Development of Automotive Time Domain Custom-Fit Speaker

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Abstract

The "ECLIPSE TD" series, Fujitsu Ten home audio system, is based on "Time Domain (TD) Theory" that is different from the conventional theory, and has been highly praised in various fields beyond the home audio use since the release in April 2001. As for automotive speakers, in June 2008, we have developed a center speaker, a satellite speaker and a tune-up subwoofer by adapting the TD theory, which provide sound space in a car with the same level as the one through home audios. In order to build an all TD system structure this time, by adopting the TD theory, we have developed a new custom-fit door speaker that is a key item to produce sounds in a car cabin. This paper explains the development background of the TD custom-fit speaker, development concepts and our unique technology to achieve them. Then it goes on to introduce the example of the automotive system structure and the market evaluation of its sound quality.

1 Introduction

Since its release in 2001, our home audio systems, ECLIPSE TD series, have been highly praised in world audio magazines and elsewhere. They are now widely used not only by audiophiles but also by worldwide top artists and in the famous music studios throughout the world.

In June 2008, three models of automotive time domain (TD) speaker series (center speaker, satellite speaker, tune-up subwoofer) were released, and since then they too have been praised. In July 2009, custom-fit door speaker: TDX1700, which is the core of the automotive TD speaker series, was newly released.

Regarding the 09 model: TDX1700, this paper explains the product development background, the development concept and our unique technology to achieve them. Then it goes on to introduce the example of this automotive system structure and market evaluations on the sound quality.

2 Product Concept of ECLIPSE TD Speakers

Most conventional speakers have been creating sounds by focusing on frequency response, emphasizing the ability to reproduce flat sound from low frequencies to high frequencies with minimum distortion. On the other hand, we have developed sounds based on the time domain theory as the product concept of ECLIPSE TD speakers, which focuses on the accurate reproduction of the movement of air from sound generation to sound loss.

The sounds of ECLIPSE TD series developed based on the concept have the following three major characteristics.

(1) Increased sound clarity
(Even minute sounds are heard without masking unwanted sound)

(2) Faster and tighter reproduction of sound
(The rising and falling of sound reproduction are both quick)

(3) Improved spatial reproducibility
(The listeners are now less aware of the existence of speakers, which means that what they hear comes from their surrounding space)

3 Background of Product Development

3.1 Development of automotive surround system

These days, reflecting the increased needs for car navigation systems, users' needs for car audios have been changing from conventional audio models to navigation / audio combination models such as AVN series. Besides, reflecting the increase of users enjoying 5.1-channel sound sources as well as 2-channel stereo sound sources, demands for realistic, natural sense and others in sound quality in a car are growing.

To meet these market needs, we have launched the development of automotive TD speaker system **(Fig. 1)** that generates sounds with surround effects providing powerful sense and the sense of sound movement akin to home theater even in the limited space of a car, by providing high level of clarity and spatial reproducibility: advantage of TD speakers, through the automotive 5.1-channel surround system based on the TD theory cultivated through our home audio speaker development.

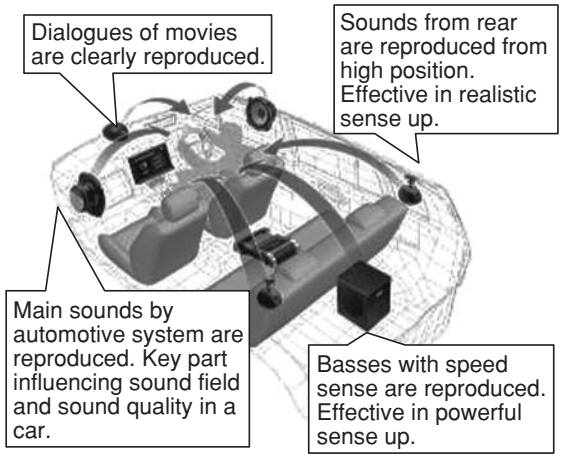


Fig.1 Automotive TD Speaker System

In June 2008, three models of automotive TD surround speaker series (center speaker: TDX700C, satellite speaker: TDX700S, tune-up subwoofer: TDX700W, refer to **Fig. 2.**) were released.

