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TOYOTA MOTOR '89 Model Audio Destined for North America

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Now that automobiles have become indispensable for everyday life, car audio is taking an important part in various aspects of peoples' lives. Under the circumstances, car audio manufacturers must quickly respond to user needs by improving design, functions, and performance with consideration to human engineering.
Jointly with TOYOTA MOTOR CORPORATION (TMC), we have developed '89 Model Audio Destined for North America to meet such demand. This paper focuses on the technology we have implemented in this model.
This audio will be delivered to TOYOTA MOTOR MANUFACTURING, U.S.A., Inc. (TMM) which started full-scale operation in the fall of 1988. In addition, its manufacturing is at our U.S. plant which has just begun operation. The paper also discusses our design activities conducted in this environment.

1. Introduction

Most automobiles require model changes to respond to ever advancing technical innovation and increasingly diversifying user needs. The audio system which is an essential part in the automobile is no exception. Model change is improvement of functions and performance to raise users' satisfaction. It is not a mere change of the external shape. Obviously, a new automobile style may have a strong impact on users. However, when the style of an automobile is changed, some identity, or a factor that reminds the user of the original nature of the automobile, is left in the automobile. Users are therefore likely to feel the concept shared by the old and new models. The reliability, expectation, and satisfaction formed through the use of the old model is easily inherited by the new model. In contrast, car audio is designed with emphasis on harmony with other interior components, so it is greatly transformed at each model change. This means that there has been a lack of continuity between old and new models of car audio. In developing this new series, we analyzed factors for decision making on design from a wide variety of angles so that the new series will be the first step to establishing the identity of TOYOTA's car audio. In addition, we had to seek human engineering-based features implemented in the preceding model and embody sound-making features with emphasis on acoustic characteristics in the passenger compartment in order to beat the keen competition in the North American market.

Some models of this series are delivered to TMM which started full-scale operation in the fall of 1988. Therefore, they are manufactured at our subsidiary in the U.S., FUJITSU TEN CORP. OF AMERICA (FTCA) on a semi-knockdown (SKD) basis. At present, we are endeavoring to shift to complete knockdown (CKD) production.

The purpose of developing this TOYOTA MOTOR '89 Model Audio destined for North America and the results of the development are reported below.

2. Purpose of development

Since the summer of 1985 when the TOYOTA Live Sound System was marketed, we have cooperated with automobile manufacturers for car audio manufacturing in the following way: From the stage of automobile planning, we participate in activities for sound production and propose plans for sound production in the passenger compartment according to a consistent design philosophy for the automobile and audio.

The manufacturing and marketing of TOYOTA MOTOR '89 Model destined mainly for the North American market began in the summer of 1988. This series covers various models, including a base-grade AM/FM two-speaker, electronic tuning radio, and a microprocessor-controlled cassette deck plus CD player with a premium-grade AM/FM electronic tuning radio. All of these models have been developed to fulfill the following purposes:

1) Much easier operation and clearer visual recognition should be achieved from a human engineering viewpoint.
2) Sound production should still be based on the philosophy of designing the automobile and audio at the same time and should be achieved through thorough analysis of user needs in the North American market.
3) Design should be made on the assumption of production overseas which is a demand at present.

The design means we adopted to serve the above purposes and the results are explained in detail below. The discussion focuses on the double DIN size, AM/FM electronic tuning radio with a microprocessor-controlled cassette deck which includes an audio security system (for theft prevention) as a function implemented for the first time in TOYOTA MOTOR '89 Model Audio.

3. TOYOTA Look Audio

We decided that an audio system should be called TOYOTA Look Audio if the following requirements are satisfied, and if the appearance of the equipment has a design consistency as one of the head-units line-up. TOYOTA Look Audio will provide a guideline for TOYOTA's car audio development in the future.

① The front layout is designed for easy operation.
② The user feels good when handling the system while driving the car.
③ The system is illuminated in different ways, each corresponding to one audio function, with consideration on operation and good visibility in the dark.

These requirements are explained below.

3.1 Front layout

The model has four separate functions. Its front layout is shown in Figure 1.

The direct change section denoted by A is provided to simplify operation. It has switches for

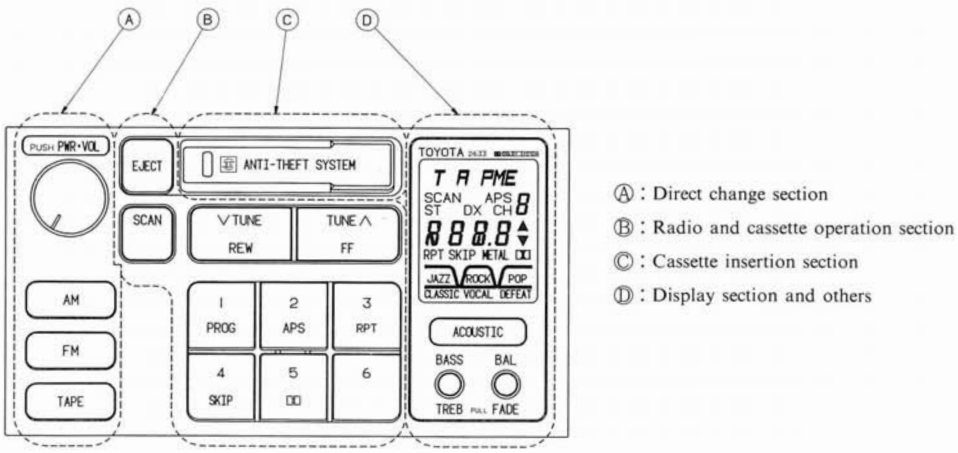


Figure 1. Front layout

directly selecting a mode — AM, FM, or tape — and turning power on and off.

