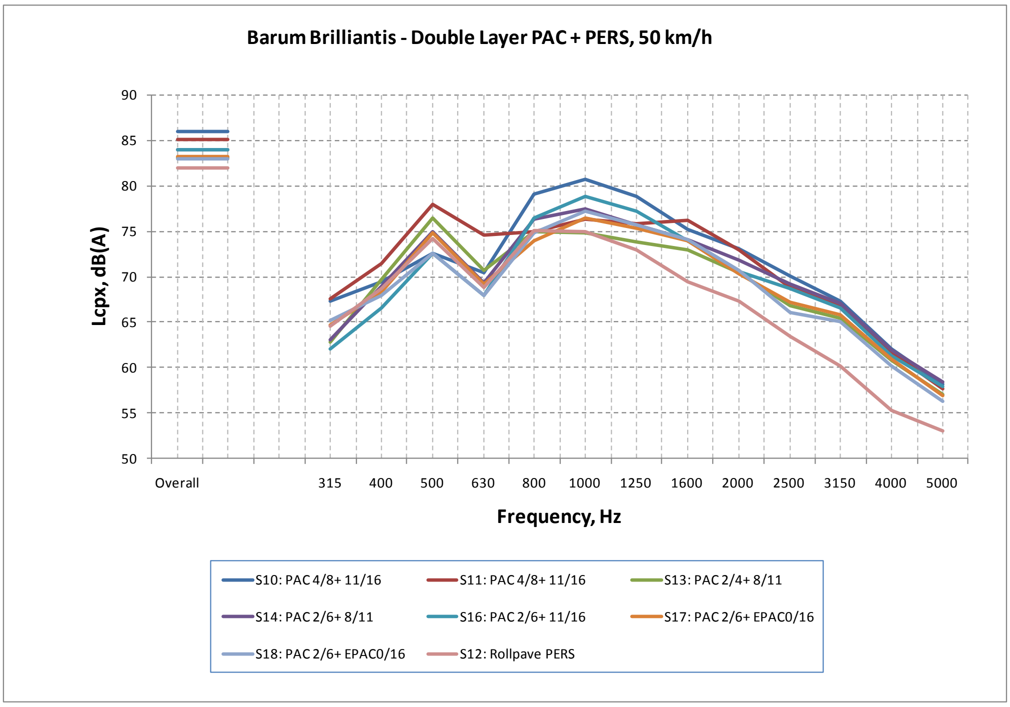

Figure A1_17 *Tyre 3: Barum Brilliantis, Double layer porous + PERS, 50 km/h*

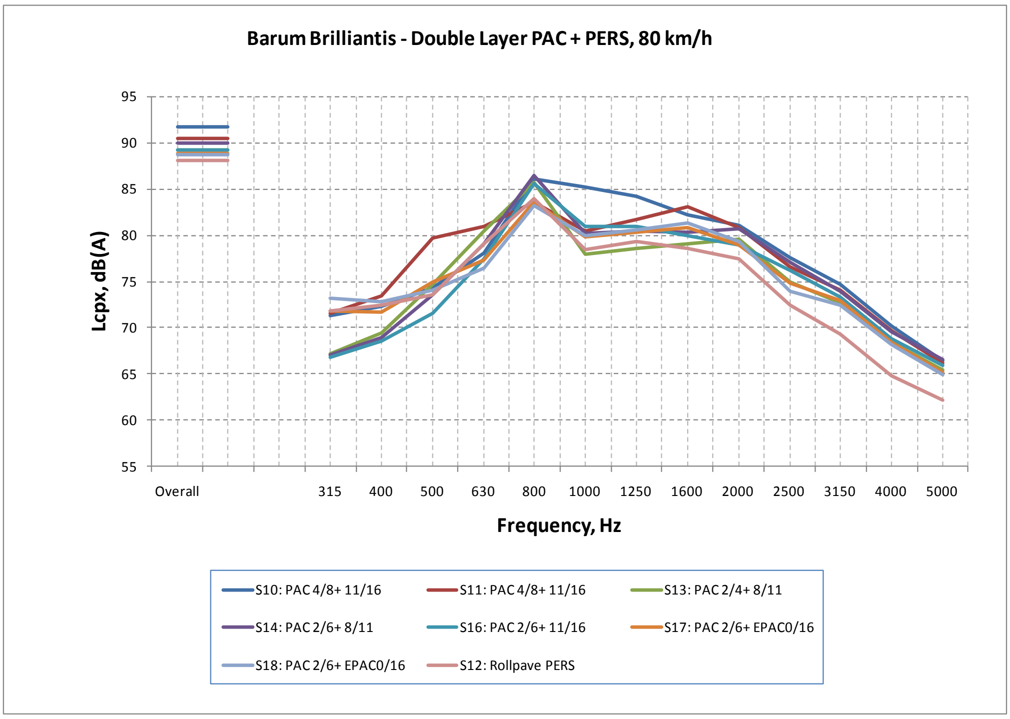

Figure A1_18 *Tyre 3: Barum Brilliantis, Double layer porous + PERS, 80 km/h*

Tyre 4: Toyo 330

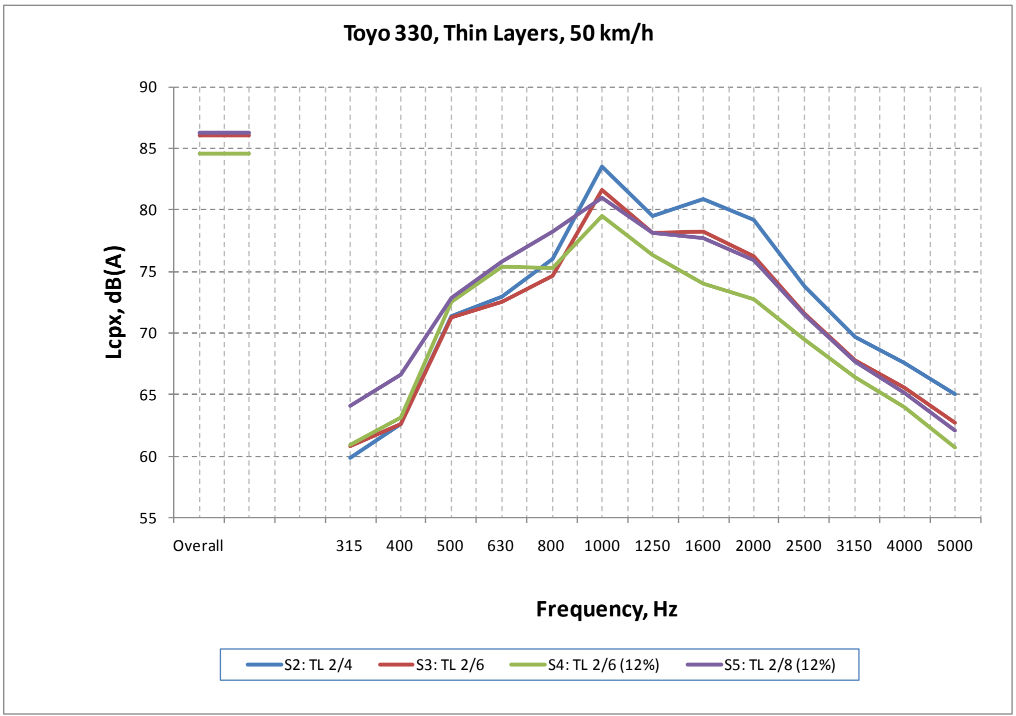

Figure A1_19 *Tyre 4: Toyo 330, Thin layers, 50 km/h*

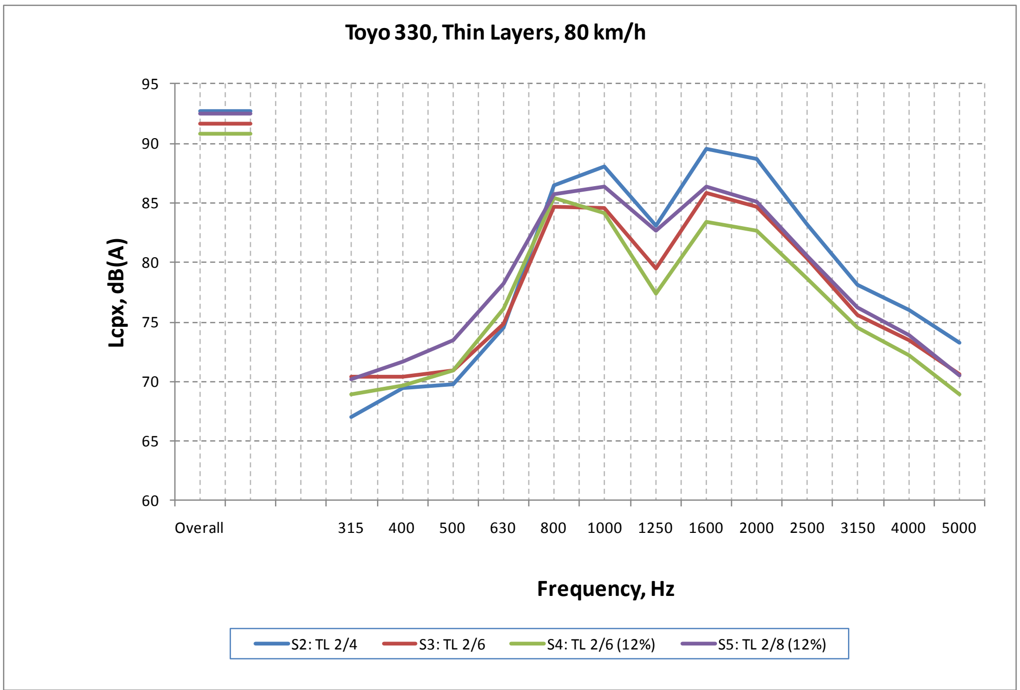

Figure A1_20 *Tyre 4: Toyo 330, Thin layers, 80 km/h*

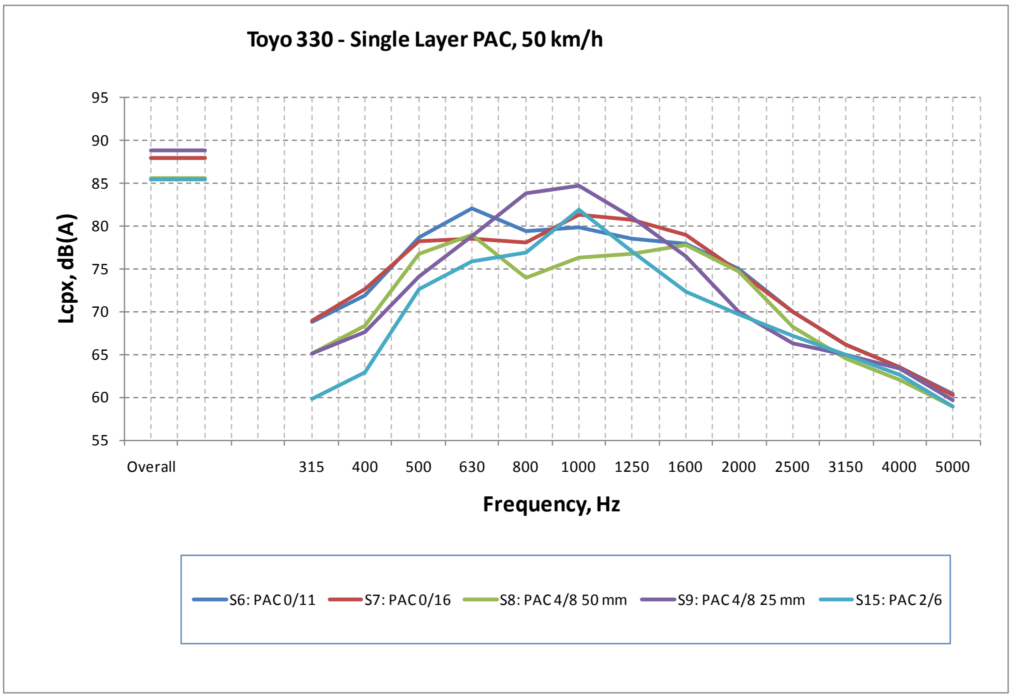

Figure A1_21 *Tyre 4: Toyo 330, Single layer porous, 50 km/h*

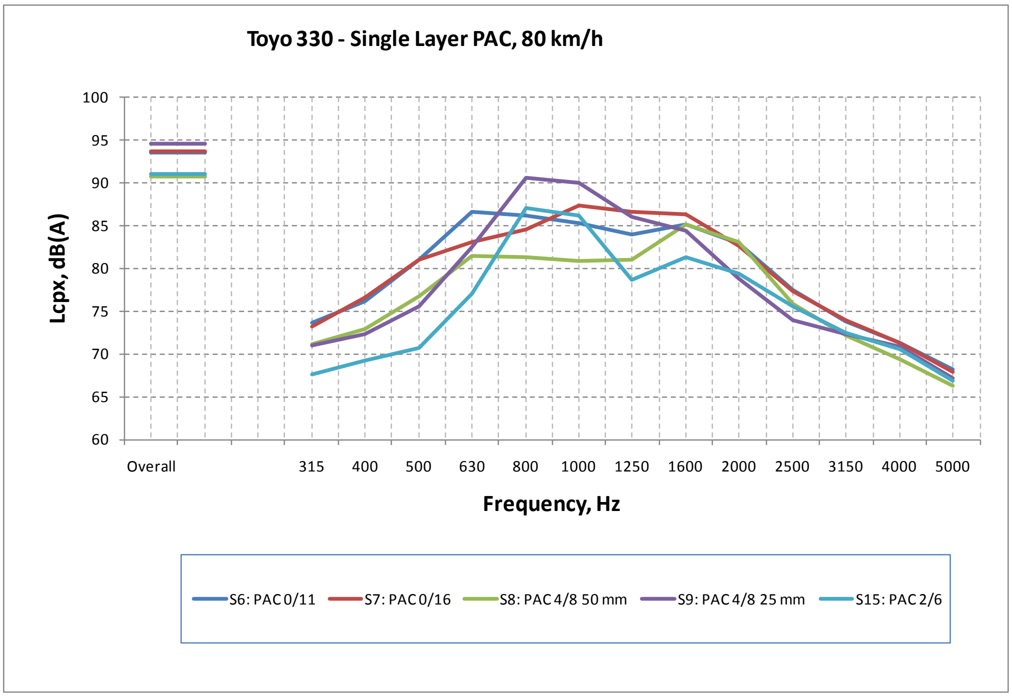

Figure A1_22 *Tyre 4: Toyo 330, Single layer porous, 80 km/h*

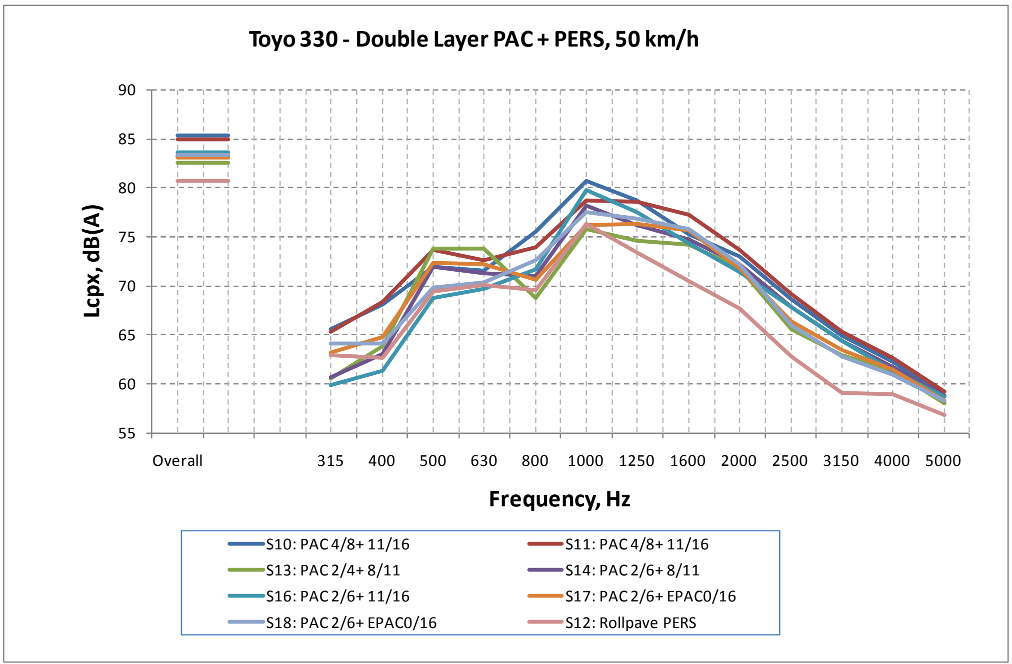

Figure A1_23 *Tyre 4: Toyo 330, Double layer porous + PERS, 50 km/h*

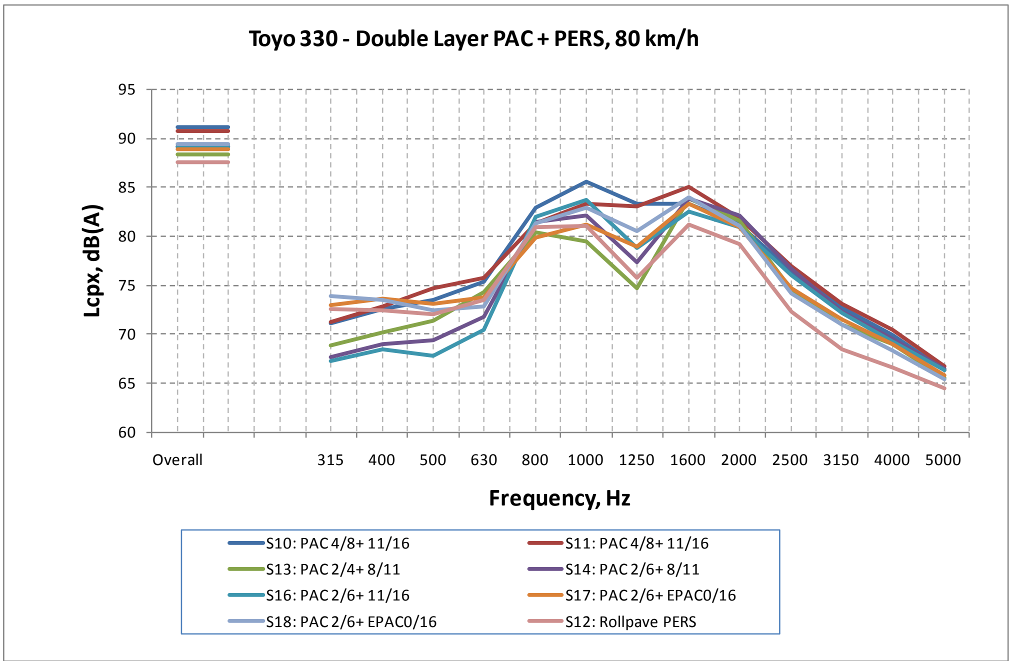

Figure A1_24 *Tyre 4: Toyo 330, Double layer porous + PERS, 80 km/h*

Tyre 5: Goodyear Excellence

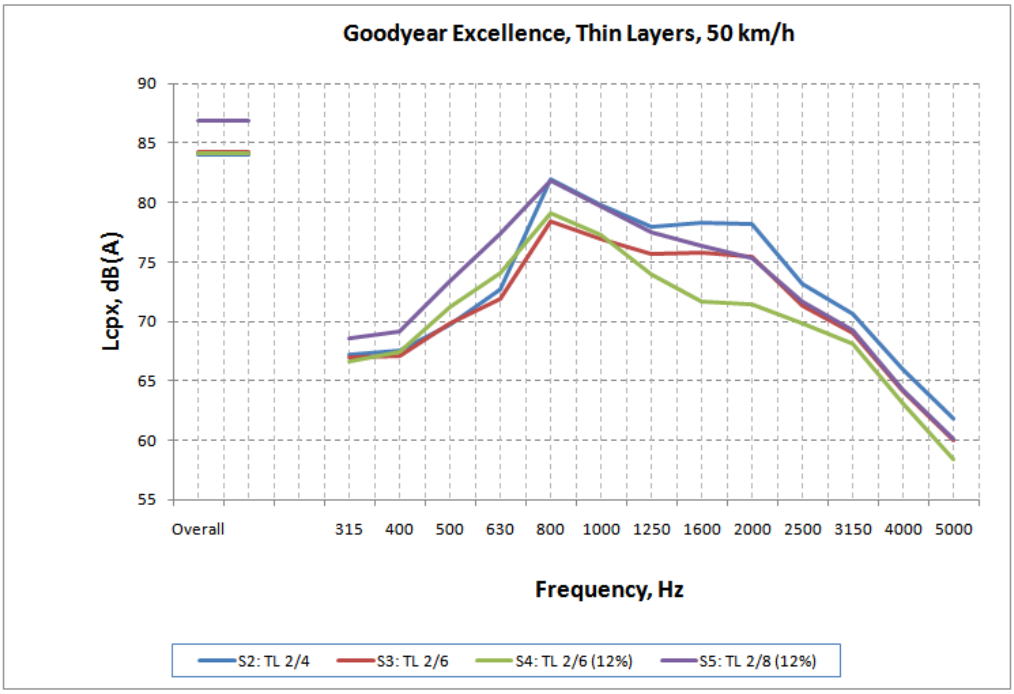

Figure A1_25 *Tyre 5: Goodyear Excellence, Thin layers, 50 km/h*

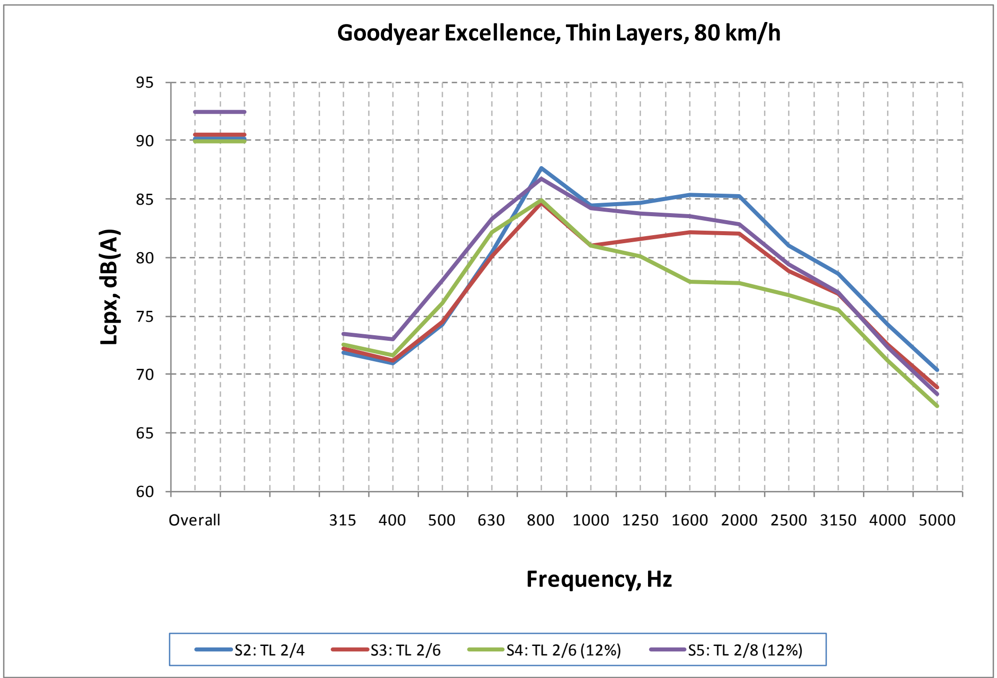

Figure A1_26 *Tyre 5: Goodyear Excellence, Thin layers, 80 km/h*

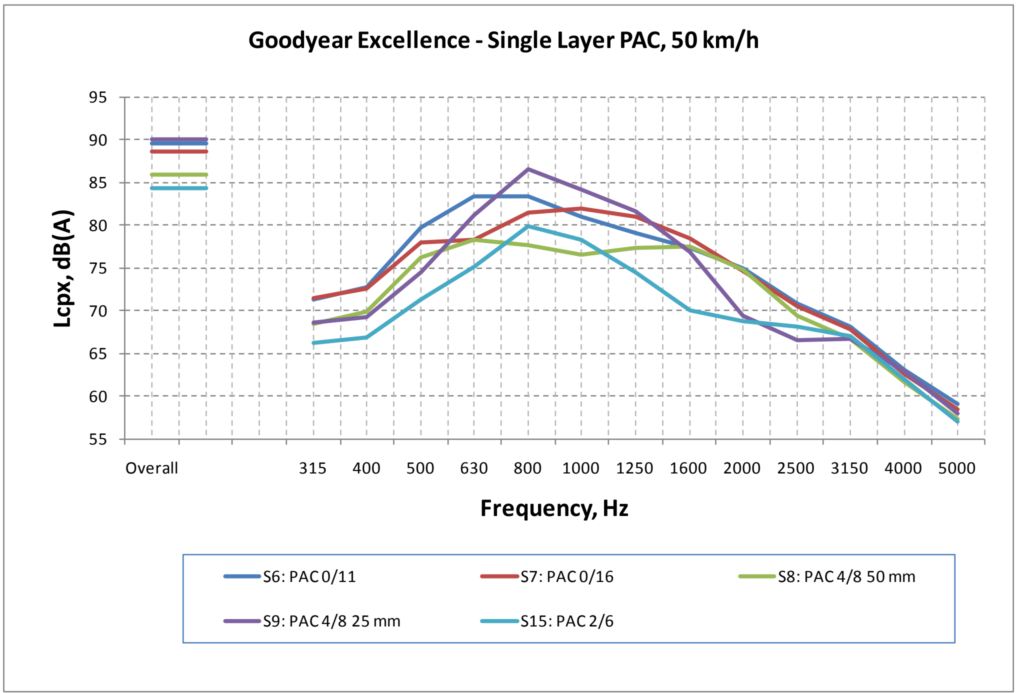

Figure A1_27 *Tyre 5: Goodyear Excellence, Single layer porous, 50 km/h*

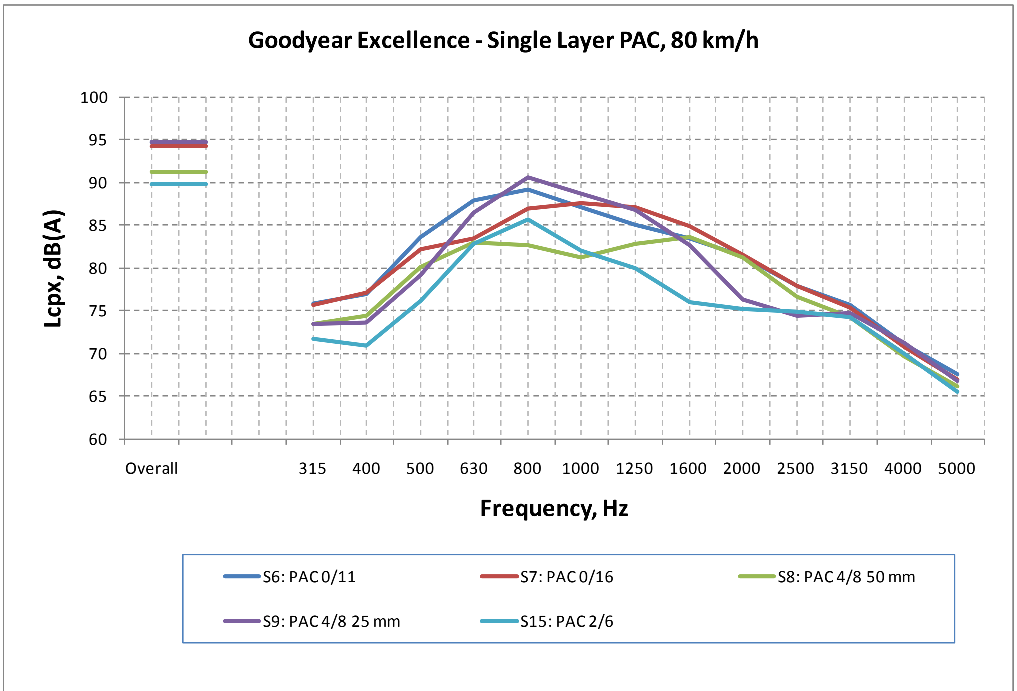

Figure A1_28 *Tyre 5: Goodyear Excellence, Single layer porous, 80 km/h*

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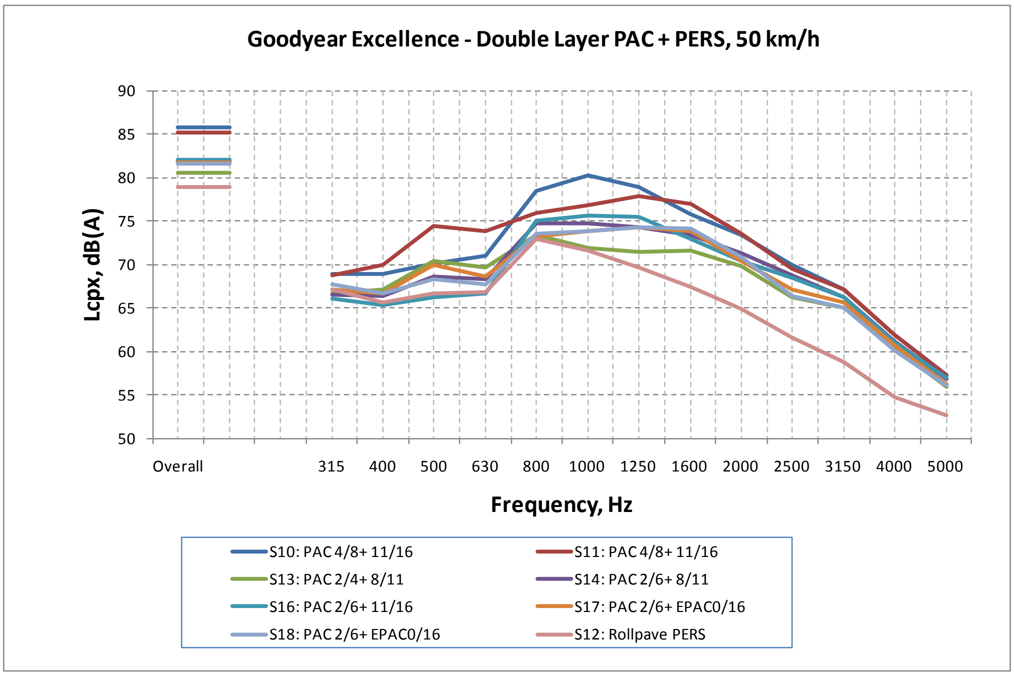

Figure A1_29 *Tyre 5: Goodyear Excellence, Double layer porous+ PERS, 50 km/h*

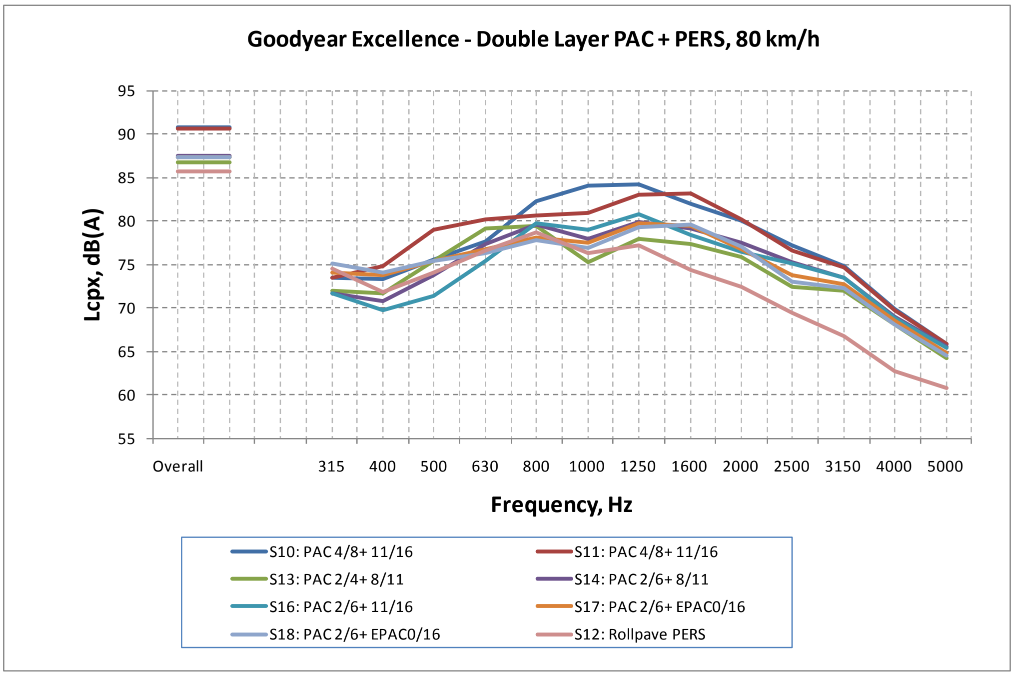

Figure A1_30 *Tyre 5: Goodyear Excellence, Double layer porous+ PERS, 80 km/h*

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Tyre 6: Conti Premium Contact2