Fig.2 08 Model Automotive TD Speaker

These center and satellite speakers adopting the time domain structure of "ground anchor"[1], "floating structure"[1] and "eggshell enclosure"[1] cultivated through our home audio series "ECLIPSE TD," provides accurate sounds without unwanted noises generated by the parts other than a sound source, such as the unique noises of speakers themselves and the vibration noises of installed part. The subwoofer adopting "R2R structure"[1] based on the technology of home audio woofer TD725SW[2], provides bass sounds with an unprecedented speed sense and reduced unwanted vibrations because of the structure in which two small diameter units are strongly joined back to back by a shaft so that the vibration reactions produced at one speaker unit absorb the ones at the other.

3.2 Aim of Development of TD Custom-Fit Speaker

The development of TD surround speakers allows the structure of surround sound environment in a car only by adding surround speakers onto a genuine system. So,

aiming at the next step to build up all TD systems, we launched the development of a custom-fit automotive front door speaker, which reproduces the sounds of major range in music or movies.

3.3 Market Trends of Custom-Fit Speakers

3.3.1 Speaker Diameter

Most of the custom-fit speakers are to be installed in doors, and various types of speakers are set according to a car model type and an automotive manufacture. Naturally, the installation of a custom-fit speaker is limited depending on various conditions such as a screw pitch, a speaker diameter and an installation depth. In this reason, a custom-fit speaker is first of all required to have high general versatility in which the custom-fit speaker is available to various cars. On the current market, three types of speakers: ϕ17cm, ϕ16cm, ϕ10cm, are mainly available. Reflecting the latest trend of genuine speakers with larger diameter, the installation rate of the custom-fit speakers with ϕ17cm diameter is increasing. (**Fig. 3**)

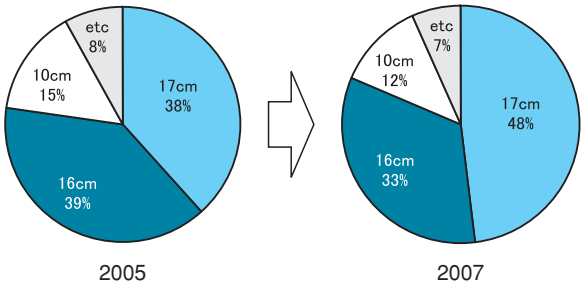


Fig.3 Installation Rate of Custom-Fit Speaker by Diameter

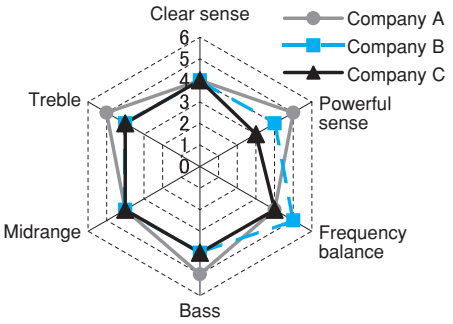
3.3.2 Trend of Other Companies

The TD custom-fit speaker in this development is categorized as the top grade among various custom-fit speakers for retail stores. **Table 1** shows the specifications of the products in the same grade, which are released by other audio manufactures.

Table 1 Comparison of Specifications by Speaker of Each Company

	Company A	Company B	Company C
System	2-way separate type	2-way separate type	2-way separate type
Diameter	17cm	17cm	16cm
Maximum dimensions	ϕ156×t64 (4-point fixing)	ϕ156×t68 (4-point fixing)	ϕ160×t54 (Multiple-point fixing)
Input (Nom. / Max.)	40W / 150W	40W / 120W	40W / 160W
Frequency response	32kHz to 46kHz	28kHz to 60kHz	28kHz to 48kHz
Sound pressure level	87dB	89dB	90dB

Fig. 4 shows our evaluation result regarding the sound quality trend of each manufacture. The sounds of company A are well-balanced as a whole, with tightness and powerful sense. The sounds of company B provide natural sense and are well-balanced in frequency. The sounds of company C are well-balanced as a whole, while they have somewhat less power.



