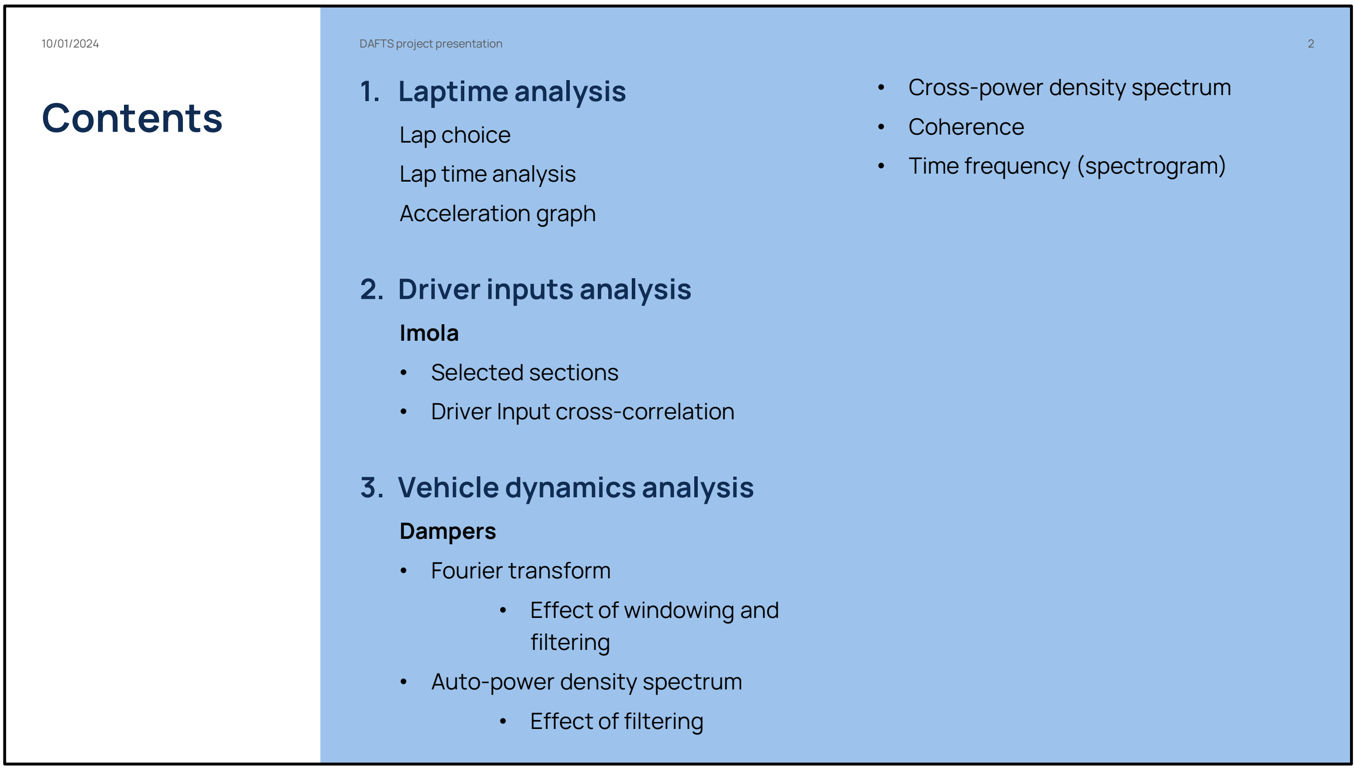
- Goal of this presentation: analyse data collected from a racecar
- The presentation held by my colleague a few weeks ago provided a global overview of the available data by comparing between two different tracks
- In this case, one of them is being analysed more into detail



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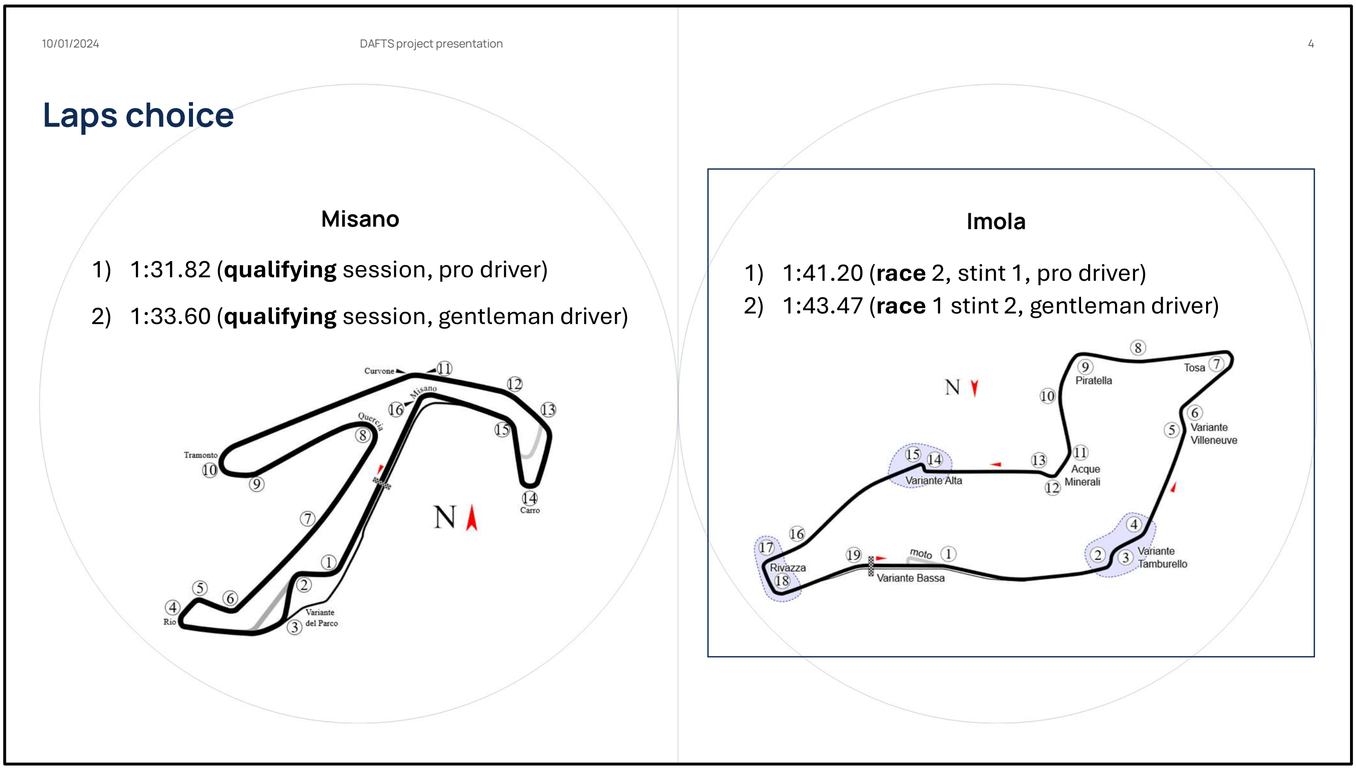
Laptime analysis

01



Misano

- Qualifying session has been chosen as it generally gives some more comparable results
    - Same tyres
    - Same track conditions
    - Almost same amount of fuel onboard

Imola

- Since there has been a technical issue in the qualifying during that weekend, I chose two similar laps, done in similar conditions, in two different races by the two drivers

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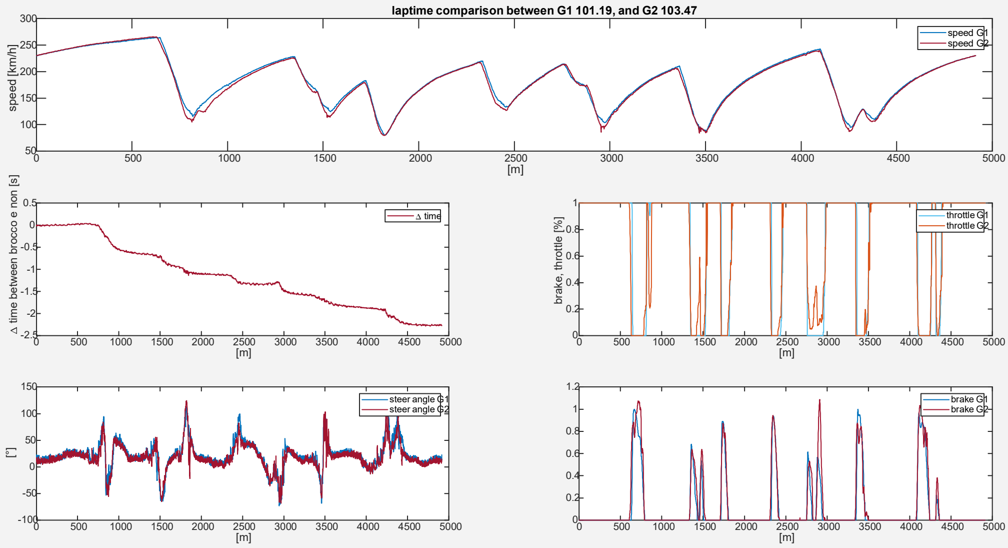
Imola

G1: **1:41.20**
G2: **1:43.47**

Total laptime difference: -2,25 s

Key points:
- **Turn 2,3,4 (-0,637)**
- Turn 17,18 (-0,376)
- Turn 5,6 (0,273)



The first analysis has been done considering mainly the laptime difference graph.

