Politecnico di Milano
M.Sc. in Mechanical Engineering

VEHICLE ACOUSTICS

Lab. 02: Structure borne noise of a car cabin, experimental analysis

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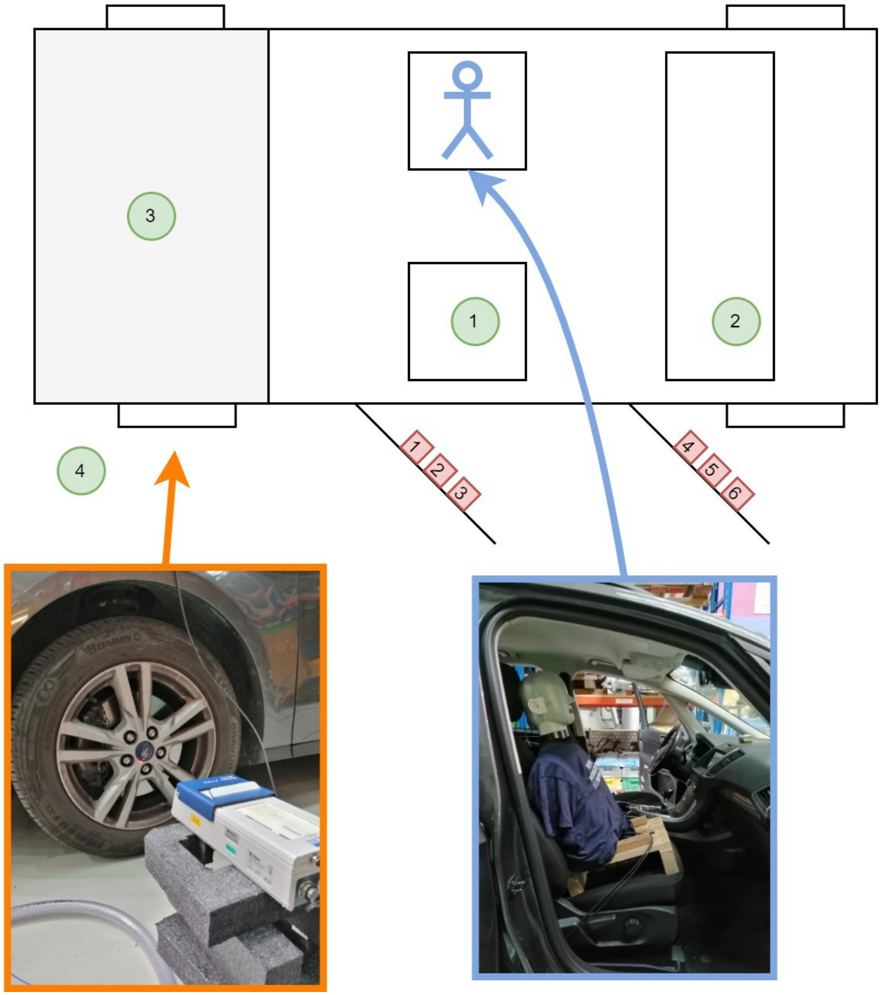
Experimental layout



Sensors

- 4 Microphones: driver position, rear left passenger position, external position (close to front left wheel), below the car's bonnet.
- 6 Accelerometers: 3 sensors on the front left door, 3 sensors on the rear left door.
- 1 vibrometer pointed at the centre of the front left door.
- 1 Head & Torso Simulator at the front passenger location.

