UDC 621.397.13:681.84:621.33

Audio-Visual Entertainment System for a Series 200 Car for Tohoku Shinkansen (Super-Express Type 249 Double Decker '1st-Class Car')

● Kohjiro Chikazawa ● Shigeaki Inamura ● Kazuo Takayama
● Shigeru Toyoshima ● Shigeki Fukuyama

East Japan Railway Company decided to introduce double-decker "1st-class cars" of Series 200 Super-express for the Tohoku Shinkansen railway. This was done to improve service for first-class passengers. Six cars were built and put into service. The upper deck consists of general first-class seats, and the lower deck of private compartments for one to four passengers. The company's specification for the first-class car equipment was to introduce information and audio-visual services for entertainment. The Tokyu Car Corp. decided to order this equipment from Fujitsu Limited. It has been decided that Fujitsu Ten will develop and supply these audio-visual systems. In accordance with the draft specification we proposed, a basic technical review was conducted using actual cars in October 1989. We began to design the system in November. In April 1990, we shipped systems to the Tokyu Car Corp. The systems were put into service in June 1990.

1. Introduction

Recently, an increasing number of audio-visual systems for entertainment are being installed in buses and trains for luxury inter-city travel.

Audio services available with headphones and video services offered by television sets have become popular for Super-express and Limited-express trains.

This has led us to develop an audio-visual system to be installed in first-class railway cars. Our activities for this development are based on years of experience in developing automobile equipment and are opening the way for new business.

This paper discusses an overview of the audio-visual system developed for double-decker, first-class cars of the Tohoku Shinkansen.

2. Background of development

Annual use of the Tohoku Shinkansen trains is growing steadily. The increase of super-express passenger traffic over the preceding year is 14 percent, and the average rate of occupied seats has reached 80 percent. It has thus become difficult to obtain first-class tickets.

To increase the number of first-class seats and improve the service, the East Japan Railway Company introduced double-decker, first-class cars and ordered six of these cars from the Tokyu Car Corp. We have developed and supplied the audio-visual systems for these cars.

The 1st-class car has two decks. The upper deck consists of general 1st-class seats, and the lower deck consists of private compartments for one to four passengers. The audio-visual system must offer services suitable for this configuration.

The performance and functions required for the audio-visual system are as follows:

① High-quality reception and reproduction of FM-broadcast programs

② High-reliability playback of compact disks and cassette tapes

③ High-reliability playback of video tapes

④ Playback of cassette tapes and video tapes belonging to passengers in the private compartments and a warning system so that these media will not be left behind

⑤ In-train FM broadcasting services

⑥ Automatic start-up and termination of the system

⑦ High reliability and long system life

⑧ Easy checking of the system on a daily basis

⑨ Easy installation of the system in the train car

3. System overview

3.1 System configuration

Currently available entertainment systems include digital systems for use in airplanes and analog systems that can be easily expanded. For the double-decker, first-class car of the Tohoku Shinkansen, we have adopted an analog system. This choice was made because it is necessary to offer not only audio service, but also FM broadcasting and video services. The audio signal is stereo-modulated in the center unit and is multiplexed and transmitted through FM coaxial cables to passenger terminals, where the signal from the selected channel is subjected to demodulation and volume control. The FM broadcasting service allows passengers to enjoy the same program as with the audio service using their own FM radio set. The video service has two programs. The video signal of each program is multiplexed and transmitted over coaxial cables using a high-frequency television band. If one of the channels is selected on the terminal, the signal is demodulated and displayed on the CRT. This system is shown in Figure 1.

3.1.1 Center unit

The center unit consists of an audio center unit (QA-150) and a video center unit (QA-151) as shown in Figures 2 and 3. It transmits programs from the audio-visual system.

Each transmitter is mounted on a rack, and the racks are installed in the equipment room of the train.

1) Audio center unit (QA-150)

The components of the audio center unit are as follows:

① FM reception antenna (RN-EAT-X1-1192)

Two FM antennas are installed on the roof of the train to provide high reception quality.

② FM receiver and system controller (AE-3350)

This component receives three FM broadcast programs. It also has MICRO PROCESSORS to interpret monitor information from the train in order to know whether the train is in service. The MICRO PROCESSORS is also in charge of system control, such as the activation and termination of the system.

③ Automatic CD changer (SD-2300)

The automatic CD changer plays ten compact disks in sequence. If an abnormality happens during automatic play, it stops automatically and displays an error message on the front panel of the equipment.

④ Cassette tape players (SP-6800)

A pair of cassette tape players that are activated alternately play four stereo programs (two programs at the same time per player). The players use a one-directional tape play back method because this method helps prolong the life of the cassette players. If an abnormality happens during automatic play, the cassette tape player stops automatically and displays an error message on the front panel of the equipment.

⑤ FM stereo modulator/multiplexer (RN-EUC-1069/RN-EUC-1068)

This component stereo-modulates audio signals, converts them to allocated high-frequency bands, multiplexes the signals, and transmits the multiplexed signals as radio waves throughout the train and transmits through coaxial cables to passenger terminals.

⑥ DC power supply (RN-EUP-1007)

This component supplies power to other components of the audio center unit and to the passenger terminals.

⑦ Terminal board (UU-144)

This component is used for all interfacing between the audio center unit and other components of the train.