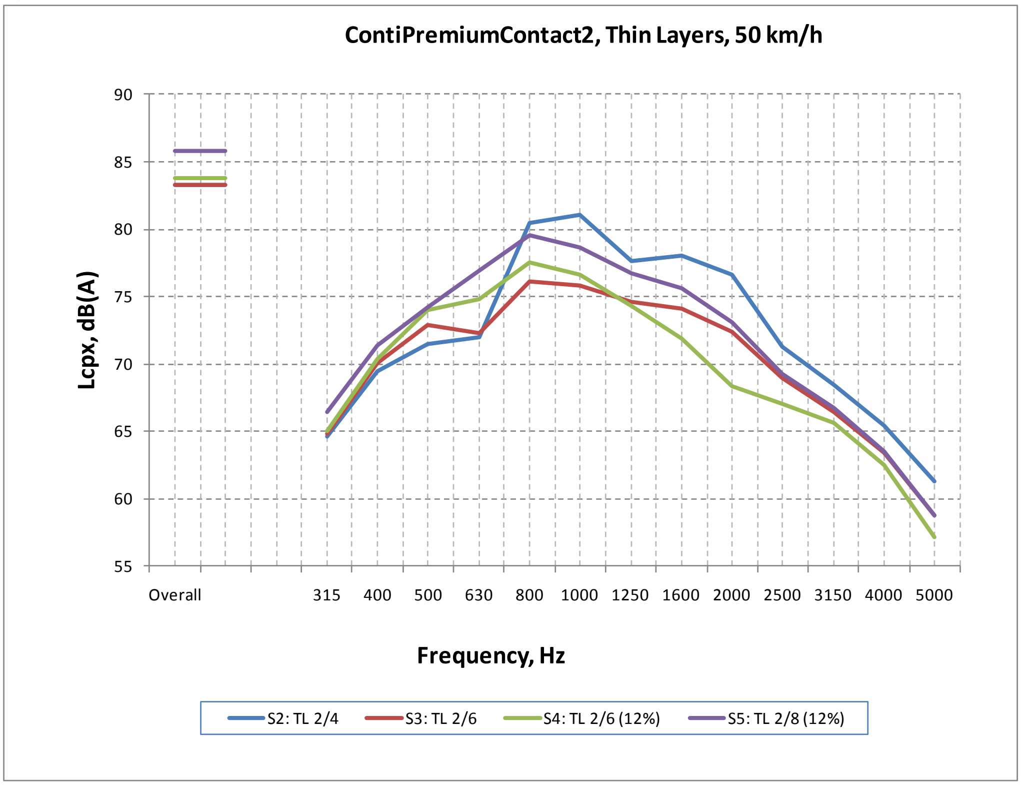

Figure A1_31 *Tyre 6: ContiPremuimContact2, Thin layers, 50 km/h*

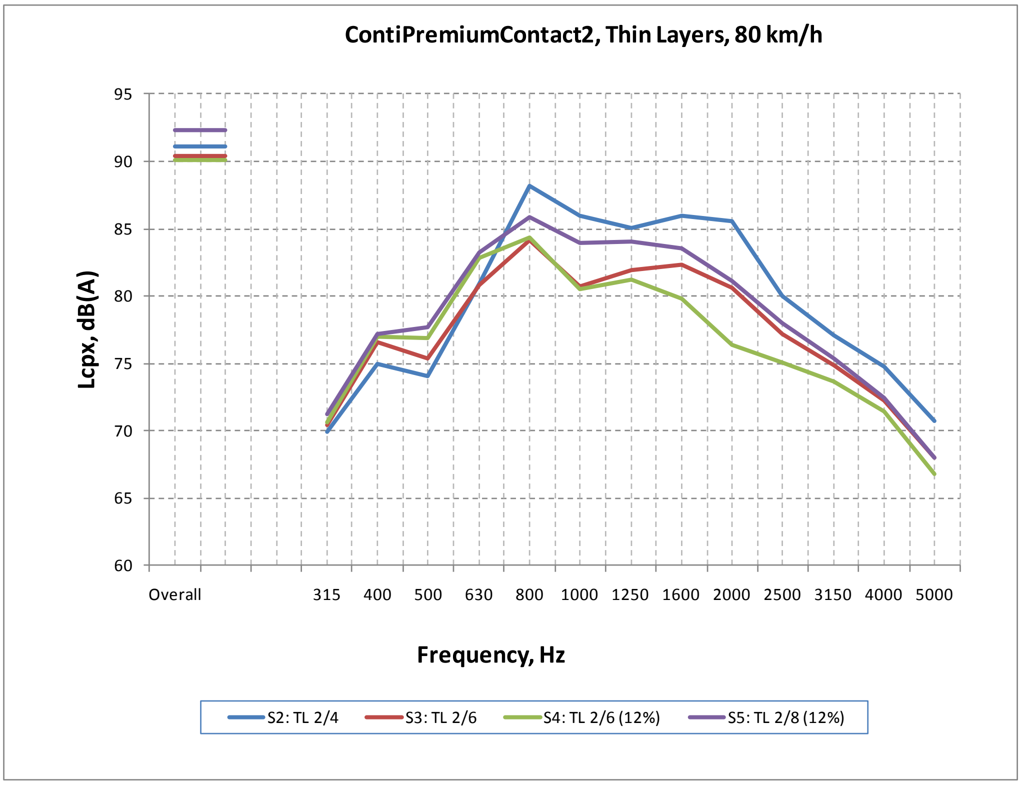

Figure A1_32 *Tyre 6: ContiPremuimContact2, Thin layers, 80 km/h*

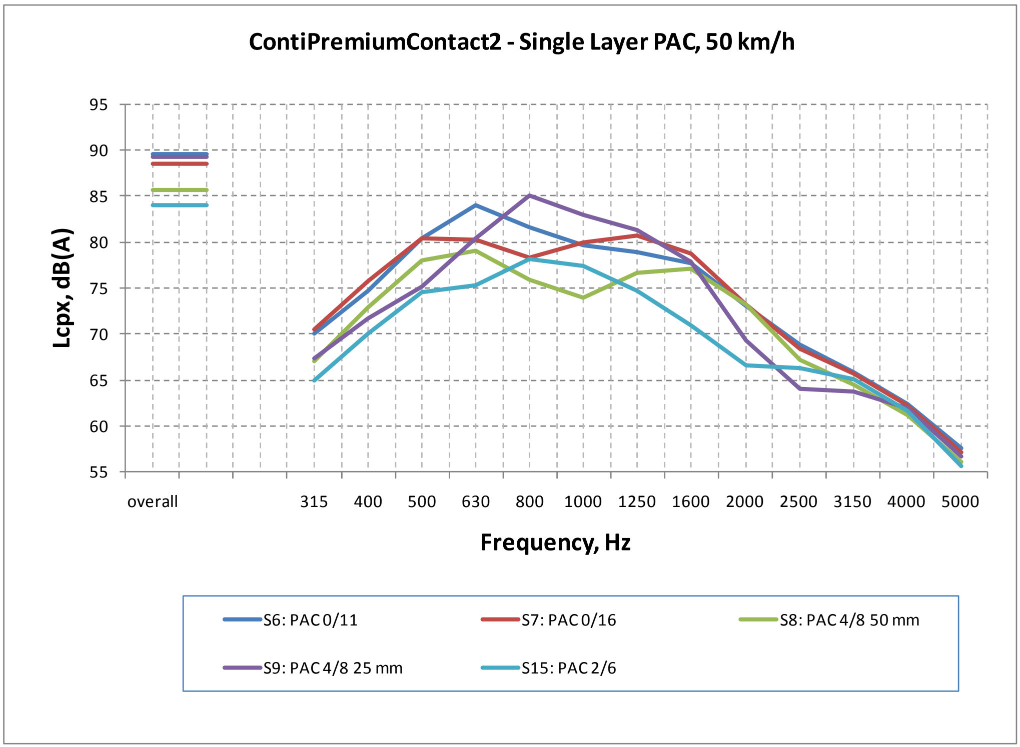

Figure A1_33 *Tyre 6: ContiPremuimContact2, Single layer porous, 50 km/h*

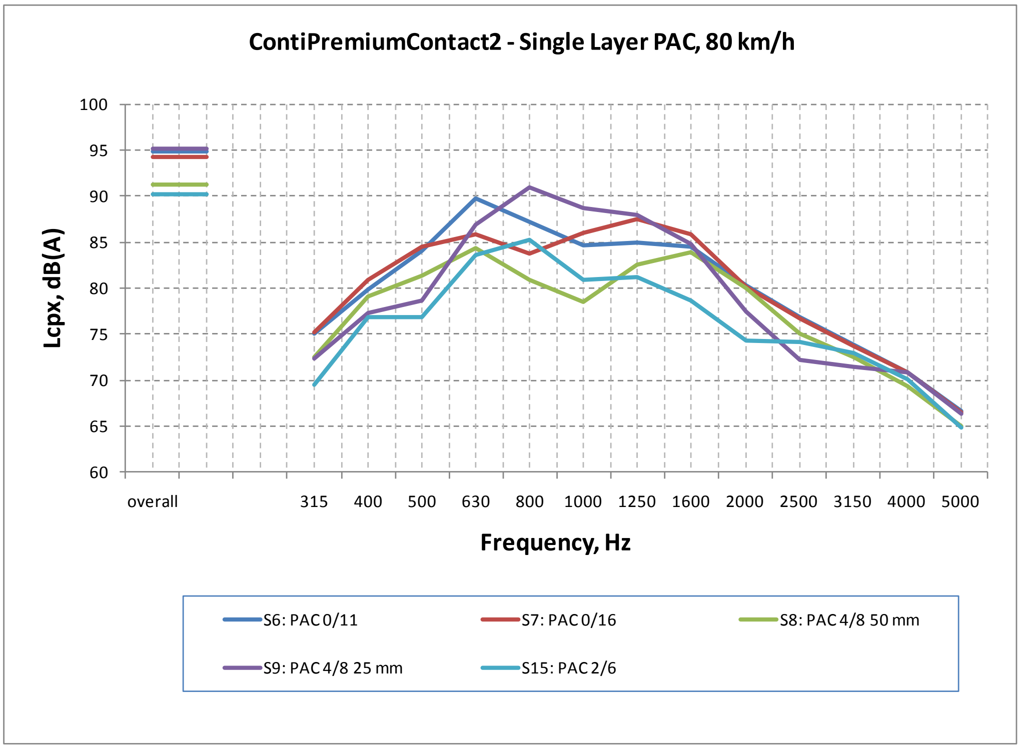

Figure A1_34 *Tyre 6: ContiPremuimContact2, Single layer porous, 80 km/h*

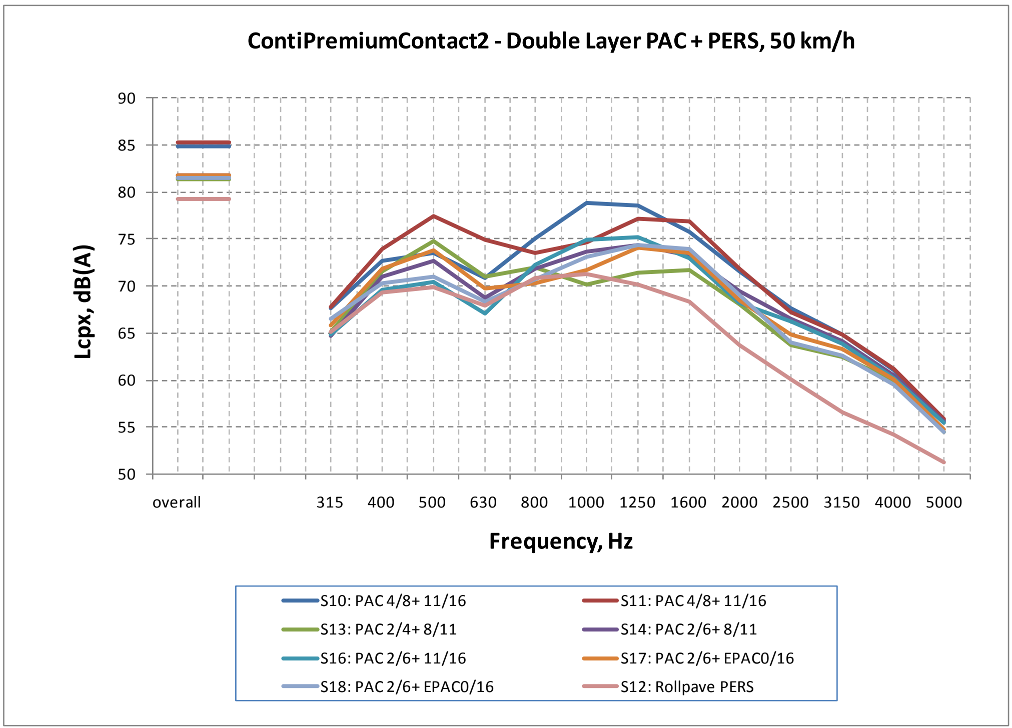

Figure A1_35 *Tyre 6: ContiPremuimContact2, Double layer porous+ PERS, 50 km/h*

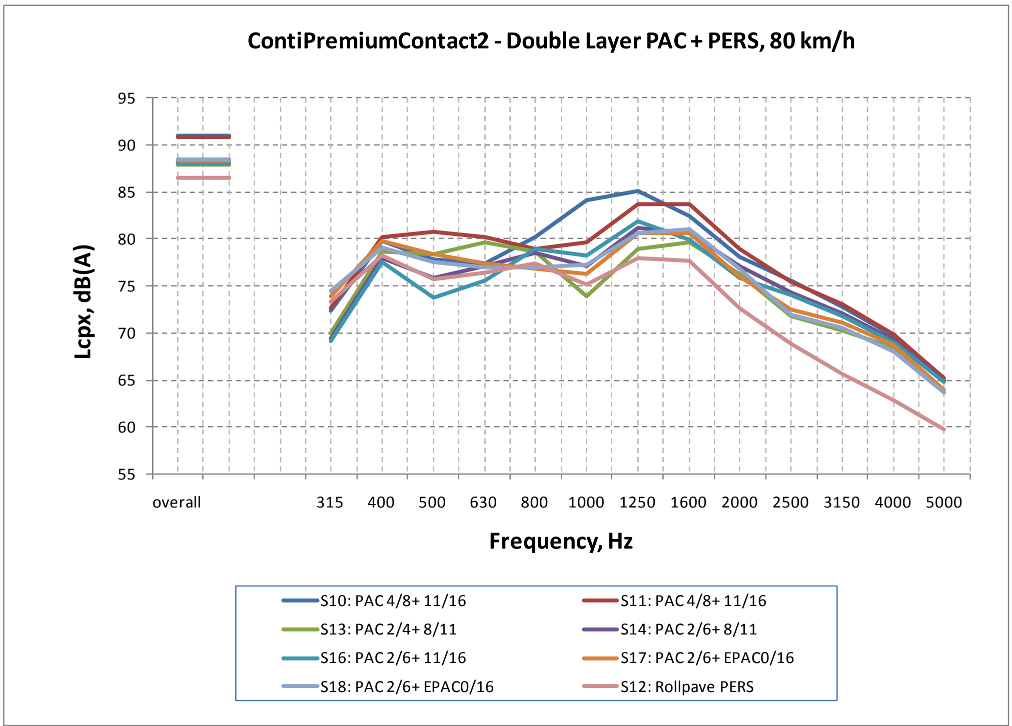

Figure A1_36 *Tyre 6: ContiPremuimContact2, Double layer porous+ PERS, 80 km/h*

Tyre 7: Toyo Proxes T1R

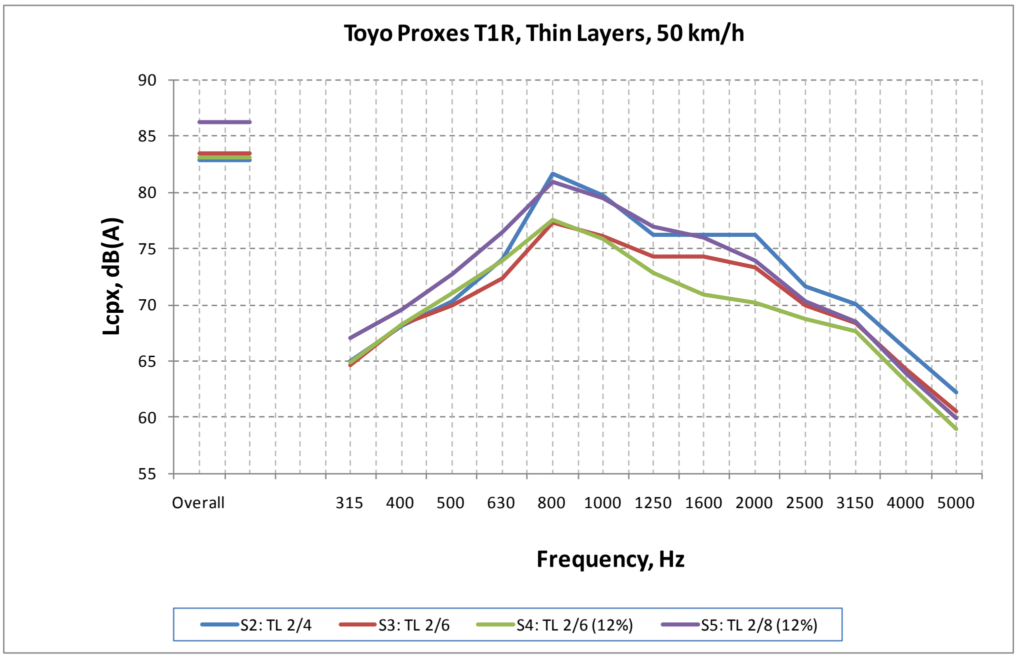

Figure A1_37 *Tyre 7: Toyo Proxes T1R, Thin layers, 50 km/h*

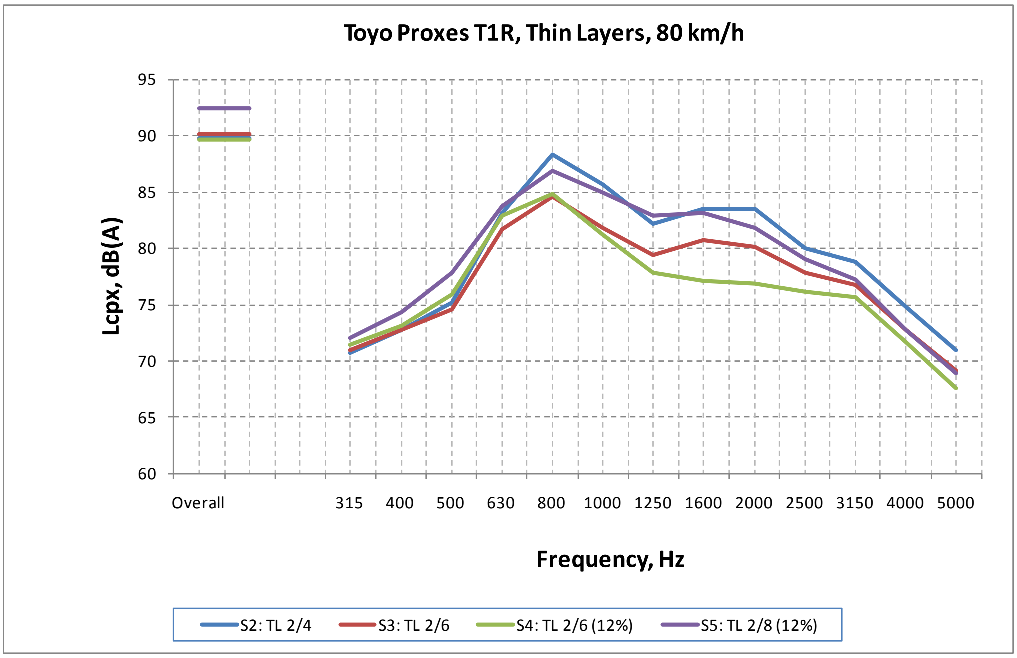

Figure A1_38 *Tyre 7: Toyo Proxes T1R, Thin layers, 80 km/h*

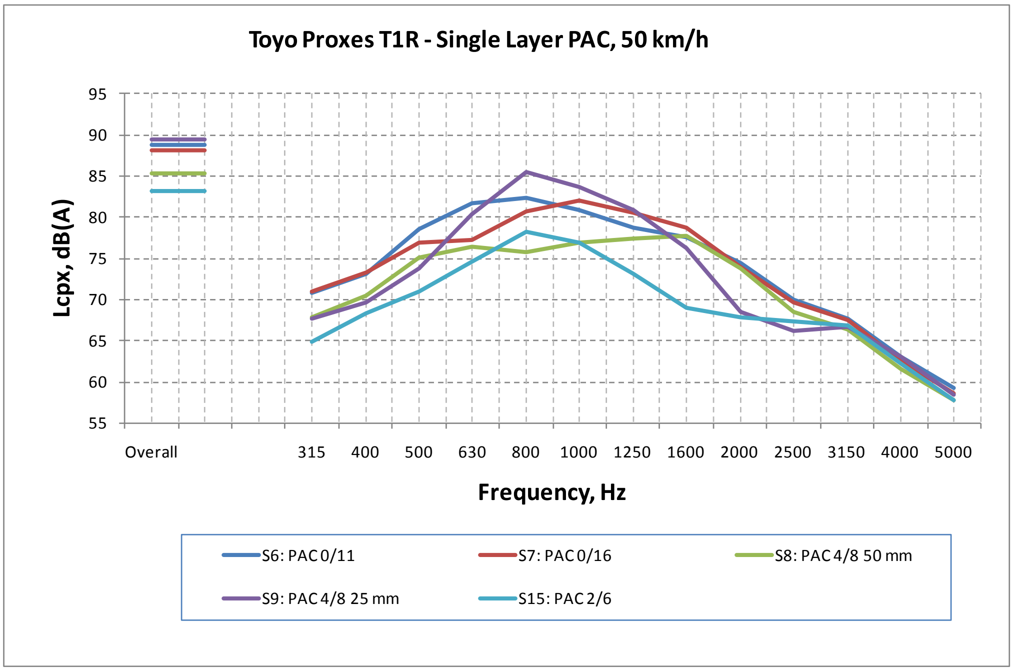

Figure A1_39 *Tyre 7: Toyo Proxes T1R, Single layer porous, 50 km/h*

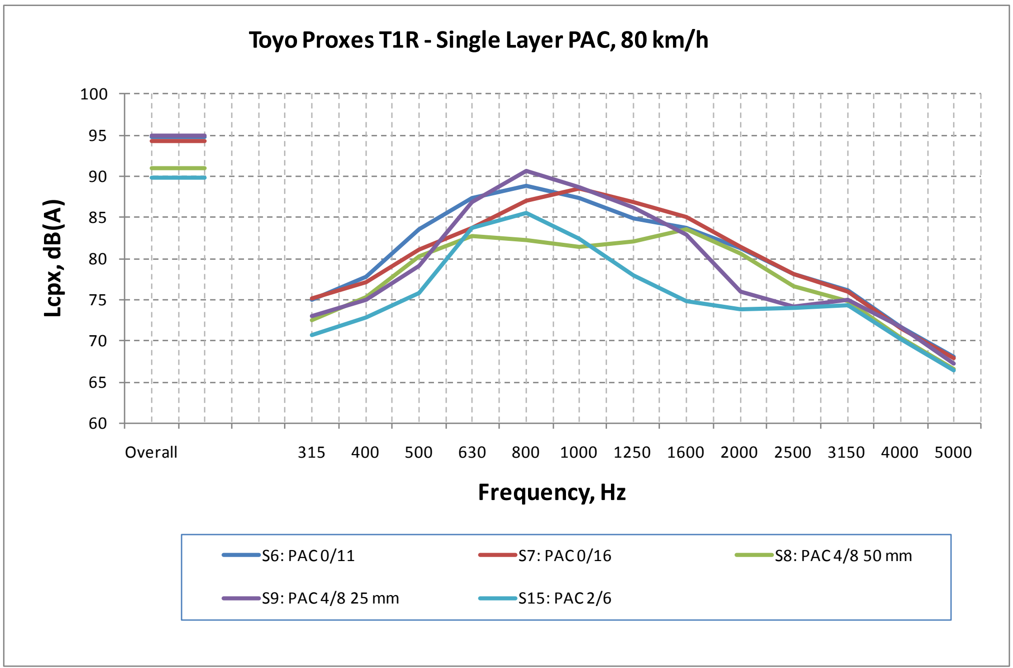

Figure A1_40 *Tyre 7: Toyo Proxes T1R, Single layer porous, 80 km/h*

