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strengthening the effect of quieter tyres on european roads

The influence of tyre inflation pressure and load on noise levels

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CEDR Call 2018: Noise and Nuisance

STEER: Strengthening the Effect of quieter tyres on European Roads

The influence of tyre inflation pressure and load on noise measurements

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Main author/person responsible: Truls Berge

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Executive summary

This report presents results from measurements of the influence of the tyre inflation pressure on the tyre/road noise for 6 C1 tyres. The measurements were conducted at the drum facilities of Gdansk University of Technology (GUT). A replica of an ISO 10844 road surface was used for the experiment, except of for one tyre, where a replica of SMA8 was used. The tyre inflation pressure was varied from 180 to 240 kPa. For some of the tyres, the tyre/road noise was found to increase in the range of 1 dB, with decreasing tyre inflation pressure.

It is not verified that increasing the tyre inflation pressure from the specification given in Reg,117 has a direct improvement of representativity of the labelling procedure. However, it is recommended to use a tyre inflation pressure which normally is used in traffic.

The report also presents some results from a previous research project, LEO (**L**ow **E**mission **O**ptimized tyres and road surfaces for electric and hybrid vehicles), between GUT and SINTEF.

In the LEO project, the results of the influence of increased load on the tyre/road noise was investigated for 11 C1 tyres, using a CPX trailer, where an additional load of up to 100 kg was possible.

Measurements on SMA surfaces in Poland and in Norway showed an increase (around 1 dB) in the tyre/road noise due to increase of the test load in the range of 50-100 kg. However, the requirements given in Reg.117 is rather flexible concerning the allowed load of the tyre, and therefore, no proposals for changes in these test requirements are proposed.

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1 Introduction

One of the measurement uncertainties when tests are performed according to UN ECE Reg.117, is the influence of the test vehicle itself. According to information by the tyre industry (ETRTO, 2019], this variation can have a standard uncertainty contribution (95 % confidence interval) up to ± 1.0 dB (p-to-p), and as such be one of the main parameters to contribute to the overall uncertainty. The variation can be related to the design of the vehicle, especially around the wheelhouse. However, different vehicles can also cause a variation in test load. In Reg.117, the tyre inflation pressure to be used for the test is directly linked to the relationship between the reference load, which is defined by the load index (LI) of the tyre. The test load of each tyre of the test vehicle shall be loaded to 50 to 90 % of the reference load as indicated by the load index (LI) of the tyre. The average load of all tyres mounted on the test vehicle shall be within 75 ± 5 % of the reference test load. The tyre inflation pressure used in the Reg.117 test is also defined by the load index:

$$p_{min} = \left(\frac{Q_t}{Q_r}\right)^{1.25} * 2.5$$

$$p_{max} = 1.1 * p_{min}$$

with:

p_{min} : minimum tyre pressure
Q_t : load of the axis
Q_r : load index
p_{max} : maximum tyre pressure

For typical C1 tyres, the tyre inflation pressure according to this definition can often be in the range of 150 to 200 kPa, depending on the load index. This is somewhat lower than normally recommended for M1 vehicles, which is the range of 220-260 kPa, depending on vehicle load. Part of this investigation was therefore to test the influence of the tyre inflation pressure, as well as the tyre load on the noise performance. When the tyre inflation pressure is low (but above the minimum of 150 kPa for C1 tyres), the contact area (see figure 1.1) can be enlarged compared with the contact area with a higher inflation pressure. This could lead to a higher noise level and this relationship was part of this small investigation.

The influence of **tyre inflation pressure** has been done at the drum facilities of the Gdansk University of Technology (GUT, previously known as TUG), as a subcontractor to the STEER project. The evaluation of the influence of the **tyre load** is based on previous measurements in the LEO project, which was a joint research project between GUT and SINTEF [Berge et al., 2016].

One way to visualise the contact between the tyre and the test surface is to make an image print of the contact area for the different test conditions of tyre inflation pressure and load. Such an image can be used to illustrate the surface pressure distribution. An example of such measurements by BASt in Germany for Continental is shown in figure 1.1 [Saemann, 2009].

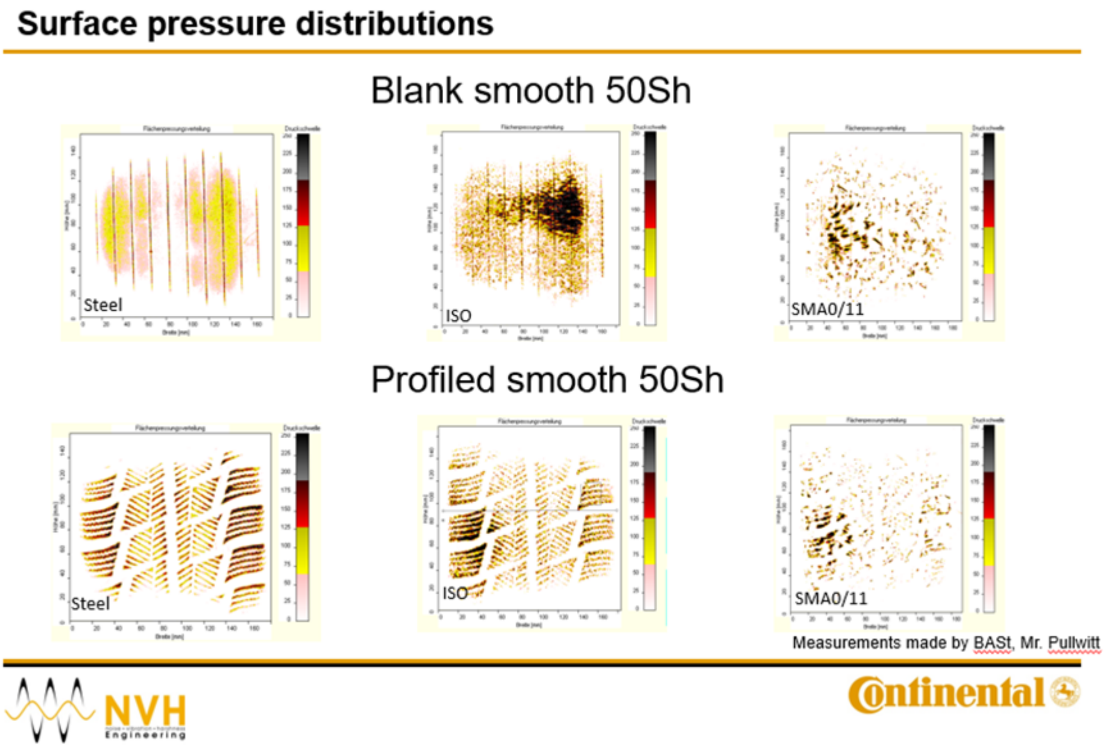

Figure 1.1 Examples of images of contact areas (surface pressure distributions) for two different tyres (smooth and profiled) on 3 different surfaces, including ISO [Saemann, 2009]

For the drum facilities of GUT used to testing (Chapter 2), it was not technically feasible to implement a technology to monitor the contact area between the surface of the drum and the tyre under test.

2 Testing of influence of tyre inflation pressure at GUT

The test at GUT has been performed at their drum facilities with a replica of an ISO surface. This replica is based on a mould from the recent built ISO track at Hagelberg in Sweden. VTI has measured the basic road surface texture values, such as the MPD-value and skewness, while GUT has measured the noise performance [STEER Deliverable 4.3.1]. This ISO track has on average an MPD value of 0.40, which is above the accepted minimum limit for ISO tracks, 0.30, as defined in ISO/DIS 10844:2020.

The drum has a diameter of 2.0 m and the set-up is shown in figure 2.1. It should be noted that below 200 Hz, the room cannot be considered as an anechoic room. This means that any differences in the frequency spectra blow 200 Hz may be caused by the room influence and not related to influence of the tyre inflation pressure. Due to this fact, only 1/3rd octave band levels from 200 Hz and above, are shown in figures and tables.

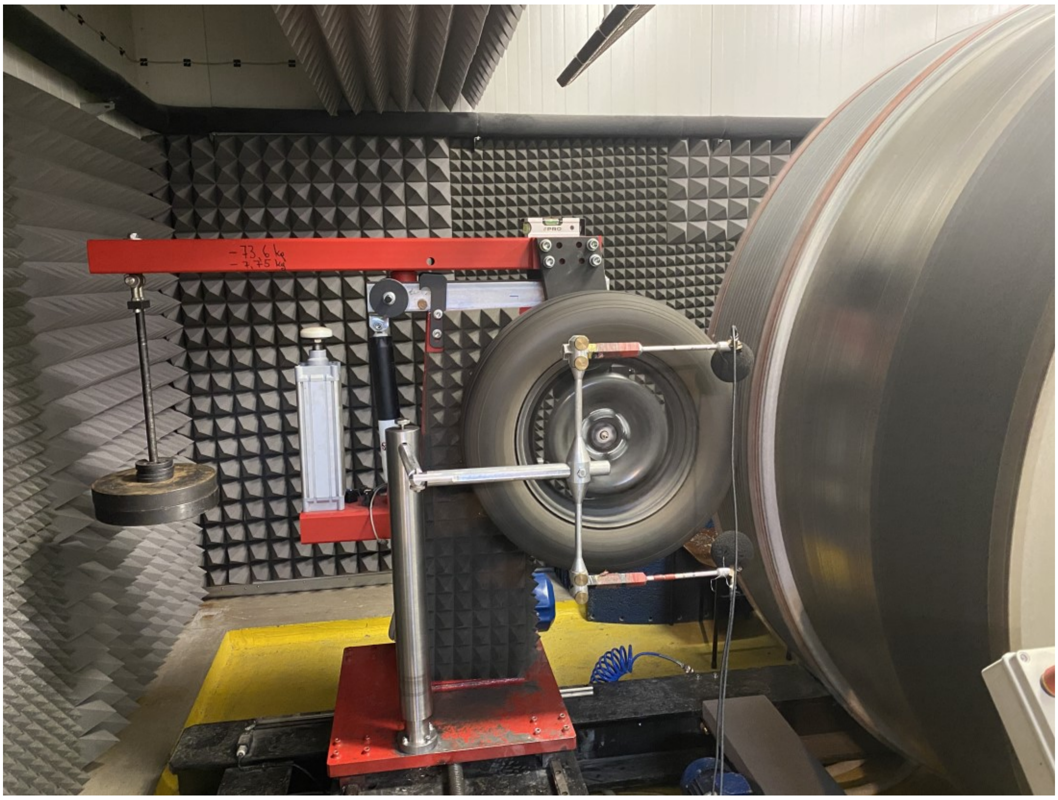

Figure 2.1: Drum testing facilities of GUT

2.1. Test tyres

The following C1 test tyres have been selected for the drum measurements:

Table 2.1 Test tyres

GUT Code	Type	Name	Size	DOT	Noise label
T1238	Summer	Conti EcoContact 6	175/60 R19	2320	70
T1225	Summer	Goodyear EffG Perform.2	205/55 R16	2920	69
T1240	Summer	Bridgestone Ecopia EP500	175/60 R19	0519	69
T1226	All-seasons	Michelin CrossClimate+	205/55 R16	1220	69
T1241	Winter	Nokian Hakkapeliitta R3	225/55 R16	3220	72
T1231	Summer	Michelin Primacy 4	205/55 R16	2420	68

The tyres were chosen, primarily because they already were part of the batch of tyres already available at GUT (and then no added expenses for the STEER project). The winter tyre T1241 was added as this tyre could be provided by Nokian, a STEER project partner. Beside this, no special criteria were set for the selection.

Due to a switch in the test program at GUT, the ISO replica was changed to an SMA8 replica before the completing of the STEER test program. Because of this, T1231 Michelin Primacy was measured on the SMA replica instead. However, the SMA8 surface is considered as a quite similar to the ISO surface, as both have a maximum chipping size of 8 mm. The results for the T1241 are therefore included in the analysis.

2.2. Test conditions

To change both the load and tyre inflation pressure in the drum is a time-consuming procedure. Therefore, it was decided to test with constant load for each tyre, as the main target for this laboratory test was to investigate the influence of the tyre inflation pressure- A variation of load on the drum should ideally be combined with images of the contact area, as shown in figure 1.1. However, it was not feasible to implement such prints at the facilities of GUT. The influence of load is described in chapter 4.

The tests were performed with 75 % of the load, as specified by the load index, while the tyre pressure was changed in steps. Table 2.2 show the test load of the tyres and table 2.3, the test speed and the tyre inflation pressure. Only one run per test condition was performed. Thus, it is not possible to say something about the repeatability. However, the measurements are done under stable and controlled conditions concerning temperature and environmental conditions. Thus, the results shown in chapter 3 should be trustworthy.

Table 2.2 Test load

GUT Code	Type	Name	Load and speed index	Test load, kg
T1238	Summer	Conti EcoContact 6	86Q	397.5
T1225	Summer	Goodyear EffG Perform.2	91V	461.3
T1240	Summer	Bridgestone Ecopia EP500	86Q	397.5
T1226	All-seasons	Michelin CrossClimate+	96H	532.5
T1241	Winter	Nokian Hakkapeliitta R3	99R	581.3
T1231	Summer	Michelin Primacy 4	91H	461.3

Table 2.3 Test speed and tyre inflation pressure

Test speed, km/h	Tyre inflation pressure, kPa
50	180
80	180
80	190
80	210
80	240

3 Tyre inflation pressure results

The measured sound levels at the drum facilities were measured at the two "CPX" positions, front and rear microphone. The average level for the 5 test conditions is presented in figures. Note that the tyre Michelin Primacy 4 was tested on a replica of SMA8. In Annex 1, the individual results, including frequency spectra for both microphone positions are shown for the 5 test conditions, as well as the average levels and frequency spectra of the two microphone positions.

Figures 3.1 and 3.2 show the overall noise levels measured at 80 km/h with increased inflation pressure for the 6 tyres tested. In figure 3.3, the changes in levels are shown for each of the tyres. Note that positive values means that the sound level has been ***decreasing*** with higher pressure than 180 kPa, while negative values show an ***increase*** in the sound level.

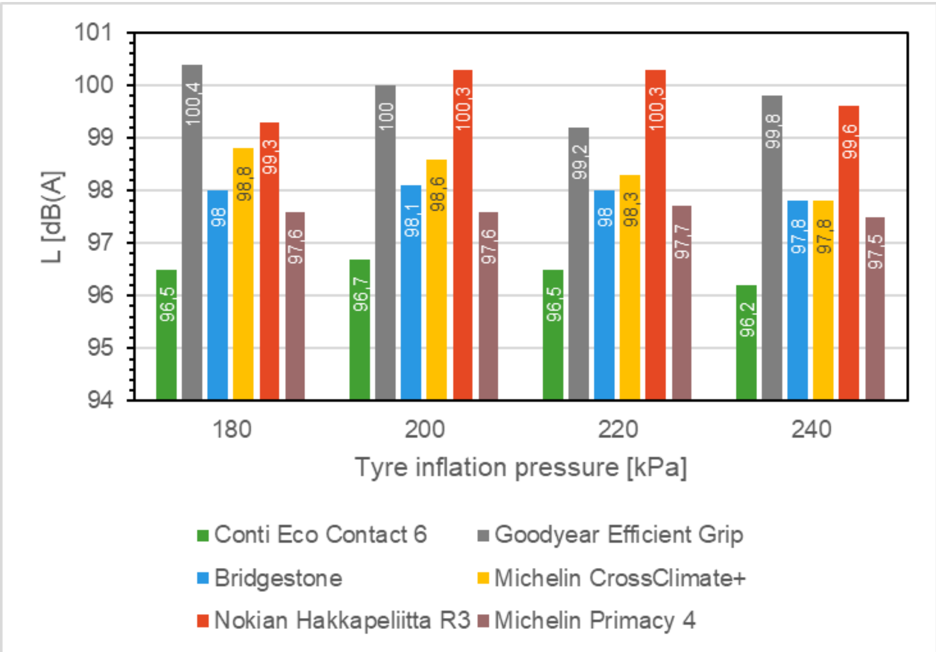

Figure 3.1 Changes in noise levels due to increase in tyre inflation pressure for 6 tyres. Speed = 80 km/h,

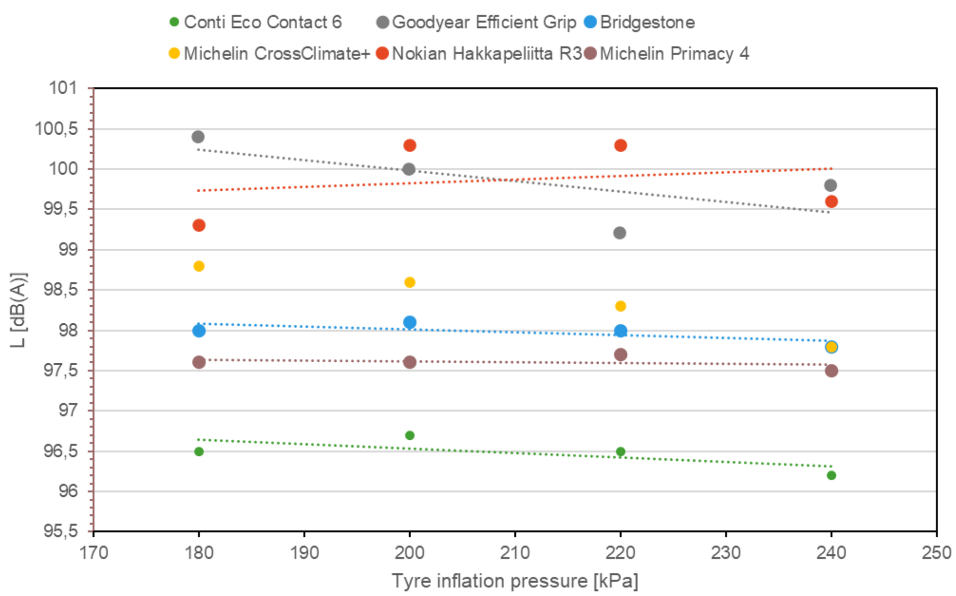

Figure 3.2 Tyre inflation pressure influence on measured noise levels for 6 C1 tyres.