2) Video center unit (QA-151)

The components of the video center unit are as follows:

① Video deck (VT-1000)

Two video decks are driven independently as directed by automatic start-up signals from the audio center unit. They play back two programs simultaneously.

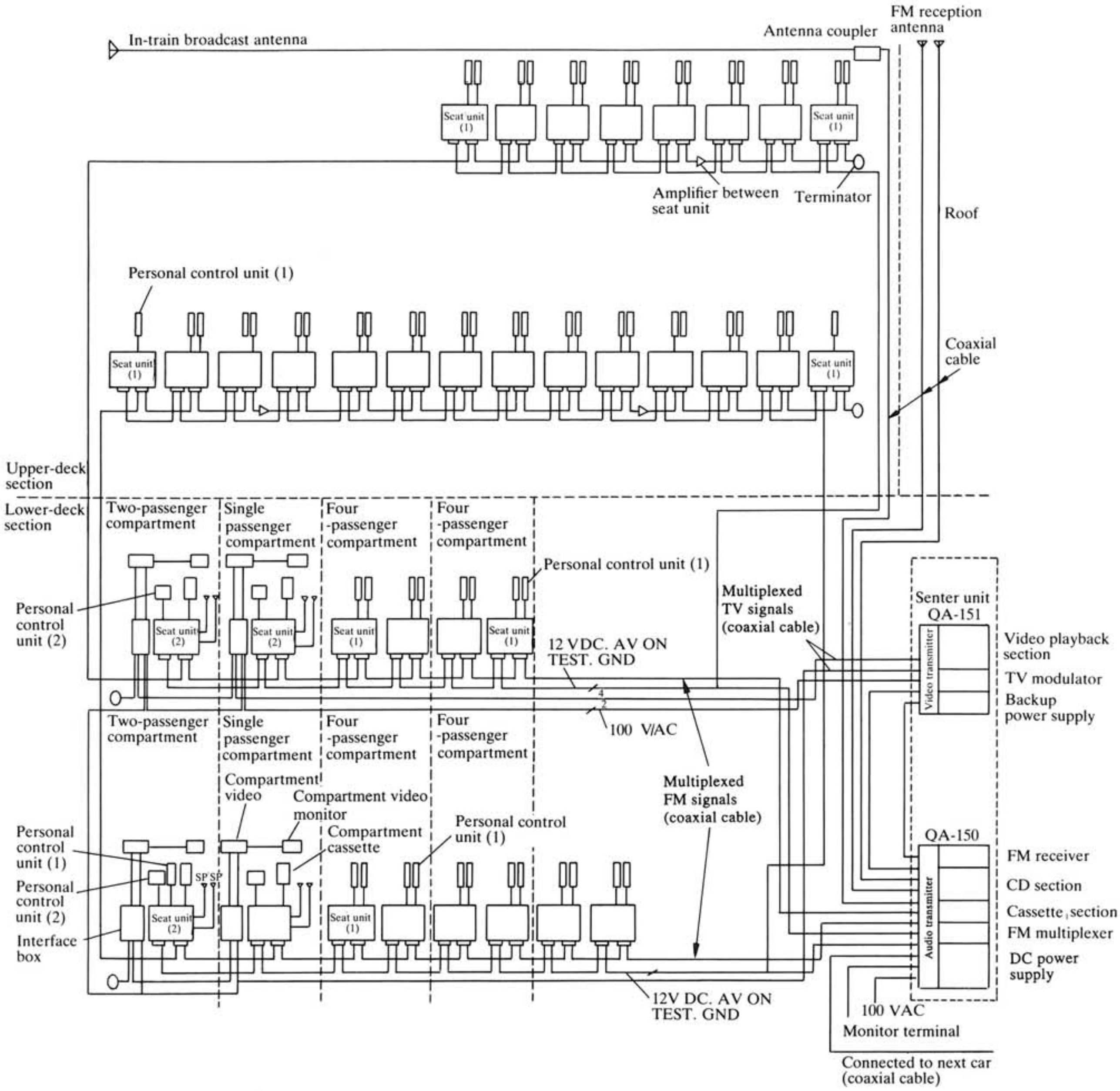


Figure 1. Audio-visual system diagram

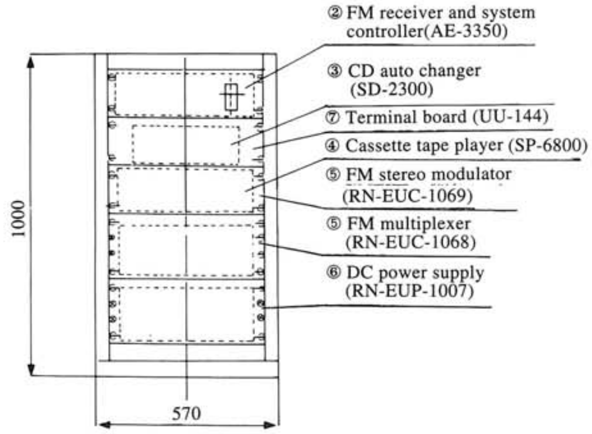


Figure 2. Audio center unit

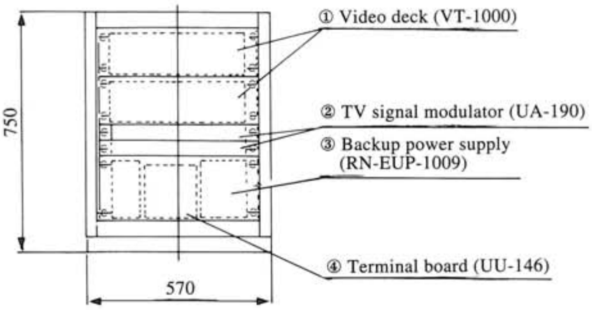


Figure 3. Video center unit

② Television signal modulator (UA-190)

This component converts the signals of the two programs being played back by the video decks to high-frequency television-band signals and transmits the signals to passenger terminals through coaxial cables.