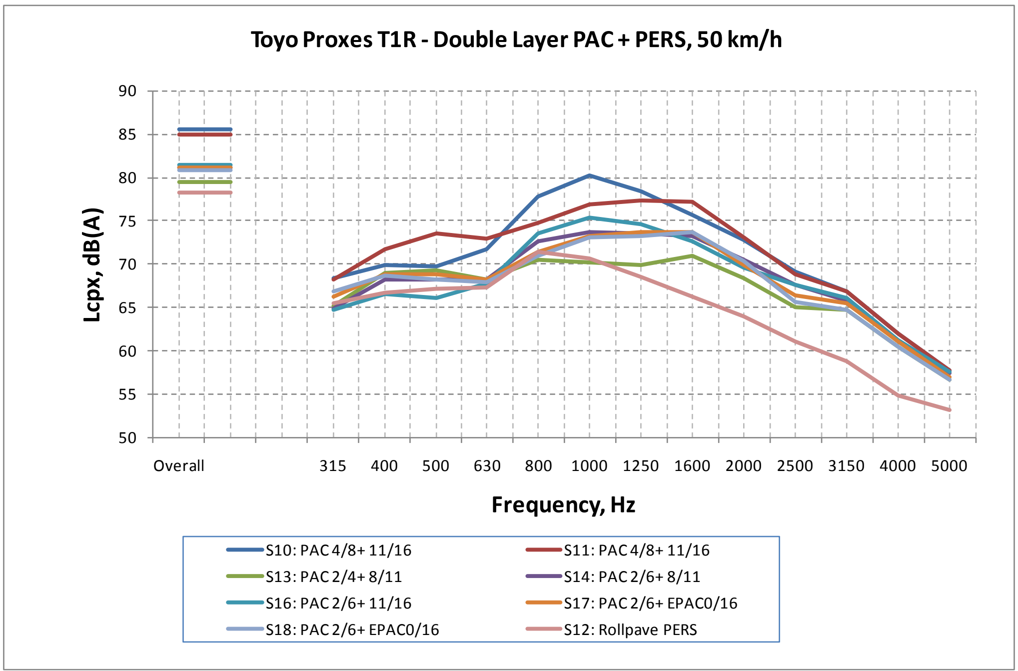

Figure A1_41 *Tyre 7: Toyo Proxes T1R, Double layer porous + PERS, 50 km/h*

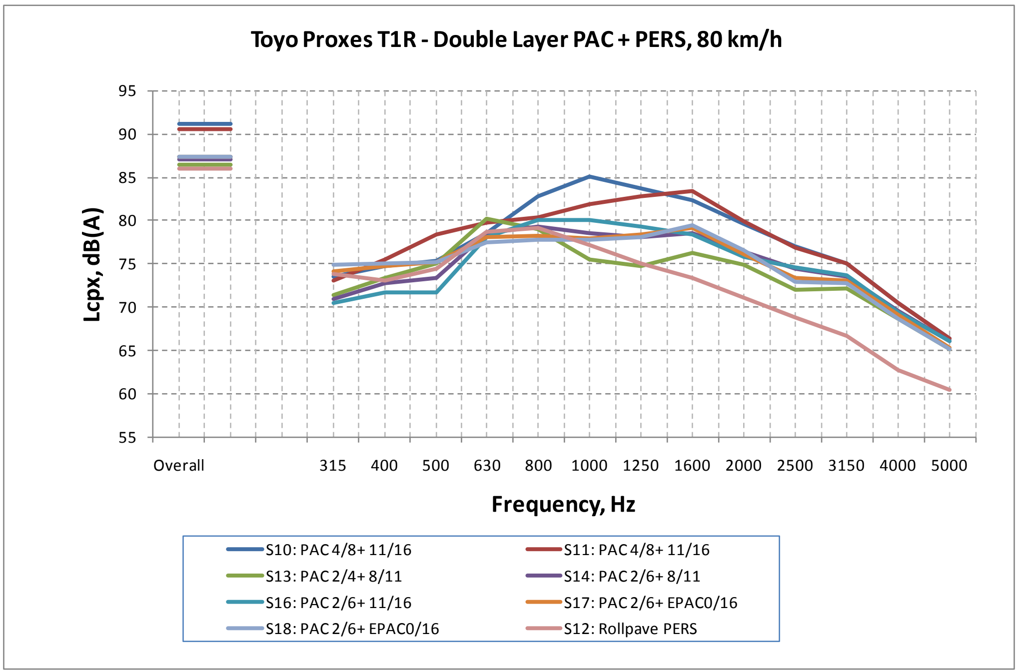

Figure A1_42 *Tyre 7: Toyo Proxes T1R, Double layer porous + PERS, 80 km/h*

Tyre 8: Nokian Hakka H

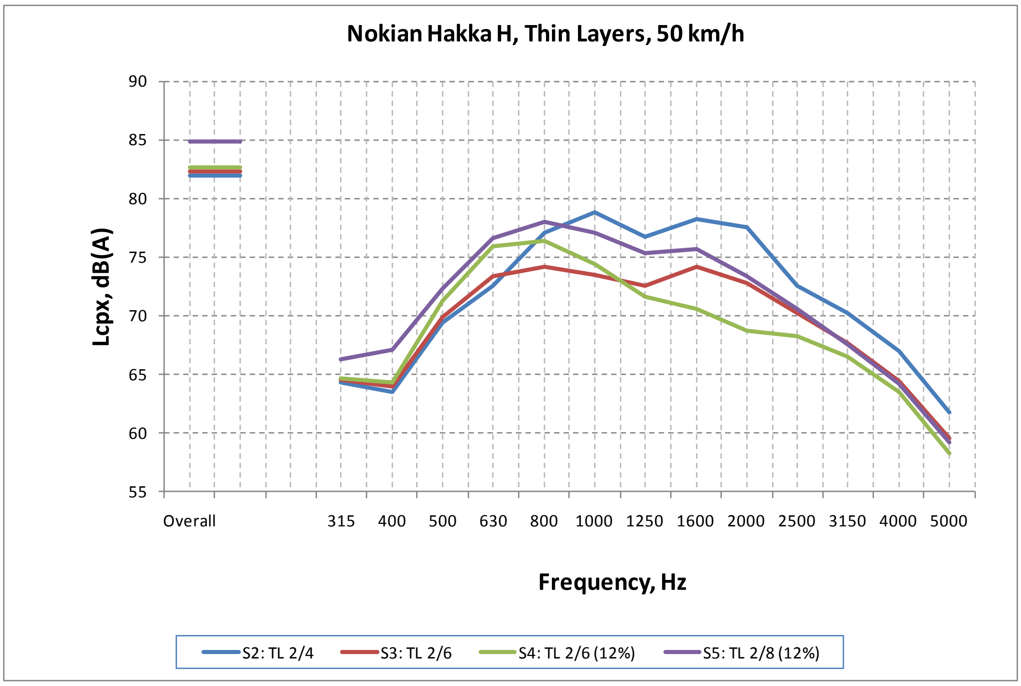

Figure A1_43 *Tyre 8: Nokian Hakka H, Thin layers, 50 km/h*

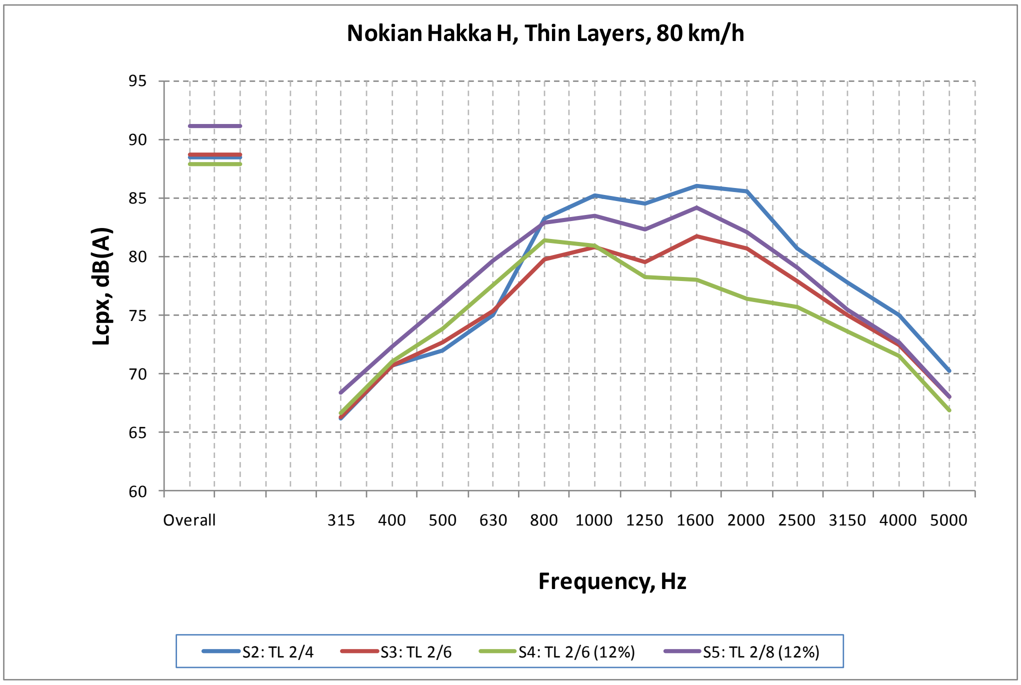

Figure A1_44 *Tyre 8: Nokian Hakka H, Thin layers, 80 km/h*

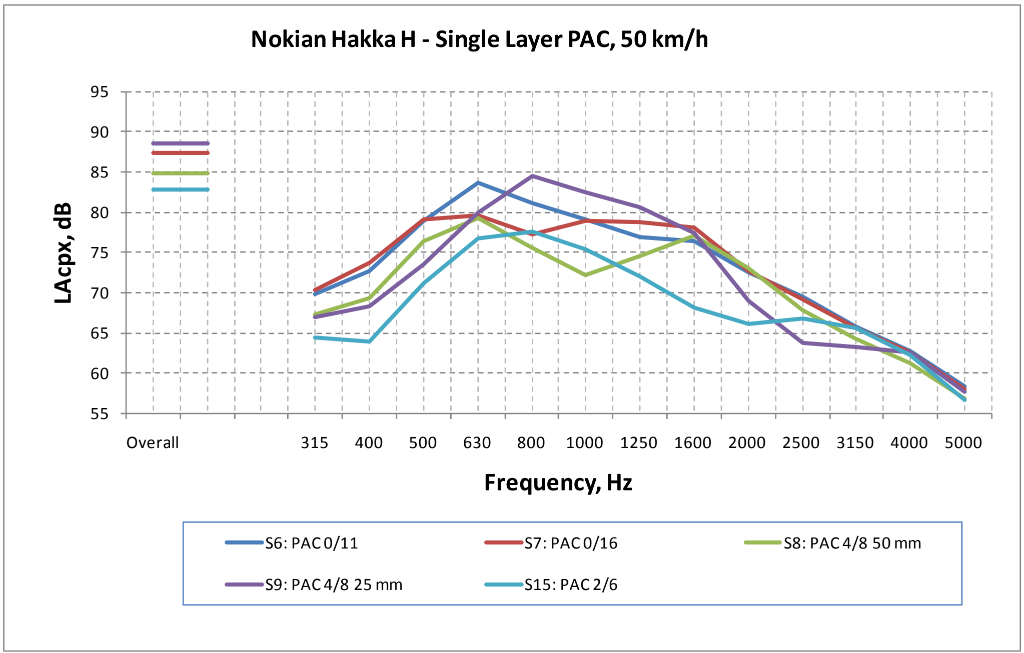

Figure A1_45 *Tyre 8: Nokian Hakka H, Single layer porous, 50 km/h*

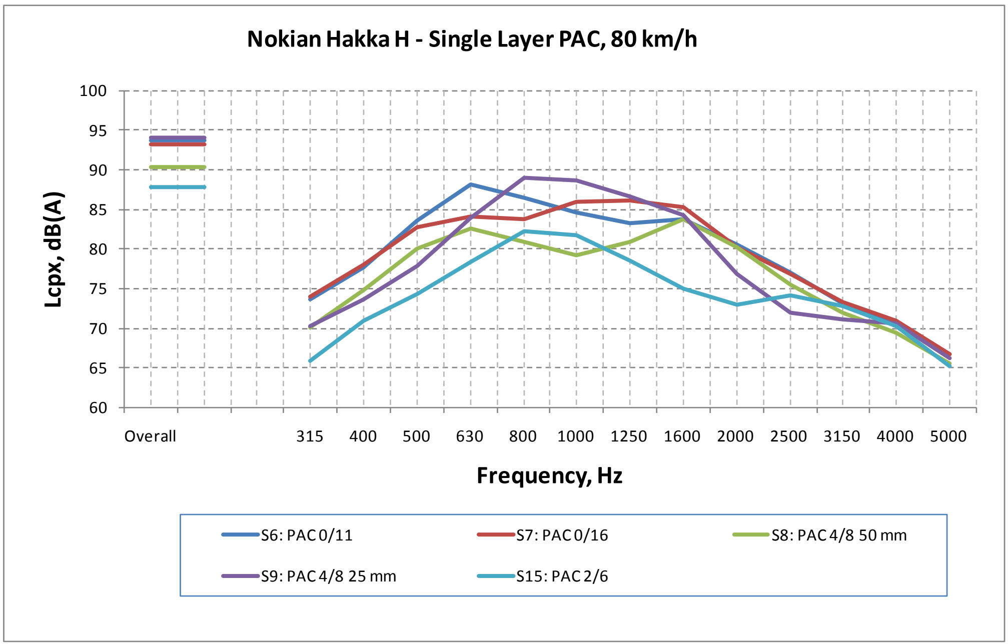

Figure A1_46 *Tyre 8: Nokian Hakka H, Single layer porous, 80 km/h*

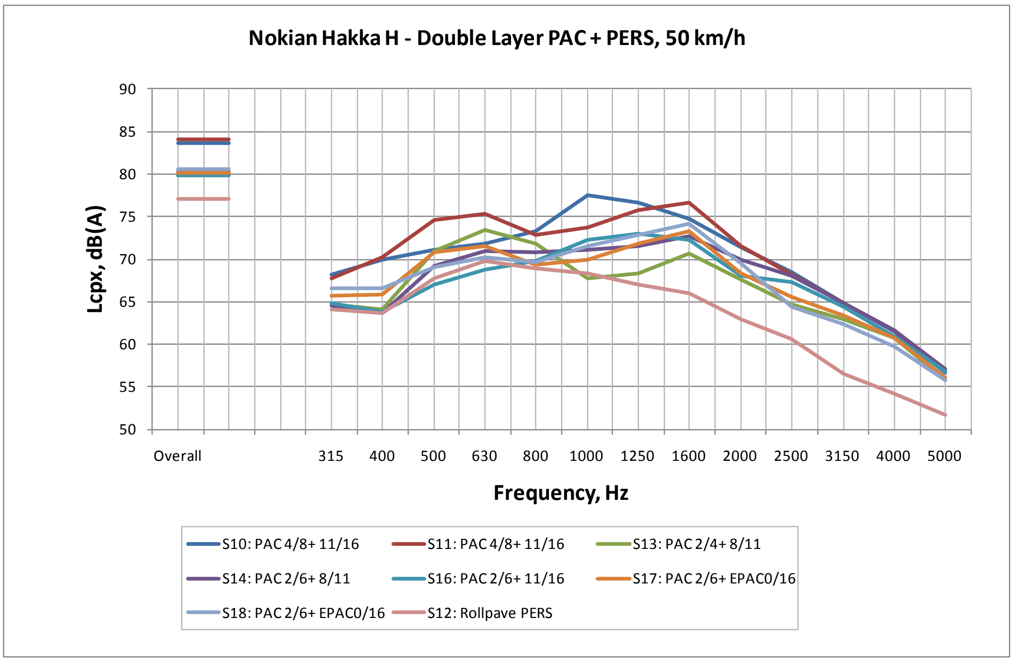

Figure A1_47 *Tyre 8: Nokian Hakka H, Double layer porous + PERS, 50 km/h*

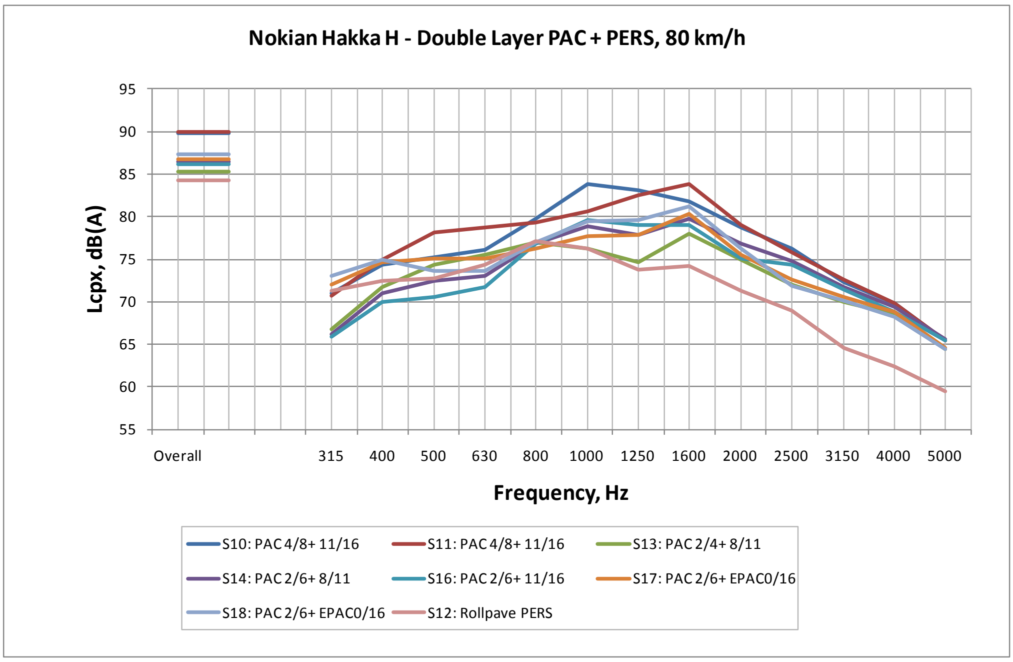

Figure A1_48 *Tyre 8: Nokian Hakka H, Double layer porous + PERS, 80 km/h*

Tyre 9: Michelin Pilot Primacy HP

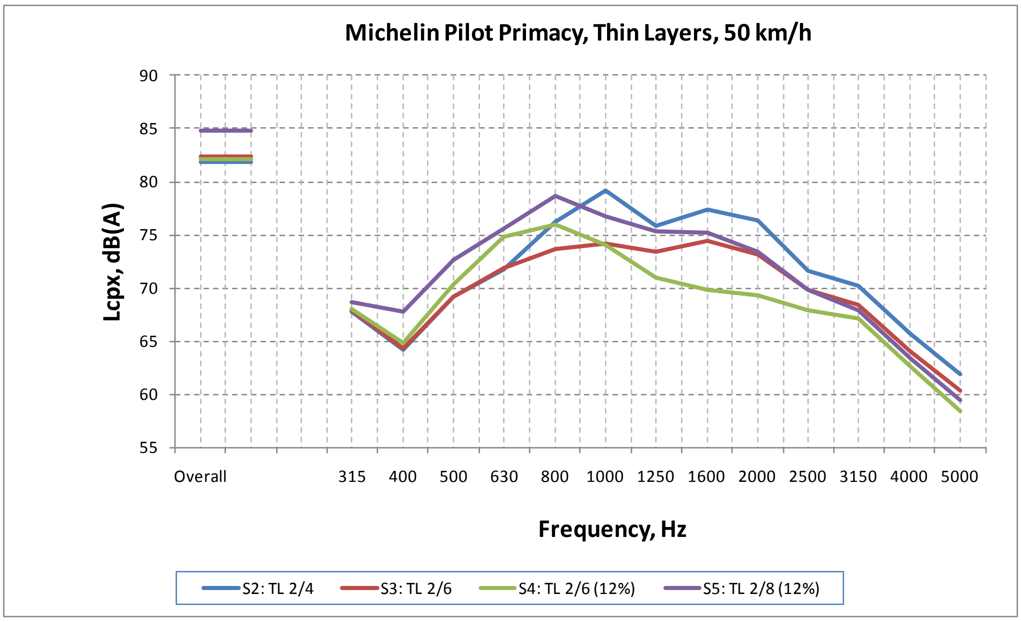

Figure A1_49 *Tyre 9: Michelin Pilot Primacy, Thin layers, 50 km/h*

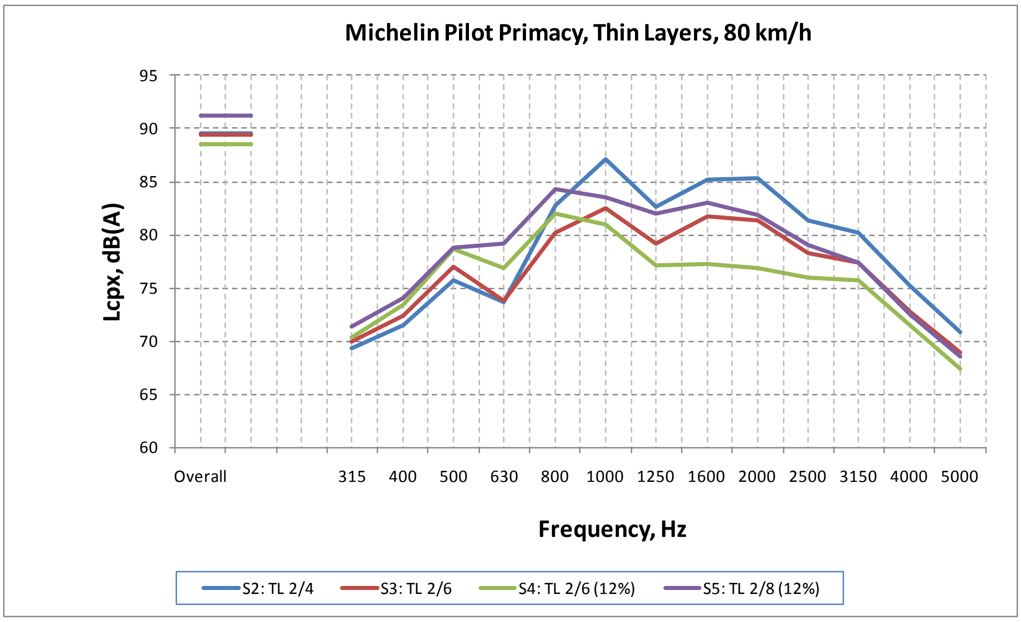

Figure A1_50 *Tyre 9: Michelin Pilot Primacy, Thin layers, 80 km/h*