Evaluation Method

Site	FUJITSU TEN's evaluation room
Number of panelists	4 members
Evaluation method	Auditorily evaluate a speaker A, B and C installed in evaluation box (70L) regarding the 6 points in the above figure.
Evaluation sound source	J-POP, ROCK, R&B, JAZZ

Fig.4 Evaluation Results of Other Companies' Products

3.4 Target Specifications

Taking into consideration of the above-mentioned market trends, we set the target specifications for this development of the TD custom-fit speaker as in **Table 2**.

We decided to adopt the versatile frame of ϕ17cm dimension aiming at emphasizing bass sounds in quality and at keeping the general versatility of installation to various vehicles while building a TD structure.

On the other hands, we set the normal input, frequency response and sound pressure level to the adequate performances in this class as target specifications in **Table 2**.

Table 2 Target Specifications

System	2-way separate type
Diameter	ϕ17cm (Unit diameter: ϕ16cm)
Maximum dimensions	ϕ156× t 68 (4-point fixing)
Input (Nom. / Max.)	40W / 120W
Frequency response	28kHz to 50kHz
Sound pressure level	89dB
Special instruction	Unwanted vibrations were reduced to 50% by adopting TD structure.

Since we had no product in this grade, we newly set the target sound quality as in **Fig. 5**, referring to the specifications of the company A's speaker that was the best speaker in the said evaluation result.

The subwoofer TDX700W to be combined as a system can add the powerful sense and bass sounds sufficiently. But in order to reinforce the differentiation of our new custom-fit speaker, in this development, we set the target to improve the clear sense of instrument and vocal and the texture of midrange sounds, in which the custom-fit speaker performs a crucial function, by adopting the TD structure to reduce unwanted vibrations.

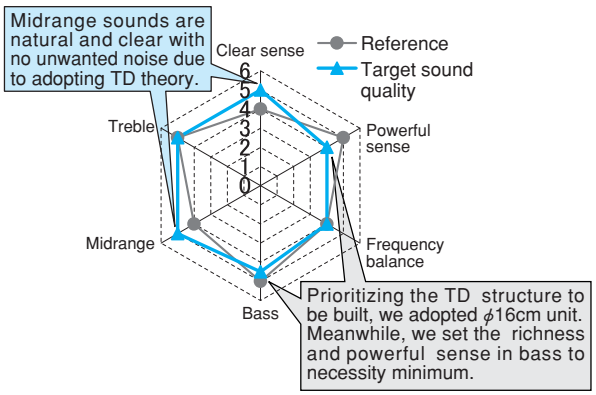


Fig.5 Target Sound Quality

4 Development Outline

4.1 Development Subject

A custom-fit speaker is to be installed directly to a vehicle door panel or with a simple spacer. But, since the door panel is normally thin, the door itself vibrates, which causes degradation in sound quality of original sounds (**Fig. 6**). Besides, the door panel that normally has many parts such as window glass and harness may generate other noises induced by the speaker vibrations. So, we launched the development of TD custom-fit speakers, which can be the solution against these problems. Adopting the TD theory, in which "the vibrations induced by a speaker unit are not transmitted outside," the vibrations of a speaker are not to be transmitted to the door panel, and the speaker can deliver high quality sounds with the unwanted vibrations reduced.

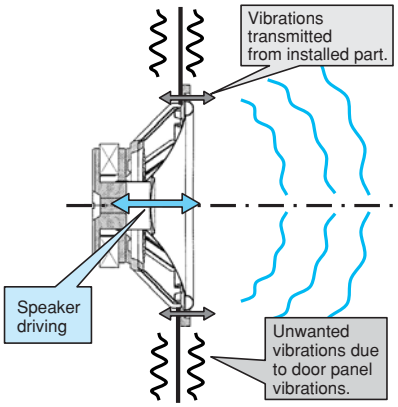


Fig.6 Door Panel Condition with Driving Conventional Custom-Fit Speaker

The environment inside a door is under severe conditions for a speaker due to rain water seepage or others. Under such a not-appropriate environment, we set the following three points as development subjects to keep the quality and obtain "accurate sounds" with clearness and high spatial reproducibility.

