Influence of individual trim items on the acoustic behavior of the car interior

Master's Thesis in the Master's programme in Sound and Vibration

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Abstract

The accuracy of predicting the vibro-acoustic response of the car bodies, and in particularly, the accuracy of predicting the NTF (Noise Transfer Function or p/F, the acoustic response measured with microphone due to mechanical excitation on the body) has always been a hot topic. This master thesis project was aimed at measuring or generating valuable test data regarding the effect of selected trim items on the response characteristics, that could be used in identifying the problem areas for CAE models.

Measurements with both A-FRFs - acoustical excitation (loudspeaker in the cavity) - and NTFs - mechanical excitation (impact hammer) - were carried out for several trim levels on a Body-in-Blue (Body-in-Prime with trimmed closures). Both acoustic response (microphones) and structural response (acc) were collected. The configurations under test included: empty cavity, cavity with carpets only, cavity with front seats only and etc, until the cavity with IP, front & rear seats, parcel shelf trim & carpets. The changes in response incurred by particular items were identified and the data prepared will be used to make comparisons with the CAE analysis results.

Keywords: A-FRF, A-MTF, NTF, VTF, Acoustical excitation, Mechanical excitation.

Contents

Acknowledgements

We would like to express our deepest gratitude to our supervisor/mentor Andrzej Pietrzyk from Volvo Car Corporation (VCC), for the morale and technical support which he has continuously given us during the period of the master thesis project.

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And special thanks to researcher Patrik Andersson for his technical guidance and his patience whenever we faced any technical doubts.

We would also like to thank Börje Wijk for his ever-patient assistance to us in terms of equipment setup issues and logistic problem before and after each measurement or experiment.

Lastly, we would like to take this opportunity to express our utmost gratitude to our families and loved ones for their unconditional care and support.

1. Introduction

1.1. Project Background and Objectives

A simplified acoustic model is currently used in the industry as vehicle trim items are often disregarded in vehicle cavity acoustic modeling. Carpets, and trim panels like parcel shelf, A,B,C(D) pillar covers are only considered as mass in the TB (trimmed body) vehicle models. And besides, bigger and heavier trim items like seats and IP are acoustically modeled in a relative simplified way in CAE (but structurally modeled in detail). The reason for it, as often mentioned, is that the acoustical influence on the vehicle cavity by most of the trim items is expected only at higher frequencies (>300Hz).

The objective of the project is to investigate the acoustical influence of different trim items on the vehicle cavity. The experiments consider both acoustical excitation and mechanical excitation. The data analysis of interest is on the A-FRF (acoustical frequency response function), A-MTF (acoustical mechanical transfer function), VTF (vibration transfer function) and the NTF (noise transfer function) on a BIB (body in blue) Volvo S80 model. Lastly, the project serves as a feasibility study to enhance and validate the current cavity acoustics CAE prediction/simulation and hence to be used for future vehicle CAE prediction/simulation models.

2. Basic Principles

2.1. Theoretical Background and Comparison

The A-FRF (Acoustical Frequency Response Function) for a vehicle measures the acoustical behavior in the vehicle cavity when excited with a sound source. The vehicle cavity are assumed to be analogous to a room, as shown in figure 2.1 with a loudspeaker exciting below microphone position 1.

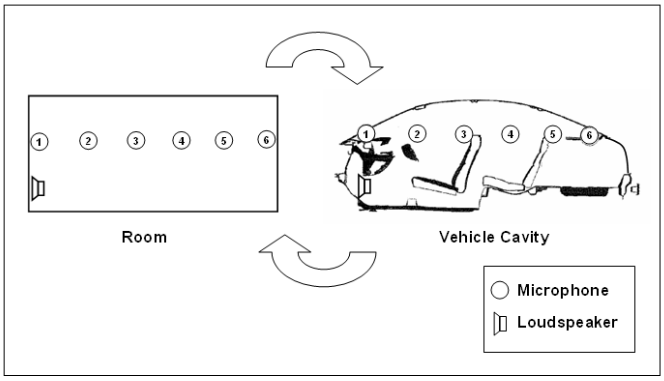


Figure 2.1.: Vehicle cavity analogous to a room.

The sound pressure over volume acceleration (p/q') can be evaluated by equation (2.1).

$$\frac{p}{q'} = \rho * c^2 * \sum_{n=0}^{\infty} \frac{\psi_n(x) * \psi_n(y)}{\Lambda_n * (\omega_n^2 - \omega^2)} \tag{2.1}$$

where:
ω=2*π*f.
p = sound pressure.
q' = volume acceleration for sound source (loudspeaker).
rho = air density.
ψ_n(x) = shape function for sound source (loudspeaker).
ψ_n(y) = shape function for receiver (microphone).
f = frequency.
Λ_n = the normalization constant for the mode of order n.

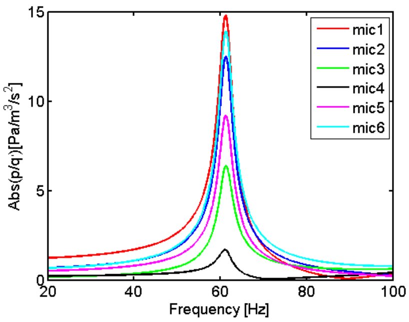
However, the actual vehicle cavity is not 'ideal' as in comparison to a room in two aspects:

1. The vehicle cavity walls are not rigid and are constructed by a combination of metal sheets, frame and windows which are susceptible to structural vibration and noise during measurement.

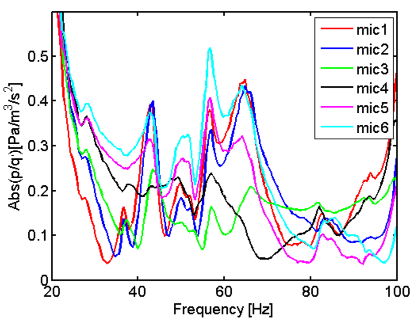
2. The vehicle cavity is not a rectangular shape relative to a room.

Figure 2.2, 2.3 and 2.4 provides a comparison of the theoretical and actual measurement plot for the absolute, real and imaginary values. The results between theoretical and actual measurement show discrepancies due to the structural vibrations and noise on the vehicle when excited by the loudspeaker. Some thoughts should be considered to select an appropriate graphical representation of the results to identify the resonance modes easily.

Based on the real plots and imaginary plots, the phase change through the resonance region (modes) is clearly characterized by a sign change in one part (real) accompanied by a peak (maximum and minimum) value in the other part (imaginary). And the absolute plots (or levels) as well as the use of logarithmic scales is not feasible in this case because it is necessary to accommodate both positive and negative values, and this would be impossible with logarithmic axes. Overall, the imaginary plot is preferred in this project as the modes with phase are more effectively identified by the maximum and minimum peaks.

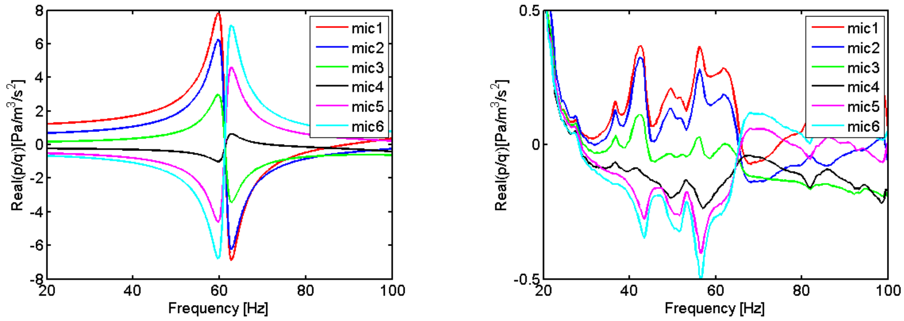


(a) Theoretical Response.



(b) Actual Measurement Response.

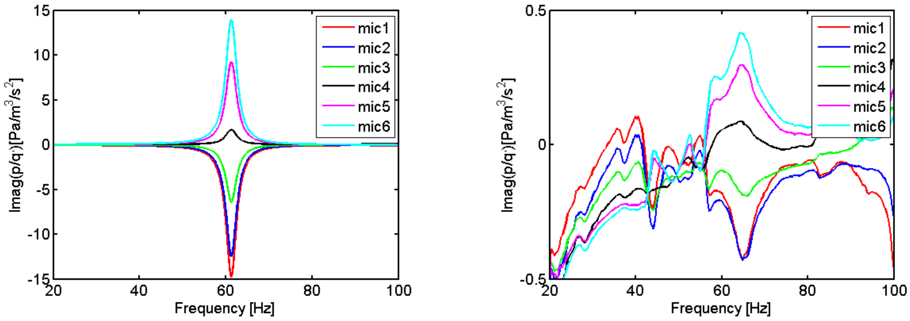
Figure 2.2.: Comparison of absolute results between theoretical and actual measurement.



(a) Theoretical Response.

(b) Actual Measurement Response.

Figure 2.3.: Comparison of real results between theoretical and actual measurement.



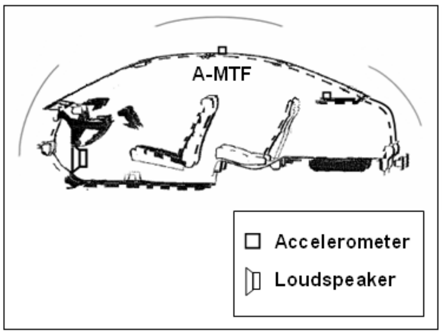
(a) Theoretical Response.

(b) Actual Measurement Response.

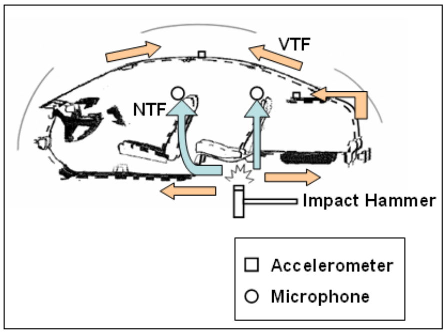
Figure 2.4.: Comparison of imaginary results between theoretical and actual measurement.

A-MTF (Acoustical-Mechanical Transfer Function) measures the vibrational response with accelerometer(s) via acoustical excitation. The response is measured by the acceleration (vibration) of the test point over the volume acceleration of the sound source (a/q'). An illustration of the A-MTF measurement is shown in figure 2.5(a).

NTF (Noise Transfer Function) measures the sound pressure with microphones via mechanical excitation. Generally, it is the noise transfer path from the excitation point, through the vehicle body, air in the cavity and to the microphones. The response is measured by the sound pressure of the test point over the force of excitation (p/F). Whereas, VTF (Vibration Transfer Function) measures the vibration in terms of acceleration over the excitation force (a/F). An illustration of NTF and VTF are shown in figure 2.5(b).



(a) A-MTF measurement by acoustical excitation.



(b) NTF and VTF measurement by mechanical excitation.

Figure 2.5.: Illustration of A-MTF, NTF and VTF measurement.

3. Vehicle Trim Configurations Investigation and Result

3.1. General Setup and Vehicle Trim Configurations

All measurements were conducted in the Applied Acoustics Department at Chalmers University. The vehicle test object, which is the Volvo S80 BIB (Body-In-Blue with the car cavity obtained by sealing all accessories holes and mounting all doors and trunk hatch), was placed on three air mounts in order to obtain a free-free conditions. The places to rest the body on the air mounts (figure 3.1) were discussed and chosen by measurement in collaboration with the thesis work of Miguel Colomo. In the collaborative experiment, the measurement for a three-air-mounts support was compared with a four-air-mounts support and the results yielded no significant difference between the two types of air mounts setup.

Figure 3.1.: Air-mounts positions

The measurements were performed on different trim configurations. The configurations were differed by the different trim parts (individual trim part or a combination of trim parts) installed to the BIB. The measurement and investigation of this master thesis project had been categorized into two sections based on the measurement excitation method:

1. Acoustical excitation.
2. Mechanical excitation.

For the acoustical excitation measurement, fourteen trim configurations had been selected and the experiment was performed with a loudspeaker as a source and the responses were measured with microphones (A-FRF) and accelerometers (A-MTF). Whereas for the mechanical excitation measurement, six configurations had been selected and the experiment was performed with an impact hammer as a source and the responses were also measured with microphones (NTF) and accelerometers (VTF). An overall description can be presented by tables 3.1 and 3.2.

Table 3.1.: Experiment overview.

Items	Acous. Excitation	Mech. Excitation
Measurement	A-FRF, A-MTF	NTF, VTF
Microphone positions	61	6
Accelerometers positions x direction(s)	3x1	9x1
Trim configurations	14	6
Excitation point(s) and direction(s)	1x1	17x3

Table 3.2.: Measured trim configurations with 'x'.

Trim Configurations	Acous. Excitation	Mech. Excitation
Empty	x	x
Rear seats (Rs)	x	x
Front seats (Fs)	x	
Carpets (Cpts)	x	
IP	x	
Rs and Parcel	x	x
Fs, Rs and Parcel	x	
Fs, Rs, Cpts and Parcel	x	
IP and Rs	x	
IP and Fs	x	
IP and Cpts	x	
IP, Rs and Parcel	x	x
IP, Rs, Cpts and Parcel		x
IP, Fs, Rs and Parcel	x	
IP, Fs, Rs, Cpts and Parcel	x	x

3.2. Measurement by Acoustical Excitation

3.2.1. Setup and Methodology

The schematic of the measurement setup for the acoustical excitation measurement is shown in figure 3.2. In this part of the experiment, a loudspeaker was used as a source to excite the modes in the cavity. White noise, acquired from the VXI acquisition system was used as the output signal for the loudspeaker and an equalizer was connected in order to obtain a flat response over the frequencies of interest as much as possible. The loudspeaker was placed on the passenger cabin floor of the vehicle facing the fire-wall (refer to appendix A.2.1 for the actual position). An accelerometer was placed on the loudspeaker membrane to measure the volume of acceleration (q') and in addition, the signal from the accelerometer was also taken as a reference signal.

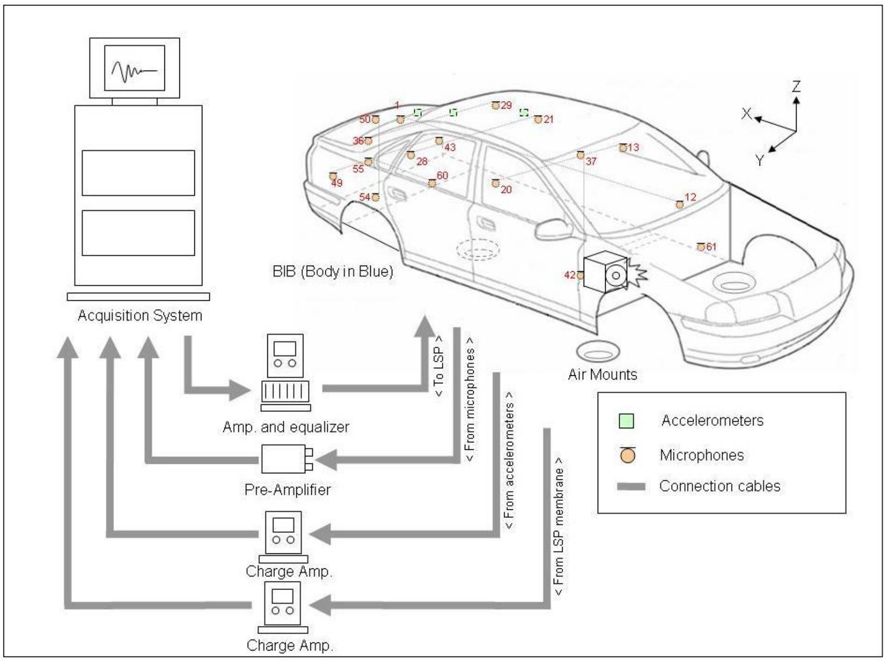


Figure 3.2.: Acoustical excitation measurement setup.

The measurement responses of interest were A-FRF and A-MTF and all the test equipment used for this experiment are shown in table 3.3.

Table 3.3.: Test equipment for A-FRF and A-MTF measurement.

Item	Equipment	Manufacturer	Model	S/N	Sensitivity
1	Microphones	Panasonic	WM-063	n/a	1V/μbar
2	Uni-axial Acc.	Brüel & Kjaer	4393V	2197929	0.3104 pC/ms^{-2}
3	Charge Amplifier	Brüel & Kjaer	2635	986722	n/a
4	Acquisition Station	Agilent Tech.	n/a	n/a	n/a
5	Mic. preamplifier	Chalmers Uni.	n/a	n/a	n/a
6	Stereo Graphic Equalizer	Technics	SH-8065	MB65263008	n/a
7	Stereo Amplifier	NAD	302	T302N11523	n/a
8	Loudspeaker	Chalmers Uni.	n/a	n/a	n/a

The measurement of A-FRF describes the acoustical modes formation in the vehicle cavity in accordance to the frequencies. The precise description of the modes formation can be achieved by placing arrays of microphones at as different locations as possible in the vehicle. Each microphone array contained a certain number of microphones, which can be shown in table 3.4.

Table 3.4.: Microphone arrays in the cavity.

Mic. arrays	No.of mic	Position in cavity
Longitudinal cabin	8	Front window to parcel shelf.
Longitudinal parcel	4	Front parcel to rear window.
Lateral front seats	8	Driver to fr. passenger outer ear.
Lateral rear seats	8	Left rear passenger to right rear passenger outer ear.
Lateral parcel	8	Left side to right side of parcel shelf.
Vertical cabin	6	Roof to vehicle 'tunnel shaft'.
Pedals	1	Pedals at driver's feet.
Longitudinal trunk	6	Longitudinal far end of the trunk above the spare tyre cavity.
Lateral trunk	7	Lateral far end of the trunk above the spare tyre cavity.
Vertical trunk	5	Parcel shelf to the bolts for the spare tyre.

The longitudinal arrays refer to the microphones placed along the x-axis of the vehicle, whereas the lateral arrays and the vertical arrays refer to the microphones placed along the y-axis and z-axis respectively. An illustration of the microphone arrays positions is also shown in figure 3.3 and the actual photographs are shown in appendix A.2.2 for reference.

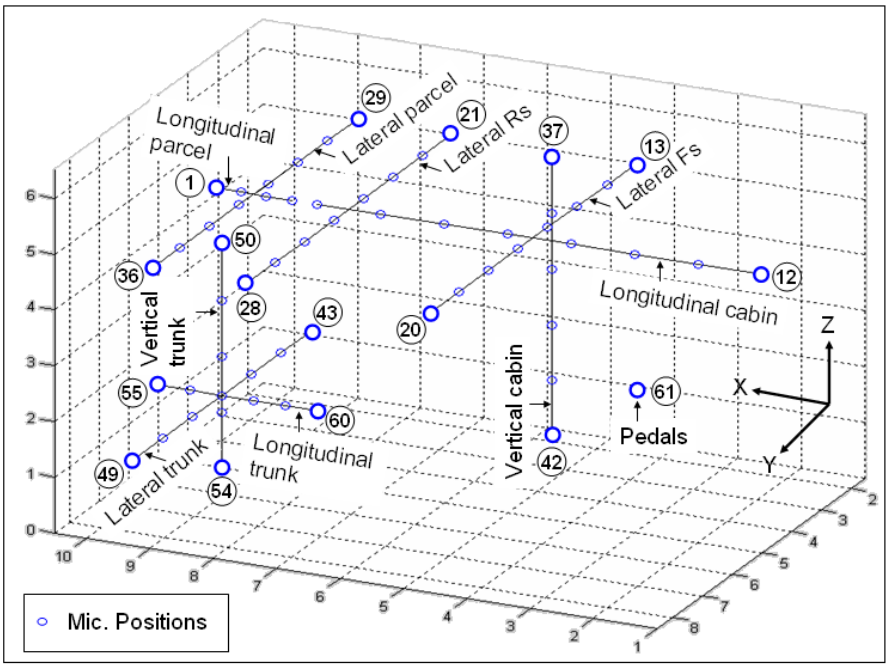


Figure 3.3.: Microphones array positions in the vehicle cavity.

Whereas, the measurement of A-MTF were performed on certain parts of the vehicle that were considered to have relatively higher influence on the acoustical levels inside the cavity. Hence, uni-axial accelerometers for the A-MTF measurement were placed on:

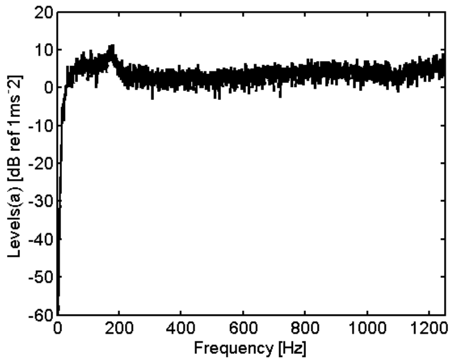
- Roof
- Parcel shelf
- Rear window

The actual photographs of the uni-axial accelerometers and positions are also shown in appendix A.2.3.

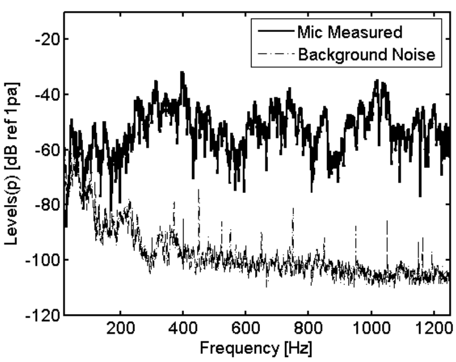
All A-FRF and A-MTF measurement were performed on all fourteen trim configurations. The trim configurations for the acoustical excitation measurement is shown in the previous table 3.2.

3.2.2. Quality of A-FRF and A-MTF measurements

Based on figure 3.4(a), the flat frequency response of the loudspeaker is indicated by the autospectra of the accelerometer situated on the loudspeaker cone. The position of the accelerometer is clearly shown in appendix A.2.1. The comparison between the background noise and measurement from a microphone position is also shown in figure 3.4(b) with SNR ranging from around 2dB to 60dB as the frequency increases.



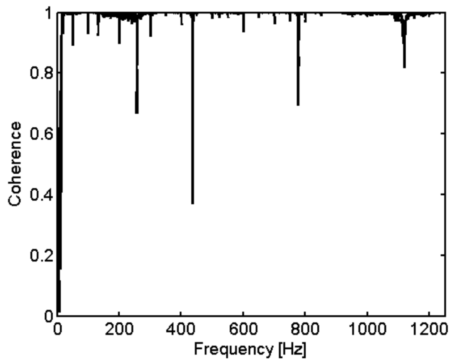
(a) Autospectra of the accelerometer response on the loudspeaker.



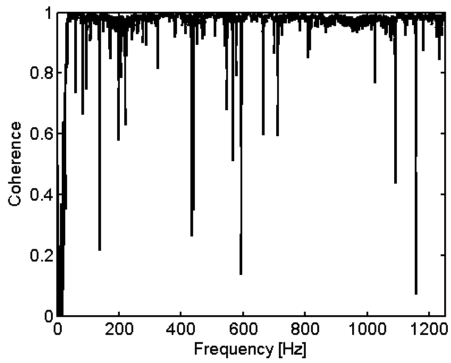
(b) Autospectra between background noise and microphone measurement.

Figure 3.4.: Loudspeaker response (accelerometer) and background noise measurement.

The A-FRF and A-MTF measurement coherences (empty trim configuration) in figure 3.5 demonstrate that the measurement quality is maintained between 20Hz and 1250Hz.



(a) Coherence of microphone response (A-FRF) at the pedals position.



(b) Coherence of accelerometer response (A-MTF) at the parcel shelf position.

Figure 3.5.: Coherences of A-FRF and A-MTF for empty trim configuration.

3.2.3. A-FRF Results and Discussion on Empty Trim Configuration

The discussion of interest for this section primarily revolves on the longitudinal modes formed in the vehicle cavity as well as comparison results on different trim configurations (mainly empty trim configuration in comparison to other trim configurations) were selected for discussion. The longitudinal modes has been mainly selected for discussion due to the relation of the mode to the 'booming' noise in the vehicle cabin. The comparison result of selected different trim configurations are useful in providing the understanding of how each or a combination of trim items influence the acoustical response in the vehicle cabin. Besides the A-FRF results discussion in the following sections, A-FRF measurement plots for other acoustical modes with the respective trim configurations are also shown in appendix A.2.4.

The acoustical response or A-FRF of an empty trim configuration can be observed in figure 3.6 where the response from all microphones along the longitudinal array is shown. Based on the figure, the first mode is located at around frequency 65Hz, whereas the second and third longitudinal modes are located at around frequency 100Hz and 148Hz respectively.

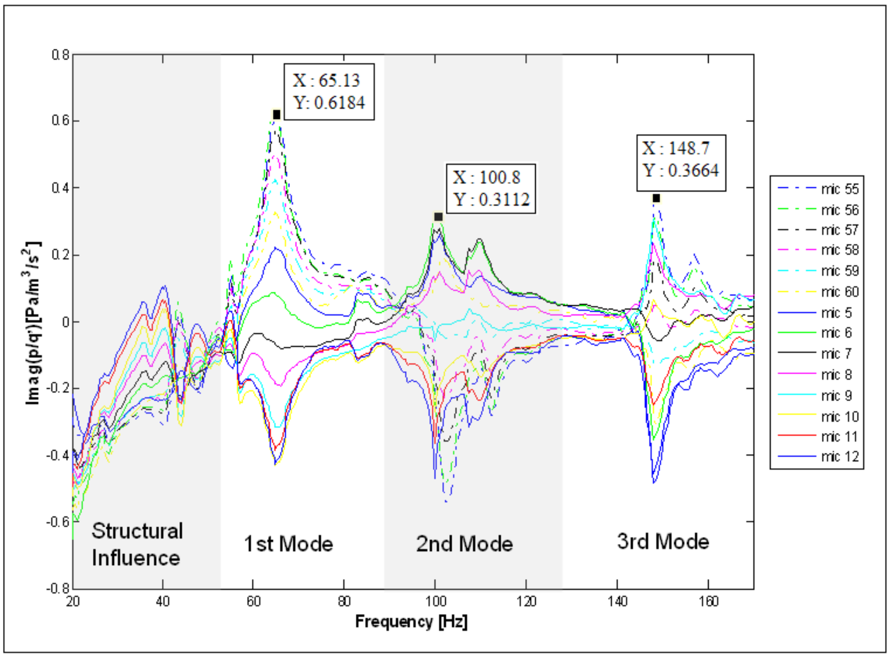


Figure 3.6.: All microphones response along the longitudinal array for empty trim configuration.

To simplify the plots, the acoustical modes can also be clearly plotted by two far end microphones (from mic 55 at the trunk to mic 12 at the front window) as shown in figure 3.7. The simplified plots will be used frequently in further comparison results and discussion. Besides the identified acoustical modes in this experiment, an unexpected acoustical response was also observed around 40Hz. The unexpected response was further investigated and the result will be discussed in section 3.2.11.

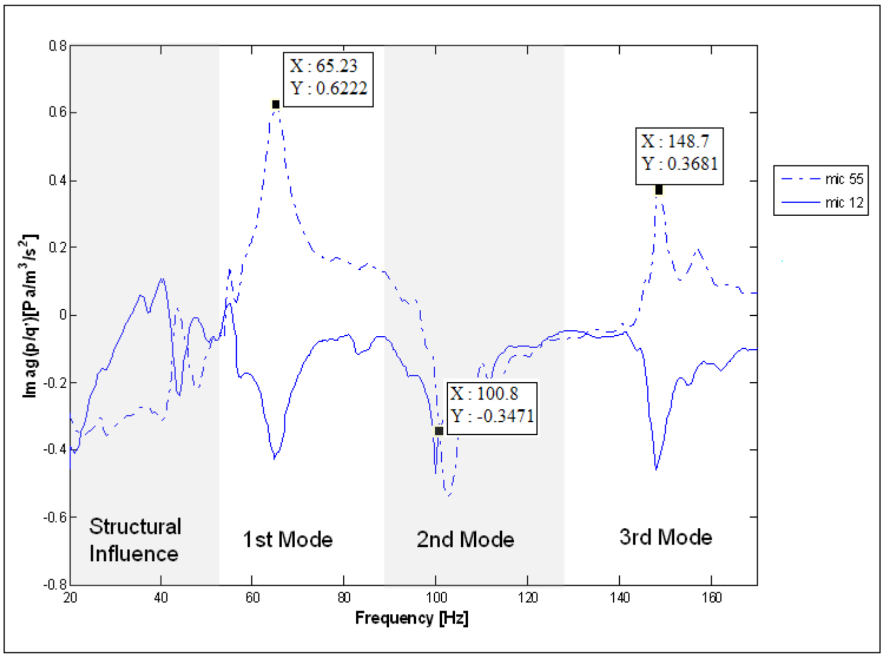
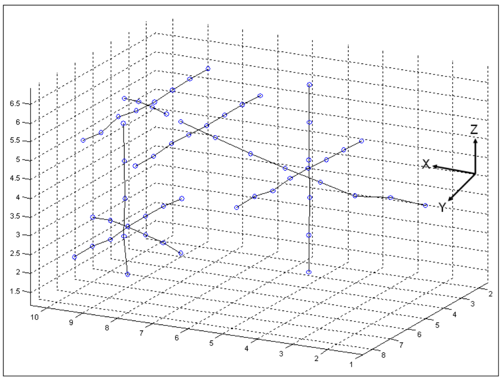
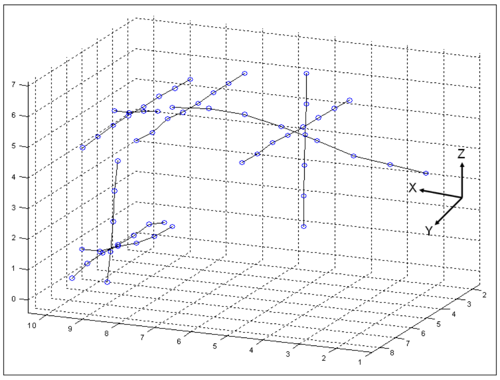


Figure 3.7.: Two far-end microphones response along the longitudinal array for empty trim configuration.

In addition, the acoustical mode shape for the first, second and third mode can also be shown in figure 3.8 and figure 3.9. Hardly any changes observed in the lateral and vertical arrays and the response for the modes corresponds well with the room modal analysis theory.



(a) First acoustical mode shape at 65Hz.



(b) Second acoustical mode shape at 100Hz.

Figure 3.8.: First and second acoustical mode shape for empty trim configuration.

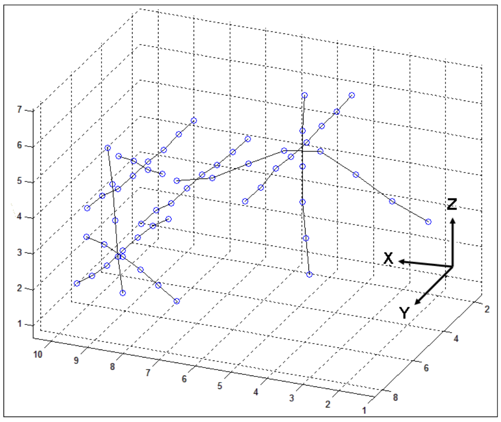


Figure 3.9.: Third acoustical mode shape for empty trim configuration at 148Hz.

3.2.4. A-FRF Results and Discussion on Empty Trim Vs Rs Parcel Trim Configuration

This section contains the result comparison and discussion between the empty trim and rs parcel trim configuration. Installing the rs (rear seats) and the parcel shelf trim actually separates or decouples the passenger cabin and the vehicle trunk. Figure 3.10 shows the comparison longitudinal response for an empty trim to the rs parcel trim configuration. The first longitudinal mode has been shifted to a higher frequency (from 65Hz to 85Hz) due to the fact that by adding the rs parcel trim items, the length of the vehicle cavity has become smaller.

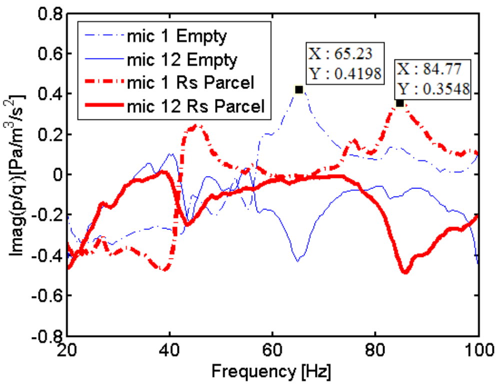


Figure 3.10.: First longitudinal mode comparison for empty vs rs parcel trim configuration.

Figure 3.11 shows the first longitudinal mode shape at 85Hz in the passenger cabin. Minimal acoustical response or changes is captured at the vehicle trunk due to the sealing by the rear seats and parcel shelf trim.

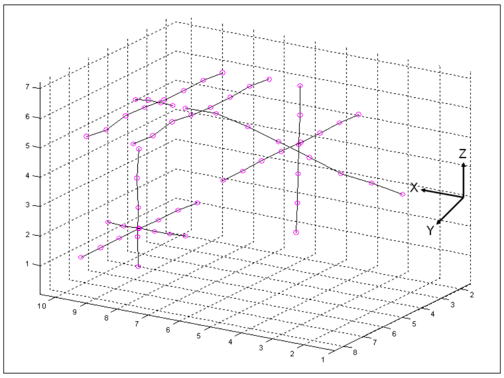
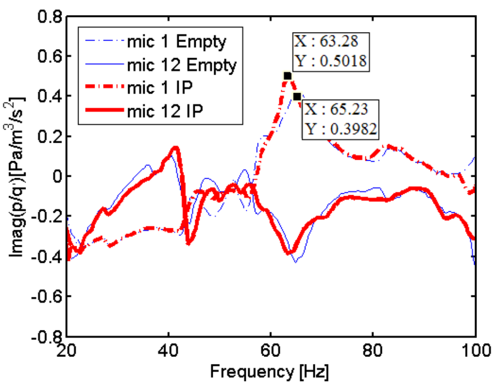


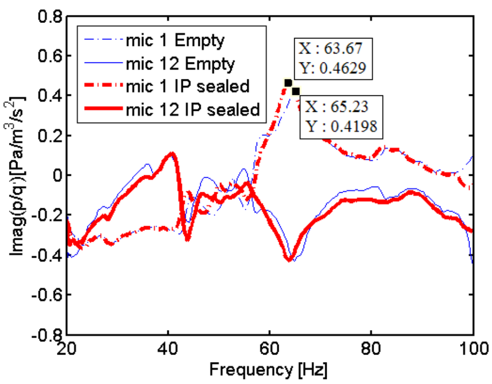
Figure 3.11.: First longitudinal mode shape for rs parcel trim configuration at around 85Hz.

3.2.5. A-FRF Results and Discussion on Empty Trim Vs IP Trim Configuration

The vehicle IP is the biggest and heaviest trim part in the experiment. The first longitudinal mode comparison between empty trim and ip trim configuration is shown in figure 3.12(a). Surprisingly, adding the vehicle IP actually decreases the longitudinal mode frequency instead of increasing the mode frequency as it was initially expected that the IP would occupy the space and make the cavity length shorter. Another suspicion of this phenomena was due to the reason that the air cavities below the IP was not sealed, allowing the air and sound to curve and travel freely into the cavity. The sound field that curves and travels into the air cavity below the IP indicates a 'longer' propagating path, which could explain the decrement at the longitudinal frequency mode.



(a) First longitudinal mode comparison for empty vs ip trim configuration.



(b) First longitudinal mode comparison after sealing IP.

Figure 3.12.: Acoustical influence on longitudinal mode with IP trim configuration.

However, the same phenomena is still observed as shown in figure3.12(b) after sealing the air cavities below the IP with mineral wools and damping layers (figure 3.13).

Figure 3.13.: IP lower cavities sealed with damping layer and mineral wool.

The phenomena can be further investigated by the impedance changes. The vehicle cavity wall can be assumed to be analogous to a mass-spring system, as shown in figure 3.14.

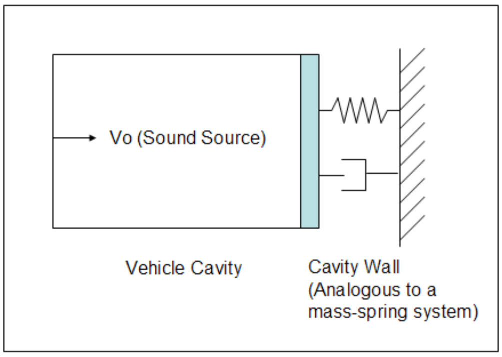


Figure 3.14.: The vehicle cavity wall analogous to a mass-spring system.

The mass and spring parameters can be simulated by a negative or positive imaginary impedance (Z) and the changes of the frequency mode with impedance can be observed by the plot in figure 3.15. Based on the plot, an increasing imaginary values (less negative) of the impedance decreases the frequency mode which indicates a heavier mass and softer surface like the vehicle IP would lower the frequency mode in the vehicle cavity.

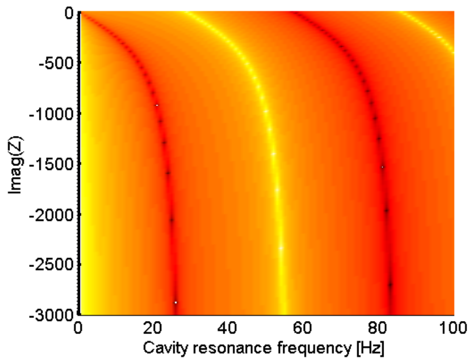


Figure 3.15.: Frequency mode changes in response to impedance changes.

3.2.6. A-FRF Results and Discussion on Empty Trim Vs Full Trim Configuration

The term full trim configuration in this context indicates a combination of IP, front seats , rear seats, carpets and parcel trim. Figure 3.16 shows the comparison between the empty trim and full trim configuration. Based on the figure, it is observed that despite the increase of the longitudinal mode frequency (basically due to the decoupling of the passenger cabin and trunk), there is also significant damping to the acoustical response incurred by the full trim parts relative to a empty cavity.

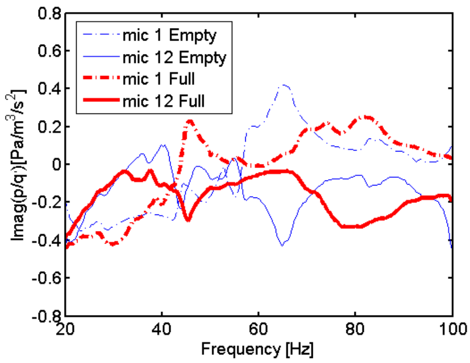


Figure 3.16.: Acoustical influence on longitudinal mode with full trim configuration.

