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Investigation of effect on the acoustic transfer function in a vehicle cabin according to change of configuration

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ABSTRACT

Recently, the various audio information are presented in a vehicle cabin not only for a driver but also other passengers and various sound field control methods had been applied for various purpose such as personal audio. Basically, the measurement of acoustic transfer function in a vehicle cabin is relatively easier than other living spaces because of its small volume and movement of objects. However the effect of configuration cannot be ignored due to the relatively large volume change, especially related to the change of number of passengers. Here, the effect on the acoustic transfer function in a vehicle cabin according to change of configuration is observed and method to estimating robust solution is investigated.

Keywords: Acoustic transfer function, sound field control, vehicle interior

1. INTRODUCTION

Nowadays, various audio information is presented in a vehicle cabin throughout its car audio system. In the early stage of car, e.g. 19 C, the vehicle do not had a space can called as 'interior space' because its cabin was very small and not enclosed. In the process of advances in 20 C, the audio system was installed for every car. In the several decades ago, the car audio was relatively simple configuration consists of couple of loudspeakers and it has been improved by applying various control with multi-channel audio [1]. Recently, various sound field control method has been applied to implement the multi-zone control in a vehicle cabin [2-5]. In order to implement these various sound field control in interior space, it is essential to apply the acoustic transfer matrix for the process of estimating the control filter. Because the estimated solution largely depends on this transfer function, the precise information of transfer function is important. However, it is not always possible to obtain and apply the exact acoustic transfer function and the problem of sound field control in vehicle interior may not be exception. In this study, the deviation of TF was investigated based on the actual measurement in a vehicle cabin.

2. PROBLEM DESCRIPTION

2.1 Acoustic transfer function in a vehicle cabin

The acoustical transfer function (TF) is the path of sound transmission from sources to receivers. In case of interior space, the TF includes the direct and reverberant components induced by various boundary condition of space. In case of vehicle cabin, the volume of space is relatively small in comparison with other type of living space. Also, the movement of objects is not frequent and its range is also small. These characteristics are suitable condition to apply the sound field control method because the TF would be stable as time passed. On the other hands, the space is relatively occupied because of its small volume and it can induce relatively large amount of change according different layouts including the number of passengers. This means that the different transfer matrix for corresponded layout should be applied for exact solution for precise control. However this approach is not practical because the real-time adaptation of control filter should be applied according to the layout change. Therefore, the application of robust solution to the layout change would be more practical approach. To this ends, it is necessary to investigate the amount of change induced by layout change in quantified manner as a baseline.

The measurement of spatial distribution of sound field is conducted by the discrete spatial

positions with microphone and dummy head system. The measured result will be obtained by the matrix form. For the problem of sound field control in a vehicle cabin, the area to be controlled is the ear position of driver and passengers. Here, not only ear position but also the surface around the head were measured by using the arc-shaped microphone array.

Four loudspeakers were originally installed in the test vehicle and 10 additional 2 inch sources were installed at the headrest positions as shown in Fig. 1(a). Figure 1(b) shows the positions of the source system.

(a) (b)

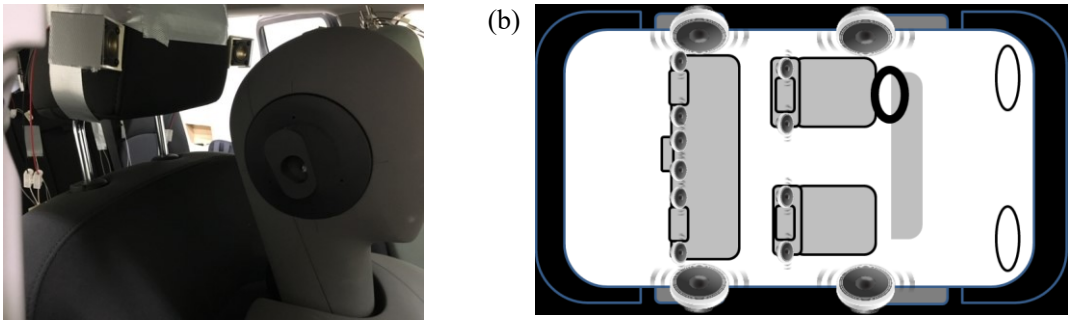

Figure 1 – (a) Photo of additional sources at headrest position, (b) tested source positions,

2.2 Test layouts

To evaluate the deviation of TF induced by the layout of vehicle inside, an actual measurement of transfer matrix was conducted with various layouts. Here, the change of number of passenger and effect of passenger's posture were mainly investigated. The case that no person seated at driver's seat was not considered because this is still not usual condition for conventional vehicle driving scenario. Table 1 shows the list the tested layouts. Instead of real passengers, the dummy heads were place on the seat.

