Tire Pavement Interaction Noise and Correlation with Pavement Texture Parameters

Presentation by

Dr. Ricardo Burdisso

Lucas Spies[1]; Sterling McBride[2]; Ricardo Burdisso[3]; Corina Sandu[4] and Vincent Bongioanni[5]

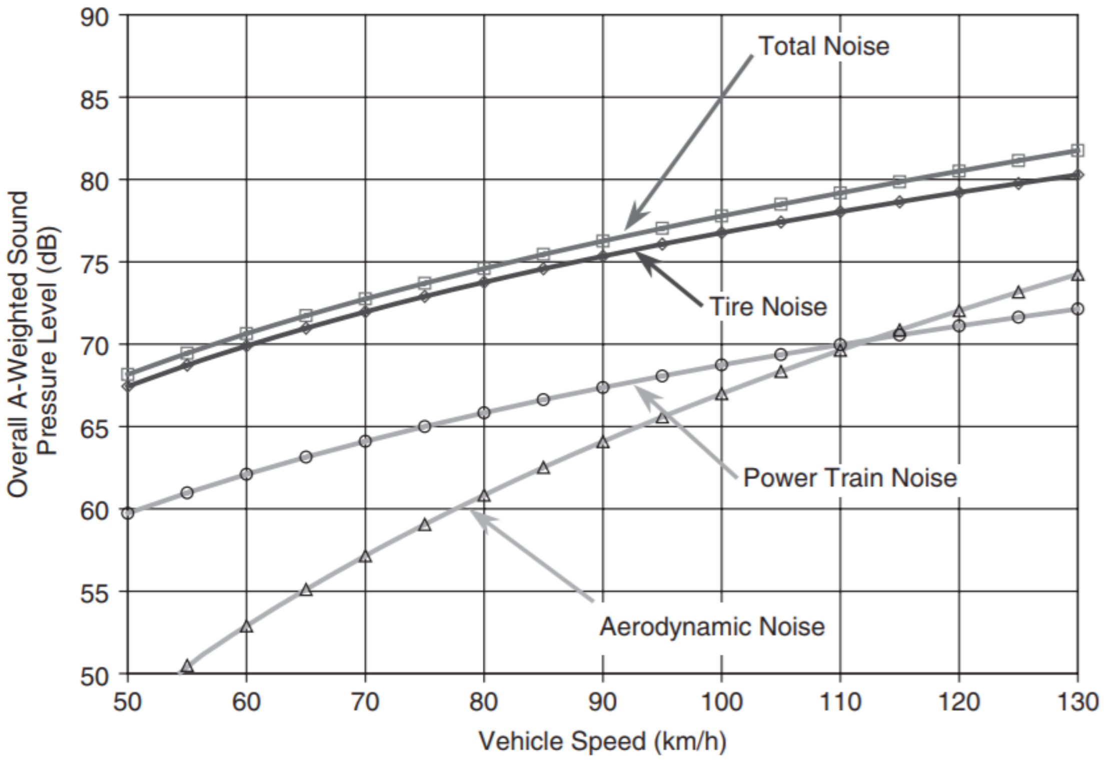
[1]lucass19@vt.edu; [2]msterl6@vt.edu; [3]rburdiss@vt.edu; [4] csandu@vt.edu; [5]VBongioanni@vtti.vt.edu

Outline

- Introduction
- Experiments
- Experimental results
  - Tread and Non-tread pattern noise
  - Relationship between pavement profile and noise
- Discussions

Introduction

- Tire noise is the main contributor to vehicle noise at highway speeds.
- Typical mitigation is to implement acoustic barriers for main highways and roads.
- The main noise sources for tire-pavement noise (TPIN) have not been accurately modeled.
- An experimental TPIN campaign was undertaken at Virginia Tech for:
  - Model development
    - Empirical and physically based predictions
  - Uncover physical insight into TPIN



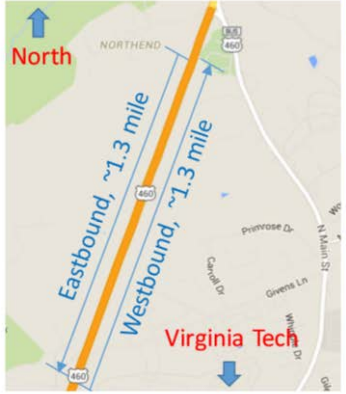
Donavan, P. (2008) - Exterior Noise of Vehicles

Outline

- Introduction
- Experiments
- Experimental results
  - Tread and Non-tread pattern noise
  - Relationship between pavement profile and noise
- Discussions

Experiments: Pavements and Tires

- US460 Road



Dense graded hot mix asphalt (HMA)

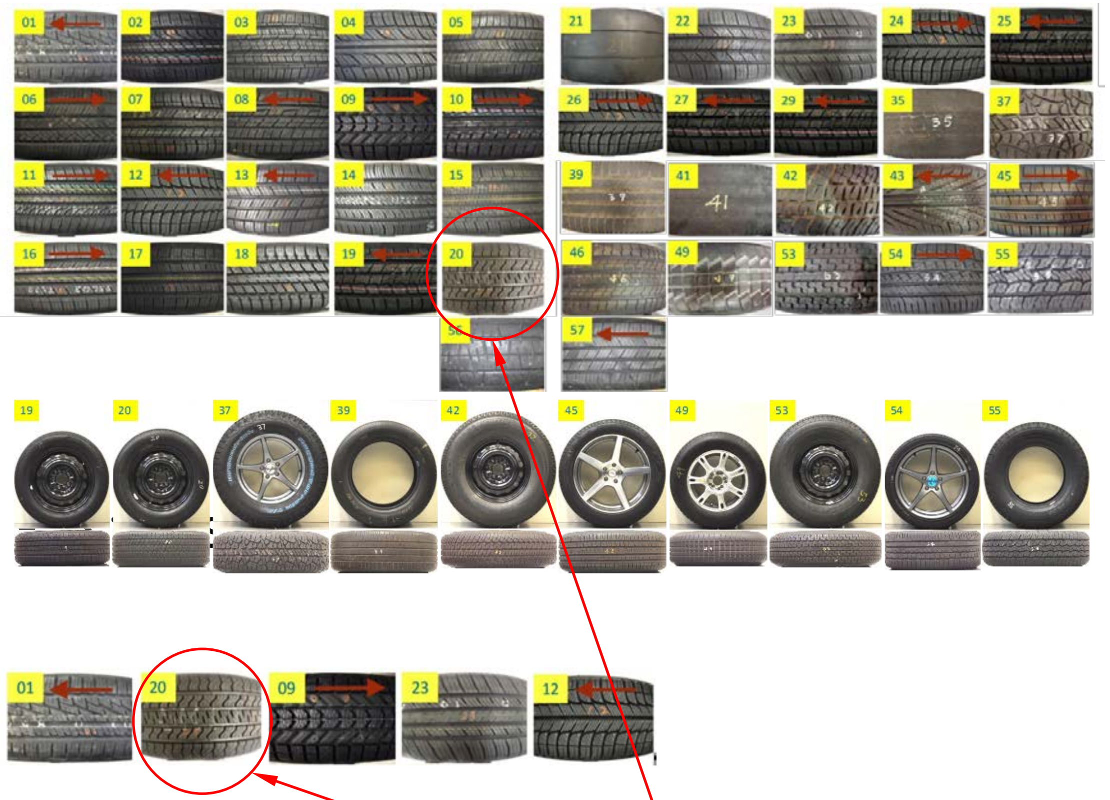
- VT SMART road

26 pavement sections:

- 14 mixes asphalt
- 8 concrete
- 3 bridges

- 1 Open Graded Friction
- 1 concrete section with longitudinal grooves
- 7 concrete sections with transverse grooves

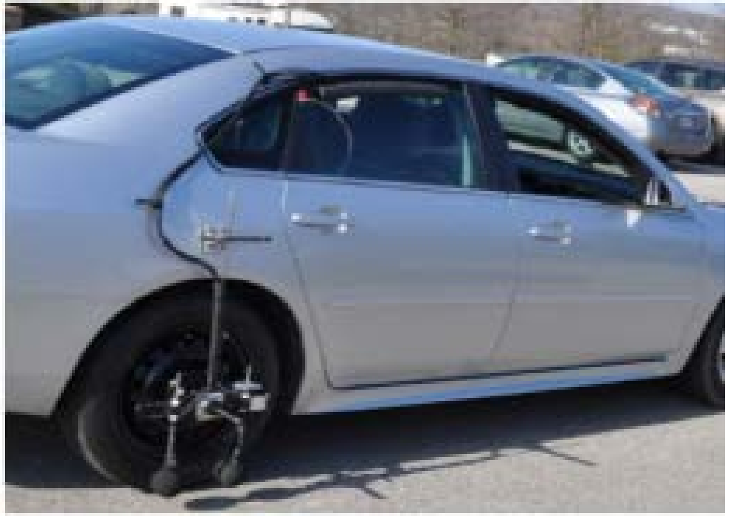
- 42 tires



SRTT Tire was tested in all pavements

Experiments: Test conditions

Test information	
Number of tires	42 8 winter tires 1 SRTT tire 1 slick tire
Hardness range¥	56 to 79 Shore A
Steady state speeds tested	45|50|55|60|65 mph
Acceleration test	45 to 65 mph
Tire pressure¥	26|32|40 psi
Ambient temperature range	37°F to 86°F
For tires with D < 700 mm	2012 Chevrolet Impala (FWD)
For tires with D > 700 mm	2017 Chevrolet Tahoe (AWD)



¥ - Tire pressure, hardness, and temperature measured at start and end of each tire test.

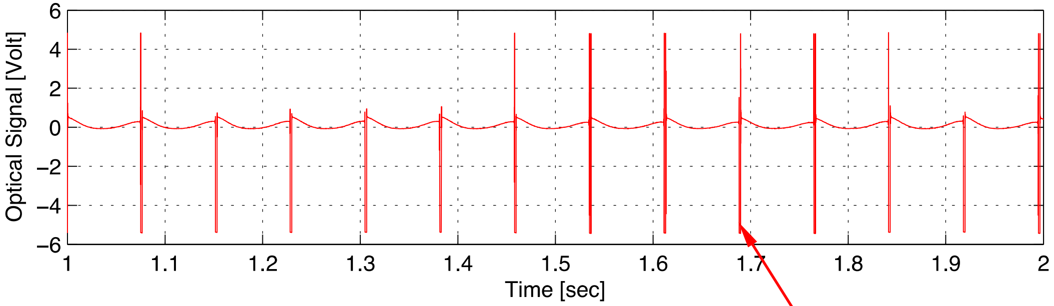
Experiments: Noise Measurements

- Noise: OBSI with optical sensor

Optical sensor and retroreflective tape

Sound intensity probes

- Optical sensor produces a once per revolution signal. It is used to
  - obtain vehicle speed accurately.
  - perform order tracking analysis.



Each peak represents the retroreflective tape going in front of the optical sensor.

OBSI: On-Board Sound Intensity system

Experiments: Pavement Measurements

- Pavement profile data was collected using a Sideway-Force Coefficient Routine Investigation Machine (SCRIM) equipped with a profiling laser.

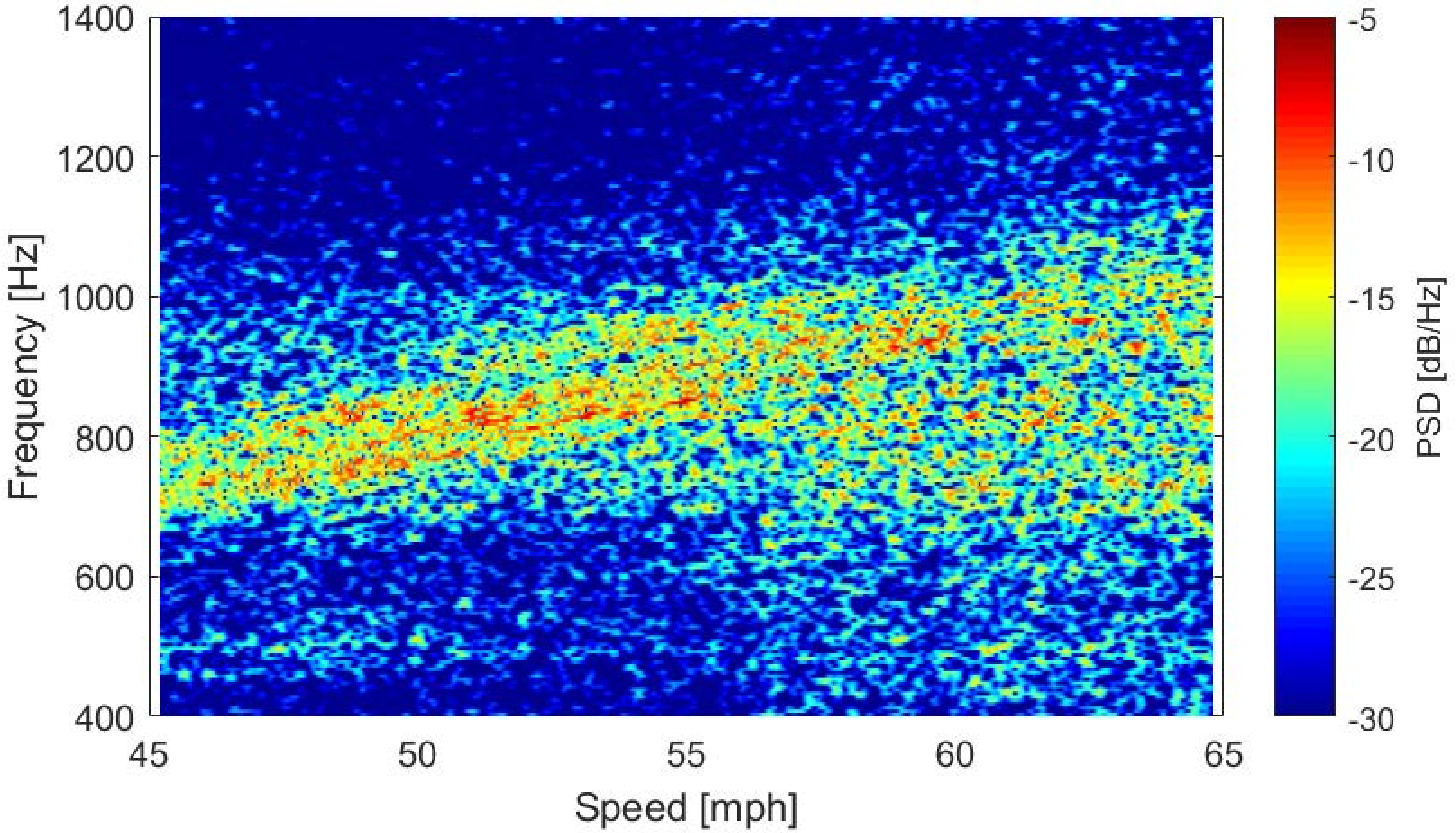
Pavement profile measurement parameters.	
Measurement resolution (after processing)	0.5 - 1 mm
Lowest velocity for noise measurements	45 mph – 20 m/s
Sampling period.	~ 49 microseconds
Sampling frequency	64 kHz