③ Backup power supply (RN-EUP-1009)

This component protects the system from troubles (see Section 4.3.3) caused by a power failure or other accident during audio-visual system operation.

④ Terminal board (UU-146)

This component is used for all interfacing between the visual center unit and other components of the train.

3.1.2 Passenger terminals

The passenger terminals are installed at each seat and in each private compartment. Passenger terminals include the following components:

1) Passenger terminal for upper-deck seat and four-passenger compartment

① Personal control unit (1) (UX-135)

Figure 4 shows the personal control unit (1) installed at a seat. It is used in combination with a seat unit (1). A headphone set is connected to it. It is used when selecting a program and controlling sound volume.

② Seat unit (1) (UU-137)

This unit is installed under the upper-deck seats and under the seats in four-passenger compartments. One unit works for two seats. The seat unit (1) demodulates the signal selected by the personal control unit (1) from the multiplexed signals transmitted from the audio center unit through a coaxial cable. Then, the seat unit sends the audio signals to the personal control unit (1).

2) Passenger terminal for special compartment

Figure 5 shows the special compartment.

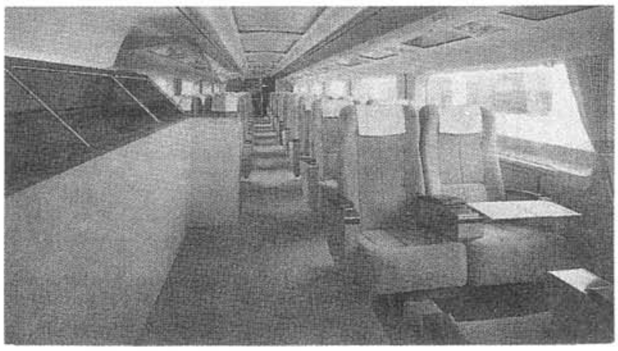


Figure 4. Personal control unit (1) installation

① Personal control unit (1) (UX-135)
In compartments for two passengers, this unit is used in combination with a seat unit (2). A headphone is connected to it. It is used when selecting a program and controlling sound volume.

② Personal control unit (2) (UX-136)
This unit is used in combination with a seat unit (2). It is used to select video or audio service and to control sound volume. The passengers listen with their headphones or compartment loudspeakers. In two-passenger compartments, two passengers can listen to the same program through independent headphone sets.

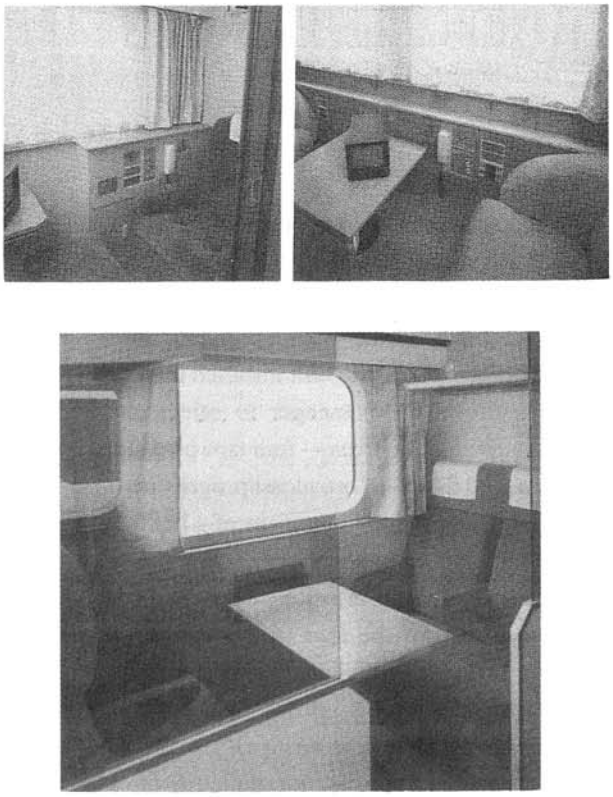


Figure 5. Special compartment

③ Seat unit (2) (UU-138)
This unit is installed in special compartments for one or two passengers.

The seat unit demodulates the signal selected by the personal control unit from the multiplexed signal transmitted from the audio center unit through a coaxial cable. Then, the seat unit transmits the audio signals to the personal control unit. It also controls the cassette tape player and video player installed in private compartments.

④ Compartment cassette tape player (SP-5230)
This component plays back cassette tapes that passengers have brought along with them.

⑤ Compartment video player (VT-1001)
This component plays back VHS video tapes that passengers have brought along with them. This player has a function to demodulate image and sound signals from the high-frequency signals transmitted from the video center unit via coaxial cable.

