Technology for Improving Image Resolution in Car-Mounted TV Sets

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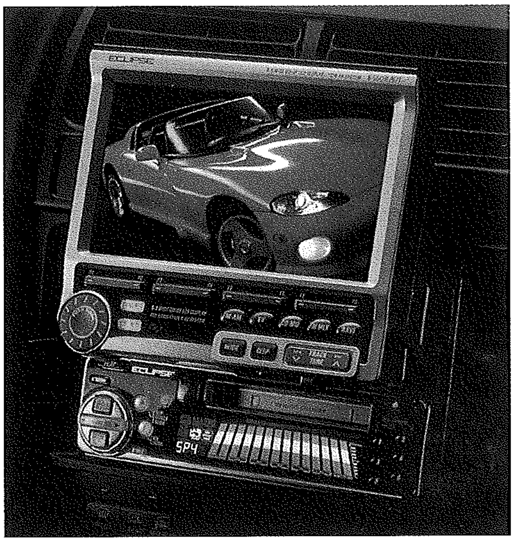

Abstract

In the last few years, the spread of car navigation technology has led to a sharp increase in the number of TV sets mounted in automobiles. However, incoming radio waves are deflected or blocked by buildings a moving car passes. Received pictures are very frequently garbled and difficult to make out. Previously, the main remedy was reliance on a diversity reception antenna, since no car-mounted TV set has been developed that incorporates stronger technology for improved picture quality.

However, we have addressed this technological issue by successfully developing an image-enhancement technology for use with car-mounted TVs. Our new technology involves digitizing TV picture signals (video signals) of the received base band, and reading the signals with a proprietary signal processing method.

We have built the digital signal processor into a custom LSI, which has made it possible to mount the system into the product.

This paper discusses the basic principle by which the system was developed, and the results obtained.

1. Introduction

In Japan, the color TV broadcasting system (NTSC system) was adopted nearly 40 years ago. Even today, TV remains the dominant "information transmission leader."

The progress that has been achieved with digitizing technologies is making wider and larger, high-quality home TV screens a reality. Car-mounted TV sets are primarily made up of 5-inch to 8-inch LCD screens. The significant growth in demand for car TV sets is being fueled partly by the growing popularity of car multimedia (such as car navigation). TV will likely remain one of the most important media for car-mounted AV equipment.

In the field of car-mounted TV sets for ground-wave TV programs, deterioration of picture quality attributable to rapid field fluctuations in the mobile environment poses a significant technical problem that remains unsolved. The conventional diversity antenna is unable to cope with fast fading that occurs when a car is running.

In particular, there exists demand for a system equipped with a rear-seat TV set that can maintain stable picture quality, allowing people to enjoy programs while the car is moving.

Under these circumstances, Fujitsu TEN has been promoting technological development to reduce radio disturbances unique to car-mounted TV sets and provide clearer pictures.

We have completed the processes from system study to custom LSI development to pave the way for the development of a practical system.

This paper introduces a picture quality improvement system and its effects.

2. Existing Picture Quality Levels and Technologies of Car-mounted TV

2.1 Radio Disturbance in Car-mounted TVs

TV broadcast radio waves emitted from a broadcasting station follow direct paths and reach an antenna directly if there is no obstacle between them and the transmitter. If the antenna picks up only these radio waves, the viewer is able to enjoy a very clear picture.

When a car is traveling, however, obstacles such as buildings and mountains come between the broadcasting station and the car-mounted antenna; these obstacles that are constantly changing in terms of shape and configuration.

Consequently, a car-mounted antenna receives direct radio waves from a broadcasting station as well as radio waves reflected and diffracted by obstacles. Since the reach distance depends on the path the radio wave is traveling on, the phases of the radio waves are input in a random state. In-phase signals increase the received field strength but reverse-phase signals reduce it mutually. This kind of transmission channel is called a multipath channel and the decrease in the field strength is referred to as fading. Figure 1 shows a radio wave propagation model during mobile reception. A car quickly passes a weak field point existing at almost every wavelength. A receiver in a car running at 40 km/h will undergo fading on TV channel 1 (video carrier wave frequency: 91.25 MHz) at a frequency of about 3 Hz and on TV channel 62 (video carrier wave frequency: 765.25 MHz) at about 28 Hz.

