



# An investigation of the relationship between texture and tyre/road noise for different types of road surfaces and passenger car tyres

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## ABSTRACT

The texture of the road surface has a major influence on the generation of tyre/road noise. For dense surfaces this may be the most important factor besides the tyre characteristics themselves. Throughout several projects, SINTEF has performed measurements of the tyre/road noise of a wide range of passenger car tyres on different types of road surfaces. These road surfaces are both normally used road surfaces in Norway and road surfaces on test areas. In this paper, some results from the analysis of the relationship between the texture levels and the tyre/road noise levels are presented. In previous investigations it has been found that there is a positive correlation between texture levels at longer wavelengths (like 20–200 mm) and the noise levels, while there is a negative correlation between texture levels at shorter wavelengths (below 8 mm) and the noise levels. In our analysis, the former is confirmed and the latter is found true for some data sets, but not for others. The analysis also shows that the noise from different tyres has a similar relationship with texture, even if the overall noise levels differ.

Keywords: Tyre/road noise

I-INCE Classification of Subjects Number(s): 11.7.1

## 1. INTRODUCTION

Tyre/road noise is a major source of road traffic noise in conditions where the traffic is free-flowing at speeds above 30 km/h (for passenger cars). To reduce this noise source, a combination of a low-noise tyre and a low-noise road surface is the most effective solution. There are different options to develop a low-noise road surface. The most common is to make it sound absorptive through an open-graded porous surface. However, in Norway, and in some of the other Nordic countries like Sweden and Finland, the use of such porous surfaces has faced some serious challenges. Due to the special winter conditions in these countries with extensive use of studded tyres, such porous surfaces are no longer sound absorptive just after 1–2 winter seasons due to clogging of the pores. Until good solutions are found to this problem, the road authorities are looking for other means to reduce the tyre/road noise by using normal dense surfaces. This can be done in several ways; by reducing the maximum aggregate size (e.g. from 16 to 8 mm), by reducing the thickness of the layer ("thin layers") or by a texture optimized top layer.

In this paper, we are studying the relationship between the texture of dense surfaces and the generation of tyre/road noise of different passenger car tyres. The investigation is based on 3 different data sets; measurements at the Kloosterzande test site (1), measurements within the NordTex-project (2), and measurements within the NordTyre-project (final report to be published in the autumn of 2014 by the Danish Road Directorate, DRD). The two last projects include measurements on the most commonly used roads in the Nordic countries. All these test sites were on normally trafficked roads.

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## 2. MEASUREMENTS

### 2.1 Tyre/road noise measurement setup

All measurements have been made using a two-wheeled CPX trailer with a sound absorbing cover, constructed by M+P. This trailer is shown in Figure 1. This means that all noise levels are measured close to the contact area between the tyre and the road surface, and as such, do not take into account the effect of sound propagating from the source to a receiver on the roadside.

Most measurements have been performed at two speeds: 50 and 80 km/h. All levels have been temperature corrected to 20°C using a generic correction factor of  $-0.05 \text{ dB}/^\circ\text{C}$ .

The measurements have been made with a fixed load (325 kg per tyre) on the trailer axle and with a fixed tyre pressure of 200 kPa. These conditions differ from the conditions for type approval of noise levels of tyres (3), where the load shall be 50–90 % of the reference load (given by the load index of the tyre) and the tyre pressure shall be 250 kPa for Class C1 tyres. Normally, this yields a load in the range of 4–600 kg for tyres with a load index of 88–96. The type approval measurements are made with the test tyre fitted on a vehicle and with the noise measurements taken at a microphone position of 7.5 m from the passing vehicle.

These differences in test conditions can influence the noise generation mechanism, due to differences in the footprint of the tyre. If the load is too low, the contact area becomes smaller, and this can reduce the influence of the tyre tread pattern on the sound emitted. This makes it difficult to compare noise levels measured according to the CPX method with the EU labelled noise value of a specific tyre, as the measurement conditions are quite different. The CPX method is basically developed to rank different road surfaces with respect to tyre/road noise levels, based on the use of a "standardised" tyre like the Uniroyal Tigerpaw (SRTT).

The main objective of this investigation is not to compare measured noise levels with the label values of a single tyre, but rather to study the correlation between different texture parameters and the generated tyre/road noise. Even if the CPX measurement conditions differ from type approval conditions, we believe it is relevant to compare the relationship between texture and noise levels for different combinations of tyres and road surfaces.