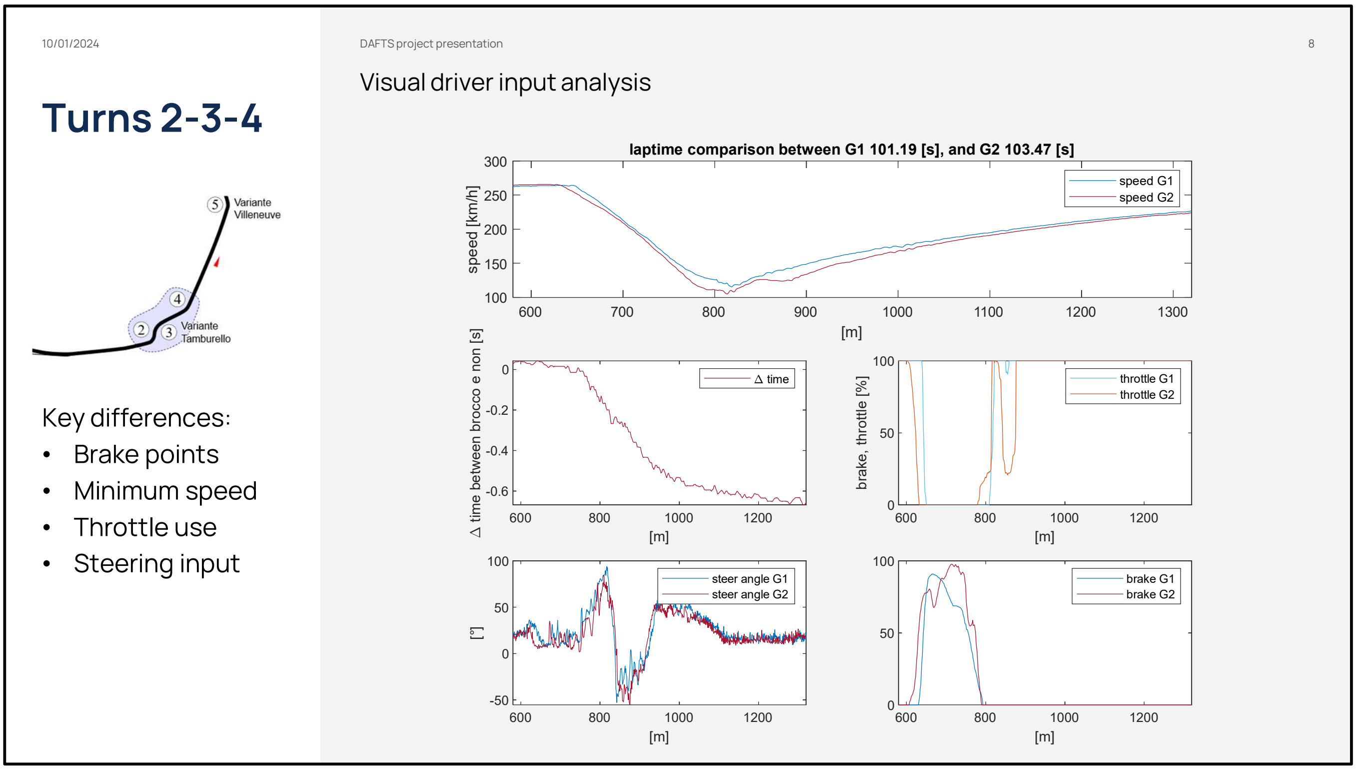
- When the delta time graph goes down it means the fastest driver is gaining time on the slower, the steeper the slope the larger the difference between the drivers in that point
- The key points highlighted here indicate the parts of the track where the difference between the two drivers (not only in terms of time but also in terms of driving style) is more evident
- I calculated the approximated time lost for each series of turn by subtracting the time difference before and after it.
- I consider the turn to start before brake application and finished after full throttle application, sometimes is better to evaluate the time difference later in the following straight, to take into account the time lost due to a bad exit from the turn. This is the case for turns 2,3,4

Driver inputs analysis

02

Turn 2-3-4

02



Section Driver input analysis:
Same input considered as for the general laptime analysis:

Speed
- the driver 1 brakes approximatively 25m after driver 2, carrying more speed into the braking phase and in mid corner. For instance, in the slowest point of the corner, the difference in speed between the two is approximately 15 km/h
- The speed of driver 1 is higher in every section of the corner
- Exit is different between the two drivers: speed profile of driver 1 is monotonically increasing while driver 2 lifts the foot from the accelerator

Delta time
- After the first apex (when steering input indicates that the driver is about to approach turn 3), driver 1 has gained 0,25 seconds over driver 2
- Due to the throttle lift in turn 3, driver 2 loses other 0,103 seconds
- By the time they are both full throttle approaching the apex of turn 4, driver 2 has lost approximately 0,3 seconds
- Due to the lower speed that driver 2 carries in the last part of the corner, by the time he reaches turn 5, he has lost other 0,3 seconds on the straight. At the breaking point of turn 5, driver 1 has gained 0,6 seconds over driver 2
- Driver 2 never gains back the time lost

Throttle

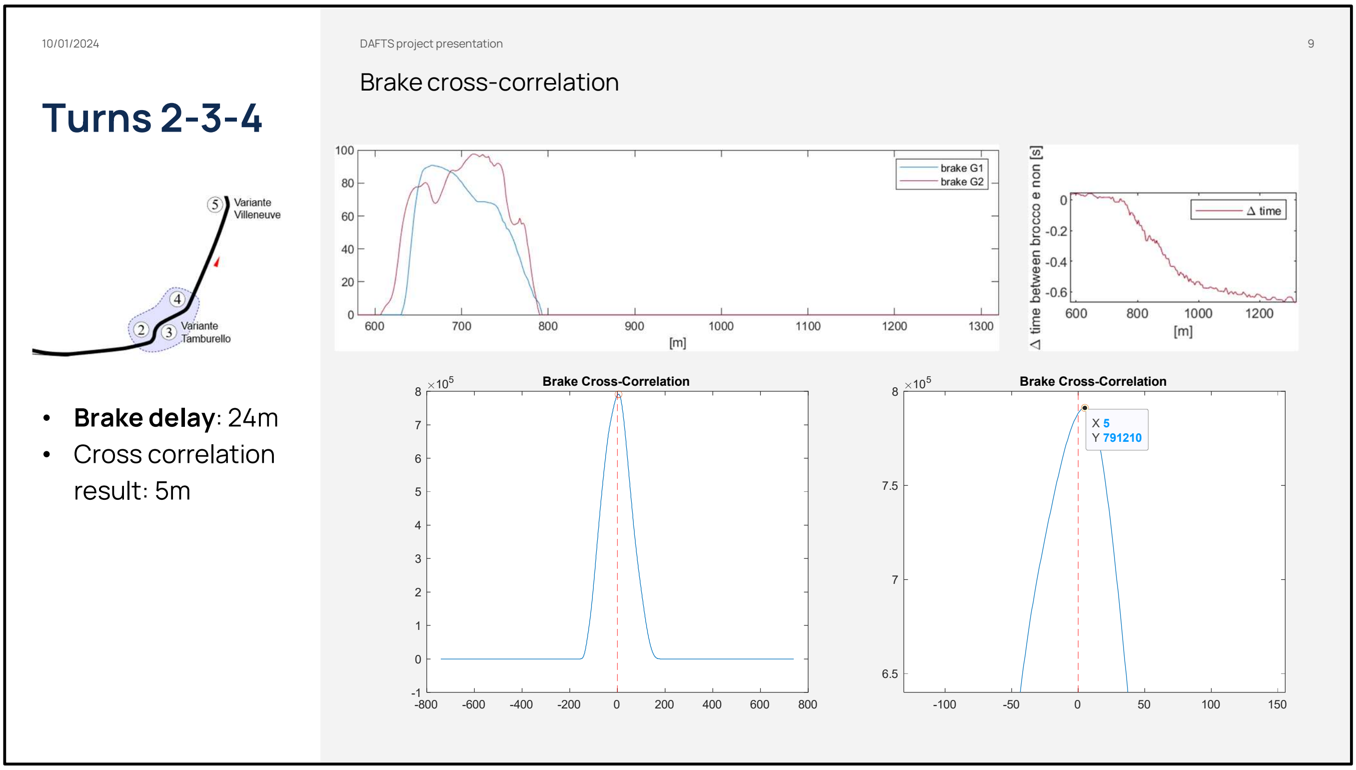
- On the second apex driver 2 releases almost completely the throttle while driver 1 doesn’t; as a consequence, the speed of driver 1 is approximately 20 km/h higher than the one of driver 2 in this section

Brake

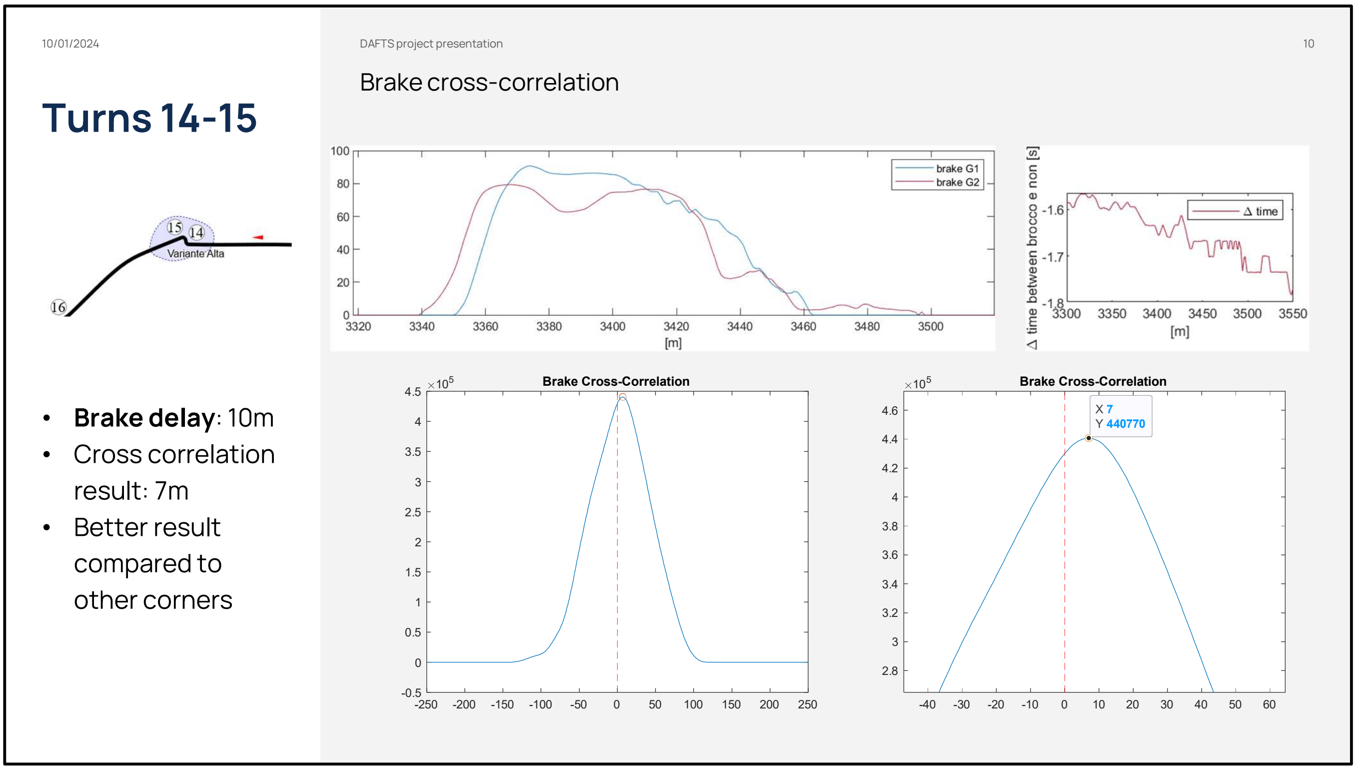
- The best brake application is from the driver 1, it has a rapid first input, followed by a slow release of the brake pressure as he enters the corner and steers
- Brake curve of driver 1 is monotonic both in the application and in the release phase, while driver 2 presses and releases the pedal multiple times

