A 2V Driving Voltage 1/3-inch 410k-pixel Hyper-D Range CCD

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Abstract

A 1/3-inch 410k-pixel hyper dynamic range CCD image sensor has been developed. Each pixel has twice the number of vertical CCD gates compared with that of a conventional interlaced-scan IT-CCD for the purpose of transferring both the normal signal and highlight signal simultaneously. By using these two types of signals, a 64-times wider dynamic range is achieved compared with a conventional CCD. The horizontal CCD which adopts a parallelogram gate structure can be driven by a 2V clock even at 28.8 MHz and can also reduce the power consumption.

1. Introduction

In recent years, CCDs have become widely used, not only in camcorders, but also in a wide range of applications such as security cameras and surveillance cameras. Due to the types of environment in which these cameras are used, there are often situations in which extreme differences in object contrast occur. This increases the demand for imaging devices of a wider dynamic range. The hyper dynamic range CCD (Hyper-D CCD) has been developed in response to these demands.[1]

We have developed a 2V driving voltage 1/3-inch 410-pixel hyper-D CCD. This Hyper-D CCD expands the dynamic range 64 times by simultaneously synthesizing the conventional normal signal stored in a standard field integration time and the highlight signal accumulated during the short integration in vertical blanking period.

The features of the device are as follows:

(1) Transfer capacity twice that of conventional vertical CCDs because both of the normal signal and highlight signal must be transferred at the same time.
(2) Low power consumption due to the 2V driving voltage of the horizontal CCD even at 28.8 MHz clock.

This report describes an overview of the device structure, design optimization of the vertical CCD (V-CCD) and horizontal CCD (H-CCD), and the characteristics of the device.

2. Device Structure

Fig. 1 shows the schematic of the device. The pixel size of this device is 6.4μm (H) x 7.5μm (V), and the effective number of pixels is 771 (H) x 492 (V).

In order to accomplish the Hyper-D operation, the vertical CCD has four phase electrodes for each pixel, which is twice the conventional two phase electrodes. This is due to the fact that it transfers two different signals, namely the normal signal and the highlight signal. As the different read-out pulses (V1 and V1') are applied to the even and the odd rows, the V-CCD of the Hyper-D CCD is driven by totally five clocks. The horizontal CCD transfers both of the normal signal and the highlight signal within 1/60 sec. Hence, it must be driven at 28.8 MHz, which is twice the rate of conventional 410k-pixel interlaced-scan type CCDs.

3. V-CCD Operation

Fig. 2 is a diagram showing the principle of the Hyper-D operation. This Hyper-D CCD achieves a wide dynamic range in exposure by synthesizing two types of signals, which are the normal signal and the highlight signal read out during the vertical blanking period. The dynamic range of conventional interlaced-scan CCDs is approximately four times of the normal signal under standard exposure, and the highlight signal extracted during the vertical blanking period does not saturate even with up to 64 times brighter. Under low exposure condition, to prevent the S/N ratio from degrading when using the highlight signal, signal during the normal integration time with a high output voltage is used. For high-illuminance objects, the dynamic range is stressed so the highlight signal is used.

As a result, a wide dynamic range can be achieved without deterioration of the normal signal S/N ratio when the Hyper-D CCD generates a one-field image, because the normal signal and highlight signal can be combined in accordance with the illuminance of objects.

3-1. Expanded Charge Handling Capacity of the V-CCD

Fig. 3 shows the pixel structures of the conventional interlaced-scan CCD and the Hyper-D CCD. With the conventional structure, the normal signal charge is accumulated at 2 of 4 gates which is 50% of the total V-CCD area. However, with the Hyper-D CCD structure, the normal signal and highlight signal must be accumulated at 2 of 8 gates, a ratio of 25%, so the charge storage area is one-half that of the conventional structure. Thus, it is necessary to double the signal charge handling capacity in the Hyper-D CCD to maintain the same dynamic range as the conventional interlaced-scan CCD.

Fig. 4 shows the cross-section of the structure of a pixel. The main points determining V-CCD capacity are:

(1) Gate oxide film thickness
(2) V-CCD channel depth
(3) Effective V-CCD surface area.

