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Super Live Sound System for Toyota Aristo and Crown

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Audio equipment is a key part of any new car design, and all manufactures strive for the most desirable functions and highest performance. Toyota continues to work with Fujitsu Ten to keep their cars at the forefront of audio design.
In the fall of 1991, Toyota Corporation released their new Aristo and Crown Majesta and the new Crown hardtop and sedan. Fujitsu Ten developed new audio systems with CD-ROM players for these cars. This paper describes the design concepts and technology used.

1. Introduction

In September 1987, Fujitsu Ten developed an audio system with a CD-drive which was incorporated into the world's first multivision system using CD-ROMs. We designed the system for Toyota's Crown range of cars. Our audio system received praise for its high performance and advanced technology.

As car audio has advanced, we have seen the emergence of CD auto-changers and high-performance navigation systems.

To meet changing needs, Toyota Motor Corporation expanded its line of luxury cars to accommodate today's discerning customers, and asked Fujitsu Ten to design audio systems for each model.

The new Aristo is at the top of Toyota's range of luxury personal sedans, and Fujitsu Ten designed its audio systems to satisfy the most critical audiophile.

We designed highly functional audio systems, including multivision systems, for three Crown models, including the new Majesta.

With these latest systems, we had to reconcile developing a line of products efficiently and meeting the high performance required.

This paper describes our development aims and the technology we used to achieve them.

2. Development aims

2.1 A variation of system arrangements

Separate audio systems tailored to the four Crown type models were required, with different users in mind.

To design individual system arrangement:

1) We developed functional units that can be used in all systems to make it easy to combine individual functions.
2) We newly developed an audio bus communication scheme. Each functional unit has a control microprocessor for flexible control of different function combinations.

2.2 Improved reception

We used some new circuits and methods for higher performance than ever before.

1) Current ways of processing the signals received by the tuner can have only a limited effect on reception performance. We developed a dual-tuner diversity system, which selects the stronger of two identical radio signals, combined with a network following system which selects the stronger of two identical broadcasts at different frequencies.
2) We developed a multipurpose noise reduction IC to cut FM multipath noise, which is inevitable in a car, and external AM noise.

2.3 Improved sound quality

Different cars need different sound systems. We pursued a natural sound, and tried to produce acoustics with an impression of reality. We improved powerful sound quality at lower audio frequencies by using large woofers and a high-power woofer amplifier with a DC-DC converter.

We improved the clarity of middle/high frequencies by using soft dome tweeters with modified diaphragms or new magnet materials or both.

We have also modified the algorithm for DSP sound field control developed for Sera and dramatically improved presence in each mode.

2.4 Improved ease of operation and readability

The most obvious feature of this latest range of products is their large, new shape giving them an opulent appearance. Buttons and knobs are bigger, making them easier to operate and the LCD is also larger, making it easier to read.

3. System overview

3.1 System features

As Figure 1 shows (head units only), we developed a total of 11 new audio systems for the four Crown type models.

All these systems have the following features:

1) CD
   There are two types of CD players: the three-in-one, which holds only one CD, and the CD autochanger separately installed which holds up to 12 CDs.
2) Separately installed high-power amplifier
   The amplifier is installed in the trunk (where space is less restricted), making it possible to use an amplifier with better sound quality and higher power. This also gives a greater degree of freedom when matching systems to cars.
3) Communications control of principal functional units
   The individual functional units are interconnected by a network to simplify control. This also reduces bugs and streamlines software development.

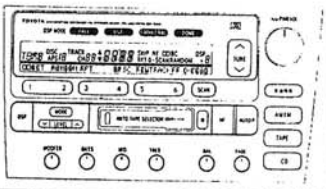
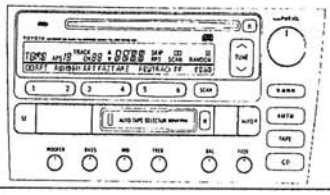
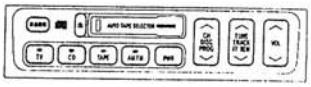
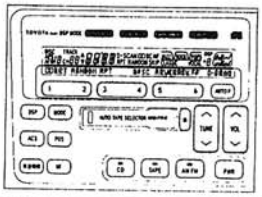
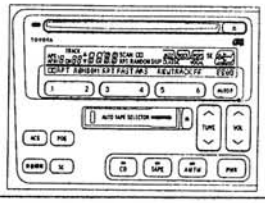
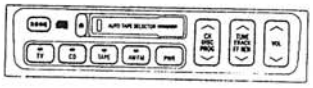
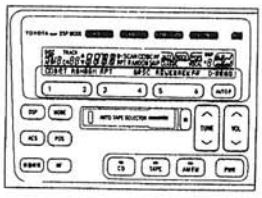
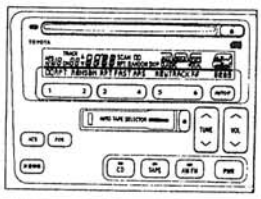
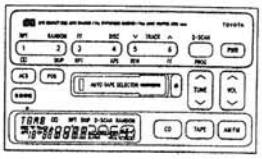
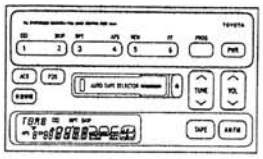
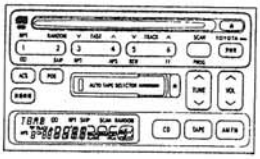
System / Car type	Multivision system	Two-in-one (autochanger) system	Three-in-one system
Arito	———		
Crown Majesta			
Crown Royal Series			
Crown Sedan			

Figure 1. Front panel designs of the audio system controller for the Aristo and Crown

3.2 System development

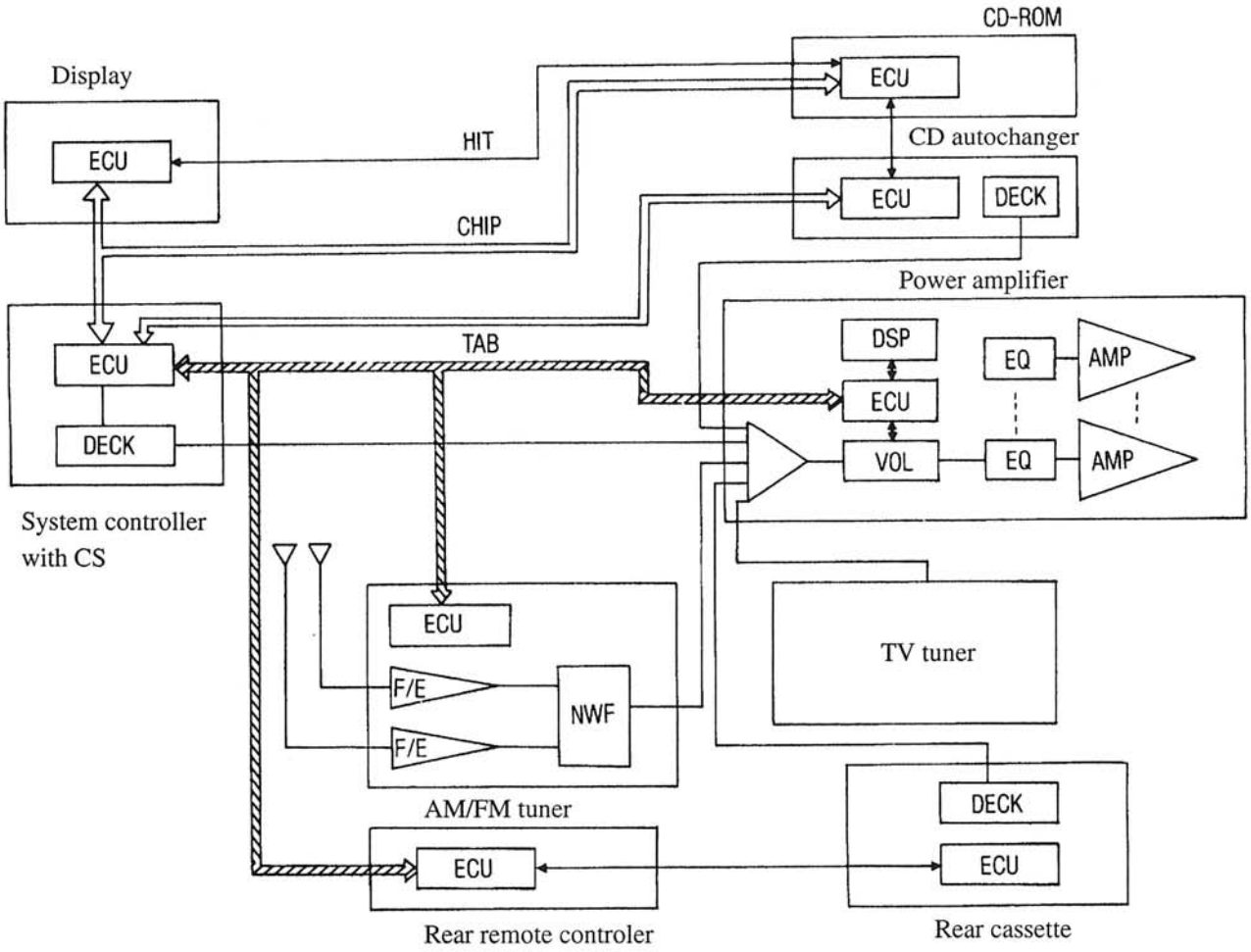
Figure 2 is a system block diagram. A complete description of the system is beyond the scope of this paper, so we will focus on the multivision system for the Crown Majesta. The multivision system is the core of the audio systems and all other systems are designed around it.