Steer

- Driver 1 has a more aggressive style and is driving close to the limit (sometimes needs to perform small corrections (very clear on the apex of turn 3))
- Driver 1 approaches the apex of turn 2 with a tighter trajectory (blue line indicates more steer angle), this allows him to have a faster trajectory in the second part of the corner (lower steering angle)



- Computing the cross correlation between the brake or the throttle input for turns 2-3-4 doesn't make much sense since the way the two drivers approach the corner is completely different and no useful data could be extracted. Still, some considerations can be made
- By definition, the result of the xcorr represents the shift needed to overlap the two different diagrams as much as possible, so it could be an indication of where the second driver could brake, maintaining the same brake application, to improve his lap time
- The braking point isn't the only relevant aspect when comparing the telemetry: the way the pressure is applied and released on the pedal also plays a key role (applying the brake at the right time ≠ applying the brake in the right way)
- The result of the xcorr provides information about "when to apply the brake"
- The difference between the result of the xcorr and the visual one provides information about "how is the brake being applied"; indeed, the large difference between the two results, in this case, indicates that the approach of driver 2 to this corner is far from being good. As a matter of fact, a significant amount of time is lost after this corner
- It is very important to clarify that this analysis is too simplified, as it doesn't take into account, the trajectory, the initial and final speed, and some other external factor. But it could be an interesting numerical indicator of different drivers' performance



- Computing the cross correlation between the brake or the throttle input for this turn doesn't make any sense since the way the two drivers approach the corner is completely different and no useful data could be extracted
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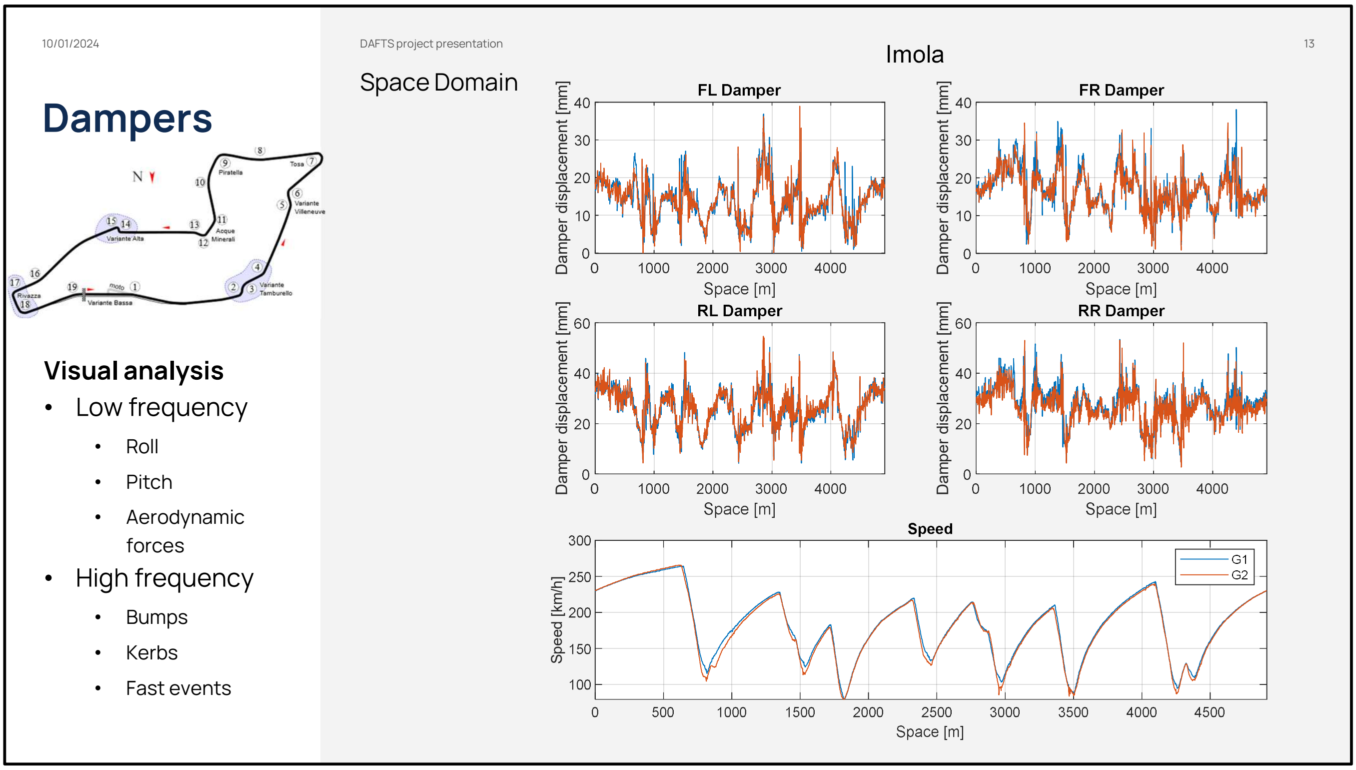
- The result of the xcorr provides information about "when to apply the brake"
- The difference between the result of the xcorr and the visual one provides information about "how is the brake being applied"; indeed, the small difference between the two results, in this case, indicates that the approach of driver 2 to this corner is not far from being good. As a matter of fact, the delta dime doesn't show a significant loss of time after turn 15
- It is very important to clarify that this analysis is too simplified, as it doesn't take into account, the trajectory, the initial and final speed, and some other external factor. But it could be an interesting numerical indicator of different drivers' performance