Table 3.1 gives the slope for the changes in dB/10kPa for the 6 tyres, based on figure 3.2.

Table 3.1 Slope of dB/kPa for the data in figure 3.8.

Tyre	Slope, dB/10kPa
Conti EcoContact 6	-0.05
Goodyear EffG Perform.2	-0.13
Bridgestone Ecopia EP500	-0.04
Michelin CrossClimate+	-0.17
Nokian Hakkapeliitta R3	0.04
Michelin Primacy 4	-0.01
Max	-0,17
Min	0.04
Mean	-0.06

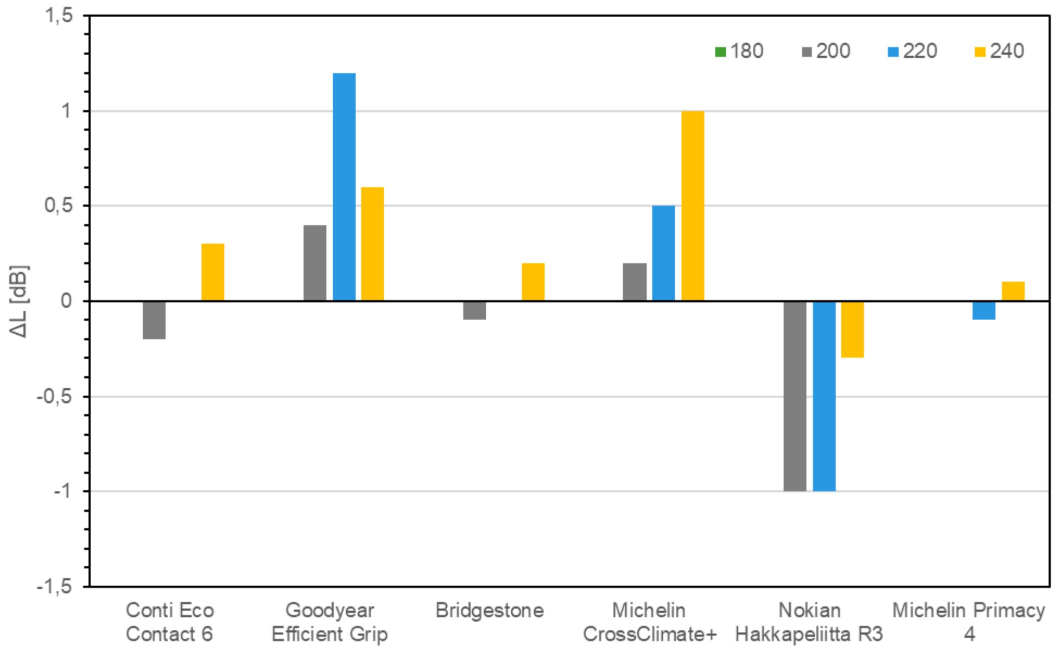

Figure 3.3 Changes in noise levels due to increase in tyre inflation pressure for 6 C1 tyres. Positive values means decreasing sound level, while negative values show increasing values from the reference of 180 kPa.

In table 3.2, the maximum measured ***increase*** in sound levels due to reduced tyre inflation pressure is shown.

Table 3.2 Maximum increase in A-weighted sound level due to reduced tyre inflation pressure. Speed = 80 km/h.

Tyre	**Increase in dB(A)**
Conti EcoContact 6	0.3
Goodyear EffG Perform.2	1.2
Bridgestone Ecopia EP500	0.3
Michelin CrossClimate+	1.0
Nokian Hakkapeliitta R3	1.0
Michelin Primacy 4	0.2

Not all tyres had the highest increase between 180 and 240 kPa (some between 190 and 240 and others between 180 and 210). We found an influence of the tyre inflation pressure on the sound level in the range 1-1.2 dB for 3 of the tyres. For the other 3 tyres, the change is in the order of 0.2-0.3 dB, which is not regarded as significant.

It has not been investigated if there are design elements of the tyres influenced by the tyre inflation pressure. However, two of the tyres that show this relationship are all-seasons/winter tyres.

These results show the following:

- For the overall A-weighed sound level, 3 of the tyres showed an influence of the tyre inflation pressure in the range of 180 to 240 kPa. The sound level increased in the range of 1-1.2 dB, when the inflation pressure was reduced down to 180-190 kPa.
- For the other tyres, the influence of changing the tyre inflation pressure gave no obvious changes in the measured noise levels.
- The ranking of the tyre based on the noise label value do not change within the tyre inflation pressure variation tested in this project.
- The Michelin Primacy 4 was tested on a different road surface (SMA8) than the other 5 tyres, but there is no influence of the inflation pressure on the noise level on this surface compared to the ISO surface.

4 Load influence - results from the LEO project

4.1. Background

The main objectives of the LEO project (**L**ow **E**mission **O**ptimized tyres and road surfaces for electric and hybrid vehicles) were to investigate the potential tyre/road noise and rolling resistance reduction of tyres optimized for electric and hybrid vehicles. As part of this investigation, a small measurement campaign was conducted to see if changes in the load of the tyres would make a change in the tyre/road noise levels.

4.2. Measurement lay-out

All measurements were made with a CPX trailer (closed trailer built by M+P) and not with a vehicle, as specified in Reg.117. However, even if the test conditions are different, it should be an indication on the influence of the load variations on the noise levels, as these are measured close to the tyre (CPX microphone positions at 0.5 m). On the CPX trailer, it was possible to add weight on the axles, to increase the load of the tyres. The standard load of the CPX trailer was 339 kg. The maximum added weight on the trailer was 100 kg. Measurements were performed on trafficked roads in Norway and in Poland. The test speed was 50 km/h. Table 4.1 show tyres and test conditions. For example, tyre 1 was tested with the CPX load of 339 kg. Then, with 53 kg added, the total extra load is 392 kg. As stated in Chapter 1, the test load requirement for each tyre is that the load shall be within 50 to 90 % of the reference load.

Table 4.1 Tyres and loading with two load conditions; CPX test load and test load with additional weight

Tyre no	Dimensions	Load index	Reference load, kg	CPX test load, kg	% of ref. load	Extra load, kg	% of ref. load	Tyre infl. Pressure, kPa
1	195/60 R15	88	560	339	61	392	70	250
2	195/60 R15	88	560	339	61	411	73	250
3	195/60 R15	88	560	339	61	392	70	250
4	195/60 R15	88	560	339	61	392	70	250
5	195/65 R15	91	615	339	55	411	67	240
6	215/55 R17	94	670	339	51	429	64	220
7	195/65 R15	91	615	339	55	429	70	250
8	195/65 R16	91	615	339	55	429	70	250
9	195/55 R16	91	615	339	55	429	70	250
10	195/55 R16	95	690	339	49	429	62	250
11	175/55 R15	77	412	339	82	339	82	250

Tyres 9 and 11 are (OE) tyres fitted for electric vehicles. Tyre 11 was measured with the same load at both conditions.

4.3. Measurement results

In Poland, the measurements were performed on two different SMA8 surfaces. In table 4.2 the results from the measurements on one of the SMA8 road surface in Poland are shown. The results from the other SMA8 surface are almost identical, with an average increase in sound levels of 0.39 dB (standard deviation of 0.22). In the table, the labelled values for the tyres are also included.

Table 4.2 Change in sound levels on Polish SM8 surface with additional load. Speed = 50 km/h

Tyre no	EU label value dB(A)	SMA8 CPX dB(A)	Added load dB(A)	Change dB(A)
1	73	90.5	91.1	0.51
2	71	88.8	89.4	0.66
3	68	91.8	92.2	0.40
4	74	90.6	91.0	0.40
5	69	89.3	90.0	0.71
6	71	90.1	90.4	0.30
7	68	91.4	92.0	0.55
8	70	90.4	90.7	0.35
9	70	90.0	90.0	-0.06
10	70	90.4	90.8	0.35
11	69	88.1	88.2	0.1
			Average	**0.39**
			Stand. dev.	**0.22**

Even if the increase is moderate (less than 1.0 dB), the trend is that an increase in load in the range of 10-15% gives an increase in noise levels around 0.4-0.5 dB on this SMA8 road surface. It should be noted that tyres 3 and 7 have the lowest EU label values of 68 dB. However, on the SMA8 surface, these tyres have been measured with the highest noise levels. There is no positive correlation between the ranking according to the EU label and measured levels, even if load is added.

Table 4.3 and figure 4.1 show the results on 7 SMA surfaces in Norway, with maximum stone sizes from 8 to 16. Two of the surfaces, NOR6-SMA8 and NOR7-SMA11 were new and not exposed to winter tyres. Tyres 1,2,3 and 5 are the tyres that gives the highest increase (more than 0.5 dB) on most of the SMA surfaces in Norway.

It should be noted that for these tests in Norway, the tyre inflation pressure during the CPX load conditions were 200 kPa, while during the added load, the tyre inflation pressure was increased to 250 kPa. This means that the test with added load is a combination of increased load and tyre inflation pressure. Based on the knowledge from the drum measurements, the design of this experiment with added load should have been made with the same tyre inflation pressure. Therefore, the results in table 4.3, must be understood as a **combination** of load and tyre inflation pressure influence.

The measured values have also been temperature corrected to a reference air temperature, using individual correction factors, established by GUT by measurements of noise/temperature relationship (see Berge, 2016).

Table 4.3 Increased sound levels on Norwegian SMA surfaces with additional load and tyre inflation pressiure. Speed = 50 km/h

Tyre no	NOR1 SMA11 [dB(A)]	NOR2 SMA16 [dB(A)]	NOR3 SMA11 [dB(A)]	NOR4 SMA16 [dB(A)]	NOR5 SMA16 [dB(A)]	NOR6 SMA8 [dB(A)]	NOR7 SMA11 [dB(A)]
1	1.27	1.01	1.05	0.35	0.23	0.90	0.27
2	1.18	0.97	0.81	0.97	1.06	0.60	1.05
3	0.91	0.92	0.94	1.23	0.91	0.34	0.65
4	0.27	0.27	0.34	0.35	0.23	0.90	0.27
5	1.81	0.84	1.03	1.14	1.16	0.75	1.17
6	0.45	0.38	0.32	0.33	0.33	0.51	0.30
7	0.53	0.17	0.30	0.52	0.33	0.01	0.32
8	0.23	0.61	0.33	0.32	0.31	0.53	0.39
9	0.14	0.07	0.39	0.27	0.31	0.64	0.23
10	0.14	0.15	0.31	0.27	0.34	0.50	0.44
11	0.01	-0.06	-0.04	0.04	-0.06	-0.05	0.01
Average	**0.63**	**0.48**	**0.53**	**0.62**	**0.53**	**0.50**	**0.54**
Stand. dev.	**0.58**	**0.40**	**0.36**	**0.46**	**0.41**	**0.30**	**0.40**

On average for all surfaces, the increase in the sound levels due to a combination of added load and increased tyre inflation pressure are 0.55 dB. Note that the standard deviation is approximately of the same order as the mean values. This indicates that there is a considerable variation of the load influence between the tyres tested.

Since tyre 11 has been measured with the same load at both tests. The only difference is in the tyre inflation pressure; increased from 200 kPa to 250 kPa. As both table 4.3 and figure 4.1 show, this has no influence on the measured tyre/road noise.

As shown in table 3.2, the increase in sound level can be in the range of 0-1.2 dB, when the tyre inflation pressure is reduced. If one assumes that the change in sound level on average is -0.5 dB if the tyre inflation pressure is **increased** (from 180 to 240 kPA), the net effect of extra loading may be +1.0 dB on average. But, as table 4.3 shows, the results from individual tyres are large. Therefore, a clear quantification of added load and reduced tyre inflation pressure on the noise levels is difficult to establish. Based on the combined findings from the drum measurements and the LEO project, a net effect of higher inflation pressure and lower load can be in the area of -1.5 dB.

In the LEO project, a special test (CPX trailer) with a tyre designed for electric vehicles, Michelin Energy E-V (195/55 R16, tyre 9 in table 4.1) was conducted using 3 test conditions, as shown in table 4.4. The first is with tyre inflation pressure and load according to the CPX standard. The second is called "modified" Reg,117 test (since it is with added load according to the load index, but with "normal" tyre inflation pressure, and the last is with the same load for Reg.117, but with the minimum allowed tyre inflation pressure of 150 kPa [Berge et al, 2016]. The added load of 90 kg to 429 kg means that the tyre load is increased from 50 to 70 % of reference load (load index).

Table 4.4 Test conditions (CPX) for load and tyre inflation pressure for Michelin Energy E-V.

Test condition	Test load kg	Inflation pressure (kPa)
CPX standard	339	200
Modified Reg.117	429	250
Reg.117	429	150

Measurements were made on 2 road surfaces in Norway, SMA8 and SMA11 (NOR6 and NOR7 in table 4.3), at two speeds, 50 and 70 km/h.

The results are shown in table 4.5.

Table 4.5 Measurement results, dB(A), on 2 SMA surfaces with influence of load and inflation pressure. Tyre: Michelin Energy E-V.

Test condition	SMA8		SMA11	
	50 km/h	70 km/h	50 km/h	70 km/h
CPX standard	89.3	94.7	91.3	96.3
Modified Reg.117	90.7	95.7	92.0	97.0
Reg.117	90.1	95.2	92.2	96.9

For this tyre, there is an **increase** in noise level in the range of 0.7 to 1.4 dB, when the added load and tyre inflation pressure. But the test where the tyre inflation pressure is reduced from 250 to 150 kPa shows a minor change in noise levels, from -0.6 to +0.2 dB. This is in line with the results of tyre 11 (table 4.3), where the changes in noise levels is clearly within the measurement uncertainty.

For this specific tyre, the influence of tyre loading is higher than the influence of the tyre inflation pressure.

A linear regression analysis between the EU label values (table 4.1) and the noise levels on the Norwegian road surfaces did not show any improvements, when the added load and inflation pressure was used. However, it should be noted that this is related to measurements using the CPX trailer and not using a test vehicle as prescribed in Reg.117.

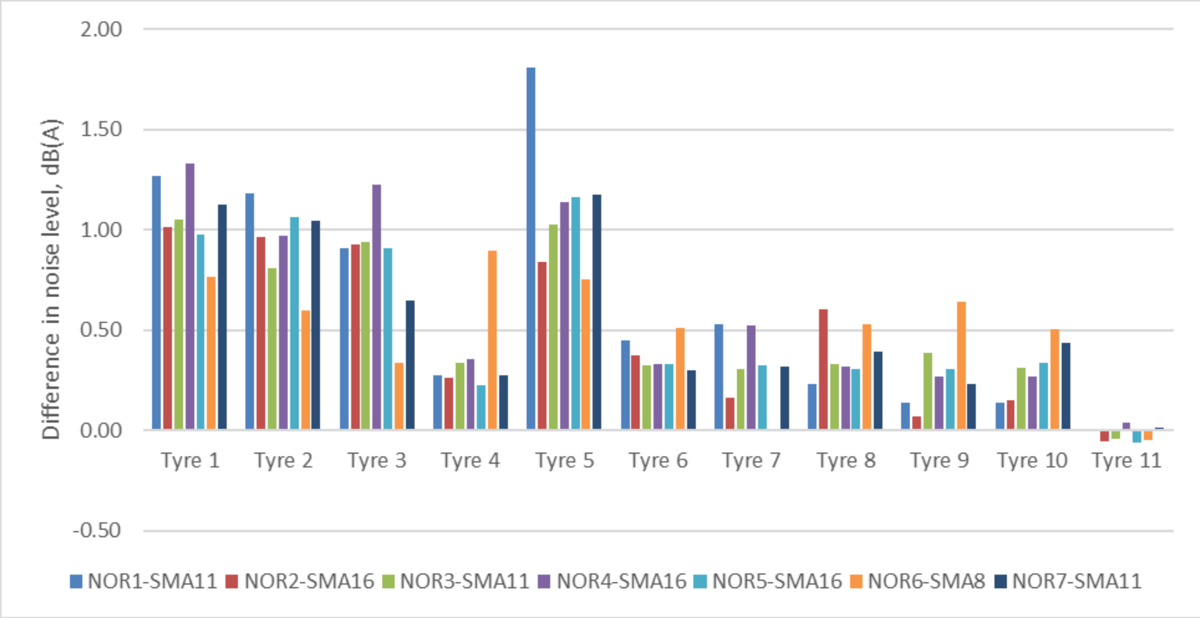

Figure 4.1 Change in sound level on 7 SMA surfaces, due to added load and inflation pressure [Berge et al., 2016].