Head & Torso Simulator

1 *Microphone*

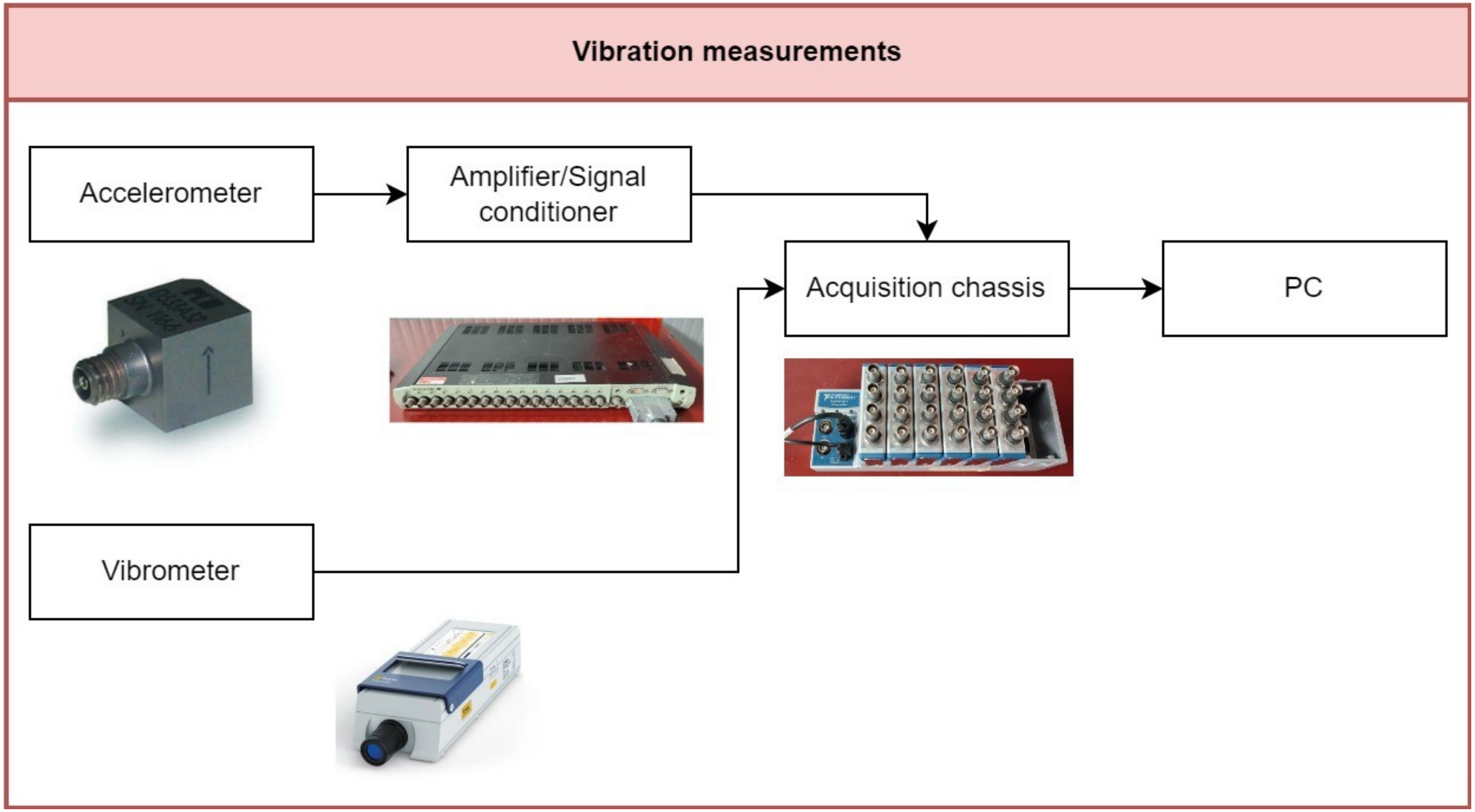
1 *Accelerometer*

Experimental layout

Accelerometers: in this experimental setup, monoaxial accelerometers are implemented to monitor the acceleration at left front and rear doors. Accelerometers measure the 3 sensors on the front left door, 3 sensors on the rear left door.
These sensors must be conditioned and provide a ±10V signal proportional to the acceleration measured along the direction indicated by the arrow.

