Development of Terrestrial Digital TV Broadcast Receiver

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Abstract

Japan's digital terrestrial TV broadcasting began in December 2003 in Tokyo, Osaka and Nagoya. At the end of 2006 the service area will be expanded, enabling 50% of the nation's households to view the broadcasts and generating a growing need for digital TV in vehicles also. Fujitsu Ten embarked on development in 2000; by December 2005 we had created commercial products, and these were adopted as factory options for the Toyota Motor Corporation in January 2006. Receiving Hi-Vision transmissions stably in under mobile conditions requires a lot of technology. We devoted particular effort to technology for stable reception in the face of Doppler shifts during high speed travel, and developed custom LSI and an antenna system. Digital broadcast come with data as well as pictures and audio. We developed a BML browser to display the data, and graphics LSI / software to enable its manipulation via touch-keys. The in-vehicle digital TV developed provides stable pictures and audio like those of home systems, and also provides broadcast data.

1 Introduction

Japan's digital terrestrial TV broadcasting (ISDB-T: Integrated Services Digital Broadcasting - Terrestrial) began in December 2003 in three conurbations (Tokyo, Nagoya, Osaka) and at the end of 2006 will be receivable by 50% of the nation's households. The reception rate will rise to 93% of households by the end of 2010, with analog broadcasts scheduled to cease in 2011.

Besides high picture and audio quality, terrestrial digital TV is able to realize multifunctional broadcasting including data broadcasts and electronic program guides (EPG). Just as TV is important for home entertainment, there is also a major need for TV in vehicles.

Reception of analog TV pictures on vehicles has been of poor quality even in locations close to the broadcasting stations, because of multipath effects. But high picture quality can be expected with digital broadcasts. The market for in-vehicle TV receivers amounts to 3 million units per year and the percentage of vehicles carrying TV is likely to rise further as the switch to digital broadcasting proceeds. Fujitsu Ten embarked on development of in-vehicle digital TV receivers in 2000 and launched receivers developed for the commercial market in December 2005. This paper describes the features of these products, which overcome issues specific to in-vehicle applications, together with the technology that realizes them.

2 Overview and features of the Fujitsu Ten digital TV products

Fig. 1 shows the exterior appearance of the terrestrial digital TV broadcast receiver and antennas developed by Fujitsu Ten in 2005. The receiver is 1DIN size hideaway type and permits viewing of digital TV broadcasts when connected to any of the various head units launched on the market by Fujitsu Ten in 2005. The antennas consist of two film antennas deployed at the front and two short pole antennas at the rear. Screen display and control are carried out on the head unit's display, whereas programs selection and control display for data broadcasts can be performed via a touch panel. Fig. 2 shows the head unit with a channel selection screen displayed.

When a mobile object receives analog TV, multipath and other effects give rise to disturbance in the picture. With digital broadcasts by contrast, it will be possible to provide pictures free of disturbance - provided that a sufficient electromagnetic field strength is obtained - thanks to various innovative measures for mobile object reception that are incorporated in our receiver.

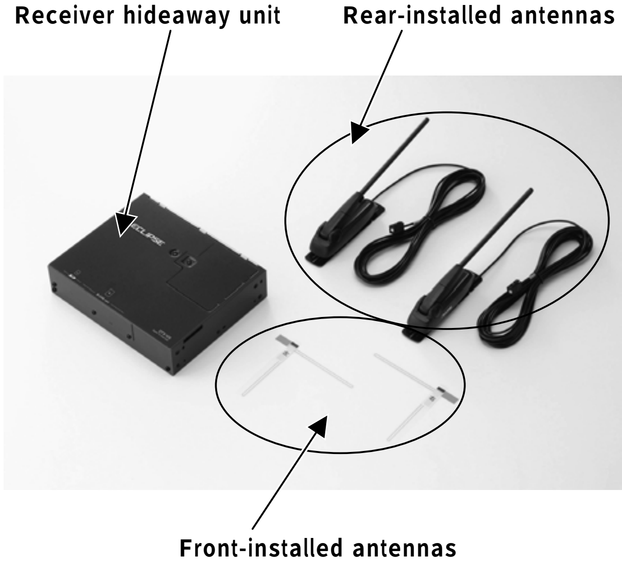

Fig.1 Digital TV receiver and antennas

Fig.2 Head unit, with channel selection screen

In order to realize in-vehicle the high picture quality of digital broadcasts, the Fujitsu Ten products achieve stable reception of Hi-Vision broadcasts together with enhanced in-vehicle operability. The features of these products are as described below.

