Development of World's First 13-bit Source Driver with 500 Mbps / Pair High-speed Interface and Creation of Demonstration Panel with Independent RGB Gamma Controls

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More than 120 years have passed since the discovery of liquid crystals by botanist Friedrich Reinitzer. Liquid crystal displays (hereinafter referred to as "LCDs") have permeated our lives and was the one which should be in our lives. LCDs are used in a diverse variety of manufactured goods, such as personal computers, navigational systems and games. LCDs have evolved in an astonishing manner and have become mainstream in the market even for products previously considered difficult for LCDs, such as television sets and high grade monitors for graphic displays.

The application of LCDs in television sets is shifting from conventional W-XGA+ (1,366 × 768) to Full-HD (1,920 × 1,080) and is about to shift further into Digital Cinema (4,096 × 2,160). Furthermore, plans to develop a Super Hi-Vision (7,680 × 4,320) broadcasting system were announced last year by NHK (Nippon Hoso Kyokai= Japanese broadcasting corporation). This resulted in an increased level of demand for improvingr image quality for which motion pictures and color management are the most crucial factors.

Although the double frame method appears to point the way towards a resolution with regards to the improvement of motion pictures, color management still remains a critical issue that needs to be addressed in the future.

This paper describes the LCD driver and timing controller (hereinafter referred to as "T-CON") used in the method for controlling the three primary colors (red, green and blue or RGB) individually, which were commonly managed with LCD panels in the past, as well as a description on the results of developments for LCD panels.

Demand for performance of LCD-TV

Along with the popularization of LCD-TV sets, demand for image quality also started to increase rapidly.

A major factor in this regard is the response time for motion pictures (motion blur) and another is the demand for color.

In terms of response time, light switching is generally used to manage color with liquid crystals utilizing such light sources as Cold Cathode Fluorescent Lamps (hereinafter referred to as "CCFL") and by directing light emitted by liquid crystal molecules using color filters (hereinafter referred to as "CF") that are colored with the three primary colors. This is what is commonly referred to as the hold-type display. An incidental image, therefore, always remains in the human eye. When LCDs are used for displaying motion pictures the displayed motion pictures appear unnatural due to this phenomenon of tailing images. This is an extremely critical problem that may prove fatal for the hold-type display.

A method used to counter this problem of tailing images involved the conversion of the frame frequency (number of frames displayed each second) by upgrading it from 60 Hz, which is generally used with conventional television broadcasts, to 120 Hz, thereby physically reducing the incidental image time to half in order to improve the motion pictures. This is referred to as the "double frame" method.

Furthermore, color reproducibility is a capability that is equally as crucial as motion pictures. In general, the three primary colors, RGB, are used in displays to display as many colors as possible. Voltage transmittance (VT) characteristics exist with LCDs, resulting from the change of transmittance depending on the amount of voltage applied to the electrodes. These VT characteristics vary, depending on the backlighting and CF in use, as well as the material of the liquid crystal itself.

With the increased popularity of television shopping programs, LCD-TV sets of the future will be required to have accurate color reproductions. However, difficulties may surface when the products ordered from television programs differ in coloration from the actual products, therefore, a high level of color reproducibility will be essential.

Furthermore, monitors used for Telemedicine, for example, need to display skin colors and the like in an accurate manner or it would not be possible to correctly diagnose medical conditions, therefore, color reproducibility is an even more critical capability for such applications.

Individual RGB gamma controls

Improvements to motion pictures and high color reproducibility, described earlier, are the two major issues required of image quality for LCD-TV sets. Approaches to implement a system level of the LCD in order to improve the level of color reproducibility have been numerous. One such approach was the expansion of the color space (gamut). The adoption of LED backlighting and CCFL of a high color rendering-type are representative examples and another is the individual RGB gamma control for which a 13-bit source driver is used.

Descriptions on the VT characteristics of the LCD have been previously provided, but they actually vary for each RGB color depending on the spectral distribution characteristics and the wavelength characteristics of the CCFL.

A concept is provided in **Fig. 1**. These are the characteristics for liquid crystals used for thin film transistor (TFT) displays of the Twisted Nematic-type (TN) in the Normally White (NW) mode, that is, the method for maximizing the transmittance rate when the power of the display is turned off. The vary voltage should be applied to individual RGB picture-elements (sub pixels) of the LCD, even when the entire screen is set to the same grayscale level.

