Development of Automotive Time Domain Speaker

Kiyosei SHIBATA
Ryousuke SOU
Masahito KAWAI

Abstract

The "ECLIPSE TD" series, Fujitsu Ten home audio system, is based on "Time Domain Theory" that is different from the conventional theory, and has been highly praised in various fields beyond the home audio use. In June 2008, we released automotive time domain speakers that provide a real surround system in a car by adapting the time domain theory cultivated through this home audio development.

The new products are three surround speaker models (center speaker, satellite speaker and tune-up subwoofer). Each of them is equipped with our unique technologies such as a ground anchor, a floating structure, and a R2R structure, and the sounds produced by these products are more excellent than ever in spatial reproduction.

This paper explains the development background of the automotive time domain speakers and our unique technology to achieve them. Then it goes on to explain our challenges for the automotive system.

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, while being used regularly in the top studios throughout the world.

In June 2008, three models of automotive TD speaker series (center speaker: TDX700C, satellite speaker: TDX700S, tune-up subwoofer: TDX700W) were released, and since then they too have been praised.

This paper explains the product development background, the development concept and our unique technology to achieve them. Then it goes on to explain some challenges for automotive systems.

2 Background of Product Development

2.1 Current Status of Home Use Product

As described in the previous section, we have developed various products since the release of our home audio system in 2001.

Current lineup consists of four models of full-range speakers and two models of subwoofers, which are highly praised in the market. Here are the explanations of our unique technology employed for the ECLIPSE TD series and its sound characteristics.

Fig.1 Home Use ECLIPSE TD Series
Left: TD712z (Full range speaker)
Right: TD725SW (Subwoofer)

2.2 Unique Technology Employed for ECLIPSE TD Series

One of the major factors that have an adverse effect on the accurate reproduction of waveforms is "reverberation" of a speaker. Here are three principal technologies that we have developed to minimize the unwanted vibrations that are the major factors of reverberation.

(1) Ground Anchor

A conical metal object called ground anchor is set in the back of the speaker unit, and its inertia mass suppresses the reaction of a speaker unit. This adopted structure enables a diaphragm to push air accurately.

(2) Floating Structure

This adopted floating structure eliminates mechanical contact between the enclosure and the speaker unit, and suppresses the transmission of vibrations of the speaker unit to the enclosure. Therefore, the enclosure-specific vibrations are reduced and this leads to the minimization of the speaker-specific unwanted sound.

(3) Eggshell Enclosure

The eggshell enclosure achieves the suppression of standing waves due to no parallel surface in the enclosure.

Besides, the shape makes baffle surfaces round with no corners and leads to the suppression of the diffraction waves that are normally generated in the process of sound (spherical wave) expansion.

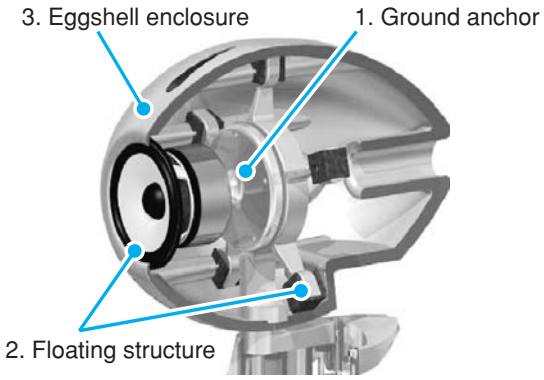


Fig.2 Internal Structure of TD712z

2.3 Sound Characteristics of ECLIPSE TD Series

The sounds of ECLIPSE TD series which are pursuing the reproduction of the most accurate waveforms possible, 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 quick)

(3) Improved space reproduction

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

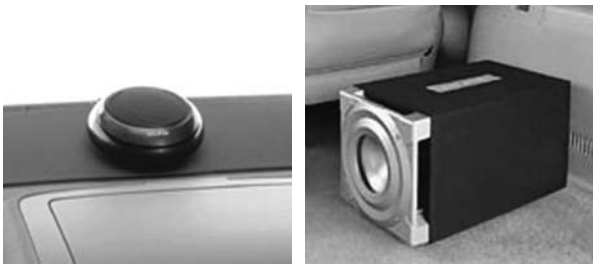
2.4 Change in Needs for Car Audios

Here are the needs for car audio sound systems. These days, reflecting the increased needs for car naviga-

tion systems, the user's needs for car audios have been changing from conventional audio models to navigation / audio combination models. In addition, the users enjoying 5.1-channel sound sources as well as 2-channel stereo sound sources are increasing. We have released a navigation / audio in-one model (AVN) as an aftermarket product since 1998, and now, half of our products in the current lineup are equipped with surround decode function.