⑥ Compartment monitor (DM-1000)
This monitor displays images of the program that the passenger has selected.

⑦ Compartment loudspeaker (SB-0905)
This unit produces sound for the program that the passenger has selected.

3.2 System operation

The audio-visual systems installed in railway trains must be able to operate without any intervention of train personnel and must have a long life. In developing the audio-visual system, we observed this design policy and have achieved the following functions:

3.2.1 Automatic operation control

In Shinkansen trains, the monitor terminal installed in each car can get information about the travel of the train. The system we have developed uses this information to run the system only when the train is in service (see Section 4.3). This has prolonged the life of the center unit by 20 to 40 percent in the automatic start and stop operation.

3.2.2 Diagnosis of terminal units

Before a train is put into service, the functions of the audio-visual system need to be checked since this is an important part of passenger services. Such a service system, which is individually operated by passengers must be checked for a large number of items. Such checking is difficult. Consider the personal control unit (1) as an example. If it is checked for all programs and functions concerning selection from eight channels and sound volume control, checking of one unit requires 80 seconds on the assumption that checking one program takes 10 seconds. For a car containing 60 personal

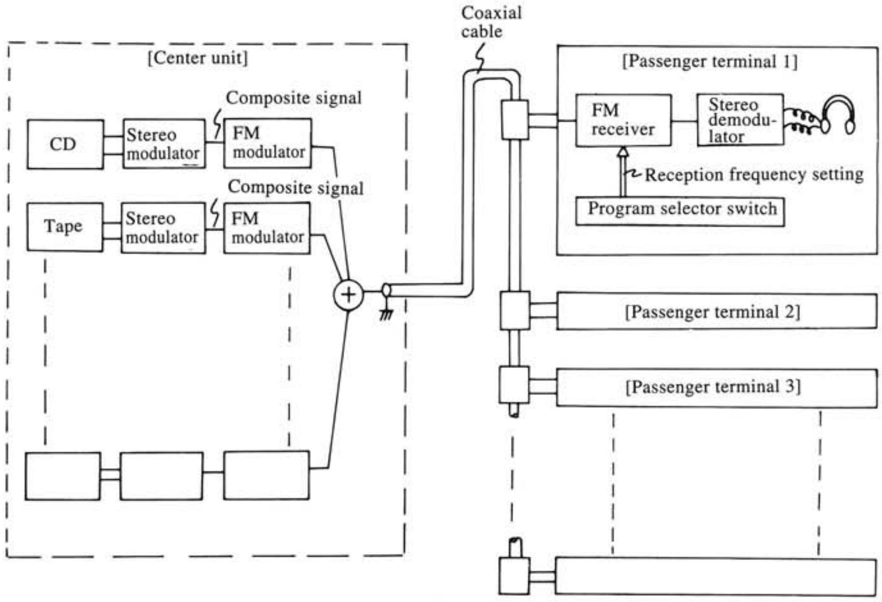


Figure 6. FM multiplex transmission

control units (1), checking thus requires 80 minutes — so long that checking is not feasible. To solve this problem, we have adopted the method of checking all functions by means of a microprocessor in the seat unit (1) and displaying the results on the panel of the personal control unit (1) according to specific rules. This method has simplified checking.

Diagnosis of the system starts immediately after the "Check" button on the center unit is pressed. All diagnosis will end in about one second. The results are displayed on the panel of the personal control unit (1). The checker needs only glance at the 60 displays to verify that the terminal units are normal. Assuming that it takes five seconds to check one display, the time required for checking all the equipment in one car is five minutes, considerably quicker than 80 minutes estimated above. Table 1 lists the display rules used for function diagnosis.

Table 1. Display rules for function diagnosis

Display	Diagnosis
Only "CD Channel" on	Normal
A certain channel is flashing	Maintenance required. The seat unit is faulty in functions related to the demodulation on the channel indicated.
All lights off	Maintenance required. The personal control unit is faulty in other functions.

3.3 Services offered

The services offered by the audio-visual system are divided into three categories. It is assumed that all audio services are offered in stereo.

1) Headphone service

The personal control unit installed in the arm rest of the seat allows the passenger to select one of eight programs as audio sources — four tape programs, one CD program, and three FM broadcast programs, and to listen to the selected program by means of a headphone set.

2) FM broadcasting service

Passengers can bring along a personal FM radio set to listen to one of the four tape programs or one CD program from the headphone service in addition to normal FM broadcast program.

3) Special compartment service

The personal control unit installed on the wall can be used to select one of twelve programs from two sources. The audio source has a total of nine programs, including four tape programs, one CD program, three FM broadcast programs, and playback of the passenger's own cassette tape. The video source has a total of three programs, including two video programs and playback of the passenger's own video tape. The passenger can switch between headphones or loudspeaker.

Tables 2 and 3 indicate how the terminal equipment is configured and what is offered for each type of service.

Table 2. Terminal equipment configuration in each type of passenger seat or compartment and each type of service

Service / Equipment	Headphone service and FM broadcasting service	Headphone service	Special compartment service	
	Passenger seats on upper deck	Four-passenger compartment on lower deck	Two-passenger compartment on lower deck	Single-passenger compartment on lower deck
Personal control unit (1)	○	○	○	
Personal control unit (2)			○	○
In-train broadcast antenna (for passenger's FM radio)	○			
Compartment loudspeaker			○	○
Compartment video monitor			○	○
Compartment video player			○	○
Compartment cassette tape player			○	○
Seat unit (1)	○	○		
Seat unit (2)			○	○

Note: A circle indicates that the equipment is installed.