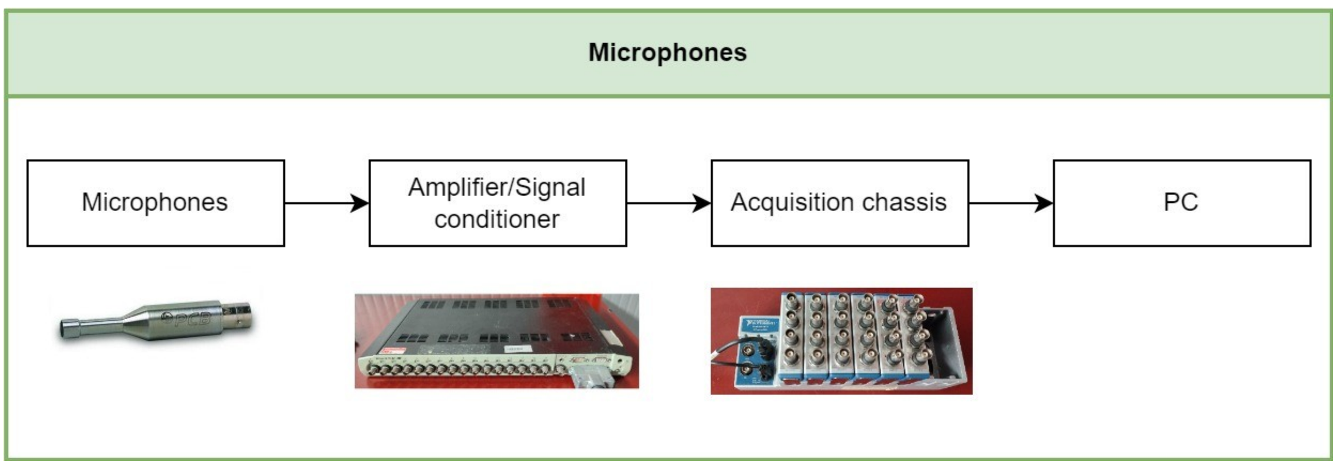
Vibrometer: this laser sensor measures the vibration velocity of a reference point. It doesn’t need to be conditioned, but the focal distance must be calibrated before measure the vibration velocity of the point under analysis. The vibrometer provides a ±10V voltage signal proportional to the vibration speed.

Experimental layout



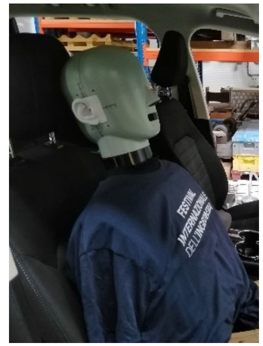
Experimental layout

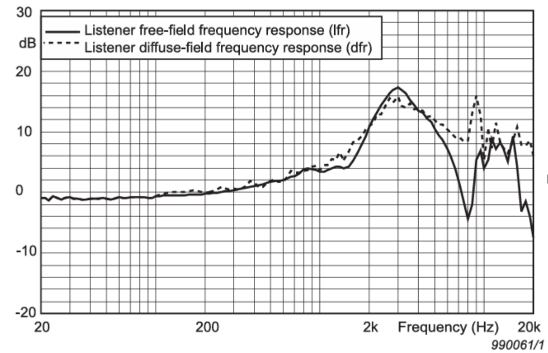
Microphones: in this experimental setup, ¼ inch microphones are used to quantify the acoustic pressure. These devices require a proper calibration. Moreover, since the sensitivity of the microphones can significantly vary in time, it is necessary to calibrate them by means of a calibrating device. These sensors provide a ±10V signal proportional to the acoustic pressure, and do not show asymmetric response.