Outline

- Introduction
- Experiments
- Experimental results
  - Tread and Non-tread pattern noise
  - Relationship between pavement profile and noise
- Discussions

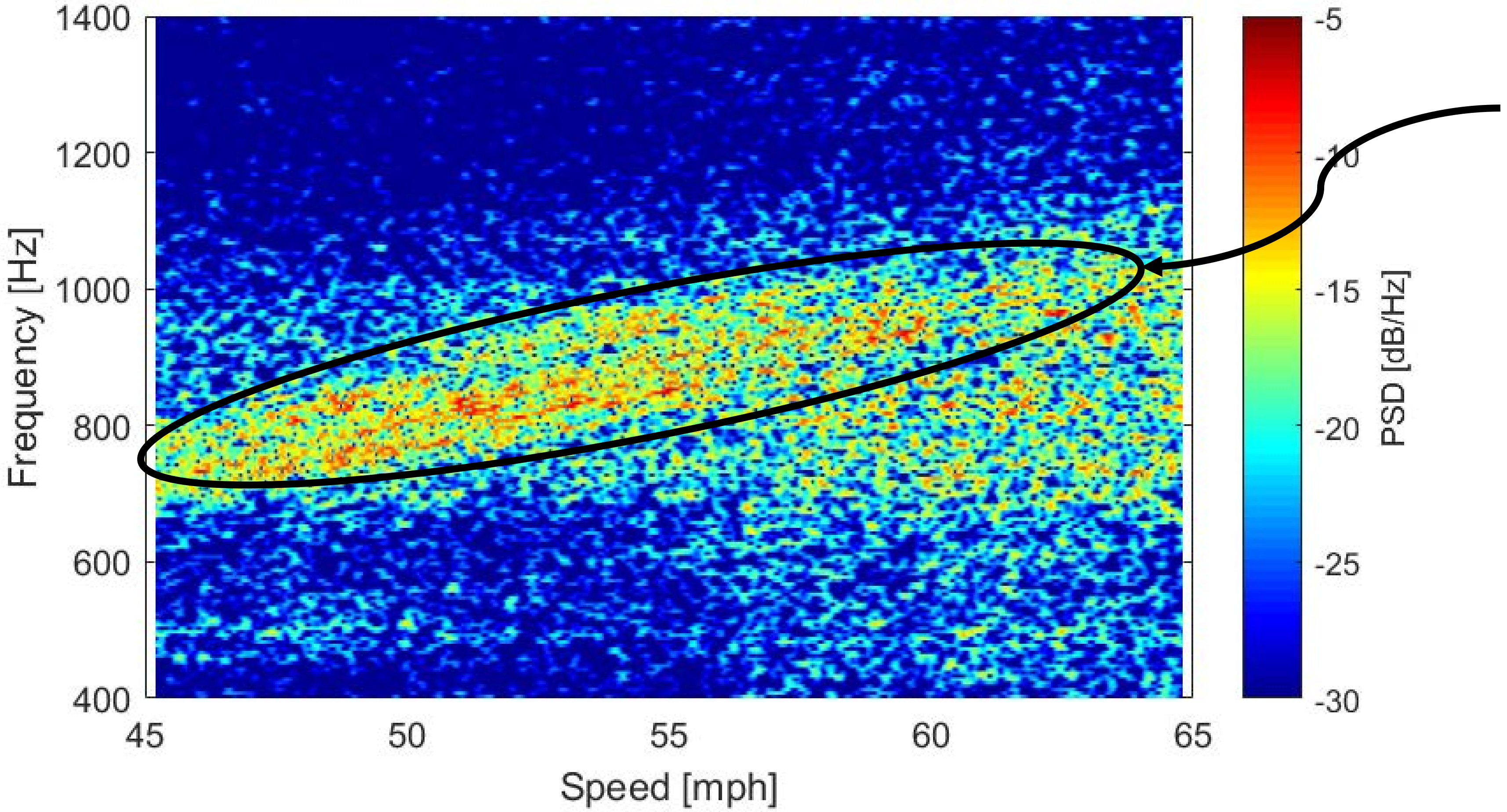
Experiments results: Tread and non-tread pattern Noise

- Noise spectrogram from acceleration test (Tire 12, 45 to 65 mph).



Experiments results: Tread and non-tread pattern Noise

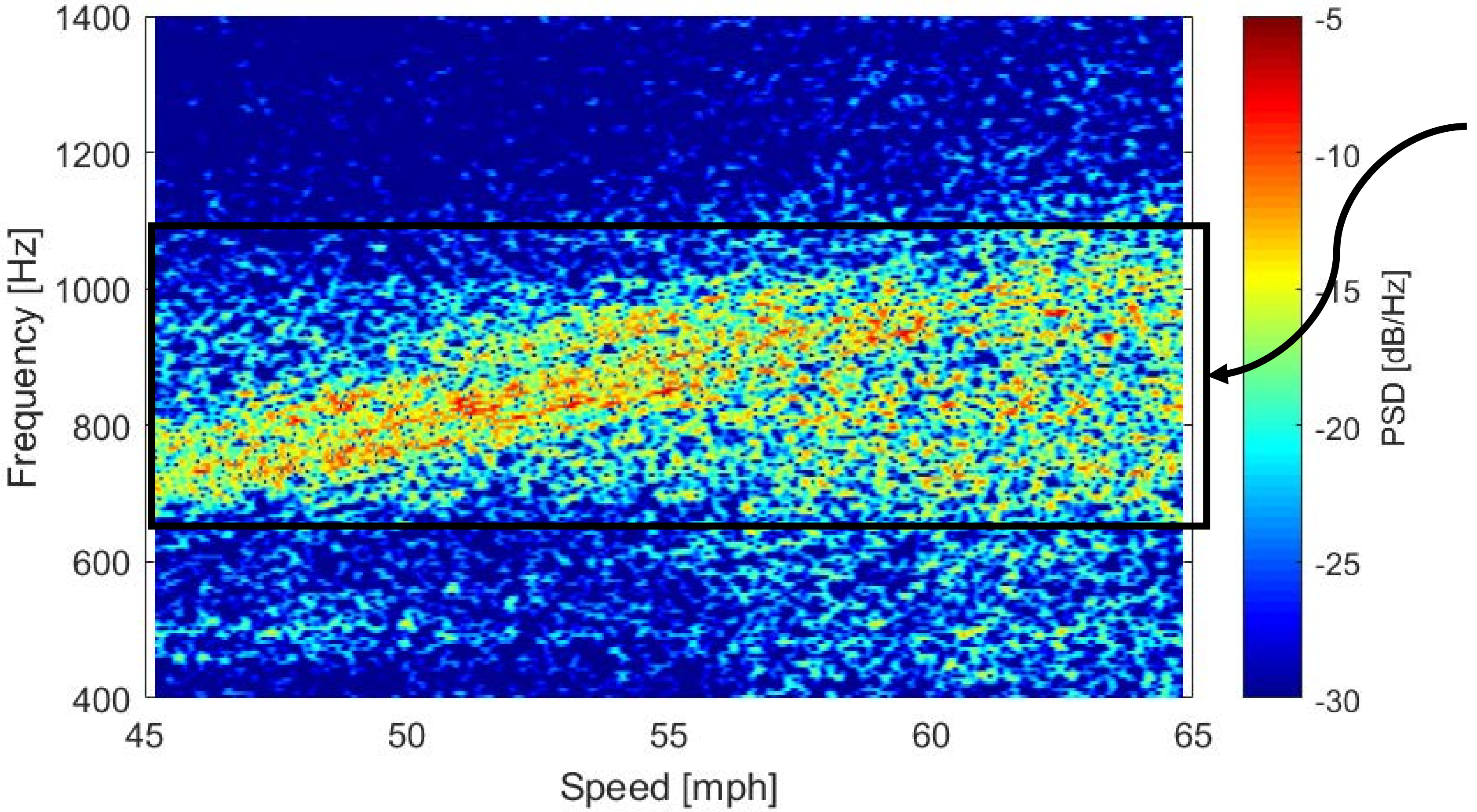
- Noise spectrogram from acceleration test (Tire 12, 45 to 65 mph).



Noise component a function of vehicle speed: amplitude and frequency increases with speed.

Experiments results: Tread and non-tread pattern Noise

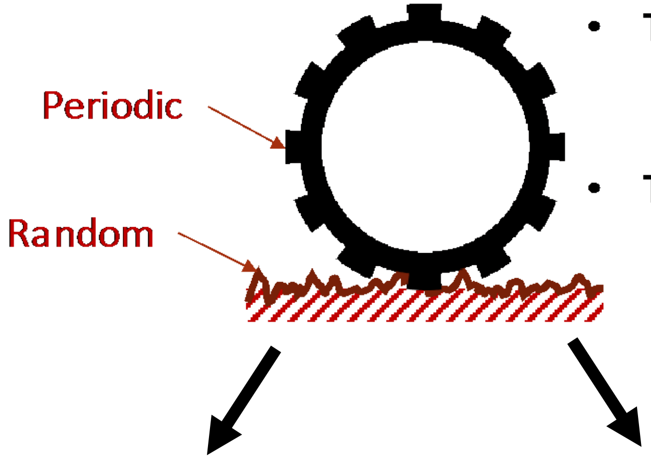
- Noise spectrogram from acceleration test (Tire 12, 45 to 65 mph).



Noise component with frequency content independent of speed. However, amplitude increases with speed.

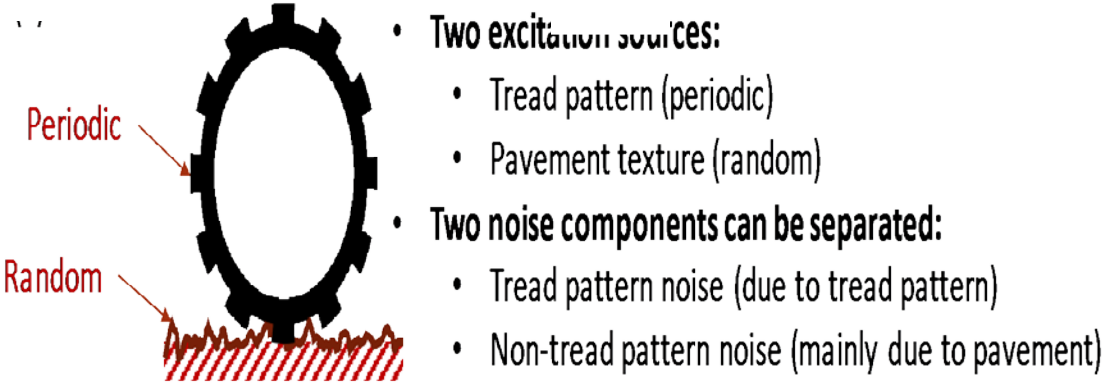
Experiments results: Tread and non-tread pattern Noise

- TPIN can be separated into two components: tread (TPN) and non-tread pattern (NTPN) noise



- **Two excitation sources:**
  - Tread pattern (periodic)
  - Pavement texture (random)
- **Two noise components can be separated:**
  - Tread pattern noise (due to tread pattern)
  - Non-tread pattern noise (mainly due to pavement)

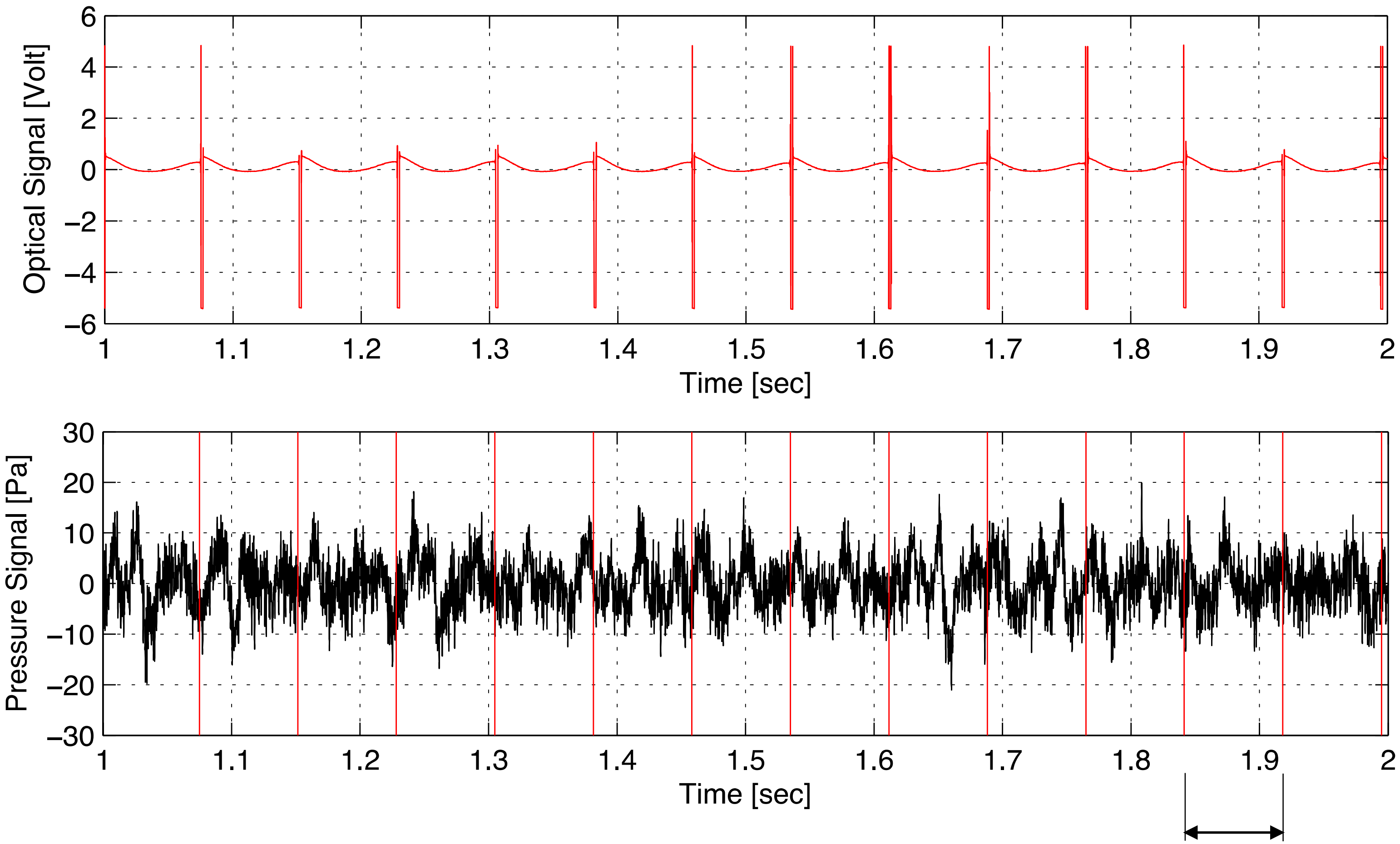
Optical signal used to perform order tracking analysis.