Table 3. Services offered in each type of passenger seat or compartment

Service / Contents	Headphone service		Special compartment service		FM broadcasting service
	Passenger seats on upper deck	Four-passenger compartment on lower deck	Two-passenger compartment on lower deck	Single-passenger compartment on lower deck	Passenger seats on upper deck
Tape: 4 programs	○	○	○	○	○
CD: 1 program	○	○	○	○	○
FM: 3 programs	○	○	○	○	
Video: 2 programs			○	○	
Passenger's cassette tape			○	○	
Passenger's video tape			○	○	
FM broadcast programs					○

Note: A circle indicates that the equipment is installed.

4. Design overview

In designing the audio-visual system, we consideredthe following points

4.1 FM program transmission through coaxial cable

A simple method for transmitting stereo audio signals for eight programs from the center unit is to use 16-pair wires. We have adopted multiplex transmission using a single coaxial cable in order to make the system light, compact, reliable, and easy to install. Super-express trains which run at high speeds emit high-level electromagnetic noise from motors, pantographs, and other equipment. Therefore, we have adopted frequency-division multiplexing of frequency-modulated waves which have good noise immunity. In addition, the composite-signal method used for FM broadcasting has been adopted for stereo audio service so that the system can offer FM broadcasting service via in-train radio transmission. On the passenger terminal, a signal frequency can be selected from the multiplex signal, so that the passenger can choose the desired program. Since this technique allows circuits and other components of general FM receivers to be used in the system, the system could be developed in a short period.

4.2 FM broadcast reception

We have developed the following techniques to allow a system to receive FM broadcast waves while the train is in motion:

① The receive frequency is switched according to the information about the present location of the train so that FM broadcast programs can be received without interruption. This technique is called relay reception.

② A technique for keeping the reception condition good by protecting the system from electromagnetic noise from the train and multipath fading.

③ An FM reception antenna suitable for installation on Super-express trains

These techniques are explained in detail below.

4.2.1 Relay reception

A microprocessor for controlling FM tuners are fed from the train with a signal which indicates the distance the train has traveled. The microprocessor has a table which relates the distance from the starting point to the most appropriate receive frequency. The receive frequency is switched according to the present location of the train.

This receive frequency table indicates the most appropriate FM station determined according to an estimation based on the locations, altitudes, and transmission

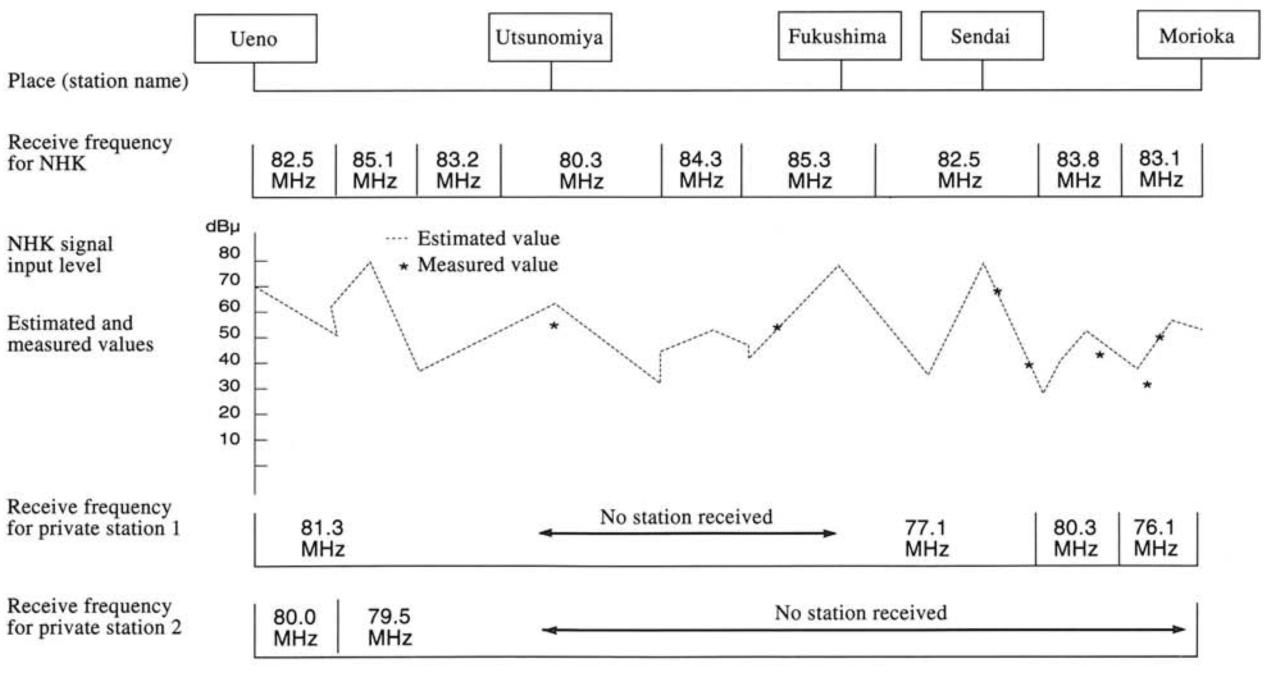


Figure 7. FM broadcast receive frequency and reception condition

powers of the broadcasting stations and to the test data which was obtained on trains in motion.