The system is characterized by a system controller (which includes a cassette player) mounted on the instrument panel. The other units (such as the tuner, CD and amplifier) are installed in the rear trunk. This layout packs many functions efficiently into a restricted space. Individual functional units are controlled by the system controller, the head unit of this system, via a newly developed audio communication bus which we call the Telecontrol Audio Bus, or TAB. The bus used by TAB communication allows the functional units to be controlled in parallel and less sophisticated systems can be made by simply removing unwanted functions.

The head unit also contains an audio cassette deck.

When audio mode is selected by pressing a mode button on the head unit, a communication command returns the status of individual functional units to the head unit. The head unit then communicates with the display electronic control unit or ECU, transmitting the necessary display information. If the display is in audio mode, it continuously shows the audio status; if it is in any other mode(such as map or drawing mode), it superimposes such maps for a few seconds. The audio status is changed by pressing an infrared touch switch on the display. The display ECU then determines which switch has been pressed and transmits the switch information to the head unit. The head unit then issues commands to the functional units just as it did during mode selection. Our other systems use similar communication, except there is no communication with the display.

The next section describes the principal technology in the multivision system.



Note: The display and TV are not made by Fujitsu Ten.

Figure 2. Block diagram of multivision system

4. New technological development

4.1 System communication

4.1.1 Aim and features

We developed the TAB communications protocol to control audio systems built around the audio ECU. TAB has the following features:

① Bus communication controlled by a 4-bit microprocessor
② No additional attachments neccessary
③ Mixed bit synchronization by shift checks and character synchronization by handshaking
④ Control by polling/selecting
⑤ Transmission rate of 9600 bps
⑥ Supports up 10 slave nodes
⑦ Up to 31 bytes of data transmitted per frame
⑧ Error detection and correction

4.1.2 Construction

The TAB is made up of shift-clock hardware full-duplex serial communication lines, plus three control lines (Table 1). Networking is accomplished by wired-OR interconnection of these lines (Figure 3).

4.1.3 Bit synchronization

Data is handled as eight-bit characters. The individual bits of a character are synchronized with each other by the TCK line (Figure 4).

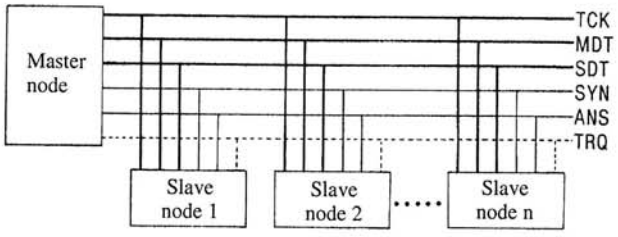


Figure 3. Building a network using TAB

Table 1. TAB signals

Abbreviation	Signal name	Function
TCK	TAB Clock	Synchronizing clock generated by the master
MDT	Master Data	Serial data sent by the master
SDT	Slave Data	Serial data sent by the slave
SYN	Synchronize Clock	Synchronization initialization request sent by the master
ANS	Answer to Master	Response to the master sent by the slave
TRQ	TAB Request	Bus use request sent by a slave

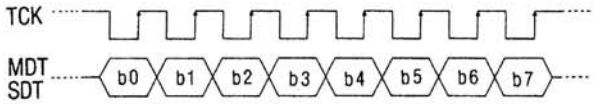


Figure 4. Synchronizing bits

4.1.4 Character synchronization

Characters are synchronized by the master node controlling the SYN line and slave nodes controlling the ANS line. Slave nodes use the TRQ line to request permission to use the bus (ENQ) to the master node (Figure 5).

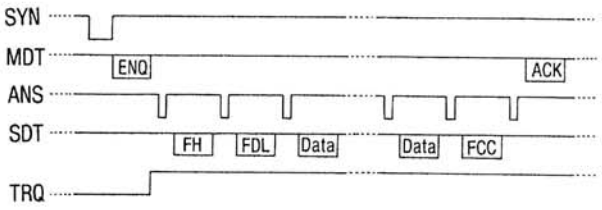


Figure 5. Synchronizing characters

4.1.5 Benefits

TAB allows us to build a bus communication network with a 4-bit microprocessor, with the following benefits:

1) The same hardware and software can be used, regardless of the system mode, which allows unit modularity.
2) Failing units can be identified by monitoring communications data, which makes system debugging and troubleshooting easier and quicker.
3) The TAB can be incorporated in test equipment in the production line to test individual units automatically.

4.2 Superlive sound

4.2.1 General system configuration

Figures 6 and 7 are block diagrams of typical Aristo and Crown audio systems. The Aristo audio system has a head unit (CD autochanger + radio/cassette integrated as a unit), a power amplifier, and eight loundspeakers. The crown has a head unit (CD autochanger + cassette/audio controller), a power amplifier, and 10 loudspeakers. All these components are new and were developed specially for the Aristo and Crown audio system. Figures 8 and 9 show the layout of each audio system in the car.

4.2.2 Loudspeaker system

The Aristo and Crown super live sound system has inherited the heat treated pulp cone full ranges and other high sound quality features of its predecessors. The new loudspeakers in the Aristo and Crown super live sound system are described below.