①Good reception characteristics during high speed driving conditions

The overcoming of the problem of Doppler shifts that occur during high speed travel conditions means that as shown in Fig. 3, the newly developed in-vehicle receivers realize a Hi-Vision reception rate of 99% in 100 km/h driving on expressways, as opposed to a rate of 60% in receivers previous to the new improvements.

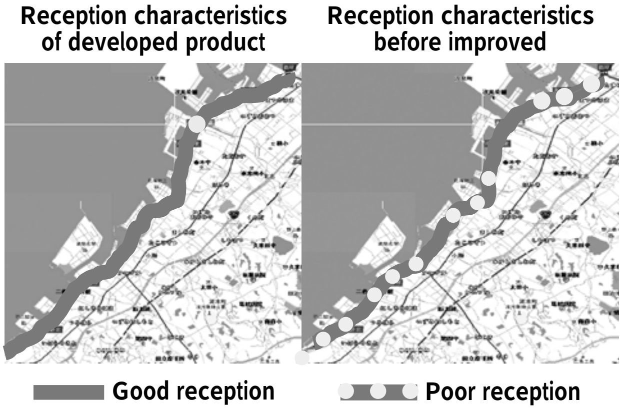

Fig.3 Reception characteristics compared: Conventional configuration vs. newly developed product

②All control performable via touch panel

For the front seats of a car, a touch panel is more convenient than a remote control. Accordingly we have made it possible to perform program selection using the EPG, as well as control display for data broadcasting services, via the touch panel. Fig. 4 shows a screen of control display for data broadcasting. Since the data broadcasts are aimed primarily at homes and require remote control style operations, we adopted the method of deploying remote control style touch keys on the touch panel screen to permit such operations.

Fig.4 Data transmission control display screen (Actual received broadcast)

3 Overview of terrestrial digital TV broadcasting

Terrestrial digital TV broadcasting employs the following technologies:

①Technology that lowers the data rate by compressing the audio and visual signals (data source encoding technology);

②Technology that turns multiple encoded data sources into a single datastream, thereby enabling interlinkage of data sources;

③Error correction technology that can correct errors occurring along the transmission paths by using the pre-assigned codes; and

④Modulation technology and transmission path encoding technology for superimposing data on radio waves.

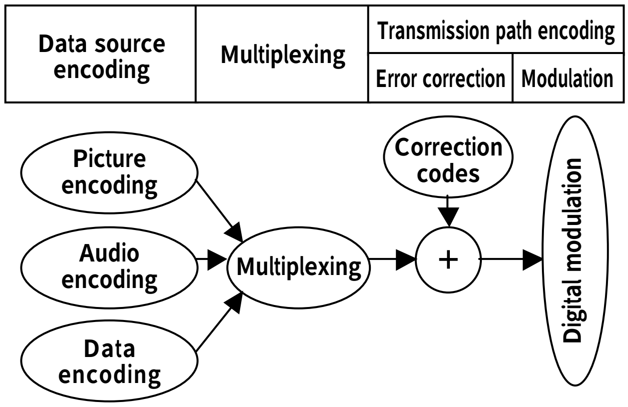

Fig.5 Schematic of technology used for digital broadcasting

Japan's digital terrestrial TV broadcasting is termed hierarchical transmissions, which permit modulation methods with multiple characteristics to be used in combination, so that using the same frequency band they can be either broadband or narrowband transmissions.

In April 2006, the "1seg" narrowband broadcast service for mobile telephones and other mobile objects was launched by the use of this method.

Though their picture quality is rough compared to Hi-Vision, the 1seg broadcast has the merit of providing a wider service area.

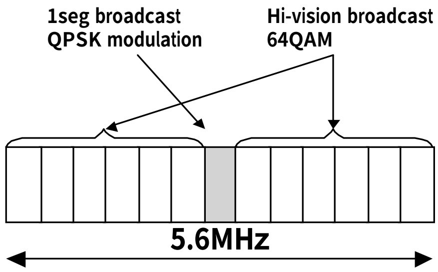

Fig.6 Hierarchical transmission

4 Issues in the development of in-vehicle terrestrial digital TV

There are the following issues for adapting digital TV receivers to use in vehicles:

①Improve mobile reception performance; and

②Realize control displays suited to vehicle applications.