3.2.7. A-FRF Results and Discussion on All Trim Configuration at Driver's Outer Ear.

This section shows and discuss the influence of the trim configurations to the driver's outer ear. The discussion basically divided the trim configurations in 3 groups: individual trim configuration, all trim configurations with rs parcel and all trim configurations with IP.

Based on figure 3.17, the influence of each trim parts varies. The carpets shows a smoother and damped characteristic throughout the frequency range relative to other trims. Installing the front seats shows higher influence with a dip at around 350Hz and lower sound pressure level from 900Hz onwards. Both the rear seats and rs parcel configuration indicates a similar response and it is observed that the two trim configurations actually increase the sound pressure level from 700Hz onwards. Whereas for the IP trim configuration, a significant drop of sound pressure for around 20dB is recorded at from 300Hz to 600Hz. In general, the significant influence at 300Hz to 600Hz is dominated by the IP trim configuration. While from 700Hz onwards, the significant influence is mainly dominated by the rear seats and rs parcel trim configurations relative to the empty trim configuration.

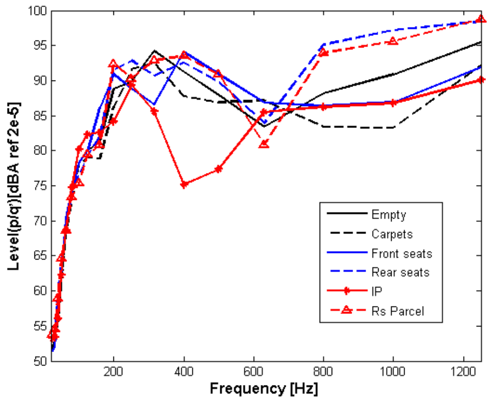


Figure 3.17.: All individual trim configurations with reference to empty trim configuration at driver's outer ear.

Figure 3.18 is selected to observe the influence of the trim items when the passenger cabin is decoupled from the trunk by the rs parcel trim configuration. As expected, the effect is similar to figure 3.17 and the significant influence is recorded whenever the IP is part of the trim configurations. In addition, the carpets still acts as a good damping item to smoothen the response in the cavity.

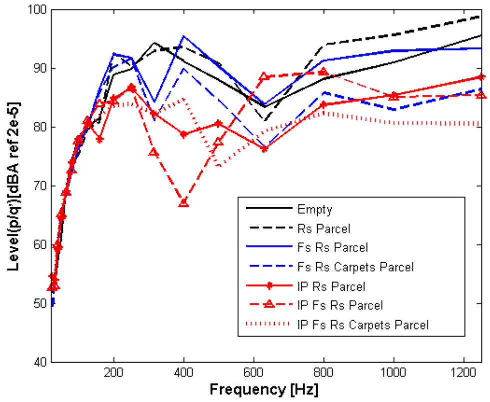


Figure 3.18.: All Rs Parcel trim configurations with reference to empty trim configuration at driver's outer ear.

Figure 3.19 shows that all trim configurations with IP significantly decrease the sound pressure level throughout almost all the frequency of measurement relative to empty trim configuration.

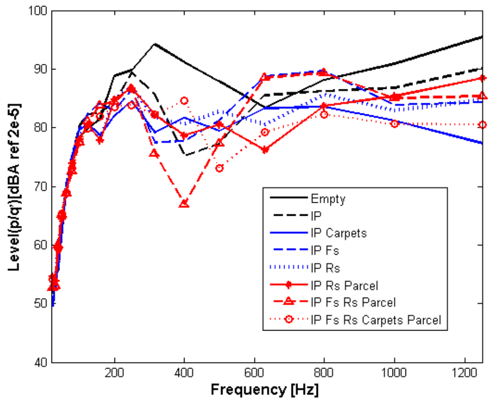


Figure 3.19.: All IP trim configurations with reference to empty trim configuration at driver's outer ear.

Lastly a more detailed numerical representation in shown in table 3.5. All values are shown in sound pressure dBA levels. The delta is the difference between the empty trim and the trim of interest. Based on the standard deviation, it is observed that the dispersion of the sound pressure level is higher and higher frequencies for different trim configurations. It is clearly shown that the the trim configuration with IP dominantly decreases the sound pressure level from 4.5dBA to 8.6dBA. However, the rear seats and rs parcel trim configuration increase the sound pressure level of 2.6dBA and 2.8dBA to the vehicle cavity.

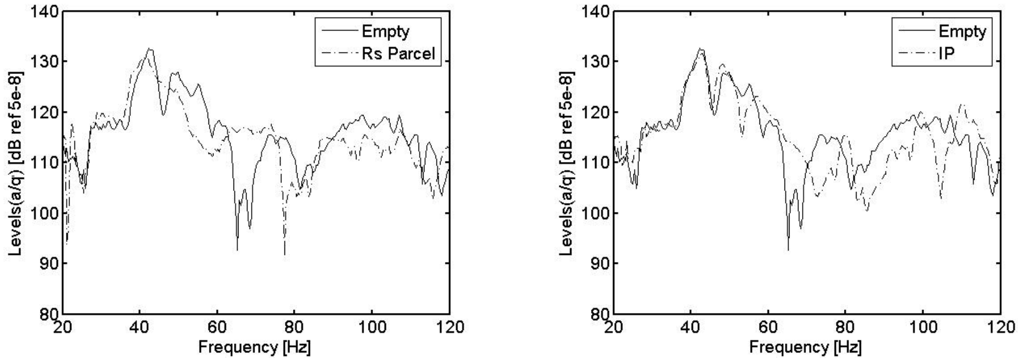
Table 3.5.: Influence of trim configurations in sound pressure levels, Lp (dBA) at driver's outer ear.

	25-50 Hz		50-250 Hz		250-1250 Hz		Total dBA	
Trim configuration	**Actual**	**Delta**	**Actual**	**Delta**	**Actual**	**Delta**	**Actual**	**Delta**
Empty	63.2	0.0	93.1	0.0	100.1	0.0	100.9	0.0
Carpets (Cpts)	62.8	0.4	93.2	-0.1	97.4	2.7	98.8	2.1
Front seats (Fs)	63.9	-0.7	94.1	-1.0	98.6	1.5	99.9	1.0
Rear seats (Rs)	65.8	-2.6	95.7	-2.5	102.9	-2.8	103.7	-2.8
IP	64.0	-0.8	92.1	1.0	94.4	5.7	96.4	4.5
Rs Parcel(Prcl)	66.3	-3.1	94.9	-1.8	102.8	-2.8	103.5	-2.6
Fs Rs Prcl	66.9	-3.7	95.8	-2.7	100.2	-0.1	101.5	-0.7
Fs Rs Cpts Prcl	66.7	-3.5	94.8	-1.7	93.8	6.3	97.4	3.5
IP Cpts	63.3	-0.1	88.8	4.3	89.7	10.3	92.3	8.6
IP Fs	64.3	-1.1	90.8	2.3	93.9	6.2	95.6	5.3
IP Rs	65.7	-2.5	90.3	2.8	91.5	8.6	94.0	6.9
IP Rs Prcl	66.1	-2.9	90.1	3.0	92.2	7.8	94.3	6.6
IP Fs Rs Prcl	66.7	-3.5	90.8	2.4	93.6	6.4	95.5	5.4
IP Fs Rs Cpts Prcl	66.8	-3.6	89.1	4.1	89.8	10.3	92.5	8.4
Average	65.2		92.4		95.8		97.6	
Standard deviation	1.5		2.4		4.5		3.8	

3.2.8. A-MTF Results and Discussion of the Roof

This section shows the A-MTF results and comparison discussion between the empty trim and other selected trim configurations of the vehicle cavity roof.

Figure 3.20(a) illustrates the first A-MTF measurement comparison on the empty trim with the RS Parcel trim configurations. The discrepancies can be seen starting from around 45Hz and both the measurement deviate higher as the frequency goes higher. Adding the trims may be similar to adding mass and damping to the vibrating structure where the resonance shift can be observed from the measurement comparison (based on the anti-resonance shift from around 65Hz to 80Hz) as well as the resonance modes are seen to be lower and damped (more spread out).



(a) Roof vibration for Empty vs Rs Parcel configuration.

(b) Roof vibration for Empty vs IP configuration.

Figure 3.20.: Comparison between Empty vs Rs Parcel configuration and Empty vs IP configuration for roof vibration.

The resonance shift and damping effect can also be clearly seen by the IP trim configuration and the effect is highest for the full trim configuration, based on figure 3.20(b) and figure 3.21, due to the higher amount of mass and damping characteristic imposed from the two trim configurations.

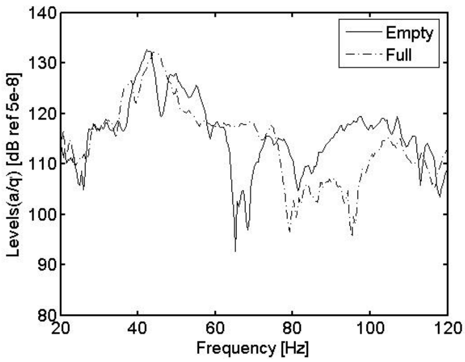
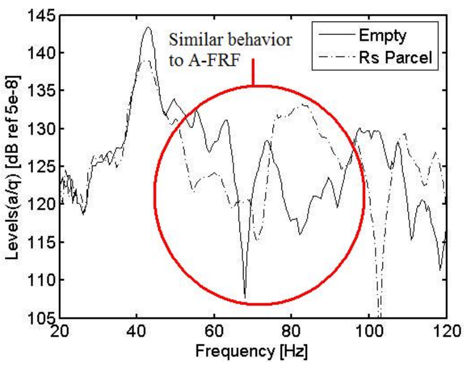


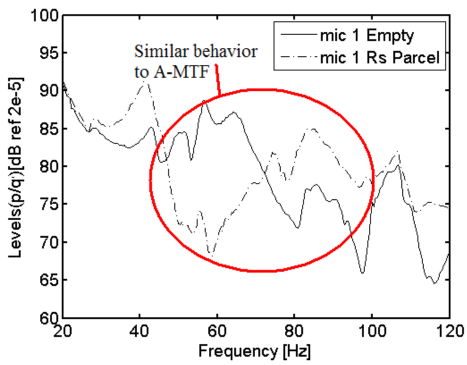
Figure 3.21.: Comparison between Empty vs Full configuration for roof vibration.

3.2.9. A-MTF Results and Discussion on the Rear Window

In this section, a comparison on the empty trim and rs parcel is initially performed for the rear window A-MTF measurement, which is shown in figure3.22(a). As it is recalled, installing the rs parcel trim actually makes the length of vehicle cavity smaller and subsequently increases the frequency of the first longitudinal acoustic resonance mode. A similar behavior is also observed at the A-MTF of the rear window the comparison is shown in figure 3.22. This is interesting as the significant changes in the rear window follows the changes in the longitudinal acoustic changes in the vehicle cavity. This may indicate the rear window is relatively sensitive (compared to roof and parcel shelf) to the longitudinal modes as the sound pressure of the mode is incidently hitting the rear window.



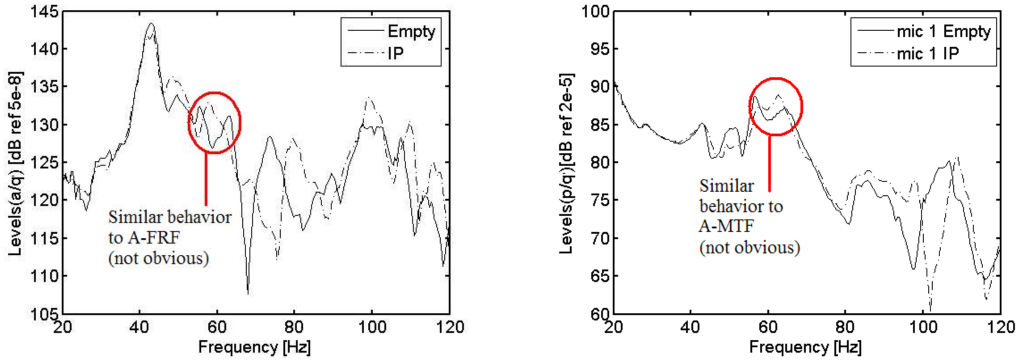
(a) A-MTF for rear window.



(b) A-FRF for mic 1.

Figure 3.22.: A-MTF rear window and A-FRF mic 1 on empty vs rs parcel trim configuration.

Whereas there are less discrepancies in the A-MTF for the empty and IP comparison and installing the IP does not yield much resemblance with the A-FRF at this frequency range, as shown in fig 3.23(a). In previous A-FRF discussion, installing the IP decreases the frequency of the first longitudinal mode. A similar characteristic is also observed in the A-MTF measurement, as shown in figure 3.23(b) although the effect is not obvious.

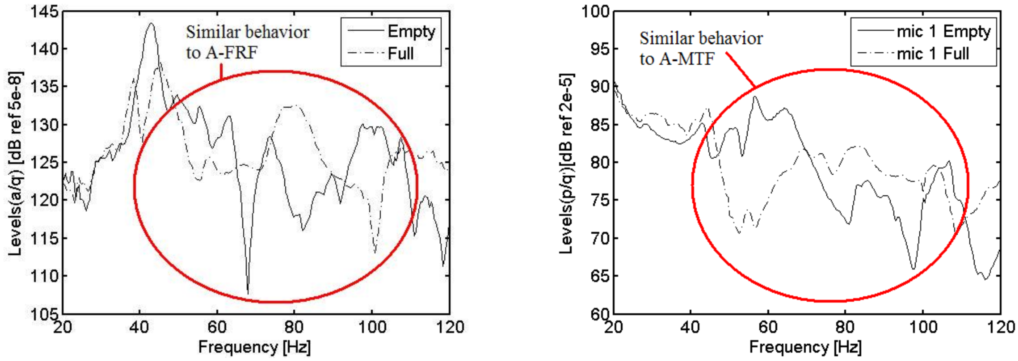


(a) A-MTF for rear window.

(b) A-FRF for mic 1.

Figure 3.23.: A-MTF rear window and A-FRF mic 1 on empty vs ip trim configuration.

Lastly, the empty trim vs full trim configuration shows a resemblance with the empty trim vs rs parcel trim configuration as the adding the rs parcel trim yielded a more dominant changes or influence to the vibration of the rear window.



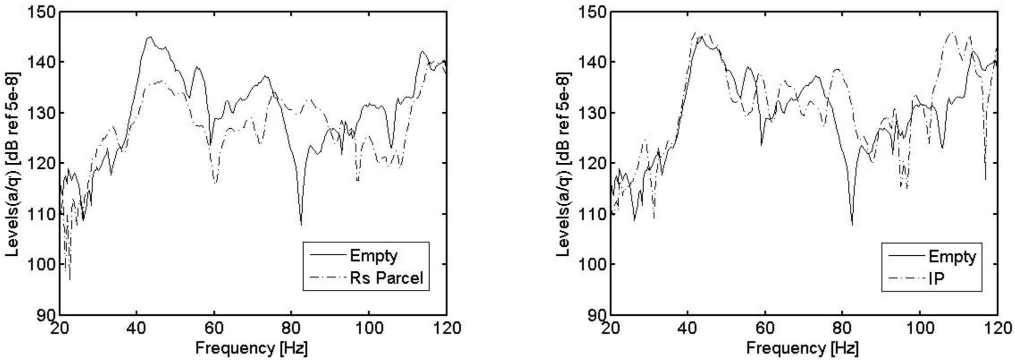
(a) A-MTF for rear window.

(b) A-FRF for mic 1.

Figure 3.24.: A-MTF rear window and A-FRF mic 1 on empty vs full trim configuration.

3.2.10. A-MTF Results and Discussion on the Parcel Shelf

The vibrational response of the parcel shelf for empty, rs parcel, ip and full configuration can be seen in this section. In figure 3.25(a) the comparison between empty and rs parcel configuration is shown. Both curves are following the same trend with small discrepancies in the levels which is due more mass is induced to the parcel shelf trim.



(a) Parcel vibration for Empty vs Rs Parcel trim configuration.

(b) Parcel vibration for Empty vs IP trim configuration.

Figure 3.25.: Comparison between Empty vs Rs Parcel trim configuration and Empty vs IP trim configuration.

Whereas in figure 3.25(b), the comparison of the empty and ip configuration is observed. In this measurement comparison, the discrepancies in terms of levels and resonance mode shift is low. Even though the IP is the trim item with the biggest mass, the influence on the vibrational response (A-MTF) of the parcel shelf is minimal.

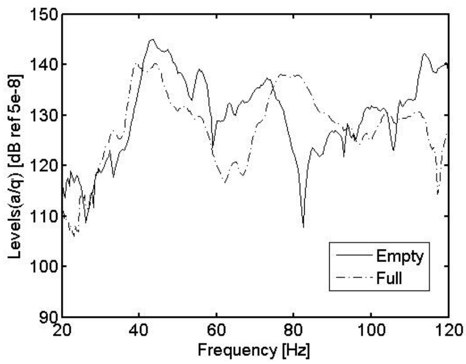


Figure 3.26.: Comparison between Empty vs Full trim configuration

Lastly in figure 3.26 for the empty vs full trim comparison, a similar phenomena or effect can be observed which is due to the increased damping and mass contributed by the total trim items in the configuration.

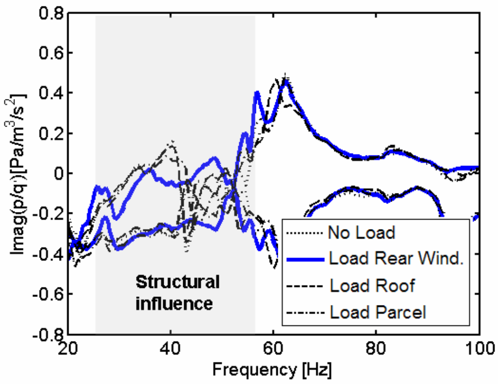
Other A-MTF measurement plots are also shown in appendix A.2.5.

3.2.11. Investigation on the 40Hz peak with mass-loading

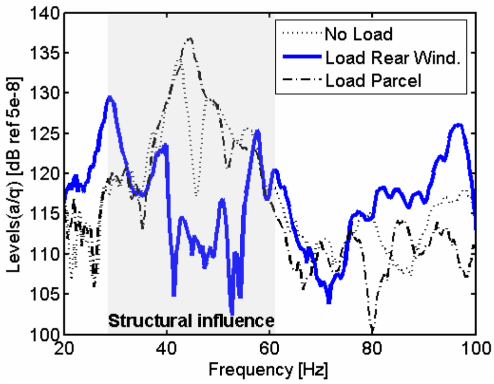
In this section, an investigation to determine the origin of the 40Hz peak was conducted. The 40Hz peak was observed in the initial stage of the project and is mentioned in section 3.2.3 as a structural influence. In order to validate and determine the source of the structural influence, the investigation involved mass-loading selectively and separately the parts that could have the highest influence in the acoustical field in the vehicle cavity: the roof, parcel shelf and the rear window. The mass-loading experiment was performed by placing sandbags (roughly 30kg) on the vehicle parts of interest, which is shown in figure 3.27.

Figure 3.27.: Mass-loading the rear window with sandbags.

The investigation and measurement were conducted during the front seats trim was mounted inside the vehicle cavity. Figure 3.28(a) and figure 3.28(b) shows the respective A-FRF and A-MTF comparison measurement results after mass-loading.



(a) Mass loading effect on acoustic longitudinal mode.



(b) Mass loading effect on roof vibration.

Figure 3.28.: Mass-loading investigation on A-FRF and A-MTF.

From these figures, it can be clearly observed that the 40Hz peak is mainly influenced by the rear window, due to the significant decrease in sound pressure and vibration. The rear window is relatively sensitive to the acoustical excitation and the mutual influence (between the rear window structure and acoustical excitation) generated the 40Hz peak in the form of sound and structural vibration which are captured by the microphones (mic 1 and mic 12) and the accelerometer on the roof. Besides the discussed investigation results, other mass-loading measurement plots can also be found in appendix A.2.6 for reference.

3.3. Measurement by Mechanical Excitation

3.3.1. Setup and Methodology

Figure 3.29 shows the equipment setup schematic for the NTF measurement on the BIB. All IEPE accelerometers are connected directly to the acquisition system except for an accelerometer at point:012 (which is a different accelerometer type and the output is amplified by a charge amplifier). The reason for this setup is the channels supply settings of the acquisition system has to be setup in groups of four (16 channels: 8 non-IEPE and 8 IEPE) and one non-IEPE accelerometer has to be chosen for this measurement.

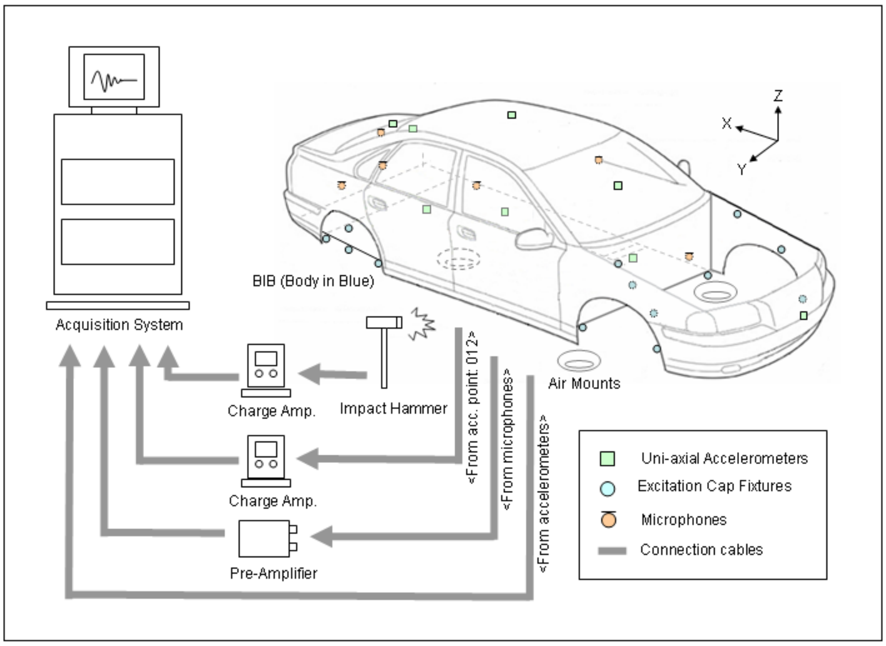


Figure 3.29.: Equipment setup for NTF measurement.

Table 3.6 shows shows the test equipment for the NTF measurement channels and table 3.7 shows the mapping of the acquisition system to the measurement points on the BIB.

Table 3.6.: Test equipment for NTF measurement.

Item	Equipment	Manufacturer	Model	S/N	Sensitivity	Exc/Meas Pos.
1	Impact Hammer	Brüel & Kjaer	8200	1225726	*0.85 pC/N	Exc. Caps
2	Microphone	Panasonic	WM-063	n/a	1V/μbar	Point:001
3	Microphone	Panasonic	WM-063	n/a	1V/μbar	Point:002
4	Microphone	Panasonic	WM-063	n/a	1V/μbar	Point:003
5	Microphone	Panasonic	WM-063	n/a	1V/μbar	Point:004
6	Microphone	Panasonic	WM-063	n/a	1V/μbar	Point:005
7	Microphone	Panasonic	WM-063	n/a	1V/μbar	Point:006
8	Uni-axial Acc.	Brüel & Kjaer	4393	1600112	0.321 pC/ms^{-2}	Point:012
9	Uni-axial Acc.	Brüel & Kjaer	4507	30245	9.798 mV/ms^{-2}	Point:606
10	Uni-axial Acc.	Brüel & Kjaer	4507	30847	9.702 mV/ms^{-2}	Point:627
11	Uni-axial Acc.	Brüel & Kjaer	4507	30848	9.832 mV/ms^{-2}	Point:641
12	Uni-axial Acc.	Brüel & Kjaer	4507	30856	10.06 mV/ms^{-2}	Point Mob
13	Uni-axial Acc.	Brüel & Kjaer	4507	30850	9.848 mV/ms^{-2}	Point:638
14	Uni-axial Acc.	Brüel & Kjaer	4507	30853	9.960 mV/ms^{-2}	Point:635
15	Uni-axial Acc.	Brüel & Kjaer	4507	30854	9.787 mV/ms^{-2}	Point:616
16	Uni-axial Acc.	Brüel & Kjaer	4507	30855	9.775 mV/ms^{-2}	Point:112
17	Charge Amplifier	Brüel & Kjaer	2635	986722	n/a	n/a
18	Acquisition Station	Agilent Tech.	n/a	n/a	n/a	n/a
19	Mic. preamplifier	Chalmers Uni.	n/a	n/a	n/a	n/a

* Please take special note that the sensitivity of the B&K impact hammer used in the experiment contains the sensitivities for the force transducer and the hammer handle (factor 4.75).

Table 3.7.: Acquisition system channels mapping and description.

Channel	Exc/Meas Position	Description
1	Impact Hammer	Excited on the cap fixtures.
2	Point:001	Driver outer ear.
3	Point:002	Pedals
4	Point:003	Front passenger outer ear.
5	Point:004	Rear right passenger outer ear.
6	Point:005	Parcel shelf.
7	Point:006	Trunk.
8	Point:012	Driver seat left front mount.
9	Point:606	Windscreen.
10	Point:627	Rear window.
11	Point:641	Parcel shelf.
12	Point Inertance	Acc. on the excitation cap fixtures.
13	Point:638	Rear floor front.
14	Point:635	Front floor rear.
15	Point:616	Roof
16	Point:112	Front bumper.

Photographs of the measurement positions be found in appendix A.3.2. Table 3.8 shows the excitation cap fixtures and the respective excitation directions for the NTF measurement a picture of an excitation cap with a hammer for point inertance measurement is shown in figure 3.30. Other photographs of excitation cap fixtures and excitation positions/direction are also shown in appendix A.3 for reference.

Table 3.8.: Impact hammer excitation cap fixtures.

Item	Exc. Cap Fixtures	Exc. Direction	Description
1	Body:101	$-X, +Y, +Z$	Front left chassis mount
2	Body:102	$+X, -Y, +Z$	Front left chassis mount
3	Body:141	$-X, +Y, -Z$	Front left suspension mount.
4	Body:201	$+X, -Y, +Z$	Front right chassis mount
5	Body:202	$+X, +Y, +Z$	Front right chassis mount
6	Body:205	$+X, +Y, -Z$	Engine mount.
7	Body:241	$+X, -Y, -Z$	Front right suspension mount.
8	Body:301	$-X, +Y, +Z$	Back left chassis mount.
9	Body:302	$-X, +Y, +Z$	Back left chassis mount.
10	Body:321	$-X, -Y, +Z$	Back left chassis mount.
11	Body:341	$-X, +Y, +Z$	Back left absorber mount.
12	Body:401	$-X, -Y, +Z$	Back right chassis mount.
13	Body:402	$+X, -Y, +Z$	Back right chassis mount.
14	Body:421	$-X, +Y, +Z$	Back right chassis mount.
15	Body:441	$-X, -Y, +Z$	Back right absorber mount.
16	Body:901	$-X, -Y, -Z$	Engine mount.
17	Body:902	$+X, -Y, -Z$	Engine mount.

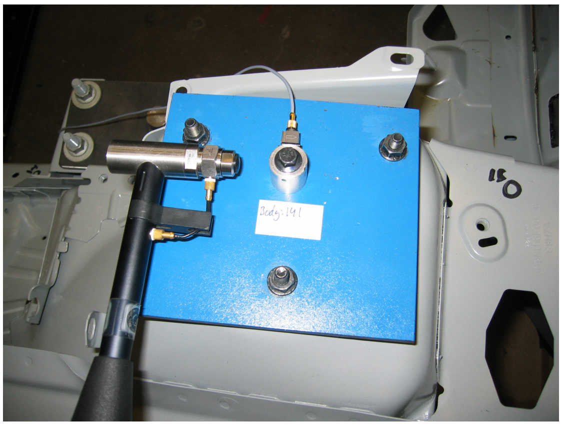


Figure 3.30.: Cap fixture with an impact hammer for point inertance measurement.

All NTF and VTF measurement were performed on all six trim configurations. The trim configurations for the acoustical excitation measurement is shown in previous table 3.2.

3.3.2. Quality of NTF and VTF measurements

Figure 3.31 shows the autospectra of the force when excited by the impact hammer (rubber tip). As expected, it can be observed that the magnitude of the force drops significantly (around 10dB when reaches 600Hz) due to the poor energy distribution from a rubber hammer tip at higher frequencies.

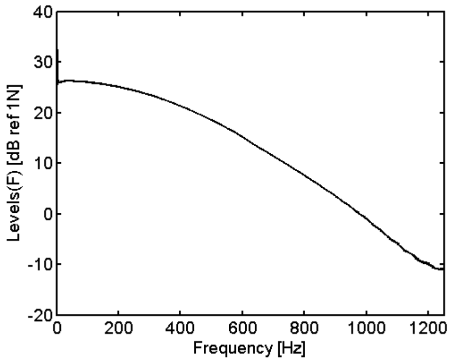
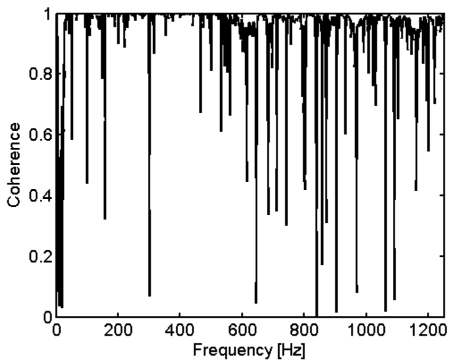
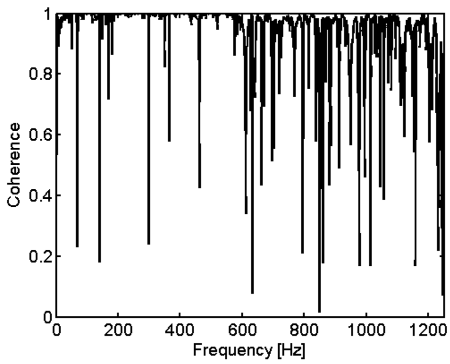


Figure 3.31.: Autospectra of the force from the impact hammer.

Hence, the quality of the measurement can be investigated from the NTF and VTF coherences shown in figure 3.32(a) and 3.32(b). The coherences indicate that the measurement starts to deteriorate at around 600Hz which leads to measurement confidence level only from 20Hz to 600Hz.



(a) Coherence of microphone response (NTF) at the driver's outer ear.



(b) Coherence of accelerometer response (VTF) at position 012.

Figure 3.32.: Coherences of NTF and VTF for empty trim configuration excited at cap fixture 201 z-direction.

3.3.3. NTF and VTF Data Representation Discussion

Extensive measurement was performed and a large database of measurement data (NTF and VTF) was collected in this part of experiment. The results and discussion selected in this section will be on four parts:

1. The influence of trim configurations to all measurement points (microphones and accelerometers) when mechanically excite at one excitation direction and excitation mount group (back suspension and chassis mounts) with a hammer.

2. The influence of trim configurations to one measurement point (driver's outer ear) when mechanically excite at all excitation points and directions with a hammer.

3. The influence of the carpet trim to one NTF and VTF measurement point when mechanically excite at one excitation point z-direction.

4. The influence of the IP trim to one NTF and VTF measurement point when mechanically excite at one excitation point z-direction.

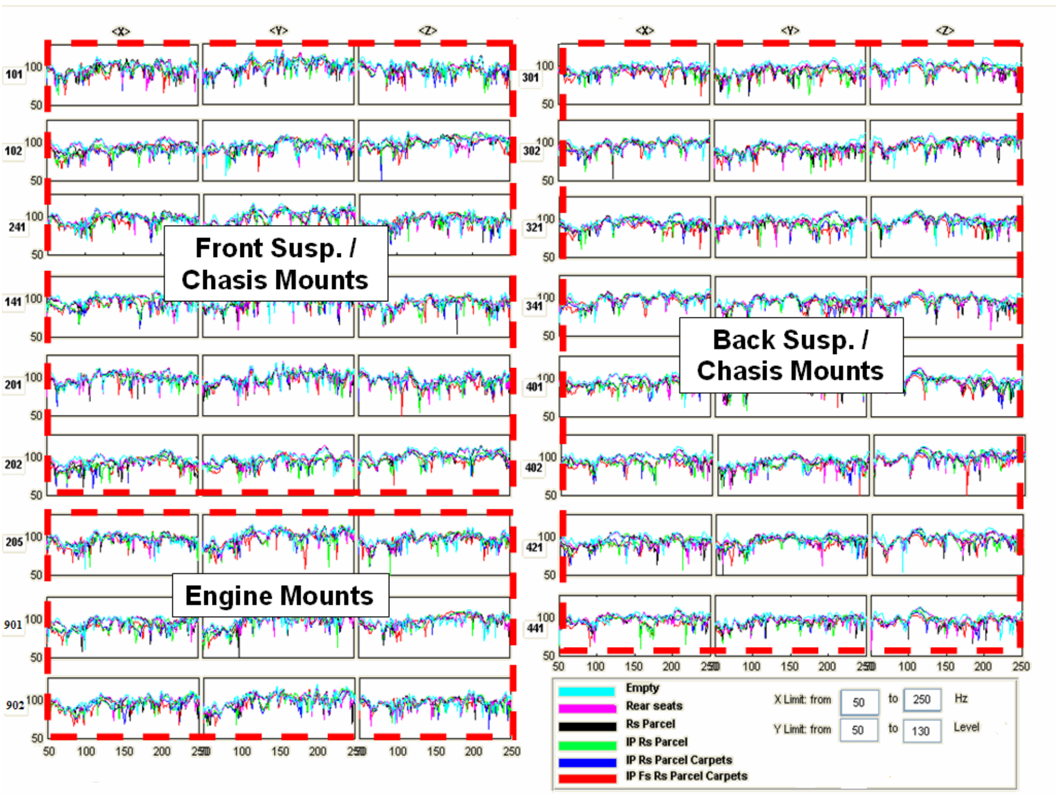


Figure 3.33.: Non-averaged results of response at driver's outer ear excited at all points and directions as well illustration of the average groups by the dotted squares.

The plots or data presented are averaged into three categories based on the excitation mounts: engine mounts, front suspension/chassis mounts and back suspension/chassis mounts. The average of the plots will be relatively strategic to discuss and clearer to visualize the influence of the trim configurations. The non-averaged results or plots for the response at driver's outer ear can be shown in figure 3.33. The dotted squares indicates the averaging categories that are imposed for further discussion plots. And finally, besides the selected NTF and VTF measurement results discussion in the following sections, other NTF and VTF measurement results can also be found in appendix A.3.3 and A.3.4.

3.3.4. NTF and VTF Influence of Trim Configurations at All Measurement Points from Back Suspension/Chassis Mounts Excitation (Z-Direction)

The discussion of interest lies on how the six trim configurations influence the response of all fifteen measurement points when excitation is induced at the back suspension/chassis mounts (z-direction), which is shown in figure 3.34.

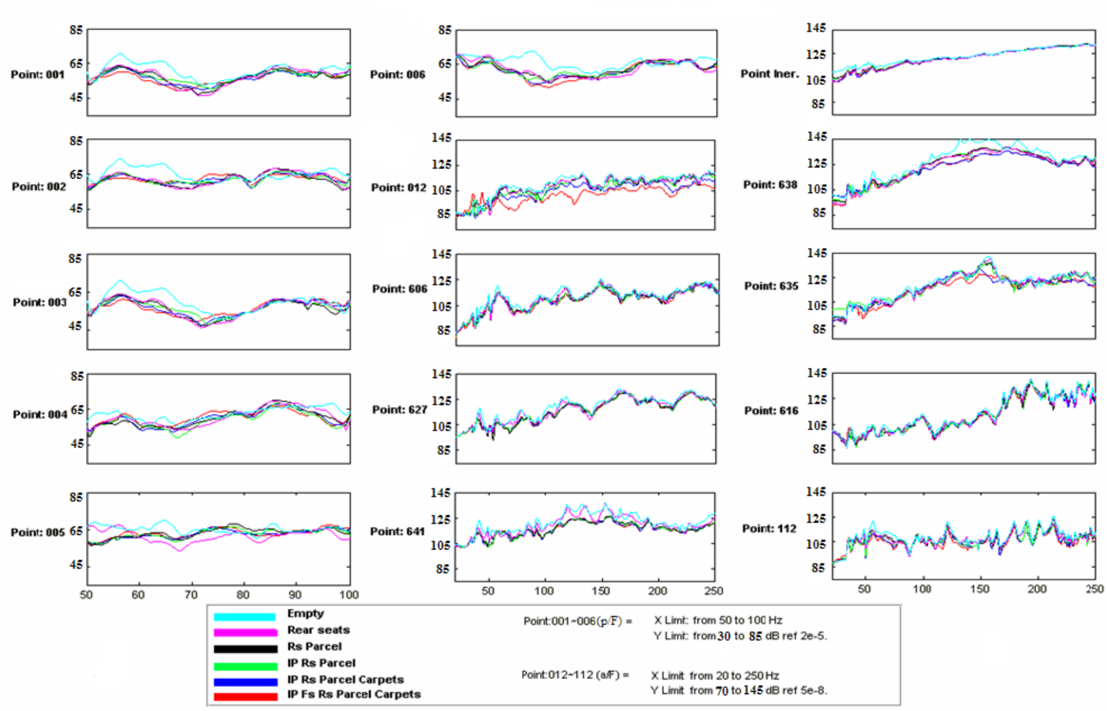


Figure 3.34.: All measurement result excited at back suspension/chassis mounts (z-direction).

Based on the figure, a systematic trend of the influence of the trim configurations is observed on the measurement results. It obvious at point 012 VTF (the measurement point below the driver front seat), the more trim item is added, the lower the vibration become. The trim items, especially the rear seats, effectively barricade the noise coming from the back suspension/chassis mounts as it can be clearly seen from the NTF results at point 001 to point 006.

However, there are measurement points that are less sensitive to the trim configurations, eg: point 112 (front bumper), point 606(front window) and point 616 (roof). The reason could be due to good vibration isolation of the structure and the vibration has been effectively damped before reaching the measurement points.