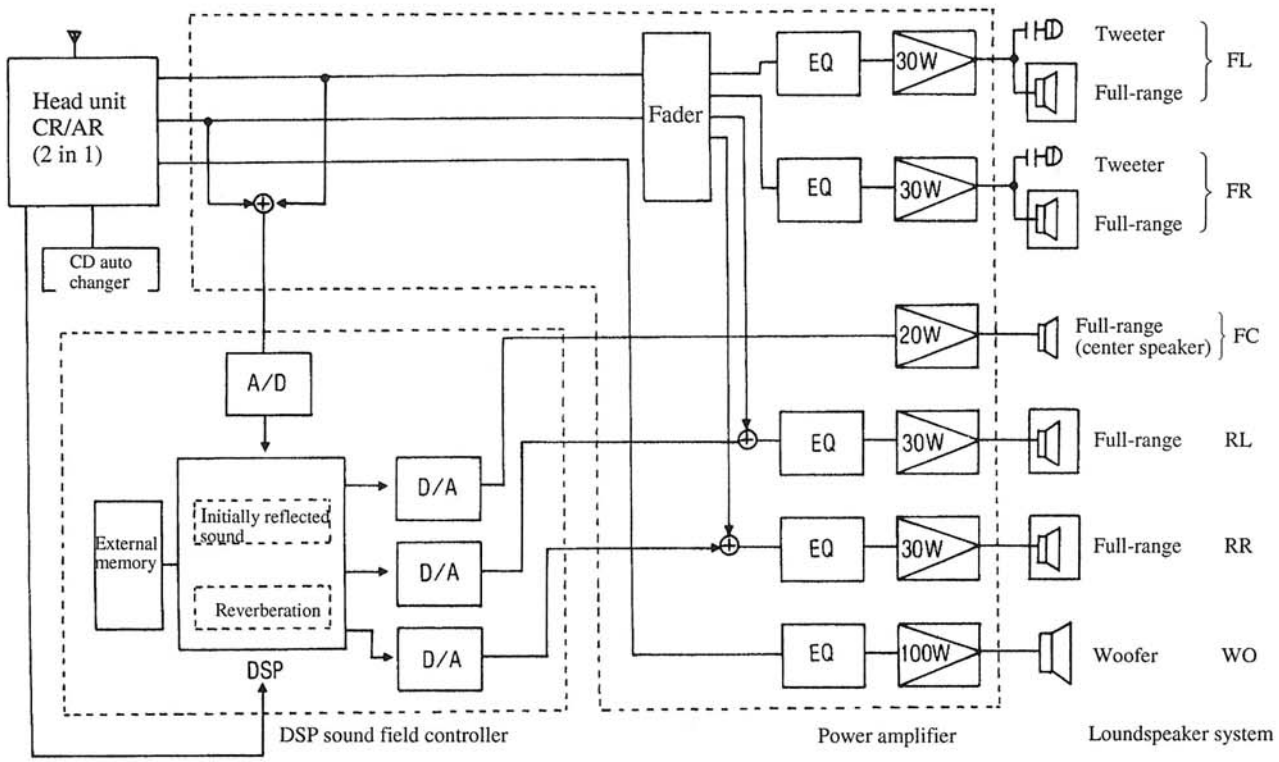


Figure 6. Aristo audio system block diagram

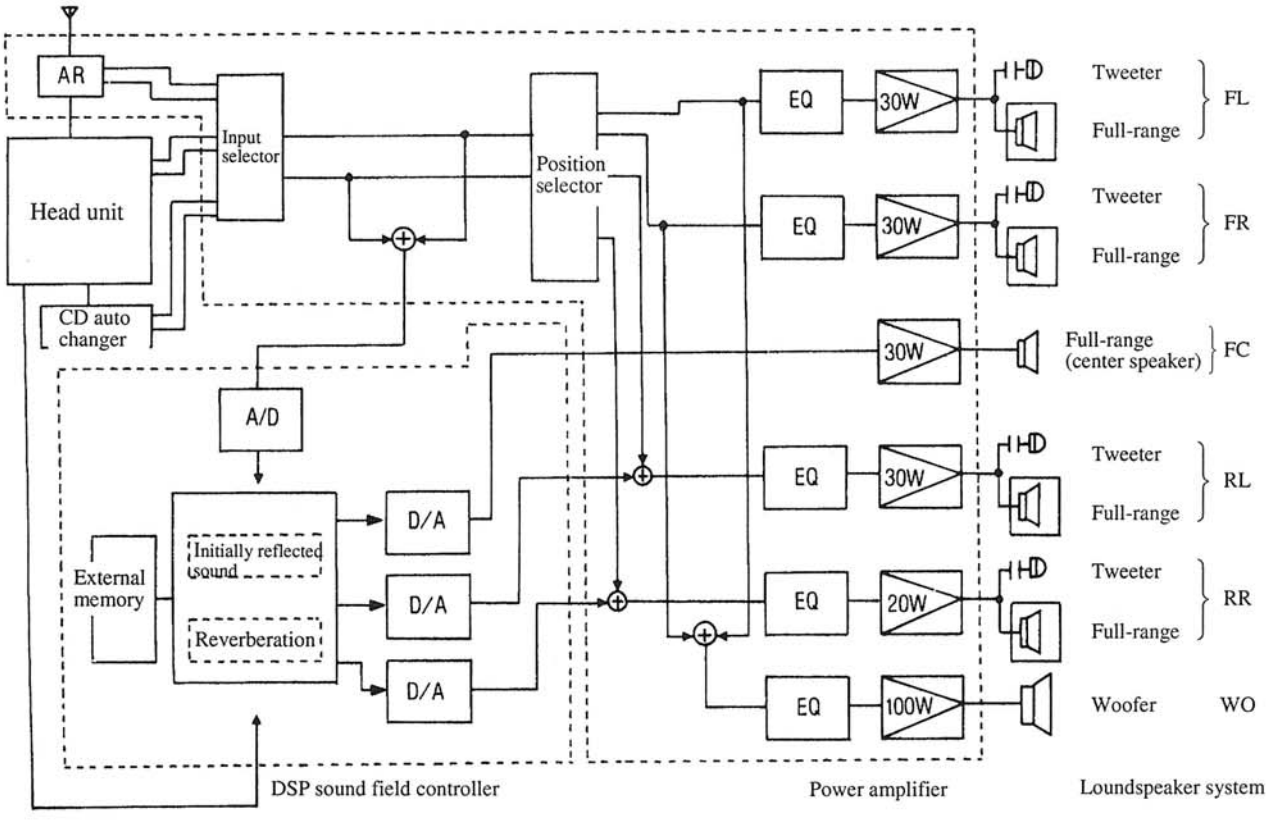


Figure 7. Crown audio system block diagram

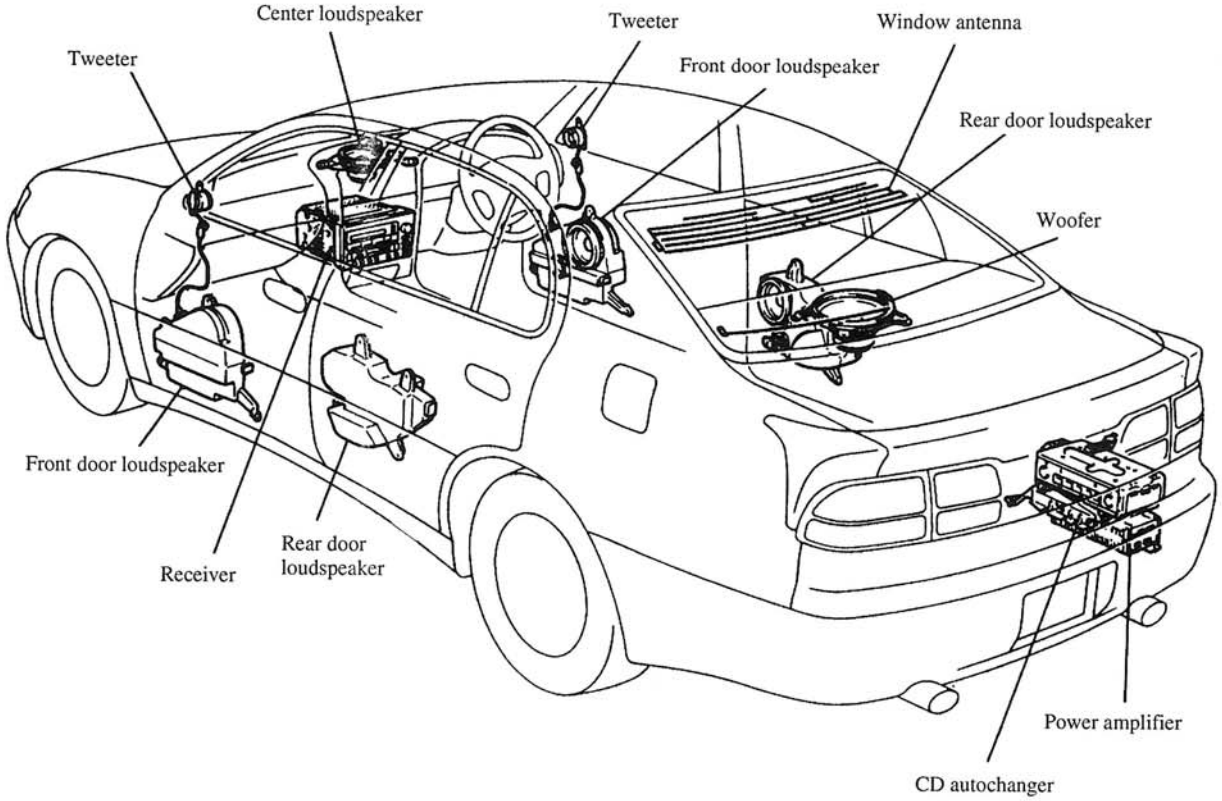


Figure 8. Aristo interior layout

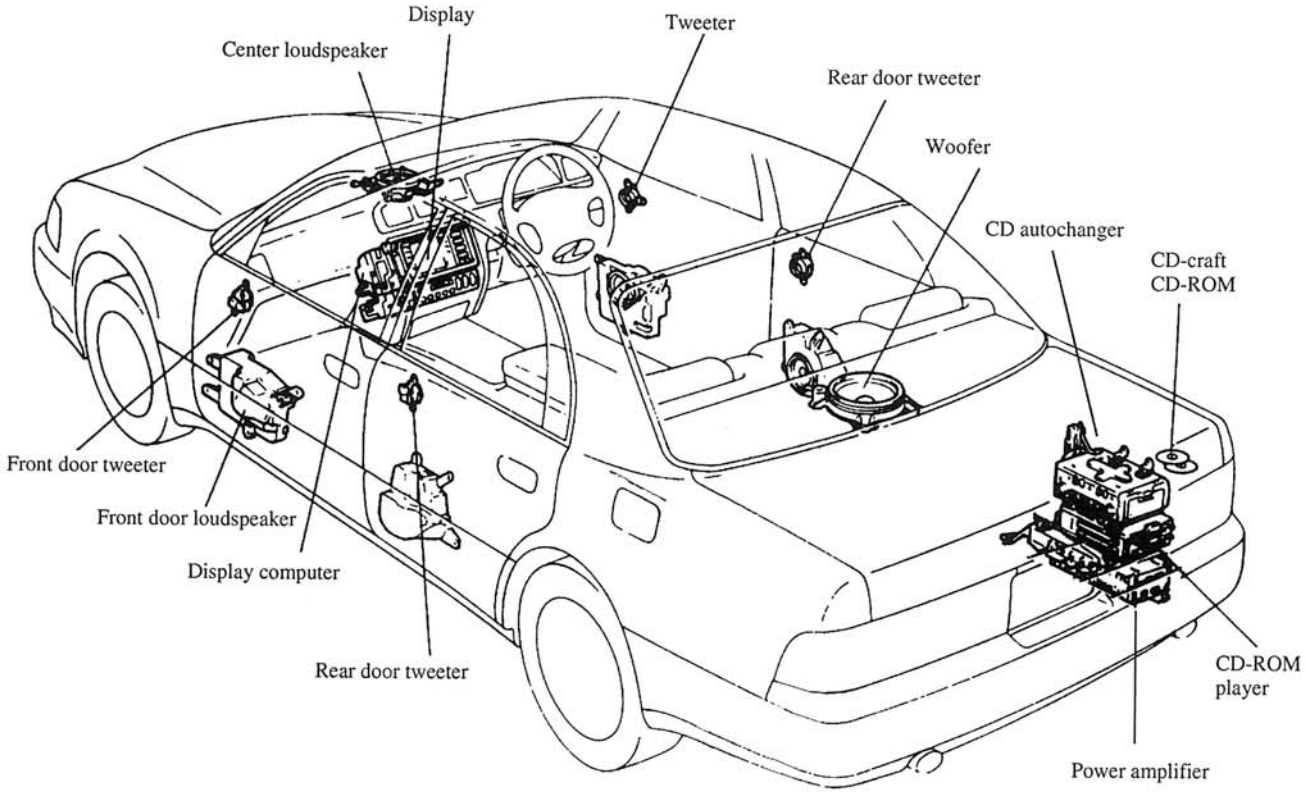


Figure 9. Crown interior layout

1) Soft dome tweeter

The diaphragm in the soft dome tweeter is made of cloth (silk), not the resin (polymide) used for the semihard dome tweeters of our previous super live sound systems. The high internal loss of the cloth has helped to improve the transient response characteristic and high frequencies are reproduced with both clarity and texture. The completely dome-shaped diaphragm also has better directional characteristics (Figure 10). Changing from a cone tweeter to the semihard dome tweeter in the previous super live sound systems had improved the directional characteristics by +1 dB to + 7 dB between ±30° and ±90°. The directional characteristics have been further improved by +1 dB to +3 dB between -60° and 60° by the switch to a soft dome tweeter.

Using silk as the diaphragm material increased the diaphragm weight, and required a very large magnet to maintain adequate sound pressure. We used a neodymium magnet, for the first time as a genuine Fujitsu Ten part, to greatly increase the maximum energy product (BH max); neodymium has a magnetic force per unit gram of eight to 10 times that of strontium ferrite. The neodymium magnet also reduced the diameter of the magnetic circuitry from 65 mm to 50 mm and made it lighter.