For example, in conventional systems, when changing mode from cassette to radio, it is necessary to eject the tape cassette. With this model, pressing the AM or FM button is all that is necessary for mode changing. The power switch always operates regardless of the present mode.

The direct change section is installed on the left (the driver's side in cars with the steering wheel on the left) because it is operated frequently.

The total front surface area is 180 mm × 100 mm. The ratio between the area of each of the following sections and the total front area is greater than in conventional models, for easier operation and better visibility as follows:

① Operating section: From about 23% to 34%
② Display section: From about 8% to 10%

3.2 Operation feel

Considering that the system is car-borne, we designed button operation characteristics to achieve a good operation feel jointly with the Human Engineering Laboratory of TOYOTA MOTOR CORPORATION. As indicated in Figure 2, when pressing the button, the user feels the stroke more strongly than with conventional models.

The operation feel characteristics are as follows:

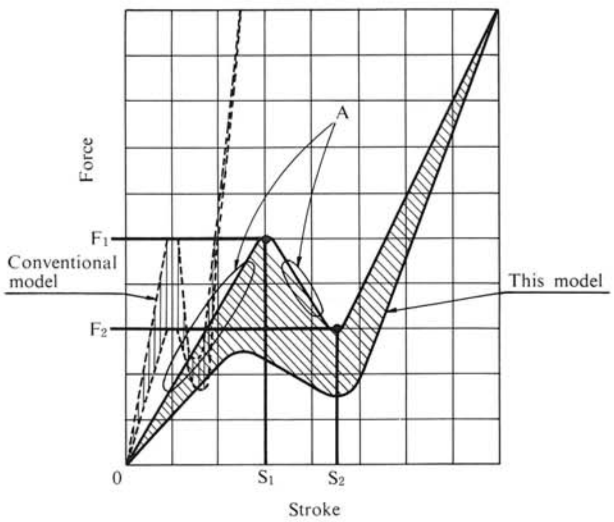


Figure 2. Button operation characteristics

The operation force is determined by F_1 and F_2/F_1 (click ratio); the stroke is determined by S_1 and S_2/S_1 (stroke ratio); the smoothness is determined by the irregularity at A.

3.3 Illumination for each function

The illumination for operation in the dark is related to the above layout. Each block is illuminated differently (Figure 3).

The eject button is illuminated regardless of the present mode when a cassette is in place.

The intensity of illumination is controlled by a rheostat controller together with the meter and heater control panels.

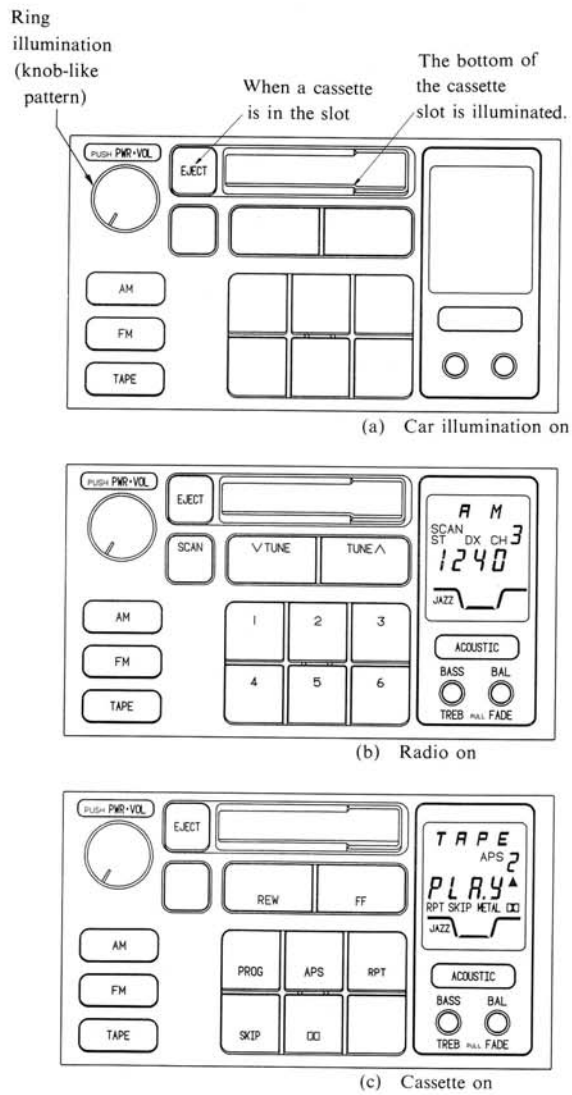


Figure 3. Illumination for each function

Therefore, operation is easy at night. The U.S. Motor Vehicle Safety Standard (MVSS) is thus satisfied.