The system contains three FM receivers so that passengers can listen to one of three FM broadcast programs — one NHK program and two private-station programs.

The relay reception technique allows the system to receive NHK programs almost continuously between Ueno and Morioka. However, because of the present configuration of private stations, there are many areas where it is impossible to receive any private-station program.

Figure 7 shows how the train location relates to the FM broadcast frequency and the reception quality.

In the estimation of NHK signal level, the interruptions due to mountains and tunnels are excluded. The experiment in a running train has shown that continuous reception is possible except in tunnels and in the underground area near Ueno. In areas where an RF input signal level is 40 dBf or more, satisfactory reception was obtained by the use of various techniques of reception on moving vehicles which will be explained later.

4.2.2 Receiver equipment

For receiving FM broadcasts in Super-express trains, the receiver must be free from problems of reception disturbance relating to signal wave propagation, such as multipath interference and fading as well as RF noise emitted from the pantographs.

To resolve these problems, we have adopted reception techniques developed for automobile receivers and have employed a receiver configuration and setting suitable for super-express trains.

The techniques used to resolve reception disturbances include diversity reception, automatic separation control (ASC), automatic tone control (ATC), Ten Dynamic Multipath Canceler (TDMC), soft muting, and noise blankers.

Figure 8 shows the configuration of the receiver equipment, and Figure 9 is a block diagram of a receiver unit.

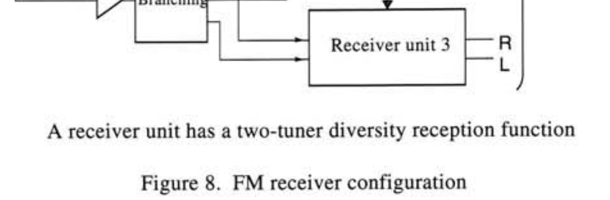
1) Diversity reception

The diversity reception technique uses multiple antennas (two antennas in this system) and selects one of these antennas according to the reception condition to optimize reception. For FM broadcast receivers, there are two types of criterion for antenna switching: Multipath noise and signal level.

Multipath noise occurs when the wave coming directly from the broadcasting station is interfered with waves reflected by mountains or buildings. In the case of mobile reception, multipath noise occurs intermittently. The intervals of noise generation become shorter as the speed of the mobile object becomes higher. Since the multipath noise generation frequency on high-speed moving objects, such as a Super-express train running at 200 km/h, falls in the audible frequency range, it is difficult to improve reception quality by switching antennas.

To overcome this difficulty, we have designed the receiver so that the antenna is switched according to only the results of level detection performed through S-level voltage comparison. This eliminates the influence of changes in wave arrival direction and the influence of meeting on-coming trains.

The circuit uses a two-tuner diversity reception technique which allows more accurate switching in response to abrupt changes in electric field.



A receiver unit has a two-tuner diversity reception function

Figure 8. FM receiver configuration

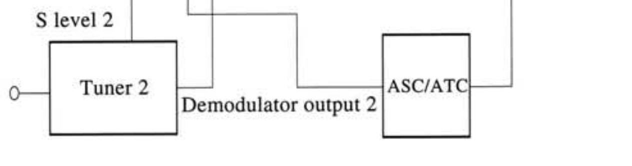


Figure 9. Receiver unit block diagram

Measures against multipath noise are provided by the TDMC circuit which will be explained later.

2) ASC

Stereo broadcast is more susceptible to noise than monaural broadcast for low signal levels.

The ASC gradually lowers the separation between channels when the received signal is weak and finally enters monaural reception mode. This technique helps improve the signal-to-noise (S/N) ratio.

3) ATC

If the reception level further lowers after monaural reception is put into effect by the ASC, noise increases, and the S/N ratio deteriorates.

In this condition, if the audio high-frequency signal level is lowered, the S/N ratio as perceived by hearing is improved. The ATC performs this function according to the input signal level.

4) Soft muting

To suppress noise generation, FM broadcast receivers perform muting when no signal is input.

Since the soft muting function of the system we developed is performed smoothly in response to the lowering of the input signal level, it is effective on periodic phasing involved in train motion.

5) TDMC

The TDMC detects noise caused by multipath interference and improves the hearing characteristics by keeping the receiver in monaural mode while noise is generated and by filtering the signal through an adaptive filter. In addition, appropriate constants have been set to the TDMC so that it can also eliminate noise caused by the pantograph.

6) Noise blanker

The noise blanker reduces impulse noise which occurs intermittently. It works as follows: A filter is used to separate the signal component from the noise component. The noise detection signal drives a gate circuit to cut off the signal during noise generation. During this period, the signal level is retained in a hold circuit so that the signal level changes smoothly.

4.2.3 Antenna for FM broadcast reception

The FM broadcast receiving antenna installed on super-express trains must satisfy the following requirements:

① The antenna can receive radio waves from any direction.

② The antenna is designed for both aerodynamic and aesthetic qualities.

To meet these requirements, we have adopted a square-low height antenna which is popular in radio communications.