With this device, the following three points were involved in solving these problems:

(1) Making the gate oxide film thinner
(2) Forming shallow V-CCD channel
(3) Low-temperature process.

Thinner gate oxide film and shallower V-CCD channel make the effective voltage applied to the V-CCD higher and the charge handling capacity is increased. As low-temperature process suppresses diffusion of the p-type wall separating the photodiode and V-CCD and the area of separation is decreased. This effectively increases the capacity of the photodiode and V-CCD. Fig. 5 shows the results of the improvement in V-CCD capacity.

(1) An improvement of 25% due to the effect of the gate oxide film.
(2) An improvement of 30% due to the shallower V-CCDs.
(3) An improvement of 45% due to the lower temperature process.

As a result, the same charge handling capacity has been obtained as the conventional interlaced-scan CCD and the density of the V-CCD has been doubled over that of the conventional type.

3-2. Typical Applications of the Hyper-D CCD Structure

Besides Hyper-D operation, the Hyper-D CCD structure also provides a smearless operation that eliminates smear, and a progressive-scan operation that improves vertical resolution. Fig. 6 shows these operations.

In the Hyper-D mode, the normal signal and the highlight signal are read independently. Thus, by handling two types of signals, this structure realizes other operations such as a smearless mode and a progress mode, etc. In the smearless mode, a normal signal including smear and an independent smear signal are read out. Images free from smear are obtained by subtracting the smear signal from the normal signal including smear. In the progressive-scan mode, vertical resolution is improved by transferring pixel signals individually without mixing them. As described above, the Hyper-D CCD can be used not only in the Hyper-D mode, but also can realize various types of read-out operations that offer a wide range of applications.

4. H-CCD Low-voltage Drive

Fig. 7 shows the H-CCD structure. Since the Hyper-D CCD transfers both the normal signal and the highlight signal within 1/60 sec. A high-speed drive of 28.8 MHz, twice that of conventional interlaced-scan CCDs, is required. In this device, the effective gate length was shortened by using a parallelogram-shaped H-CCD structure and the H-CCD driving voltage can be lowered for lower power consumption. The effective gate length is $L \times \cos\theta$ and can be shortened by increasing the angle θ.

Fig. 8 shows the cross-section of the H-CCD. When the gate length of an H-CCD is long, it is difficult for a fringing field to appear in the center of the transfer gate and a residual charge will remain. To avoid this, it is necessary to increase the H-CCD driving voltage which results in higher power consumption.

A parallelogram-shaped H-CCD structure is used to shorten the effective H-CCD gate length and increase the fringing field below the transfer gate. This makes it possible to lower the clock voltage and subsequently lowers power consumption.

Fig. 9 shows a simulated result of the fringing field below the H-CCD gate. The fringing field below the H-CCD gate increases rapidly as the gate length is decreased. When the H-CCD gate angle is 50 degrees where the effective gate length is 4.0μm at 2V clock voltage, the field is about the same as that at 5V with the conventional gate structure (gate length 6.4μm). Thus, a 2V driving voltage can be achieved with an H-CCD by using the parallelogram-shaped structure of 50 degree that makes an effective gate length approximately 60% of the conventional gate length, which in turn lowers power consumption drastically.

5. Device Characteristics

Table 1 summarizes the characteristics of this device. Saturation output voltage is 1300mV, the exposure dynamic range in Hyper-D operation is 64 times greater than standard condition, smear is -100dB, and the H-CCD driving clock voltage is 2V.

Fig. 10 shows examples of reproduced image captured by this device. Fig.10-1,-2 and -3 show the images displayed on a monitor of normal-illuminance object, high-illuminance object in the interlaced-scan operation and a reproduced image in the Hyper-D operation, respectively.

In the Hyper-D operation saturation-free images of high illuminance objects can be obtained that are not possible with conventional interlaced-scan operation. In Fig.10-1, the lens aperture was adjusted for indoor illuminance so highlight objects outside are saturated and the outdoor scenery cannot be seen clearly. In Fig.10-2, the lens aperture was set for outdoor scenery, so the indoor portion appears too dark and cannot be clearly seen. With the Hyper-D CCD, as shown in Fig.10-3, the highlight signal is used for the outdoor object and the normal signal is used for the indoor object, resulting in offering a wider dynamic range of image.

