NOTE

Acoustic measurement trend in a car compartment

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1 Introduction

In the heyday of AM radio, the sounds created by car audios with one speaker in an instrument panel were deemed acceptable if they did not cause discomfort to listeners. Then, the advent of compact cassettes and CDs brought the demand to broaden playback frequency range and dynamic range.

Today, speakers are in multi-way systems reflecting the broadening of the playback frequency range and dynamic range, and many cars are now equipped with a system using ten or more speakers in order to respond to DVD5.1ch system. **(Fig. 1)**[1)]

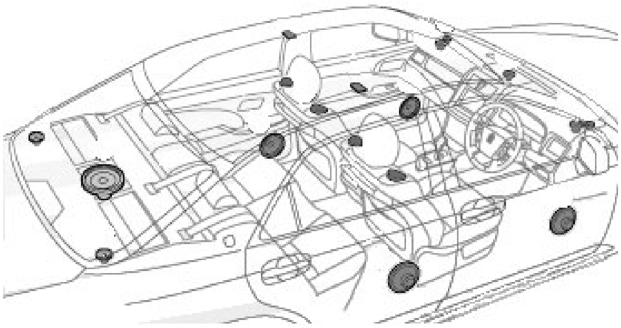

Fig.1 Example of speaker layout (TOYOTA 08 CROWN)

With these changes in audio systems, the measuring instruments to evaluate acoustic characteristics have also been evolving. In olden times, major measuring instruments adopted an analog method that was only to record the signal levels of sounds picked up through a microphone on roll paper by pen recorder. Then, with the development of digital equipment, many measuring instruments have been adopting FFT analyzer that enables frequency analysis by itself. **(Fig. 2)** Today's major acoustic measuring instruments adopt a method using computer processing, as the personal computer capabilities have improved. This makes acoustic processing more flexible and enables original acoustic analysis / data display by each company easily, unlike the times when dedicated measuring instruments were used.

Fig.2 Example of portable FFT analyzer (CF-360 produced by Ono Sokki)

2 Characteristics of acoustic measurement in a car compartment

Compared to a normal listening room, a car compartment is a very special sound field. As the car compartment has only approx. 3m^3 space and is full of sound-absorbing objects such as seats, reverberation of sound is very little. On the other hand, as the reflective objects such as glass windows are close to speakers in a car compartment, naturally there are large early-reflected sounds close to the direct sound. Listeners feel the reflected sounds as the changed timbre of direct sounds, not as reverberation of sounds.

Fig. 3 shows the example of impulse response in a listening room and **Fig. 4** shows the example of impulse response in a car compartment. The example of measurement in a listening room **(Fig. 3)** shows that the reflected sound is still present even 100ms later. On the other hand, the measurement data in a car compartment **(Fig. 4)** shows that the reflection converges within 20ms.