No ISO surfaces are included in this investigation, but the ISO surface can be regarded as a variation of a dense asphalt concrete (DAC) with maximum 8 mm chipping size. Therefore, it is more relevant to see the effect on the added load/inflation pressure on the measured SMA8 surfaces. In figure 4.2, the linear regression analysis between the measured levels with the CPX method (load of 339 kg) and the condition with added load/inflation pressure (as shown in table 4.1). The y-axis is named "modified Reg.117 and this is because the load is meeting the specifications in this regulation, but measurements are made with a CPX trailer and not with a vehicle. The figure shows a high correlation and a slope more or less equal to 1.0.

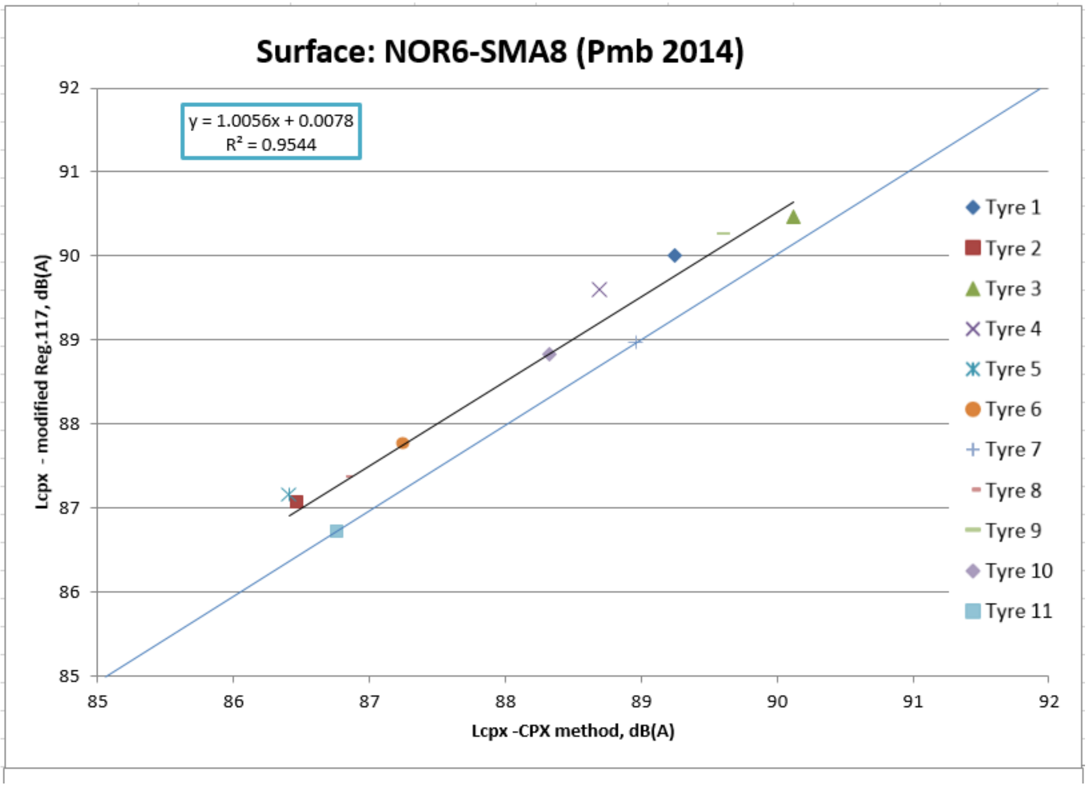

Figure 4.2 Regression analysis on a new SMA8 surface with standard load for CPX and added load (modified Reg,117) [Berge et al, 2016]

5 Conclusions and discussion

Conclusions and discussion

5.1. General

Ideally, a test of the influence of tyre inflation pressure and load which is optimal for the evaluation of Reg.117 and the labelling procedure, should have been made on an ISO track, with a vehicle. Such tests were originally planned within the STEER project but had to be skipped for budget reasons. However, the performed test at the drum facilities of GUT, gives an indication of the tyre inflation pressure on the pass-by noise levels. The results show also that there is a spread in the results for the chosen C1 tyres for the influence of tyre inflation pressure. Previous measurements in the LEO project confirms this, as some tyres show only minor influence of the tyre inflation pressure on smooth surfaces like SMA8.

The influence of tyre inflation pressure and load from a wide range of studies has been reviewed in the Tyre/Road Noise Reference Book [Sandberg, Ejsmont 2002]. Their main conclusions regarding the load and tyre inflation pressure influence, which are relevant for the STEER project, were:

1. Tyre/road noise is sensitive to tyre load for most but not for all tyres.
2. The load influence is much higher at low speeds than at high speeds.
3. Doubling of load can give an increase in noise level of approx.2 dB.
4. The influence of the tyre inflation pressure is highly sensitive to the road surface. On a rougher surface, drum measurements at GUT found a decrease of 0.2 dB if the tyre inflation pressure was increased by 10 %. On a smooth "ISO" surface, the effect was opposite, with an increase in the range of 0-0.3 dB.

5.2. Tyre inflation pressure

In the drum test, the influence of tyre inflation pressure on the tyre/noise levels have been investigated for a limited number of C1 tyres. The tyre inflation pressure varied from 180 to 240 kPa. The measurement results show that the reduction in tyre pressure results in higher noise levels (range -0.01 dB to -0.17 dB/10 kPa) and the behaviour of the tyre and its sensitivity to tyre inflation pressure us influenced by the tread pattern. However, since the noise ranking of the tyres did not change, there is no clear indication that the present requirements in Reg.117 for tyre inflation pressure should be revised to improve the labelling procedure. Tests with a single tyre on 2 SMA surfaces also indicate a small influence on the noise levels, even with a reduction from 250 kPa to 150 kPa. However, this finding was made in a single C1 tyre.

5.3. Tyre load

The findings of the load influence are based on measurements made in the LEO project. These measurements were made with a CPX trailer, and not with a vehicle, as specified in Reg.117. Due to this fact, one shall be careful to make firm conclusions only based on these tests. Also, a part of the tests was done with a combination of increased both load and tyre inflation pressure. Therefore, it is difficult to draw firm conclusions based on these tests.

Measurements on smooth dense surfaces, such as SMA8 indicate an increase in the tyre/road noise at 50 km/h around 0.5 dB(A), when the load is increased with 80-90 kg (24-27%) from the initial load of 339 kg per tyre and with an increase in tyre inflation pressure from about 20 to 50 kPa (10-30 %).

For measurements on rougher surfaces, like SMA11-SMA16, the increase in the noise levels is even higher for some tyres, 1-1.8 dB(A).

It should be noted that both test conditions have been made with the individual load of the tyres which is in the allowed range of 50-90 % of the reference load, as specified by Reg.117. Thus, a conclusion based on this data can be that also the requirements of the test load as specified in Reg.117 should be kept.

Based on this limited investigation one can conclude that the noise does increase with increased load. A load influence of around 1 dB seems to be relevant, when the load is increased from 50 to 70 % of the reference load. This is in line with previous investigations [Sandberg, Ejsmont, 2002]. However, it seems not to change the noise ranking of tyres in a way that it correlates well with the ranking of the tyres according to the EU label values.

6 References

[Saemann, 2009] Personal communication with U. Saemann at Continental AG, 2009.

[Berge et al. 2016] T. Berge, P. Mioduszewski, J. Ejsmont. Final Report on Noise Measurements. LEO Report WP3-D003-20161228.

[Sandberg, Ejsmont, 2002] U. Sandberg, J. Ejsmont. Tyre/Road Noise Reference Book. Informex ISBN 91-631-2610-9, First edition, 2002.

[ETRTO. 2019] TFMU-02-02 Rev.1 (ETRTO) Tyre noise uncertainties (available at https://wiki.unece.org/display/trans/TF+MU+-+2nd+session%2C+Belgium+November+2019)

Annex 1. Noise levels and frequency spectra for all tyres

In this Annex, all individual noise levels and frequency spectra for the 6 tyres and 5 test conditions are shown.

Tyre: Continental EcoContact 6.

Table A1.1: Drum test results, Conti EcoContact5

Test speed, km/h	Tyre inflation pressure, kPa	Front dB(A)	Rear dB(A)	Average dB(A)
50	180	87.9	87.3	87.6
80	180	96.6	96.4	96.5
80	190	96.8	96.5	96.7
80	210	96.7	96.4	96.5
80	240	96.5	95.9	96.2

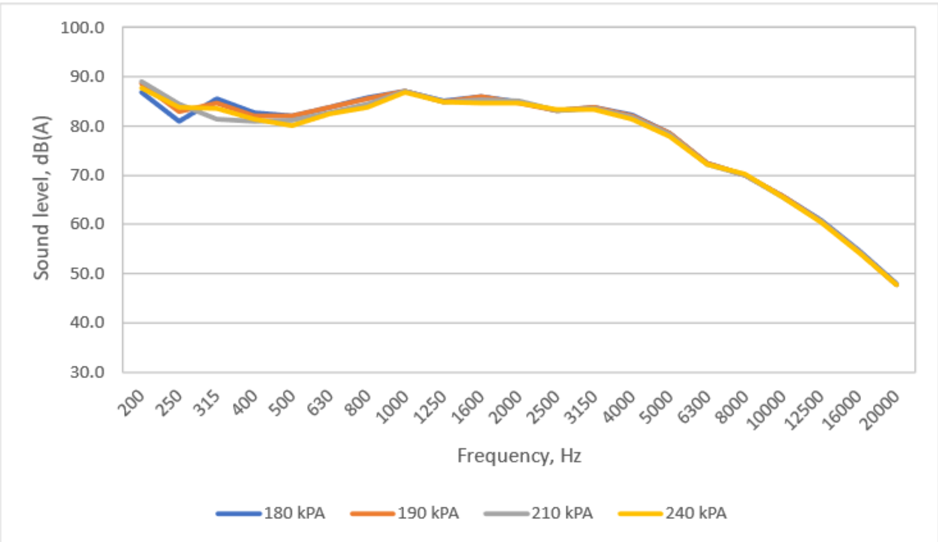

Figure A.1.1: Conti EcoContact6. Speed = 80 km/h. Tyre inflation pressure 180 to 240 kPa

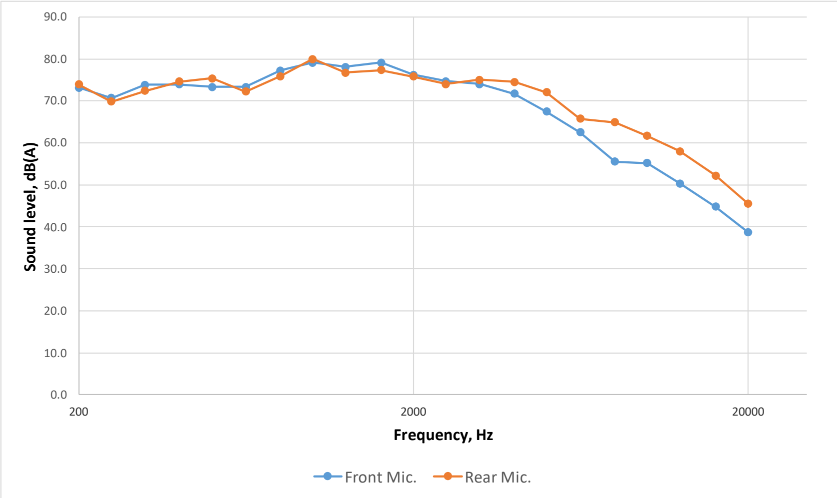

Figure A1.2: Conti EcoContact 6. Speed = 50 km/h, Tyre inflation pressure = 180 kPa

Table A1.2: Speed = 50 km/h, Tyre inflation pressure = 180 kPa

Frequences	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	73.2	74.0	73.6
250	70.7	69.8	70.3
315	73.9	72.4	73.2
400	73.9	74.6	74.3
500	73.4	75.4	74.4
630	73.3	72.3	72.8
800	77.2	75.9	76.6
1000	79.1	80.0	79.5
1250	78.1	76.8	77.4
1600	79.1	77.3	78.2
2000	76.3	75.9	76.1
2500	74.7	74.1	74.4
3150	74.0	75.0	74.5
4000	71.7	74.5	73.1
5000	67.5	72.1	69.8
6300	62.5	65.8	64.1
8000	55.6	64.9	60.2
10000	55.2	61.7	58.4
12500	50.4	58.0	54.2
16000	44.8	52.2	48.5
20000	38.8	45.6	42.2
LA=	**87.9**	**87.3**	**87.6**

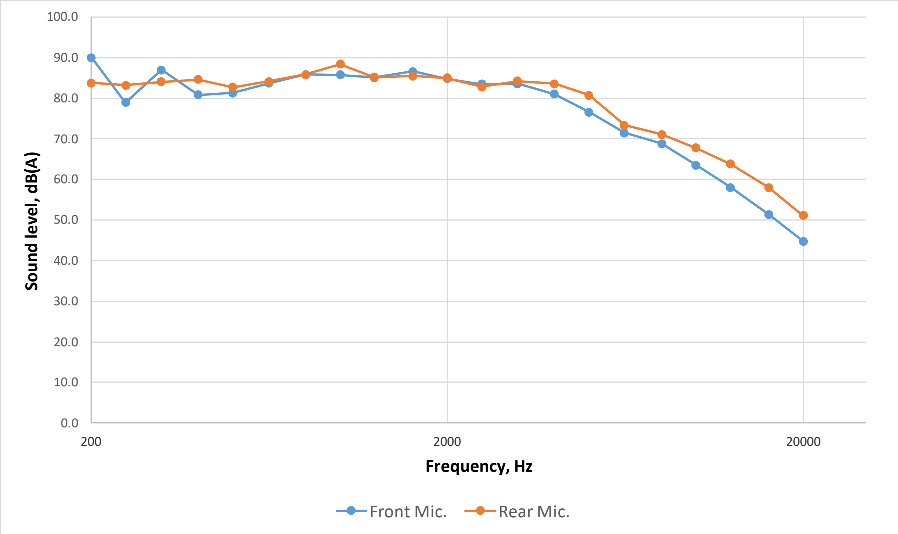

Figure A1.3: Conti EcoContact 6. Speed = 80 km/h, Tyre inflation pressure = 180 kPa

Table A1.3: Speed = 80 km/h, Tyre inflation pressure = 180 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	90.0	83.8	86.9
250	78.9	83.2	81.1
315	87.0	84.1	85.5
400	80.8	84.6	82.7
500	81.3	82.7	82.0
630	83.7	84.1	83.9
800	85.9	85.8	85.8
1000	85.8	88.4	87.1
1250	85.0	85.2	85.1
1600	86.6	85.4	86.0
2000	84.8	85.0	84.9
2500	83.5	82.8	83.1
3150	83.5	84.3	83.9
4000	81.0	83.5	82.3
5000	76.5	80.7	78.6
6300	71.5	73.4	72.4
8000	68.9	71.1	70.0
10000	63.6	67.8	65.7
12500	58.1	63.8	60.9
16000	51.4	58.0	54.7
20000	44.8	51.2	48.0
LA=	**96.6**	**96.4**	**96.5**

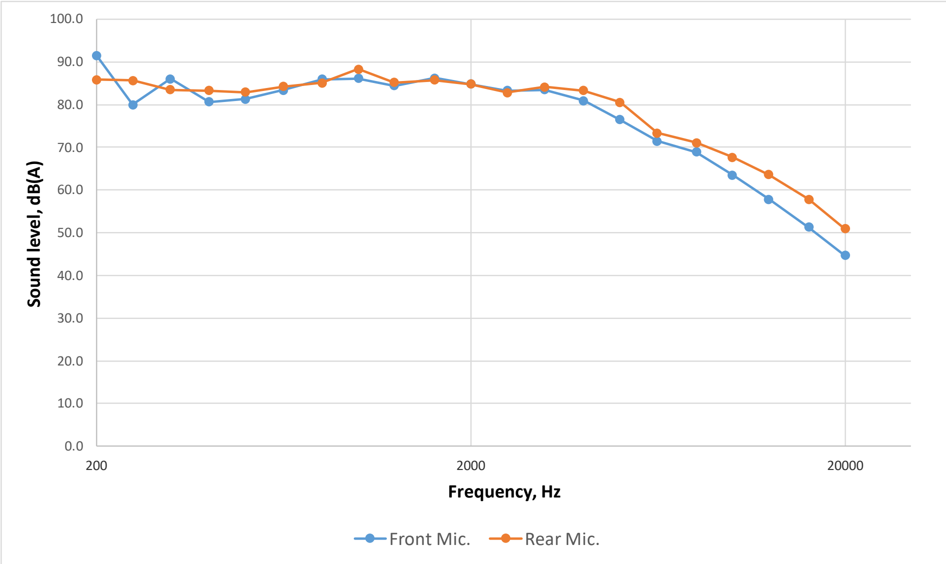

Figure A1.4: Conti EcoContact 6. Speed = 80 km/h, Tyre inflation pressure = 190 kPa