6. Conclusion

A 1/3-inch 410k-pixel hyper dynamic range CCD has been developed. This device has twice the transfer capacity of the conventional vertical CCD and a 64 times wider dynamic range can be obtained by externally synthesizing of the normal signal and highlight signal. Also, a parallelogram-shaped gate structure enables a 2V driving that results in lower power consumption, even at the high frequency of 28.8 MHz.

7. Acknowledgment

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8. References

[1] H. Komobuchi et al. : "1/4 Inch NTSC Format Hyper-D Range IL-CCD", 1995 IEEE Workshop on Charge-Coupled Devices and Advanced Image Sensors.

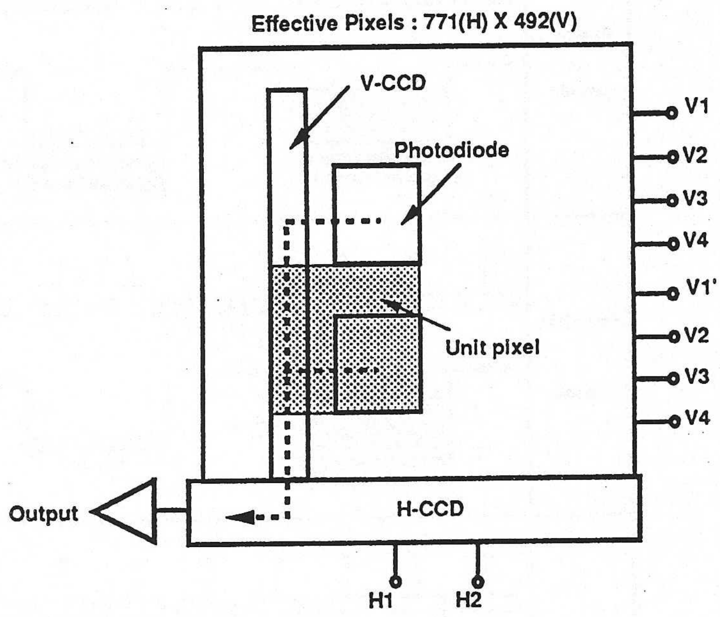


Figure 1 Schematic diagram of the device

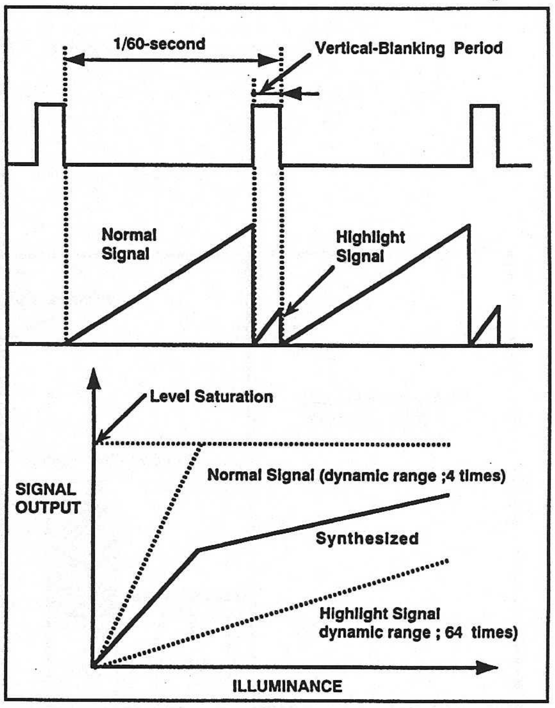


Figure 2 Principle of Hyper-D Operation

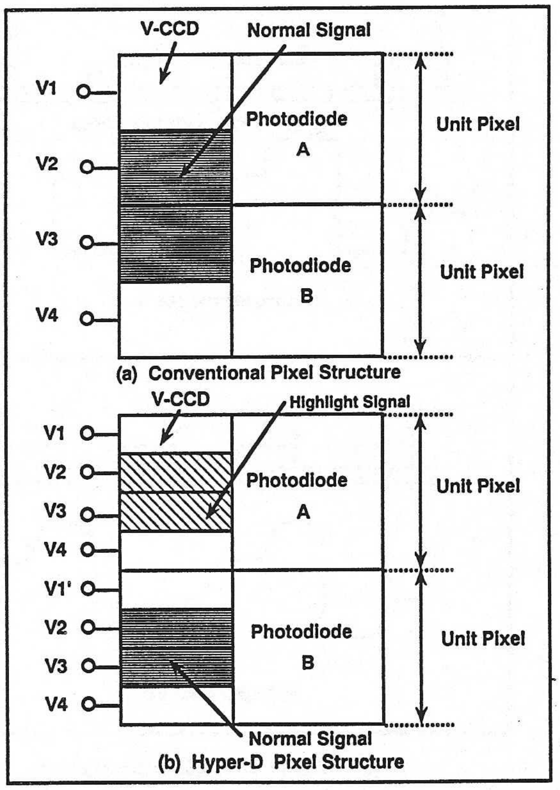


Figure 3 Unit Pixel

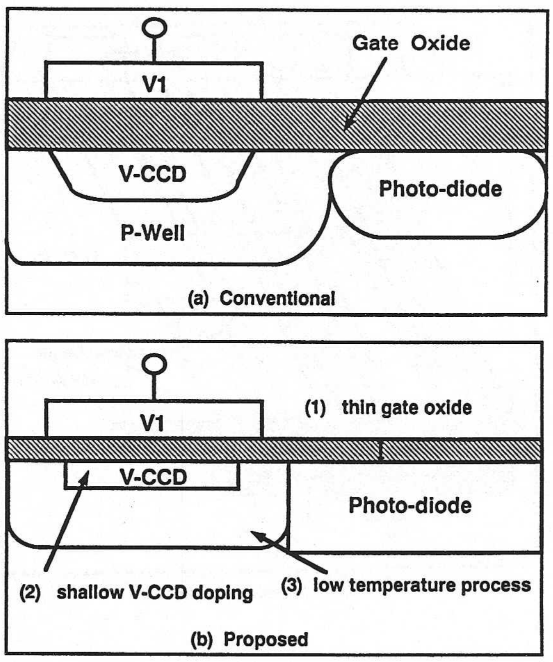