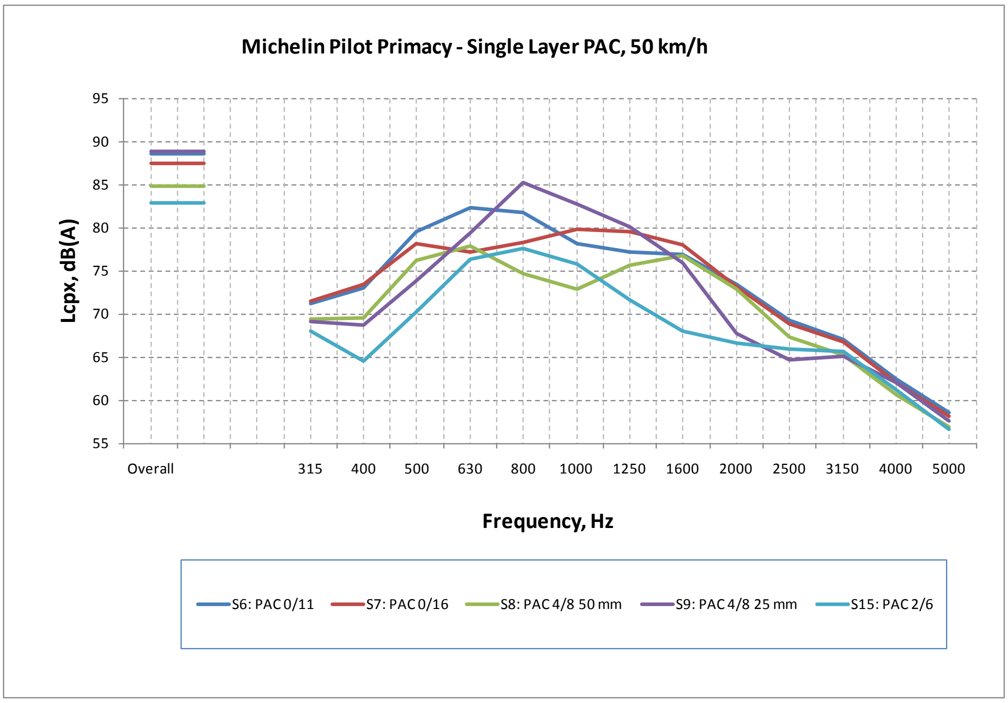

Figure A1_51 *Tyre 9: Michelin Pilot Primacy, Single layer porous, 50 km/h*

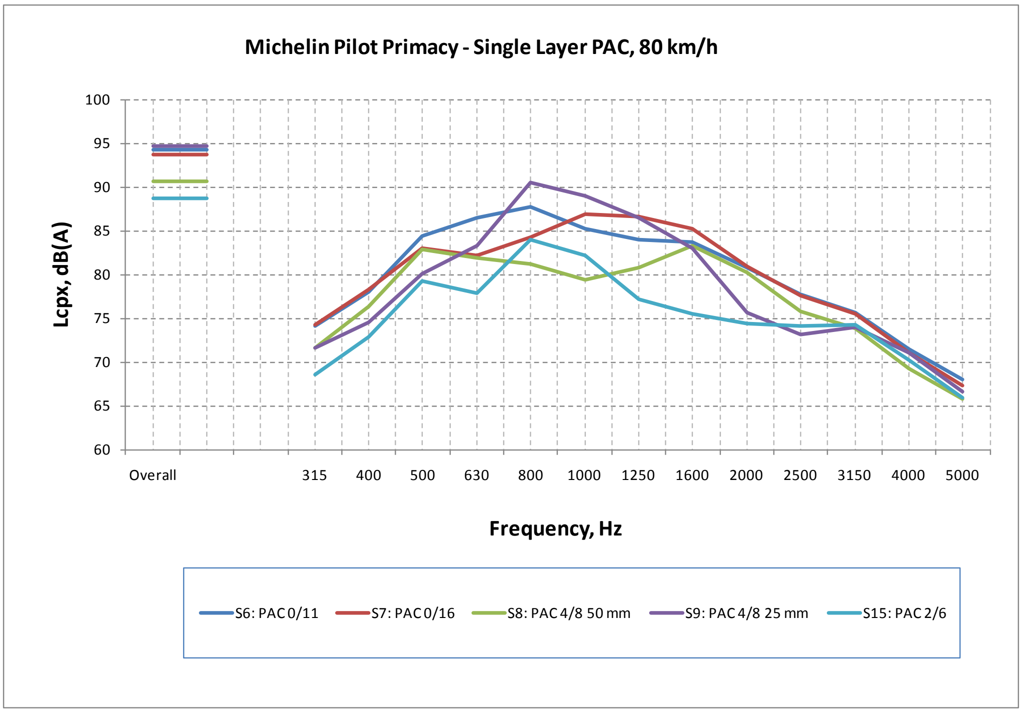

Figure A1_52 *Tyre 9: Michelin Pilot Primacy, Single layer porous, 80 km/h*

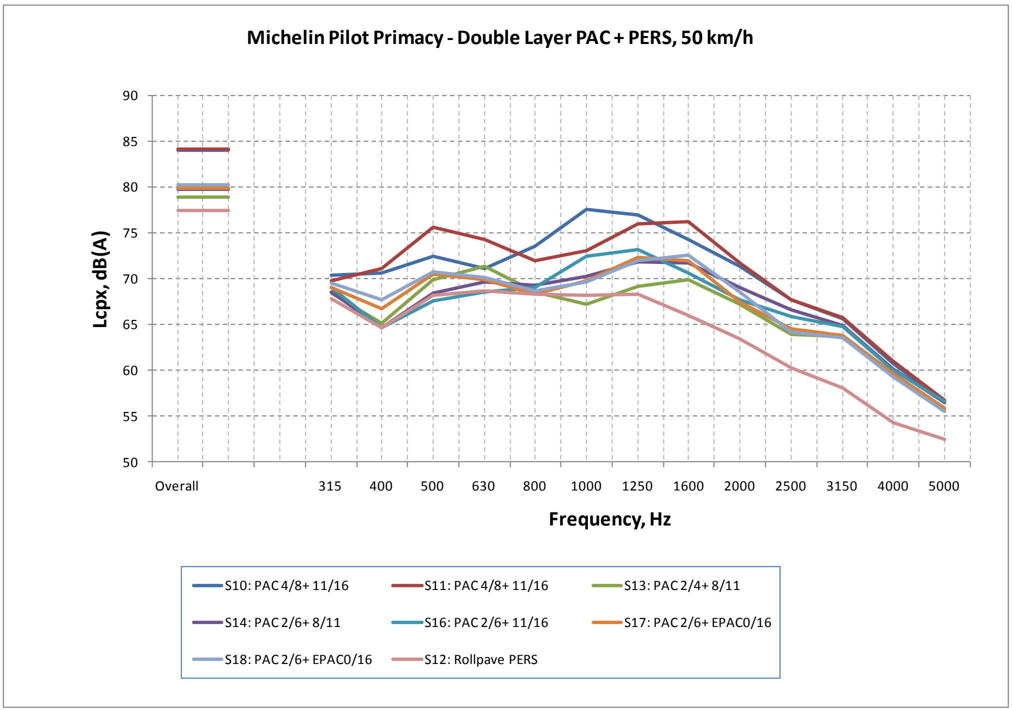

Figure A1_53 *Tyre 9: Michelin Pilot Primacy, Double layer porous + PERS, 50 km/h*

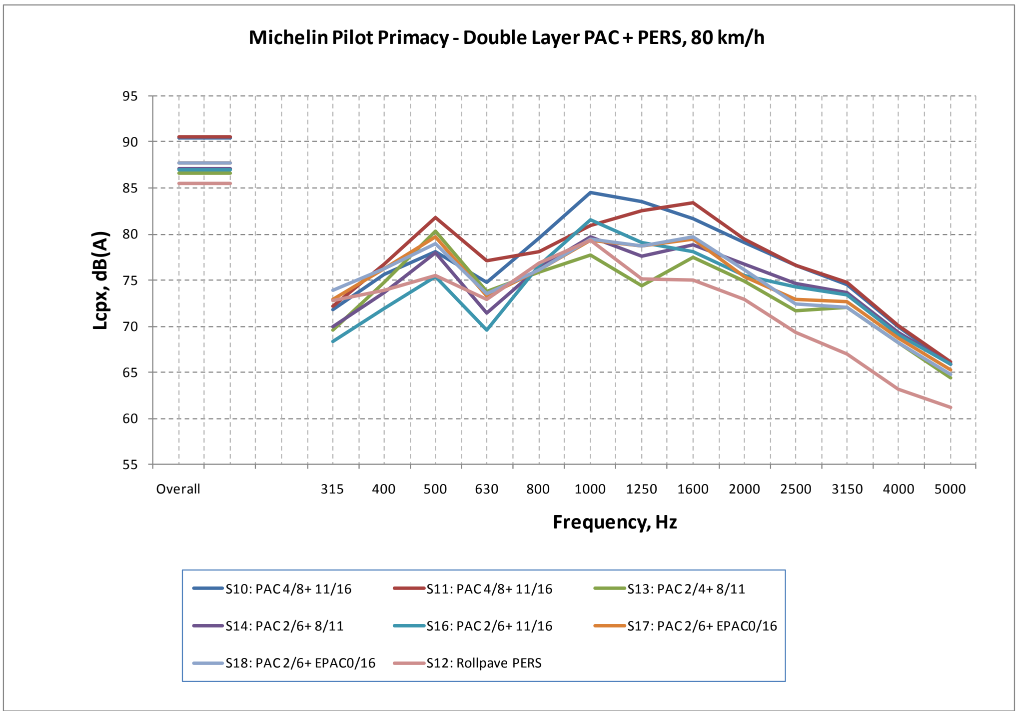

Figure A1_54 *Tyre 9: Michelin Pilot Primacy, Double layer porous + PERS, 80 km/h*

Tyre 10: Firestone Firehawk TZ200

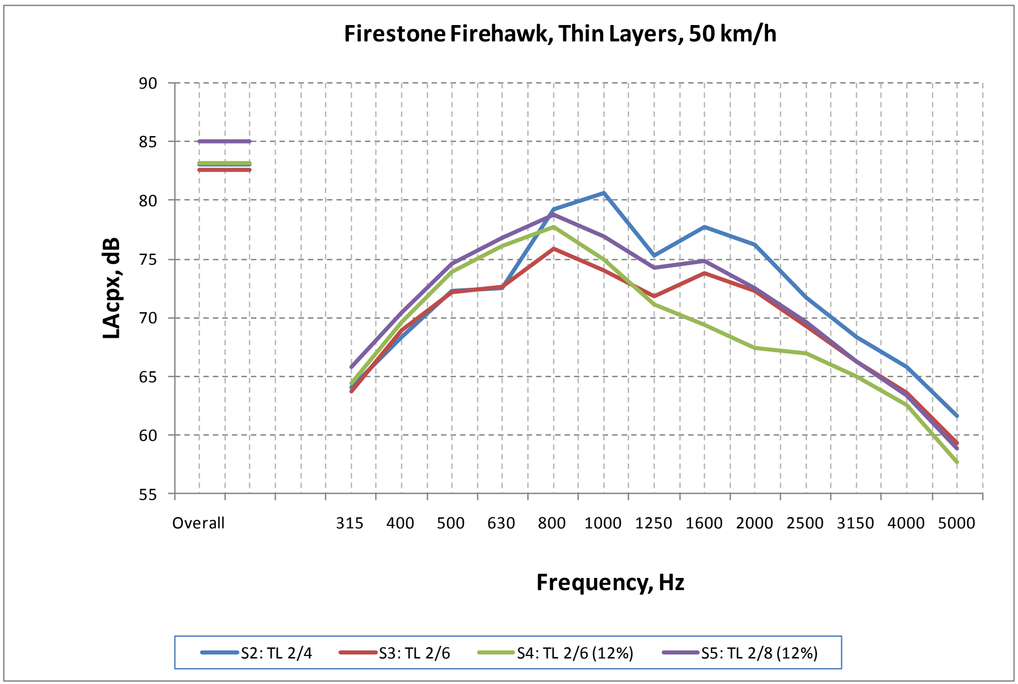

Figure A1_55 *Tyre 10: Firestone Firehawk TZ200, Thin layers, 50 km/h*

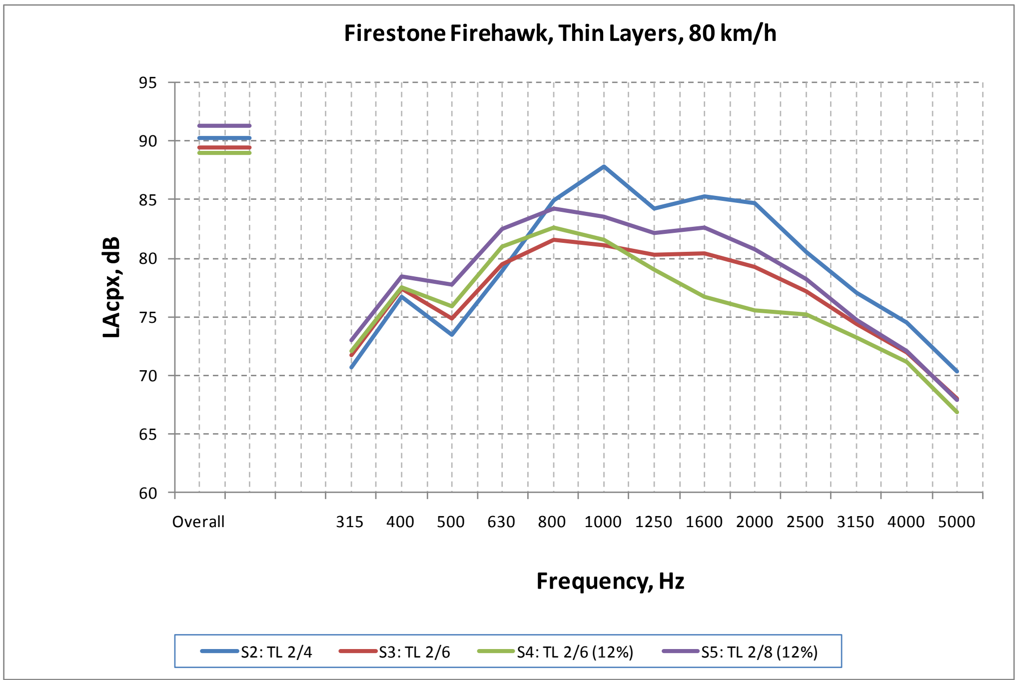

Figure A1_56 *Tyre 10: Firestone Firehawk TZ200, Thin layers, 80 km/h*

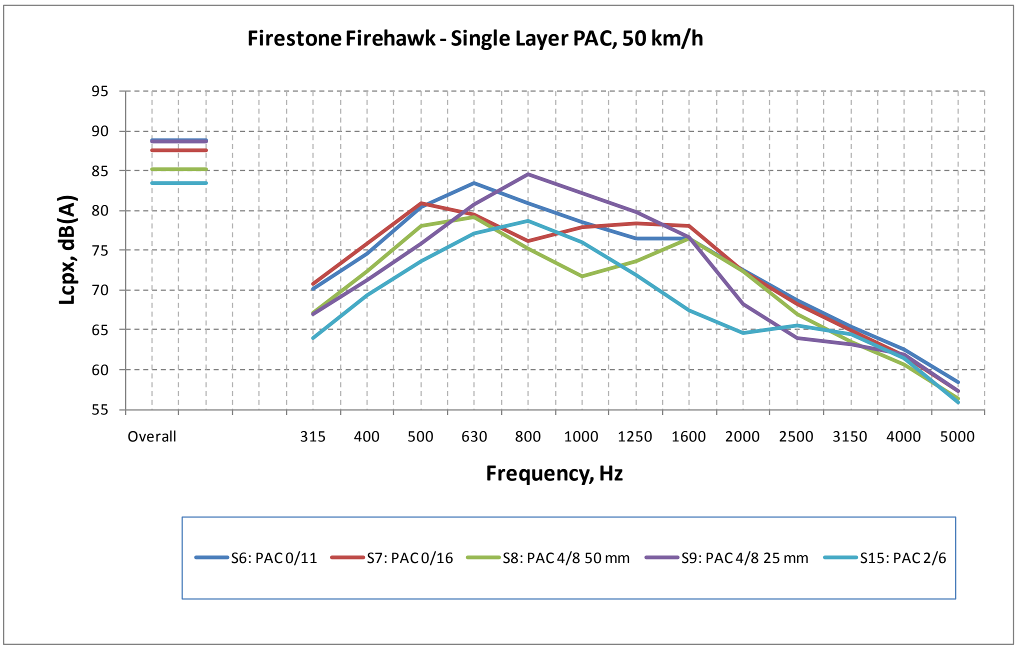

Figure A1_57 *Tyre 10: Firestone Firehawk TZ200, Single layer porous, 50 km/h*

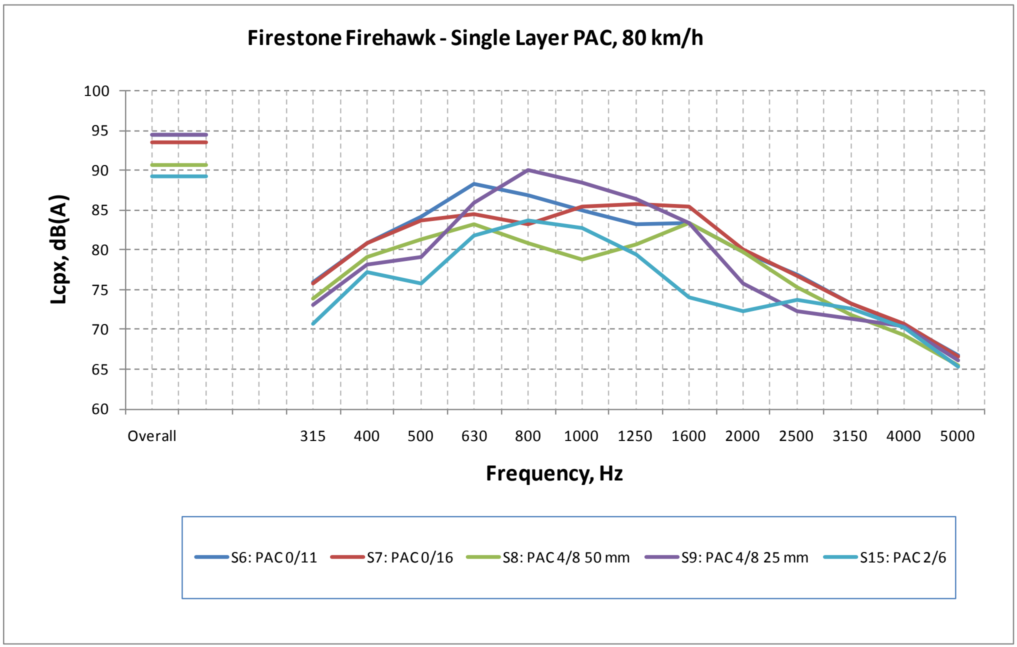

Figure A1_58 *Tyre 10: Firestone Firehawk TZ200, Single layer porous, 80 km/h*

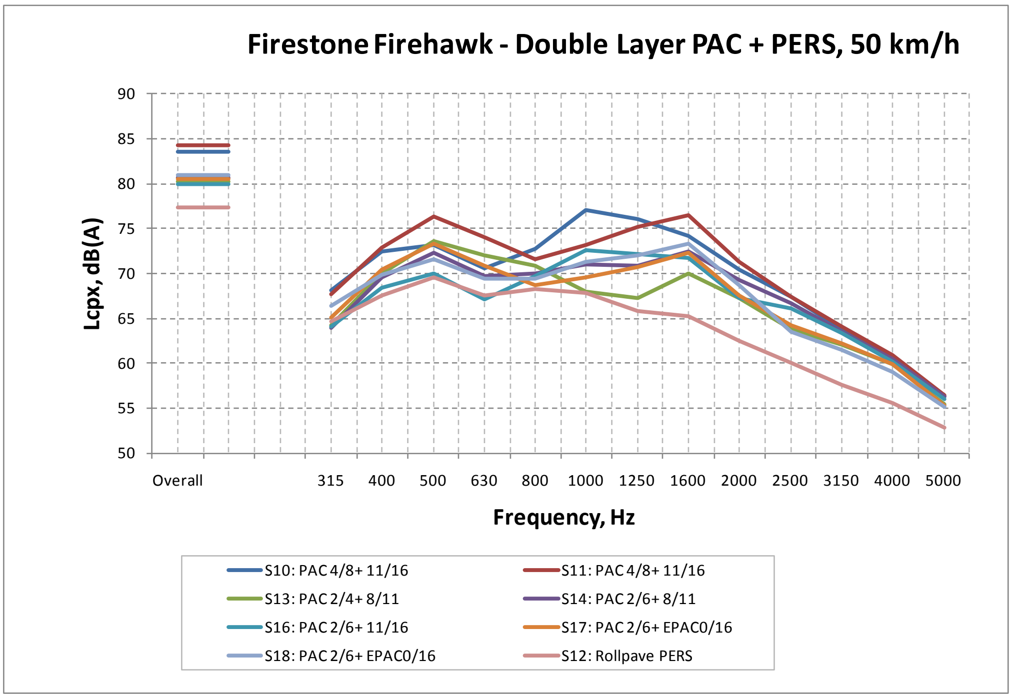

Figure A1_59 *Tyre 10: Firestone Firehawk TZ200, Double layer porous + PERS, 50 km/h*