Table A1.4: Speed = 80 km/h, Tyre inflation pressure = 190 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	91.4	85.8	88.6
250	80.0	85.7	82.8
315	86.0	83.4	84.7
400	80.7	83.3	82.0
500	81.4	82.9	82.1
630	83.4	84.3	83.8
800	85.9	85.1	85.5
1000	86.1	88.3	87.2
1250	84.5	85.2	84.8
1600	86.2	85.7	86.0
2000	84.8	84.8	84.8
2500	83.3	82.8	83.1
3150	83.5	84.1	83.8
4000	81.0	83.3	82.1
5000	76.5	80.6	78.5
6300	71.5	73.4	72.4
8000	68.9	71.1	70.0
10000	63.5	67.7	65.6
12500	57.8	63.6	60.7
16000	51.3	57.9	54.6
20000	44.7	50.9	47.8
LA=	**96.8**	**96.5**	**96.7**

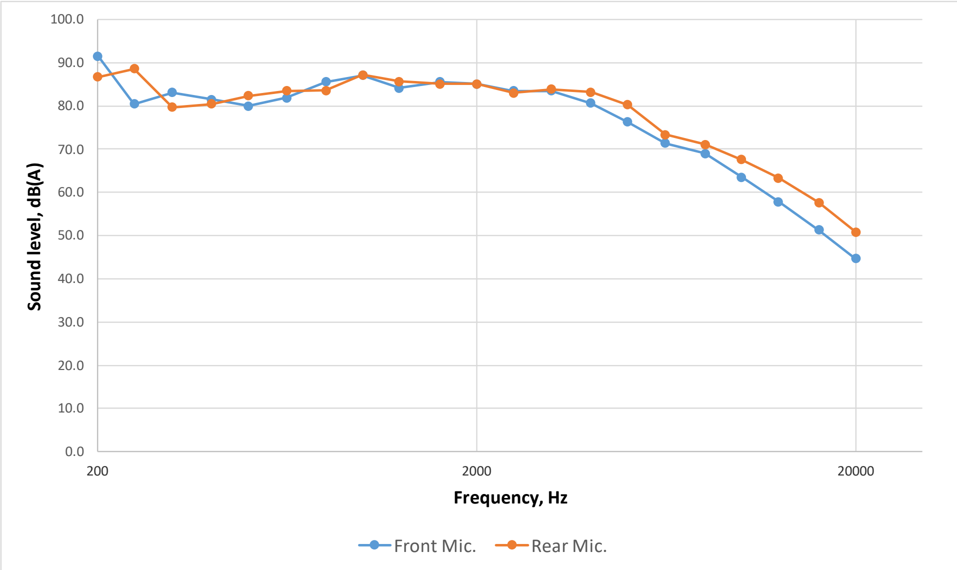

Figure A1.5: Conti EcoContact 6. Speed = 80 km/h, Tyre inflation pressure = 210 kPa

Table A1.5: Speed = 80 km/h, Tyre inflation pressure = 210 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	91.5	86.7	89.1
250	80.5	88.6	84.5
315	83.1	79.7	81.4
400	81.5	80.4	80.9
500	80.0	82.4	81.2
630	81.8	83.4	82.6
800	85.6	83.6	84.6
1000	87.0	87.1	87.1
1250	84.1	85.6	84.9
1600	85.6	85.1	85.3

2000	85.1	85.1	85.1
2500	83.5	83.0	83.2
3150	83.5	83.9	83.7
4000	80.7	83.2	81.9
5000	76.3	80.2	78.3
6300	71.3	73.3	72.3
8000	69.0	71.1	70.0
10000	63.5	67.6	65.5
12500	57.9	63.3	60.6
16000	51.3	57.7	54.5
20000	44.7	50.8	47.7
LA=	**96.7**	**96.4**	**96.5**

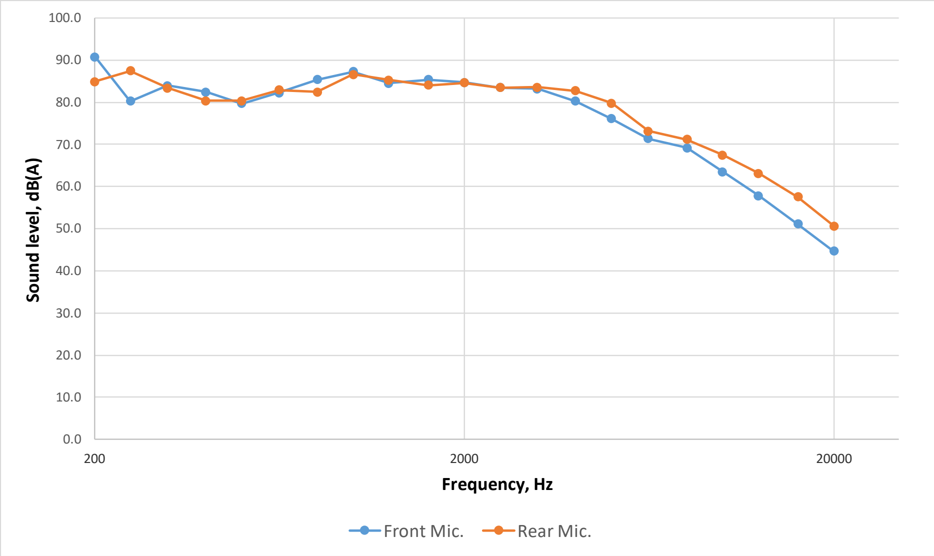

Figure A1.6: Conti EcoContact 6. Speed = 80 km/h, Tyre inflation pressure = 240 kPa

Table A1.6: Speed = 80 km/h, Tyre inflation pressure = 240 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	90.8	84.9	87.8
250	80.3	87.5	83.9
315	83.9	83.4	83.7
400	82.5	80.4	81.4
500	79.7	80.4	80.0
630	82.2	82.9	82.6
800	85.3	82.5	83.9
1000	87.2	86.6	86.9
1250	84.5	85.3	84.9
1600	85.4	84.0	84.7

2000	84.8	84.6	84.7
2500	83.5	83.5	83.5
3150	83.2	83.6	83.4
4000	80.3	82.7	81.5
5000	76.1	79.8	78.0
6300	71.4	73.2	72.3
8000	69.2	71.2	70.2
10000	63.5	67.4	65.5
12500	57.8	63.1	60.5
16000	51.2	57.5	54.3
20000	44.7	50.6	47.7
LA=	**96.5**	**95.9**	**96.2**

Tyre: Goodyear EfficientGrip Performance 2.

Table A1.7: Drum test results, Goodyear EfficientGrip Performance 2

Test speed, km/h	**Tyre inflation pressure, kPa**	**Front dB(A)**	**Rear dB(A)**	**Average dB(A)**
50	180	90.7	90.6	90.7
80	180	100.4	100.3	100.4
80	190	99.9	100.1	100.0
80	210	99.3	99.1	99.2
80	240	100.2	99.4	99.8

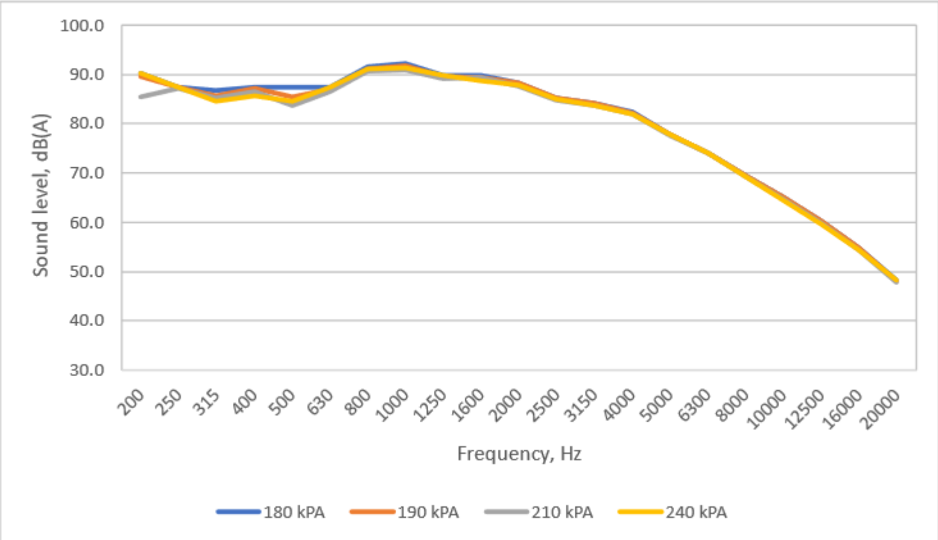

Figure A1.7: Goodyear EfficientGrip Performance 2. Speed = 80 km/h. Tyre inflation pressure 180 to 240 kPa

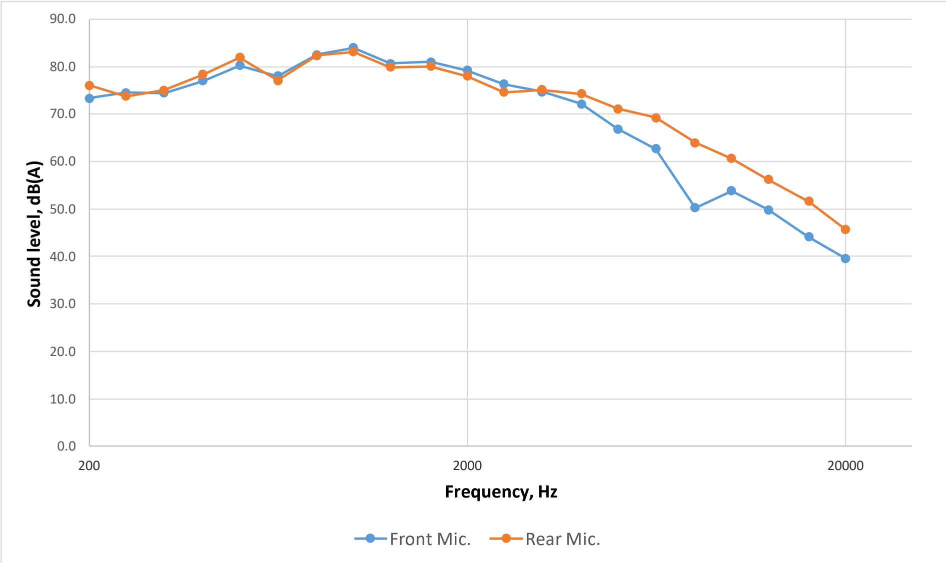

Figure A1.8: Goodyear Eff.Grip Perf. Speed = 50 km/h, Tyre inflation pressure = 180 kPa

Table A1.8: Speed = 50 km/h, Tyre inflation pressure = 180 kPa

Frequen-cies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	73.4	76.1	74.7
250	74.5	73.7	74.1
315	74.4	75.1	74.7
400	77.0	78.3	77.7
500	80.2	82.0	81.1
630	78.1	77.1	77.6
800	82.6	82.4	82.5
1000	84.0	83.2	83.6
1250	80.7	79.9	80.3
1600	81.0	80.1	80.5
2000	79.2	78.0	78.6
2500	76.3	74.6	75.5
3150	74.7	75.2	74.9
4000	72.1	74.3	73.2
5000	66.9	71.1	69.0
6300	62.7	69.3	66.0
8000	50.2	64.0	57.1
10000	53.9	60.6	57.3
12500	49.8	56.2	53.0
16000	44.1	51.7	47.9
20000	39.7	45.7	42.7
LA=	**90.7**	**90.6**	**90.7**

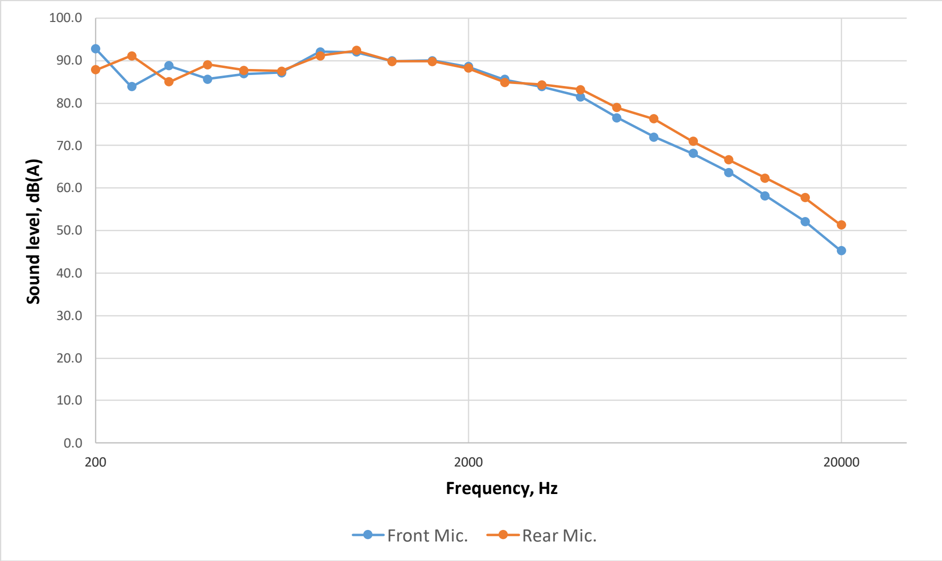

Figure A1.9: Goodyear Eff.Grip Perf. Speed = 80 km/h, Tyre inflation pressure = 180 kPa

Table A1.9: Speed = 80 km/h, Tyre inflation pressure = 180 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	92.8	87.8	90.3
250	83.8	91.2	87.5
315	88.8	85.0	86.9
400	85.7	89.1	87.4
500	86.9	87.8	87.3
630	87.1	87.6	87.4
800	92.1	91.2	91.6
1000	92.0	92.4	92.2
1250	89.9	89.8	89.9
1600	90.0	89.8	89.9

2000	88.6	88.2	88.4
2500	85.6	84.9	85.2
3150	83.9	84.4	84.1
4000	81.5	83.2	82.3
5000	76.5	79.0	77.8
6300	72.0	76.3	74.1
8000	68.1	71.0	69.6
10000	63.7	66.7	65.2
12500	58.2	62.4	60.3
16000	52.1	57.7	54.9
20000	45.2	51.3	48.3
LA=	**100.4**	**100.3**	**100.4**

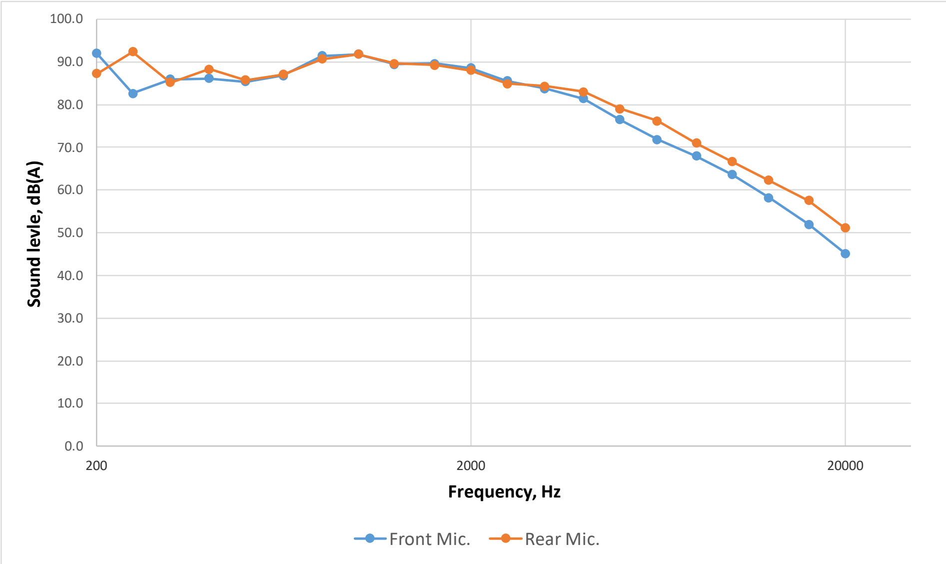

Figure A1.10: Goodyear Eff.Grip Perf. Speed = 80 km/h, Tyre inflation pressure = 190 kPa

Table A1.10: Speed = 80 km/h, Tyre inflation pressure = 190 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	92.0	87.3	89.6
250	82.7	92.3	87.5
315	85.9	85.2	85.6
400	86.2	88.3	87.2
500	85.3	85.7	85.5
630	86.8	87.1	86.9
800	91.5	90.7	91.1
1000	91.8	91.8	91.8
1250	89.5	89.6	89.5
1600	89.6	89.2	89.4
2000	88.6	88.0	88.3
2500	85.6	84.9	85.2
3150	83.8	84.3	84.1
4000	81.4	83.0	82.2
5000	76.5	79.0	77.7
6300	71.9	76.2	74.1
8000	67.9	71.0	69.5
10000	63.6	66.6	65.1
12500	58.2	62.3	60.2
16000	52.0	57.6	54.8
20000	45.2	51.1	48.2
LA=	**99.9**	**100.1**	**100.0**