Figure 4 The Cross Section of Unit Pixel

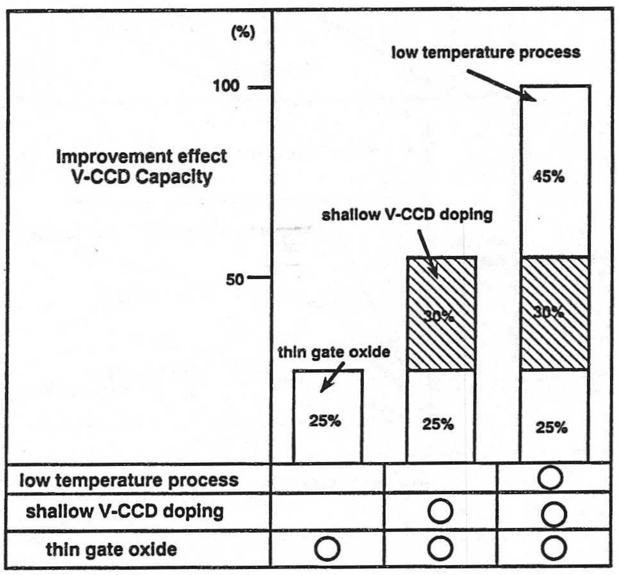


Figure 5 Improvement of V-CCD Capacity

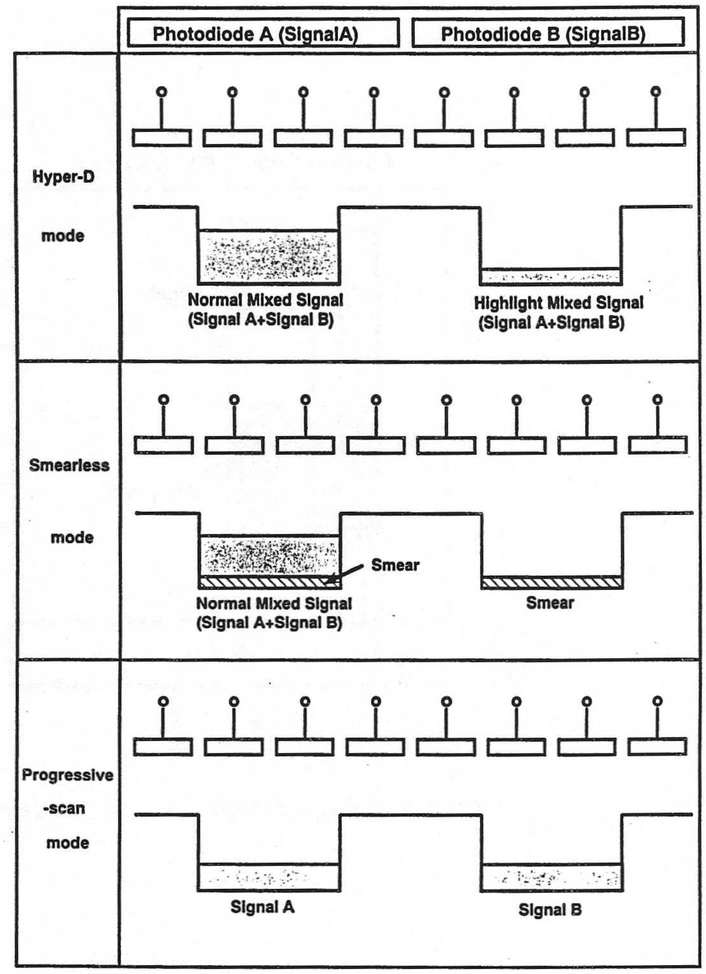


Figure 6 Possibility of other operations using Hyper-D CCD

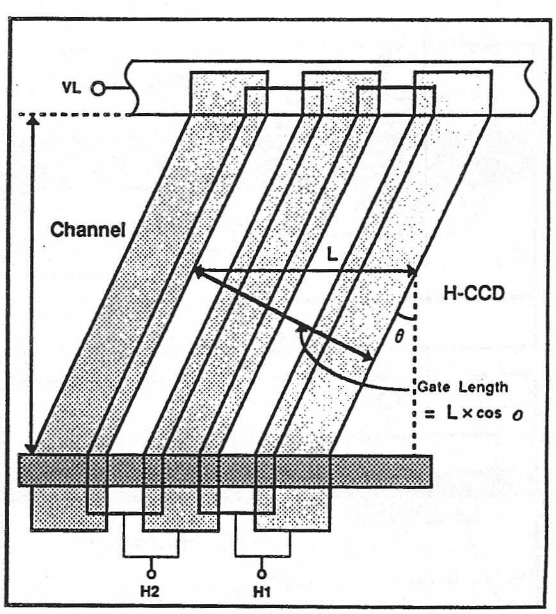


Figure 7 Parallelogram-shaped Gate H-CCD

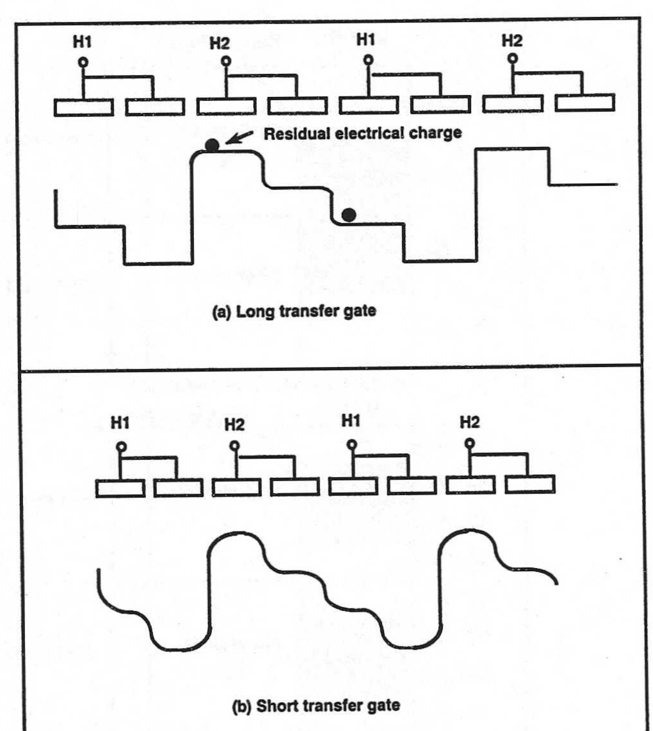


Figure 8 H-CCD cross section

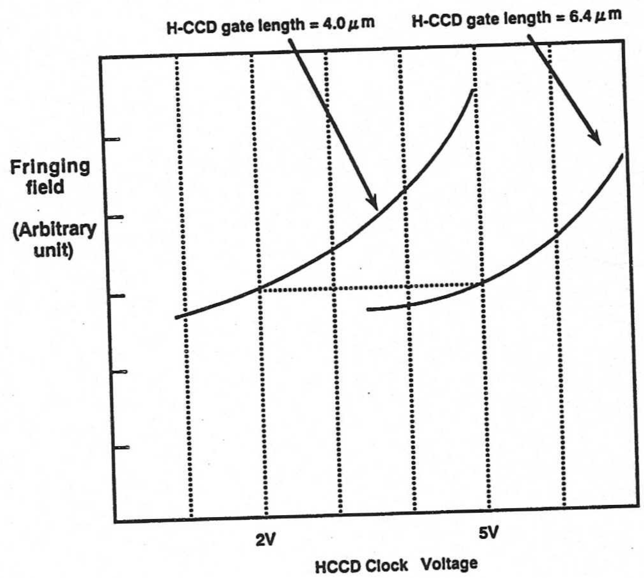
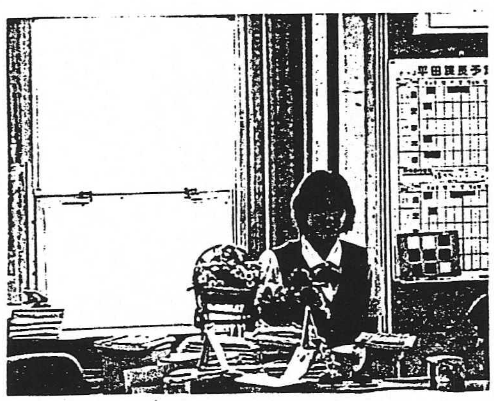


