Reduction of Random Telegraph Signal (RTS) Noise in CMOS Image Sensors Using Histogram Analysis

Mohd Amrallah bin Mustafa, Sinya Itoh, Shoji Kawahito

Abstract:

The paper presents column parallel signal processing techniques for reducing Random Telegraph Signal (RTS) noise of in-pixel source follower by using histogram analysis for the development of a very low-noise CMOS image sensor. In this method, a histogram with multiple samples for reset level is used to estimate the amplitude of the RTS noise. With the median of the histogram and the estimated amplitude, the RTS noise components are removed and the average is calculated with the histogram due to thermal noise only, to further reduce the noise level. Result of the application of the histogram-based noise suppres-sion to an implemented CMOS image sensor prototype for a large sampling numbers is demonstrated.

Keywords: *histogram analyses, random telegraph signal (RTS) noise, CMOS image sensor, low-noise, estimated amplitude.*

1. Introduction

Noise performance in CMOS image sensors is one of the most important factors. Recently, reduction of Random Telegraph Signal (RTS) noise due to transistors of in-pixel source follower amplifier becomes an important issue [1]. RTS noise is described as a fluctuation in the current or voltage with random discrete impulses of equal heights and it is observed as two or multi-level impulses. This noise occurs in the inherent noise of electronic devices as a non-Gaussian component [2].

Available methods for RTS noise reduction, such as Correlated Double Sampling (CDS) and Correlated Multiple Sampling Differential, and Averaging (CMSDA) have been introduced and the effectiveness in noise reduction has been proven [3], [4]. In this paper, the research focuses on histogram-based RTS-noise suppression and averaging (HRNSA) method, as well on its effectiveness in reducing the source follower RTS noise.

2. Histogram Based RTS-noise Suppression and Averaging.

Figure 1 shows the timing diagram of the multiple sampling for both reset and signal levels, which is the basic idea for noise reduction. The timing diagram was obtained from the CMOS image sensor with column-parallel mixed-signal processing circuits.

In Figure 1, M represents the total number of sampling in reset and signal for one pixel that is selected during the measurement. The paper focuses only in reset level for RTS noise reduction. The 256 samples in the reset level are chosen and CDS is applied.

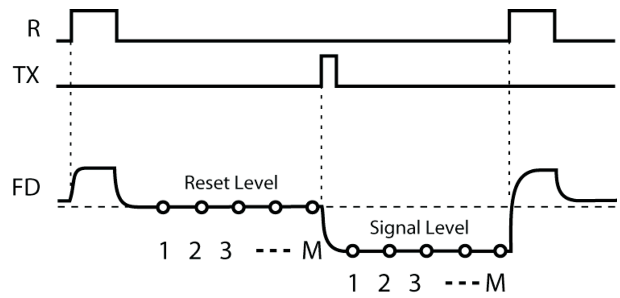

Fig. 1. Timing diagram of the multiple sampling for both reset and signal levels.

Figure 2 shows a histogram of RTS-noise after CDS, and it is seen that three peaks of histogram appear due to large of RTS noise. Both right and left peaks are due to RTS noise and the center peak corresponds to the reset level without the influence of any RTS noise.

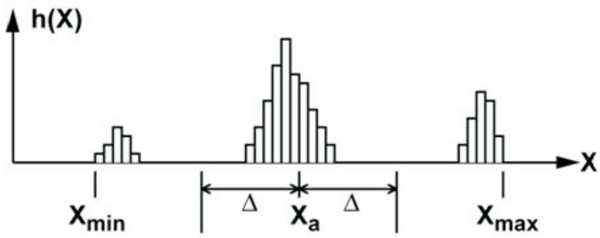

Fig. 2. Histogram of RTS –noise after CDS.

In order to remove this RTS noise, a few requirements should be considered. First, the maximum and minimum value of the histogram are identified, and then an average of both values is calculated as:

$$X_m = \frac{X_{max} - X_{min}}{2} \quad (1)$$

This average value represents the center value of the histogram. Next, the average of histogram in the range of $X_a - \Delta$ and $X_a + \Delta$ is calculated to estimate the reset level, by using the equation below:

$$Y = \sum_{X_m = X_m - \Delta}^{X_m + \Delta} h(X)X \Big/ \sum_{X_m = X_m - \Delta}^{X_m + \Delta} h(X) \quad (2)$$

Finally, the range of parameter Δ should be selected. The value can be 3 times of it r.m.s thermal noise amplitude.

3. Results and Discussions

The HRNSA method is implemented to 0.18 µm pinned-photodiode CMOS image sensor with a gain of 22 under dark condition as shown in Figure 3.

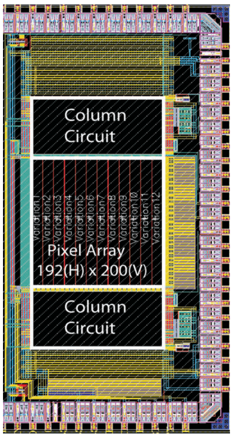

Fig. 3. Implemented prototype chip.

