1/4 Inch NTSC Format Hyper-D Range IL-CCD

Hiroyoshi KOMOBUCHI, Akira FUKUMOTO, Takahiro YAMADA, Yuji MATSUDA*, Takao KURODA*.

Central Research Laboratory MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.
*Kyoto Research Laboratory MATSUSHITA ELECTRONICS CORPORATION

ABSTRACT

1/4 inch 510H NTSC format horizontally half size IL-CCD, test emulation device, was newly produced for the purpose to extend the incident light level more than 20 times larger than that of conventional 1/4 inch CCD. The features of this hyper dynamic range CCD(Hyper-D CCD) is described as follows; A) read-out gate passed over the top of the photodiode horizontally to make twice the number of VCCD electrodes into one photo site, four electrodes in one photo site. B) new structure with a gentle potential slope under the readout gate was designed to realize read out operation completely. C) both normal signal in a field period and electric shutter signal in vertical blanking period are read out sequentially from the same photo site into the VCCD with the aid of 8 phase operation. This combination of two kinds of new structures and one operation realized totally more than 13 bit dynamic range CCD imager, without using external field memory.

1. Introduction

The size of CCD's currently used in camcorders and other devices is as small as 1/4 inches. The development of small-sized CCD's has continued as a imager in TV systems, with main focus on the basic characteristics such as sensitivity and saturation level. Therefore, the dynamic range has not been required to significantly exceed the CRT's maximum bit depth of about 8 bits (256 grays). If it ever has, the conventional CCD could not precisely reproduce commonly taken images including both bright and dark subjects in the same frame, such as a figure in front of sunset, or a summer beach viewed from the shade of a tree.

However, today's CCD's are facing a rapidly changing environment, with "multimedia" as a watchword. As has been known, application is expanding from the conventional TV systems to image scanners in network systems and portable personal terminals. This fact tells that pixel number and dynamic range will be increasingly important factors although sensitivity and smear remain essential. The pixel number is in the scope of the conventional type development, whereas, for a wider dynamic range, making full use of the computer's data bus will be a major challenge. In consideration of this, it is expected that 13 bits (about 10,000 grays) or more will be required, which is significantly higher than the maximum bit depth of 9 bits (512 grays) of the conventional CCD.

We have developed a prototype of hyper-D range CCD with newly engineered element structure and driving method, based on the currently most common 1/4-inch CCD. As a result, we have succeeded to improve the dynamic range by 20 times or even more as compared to the conventional CCD, which corresponds to the difference between a completely open iris and a fully-closed iris. This is ample for everyday use. The following explains more into details.

2. Various Techniques for Dynamic Range Improvement

First, various techniques for the improvement of dynamic range are roughly classified to correctly understand the character of the hyper-D CCD. Note that the following discussion is limited to single-plate CCD cameras, which are considered the prospectively most prominent candidate.

Dynamic range improving techniques for various parts of an imaging system are classified into the following four groups:

1) Read out the signal charge into the external memory twice or more during one field period to add the signal, using the conventional CCD .
2) Control the g-value (conversion characteristic of incident light to signal charge) in the photosite to less than unity in order to compress the signal, making use of the non-linear input-output characteristic in an avalanche phenomena in charge storage mode operation or the sub-threshold range of a MOS-FET [1,2].
3) Excess charge skimming operation by stepping up the storage capacity of the photodiode during one field period to control the knee slope of the photoelectric transfer characteristic [3].
4) Read out signal charges of different exposure times independently into different signal packets from a single photosite.

Of these techniques, method 1) has a limitation in the number of readouts depending on the frequency characteristics of the HCCD's output amplifier, and requires external frame memory. Method 2) is already in use with non-linear multiplying techniques such as the HARP tube, though no solid state application is available yet. Method 3) is directly dependent on the effects of product dispersions in capacity or driving voltage when using a photodiode with a fully depleted photosite. In a stacked layer type, image lag under high light should be eliminated if the dynamic range is to be extended to the high illuminance end. In consideration of all this, we concluded that the fourth option is the most promising and, on that ground, developed a Hyper-D CCD as explained below.

3. Hyper-D CCD

The CCD is characterized by the structure of the readout electrodes and the driving method, as explained below:

Structure of Readout Electrodes

Fig. 1 schematically shows the entire structure of the hyper-D CCD. The VCCD element transfers the signals with 8-phase pulses. The base CCD was a 1/4-inch, 510H format half-sized CCD TEG, with a pixel size of 5.6mmx7.2mm. The number of VCCD electrodes for each pixel has been doubled to four. As shown in Fig. 2 (a), the process face has a two-layer polysilicon process, in which the level difference in hight between the electrode wiring and the photodiode in the photosite has been reduced as compared to the three-layer polysilicon process. For simplicity, the second-layer of the polysilicon is not shown in Fig. 2 (b). If the overall vertical density is doubled in the conventional structure, the following problems arise:

- The proportion of the vertical separation area between photodiodes, which do not contribute to photoelectric transfer and signal charge storage capacity, is twice. Also, a lower yield is expected in the fine production process.
- The readout gate, through which the signal charge is read out from the photodiode into the VCCD, is narrower, requiring a higher readout voltage due to the narrow channel effect.