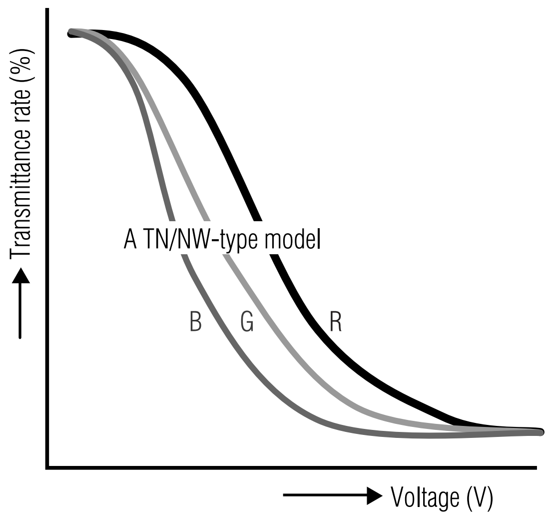

Fig. 1 VT characteristics that vary individually for RGB (gamma)

Furthermore, it is common knowledge that VT characteristics vary for RGB and various methods are in use to compensate for this phenomenon. These are referred to as RGB compensations (color tracking) and are generally performed in the graphic processor (engine).

Image (grayscale) data that has been compensated is sent to the LCD module, where timing signals are generated and the DA conversion of data is performed by the LCD driver, which is then used to drive the TFT on the LCD panel. This means that except in extremely rare cases, the color management function is performed in the engine. Compensation through color tracking in the engine, however, has continuously been known for some time now to be insufficient. This is because too many variables relate to color, such as the materials used to produce LCD panels. Besides these, other factors exist, such as:

- Orientation of the liquid crystals (MODE): Vertical alignment (VA), in plain switching (IPS), etc.
- Tilt angle in vicinity of electrodes for liquid crystal molecules.
- Polarizer, as well as transmittance and refraction characteristics of optical phase compensation film.

All the factors described so far create problems for television set manufacturers when the coloration of LCD modules, purchased from multiple LCD module manufacturers, is completely unmatched depending on the supplier, even when they have identical specifications. Incidentally, color characteristics can also vary with time, even when the modules are produced on the same LCD cell manufacturing line.

Because of the aforementioned phenomenon and tendencies, several manufacturers of television sets and monitors, that is to say set manufacturers, started demanding color tracking for individual LCD module units, in other words individual RGB gamma controls. Such a demand is becoming even stronger as digital broadcasting and shopping on the network are rapidly becoming popular and monitors for medical use are converted into LCD monitors from CRT.

Outline of independent RGB gamma controls

The individual RGB gamma control mentioned above is an essential technology achieved for the success of future businesses involving LCD drivers and T-CON.

An outline of the method employed is shown in **Fig. 2**.

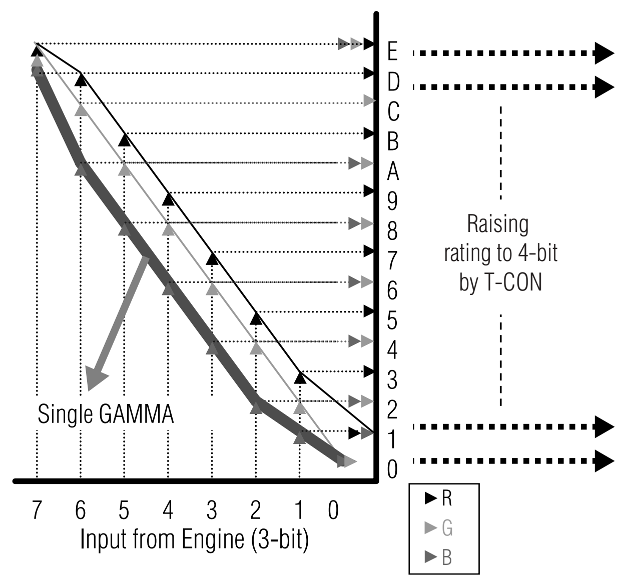

Fig. 2 Generation of data for independent RGB gamma

In order to facilitate an easier understanding an example case is shown here involving the control of individual RGB gamma control for 3-bit grayscale data.

