# This is TCM

# What does a TCM do?

TCM is a remote controlled radio microphone designed to capture the noise inside the tyre's cavity.

The TCM comprises two small curved aluminium modules.

These are tensioned against the wheel hub by a stainless steel harness and connected by a multi-core cable and antenna.

The TCM is controlled by a radio key fob. On standby the battery lasts 7 days and when transmitting continuously 8 hours. It can be turned off between recordings to allow recording over several days.

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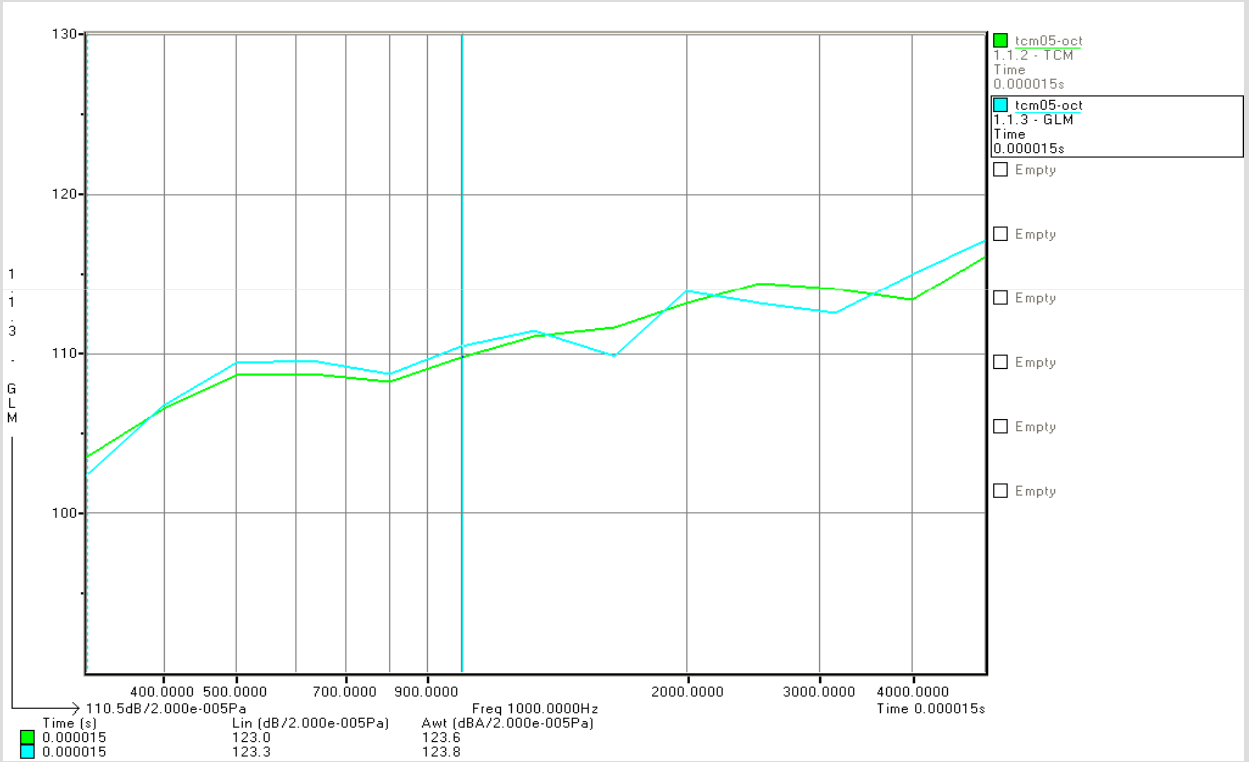
# TCM data is accurate and repeatable

## TCM's are calibrated in a travelling wave tube

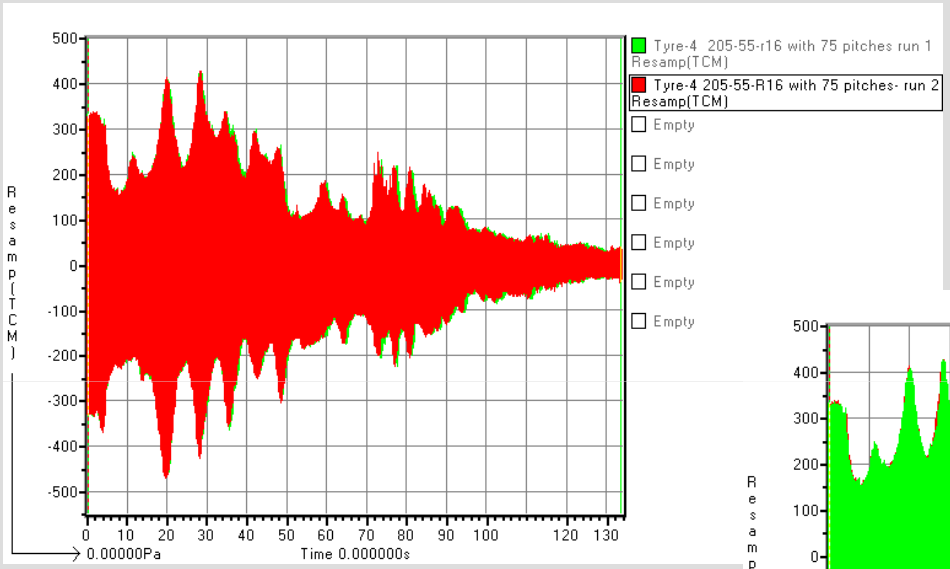



**Green = TCM**
**Cyan = reference**

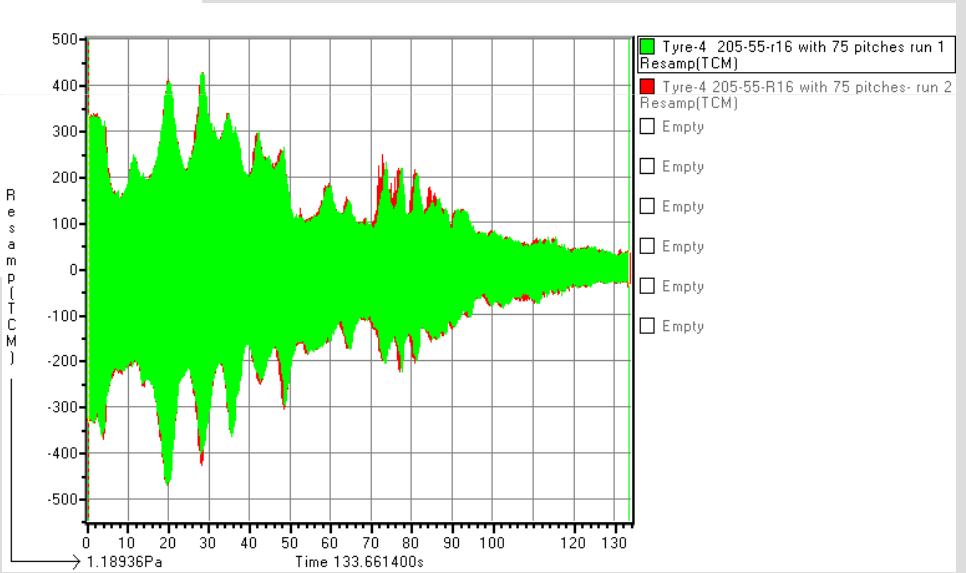
**The size of the wave tube and the driver limit the frequency range to 300-3200Hz**
**(The TCM frequency response is from 10Hz to 10kHz; essentially flat from 30Hz-8kHz)**

# Repeatability is excellent

## Run 2 in front of Run 1




## Run 1 in front of Run 2




**Run 1 and run 2 superposed – the runs are identical coast downs on a steel road wheel**

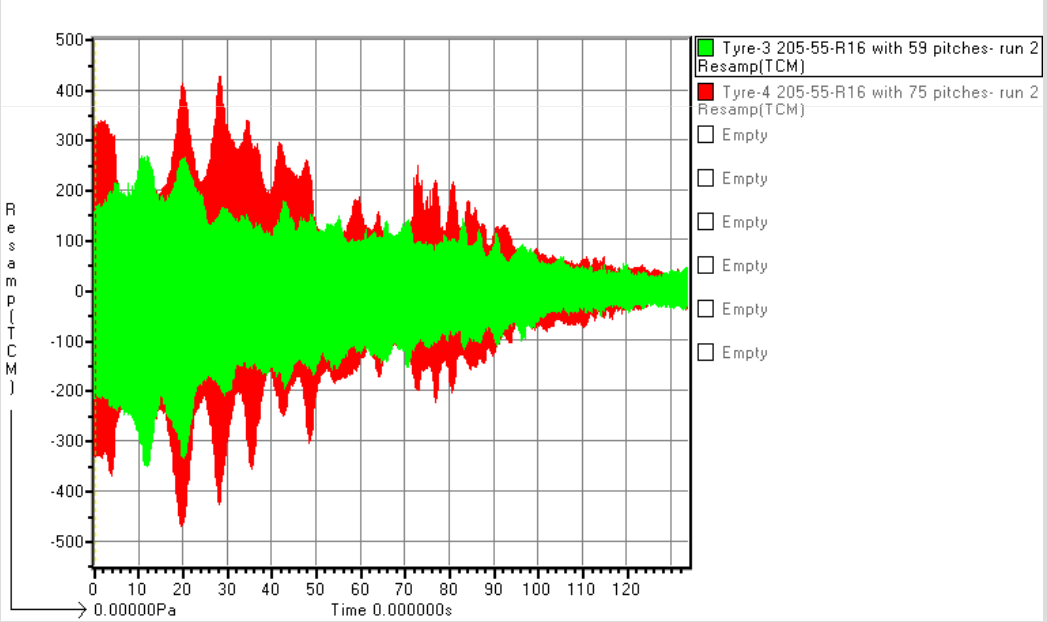
## Why is a TCM needed in the auto industry ?