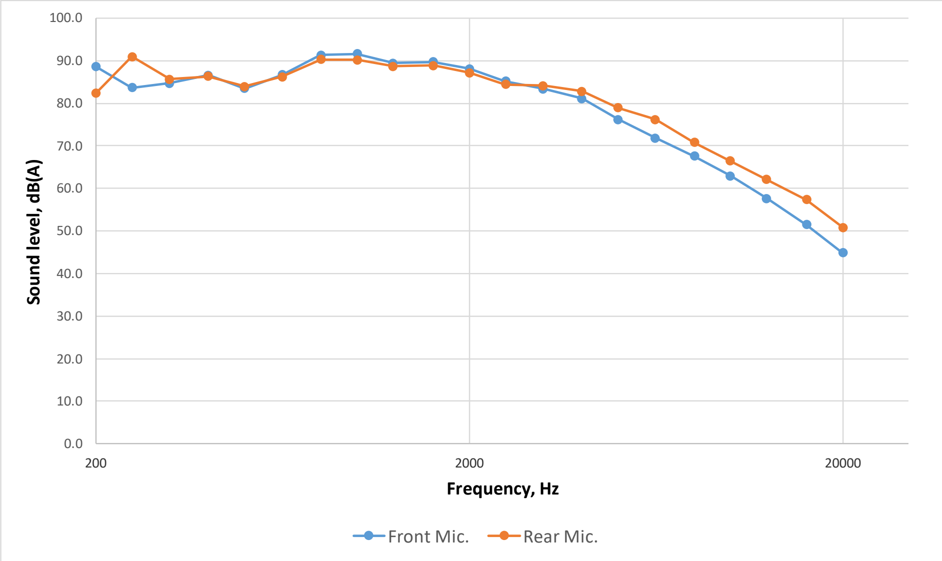

Figure A1.11: Goodyear Eff.Grip Perf. Speed = 80 km/h, Tyre inflation pressure = 210 kPa

Table A1.11: Speed = 80 km/h, Tyre inflation pressure = 210 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	88.6	82.4	85.5
250	83.6	90.9	87.3
315	84.7	85.7	85.2
400	86.6	86.4	86.5
500	83.5	83.9	83.7
630	86.7	86.2	86.5
800	91.3	90.3	90.8
1000	91.7	90.2	90.9
1250	89.5	88.7	89.1
1600	89.7	88.9	89.3
2000	88.2	87.2	87.7
2500	85.2	84.4	84.8
3150	83.4	84.2	83.8
4000	81.1	82.9	82.0
5000	76.2	79.0	77.6
6300	71.8	76.2	74.0
8000	67.6	70.8	69.2
10000	62.9	66.4	64.7
12500	57.7	62.1	59.9
16000	51.5	57.3	54.4
20000	44.9	50.9	47.9
LA=	**99.3**	**99.1**	**99.2**

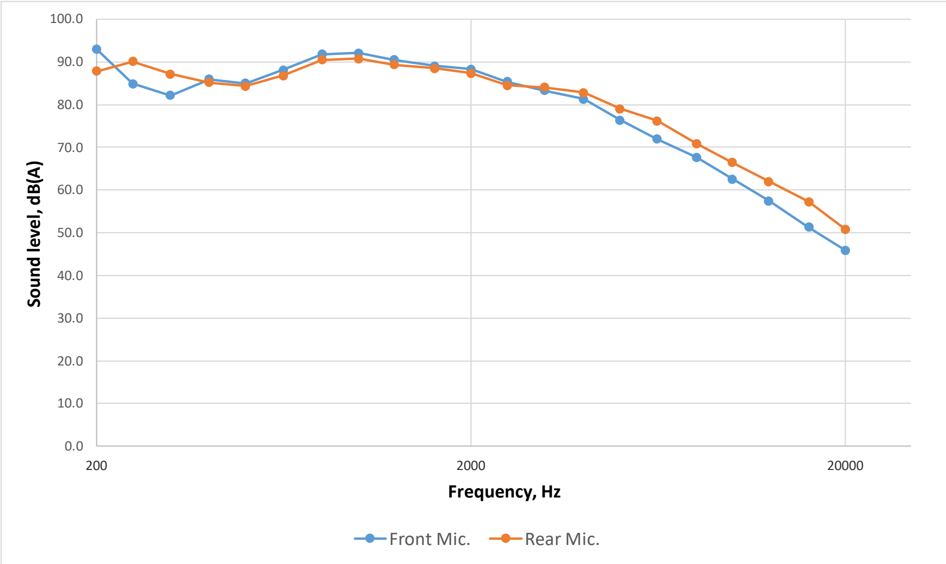

Figure A1.12: Goodyear Eff.Grip Perf. Speed = 80 km/h, Tyre inflation pressure = 240 kPa

Table A1.12: Speed = 80 km/h, Tyre inflation pressure = 240 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	92.9	87.8	90.4
250	84.9	90.1	87.5
315	82.2	87.2	84.7
400	86.0	85.2	85.6
500	85.0	84.3	84.6
630	88.1	86.8	87.4
800	91.8	90.5	91.1
1000	92.1	90.7	91.4
1250	90.5	89.4	89.9
1600	89.0	88.5	88.8

2000	88.3	87.4	87.9
2500	85.4	84.6	85.0
3150	83.3	84.1	83.7
4000	81.3	82.8	82.1
5000	76.4	79.0	77.7
6300	72.0	76.2	74.1
8000	67.7	70.9	69.3
10000	62.5	66.5	64.5
12500	57.4	62.0	59.7
16000	51.3	57.3	54.3
20000	45.9	50.8	48.4
LA=	**100.2**	**99.4**	**99.8**

Tyre: Bridgestone Ecopia EP500.

Table A1.13: Drum test results, Bridgestone Ecopia EP500

Test speed, km/h	**Tyre inflation pressure, kPa**	**Front dB(A)**	**Rear dB(A)**	**Average dB(A)**
50	180	88.2	87.9	88.1
80	180	98.2	97.9	98.0
80	190	98.1	98.1	98.1
80	210	97.9	98.2	98.0
80	240	97.9	97.8	97.8

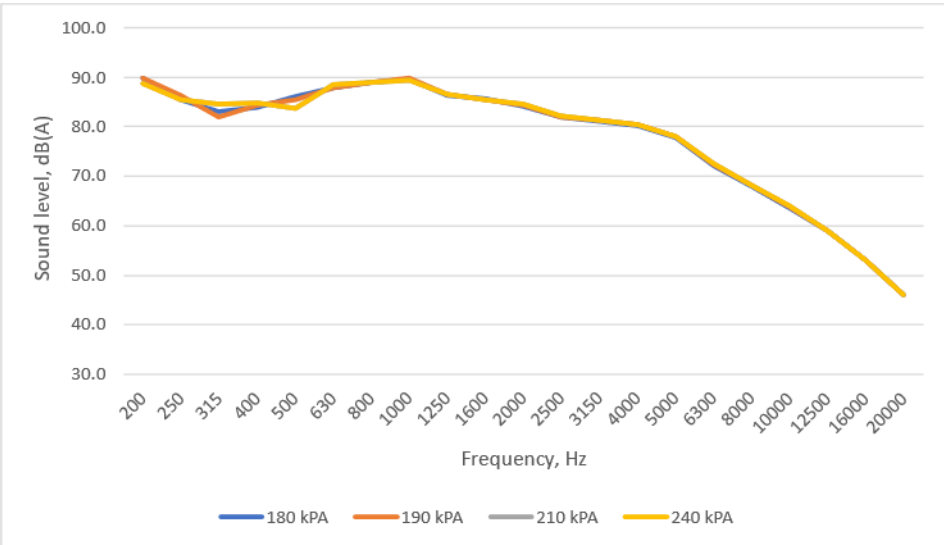

Figure A1.13: Bridgestone Ecopia EP500. Speed = 80 km/h. Tyre inflation pressure 180 to 240 kPa

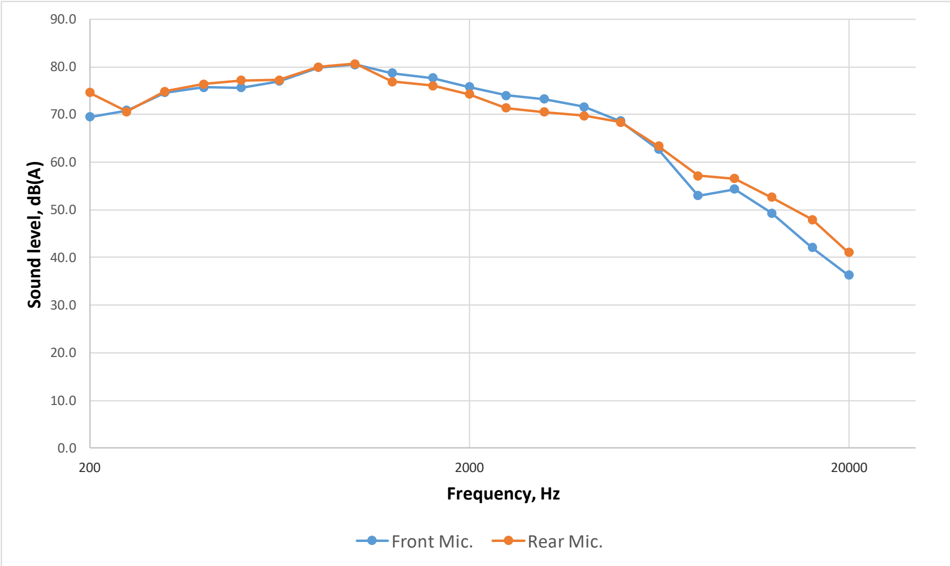

Figure A1.14: Bridgestone Ecopia EP500. Speed = 50 km/h, Tyre inflation pressure = 180 kPa

Table A1.14: Speed = 50 km/h, Tyre inflation pressure = 180 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	69.5	74.6	72.1
250	70.9	70.6	70.7
315	74.6	74.9	74.8
400	75.7	76.4	76.1
500	75.6	77.2	76.4
630	77.0	77.3	77.1
800	79.9	80.0	80.0
1000	80.5	80.6	80.6
1250	78.7	76.9	77.8
1600	77.7	76.0	76.9
2000	75.8	74.3	75.0
2500	74.0	71.4	72.7
3150	73.2	70.5	71.9
4000	71.7	69.8	70.7
5000	68.7	68.4	68.5
6300	62.7	63.4	63.0
8000	53.0	57.2	55.1
10000	54.3	56.6	55.5
12500	49.3	52.6	51.0
16000	42.1	48.0	45.0
20000	36.3	41.0	38.7
LA=	**88.2**	**87.9**	**88.1**

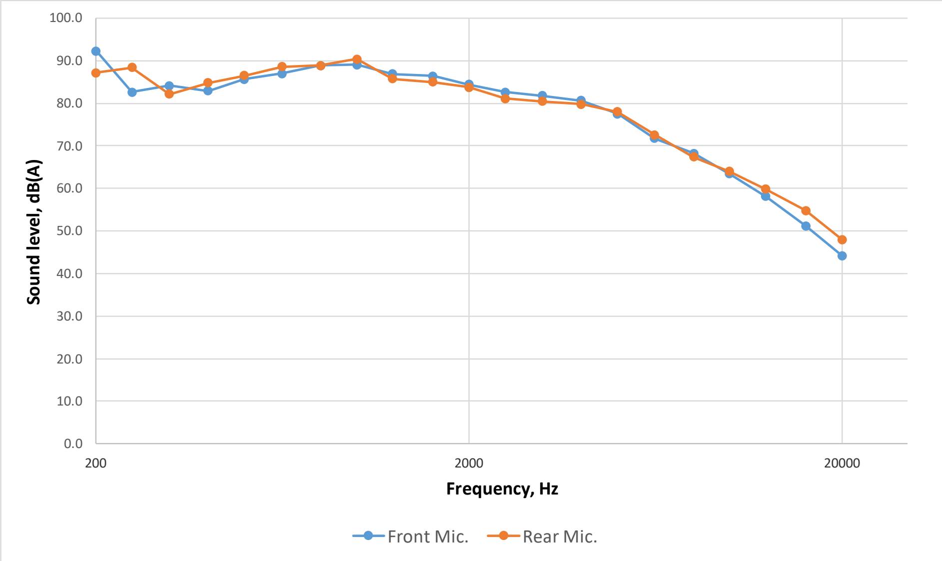

Figure A1.15: Bridgestone Ecopia EP500. Speed = 80 km/h, Tyre inflation pressure = 180 kPa

Table A1.15: Speed = 80 km/h, Tyre inflation pressure = 180 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	92.3	87.2	89.7
250	82.6	88.4	85.5
315	84.1	82.2	83.2
400	82.9	84.8	83.9
500	85.7	86.5	86.1
630	87.0	88.6	87.8
800	88.8	88.9	88.9
1000	89.1	90.4	89.7
1250	86.9	85.7	86.3
1600	86.4	85.0	85.7
2000	84.4	83.8	84.1
2500	82.6	81.2	81.9
3150	81.8	80.5	81.1
4000	80.6	79.8	80.2
5000	77.5	78.0	77.7
6300	71.7	72.6	72.2
8000	68.3	67.4	67.9
10000	63.4	63.9	63.7
12500	58.1	59.8	59.0
16000	51.2	54.8	53.0
20000	44.2	48.0	46.1
LA=	**98.2**	**97.9**	**98.0**

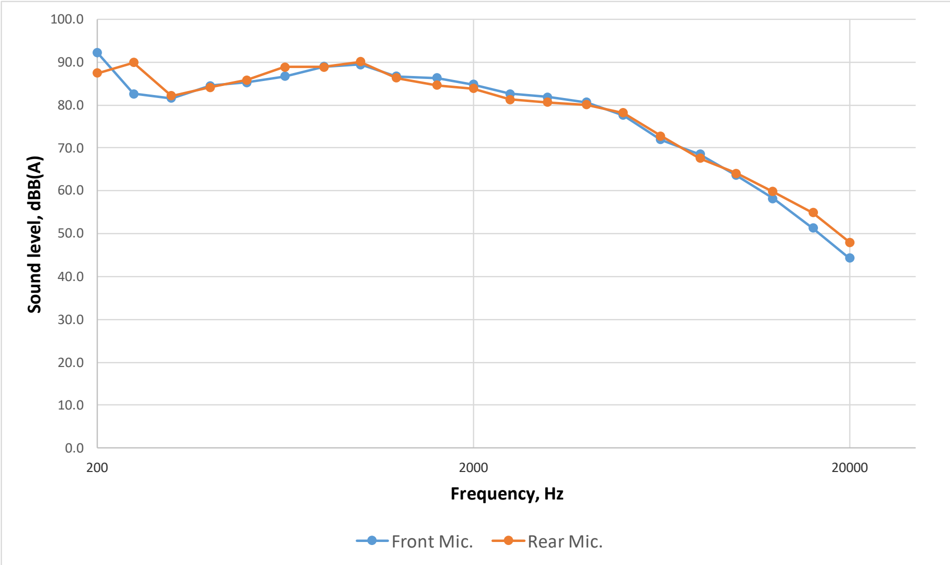

Figure A1.16: Bridgestone Ecopia EP500. Speed = 80 km/h, Tyre inflation pressure = 190 kPa

Table A1.16: Speed = 80 km/h, Tyre inflation pressure = 190 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	92.2	87.5	89.8
250	82.6	89.9	86.3
315	81.6	82.1	81.9
400	84.5	84.1	84.3
500	85.3	85.9	85.6
630	86.7	88.9	87.8
800	88.9	88.9	88.9
1000	89.4	90.1	89.8
1250	86.7	86.3	86.5
1600	86.3	84.6	85.5
2000	84.8	83.8	84.3
2500	82.7	81.3	82.0
3150	81.9	80.7	81.3
4000	80.6	80.0	80.3
5000	77.6	78.2	77.9
6300	71.9	72.8	72.3
8000	68.6	67.6	68.1
10000	63.6	64.1	63.8
12500	58.3	59.9	59.1
16000	51.3	54.9	53.1
20000	44.3	48.0	46.2
LA=	**98.1**	**98.1**	**98.1**

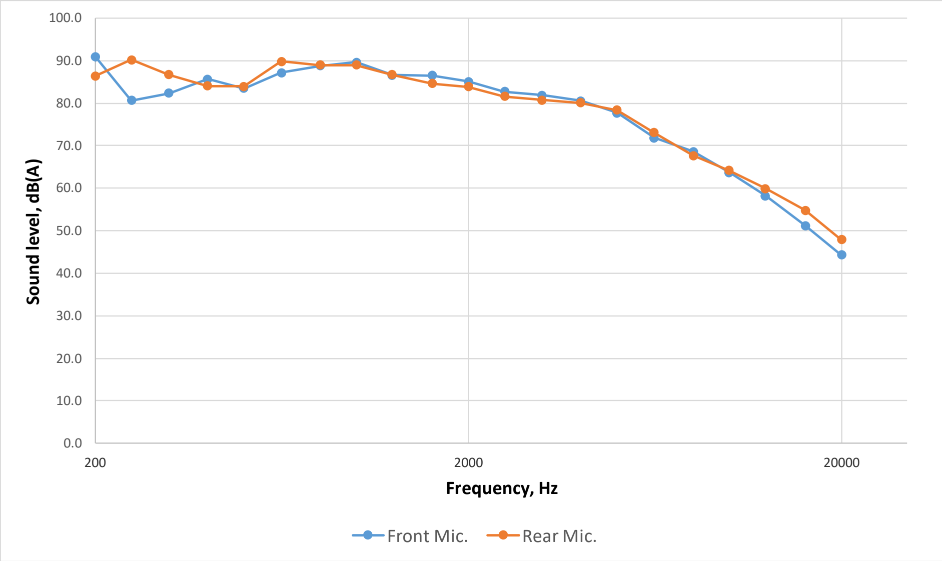

Figure A1.17: Bridgestone Ecopia EP500. Speed = 80 km/h, Tyre inflation pressure = 210 kPa