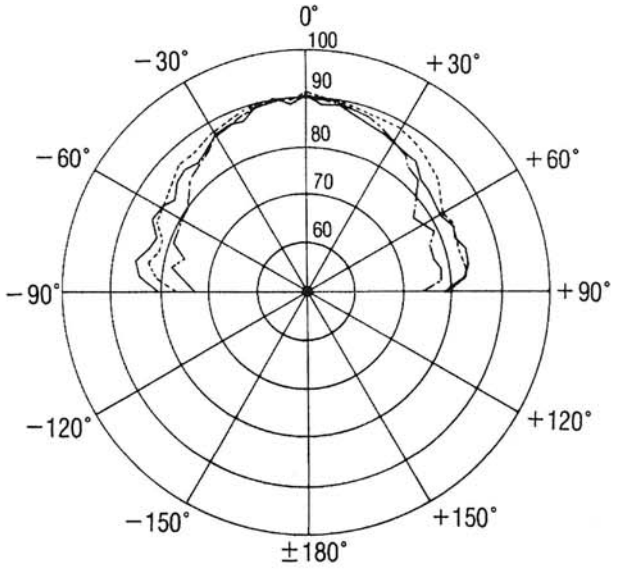


Figure 10. Comparison of directional characteristics of tweeters

2) 30 cm woofer (Aristo)

We mounted a large 30 cm woofer in the center of the rear shelf to extend reproduction to the heavy low frequencies. It is the first we have used this technique with genuine parts. Table 2 gives typical relationships between the loudspeaker diameter and distortion factor. As you would expect, the 30 cm woofer reproducing 60 Hz with an SPL of 90 dB has a distortion factor more than 20 dB better than a general-purpose 16 cm woofer. We combined the frame and bracket of the 30 cm woofer so we could fully exploit the rear trunk as a loudspeaker enclosure. The woofer reproduces low frequencies with clarity and low distortion.

Table 2. Loudspeaker diameters and distortion factors (60 Hz)

Level: 90 dB SPL

Loudspeaker diameter	Third-harmonic distortion factor (60 Hz)
ϕ16 cm: Standard size	6.3%
ϕ20 cm: As used in the present Crown	1.3%
ϕ30 cm: As used in the present Aristo	0.4%

4.2.3 Sound field control in the car space

We designed the acoustics of the Aristo and Crown sound field control system with the following goals in mind:

① Maintaining a sense of being in front of the music with emphasis on the quality of the unprocessed sound.

② Creating a sound field with a feeling of reality based on acoustics data from concert halls.