- To stay in business our products must be :-
  efficient, reliable, attractive and quiet
- There are two reasons for lowering noise:-
  - Legislation that demands lower levels of noise
    If we do not comply we cannot deliver
  - Customer pressure for quieter products
    People will not buy a noisy product
    (a second time)
- **TCM Data + Engineers = Solutions to tyre and road noise**

# Surely we know all there is to know about tyre cavity resonances and tyre tread noise

Well apparently not!

Here are two winter tyres of the same size from a manufacturer




Was it sensible to allow the cavity modes to double in amplitude?
Why did they double?
The older Mk3, in green, has been replaced by the new Mk4 in red!

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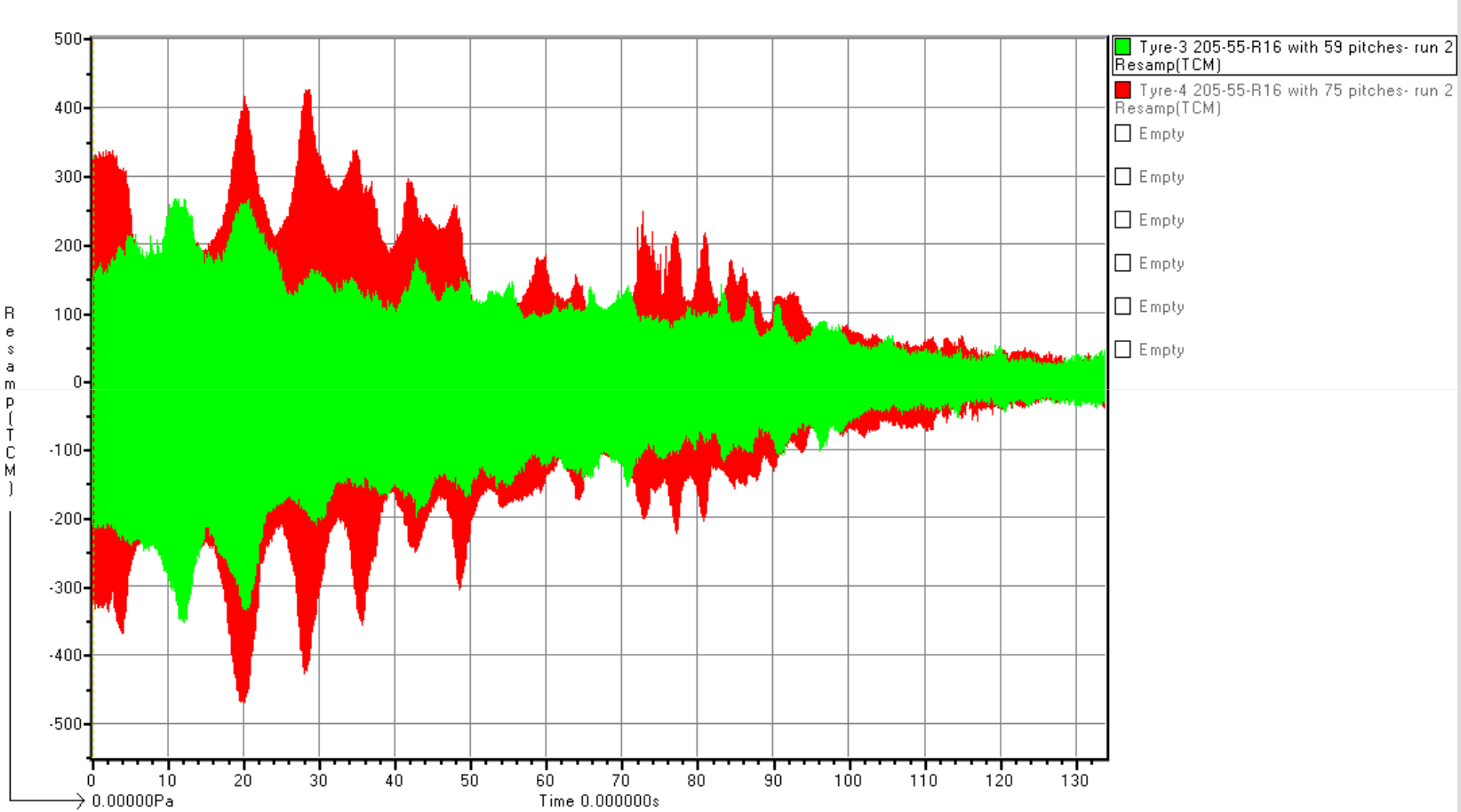
# Example internal SPL for 205/55R16 tyres




**The profile of Mk4 is, for much of the coast down (100kph to 30kph), an inflated version of the Mk3; but why is the response so much stronger?**

# Does the internal tyre cavity SPL really matter?

We have seen in the previous slide that the SPL in the tyre cavity can change in amplitude by a factor of 2. This change happened in seemingly identical tyres that differed only in tread design.

The company making the tyres presumably thought the Mk4 was going to be an improvement over the Mk3.

If the Mk4 tyre was fitted on certain “sensitive” automobiles then the primary cavity tones, principally @ 200Hz, would become loud enough for most occupants to notice and object.

**So the answer is Yes it does matter!**

## The TCM will enable engineers to : -

**Measure tyre noise accurately**

**Gather data free from background noise**

**Develop tyres more quickly**

**Select the best tyres for a vehicle**

**Reduce vehicle interior road noise levels**

# TCM Uses - 1

- Measurement of tyre coast-by noise
  - Internal tyre noise can be accurately mapped to radiated noise. The measurement is unaffected by: -
    - Background noise
    - High winds
    - Rain
- Compare tyres during development
  - Comparisons made while running on the road allowing tyres to be optimized for real roads. Complete freedom from weather allowing testing at any time.

# TCM Uses - 2

- **Road noise route tracking**

  Road texture, tyre tread pattern and tyre cavity resonances drive cabin noise levels and are all captured by the TCM at source, inside the tyre. The degree to which the cabin responds is controlled by the effectiveness of the transmission path(s). Route tracking is the ranking by efficiency of the possible transmission paths