The principle of a square-low-hight antenna is identical to a half-wavelength dipole antenna that is bent to a square. The dipole antenna has a figure-8 directivity, whereas the square-low height antenna is almost nondirectional.

The antenna is installed, near the air-conditioner, between the roof and ceiling of the passenger car as shown in Figure 10. Therefore, if only one antenna is installed on the left, radio waves from the right cannot be received because the air-conditioner blocks reception. To solve this problem, two antennas are installed on the right and left to achieve good reception for radio waves in all directions.

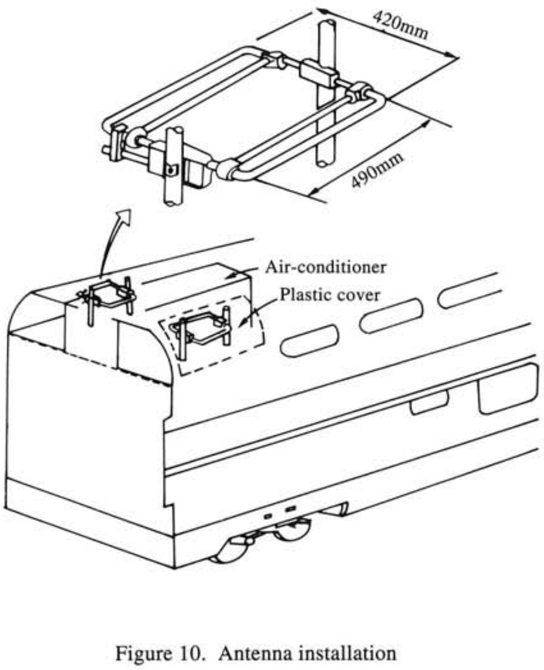


Figure 10. Antenna installation

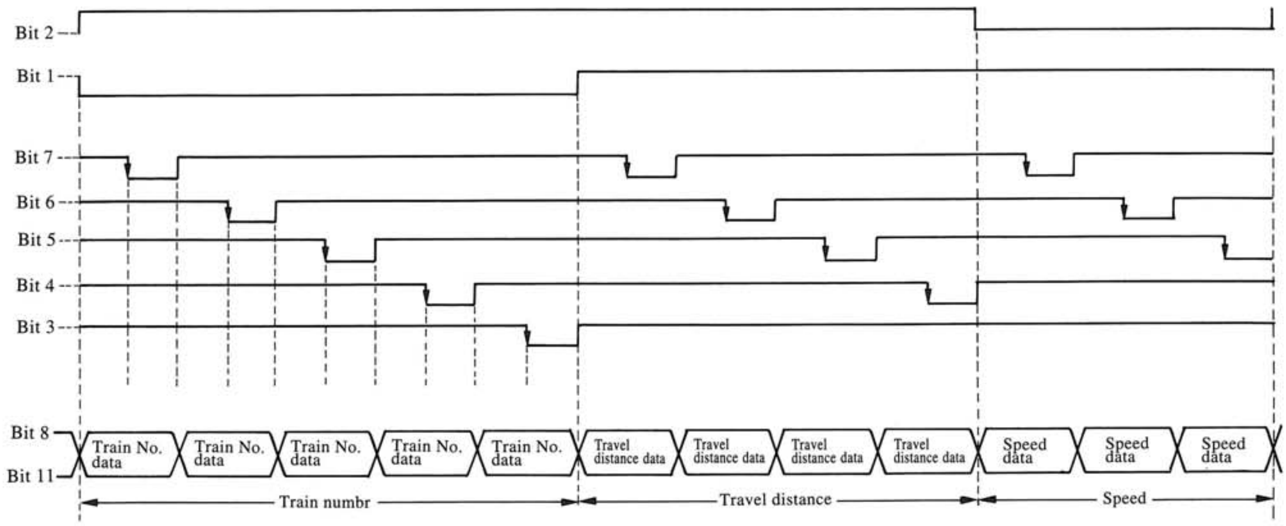


Figure 11. Train monitor information (11 bits)

Since the car roof is made of metal, the antenna installed under the roof cannot receive radio waves because the roof hinders reception. To solve this problem, the side area through which radio waves arrive has been changed from metal to plastic so that FM reception inside the car is possible.

4.3 Automatic system control

The system is activated and stopped by the following method, thus achieving automatic system control. This method reduces the running time of the units containing moving parts to a minimum, thereby contributing to long system life.

4.3.1 Reception of train monitor information

For super-express trains, information as to whether a train is in service as well as where and how fast it is running can be obtained from the train monitor terminal equipment. This information is represented as 11 bits of parallel data as shown in Figure 11. This data is fed to the audio-visual system and interpreted to obtain information about:

① Train number (indicating whether the train is in service and whether the train is headed toward Ueno or Morioka.)

② Distance from Ueno to the present location

③ Speed (absolute)

This information is processed to generate various control signals for activating and stopping the audio-visual system and for other functions.

4.3.2 Automatic operation of CD, cassette tape, and video tape players

As explained above, the signal for activating the audio-visual system is used to achieve automatic control for starting CD, cassette tape, and video tape players in the center unit. The stop signal is used to put the system into standby state. This method for intermittent operation will prolong the life of the system by 20 to 40 percent when compared with the method of non-intermittent operation.