Figure 1 – The CPX trailer of the Norwegian Public Roads Administration during measurements at the Kloosterzande test track.

### 2.2 Surface texture level measurement setups

The surface texture has been measured with different laser equipment:

- 1) At the Kloosterzande test track: Measurement by M+P, using a stationary laser of type LMI LDS 80/20 M. This laser measures the texture of a length of about 3 m, and 20 parallel profiles can be measured over a width of 0.20 m. This gives a quasi-3D texture picture. The texture is sampled every 0.2 mm.
- 2) On all Norwegian roads, the texture is measured with a laser mounted on a vehicle. The laser is

of the type Optocator Type 2008-180/390A as a part of the measuring system ViaTecPPS. A single profile is measured either in the left or the right wheel track, at a speed of 40 km/h. The sample frequency is 32 kHz. At one location in Norway, both the stationary M+P laser and the Norwegian laser were used to compare results regarding texture spectra and Mean Profile Depth (MPD). The two systems gave very similar results, which indicate that their results may be directly compared.

- 3) The laser by the Danish Road Directorate is of a type LMI Selcom 2207-64/180-P with a sampling frequency of 74 kHz. It has been used for measurements within the NordTex and NordTyre projects on Swedish and Danish roads. During the measurement analysis from the NordTex/NordTyre data sets, it was found that the DRD had used an enveloping technique, which influenced the results in the short texture wavelength area, giving lower levels. Due to this difference in signal processing, it was decided not to include any analysis of data measured with the DRD laser in this investigation.

## **2.3 Data sets**

### **2.3.1 Kloosterzande data**

The Kloosterzande test area in the Netherlands is a closed part of the N60 and in 2006 a total of 41 different road surfaces were laid here. Each test surface is about 80 m long. The surface types are of many different types: Dense (including an ISO 10844 surface), thin-layers, single- and double-layer porous, surface dressing, and some poroelastic surfaces. In 2009, SINTEF performed measurements of 22 summer car tyres on 23 of the 41 different road surfaces (1). The surfaces included 6 dense, 4 thin-layer, 5 single-layer porous, and 7 double-layer porous surfaces, with the addition of and one new poroelastic surface (Rollpave).

The tyres included "budget" types of tyre brands (Barum, Sportiva, Dayton), "medium" brands (Hankook, Toyo, Yokohama, Firestone) and "premium" brands (Michelin, Continental, Good Year, Pirelli). Tyre sizes varied from 175/70 R14 up to 215/55 R16. The CPX reference tyres Uniroyal Tigerpaw/SRTT (225/60 R16) and Avon AV4 (195R14) were also part of the test tyres.

### **2.3.2 The NordTyre data**

In this project, a total of 31 passenger car tyres were measured on 10 Norwegian dense road surfaces, 5 Swedish dense surfaces (including the ISO 10844 surface at the Volvo test track at Hällered), and 15 surfaces in Denmark (14 SMA/DAC and 1 porous surface). Since the texture on the Swedish and Danish road surfaces was measured with the Danish laser, giving somewhat different results from the Norwegian laser as described above, it was decided to only use the noise and texture data from the 10 Norwegian road surfaces in this analysis.

The passenger car tyres selected for measurements were 22 summer tyres, 5 winter tyres, and 4 all-season tyres. The winter tyres were all of Mid-European types, i.e. non-studded.

The tyres included low-priced Asian tyres, medium and premium tyres with dimensions ranging from 155/65 R14 to 225/50 R16. The SRTT tyre was also among the test tyres. All tyres were new and unworn except for the required run-in conditions.

The 10 Norwegian road surfaces were 5 SMA with maximum chipping sizes from 6 to 16 mm and 5 DAC with maximum chipping sizes from 6 to 11 mm.

All measurements were performed during the summer of 2012.

### **2.3.3 The NordTex data**

In the NordTex project, only two types of tyres were included in the test program; Avon ZV1, also known as "Tyre A" in the former draft version of the CPX standard (ISO/CD 11819-2 from 2000) and the Uniroyal Tigerpaw/SRTT replacing the Avon ZV1 in the new version of the CPX standard (4).