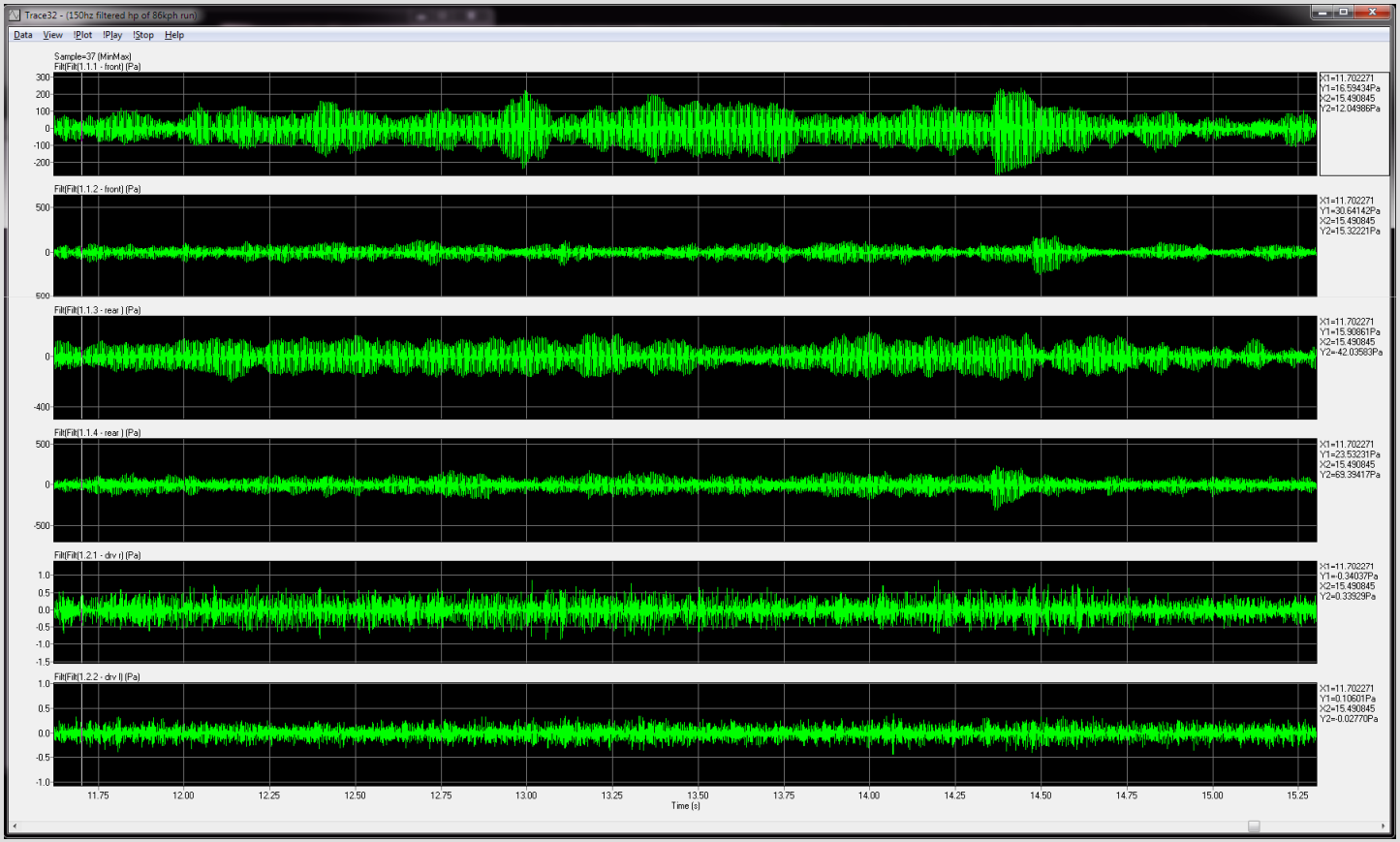
- **Tyre to vehicle matching**

  Which tyre offers the best compromise can be helped by using the data generated by the TCM to confirm which tyre generates the least cabin noise

# Product Features:

- Accurate over wide range of frequencies and levels
  - Frequency range 30Hz – 10kHz
  - Level range from 90dB – 150dB
    (20- 150dB this 60dB dynamic range may be set anywhere within this window)
  - Accuracy better than 2dB
    (from travelling wave tube comparison)
- Wireless transmission
  - Transmission range 10-100 metres
  - Reception inside car using external antenna
    (magnetic or suction cup attachment to body)
  - Phase modulation for interference free radio reception

# Measuring out on the open road because that's where the customers drive




Wheels:
Front left

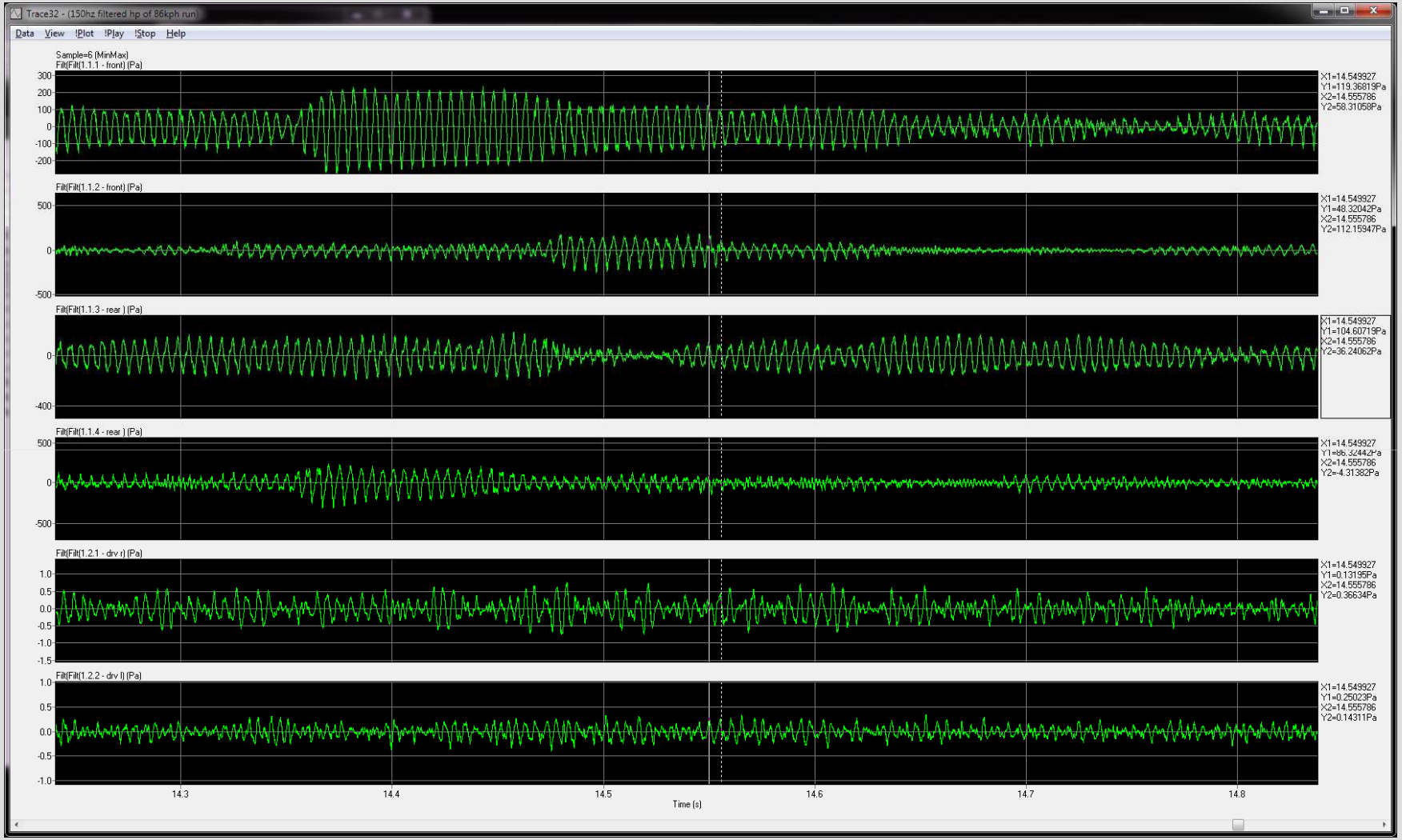
Front right

Rear right

Rear left

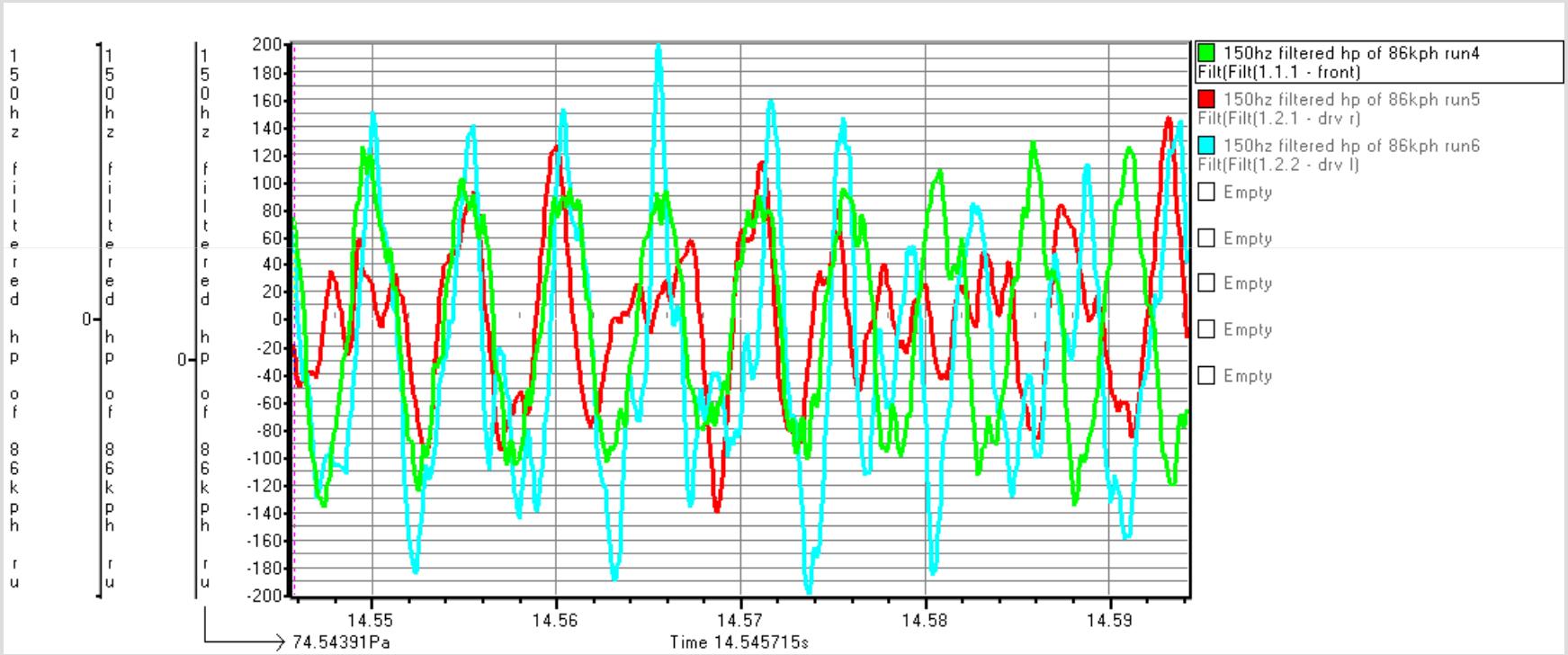
Drivers head
Drv rt ear

Drv lt ear




**Does the time signal at the drivers ear look a little like the time signal in the tyre?**

When expanded the degree of correlation between the Front left wheel TCM data and the two Drivers ear microphones is surprising. A principle input at the drivers ear is the noise in the tyre measured by the TCM. In this case it can be assigned to the primary cavity mode by simply taking the period and it's inverse to get the frequency.