Table A1.17: Speed = 80 km/h, Tyre inflation pressure = 210 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	90.9	86.5	88.7
250	80.6	90.2	85.4
315	82.4	86.7	84.5
400	85.6	84.1	84.9
500	83.5	84.0	83.7
630	87.2	89.8	88.5
800	88.8	89.0	88.9
1000	89.7	89.0	89.3
1250	86.6	86.7	86.7
1600	86.5	84.6	85.5
2000	85.1	83.9	84.5
2500	82.7	81.6	82.2
3150	81.9	80.8	81.3
4000	80.6	80.1	80.3
5000	77.7	78.4	78.0
6300	71.9	73.1	72.5
8000	68.6	67.7	68.2
10000	63.7	64.2	63.9
12500	58.2	59.9	59.1
16000	51.2	54.8	53.0
20000	44.3	47.9	46.1
LA=	**97.9**	**98.2**	**98.0**

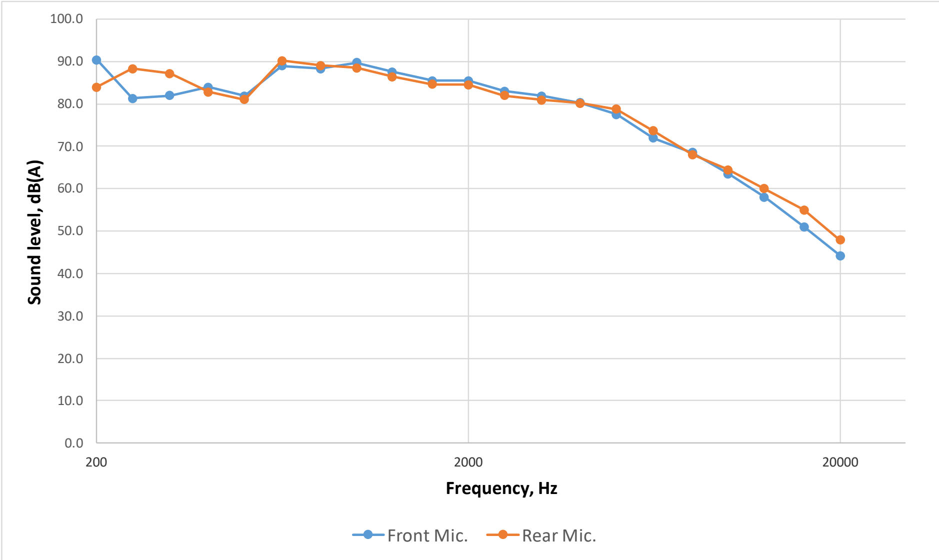

Figure A1.18: Bridgestone Ecopia EP500. Speed = 80 km/h, Tyre inflation pressure = 240 kPa

Table A1.18: Speed = 80 km/h, Tyre inflation pressure = 240 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	90.4	84.0	87.2
250	81.3	88.3	84.8
315	82.0	87.2	84.6
400	84.0	82.8	83.4
500	81.9	81.1	81.5
630	89.0	90.2	89.6
800	88.3	89.1	88.7
1000	89.7	88.5	89.1
1250	87.5	86.5	87.0
1600	85.5	84.6	85.1
2000	85.5	84.6	85.0
2500	83.0	82.0	82.5
3150	81.9	80.9	81.4
4000	80.3	80.2	80.2
5000	77.5	78.8	78.2
6300	71.9	73.6	72.8
8000	68.6	68.1	68.3
10000	63.5	64.5	64.0
12500	58.1	60.1	59.1
16000	51.0	55.0	53.0
20000	44.2	47.9	46.1
LA=	**97.9**	**97.8**	**97.8**

Tyre: Michelin CrossClimate+.

Table A1.19: Drum test results, Michelin CrossClimate+

Test speed, km/h	Tyre inflation pressure, kPa	Front dB(A)	Rear dB(A)	Average dB(A)
50	180	90.7	90.3	90.5
80	180	99.2	98.4	98.8
80	190	99.0	98.1	98.6
80	210	98.6	98.0	98.3
80	240	98.3	97.3	97.8

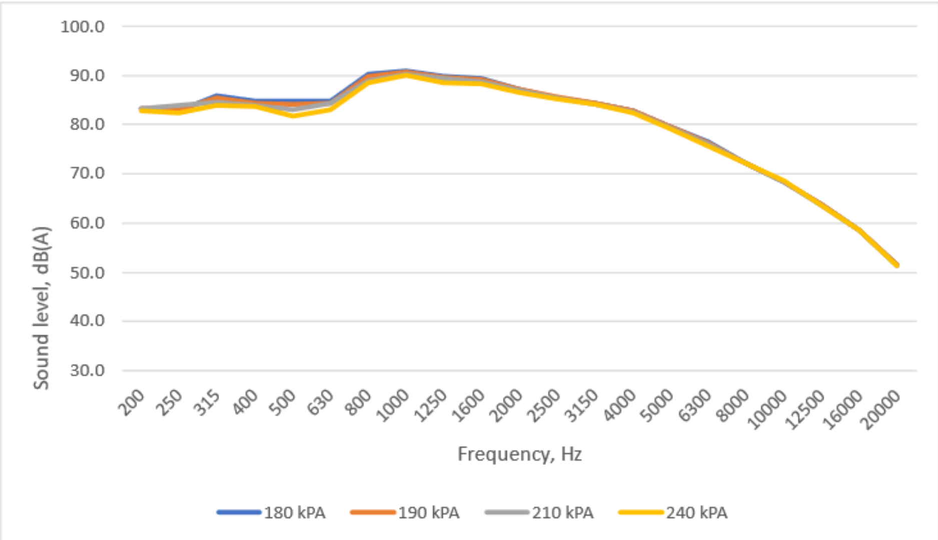

Figure A1.19: Michelin CrossClimate+. Speed = 80 km/h. Tyre inflation pressure 180 to 240 kPa

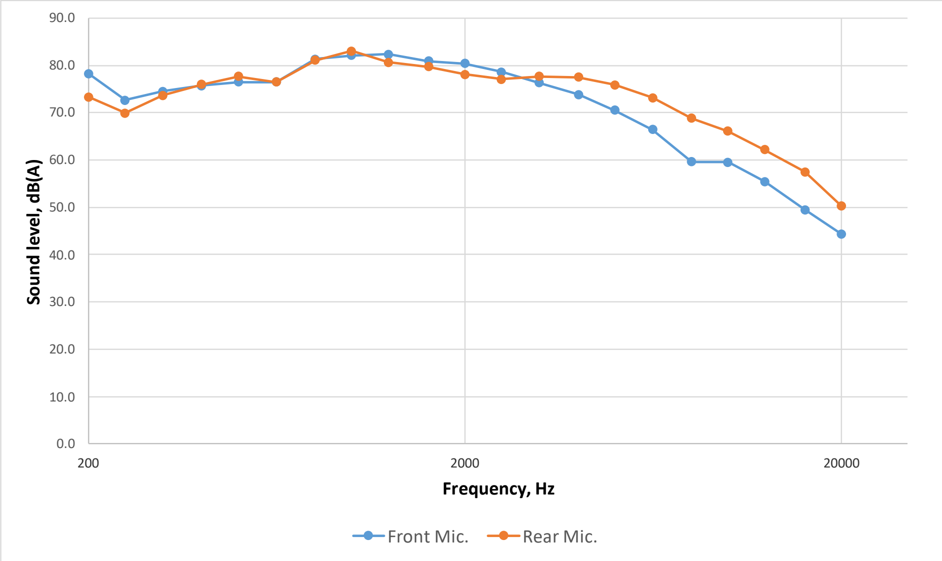

Figure A1.20: Michelin CrossClimate+. Speed = 50 km/h, Tyre inflation pressure = 180 kPa

Table A1.20: Speed = 50 km/h, Tyre inflation pressure = 180 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	78.3	73.3	75.8
250	72.6	69.9	71.3
315	74.5	73.7	74.1
400	75.7	76.0	75.9
500	76.5	77.7	77.1
630	76.5	76.5	76.5
800	81.4	81.1	81.2
1000	82.1	83.1	82.6
1250	82.3	80.7	81.5
1600	80.9	79.7	80.3
2000	80.4	78.1	79.3
2500	78.6	77.1	77.9
3150	76.3	77.7	77.0
4000	73.9	77.5	75.7
5000	70.6	75.9	73.2
6300	66.5	73.2	69.8
8000	59.7	68.8	64.3
10000	59.5	66.1	62.8
12500	55.4	62.2	58.8
16000	49.5	57.5	53.5
20000	44.4	50.3	47.3
LA=	**90.7**	**90.3**	**90.5**

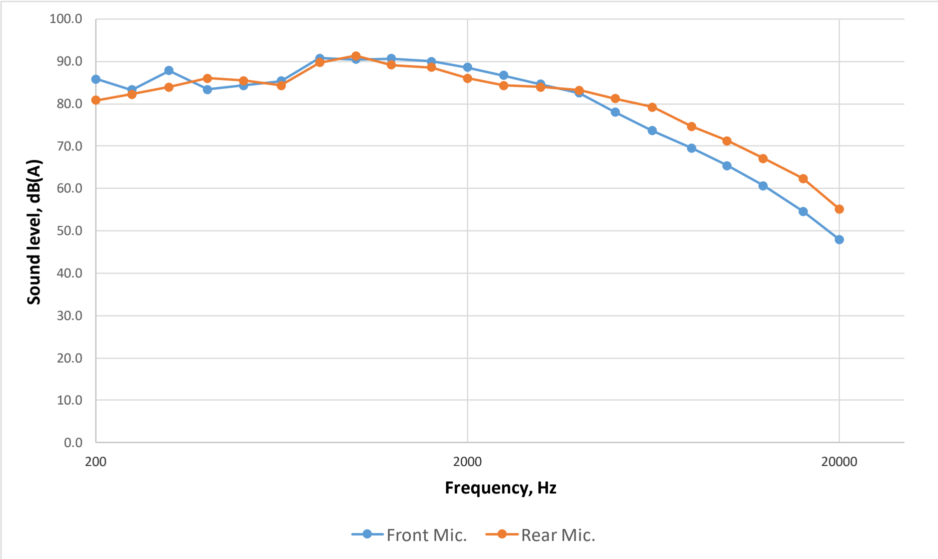

Figure A1.21: Michelin CrossClimate+. Speed = 80 km/h, Tyre inflation pressure = 180 kPa

Table A1.21: Speed = 80 km/h, Tyre inflation pressure = 180 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	85.8	80.8	83.3
250	83.3	82.2	82.7
315	87.8	84.0	85.9
400	83.4	86.1	84.8
500	84.3	85.4	84.9
630	85.4	84.4	84.9
800	90.7	89.7	90.2
1000	90.5	91.3	90.9
1250	90.7	89.1	89.9
1600	90.0	88.6	89.3
2000	88.6	86.0	87.3
2500	86.7	84.4	85.5
3150	84.7	83.9	84.3
4000	82.5	83.2	82.9
5000	78.0	81.2	79.6
6300	73.6	79.2	76.4
8000	69.5	74.7	72.1
10000	65.4	71.3	68.4
12500	60.7	67.1	63.9
16000	54.6	62.4	58.5
20000	48.0	55.2	51.6
LA=	**99.2**	**98.4**	**98.8**

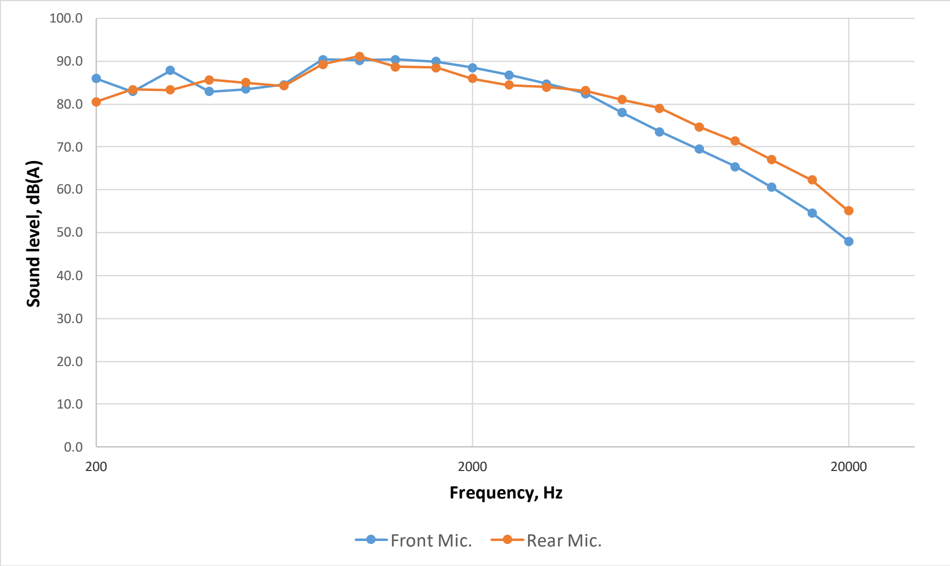

Figure A1.22: Michelin CrossClimate+. Speed = 80 km/h, Tyre inflation pressure = 190 kPa

Table A1.22: Speed = 80 km/h, Tyre inflation pressure = 190 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	85.9	80.6	83.2
250	82.9	83.4	83.1
315	87.8	83.3	85.5
400	83.0	85.7	84.3
500	83.5	85.0	84.3
630	84.6	84.3	84.4
800	90.4	89.2	89.8
1000	90.2	91.1	90.6
1250	90.4	88.7	89.5
1600	89.9	88.5	89.2
2000	88.5	86.0	87.2
2500	86.8	84.5	85.6
3150	84.7	84.0	84.3
4000	82.5	83.1	82.8
5000	78.0	81.0	79.5
6300	73.6	79.0	76.3
8000	69.5	74.7	72.1
10000	65.4	71.3	68.4
12500	60.6	67.0	63.8
16000	54.6	62.3	58.5
20000	48.0	55.1	51.5
LA=	**99.0**	**98.1**	**98.6**

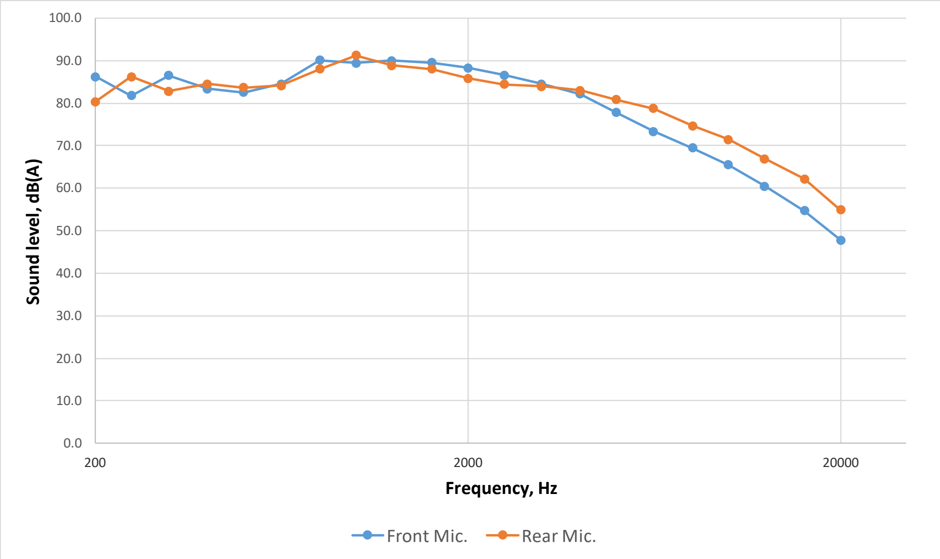

Figure A1.23: Michelin CrossClimate+. Speed = 80 km/h, Tyre inflation pressure = 210 kPa

Table A1.23: Speed = 80 km/h, Tyre inflation pressure = 210 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	86.2	80.3	83.3
250	81.8	86.2	84.0
315	86.5	82.8	84.7
400	83.4	84.5	84.0
500	82.5	83.7	83.1
630	84.5	84.1	84.3
800	90.1	88.0	89.1
1000	89.4	91.2	90.3
1250	90.0	88.9	89.4
1600	89.5	88.1	88.8
2000	88.3	85.8	87.1
2500	86.6	84.4	85.5
3150	84.5	83.9	84.2
4000	82.1	83.0	82.6
5000	77.8	80.8	79.3
6300	73.3	78.8	76.1
8000	69.5	74.7	72.1
10000	65.5	71.5	68.5
12500	60.5	66.9	63.7
16000	54.7	62.2	58.5
20000	47.8	54.9	51.4
LA=	**98.6**	**98.0**	**98.3**