For ①, we used a center loudspeaker system, as used in the Corolla and Sera. There is one auxiliary loudspeaker that reproduce reflected sound only, at the center of the installation panel for sound field control.

For ②, and to create a sound field with a feeling of reality, we collected and analysed a large amount of acoustics data from concert halls. Our analysis highlighted reverberation as the key factor in producing a natural sound. We found that reverberation decays faster at high frequencies than at medium frequencies, as shown in Figure 11. We noticed a similar effect when we analysed acoustic data collected from many concert halls. We incorporated these characteristics into the sound field control system. Figure 12 shows acoustics data for the Aristo, and Figure 13 shows acoustics data for Fujitsu Ten's conventional sound field control system. High frequencies between 2 and 5 kHz persist in the conventional sound field

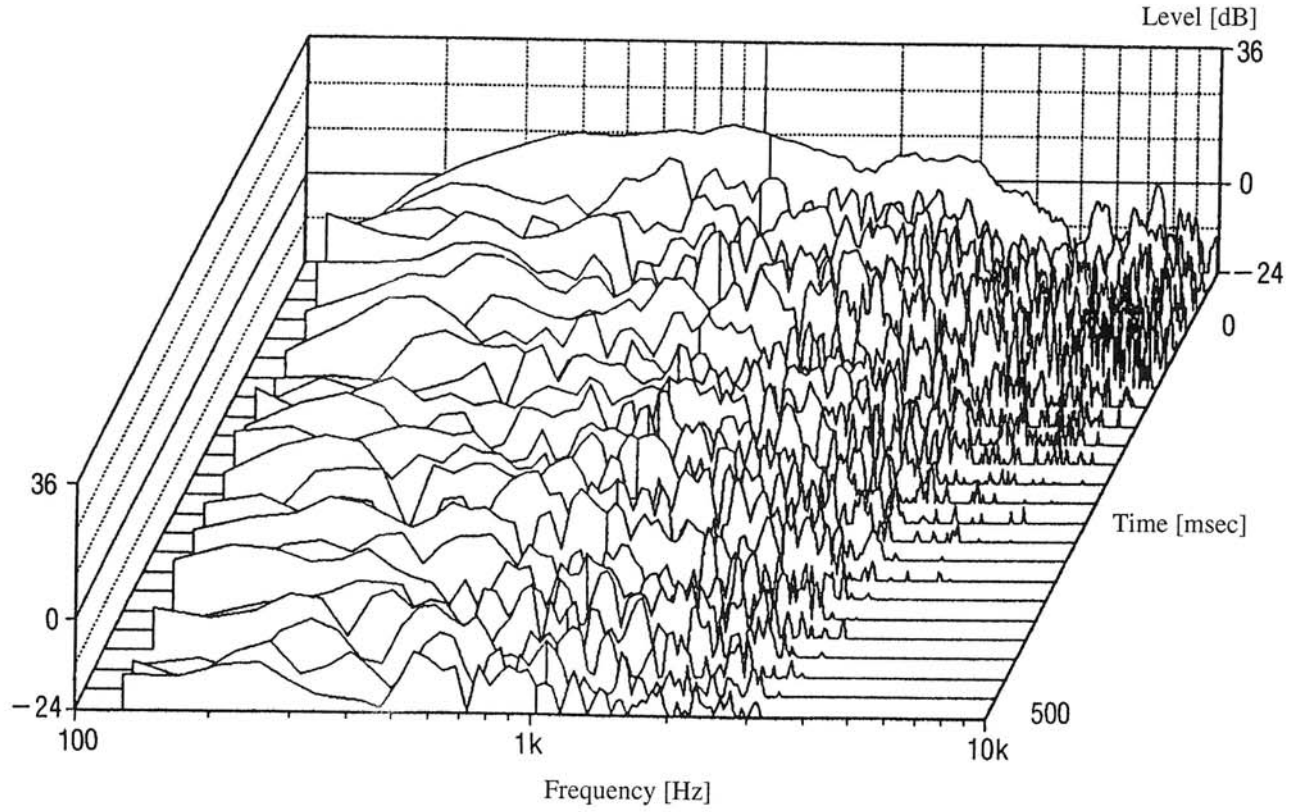


FIgure 11. Running power spectrum in a concert hall

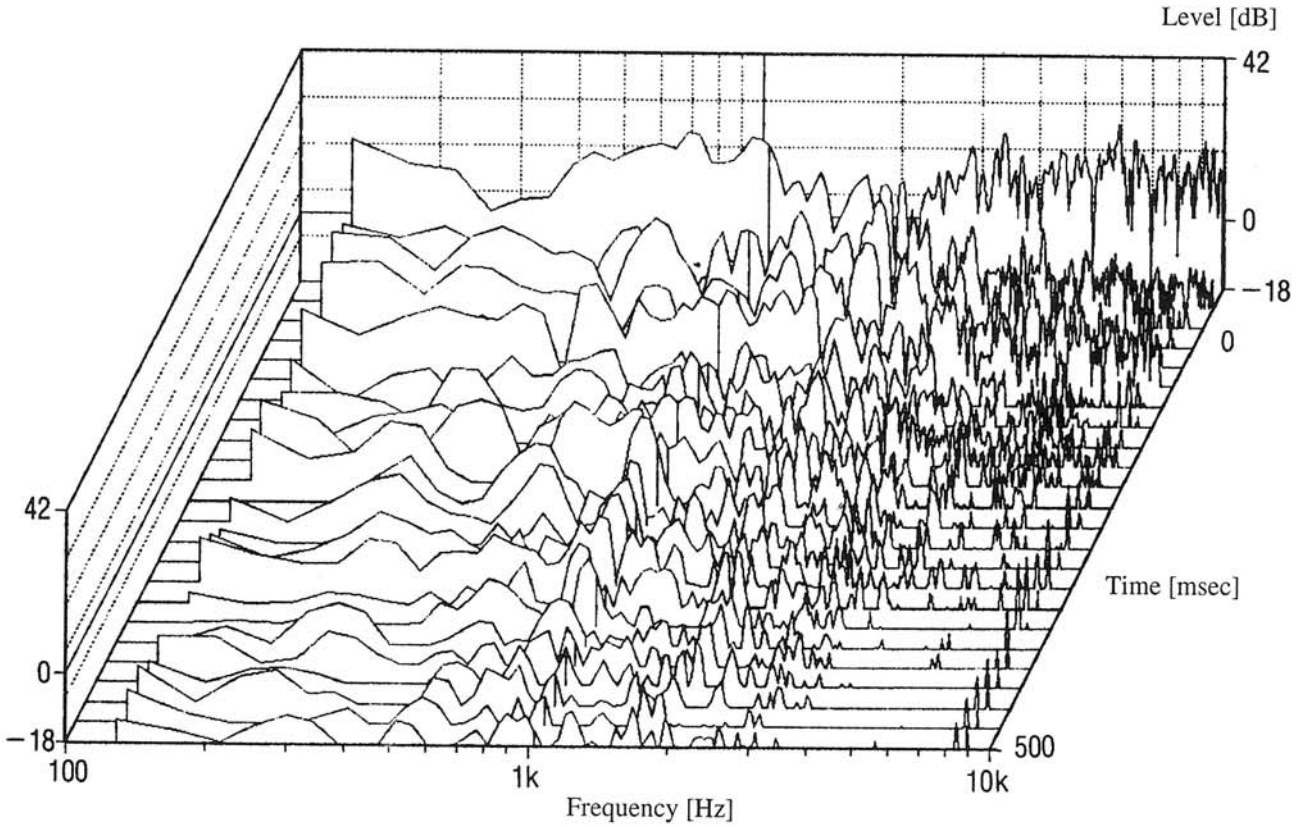


Figure 12. Running power spectrum in the Aristo

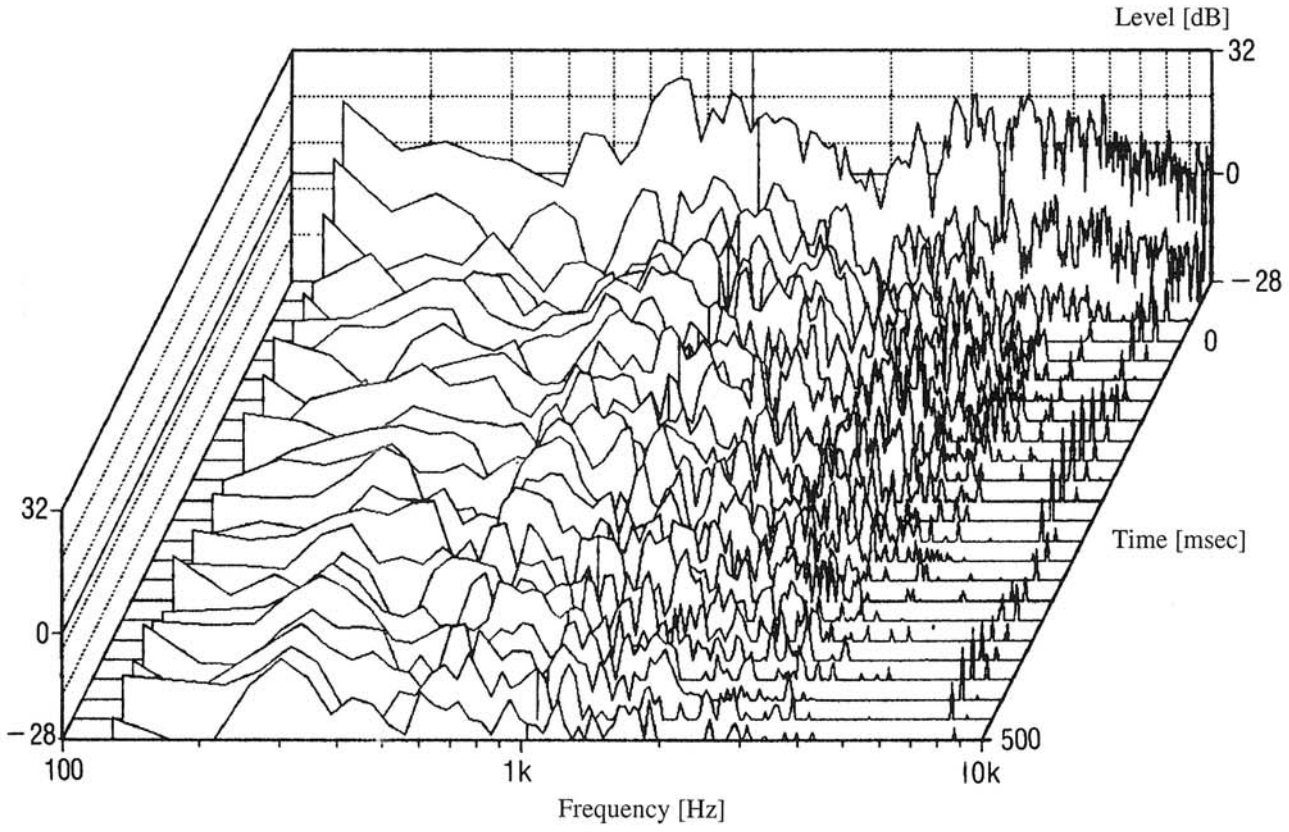
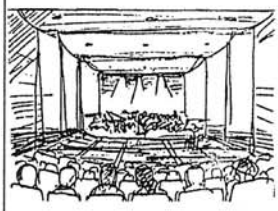
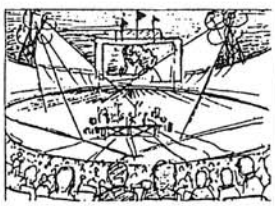


Figure 13. Running power spectrum for the conventional sound field control system

Table 3. Sound field controls

Mode name		HALL	LIVE	CATHEDRAL	DOME
Listener impression					
		A large concert hall with a seating capacity of 2000 or so. This mode has reverberations with echoes and a rich sound and produces a natural, surround sound with a feeling of expanse and presence. A long initial delay helps create the impression of width.	A medium-sized music club with a seating capacity of 20 to 30. It has a powerful direct sound and a high level of initially reflected sound. It recreates the power and presence of a live performance right in front of the listener.	The interior of a large marble cathedral in Europe. This mode gives the impression of a space several dozens of meters in diameter and height, with a rich sound with a long reverberation time. This atmosphere is ideal for reproducing church music, such as pipe organ music, and chamber music, such as a chorus.	The atmosphere of a live performance in an outdoor stadium, such as a ball park. The initially reflected sound reaches the listener with a considerable delay, recreating the openness of a broad, open-air ball park.
Signals	Front	Direct sound			
	Center	Initially reflected sound + Reverberation			
	Rear	Direct sound + Initially reflected sound + Reverberation			
	Woofer	Woofer			
Initially reflected sound + Reverberation		40 msec	20 msec	50 msec	100 msec
Reverberation time		1.9 sec	0.3 sec	4.1 sec	——