Green = Front left wheel TCM, Red = Drivers right ear, Cyan=Drivers left ear

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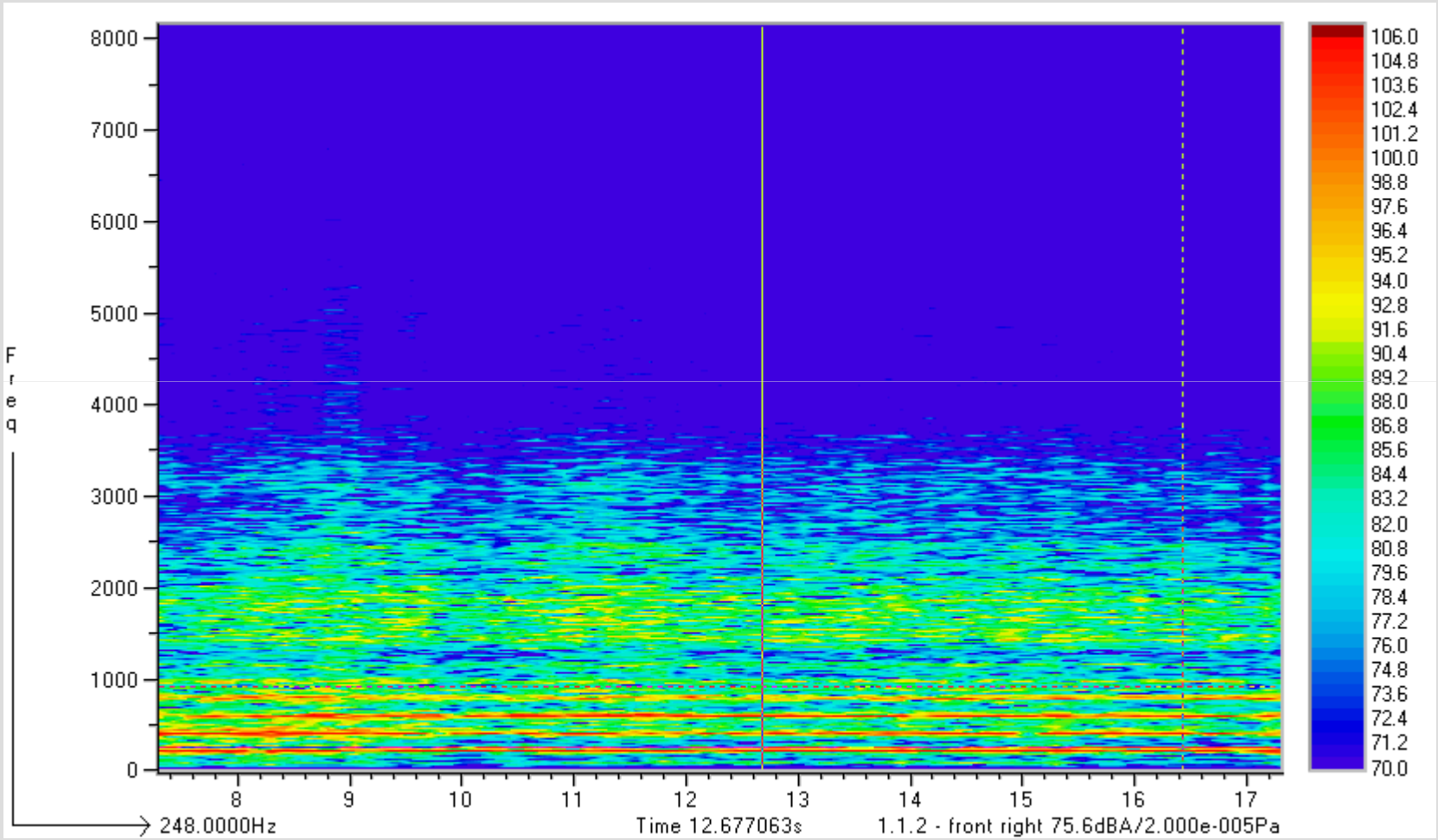
# Inside the right front tyre at 86kph (Awt)

## (During a power off coast down)



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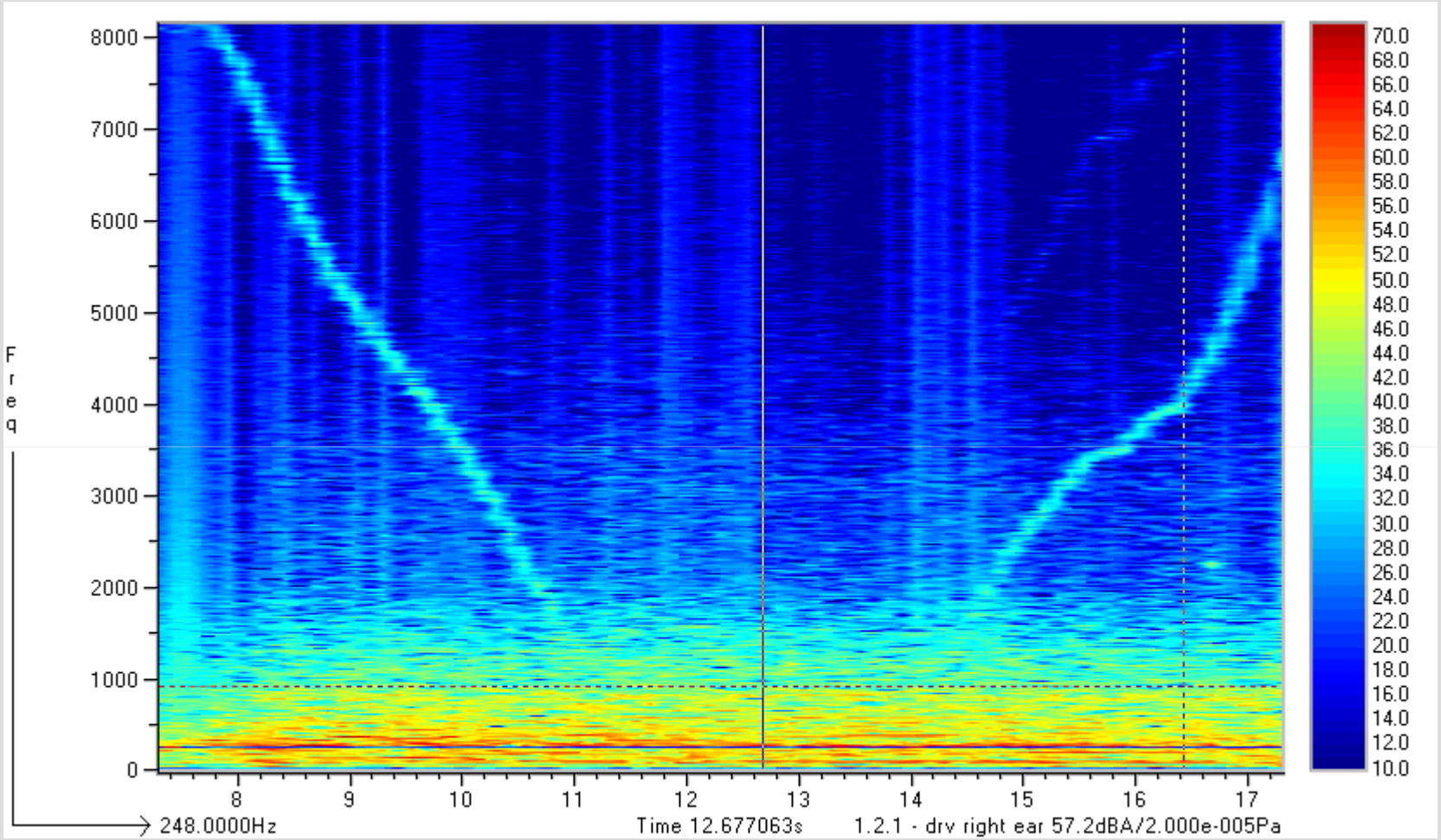
# Inside the car at 86kph – (Driver Right Ear Awt)