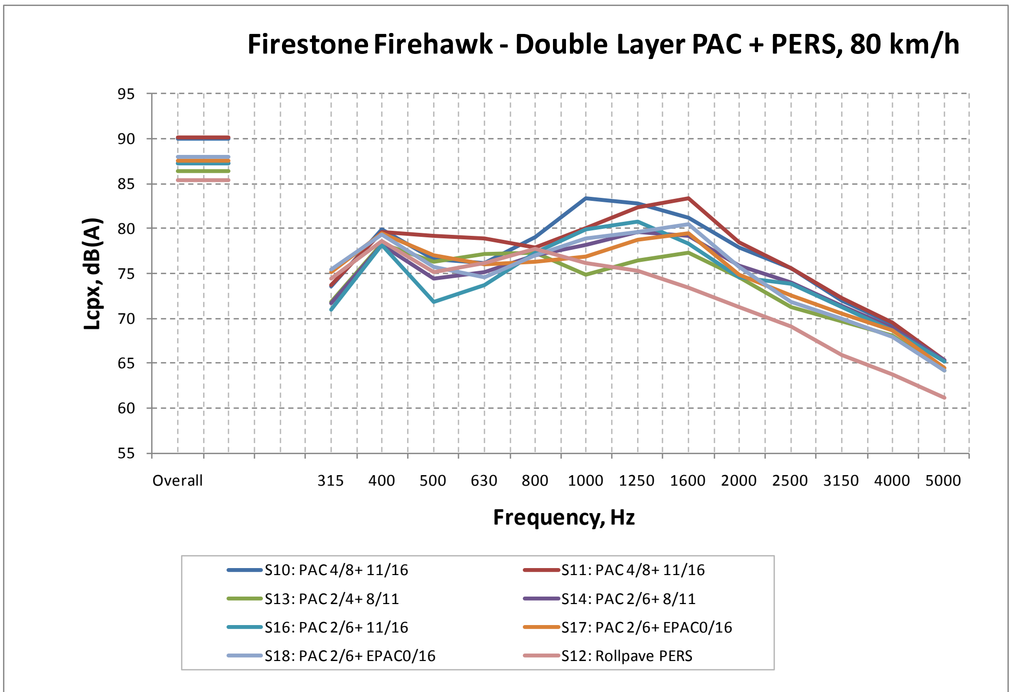

Figure A1_60 *Tyre 10: Firestone Firehawk TZ200, Double layer porous + PERS, 80 km/h*