The data set contains of 37 Norwegian road surfaces (SMA, DAC, and thin-layer) measured with the Avon ZV1 tyre, and 16 Norwegian road surfaces (largely SMA) measured with the SRTT tyre. The maximum chipping sizes varied from 6 to 16 mm. All measured CPX noise levels are on road surfaces that are more than 1 year old and that have therefore been exposed to winter conditions and studded tyres. The measurements were performed in 2008.

### 3. STATISTICAL ANALYSIS OF MEASUREMENTS

One classic method has been used throughout the literature to analyse the correlation between *texture levels* and *tyre/road noise level* (5). In this method, a linear correlation is estimated between the two variables of measured 1/3 octave band texture levels  $L_{\text{tex}}$  at wavelength  $\lambda$  and 1/3 octave band A-weighted CPX noise levels  $L_{A,\text{cpX}}$  at frequency  $f$ . The correlation is estimated over a sample of various measured road surfaces. Such a linear correlation is based on the following assumptions:

- The variables are normally distributed.
- The number of single data points is sufficiently large, normally about 10–15 points per explained variable.
- The standard error between observations and predictions of the model is also normally distributed.

In this method, the linear correlation is typically estimated using Pearson's correlation coefficient  $r$ , which takes values in the interval  $[-1, 1]$ . A value of  $r$  close to 1 indicates a strong *positive* correlation, a value close to  $-1$  indicates a strong *negative* correlation, and a value close to 0 indicates *little* correlation.

In the literature, the typical finding is a strong *positive* correlation between texture and noise level for *long wavelengths* and *low frequencies*, and a strong *negative* correlation for *short wavelengths* and *high frequencies* (5,6). Such typical results are shown in Figure 2.

As we have measurement data from the wide range of data sets described above, we are able to perform this analysis over a wide range of different surface types that have been exposed to varying degrees of wear and tear, over different tyres, and over different vehicle velocities.

The differences in tyre/road noise variation for different groups of road surfaces are not only dependent on variations in texture spectra variations, but also dependent on other road parameters such as maximum aggregate size, layer thickness, porosity, etc. (5,6). However, we did not take this into account in our analysis.

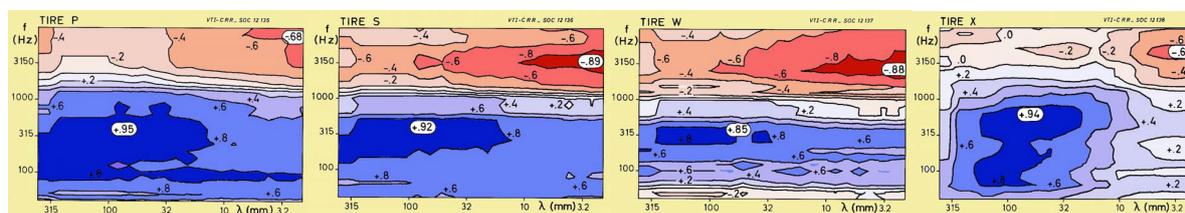


Figure 2 – Typical contour plots of Pearson's  $r$  as function of frequency  $f$  and wavelength  $\lambda$ , for four different tyres. Taken from (6) with permission.

#### 3.1 Kloosterzande measurements

The Kloosterzande data set contains measurements from 4 SMA surfaces, 5 single-layer PAC surfaces, 7 double-layer PAC surfaces, and 4 thin-layer surfaces, in addition to a small number of other surface types which will not be used in this analysis. Since the surfaces are part of a test track, they are relatively unworn.

By analysing the correlation between  $L_{\text{tex}}$  and  $L_{A,\text{cpX}}$  for these surfaces, for measurements performed using SRTT tyres and at speeds of 50 km/h and 80 km/h, we find Pearson's  $r$  values as shown as contour plots in Figure 3.

These results closely resemble those of Figure 2; they indicate a strong positive correlation between texture and noise levels for low frequencies and long wavelengths, and a negative correlation at high frequencies and short wavelengths. The results for both speeds are very similar to each other.