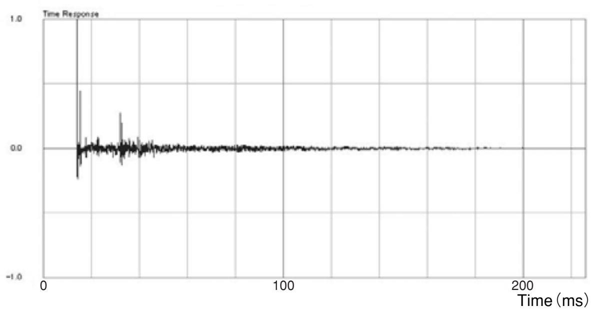

Fig.3 Example of impulse response in a listening room

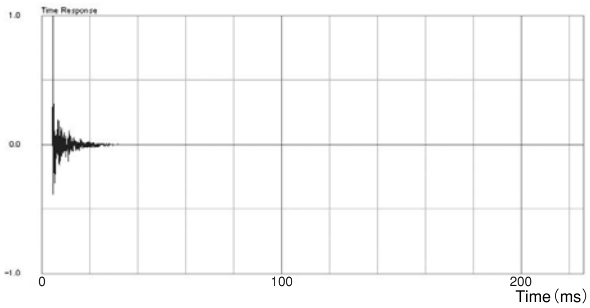

Fig.4 Example of impulse response in a car compartment

The large reflected sounds such as by glass windows in a car change greatly even by the slight movement of a microphone at acoustic measurement, since the reflections come from the specific direction. Both **Fig. 5** and **Fig. 6** are the correlation graphs of the results calculated with impulse responses picked up by two microphones set 5cm apart. They show the results of the calculated similarity between two impulse response waveforms by sliding the waveforms within ±1ms. **Fig. 6** shows the measured data by reproducing signal hrough the front door speakers in a car compartment, and **Fig. 5** shows the data measured in a listening room where the positional relation for measurement was similar to the one in a car compartment.

The listening room data of **Fig. 5** shows a very clear correlation peak, and the peak value is 0.9 or more. Meanwhile, the car compartment data of **Fig. 6** shows no clear correlation peak, and the unclear peak value is approx. 0.6. These data indicate that the acoustic characteristics in a car compartment vary greatly depending on the measurement position, comparing the data in a car compartment to that in a listening room. In other words, the acoustic characteristics vary greatly depending on the movement of seats or passengers' heads. Therefore, as for the acoustic measurement in a car compartment, it is important to define how to express these acoustic characteristics by data.

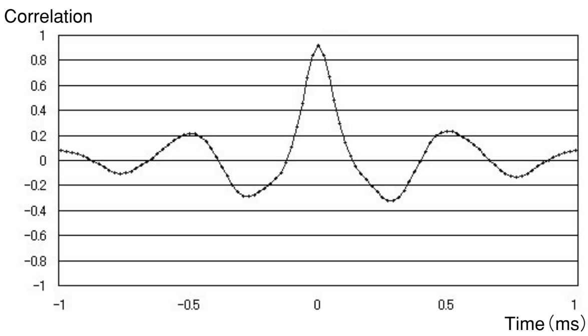

Fig.5 Correlation graph in a listening room

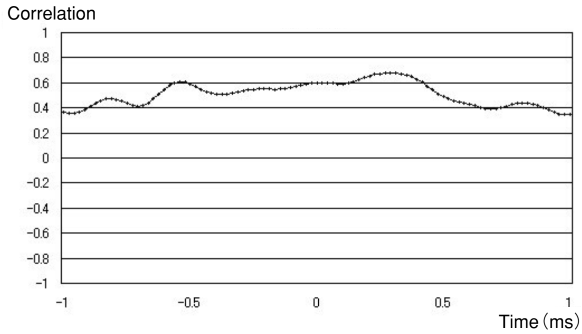

Fig.6 Correlation graph in a car compartment

There are other major characteristics of the sound field in a car compartment. For example, since speakers are normally installed in both front doors or both ends of the instrument panel due to the restriction of available positions of on-board speakers to be installed, passengers' positions are unsymmetrical to the speaker arrangement and also the stereo balance is off. To express the localization status of these sounds, the measurements of interaural cross-correlation using HATS (Head And Torso Simulator) are frequently conducted. (**Fig. 7**)

Fig.7 HATS (Head and Torso Simulator)

3 Introduction of acoustic measurement method in a car compartment

In this section, we introduce a general acoustic measurement method in a car compartment. The most general and conventional method is to measure frequency response. The frequency response is generally recorded by a microphone while reproducing sine waves through speakers. However, as explained above in Section 2, in a car compartment, as the initial part of the sound following the direct sound contains large reflection sound, phases face excessive interference between these reflection sounds. **Fig. 8** shows the frequency response using sine waves in a car compartment, which has fine peak-dips. As it is generally said that people cannot feel aurally the peak-dips in the range less than one-third of an octave band, when measuring the frequency response in a car compartment, it is common to conduct 1/3 octave-band analysis by reproducing pink noises. **Fig. 9** shows the result obtained by conducting the 1/3 octave-band frequency response in the car of **Fig. 8**. Compared to **Fig. 8**, **Fig. 9** is more easy-to see than **Fig. 8,** since **Fig. 9** has less peak-dips by being averaged.