4. For better sound

4.1 Seeking user needs in North American market

The relative weight of the car-borne audio system to the entire automobile has recently increased when the automobile is evaluated. Advanced sound production which meets diversifying user needs is necessary rather than conventional "mere" sound production. We have already established a technical center in our subsidiary in the U.S. (FTCA) to research sound needs in the North American market and cultivate the sound market. The discussion below focuses on sound quality favored in North America and techniques for implementing such sound quality in '89 Model Audio.

4.1.1 Sound quality favored in North America

Sound favored varies from one person to another because sound is anobject of a person's sensing. It greatly depends on custom, climate, religion, and other environmental and social factors. It is also divided according to sex, age, job, character, and other personal factors. In addition, fashion and other time-dependent factors should not be overlooked. This is true of the North American market. Until a few years ago, North Americans favored relatively boomy, loud low-frequency sound. However, they are beginning to dislike such sound. According to the results of our survey, well balanced quality combining clear, brisk high-frequency sound, lively middle-frequency sound, and hard, punchy low-frequency sound is most favored. To fulfill this need, we implemented sound production features in TOYOTA MOTOR '89 Model Audio while getting the co-operation of TOYOTA MOTOR SALES, USA, INC. (TMS), TMM, and TMC.

4.1.2 Techniques for the implementation of sound production features in '89 Model Audio

To achieve the above "North American Sound," we considered the following three points:

① Development of a loudspeaker unit

② Improvement of the head unit

③ Best tuning for set equalization meeting passenger compartment characteristics

These points are briefly explained below.

1) Development of a loudspeaker unit

The loudspeaker unit is the most important component to achieve the desired sound quality. It is also important in that it influences the sense of quality which could not be represented only by the frequency characteristics. To achieve "hard, punchy low-frequency sound and lively middle-frequency sound," we designed the vibrating system to be light and rigid. To achieve "clear, brisk high-frequency sound," we used a diaphragm containing mica particles, a semi-hard dome tweeter made of a newly developed resin, and a copper cap designed to improve the high-frequency response. This copper cap not only prevents the high-frequency impedance from rising and raises the high-frequency sound pressure level, but also has a good effect of suppressing eddy current distortion which would otherwise occur on the surface of the pole in the loudspeaker, thereby reducing the middle- and high-frequency distortion by some ten decibels or more (Figure 4).

2) Improvement of the head unit

The cassette deck uses a grooved head to suppress the low-frequency contour effect*1 and reduce low-frequency disturbance.

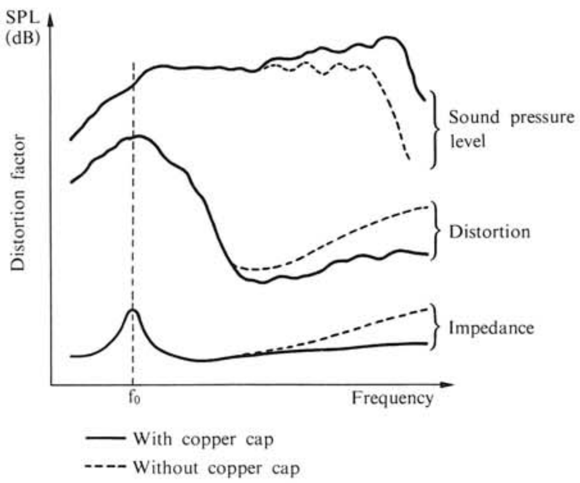


Figure 4. Copper cap effects

*1 Contour effect: Beat of reproducing frequencies in the low-frequency range (100 Hz or less) depending on the head shape.

In the FM tuner, the high-frequency reproduction frequency characteristics have been improved from −7 dB at 10 kHz in conventional FM tuners to −1.5 dB at 10 kHz (400 Hz as reference). Since this improvement is combined with a measure adopted to improve the receiving performance when the car is running, a major problem of improving both FM receiving performance and sound quality has been solved.

3) Tuning for set equalization

The acoustic characteristics in the passenger compartment depend on the shape of the car, types of interior material, the position and angle of loudspeaker installation, and other factors. To achieve "North American Sound," we adopted a method of tuning with fixed equalizer characteristics which helps make best use of the loudspeaker unit performance and are best suited to particular automobiles. The timbre thus determined is corrected by the loudness circuit so that it can be maintained in the range from low to high sound volume.

4.2 Achievement of maximum sound pressure without distortion

1) Necessity of distortion suppresser

To solve the problem of distorted sound which is serious and common in conventional car audio equipment, we developed a new distortion suppression circuit (DSC).

A major problem to be solved for car audio systems is how to fulfill requirements for such sound quality, like broad band and high power, that is achieved in home audio and to fulfill them under conditions specific to automobiles. To prevent distorted sound and achieve high power with the limited supply voltage available in automobiles, it is necessary to adopt one of the following methods: ① increase the supply voltage using a DC-DC converter and ② raise the acoustic power by driving a low-impedance loudspeaker unit. However, method ① has the drawback that a power supply booster is expensive and requires much space, and method ② is not easily applicable to general models because it involves the problem of power loss in the power IC capable of driving the low-impedance loudspeaker unit, loudspeaker cord, and other wire harnesses. The DSC can suppress the peak power without raising the amplifier output substantially. Noticing that it helps raise the average output level safely and increase auditory power, we developed the DSC.