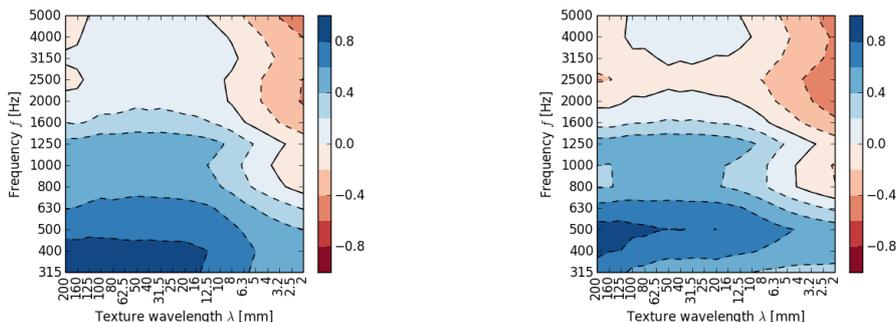


Figure 3 – Contour plots of Pearson's  $r$  for measurements at 50 km/h (left) and 80 km/h (right) at Kloosterzande on a group containing SMA, single- and double-layer PAC, and thin-layer surfaces, using SRTT tyre

However, we believe that this particular analysis is somewhat misleading, as it lumps different surface types together as one. This scepticism is motivated by looking at the data underlying the contour plots in Figure 3, which is shown for two different combinations of frequency and wavelength in Figure 4. The data shown in the latter figure was measured at 80 km/h, though the trends for 50 km/h are similar.

For low  $f$  (long wavelengths) and high  $\lambda$  (short wavelengths), the different groups of surface types have similar texture and noise levels, and all groups have a similar positive correlation between the two variables. However, for high  $f$  and low  $\lambda$ , the groups' texture and noise levels fall into different regions and different correlations between the two variables are found for the different groups.

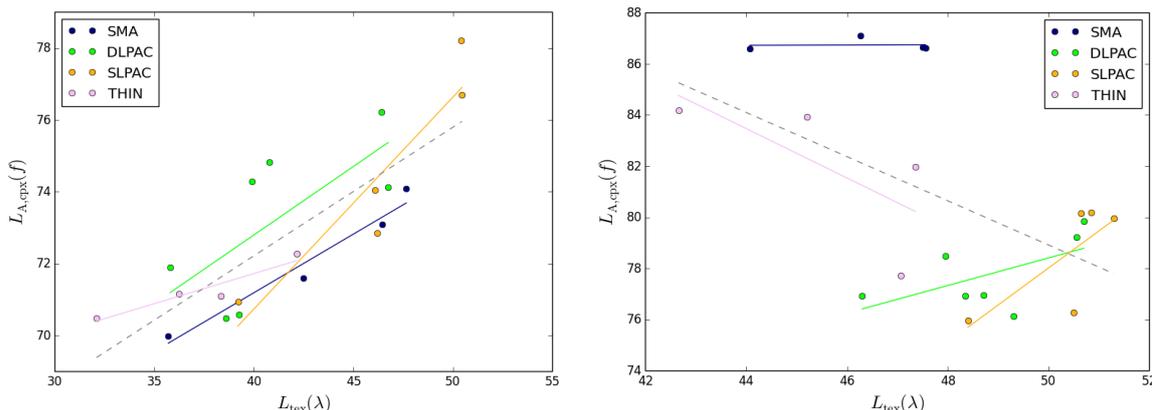


Figure 4 – Underlying data for the rightmost plot in Figure 3, at  $f = 400$  Hz and  $\lambda = 80$  mm (left) and  $f = 2000$  Hz and  $\lambda = 5$  mm (right). Each colour represents one surface type group, with points representing measurements and lines representing a linear regression over these. The dashed grey line represents a linear regression over *all* measurements.

This is an example of Simpson's Paradox, where combining different groups of data into one leads to a different trend than what is found in each group individually: The union of all four surface groups shows a clear negative correlation, while individually only the thin-layer surface group shows such a correlation.

This shows that one must be very careful when performing such an analysis, as different types of road surfaces may not be directly comparable and should not be grouped together. If such a grouping is done, the results of the following analysis may not be usable for optimising the texture of a particular surface type for low noise. In the following analysis, we will always treat groups of surface types separately.

The measurements at Kloosterzande were performed over a large variety of tyres, which were ranked based on measured CPX levels (1). In addition to the SRTT tyre, which performs fairly averagely, we have performed the same analysis with a Michelin Energy Saver tyre, which was ranked as the noisiest tyre on most of the surfaces, and a Toyo Proxes tyre, which was an average-to-silent tyre

on most of the surfaces. (All three tyres were also tested in the NordTyre project and have also been used in that analysis.) Contour plots of Pearson's  $r$  for these tyres on SMA and thin-layer surfaces are shown in Figure 5.