Tyre 11: Conti EcoContact3

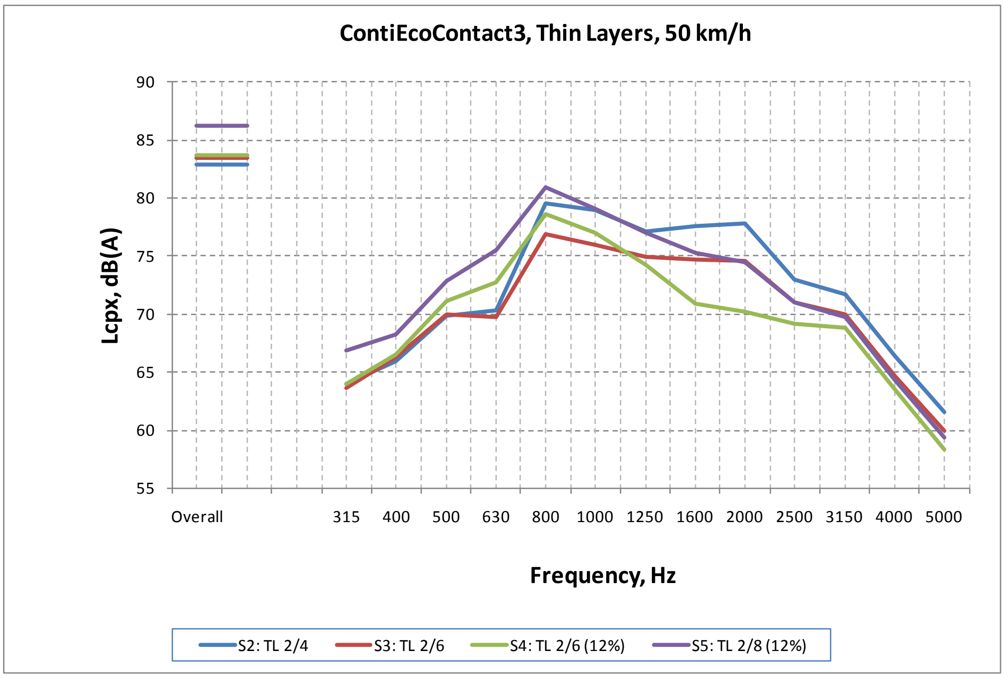

Figure A1_61 *Tyre 11: ContiEcoContact3, Thin layers, 50 km/h*

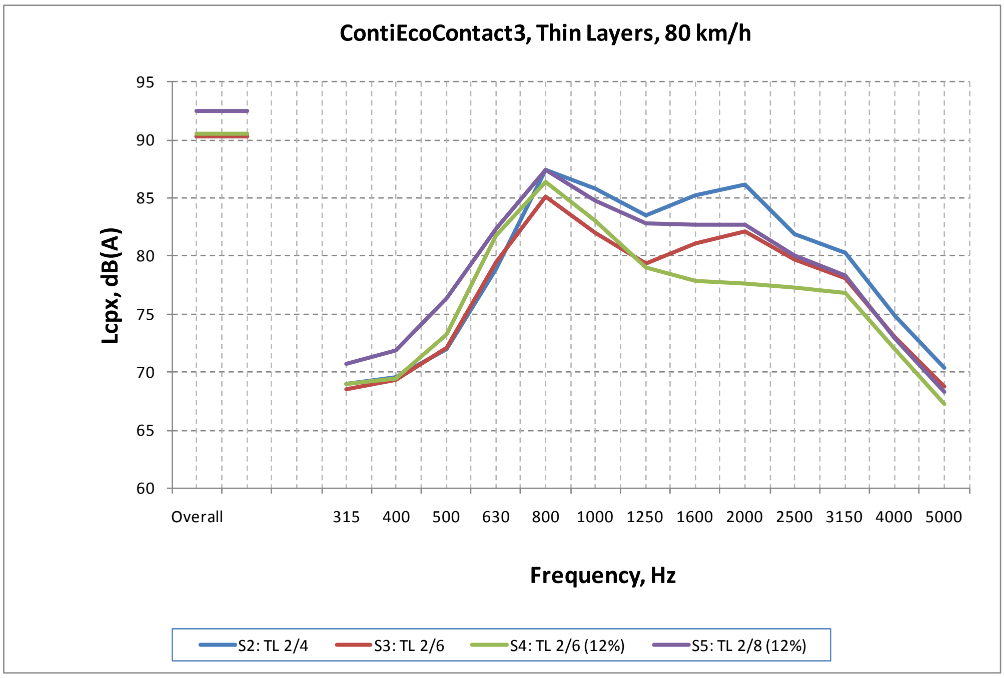

Figure A1_62 *Tyre 11: ContiEcoContact3, Thin layers, 80 km/h*

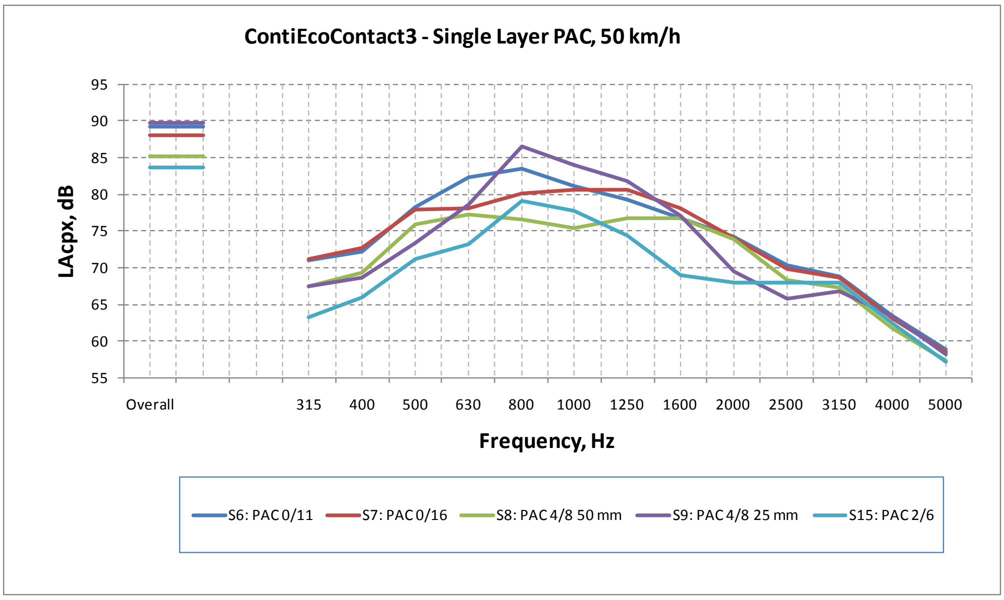

Figure A1_63 *Tyre 11: ContiEcoContact3, Single layer porous, 50 km/h*

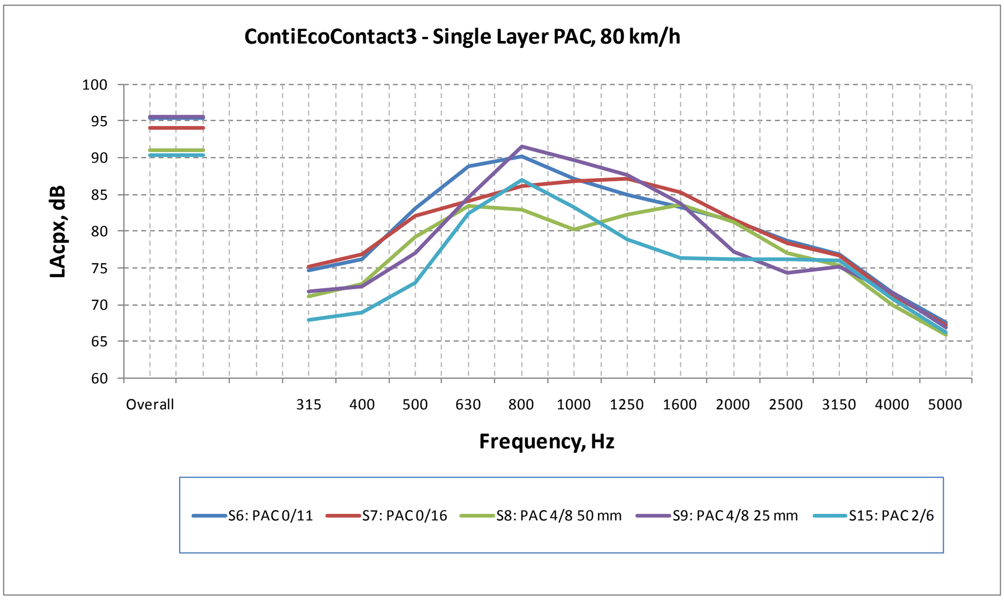

Figure A1_64 *Tyre 11: ContiEcoContact3, Single layer porous, 80 km/h*

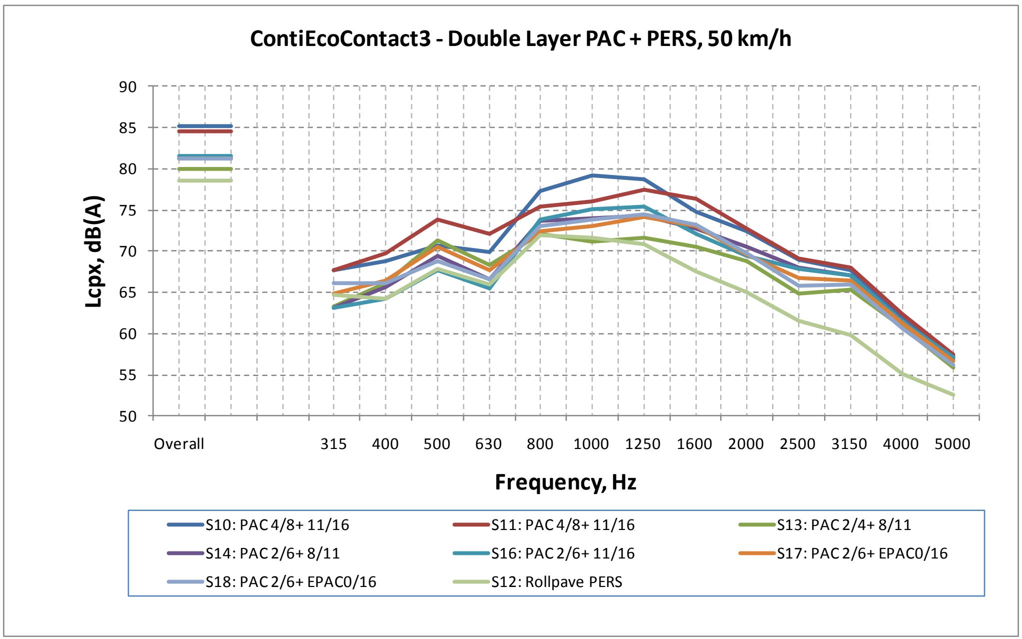

Figure A1_65 *Tyre 11: ContiEcoContact3, Double layer porous + PERS, 50 km/h*

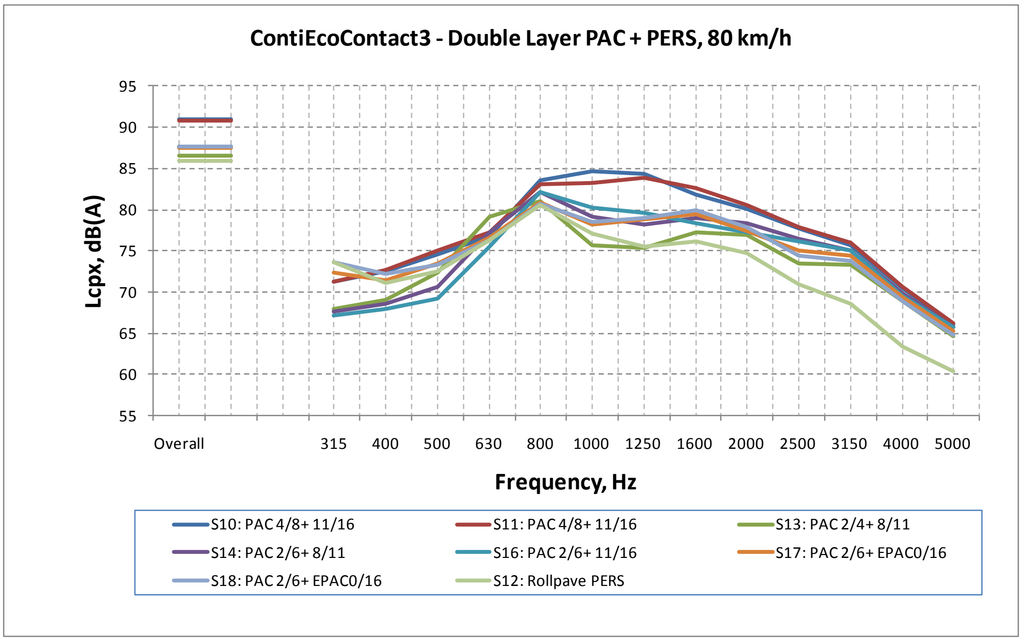

Figure A1_66 *Tyre 11: ContiEcoContact3, Double layer porous + PERS, 80 km/h*

SINTEF

Tyre 12: Yokohama AVS dB V500

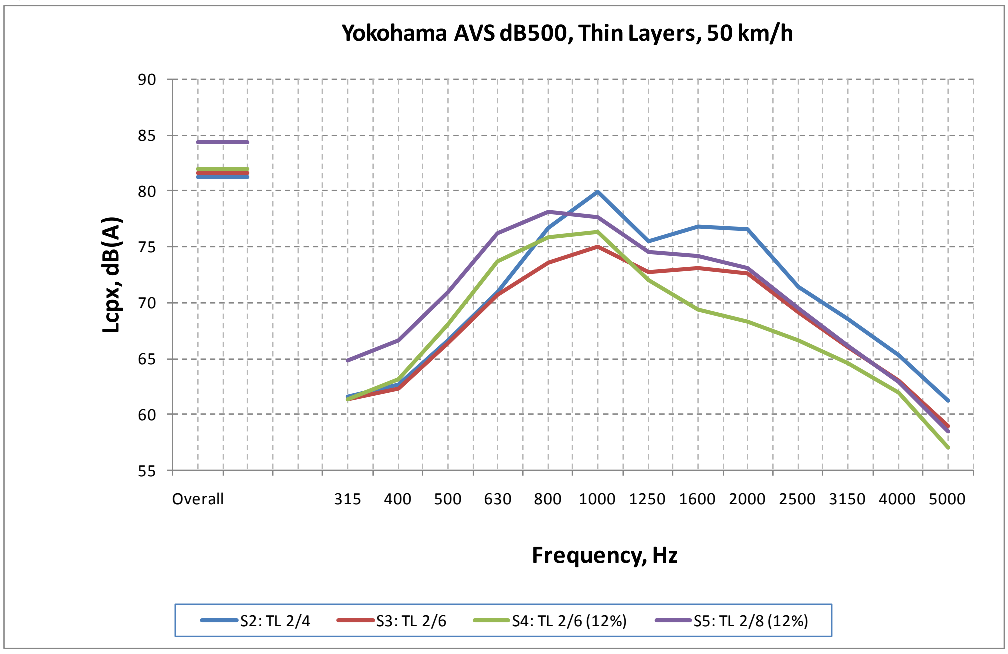

Figure A1_67 *Tyre 12: Yokohama AVS dBV500, Thin layers, 50 km/h*

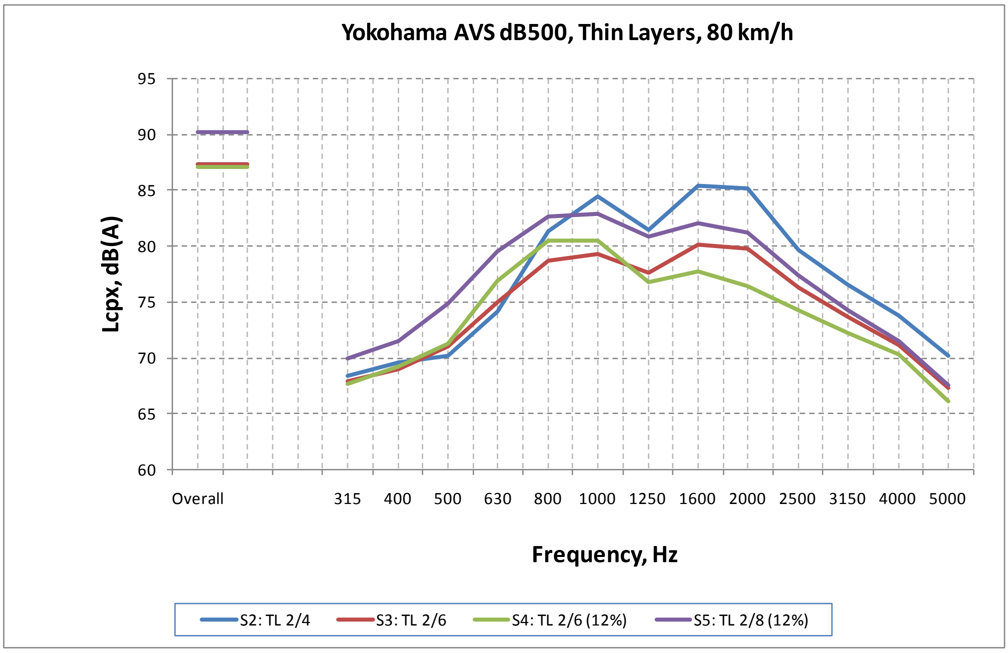

Figure A1_68 *Tyre 12: Yokohama AVS dBV500, Thin layers, 80 km/h*

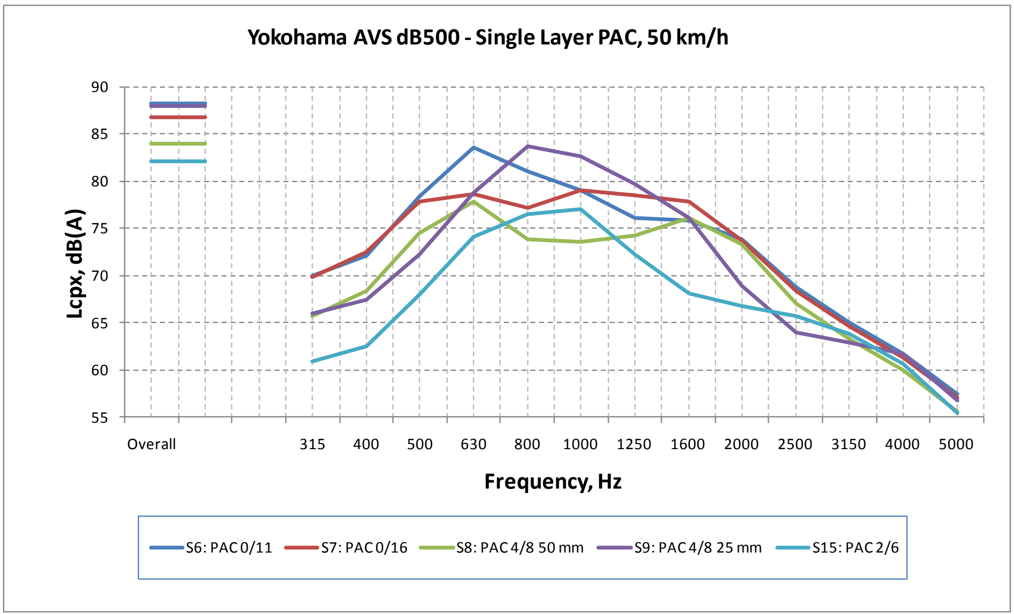

Figure A1_69 *Tyre 12: Yokohama AVS dBV500, Single layer porous, 50 km/h*

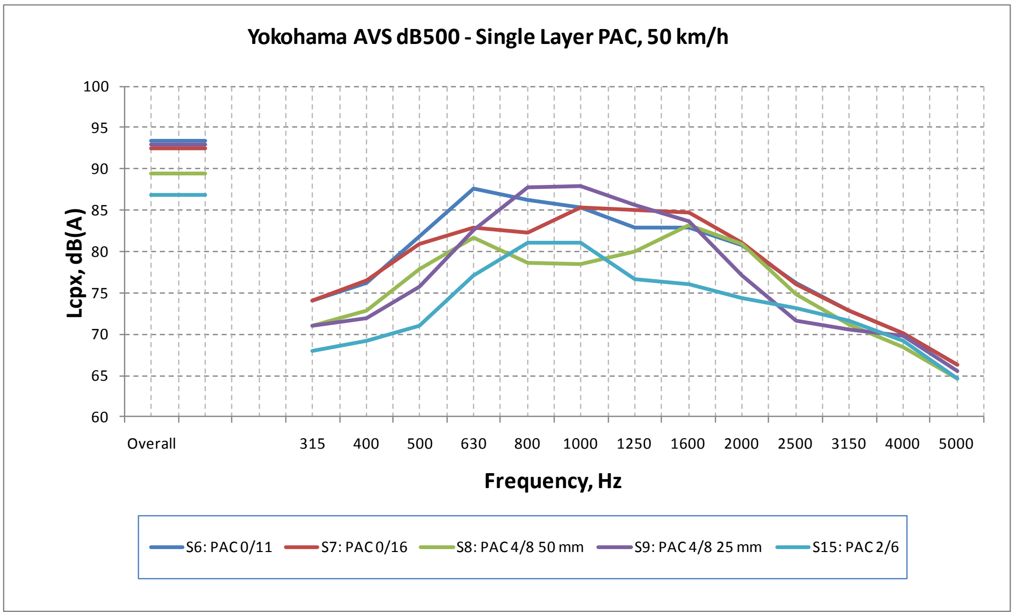

Figure A1_70 *Tyre 12: Yokohama AVS dBV500, Single layer porous, 80 km/h*

SINTEF

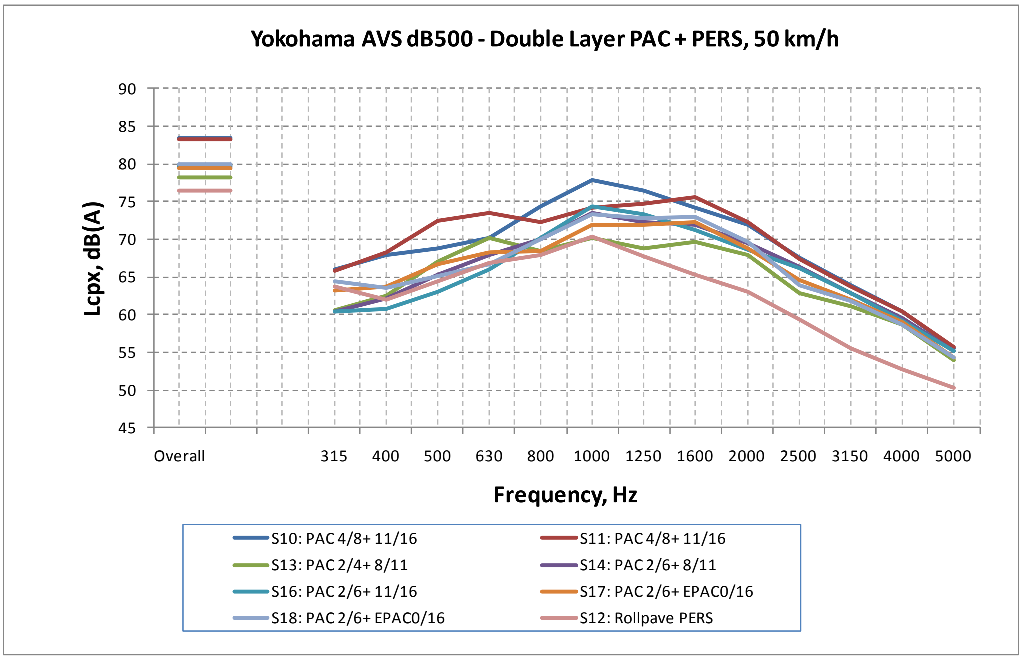

Figure A1_71 *Tyre 12: Yokohama AVS dBV500, Double layer porous + PERS, 50 km/h*

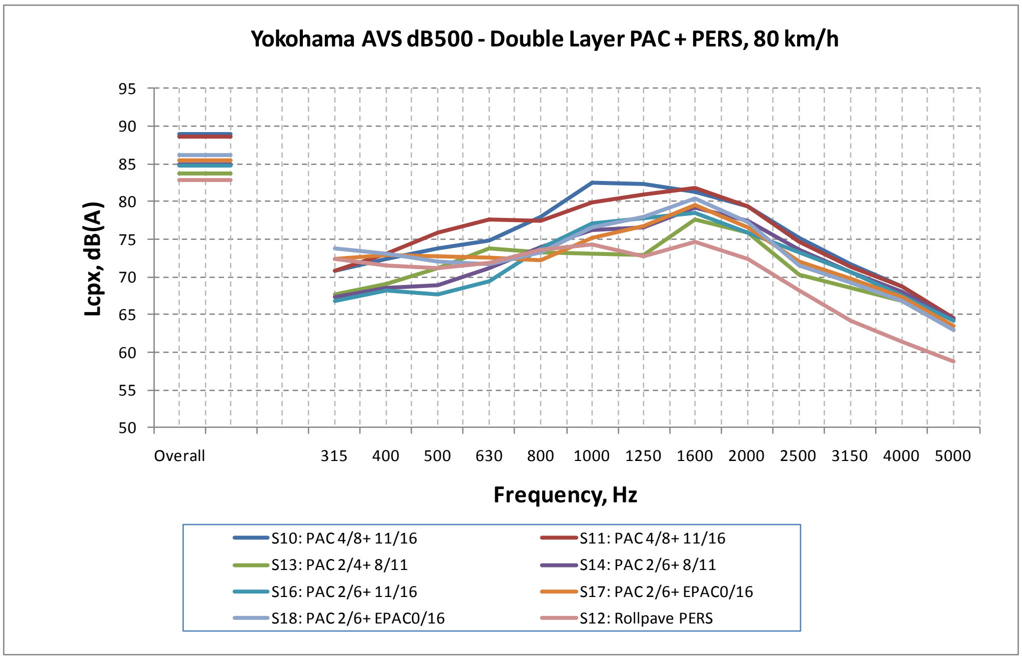

Figure A1_72 *Tyre 12: Yokohama AVS dBV500, Double layer porous + PERS, 80 km/h*

SINTEF

Tyre 13: Pirelli P7

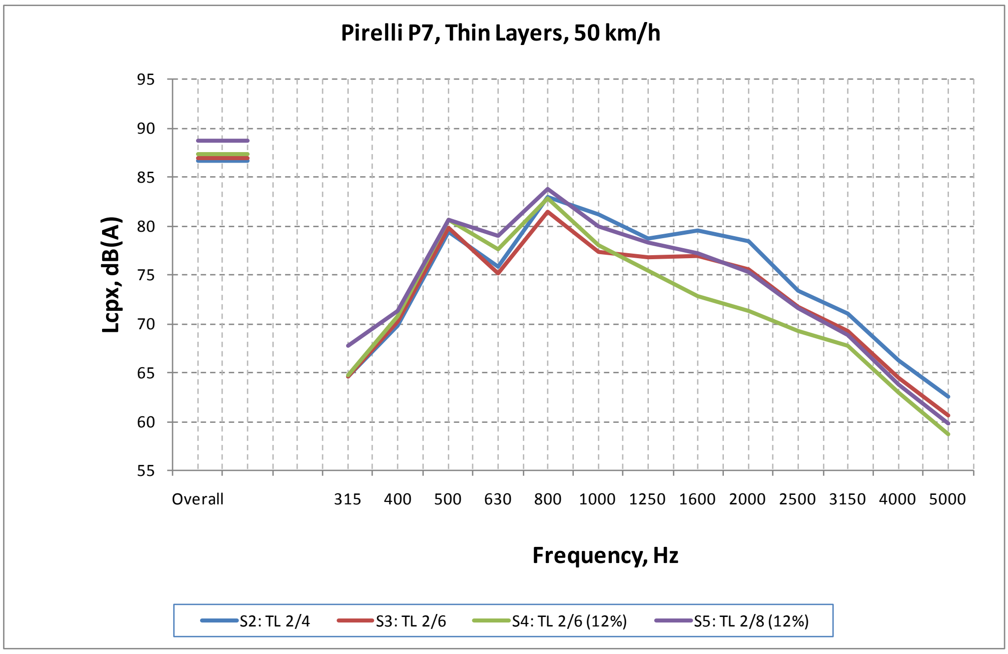

Figure A1_73 *Tyre 13: Pirelli P7, Thin layers, 50 km/h*

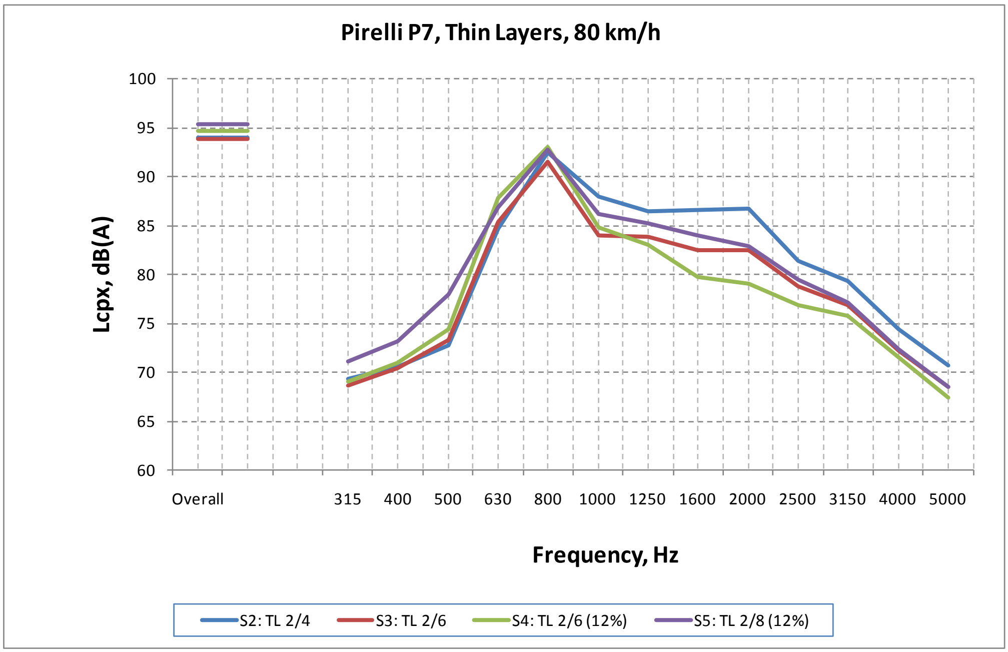

Figure A1_74 *Tyre 13: Pirelli P7, Thin layers, 80 km/h*

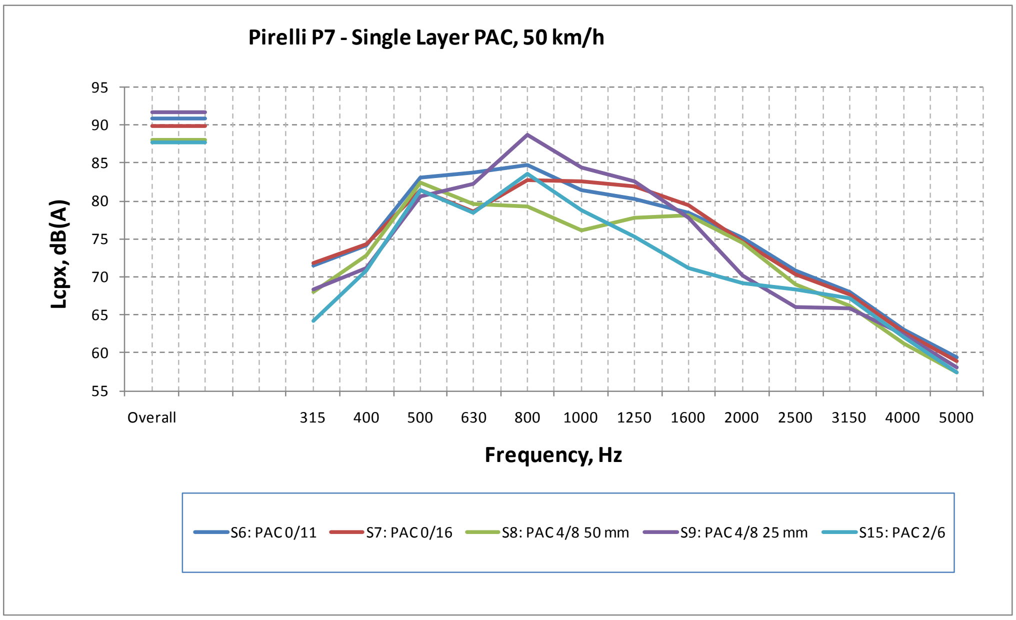

Figure A1_75 *Tyre 13: Pirelli P7, Single layer porous, 50 km/h*

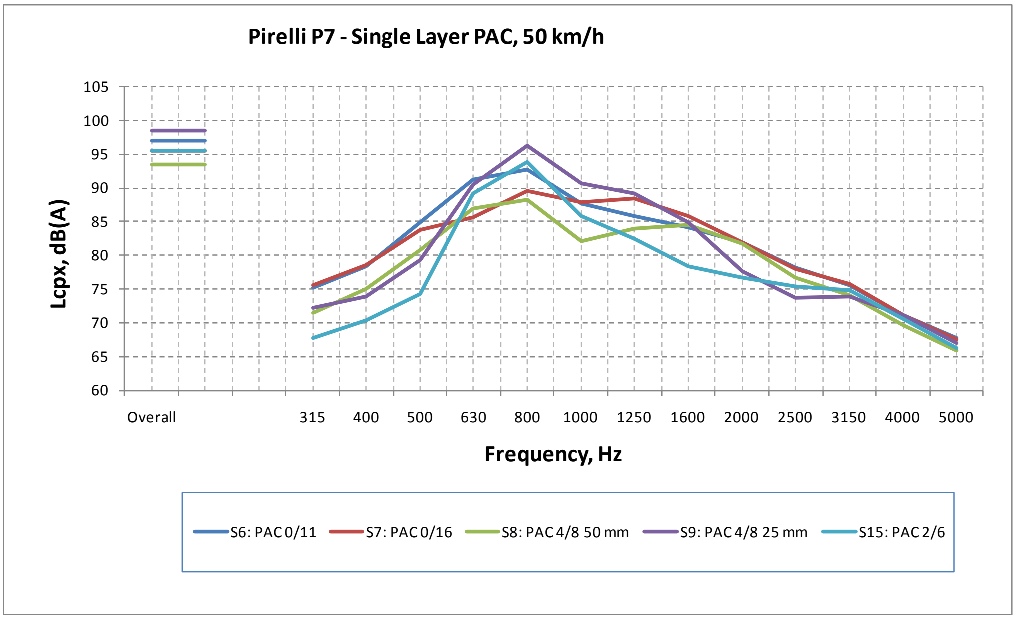

Figure A1_76 *Tyre 13: Pirelli P7, Single layer porous, 80 km/h*