2) Principle of operation

The DSC consists of the following function blocks:

① Rectifying and logic block
② Compensation circuit block
③ Voltage-controlled amplifier (VCA) block
(See Figure 5)

The rectifying and logic block rectifies and smooths the voltage from the power amplifier into a DC voltage. The output voltage e_0 to each channel passes through a time constant circuit consisting of R_1 and C_1. The resulting voltages on the left and right channels for each of the front and rear loudspeakers are added together, then rectified. Thereafter, the voltage is smoothed through a time constant circuit consisting of R_2 and C_2. The voltages on the front and rear loudspeakers are added together to obtain "distorted sound" information e_1. The signals on all channels should be added after rectification. However, it is rare that users turn the balance control to select only the left or right loudspeaker. However, to reduce the number of components, we designed this circuit so that fader control applies only to variable follow-up of front-rear balance control. The two time constants — attack time τ_1 and release time τ_2 — which determine the transient response of the DSC were determined through auditory evaluation using sources belonging to several categories.

The compensation circuit block produces a control voltage to be applied to the VCA. Since the maximum output level that can be obtained from the power amplifier depends on the supply voltage, "distorted sound" information e_1 is corrected at Q_1 through arithmetic operation and compensation according to information from the supply voltage detection circuit. Corrected voltage e_2 is supplied to external gain control terminal C on the VCA as e_{cont} which is obtained through an arithmetic operation at Q_2 on e_2 and e_{cont} which would otherwise be supplied to terminal C through sound volume control VR_1.

In the VCA block, as its name implies, the amplifier gain is controlled according to a DC voltage. It is the heart of the DSC. In this system, the VCA block also serves as a sound volume control which is included in the DSC feedback loop.

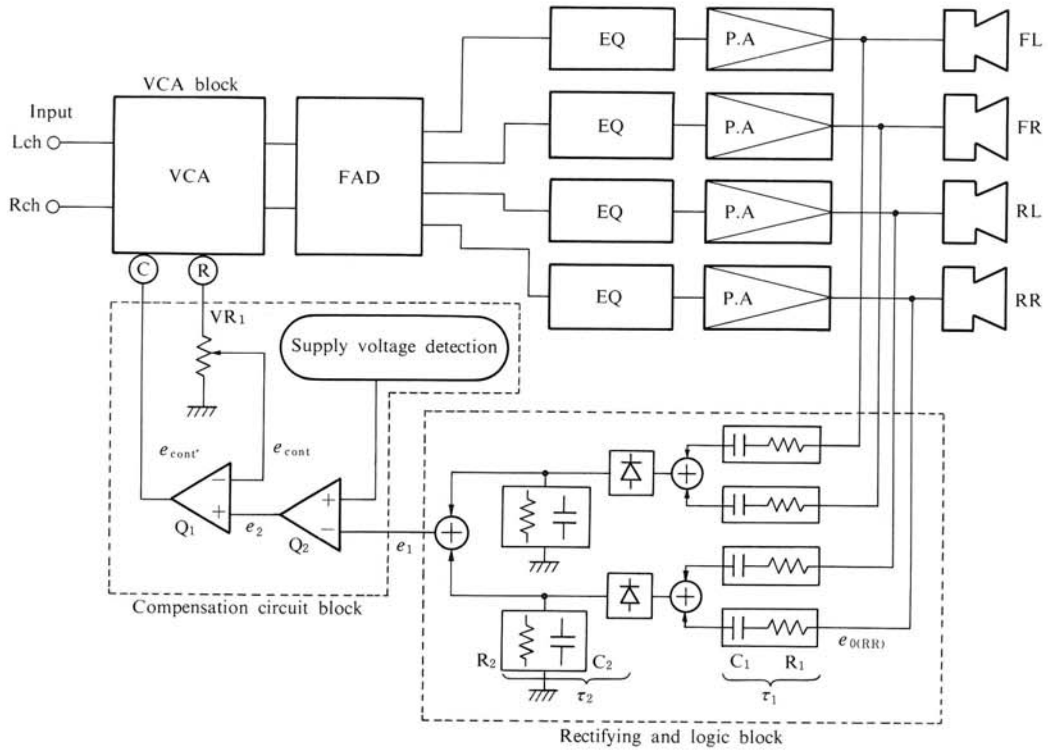


Figure 5. DSC equivalent circuit block diagram

The gain is controlled according to feedback voltage $e_{cont'}$. When the amplifier output is free from distortion and, therefore, "distorted sound" information $e_2 = 0$, the sound volume control produces $e_{cont'} = e_{cont}$. Distortion suppression is not performed. If the amplifier output is distorted, "distorted sound" information e_2 is used for compensation as $e_{cont'} = e_{cont} - e_2$. The VCA gain control voltage is reduced by a voltage corresponding to the distortion in the amplifier output voltage in order to suppress the distortion. The feeling of distorted sound is thus reduced.

The operation of the newly developed DSC is discussed above. Figure 6 shows how the DSC output varies.

3) Effect

The new DSC circuit and high-power (20 W) amplifiers for four channels are combined to eliminate sound distortion and impurity even when the recording level of the tape is relatively high or when the volume control is set to maximum, thus producing clear sound without distortion.