Table 1 – List of the test layouts

Index	Driver seat	Front passenger seat	Rear passenger seat (Driver side)	Rear passenger seat (Driver side)
Set 1	Dummy 1	Empty	Empty	Empty
Set 2	Dummy 1	Dummy 2	Empty	Empty
Set 3	Dummy 1	Dummy 2	Empty	Dummy 3
Set 4	Dummy 1	Dummy 2	Dummy 3	Empty
Set 5	Dummy 1	Empty	Empty	Dummy 3
Set 6	Dummy 1	Empty	Dummy 2	Dummy 3
Set 7	Dummy 1	Empty	Dummy 2	Empty

3. MEASUREMENT OF TF

3.1 Measurement setup

The measurement was conducted in an SUV type vehicle for 5 passengers and the test vehicle was placed in a semi-anechoic chamber. Figure 2 shows the configuration of the measurement system. The array microphones (B&K Type 4958) were applied to the array system and the microphone out signals were recorded by the multi-channel DAQ system (B&K LAN-XI modules + B&K PULSE) with sampling rate of 32 kHz. As the test signal, the band limited white noise to up 12.8 kHz is supplied by the generator module (B&K LAN-XI Type 3060) to the multichannel amplifier system (minDSP 16CH).

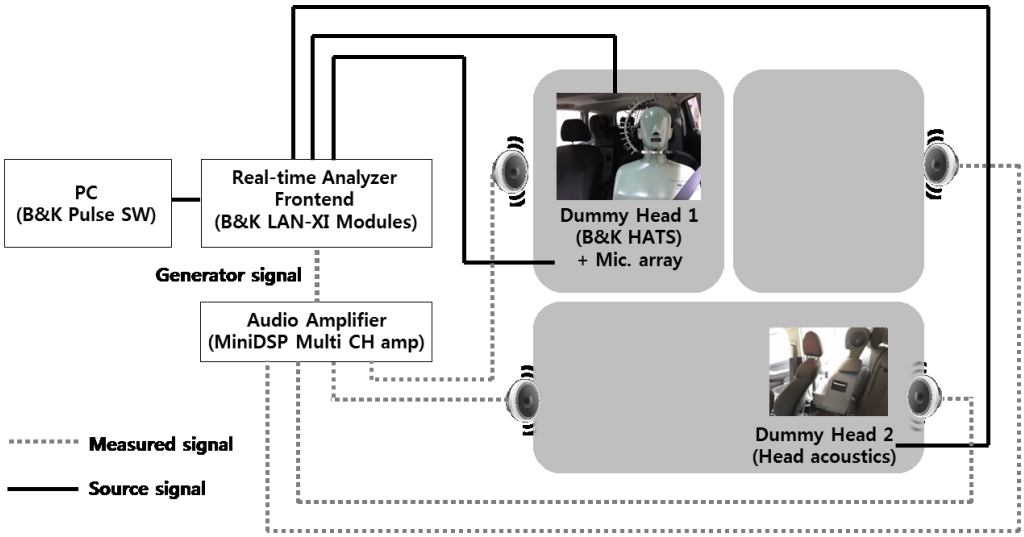

Figure 2 – Configuration of the measurement system.

To measure the surface around the head, the arc-shaped array shown in Fig. 3 were designed and attached on the neck of dummy head (B&K HATS). The spacing between microphones is 10° for the vertical direction and it was rotated 20° step to horizontal direction. Also, this dummy head set on the zig which is possible to change of inclination and two different case, upright and lean to back of seat were observed.

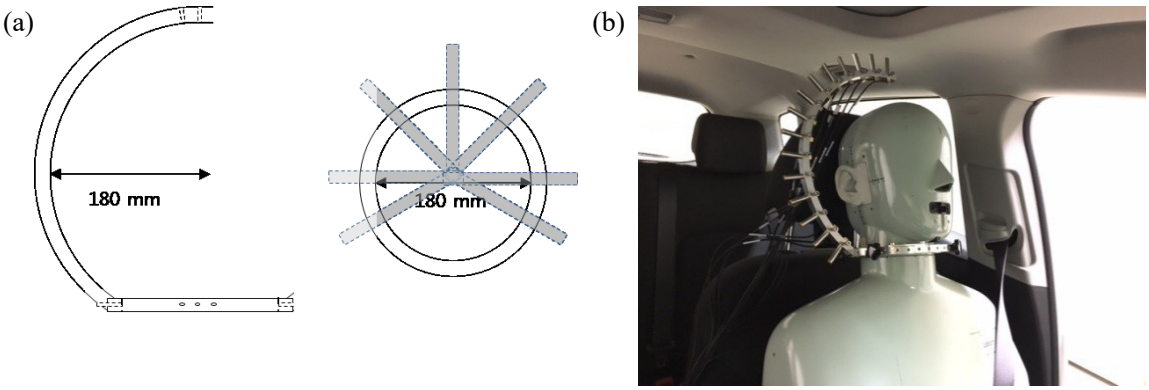

Figure 3 – Microphone array to measure the acoustical TF on the surface around a dummy head: (a) Array design, (b) example of installation to the dummy head.