3.3.5. NTF Influence of Trim Configurations at Driver's Outer Ear from All Excitation Points and Directions.

In this section, a numerical description of the influence of trim configurations at the driver's outer ear is shown in table 3.9. Based on the average in the table, it can be observed that the noise induced by the engine mounts is relatively higher than the noise induced by the front suspension/chassis mounts and back suspension/chassis mounts. It indicates that the passenger cabin is more susceptible to noise induced by the engine mounts. The standard deviations shows that the influence of the trim configurations demonstrates the highest influence at the back suspension/chassis excitation.

The influence of the trim configurations at the engine mounts (especially the x-direction) seems to show similar characteristic with the A-FRF response at the driver's ear, which installing the rear seats and rs parcel actually increases the noise level while IP dominantly decreases the noise.

The effect of the trim configurations varies with the excitation directions. It can be clearly seen that depending on the direction for full trim at back suspension/chassis mounts excitation, the effect may range from 6.1dBA (x-direction) to 12.6dBA (y-direction)

Generally, the influence of the trim configurations in this context is dependent on the direction and the place of excitation.

Table 3.9.: Influence of trim configurations in sound pressure levels, Lp (dBA) at driver's outer ear excited at all excitation points and direction with frequency range from 20-600Hz.

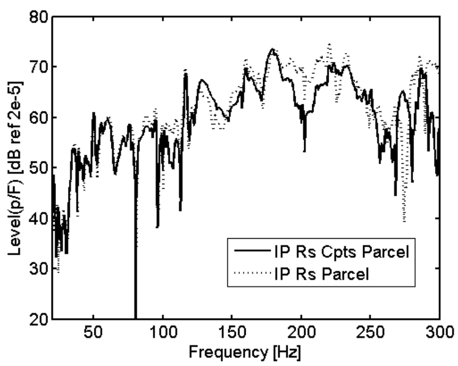
	Engine Mounts						**Front Suspension / Chassis Mounts**					
	X		**Y**		Z		**X**		**Y**		**Z**	
Trim configuration	**Actual**	**Delta**	**Actual**	**Delta**	**Actual**	**Delta**	**Actual**	**Delta**	**Actual**	**Delta**	**Actual**	**Delta**
IP Fs Rs Parcel Carpets	69.0	1.3	78.8	3.7	75.4	3.1	67.2	5.2	70.1	6.7	71.8	4.7
IP Rs Parcel Carpets	69.1	1.2	78.7	3.9	75	3.5	67.2	5.2	72.1	4.7	71.5	5.0
IP Rs Parcel	70.3	0.0	79.1	3.4	76	2.6	69	3.4	74.9	1.9	74.9	1.6
Rs Parcel	71.8	-1.5	82.7	-0.2	78.1	0.5	70.1	2.3	77.5	-0.7	75.5	1.0
Rear seats	71.6	-1.3	81.1	1.4	77.4	1.2	71.4	1.1	76.5	0.3	74.9	1.6
Empty	70.3	0.0	82.6	0.0	78.6	0.0	72.4	0.0	76.8	0.0	76.5	0.0
Average	70.3		81.5		76.7		69.6		74.7		74.2	
Standard deviation	1.2		1.9		1.5		2.1		2.9		2.0	

	Back Suspension / Chassis Mounts					
	X		**Y**		Z	
Trim configuration	**Actual**	**Delta**	**Actual**	**Delta**	**Actual**	**Delta**
IP Fs Rs Parcel Carpets	65.7	6.1	60.0	12.6	64.3	10.5
IP Rs Parcel Carpets	68.2	3.5	65.4	7.1	67.5	7.2
IP Rs Parcel	68.7	3.0	65.5	7.1	66.9	7.8
Rs Parcel	69.9	1.8	61.6	11.0	67.3	7.4
Rear seats	70.2	1.5	67.0	5.6	68.8	6.0
Empty	71.7	0.0	72.6	0.0	74.8	0.0
Average	69.1		65.3		68.3	
Standard deviation	2.1		4.4		3.5	

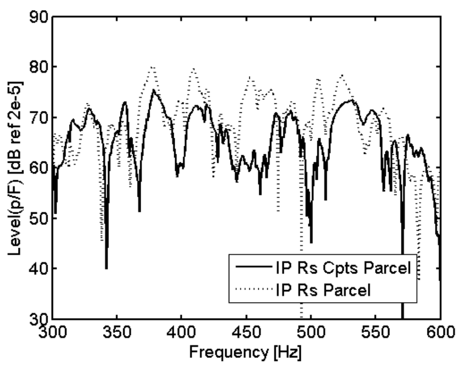
3.3.6. NTF and VTF Influence of Carpet Trim at Driver's Outer Ear and Windscreen from Excitation Point 102 Z-Direction.

In this section, the influence of the carpet trim on a single NTF and VTF measurement point excited at cap fixture 102 z-direction is investigated. For easy viewing, the measurement results for NTF and VTF are represented in two plots: range of 20Hz to 300Hz and range of 300Hz to 600Hz.

Figure 3.35 shows the NTF comparison results measured at the driver's outer ear. The carpets are observed to be effective sound absorbers as the discrepancies between the two trim configurations start to increase from around 170Hz onwards.



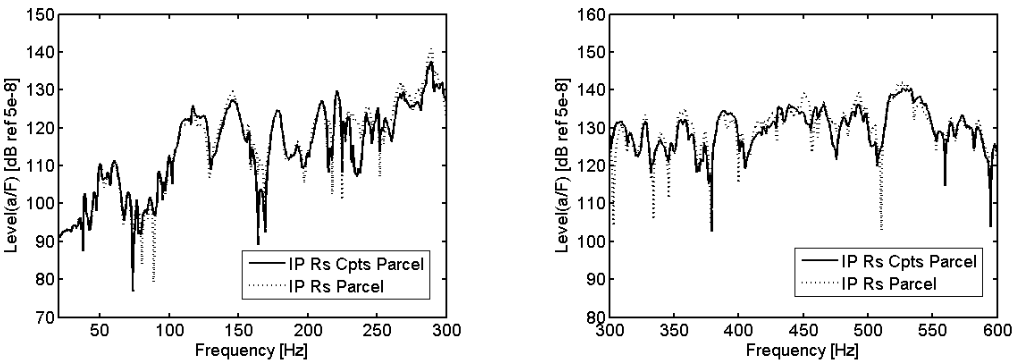
(a) NTF from 20Hz to 300Hz.



(b) NTF from 300Hz to 600Hz.

Figure 3.35.: NTF investigation on the carpets influence measured the driver's outer ear position and excited at cap fixture 102 z-direction.

As for VTF, the comparison results are plotted based on the measurement at the vehicle windscreen as shown in figure 3.36. Contrary to NTF, the VTF comparison results at the windscreen yield no significant difference. This phenomena indicates that the mass of the carpets is probably not sufficient enough to inhibit the vibration substantially or simply, the vibration is transmitted through another path in the vehicle (bypassing the carpets) from the excitation point to the windscreen.



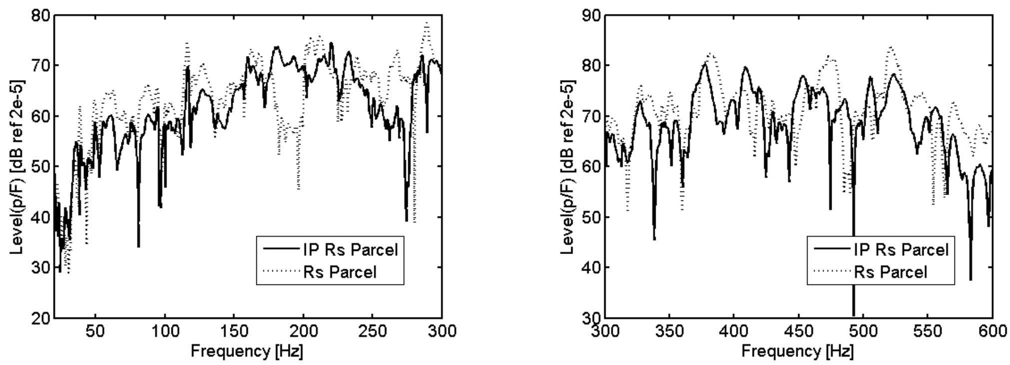
(a) VTF from 20Hz to 300Hz.

(b) VTF from 300Hz to 600Hz.

Figure 3.36.: VTF investigation on the carpets influence measured at the windscreen and excited at cap fixture 102 z-direction.

3.3.7. NTF and VTF Influence of IP Trim at Driver's Outer Ear and Windscreen from Excitation Point 102 Z-Direction.

The influence of the heaviest trim in the experiment (the IP) is investigated. The excitation position and measurement point for NTF and VTF are the same as the previous section (section 3.3.6). Relative to the carpet trim, the IP trim already produces a higher influence in terms of damping on the NTF from 50Hz onwards and the discrepancies increase with frequency (as shown in figure 3.37).

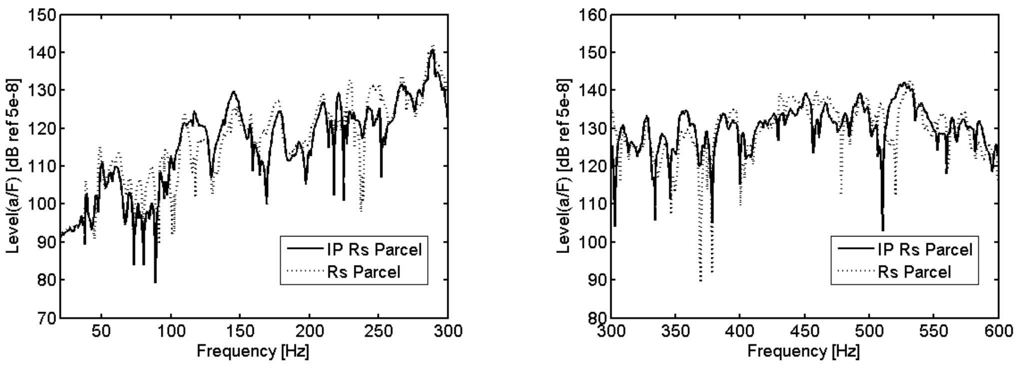


(a) NTF from 20Hz to 300Hz.

(b) NTF from 300Hz to 600Hz.

Figure 3.37.: NTF investigation on the IP influence measured at the driver's outer ear and excited at cap fixture 102 z-direction.

As for the VTF results measured at the windscreen, some levels of damping can also be observed in figure 3.37 along the frequency range. The mass and the mounting position of the IP trim have inhibited the vibration excited at cap fixture 102 (although not truly significant).



(a) VTF from 20Hz to 300Hz. (b) VTF from 300Hz to 600Hz.

Figure 3.38.: VTF investigation on the IP influence measured at the windscreen and excited at cap fixture 102 z-direction.

4. Conclusion

Based on the measurement results and discussion, the trim parts that significantly influence the acoustical behavior in the vehicle cavity are the rear seats and the IP. Mounting these trim parts basically changes or shifts the acoustical modes as well as inducing additional damping and mass to the vehicle test structure (BIB). When the rear seats and the parcel shelf trims are mounted, decoupling of the passenger cabin from the trunk occurs and the acoustic field responds with a shifting of the longitudinal modes due to the shorter length of the vehicle cavity.

Introducing the IP inside the vehicle cavity yields some interesting effects. A decrease in frequency of the first longitudinal mode is observed, which is initially suspected due to the air cavity below the IP. However, sealing the air cavity below the IP with damping layers and mineral wool does not show any noticeable changes. The second hypothesis explains the effect by treating the wall of the vehicle cavity as a mass-spring system. Adding the IP is analogous to introducing additional mass (which is significant) and reducing stiffness (softer surface of the IP) to the system which subsequently lower the longitudinal modes based on the system characteristic.

At the driver's outer ear standpoint, the sound pressure level of the carpets show a smoother and damped characteristic throughout the frequency range, whereas the front seats demonstrate a significant dip at frequency (around 350Hz) and only show more damping characteristic from 900Hz onwards. The IP again dominantly influence the acoustic field in the vehicle cavity regardless which combination of other trim parts, and could potentially decreases the overall sound pressure 4.5dBA to 8.6dBa. Finally, it is observed that the rear seats and rs parcel trim configuration show an increment of the sound pressure level at certain frequency range.

The investigation of the 40Hz peak shows that main structural influence to the acoustic modes in the vehicle cavity comes from the rear window vibration. For both cases of A-MTF and A-FRF the level of the 40Hz peak was significantly decreased when the rear window was mass-loaded. The sound field in the vehicle cavity and vehicle structure are mutually affecting each other where there are resemblance between the A-MTF curves of the rear window (vibration) and the A-FRF of the longitudinal modes. This indicates that the rear window structure is relatively sensitive to the longitudinal acoustic modes.

The data from the NTF and VTF were averaged into excitation mount groups to ease analysis. Based on the results, a systematic trend can be observed where more trim parts generally contribute to more damping to the measurement response. At the driver's outer ear standpoint, the noise is easily transmitted to the passenger cabin from the engine mounts in comparison with front suspension and back suspension chassis mounts. The IP and the rear seats dominantly influences the behavior of the measurement response.

All the data/measurement boils down to the usefulness of aiding and validating the company's CAE vehicle model as well as highlighting trends or behaviors that are never noticed before (or taken lightly). Trim items like rear seats, IP and parcel shelf and their combinations should be taken in account in future modeling specially for frequencies below 250 Hz. Figure 4.1 is illustrated to show a subjective guideline of the influence of each individual trim items in the respective frequency range. The guideline will also serve as a form of priority call before the CAE modeling.

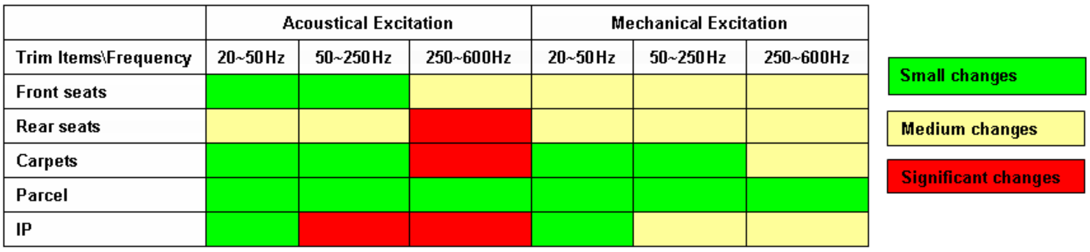


Figure 4.1.: Vehicle trim parts influence according to frequency.

5. Future Work

Several investigation and experiment can be performed as a future resort. The interesting phenomena of the IP trim (frequency decrement at the longitudinal mode) can still be further investigated by constructing a wooden or steel IP without the air cavity below. On the other hand, the sealing of the air cavity below the IP can be improved by using proper and heavier materials for more effective sealing.

This master thesis was designed primarily to aid and validate the CAE vehicle model due to the project's nature of having extensive measurement activities. A comparison of the measurement and CAE results will be beneficial in further understanding and enhancing the future CAE vehicle model.

Lastly, measurement on more than one vehicle for data collection in future may allow a relatively more effective data comparison, validation as well as commonality study. Besides, a wider or refined range of trim configurations can also be selected in future.

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A. Measurement Setup Pictures and Plots

A.1. Vehicle Trim Parts Description

Front Seats

Left and right front seats (including the head rest) were only used, each mounted with four screws during measurement. The textures of the front seats were made of fabric.

Rear Seats

Rear seats (including the back rest) were only used. The bottom seat was mounted by clips and the back rest was mounted by two screws at each sides. The textures of the rear seats were made of fabric (can be seen in figure A.4). No damping layer was placed under the bottom seat during measurement. The damping layer was regarded as part of the carpets trim configuration.

Carpets

Four pieces of carpets (front right, front left, middle and back) were used as shown in figure A.1. The back piece was actually the damping layer beneath the rear seats. No glue or any form of adhesives were used to mount the carpets during measurement.

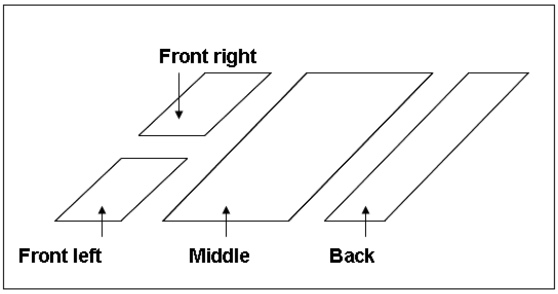
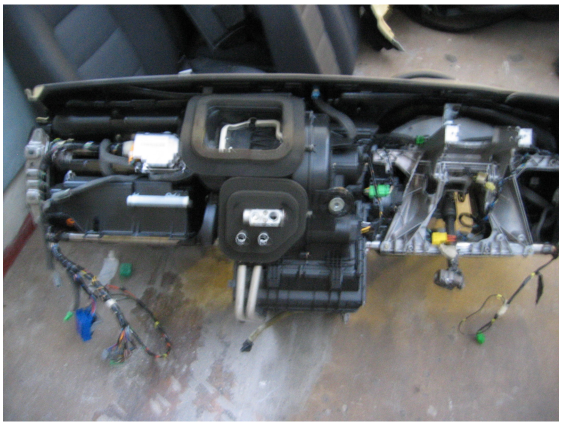


Figure A.1.: Trim carpets arrangement in the vehicle.

IP

The IP (as shown in figure A.2) was mounted by screws only on the BIB during measurement. No additional parts were used and the IP was mounted as-is. Metal plates on the BIB (as shown in figure A.3) were removed prior to the IP mounting.

(a) IP front view.



(b) IP back view.

Figure A.2.: Trim IP used in the measurement.

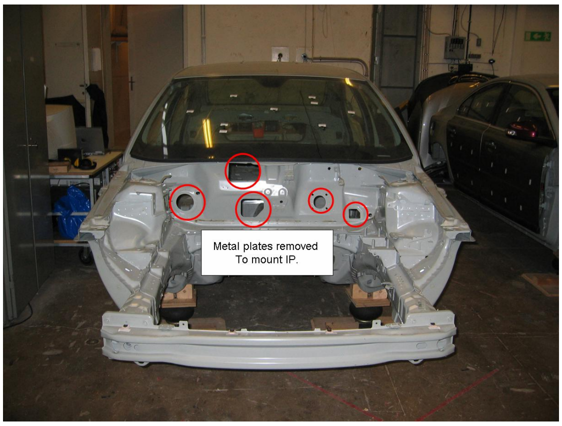


Figure A.3.: Metal plates removed to mount the IP.

Parcel shelf

The parcel shelf trims included the two side pillar trims, the parcel shelf cover and a damping layer beneath. The holes from the side pillar trims were covered by mineral wools. No adhesives were used and the parcel shelf configuration was mounted as-is during the measurement (as shown in figure A.4). Kindly ignore the rear seats from the figure as the rear seats was only used later in other trim combinations.

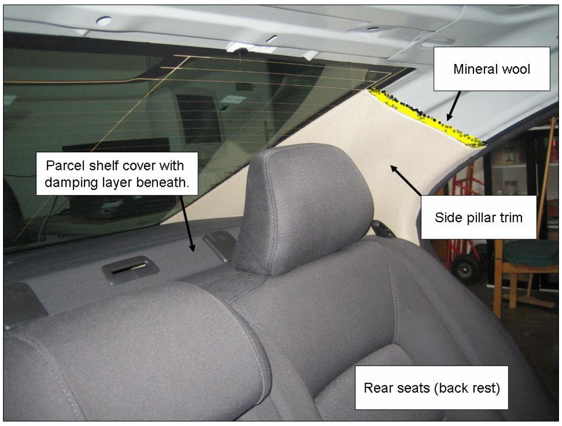


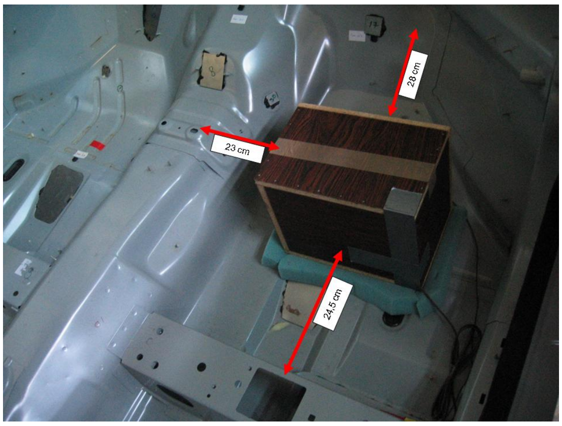
Figure A.4.: Parcel shelf trim (without the seat) mounted in the vehicle.

Trim combinations

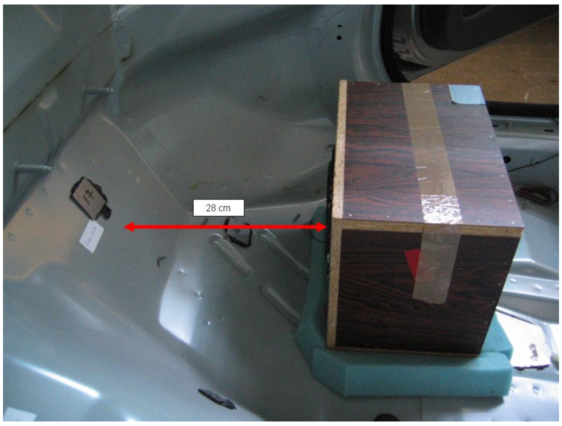
Measurement for other trim combinations were performed with all the trims described previously only. NO additional trims were used other than the mentioned. Only the SAME trim parts were repeatedly used.

A.2. Acoustical Excitation and Measurement Positions

A.2.1. Loudspeaker Dimension and Position Co-ordinates



(a) Top view of loudspeaker position in the vehicle cavity.



(b) Side view of loudspeaker position in the vehicle cavity.

Figure A.5.: Loudspeaker position in the vehicle cavity.

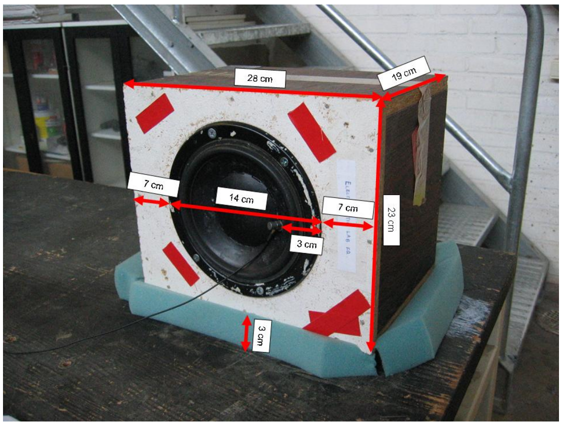
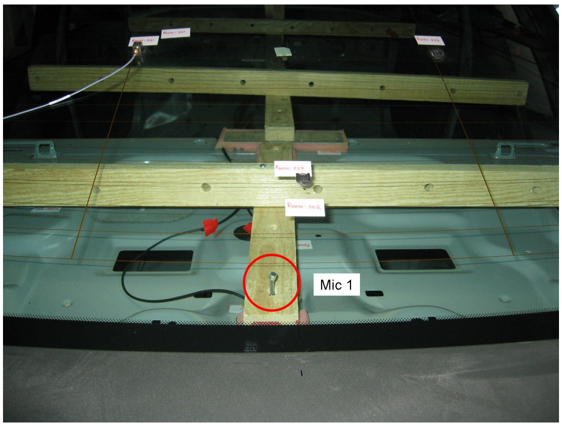
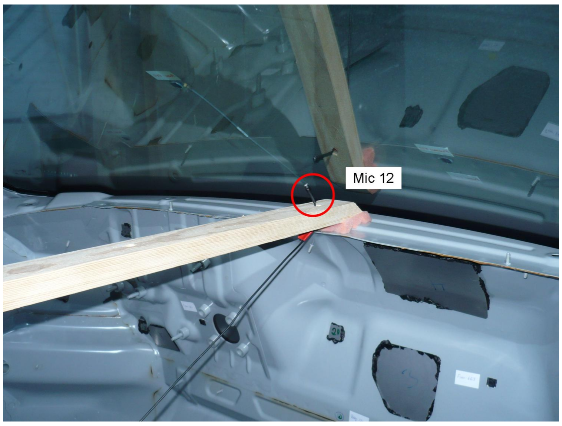


Figure A.6.: LSP dimensions

A.2.2. Microphones Positions



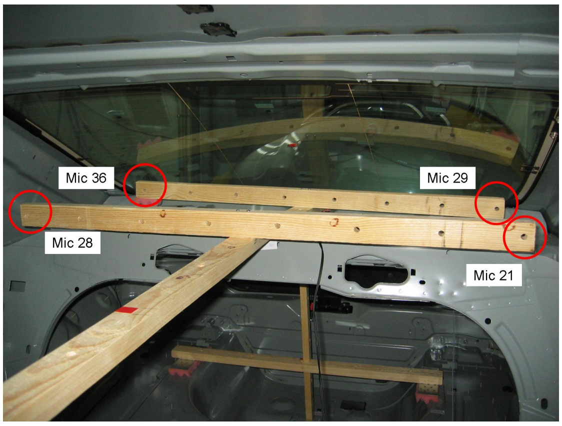
(a) Microphone 1 position.



(b) Microphone 12 position.

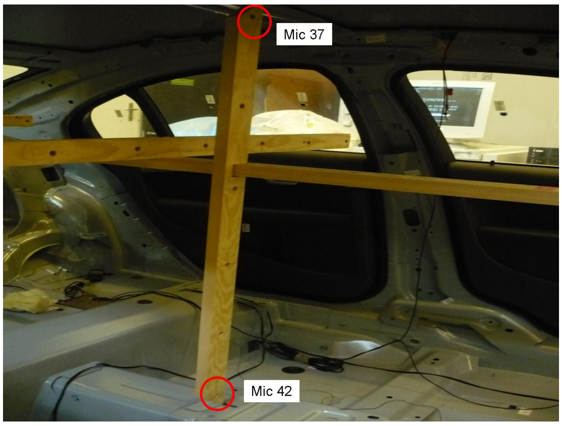
Figure A.7.: Microphones 1 and 12 positions.

(a) Microphones 13 to 20 position.

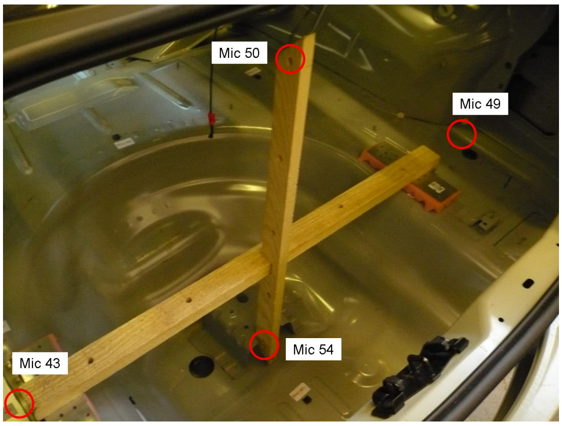


(b) Microphones 21 to 36 position.

Figure A.8.: Microphones 13 to 36 positions.

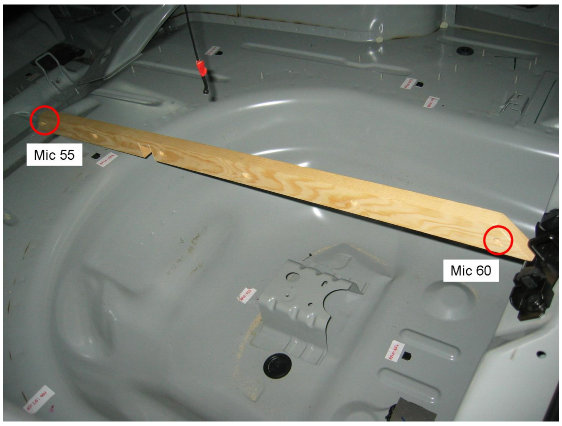


(a) Microphones 37 to 42 position.



(b) Microphones 43 to 54 position.

Figure A.9.: Microphones 37 to 54 positions.



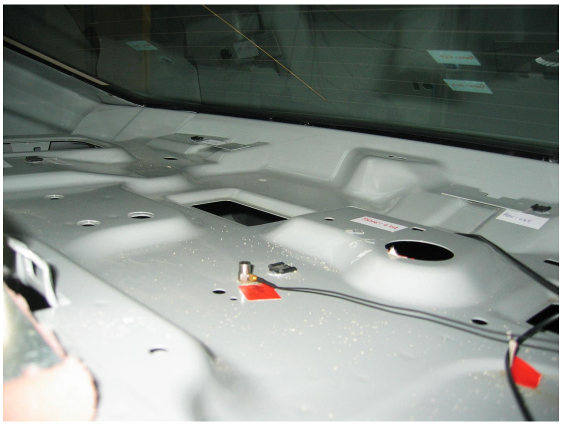
(a) Microphones 55 to 60 position.

(b) Microphone 61 position.

Figure A.10.: Microphones 55 to 61 positions.

A.2.3. Accelerometers Positions

(a) Accelerometer position on the roof.



(b) Accelerometer position on the parcel.

Figure A.11.: Accelerometers positions on the roof and the parcel shelf.

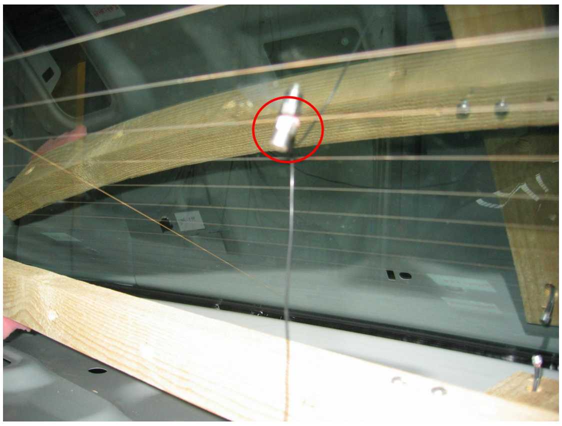
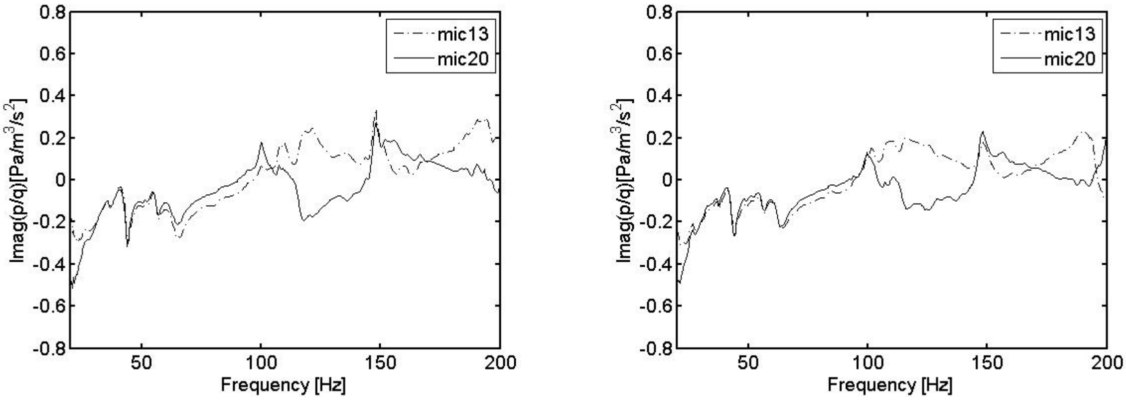


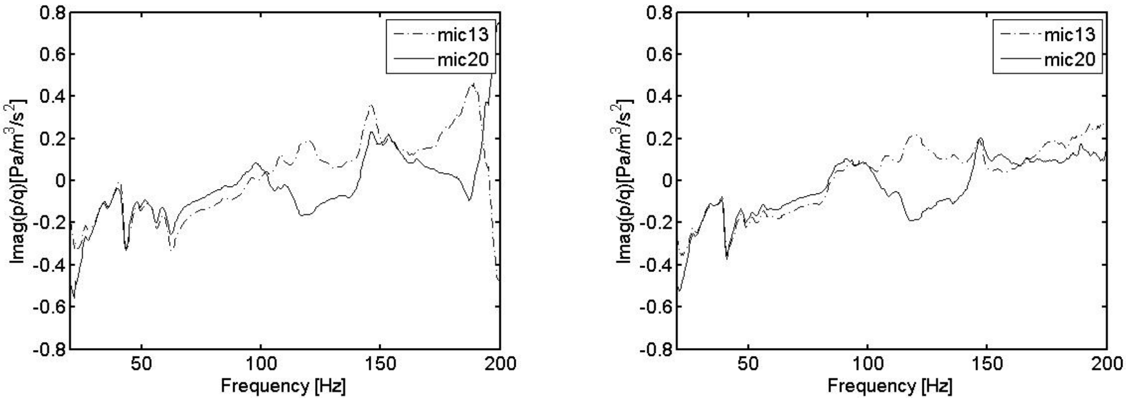
Figure A.12.: Accelerometer position on the rear window

A.2.4. A-FRF Plots



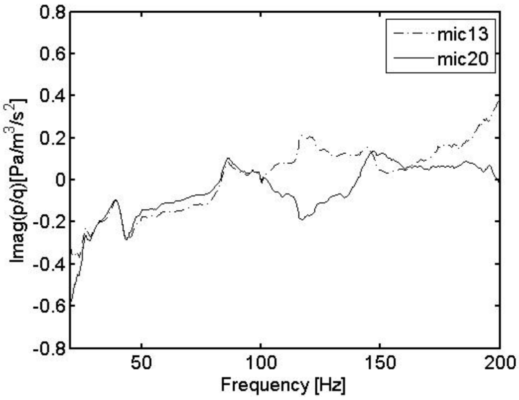
(a) Lateral Fs mode for Empty configuration. (b) Lateral FS mode for Carpets configuration.

Figure A.13.: Lateral Fs mode for Empty and Carpets configuration.

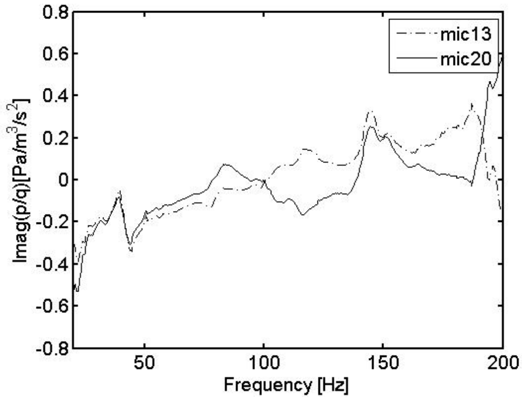


(a) Lateral Fs mode for Front Seats configuration. (b) Lateral Fs mode for Rear Seats configuration.

Figure A.14.: Lateral Fs mode for Front and Rear Seats configurations.

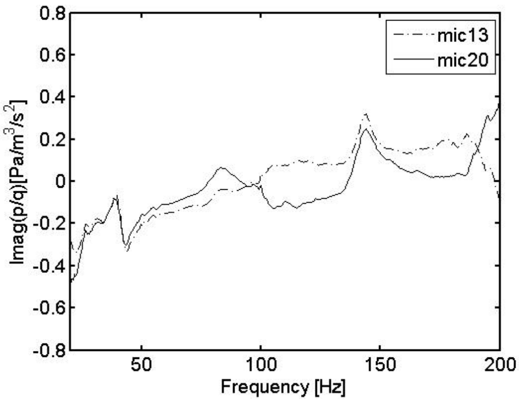


(a) Lateral Fs mode for Rear Seats Parcel configuration.

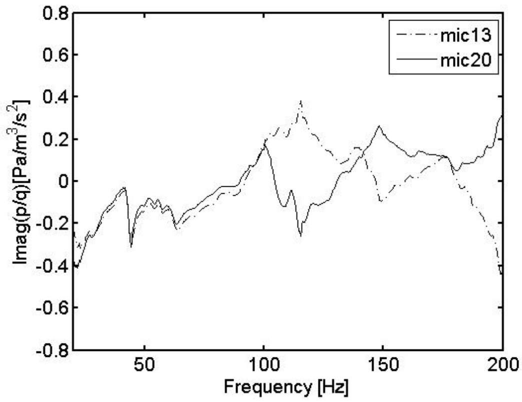


(b) Lateral Fs mode for Front Seats Rear Seats Parcel configuration.

Figure A.15.: Lateral Fs mode for Rear Seats Parcel and Front Seats Rear Seats Parcel configurations.

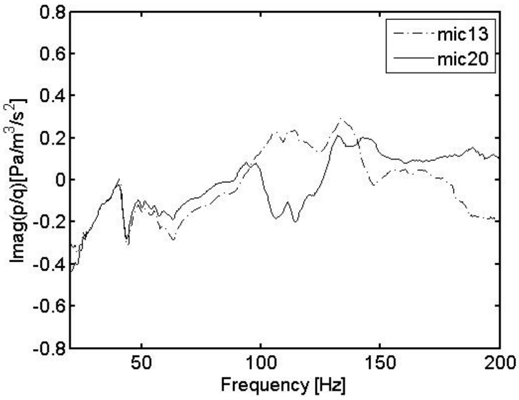


(a) Lateral Fs mode for Front Seats Rear Seats Carpets Parcel configuration.

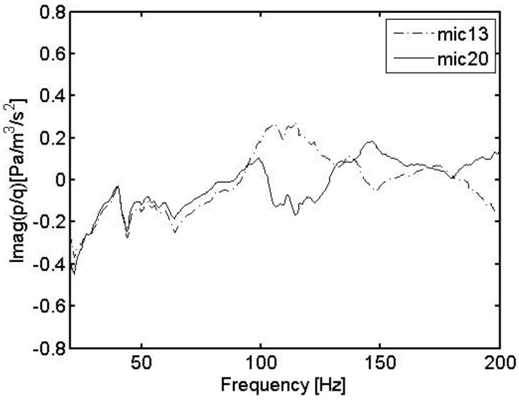


(b) Lateral Fs mode for IP configuration.

Figure A.16.: Lateral Fs mode for Front Seats Rear Seats Carpets Parcel and IP configurations.