5. Theft prevention

The automobile is a means of transportation familiar to our everyday life and is expensive property. Automobiles are often left for a long time on the streets and are likely to be the target of theft.

At present in Japan, about 40,000 automobiles are stolen per year. (If theft of items from automobiles, but not automobiles themselves is included in the statistics, the number of affected automobiles is about 160,000.) Automobile theft is not recognized as a serious problem in Japan.

In contrast, the United States is quite different. According to the Federal Bureau of Investigation (FBI) and National Automobile Theft Bureau (NATB), 1.10 million automobiles per year are stolen (far more than in Japan), and the damage amounts to 5 billion dollars. Theft is done in various and subtle ways. Automobile theft is now a big social problem. Jointly with TOYOTA MOTOR CORPORATION, we developed an audio security system, which is installed in higher-class models of '89 Model Audio. Automobile theft in the U.S. and audio security systems are outlined below.

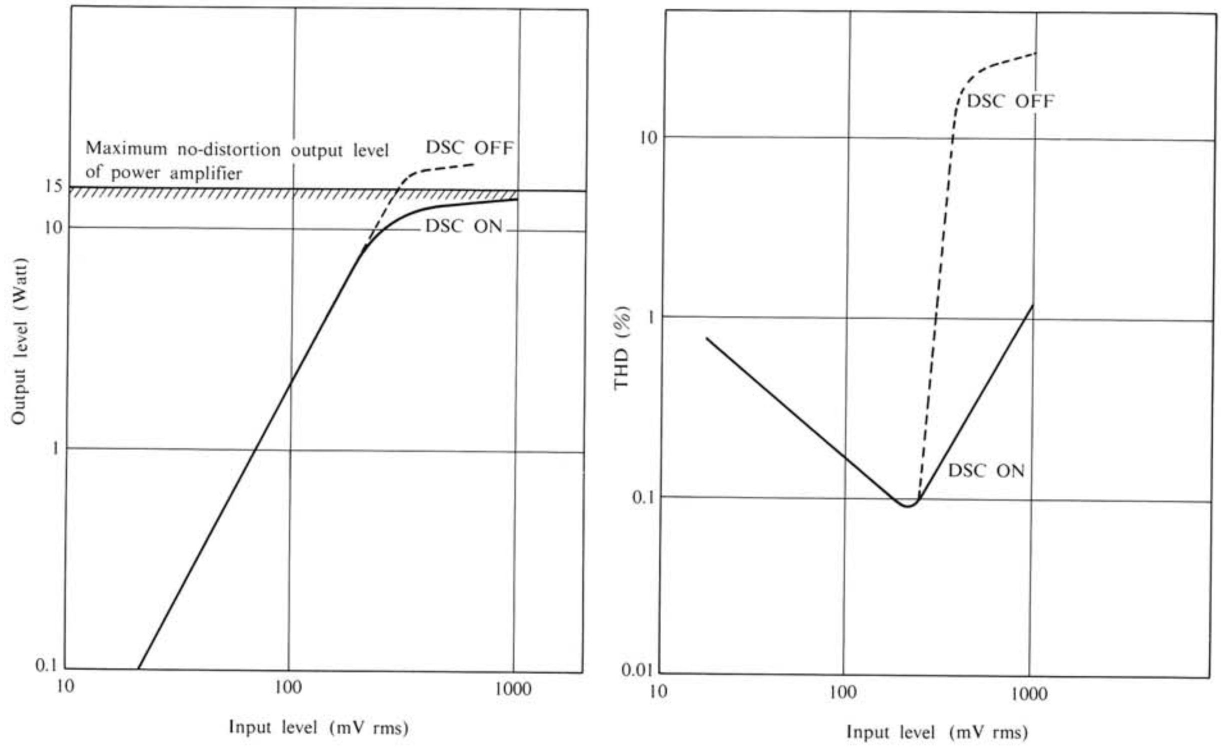


Figure 6. Comparison of DSC output and distortion characteristics

5.1 Automobile theft in the U.S.

In the U.S., the number of automobiles stolen in 1980 was about 1,100,000. This means that one of every 145 registered automobiles was stolen — a 16% increase over 1976.

According to the record of automobiles stolen per 100,000 people in each district, the rate is higher in bigger cities — 3185 thefts per 100,000 people in Boston and 1555 in Los Angeles. Table 1 lists models of stolen automobiles.

It is interesting to note that six Japanese models are included in the ten top models. It seems to suggest that Japanese cars are attractive. The condition of recovered cars seems to suggest that reason for theft is twofold as follows:

1) Money and material (reselling of cars and components)
2) For transportation

About 70% of all stolen cars are recovered in the U.S. Components have been removed from two-thirds of the recovered cars. Frequently stolen items include audio equipment, aluminum wheels, window glass, seats, and tires.