2.5 Sound Surround System in Car

The system with four speakers (front, rear) is normally adopted as a genuine speaker system, and not many cars are equipped with a center speaker or a subwoofer from the beginning. So, many easy add-on center speakers and subwoofers are marketed by various audio makers.



Center speaker (E505CSP released in 2005) Subwoofer (E703TSW released in 2003)

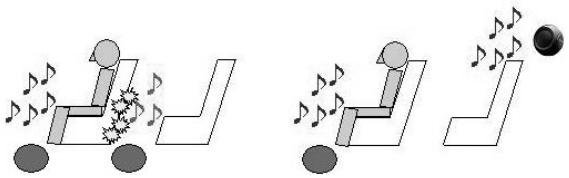
Fig.3 Center Speaker and Subwoofer

Besides, under the special sound space in a car, there are many requirements for improvement in the sound quality of rear speakers. At the position of a driver seat or a front-passenger seat for listening, the seats between the rear speakers and a listener interrupt the sounds (**Fig. 5**). Therefore, it is difficult for such an add-on type 5.1-channel surround system to have sufficient effects. To overcome this problem, many satellite speakers are marketed by various audio makers.

By hanging a satellite speaker from the ceiling, the location of sound generation is moved upward and it leads to the realization of the appropriate acoustical space in a car. The satellite speaker has also an easy add-on structure as well as a center speaker and a subwoofer.

Satellite Speaker (E505SSP released in 2005)

Fig.4 Satellite Speaker



a) Rear Door Speaker b) Satellite Speaker

Fig.5 Effect of Satellite Speaker

3 Aim of Development

The conventional products were generally used supplementarily- for example, by being added to a four-speaker system in order to correct acoustic field. So, the development has been specialized in miniaturized and thinned products that are convenient for add-on rather than superior in sound quality. However, reflecting the recent needs for surround sounds in a car as mentioned above, the demands in sound quality such as with realistic or natural sense at the same level of that through home audios are growing.

So, we set our aim on "how to reproduce the sounds in a car with the same level as the sounds through home audios" in this product development, and decided to develop more excellent speakers in spatial reproduction than ever by applying the time domain technology praised in our home audio products.

4 Development Outline

4.1 Development of Center Speaker (TDX700C) and Satellite Speaker (TDX700S)

4.1.1 Development Premise (Securing of visibility)

A center speaker has to be short in height in order to secure driver's forward visibility as the speaker is set on the center of the dashboard. Through repeating verifications with the speakers set in various heights on the dashboard, we concluded that the appearance height of 80mm or less creates no problem in forward visibility. **Fig. 6** (left) shows the situation of forward-visibility verifying with a 80mm-height speaker.

On the other hand, since a satellite speaker is normally set around the D pillar, it is required to be small in width in order to secure the visibility at backing. In the same manner, through repeating verifications by taking various sizes of speakers into a car, we concluded that the width of 100mm or less creates no driving problem. **Fig. 6** (right) shows the situation of backward-visibility verifying with a 100mm-width speaker.

Forward visibility　　Backward visibility

Fig.6 Visibility Verification from Driver Seat

Judging by the above verification results, we set ideal products to be developed as follows: height of a center speaker: 80mm, width of a satellite speaker: 100mm, diameter of a speaker unit: ϕ5cm (The size is the maximum limit within the feasible sizes mechanically)

4.1.2 Development Subject

For the development of these products, it would be ideal if we can apply the time domain technology cultivated through our home audio product development as is. But unfortunately, there are restrictions in appearance dimensions for car use, as indicated above. With sufficient consideration to these restrictions, we worked to develop the automotive time domain speakers to be excellent in space reproduction through the both approaches of speaker unit development and structural development. The following two points are the outlines of development subjects.

(1) To secure the reproduction range and improve the space reproduction by a small-diameter speaker unit

⇒ How the sounds can be provided in wide range and be excellent in spatial reproducibility under the restrictions of dimensions for car use

(2) Building of time domain structure

⇒ Building of the structure to make full use of the time domain technology with sufficient consideration to car vibrations

Here are the concrete development details to solve these subjects.