The conventional method shown in **Fig. 2** involved the output of data to an LCD driver (depicted by a bold line showing Single GAMMA) through the treatment of the 3-bit grayscale data supplied as it is by the graphic processor (input from the engine as shown in **Fig. 2**), as data with identical RGB. The new method converts the data for individual RGB in the T-CON according to the characteristics of the LCD panel. Therefore, the resolution of the data must be finer than the input data. This means that more grayscale data becomes necessary in comparison with a common RGB control. An example is shown in **Fig. 2** of an upgraded rate of grayscale data converted to finer 4-bit data by allocating 3-bit grayscale data to the individual RGB.

We believe that a 10-bit grayscale will become the mainstream for LCD-TV in the future. A 12 or 13-bit divided data (resolution) is required for individual RGB control of 10-bit data. We determined that 13-bit data is necessary (details described below).

Creation of demonstration panel incorporating individual RGB gamma controls

As described thus far, individual RGB gamma controls for LCD modules will be essential in the future. Coloration, however, is a characteristic that is extremely difficult to be quantified. It is for this reason a demonstration panel must be created for the purpose of testing, verifications and confirmations made with set manufacturers of LCD-TV sets.

Previously test panels loaded with individual RGB gamma controls were prototyped by multiple LCD driver manufacturers and panel manufacturers. Furthermore, they are already in common use with the panels such as mobile phones. In the past, however, the maximum resolution for television sets had been 12-bit, whereas panels for mobile phones with RGB totaled 18-bit (6-bit for each RGB) or 16-bit (R:G:B = 6:5:5-bit). Some television set manufacturers pointed out that "coloration (details described below) in grayscale units occurs with a resolution of about 12-bit", causing large expectations for 13-bit resolution.

In order to respond to such expectations we created a demonstration (prototype) panel that provides 13-bit resolution and provided demonstrations to TV set manufacturers and panel manufacturers in order to verify the effects and uncover any difficulties together.

To create the demonstration system we used MT3100 (**Table 1**), which is the world's first 13-bit (source) driver and a proprietary development of OKI for the LCD driver, whereas the Field Programmable Gate Array (FPGA) was selected for the T-CON, as a large number of reviews on the functions were anticipated.

Table 1 Specifications of MT3100 (outline)

Grayscale level	Max. 13-bit (8192 levels)
Typical VDD (Logic / LCD)	2.7 V / 16.5 V
Interface	FP-LVDS / 6 pairs
Max. clock rate	216 MHz
Output ports	414 / 420 / 480 / 516 CH

The most important component in the creation of a demonstration system was the LCD panel (cell), which was supplied by an LCD manufacturer in Taiwan.

Specifications of this panel are shown in **Table 2**.

Table 2 Outline of prototype panel (supplied by a manufacturer in Taiwan)

Size	37 inches
Picture format	W-XGA+ (1,366 × 768)
Color space	72% (for NTSC)
LCD type	VA(NB)
Grayscale input	8-bit, compressed

We do not claim that the specifications of this prototype are satisfactory for evaluating individual RGB resolutions of the 13-bit level. In order to bring out the capability of a 13-bit level panel, for example, we needed a Full-HD (1,920 × 1,080) for pixel numbers (picture format). However, since the focus of our evaluation and verification was on coloration (color reproducibility) we determined that the prototype was adequate for such purposes.

Following is the T-CON part in which our design involved the use of the FPGA that can be flexibly adopted with changes to circuits, as mentioned earlier. The main functions are described in **Fig. 3**.

This means that the input image data is split into two on line, with adjustments to the timing only on one (left in the diagram) with gamma that is common to all RGB. On the other hand, gamma compensation for each of the three primary colors is made according to the RGB transmittance characteristics of the LCD panel on the remaining half (right in this case), then the data is stored in the output line memory and output to the source driver by the timing of the line selection signal. Furthermore, this T-CON is capable of providing output that can be used to compare the image of a conventional method with the image of an individual RGB gamma control on the same screen, as shown in **Fig. 3**.

The control board is also loaded with a Look Up Table (hereinafter referred to as "LUT"), allowing compensation according to the RGB transmittance characteristics of the LCD panel. Since the compensation parameters can be rewritten externally it is possible to use the table with various gamma constants (such as 1.8, 2.2, 2.4, etc.), which occur when the panel is replaced.