(1) Achievement of TD structure (floating structure)
(2) Ensuring of water proof property
(3) Improvement of impulse response characteristics of driver unit

4.2 Achievement of TD Structure

4.2.1 Achievement of Floating Structure

The precondition of a custom-fit speaker is that it can be installed as is with no process after taking away a genuine speaker. In other words, physical constraints for installation regarding a door trim, vehicle parts around a speaker, the opening shape of a door panel and others are really severe. In order to ensure the general versatility of this ϕ17cm speaker to be installed, the maximum dimensions must be designed within ϕ156 × t68mm.

In this development, we decided to design the above-mentioned size as the maximum dimensions including installation parts and one-size smaller ϕ16cm size as the driver unit diameter, and to build a floating structure at the margins of the outer circumference. **Fig. 7** shows the cross-section diagram of speaker. As the diagram indicates, the structure has voids between a front spacer and a rear spacer and has the speaker held at its frame via absorbers with high damping performance. With this floating structure, comparing to the conventional structure where vibrations are transmitted due to the speaker frame directly attaching to the door panel, the unwanted vibrations of the door panel are reduced to the minimum due to the speaker frame itself not attaching to the vehicle.

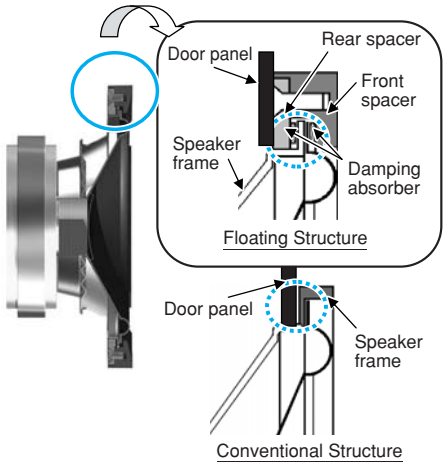


Fig.7 Floating Structure

4.2.2 Validation of TD Structure's Superiority

We validated the TD structure's superiority by using prototype sample incorporating the said floating structure. **Fig. 8** shows the measurement results of distortion rates. The two samples: one incorporating the conventional structure and the other incorporating the TD structure, used in this measurement have the same driver unit, and the only difference between the two samples is whether the floating structure is incorporated or not. The line graph of the conventional structure in the figure indicates that the distortion rates at around 120Hz are high. We assumed that the vibrations of the speaker was transmitted to the installed part and that resulted in the generation of unwanted vibrations. To validate this further, installing a speaker in an actual car, we measured the vibrations of the door panel near the speaker. **Fig. 9**

shows the result indicating the vibrations of the door panel near the speaker when sign waves equivalent to rating are input. As indicated in the figure, compared to the conventional structure, the vibrations of the TD structure are reduced to the approx. half level. With this result, we confirmed that the speaker has the structure superior in the vibration damping performance, where the vibrations of the speaker are hardly-transmitted outside. In other words, we achieved the reproduction of more accurate sounds with less distortion resulting from the reduction of the unwanted radiated sounds from door panel.