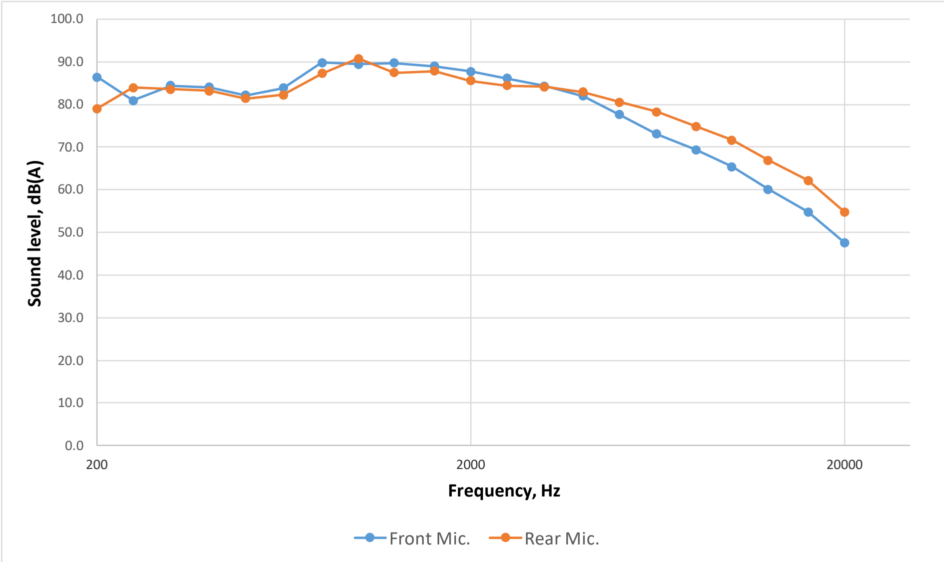

Figure A1.24: Michelin CrossClimate+. Speed = 80 km/h, Tyre inflation pressure = 240 kPa

Table A1.24: Speed = 80 km/h, Tyre inflation pressure = 240 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	86.4	79.1	82.8
250	80.9	83.9	82.4
315	84.4	83.6	84.0
400	84.1	83.2	83.6
500	82.2	81.4	81.8
630	83.9	82.3	83.1
800	89.9	87.3	88.6
1000	89.5	90.7	90.1
1250	89.8	87.5	88.6
1600	89.0	87.8	88.4
2000	87.7	85.5	86.6
2500	86.2	84.4	85.3
3150	84.3	84.1	84.2
4000	81.9	82.9	82.4
5000	77.6	80.5	79.1
6300	73.1	78.3	75.7
8000	69.4	74.8	72.1
10000	65.4	71.7	68.5
12500	60.1	67.0	63.5
16000	54.8	62.2	58.5
20000	47.6	54.8	51.2
LA=	**98.3**	**97.3**	**97.8**

Tyre: Nokian Hakkapeliitta R3.

Table A1.25: Drum test results, Nokian Hakkapeliitta R3

Test speed, km/h	Tyre inflation pressure, kPa	Front dB(A)	Rear dB(A)	Average dB(A)
50	180	92.5	93.5	93.0
80	180	100,1	99.8	99.9
80	190	100.4	100.2	100.3
80	210	100.4	100.3	100.3
80	240	99.4	99.8	99.6

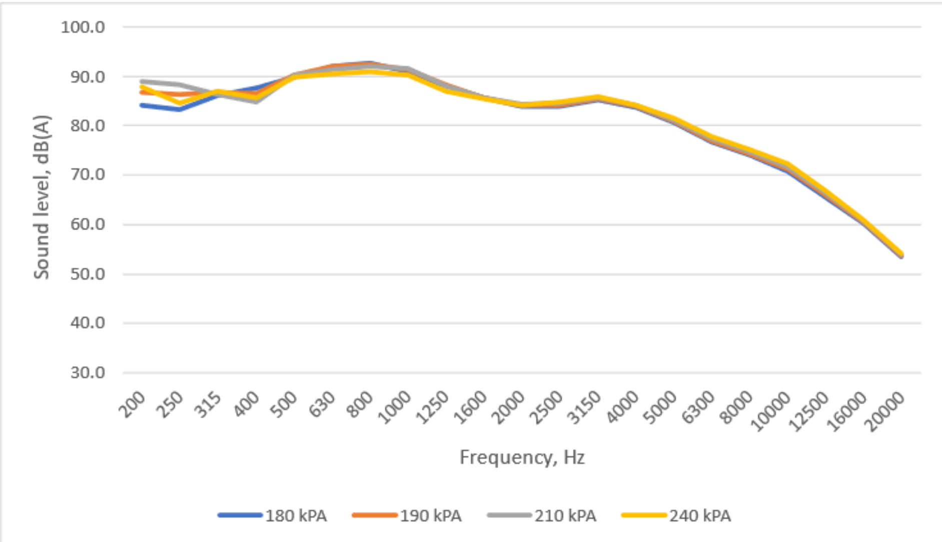

Figure A1.25: Nokian Hakkapeliitta R3. Speed = 80 km/h. Tyre inflation pressure 180 to 240 kPa

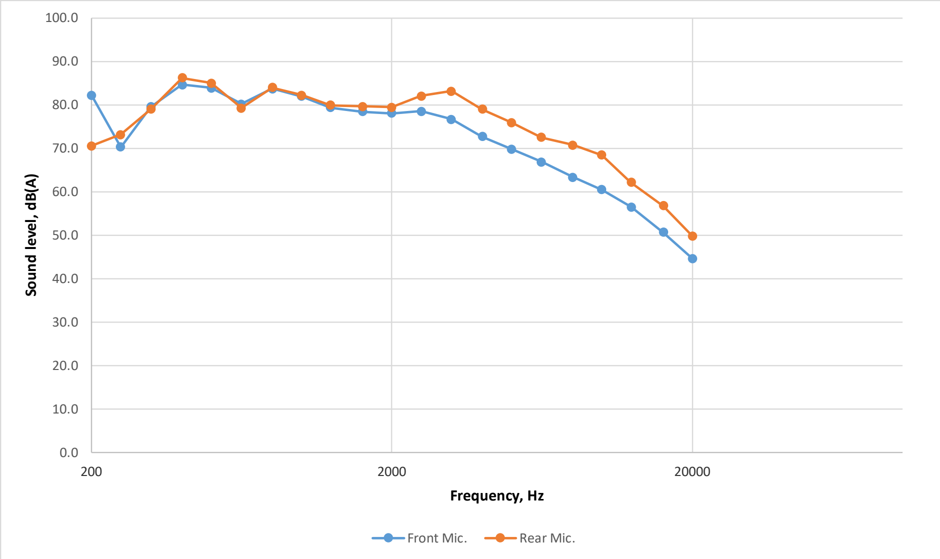

Figure A1.26: Nokian Hakkapeliitta R3. Speed = 50 km/h, Tyre inflation pressure = 180 kPa

Table A1.26: Speed = 50 km/h, Tyre inflation pressure = 180 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	82.2	70.6	76.4
250	70.3	73.3	71.8
315	79.6	79.0	79.3
400	84.7	86.3	85.5
500	83.9	85.0	84.5
630	80.3	79.3	79.8
800	83.8	84.1	83.9
1000	82.0	82.3	82.1
1250	79.4	79.9	79.7
1600	78.5	79.6	79.1
2000	78.2	79.5	78.8
2500	78.6	82.1	80.4
3150	76.7	83.2	80.0
4000	72.7	79.0	75.9
5000	69.9	76.0	73.0
6300	66.9	72.6	69.7
8000	63.4	70.8	67.1
10000	60.6	68.5	64.5
12500	56.6	62.2	59.4
16000	50.8	56.8	53.8
20000	44.7	49.9	47.3
LA=	**92.5**	**93.5**	**93.0**

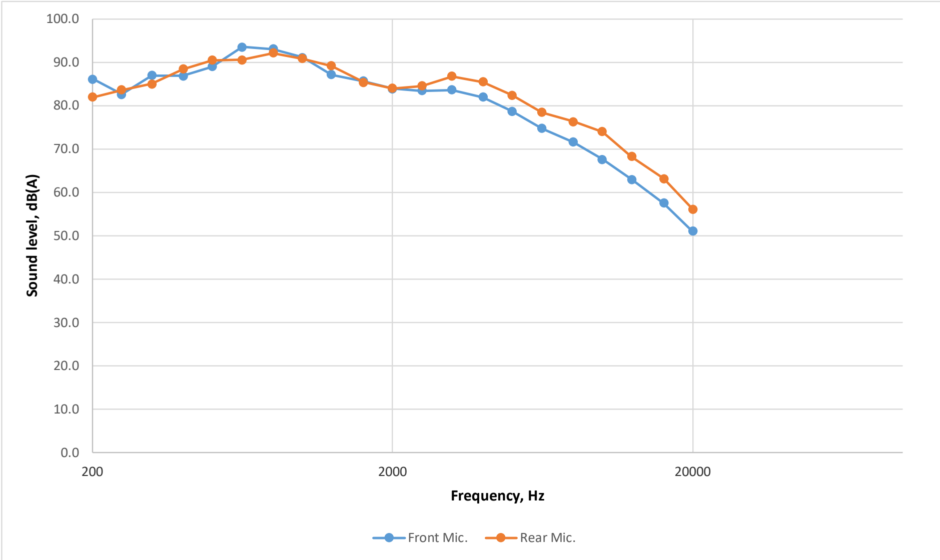

Figure A1.27: Nokian Hakkapeliitta R3. Speed = 80 km/h, Tyre inflation pressure = 180 kPa

Table A1.27: Speed = 80 km/h, Tyre inflation pressure = 180 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	86.2	82.0	84.1
250	82.7	83.7	83.2
315	87.0	85.1	86.0
400	86.9	88.4	87.7
500	89.0	90.5	89.7
630	93.6	90.6	92.1
800	93.1	92.2	92.6
1000	91.2	90.8	91.0
1250	87.2	89.2	88.2
1600	85.7	85.4	85.6
2000	84.0	84.0	84.0
2500	83.5	84.6	84.0
3150	83.6	86.9	85.3
4000	82.0	85.5	83.8
5000	78.8	82.5	80.6
6300	74.8	78.5	76.6
8000	71.6	76.4	74.0
10000	67.7	74.1	70.9
12500	63.0	68.3	65.7
16000	57.6	63.3	60.4
20000	51.1	56.2	53.6
LA=	**100.1**	**99.8**	**99.9**

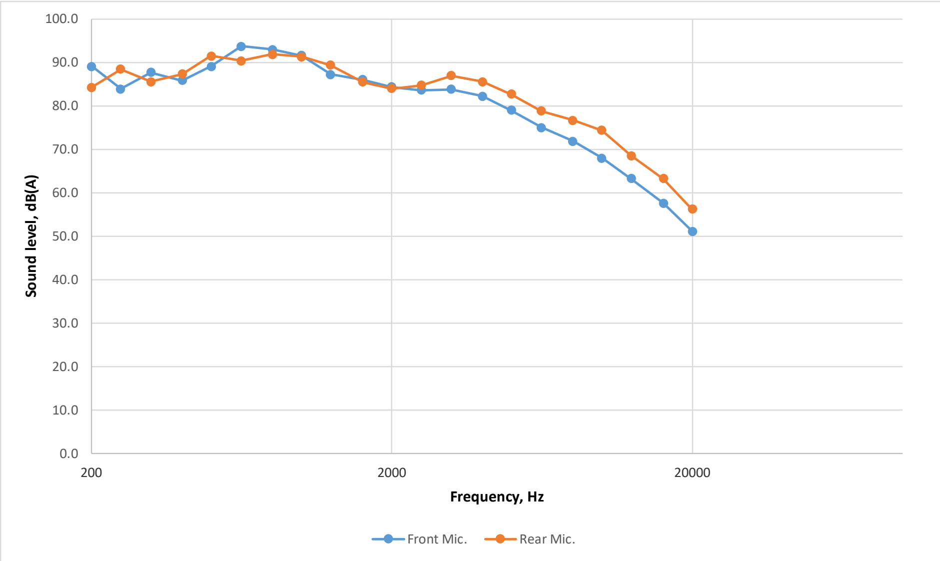

Figure A1.28: Nokian Hakkapeliitta R3. Speed = 80 km/h, Tyre inflation pressure = 190 kPa

Table A1.28: Speed = 80 km/h, Tyre inflation pressure = 190 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	89.1	84.3	86.7
250	84.0	88.5	86.2
315	87.8	85.6	86.7
400	85.9	87.4	86.6
500	89.1	91.5	90.3
630	93.7	90.4	92.1
800	93.0	91.9	92.5
1000	91.6	91.3	91.5
1250	87.3	89.4	88.3
1600	86.1	85.5	85.8
2000	84.4	84.1	84.2
2500	83.7	84.8	84.2
3150	83.9	87.0	85.4
4000	82.3	85.6	84.0
5000	79.0	82.8	80.9
6300	75.1	78.9	77.0
8000	72.0	76.7	74.4
10000	68.1	74.4	71.3
12500	63.3	68.5	65.9
16000	57.7	63.3	60.5
20000	51.2	56.3	53.7
LA=	**100.4**	**100.2**	**100.3**

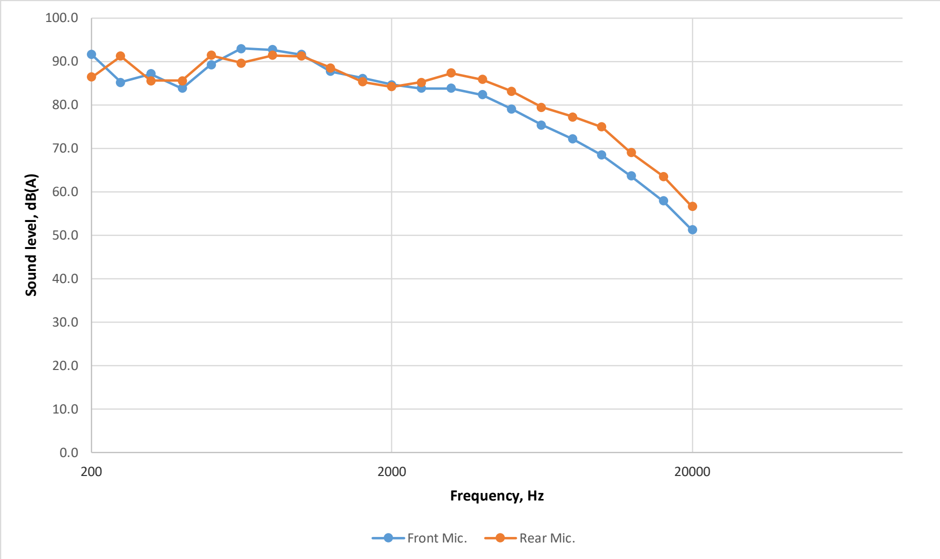

Figure A1.29: Nokian Hakkapeliitta R3. Speed = 80 km/h, Tyre inflation pressure = 210 kPa

Table A1.29: Speed = 80 km/h, Tyre inflation pressure = 210 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	91.6	86.4	89.0
250	85.3	91.2	88.3
315	87.2	85.6	86.4
400	83.8	85.6	84.7
500	89.3	91.4	90.4
630	93.0	89.7	91.4
800	92.7	91.5	92.1
1000	91.6	91.3	91.5
1250	87.7	88.6	88.2
1600	86.2	85.3	85.8
2000	84.6	84.2	84.4
2500	83.9	85.2	84.6
3150	83.9	87.4	85.6
4000	82.4	85.9	84.1
5000	79.2	83.2	81.2
6300	75.4	79.5	77.4
8000	72.2	77.3	74.8
10000	68.5	74.9	71.7
12500	63.7	69.0	66.3
16000	58.0	63.6	60.8
20000	51.3	56.6	54.0
LA=	**100.4**	**100.3**	**100.3**

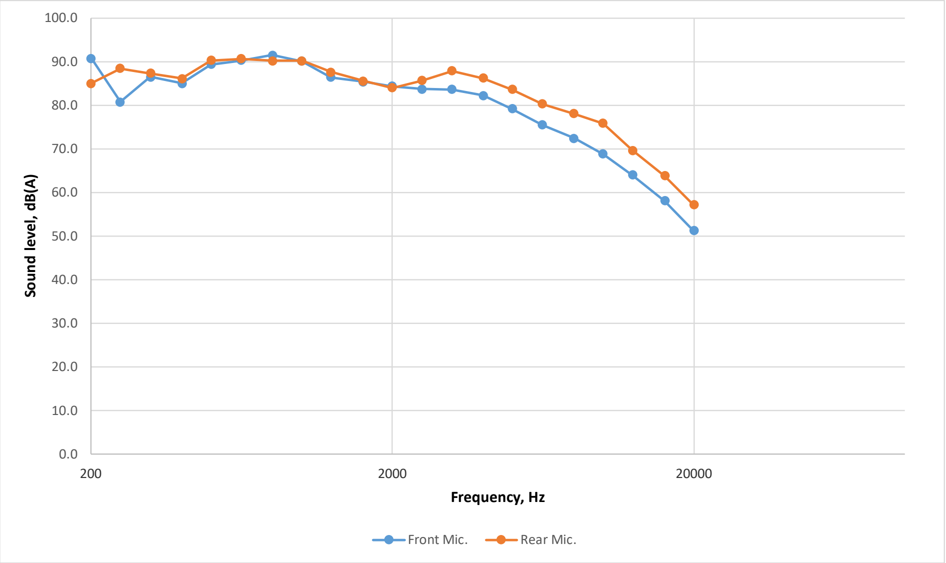

Figure A1.30: Nokian Hakkapeliitta R3. Speed = 80 km/h, Tyre inflation pressure = 240 kPa