Figure 5, where the surface type groups are kept separate, gives a different impression than Figure 3. The plots for the three tyres on SMA surfaces all show a very strong positive correlation between  $L_{\text{tex}}$  and  $L_{A,\text{cpx}}$  for all frequencies and wavelengths, with the exception of the band around  $f=2500$  Hz for the SRTT tyre. The plots for the three tyres on thin-layer surfaces are more in agreement with the previous literature and Figure 2. Comparing the plots for each surface group across different tyres shows that while the tyres do not behave exactly the same, the same correlation patterns are found for all three. However, when looking at these results it should be kept in mind that the sample size is very small; only four surfaces for each of the surface groups in Figure 5. Based on the requirements for doing such analysis, the small number of samples may bias the results. However, the same analysis was made for a wide range of the 22 tested tyres, with more or less the same results as for the tyres shown here.

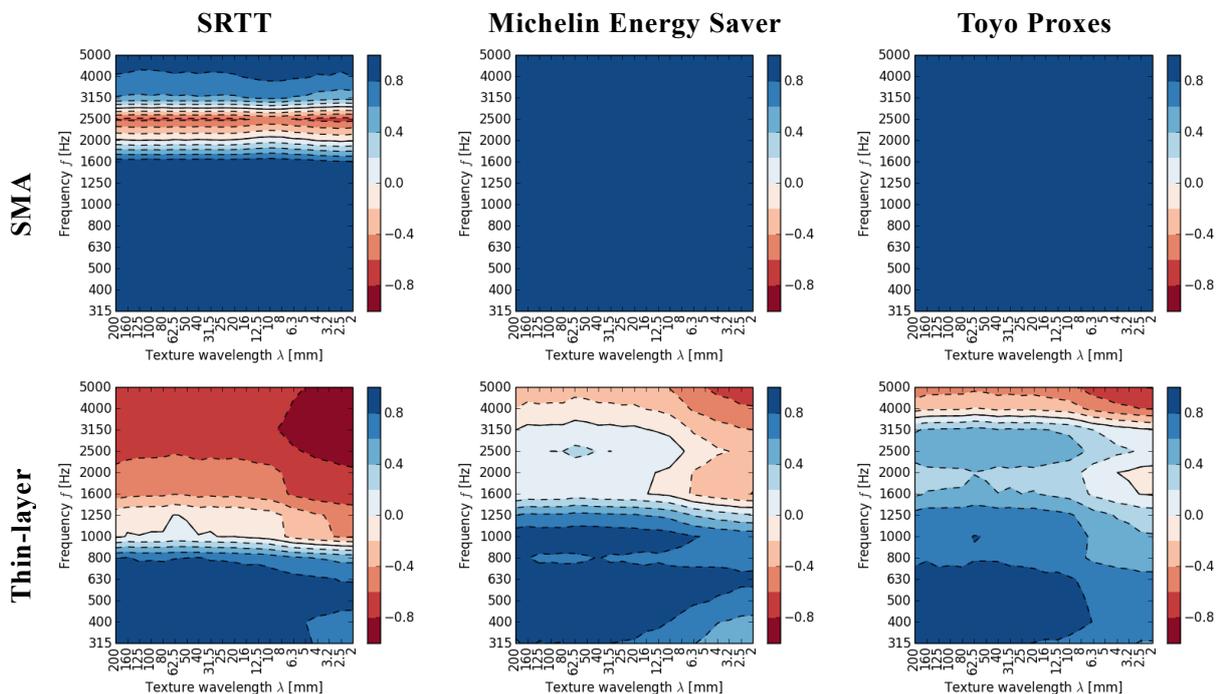


Figure 5 – Contour plots of Pearson's  $r$  for measurements at 80 km/h at Kloosterzande, on groups of 4 SMA and 4 thin-layer surfaces (rows), using three different sets of tyres (columns)

### 3.2 NordTyre measurements

Unlike the measurements at Kloosterzande, the Norwegian data we are using from the NordTyre project were performed on 10 dense surfaces on normal roads, meaning that the surfaces have been exposed to normal wear and tear from traffic. These 10 surfaces consist of 5 SMA surfaces and 5 DAC surfaces.

We use measurement results from the same tyres as in section 3.1, namely the SRTT, Michelin Energy Saver, and Toyo Proxes tyres. All measurements were performed at 80 km/h. Contour plots of Pearson's  $r$  are shown in Figure 6.