3.2 Result of TF measurement

Figure 4 shows an example of the measured binaural response and the example of measured response distribution around the head is shown in Fig. 5. These data can be applied to design the filter to control sound field.

To observe the deviation induced by the change of number of passengers, the measurements were conducted with the layouts listed in Table 1. Figure 6 shows the example of the change of the frequency response induced by the number of passengers and the difference from the layout (driver only) are shown in Fig. 7. Most of frequency range, the deviation is bounded ±2 dB however the frequency range near of the trough in the response, shows much higher deviation. More drastic deviation was observed if the posture of passenger is changed as shown in Fig. 8. The tendency of deviation is also changed according to the relative position between sources and receiver.

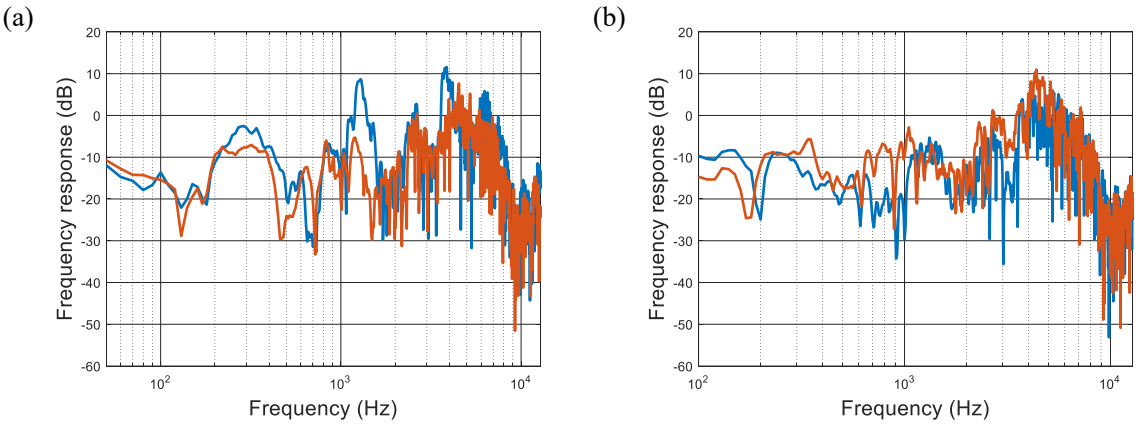

Figure 4 – Example of the measured response at ear position: (a) loudspeaker at near of driver seat is ON, (b) loudspeaker at near of front passenger seat is ON (blue line: left ear, red line: right ear).

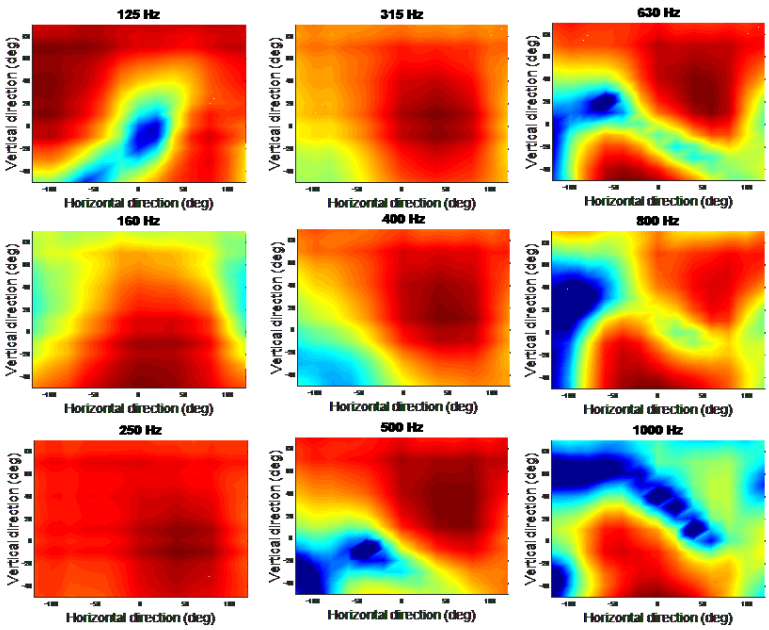

Figure 5 – Example of the measured response distribution around the head (Driver seat, Loudspeaker at near of driver seat is ON).