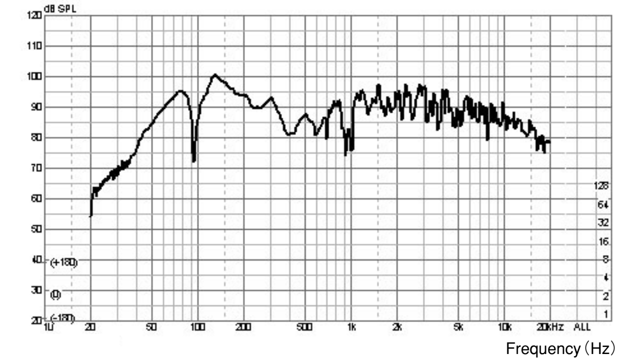

Fig.8 Measurement of Frequency Response (Sine-wave sweep)

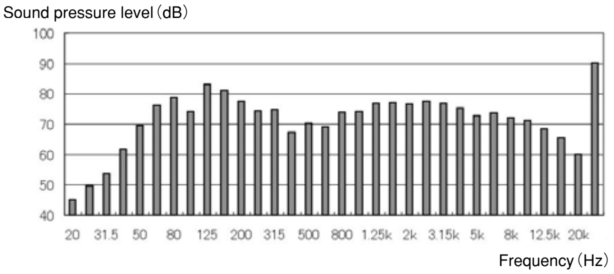

Fig.9 Frequency Response (1/3 octave band analysis)

HATS may be used for the measurement of frequency response on the assumption of condition with passengers in a car. However, since the characteristics vary by the sound arrival direction due to the head part or the pinna in the measurement with HATS, it is difficult to evaluate the absolute value of the frequency response. Hence, for the evaluation of the frequency response, it is common to evaluate the difference between the responses of the right and the left ears. **Fig. 10** is an example that shows the differences of the frequency response obtained at both ears of HATS set on a driver seat during reproducing through the front speakers in a car. (Frequency response of a right ear based on the ones of a left ear) It shows that the level differences between both ears vary depending on the frequency.

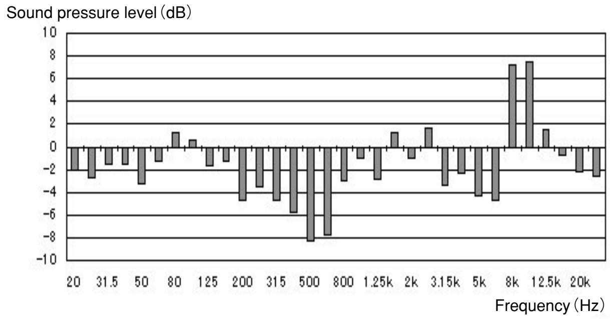

Fig.10 Difference of Frequency Response (Right ear / left ear of HATS)

On the other hand, now that the instrument for acoustic measurement using a personal computer is mainstream, it is common to use the data obtained by impulse response measurement for various analyses. Here are the common analysis items using the impulse response data whose examples are shown in Section 2 above. **Fig. 11** is an example within these items, showing the calculated "cumulative spectra" of front door speakers. This figure indicates that vibrating frequencies last long, and it is used for vibration condition analyses of doors or trim.

[Analysis item example by using impulse responses]

- **Calculation of frequency response by FFT analysis**
- **Calculation of "cumulative spectra" with the frequency characteristics accumulated by gradually sliding analysis window of FFT**
- **Reverberation analysis (reverberation time, Value C: Clarity, Value D: Definition, etc.)**
- **Clearness analysis (STI: Speech Transmission Index, RASTI: Rapid STI, etc.)**
- **Calculation of energy response**