Vehicle dynamics

03

Dampers

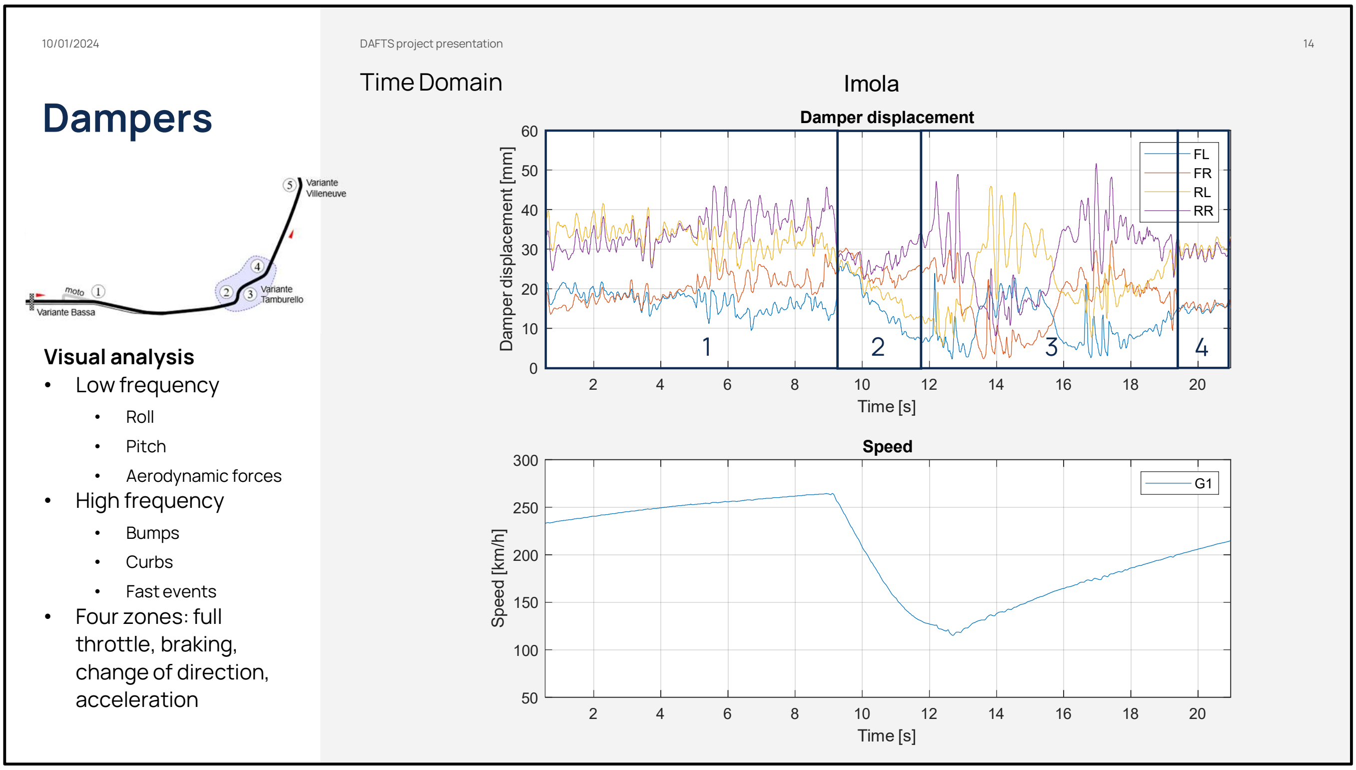
03



The space domain signal of the dampers

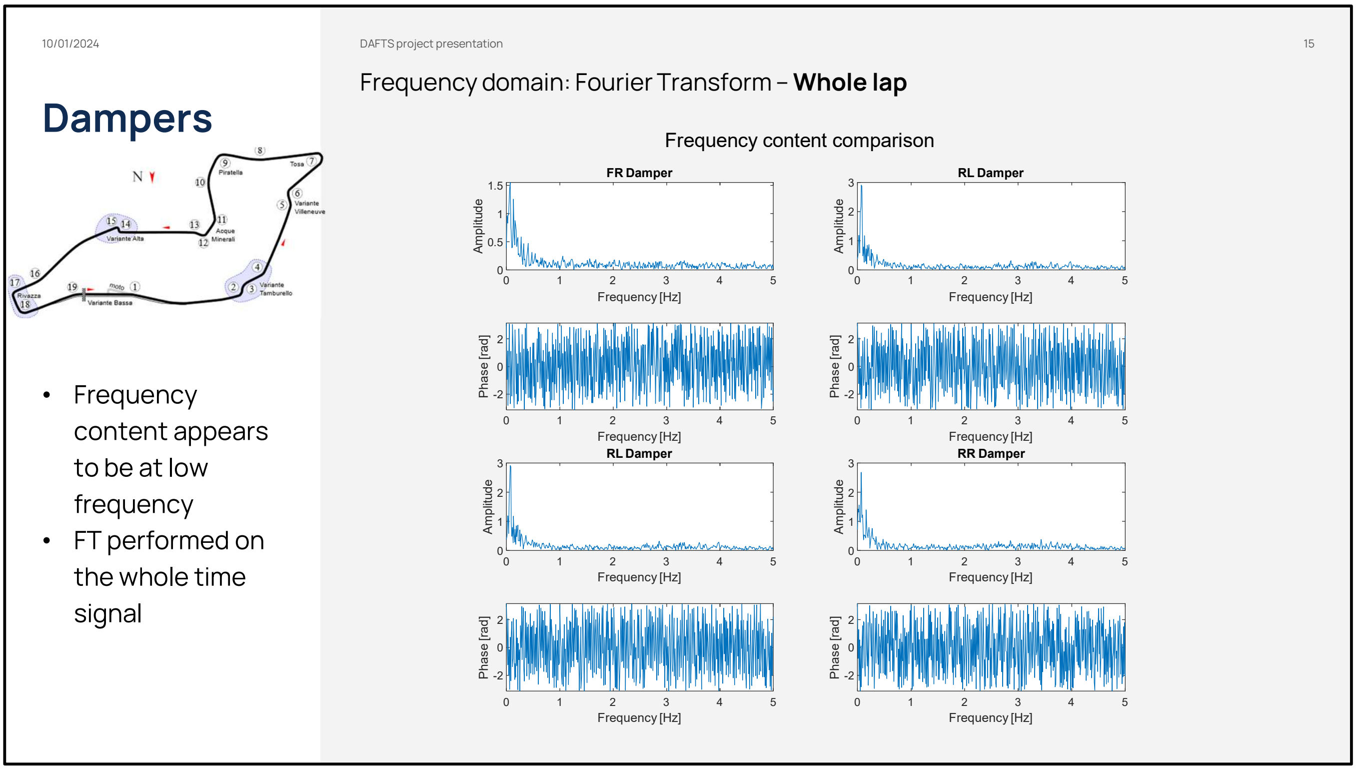
- It is expressed in terms of vertical displacements, measured by a potentiometer installed in parallel with the damper and spring unit of the suspension
- They are tuned in compression and extension and in high and low speed
- The signal is visually characterized by different frequency component, generally:
    - Low frequency
        - associated to
            - Rolling
            - Pitching
            - Vertical load due to the presence of aerodynamic forces
    - High frequency
        - Mainly given to road surface roughness: kerbs and bumps
        - Some other rapid events occurring such as gear changes
- Positive slope = compression
- Negative slope = extension
- Some observations:
    - NB: we notice that RR and FR are compressed on the main straight (slope is different compared to left side) → setup is not asymmetric but between the start finish line and turn 2,3,4 the track turns to the left, this generates compression of the dampers on the right side
    - It is very clear in some corners that driver 1 (G1) is using the kerbs more, the

most evident example is in correspondence of the penultimate corner (turn 17), where FL has a significant rapid compression

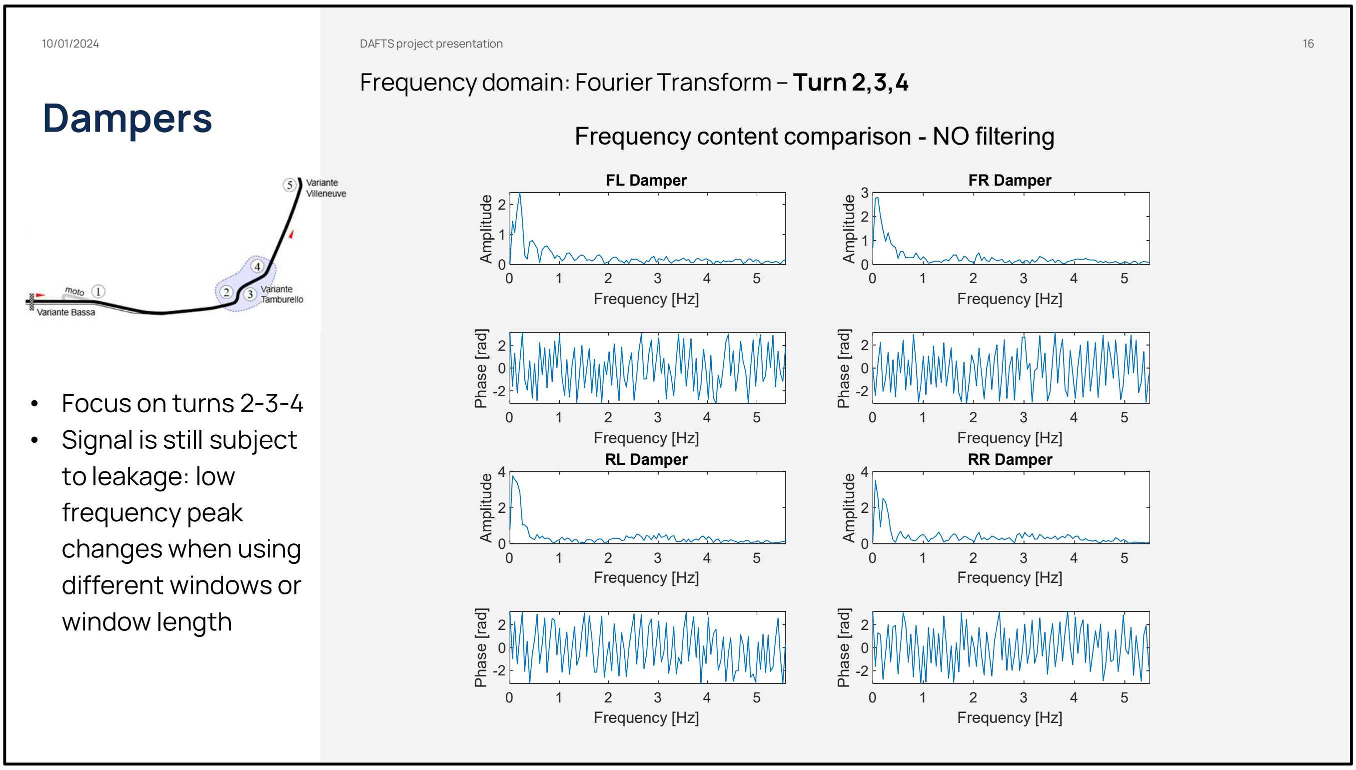


Focus on turns 2-3-4:

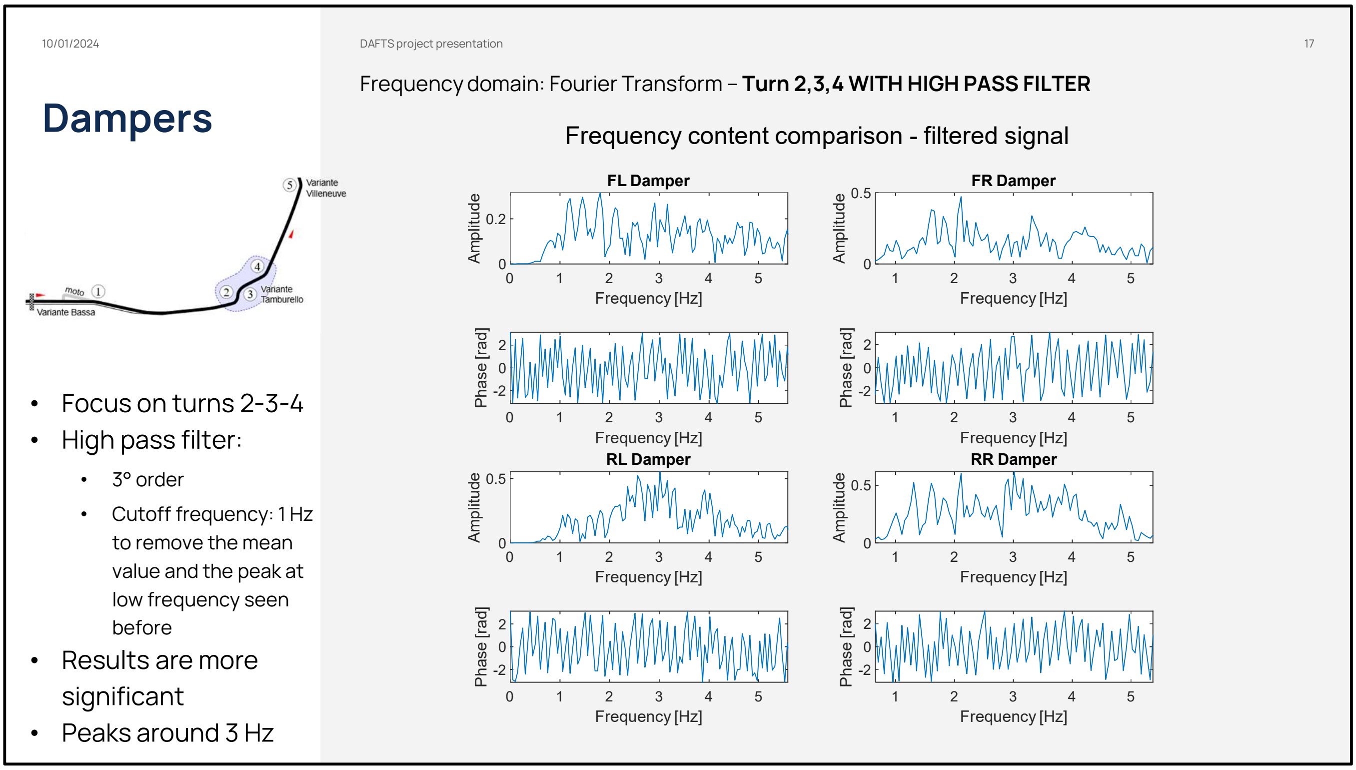
- Some observations:
  - 4 zones: main straight, braking, change of direction, exit
    1. Full acceleration → rear more compressed; probably there is a bump on the track since all the dampers experience the same vibration in phase
    2. Braking phase → it is not approached with a rectilinear trajectory since the track is slightly turning left, as a consequence, FR and RR are more compressed than the ones left side
    3. Change of direction during acceleration → very clear by looking at the rear dampers. Left turn (RR compression), right turn (RL compression), left turn (RR compression)
    4. Exit → same as main straight: rear more compressed
  - Car is for sure hitting some curbs: see compression of FL in the change of direction followed immediately by the compression of RL
- The goal of the frequency domain analysis is to extract some more information about these oscillations seen in time domain