5.2 Audio security systems

There are three types of car audio security systems currently available on the market. Table 2 outlines the three types and problems involved in them. The audio security system we developed uses a code entry method which can be implemented in the radio without need for modification to the car. There are two code entry methods: Variable code

Table 1. Top ten models of cars stolen in Los Angles

Manufacturer	Model	Year	Number of stolen cars
1. Volkswagen	Bug	1966-75	1,624
2. Toyota	Celica	1976-85	1,466
3. Toyota	Corola	1976-85	965
4. Ford	Mustang	1966-75	944
5. Datsun	210	1976-85	915
6. Toyota	Corola	1966-75	821
7. Toyota	Corona	1966-75	811
8. Chevrolet	Camaro	1976-85	768
9. Volkswagen	Bug	1956-65	731
10. Mazda	RX7	1976-85	673

Source: 1985 California Highway Patrol Record

Table 2. Three types of car audio security systems

Method	Outline	Problems
Removable	The equipment can be removed from the car. The user removes the audio when he or she leaves the car.	• Much structure modification is required (on both the car and audio). • It is difficult to install this type of equipment in different car models.
Alarm	When the radio connector is disconnected, an audible alarm like the horn sounds.	• Usable when the car security system is inactive. • Not usable when the battery is removed.
Code entry	The radio is inactive until a code determined by the manufacturer or user is entered.	• Consideration must be taken for code management or against forgetting the code.

entry method whereby the user can register a code freely and fixed code entry method whereby the manufacturer assigns a fixed code to each radio. We adopted the former.

The basic specification is as follows:

① When the car is delivered to the user, security mode is not in effect. (The system works as an ordinary radio.)
② The system enters security mode when the user performs some operation (enters a user code).
③ Once the user code is entered, the system continues to work as an ordinary radio until it is stolen and power to the radio is cut off.
④ Once power to the radio is cut off, the system is inoperable (security on) until the user code is entered again.
⑤ The user code can be changed by a special operation including code entry.
⑥ If the user forgets his or her code, the dealer can reset security mode by performing a special operation including code entry.

As explained above, the audio incorporates a security system. The functions of the security system are not explained here in detail because of the nature of security.

6. Structure

6.1 Outline

An essential problem involved in designing the structure of this series is consideration on value engineering (VE) and value analysis (VA) and means for SKD production (a form of production overseas). In fact, the structure was designed to fulfill the following basic requirements for the necessary performance and SKD production:

1) Stable performance
2) Assurance of performance of each function
3) No need for adjustment in the last process
4) Reduced component cost
5) Reduced manufacturing cost

To fulfill the above requirements, we adopted the idea of integrating units into the system and giving each unit a single function by developing families of similar components as well as integrating components.

6.2 Example of structure

Figure 7 is an example of a structure which is a system integrating double DIN size.

6.3 Structure of function block

The system consists of units, each corresponding to one function block. Need for adjustment at the final assembly process was eliminated by adopting a method whereby it is possible to conduct electric adjustment and measurement on individual units and to assure the performance of each unit in previous processes. The assembly processes were arranged to allow flexible production.

6.4 Reduced component cost

One of the VA measures we adopted is the designing of printed circuit boards as specific series. Dimensions that are most convenient for board manufacturing are determined from sized board materials. Within this dimensional restriction, multiple boards were designed as a single series in order to reduce material cost. As a result, the cost of printed circuit boards was reduced by about 15%.