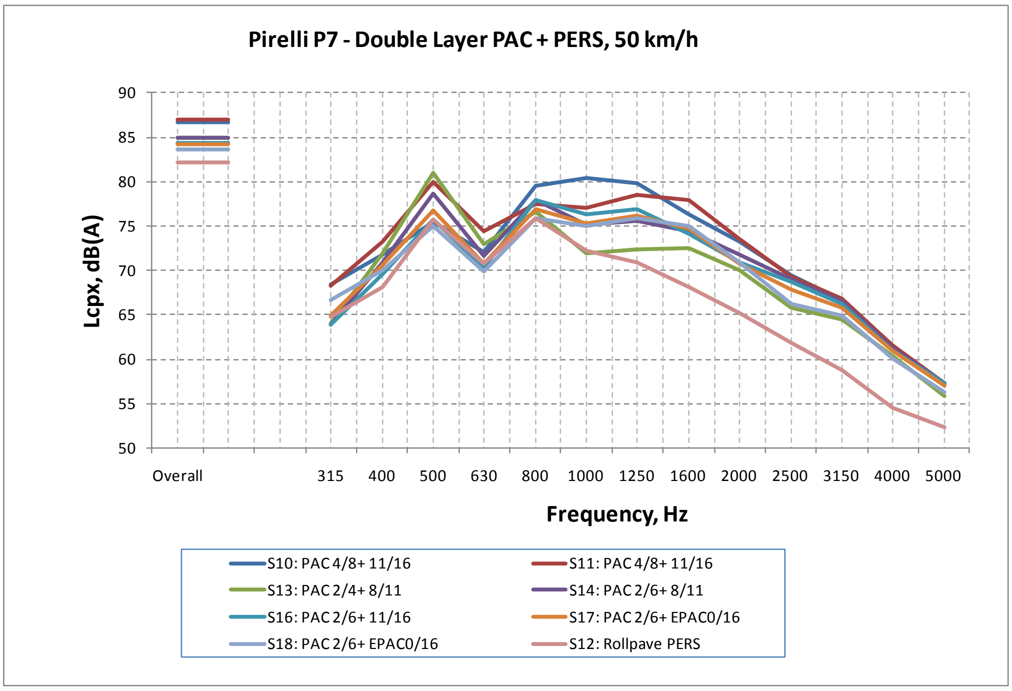

Figure A1_77 *Tyre 13: Pirelli P7, Double layer porous + PERS, 50 km/h*

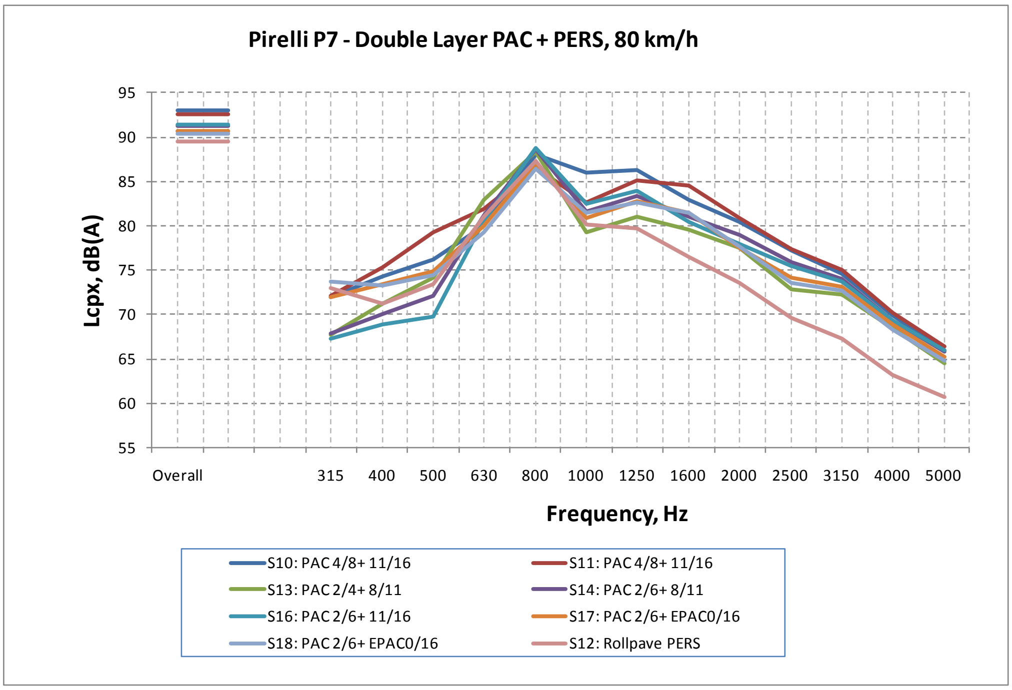

Figure A1_78 *Tyre 13: Pirelli P7, Double layer porous + PERS, 80 km/h*

Tyre 14: Hankook Ventus Prime K105

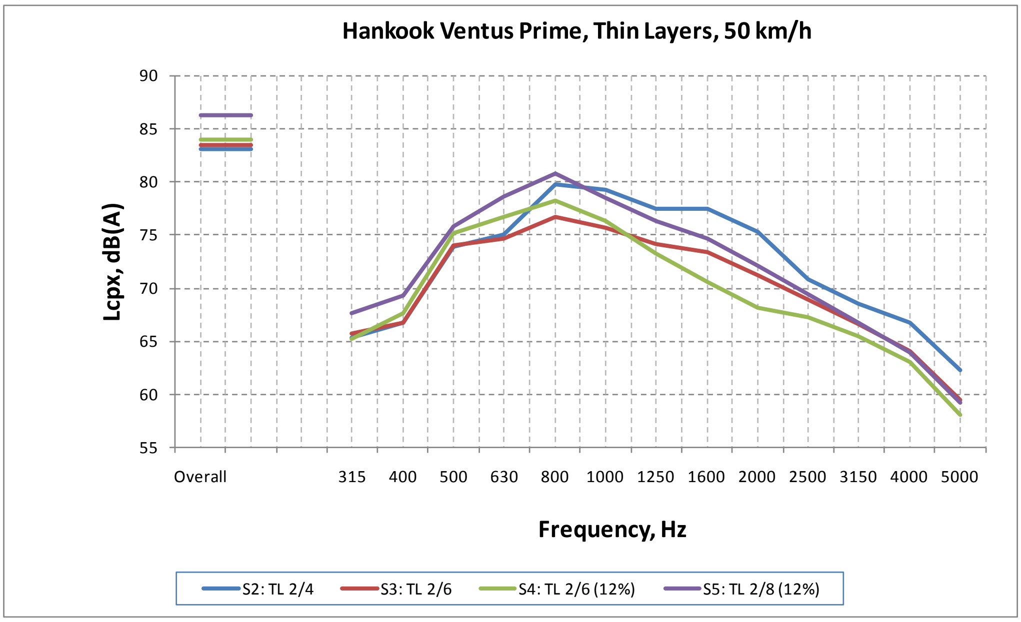

Figure A1_79 *Tyre 14: Hankook Ventus Prime K105, Thin layers, 50 km/h*

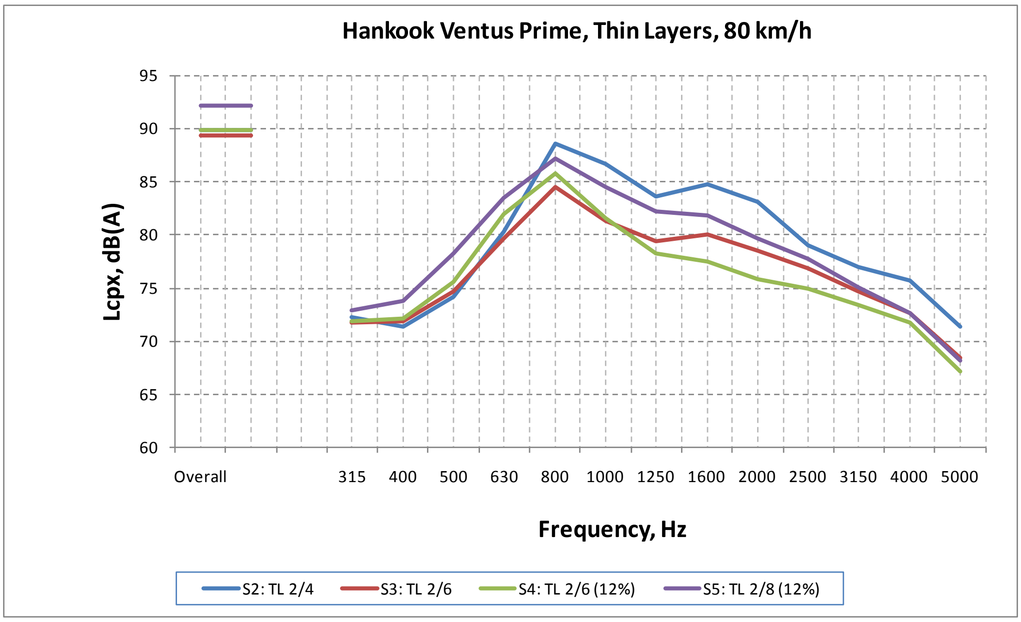

Figure A1_80 *Tyre 14: Hankook Ventus Prime K105, Thin layers, 80 km/h*

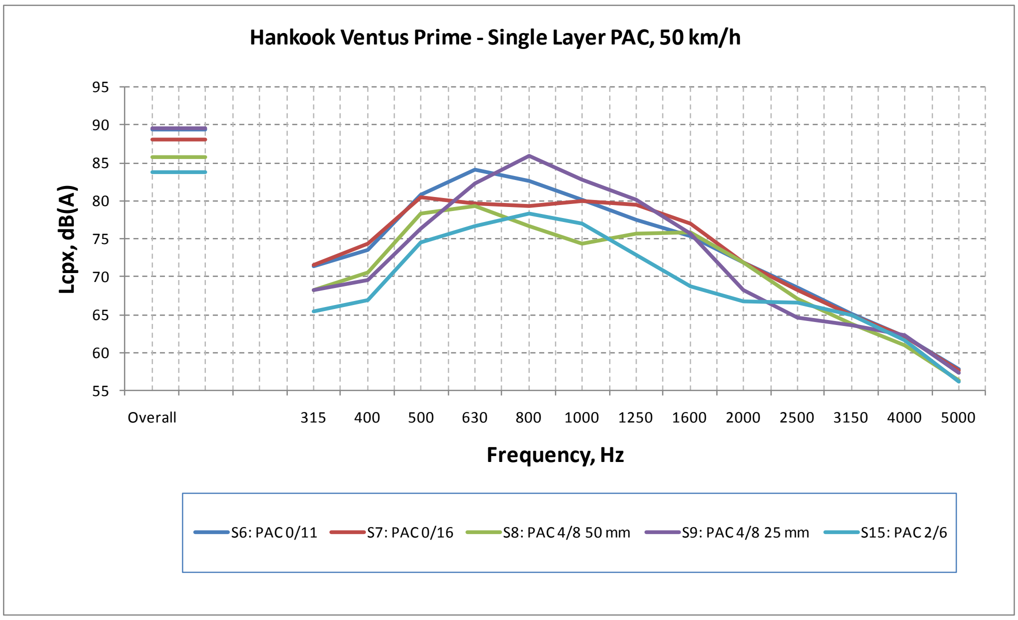

Figure A1_81 *Tyre 14: Hankook Ventus Prime K105, Single layer porous, 50 km/h*

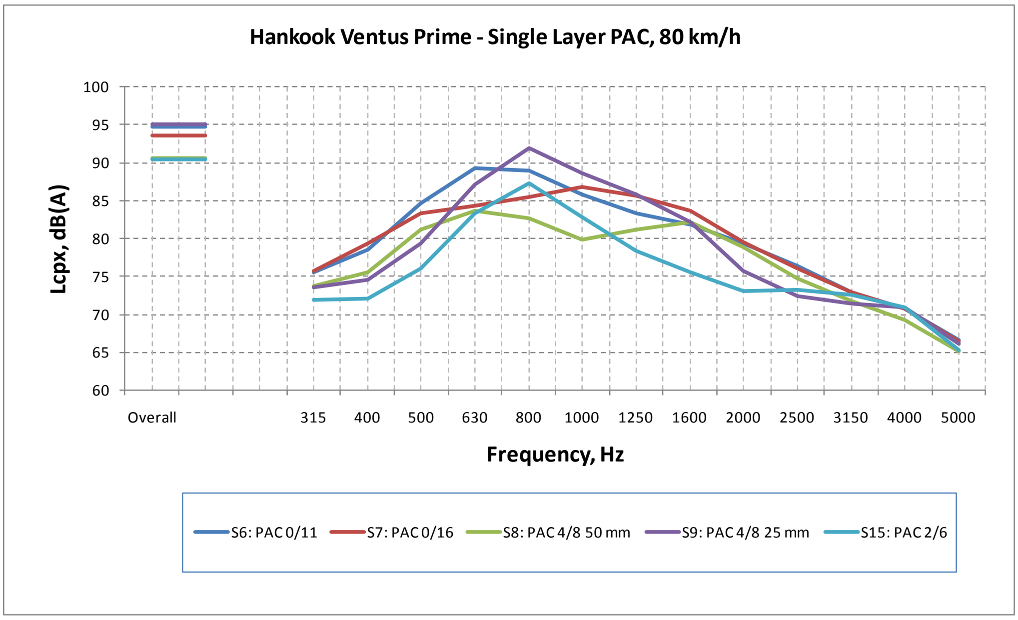

Figure A1_82 *Tyre 14: Hankook Ventus Prime K105, Single layer porous, 80 km/h*

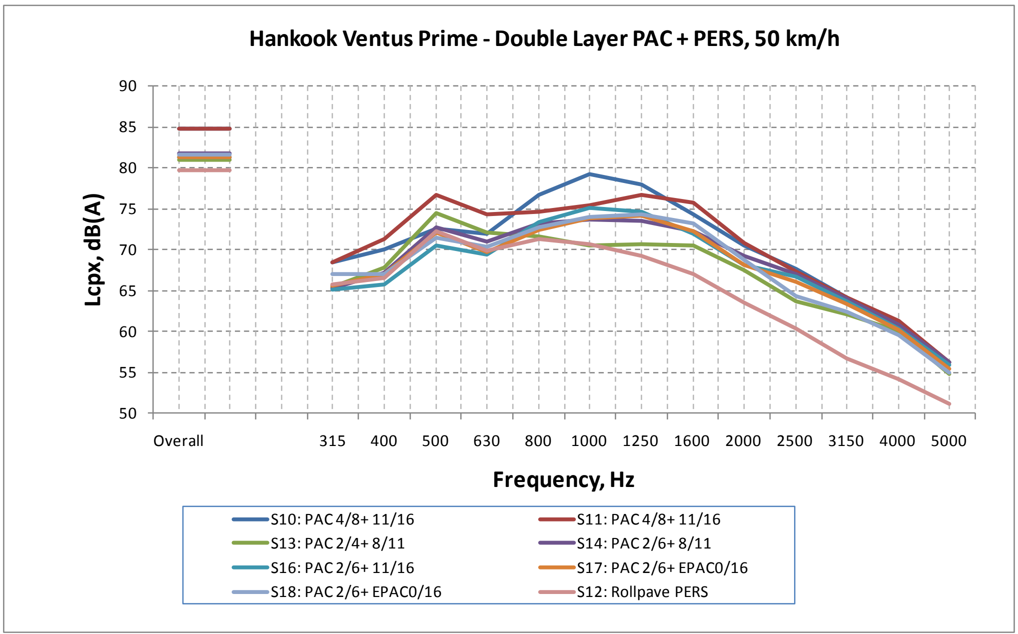

Figure A1_83 *Tyre 14: Hankook Ventus Prime K105, Double layer porous + PERS, 50 km/h*

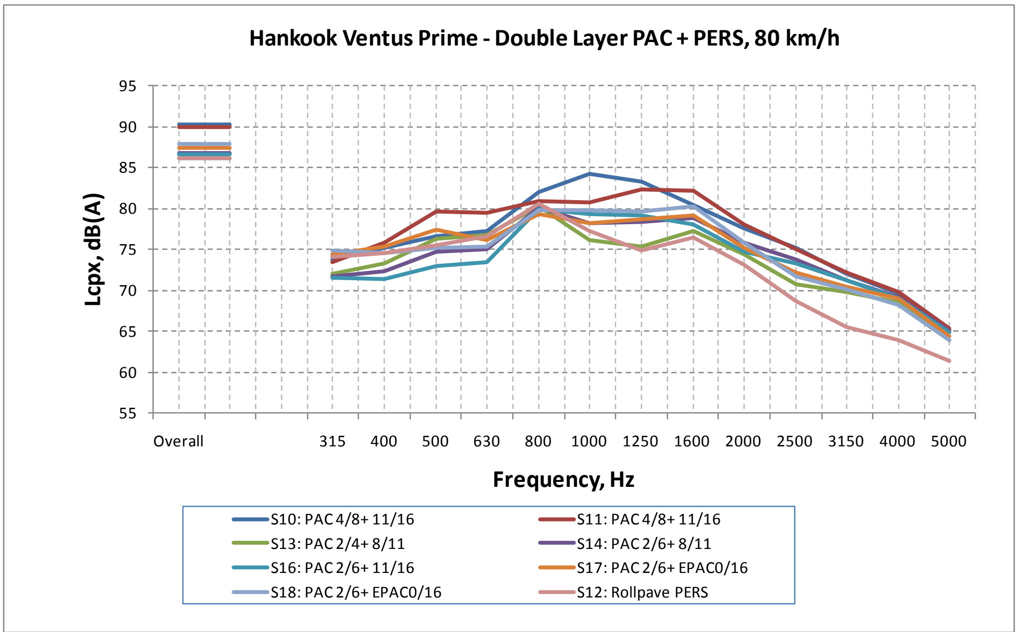

Figure A1_84 *Tyre 14: Hankook Ventus Prime K105, Double layer porous + PERS, 80 km/h*

Tyres 15-18: Michelin Energy Saver

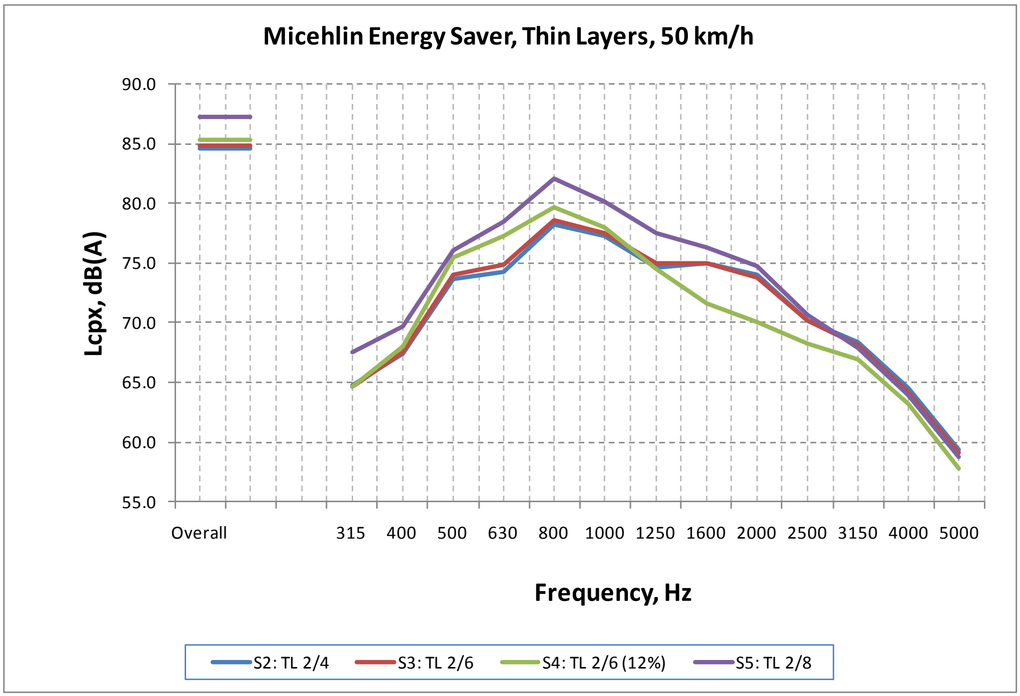

Figure A1_85 *Tyres 15-18: Michelin Energy Saver, Thin layers, 50 km/h*

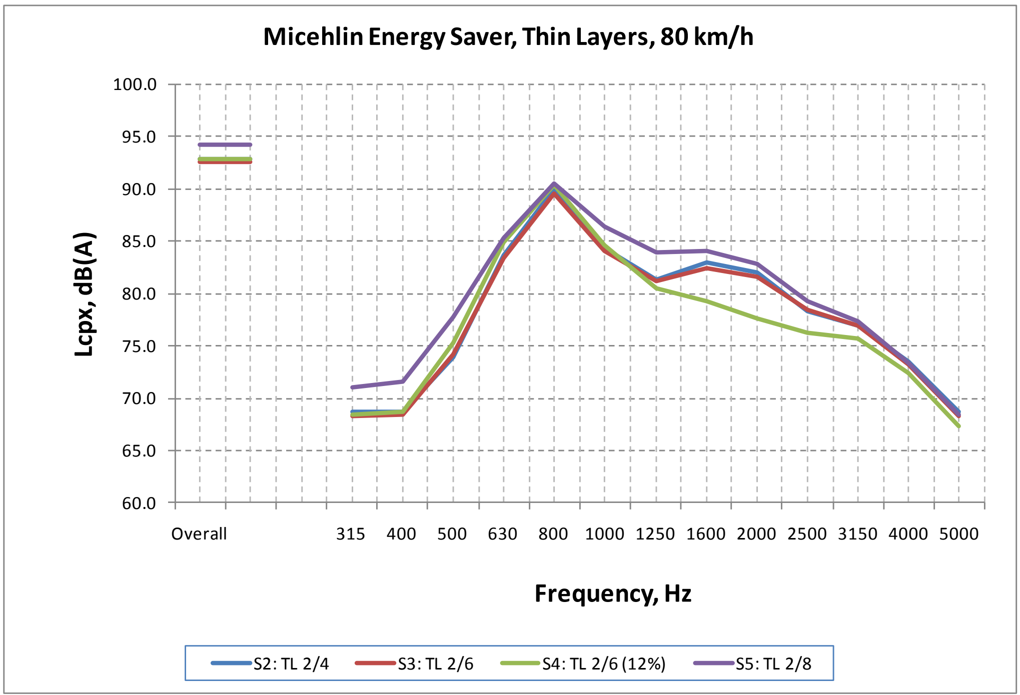

Figure A1_86 *Tyres 15-18: Michelin Energy Saver, Thin layers, 80 km/h*

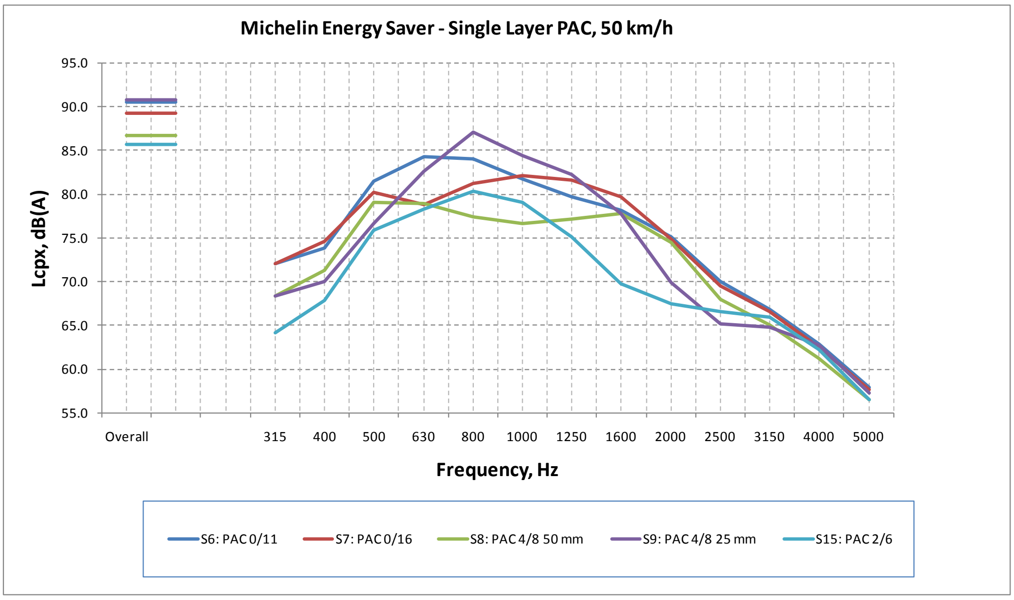

Figure A1_87 *Tyres 15-18: Michelin Energy Saver, Single layer porous, 50 km/h*

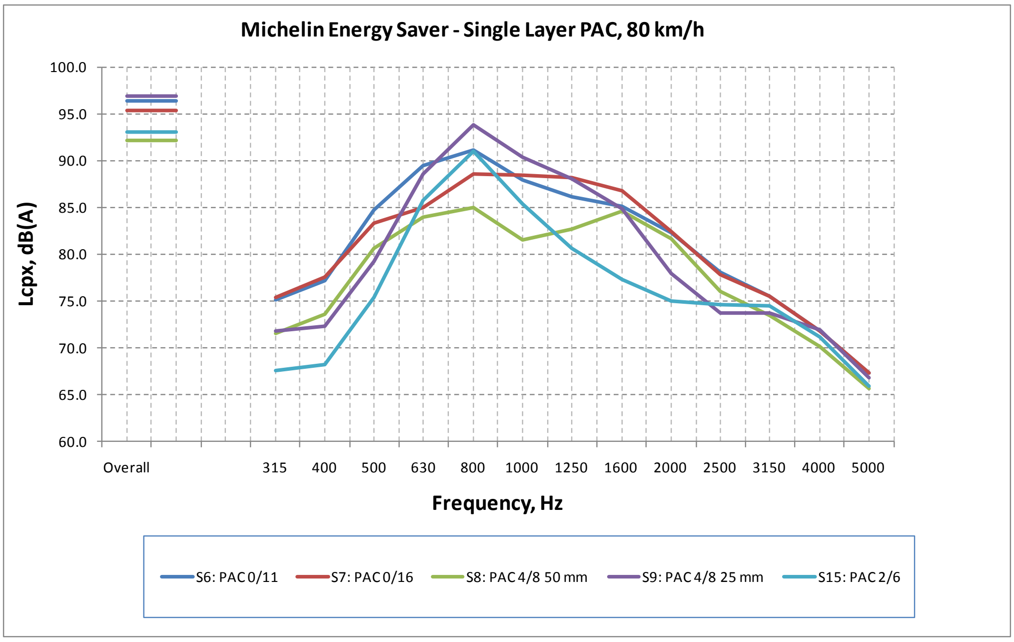

Figure A1_88 *Tyres 15-18: Michelin Energy Saver, Single layer porous, 80 km/h*

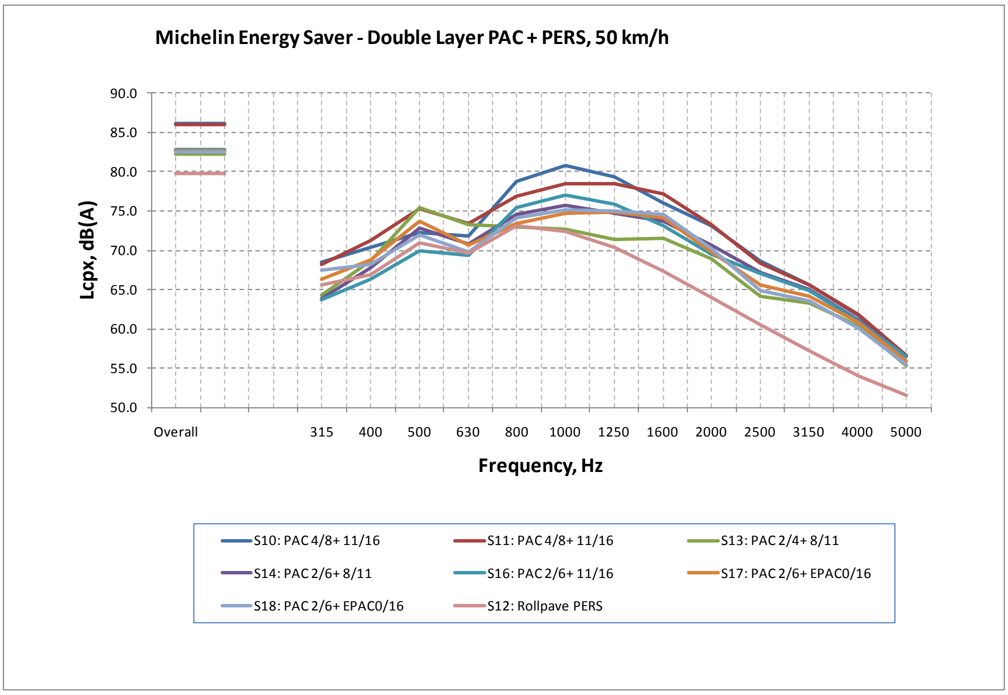

Figure A1_89 *Tyres15-18: Michelin Energy Saver, Double layer porous + PERS, 50 km/h*

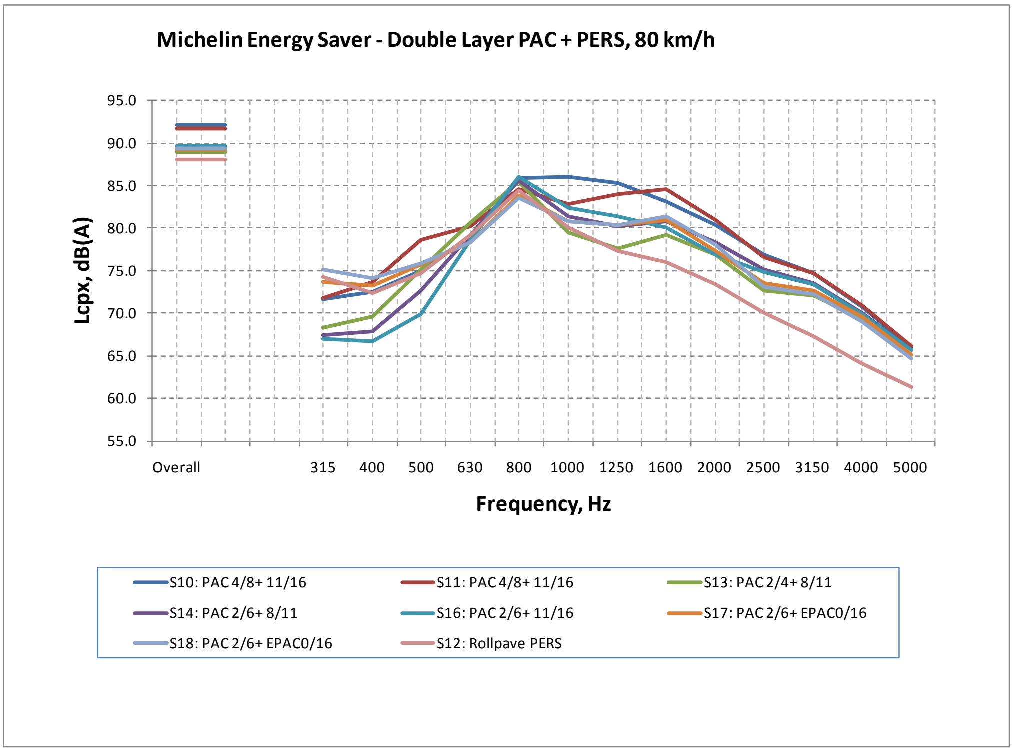

Figure A1_90 *Tyres 15-18: Michelin Energy Saver, Double layer porous + PERS, 80 km/h*

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Tyres 19-20: Uniroyal Tigerpaw SRTT