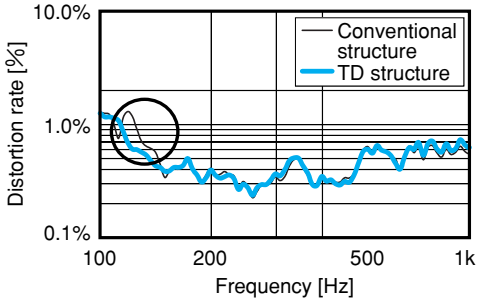


Fig.8 Measurement Result of Distortion Rate

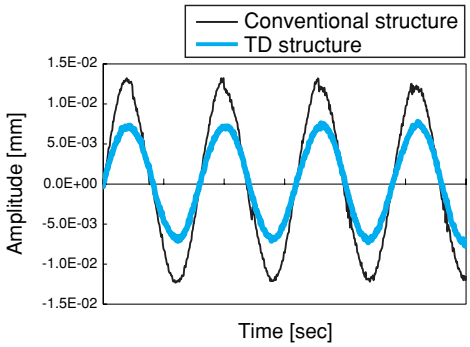


Fig.9 Measurement Result of Vibrations Around Speaker-Installed Part

4.3 Ensuring of Water-Proof Property

In some cases, the speaker may soak at the back due to the water that has seeped inside a door at raining or car wash. The water-proof property of the custom-fit speaker must be ensured so that water does not seep into a car cabin. The above floating frame structure was required to improve its water-proof property because the structure has a void at the spacer parts even with a damping absorber. So, as in **Fig. 10**, by inserting a closed-cell foam cushion material with a high water-proof property at the spacer's inner circumference, the structure was improved in water-proof property.

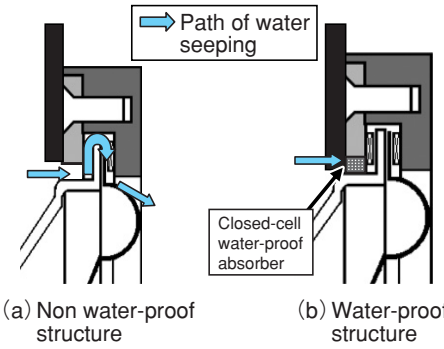


Fig.10 Water-Proof Countermeasure of TD Structure Part

4.4 Improvement of Impulse Response Characteristics of Driver Unit

A time domain speaker is developed with a focus on the accuracy of sound time waveforms - i.e., impulse response characteristics - that the speaker can reproduce. So, we tackled the following developments so as to improve the impulse response characteristics of a driver unit.

(1) Selection of diaphragm material (aiming to reduce unwanted vibrations by means of increasing inner loss)

(2) Improvement of forward-and-backward symmetry of damper amplitude

(3) Improvement of driving force (magnetic efficiency)

4.4.1 Selection of diaphragm Material

A diaphragm is required to be lightweight and to have high rigidity and appropriate inner loss. Especially in consideration of the development for woofers, focusing on reducing unwanted resonances, we examined various new materials with higher inner loss property than that of fiberglass (GF) adopted for a home audio full range speaker so far. As a result, we adopted a compound fiber, which is a fabric knitted with two different fibers: PEN used for warp and Technora®(1) used for woof. As a woofer diaphragm, the fabric provides splendid property of both high rigidity and high inner loss from the advantages of respective materials. **(Fig. 11 and Fig. 12)**

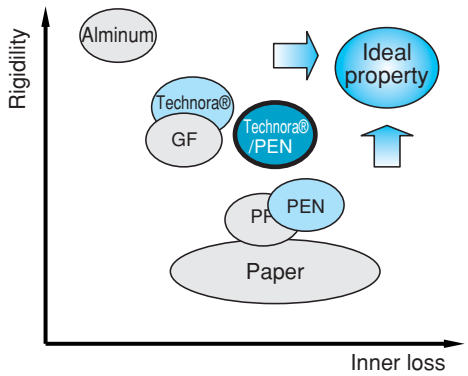


Fig.11 Diaphragm Property

∗(1) Technora® is a trademark of Teijin Techno Products Limited.

Fig.12 Appearance of Diaphragm

4.4.2 Improvement of Forward-and-Backward Symmetry of Damper Amplitude

A damper is required to have improved forward-and-backward symmetry of amplitude for reproducing accurate sound time waveforms. If the diaphragm can not follow the input signals accurately in forward-and-backward amplitude, the reproduced waveforms are distorted.

We adopted the same type of damper as the one we developed for a home speaker TD712zMK2 (**Fig. 13**). With the shape of this damper whose corrugation center is heightened, the damper can provide smooth forward-and-backward amplitude with no stress concentration at certain spots. So, we optimized this corrugation shape to suit this driver unit diameter by means of simulation.