The cassette tape player adopted in the system uses normal Philips-type compact cassette tape. The player life has been doubled in comparison with conventional cassette players for automobiles by using the following

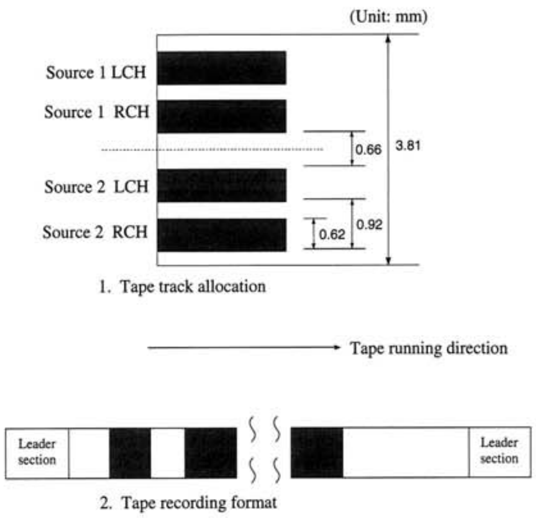


Figure 12. Cassette tape formatting

cassette players for automobiles by using the following techniques:

① Two tape decks are paired and are used alternately.
② This system adopts a recording format for one-directional tape playback for two stereo programs at a time (Figure 12).
③ The leader section of the tape is used for head cleaning.

4.3.3 System backup

This system has no uninterruptible power supply. When the train power turns off, the power to the audio-visual system is also cut off. Therefore, all programs and data are stored in ROM to make the system immune to problems caused by power failure. However, a power failure could cause problems in the video tape deck, compartment video tape player, and other units which have mechanically moving components. These problems include the inconvenience of being unable to remove the passenger's personal cassette tapes. To resolve this problem, a backup power supply is provided to supply power for about 30 seconds if a power failure occurs. During this period, the mechanically moving components are returned to their stop positions to eliminate mechanical stress from the tape and moving components. The compartment video player ejects the tape automatically.

Figure 13 is a timing chart for system control which has achieved the prolonged system life and automatic system operation by means of the functions and facilities explained above.

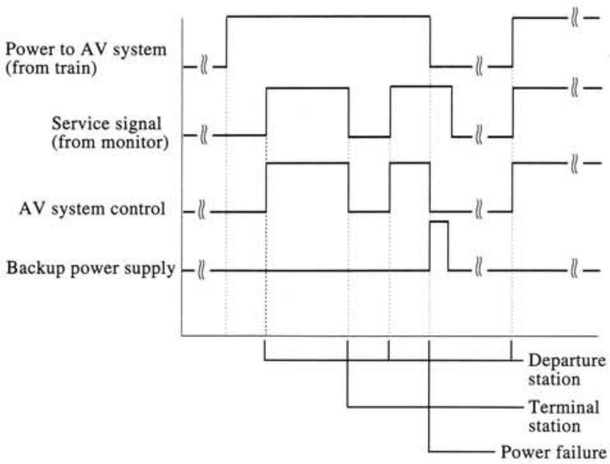


Figure 13. System control timing chart

5. Evaluation of the system

We have years of experience in developing and supplying audio-visual equipment for automobiles, but the development of audio-visual equipment to be installed in super-express trains is our first opportunity for train equipment. To fulfill the requirements in quality, we have conducted the following system evaluations.

5.1 Evaluation using actual trains

Super-express trains which are running at high speed emit a variety of noise, including spark noise from the pantographs and electromagnetic noise from motor and control equipment. To estimate how high quality can be achieved in such an environment, we conducted an evaluation test using actual super-express trains which ran between Sendai and Kitakami Stations of the Tohoku Shinkansen Line. During this test, we also measured vibration levels when the train was running. The test results have shown that the targeted quality was achieved.

5.2 Shipment inspection

Before shipment, we inspected individual units. In addition, we fabricated a pseudo monitor data generator which would be used for testing in place of actual monitor terminals. All units to be installed in one car were connected to the pseudo monitor data generator, and system checking was conducted. In addition, a full car of passengers was used to test the terminals in various ways, such as simultaneous operation, arbitrary operation, and intentional mis-operations, in order to check the system. According to the results of the tests and checking, we confirmed all possible modes in actual use conditions, identified problems, and implemented solutions to these problems.

At present, six systems are in operation, and there are plans to add new systems.

6. Acknowledgment

We would like to express acknowledgment to the East Japan Railway Company, Tokyu Car Corp., and Fujitsu Limited for their cooperation and advice.

Kohjiro Chikazawa

Entered the company in 1986. He has been engaged in the development of car audio equipment, and currently works in the Audio-Visual Engineering Department of the 2nd Audio Products Division.

Shigeru Toyoshima

Entered the company in 1984. He has been engaged in the development of car audio equipment, and currently works in the Audio-Visual Engineering Department of the 2nd Audio Products Division.

Shigeaki Inamura

Entered the company in 1982. He has been engaged in the development of car audio equipment, and currently works in the Audio-Visual Engineering Department of the 2nd Audio Products Division.

Shigeki Fukuyama

Entered the company in 1971. He has been engaged in the development of car audio equipment, and currently works in the Audio-Visual Engineering Department of the 2nd Audio Products Division.

Kazuo Takayama

Entered the company in 1976. He has been engaged in the development of circuitry and ICs for car audio equipment, and is now in the Engineering Section of the Audio Development Department.