Order tracking analysis allows to extract the tread pattern noise from the total noise signal

Experiments results: Tread and non-tread pattern Noise

- Extraction of TPN noise:



1 revolution of the tire (window).

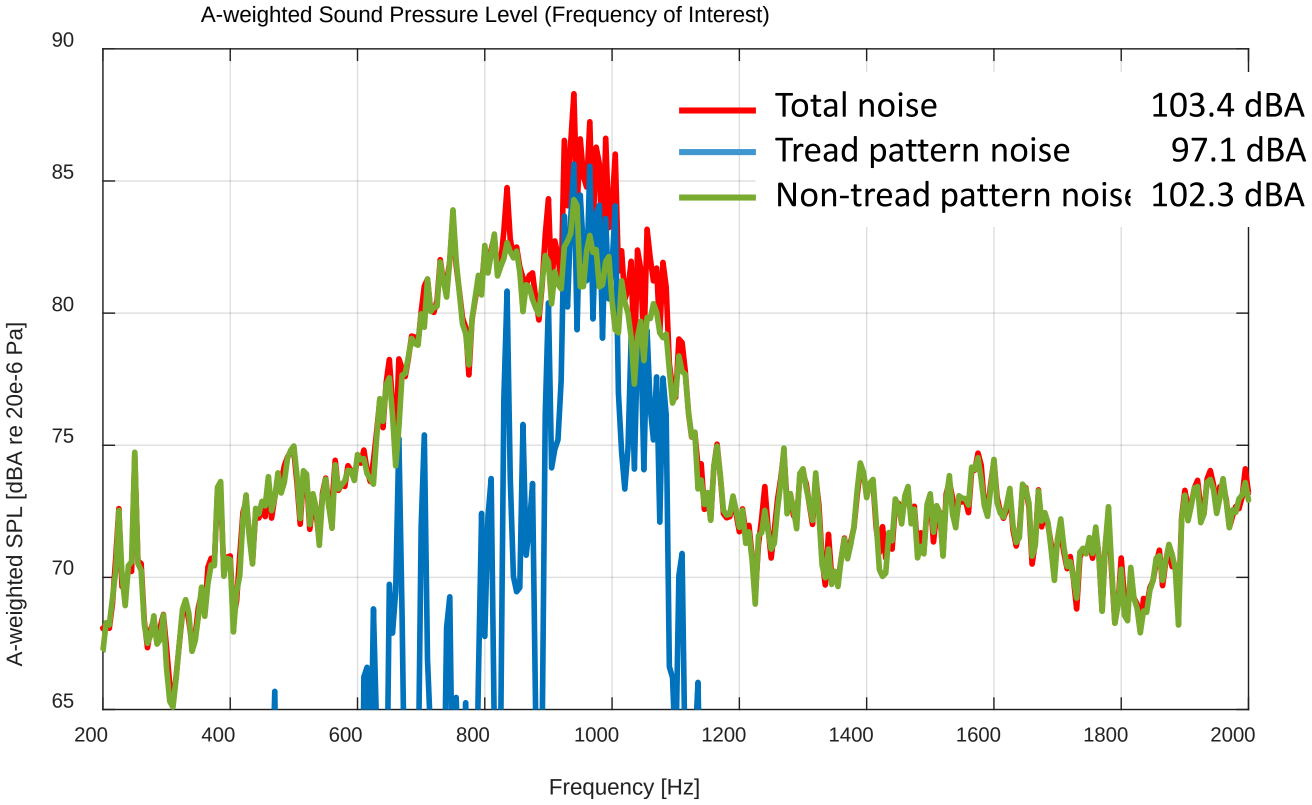
Order tracking analysis:
For each window

- Noise signal resampled
- Compute DFT
- Average DFTs (TPN in frequency domain)
- Take inverse DFT of average DFT (TPN in time domain)
- Subtract TPN signal from total signal (NTPN in time domain)

103.4	97.1	102.3

Experiments results: Tread and non-tread pattern Noise

- Tire noise separation results: winter tire – US460 – 60 mph

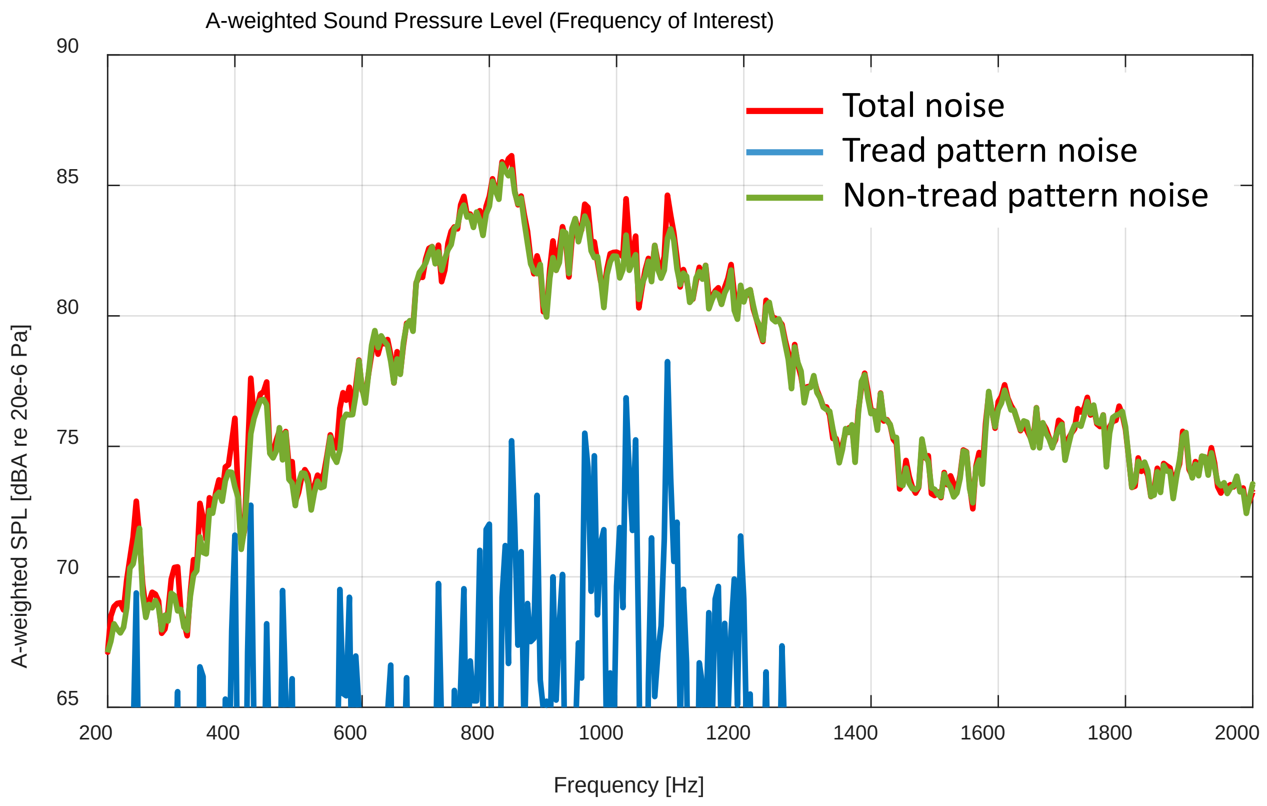


Michelin X-ICE X13
(Winter tire)
215/60R16

TPN accounts for 23.4% of total acoustic energy.

Experiments results: Tread and non-tread pattern Noise

- Tire noise separation results: SRTT – US460 – 60 mph



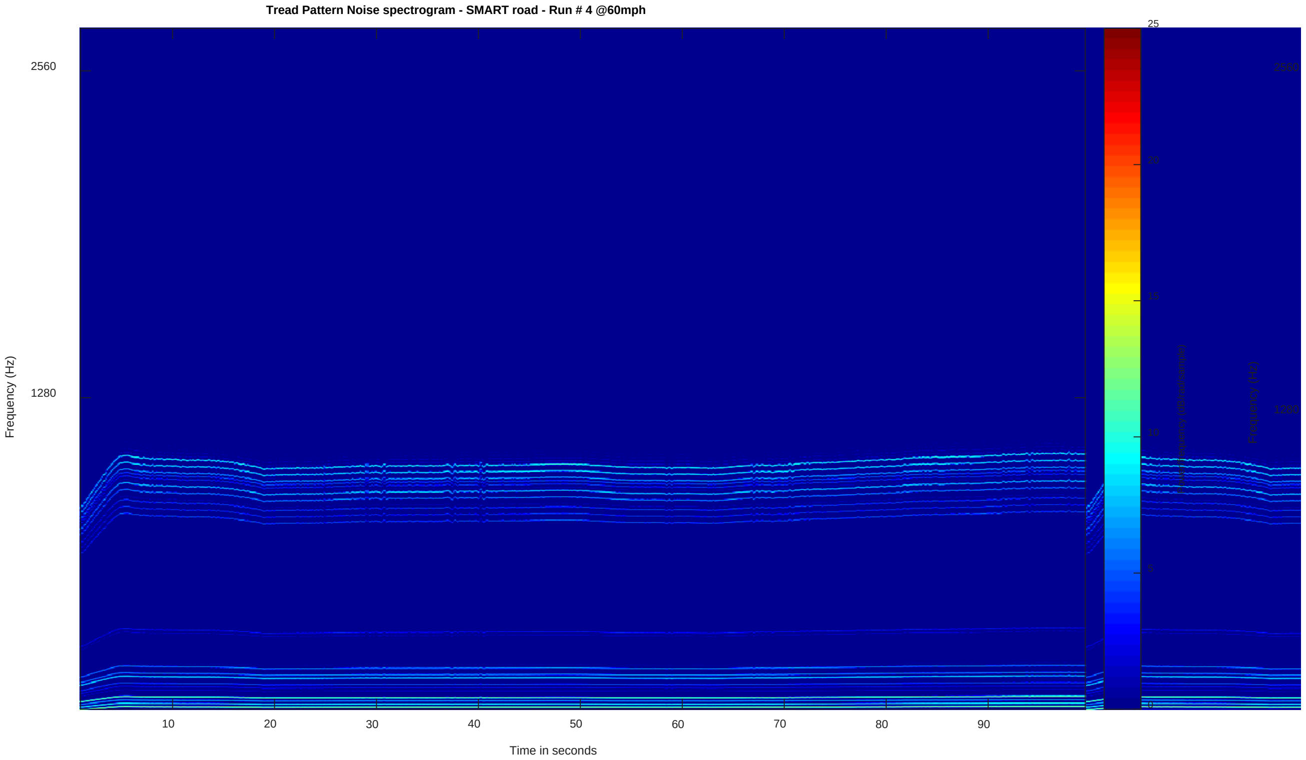
SRTT - Standard Reference Test Tire

TPN accounts for 3.8% of total acoustic energy (for the pavement tested).