When a car is traveling, radio disturbances tend to occur. These disturbances are referred to as ghost images (multiple pictures) and multipath (selective fading by multipath propagation) phenomena. Because of these disturbances, pictures undergo deformation, synchronization disorder, color deviation, and color loss,

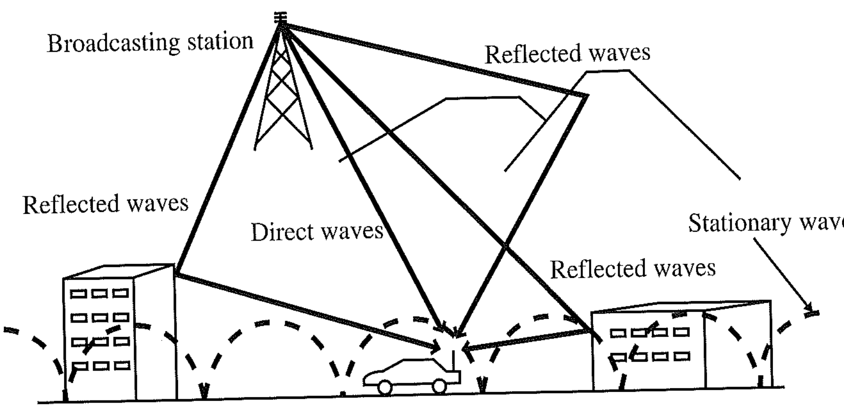

Figure 1 Radio wave propagation model

making them rather difficult to view. When the receiver is outside the service area of a broadcasting station, the field strength tends to weaken and pictures become tend to become impaired by noise.

In general, the wider the signal transmission band, the greater the influence of multipath disturbance. Multipath disturbances affect TV image signals greatly because the signal band is about 4.2 MHz.

2.2 Improvement of the Picture quality

Conventional TV systems use a diversity antenna method where several (usually four) antennas are arranged on a car and the optimum one is selected in accordance with the reception status.

Figure 2 shows the configuration of the diversity antenna mode TV system.

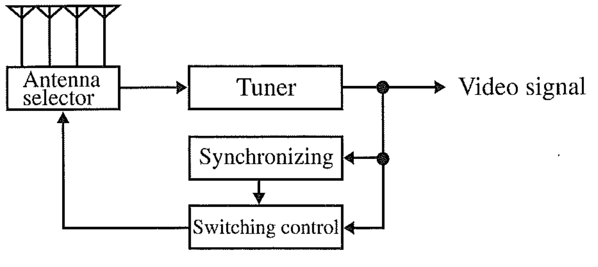

Figure 2 Diversity antenna mode TV system

The diversity antenna system switches the receiving antennas in a vertical interval when no TV image signals are displayed, because switching the receiving antennas in a picture display produces switching noise (white line noise) on the screen. Therefore, this system cannot follow the signal if the fading cycle becomes shorter than the vertical synchronizing cycle (about 16.7 ms).

The synchronizing circuit often uses a synchronous generation system called the countdown system to extract synchronizing signal components accurately from deteriorated video signals. This system stabilizes horizontal synchronizing signals by using an automatic frequency control (AFC) circuit. Vertical synchronizing signals are stabilized by the implementation of certain count processing that makes use of the frequency relationship with horizontal synchronizing signals.

3. Picture Quality Improvement Technologies for Home TV

Technological advances supported the remarkable development of broadcast media to satisfy varying needs. The growing size of home TV screens, however, began to expose the disadvantages of NTSC, the conventional epoch-making system (for analog broadcasting in Japan and the United States), in the form of screen disturbances. A new technology was developed to produce the best picture quality via the maximum use of information from a broadcasting station.