4.1.3 Subject Solution

(1) To secure the reproduction range and improve the spatial reproducibility by a small-diameter speaker unit

First, we studied reproduction range that is a basic characteristic.

The ideal reproduction range must cover from 120Hz to 20kHz where the speeches in movies or vocals in songs are in. Especially for a ϕ5cm speaker unit, securing bass characteristics is required.

For this subject, we verified bass reproducibility through simulations (**Fig. 7**) based on whether the target bass characteristics can be obtained or not by optimizing a unit: f0, enclosure volumes, and bass-reflex duct dimensions. This result indicated that even ϕ5cm speaker unit can provide ideal reproduction range.

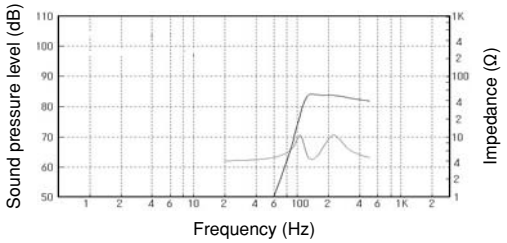


Fig.7 Simulation of Bass Reproduction

Next, we tackled the development of a speaker unit to improve the space reproduction for a time domain speaker. Here are the outlines.

It is important how accurately a diaphragm can operate in response to input signals so as to improve the space reproduction. To begin with, we decided to adopt low hardness rubber for surround material to improve the supporting structure. The rubber surround hardly makes unwanted resonance due to the rubber characteristic of relatively large energy loss. Besides, the rubber has an accurate amplitude characteristic due to its characteristic of quick response (**Fig. 8**).

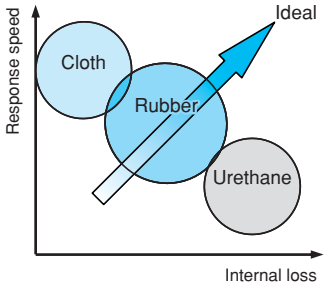


Fig.8 Index for Edge Material Selection

Then, we decided to adopt a combination dome cap (**Fig. 9**) to improve the response speed of a vibration system. In this structure, the cap adheres directly to a voice coil bobbin and a diaphragm adheres to the cap. Since the voice coil bobbin transmits driving force directly to the cap, the cap can work responding to the diaphragm with no time lag, and it results in the transient response being very fast.

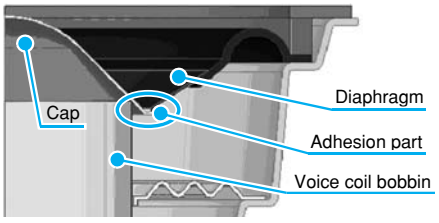


Fig.9 Figure for Explanation of Combination Dome Cap

Innovating these items above leads to development of an appropriate speaker unit for a time domain speaker. **Fig. 10** shows an listening evaluation result. Compared to our conventional products, the elements such as clear sense and natural sense specially affecting the space reproduction were much improved.

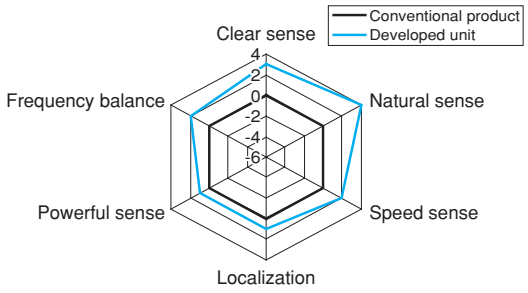


Fig.10 Listening Evaluation Result

(2) Building of time domain structure

Here is an explanation for the time domain structure of a center speaker. Adopting zinc die-cast with high specific gravity for a ground anchor to improve a sound rise characteristic achieved a sufficient anchor effect despite the small size. Since an automotive center speaker requires relatively wide surface to adhere to a car, because of the vehicle vibrations transmitted through this surface the enclosure may generate unwanted resonances. So, by placing a buffer at the attaching surface between the bottom plate and the enclosure, we made a structure with the enclosure floating. Also a quality buffer similar to that used in home audios was used in the floating structure of the speaker unit to prevent the speaker unit from vibrating. For further details of the floating structure, a resin-material buffer is used between the speaker unit and the enclosure and a fiber-material buffer is used between a stay and the enclosure. This enables minimizing the unwanted sounds emitted from the enclosure. The semi-oval shape of the appearance reduces the internal standing waves and diffracted sounds, and also secures the surface to attach to the vehicle. **Fig. 11** is the figure of the center speaker structure.