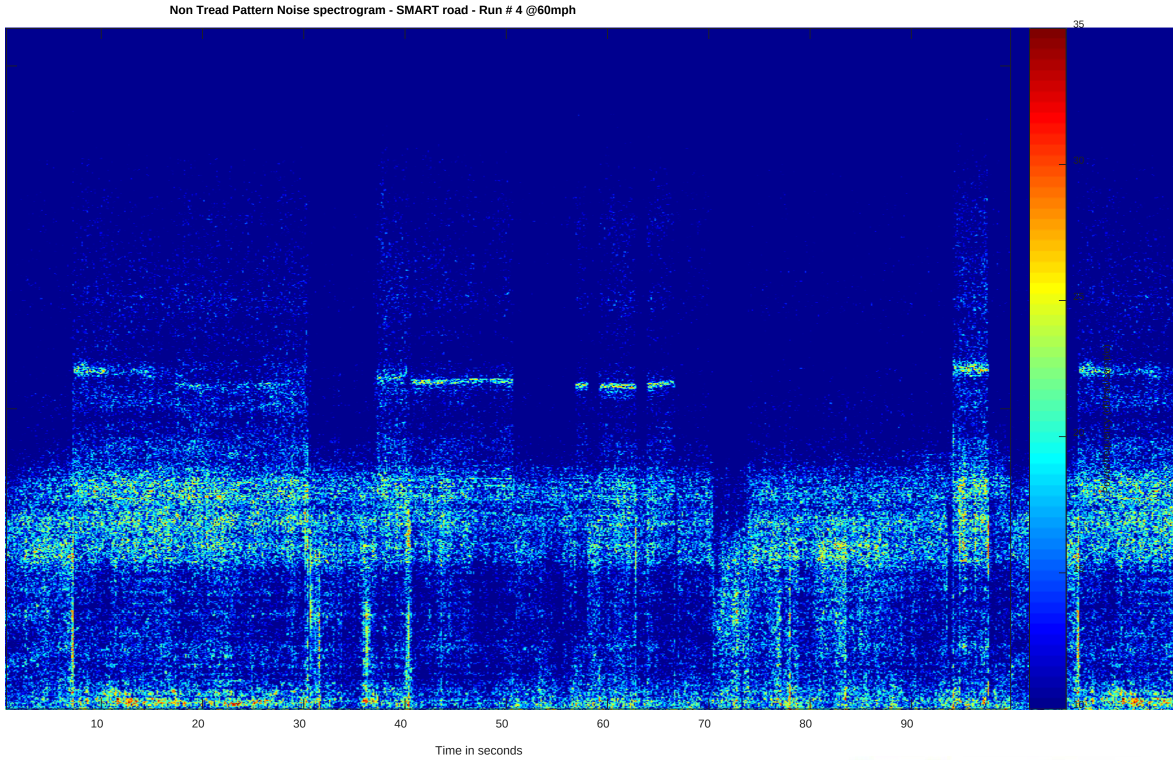
Experiments results: Tread and non-tread pattern Noise

Effect of different pavement surfaces on the TPN and NTPN

Tread pattern noise spectrogram



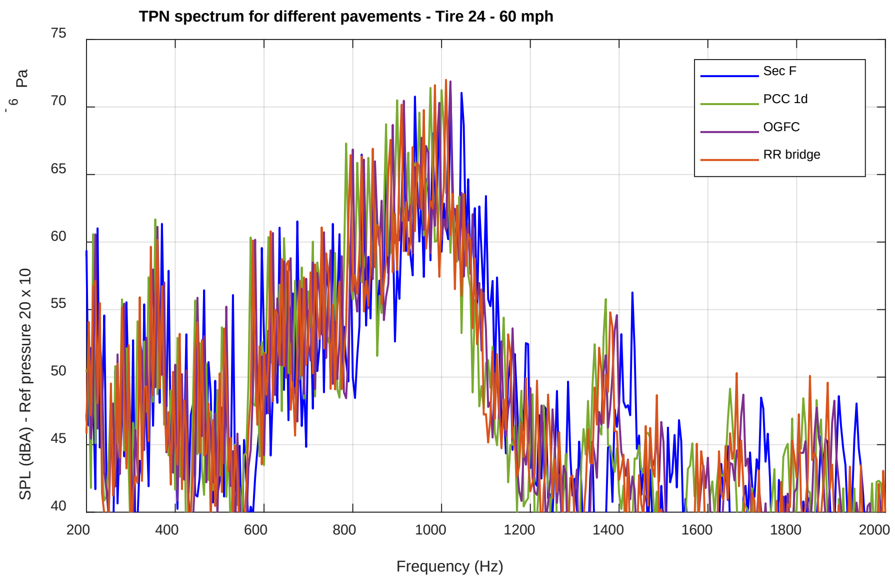
Non-Tread pattern noise spectrogram

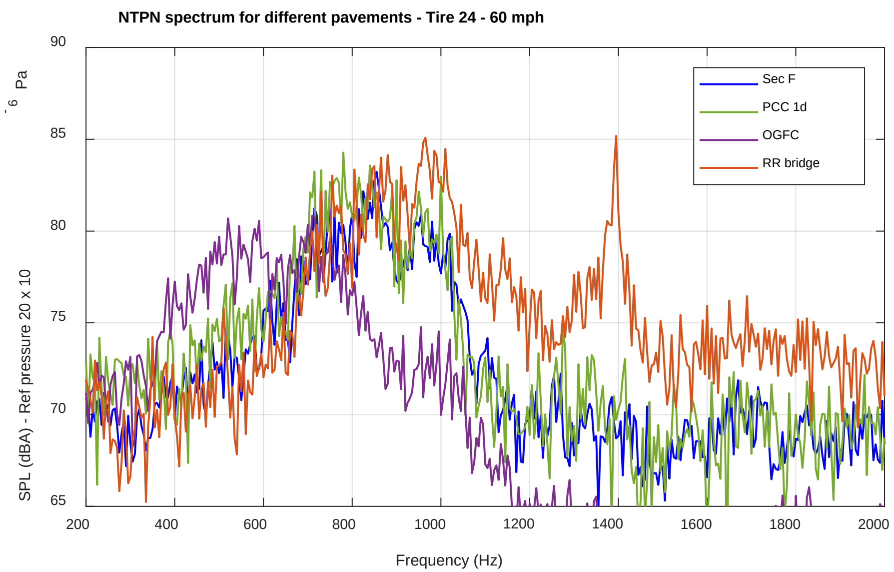


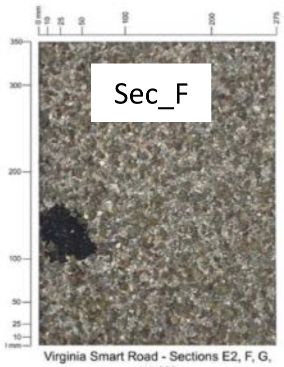
SMART road data – 60 mph

Experiments results: Tread and non-tread pattern Noise

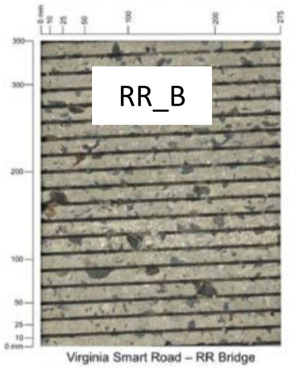
Effect of different pavement surfaces on the TPN and NTPN



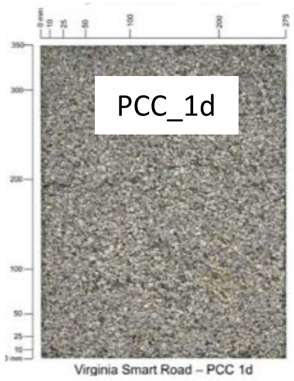




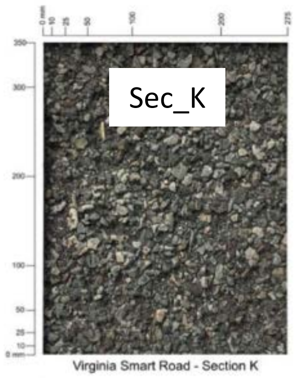
Dense graded HMA



Concrete with transverse grooves



PCC section



OGFC

Experiments results: Tread and non-tread pattern Noise

- TPN is produced only by the tread pattern.
- NTPN is mainly produced by the pavement (independent of tread pattern).
- These observations suggest that the characterization of pavement noise should be based only on the NTPN.
- The rest of the results will focus on NTPN component.

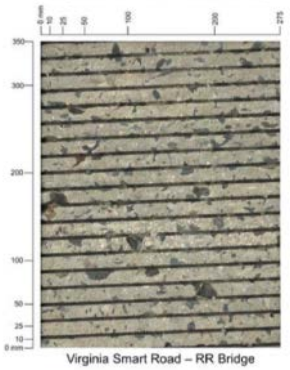
Outline

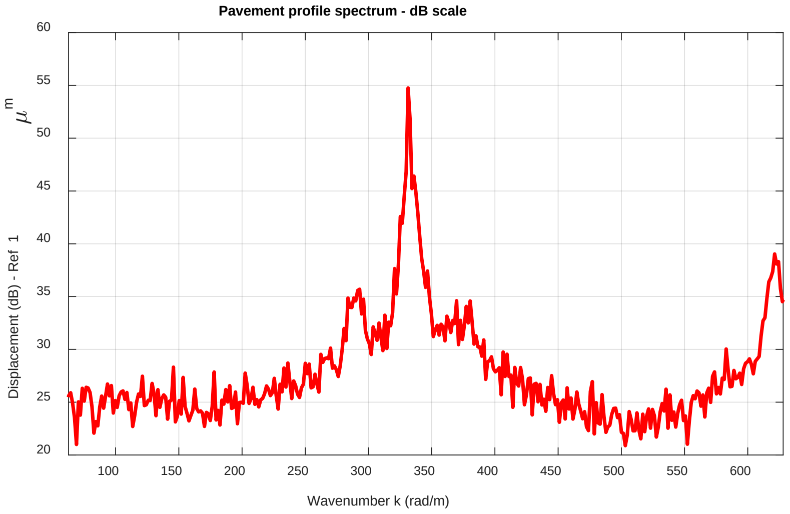
- Introduction
- Experiments
- Experimental results
  - Tread and Non-tread pattern noise
  - Relationship between pavement profile and noise
- Discussions

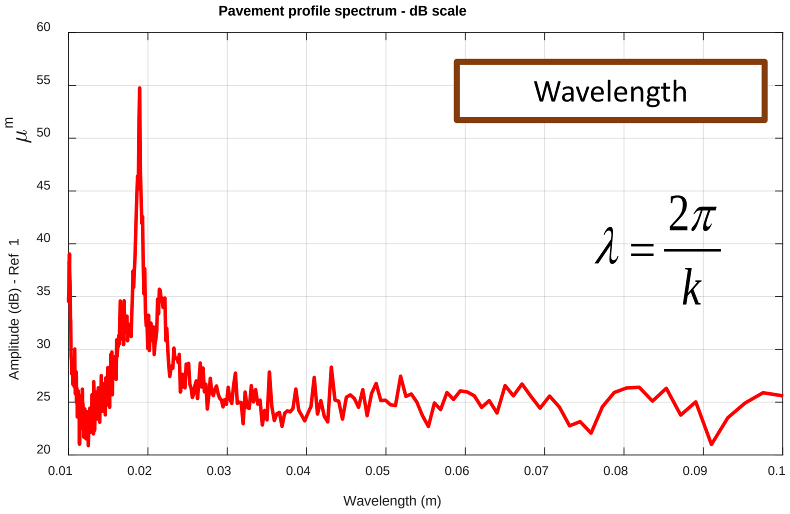
Experiments results: Pavement profile vs Noise