The main technologies for improving picture quality are three-dimensional Y/C separation, sequential scanning (non-interlace), ghost canceling, and noise reduction. All of these technologies are for digital signal processing on baseband video signals. Figure 3 shows the construction of TV image signal processing.The TV tuner detects, amplifies, and digitizes video signals and the ghost canceler generates ghost-free digital video signals. The signals are input into the Y/C separator circuit for separation into luminance (Y) and color (C) signals. The noise reducer circuit reduces noise from the Y and C separate signals. The scan line interpolator circuit scans the signals sequentially and the RGB matrix circuit generates primary RGB signals.

3.1 Canceling Ghost Images

Since ghost images are said to occur at about 75% of the receiving points in city areas, eliminating this phenomenon is expected to lead to high picture quality.

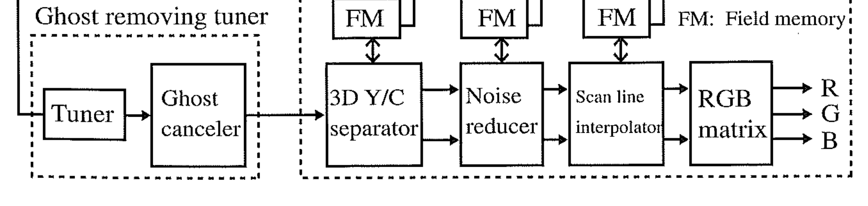

Figure 3 Construction of TV image signal processing

Figure 4 shows the basic principle behind removing ghost images. If the characteristic of a ghost transmission channel is expressed as 1+G(w), an equalizing filter of 1/{1+ G(w) }on the reception side will make the general characteristic flat, thereby eliminating this phenomenon.

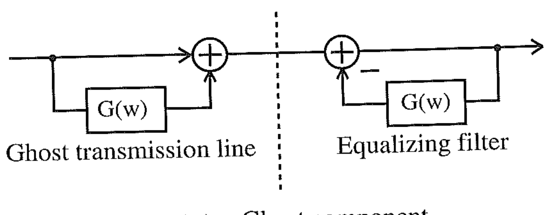

Figure 4 Basic principle of ghost removal

Ghost canceling is used to set up an equalizing filter on the reception side for a characteristic opposite to the transmission characteristic. The key factors that make this possible are shown in the two processes described below:

1) Detecting the transmission characteristic on the reception side
2) Setting up an equalizing filter of a characteristic opposite to the transmission characteristic

As for (1), a broadcasting station pre-inserts ghost canceling reference (GCR) signals into vertical intervals. A receiver calculates the time and level differences of the GCR signals to cancel ghost radio waves.

As to (2), a transversal filter for recursive and non-recursive filtering is in practical use as an equalizing filter that can precisely realize a characteristic opposite to the ghost transmission line characteristic.

3.2 Three-dimensional Y/C Separation

In TV image signal processing, the characteristic of the Y/C separator circuit is the greatest factor affecting picture quality. Three-dimensional Y/C separation is executed not in the vertical-horizontal interval frequency domain but also in the time frequency domain where frame memory is used. This technology is generally called three-dimensional comb filtering. Considering that the main screen size of home TV sets is about 28 inches, three-dimensional Y/C separation is essential.

3.3 Noise Reducer

Noise reduction is for the purpose of reducing picture noise on a real time basis. Although fine picture noise reduction called coring is one of the methods for noise reduction, it can improve the S.N ratio by only 2 or 3 dB. On the contrary, using frame memories (storing one frame of video signals) boosts the improvement in the S/N ratio to about 20 dB. Figure 5 shows the principle of noise reduction.