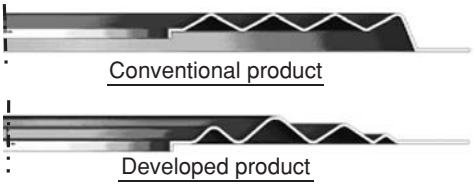


Fig.13 Cross-Section Shape of Damper

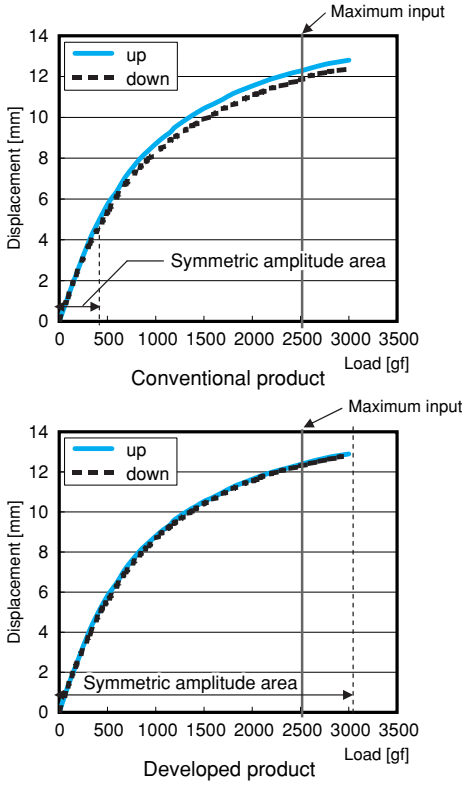


Fig.14 Damper Amplitude Simulations

Fig. 14 shows the simulation result. Compared to a conventional damper, the figure of this developed damper indicates that the symmetric amplitude area where the forward amplitude (solid line) overlaps with the backward amplitude (dotted line) is expanded significantly over the line of maximum input.

4.4.3 Improvement of Driving Force (magnetic efficiency)

In order to reproduce signals with quick rising characteristics like an impulse accurately, driving force of the driver unit must be powered up. To power up the driving force, we took two measures: enhancing magnetic circuit efficiency as a general measure and especially adopting voice coils in square shape. The square shape wire as in the cross section view of **Fig. 15** provides higher winding density and higher efficiency than the normal round wire. With these measures, we obtained higher performances in winding density by 21% up and in efficient flux by 8% up, by optimizing the wire shape, wire length and winding width.

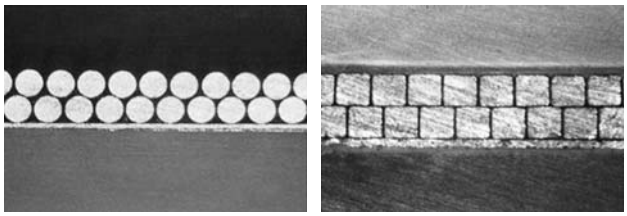


Fig.15 Cross Section of Voice Coil

4.4.4 Verification of Impulse Response

An impulse is a pulse wave with 0 width and infinity height.

The closer to the impulse shape the impulse response is, the more faithful to the original sounds the reproduced sounds are. **Fig. 16** shows the comparison of impulse response characteristics between the conventional product and the developed product. The developed product graph shows that the time width (A) of the first wave is narrower and the overshoot (B) is smaller than those of the conventional product. With this result, we verified the developed product has closer characteristics to the impulse.