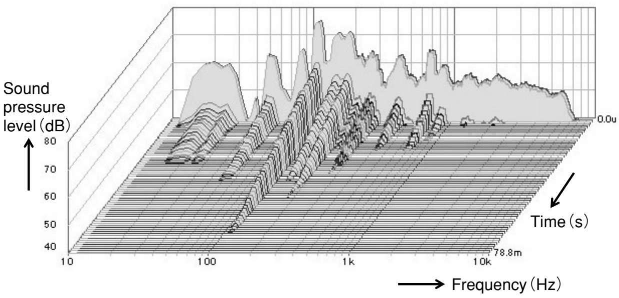

Fig.11 Cumulative spectra

4 Efforts of FUJITSU TEN

FUJITSU TEN has developed original audio systems, the world's first products for on-board use, and more. In this section, we introduce these original efforts of FUJITSU TEN regarding the original acoustic measuring methods that we have developed to accompany these product developments.

4.1 Measurement of spatial information

FUJITSU TEN has commercialized a sound field controller (α-5000P), which was a world's first product for on-board use in 1989.[2] This product adopted the system reproducing sound field inside a car compartment as in a concert hall and elsewhere by adding reflection sounds. In the development process for this product, since we needed to analyze the reflection sound structure in the actual sound field of a concert hall, we developed a measuring system by closely located fourpoint-microphone measurement with the cooperation of Waseda University.[3] The closely located fourpoint-microphone measurement is to calculate the reflection sound locations (virtual sound sources) using the time differences of the impulse responses measured by closely located fourpoint-microphone and display them. **Fig. 12** is the example (directional diffusion figure) measured in a concert hall. The direction and the length of a line indicate the direction and the loudness of each reflection sound. This closely located ourpoint-microphone measurement is also used to understand the effect in a car compartment where the sound field is controlled.

The instrument for measuring spatial information by the closely located fourpoint-microphone measurement has been miniaturized in accordance with the improvement of personal computers and digital equipment. We have started to develop Windows-compliant analysis software since 2000 and have operated it since 2004.

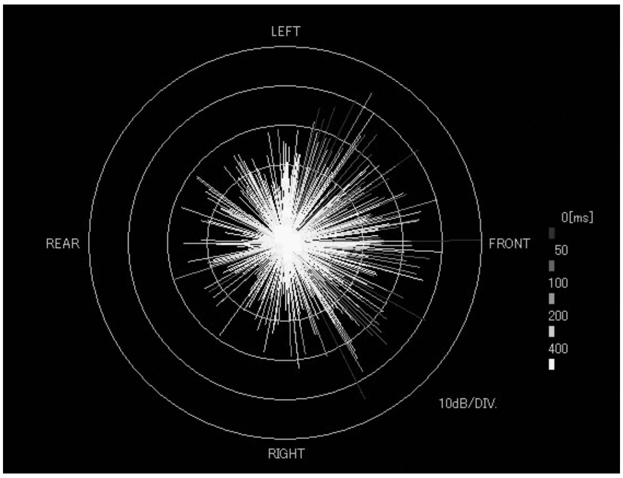

Fig.12 Distribution figure of virtual sound source in concert hall

In order to create the sound field with naturally broadening sense in a car compartment, we adopted "Spatial Control" system for TOYOTA CROWN in 2008.[4] In this process, we developed an original acoustic measuring instrument. This instrument enables various data analyses using personal computers, in addition to the same function of the instruments to calculate the virtual sound source by the closely located fourpoint-microphone measurement. This instrument adopts four-input and one-output structure, and analyzes data by a personal computer with measuring four-channel impulse responses. The correlation graphs in **Fig. 5** and **Fig. 6** are the analysis examples. The instrument also analyzes the variations of frequency characteristics and reflection sound conditions to evaluate the sound field uniformity. **Fig. 13** is the directional diffusion figure analyzed by the new measuring instrument with setting speakers at the front in a listening room. The Y-axis indicates the data of the front direction. The data is indicated in three dimensions and can be seen from other viewpoints in a computer screen. Also, **Fig. 14** shows the result of the same data but indicated in wind direction. The round point in the figure shows the virtual sound source location and the line length shows the loudness.