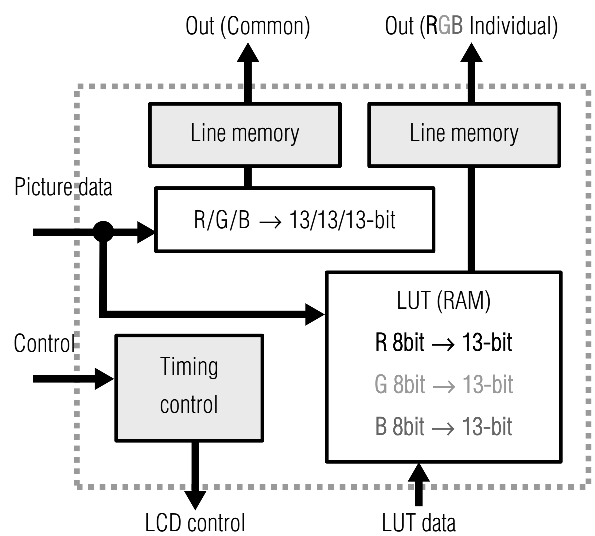

Fig. 3 Outline of T-CON (FPGA)

Control signals, such as the start pulse sent to the gate driver and source driver used for controlling screen scans, are generated in the Timing Control section.

Outline of demonstration panel

An external view of the created demonstration panel is shown in **Photo 1**.

The size of the LCD panel (cell) is 37 inches with the Wide-XGA+ format (supporting 16:9 HDTV). Incidentally, the liquid crystal type is a Vertical Alignment-type (VA), which delivers a higher contrast, but the VT characteristics of the black side shows a steep curve, meaning that a slight fluctuation in the driver output voltage greatly impact the transmittance rate. For this reason it is estimated that a more detailed resolution (13-bit rather than 12-bit) is required.

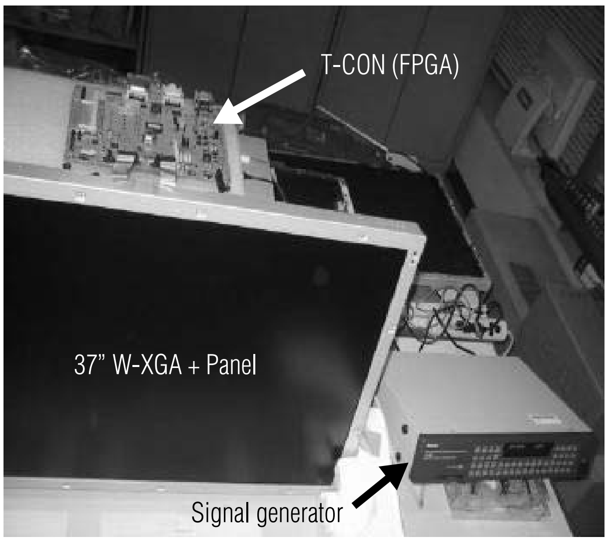

Photo 1 External appearance of demonstration system

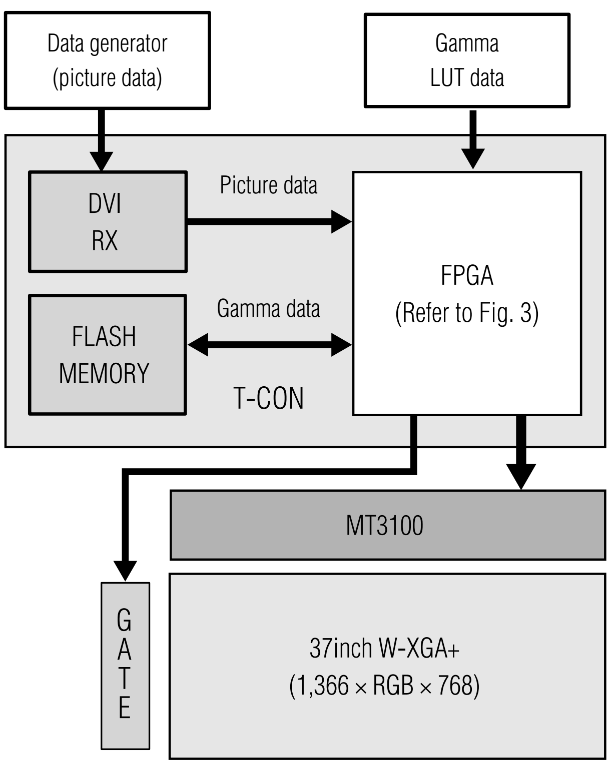

Fig. 4 Block diagram of demonstration system

A Digital Visual Interface (DVI) receiver, image processing LSI and other items necessary for the function of the T-CON are mounted on the T-CON (FPGA) board.