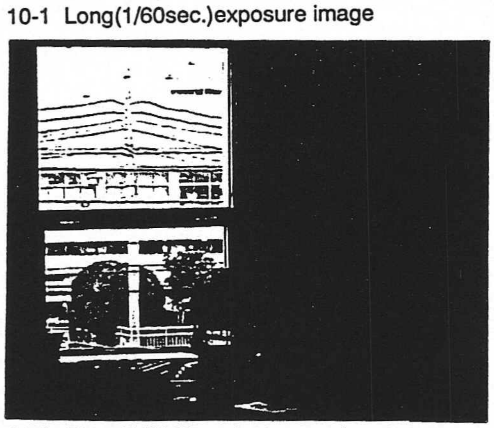
Figure 9 Simulated Result of H-CCD Potential

Table 1 Characteristics of the device

Optical Format	1/3 inch
Effective Pixels	771 (H) × 492 (V)
Pixel Size	6.4 (H)μm × 7.5 (V)μm
Dynamic Range	64 times
Saturation Voltage	1300mV
Smear	-100dB
H-CCD Clock Voltage	2V



10-1 Long(1/60sec.)exposure image



10-2 Short(1/2000sec.)exposure image

Composite

10-3 Hyper-D camera image

Figure 10 Typical image taken with a Hyper-D camera