At the EXPO 2005 AICHI, JAPAN, the single seater "i-unit," a future concept vehicle, was submitted to the Toyota Group Pavilion for display. This i-unit is loaded with a driving support system which utilizes various types of IT technology geared towards future societies. In this project, with the aim of a fusion of humans and vehicles, a human interface has been developed which, using sound, light and vibration, provides the driver with easy-to-understand information regarding driving support. FUJITSU TEN also cooperated in this audio system development.

This document introduces i-unit audio system hardware. This introduction includes an outline of "audio contents" created with the aim of human interface enhancement, as well as an introduction regarding sound image control methods which are used to localize sound within a 360-degree circumference around the driver with two loudspeakers.
Introduction

Outline of i-unit

2.1 Outline

2.2 Major functions and features

2.3 Vehicle development theme and IT technology

Audio system

Creation of pleasant audio space

Information provision through situation-oriented sound

Acoustic specifications
Development of Audio System for TOYOTA "i-unit"

4.1 USB unit

4.1.1 Aim and outline

4.1.2 Form

4.1.3 Reliability

Hardware outline
4.1.4 Performance

- Output: 12 W or more compatible with 2 channel stereo
- Size: 90 mm × 80 mm × 20 mm or less (50% of conventional models)
- Noise reduction (S/N ratio, separation 70 dB or more)

4.2 Power amp

4.2.1 Aim and outline

4.2.2 Requirement specifications

- Output: 12 W or more compatible with 2 channel stereo
- Size: 90 mm × 80 mm × 20 mm or less (50% of conventional models)
- Noise reduction (S/N ratio, separation 70 dB or more)

4.2.3 Miniaturization

1) Content of implementation of slim dimension
   - Basic concept

2) Comparison of analog amp and digital amp efficiency
4.2.5 Noise reduction

- To suppress noise, sound pressure level at each frequency was measured.
- Sound pressure level was measured in the response and vibration of the loudspeaker cabinets.
- Noise was reduced by using a low-pass filter and a noise reduction technique.

4.3 Speaker unit

4.3.1 Aim and outline

- The aim of this section is to develop a speaker unit that meets the target performance.
- The speaker unit is designed to have a BOX-less structure.

4.3.2 Conditions for speaker installation

- The conditions for speaker installation include the following:
  - The installation angle should be within ±15°.
  - The installation angle should be within ±15°.
  - The installation angle should be within ±15°.

- BOX-less speaker

- The BOX-less speaker is designed to be compact and lightweight.

- Voice coil interpolation damper

- The voice coil interpolation damper is designed to reduce the vibration of the voice coil.

4.3.3 Development of speaker unit

- The development of the speaker unit includes the following:
  - The development of the speaker unit includes the following:
  - The development of the speaker unit includes the following:
  - The development of the speaker unit includes the following:

- Foam rubber edge

- The foam rubber edge is designed to reduce the vibration of the speaker unit.

- Dome-shaped diaphragm

- The dome-shaped diaphragm is designed to improve the sound quality of the speaker unit.
Acoustic processing

5.1 Installment environment

I: No display
II: Speakers positioned at a close distance of approximately 30 cm from the driver’s ears
III: Canopy-enclosed narrow space

5.2 Acoustic processing outline

ᶃ Measure in advance HRTF [right: SR, left: SL] for the target environment.
ᶅ Calculate the FIR filter coefficient from HRTF.
ᶆ Multiple audio signals by FIR filter coefficient.

5.3 Localization control for monaural sound

The coordinates of the point of localization for perception in the reproduction environment are determined as follows:

- The coordinates of the point of localization for perception in the reproduction environment are the same as those in the target environment when the target environment is a forward sound.
- The coordinates of the point of localization for perception in the reproduction environment are determined by the distance from the human head at the point of the target environment when the target environment is a monaural sound.

Acoustic processing
Development of Audio System for TOYOTA "i-unit"

5.4 Application to i-unit

5.4.1 Creation of 360° revolving sound source

Creation of audio contents
6.1 i-unit operation and audio contents

- Sounds following i-unit switch operation
- Sounds aiming for harmony with the surrounding environment
- Warnings
- BGM

6.2 Creation method

- STEP 1. Decision on standard sound source
- STEP 2. Vehicle inspection

6.3 Sound source outline

- Warning alarm sounds
- Sounds comfortable for people
- Control of sense of distance
- Control of sense of direction
- Fusion of human and vehicle
<table>
<thead>
<tr>
<th>Sense of distance</th>
<th>Far</th>
<th>Near</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Frequency property</td>
<td>Treble zone damping</td>
<td>Treble zone damping</td>
</tr>
<tr>
<td>Echo</td>
<td>Large</td>
<td>Small</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Urgency</th>
<th>Little</th>
<th>Great</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Frequency property</td>
<td>Treble zone damping</td>
<td>Treble zone damping</td>
</tr>
<tr>
<td>Repeat cycle</td>
<td>Long</td>
<td>Short</td>
</tr>
</tbody>
</table>

6.3.2 Individual identification sounds

- 高音域の音を用いる
- 中音域の音を用いる
- 低音域の音を用いる

Medium-range sound
- 低音域の音を用いる
- 中音域の音を用いる
- 高音域の音を用いる

Short-range sound
- 高音域の音を用いる
- 中音域の音を用いる
- 低音域の音を用いる

Development of Audio System for TOYOTA "i-unit"
Sound during identification

(Aim)

- To analyze the sound emitted during the identification process.
- To identify the components contributing to the sound.
- To understand the factors affecting the sound level.

(Outline of sound)

- The sound was recorded using a microphone placed near the identification area.
- The sound was analyzed using a spectral analysis tool.
- The results were compared with the expected sound patterns.

Sound for completion of identification

(Aim)

- To study the sound emitted during the completion of the identification process.
- To identify the components contributing to the sound.
- To understand the factors affecting the sound level.

(Outline of sounds)

- The sound was recorded using a microphone placed near the completion area.
- The sound was analyzed using a spectral analysis tool.
- The results were compared with the expected sound patterns.

Conclusion

The study revealed that the sound during identification and completion is largely dependent on the type of identification method used.

Further research is needed to identify the specific components contributing to the sound and to develop methods to reduce the sound level.
Profiles of Writers

Akira Motojima
Entered the company in 1983. Since then, has engaged in development of in-car sound systems. Currently in the Acoustic System Department of Audio Business Division, Business Division Group.

Yoichi Yamaguchi
Entered the company in 1980. Since then, has engaged in development of in-car audio systems (head unit). Currently in the Acoustic Engineering Department of Audio Business Division, Business Division Group.

Tadashi Imamura
Entered the company in 1992. Since then, has engaged in development of in-car audio power amps. Currently in the Acoustic Engineering Department of Audio Business Division, Business Division Group.

Shohei Yoshii
Entered the company in 2003. Since then, has engaged in 07 system development. Currently in the Engineering Department 2 of Engineering Division 1, Business Division Group.

Masanobu Maeda
Entered the company in 2002. Since then, has engaged in development of in-car sound systems and DSP algorithms. Currently in the Acoustic System Department of Audio Business Division, Business Division Group.

Masami Ando
Entered the company in 1999. Since then, has engaged in development of in-car sound systems. Currently in the Acoustic System Department of Audio Business Division, Business Division Group.