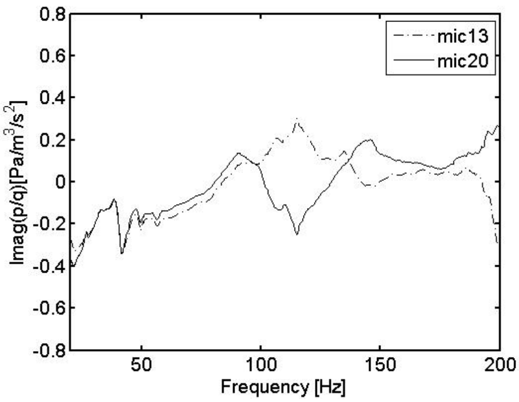


(a) Lateral Fs mode for IP Front Seats configuration.

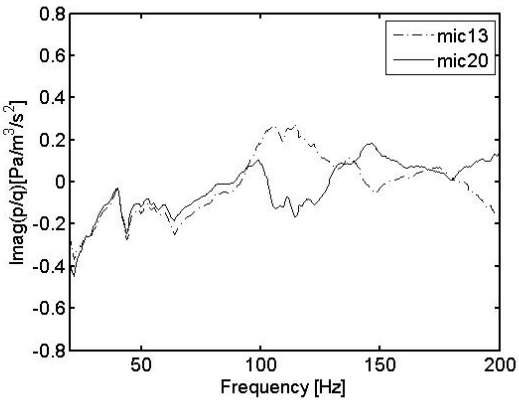


(b) Lateral Fs mode for IP Carpets configuration.

Figure A.17.: Lateral Fs mode for IP Front Seats and IP Carpets configurations.

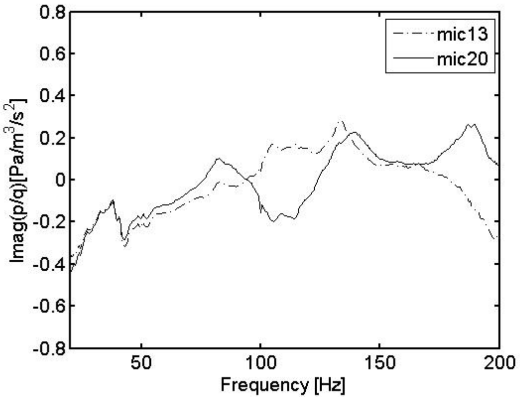


(a) Lateral Fs mode for IP Rear Seats configuration.

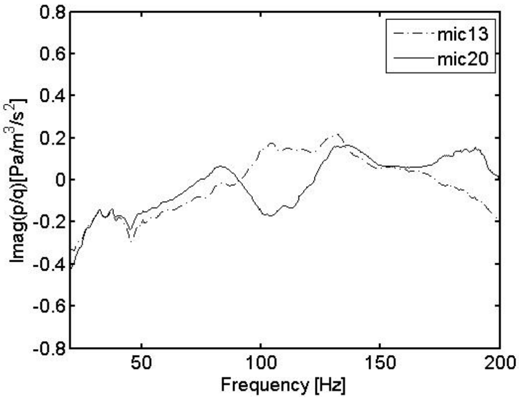


(b) Lateral Fs mode for IP Rear Seats Parcel configuration.

Figure A.18.: Lateral Fs mode for IP Rear Seats and IP Rear Seats Parcel configurations.

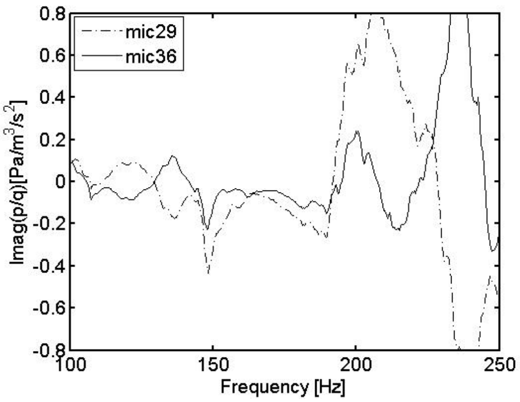


(a) Lateral Fs mode for IP Front Seats Rear Seats Parcel configuration.

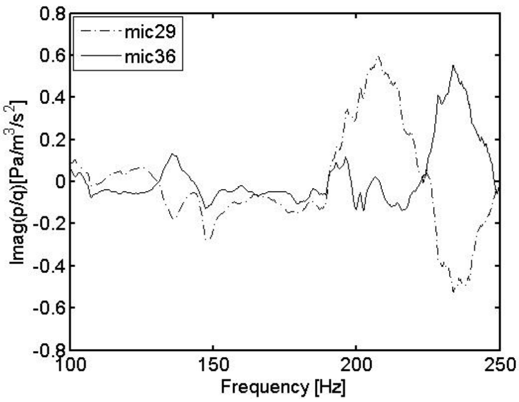


(b) Lateral Fs mode for IP Front Seats Rear Seats Carpets Parcel configuration.

Figure A.19.: Lateral Fs mode for IP Front Seats Rear Seats Parcel and IP Front Seats Rear Seats Carpets Parcel configurations.

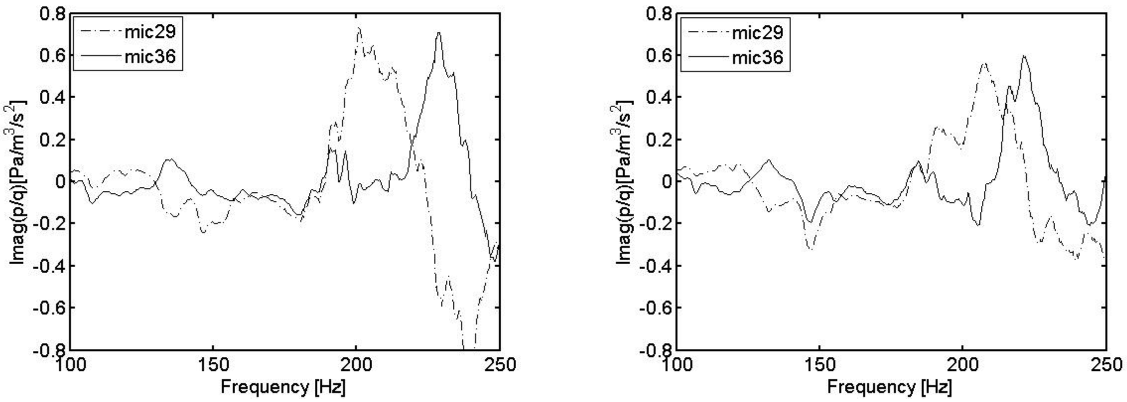


(a) Lateral Parcel mode for Empty configuration.



(b) Lateral Parcel mode for Carpets configuration.

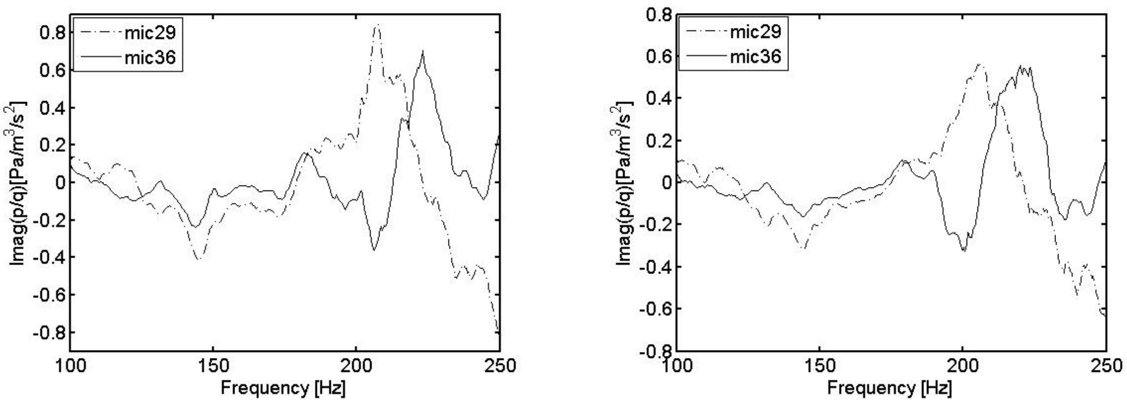
Figure A.20.: Lateral Parcel mode for Empty and Carpets configuration.



(a) Lateral Parcel mode for Front Seats configuration.

(b) Lateral Parcel mode for Rear Seats configuration.

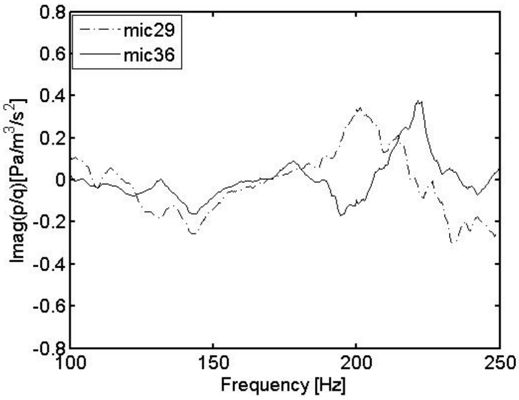
Figure A.21.: Lateral Parcel mode for Front and Rear Seats configurations.



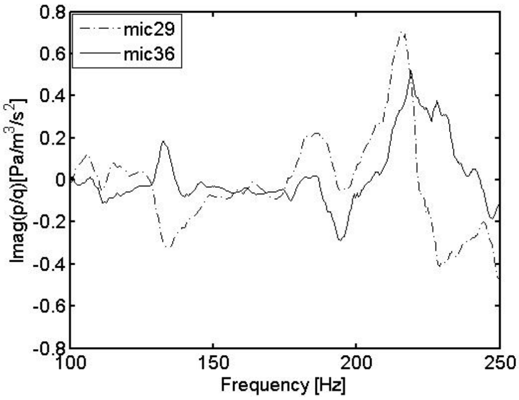
(a) Lateral Parcel mode for Rear Seats Parcel configuration.

(b) Lateral Parcel mode for Front Seats Rear Seats Parcel configuration.

Figure A.22.: Lateral Parcel mode for Rear Seats Parcel and Front Seats Rear Seats Parcel configurations.

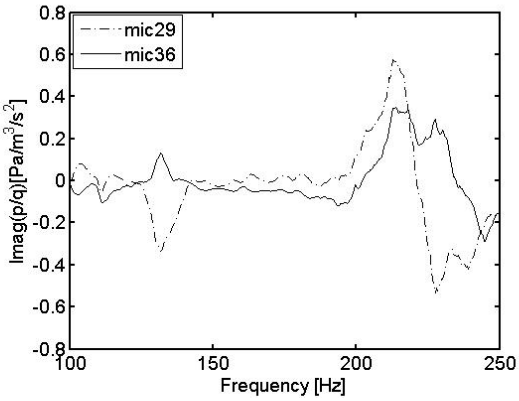


(a) Lateral Parcel mode for Front Seats Rear Seats Carpets Parcel configuration.

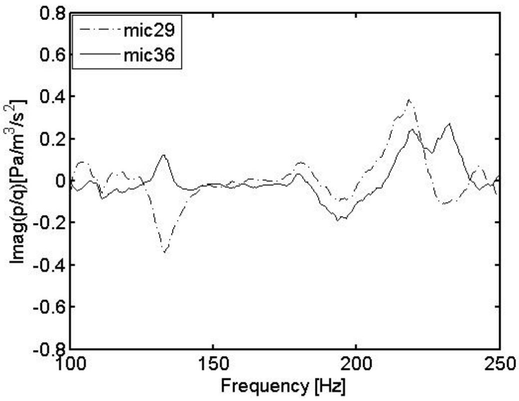


(b) Lateral Parcel mode for IP configuration.

Figure A.23.: Lateral Parcel mode for Front Seats Rear Seats Carpets Parcel and IP configurations.

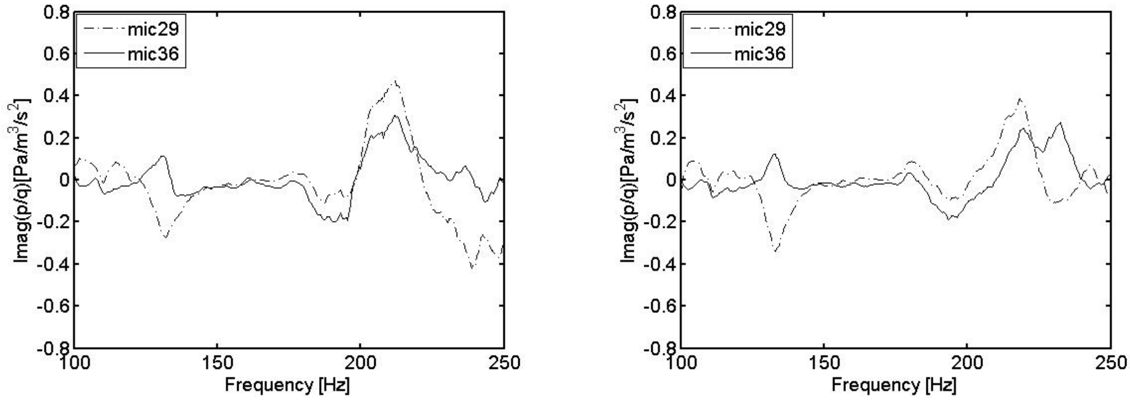


(a) Lateral Parcel mode for IP Front Seats configuration.



(b) Lateral Parcel mode for IP Carpets configuration.

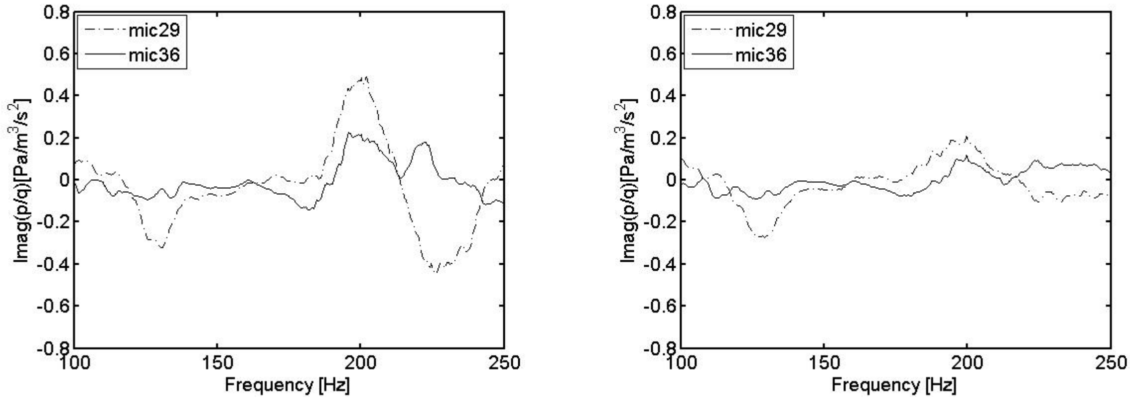
Figure A.24.: Lateral Parcel mode for IP Front Seats and IP Carpets configurations.



(a) Lateral Parcel mode for IP Rear Seats configuration.

(b) Lateral Parcel mode for IP Rear Seats Parcel configuration.

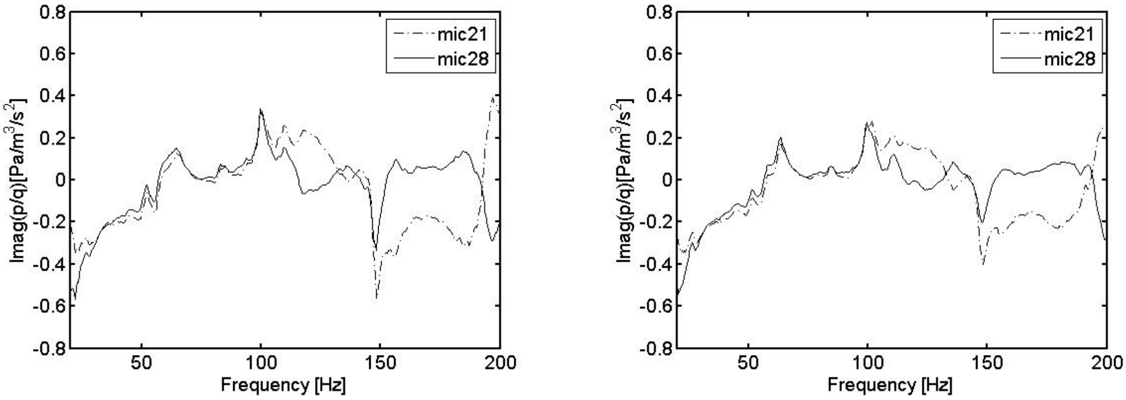
Figure A.25.: Lateral Parcel mode for IP Rear Seats and IP Rear Seats Parcel configurations.



(a) Lateral Parcel mode for IP Front Seats Rear Seats Parcel configuration.

(b) Lateral Parcel mode for IP Front Seats Rear Seats Carpets Parcel configuration.

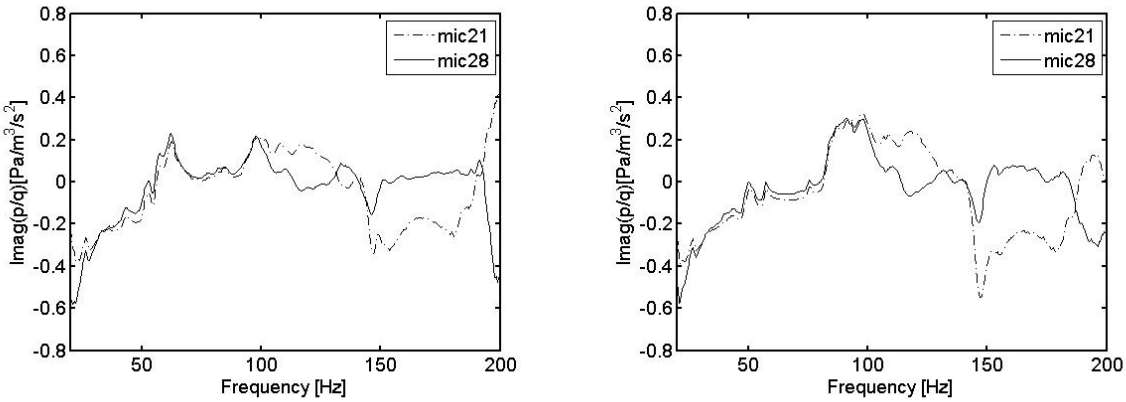
Figure A.26.: Lateral Parcel mode for IP Front Seats Rear Seats Parcel and IP Front Seats Rear Seats Carpets Parcel configurations.



(a) Lateral Rs mode for Empty configuration.

(b) Lateral Rs mode for Carpets configuration.

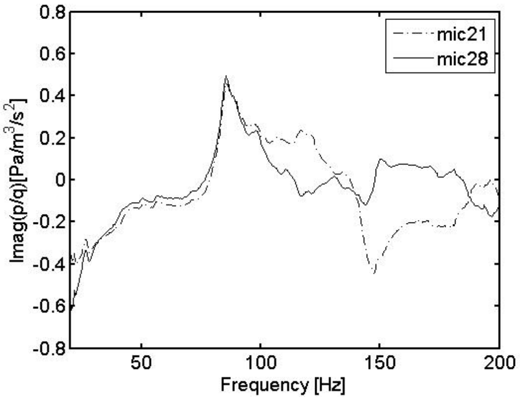
Figure A.27.: Lateral Rs mode for Empty and Carpets configuration.



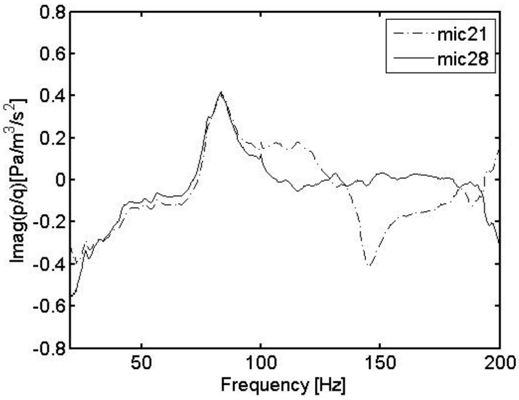
(a) Lateral Rs mode for Front Seats configuration.

(b) Lateral Rs mode for Rear Seats configuration.

Figure A.28.: Lateral Rs mode for Front and Rear Seats configurations.

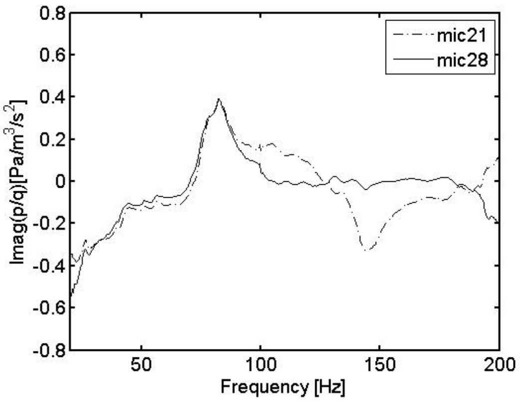


(a) Lateral Rs mode for Rear Seats Parcel configuration.

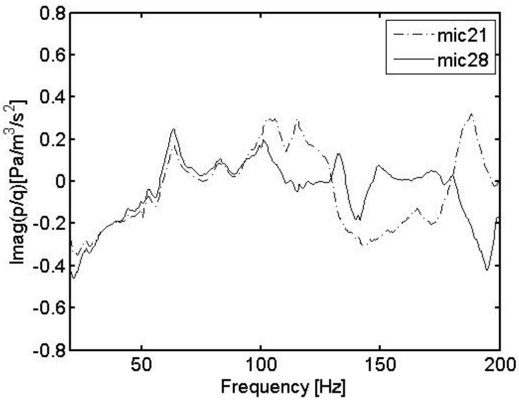


(b) Lateral Rs mode for Front Seats Rear Seats Parcel configuration.

Figure A.29.: Lateral Rs mode for Rear Seats Parcel and Front Seats Rear Seats Parcel configurations.

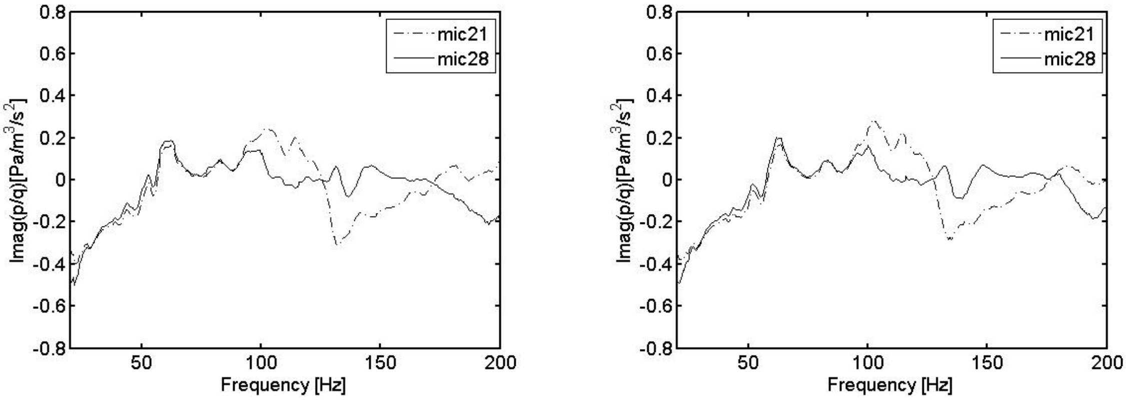


(a) Lateral Rs mode for Front Seats Rear Seats Carpets Parcel configuration.



(b) Lateral Rs mode for IP configuration.

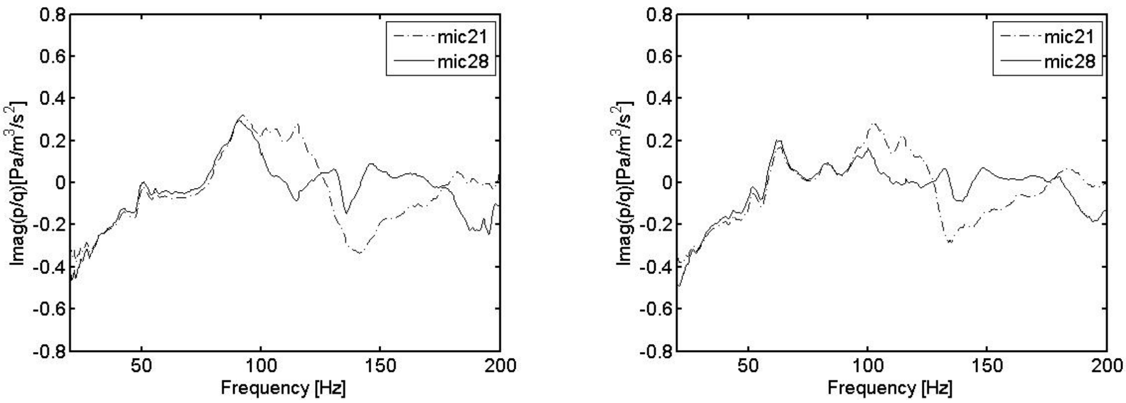
Figure A.30.: Lateral Rs mode for Front Seats Rear Seats Carpets Parcel and IP configurations.



(a) Lateral Rs mode for IP Front Seats configuration.

(b) Lateral Rs mode for IP Carpets configuration.

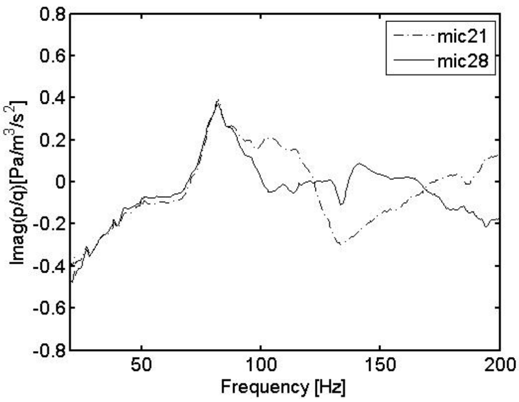
Figure A.31.: Lateral Rs mode for IP Front Seats and IP Carpets configurations.



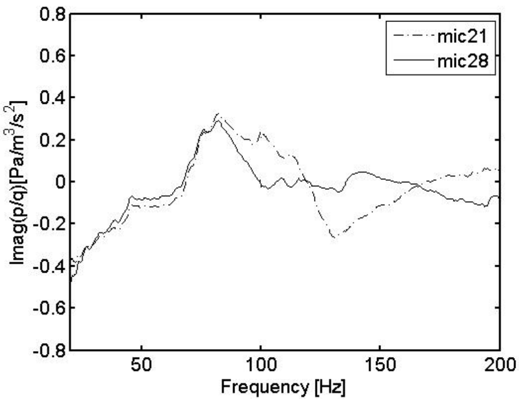
(a) Lateral Rs mode for IP Rear Seats configuration.

(b) Lateral Rs mode for IP Rear Seats Parcel configuration.

Figure A.32.: Lateral Rs mode for IP Rear Seats and IP Rear Seats Parcel configurations.

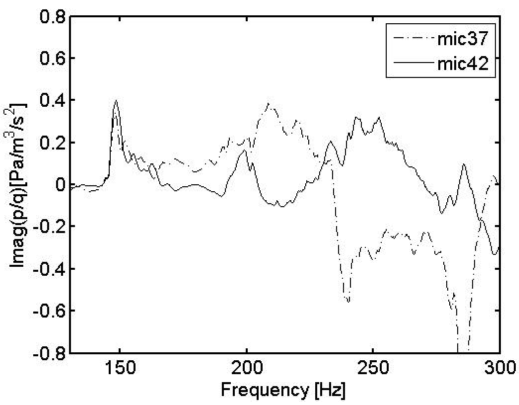


(a) Lateral Rs mode for IP Front Seats Rear Seats Parcel configuration.

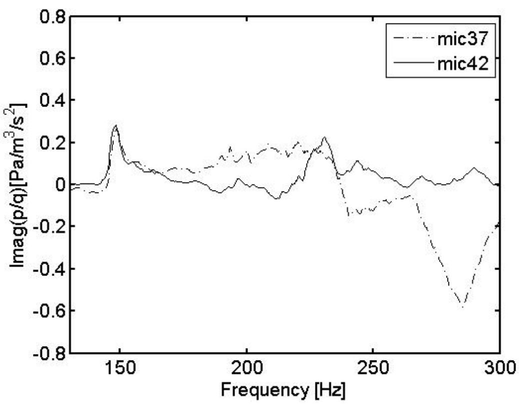


(b) Lateral Rs mode for IP Front Seats Rear Seats Carpets Parcel configuration.

Figure A.33.: Lateral Rs mode for IP Front Seats Rear Seats Parcel and IP Front Seats Rear Seats Carpets Parcel configurations.

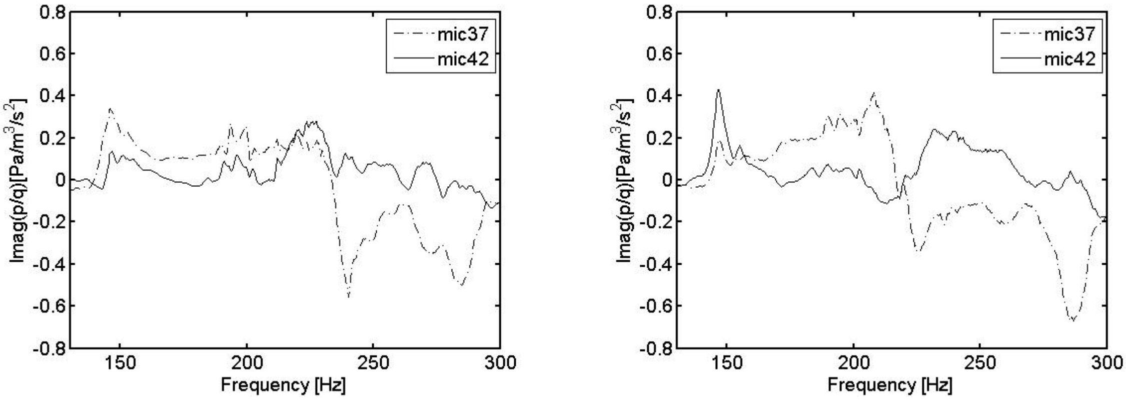


(a) Vertical mode for Empty configuration.



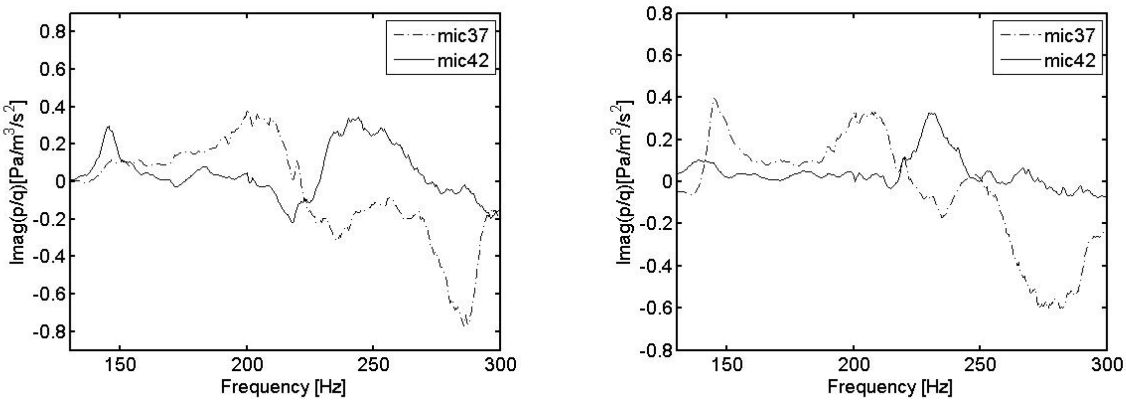
(b) Vertical mode for Carpets configuration.

Figure A.34.: Vertical mode for Empty and Carpets configuration.



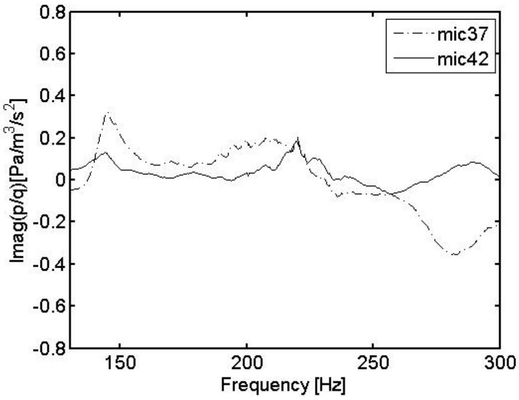
(a) Vertical mode for Front Seats configuration. (b) Vertical mode for Rear Seats configuration.

Figure A.35.: Vertical mode for Front and Rear Seats configurations.

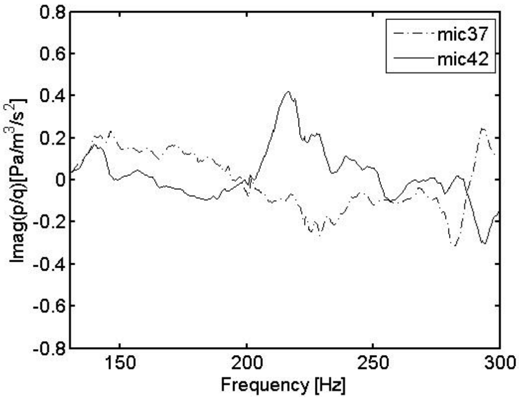


(a) Vertical mode for Rear Seats Parcel configuration. (b) Vertical mode for Front Seats Rear Seats Parcel configuration.

Figure A.36.: Vertical mode for Rear Seats Parcel and Front Seats Rear Seats Parcel configurations.

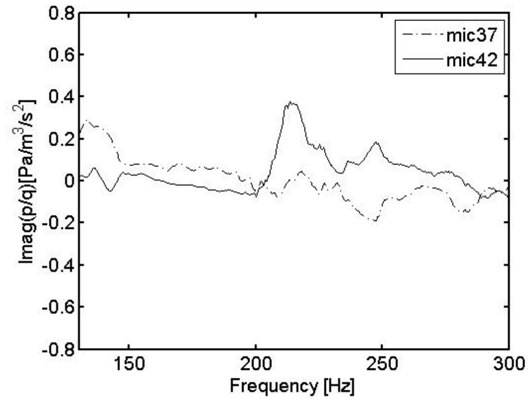


(a) Vertical mode for Front Seats Rear Seats Carpets Parcel configuration.

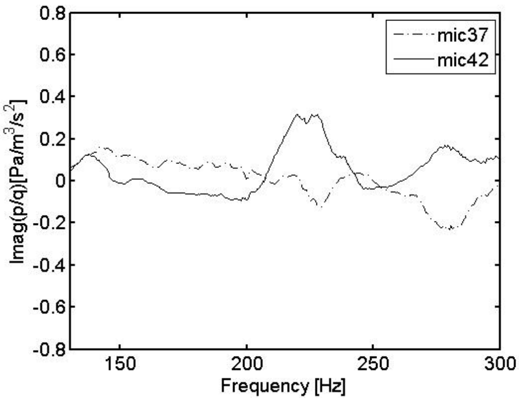


(b) Vertical mode for IP configuration.

Figure A.37.: Vertical mode for Front Seats Rear Seats Carpets Parcel and IP configurations.

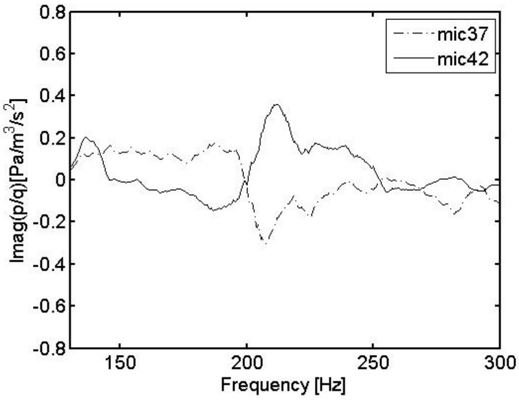


(a) Vertical mode for IP Front Seats configuration.

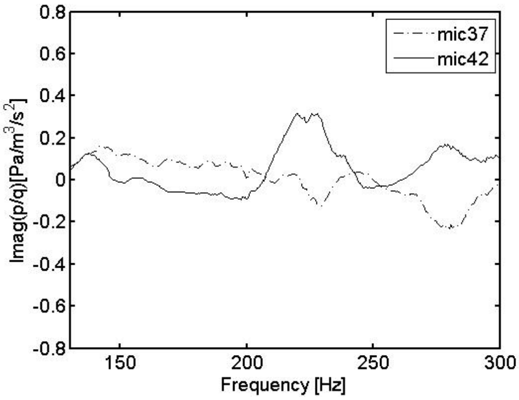


(b) Vertical mode for IP Carpets configuration.

Figure A.38.: Vertical mode for IP Front Seats and IP Carpets configurations.

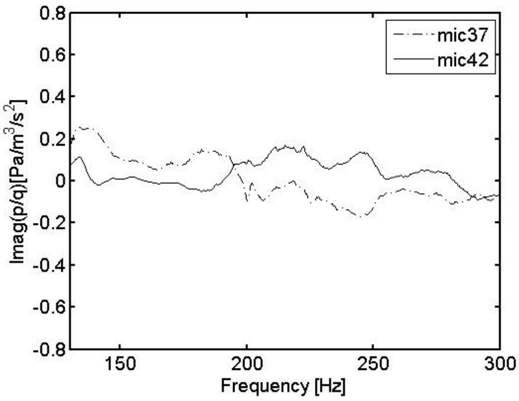


(a) Vertical mode for IP Rear Seats configuration.

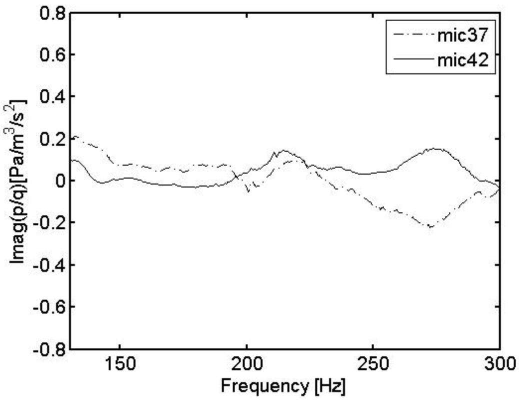


(b) Vertical mode for IP Rear Seats Parcel configuration.

Figure A.39.: Vertical mode for IP Rear Seats and IP Rear Seats Parcel configurations.