Fig. 4 shows a block configuration diagram of the demonstration system.

The image data is 8-bit information provided in a DVI format. This is supplied to the LCD driver as gamma data with a 13-bit resolution for each RGB with gamma compensation parameters stored on the LUT (flash memory).

The gamma compensation data loaded on the LUT is calculated from the luminance data of each RGB, measured by the manufacturer of the panel, which was converted to match the respective VT characteristics.

How to create an LUT with a high accuracy was the most critical aspect of the system for this method. Attempts were made to devise a highly precise measurement of luminance, as well as a conversion algorithm for the “luminance data-to-LUT data” conversion.

Photo 2 is a photograph taken of the image displayed by the demonstration system. The left half of the center division is the conventional method, whereas the right half is the result of individualized gamma compensation for RGB.

A clear difference in gradation was evident, although on the photograph it is not easy to see this due to the difference in the color gamut of the digital camera between the demonstration panel as well known and because repeated image compressions were performed in the photo process.

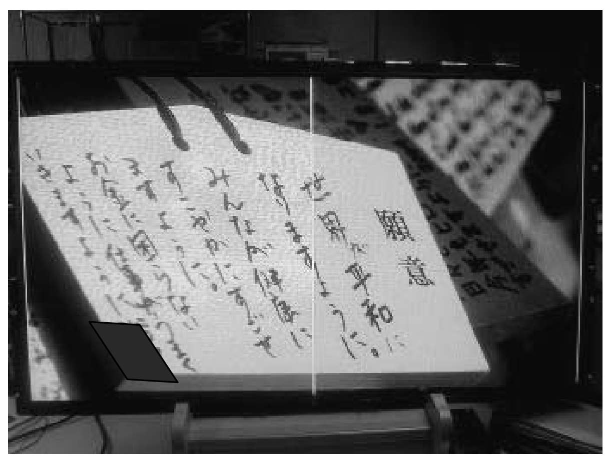

Photo 2 Actual image on panel (right half is image with individualized gamma compensation for RGB)

Evaluation and comments by customers regarding demonstration panel

Once the demonstration system had been completed we held demonstrations in Japan as well as in Korea and the United States following invitations from our customers and television set manufacturers.

A great deal of interest was shown by the respective companies and discussions with engineers of major manufacturers both in Japan and overseas were held in front of the actual screen, since the importance of such technologies is extremely high, as described in the abstract.

Responses from the respective companies have been favorable overall:

- A clear difference is evident in the gradation of skin color.
- A more natural rendering of the coloration is perceived.
- Although color perception varies from person to person the (probable) ability to display standard colors has quite significant implications.
- Since the burden of color tracking by the engine is reduced, simplification of the total system can be expected.

The majority of views were similar to those above, however, others pointed out drawbacks, such as:

- The panel has an insufficient capability for demonstrations. It is not possible to verify the improvements as hoped, due to the effects from the narrow gamut and narrow field of view, etc.
- Coloration that has a grayscale with a steep VT characteristic curve is randomly visible. This is something that was not seen with conventional methods.
- Other prototypes often built for systems with12-bit resolution do not seem to be that different from the 13-bit prototype from OKI.

Manufacturers oriented to producing high-end products pointed out that “it should be possible to bring out a visible difference using a panel that is the Full-HD, which offers a wider color gamut and deeper color depth” and they asked us to create a new demonstration system.

At any rate, even the problems that were pointed out can be considered as the flip side of expectations for this method.

Drawbacks and considerations for strategies

As suggested through feedback from our demonstrations, a peculiar problem of this system is “coloration with grayscale that has a steep VT characteristic curve”. Coloration (such as blue shifting) does occur in all grayscales, which is to say over the entire screen with conventional methods, but coloration in grayscale units is a unique problem of individual RGB gamma control.

This phenomenon is called Micro Color Shift (MCS) effect (hereinafter referred to as the “MCS effect”), which is shown in **Photo 3**. Green coloration can be seen with a portion of grayscales on the black side.