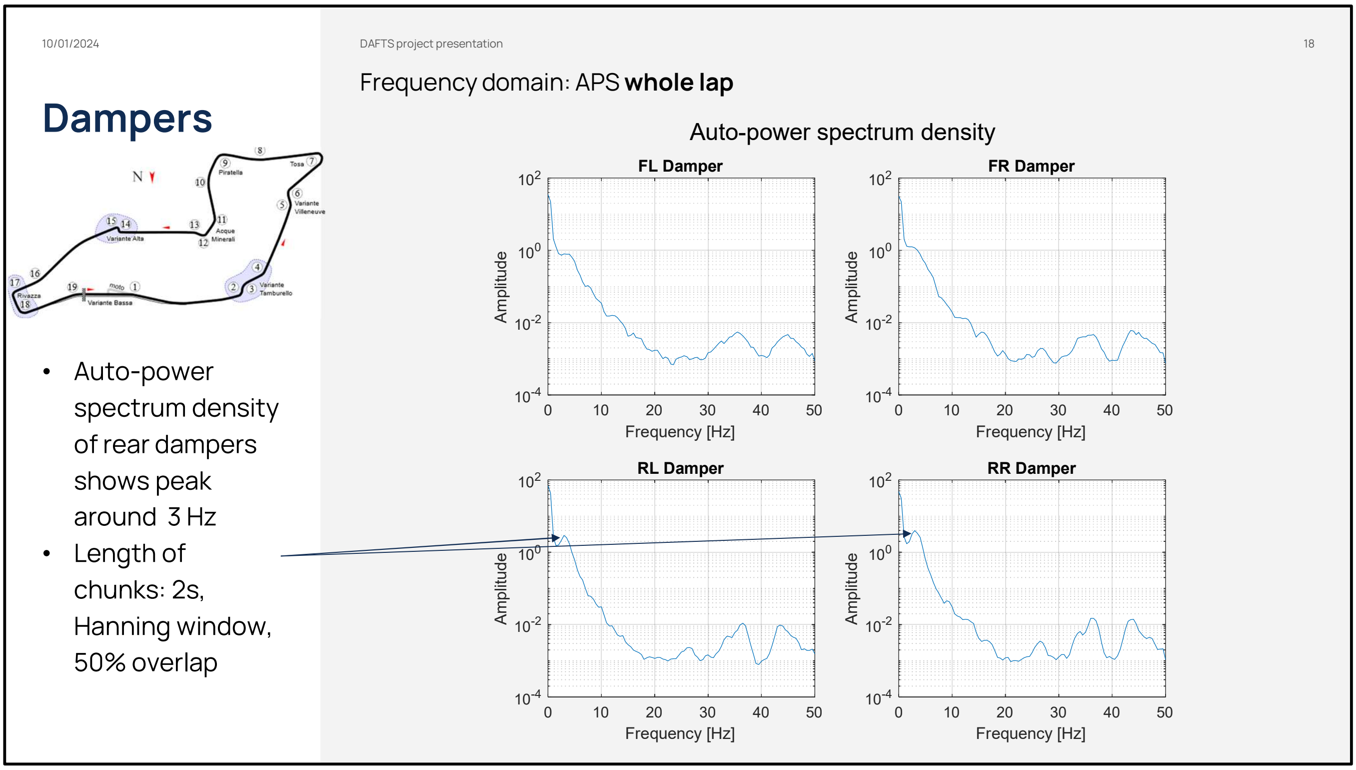
- The average value has been removed removed
- Considering the whole lap, no interesting conclusions can be inferred except that, on average, the frequency content appears to be at frequencies
- FT performed on the whole time signal
- Phase reported here is not relative → we cannot get information whether the dampers are oscillating in phase or in anti phase
- Considering what has been observed in the time domain analysis of the dampers, FT is performed considering only the very first part of the track since it seems interesting



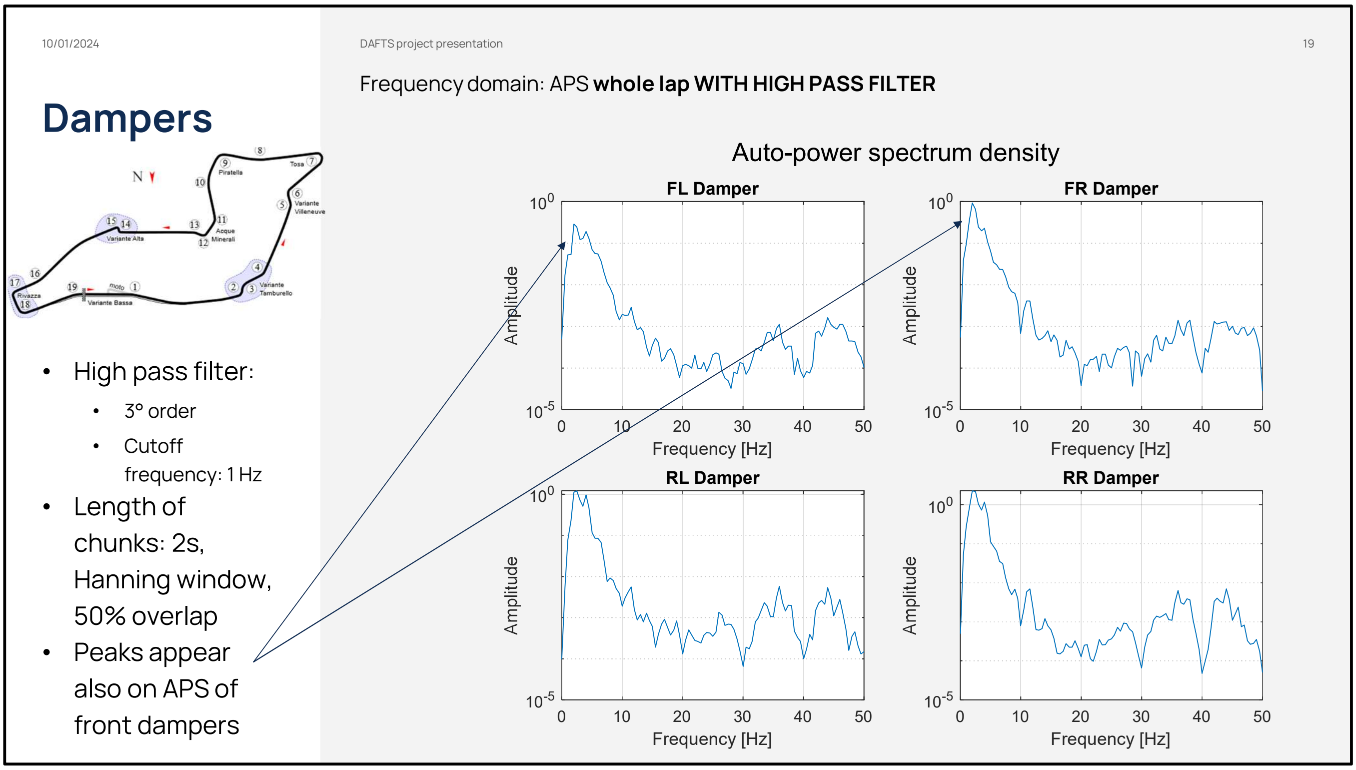
- Signal has been windowed to extract this first part, hanning window has been used (1 average)
- Amplitude hasn't been compensated because we are only interested in identifying peaks
- Signal is still subject to leakage → the peak at low frequency changes with the observation time (different tests have been done with different windows) → es. With rectangular window the peak is split in 2, this is because the rectangular window has the smallest main lobe
- No useful information are obtained because an average is performed considering vectors with different phase that therefore cancel each other
- Conclusion: still no useful results have been obtained, possibly the power spectrum analysis is going to provide more useful results



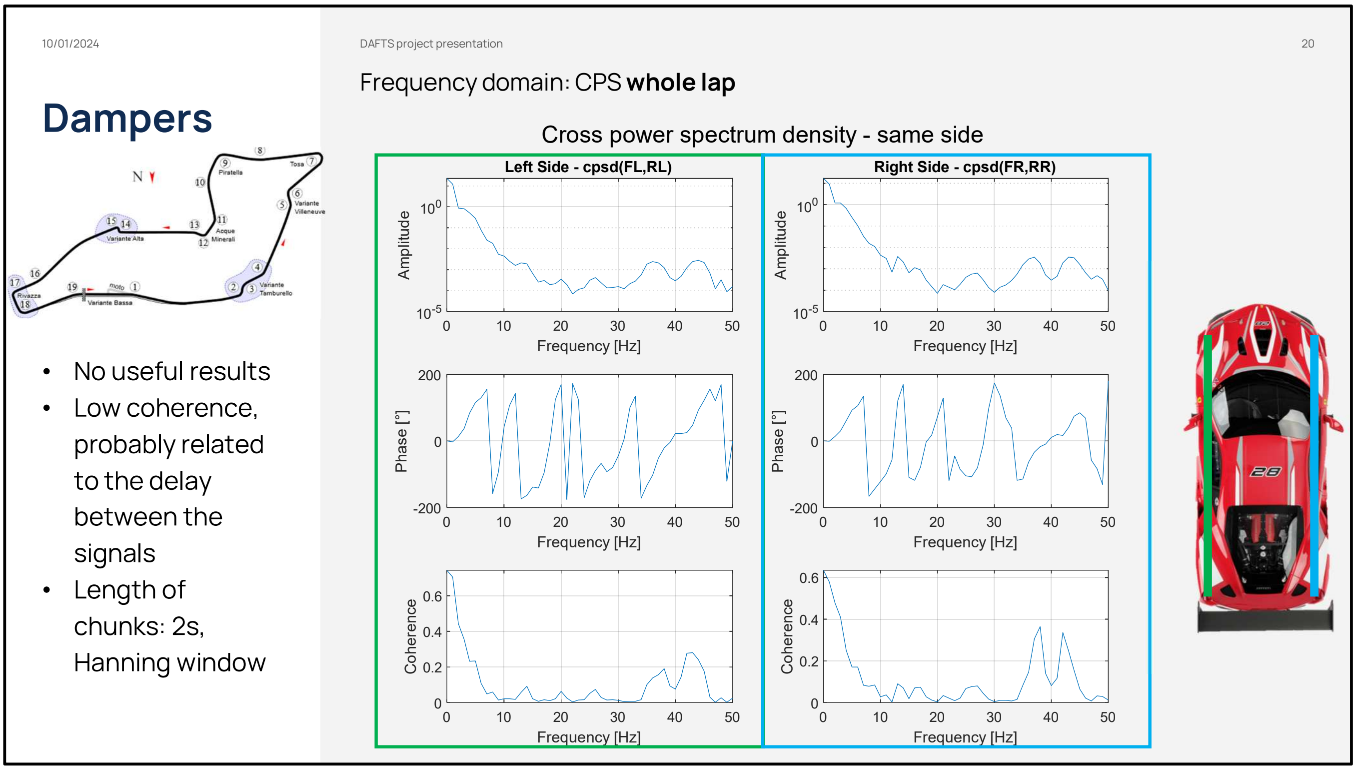
- Signal has been filtered and windowed to extract this first part, hanning window has been used (1 average)
- Amplitude hasn't been compensated because we are only interested in identifying peaks
- A high pass filter has been used
    - 3° order
    - Cutoff frequency = 1 Hz allows removing the mean value and the low frequency peak associated to leakage seen before
    - Peaks around 2-3 Hz can be identified