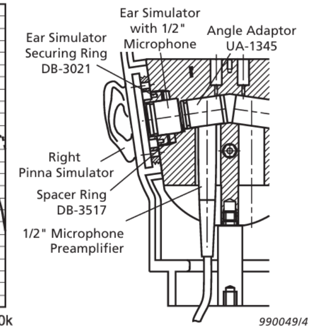


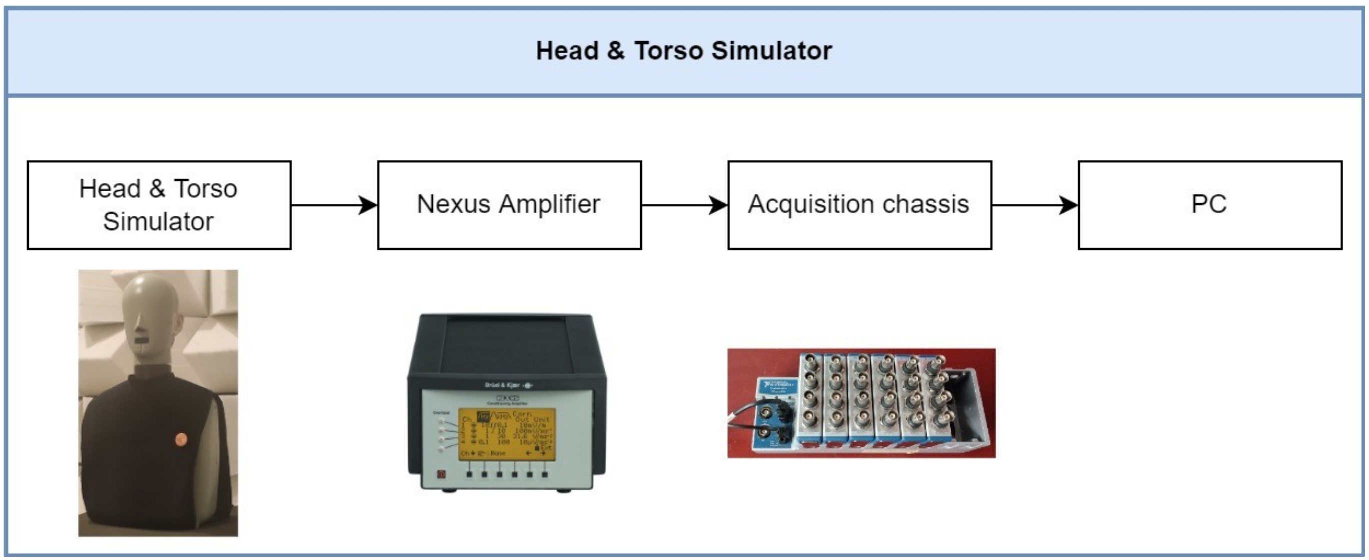
Experimental layout

Head & Torso Simulator: this system aims to emulate the acoustic features of the human head & torso. It features two internal ½ microphones at ears position. The response of the HTS is therefore aligned to that of a typical human listener.









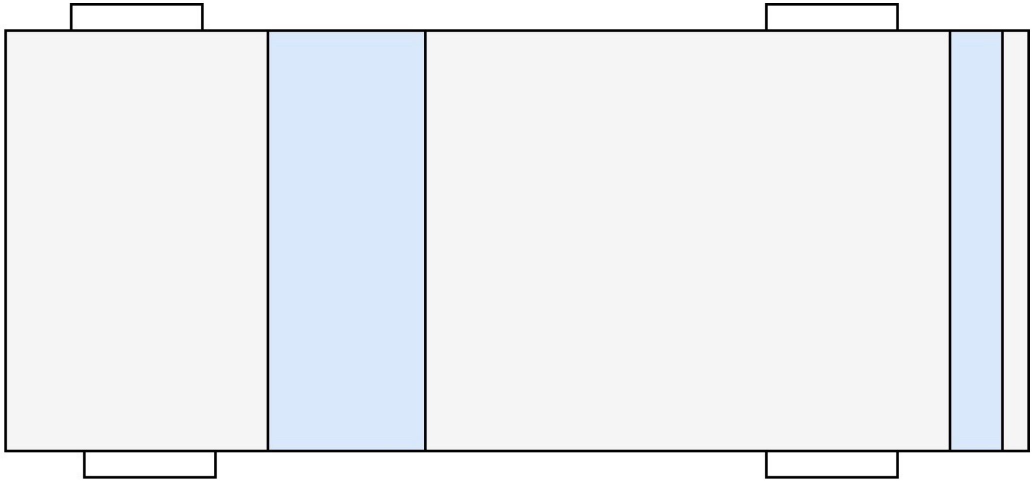
Experimental layout

Structural excitations: in this experimental tests, the structure borne noise of the car cabin is assessed.

1. Firstly, the structural/acoustic features of the car cabin are assessed by means of impact tests. This forcing condition imposes a broadband energetic input able to excite all the structural modes of the cabin. Therefore, impact tests allows to understand the dynamics of the car cabin in terms of eigenfrequencies and eigenvectors.

2. Then, a real load case is tested: with turned on engine, a ramp input is simulated. This allows to study a wide frequency range and to obtain measurements of the acoustic pressure in the cabin during a realistic scenario.

Experimental layout: impact tests



Impact hammer: in this experimental tests, the impulsive force is applied by means of a dynamometric hammer, which allows to measure the actual force input on the structure.
The front left rear is excited by several inputs to assess the dynamic performance of the car cabin.