6.5 Reduced manufacturing cost

At the assembly processes, we used the method

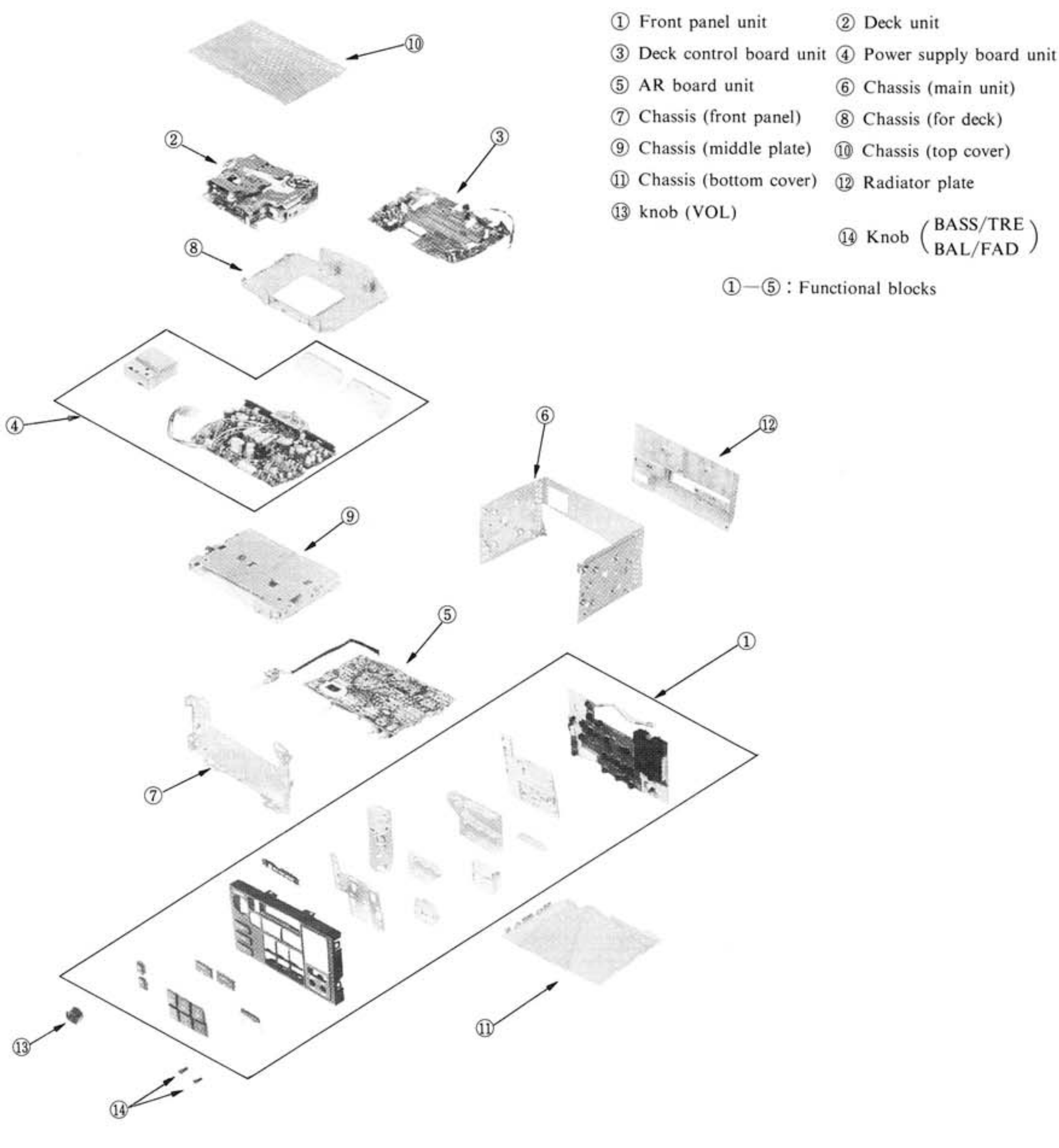


Figure 7. An example of a structure

of stacking the units so that completed units were assembled in one direction. As a result, efficiency in automatic processing on the boards was improved. Also, the total manufacturing cost was reduced by about 20%.

7. Semi-knockdown physical distribution

1) Distribution route

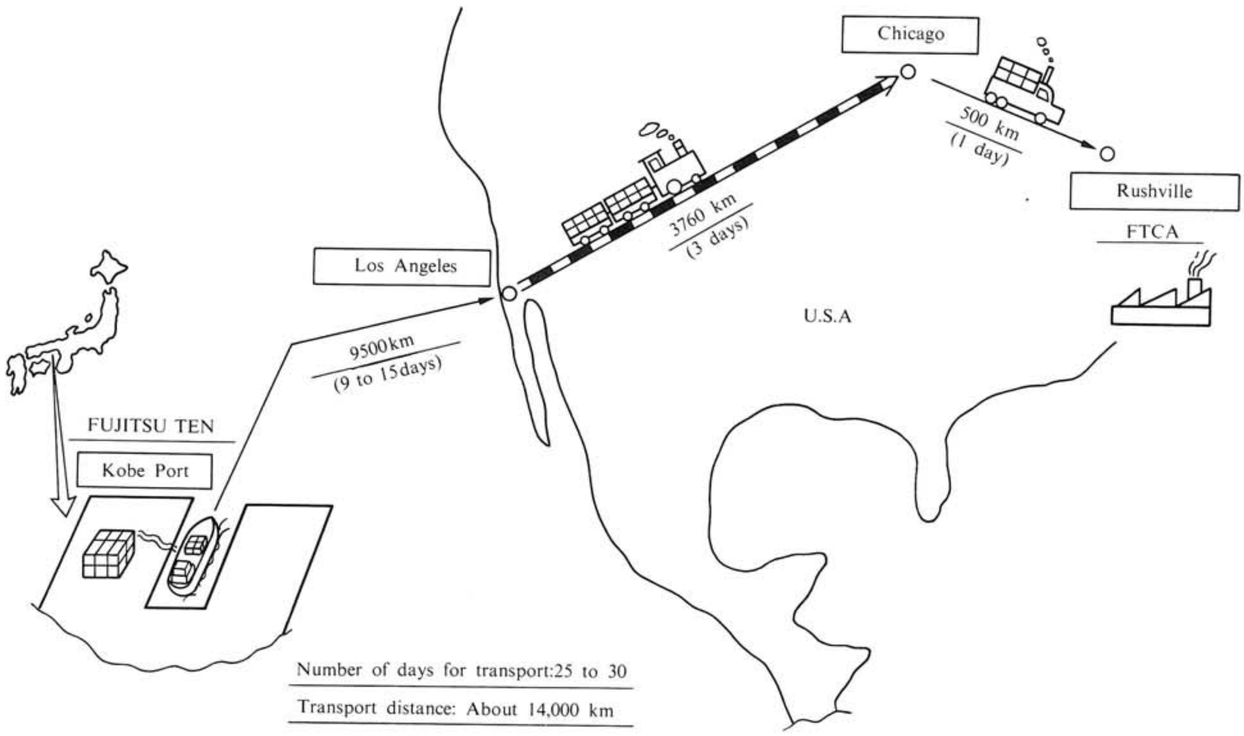
Figure 8 shows the physical distribution route and the environmental conditions during transportation.