To solve these problems we have determined to employ a new readout electrode structure in which the horizontal readout gate passes over the center of the conventional photodiode. Furthermore to solve the following problems expected to newly arise:

- During the readout of the signal charge, the signal charge may leak to the opposite VCCD from the photodiode.
- Low illuminance after-image may be produced due to the long channel length, i.e., the readout length of the readout gate.

We have succeeded in solving all the above problems by providing a gentle potential slope under the readout electrode run over the top of the photodiodes.

Readout and Transfer Sequence

Fig. 3 shows the readout sequence which is characteristic of the hyper-D CCD with double vertical electrodes in the new readout structure. The readout and transfer are driven by 8-phase driving pulses. A maximum of two packets are transferred independently per two pixels. The figure shows the two modes available with this CCD: the progressive scan mode, and the high dynamic range mode which can reproduce high-illuminance subjects at the conventional resolution. The following discussion focuses on the readout and transfer sequence of the high dynamic range mode, referring to Fig. 4. In NTSC, a standard-illuminance subject is imaged during the display period of each field and read out. For a high-illuminance subject in which the signal charge saturates during this display period, a signal charge proportional to the illuminance is given in the subsequent vertical interval. At TAF1, the standard signal of the odd line as seen in photodiode PD-1 is read out. At TAF15, the high-illuminance signal of the odd line are read out. Simultaniously the standard signal of the even line as seen in PD-2 are read out and superimposed on the standard signal of PD-1 that has been read out at TAF1. At TAF29, the high-illuminance signal of the even line is superimposed on the high-illuminance signal of PD-1 that has been read out at TAF15. As a result, a signal packet as shown in the bottom of Fig. 3 is obtained. Period Th can be varied from about 1/500 to 1/100,000 seconds by interposing a waiting time. Display of colors can be realized by signal processing with the line [4] since the standard signal and the high-illuminance signal are mixed in the same pixel both for the A-field and B-field.

Fig. 5 shows the process sequence for the image production from the standard and high-illuminance signals. Since we experimented with a half size, a frequency of f_H = 9 MHz was used. For the normal size, however, the double frequency of $2f_H$ is used for readout as shown in the figure. The output signal voltage is controlled to Vth or lower by the slicer. After digital conversion, the high- and standard-illuminance signals are stored in separate FIFO memory. The standard-illuminance signal is compressed by a_N (< 1) times, while the high-illuminance signal is multiplied by a_H times. Normally, only the standard signal is read. However, when the signal voltage of the standard signal