Experimental layout

Microphones calibration

In calibration test, a reference signal is imposed by a calibrator device to a single microphone. The calibrator is a device designed to provide a 1000 Hz signal with amplitude of 94 dB. Microphone provide tension signal V proportional to the acoustic pressure according to the sensitivity K:

$$p_{dB,Ref} = 20\log_{10}\left(\frac{p_{RMS,1000\,Hz}}{p_{Ref}}\right)$$

$$p_{Ref} = 2 * 10^{-5}$$

$$V = Kp_{meas}$$

Microphones in the Head & Torso simulators must be calibrated adding an adaptor which modifies the $p_{dB,Ref}$ to 94.5 dB. Calibration tests considered a **sampling frequency of 12500 Hz.**

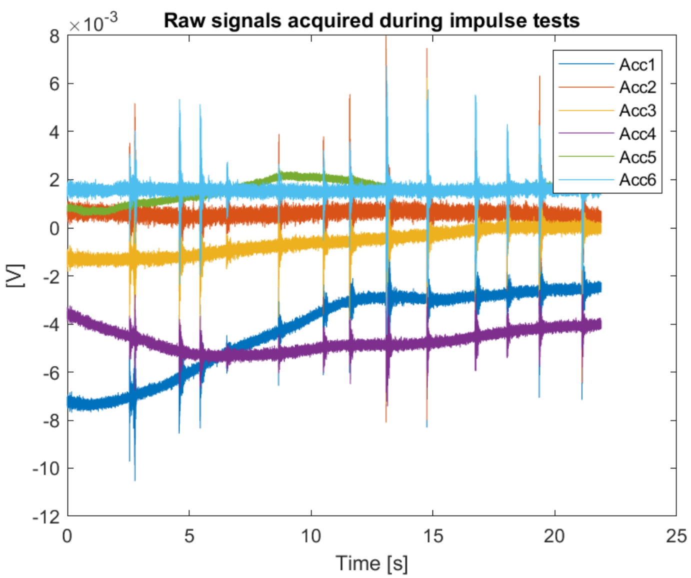
Input hammer sensitivity is 2.25 mV/N, while accelerometers sensitivity is equal to 100 mV/g. The scaling factor or the vibrometer is 12.5 mm/s/V.

Impulse tests

Impulsive tests were performed considering two layouts:

- Empty cabin
- Two passengers in the cabin

The tests considered a **sampling frequency of 12500 Hz.** In these tests, raw signals may present low frequency contributions which can be **removed by filtering**.




```
[b, a] = butter(order, Wn, '    '); % Design filter

Data(:,ii) = filtfilt(b, a, Data(:,ii));
```

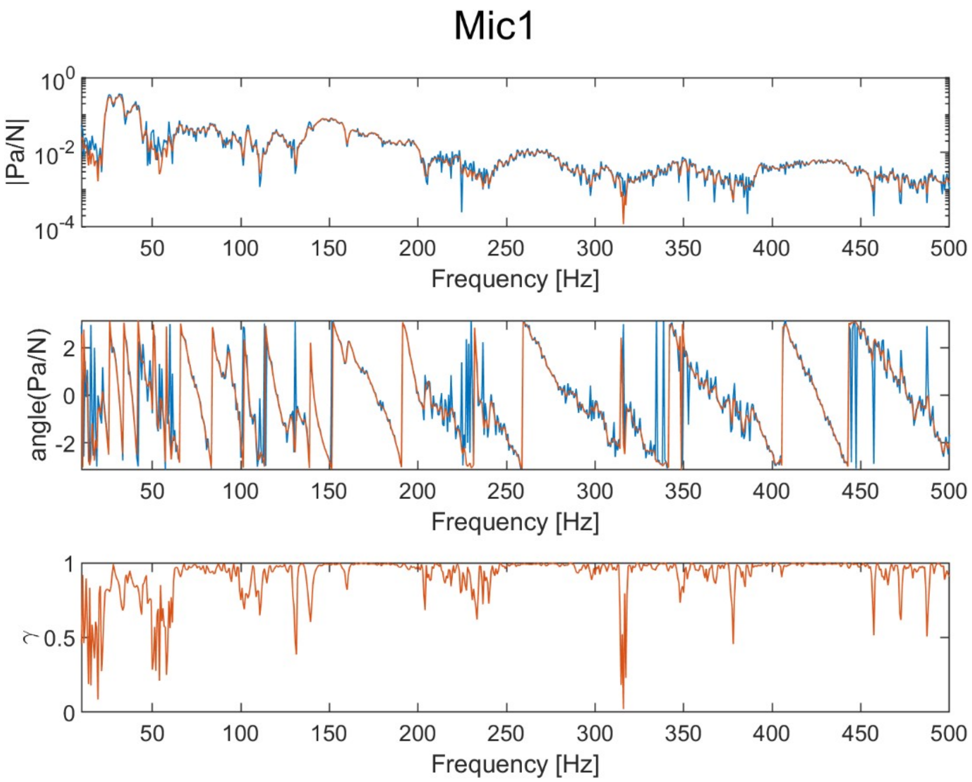
Single impulse response

Impulses were imposed on the front left wheel hub at slightly different positions. Considering a **single impulse**, the transfer function between the imposed force and the measured signals (acceleration, acoustic pressure or vibration speed) can be obtained in two ways:

1. Rough estimation by means of the ratio of the complex signals obtained from **ffg function**. Since no average are performed, noisy results should be expected.