**N.B. The turbo run in/out as the car goes through the PBN gate**

# Direct comparison at lower frequencies

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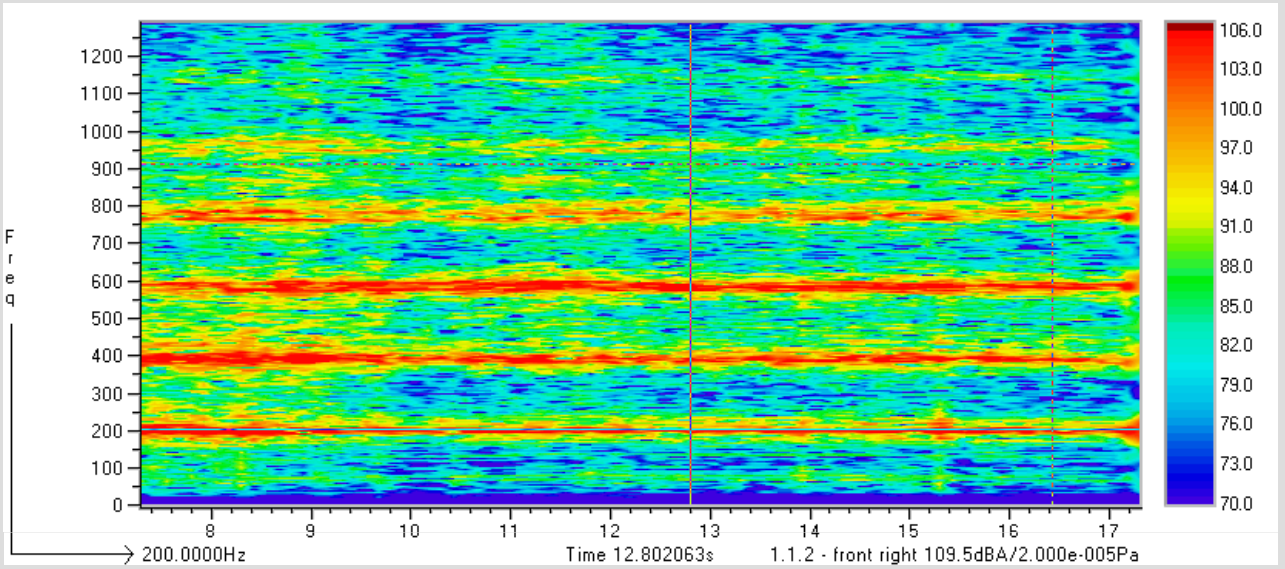
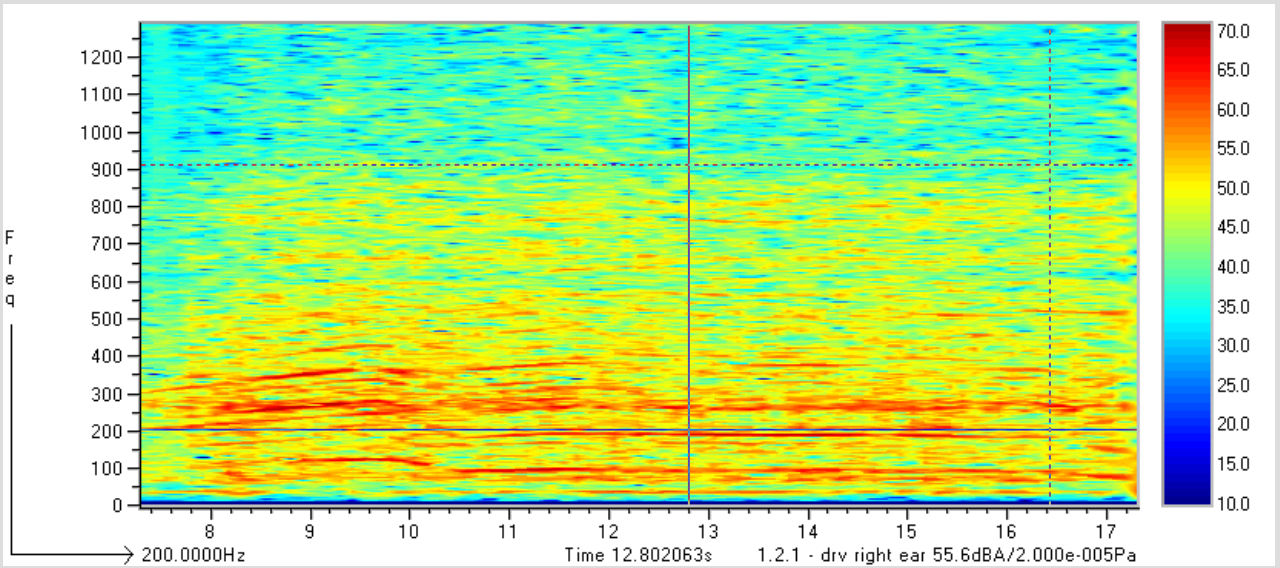
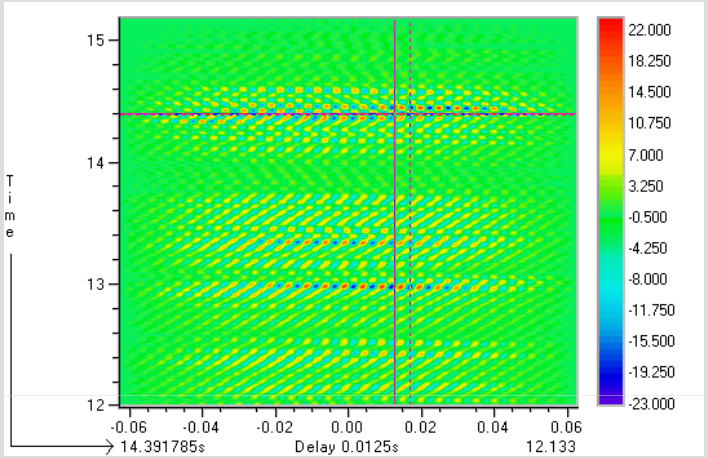