4.1 Improvement of mobile reception performance

In reception by a mobile object such as a vehicle, the signals received by the antennas attached to the vehicle will contain, in addition to direct waves, delayed waves that have been reflected by buildings and so forth and consequently arrive later in time than the direct waves. These delayed waves are eliminated via a mechanism that discards the signal called the "guard interval" that is added at the beginning of the -valid symbol. In the case of low-speed travel, the Doppler shift due to traveling is deduced by means of the pilot signal inside the OFDM

(Orthogonal Frequency Division Multiplexing) signal and can be corrected for without any problem. But with an object moving at high speed, the Inter-Carrier Interference (ICI) that is produced by the Doppler shift is a serious problem that is compounded by the multipath effects mentioned above. With high speed driving, the aforementioned transmission path correction via the pilot signal becomes impossible and signals cannot be received normally. The Doppler shift frequency with which reception is possible is generally held to be 2.5% of the carrier interval, which means that for 64QAM reception on the channel 62, 35 km/h will be the limit speed for reception.

Further, if the OFDM demodulation unit fails to perform decoding correctly, block-level distortion will occur in the picture received. Accordingly, in-vehicle receivers require technology that will prevent the occurrence of block distortion even at times when demodulation does not take place correctly.

4.2 Realization of control displays suited to vehicles

As in-vehicle display devices are on the whole smaller than home display devices, writing and other characters received in data broadcasts must be displayed so as to be clearly visible. Further in the vehicle, the displays must be able to accommodate overlay with other screens such as navigation screens and control menus displayed. Additionally, while the broadcasts are premised on remote control for use with a home receiver, remote control is problematic inside a vehicle. Therefore it is needed to be replaced with touch panel control.

5 Technology to improve mobile reception performance

5.1 Reception performance enhancing algorithm

With the aim of receiving, during traveling at 100 km/h, Hi-Vision broadcasts transmitted using 64QAM modulation, the following three algorithms have been developed:

(1) Frequency division/multiplexing diversity;
(2) High-precision interpolation for transmission path distortion by means of pilot signal; and
(3) Directional antenna switching reception

(1) Frequency division/multiplexing diversity

The digital TV transmission spectrum is of the multi-carrier type, with the broadcasts being transmitted flat along frequency domain. But multipath effects will cause dips to occur in the spectrum, and reception will be impossible in the dipped frequencies. To counteract this, the signals from the two antenna systems are synthesized in each of the subcarriers divided along the frequency axis, so that the dipped portions are interpolated and the reception status is improved.

Fig. 7 illustrates the operation principle of frequency division/multiplexing diversity. Fig. 8 shows the results of testing of diversity effect during low speed driving (30 km/h); the horizontal axis represents the reception rate when diversity is absent and the vertical axis the reception rate when it is present. The reception rate of 30% without diversity is improved to 90% by the adoption of frequency division/multiplexing diversity.

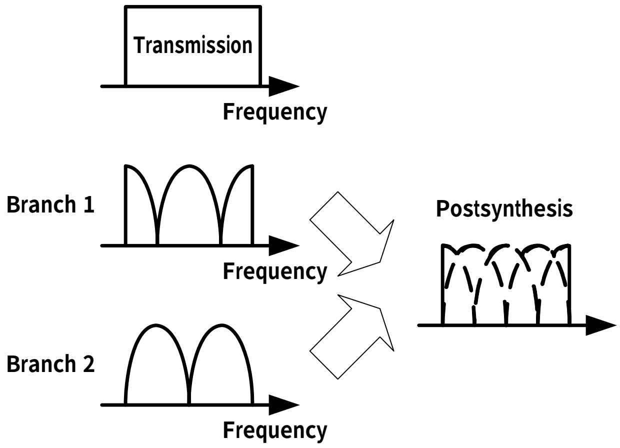

Fig.7 Operation of frequency division/multiplexing diversity

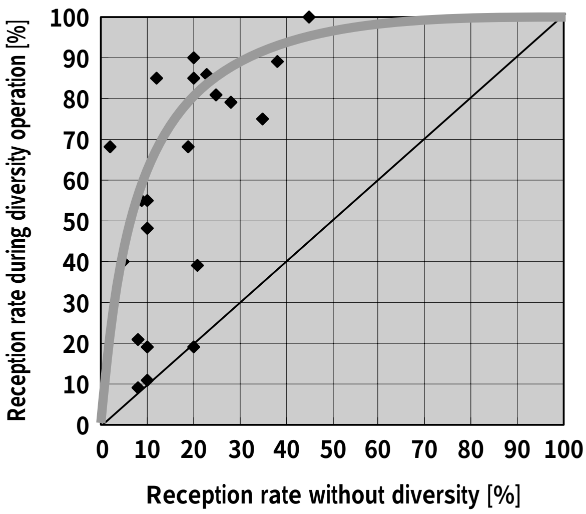

Fig.8 Diversity effects during low speed driving

(2) High-precision interpolation for transmission path distortion by means of pilot signal