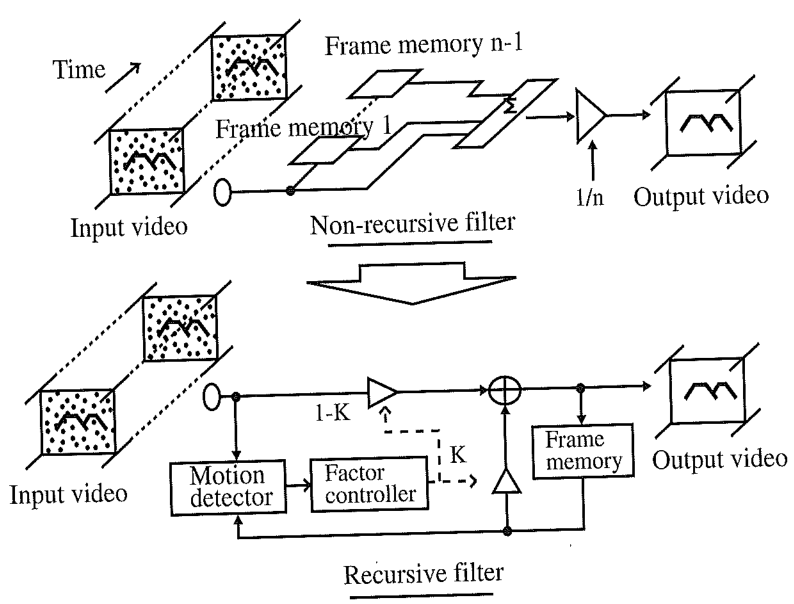

Figure 5 Principle of noise reduction

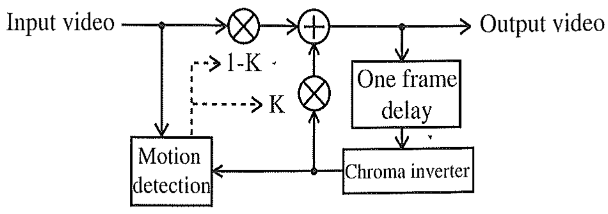

Figure 6 Basic construction of noise reducer

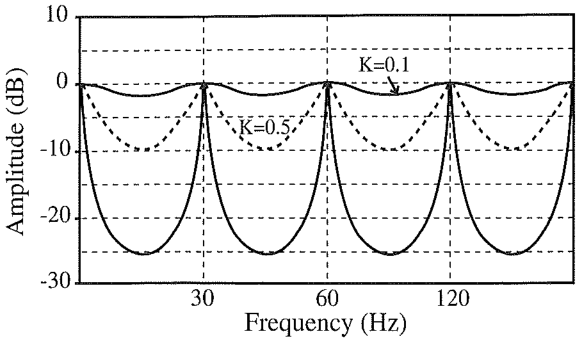

Figure 7 Frequency characteristics of noise reducer

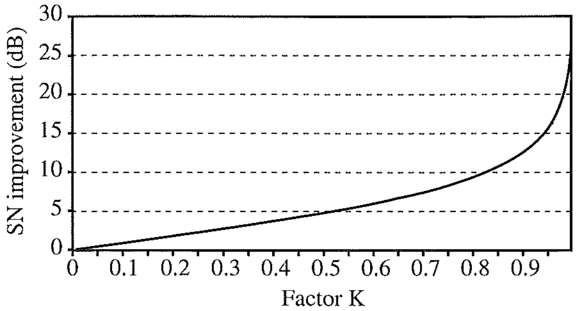

Figure 8 SN ratio improvement due to factor K

Video signals are stored in frame memories with n frames averaged. Video signal components are kept because they do not differ between frames, but noise is removed because it does not have correlation between frames and attenuates to 1/n in power and $1/\sqrt{n}$ in amplitude. However, since frame memories are expensive, a recursive filter consisting of a single frame memory is used instead of a non-recursive filter consisting of n frame memories.

The above technology reduces noise in static pictures but simply adding the video signals will generate afterimages in dynamic pictures because actual images have motion. The point of noise reduction is to prevent afterimages from causing visual disturbances. See Figure 6 for the basic construction of a noise reducer, Figure 7 for the frequency characteristics of noise reducer, and Figure 8 for the SN ratio improvement due to factor K.