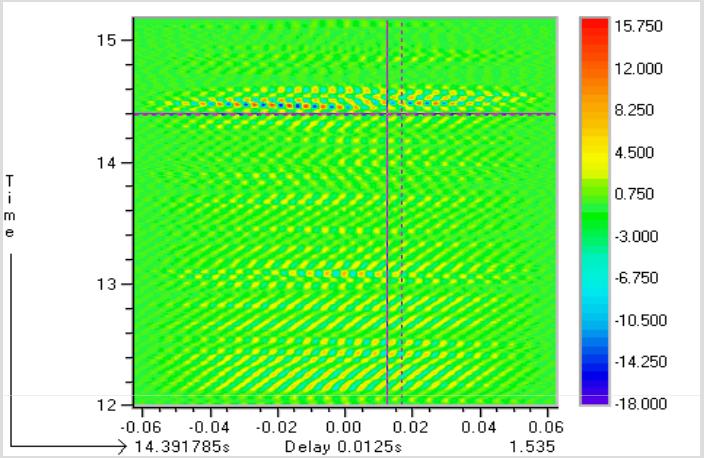

In tyre SPLs front right wheel




In car SPLs Drivers right ear

# Cross Correlation and coherence can give some additional confidence to the evidence of out own eyes.

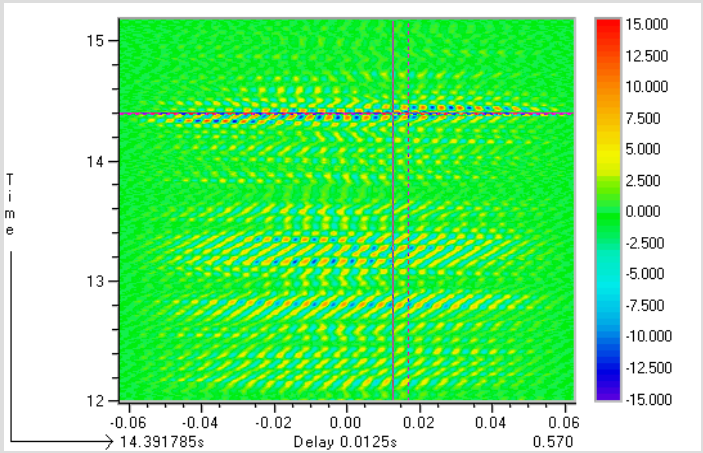


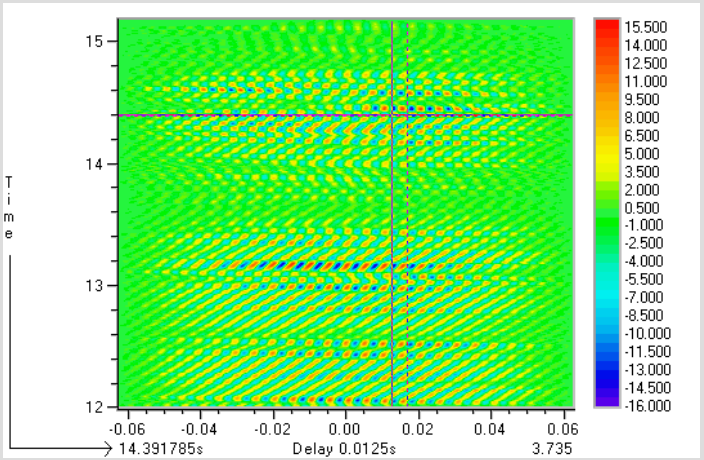




**Front Left**
**Rear Left**

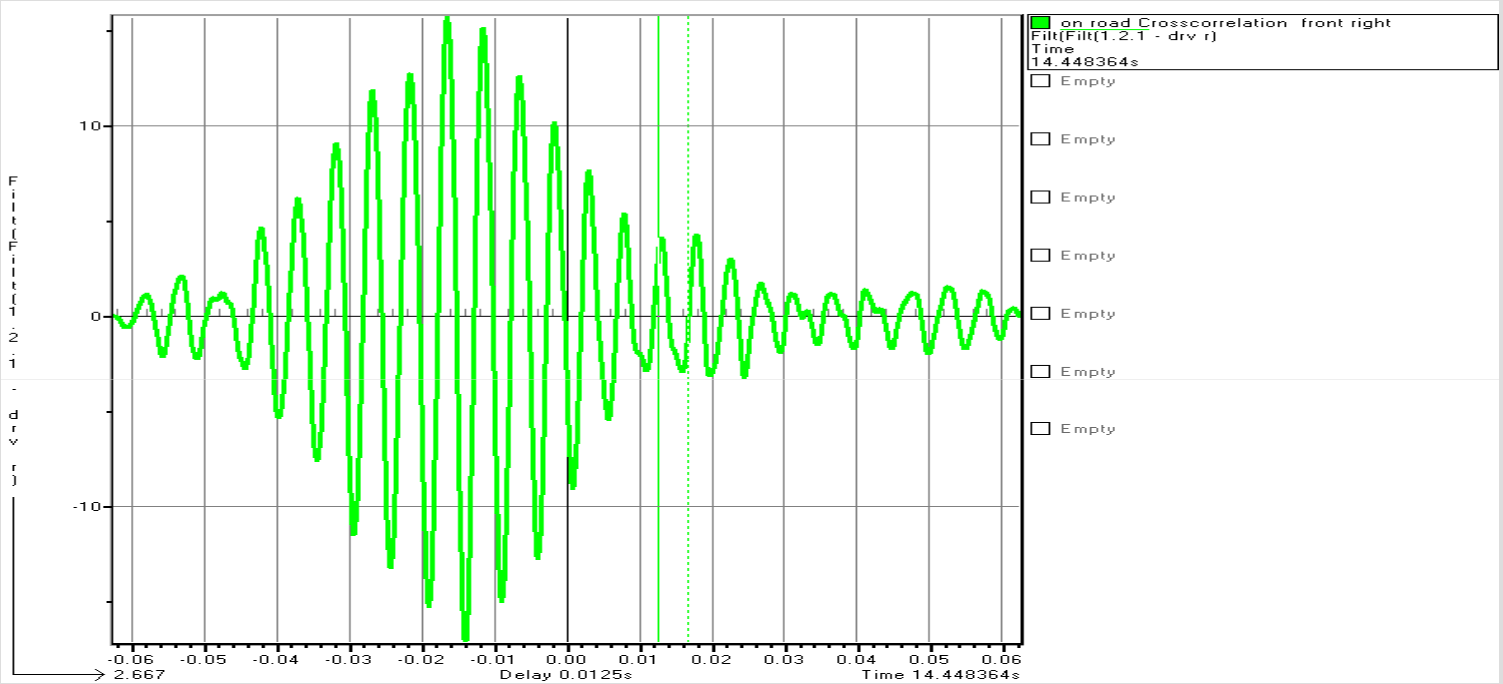
**Cross correlations with drivers right ear**

**Front Right**
**Rear Right**



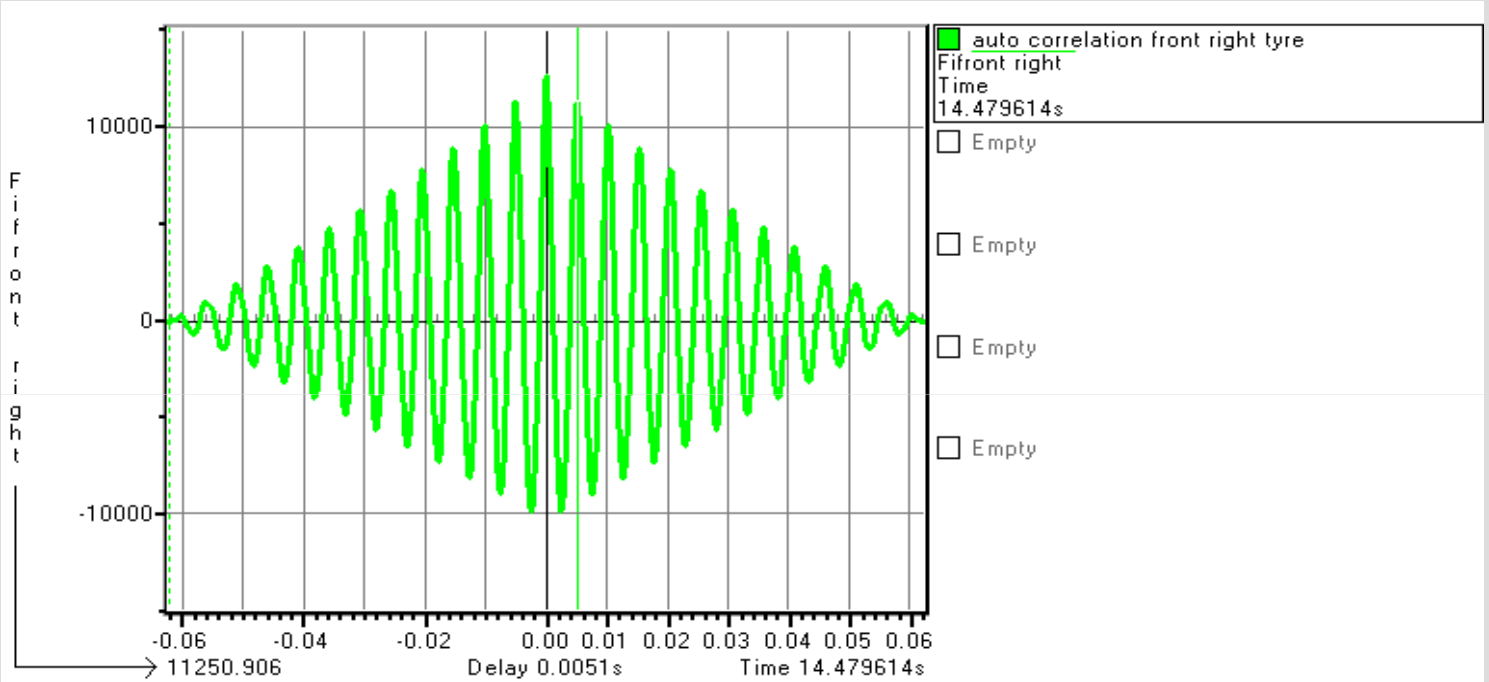



# Cross correlation at 14.44 seconds for drivers right ear and front right tyre (the louder)




Correlation effectively moves two signals past each other in small steps. If there is a common component in the signals then the correlation value goes up. If the shared component is a sine wave then the correlation is also a sine wave. The frequency is that of the common signal = 204Hz

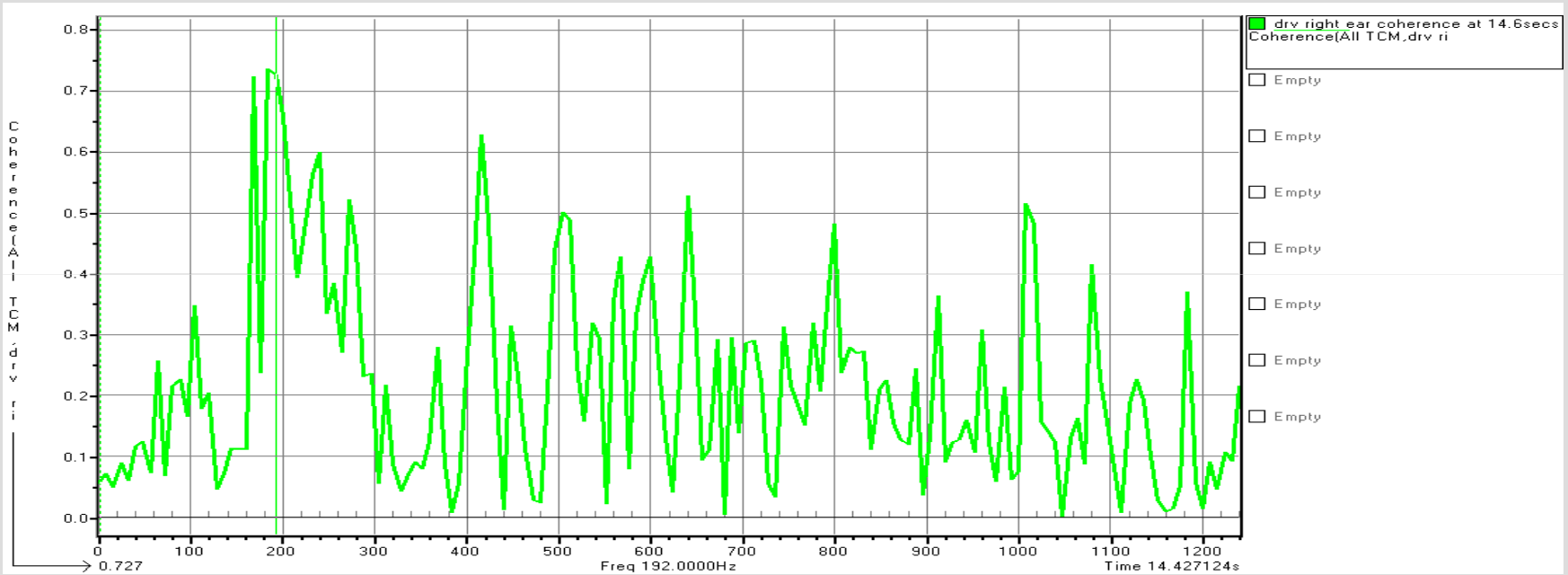
# Auto correlation at 14.44 seconds for front right tyre




The maximum is not displaced from the Zero time mark ( correct for auto correlation)

The time separation between peaks is 0.0051 seconds = 196Hz

# The final test for validity is the Coherence function which should have values near to 1 if the noise measured at the Drivers Ear is due to the noise measured in the tyre




Coherence Peaks at: 192, 360, 424, 512, 568, 688, 760, 960, 1016, 1120

Spectral peaks Tyre: 196, 400, 572, 776, 960, 1444Hz.