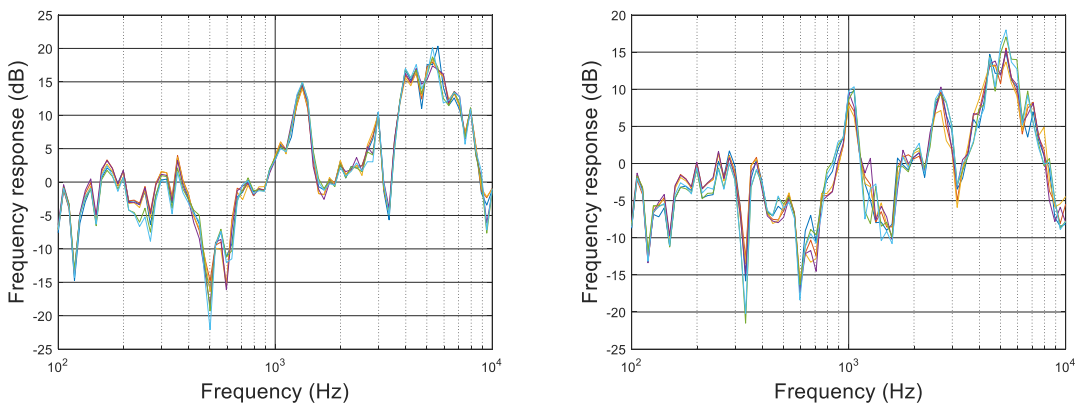

Figure 6 – Example of the change of the frequency response induced by the number of passengers (Driver seat, Loudspeaker at near of driver seat is ON).

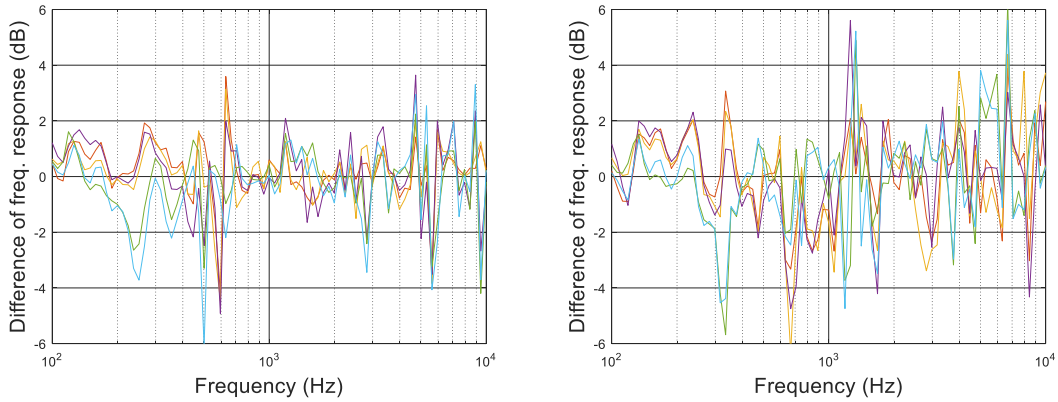

Figure 7 – Example of the difference of frequency response according to the change of number of passenger, reference to the case of driver only (LEFT: left ear, RIGHT: right; Driver seat, Loudspeaker at near of driver seat is ON).

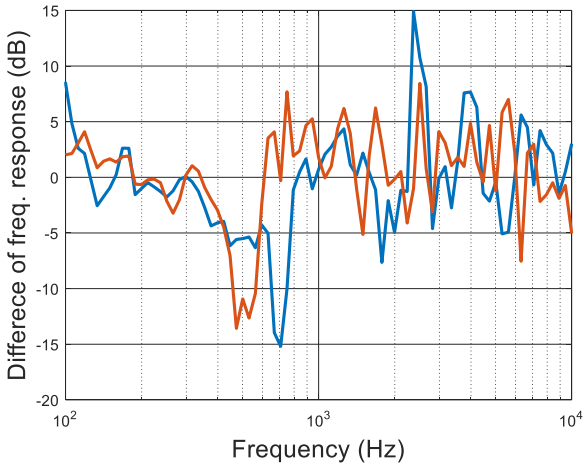

Figure 8 – Example of the difference of frequency response according to passenger's posture (Upright and lean to back of seat; Driver seat, Loudspeaker at near of driver seat is ON).

4. CONCLUSIONS

The deviations of acoustical transfer matrix induced by the change of number of passengers are investigated in a real vehicle condition. To evaluate the deviation of TF induced by the layout of vehicle inside, an actual measurement of transfer matrix was conducted with various layouts. Here, the change of number of passenger and effect of passenger's posture were mainly investigated. The measurement was conducted in an SUV type vehicle for 5 passengers and the test vehicle was placed in a semi-anechoic chamber.

In the example measured at the driver position, the deviation is bounded ±2 dB however the frequency range near of the trough in the response, shows much higher deviation. More drastic deviation was observed if the posture of passenger is changed. The tendency of deviation is also changed according to the relative position between sources and receiver.

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