Digital TV broadcasting is transmitted with a pilot signal superimposed on the main signal. The fluctuation in the radio waves is deduced through liner interpolation between two of the pilot symbols. However, this method will result in error in the case of steep drops. Accordingly the method of using an FIR (Finite Impulse Response) filter was examined. As shown in Fig. 9, the results demonstrated that it would permit accurate tracking even in the face of sharp drops. Fig. 10 shows the specific composition of the transmission path distortion interpolation: the pilot signal is extracted, then a correction signal is generated via the FIR filter, and the distortion is corrected using complex division. In terms of vehicle speed, as shown in Fig. 11, such FIR filter interpolation alone yields an improvement of around 20 km/h.

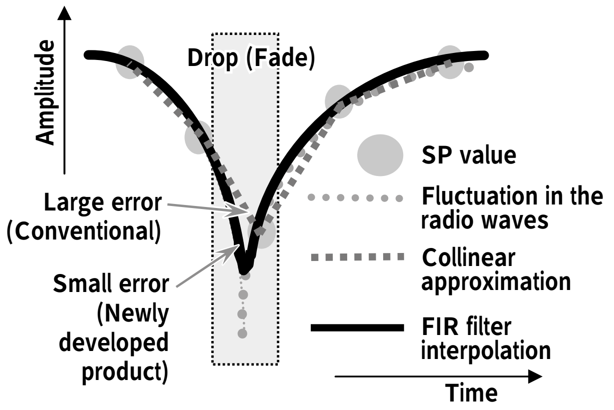

Fig.9 Conceptual representation of high-precision interpolation for transmission path distortion

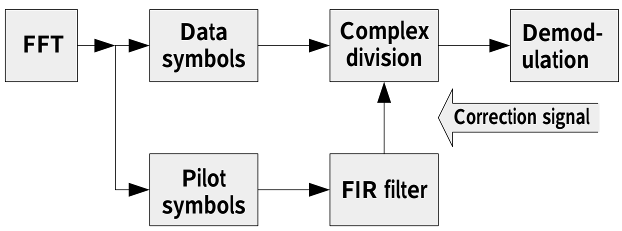

Fig.10 Composition of transmission path distortion interpolation

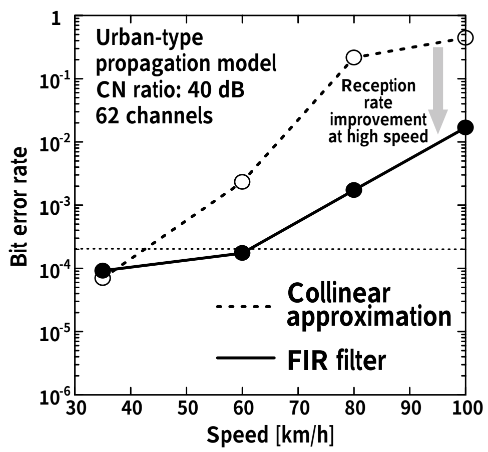

Fig.11 Effects of transmission path distortion interpolation

(3) Directional antenna switching reception

With reception through omni directional antennas, the radio wave is received from all directions. This means that during high speed driving in a multipath environment, both positive and negative Doppler shifts will occur, giving rise to Inter-Carrier Interference (ICI) as shown in Fig. 12.

By narrowing antenna beam pattern to the forward or backward directions, the Doppler shifts can be channeled into a single direction as shown in Fig. 13. When such channeling into a single direction is implemented via switching of the antenna directionality, it becomes possible to reduce the ICI by means of frequency shift correction circuits that utilize the correlativity with the guard interval, resulting in improvement in the reception characteristics during high speed travel. We conducted actual driving tests in which directionality switching ("beam switching") of the newly-developed directional antennas was implemented in combination with frequency division/multiplexing diversity. The result was that the reception rate of 65% with omni directional antennas (no beam switching) was improved to 90% by implementation of the beam switching.

The abovementioned improvements in mobile reception performance are summarized in Table 1.