Furthermore, on the used panel, alignment method of Liquid Crystal molecule is Vertical Align (VA) in the Normally Black (NB) mode, resulting in a steep VT characteristic curve on the black side, which makes it susceptible to the effects of voltage changes.

This MCS effect occurs because gamma compensation is performed for each individual RGB and individual grayscales.

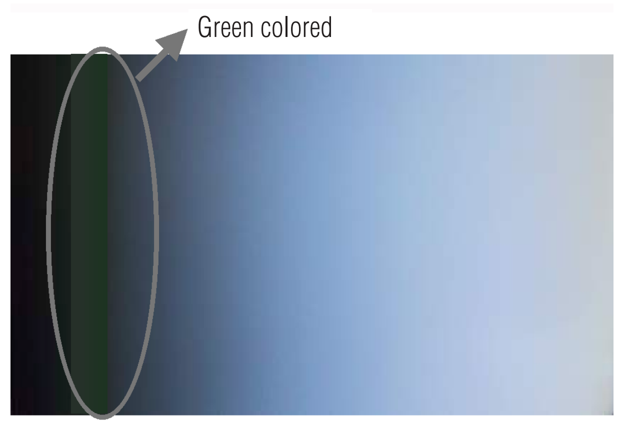

Photo 3 Micro Color Shift (MCS) effect

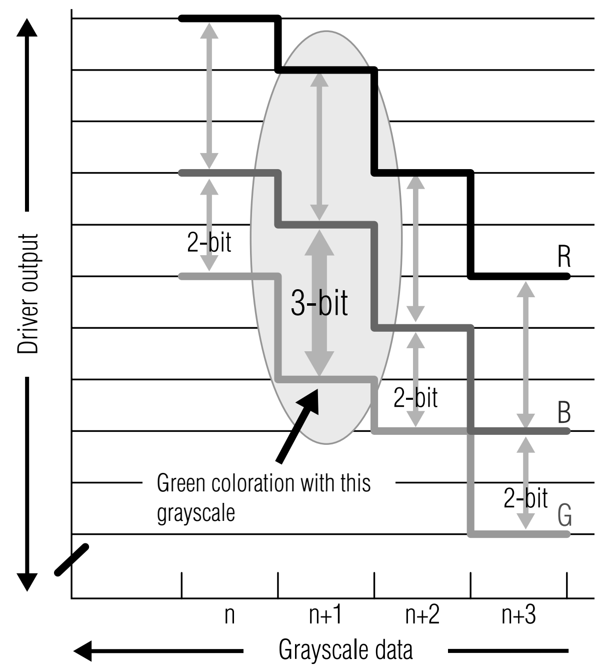

Fig. 5 MCS effect (cause of green coloration)

Fig. 5 is a schematic representation of the effect. The output voltage difference for green (G) and blue (B) is shifted by one bit in comparison with those preceding and following for the grayscale data of n+1. This phenomenon is caused by the lack of balance among RGB for particular grayscales when individual controls of gamma are performed, resulting in the enhancement of particular colors.

Possible causes include:

- Poor measurement accuracy of RGB luminance on the panel.
- Calculation errors for data loaded on the LUT of the TCON (conversion error of the lowest bit, for example).
- Resemblance errors for digital grayscale of the VT

characteristic curve.

We attempted to reduce this phenomenon by converting the system into a 13-bit system and the particular effects were verified together with a TV set manufacturer, but we have been told that the condition is still insufficient. We can also say, however, that the 12-bit resolution proposed by other companies is insufficient for their purposes.

Conclusion and future considerations

The individual RGB gamma control for 13-bit resolution (8,192 levels) with the T-CON and a source driver are essential technologies for LCD monitors and television sets of the future.

We will be considering improvements to the current systems and systems with high grade panels in order to become technology leaders for the color management of drivers for LCD-TV sets and high-end monitors, as well as the T-CON.

Also, we will be proceeding with strategies to counter the MCS effects to this system in order to bring our technologies to maturity.

Furthermore, since the transfer rate of data and clock signals between the T-CON and the source driver will be accelerated drastically due to the system conversion to 13-bit, exposure of the problems relating to transmissions, such as electromagnetic interference (EMI), will be enhanced. Strategies are currently being implemented using the FP-LVDS or mini-LVDS, however, we will be considering new technologies, such as the Clock Embedded method in anticipation of the emergence of Digital Cinema, etc.

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