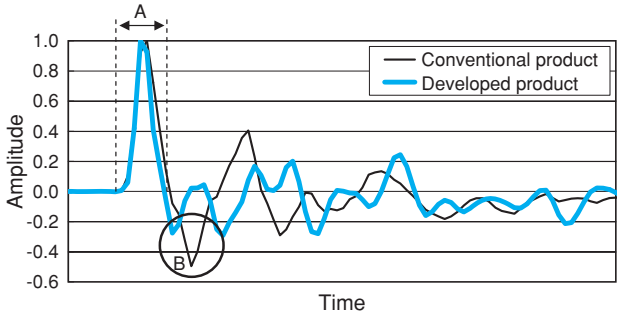


Fig.16 Comparison of Impulse Response Characteristics to Conventional Product

4.5 Development Result

Table 3 shows the developed product specifications. **Fig. 17, Fig. 18 and Fig. 19** respectively show product fre-

quency response, sound quality evaluation result and product appearance. We succeeded to develop this product in specifications meeting the target values and in sound quality meeting the target sounds having excellent sound texture and clearness especially in midrange.

Table 3 TDX1700 Product Specifications

Input (Nom. / Max.)	40W / 120W
Frequency response	28Hz to 50kHz
Sound pressure level	89dB
Impedance	4Ω
<Woofer part>	
Diameter	Equivalent to 17cm product, Unit part: 16cm
Maximum dimensions	ϕ156mm × t68mm
Weight	Approx. 1440g
<Tweeter part>	
Diameter	4cm
Maximum dimensions	W67.1mm × H67.8mm × D69.3mm
Weight	Approx. 155g
<Network part>	
Maximum dimensions	W140.8mm × H102.6mm × D37.9mm
Weight	Approx. 313g

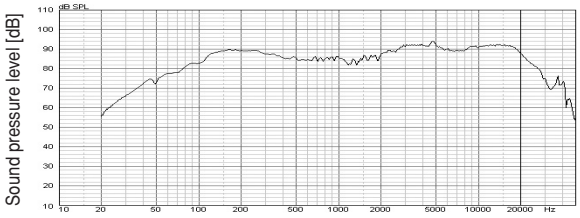
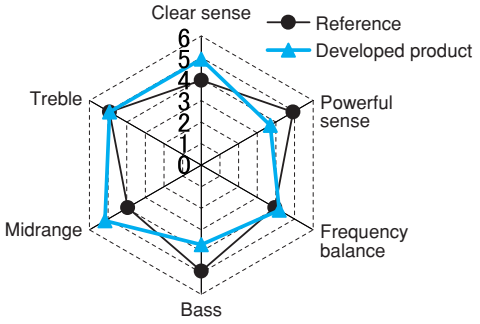


Fig.17 Frequency Response (TDX1700)



Evaluation Method

Site	FUJITSU TEN's evaluation room
Numbers of panelists	4 members
Evaluation method	Auditorily evaluate speaker A, B and C installed in evaluation box (70L) regarding six points in the above figure.
Evaluation sound source	J-POP, ROCK, R&B, JAZZ

Fig.18 Sound Quality Evaluation Result of Developed Product

Fig.19 Product Appearance

5 Automotive System Structure

5.1 5.1-channel Surround System Built with All TD Speakers

With the TD custom-fit speaker developed this time, 5.1-channel surround system with all TD speakers as in **Fig. 20** can be built in a car. AVN779HD used as a head unit in this system is equipped with "ECLIPSE TD mode," which is a tuning tool with all characteristics of TDX series including TDX1700 developed this time. This ECLIPSE TD mode can provide a chance to users to set up an optimum surround environment in a car with the most advantageous characteristics of the system with all TD series.