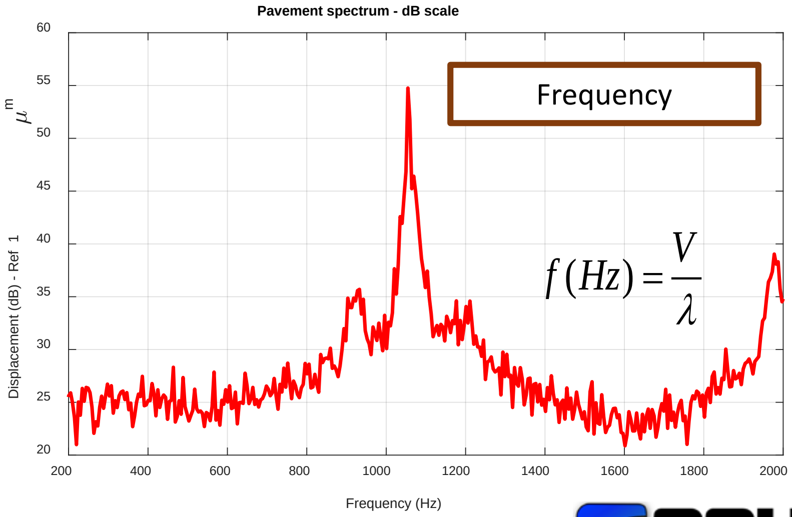
Pavement Profile Spectrum

Railroad bridge





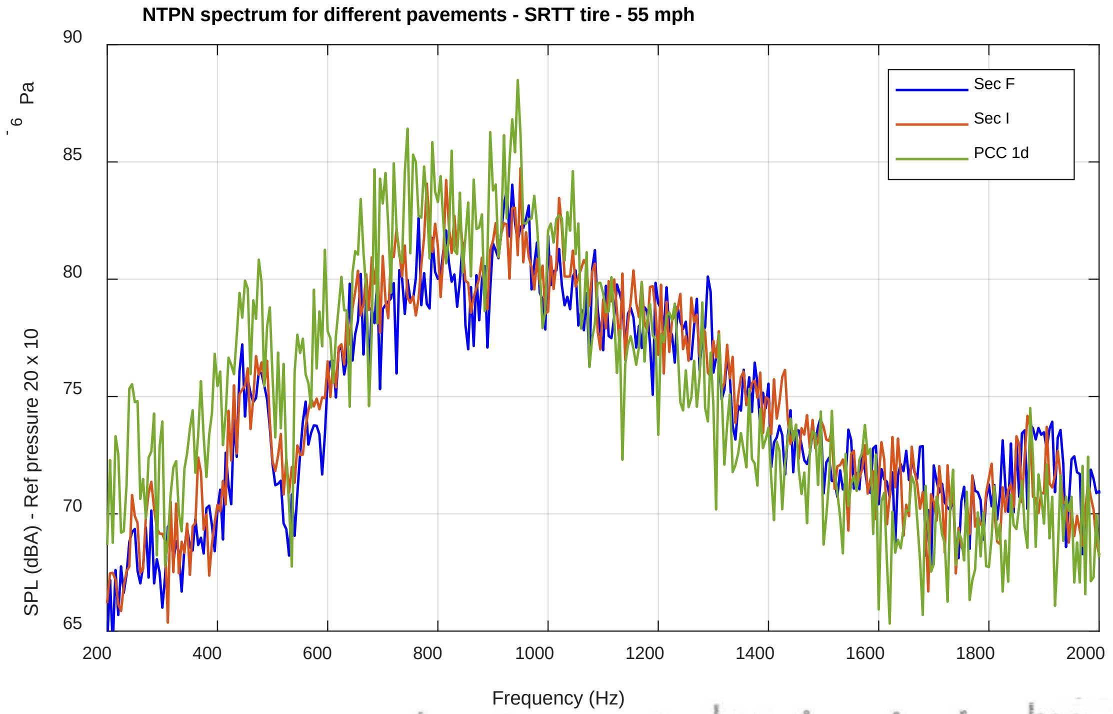




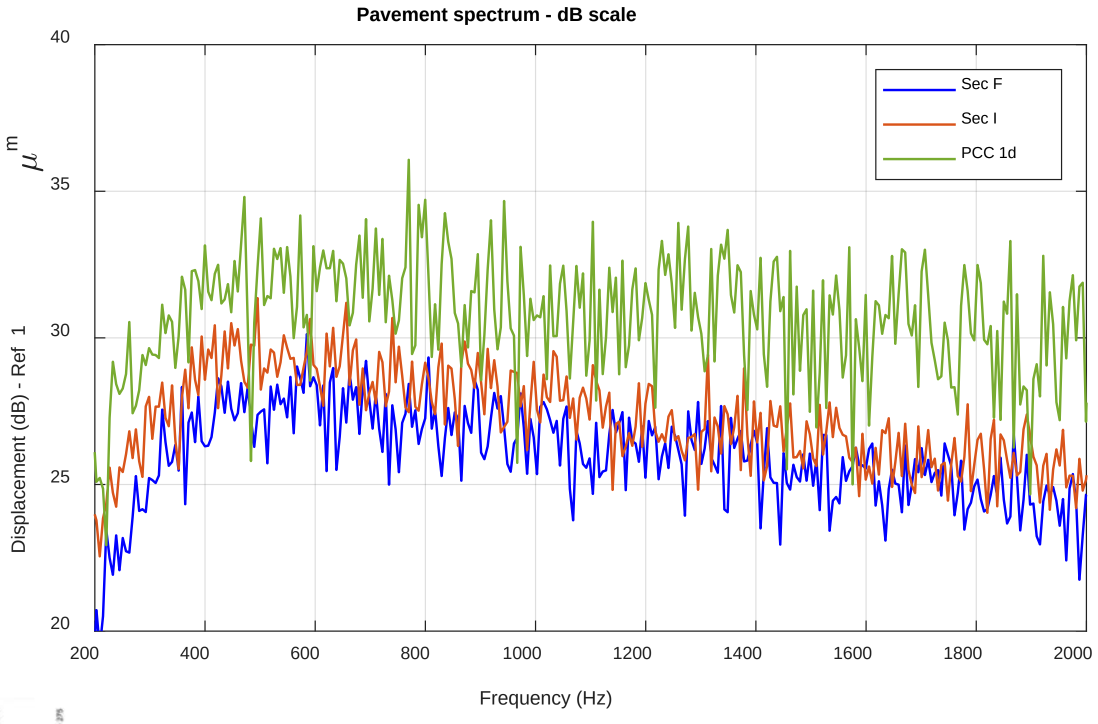
- Pavement profile spectrum is computed using the wavenumber transform (plotted vs *k*).
- It is also plotted vs wavelength (λ) to easily observe periodicity of wavenumber components.
- It is also plotted vs frequency (based on vehicle speed, V) to compare to noise spectrum.

Experiments results: Pavement profile vs Noise

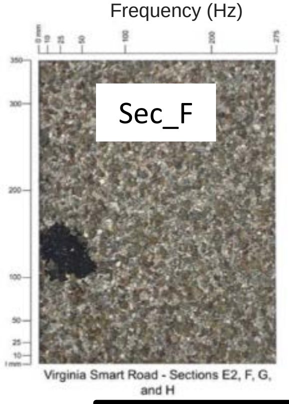
NTPN Spectrum

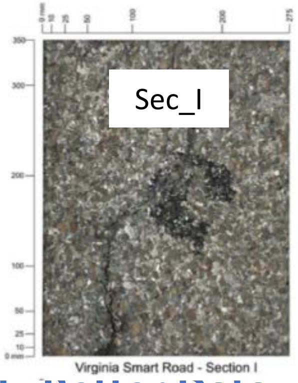


Pavement Profile Spectrum (Non-porous)

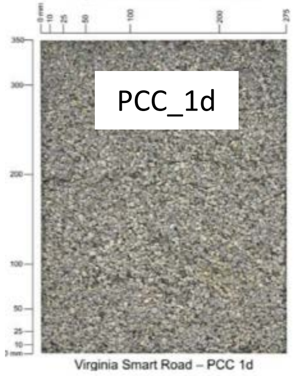


Non-porous pavements





Dense graded HMA

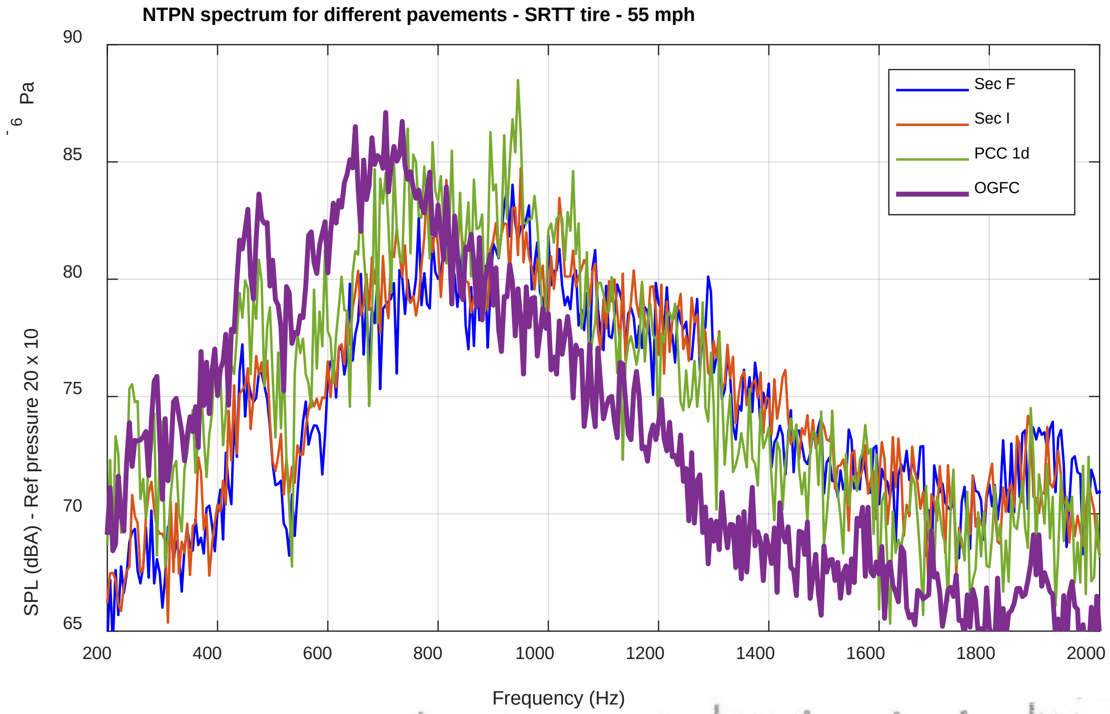


PCC section

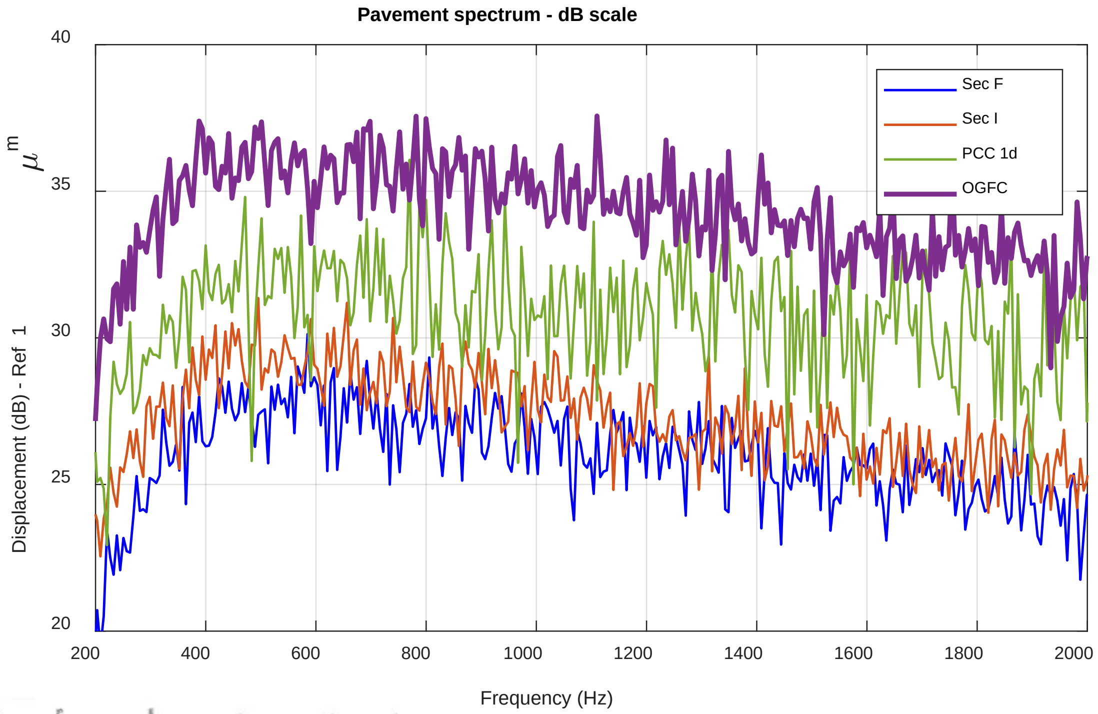
SRTT

Experiments results: Pavement profile vs Noise

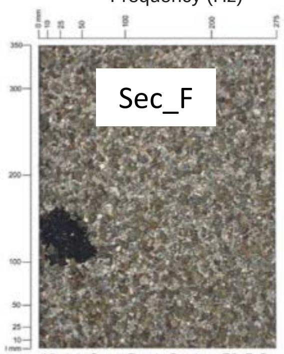
NTPN Spectrum



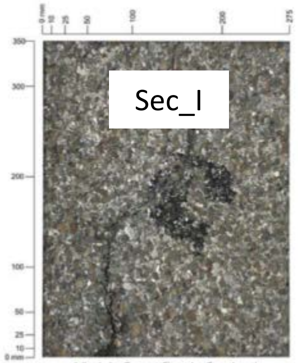
Pavement Profile Spectrum



Non-porous pavements

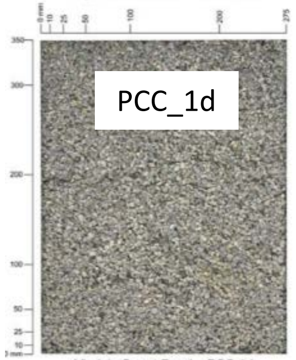


Virginia Smart Road - Sections E2, F, G, and H



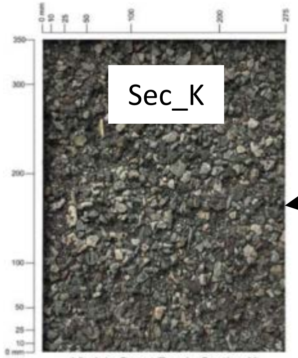
Virginia Smart Road - Section I

Dense graded HMA



Virginia Smart Road – PCC 1d

PCC section



Virginia Smart Road - Section K

OGFC

Porous pavement

SRTT

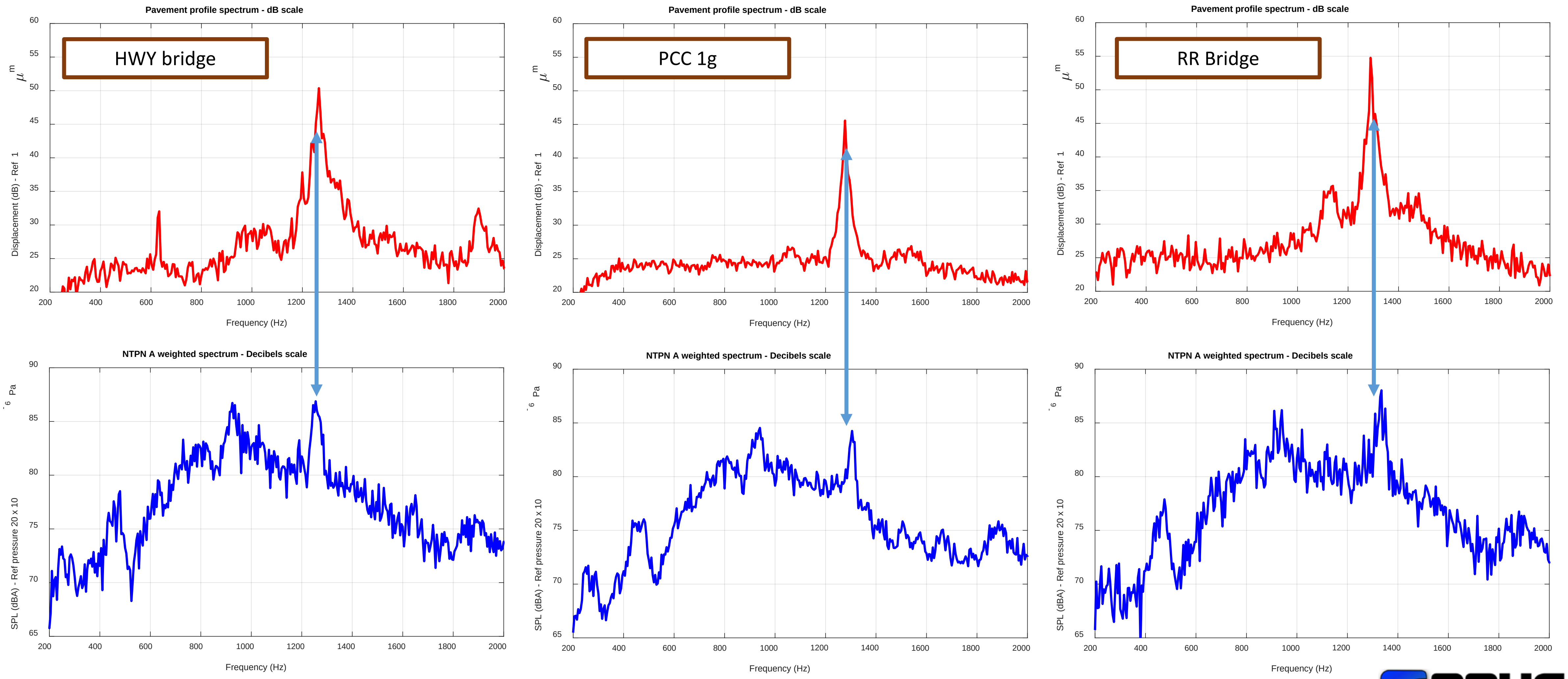
Experiments results: Pavement profile vs Noise

SRTT

Tonal noise associated with transverse grooves.