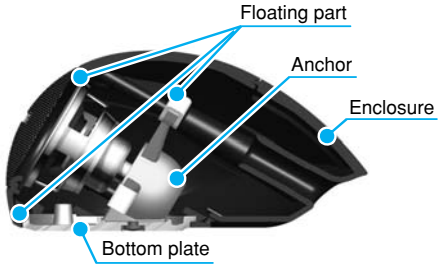


Fig.11 Figure of Center Speaker Structure (TDX700C)

For the ground anchor of a satellite speaker, we adopted an aluminum die-cast that is relatively light in specific gravity, but low price and processed easily. It is because we thought the total weight of the satellite speaker was fully effective as an anchor due to the adoption of a high-weight outer magnet type circuit. Further, as well as a center speaker, to reduce the influence of vehicle vibrations, we made the structure with the floating enclosure absolutely separate from the car body by placing a buffer between a bracket and the enclosure. Besides, resin-material buffers or fiber-material buffers are used at the speaker unit and the floating part of a stay. The appearance style is in an egg shape perfectly following the home audio design, and the shape reduces the internal standing waves and diffracted sounds. **Fig. 12** is the cross view of the satellite speaker structure.

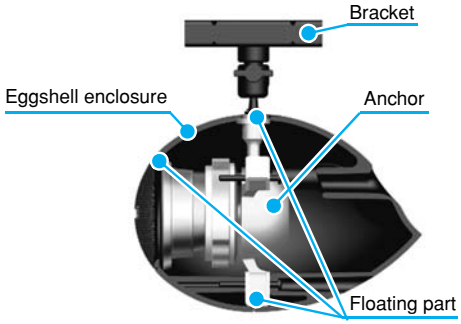


Fig.12 Figure of Satellite Speaker Structure (TDX700S)

As explained so far, for both the center speaker and the satellite speaker, we made effective use of the time domain structures cultivated through the home audio "ECLIPSE TD" series development, which are "ground anchor", "floating structure" and "eggshell enclosure." Through these adoptions, the speaker is now more excellent than ever in space reproduction as a finished automotive speaker.

4.1.4 Verification of Effects

Fig. 13 and **Fig. 14** show the impulse response characteristics of a center speaker and a satellite speaker. With the speaker development and the structure development, both speakers can provide greater impulse response characteristics than our conventional speakers.

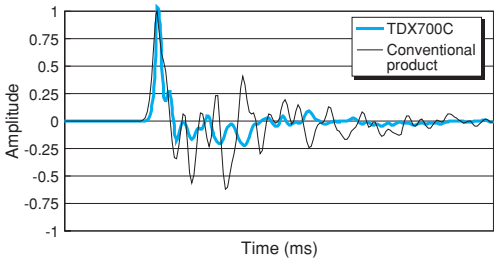


Fig.13 Impulse Response Characteristics (TDX700C)

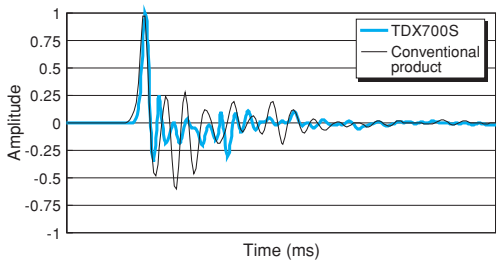


Fig.14 Impulse Response Characteristics (TDX700S)

4.2 Development of Tune-up Subwoofer (TDX700W)

4.2.1 Development Subject

As for a tune-up subwoofer in this newly developed class, the body size is not required to be so small since it is a prerequisite that the subwoofer is basically installed in a luggage area. But the sound quality is being required to be more natural and speedy in bass sounds reflecting the recent trend toward surround sounds. So, to deal with these requirements in sound quality, we decided to develop the tune-up subwoofer to be excellent in transient characterization through speaker unit development and structure development by adopting our unique time domain technology. The following two points are the outlines of development subjects.