control system, while in the Aristo sound field control system, high frequencies decay up to 2 kHz. This is similar to the acoustics data from concert halls and adds to the reality of the sound in the car.

We used the results of out research to provide four modes of hall, live, cathedral, and dome in the Aristo and Crown sound field control systems. Table 3 summarizes the audio impression and controls for each mode.

4.3 Radio reception

4.3.1 Improving radio reception

In keeping with the modern trend, the Aristo and Crown interiors are very quiet. The highly developed sound control of our audio systems needs the particularly quiet environment of these cars.

The radio signal environment, however, is getting worse. Radio interference is a growing concern because more radio stations are being installed, there are more high-rise buildings, and more traffic signals and vehicles.

Tuner designers must work increasingly hard to provide the performance needed by advanced audio systems in a poor reception environment.

We used a variety of new techniques in the Aristo and Crown to maintain radio sound quality. Some of the major techniques we used are summarized below.

4.3.2 Network following system (NWF)

The same radio broadcast uses different frequencies, and a broadcast is transmitted by a number of broadcasting or repeater stations which cover the service area. If a car drives out of the service area covered by a broadcasting station, the driver must retune to the new broadcasting station's frequency.

For the Aristo and Crown, we developed a dual-tuner network following system which saves the user retuning manually and improves reception between station service areas. The network following system automatically tracks a selected broadcast comparing its content with broadcasts on other frequencies. It also monitors the intensity of a broadcast's radio signals and tunes into the stronger signal.

The voice comparator circuit is central to the network following facility. If two audio signals are identical, subtracting one from the other would give 0, showing the similarity of the broadcasts. In reality, however, subtraction rarely gives 0 because of level and phase differences between broadcasts form different sources.

To accommodate phase differences, a comparator looks only at audio frequencies without large changes with time. Comparing the frequency distributions of the broadcasts of interest also makes their level differences irrelevant.

Field tests of the network following facility showed it switched smoothly in most districts. With FM reception, in particular, the tuner switched before a dropping field intensity caused multipath or other noise. Network following greatly improves reception and makes the tuner easier to use. Figure 14 illustrates the results of field tests.