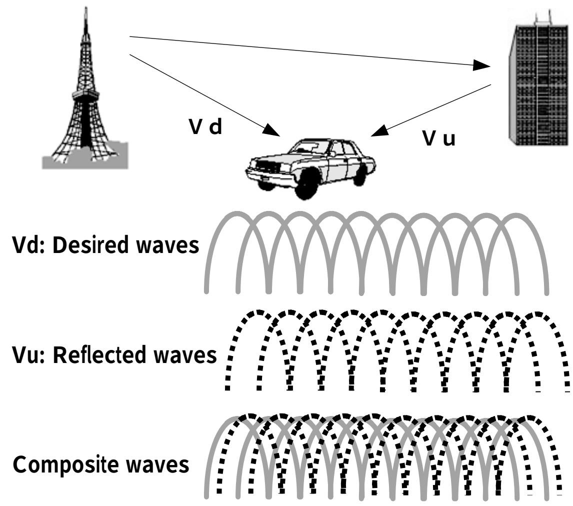

Fig.12 Doppler shift

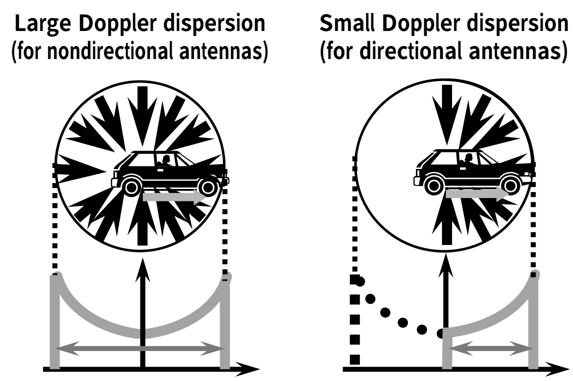

Fig.13 Improvement due to directional antennas

Table 1 Moving object reception characteristic enhancement measures and improvement effects (reception rates during fast driving)

Category	A	B	C	D
Composition	No diversity (home receiver composition)	"A" with 2-branch diversity antennas added	"B" with switched beam antennas added	"C" with high-precision interpolation for transmission path distortion
Reception rate	30%	65%	90%	99%

5.2 Development of directional antennas

The method adopted in order to realize the above directional antennas was to obtain the desired directionality by making active use of the reflection of incoming waves by the vehicle body. This method has the merit of realizing directional antennas with a simple structure, since it renders it unnecessary to equip the antennas themselves with functions for creating directionality, such as reflector elements.

An efficient way to have the incoming waves, which are horizontally-polarized waves, reflected efficiently prior to reception is for the forward directional antennas to utilize reflection off the front edge of the roof and for the backward directional antennas to utilize reflection off the rear edge of the roof or off a defogger installed on the rear window. Accordingly, as shown in Fig. 14, it was decided to install the forward directional antennas to the windshield and the backward ones to the rear window.

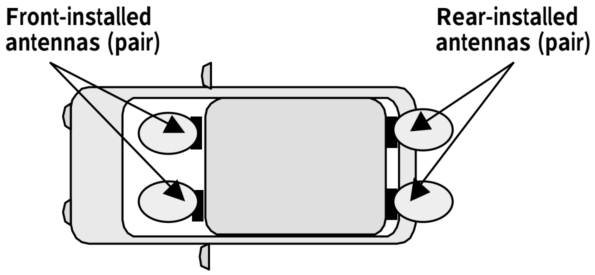

Fig.14 Layout of directional antennas

5.2.1 Front-installed antennas

Fig. 15 gives an example of front antenna installation and its radiation pattern. A folded-dipole type is used for the forward directional antennas, which are realized as film antennas. In the present application, folded-dipole antennas have the following merits:

- By themselves they have directivity in the rectangular direction; this enables them to effectively utilize the reflection off the front edge of the roof, so that the forward directivity can be made stronger.
- The antennas themselves possess a balanced-to-unbalanced conversion function, thus eliminating the need to secure grounding at their feeding points, and permitting their matching circuits to be made simpler.

Being installed in the vicinity of the A pillar of the windshield, these antennas posed a risk of impairing forward visibility, with the result that safety standards would not be complied with. Accordingly the folded-dipole antennas are bent so as to form an L-shape and the pickup terminal installation portion is located in proximity to A pillar, thus enabling installation of the antenna close to the A pillar while also securing forward visibility. The pickup terminal has a built-in amplifier that amplifies the reception signal directly at the antenna, thereby compensating for reception signal degradation due to the feeding cable.