The motion detection section detects picture motions and reduces afterimages in dynamic images by varying factor K. The chroma inverter matches NTSC color TV signals because their phases are inverted in each frame. A static picture has a signal component at each peak of a comb pattern and only a noise component at each trough. Attenuating the troughs will reduce noise.

$$\text{SN improvement} = 10 \log \{(1+K)/(1-K)\}$$

(Where, $0 \leq K \leq 1$)

This noise reducer is mounted on high-grade home TV sets only because the expensive frame memory used in the three-dimensional Y/C separator circuit is also necessary elsewhere. Afterimages are noticeable on home TV sets because the screens are large. Since the received field is comparatively stable, factor K cannot or need not be increased. This is why fixed pattern control is applied to factor K.

3.4 Sequential Scanning (Non-interlace)

The current NTSC TV system has 525 scan lines. This system scans these lines in two portions (every other line) to generate a single picture via skip scanning (interlace scanning). Sequential scanning is a technique for raising the vertical resolution and eliminating line flickering and other disturbances.

4. Development of a Picture Quality Improvement System

4.1 Purpose of Development

As mentioned earlier, a number of picture improvement technologies that have been developed for home TV sets cannot be applied to car-mounted TV sets as is.

To improve the picture quality of car-mounted TV sets, we will require new technologies that will be adaptable to the special conditions unique to mobile and car mounting environments. In a mobile environment, the received field fluctuates rapidly and causes frequent display and synchronization disorders, resulting in lowered picture quality.

We attempted to improve the picture quality of ground-wave TV broadcasting under such unfavorable conditions.

4.2 Study of Technologies Applicable to Car-mounted TVSets

This section explains the applicability of picture improvement technologies for home TV sets to car- mounted TVsets.

4.2.1 Ghost canceling

The ghost canceling technology is not applicable to a car-mounted TV set for the following reasons:

(1) It takes about three seconds to remove a ghost image. (Waveform equalizing operation)

(2) A ghost image cannot be removed if it is excessive or the field is weak.

→A synchronous separation failure disables GCR signal detection.

4.2.2 Three-dimensional Y/C separation

A car-mounted TV set does not require a high-precision circuit for three-dimensional Y/C separation because the screen size is about 6 inches.

4.2.3 Noise reduction

If applied to a car-mounted TV set, the noise reduction technology is expected to lead to significant improvements in picture quality for the following reasons:

(1) Considering the human visual characteristics, factor K may be greater for the same motions (to increase SN improvement) because the SN ratio is low in a weak received field and the screen size is comparatively small.

(2) Varying factor K on the basis of the degree of video signal deterioration optimizes display pictures.

(3) In case of rapid picture deterioration (synchronization disorder and color shear or loss by radio blocking or strong fading), increasing factor K stabilizes display pictures.

4.2.4 Sequential scanning

The sequential scanning technology is applied only to high-grade models of home TV sets because expensive frame memories are required as for noise reduction. This technology will not improve the picture quality of a car-mounted TV set whose screen size is only about 6 inches.

4.3 Newly Developed Picture quality Improvement System

TV signals have strong correlation between frames. In other words, "certain picture elements show almost no change between screens." A frame recursive filter is a low-pass filter based on this characteristic.

Table 1 VNR signal processing specifications

Item	Specification
Quantize bit	8 bits
Sampling frequency	14.31818 MHz (burst-lock clock)
Picture memory	Line memory X2 (910 X 8 X 2bits): For Y/C separation Field memory X 2 (2M X 2bits): For noise reduction Field memory X1 (2M X 1bits): For delay
Y/C separator	Three-line adaptive digital comb filter
Motion detector	Inter-frame differential system
Filter factor control	Adaptive control depending on field status (S level)
Filter factor RAM/ROM	64 X 8 bits/64 X 8 bits
CPU interface	Four-line clock-synchronous serial communication

As a picture quality improvement system, an adaptive digital noise reduction system was developed with a recursive filter consisting of frame memory. This unique system optimizes the characteristic of the frame recursive filter according to the car-mounted TV reception environment. In other words, this system always realizes the optimum filter characteristic for picture motion while detecting the reception level and its change.