(1) Improvement of speaker unit in transient response

⇒ Improvement of natural sense and speed sense of sound suitable for a time domain speaker

(2) Building of time domain structure

⇒ Building of time domain structure durable against car vibrations during driving suitable for on-board use

4.2.2 Subject Solution

(1) Improvement of speaker unit in transient response

The conventional tune-up subwoofers were developed with large speaker units of ϕ20cm class by an emphasis on the richness and punch in bass sounds. However the larger the diameter becomes, the heavier the weight of the vibration system becomes. It causes the speed sense of the sounds to lower due to the low performance in transient response. So, we set the goal for this product development "to reproduce bass sounds with a natural and speed sense." Here are the three solutions to improve the sounds with a speed sense.

①To obtain quicker response by reducing the weight of a vibration system

②To secure amplitude linearity by optimizing a support system

③To power up in driving force by enlarging a magnetic circuit

Here are the concrete solutions for the development.

①Reducing weight of vibration system

To reduce the weight of a vibration system, by using the smaller diameter from ϕ20cm to ϕ16cm, the new product became lighter by approximately 30% in weight than the conventional product. Besides, using smaller diameter may lead to a lack of richness of the bass sounds. Then, to keep the bass sounds as rich as that of the conventional product, we ensured the diaphragm space equal to that of ϕ20cm diameter by using two speaker units.

②Optimizing support system

Reducing the weight of the vibration system, to the contrary, makes the lowest resonance frequency (f0) higher and the bass sounds less in volume. In this case, to keep the f0 lower, we used a damper with smaller stiffness. Furthermore, to respond to large amplitude, we adopted a double damper to suppress the rolling so that the amplitude linearity was improved. Also, the bass sounds with a quick response characteristic and a speed sense are obtained by using the high hardness rubber for the surround.

③Enlarging magnetic circuit

By using a ϕ100mm large magnet, the magnetic flux density of a magnet circuit to be ensured became enough, and at the same time, by using a 4-layer voice coil, the driving force to be generated became efficient.

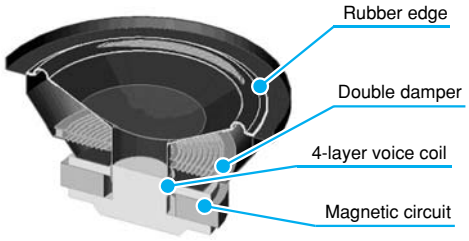


Fig.15 Appearance of Speaker Unit

Adopting these items above led to the development of the speaker unit with excellent transient characteristics. **Fig. 16** shows the tone-burst response characteristics of the conventional speaker unit (ϕ20cm) and the newly developed speaker unit (ϕ16cm). It indicates that the newly developed unit (ϕ16cm) is superior in the rise characteristics of the first and second waves.

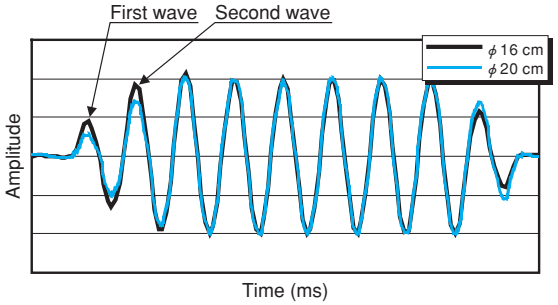


Fig.16 Tone-Burst Response Characteristics

(2) Building of Time Domain Structure

The tune-up subwoofer "TDX700W" adopts R2R structure in which two speaker units are set back to back. The R2R structure is exceptional in vibration suppression, and the two magnetic circuit parts are joined by a shaft so that the vibration reactions produced at one speaker unit absorb the ones at the other. Besides, this structure can be light in weight because it eliminates the need for the ground anchor, and the unwanted vibrations generated by this product are minimized. Therefore, this structure can be said to be the best for car use.

In addition, we developed a new shaft structure durable against car vibrations during driving, and suitable especially for car use. In the conventional mechanism of the shaft for home audios, the joint had left-hand threads at both ends, and the action to screw the joint pulled the connected speaker units to the setting position, then the built-in work of the cabinet was completed. However, this structure had a potential risk of the screw being loosened by car vibrations during driving. To solve this problem, we developed s new structure that the two shafts connecting to the speaker unit respectively are connected and fixed tightly by the following method: holding the shafts with the joint divided horizontally into two parts, and clenching this part with bolts / nuts. **Fig. 17** shows the section view of the tune-up subwoofer structure.