The results are consistent with previous results, with the exception of the strong positive correlation seen at high frequencies for Michelin Energy Saver tyres on DAC surfaces.

Again, we see that the contour plots are similar across the different tyres (with the exception of the Michelin Energy Saver tyre on DAC surfaces at high frequencies), while there is a larger difference between the two groups of surfaces.

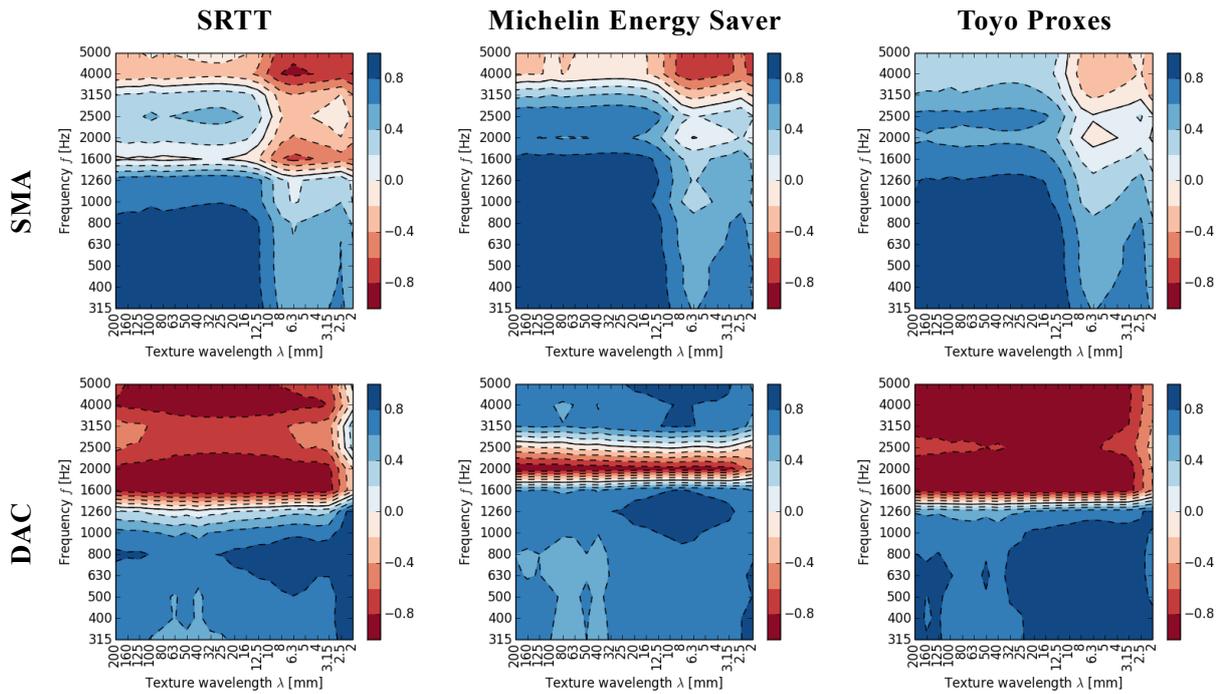


Figure 6 – Contour plots of Pearson's  $r$  for measurements at 80 km/h taken from the NordTyre project, on groups of 5 SMA and 5 DAC surfaces (rows), using three different sets of tyres (columns). (The values at  $\lambda = 2.5$  mm for DAC surfaces were extrapolated due to a clear error in the texture measurements.)