Mode number : 1 2 3 4 5

# Coherence



The coherence function will record values near 1, the maximum possible, where there is a signal present in the tyre that actually travels to the drivers ear and is dominant.

There are two types of signal present in the TCM data: -
1. Strong cavity resonances
2. General tread and road surface noise.

In the cabin there are three sets of noises:
1. Tyre/road - tones and broadband
2. Power-train - tones and broadband combustion
3. Wind - broadband

The ability of the tyre cavity modes to couple to wheel/suspension/body and then to the cabin microphone will potentially show up as maxima in the coherence plot. The result indicates that although the cavity modes are strong only the primary 196Hz, the third 572Hz and possibly the 5th mode at 960Hz actually propagate all the way to the drivers ear.

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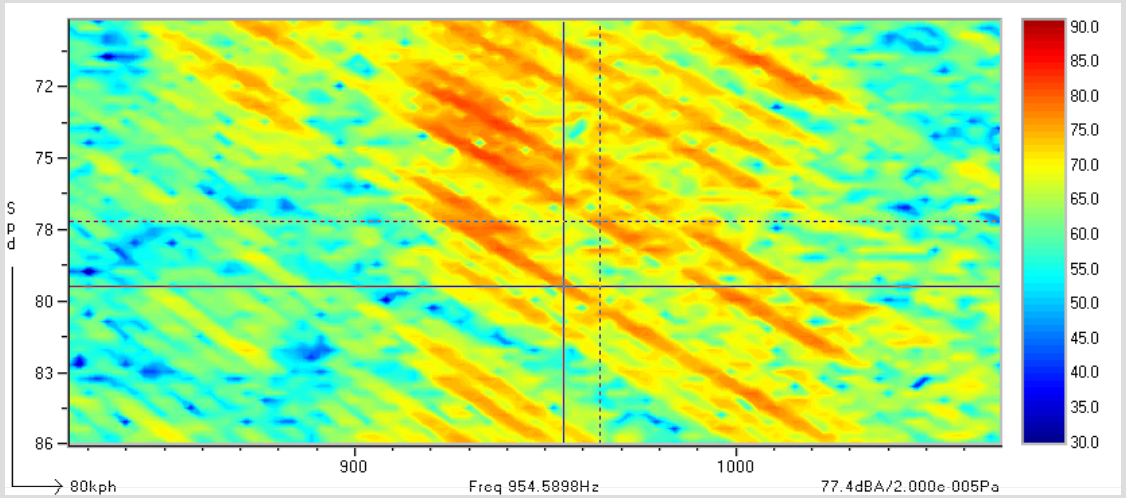
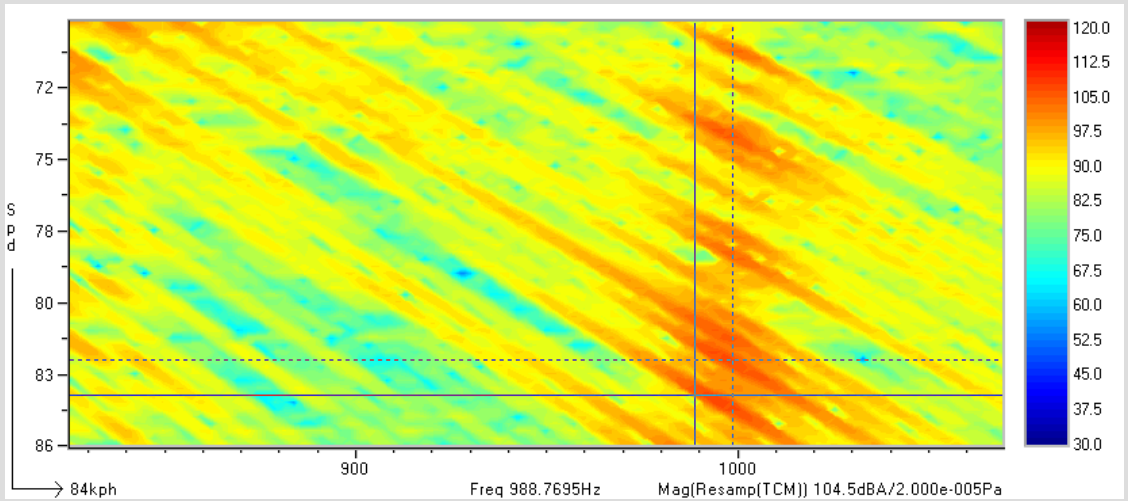
# Tread noise measured in the laboratory




Fine structure of the noise signal at the external normal microphone@ 80kph




Fine structure of the noise signal of the TCM @ 80kph

The "red lines" are spaced at the wheel rotation rate.

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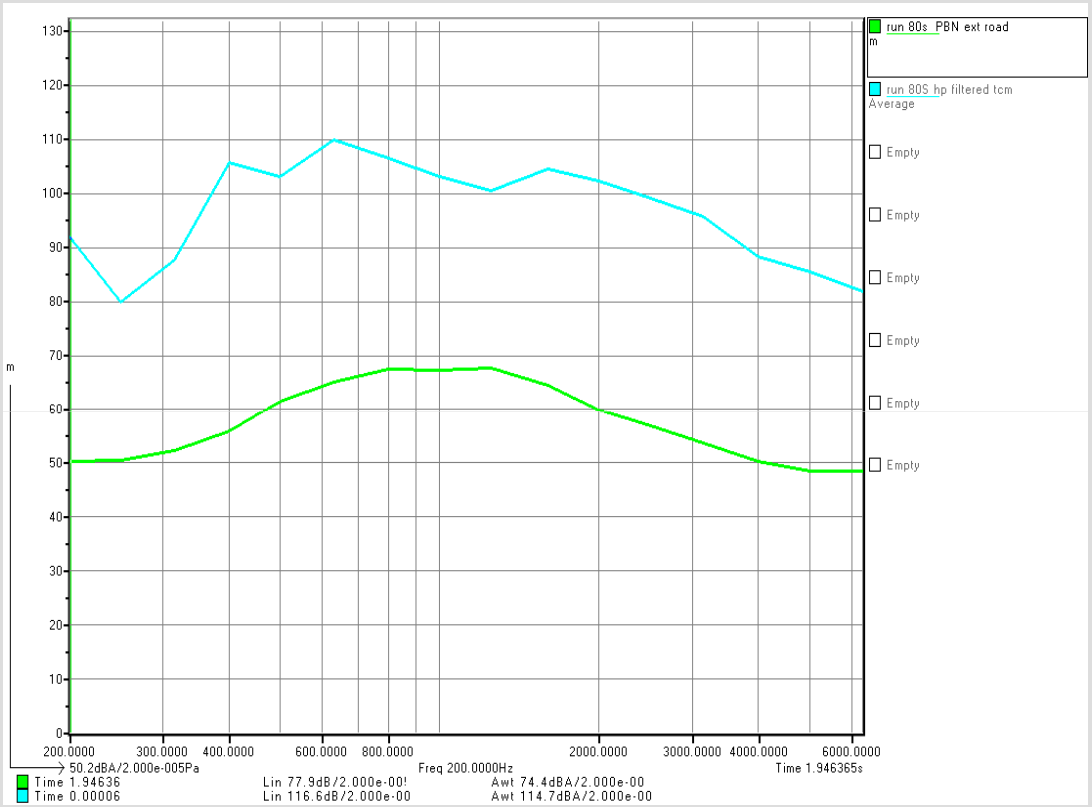
# Comparison of Awt TCM with averaged radiated noise on normal road@80kph




**TCM overall level = 114.7dBA**

**PBN overall level = 74.4dBA**

**HP filtering removes the dominant cavity modes that do not radiate strongly.**
**The resulting difference in level is 40.3dBA ( 114.7 – 74.4 = 40.3dBA)**

# PBN comparison with TCM



The level off-sets appear to be stable for a given tyre type i.e.