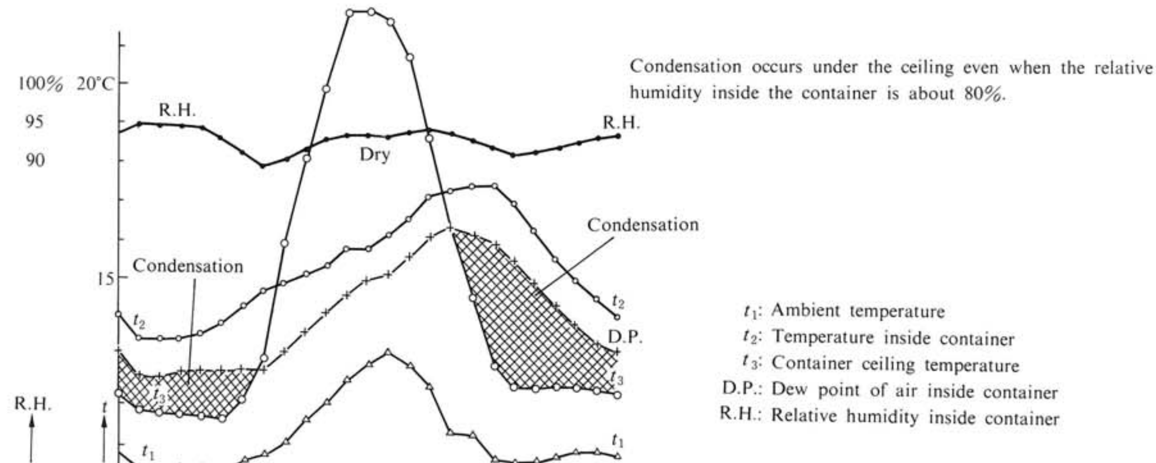
2) Packing specification

When deciding the packing specification, we established the following requirements in order to minimize transportation cost:

① Individual units or components are packed.
② The sizes of unit boxes are standardized.
③ The number of items per box is 10, 20, 50, 100, or multiples of 100.

The following evaluation tests were conducted





Time-dependent changes within a day of temperatures at various locations (including inside and ceiling) of container loaded on the desk

Figure 8. Physical distribution route and environmental conditions

for quality assurance considering that individual units and components might be affected by transport conditions in the physical distribution route explained in Item 1) from the factory in Japan to the factory in the U.S.:

- Simulation test
- Trial transport

Using the results of these tests, we decided a packing specification which was satisfactory in terms of cost and quality assurance.

Table 3. System specifications (integrated model)

Maximum output power	20 W or more ×4
Maximum current	10 A or less
Applicable antenna	80 pF ± 10 pF
Dark current	5 mA or less
Standard supply voltage	13.2 VDC
Load impedance	4 Ω
AM	
Receiving frequency	530 - 1620 kHz
Maximum sensitivity	30 dB or less
Electrical fidelity	100 Hz : 0 ± 3 dB
	4 kHz : − 13 ± 3 dB
Intermediate frequency	450 kHz
Automatic tuning sensitivity	D : 30 ± 5 dB
	DL difference : (DX) + 20 ± dB
Frequency separation	10 kHz
FM	
Stereo sensitivity	30 dB or less
Receiving frequency	87.9 - 107.9 MHz
Usable sensitivity	10 ± 6 dB
Electrical fidelity	100 Hz — 0 ± 3 dB
	10 kHz — 0 ± 3 dB
	(Preemphasis on)
C/N ratio	− 8 ± 5 dB
Automatic tuning sensitivity	D : 22 ± 6 dB
	DL difference: (DX) + 25 ± 6 dB
Frequency separation	0.2 MHz
Intermediate frequency	10.7 MHz
Stereo sensitivity	18 dB or less
Player	
Type	Compact cassette
Tape speed	4. 76 cm/sec
Wow and flutter	0.35 % or less
Crosstalk	40 dB or more
Separation	30 dB or more
S/N ratio	48 dB or more
Frequency characteristics	63 - 15,000 Hz

8. Conclusion

The purpose of developing '89 Model Audio and an outline of its design were discussed above. The system specifications are given in Table 3. Figure 9 shows the developed models.

When developing this system, we had to struggle to solve many problems, such as consideration on production at a factory in the U.S., appealing

AM/FM electronic tuning radio with 2 speakers

AM/FM electronic tuning radio with 4 speakers

Microprocessor-controlled stereo cassette-deck with AM/FM electronic tuning radio and 4-channel amplifiers

Microprocessor-controlled stereo cassette-deck with AM/FM electronic tuning radio and 4-channel amplifiers

Microprocessor-controlled stereo cassette-deck with AM/FM electronic tuning radio and 4-channel amplifiers having fixed equalizer for acourstic facilities

Microprocessor-controlled stereo cassette-deck and CD player with AM/FM electronic tuning radio

Figure 9. '89 Model Audio products line-up

appearance, sound production that meets user needs in North America, and security. Fortunately, we believe that the results are generally satisfactory. Market demand for higher quality and more sophisticated functions as well as production overseas and low cost will be inevitable in the future. We shall make further improvement for the next model by making use of the know-how obtained through the development of this model.

We would like to acknowledgment all who cooperated with us and advised us for the development of '89 Model Audio.

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