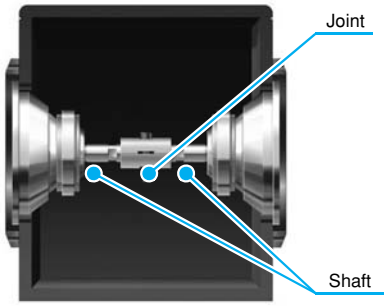


Fig.17 Figure of Tune-up Subwoofer Structure (TDX700W)

4.2.3 Verification of Effects

Fig. 18 shows the fall characteristics of the two tune-up subwoofers: the conventional speaker and TDX700W. This figure shows that the longer characteristics remain in the left bottom part, the more unwanted resonances exist. With this result in the figures, the new developed TDX700W is excellent in fall characteristics due to fewer unwanted resonances.

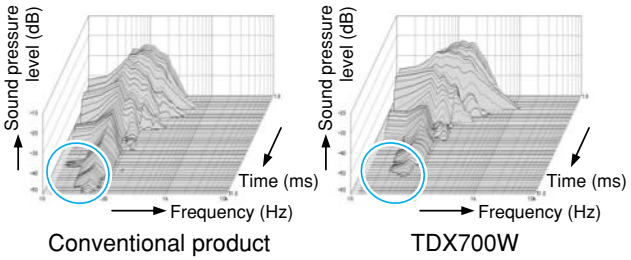


Fig.18 Pulse fall cumulative spectrum of Tune-up Subwoofer

5 Development Result

5.1 Product Specifications

Tables 1 to **3** show the newly developed product specifications. In addition, **Figures 19** to **21** show respective product frequency responses. All of them satisfy the sound performance as car audios to build 5.1-channel surround system.

Table 1 Product Specifications of Center Speaker (TDX700C)

Speaker diameter	5cm
Input (Nom./Max.)	20W / 60W
Frequency response	120Hz to 30kHz
Sound pressure level	83dB
Impedance	4Ω
Maximum dimensions	W129mm×H80mm×D154mm
Weight	Approx. 400g

Table 2 Product Specifications of Satellite Speaker (TDX700S)

Speaker diameter	5cm
Input (Nom./Max.)	20W / 60W
Frequency response	120Hz to 30kHz
Sound pressure level	83dB
Impedance	4Ω
Cord length	6m
Maximum dimensions	W100mm×H148mm×D146mm
Weight	600g

Table 3 Product Specifications of Tune-up Subwoofer (TDX700W)

Speaker diameter	16cm×2
Input terminal	LINE IN 1, Speaker input 1
Built-in amp max. output	120W (60W+60W)
Frequency response	30Hz to 200Hz
Sound pressure level	82.5dB
L.P.F.	40Hz to 200Hz (variable); -12dB/oct.
Supply voltage	DC 14.4V (For minus earth car)
Max. power consumption	10A
Maximum dimensions	W300mm×H350mm×D350mm
Weight	Approx. 9.8kg

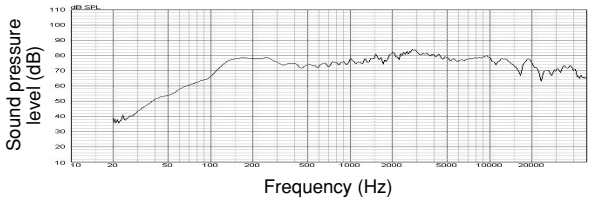


Fig.19 Frequency Response (TDX700C)

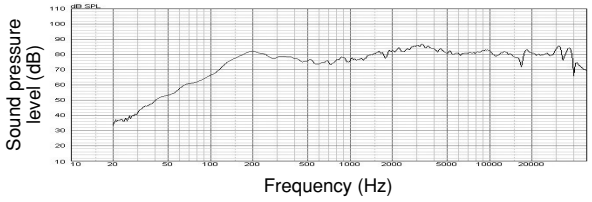


Fig.20 Frequency Response (TDX700S)

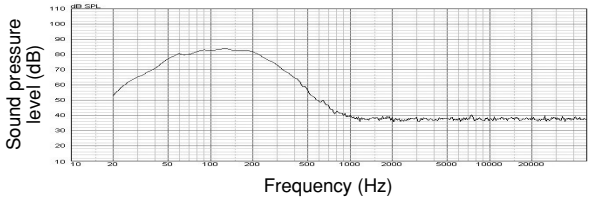


Fig.21 Frequency Response (TDX700W)

5.2 Product Appearance

Fig.22 Appearance of Product

6 Car Surround System

6.1 Example of System Structure

Fig. 23 shows the example of an available system structure for building a surround system in a car using the newly developed automotive time domain speaker.