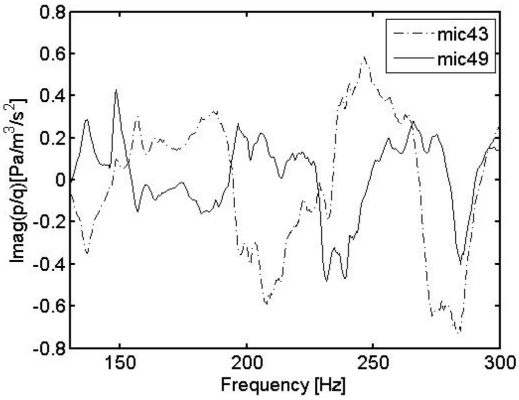


(a) Vertical mode for IP Front Seats Rear Seats Parcel configuration.

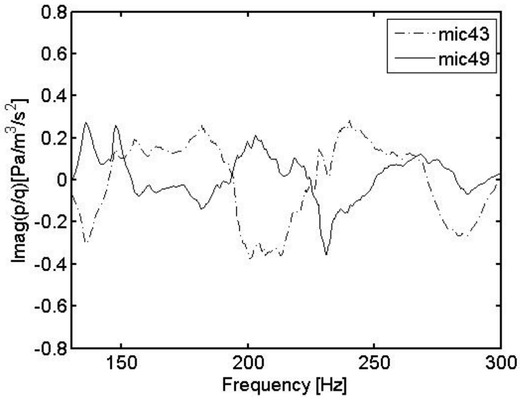


(b) Vertical mode for IP Front Seats Rear Seats Carpets Parcel configuration.

Figure A.40.: Vertical mode for IP Front Seats Rear Seats Parcel and IP Front Seats Rear Seats Carpets Parcel configurations.

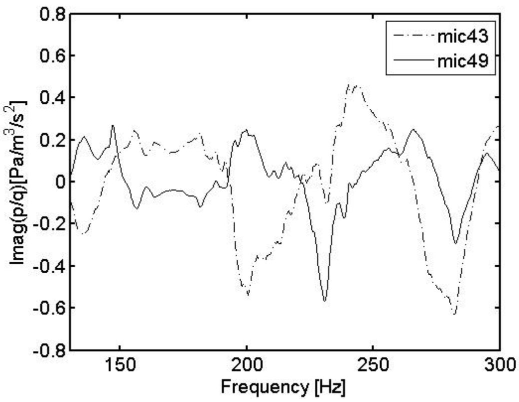


(a) Trunk Lateral mode for Empty configuration.

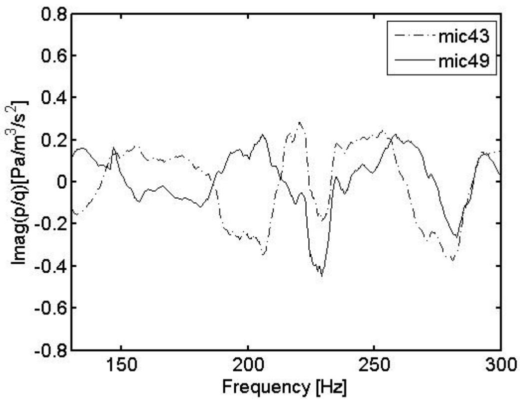


(b) Trunk Lateral mode for Carpets configuration.

Figure A.41.: Trunk Lateral mode for Empty and Carpets configuration.

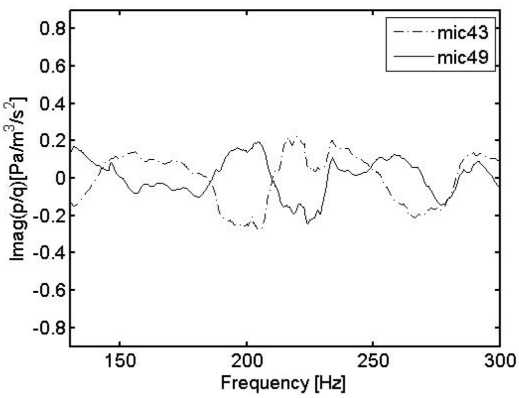


(a) Trunk Lateral mode for Front Seats configuration.

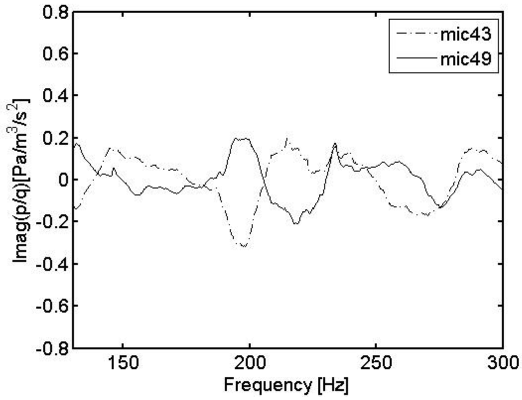


(b) Trunk Latreal mode for Rear Seats configuration.

Figure A.42.: Trunk Lateral mode for Front and Rear Seats configurations.

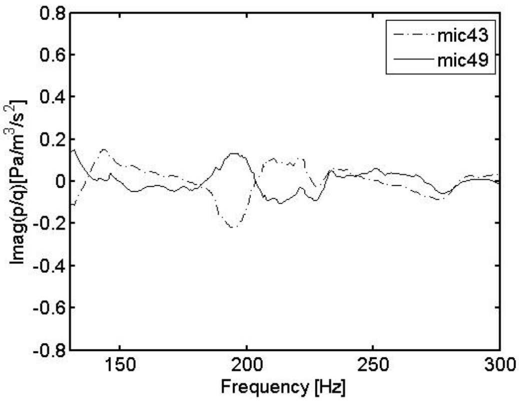


(a) Trunk Lateral mode for Rear Seats Parcel configuration.

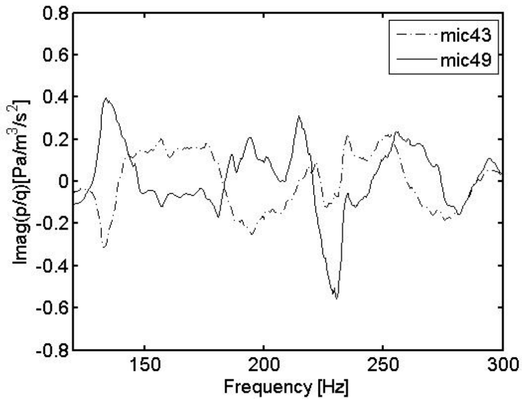


(b) Trunk Lateral mode for Front Seats Rear Seats Parcel configuration.

Figure A.43.: Trunk Lateral mode for Rear Seats Parcel and Front Seats Rear Seats Parcel configurations.

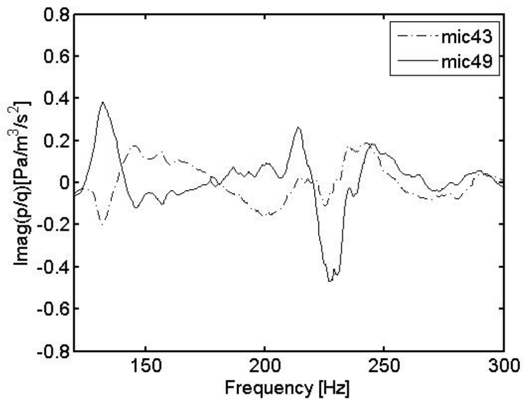


(a) Trunk Lateral mode for Front Seats Rear Seats Carpets Parcel configuration.

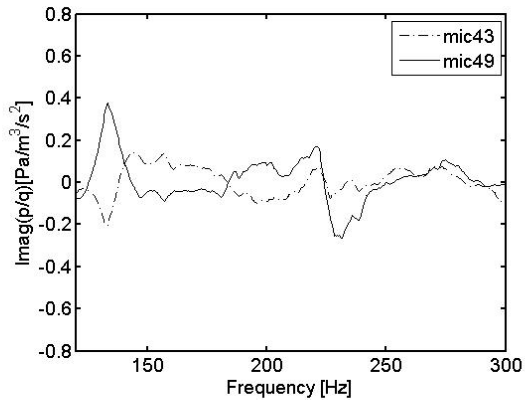


(b) Trunk Lateral mode for IP configuration.

Figure A.44.: Trunk Lateral mode for Front Seats Rear Seats Carpets Parcel and IP configurations.

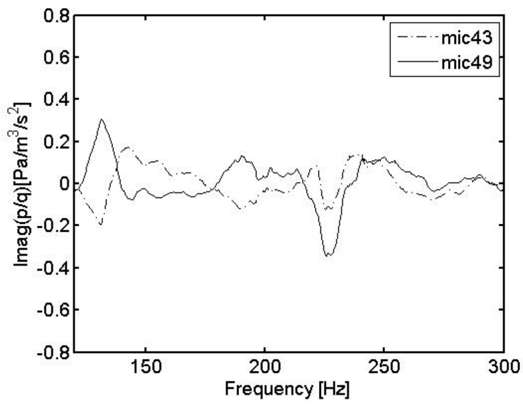


(a) Trunk Lateral mode for IP Front Seats configuration.

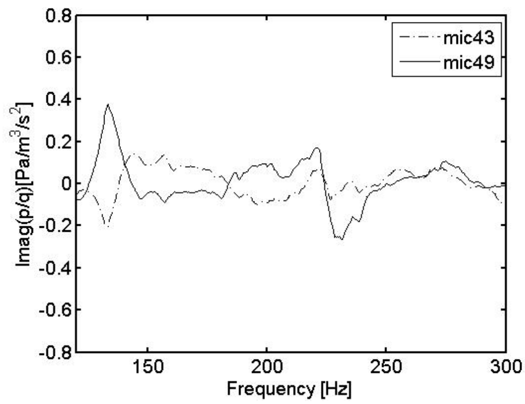


(b) Trunk Lateral mode for IP Carpets configuration.

Figure A.45.: Trunk Lateral mode for IP Front Seats and IP Carpets configurations.

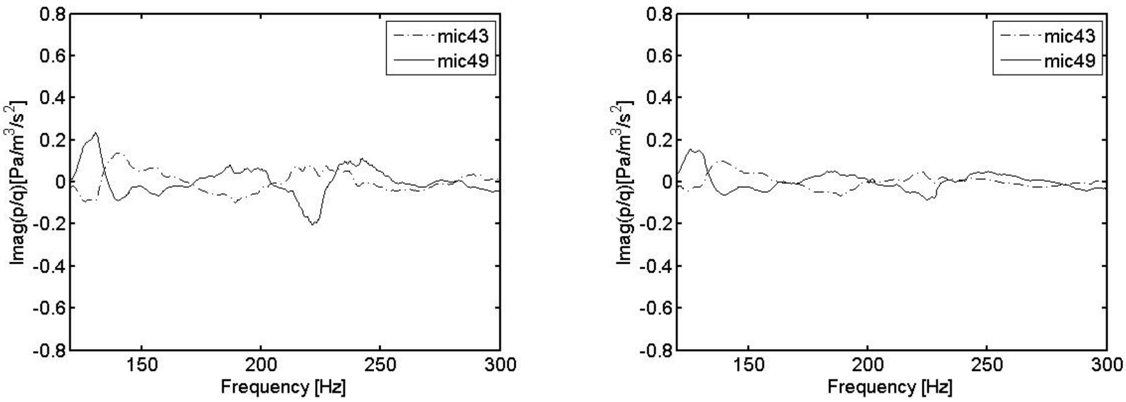


(a) Trunk Lateral mode for IP Rear Seats configuration.



(b) Trunk Lateral mode for IP Rear Seats Parcel configuration.

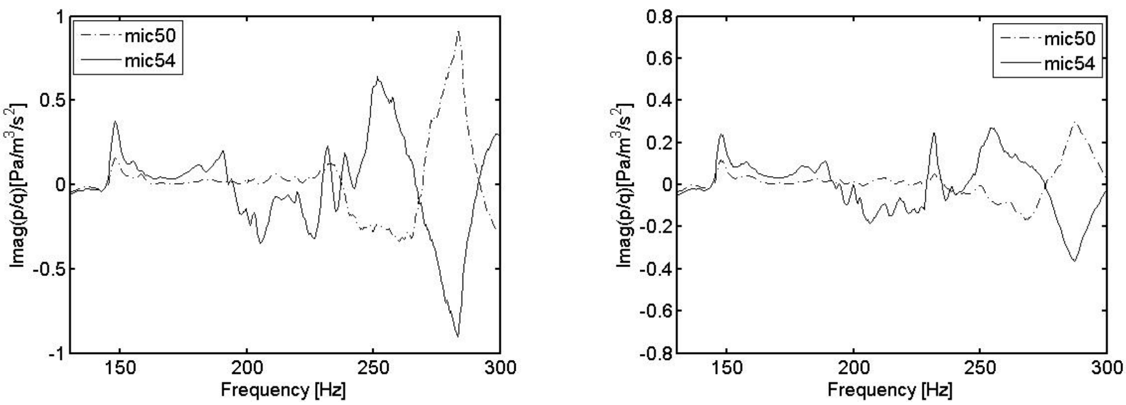
Figure A.46.: Trunk lateral mode for IP Rear Seats and IP Rear Seats Parcel configurations.



(a) Trunk Lateral mode for IP Front Seats Rear Seats Parcel configuration.

(b) Trunk Lateral mode for IP Front Seats Rear Seats Carpets Parcel configuration.

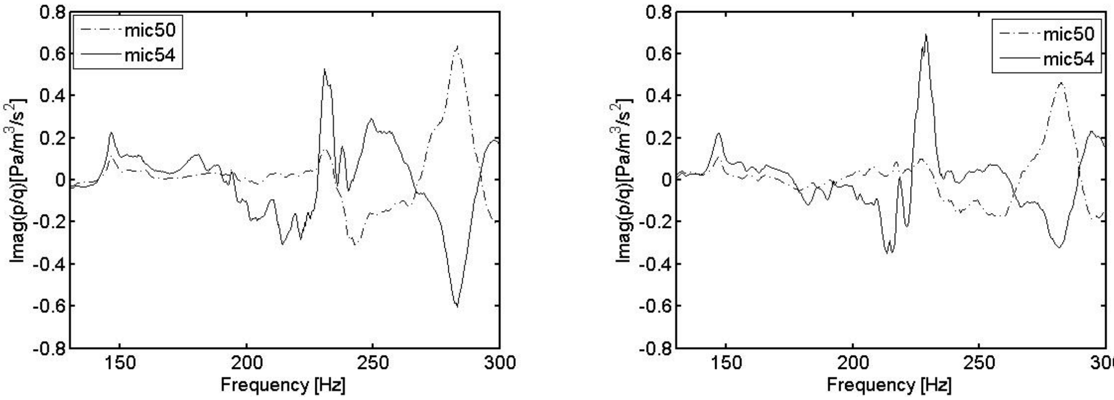
Figure A.47.: Trunk Lateral mode for IP Front Seats Rear Seats Parcel and IP Front Seats Rear Seats Carpets Parcel configurations.



(a) Trunk Vertical mode for Empty configuration.

(b) Trunk Vertical mode for Carpets configuration.

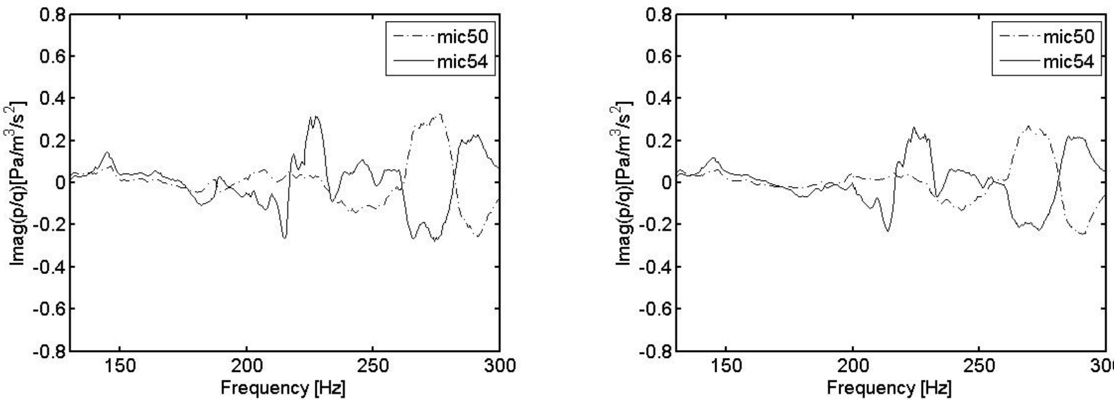
Figure A.48.: Trunk Vertical mode for Empty and Carpets configuration.



(a) Trunk Vertical mode for Front Seats configuration.

(b) Trunk Vertical mode for Rear Seats configuration.

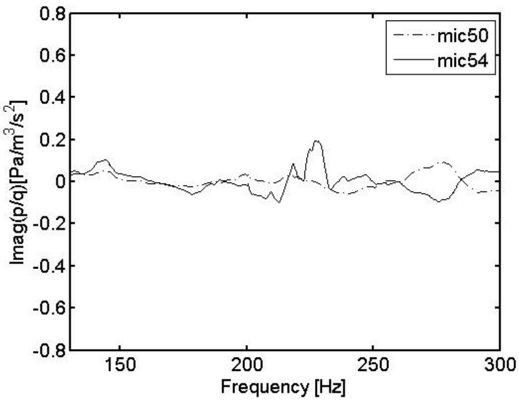
Figure A.49.: Trunk Vertical mode for Front and Rear Seats configurations.



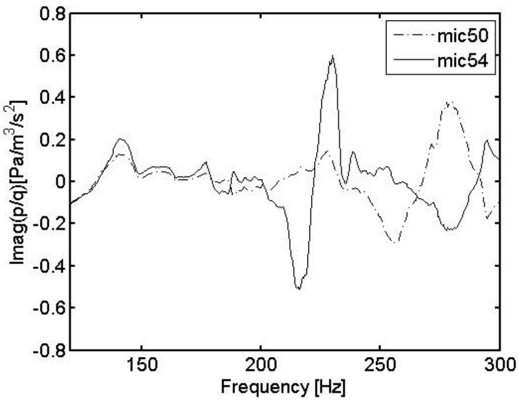
(a) Trunk Vertical mode for Rear Seats Parcel configuration.

(b) Trunk Vertical mode for Front Seats Rear Seats Parcel configuration.

Figure A.50.: Trunk Vertical mode for Rear Seats Parcel and Front Seats Rear Seats Parcel configurations.

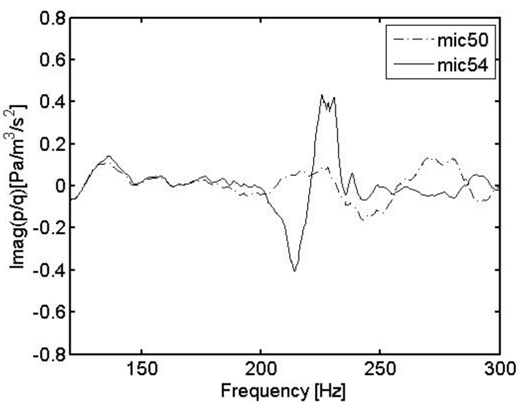


(a) Trunk Vertical mode for Front Seats Rear Seats Carpets Parcel configuration.

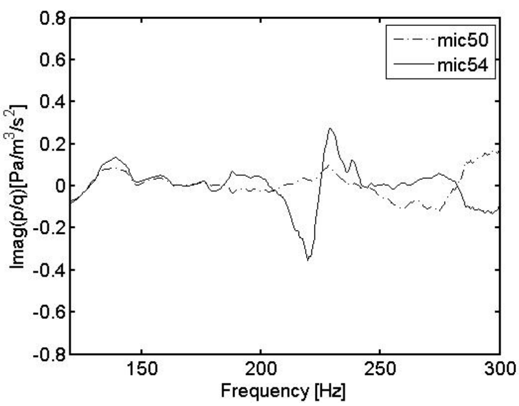


(b) Trunk Vertical mode for IP configuration.

Figure A.51.: Trunk Vertical mode for Front Seats Rear Seats Carpets Parcel and IP configurations.

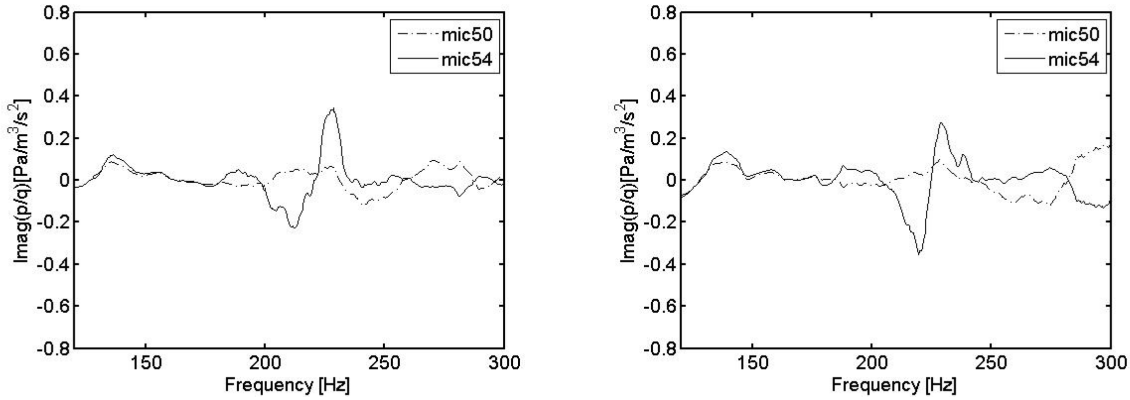


(a) Trunk Vertical mode for IP Front Seats configuration.



(b) Trunk Vertical mode for IP Carpets configuration.

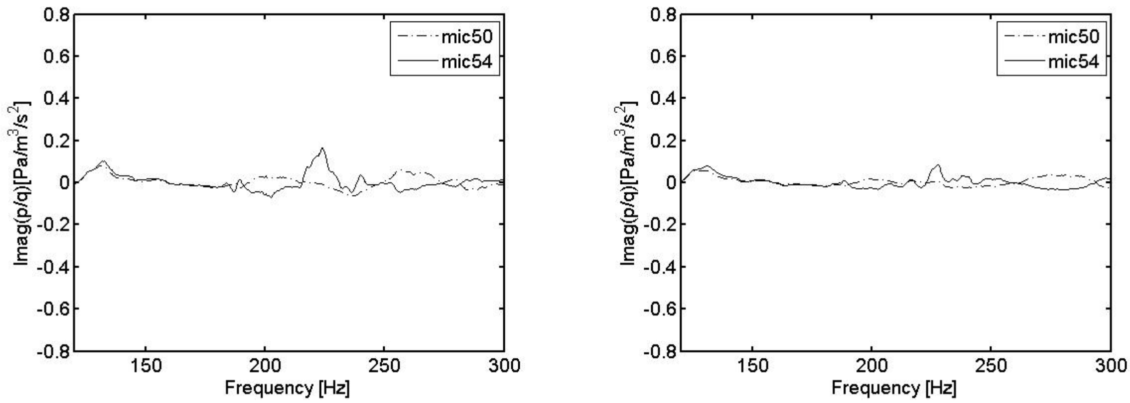
Figure A.52.: Trunk Vertical mode for IP Front Seats and IP Carpets configurations.



(a) Trunk Vertical mode for IP Rear Seats configuration.

(b) Trunk Vertical mode for IP Rear Seats Parcel configuration.

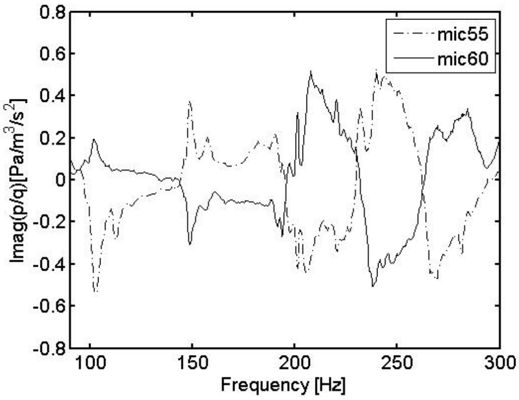
Figure A.53.: Trunk Vertical mode for IP Rear Seats and IP Rear Seats Parcel configurations.



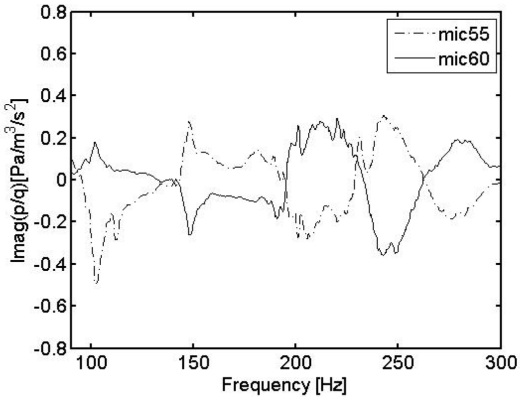
(a) Trunk Vertical mode for IP Front Seats Rear Seats Parcel configuration.

(b) Trunk Vertical mode for IP Front Seats Rear Seats Carpets Parcel configuration.

Figure A.54.: Trunk Vertical mode for IP Front Seats Rear Seats Parcel and IP Front Seats Rear Seats Carpets Parcel configurations.

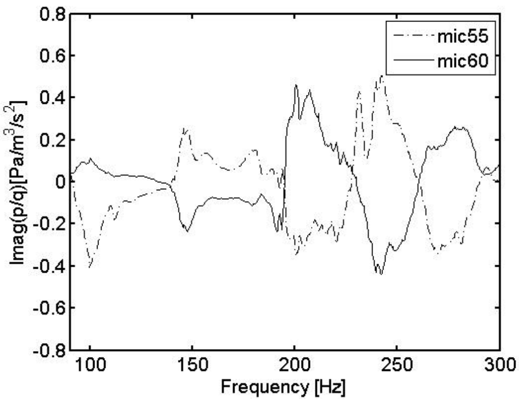


(a) Trunk Longitudinal mode for Empty configuration.

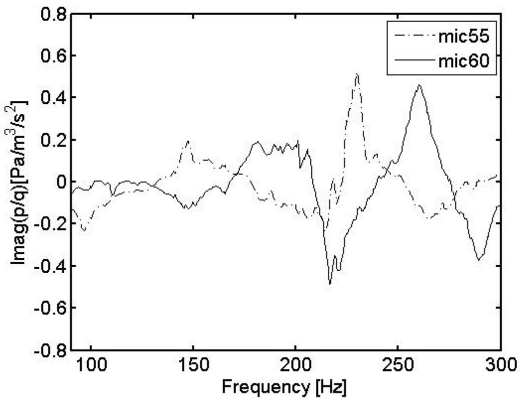


(b) Trunk Longitudinal mode for Carpets configuration.

Figure A.55.: Trunk Lonitudinal mode for Empty and Carpets configuration.

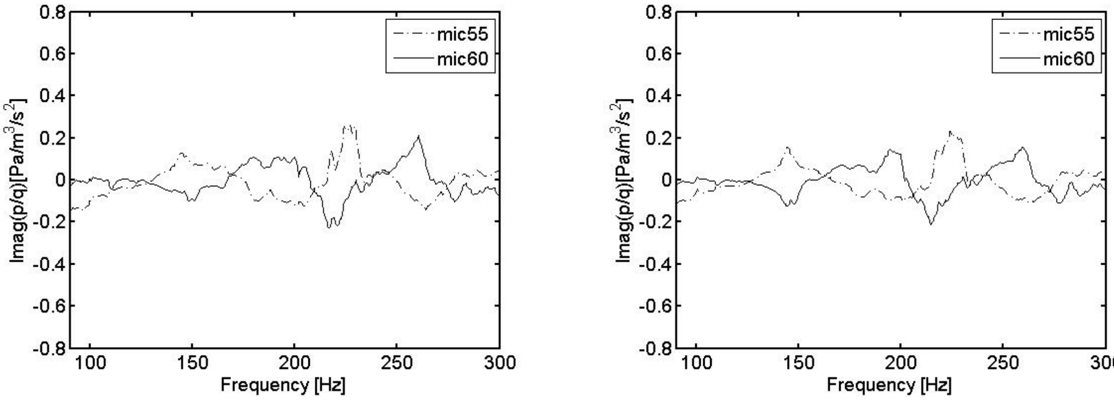


(a) Trunk Longitudinal mode for Front Seats configuration.



(b) Trunk Longitudinal mode for Rear Seats configuration.

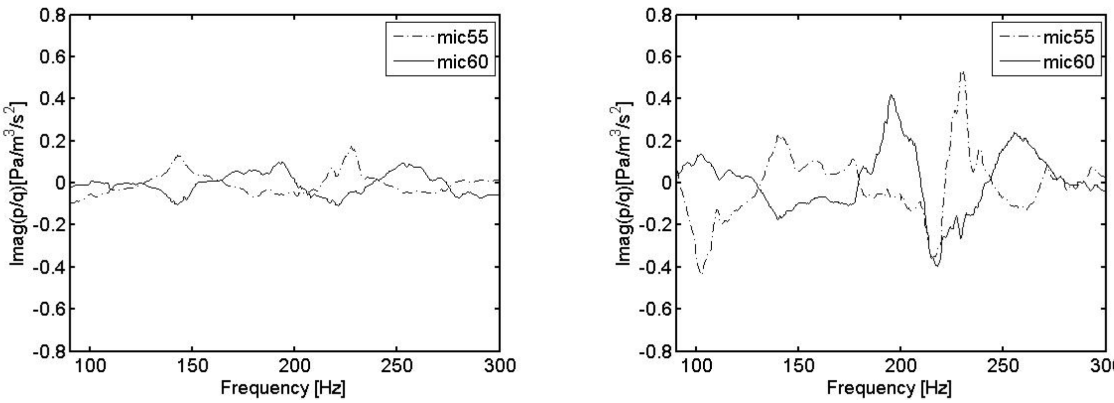
Figure A.56.: Trunk Longitudinal mode for Front and Rear Seats configurations.



(a) Trunk Longitudinal mode for Rear Seats Parcel configuration.

(b) Trunk Longitudinal mode for Front Seats Rear Seats Parcel configuration.

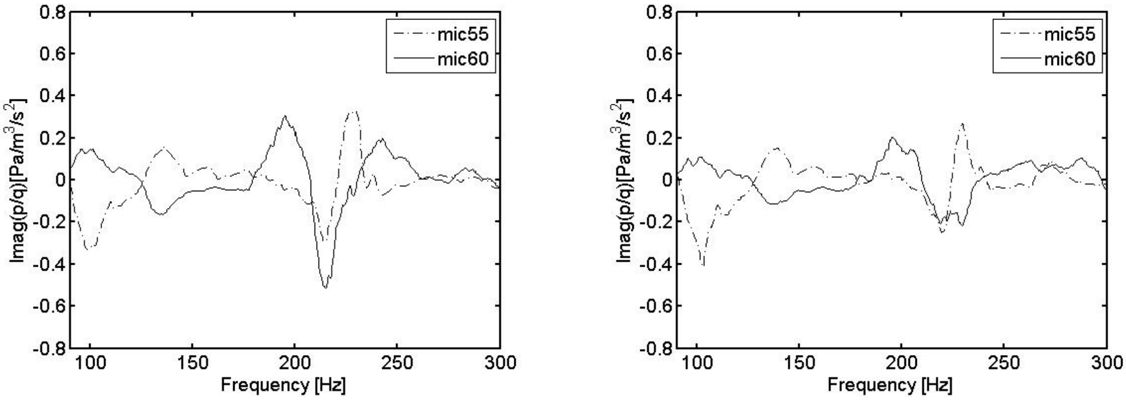
Figure A.57.: Trunk Longitudinal mode for Rear Seats Parcel and Front Seats Rear Seats Parcel configurations.



(a) Trunk Longitudinal mode for Front Seats Rear Seats Carpets Parcel configuration.

(b) Trunk Longitudinal mode for IP configuration.

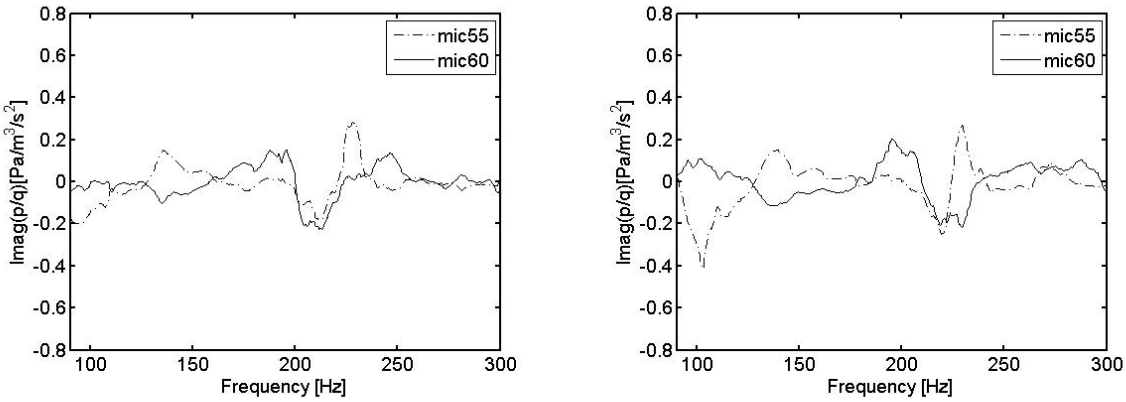
Figure A.58.: Trunk Longitudinal mode for Front Seats Rear Seats Carpets Parcel and IP configurations.



(a) Trunk Longitudinal mode for IP Front Seats configuration.

(b) Trunk Longitudinal mode for IP Carpets configuration.

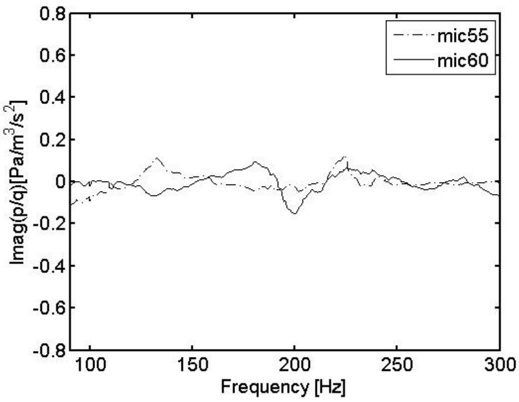
Figure A.59.: Trunk Longitudinal mode for IP Front Seats and IP Carpets configurations.



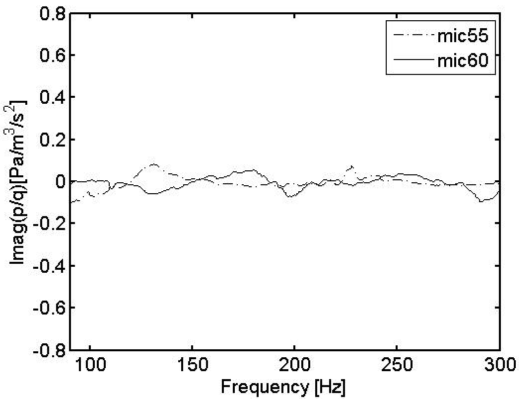
(a) Trunk Longitudinal mode for IP Rear Seats configuration.

(b) Trunk Longitudinal mode for IP Rear Seats Parcel configuration.

Figure A.60.: Trunk Longitudinal mode for IP Rear Seats and IP Rear Seats Parcel configurations.



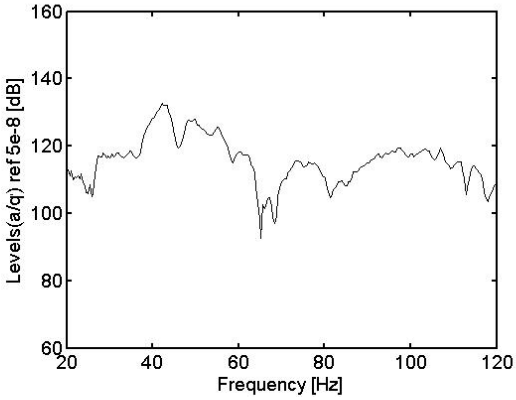
(a) Trunk Longitudinal mode for IP Front Seats Rear Seats Parcel configuration.



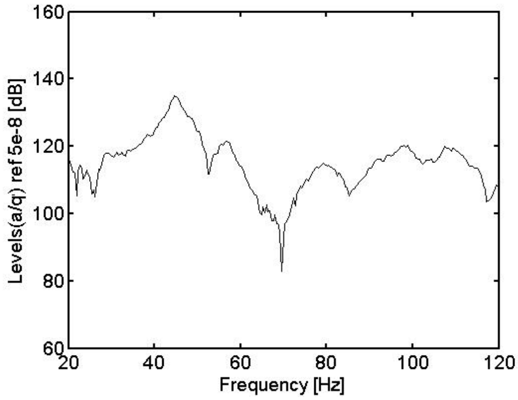
(b) Trunk Longitudinal mode for IP Front Seats Rear Seats Carpets Parcel configuration.

Figure A.61.: Trunk Longitudinal mode for IP Front Seats Rear Seats Parcel and IP Front Seats Rear Seats Carpets Parcel configurations.

A.2.5. A-MTF Plots

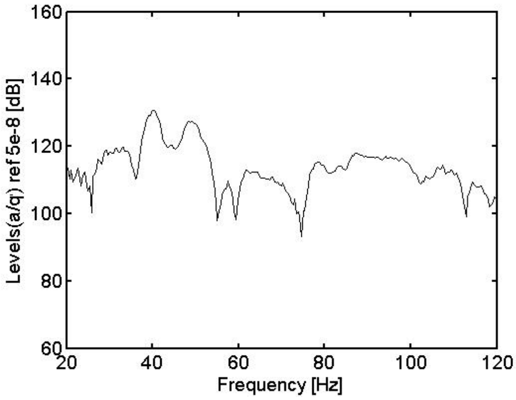


(a) Roof vibration for Empty configuration.

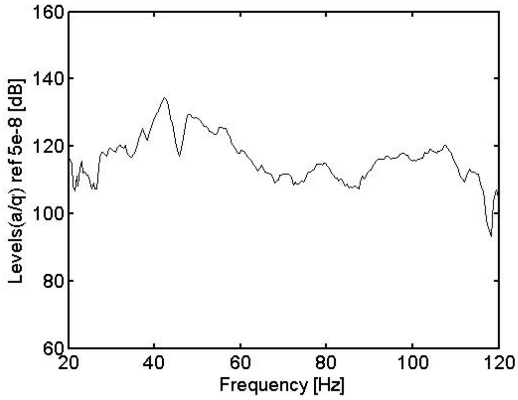


(b) Roof vibration for Carpets configuration.