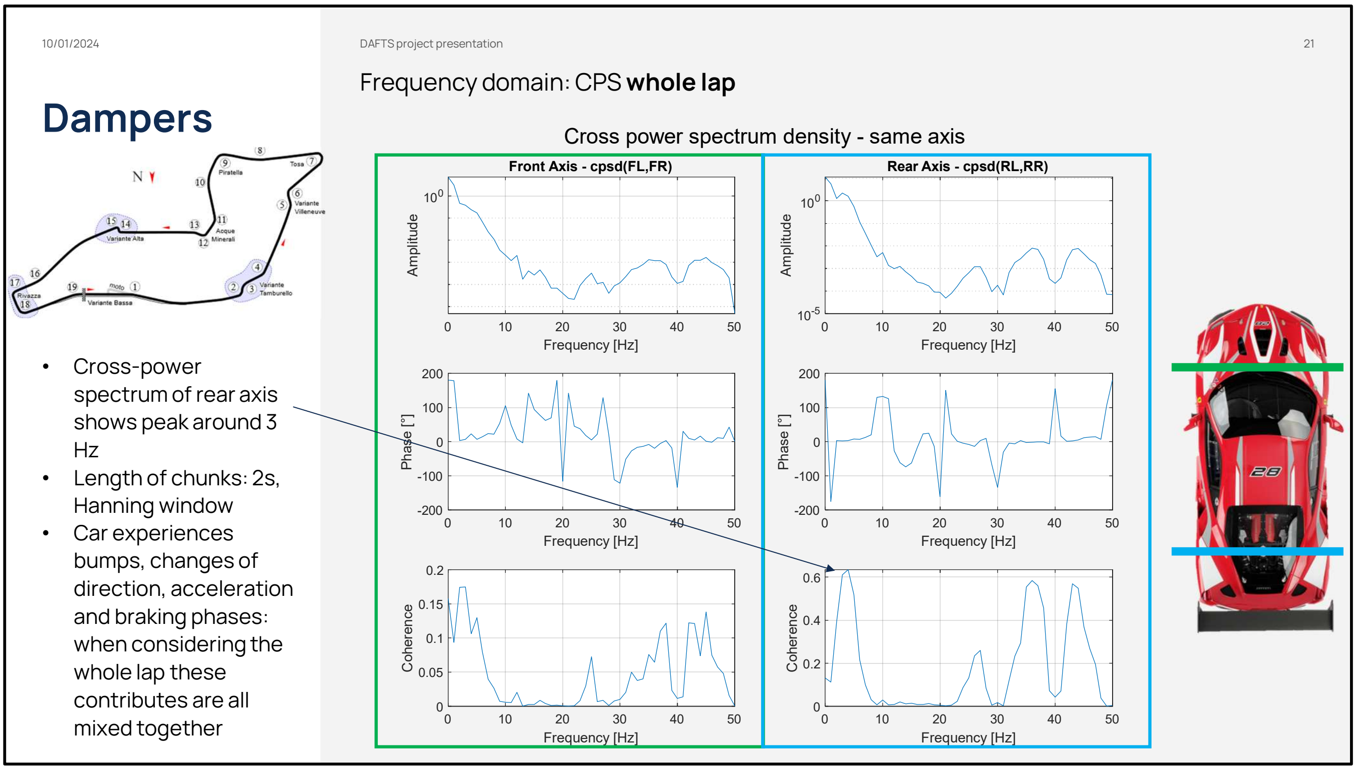
- Since the signal is not deterministic, power spectrum density has been used to make sure the amplitude is independent from the frequency resolution
- Whole track has been considered
- Length of chunks: 2s, 50% overlap, Hanning window has been used
- Random noise disappears as expected in auto-power density (actual signal averages with the same phase, noise averages with random phase and tends to disappear) and two peaks appear in correspondence of frequency 3 Hz



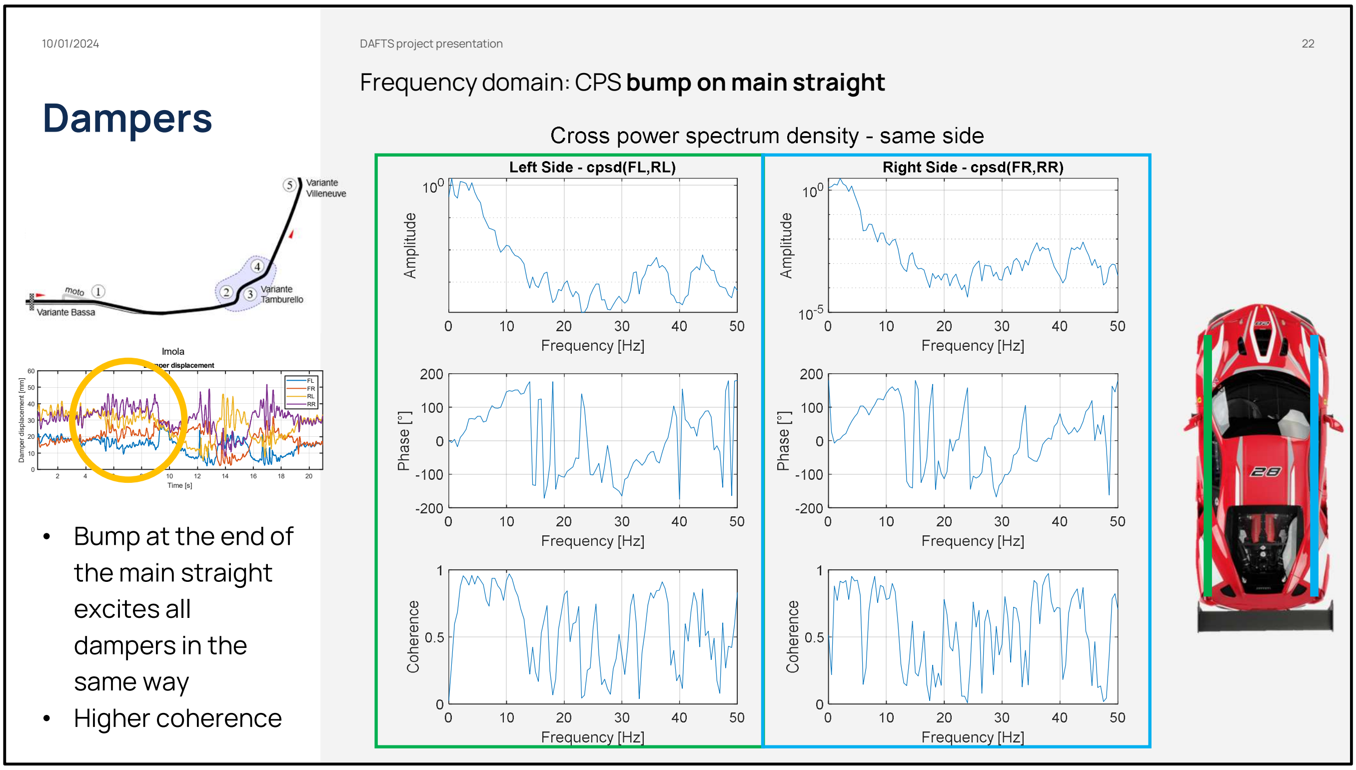
- High pass filter allows once again to get better results on the front axis



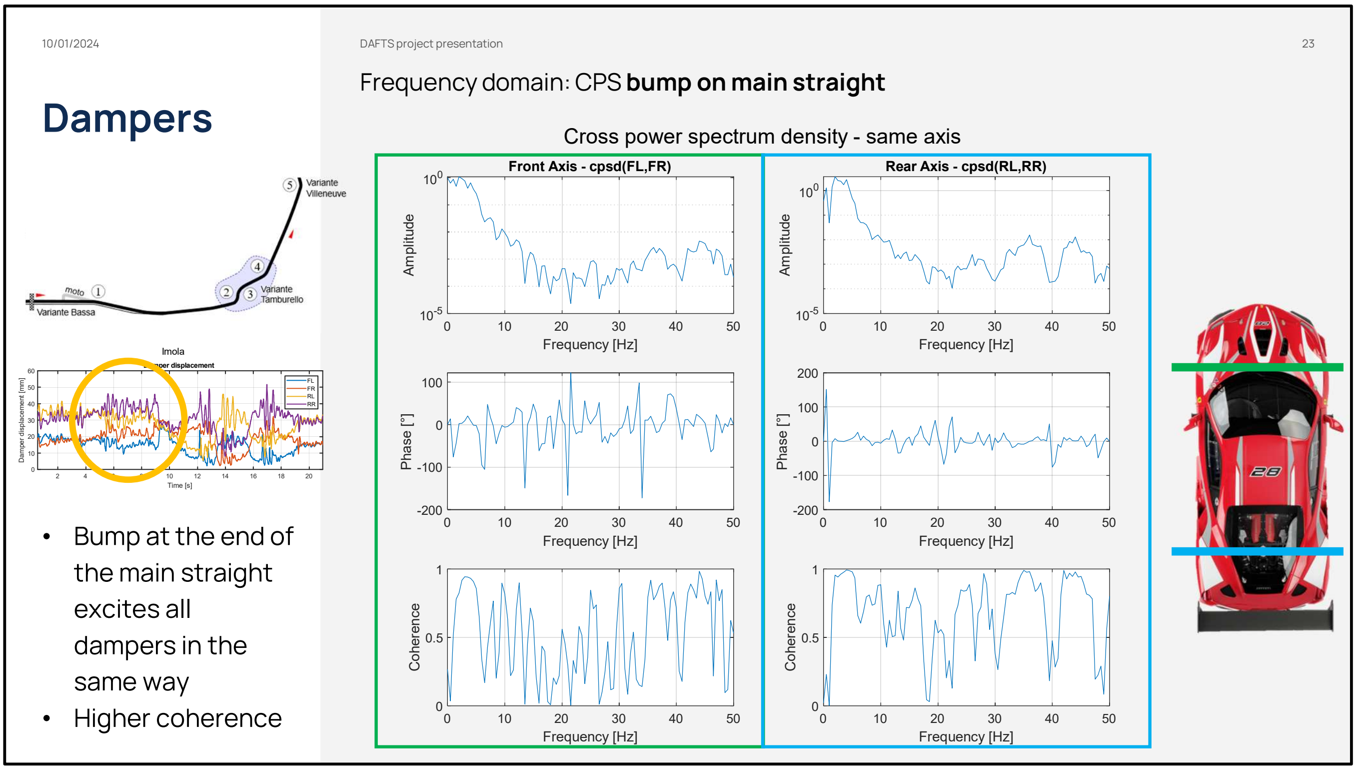
- Notice that the two plots have a very similar shape
- Cross power spectrum density between dampers on the same side of the car doesn't provide any useful results: coherence is always low and no peaks can be seen
- NB: when considering two dampers on the same side of the car, the two signals are delayed: the one of the rear tires is delayed with respect to the one of the front tires. This might also be a cause of the low coherence values
- Once again, filtering improves the result but the quality of the result without filtering is already good enough