Table A1.30: Speed = 80 km/h, Tyre inflation pressure = 240 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	90.8	85.1	87.9
250	80.8	88.5	84.7
315	86.6	87.4	87.0
400	85.1	86.1	85.6
500	89.4	90.3	89.9
630	90.4	90.7	90.5
800	91.6	90.2	90.9
1000	90.2	90.2	90.2
1250	86.4	87.7	87.1
1600	85.4	85.6	85.5

2000	84.4	84.1	84.2
2500	83.8	85.7	84.7
3150	83.7	87.9	85.8
4000	82.2	86.3	84.3
5000	79.2	83.7	81.4
6300	75.5	80.3	77.9
8000	72.4	78.1	75.3
10000	68.9	75.9	72.4
12500	64.0	69.7	66.9
16000	58.1	63.9	61.0
20000	51.2	57.2	54.2
LA=	**99.4**	**99.8**	**99.6**

Tyre: Michelin Primacy 4. All measurements on SMA8 replica

Table A1.31: Drum test results, Michelin Primacy 4. Drum surface: SMA8

Test speed, km/h	Tyre inflation pressure, kPa	Front dB(A)	Rear dB(A)	Average dB(A)
50	180	90.5	90.3	90.4
80	180	97.4	97.8	97.6
80	190	97.4	97.8	97.6
80	210	97.6	97.8	97.7
80	240	97.7	97.3	97.5

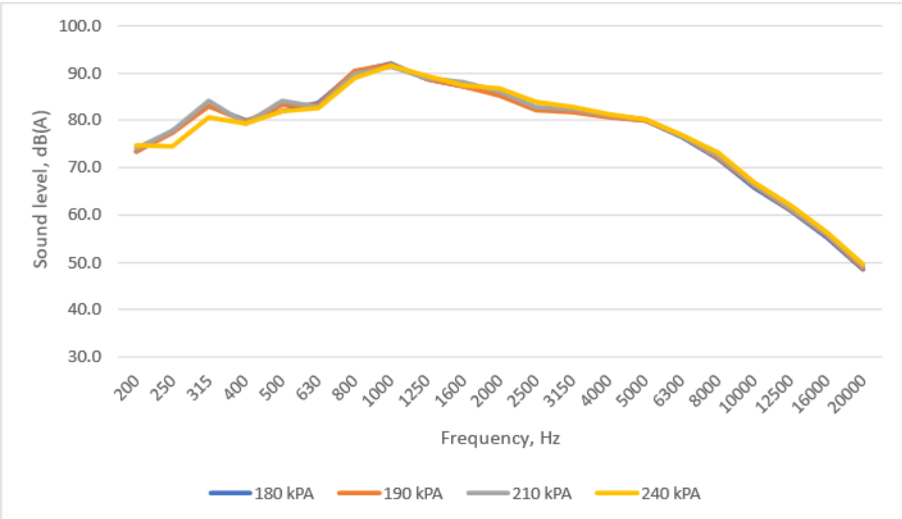

Figure A1.31: Michelin Primacy 4. Speed = 80 km/h, Tyre inflation pressure from 180 to 240 kPa

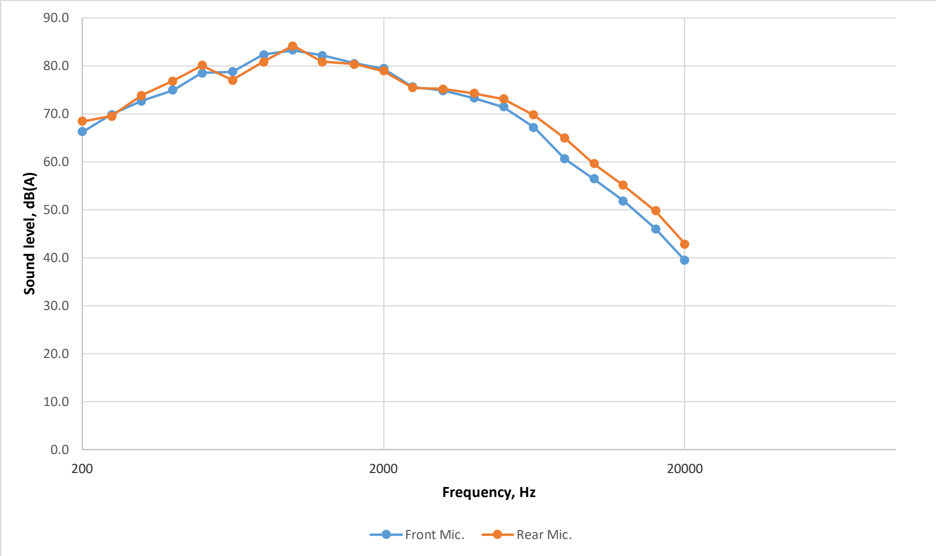

Figure A1.32: Michelin Primacy 4. Speed = 50 km/h, Tyre inflation pressure = 180 kPa

Table A1.32: Speed = 50 km/h, Tyre inflation pressure = 180 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	66.3	68.5	67.4
250	69.9	69.5	69.7
315	72.7	73.9	73.3
400	75.0	76.9	76.0
500	78.5	80.1	79.3
630	78.8	77.0	77.9
800	82.4	80.9	81.6
1000	83.3	84.2	83.7
1250	82.2	80.9	81.6
1600	80.6	80.4	80.5
2000	79.5	78.9	79.2
2500	75.6	75.5	75.6
3150	74.9	75.2	75.1
4000	73.3	74.3	73.8
5000	71.4	73.2	72.3
6300	67.2	69.8	68.5
8000	60.7	65.0	62.8
10000	56.5	59.6	58.0
12500	51.9	55.2	53.6
16000	46.1	49.8	48.0
20000	39.5	42.9	41.2
LA=	**90.5**	**90.3**	**90.4**

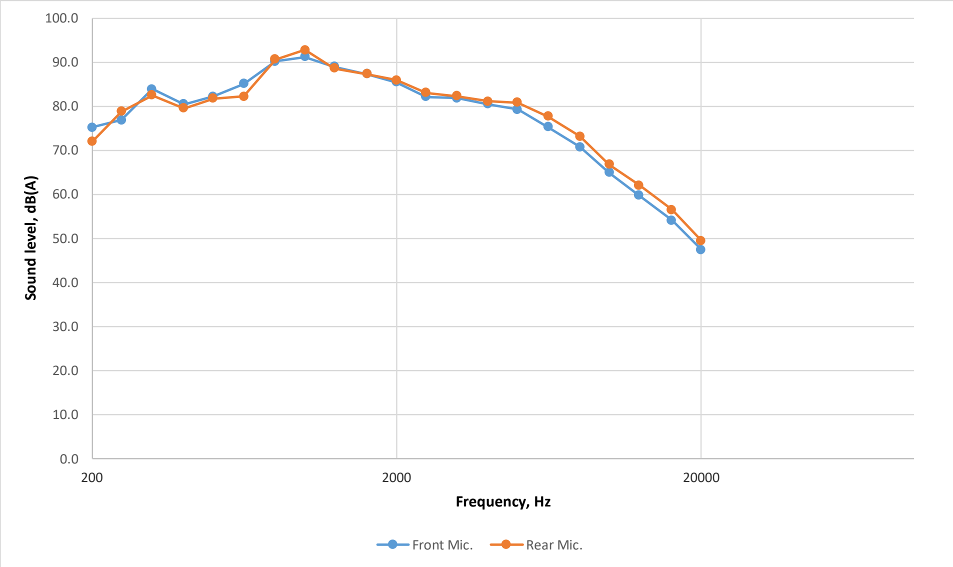

Figure A1.33: Michelin Primacy 4. Speed = 80 km/h, Tyre inflation pressure = 180 kPa

Table A1.33: Speed = 80 km/h, Tyre inflation pressure = 180 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	75.1	71.9	73.5
250	76.9	78.7	77.8
315	83.8	82.5	83.1
400	80.4	79.5	80.0
500	82.2	81.7	81.9
630	85.0	82.2	83.6
800	90.1	90.6	90.4
1000	91.2	92.8	92.0
1250	89.0	88.6	88.8
1600	87.3	87.3	87.3

2000	85.4	85.9	85.7
2500	82.1	83.0	82.5
3150	81.8	82.3	82.1
4000	80.5	81.1	80.8
5000	79.2	80.8	80.0
6300	75.3	77.7	76.5
8000	70.8	73.1	71.9
10000	64.9	66.7	65.8
12500	59.7	62.0	60.9
16000	54.1	56.5	55.3
20000	47.4	49.4	48.4
LA=	**97.4**	**97.8**	**97.6**

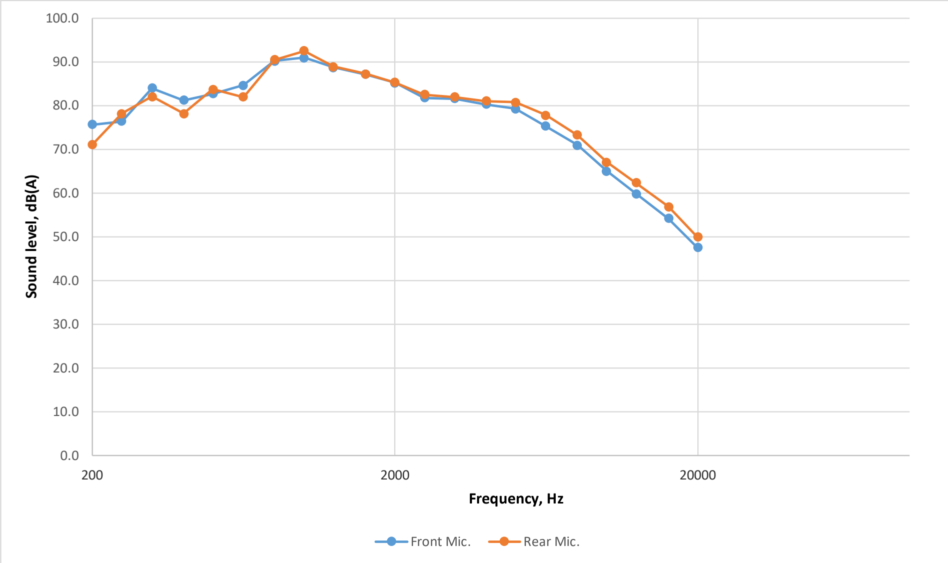

Figure A1.34: Michelin Primacy 4. Speed = 80 km/h, Tyre inflation pressure = 190 kPa

Table A1.34: Speed = 80 km/h, Tyre inflation pressure = 190 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	75.7	71.2	73.5
250	76.4	78.2	77.3
315	84.0	82.1	83.0
400	81.3	78.3	79.8
500	82.7	83.7	83.2
630	84.7	82.0	83.3
800	90.3	90.5	90.4
1000	91.0	92.5	91.8
1250	88.7	89.0	88.8
1600	87.2	87.3	87.3
2000	85.3	85.3	85.3
2500	81.8	82.5	82.2
3150	81.6	82.0	81.8
4000	80.4	81.0	80.7
5000	79.3	80.8	80.1
6300	75.4	77.9	76.6
8000	71.0	73.3	72.2
10000	65.1	67.1	66.1
12500	59.9	62.4	61.2
16000	54.3	57.0	55.6
20000	47.6	50.0	48.8
LA=	**97.4**	**97.8**	**97.6**

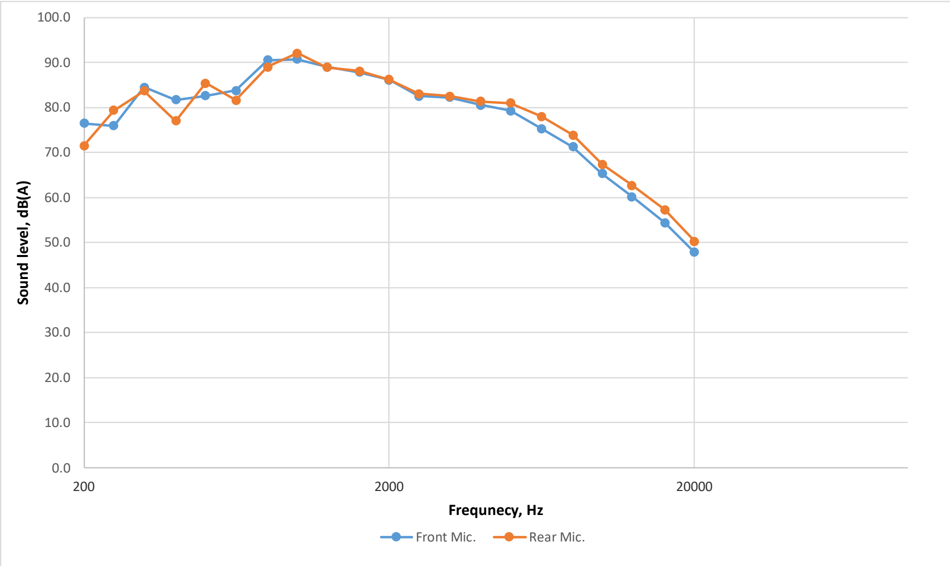

Figure A1.35: Michelin Primacy 4. Speed = 80 km/h, Tyre inflation pressure = 210 kPa

Table A1.35: Speed = 80 km/h, Tyre inflation pressure = 210 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	76.6	71.5	74.0
250	76.0	79.4	77.7
315	84.5	83.7	84.1
400	81.8	77.1	79.4
500	82.6	85.4	84.0
630	83.8	81.7	82.7
800	90.6	89.1	89.8
1000	90.7	92.2	91.4
1250	89.0	88.9	89.0
1600	87.8	88.1	88.0
2000	86.1	86.3	86.2
2500	82.6	83.1	82.9
3150	82.3	82.6	82.4
4000	80.6	81.4	81.0
5000	79.3	81.0	80.2
6300	75.4	78.1	76.7
8000	71.3	73.9	72.6
10000	65.4	67.4	66.4
12500	60.2	62.8	61.5
16000	54.5	57.3	55.9
20000	47.9	50.3	49.1
LA=	**97.6**	**97.8**	**97.7**

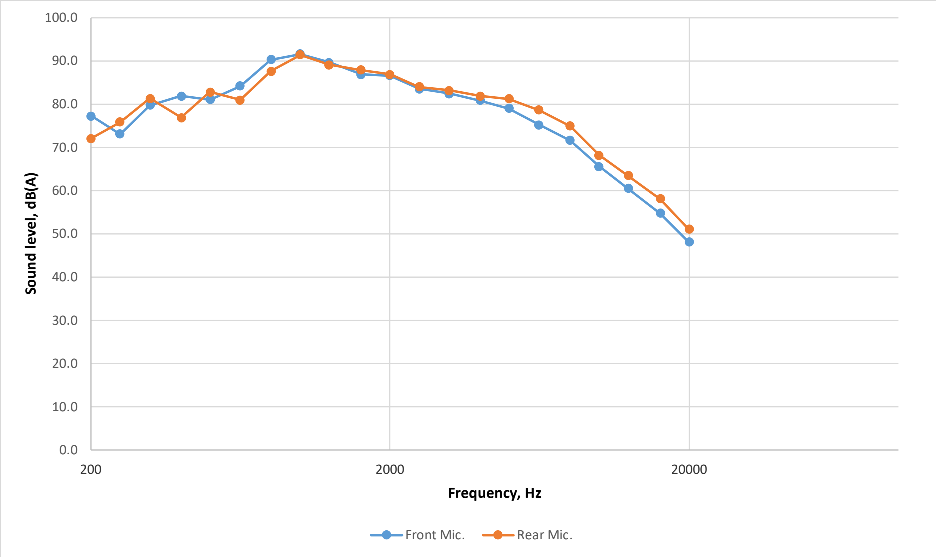

Figure A1.36: Michelin Primacy 4. Speed = 80 km/h, Tyre inflation pressure = 240 kPa

Table A1.36: Speed = 80 km/h, Tyre inflation pressure = 240 kPa

Frequencies	**Front Mic.**	**Rear Mic.**	**Aver.**
[Hz]	**[dB]**	**[dB]**	**[dB]**
200	77.3	72.1	74.7
250	73.1	75.9	74.5
315	79.7	81.4	80.6
400	81.9	76.9	79.4
500	81.1	82.8	81.9
630	84.2	81.0	82.6
800	90.4	87.6	89.0
1000	91.6	91.4	91.5
1250	89.7	89.1	89.4
1600	86.9	87.9	87.4
2000	86.6	86.9	86.7
2500	83.6	84.1	83.8
3150	82.5	83.3	82.9
4000	80.9	81.9	81.4
5000	79.1	81.3	80.2
6300	75.2	78.6	76.9
8000	71.6	74.9	73.3
10000	65.6	68.2	66.9
12500	60.5	63.5	62.0
16000	54.8	58.1	56.5
20000	48.2	51.1	49.7
LA=	**97.7**	**97.3**	**97.5**