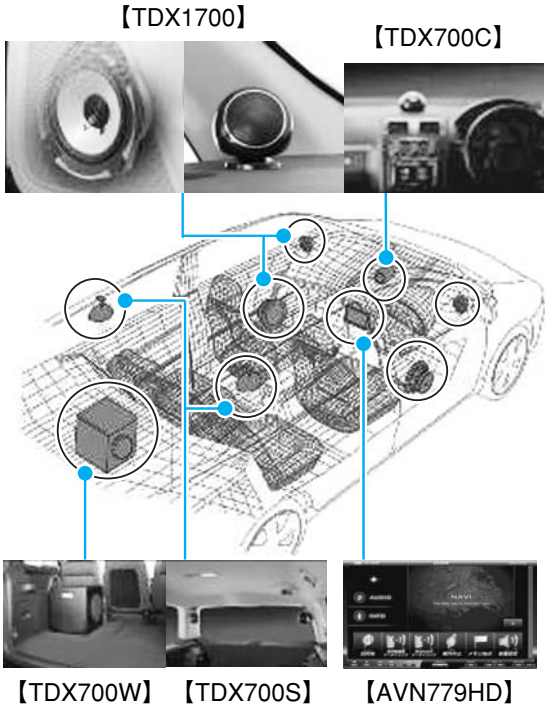


Fig.20 All TD 5.1-Channel Surround System

5.2 Evaluation under Installed Conditions

Preparing the demonstration car equipped with the surround system as in **Fig. 20**, we held in-house evaluation meetings and demonstrations to magazines.

At the in-house evaluation meetings, we obtained honest evaluation comments from general users' points of view from 72 people in total not relating to acoustic departments, after listening to 5.1-channel source (movie) and 2-channel source (music). **Fig. 21** shows the result, in which the obtained comments were categorized into realistic sense, clear sense, localization and etc. and tallied them. The top comment was about the good realistic sense particularly to the 5.1-channel source. The second comment was about the clear sense for sound quality. These comments indicated the reproduced sounds are high in clear sense and spatial reproducibility, which are the characteristics of the TD speaker, and thus we concluded the targeted sounds are provided.

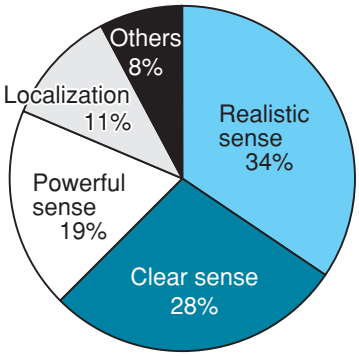


Fig.21 Listening Evaluation Result Count

Table 4 shows the typical evaluation comments among the in-house evaluation comments and the comments obtained at the demonstration to magazines using the demonstration car.

Table 4 Sound Quality Evaluation Comments

In-house evaluation comment (General user's point of view)
• The sound environment in a car like being in a theater is reproduced.
• The sounds are as powerful as in a theater.
• The sounds have excellent sharpness.
Comments from people of magazines (Profession's point of view)
• The sounds have strong localization of surround system.
• The vocal sounds clear enough for me to feel sound space ahead.
• The sounds are audible up to fine change and are fresh.

6 Conclusion

This paper has described the aim of development and the characteristics of automotive TD custom-fit speakers.

For the sound creation with high in sound quality in a car through the conventional custom-fit speakers, we had to improve the sound environment around speakers by implementing some additional works of damping material, highly-functional spacer, deadening, and etc. On the other hands, this product is already equipped with countermeasure against vibration generated from the speaker itself. This product is as easy to be installed as a conventional custom-fit speaker, while it provides high damping performance and high sound quality. We verified that the TD technology is also effective in a car, which contributes to preventing the sounds from deterioration caused by unwanted vibrations: as is often the case in a car. Now, we can build a full-scale surround system in a car, combining this developed product with the formerly-developed surround TD speakers. We look forward to many users having chances to feel our sounds with high spatial reproducibility, which give no impression of restricted space in a car.

With the further advancement of media such as Blu-ray and data distribution using uncompressed audio source, the demand for higher sound quality of audio equipment including speakers will be increasing. We are confident that the TD theory underlying ECLIPSE will meet the demand. We will develop various products further aiming to "accurate sounds:" sounds faithful to the recorded source, so as to provide comfortable vehicle space to many users through this sound production.

Finally, regarding the development of this model, we sincerely appreciate the great help from many people inside and outside the company.

Reference

1) "Development of Automotive Time Domain Speaker" written by Kiyosei Shibata and others
: Fujitsu Ten Technical Journal No.52 (2008)
2) "Development of Premium Subwoofer based on Time Domain Theory" written by Yoshikuni Miki and others: Fujitsu Ten Technical Journal No.48 (2006)

Profiles of Writers

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