2. Implementation of tfestimate & mscohere Matlab functions. They can be set up to perform average estimation considering multiple windows around a single peak.

Single impulse response



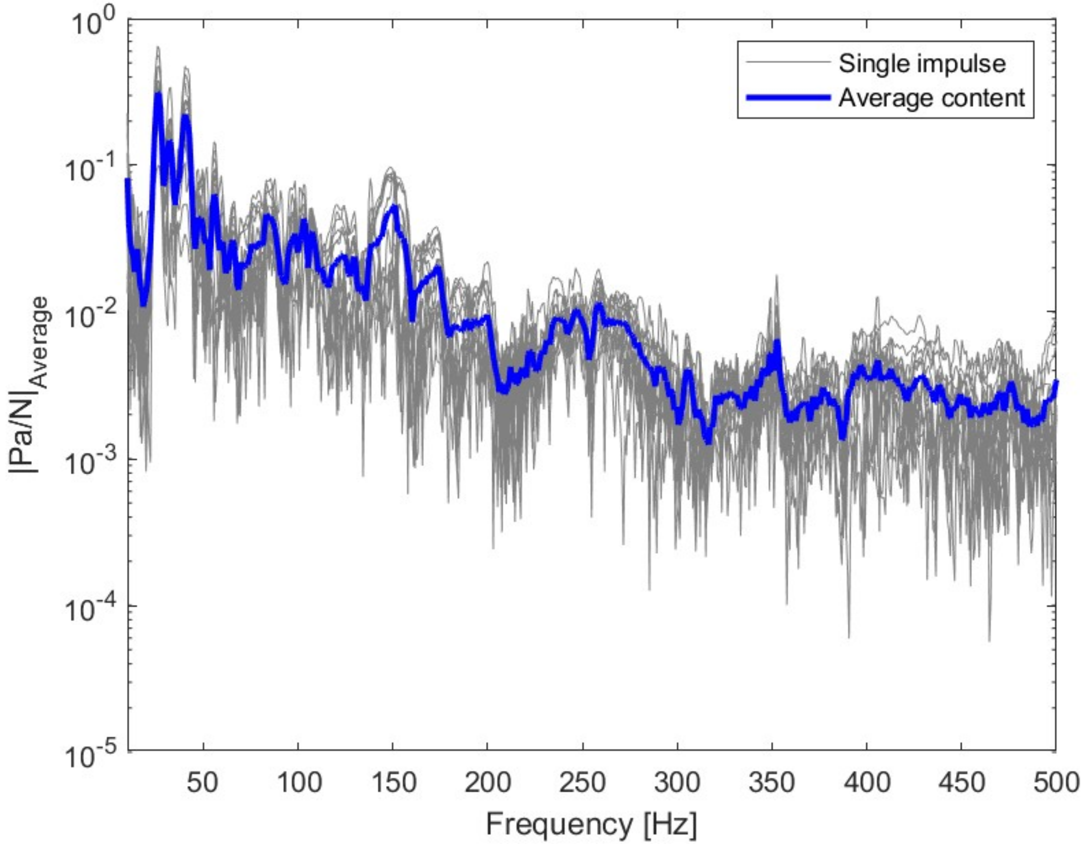

```
[out_cmplx,out_freq]=ffg(        );
[inp_cmplx,inp_freq]=ffg(        );

TF = out_cmplx./inp_cmplx;
```

```
[TF_2, f_est] = tfestimate( );
[cxy,fcohe] = mscohere( );
```