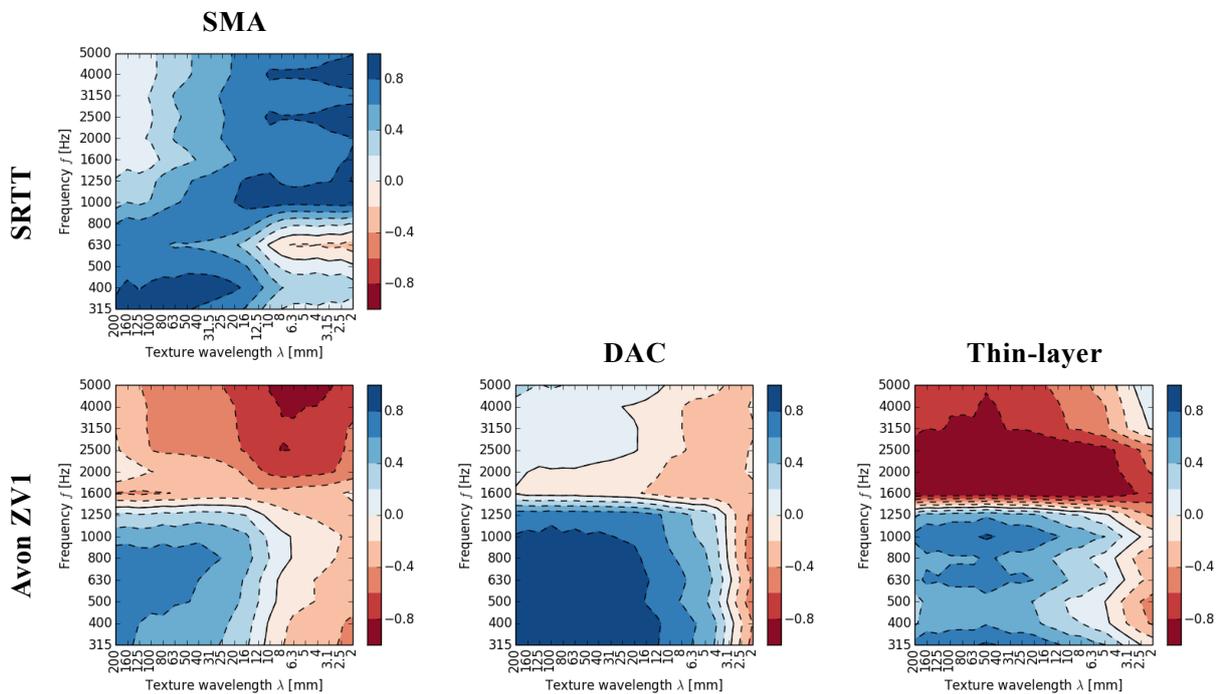


Figure 7 – Contour plots of Pearson's  $r$  for measurements at 50 km/h taken from the NordTex project. Two sets of measurements were used, one with SRTT tyres on 12 SMA surfaces (upper row), and one with Avon ZV1 tyres (lower row) on 20 SMA, 9 DAC, and 5 thin-layer surfaces (columns).

### 3.3 NordTex measurements

The measurements on normally worn Norwegian roads were performed at 50 km/h for two different tyres, each on its own set of roads. Of the 16 measurements performed with SRTT tyres on Norwegian roads, we will use only the 12 measurements on SMA surfaces. Of the 37 measurements performed with Avon ZV1 tyres on Norwegian roads, we will use 20 on SMA surfaces, 9 on DAC surfaces, and 5 on thin-layer surfaces. The resulting contour plots of Pearson's  $r$  are shown in Figure 7.

The Avon ZV1 measurements largely reproduce the established behaviour on every surface. However, the SRTT measurements do *not*; they indicate a strong *positive* correlation between  $L_{\text{tex}}$  and  $L_{A,\text{CPX}}$  for high  $f$  and low  $\lambda$ , similar to the SMA analysis in section 3.1.

## 4. CONCLUSION

The main conclusions from this investigation are:

- When performing an analysis of the relationship between the texture of a road surface and the generated tyre/road noise, one should be careful to put different categories of surfaces, e.g. worn, unworn, dense, porous, and thin-layer surfaces, in separate groups. If all surfaces are put into a single group, the results may be dominated by Simpson's Paradox.
- In all three data sets, we do find a strong positive correlation between tyre/road noise levels at low frequencies (below 800 Hz) and texture levels at long wavelengths (50–200 mm), independent of tyre brand/name. This correlation therefore seems to be robust.
- However, for high frequencies (above 2000 Hz) and short wavelengths (below 10 mm), we observe a large variety of correlations: Strongly negative, weak, and strongly positive. The latter is even observed for the NordTex data set where a relatively large number of measurements were available.
- The analysis indicates that the correlation between texture and tyre/road noise is similar for the various passenger car tyres included in these projects.

It should be noted that all the tyre/road noise measurements presented here have been made according to the CPX method. This means measuring with a fixed tyre pressure (200 kPa) and a fixed load (325 kg), which of course influences the footprint of the contact patch between the tyre and the road surface. This may influence the generated noise levels, depending on the type of road surface tested.

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