In this document, this system is referred to as the Video-Noise Reducer (VNR).

4.3.1 Basic operations

Figure 9 shows the TV system using VNR technology. This system obtains baseband TV image signals (video signals) from the tuner and executes VNR processing. The VNR signal processing circuit consists of an adaptive filter that digitizes received video signals for signal processing and a picture deterioration detector that monitors the reception status. The VNR signal processing circuit converts video signals from analog to digital and inputs them into the adaptive filter (frame recursive filter). This filter characteristic is adapted depending on the field information and video signal disorder status.

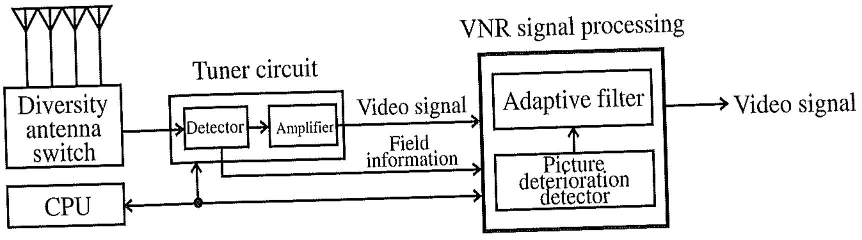

Figure 9 TV system using VNR technology

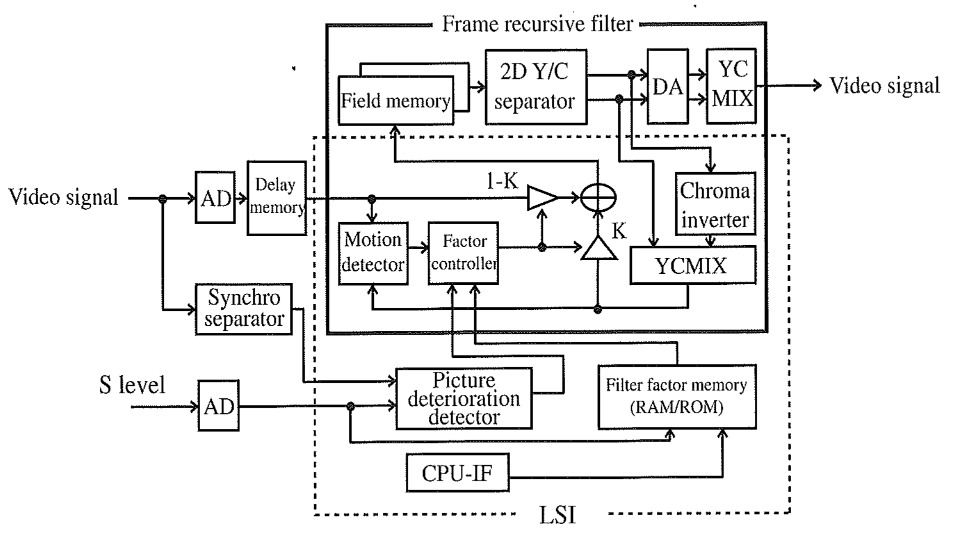

Figure 10 Construction of VNR signal processing circuit

4.3.2 VNR signal processing circuit

Figure 10 shows the construction of the signal processing circuit and Table 1 lists the VNR signal processing specifications.

The VNR signal processing circuit obtains baseband video signals from the tuner and converts them from analog into digital. This circuit inputs the signals into the frame recursive filter with some delays. The factors determining the filter characteristic are stored in a dedicated memory and used for adaptive control by the S level (IF-AGC voltage) indicating the field strength.

If the strength of field induced at the antenna is not stable, the video detection output also fluctuates and causes the screen contrast to vary. An IF-AGC circuit is set up to keep the video detection output stable without the fluctuation. To prevent the display from varying with the field strength, the gain is lowered when the input field is strong and raised when it is weak. The IF-AGC voltage controls this gain.