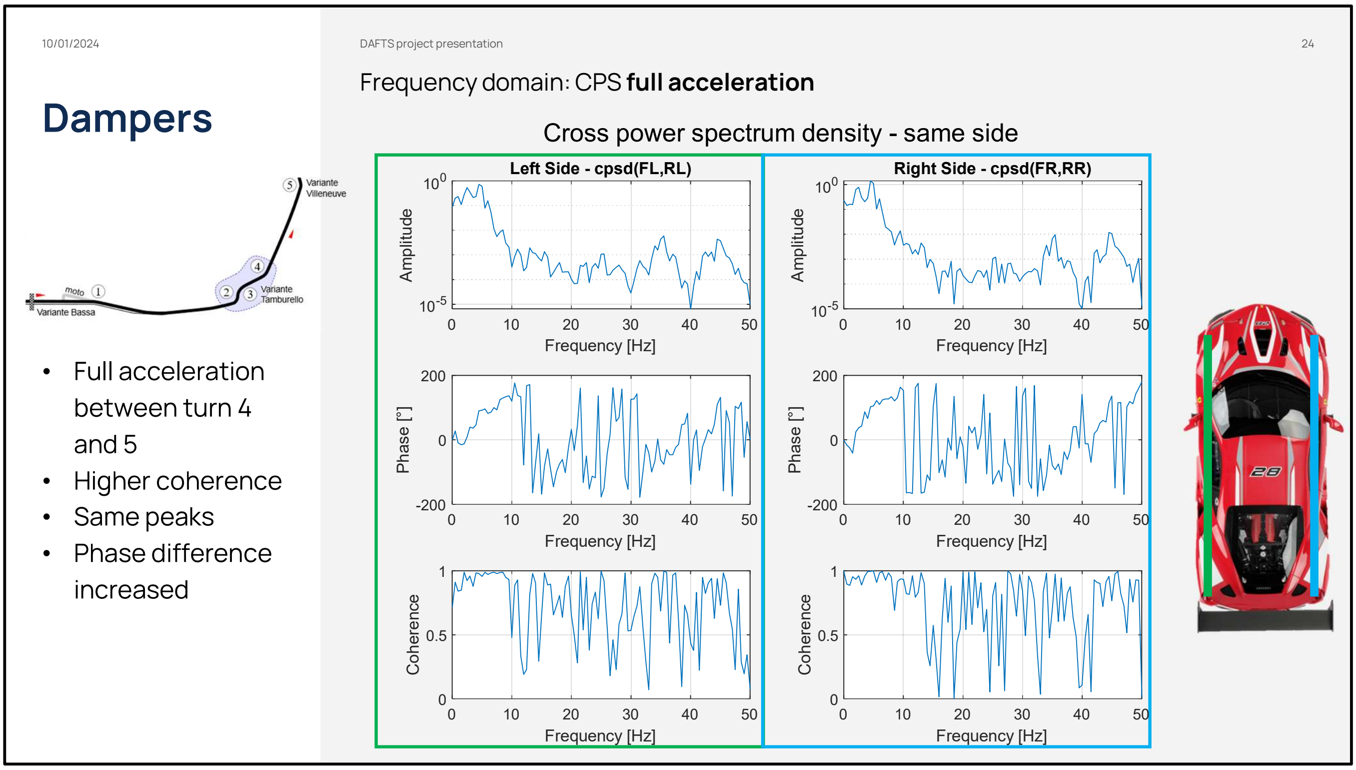
- Cross power spectrum density between dampers on front axis doesn't provide any useful result: coherence is very low and no peaks can be seen
- Cross power spectrum density between dampers on the rear axis provides some more useful results, once again a peak around the frequency of 3 Hz can be seen
    - Coherence is a bit higher but still not extremely high
    - Interesting to notice that in correspondence of that peak the phase difference between the two signals considered is 0°, they are moving in phase → it could be a movement about the pitch axis or simply a vertical synchronized motion (surely it is not about the roll axis)
    - Some other coherence peaks can be seen but the amplitude is too low to consider them
- NB: car experiences bumps, changes of direction, acceleration and braking phases and each one of these phenomena is going to excite the dampers in a different way → when considering the whole lap these contributes are all mixed together → to "separate" them each one of them we need to select specific sections of the track



- Peaks arise also in the cross power spectrum density between dampers on the same side of the car. Note that they are once again around 3 Hz (between 2.5 and 4)
- Coherence is much higher than when considering the whole lap
- Phase difference is the same in the two diagrams
- Note that the phase difference is not zero → reasonable result considering the bump is just before the beginning of the braking zone



- Peaks arise once again around 3 Hz (between 2.5 and 4)
- Coherence is much higher than when considering the whole lap
- Phase difference is the same in the two diagrams
- Note that the phase difference in this case is zero → reasonable result considering the bump is just before the beginning of the braking zone and dampers on the same axis are compressed in the same way



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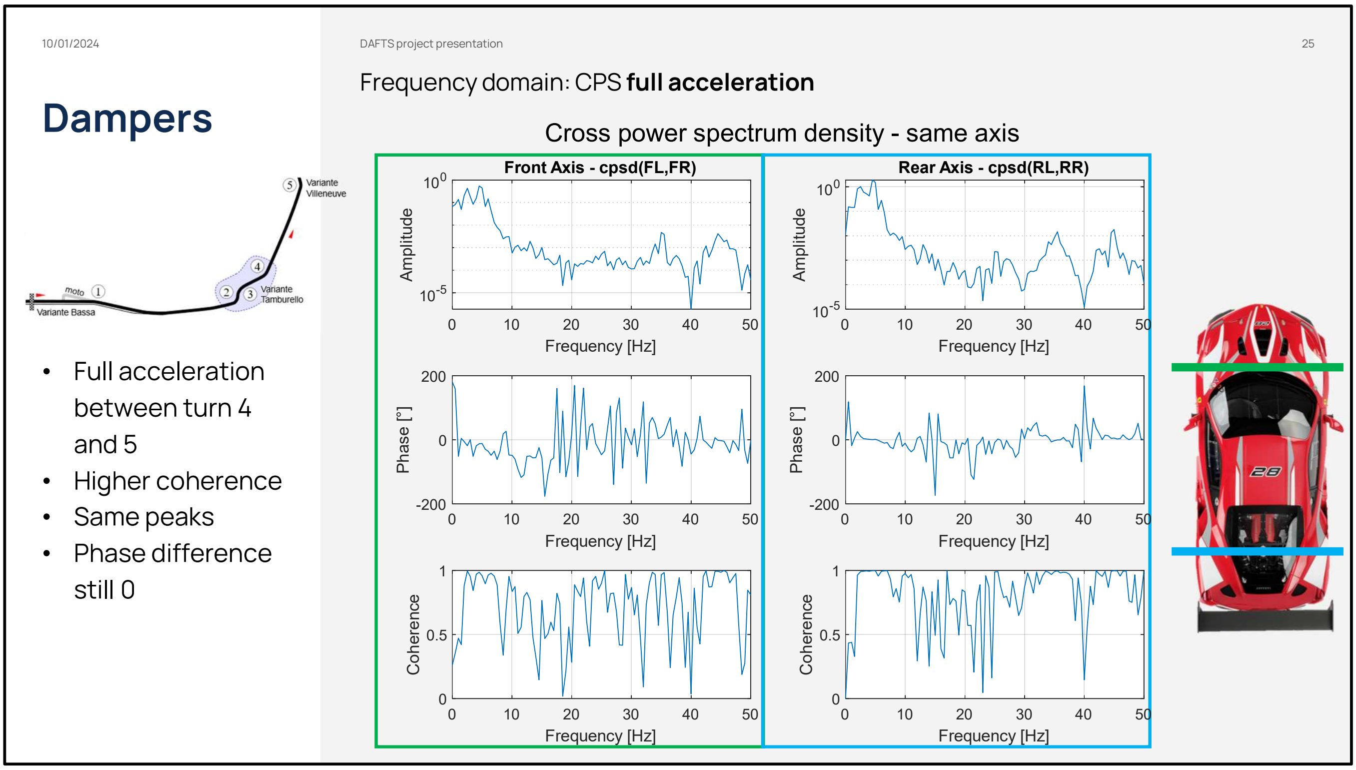
- Phase difference is the same in the two diagrams
- Note that the phase difference is not zero and it is higher than the previous case → reasonable result considering this is full acceleration