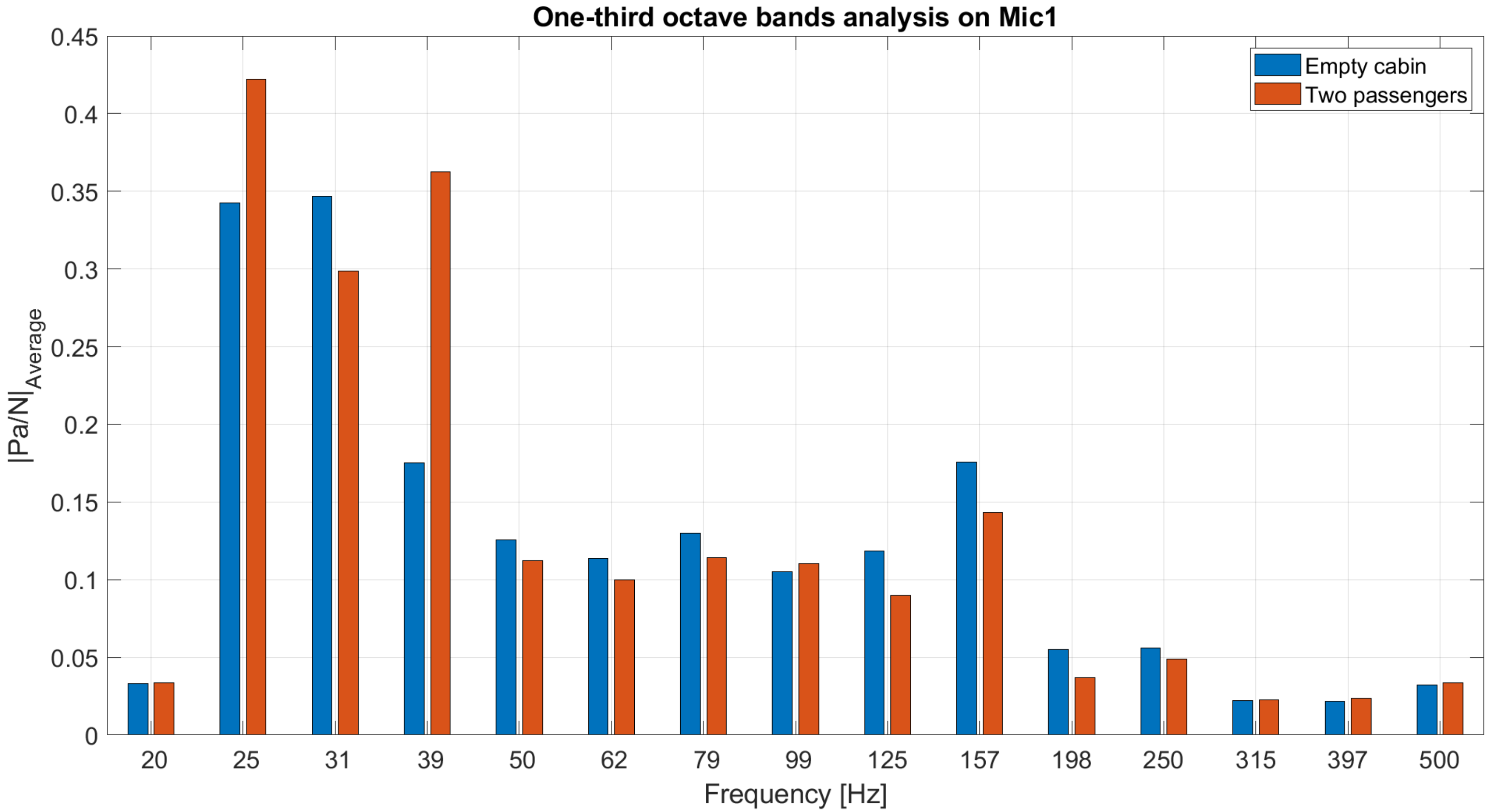
Impulse tests: energetic average

Forcing the wheel hub at different locations allows to measure responses in which all the vibration modes are excited. Therefore, an average analysis on the absolute value of the Transfer Functions measured from different peaks can be performed.