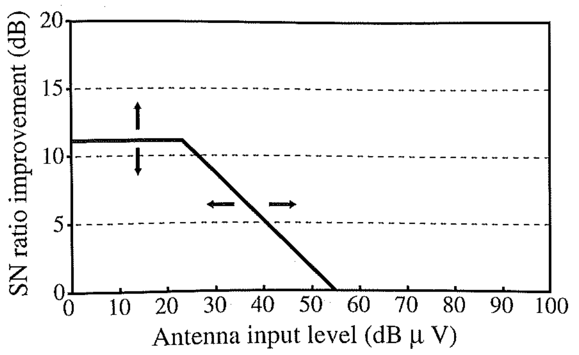

Figure 11 Antenna input level vs. SN ratio improvement

The motion detector detects a picture motion through discrepancies between frames. This circuit eases an afterimage by making factor K smaller (setting factor K closer to 0) at detection. The delay memory pre-compensates S-level response and picture deterioration detection delays. The picture deterioration detector detects a synchronization disorder or S-level change by steep field fluctuation or multipath. At detection, the noise reducing effect is raised (setting factor K close to 1).

Figure 11 shows an example of SN improvement characteristic seemingly optimum for the antenna input level or field strength. When the antenna input level is about 55 dB(V or higher, noise reduction processing is skipped because the field is strong enough. The SN improvement is set to 0 dB. Between 55 and 25 dB(V, adaptive control is applied as the curve shows in the figure. In a weak field of 25 dB(V or less, SN improvement is set at about 11 dB to limit afterimages by fixed control. Since the afterimage and noise reducing effect have a trade-off relationship, this system allows the user to set the characteristic curve freely as desired.

4.4 VNR Signal Processing LSI

For a more compact VNR circuit, a custom LSI (176-pin SQFP) is used as the digital signal processor in the construction of the VNR signal processing circuit (Figure 10). This LSI contains a frame recursive filter, a motion detection circuit, a factor RAM/ROM, a CPU-IF, and a picture deterioration detector.

Before processing

After processing

Figure 12 Example of picture quality improvement by VNR

Table 2 Improvement effects

Item	Improvement effect
SN ratio improvement	15 dB
Frequency of synchronization disorder	1/10 or less
Objective improvement	1.3 level up

4.5 Improvement Effects by VNR

We confirmed the effectiveness of VNR for improving the picture quality effectively without the sense of congruity. VNR improves the picture quality via the optimum noise reduction control (maximum SN improvement: 15 dB) depending on the received field strength and the detection of steep picture deterioration (field fluctuation) during high-speed drive. Table 2 lists the improvement effects and Figure 12 shows an example of picture quality improvement using VNR. The improvement is evaluated objectively on a seven-level scale by making comparisons with conventional Fujitsu TEN products. The effects of improvement were as follows:

(1) The picture quality is improved most effectively in a weak field area to allow natural picture display even where picture display used to be impossible. (VNR extends the reception service area.)

(2) Synchronization disorders are eliminated almost completely.

(3) Steep picture deterioration (image deformation or flickering) during high-speed drive is eliminated to the point where the viewer's eyes do not tire even when watching TV for a long time.

(4) Since the acceptable degree of afterimage differs depending on the person, a user setting function is effective.

5. Conclusion

VNR is a unique technology Fujitsu TEN developed for improving the picture quality of car-mounted TV sets. This technology can greatly suppress picture deterioration that occurs frequently when a car is traveling.

Because of baseband video signal processing, VNR can be applied flexibly also to future digital TV broadcasting (expected around 2000).

We will work toward further improvements in picture quality to accommodate user needs for high picture quality that are expected to grow more in future.

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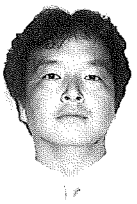

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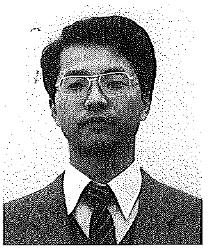

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