Pavement Spectrum

NTPN Spectrum



Outline

- Introduction
- Experiments
- Experimental results
  - Tread and Non-tread pattern noise
  - Relationship between pavement profile and noise
- Discussions

Discussions

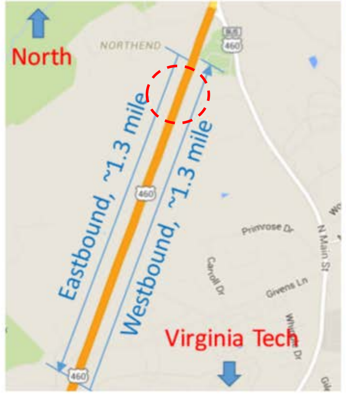
- A large number of tire noise data was collected using an OBSI system with an optical sensor (for order tracking analysis) under multiple testing conditions.
- Pavement profile data was acquired using a scanning laser.
- Tire noise was separated into two main components: tread (TPN) and non-tread-pattern (NTPN) noise
  - TPN is due only the tread pattern
  - NTPN is mainly a function of pavement.
- The NTPN spectrum is correlated to the pavement profile spectrum only over a limited frequency range (~ 200 to 900 Hz).

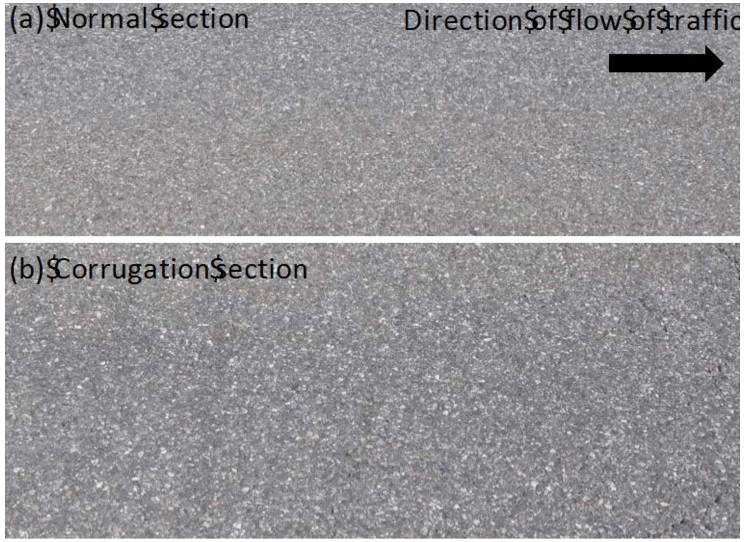
Extras

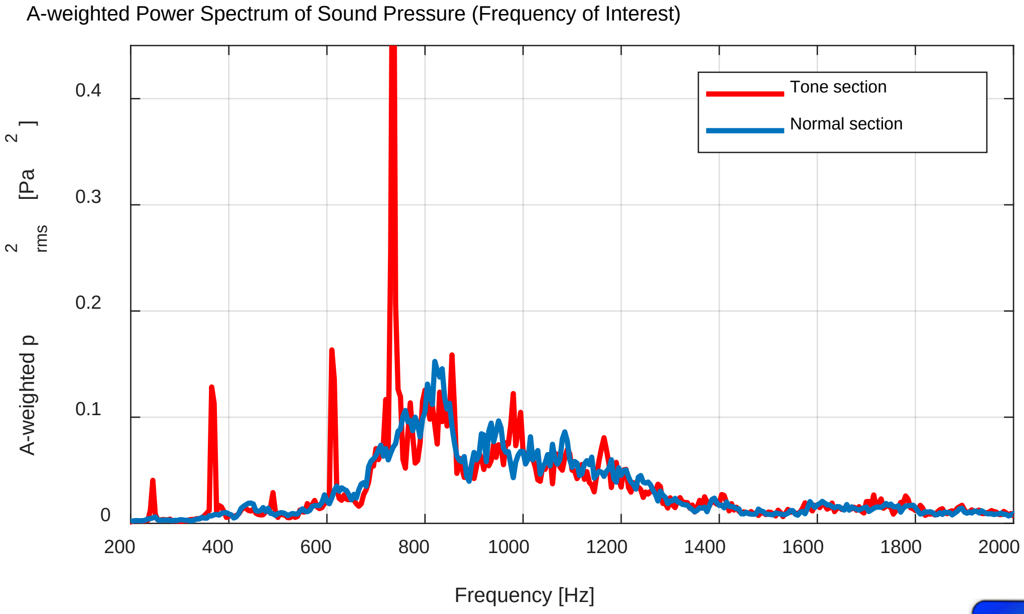
TPIN vs pavement transverse corrugation distress

US460 road data – 60 mph – Tonal noise associated with the pavement distress.

- On the US460 road test section, there was a segment (~300 m) where the non-tread pattern noise component showed tonal components.
- It was speculated that the tonal noise was due to corrugation of the pavement. However, visual inspection of the pavement didn't revealed these corrugations.



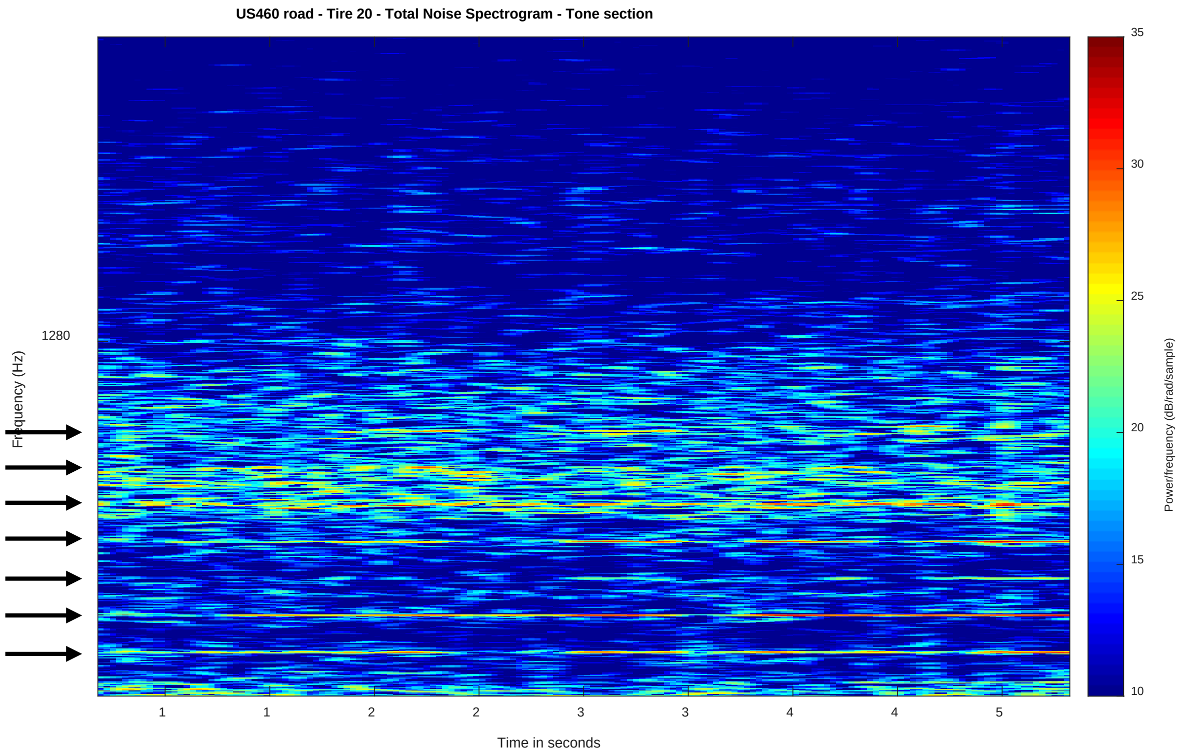


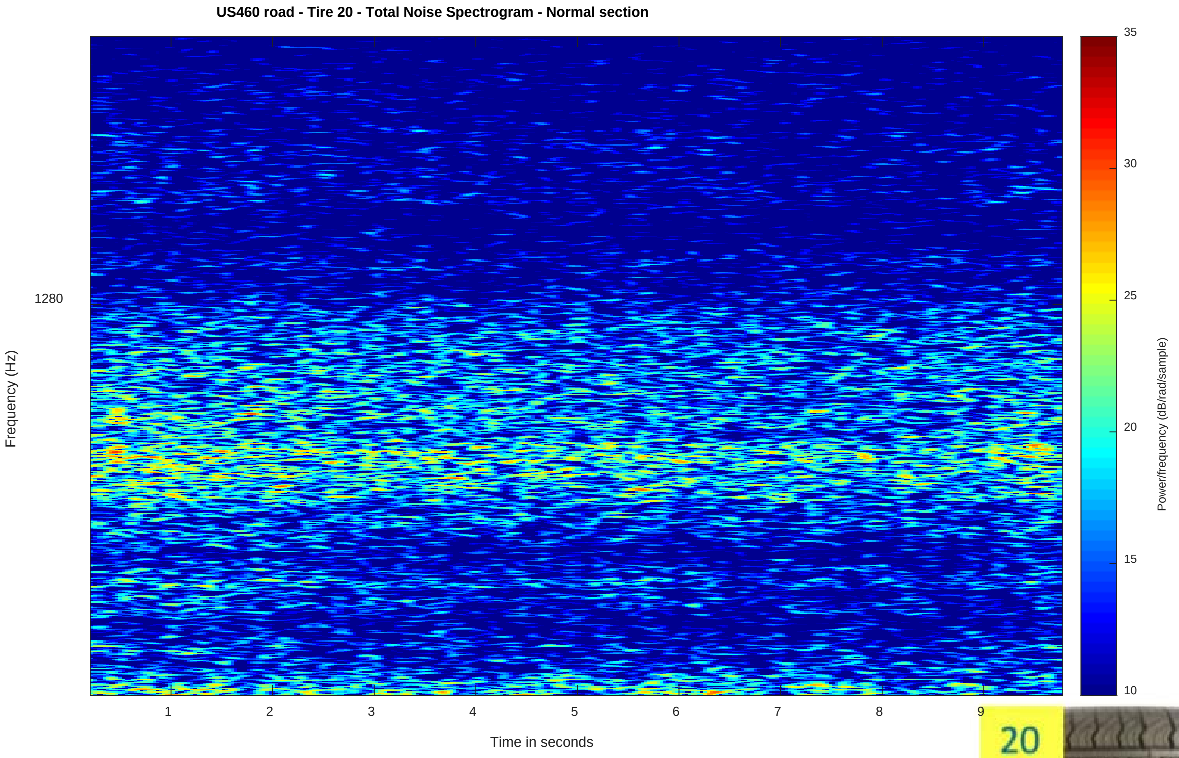


TPIN vs pavement transverse corrugation distress

US460 road data – 60 mph – Tonal noise associated with the pavement distress.

Spectrograms shown are for tire 20 (i.e. SRTT tire). It is important to highlight that the similar behavior was observed in all 5 tested tires.

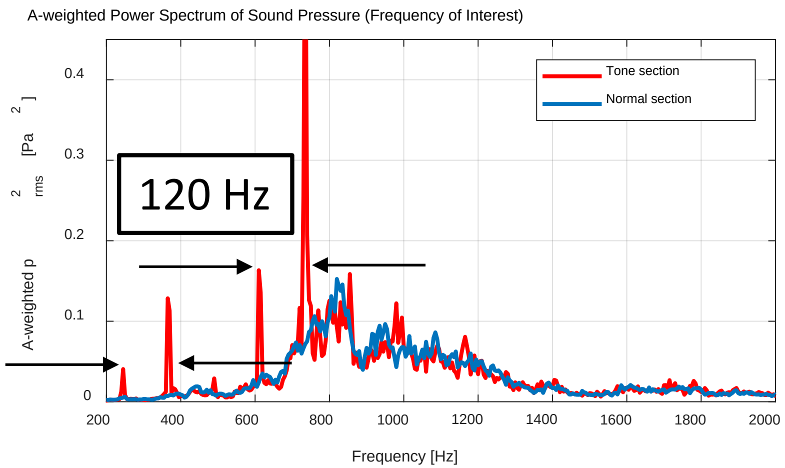




TPIN vs pavement transverse corrugation distress

The non-tread pattern noise can be used to estimate the wavelength of the corrugated pavement.