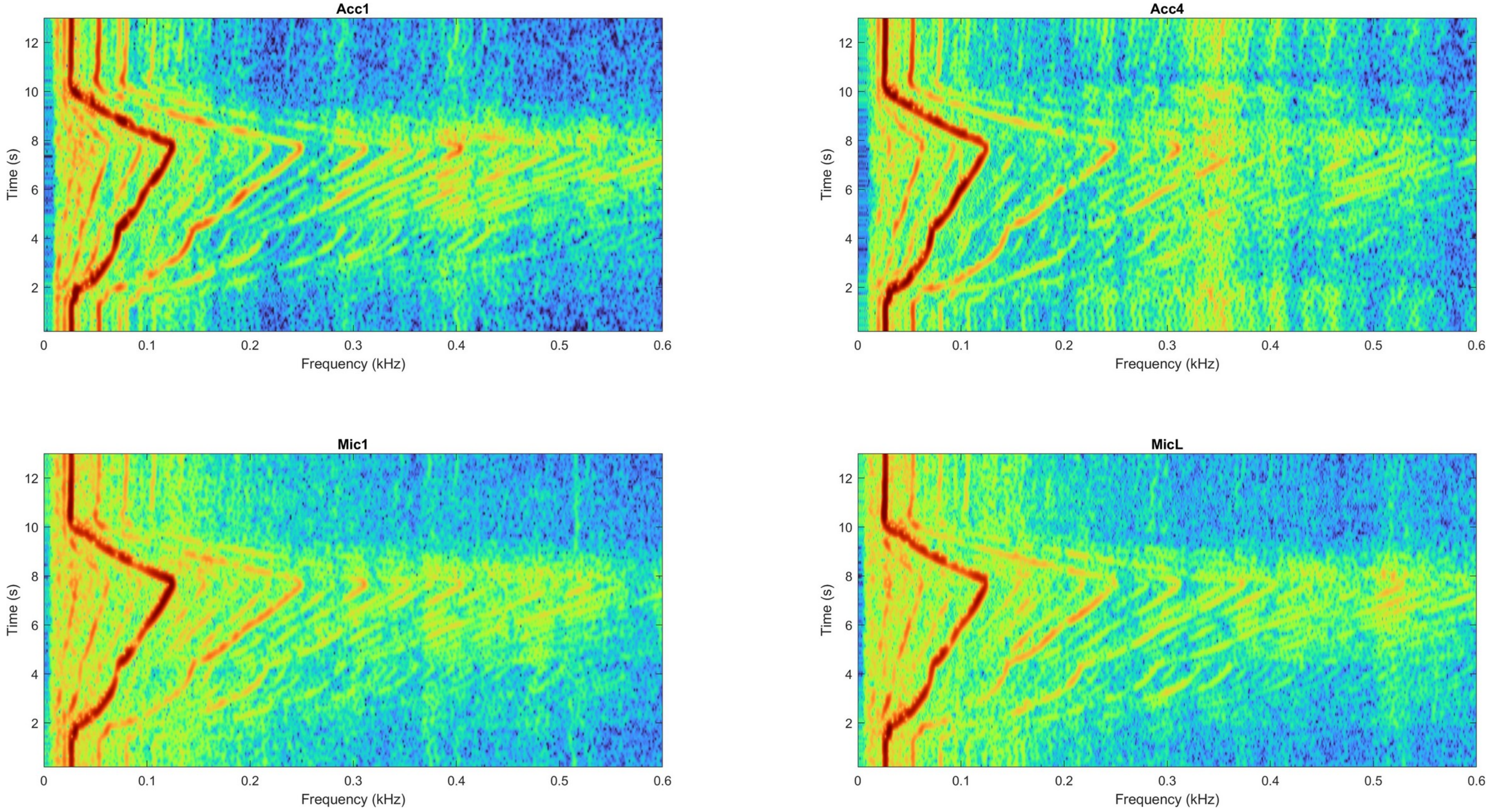
Impulse tests: energetic average

The narrow-bands average responses obtained considering empty cabin and two passengers inside the cabin can be compared by summarising the results in one-third octave bands.



Ramp test, order analysis

The ramp test is performed starting from idle conditions ($\Omega_{Idle} \sim 850\ rpm$). Then, the engine rotation speed is increased in a progressive way.
A spectrogram plot can be obtained from accelerometers and microphones signals to study the time-dependent phenomena taking place during the ramp test.



Assignment

1. Perform calibration procedure to the microphones used during the tests.

2. Impulse tests (empty cabin, cabin with two passengers). Estimate the Transfer Functions of the internal microphones, accelerometers and vibrometer with respect to the dynamic excitation of the hammer considering a single peak.

3. Impulse tests, average approach: compare the average absolute value of the internal microphones Transfer Functions obtained from the different impulses at the two test configurations (empty cabin, cabin with two passengers). Express the results in terms of one-third octave bands.

4. Ramp tests: obtain spectrograms from accelerometers and microphones during the test. Identify the most significant order in the microphone signal and correlate it with the vehicle specs (Ford Galaxy my 2020 TDCi). Correlate results with narrow-band analysis at idle condition.