A low noise global shutter CMOS image sensor with multiple sampling

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Abstract In general, the CMOS image sensor is used as a rolling shutter, but in recent years the demand for a CMOS image sensor as a global shutter is increasing in various cases. Many methods have been proposed as noise reduction methods for a global shutter, but most of them are for fixed pattern noise and not for random noise. In this paper, we propose a method to reduce random noise by multiple sampling.

Keywords: noise reduction, multiple sampling, global shutter

1. Introduction

In recent years, CMOS image sensors are widely used as imaging devices. In addition, there is an increasing demand for the global shutter CMOS image sensor when there is a need to accurately capture a high-speed moving subject such as automobile or machine vision. But in the global shutter CMOS image sensor, many transistors and sample/hold capacitors are needed to hold the reset level and signal level voltages [1]. Therefore, in the global shutter pixel circuit, there is a problem that the noise in the transistor is increased. So far, several methods have been proposed to suppress this increase in the noise, but further reduction in noise is required.

In this research, we focused on the source follower transistor near the photodiode, in order to reduce the noise of the global shutter CMOS image sensor. In general, the source follower transistor is driven by a constant current source. But there is a report that low noise can be realized by driving this transistor with a charging current of the parasitic capacitor [2]. Also, multiple sampling has been proposed [3] as a method for reducing random noise occurring in pixel circuits and peripheral circuits. Therefore, in this paper, we propose a low noise global shutter CMOS image sensor applying these low noise technologies. Also, we fabricated a prototype of the proposed global shutter CMOS image sensor, so we report the outline.

2. Proposed global shutter pixel circuit

Figure 1 shows the pixel circuit we designed. This pixel circuit is based on a general pixel composed of three transistors and a photodiode PD. The three transistors are a transfer gate M1, a reset transistor M2, and a source follower transistor M3. In addition, this time we have a constant current source transistor M4 in the pixel circuit that drives M3 for comparative verification. By setting M4 to the OFF state, it is possible to drive M3 with the charging current of the capacitor. In order to obtain a global shutter pixel circuit, there are two sample/hold capacitors to hold a reset level and a signal level and two transistors M5 and M6 to control charging the capacitors in this circuit. Furthermore, source follower transistors M7, M9, and select transistors M8, M10 to read out the voltage of the capacitors.

In general, most of the noise generated in the pixel circuit is thermal noise. This noise is generated by movement of electrons in the transistor. In the proposed method, M4 is turned off in the pixel circuit. And M3 is driven by using the current charging the sample/hold capacitors. As a result, M3 becomes a minute drain current and operates in the weak inversion region. So that transconductance becomes large and thermal noise is reduced.

3. Proposed differential single-slope ADC

Figure 2 shows a schematic diagram of a differential single-slope ADC. This differential single-slope ADC is composed of a differential comparator, a TDC (Time-to-Digital Convert) latch, an encoder, and two counters. The resolution of this ADC is 12 bits.

Many methods for reducing noise in ADCs have been proposed [4]. However, many of them are methods to reduce fixed pattern noise. And there are only few methods to reduce random noise. In one of them, there is a method of executing multiple A/D conversion on one vertical signal line readout and averaging it [3]. With this multiple sampling, random noise can be reduced to \( \sqrt{M} \) by M times sampling. However, in multiple sampling, there is a problem that it takes more time than usual A/D conversion.
Therefore, we used several D latches and multiple clocks of which the phase is shifted and we execute TDC [5]. These D latches hold the value of the clock at the moment when the output of the comparator changes. Then, These D latches can express further lower bits from the output of the ADC. In this case, 16 D latches and 16 clocks with phase shifted by $\pi/8$ are used to represent 4 bits. So, A/D conversion time is shortened to about 1/16 of without TDC. As a result, the A/D conversion speed is improved. Also, we designed the single-slope ADC capable of multiple sampling and the TDC in the global shutter.

4. Outline of image sensor chip and acquired images

Figure 3 shows the layout of the image sensor which we designed. Table 1 shows characteristics of the image sensor. The chip size is $4.8 \times 4.8$ mm, and the number of effective pixels is $320 \times 240$ (V). Furthermore, the pixel pitch is $11.2 \times 11.2$ (V), and the aperture ratio is 17.10%. Also, the maximum frame rate is 208.20 fps in the case of four times sampling.

Next, Figure 4 shows the chaptered sampling images from this image sensor. At this time, Fig. 4 (a) shows an image obtained when the source follower transistor in the pixel circuit is driven by a constant current. Further, Fig. 4 (b) shows an image obtained when the source follower transistor in the pixel circuit is driven by charging current. Comparing Fig. 4 (a) with Fig. 4 (b), it can be seen that the noise on the left side of the image which is noticeable in Fig. 4 (a) is reduced in Fig. 4 (b).

5. Conclusion

In this paper, we proposed a low noise global shutter CMOS image sensor. In the global shutter pixel circuit, a source follower transistor was driven by using the charging current of a sample/hold capacitor. And we used a differential single slope ADC which can be multiple sampling. In addition, with regard to the A/D conversion speed, we used the TDC latches. As a result, the sensor achieves 208.20fps with multiple sampling.

However, if the image sensor which we design converts the number of pixels to 4 K resolution, it remains at 5 fps. Therefore, we plan to further increase the speed while maintaining low noise in the future. Also, we have not finished verification of the sensor yet perfectly. So, we will continue to verify it.

References