Non- Tread pattern noise



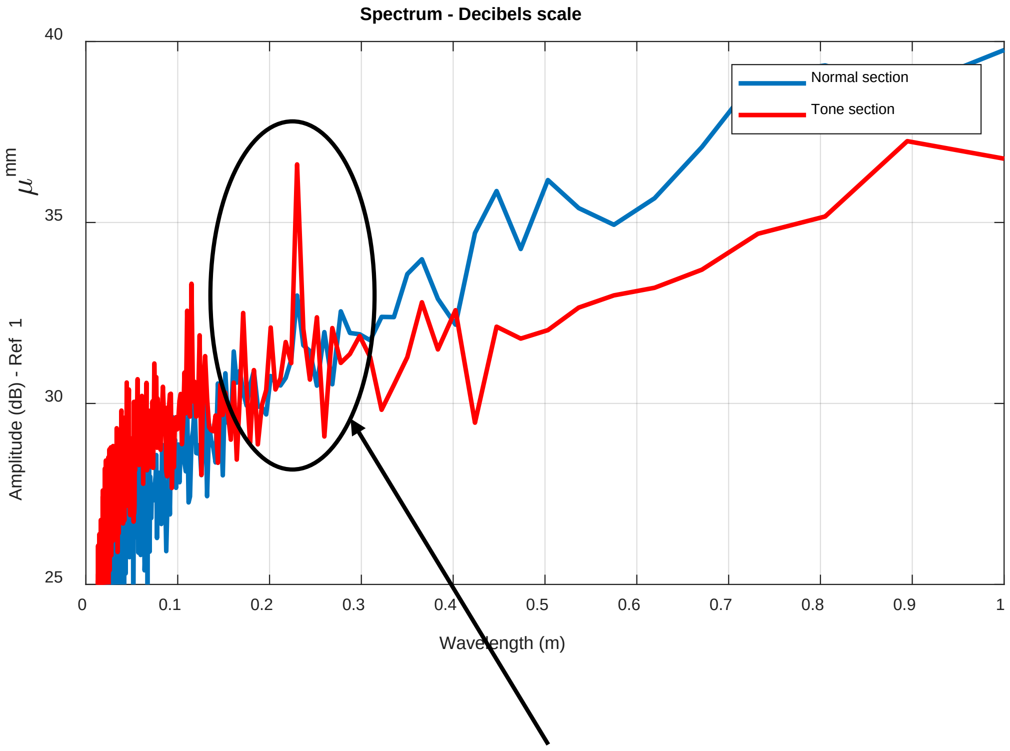
$$\lambda_{corrugation} = \frac{f_{rot-tire} \cdot l_{tire}}{f_{tone}} = \frac{13.1Hz \cdot 2.1m}{120Hz} \cong 230mm$$

l_{tire} : Circumference of the tire

$f_{rot-tire}$: Rotational speed of the tire in Hz

f_{tone} : Frequency interval between noise tones

The corrugated pavement wavelength was confirmed from direct measurements of the pavement profile and the computation of the spectrum.



Tone with ~ **230 mm** wavelength, which matches the wavelength predicted by the noise data

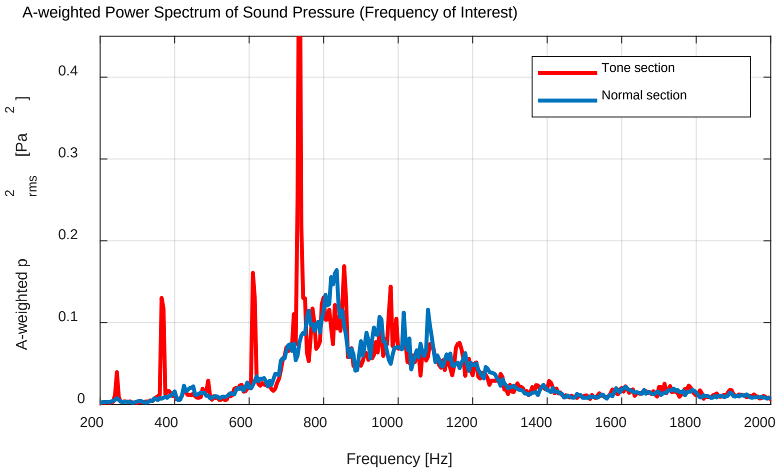
Non-tread pattern TIPN can be used for efficienlty monitoring pavement distress

TPIN vs pavement transverse corrugation distress

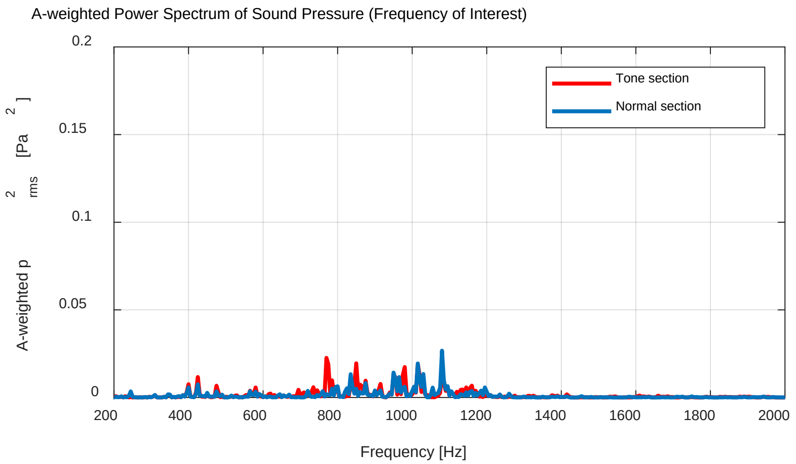
US460 road data – 60 mph – Tonal noise associated with the pavement distress.

Results shown are for tire 20 (i.e. SRTT tire). It is important to highlight that the similar behavior was observed in all 5 tested tires.

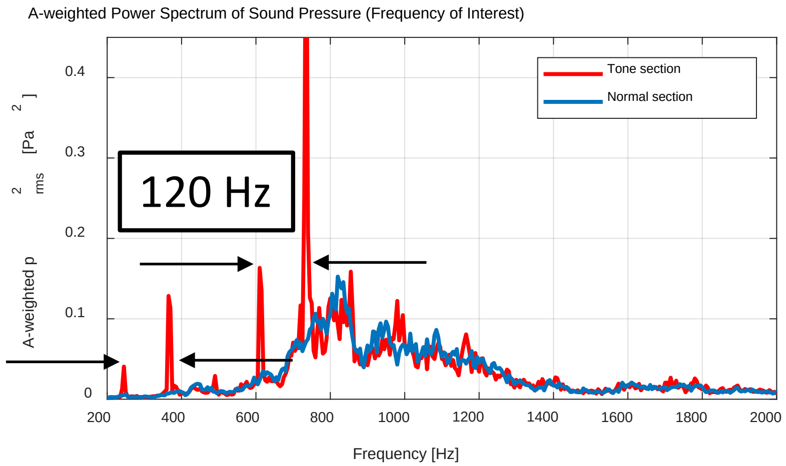
Total tire noise



Tread pattern noise



Non- Tread pattern noise



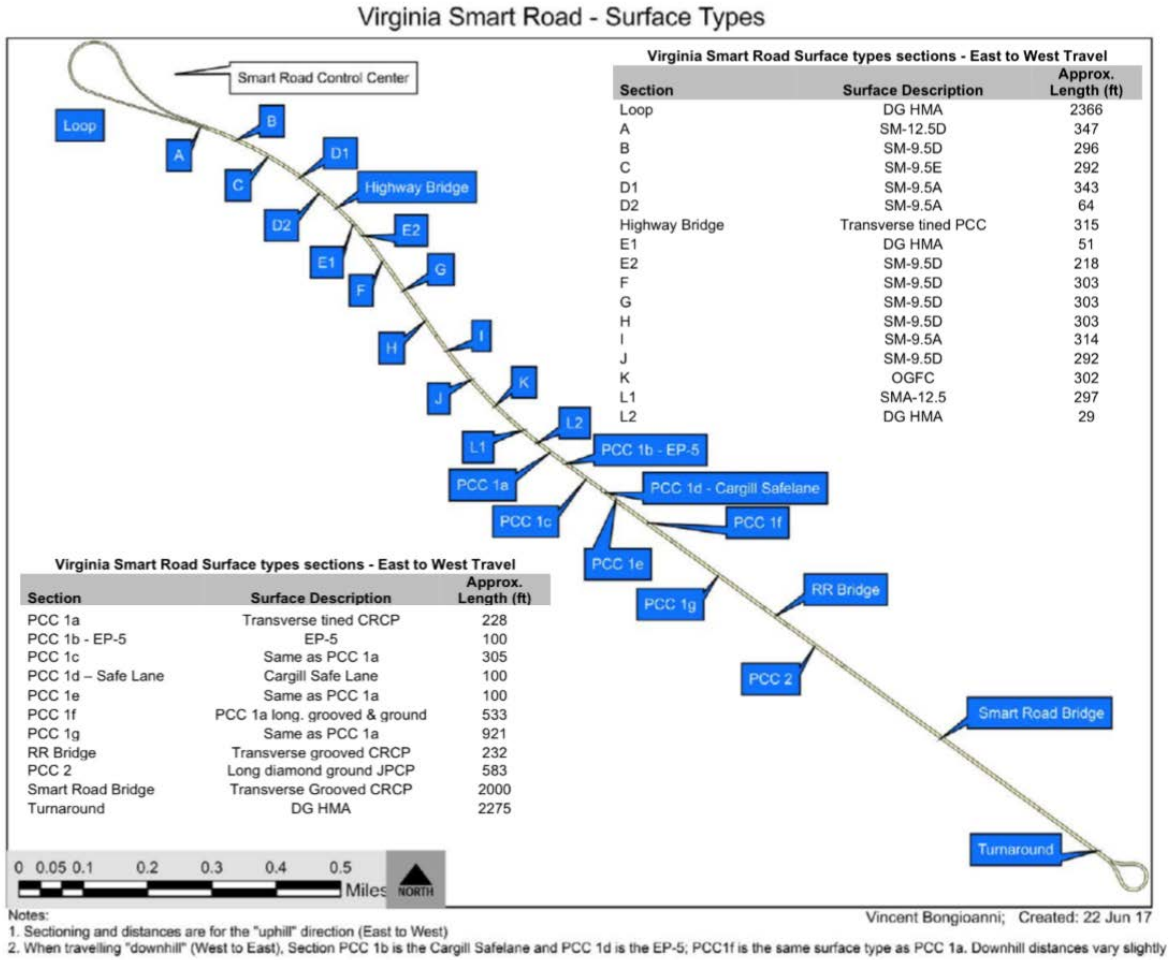
Experiments

- VT SMART road test

Test information	
Number of pavements	26

Among the tested pavement there were:

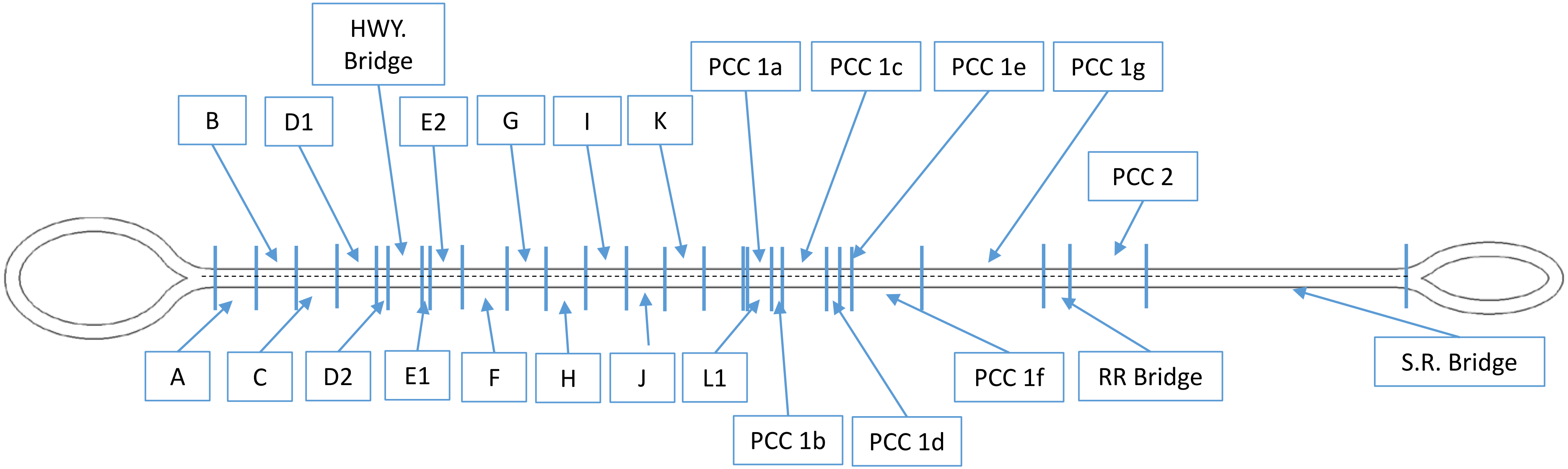
- 14 surface mixes asphalt sections
- 8 concrete sections
- 3 bridges sections
- 1 Open Graded Friction Course
- 1 concrete section with longitudinal grooves
- 7 concrete sections with transverse grooves



Extend TPIN model to include pavement parameters.

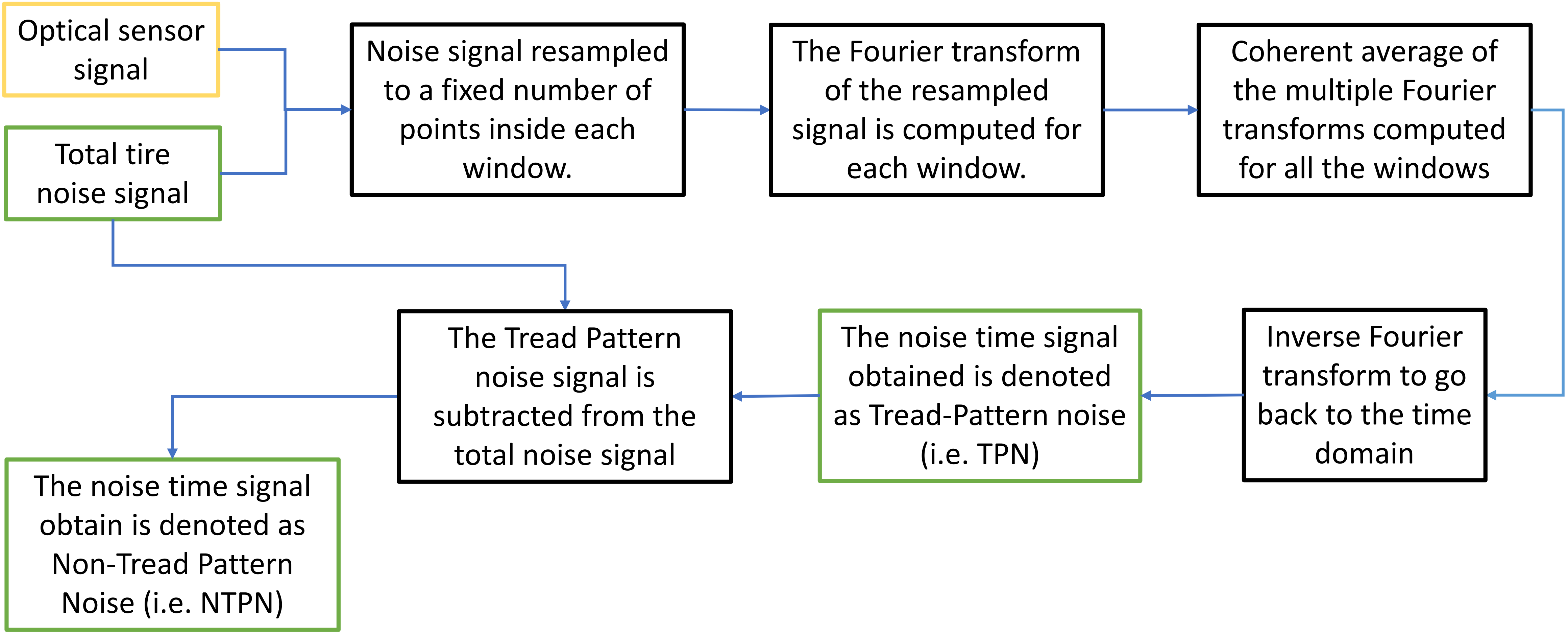
SMART Road pavement data.