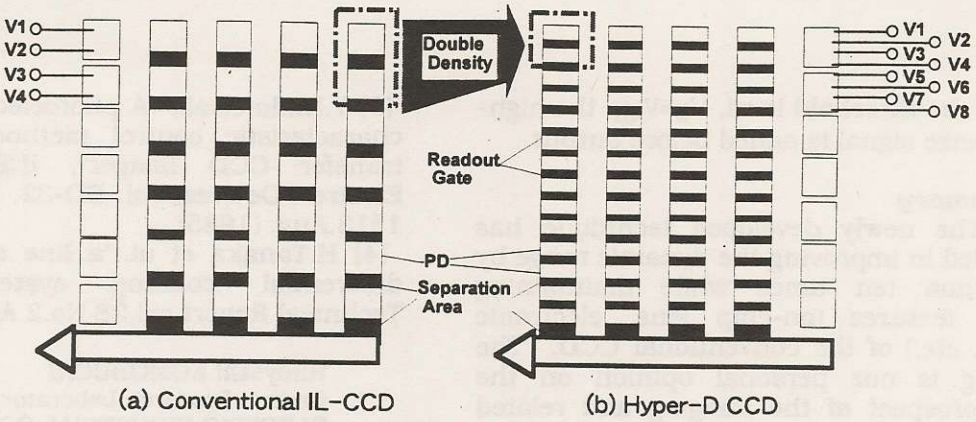

Fig.1 Illustration of Hyper-D Range CCD

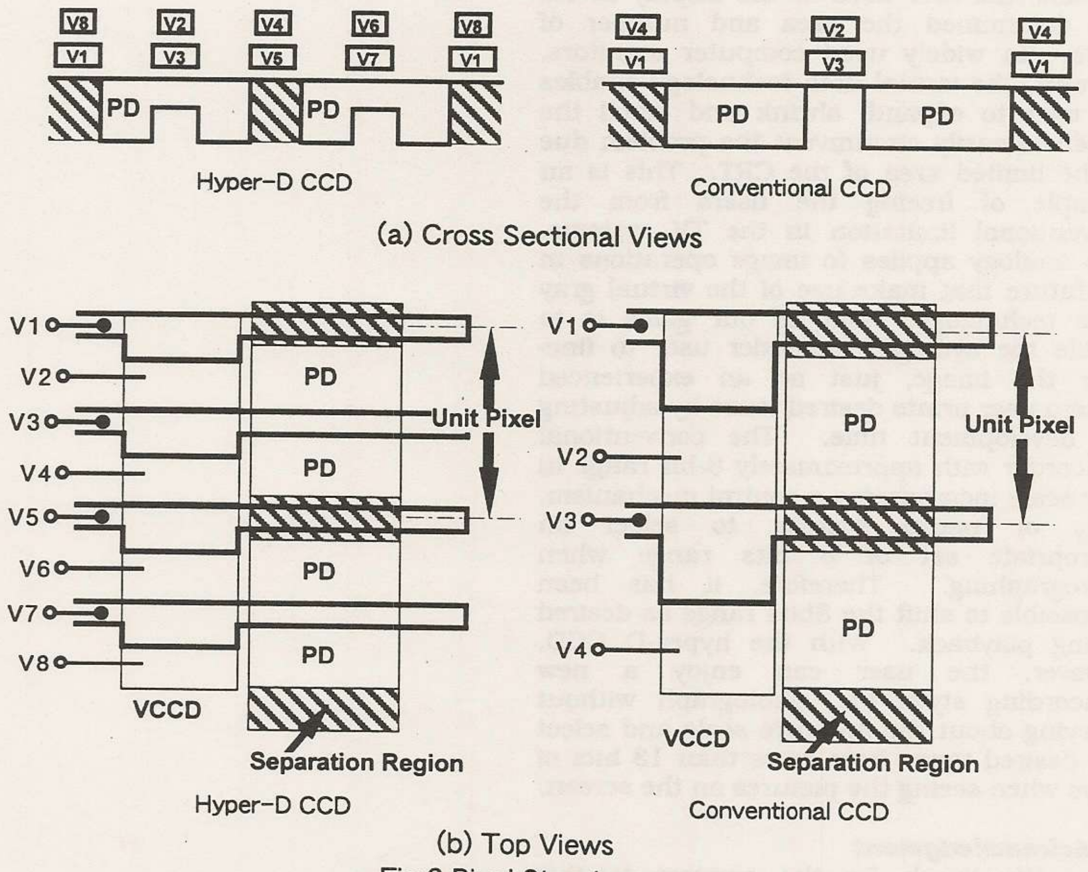

Fig.2 Pixel Structures

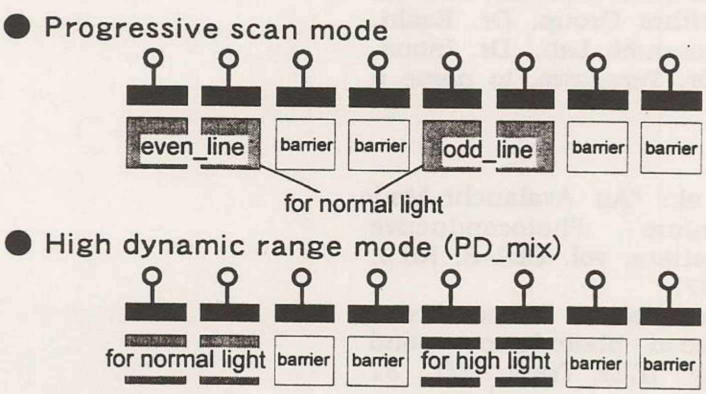

Fig.3 Driving Mode

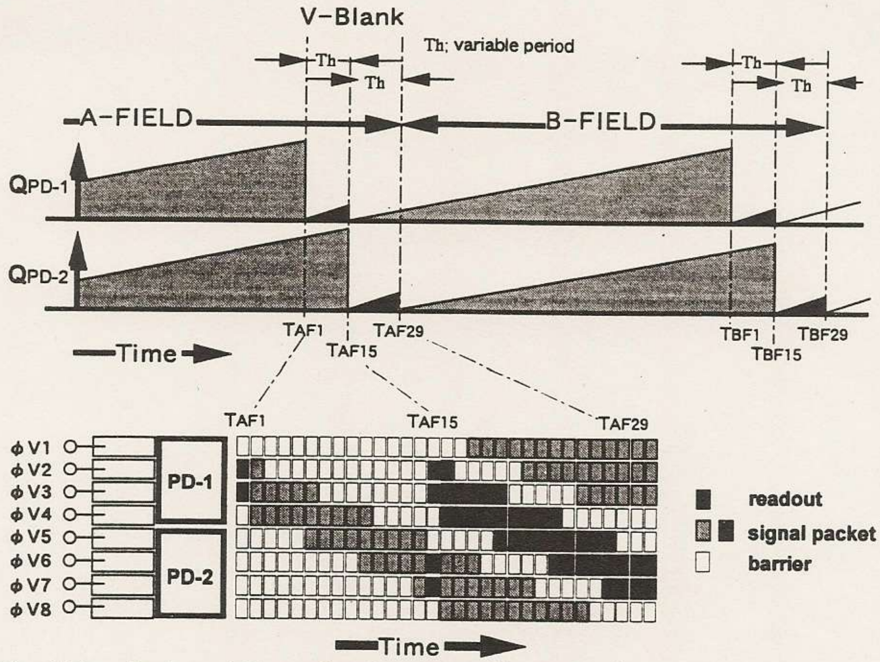

Fig.4 Readout and Transfer Sequence (High Dynamic Range Mode)

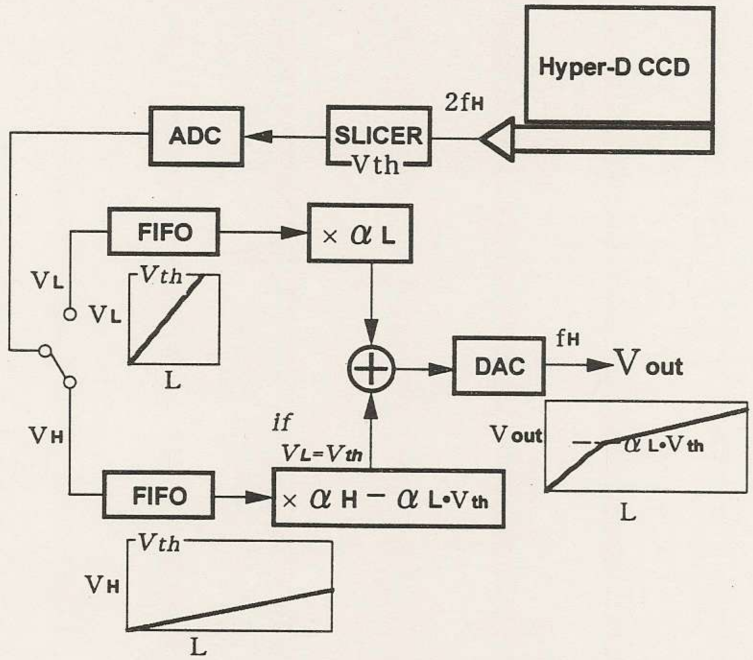

Fig.5 Block Diagram of Image Production

reaches the threshold level, $V_L=V_{th}$, the high-illuminance signal is added before output.

4. Summary

The newly developed technique has succeeded in improving the dynamic range by more than ten times while maintaining various features (on-chip lens, electronic shutter, etc.) of the conventional CCD. The following is our personal opinion on the future prospect of the imaging and related technologies which could be made possible by this new type of CCD.

In the conventional application to TV systems, the CRT used as the display device has determined the area and number of grays. In widely used computer monitors, however, the virtual area technology enables the user to expand, shrink and scroll the screen to easily circumvent the problem due to the limited area of the CRT. This is an example of freeing the users from the conventional limitation in the TV systems. This analogy applies to image operations in the future that make use of the virtual gray scale technology. One of our goals is to enable the average camcorder user to