Summer/Winter/SUV for a normal road. (N.B. An ISO surface is typically 2 to 4 dBA quieter than a UK road)

| | | |
|---|---|---|
| TCM Road @ 80kph = 114.7dBA | ) | +42.7dBA |
| Road PBN @ 80kph = 74.4dBA | ) | + 2.4 dBA |
| ISO PBN @ 80kph = 72.0dBA | ) | 72.0 dBA |

**Subtracting 42.7dBA from the TCM level at 80kph on a "normal" road will give a predicted ISO surface PBN number**

Tyre Cavity Microphone (TCM)

# Comparison of TCM & ISO measured

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| Speed kph | Averaged road TCM dBA | PBN road dBA | PBN ISO Surface dBA | Predicted ISO TCM-42.7 dBA |
|---|---|---|---|---|
| 72 | 114.1 | 76.7 | 71.3 | 71.4 |
| 74 | 114.0 | | 71.1 | 71.3 |
| 76 | 114.1 | 75.2 | 72.0 | 71.4 |
| 77 | 115.2 | 76.0 | 71.9 | 72.5 |
| 80 | 114.7 | 74.4 | 72.0 | 72.0 |
| 82 | 115.7 | 75.6 | 73.0 | 73.0 |
| 84 | 117.3 | 75.5 | 73.7 | 74.6 |
| 86 | 116.8 | 76.7 | 74.8 | 74.8 |
| 88 | 117.6 | 77.6 | 74.6 | 74.9 |
| 90 | 117.2 | 77.8 | | 74.5 |

**Both ISO and TCM based predicted noise levels are subject to some scatter however agreement is still good**

# TCM spectral content at 72-84 kph

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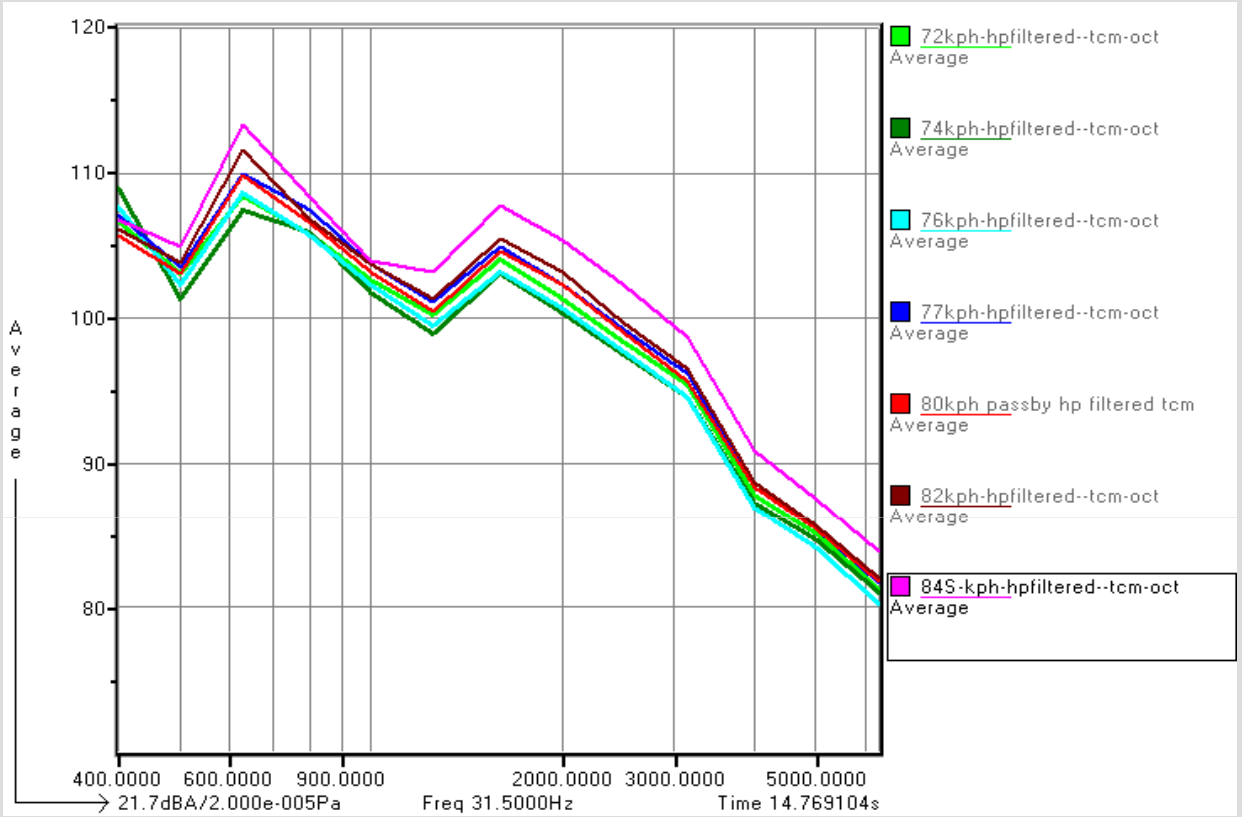


72 Kph

74

76

77

80

82

84

**The averaged "over 4 wheels" TCM data tends to increase with speed in a very similar manner to the external PBN levels for tyre coast by runs**

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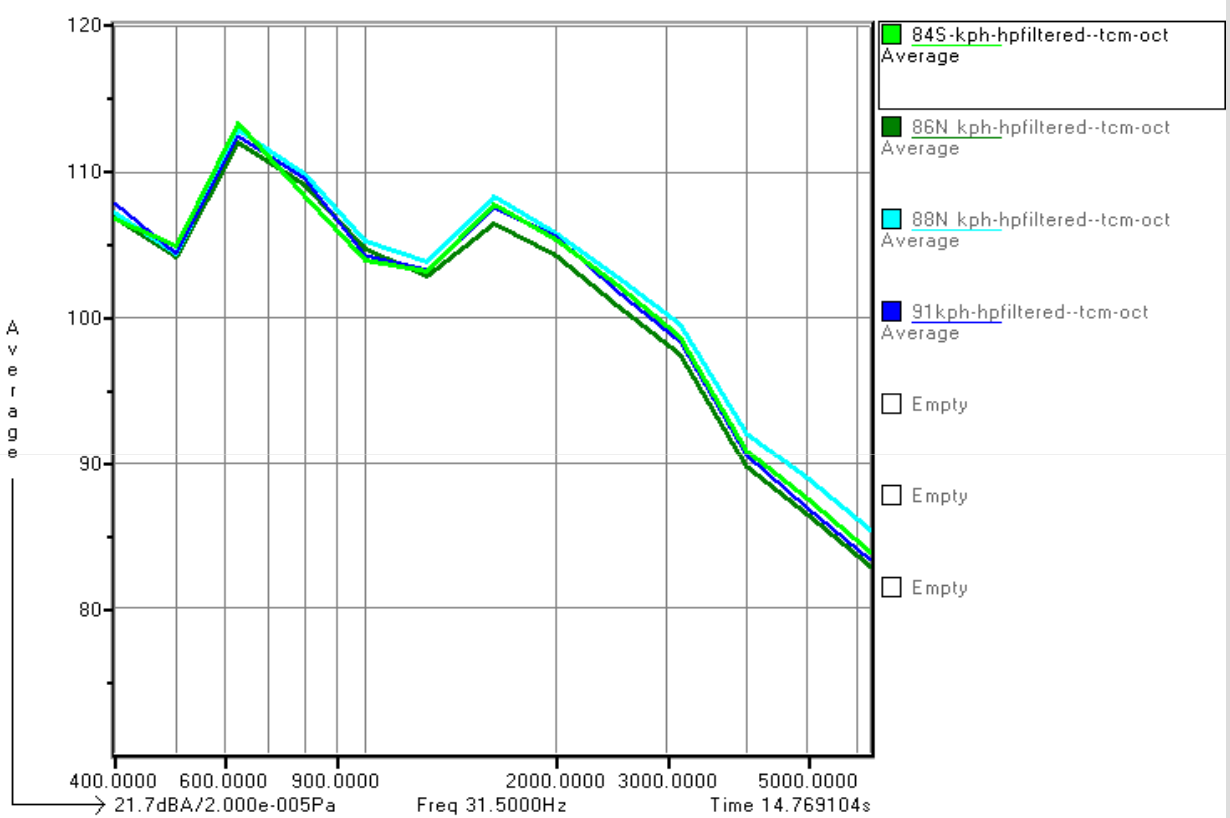
# TCM spectral content at 84-91kph




84 kph

86

88

91

**The averaged over 4 wheel TCM data tends to increase with speed in a very similar manner to the external PBN levels for tyre coast by runs**

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# Conclusions

## For the Auto Maker

Inexpensive, accurate and convenient way to evaluate tyres

Selection of tyre that minimise the annoying tyre singing

Selection of the best tread noise profile for a given vehicle

Road noise route tracking

## For the Tyre Maker

Noise evaluation of the proto type tyres on test wheel without expensive anechoic treatments to test rooms

Pass by noise evaluation without going to the ISO surface

On public road tyre noise testing that is weather and background noise insensitive

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