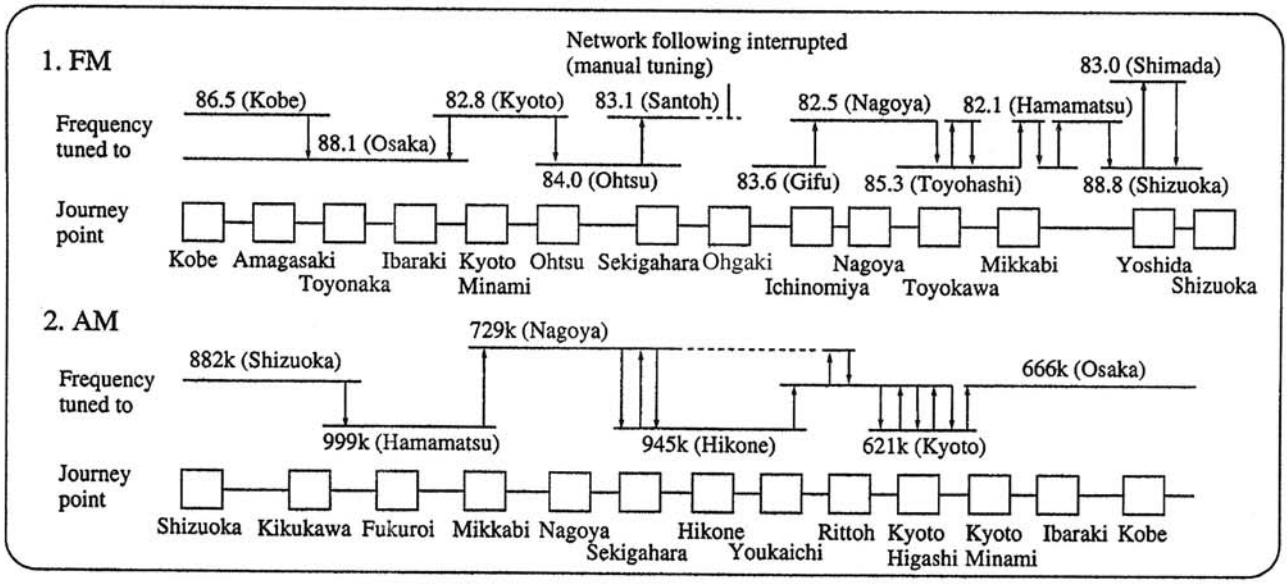


Figure 14. Results of field tests

4.3.3 Dual-tuner diversity

There are two broad types of diversity receivers designed to reduce FM multipath noise. The first is the scanning type, which has many antennas and one receiver system, with a selector circuit at the receiver input. An antenna is selected when a multipath detection signal exceeds a certain limit. The second is the selection type, which has as many receivers as there are antennas and compares reception continuously to always tune in the strongest signal.

Until now, Fujitsu Ten has always used the scanning type because it is small and low-cost. The selection type has better performance, however, selecting the strongest frequency, even when there is no noise or only a small amount of noise. This is true because it monitors noise and signal levels at all times. In our audio system, we used a selection dual-tuner diversity receiver which shares the two receivers in the network following facility; this solves the cost problem.

4.3.4 Multipurpose noise reduction IC

Because the car tuner is moving, its reception performance must be maintained in a variety of signal conditions.

Fujitsu Ten has developed various schemes for suppressing FM pulse noise and multipath noise. Despite the increasing need for AM noise suppression, however, little progress has been made.

We have developed a scheme for suppressing AM pulse noise. We developed a multipurpose noise reduction IC which is a single-ship implementation of suppression circuits for AM and FM pulse noise and multipath noise.

Figure 15 shows the S/N characteristics of the noise reduction IC for AM broadcasts.

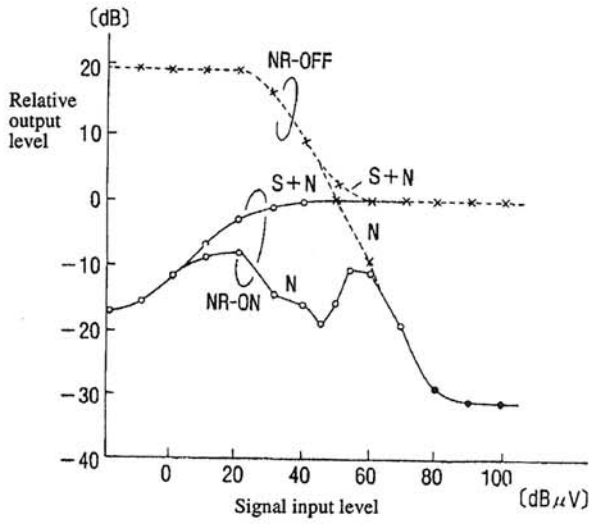


Figure 15. S/N characteristics of AM noise reduction circuit

4.3.5 Auto preset

Although it does not directly improve reception, the auto preset automatically searches for and stores up to six stations having the strongest signal in one operation. Monitoring stations with strong radio signals improves reception performance. Auto preset in the Aristo and Crown uses the dual-tuner diversity process of the NWF system to continuously monitor the station tuned-in. To reduce local oscillator frequency interference in the dual-tuner system, any interfering frequency band is searched for, immediately after the start of operation, and is immediately muted.

Station radio signal intensity is measured by averaging 16 intensity values for AM broadcasts and four intensity values for FM broadcasts. At nighttime, AM broadcasts from the Asian continent become stronger than Japanese broadcasts due to fading, making it difficult to detect the preset stations. Stations can be detected at two levels of sensitivity which reduces these detection failures.

4.4 CD autochanger

4.4.1 Functions

Figure 16 shows the arrangement of the CD autochanger deck in our latest system. Below is a summary of the principal functions and principle of operation of the deck.

① Magazine loading/unloading

The magazine is of the tray type which prevents the discs being scratched. It houses 12 trays.

We developed two types of dedicated trays to hold 12 cm and 8 cm discs. These trays allow random loading into the magazine. The magazine is loaded into the deck manually, then motor-driven power ejection is

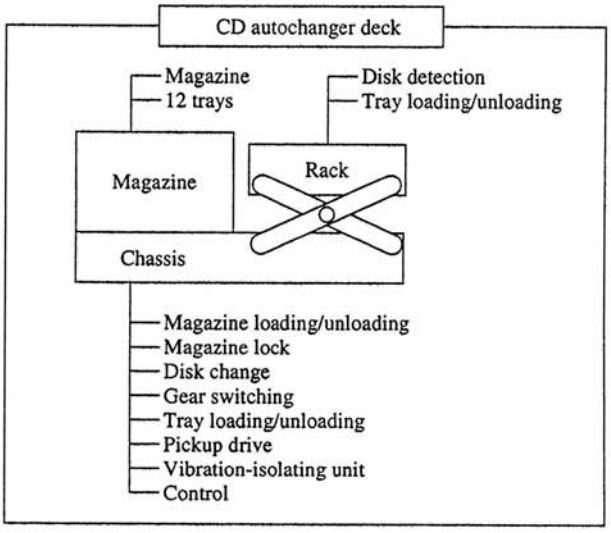


Figure 16. Components of the CD deck mechanism

used to lift the rack and to load and unload trays, thus providing stable operation. This is in addition to the spring loading used before.

② Pickup drive feature

We designed a dedicated drive feature and a chassis with pickup feed screws, and a thin pickup drive with 8/12 cm tray discrimination and tray guide features.

4.2.2 Features

① Compact and lightweight

The rack (tray loading/unloading feature) is lifted to change discs. Also, the thin pickup drive is 40% the weight and 50% the volume of its predecessor.

② Improved CD readability

We have reduced the power-on settling time of the error correction circuit. Further, we have greatly improved error correction during signal processing for fingerprints and other stains by using quadruple correction with C2 code.

③ CD-Craft playback function

The CD autochanger can play both music discs and CD-Craft (ROM discs). ROM discs are mounted in the magazine slots, starting with the 12th disc. When a ROM disc is selected while music is being played, the CD autochanger stores the disc number and the track number of the disc being played so when it returns to the music disc mode, it can start playing again where it stopped.

4.5 Automated manufacturing

4.5.1 Surface mounted lamps

Indicating the large number of functions available requires more lamps than ever. We developed completely new surface-mounted lamps which can be mounted automatically. This has reduced the assembly workload to about one ninth of that required before. Table 4 lists the lamp specifications and Figure 17 shows the lamp design.

4.5.2 Automation of testing by TAB

We built an automatic checker which uses the TAB communication technology described in Section 4.1, to automate the sequence of new product tests in the production line.