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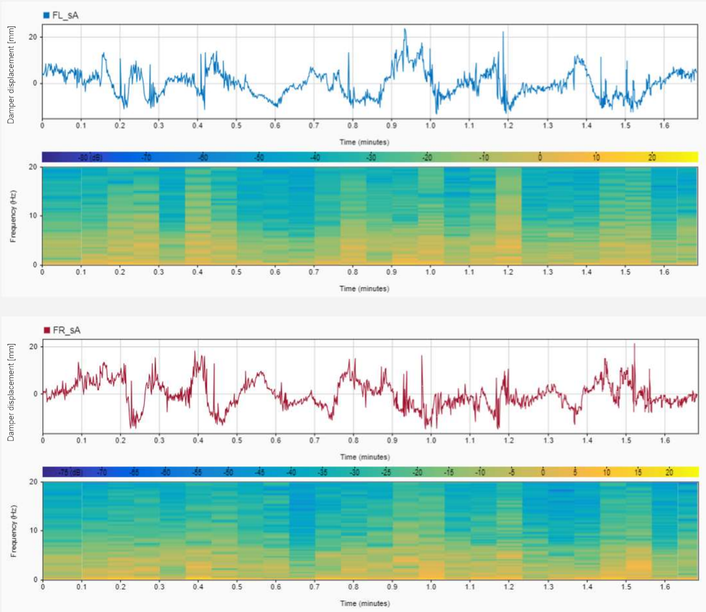
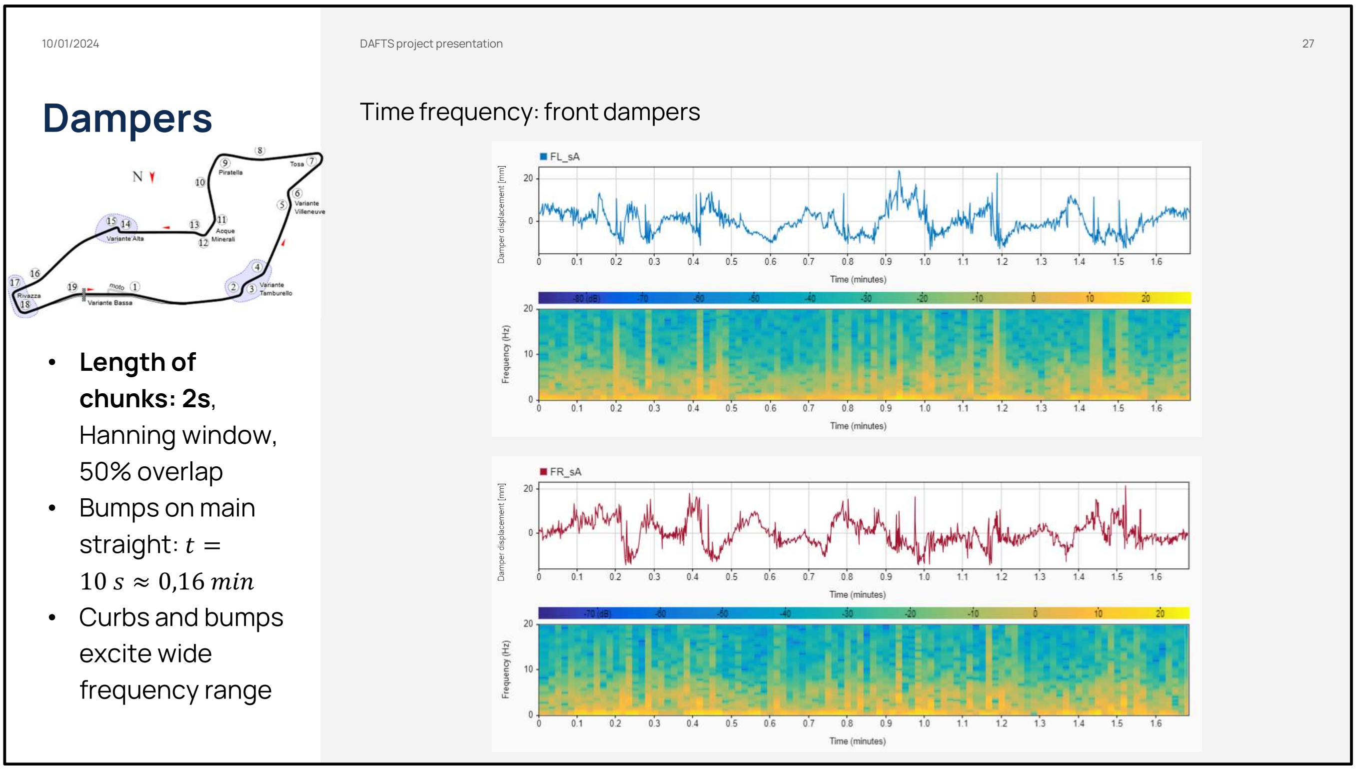
Dampers

- **Length of chunks: 8s**, Hanning window, 50% overlap
- Bumps on main straight: $t = 10\ s \approx 0{,}16\ min$
- Curbs and bumps excite wide frequency range

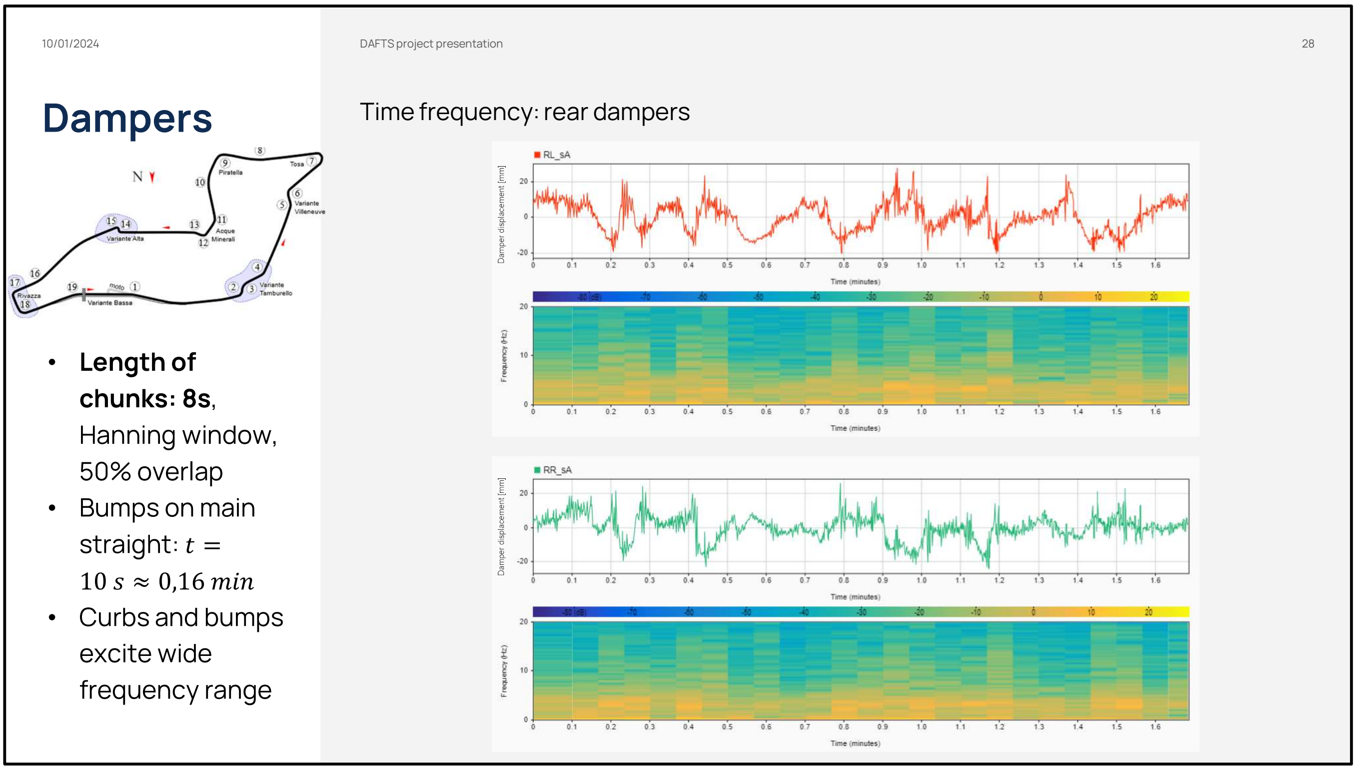
Time frequency: front dampers



- Length of windows increased to get better frequency resolution
- Bumps and kerbs act like impulse excitations that excite a large frequency range
- Time axis is in min → bumps on main straight: 10 s $\approx 0{,}16\ min$ → in correspondence of this time instant we see a large frequency range excited including the 2-4 Hz range observed before



- Length of windows decreased to get better time resolution in the turns and bumps but still good frequency resolution
- Bumps and kerbs act like impulse excitations that excite a large frequency range
- Time axis is in min → bumps on main straight: 10 s ≈ $0{,}16\ min$ → in correspondence of this time instant we see a large frequency range excited including the 2-4 Hz range observed before



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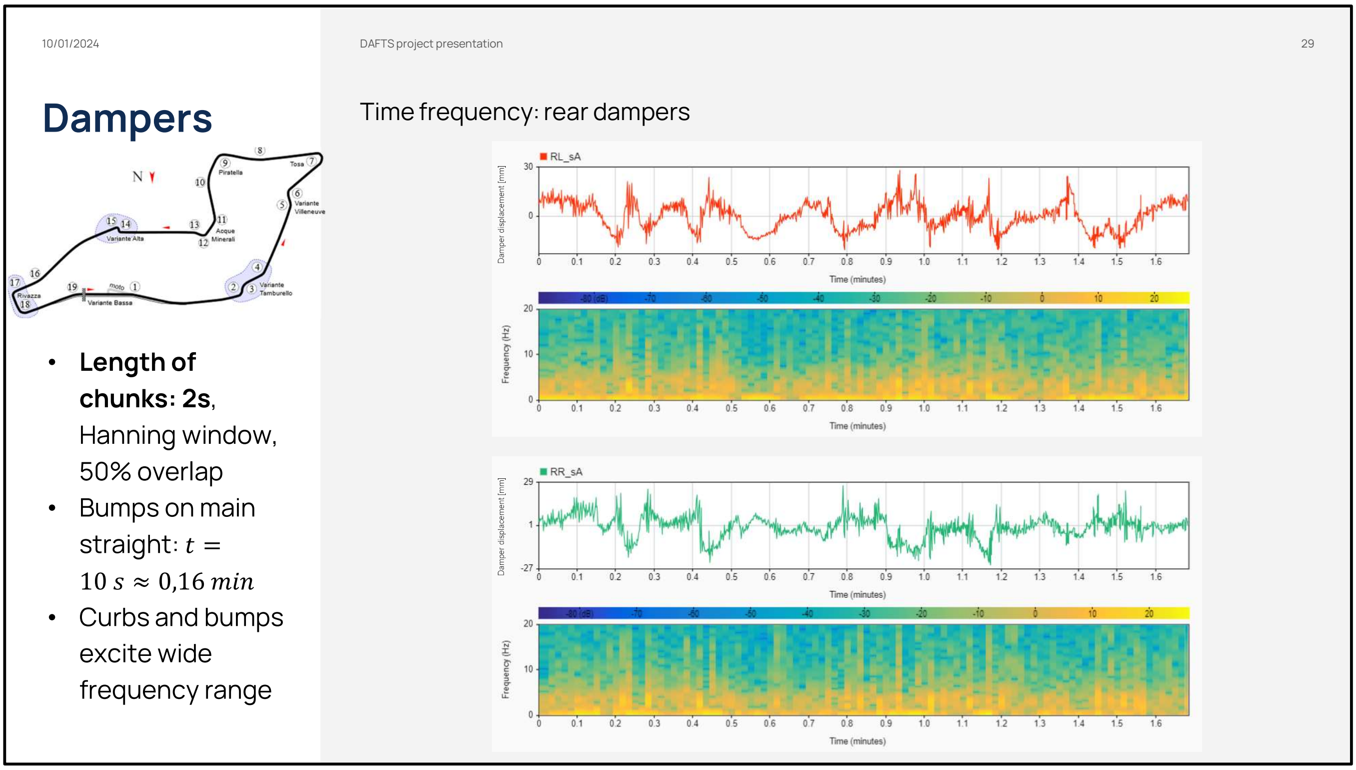
- Rear dampers excited in a higher frequency range than front dampers



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End.