Figure A.62.: Roof vibration for Empty and Carpets configurations.

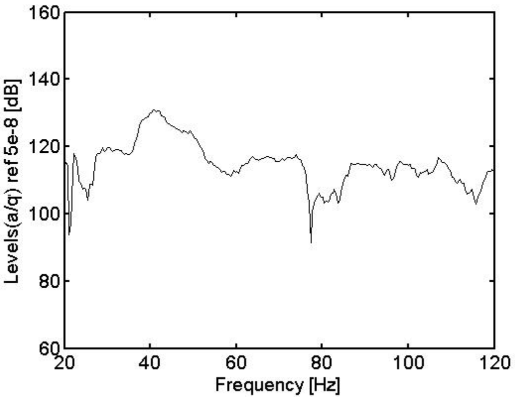


(a) Roof vibration for Rear seats configuration.

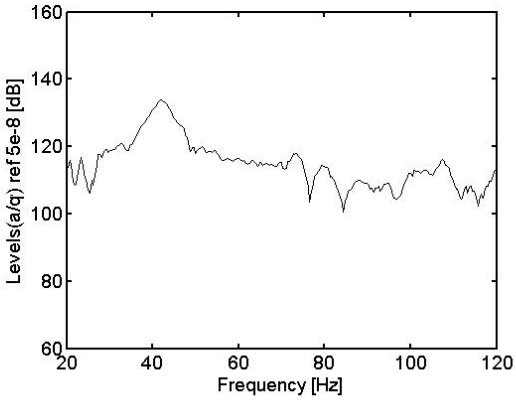


(b) Roof vibration for Front seats configuration.

Figure A.63.: Roof vibration for Rear seats and Front seats configurations.

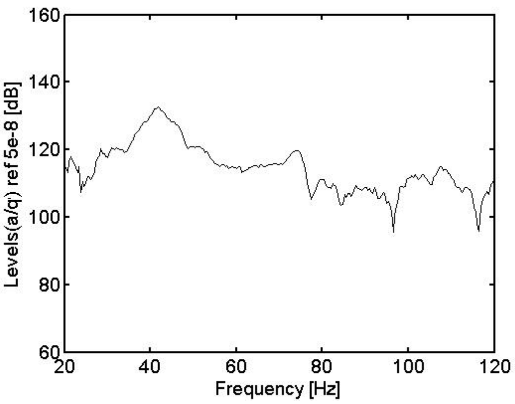


(a) Roof vibration for Rear seats Parcel configuration.

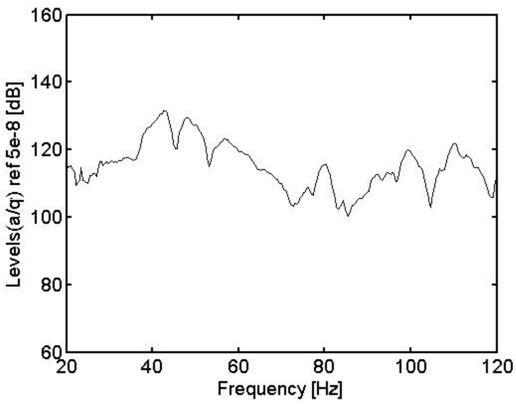


(b) Roof vibration for Front seats Rear seats and Parcel configuration.

Figure A.64.: Roof vibration for Rear seats Parcel and Front seats Rear seats Parcel configurations.

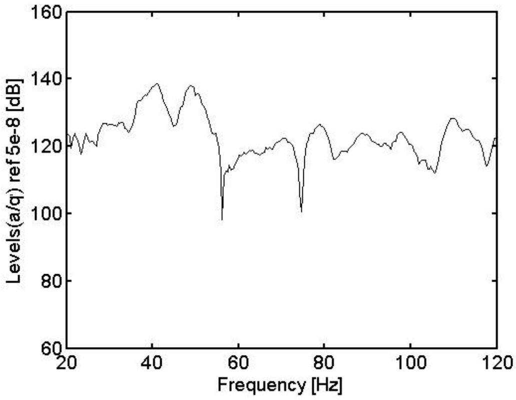


(a) Roof vibration for Front seats Rear seats Carpets Parcel configuration.

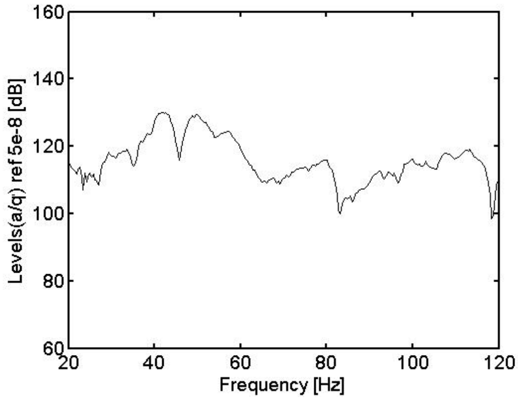


(b) Roof vibration for IP configuration.

Figure A.65.: Roof vibration for Front seats Rear seats Carpets Parcel and IP configurations.

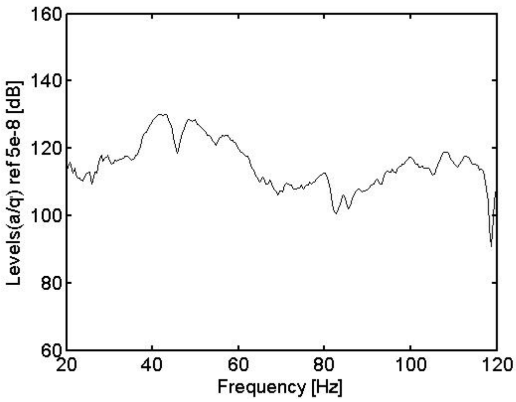


(a) Roof vibration for IP Rear seats configuration.

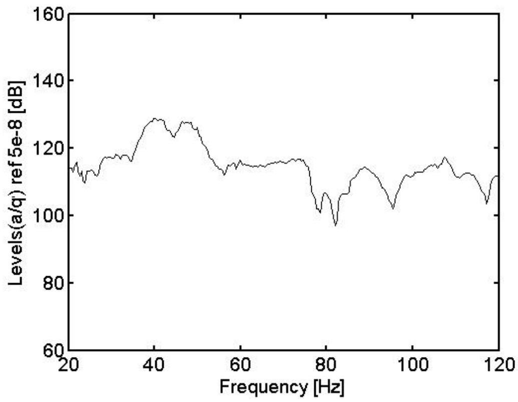


(b) Roof vibration for IP Front seats configuration.

Figure A.66.: Roof vibration for IP Rear seats and IP Front seats configurations.

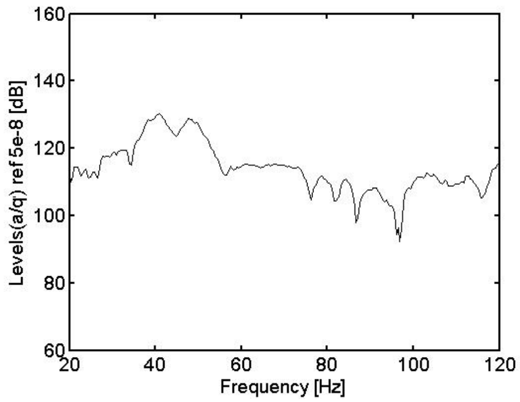


(a) Roof vibration for IP Carpets configuration.

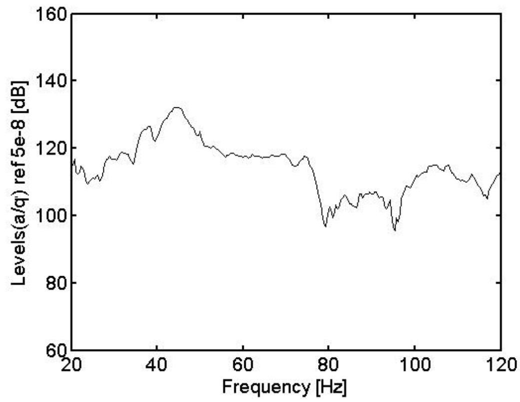


(b) Roof vibration for IP Rear seats Parcel configuration.

Figure A.67.: Roof vibration for IP Carpets and IP Rear seats Parcel configurations.

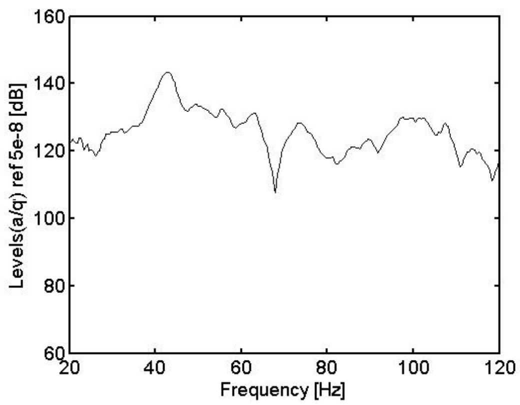


(a) Roof vibration for IP Front seats Rear seats Parcel configuration.

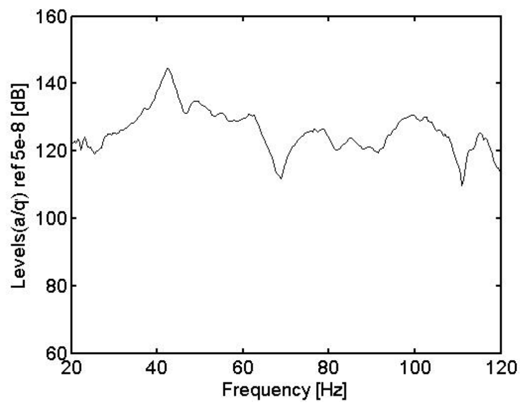


(b) Roof vibration for IP Front seats Rear seats Carpets Parcel configuration.

Figure A.68.: Roof vibration for IP Front seats Rear seats Parcel and IP Front seats Rear seats Carpets Parcel configurations.

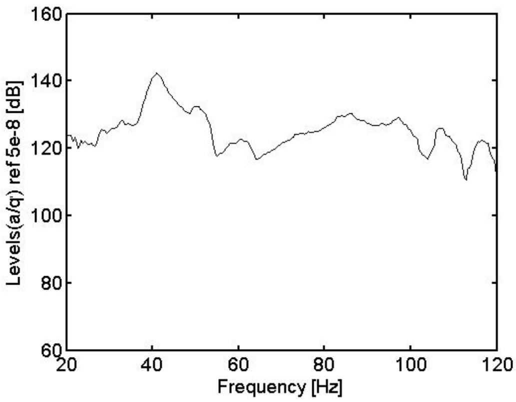


(a) Rear window vibration for Empty configuration.

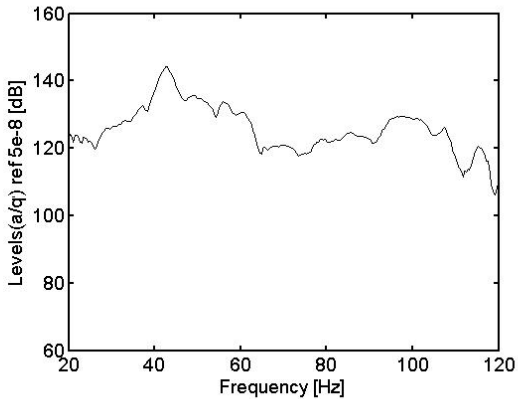


(b) Rear window vibration for Carpets configuration.

Figure A.69.: Rear window vibration for Empty and Carpets configurations.

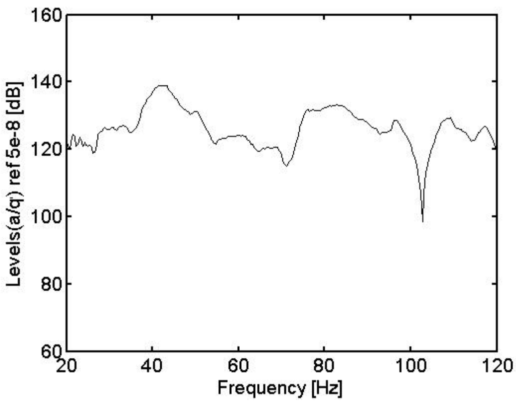


(a) Rear window vibration for Rear seats configuration.

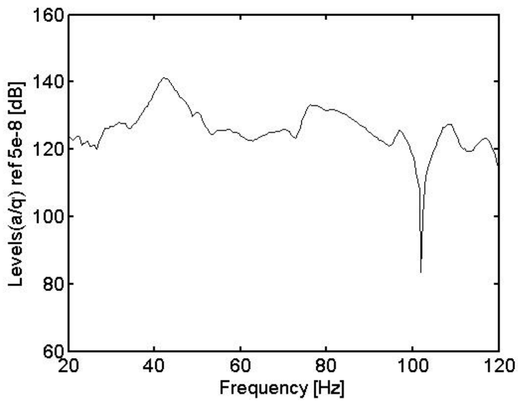


(b) Rear window vibration for Front seats configuration.

Figure A.70.: Rear window vibration for Rear seats and Front seats configurations.

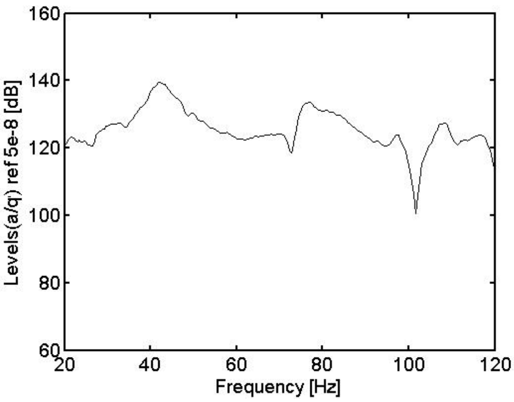


(a) Rear window vibration for Rear seats Parcel configuration.

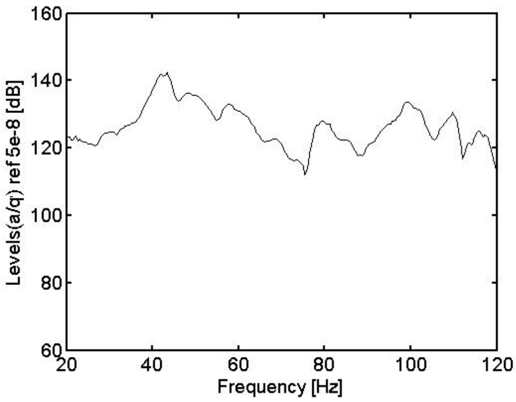


(b) Rear window vibration for Front seats Rear seats and Parcel configuration.

Figure A.71.: Rear window vibration for Rear seats Parcel and Front seats Rear seats Parcel configurations.

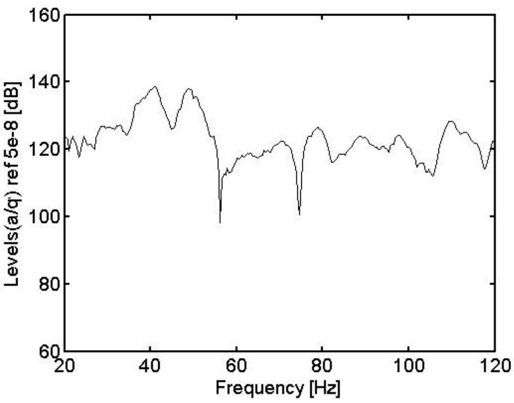


(a) Rear window vibration for Front seats Rear seats Carpets Parcel configuration.

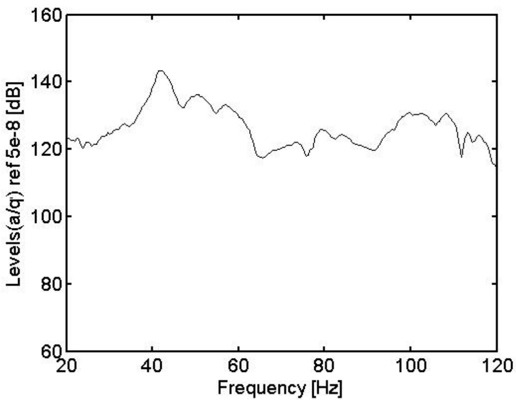


(b) Rear window vibration for IP configuration.

Figure A.72.: Rear window vibration for Front seats Rear seats Carpets Parcel and IP configurations.

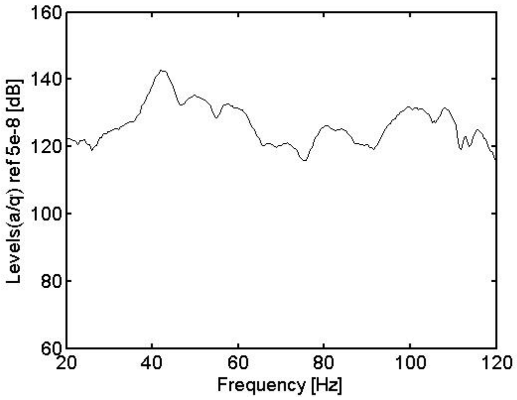


(a) Rear window vibration for IP Rear seats configuration.

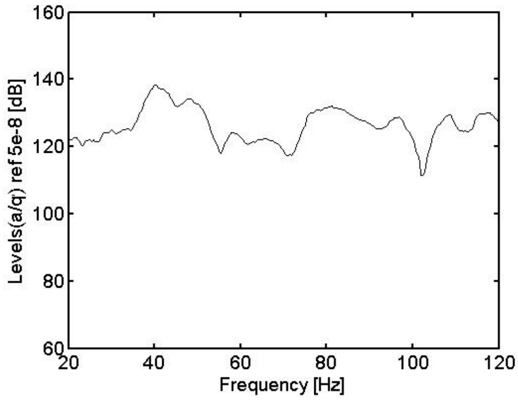


(b) Rear window vibration for IP Front seats configuration.

Figure A.73.: Rear window vibration for IP Rear seats and IP Front seats configurations.

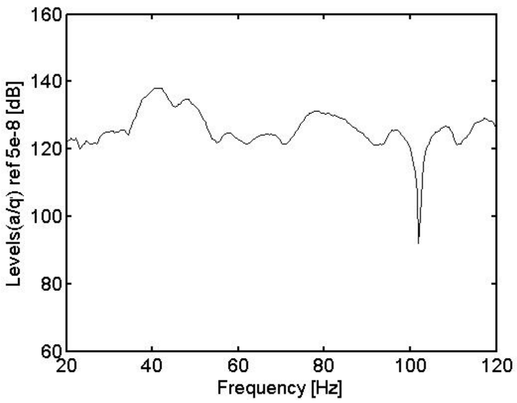


(a) Rear window vibration for IP Carpets configuration.

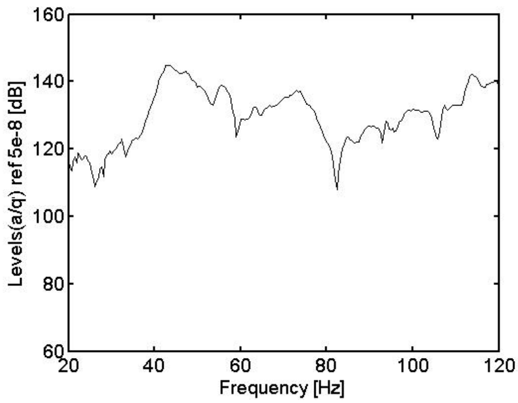


(b) Rear window vibration for IP Rear seats Parcel configuration.

Figure A.74.: Rear window vibration for IP Carpets and IP Rear seats Parcel configurations.

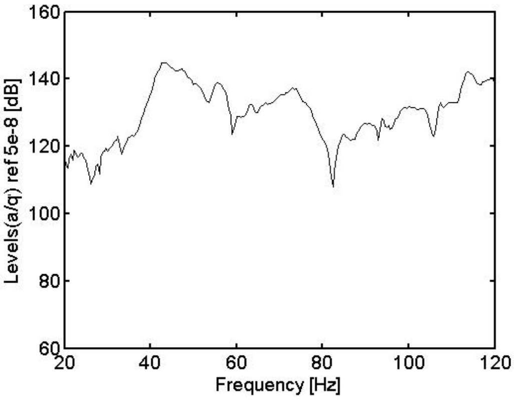


(a) Rear window vibration for IP Front seats Rear seats Parcel configuration.

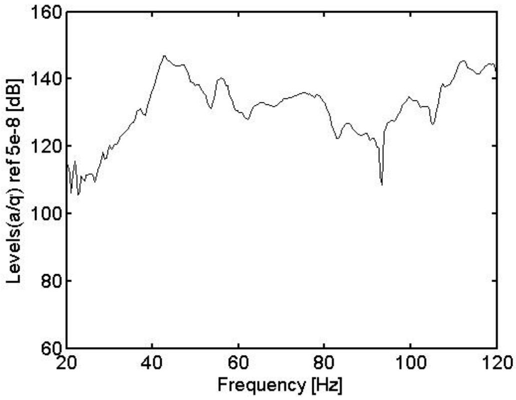


(b) Rear window vibration for IP Front seats Rear seats Carpets Parcel configuration.

Figure A.75.: Rear window vibration for IP Front seats Rear seats Parcel and IP Front seats Rear seats Carpets Parcel configurations.

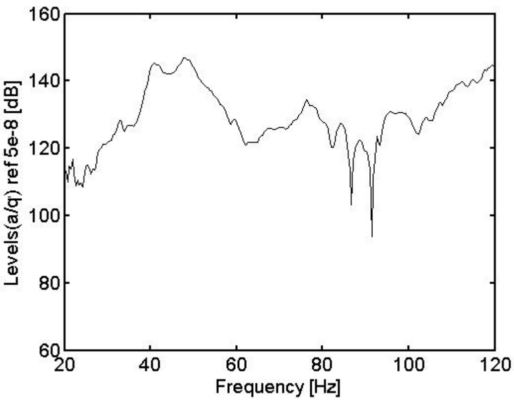


(a) Parcel vibration for Empty configuration.

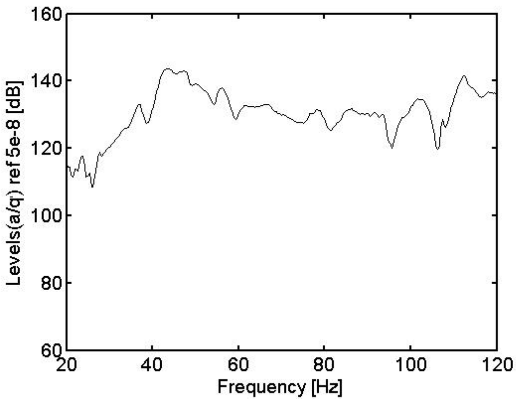


(b) Parcel vibration for Carpets configuration.

Figure A.76.: Parcel vibration for Empty and Carpets configurations.

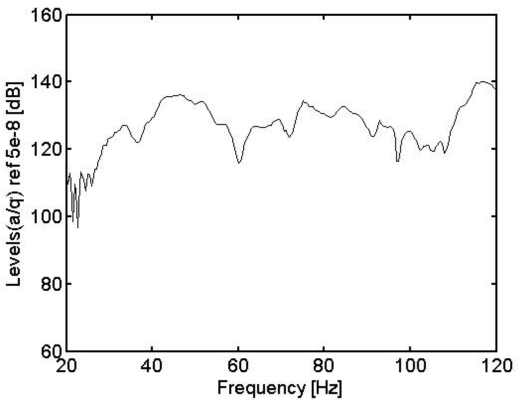


(a) Parcel vibration for Rear seats configuration.

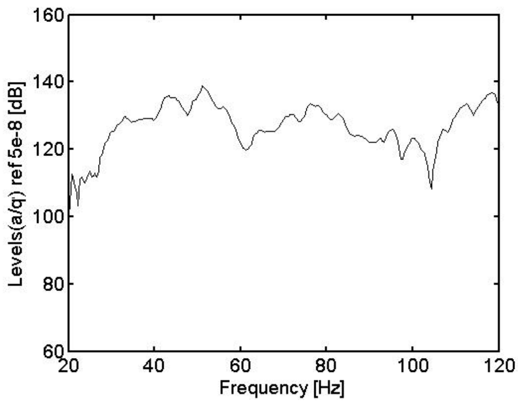


(b) Parcel vibration for Front seats configuration.

Figure A.77.: Parcel vibration for Rear seats and Front seats configurations.

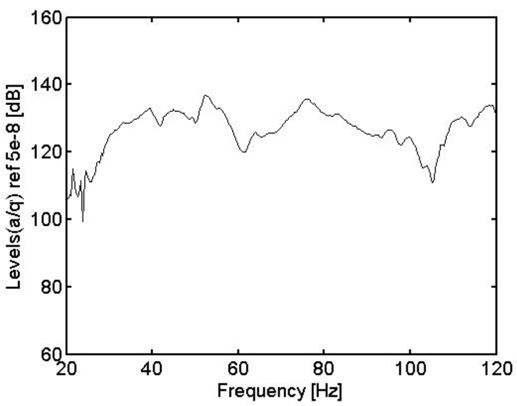


(a) Parcel vibration for Rear seats Parcel configuration.

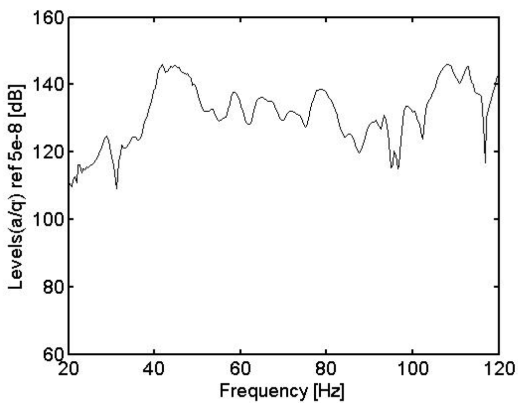


(b) Parcel vibration for Front seats Rear seats and Parcel configuration.

Figure A.78.: Parcel vibration for Rear seats Parcel and Front seats Rear seats Parcel configurations.

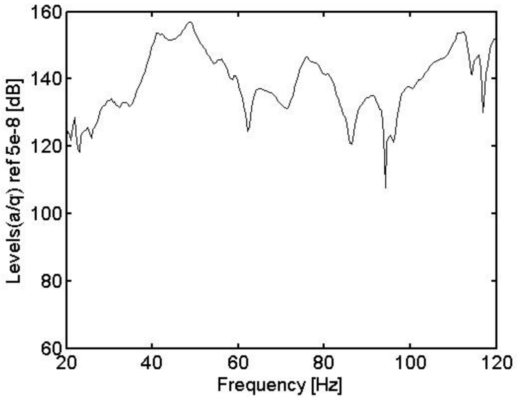


(a) Parcel vibration for Front seats Rear seats Carpets Parcel configuration.

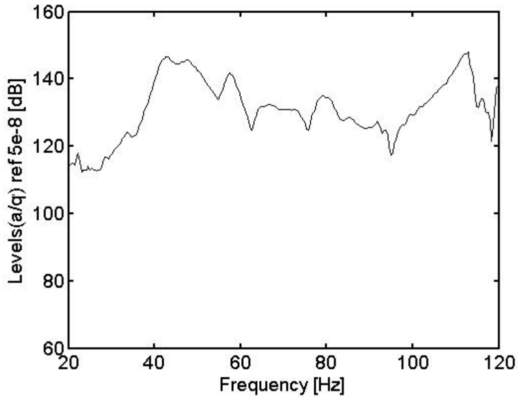


(b) Parcel vibration for IP configuration.

Figure A.79.: Parcel vibration for Front seats Rear seats Carpets Parcel and IP configurations.

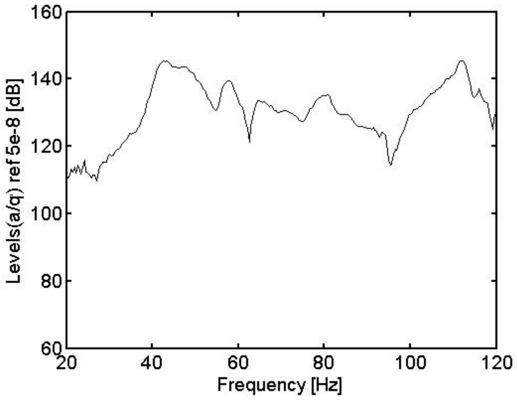


(a) Parcel vibration for IP Rear seats configuration.

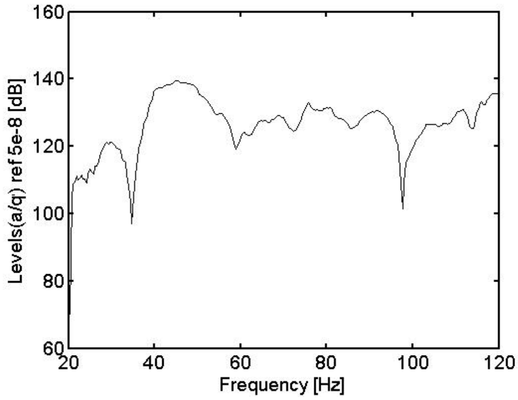


(b) Parcel vibration for IP Front seats configuration.

Figure A.80.: Parcel vibration for IP Rear seats and IP Front seats configurations.

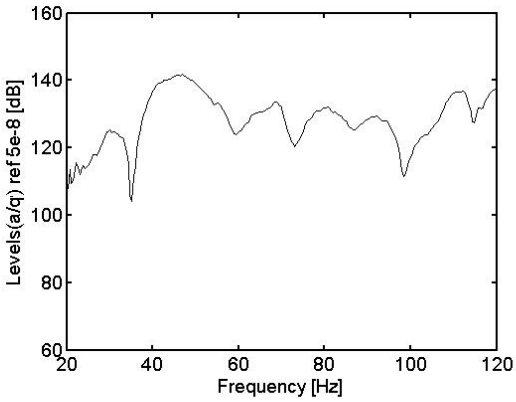


(a) Parcel vibration for IP Carpets configuration.

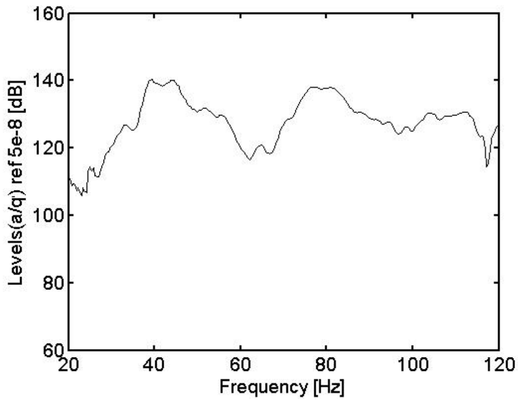


(b) Parcel vibration for IP Rear seats Parcel configuration.

Figure A.81.: Parcel vibration for IP Carpets and IP Rear seats Parcel configurations.



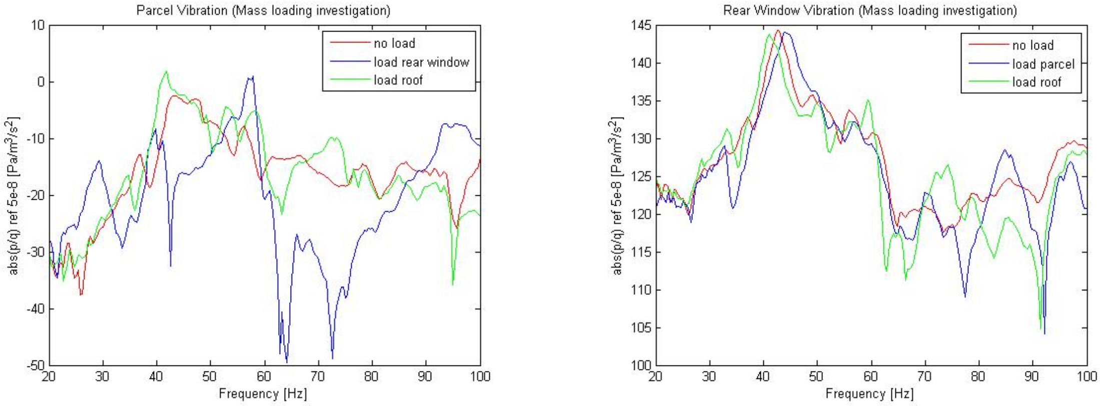
(a) Parcel vibration for IP Front seats Rear seats Parcel configuration.



(b) Parcel vibration for IP Front seats Rear seats Carpets Parcel configuration.

Figure A.82.: Parcel vibration for IP Front seats Rear seats Parcel and IP Front seats Rear seats Carpets Parcel configurations.

A.2.6. Mass-load investigation Plots



(a) Mass loading effect on Parcel vibration response.

(b) Mass loading effect on Rear window vibration response.

Figure A.83.: Parcel vibration for IP Front seats Rear seats Parcel and IP Front seats Rear seats Carpets Parcel configurations.

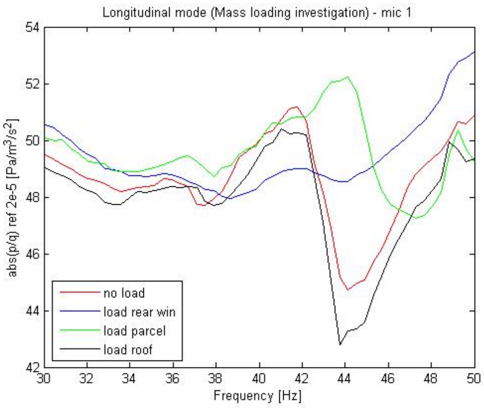
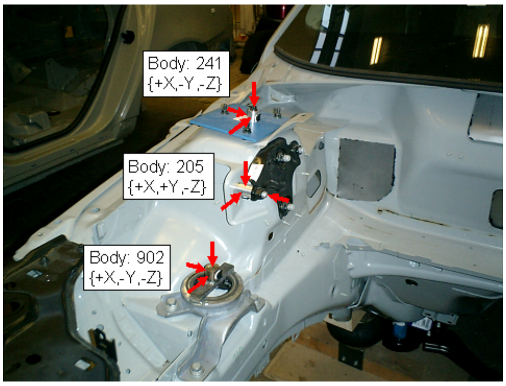


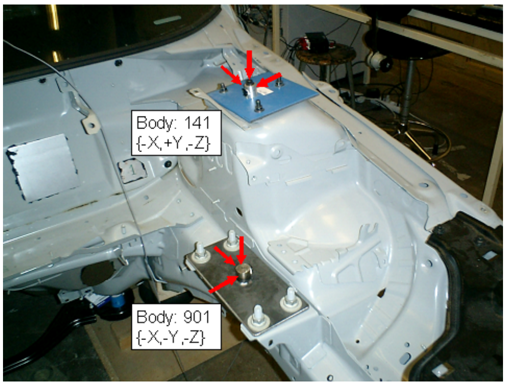
Figure A.84.: Mass loading effect on mic 1

A.3. Mechanical Excitation and Measurement Positions

A.3.1. Excitation Positions and Directions

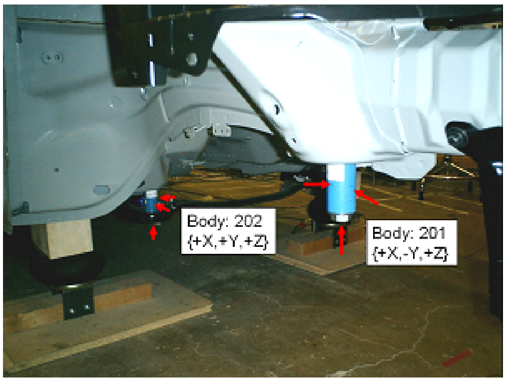


(a) Cap fixtures for body 241, 205 and 902.

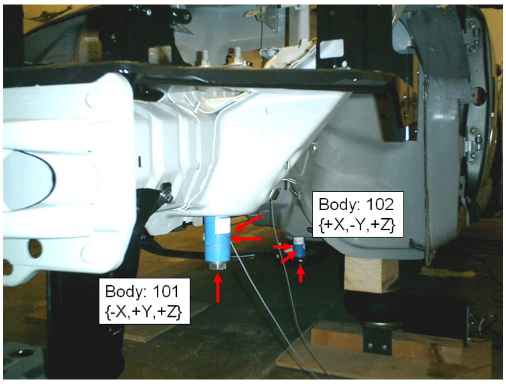


(b) Cap fixtures for body 901 and 141.

Figure A.85.: BIB front top cap fixtures location and mechanical excitation directions.

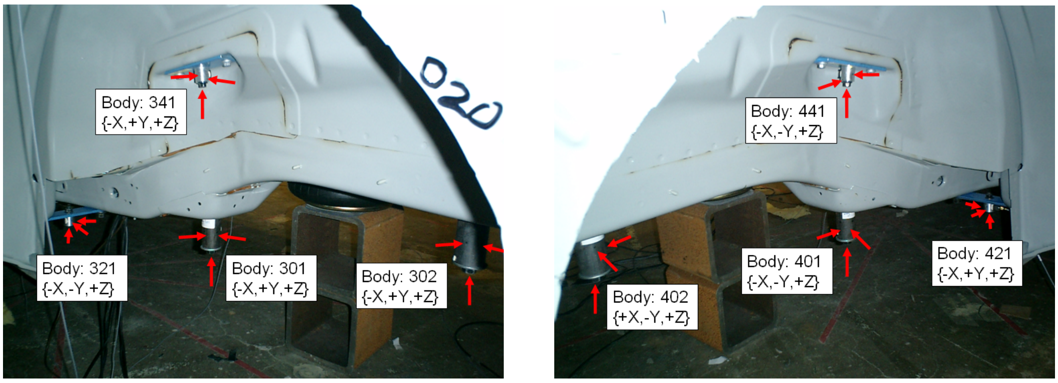


(a) Cap fixtures for body 201 and 202.



(b) Cap fixtures for body 101 and 102.

Figure A.86.: BIB front bottom cap fixtures location and mechanical excitation directions.

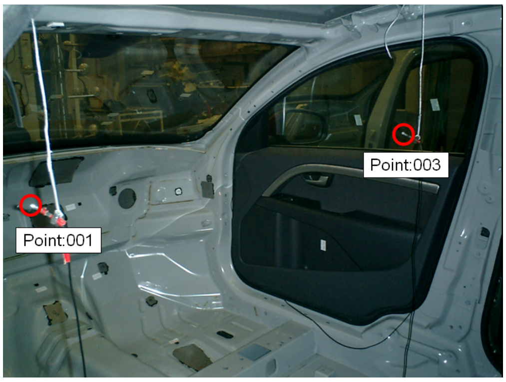


(a) Cap fixtures for body 301, 302, 321 and 341.