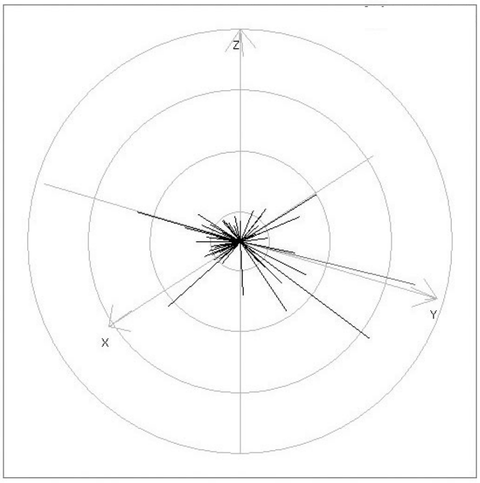

Fig.13 Figure of directional diffusion in a listening room

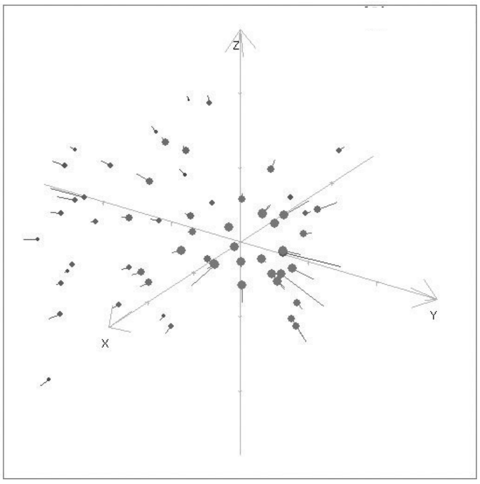

Fig.14 Figure of directional diffusion in a listening room (Wind direction indication)

4.2 Measurement of transient characteristics

We have commercialized a speaker[5] in 2000 with the time domain system that is excellent in transient characteristics. In the development process of this product, we have also developed original analysis method enabling the evaluation of transient characteristics from various angles. Although impulse responses indicate their transient characteristics, since it is difficult to understand the transient characteristics by comparing only the waveforms, we provide the second treatment to impulse responses in order to make the data clearer.

For the example of the second treatment provided, **Fig. 15** shows the multi impulse responses of a speaker measured in an anechoic chamber. The method is to measure the impulse responses at approx. 800 points around the speaker by a robot, and then to compose the waveforms using a personal computer. The figure shows the process of waveform broadening. This data can also be seen in moving image of waveforms by time.

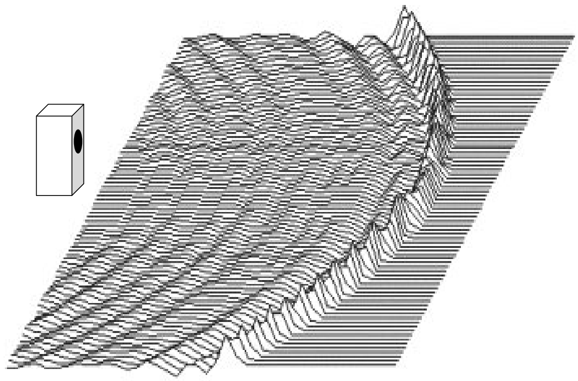

Fig.15 Multi impulse response

5 Conclusion

Car audio systems are normally to be sold after the sound created in a car compartment, as typified by factory-installed genuine parts. Although the accuracy varies by the scene of usage, acoustic measurement results are deemed to be important evaluation gauges. This paper introduced general measurement methods and FUJITSU TEN original measurement methods. In the future, since digital equipment will be miniaturized and will plummet in price, the acoustic analysis will be conducted generally by the original method of each maker. On the other hand, although the sounds have been created through watching the data obtained by acoustic measurement, in the future, automatic tuning system enabling control of the audio system parameters automatically will be developed. FUJITSU TEN has commercialized E-iSERV function as a market product, which can control parameters automatically based on the data measured in a car compartment. We are now aiming to shorten the design period and to improve the accuracy in creating sounds. We have a plan to develop a system with built-in measuring instrument, which will enable automatic control of the finer control parameters.

Reference:

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