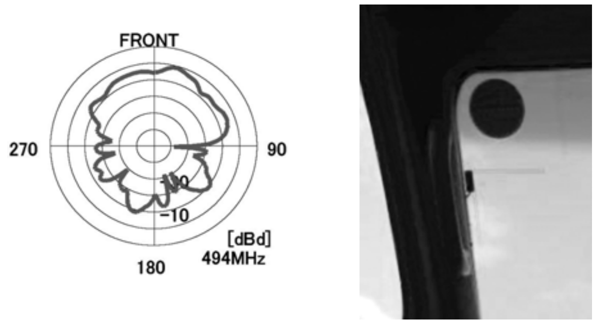

Fig.15 Example of installation and directionality

5.2.2 Rear-installed antennas

Fig. 16 gives an example of rear antenna installation and radiation pattern. The backward directional antennas are L-shaped pole antennas that allow adequate backward directivity even with a defogger installed. With the end of the monopole antenna bended to form an L-shape, reflection from the body is effectively utilized and backward directivity is obtained. Like the front-installed antennas, these antennas have built into their bases amplifiers that compensate for degradation of the reception signal due to the feeding cable loss, thereby assuring reception performance.

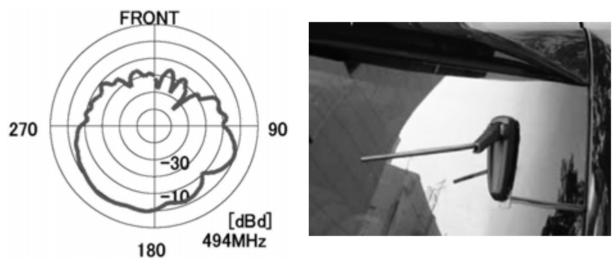

Fig.16 Further example of installation and directionality

5.2.3 Directional antenna switching control

The configuration of the directional antenna switching control is shown in Fig. 17. This is a 2-branch configuration, for selecting either the front pair or the rear pair of antennas. The reception status is constantly ascertained from the tuner and ODFM data, and switching control is implemented whenever reception becomes poor. The selection of the antenna between the front and rear is determined by temporary setting one antenna as the front-installed antenna and anther antenna as the rear-installed antenna, then comparing the reception condition between them. Reception degradation is caused not only by electrical field deficiency but also by frequency selective fading and by Doppler shift. Therefore the comparison of reception statuses uses the pilot signal to examine the reception CNR (Carrier to Noise Ratio), in addition to the reception level, thereby enhancing the accuracy of the determination.

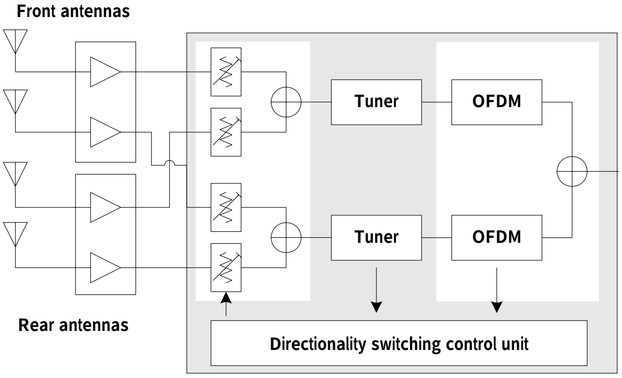

Fig.17 Configuration of directional antenna switching control

Thus, by controlling switching of the directional antennas so as to match the radio wave environment, directivity in all directions is obtained and moreover the effects of Doppler shift are averted.

We have developed LSI circuits that incorporate the frequency division/multiplexing diversity and high-precision interpolation for transmission path distortion by means of pilot signal that were described above. Fig. 18 shows the external appearance of the newly-developed LSI.

Fig.18 Newly developed OFDM-LSI

6 Realization of control displays suited to vehicles

Now we describe the backend unit, which plays back the pictures and audio from the reception signals.

The backend unit is composed of a CPU, a decoder and an image processor. An in-vehicle specification image processor has to provide ① reduction of block noise during momentary interruption of radio waves, ② unique in-vehicle design graphics/display functions, and ③ high speed / high quality graphics. To realize such functions tailored specifically to in-vehicle use, a special image processing LSI has been developed.

6.1 Block noise reduction during momentary interruption of radio waves

Signals between the front end unit (demodulation unit) and backend unit are transmitted in fixed-length packets of 188 bytes that are called Transport Streams (TS). If errors occur in these signals, block-level distortion will occur in the pictures. Therefore at such times, the picture is stopped ("frozen") just before it would otherwise enter the "without freeze control" state in With freeze control

(Picture stops just before block noise would occur.)