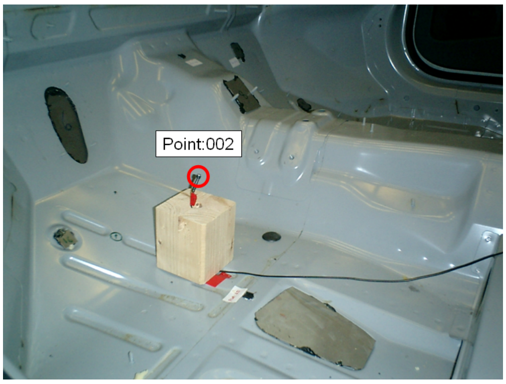
(b) Cap fixtures for body 401, 402, 421 and 441.

Figure A.87.: BIB back bottom cap fixtures location and mechanical excitation directions.

A.3.2. Measuremant Positions



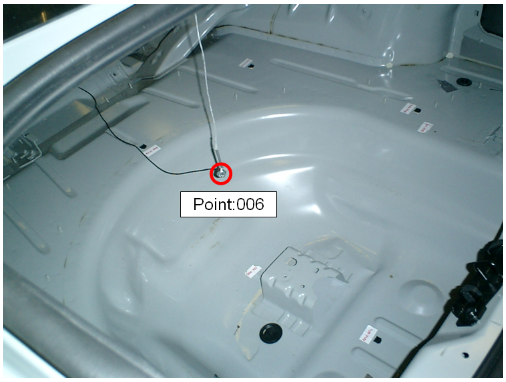
(a) Measurement points 001 and 003.



(b) Measurement point 002.

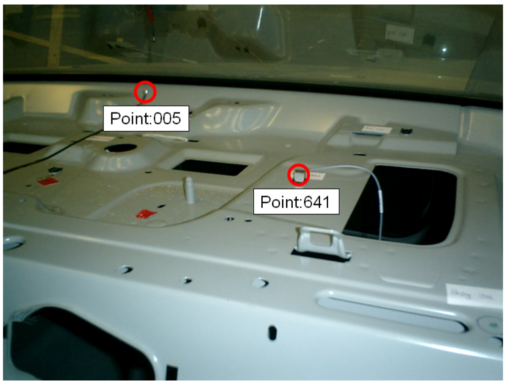
Figure A.88.: BIB NTF measurement positions.

(a) Measurement point 004.



(b) Measurement point 006.

Figure A.89.: BIB NTF measurement positions.

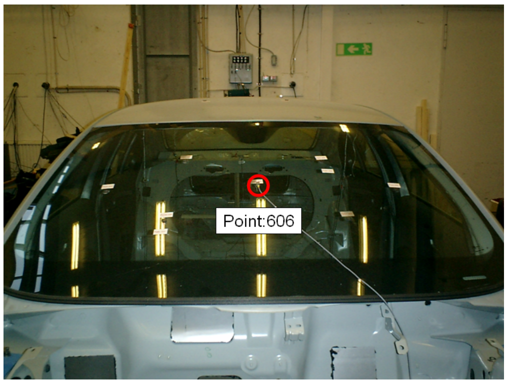


(a) Measurement points 005 and 641.

(b) Measurement point 012.

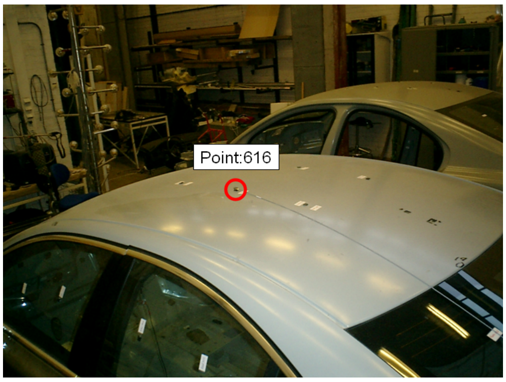
Figure A.90.: BIB NTF measurement positions.

(a) Measurement point 112.

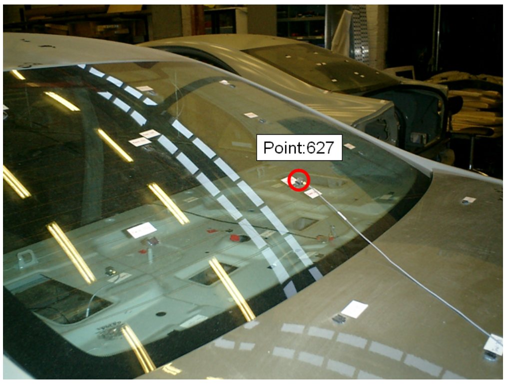


(b) Measurement point 606.

Figure A.91.: BIB NTF measurement positions.



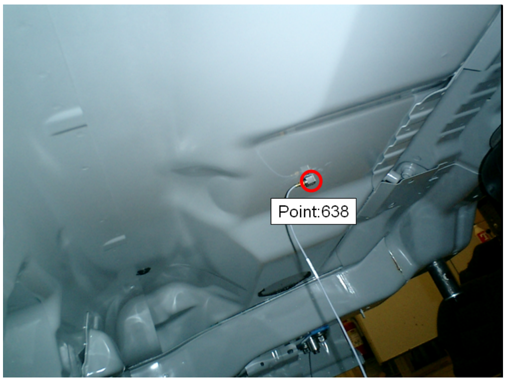
(a) Measurement point 616.



(b) Measurement point 627.

Figure A.92.: BIB NTF measurement positions.

(a) Measurement point 635.



(b) Measurement point 638.

Figure A.93.: BIB NTF measurement positions.

A.3.3. NTF Plots

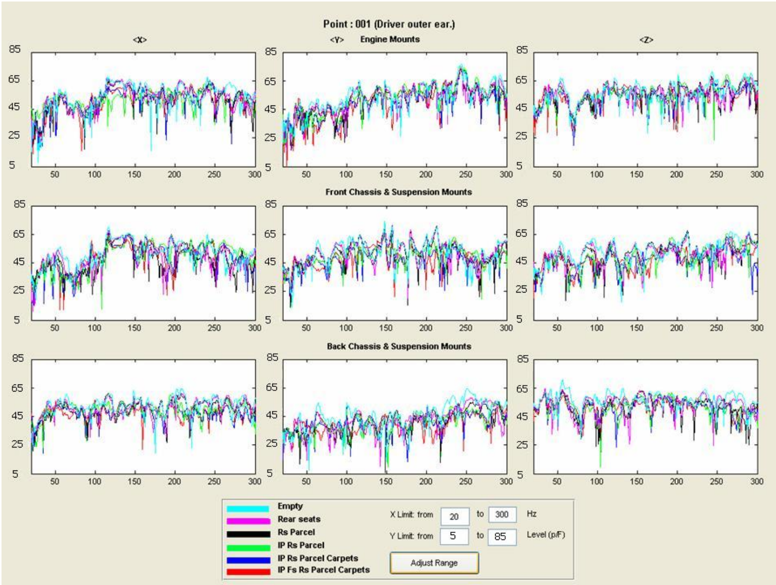


Figure A.94.: Driver outer ear 0-300 Hz

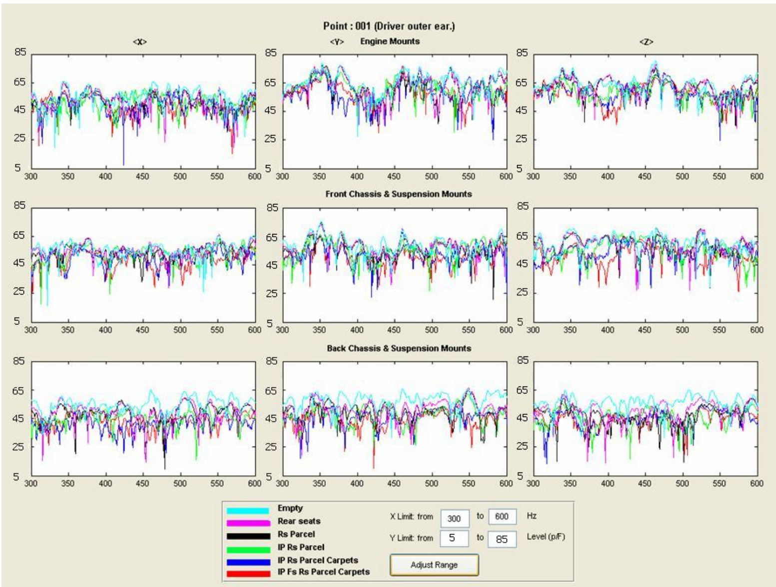


Figure A.95.: Driver outer ear 300-600 Hz

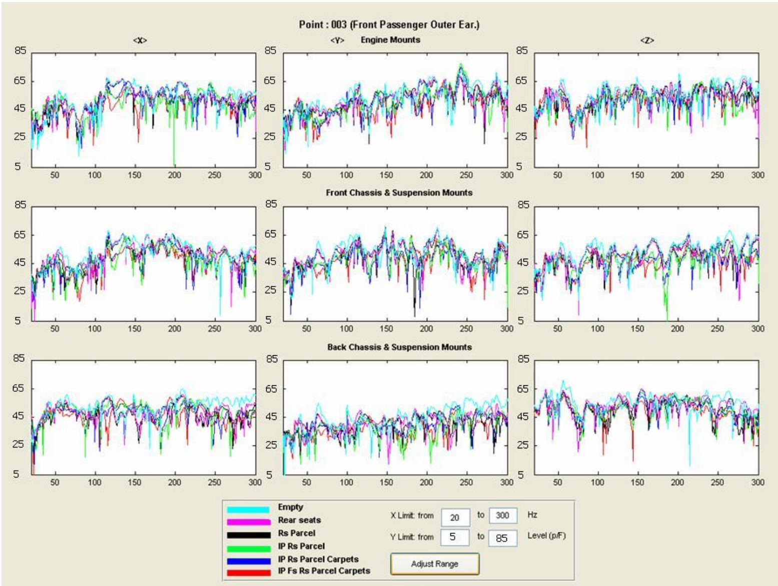


Figure A.96.: Passenger outer ear 0-300 Hz

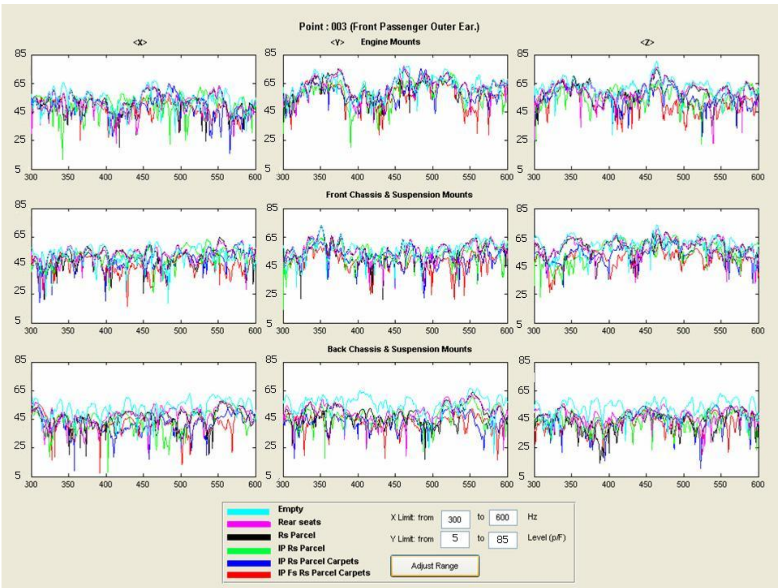


Figure A.97.: Passenger outer ear 300-600 Hz

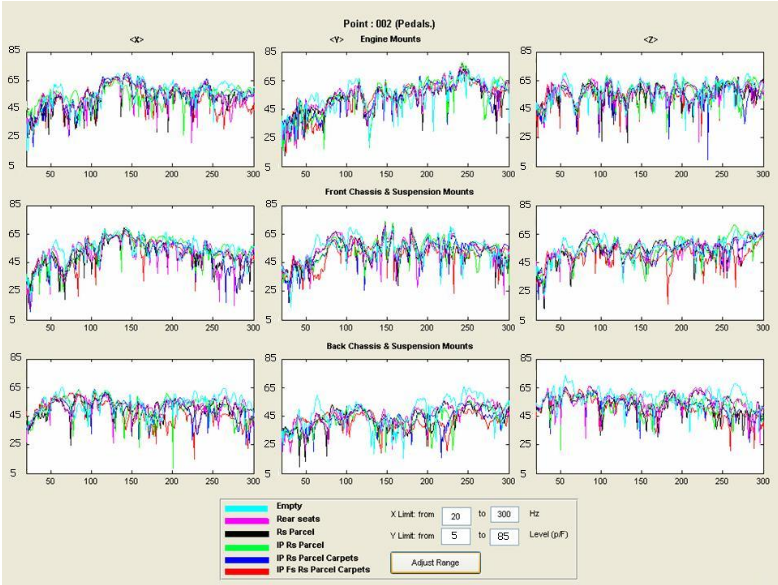


Figure A.98.: Pedals 0-300 Hz

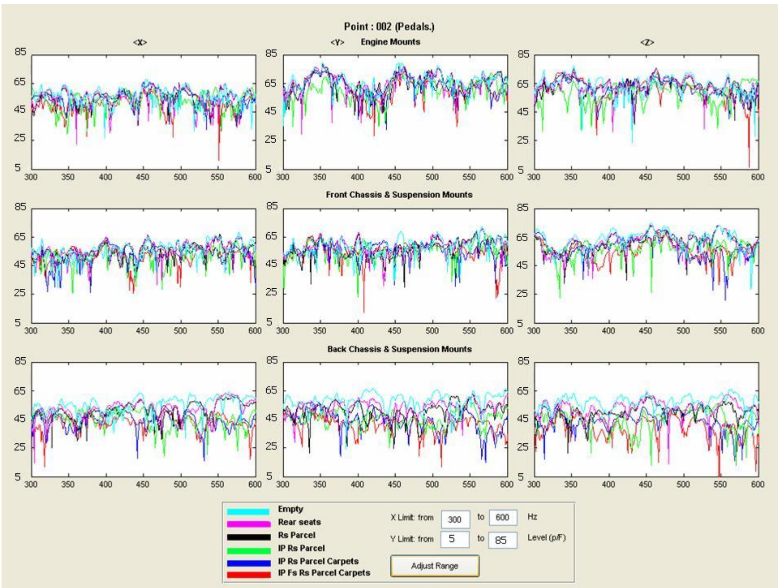


Figure A.99.: Pedals 300-600 Hz

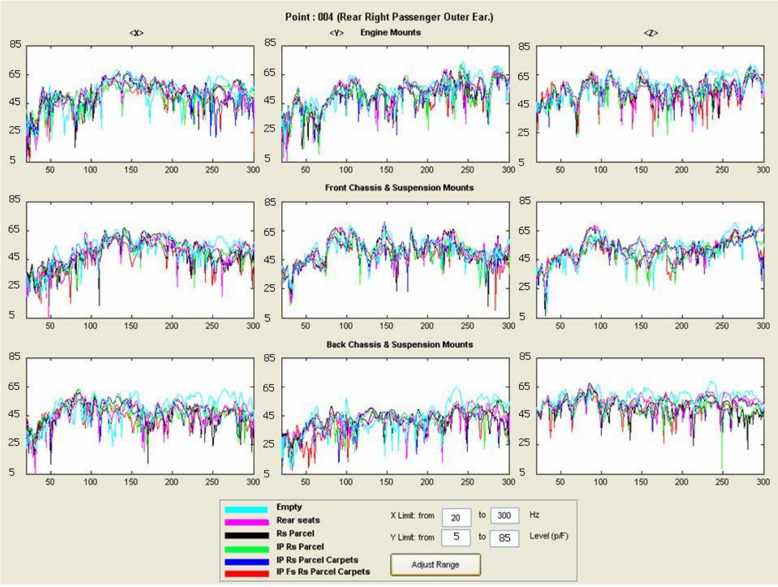


Figure A.100.: Rear passenger outer ear 0-300 Hz

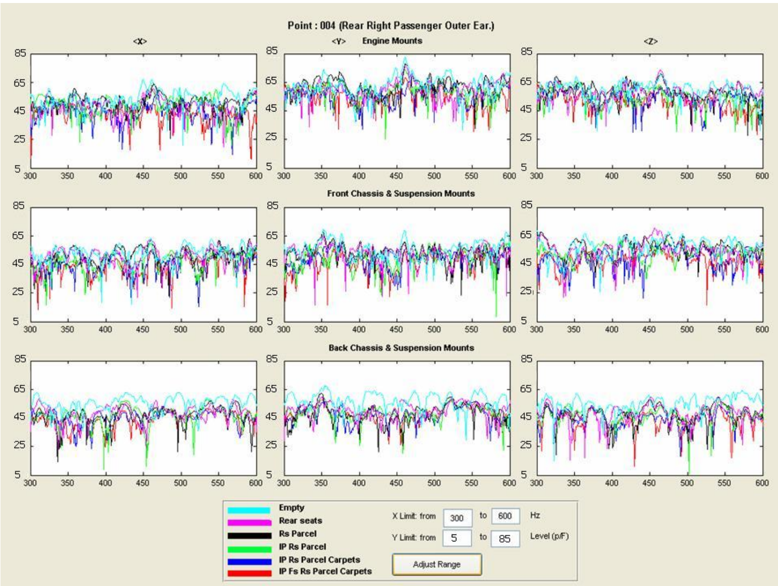


Figure A.101.: Rear passenger outer ear 300-600 Hz

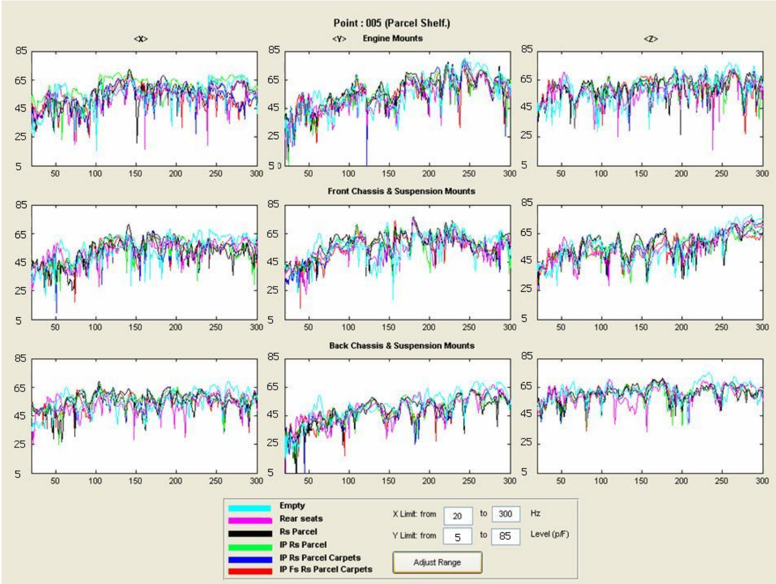


Figure A.102.: Parcel shelf 0-300 Hz

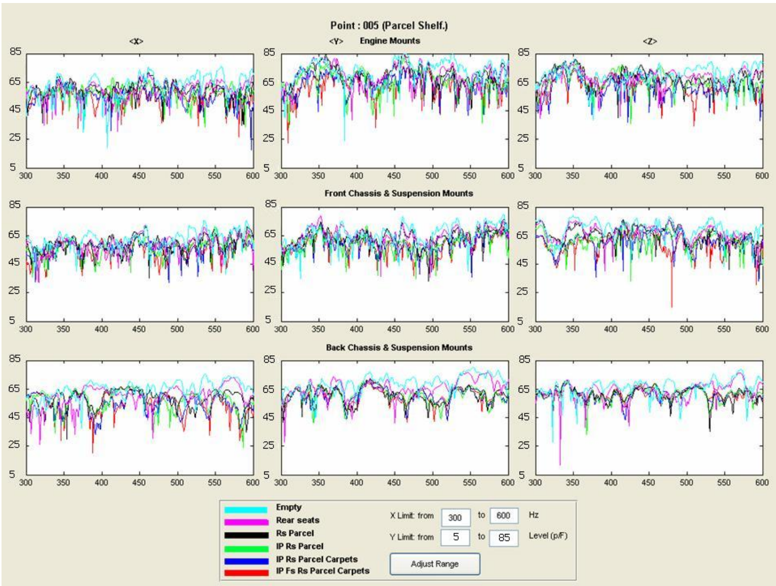


Figure A.103.: Parcel shelf 300-600 Hz

On figure A.102 and figure A.103 the results for the parcel shelf are presented.

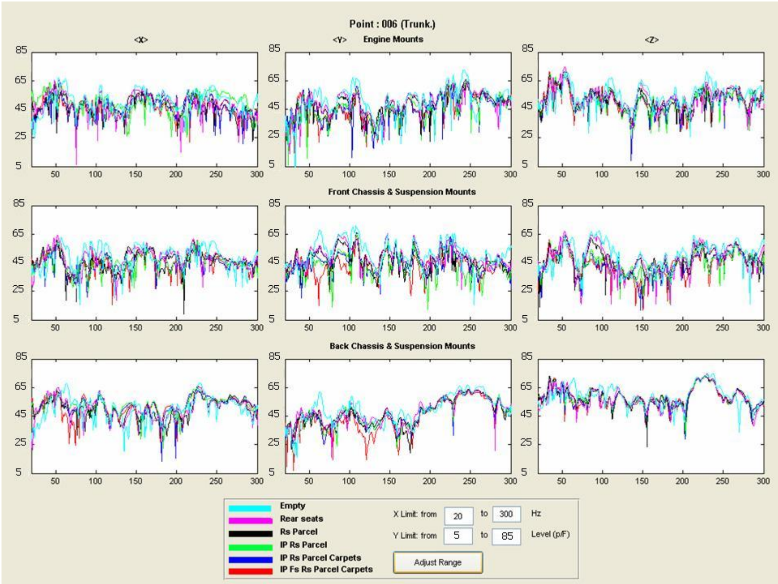


Figure A.104.: Trunk 0-300 Hz

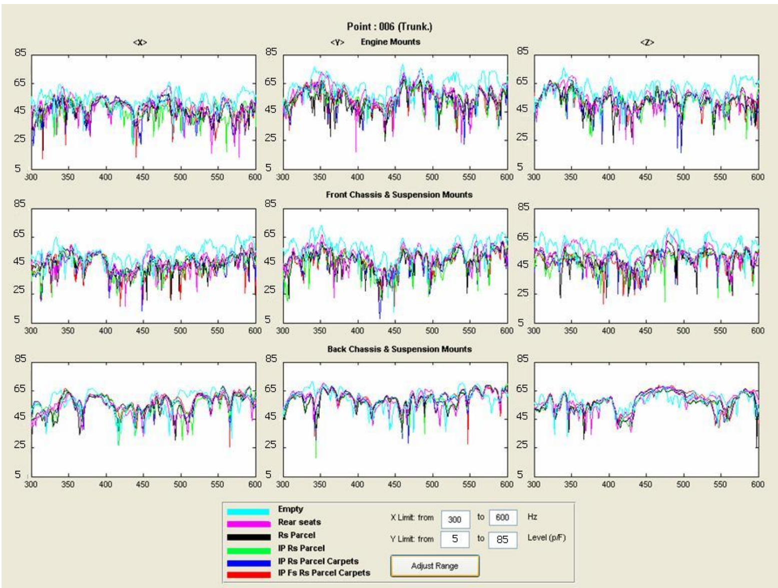


Figure A.105.: Trunk 300-600 Hz

On figure A.104 and figure A.105 the results for the trunk are presented.

A.3.4. VTF Plots

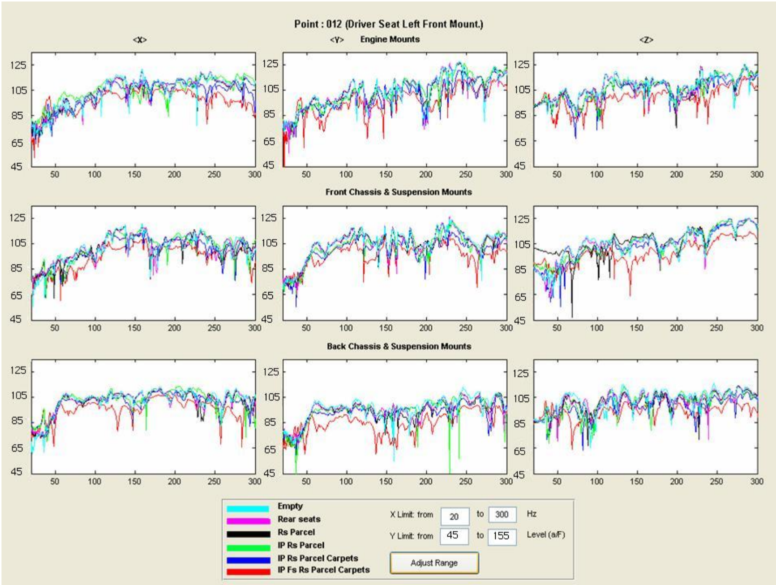


Figure A.106.: Driver seat left mount 0-300 Hz

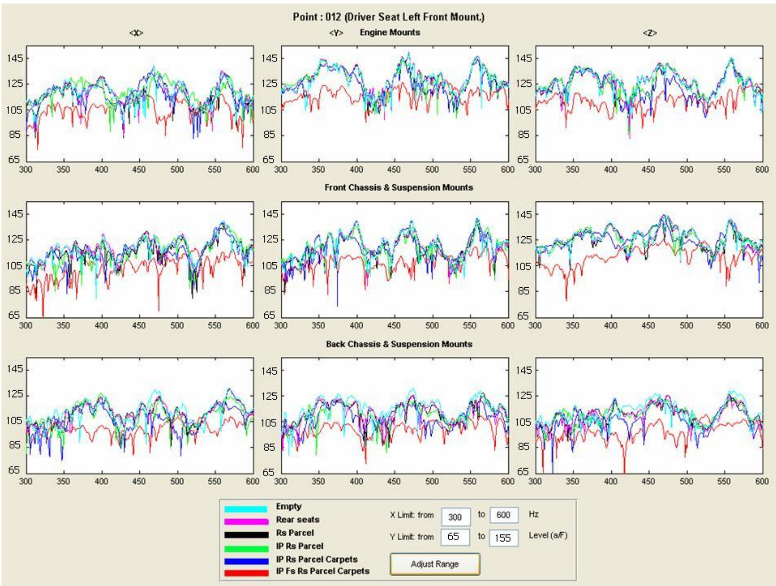


Figure A.107.: Driver seat left mount 300-600 Hz

On figure A.106 and figure A.107 the results for the driver seat left mount are presented.

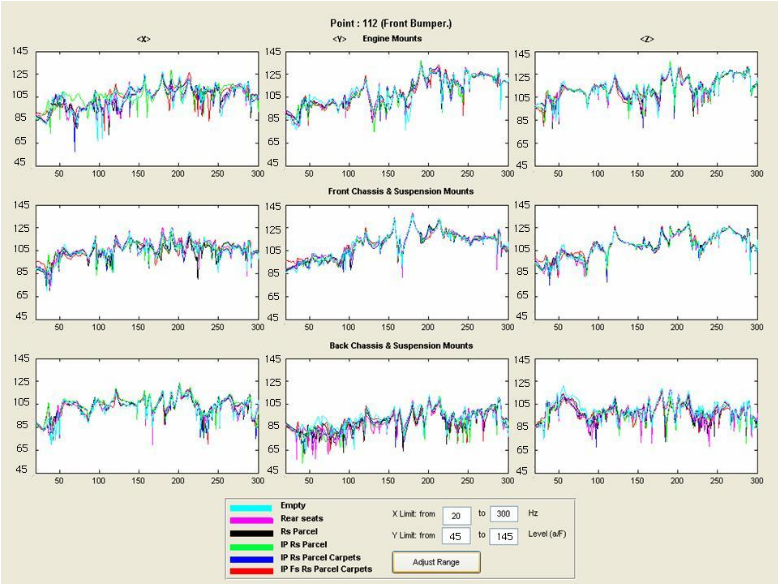


Figure A.108.: Front bumper 0-300 Hz

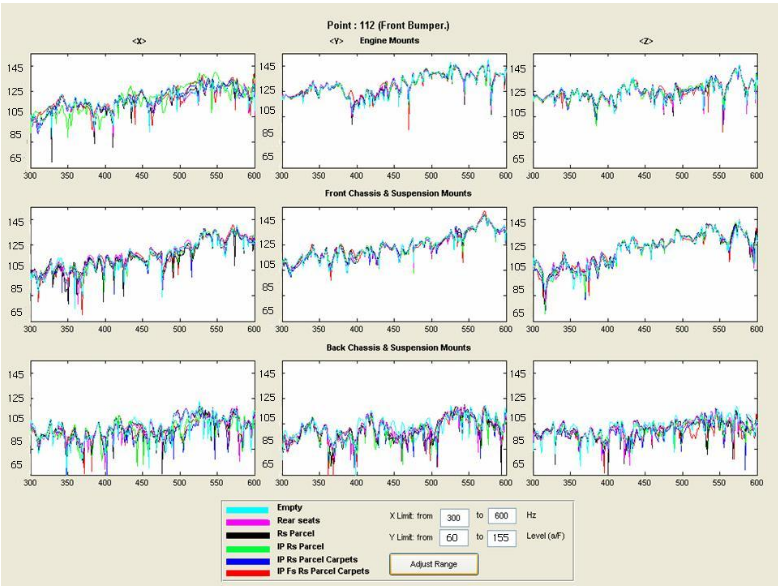


Figure A.109.: Front bumper 300-600 Hz

On figure A.108 and figure A.109 the results for the front bumper are presented.