- There are 26 different pavements.



Experimental results

- Tire noise separation procedure



Tread Pattern Noise Contribution

- Overall A-weighted sound pressure level for all tires (dBA)

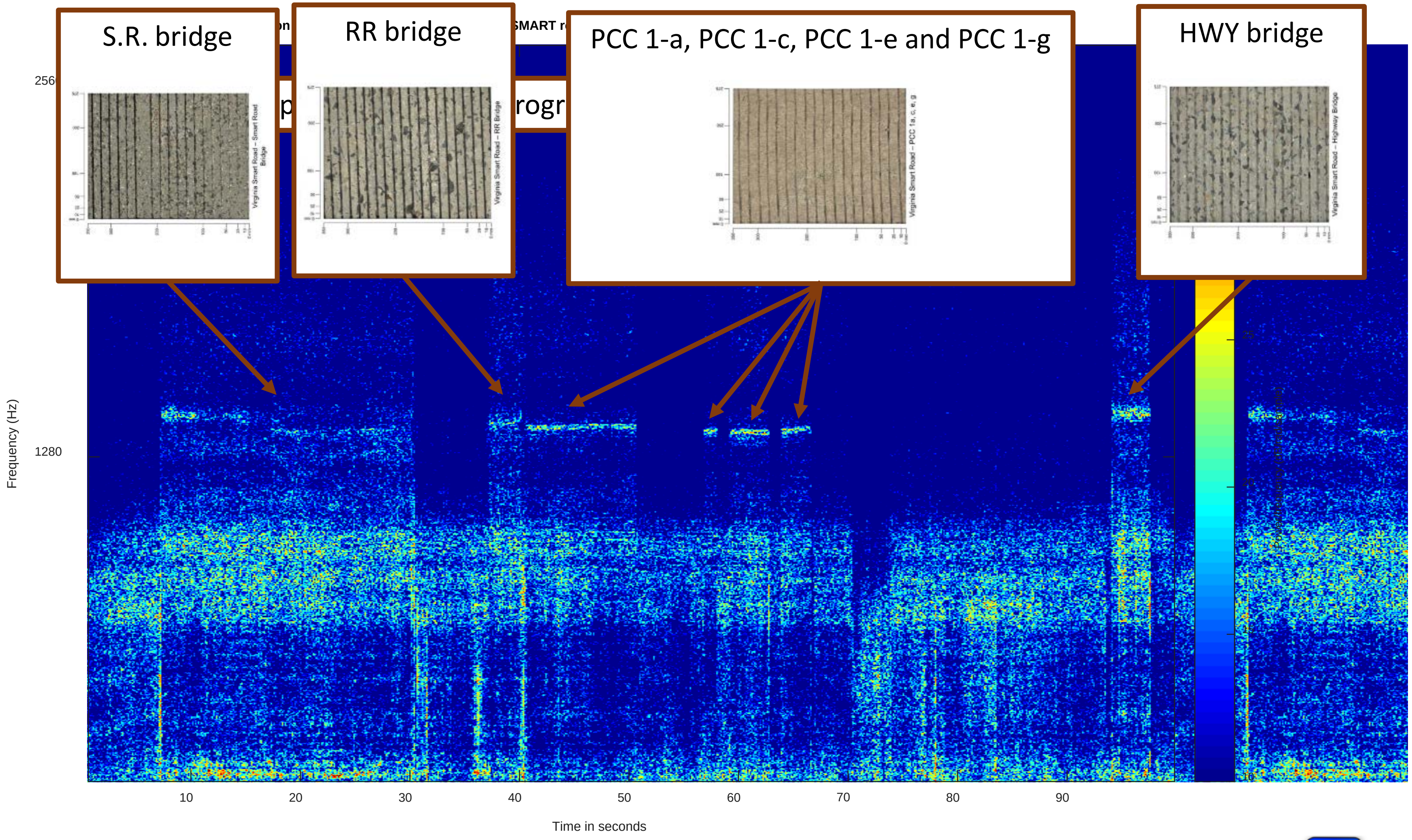
No.	Total Noise Level [dBA]	Tread Pattern Noise Level [dBA]	Non-Tread Pattern Noise Level [dBA]	Tread Pattern Noise Contribution [%]
12	103.4	97.1	102.3	23.4
15	102.1	86.6	102.0	2.8
18	105.2	90.6	105.1	3.5
19	102.4	93.1	101.8	12.0
20	105.0	90.7	104.8	3.8

- For the **pavement tested**, the tread pattern noise is not the dominant noise source.
- For a **newer/smoother pavement** (very limited data), the tread pattern noise component account for about 50% of the total noise (Tire 12).

Experimental results

SMART road data – 60 mph – Tonal noise associated with transverse grooves.

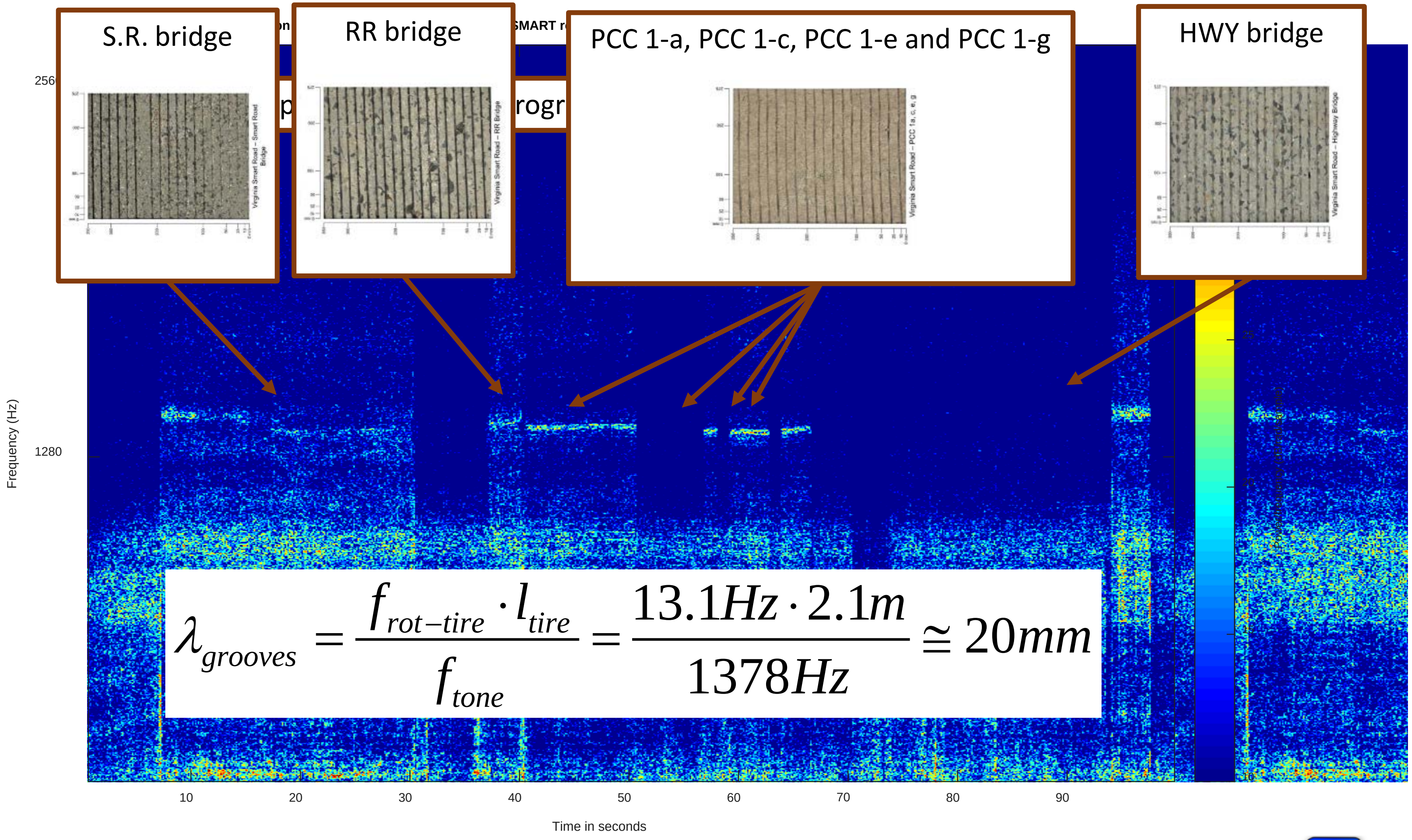
The NTPN spectrogram shows tonal content at certain intervals, considered to be associated with the presence of transversal grooves on the pavement.



Experimental results

SMART road data – 60 mph – Tonal noise associated with transverse grooves.

The NTPN spectrogram shows tonal content at certain intervals, considered to be associated with the presence of transversal grooves on the pavement.

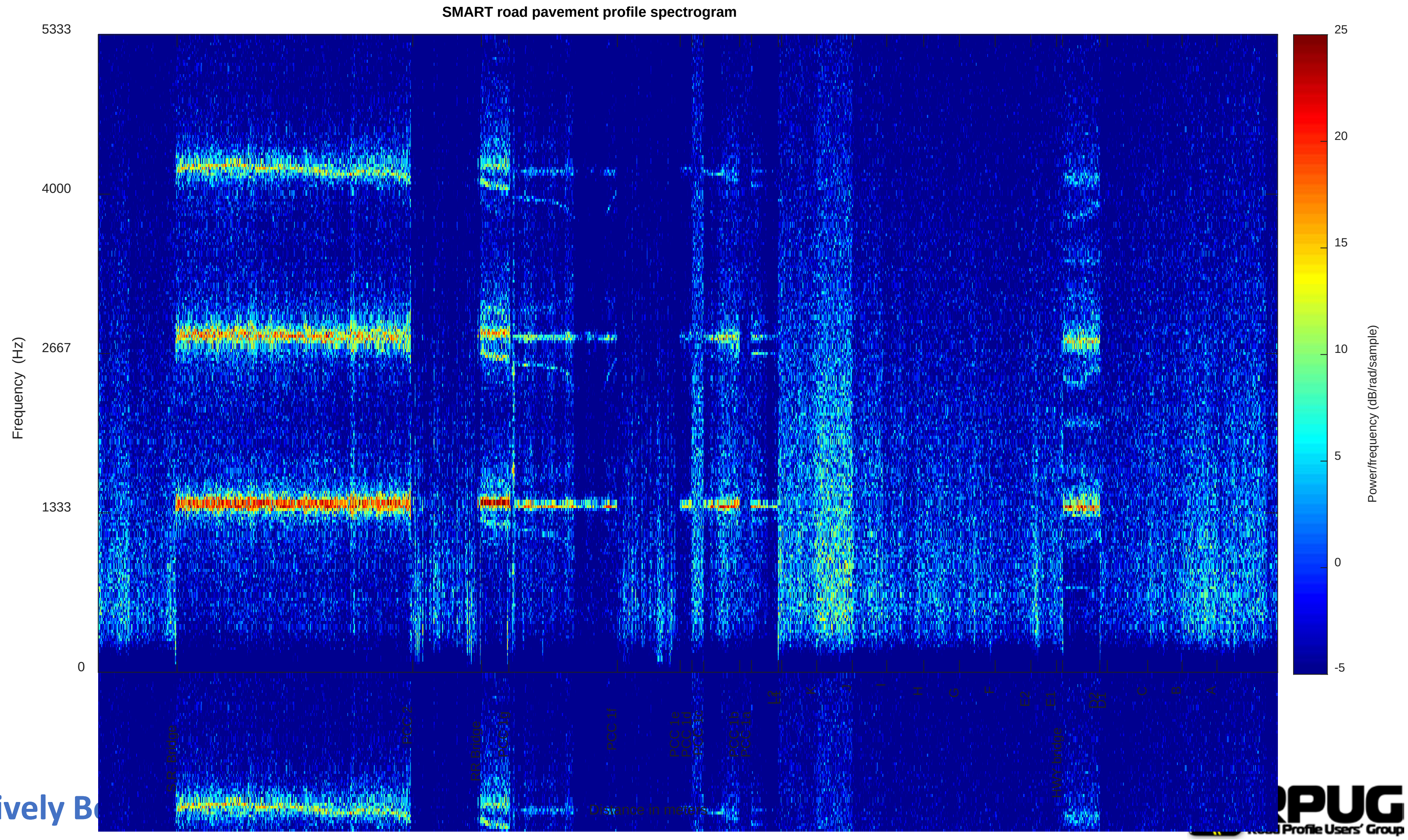


$$\lambda_{grooves} = \frac{f_{rot-tire} \cdot l_{tire}}{f_{tone}} = \frac{13.1Hz \cdot 2.1m}{1378Hz} \cong 20mm$$

Experimental results

SMART road data – 60 mph – Tonal noise associated with transverse grooves.

The pavement data spectrogram is also computed. The first tone appears at a similar frequency as in the NTPN spectrogram



Experimental results

SMART road data – 60 mph – Tonal noise associated with transverse grooves.

The pavement data spectrogram is also computed. The first tone appears at a similar frequency as in the NTPN spectrogram.