Fig. 19, and processing to cancel the freezing is implemented as soon as the reception status has returned to normal. In this way, block distortion is curbed and the display is swiftly restored from the frozen state. The freeze processor carries out picture freeze control on the basis of error bits (transport error indicators) that are added by the demodulation processor in cases where it cannot correct errors, and of the decoding processor's macro block errors, as shown in Fig. 20. The freeze processor comprises packet counters for sampling the reception status and error counters for showing the error occurrence frequency; there is a separate one of each of these for the time of freeze onset and the time of freeze cancellation. Thus equipped, the processor implements hysterisis-style control. Additionally, the error counters have two sets of circuits: one for the main picture (broadcasts to fixed objects) and one for sub-pictures (broadcasts to mobile objects).

Without freeze control (Large amount of block noise occurs.)

With freeze control (Picture stops just before block noise would occur.)

Fig.19 Comparison of pictures with and without freeze control (Actual received broadcast)

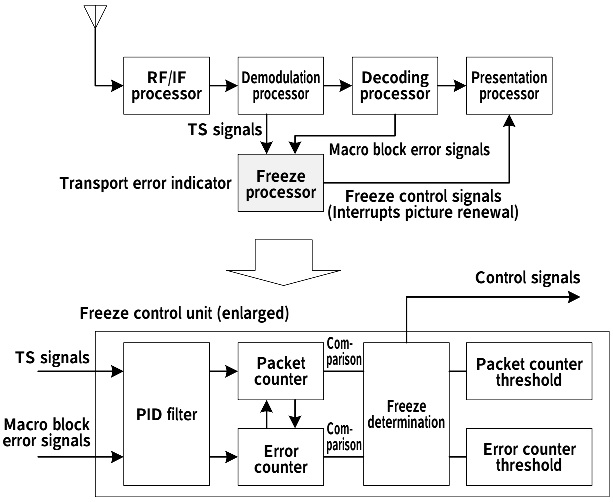

Fig.20 Composition of freeze control unit

6.2 Unique in-vehicle design graphics/display functions

Fig. 23 shows the composition of the backend unit's hardware and the newly developed ASIC. The composition is such that the TS packets from the OFDM demodulation processor are first decoded, then expanded or reduced to a W-VGA or W-EGA size. The features of the hardware are described below.

1) The unique in-vehicle design specification is able to display up to eight screens - six graphics and two TV picture screens - that can freely overlay one another. An example of such a display is shown in Fig. 21. This is a display of a total of six overlaid screens (planes): ① moving picture 1 (for fixed object broadcasts), ② walling, ③ warning message, ④ scroller, ⑤ key panel, and ⑥ key names. Fig. 22 is a diagram of the overlaying configuration of the newly-developed ASIC. In addition to the planes in the foregoing example, it can provide a video adjuster plane and a moving picture 2 plane (for 1seg expansion). Additionally it implements fade-in and fade-out effects when picture displays are switched - a function that gives a smooth feel to picture transition.

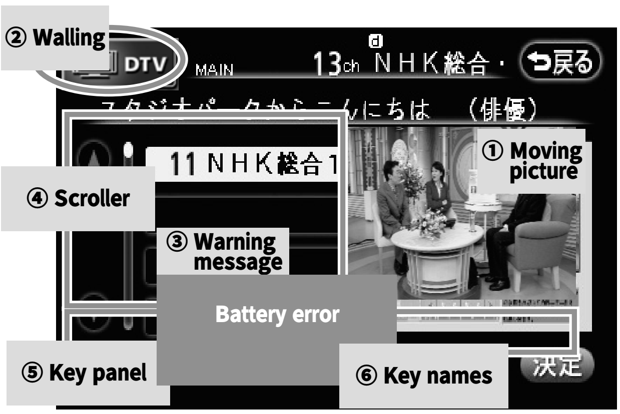

Fig.21 Sample in-vehicle display (6-plane)

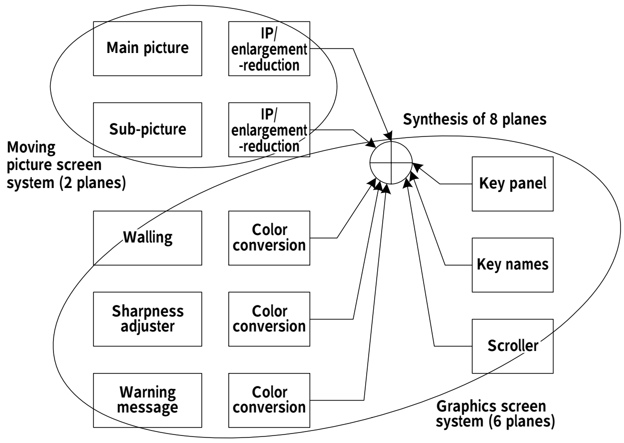

Fig.22 Configuration of overlay

2) The unit is equipped with SDRAM, Flash and other CPU peripheral control, and with an SD card interface, AVC-LAN, I2C and various other external interface capabilities.