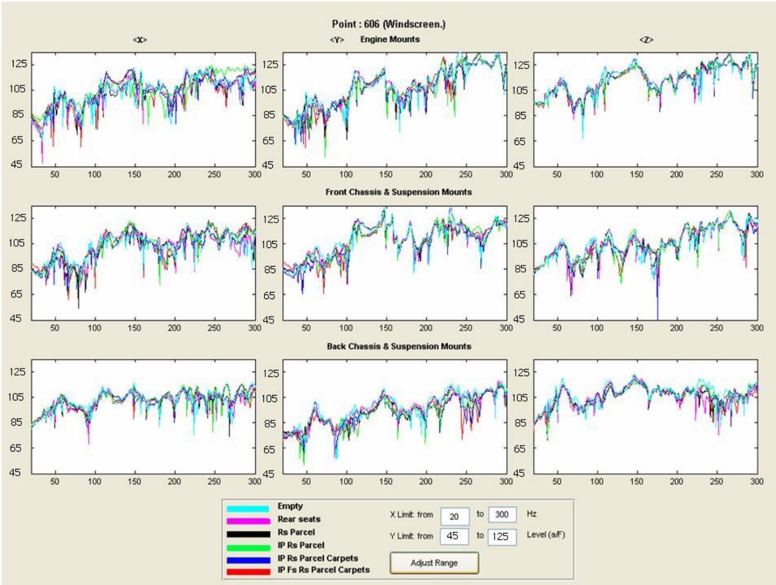


Figure A.110.: Windscreen 0-300 Hz

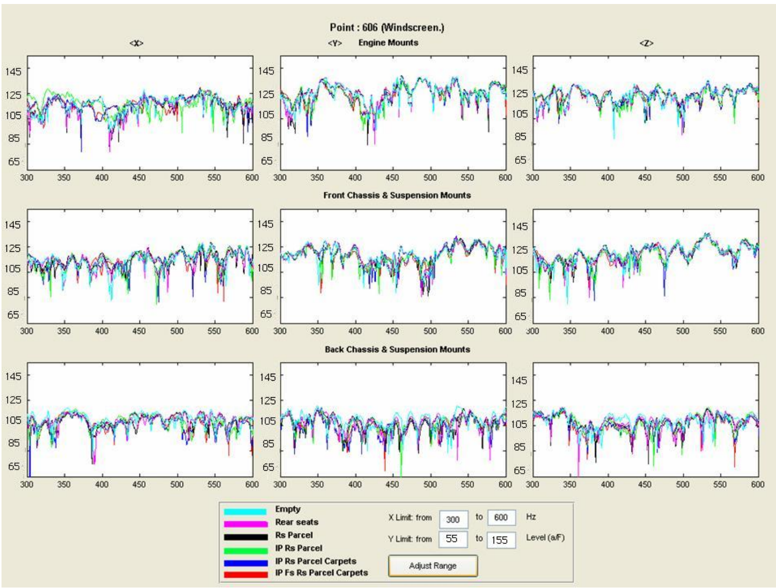


Figure A.111.: Windscreen 300-600 Hz

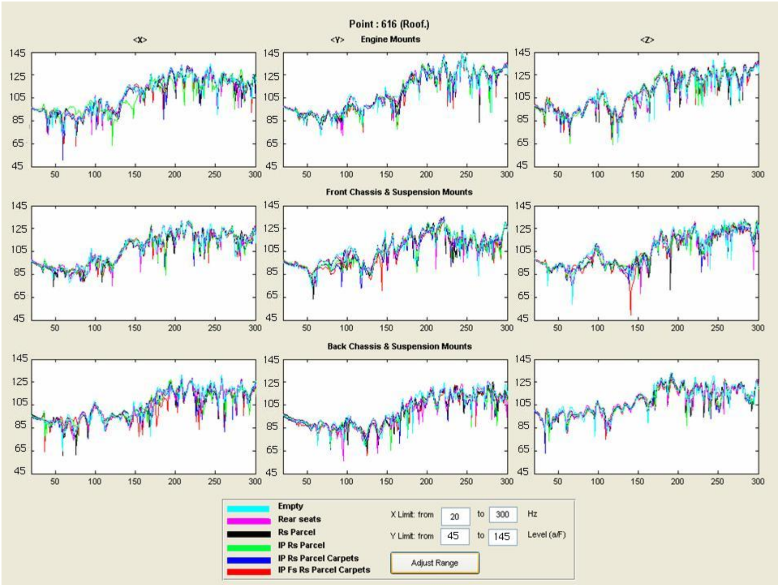


Figure A.112.: Roof 0-300 Hz

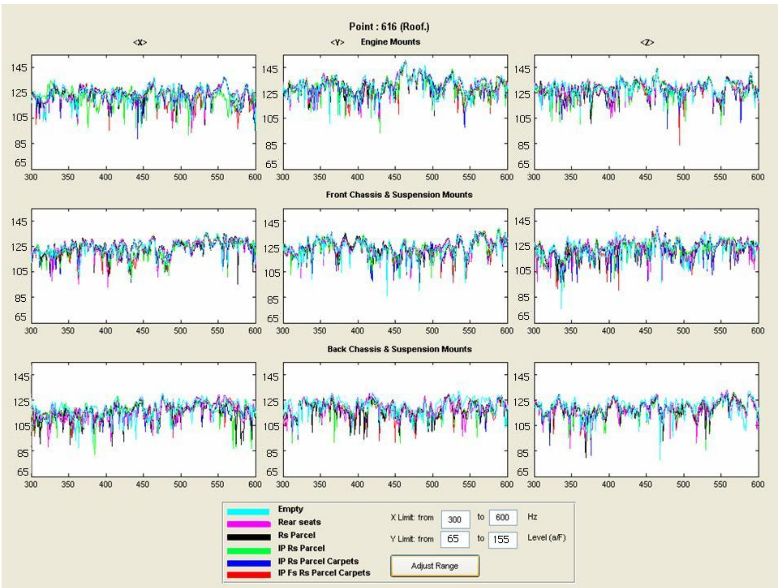


Figure A.113.: Roof 300-600 Hz

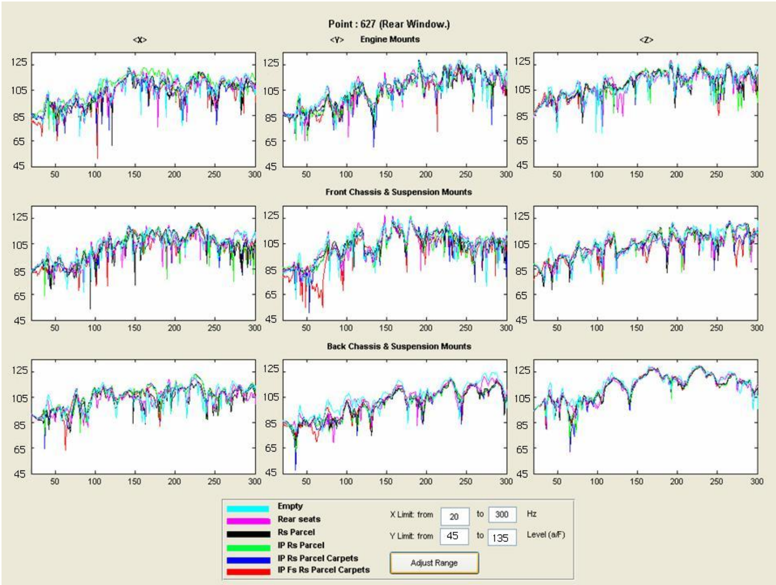


Figure A.114.: Rear window 0-300 Hz

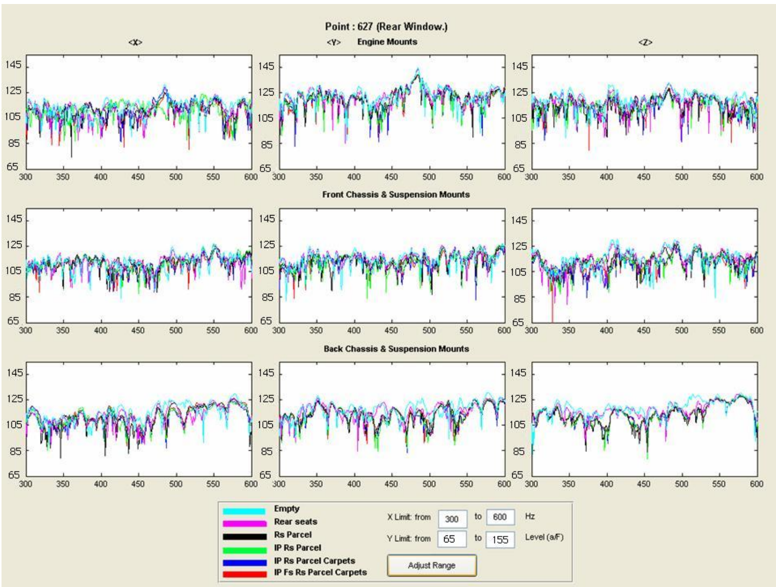


Figure A.115.: Rear window 300-600 Hz

Figure A.116.: Front floor rear 0-300 Hz

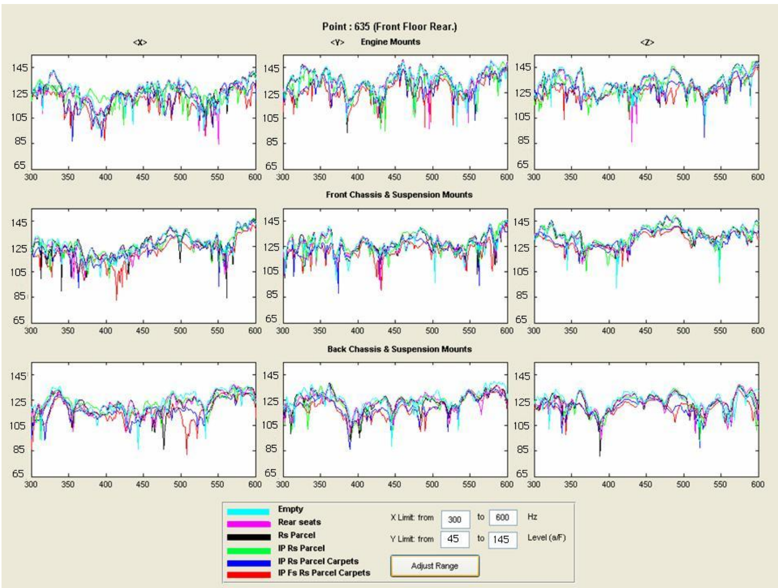


Figure A.117.: Front floor rear 300-600 Hz

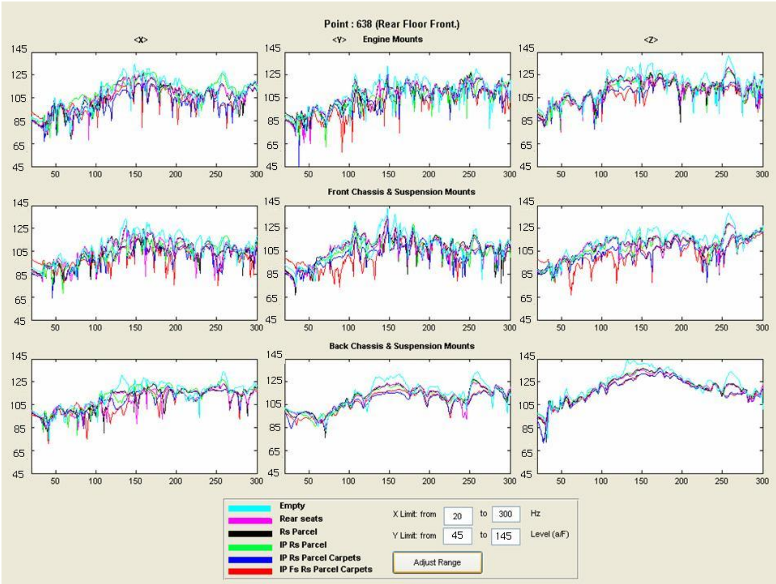


Figure A.118.: Rear floor front 0-300 Hz

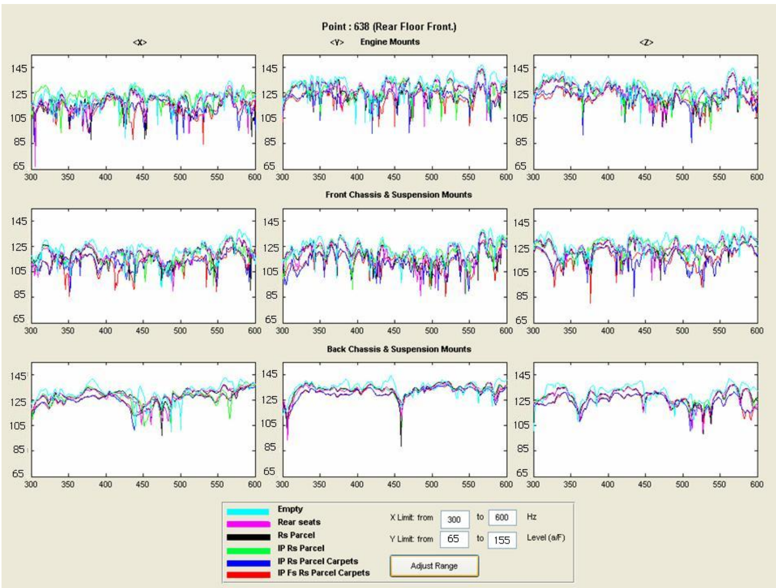


Figure A.119.: Rear floor front 300-600 Hz

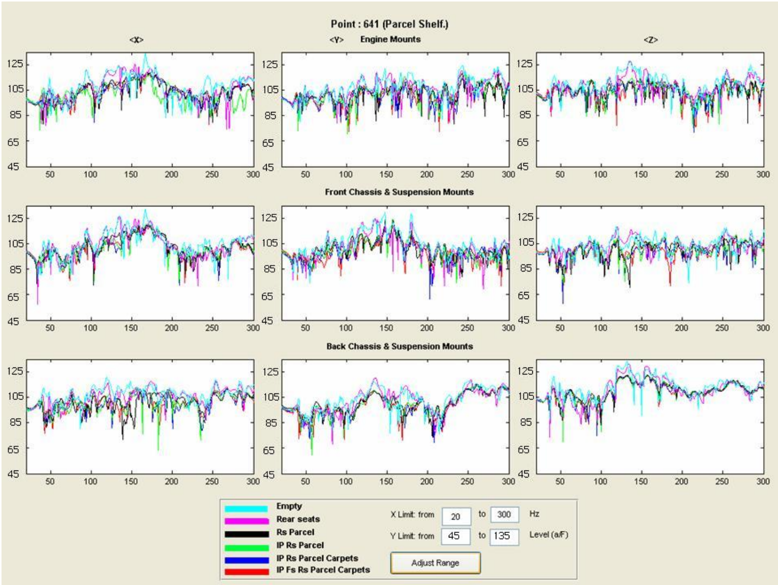


Figure A.120.: Parcel shelf 0-300 Hz

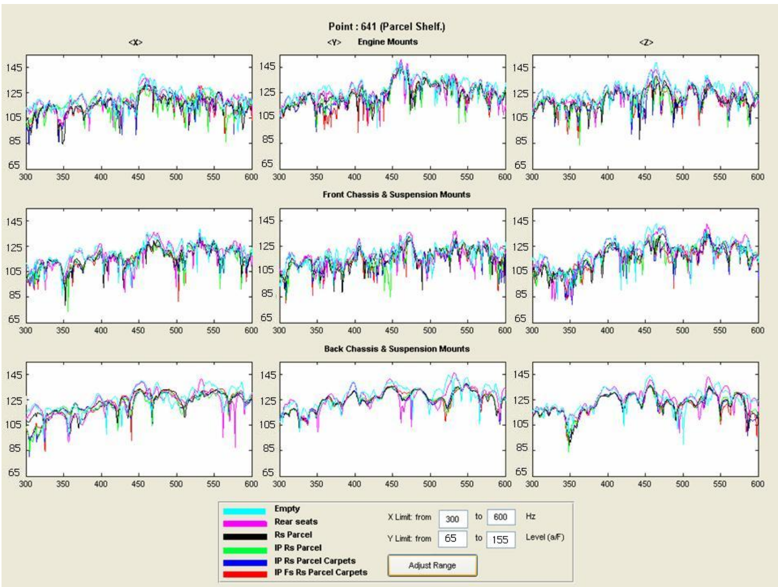


Figure A.121.: Parcel shelf 300-600 Hz

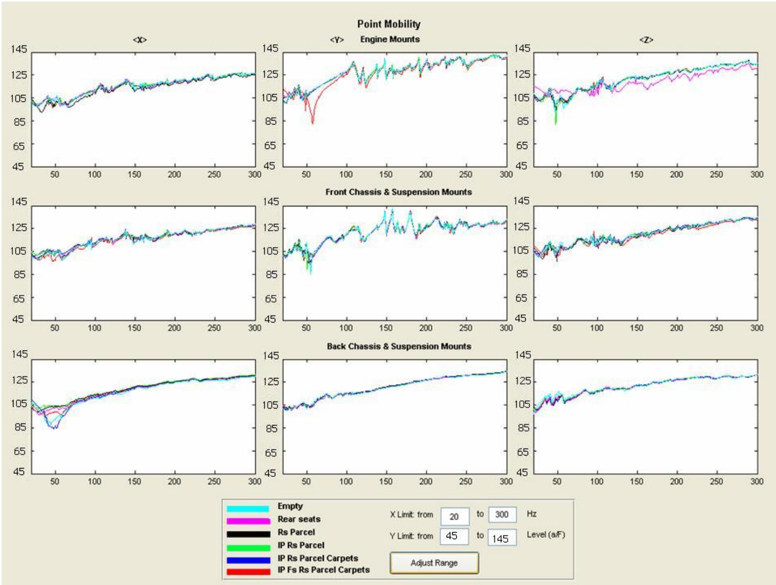


Figure A.122.: Point mobility 0-300 Hz

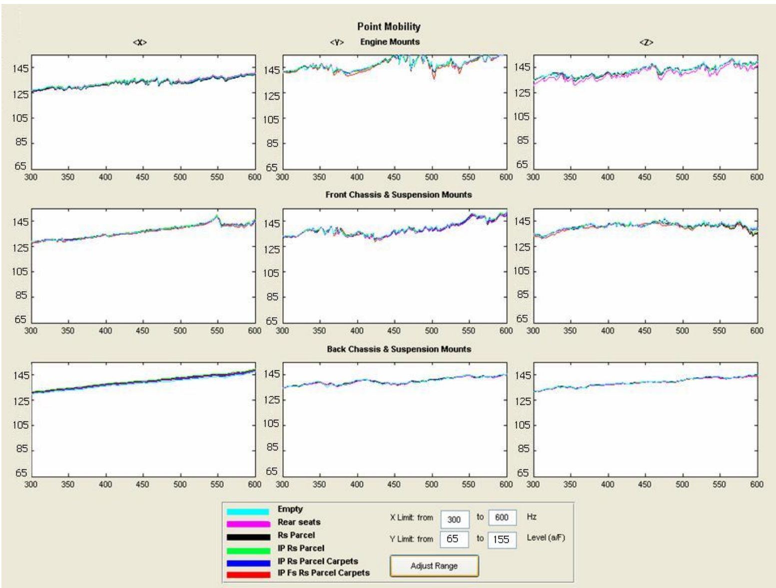


Figure A.123.: Point mobility 300-600 Hz

B. Matlab GUI and Code

B.1. Acoustical Excitation Matlab Code

B.1.1. A-FRF Matlab Code

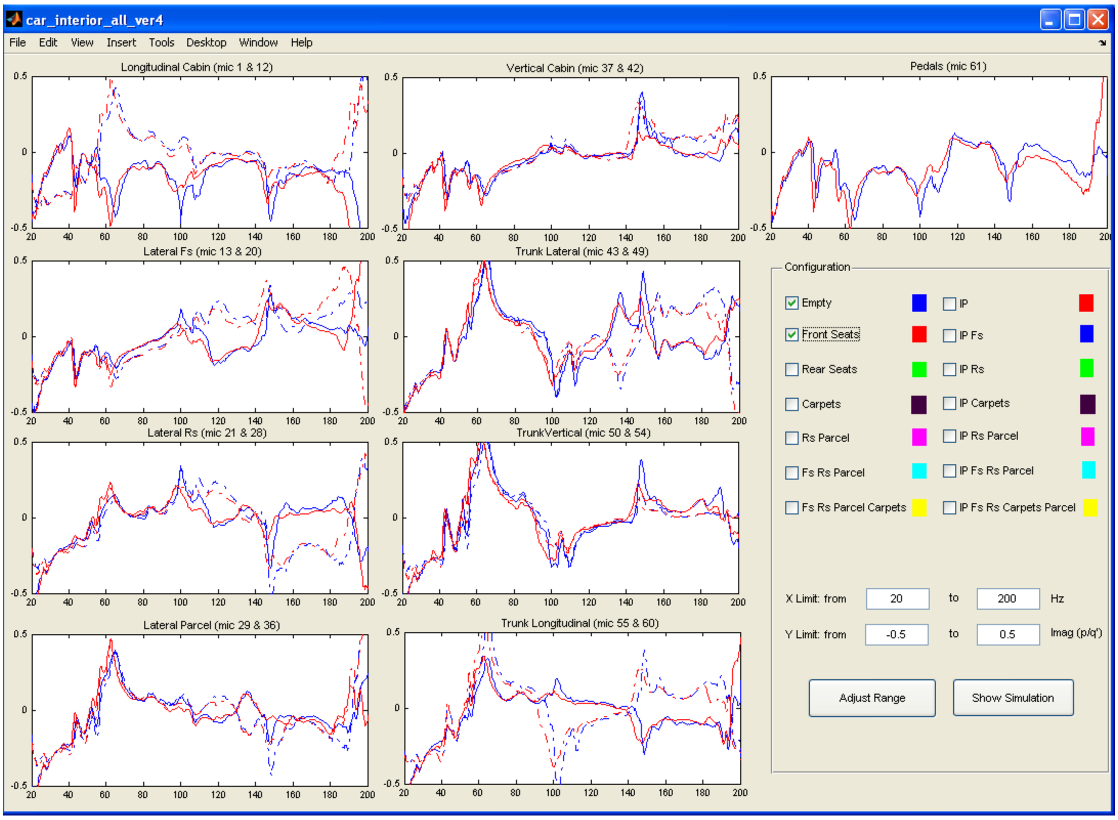


Figure B.1.: GUI matlab program to analyze A-FRF measurements.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% CAR_INTERIOR_ALL_VER4 M-file for car_interior_all_ver4.fig - Created by
% Teik Huat Ong & Branislav Ivanov 2007
% A matlab graphical interface program to analyze all the a-frf responses.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Function to initialize the graphical handlers and state.
function varargout = car_interior_all_ver4(varargin)
% Begin initialization code
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @car_interior_all_ver4_OpeningFcn, ...
                   'gui_OutputFcn',  @car_interior_all_ver4_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Function to plot all the measurement arrays for Empty Trim Configuration
% while the figure is opening.
function car_interior_all_ver4_OpeningFcn(hObject, eventdata, handles, varargin)

handles.output = hObject;
guidata(hObject, handles);

load .\frequency.mat;
%Longitudinal
axes(handles.axes1);
load '.\lsp_data\empty\lsp_ect_mic_meas\c1_empty_longitudinal_parcel';
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(2) '-.']);
hold on;
load '.\lsp_data\empty\lsp_ect_mic_meas\c1_empty_longitudinal';
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),collar(2));
xlim ([20 300]);
ylim ([-1.5 1.5]);

%Lateral Fs
axes(handles.axes2);
```

```
load '.\lsp_data\empty\lsp_ect_mic_meas\c1_empty_lateral_fs';
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(2) '-.']);
hold on;
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),collar(2));
xlim ([20 300]);
ylim ([-1.5 1.5]);

%Lateral Rs
axes(handles.axes3);
load '.\lsp_data\empty\lsp_ect_mic_meas\c1_empty_lateral_rs';
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(2) '-.']);
hold on;
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),collar(2));
xlim ([20 300]);
ylim ([-1.5 1.5]);

%Lateral Parcel
axes(handles.axes4);
load '.\lsp_data\empty\lsp_ect_mic_meas\c1_empty_lateral_parcel';
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(2) '-.']);
hold on;
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),collar(2));
xlim ([20 300]);
ylim ([-1.5 1.5]);

%Vertical
axes(handles.axes5);
load '.\lsp_data\empty\lsp_ect_mic_meas\c1_empty_vertical';
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(2) '-.']);
hold on;
plot(fa,imag(Hxy(:,1,7)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),collar(2));
xlim ([20 300]);
ylim ([-1.5 1.5]);

%Longitudinal Trunk
axes(handles.axes8);
load '.\lsp_data\empty\lsp_ect_mic_meas\c1_empty_trunk_long_lateral';
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(2) '-.']);
hold on;
plot(fa,imag(Hxy(:,1,7)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),collar(2));
xlim ([20 300]);
ylim ([-1.5 1.5]);

%Lateral Trunk
axes(handles.axes6);
load '.\lsp_data\empty\lsp_ect_mic_meas\c1_empty_trunk_long_lateral';
plot(fa,imag(Hxy(:,1,8)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(2) '-.']);
hold on;
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),collar(2));
```

```
xlim ([20 300]);
ylim ([-1.5 1.5]);

%Vertical Trunk
axes(handles.axes7);
load '.\lsp_data\empty\lsp_ect_mic_meas\c1_empty_trunk_vertical';
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(2) '-.']);
hold on;
plot(fa,imag(Hxy(:,1,6)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),collar(2));
xlim ([20 300]);
ylim ([-1.5 1.5]);

%Pedals
axes(handles.axes9);
load '.\lsp_data\empty\lsp_ect_mic_meas\c1_empty_pedals';
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),collar(2));
xlim ([20 300]);
ylim ([-1.5 1.5]);

datacursormode on
set(handles.empty_box,'Value',1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Functions to plot according to chosen 'trim configuration' checkboxes.
function empty_box_Callback(hObject, eventdata, handles)
if (get(handles.empty_box,'Value') == get(handles.empty_box,'Max'))
    trim_check('empty','b',handles)
else
    trim_check_remove('b',handles)
end

function fs_box_Callback(hObject, eventdata, handles)
if (get(handles.fs_box,'Value') == get(handles.fs_box,'Max'))
    trim_check('front_seats','r',handles)
else
    trim_check_remove('r',handles)
end

function rs_box_Callback(hObject, eventdata, handles)
if (get(handles.rs_box,'Value') == get(handles.rs_box,'Max'))
    trim_check('rear_seats','g',handles)
else
    trim_check_remove('g',handles)
end

function cpt_box_Callback(hObject, eventdata, handles)
if (get(handles.cpt_box,'Value') == get(handles.cpt_box,'Max'))
    trim_check('carpets','k',handles)
else
```

```
    trim_check_remove('k',handles)
end

function rs_prcl_box_Callback(hObject, eventdata, handles)
if (get(handles.rs_prcl_box,'Value') == get(handles.rs_prcl_box,'Max'))
    trim_check('Rs_parcel','m',handles)
else
    trim_check_remove('m',handles)
end

function fs_rs_prcl_box_Callback(hObject, eventdata, handles)
if (get(handles.fs_rs_prcl_box,'Value') == ...
        get(handles.fs_rs_prcl_box,'Max'))
    trim_check('Fs_Rs_parcel','c',handles)
else
    trim_check_remove('c',handles)
end

function fs_rs_prcl_cpt_box_Callback(hObject, eventdata, handles)
if (get(handles.fs_rs_prcl_cpt_box,'Value') == ...
        get(handles.fs_rs_prcl_cpt_box,'Max'))
    trim_check('Fs_Rs_carpets_parcel','y',handles)
else
    trim_check_remove('y',handles)
end

function ip_box_Callback(hObject, eventdata, handles)
if (get(handles.ip_box,'Value') == get(handles.ip_box,'Max'))
    trim_check('ip','r',handles)
else
    trim_check_remove('r',handles)
end

function ip_sealed_box_Callback(hObject, eventdata, handles)
if (get(handles.ip_sealed_box,'Value') == get(handles.ip_sealed_box,'Max'))
    trim_check('ip_sealed','k',handles)
else
    trim_check_remove('k',handles)
end

function ip_fs_box_Callback(hObject, eventdata, handles)
if (get(handles.ip_fs_box,'Value') == get(handles.ip_fs_box,'Max'))
    trim_check('ip_fs','b',handles)
else
    trim_check_remove('b',handles)
end

function ip_rs_box_Callback(hObject, eventdata, handles)
if (get(handles.ip_rs_box,'Value') == get(handles.ip_rs_box,'Max'))
```

```
    trim_check('ip_rs','g',handles)
else
    trim_check_remove('g',handles)
end

function ip_rs_parcel_box_Callback(hObject, eventdata, handles)
if (get(handles.ip_rs_parcel_box,'Value') == ...
        get(handles.ip_rs_parcel_box,'Max'))
    trim_check('ip_rs_parcel','m',handles)
else
    trim_check_remove('m',handles)
end

function ip_fs_rs_parcel_box_Callback(hObject, eventdata, handles)
if (get(handles.ip_fs_rs_parcel_box,'Value') == ...
        get(handles.ip_fs_rs_parcel_box,'Max'))
    trim_check('ip_fs_rs_parcel','c',handles)
else
    trim_check_remove('c',handles)
end

function ip_carpets_box_Callback(hObject, eventdata, handles)
if (get(handles.ip_carpets_box,'Value') == get(handles.ip_carpets_box,'Max'))
    trim_check('ip_carpets','k',handles)
else
    trim_check_remove('k',handles)
end

function ip_fs_rs_carpets_parcel_box_Callback(hObject, eventdata, handles)
if (get(handles.ip_fs_rs_carpets_parcel_box,'Value') == ...
        get(handles.ip_fs_rs_carpets_parcel_box,'Max'))
    trim_check('ip_fs_rs_carpets_parcel','y',handles)
else
    trim_check_remove('y',handles)
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Function to adjust the x and y axis range of the plot.
function bt_range_Callback(hObject, eventdata, handles)
fig=handles.figure1;
dcm_obj = datacursormode(fig);
c_info = getCursorInfo(dcm_obj);
load '.\lsp_data\empty\lsp_ect_mic_meas\c1_empty_longitudinal_parcel';

axes(handles.axes1);
axis ([str2double(get(handles.edt_xlower,'String')) ...
    str2double(get(handles.edt_xupper,'String')) ...
    str2double(get(handles.edt_ylower,'String')) ...
    str2double(get(handles.edt_yupper,'String'))]);
```

```
axes(handles.axes2);
axis ([str2double(get(handles.edt_xlower,'String')) ...
    str2double(get(handles.edt_xupper,'String')) ...
    str2double(get(handles.edt_ylower,'String')) ...
    str2double(get(handles.edt_yupper,'String'))]);
axes(handles.axes3);
axis ([str2double(get(handles.edt_xlower,'String')) ...
    str2double(get(handles.edt_xupper,'String')) ...
    str2double(get(handles.edt_ylower,'String')) ...
    str2double(get(handles.edt_yupper,'String'))]);
axes(handles.axes4);
axis ([str2double(get(handles.edt_xlower,'String')) ...
    str2double(get(handles.edt_xupper,'String')) ...
    str2double(get(handles.edt_ylower,'String')) ...
    str2double(get(handles.edt_yupper,'String'))]);
axes(handles.axes5);
axis ([str2double(get(handles.edt_xlower,'String')) ...
    str2double(get(handles.edt_xupper,'String')) ...
    str2double(get(handles.edt_ylower,'String')) ...
    str2double(get(handles.edt_yupper,'String'))]);
axes(handles.axes6);
axis ([str2double(get(handles.edt_xlower,'String')) ...
    str2double(get(handles.edt_xupper,'String')) ...
    str2double(get(handles.edt_ylower,'String')) ...
    str2double(get(handles.edt_yupper,'String'))]);
axes(handles.axes7);
axis ([str2double(get(handles.edt_xlower,'String')) ...
    str2double(get(handles.edt_xupper,'String')) ...
    str2double(get(handles.edt_ylower,'String')) ...
    str2double(get(handles.edt_yupper,'String'))]);
axes(handles.axes8);
axis ([str2double(get(handles.edt_xlower,'String')) ...
    str2double(get(handles.edt_xupper,'String')) ...
    str2double(get(handles.edt_ylower,'String')) ...
    str2double(get(handles.edt_yupper,'String'))]);
axes(handles.axes9);
axis ([str2double(get(handles.edt_xlower,'String')) ...
    str2double(get(handles.edt_xupper,'String')) ...
    str2double(get(handles.edt_ylower,'String')) ...
    str2double(get(handles.edt_yupper,'String'))]);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Function to lauch the simulation plot (all microphones array in the
%vehicle cavity) and view the mode shapes.
function bt_simul_Callback(hObject, eventdata, handles)
fig=handles.figure1;
dcm_obj = datacursormode(fig);
c_info = getCursorInfo(dcm_obj);

```

```
figure(2);
cla;
hold on;

if (get(handles.empty_box,'Value') == get(handles.empty_box,'Max'))
    config_simul('empty','b',c_info)
end

if (get(handles.fs_box,'Value') == get(handles.fs_box,'Max'))
    config_simul('front_seats','r',c_info)
end

if (get(handles.rs_box,'Value') == get(handles.rs_box,'Max'))
    config_simul('rear_seats','g',c_info)
end

if (get(handles.cpt_box,'Value') == get(handles.cpt_box,'Max'))
    config_simul('carpets','k',c_info)
end

if (get(handles.rs_prcl_box,'Value') == get(handles.rs_prcl_box,'Max'))
    config_simul('Rs_parcel','m',c_info)
end

if (get(handles.fs_rs_prcl_box,'Value') == get(handles.fs_rs_prcl_box,'Max'))
    config_simul('Fs_Rs_parcel','c',c_info)
end

if (get(handles.fs_rs_prcl_cpt_box,'Value') == ...
        get(handles.fs_rs_prcl_cpt_box,'Max'))
    config_simul('Fs_Rs_carpets_parcel','y',c_info)
end

if (get(handles.ip_box,'Value') == get(handles.ip_box,'Max'))
    config_simul('ip','r',c_info)
end

if (get(handles.ip_fs_box,'Value') == get(handles.ip_fs_box,'Max'))
    config_simul('ip_fs','b',c_info)
end

if (get(handles.ip_rs_box,'Value') == get(handles.ip_rs_box,'Max'))
    config_simul('ip_rs','g',c_info)
end

if (get(handles.ip_rs_parcel_box,'Value') == ...
        get(handles.ip_rs_parcel_box,'Max'))
    config_simul('ip_rs_parcel','m',c_info)
end
```

```
if (get(handles.ip_fs_rs_parcel_box,'Value') == ...
        get(handles.ip_fs_rs_parcel_box,'Max'))
    config_simul('ip_fs_rs_parcel','c',c_info)
end

if (get(handles.ip_carpets_box,'Value') == get(handles.ip_carpets_box,'Max'))
    config_simul('ip_carpets','k',c_info)
end

if (get(handles.ip_fs_rs_carpets_parcel_box,'Value') == ...
        get(handles.ip_fs_rs_carpets_parcel_box,'Max'))
    config_simul('ip_fs_rs_carpets_parcel','y',c_info)
end

if (get(handles.ip_sealed_box,'Value') == get(handles.ip_sealed_box,'Max'))
    config_simul('ip_sealed','k',c_info)
end
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Function to plot the graph(s) when the checkbox is checked.
function trim_check(x,y,z)

load .\frequency.mat % To load the frequency array, fa.
%Longitudinal
axes(z.axes1);
hold on;
load(['.\lsp_data\' x '\lsp_ect_mic_meas\c1_' x '_longitudinal_parcel'])
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[y '-.']);
load(['.\lsp_data\' x '\lsp_ect_mic_meas\c1_' x '_longitudinal'])
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),y);

%Lateral Fs
axes(z.axes2);
hold on;
load(['.\lsp_data\' x '\lsp_ect_mic_meas\c1_' x '_lateral_fs'])
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[y '-.']);
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),y);

%Lateral Rs
axes(z.axes3);
hold on;
load(['.\lsp_data\' x '\lsp_ect_mic_meas\c1_' x '_lateral_rs'])
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[y '-.']);
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),y);

%Lateral Parcel
axes(z.axes4);
hold on;
```

```
load(['.\lsp_data\' x '\lsp_ect_mic_meas\c1_' x '_lateral_parcel'])
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[y '-.']);
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),y);

%Vertical
axes(z.axes5);
hold on;
load(['.\lsp_data\' x '\lsp_ect_mic_meas\c1_' x '_vertical'])
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[y '-.']);
plot(fa,imag(Hxy(:,1,7)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),y);

%Longitudinal Trunk
axes(z.axes8);
hold on;
load(['.\lsp_data\' x '\lsp_ect_mic_meas\c1_' x '_trunk_long_lateral'])
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[y '-.']);
plot(fa,imag(Hxy(:,1,7)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),y);

%Lateral Trunk
axes(z.axes6);
hold on;
load(['.\lsp_data\' x '\lsp_ect_mic_meas\c1_' x '_trunk_long_lateral'])
plot(fa,imag(Hxy(:,1,8)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[y '-.']);
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),y);

%Vertical Trunk
axes(z.axes7);
hold on;
load(['.\lsp_data\' x '\lsp_ect_mic_meas\c1_' x '_trunk_vertical'])
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[y '-.']);
plot(fa,imag(Hxy(:,1,6)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),y);

%Pedals
axes(z.axes9);
hold on;
load(['.\lsp_data\' x '\lsp_ect_mic_meas\c1_' x '_pedals'])
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),y);
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Function to plot the graph(s) when the checkbox is unchecked.
% The plot is removed based on color selection.
function trim_check_remove(y,z)
%Longitudinal
axes(z.axes1);
h = findobj('color',y);
set(h,'Visible','off');

%Lateral Fs
axes(z.axes2);
```

```
h = findobj('color',y);
set(h,'Visible','off');
%Lateral Rs
axes(z.axes3);
h = findobj('color',y);
%set(h,'Color','white');
set(h,'Visible','off');
%Lateral Parcel
axes(z.axes4);
h = findobj('color',y);
set(h,'Visible','off');
%Vertical
axes(z.axes5);
h = findobj('color',y);
set(h,'Visible','off');
%Longitudinal Trunk
axes(z.axes8);
h = findobj('color',y);
set(h,'Visible','off');
%Lateral Trunk
axes(z.axes6);
h = findobj('color',y);
set(h,'Visible','off');
%Vertical Trunk
axes(z.axes7);
h = findobj('color',y);
set(h,'Visible','off');
%Pedals
axes(z.axes9);
h = findobj('color',y);
set(h,'Visible','off');
```

B.1.2. A-MTF Matlab Code

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% A-MTF example code - Empty trim Vs Full trim comparisons for Roof
close all;
clear all;
figure(1);
```

```
hold on;

load '.\empty\lsp_ect_acc_meas\c1_empty_roof';
plot(fa,20*log10(abs(Hxy(:,1,2)).*10^-2./((4*pi*(7.5*10^-2)^2)*10*10^-3)...
    ./5e-8),'k');

load '.\ip_fs_rs_carpets_parcel\lsp_ect_acc_meas\c1_ip_fs_rs_carpets_parcel_roof_100';
plot(fa,20*log10(abs(Hxy(:,1,2)).*10^-2./((4*pi*(7.5*10^-2)^2)*100*10^-3)...
    ./5e-8),'k-.');

set(gca, 'LineWidth',2,...
          'FontSize',14);

legend('Empty','Full');
ylabel('Levels(a/q^,) [dB ref 5e-8]');
xlabel('Frequency [Hz]');
xlim ([20 120]);
ylim ([60 140]);
```

B.1.3. Mass-loading Matlab Code

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% No mass loading and mass loading -
% Longitudinal LSP excitation microphone 1&12 measure
% Front seats trim configuration.
close all;
clear all;
collar=['rbgkmcyrbgkmcyrbgkmcy'];

figure(1);
hold on;

%No load
load '.\front_seats\lsp_ect_mic_meas\c1_front_seats_longitudinal_parcel';
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(1) '-.']);

load '.\front_seats\lsp_ect_mic_meas\c1_front_seats_longitudinal';
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(1)]);

%Load rear window
load '.\front_seats\lsp_ect_mic_meas\c1_front_seats_longitudinal_parcel_load_rear_window';
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(2) '-.']);

load '.\front_seats\lsp_ect_mic_meas\c1_front_seats_longitudinal_load_rear_window';
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(2)]);

%Load roof
load '.\front_seats\lsp_ect_mic_meas\c1_front_seats_longitudinal_parcel_load_roof';
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(3) '-.']);
```

```matlab

load '.\front_seats\lsp_ect_mic_meas\c1_front_seats_longitudinal_load_roof';
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(3)]);

%Load parcel
load '.\front_seats\lsp_ect_mic_meas\c1_front_seats_longitudinal_parcel_load_parcel';
plot(fa,imag(Hxy(:,1,2)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(4) '-.']);

load '.\front_seats\lsp_ect_mic_meas\c1_front_seats_longitudinal_load_parcel';
plot(fa,imag(Hxy(:,1,9)).*5.62.*(10^-2)./((4*pi*(7.5*10^-2)^2)),[collar(4)]);

set(gca, 'LineWidth',2,...
         'FontSize',14);

xlim([20 100]);
ylim ([-0.8 0.8]);
legend('Mic 1 No Load','Mic 12 No Load','Mic 1 Load Rear Wind.',...
    'Mic 12 Load Rear Wind.','Mic 1 Load Roof','Mic 12 Load Roof',...
    'Mic 1 Load Parcel','Mic 12 Load Parcel');
ylabel('Imag(p/q^,) [Pa/m^3/s^2]');
xlabel('Frequency [Hz]');

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% LSP excitation vibration measurement at Roof
% Front seats trim configuration.
figure(2);
hold on;

load '.\front_seats\lsp_ect_acc_meas\c1_front_seats_roof';
plot(fa,20*log10(abs(Hxy(:,1,2)).*10^-2./((pi*(7.5*10^-2)^2)*31.6*10^-3)...
    ./5e-8),collar(1));

load '.\front_seats\lsp_ect_acc_meas\c1_front_seats_roof_load_rear_window';
plot(fa,20*log10(abs(Hxy(:,1,2)).*10^-2./((pi*(7.5*10^-2)^2)*31.6*10^-3)...
    ./5e-8),collar(2));

load '.\front_seats\lsp_ect_acc_meas\c1_front_seats_roof_load_parcel';
plot(fa,20*log10(abs(Hxy(:,1,2)).*10^-2./((pi*(7.5*10^-2)^2)*31.6*10^-3)...
    ./5e-8),collar(3));

set(gca, 'LineWidth',2,...
         'FontSize',14);

xlim([20 100]);
legend('No Load','Load Rear Wind.','Load Parcel');
ylabel('Levels(a/q^,) [dB ref 5e-8]');
xlabel('Frequency [Hz]');
```

B.2. Mechanical Excitation Matlab Code

B.2.1. NTF and VTF Matlab Code

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Matlab GUI program to average and analyze the NTF and VTF
% of the back suspension and chasis mounts.
function varargout = car_interior_ntf_avg_rear_z_ver2_sqr(varargin)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', ...
                   @car_interior_ntf_avg_rear_z_ver2_sqr_OpeningFcn, ...
                   'gui_OutputFcn',  ...
                   @car_interior_ntf_avg_rear_z_ver2_sqr_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

function car_interior_ntf_avg_rear_z_ver2_sqr_OpeningFcn(hObject, ...
    eventdata, handles, varargin)

handles.output = hObject;
guidata(hObject, handles);

x_min=20;
x_max=250;
y_min=30;
y_max=100;

eng_mnt_Hxy=zeros(1,3201)';

load frequency.mat;

for j=1:15

    axes_hd=['handles.axes' int2str(j)];
    eval(['axes(' axes_hd ');']);
    hold on;
    meas_pos = j+1;

```

```
    if meas_pos>7
        for i=1:6
            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_301z']);
            eng_mnt_Hxy=abs(Hxy(:,1,meas_pos)).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_302z']);
            eng_mnt_Hxy=abs(Hxy(:,1,meas_pos)).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_321z']);
            eng_mnt_Hxy=abs(Hxy(:,1,meas_pos)).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_341z']);
            eng_mnt_Hxy=abs(Hxy(:,1,meas_pos)).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_401z']);
            eng_mnt_Hxy=abs(Hxy(:,1,meas_pos)).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_402z']);
            eng_mnt_Hxy=abs(Hxy(:,1,meas_pos)).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_421z']);
            eng_mnt_Hxy=abs(Hxy(:,1,meas_pos)).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_441z']);
            eng_mnt_Hxy=abs(Hxy(:,1,meas_pos)).^2 + eng_mnt_Hxy;

            eng_mnt_Hxy = eng_mnt_Hxy./8;

            plot(fa,20*log10((eng_mnt_Hxy).^(0.5)./5e-8),[collar(i)]);

            eng_mnt_Hxy=zeros(1,3201)';
        end

        xlim ([x_min x_max]);
        ylim ([y_min y_max]);

    else

        for i=1:6
            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_301z']);
```

```
            eng_mnt_Hxy=(abs(Hxy(:,1,meas_pos))).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_302z']);
            eng_mnt_Hxy=(abs(Hxy(:,1,meas_pos))).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_321z']);
            eng_mnt_Hxy=(abs(Hxy(:,1,meas_pos))).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_341z']);
            eng_mnt_Hxy=(abs(Hxy(:,1,meas_pos))).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_401z']);
            eng_mnt_Hxy=(abs(Hxy(:,1,meas_pos))).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_402z']);
            eng_mnt_Hxy=(abs(Hxy(:,1,meas_pos))).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_421z']);
            eng_mnt_Hxy=(abs(Hxy(:,1,meas_pos))).^2 + eng_mnt_Hxy;

            load (['.\hammer_data\hammer_config' int2str(i) '\c1_config'...
                int2str(i) '_441z']);
            eng_mnt_Hxy=(abs(Hxy(:,1,meas_pos))).^2 + eng_mnt_Hxy;

            eng_mnt_Hxy = eng_mnt_Hxy./8;

            plot(fa,20*log10((eng_mnt_Hxy).^(0.5)),[collar(i)]);

            eng_mnt_Hxy=zeros(1,3201)';

        end

        xlim ([x_min x_max]);
        ylim ([y_min y_max]);
    end
end
axes(handles.axes1);axis([50 100 50 100]);
axes(handles.axes2);axis([50 100 50 100]);
axes(handles.axes3);axis([50 100 50 100]);
axes(handles.axes4);axis([50 100 50 100]);
axes(handles.axes5);axis([50 100 50 100]);
axes(handles.axes6);axis([50 100 50 100]);
```