fine-tune the image, just as an experienced camera user prints desired tones by adjusting the development time. The conventional camcorder with approximately 8-bit range in gray scale incorporates a control mechanism, fuzzy or neuro system, to select an appropriate set of 8 bits range when photographing. Therefore, it has been impossible to shift the 8bits range as desired during playback. With the hyper-D CCD, however, the user can enjoy a new camcording style, i.e., photograph without worrying about the aperture scale and select any desired tones from more than 13 bits of grays when seeing the pictures on the screen.

5. Acknowledgment

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References

[1] K.Tanioka et al.: "An Avalanche-Mode Amorphous Selenium Photoconductive Target", IEEE ED letters, vol. EDL-8, No.9, pp.392-394 (sep.1987).

[2] S.G.Chamberlain, et. al. 'A novel wide dynamic range silicon photodetector and linear imaging array', IEEE Trans. ED., 31 pp.175-182 (1984).

[3] Y.Endo et al.: "A photoelectric conversion characteristic control method for interline transfer CCD imager", IEEE Trans. in Electron Devices, vol. ED-32, No.8, pp.1511-1513,Aug. (1985).

[4] H.Tanaka et al.:"a line sequential color differential coloring system", National Technical Report vol.28 No.2 Apr.(1982).

Hiroyoshi KOMOBUCHI
Central Research Laboratory MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.
e-mail kom@crl.mei.co.jp