The new automatic checker consists of the testing system in service we use for the current Crown models, plus a new TAB commander and new testing software. We have broadened the tests and how use the test equipment more effectively (Figure 18).

The new automatic checker has cut the line testing workload drastically.

Table 4. Surface-mounted lamp design

	Requirement	Item	Design standard
1	External dimensions suitable for surface mounting	Depth × Width × Height	9 × 6 × 9/MAX (mm)
2	Component takeup stability	Adsorption surface maintenance	Lamp sphere nozzle clearance diameter ϕ2.5
		Lightweight lamp assembly	500 mg
		Automatic loading and packing	Embossed tape (one reel: 800 pcs)
3	Solderability	Solder wettability	1 second or less (Zero cross time)
		Soldering strength	1 kg or more
4	Heat resistance	Double-sided far infrared furnace temperature profile requirement must be satisfied	235°C, 20 seconds or longer

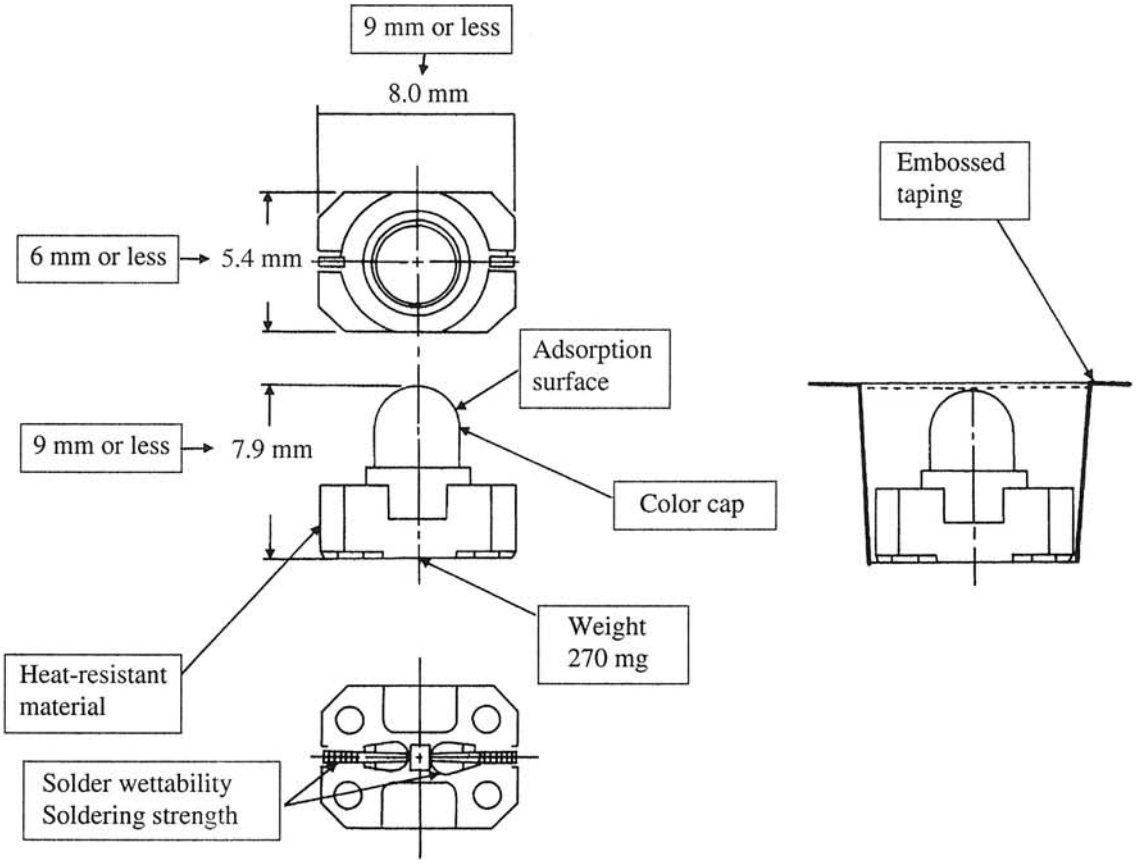


Figure 17. Lamp design

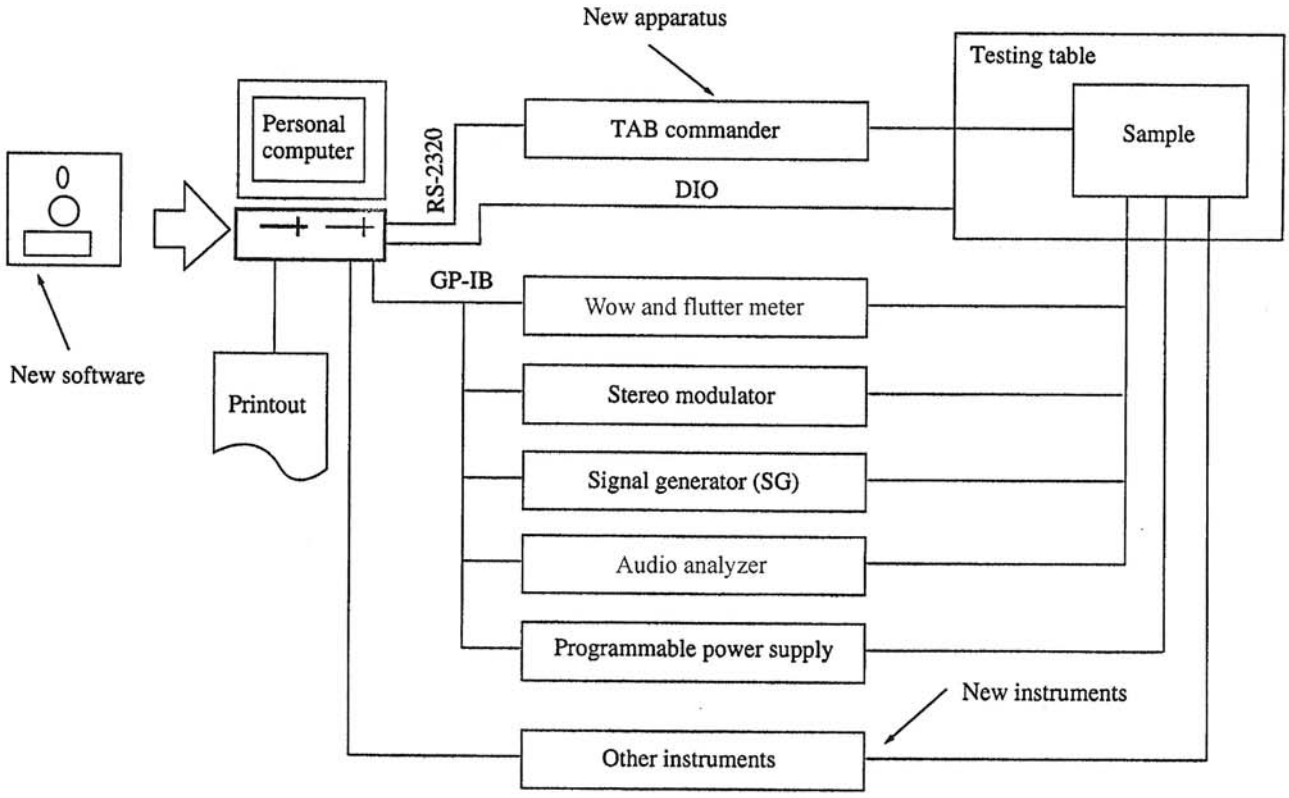


Figure 18. Automatic checker

5. Conclusions

We developed audio systems for the Aristo and Crown with new features and concepts for today's most discerning customers. The system we built has improved reception performance, acoustic performance, ease of operation, and control and display readability. While developing these systems, we added efficient development techniques and communications know-how to our experience. The lessons we learned this time will help us continue to respond to the needs for increasingly diverse and sophisticated systems.

In concluding this paper, the authors express their deepest thanks to Toyota Motor Corporation and other customers for their valuable assistance with developing this audio system.

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