3) The unit's interface with the image memory is made up of a bus A (128 Mbit, bus width 64 bits) for three screens capable of 16 million-color displays, and a bus B (64 Mbit, bus width 32 bits) for three 256-color (8-bit index type) display screens and two video picture screens.

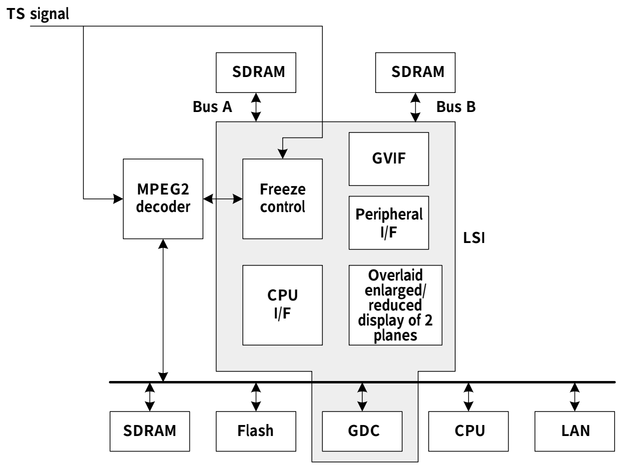

Fig.23 Composition of hardware

6.3 High speed / high quality graphics

Graphics commands are provided so as to achieve high speed graphics by using the hardware to assist the graphics processing. The graphics commands are Paint, Point, Line and Copy, plus additionally the commands BMP-Copy, Wrect and Rrect, which can be automatically transmitted while the CPU is halted following acquisition of CPU bus rights from the CPU's Flash and SDRAM, making a total of six commands. These commands enable the memory to be utilized efficiently (the unit has no duplicate memory for graphics). Further, the start and finish point coordinates are set in the ASIC's register via the CPU and the sections where there is no display operation (times when HSYNC and VSYNC are absent) are automatically utilized to draw graphics, so that the generation speed is not dependent on the CPU status and it becomes possible to generate graphics at an almost constant speed. This function will be effective for raising graphics generation speed in equipment that frequently generates graphics via transmission of BMP data. The newly-developed image processing ASIC is shown in Fig. 24 and the graphics commands are listed in Table 2. The features are summarized below.

1) The image processing LSI has built-in freeze control that was developed to detect the errors that occur during mobile reception and lessen their visual effects on the pictures via the image processor.
2) The menu displays needed for operation of the receiver are 16 million-color screens, enabling vivid gradation displays and faithful reproduction of GUI (graphical user interface) designs (screen design specifications) for automobile manufacturers' own unique display unit

Fig.24 Image processing ASIC

Table 2 Graphics command types and speed-up

Name	Function
PAINT	Clears whole screen.
POINT	Draws 1 dot.
LINE	Draws line (straight, oblique).
COPY	Transfers any rectangular area of a screen.
BMP-COPY	Transfers bit map data.
RRECT/WRECT	Transfers characters and graphic areas.
Clear VGA screen (800 × 480)	158 ms (conventional) → 25.8 ms (PAINT) **(Approx. 6 times higher speed is achieved)**

7 Conclusion

We carried out development of OFDM demodulation ASIC, image processing ASIC, and antennas specialized for digital terrestrial TV. By so doing we have developed a digital TV receiver with the features of good reception characteristics during traveling and allowing data broadcasts to be perused via touch key operation. Digital terrestrial TV has overwhelmingly better picture quality during traveling than analog TV and is highly rated by users. From now on we will be working to develop receivers that also accommodate 1seg broadcasts, and beyond that, receivers that are built into AVN systems, etc.

References

・Association of Radio Industries and Businesses standard ARIB STD-B31, Transmission Methods for Terrestrial Digital TV Broadcasting
・Association of Radio Industries and Businesses standard ARIB STD-B31, Picture Encoding, Audio Encoding and Multiplexing Methods for Digital Broadcasting

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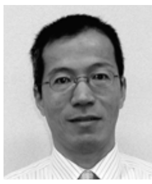

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