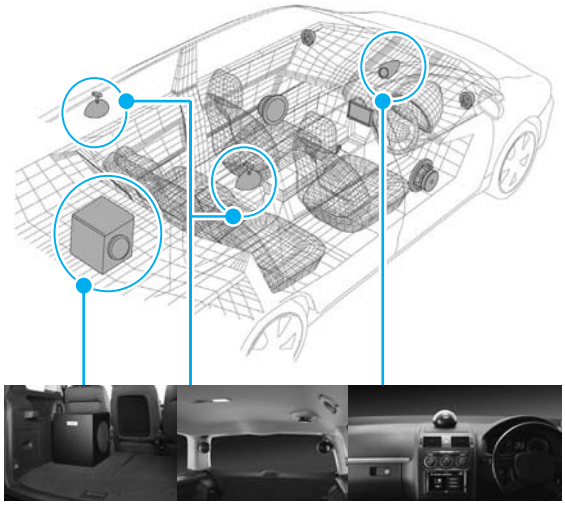


Fig.23 Example of System Structure

In the systems like above, to achieve comfortable surround conditions in a car compartment, tuning respective audio parameters on H/U is needed so as to obtain the appropriate values for the respective car compartments. To make this tuning easy for users, we developed the new function, "ECLIPSE TD mode." In the next section, we explain the "ECLIPSE TD mode."

6.2 Development of ECLIPSE TD Mode

ECLIPSE TD mode is an audio function installed in AVN778HD, which enables users to tune the audio parameters (e.g. parametric equalizer, crossover) on H/U to obtain the appropriate values simply by pushing a button.

These parameters are registered in advance in the memory of H/U, which are obtained through calculating the high-versatile values so as to make full use of the performance of the newly developed center speaker, the satellite speaker, and the subwoofer to be installed in various car models. Also, since a time alignment function and respective channel levels largely vary by the installation condition, they are to be gone through by an auto measurement function. To obtain the surround sound space in high reproducibility through time domain speakers, all the users have to do is call up the versatile parameters through ECLIPSE TD mode, and then tune the parameters suited to the characteristics specific to each car using auto measurement function.

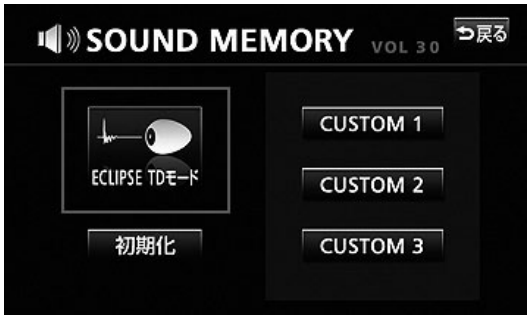


Fig.24 ECLIPSE TD Mode

7 Conclusion

This paper has described the aim of development and the characteristics of automotive time domain speakers.

For the sound creation through speakers, you never succeed in gaining quality sounds only by upgrading the speaker unit's specifications, which is because you need to make efforts with regard to the enclosure and other peripherals of the structure that cover up the speaker unit. While, only striving to improve the enclosure does not lead to a better sound than the speaker unit performance. These time domain speakers are exceptional and unique products succeeding in producing completely pure and natural sounds, by making full use of the both speaker unit development and structure development.

The three surround type models we developed this time enable building the surround system in a car compartment akin to home audios. We will further develop and strengthen the product lineup so that more customers listen to the "ECLIPSE TD sound."

Finally, regarding these newly developed products, we sincerely appreciate the great help from many people at our suppliers who are concerned in the bracket design for satellite speakers, the design development of enclosure parts, the appearance finishing, and all the aspects of these products.

Profiles of Writers

Kiyosei SHIBATA

Entered the company in 1998. Since then, has engaged in the development of OEM car speakers, sound systems, and then commercial speakers. Currently in the Acoustic Engineering Dept, Audio Business Div, CI Grp.

Ryousuke SOU

Entered in the company in 2005. Since then, has engaged in the development of commercial speakers. Currently in the Acoustic Engineering Dept, Audio Business Div, CI Grp.

Masahito KAWAI

Entered in the company in 1984. Since then, has engaged in the structure design of car stereo systems. Currently the Team Leader of the Acoustic Engineering Dept, Audio Business Div, CI Grp.