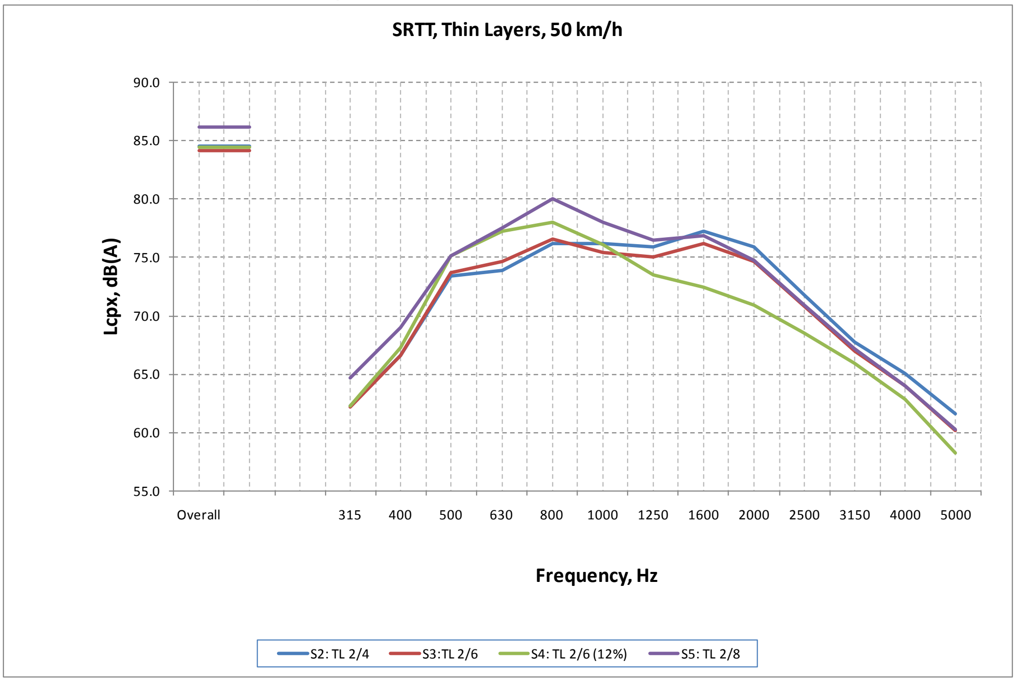

Figure A1_91 *Tyres 19-20: Uniroyal Tigerpaw SRTT, Thin layers, 50 km/h*

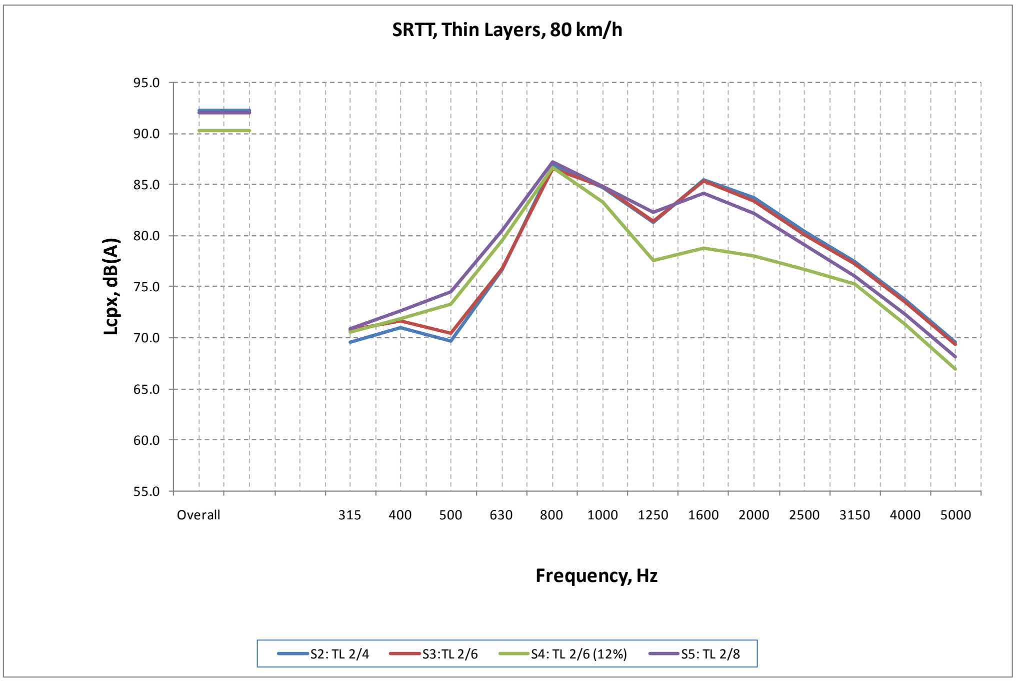

Figure A1_92 *Tyres 19-20: Uniroyal Tigerpaw SRTT, Thin layers, 80 km/h*

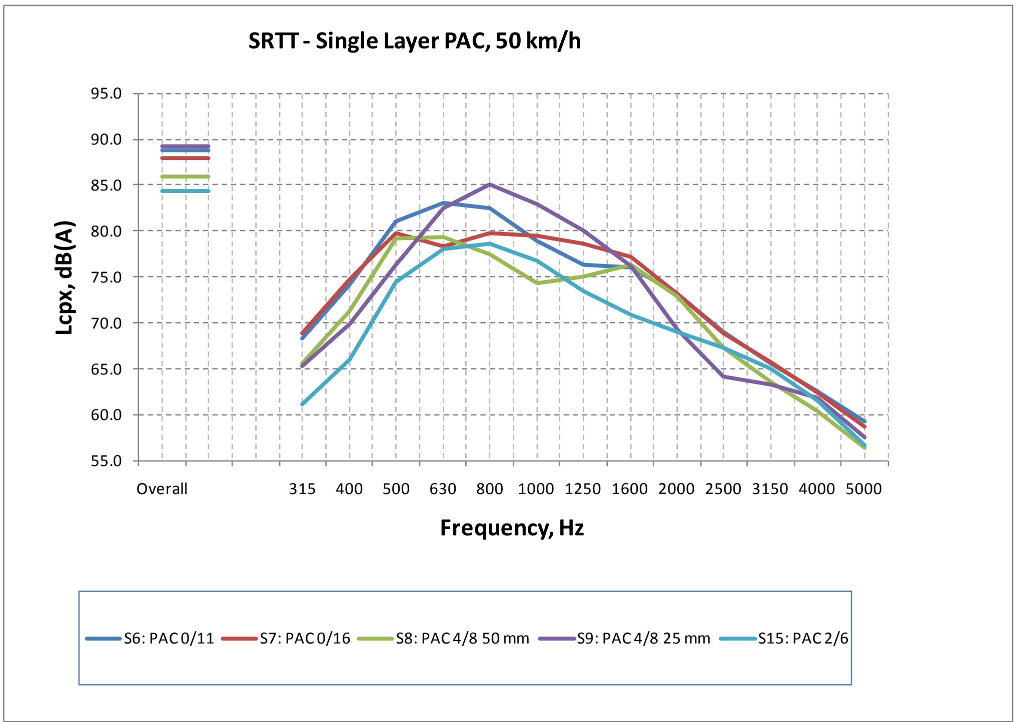

Figure A1_93 *Tyres 19-20: Uniroyal Tigerpaw SRTT, Single layer porous, 50 km/h*

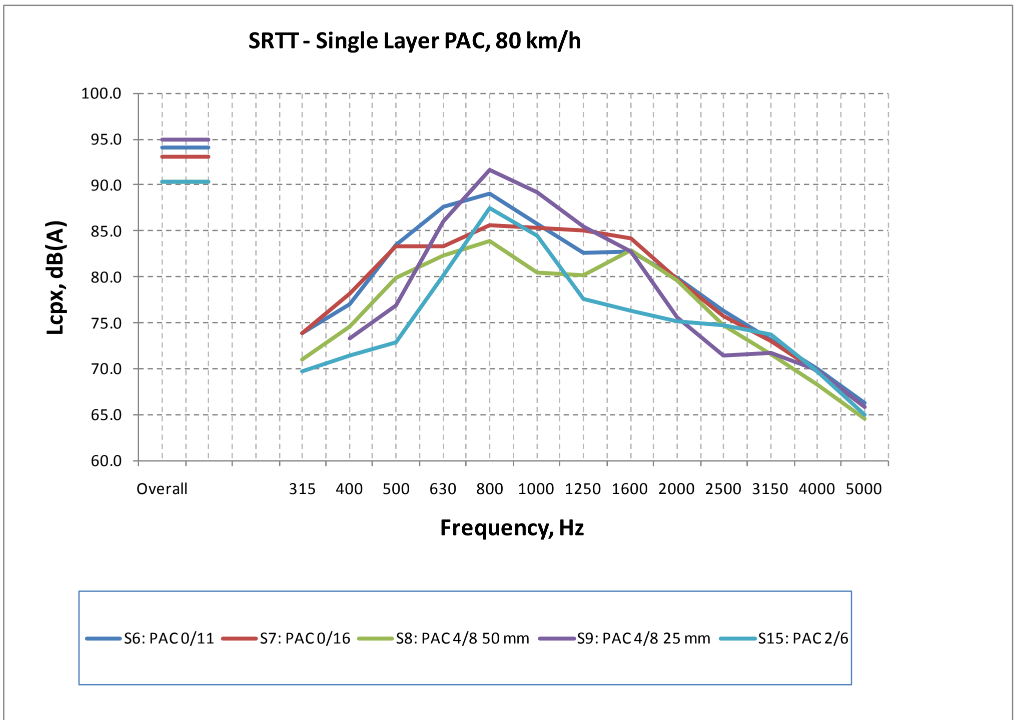

Figure A1_94 *Tyres 19-20: Uniroyal Tigerpaw SRTT, Single layer porous, 80 km/h*

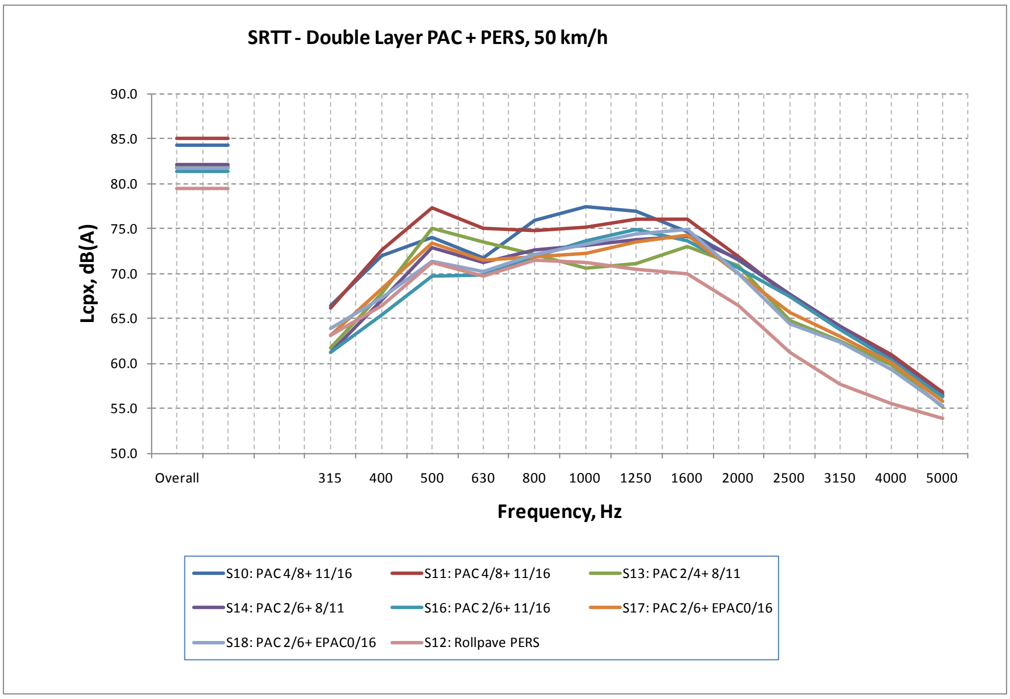

Figure A1_95 *Tyres 19-20: Uniroyal Tigerpaw SRTT, Double layer porous + PERS, 50 km/h*

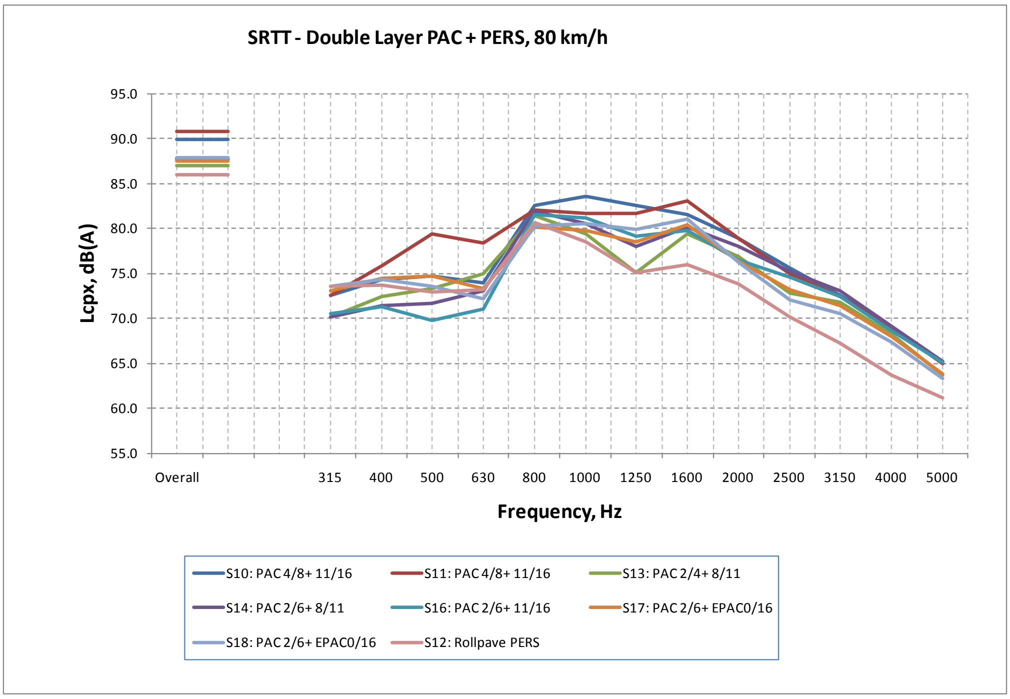

Figure A1_96 *Tyres 19-20: Uniroyal Tigerpaw SRTT, Double layer porous + PERS, 80 km/h*

Tyres 21-22: Avon Supervan AV4

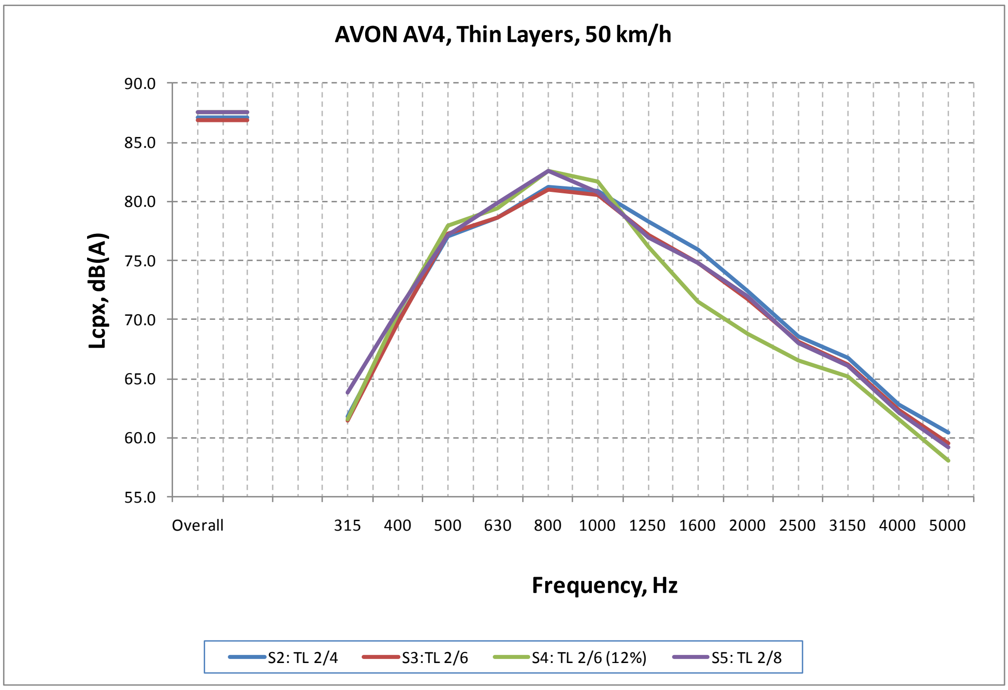

Figure A1_97 *Tyres 21-22: Avon Supervan AV4, Thin layers, 50 km/h*

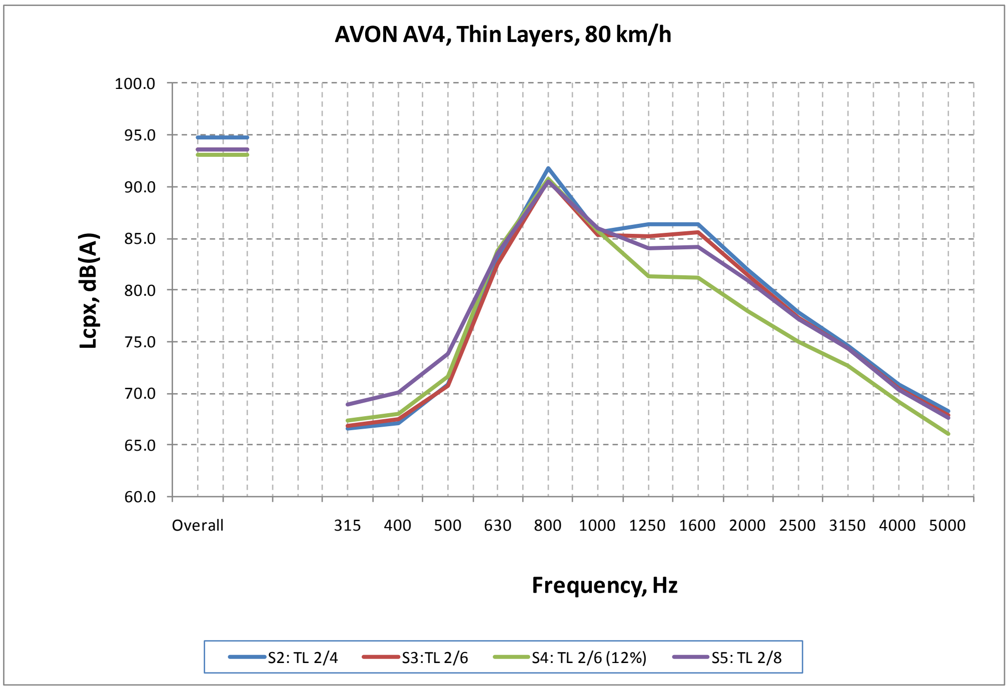

Figure A1_98 *Tyres 21-22: Avon Supervan AV4, Thin layers, 80 km/h*

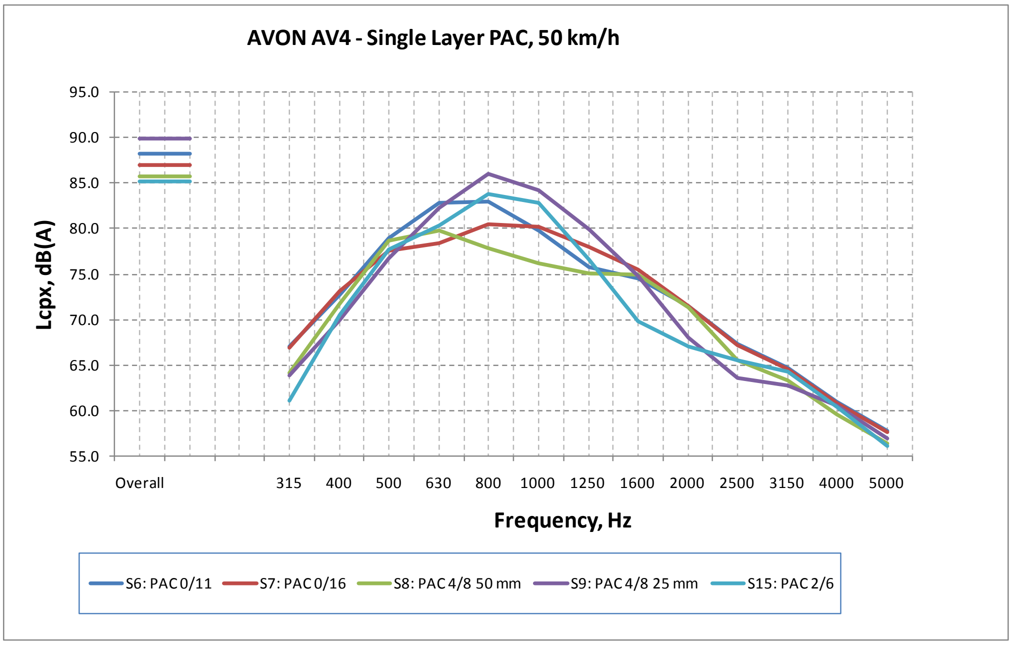

Figure A1_99 *Tyres 21-22: Avon Supervan AV4, Single layer porous, 50 km/h*

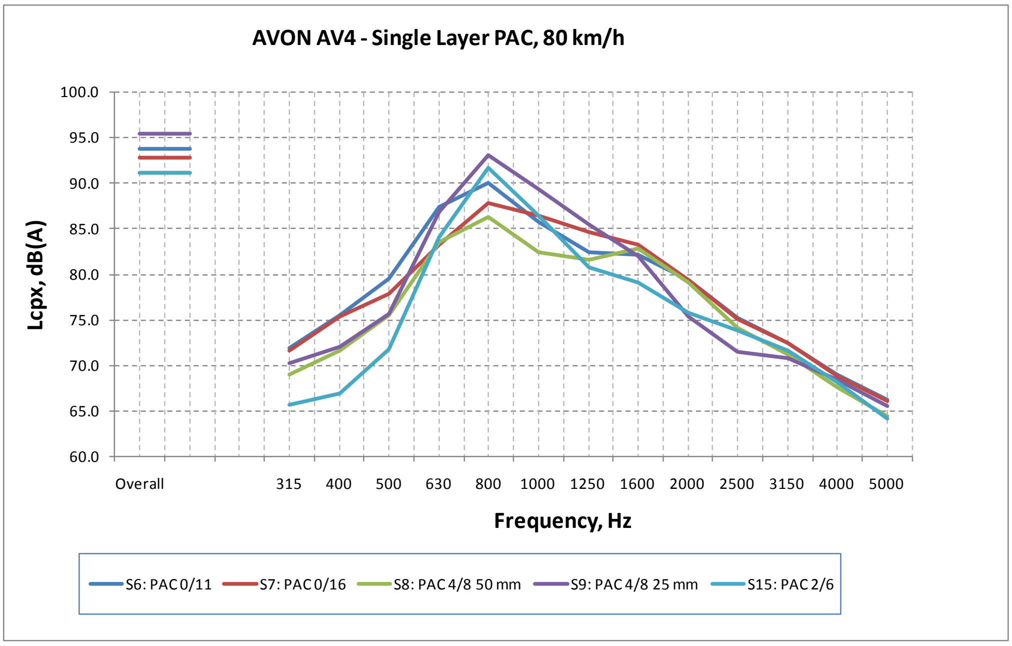

Figure A1_100 *Tyres 21-22: Avon Supervan AV4, Single layer porous, 80 km/h*

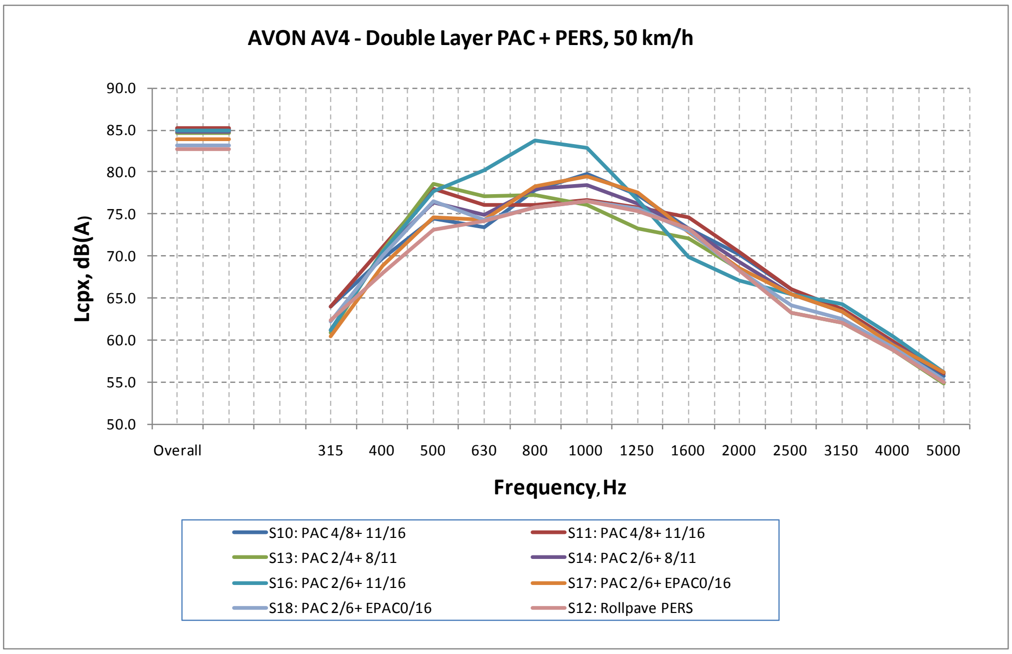

Figure A1_101 *Tyres 21-22: Avon Supervan AV4, Double layer porous+ PERS, 50 km/h*

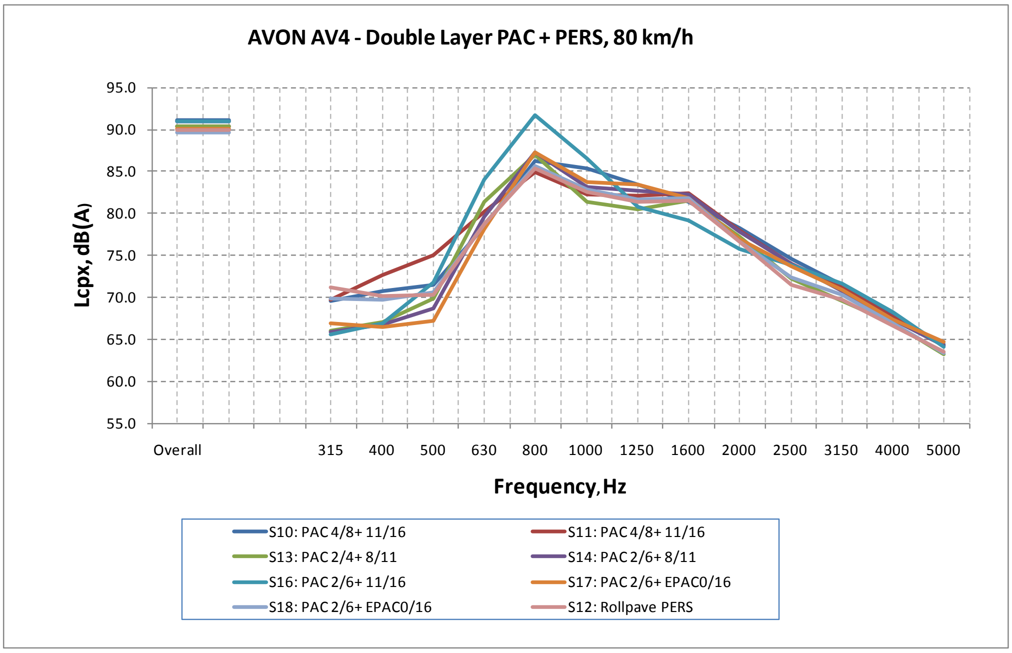

Figure A1_102 *Tyres 21-22: Avon Supervan AV4, Double layer porous+ PERS, 80 km/h*

A.2 Road surfaces tested at Kloosterzande

Surface S1: ISO 10844

Surface S3: Thin layer 2/6, 8 %

Surface S2: Thin layer 2/4,12 %

Surface S4: Thin layer 2/6, 12 %

Surface S5: Thin layer 4/8, 12 %

Surface S8: Single layer porous 4/8

Surface S6: Single layer porous 0/11

Surface S9: Single layer porous 4/8

Surface S7: Single layer porous 0/16

Surface S10: Double layer porous 4/8+11/16

Surface S11: Double layer porous 4/8+11/16

Surface S14: Double layer porous 2/6 + 8/11

Surface S12: Rollpave PERS

Surface S15: Single layer porous 2/6

Surface S13: Double layer porous 2/4 + 8/11

Surface S16: Double layer porous 2/6 + 11/16

Surface S17: Double layer porous 2/6 + EPAC 0/16

Surface S18: Double layer porous 2/6 + EPAC 0/16

Surface S19: SMA 0/6

Surface S20: SMA 0/8

Surface S21: SMA 0/11

Surface S22: SMA 0/16

Surface S23: DAC 0/16

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