Figure 4 shows slow relaxation-time RTS noise of pixel source follower for a reset level. This type of noise waveform is used in proving the effectiveness of HRNSA method.

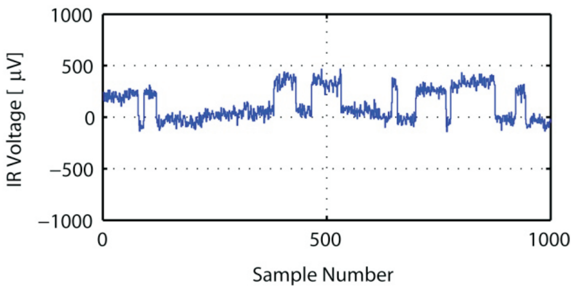

Fig. 4. Slow relaxation-time RTS noise.

Figure 5 shows the distribution of CDS output for 128 samples and its histogram. The histogram limitation is also shown once the parameter Δ is selected, which is in this case it is equal to 10.

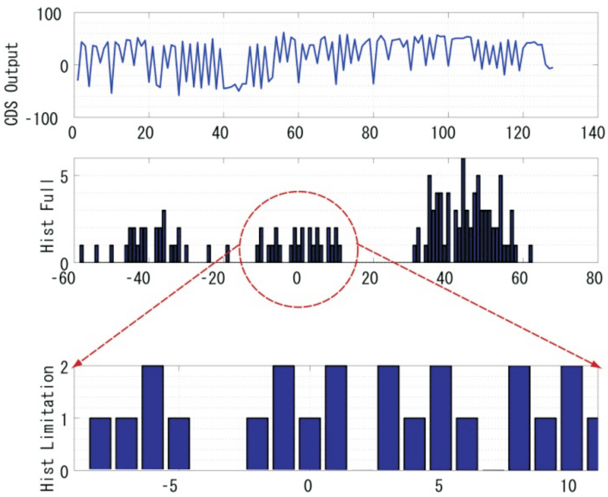

Fig. 5. Histogram of 128 samples.

Figure 6 shows the relation between the input reference noise and the sampling number. From this figure, the output of HRNSA is started from sampling number equals to 16 up to 128, because the histogram with three peaks only appears during this range of sampling numbers. The value of input referred noise is decreased when the sampling number is increased. In the experiment, the value of input referred noise is not available for sampling number 1, 2, 4 and 8. This is because those three peaks in the histogram do not appear at this range of sampling numbers. It shows that the final value of input referred noise is reduced to 85.4 μV for 128 sampling numbers.

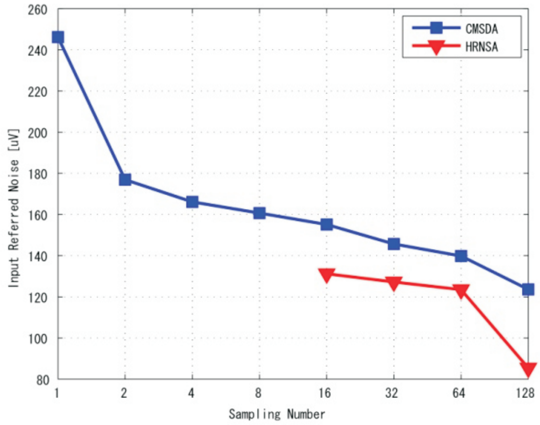

Fig. 6. Effect of the pre-amplified HRNSA for reducing RTS noise.

4. Conclusion

The reduction of RTS noise in CMOS image sensors by using histogram analysis has been shown in this paper. It proves that this method is effective in reduction of RTS noise for slow relaxation time RTS noise waveform. The RTS noise suppression is effective when the sampling number is increased.

ACKNOWLEDGMENTS

The present work was partially supported by the Knowledge Cluster Initiative of the Ministry of Education, Culture, Sports, Science and Technology, Japan.

AUTHORS

Mohd Amrallah bin Mustafa* - Graduate School of Science and Technology, Shizuoka University, Japan. E-mail: amrallah@idl.rie.shizuoka.ac.jp.

Sinya Itoh and Shoji Kawahito - Research Institute of Electronics, Shizuoka University 3-5-1, Johoku, Hamamatsu, 432-8011, Japan.

* Corresponding author

References

[1] Kawahito S., Kawai N., "Column parallel signal processing techniques for reducing thermal and random telegraph noise in CMOS image sensor", *Int. Image Sensors Workshop*, Maine, June 2007.

[2] Konczakowska A., Cichosz J., Szewczyk A., "A new method for identification of RTS noise", *Bulletin of the Polish Academy of Science, Technical Science*, vol. 54, no. 4, 2006.

[3] Kawai N., Kawahito S., "Effectiveness of a correlated multiple sampling differential average for reducing 1/f noise", *IEICE Electronics Express*, vol.2, no. 13, Jul. 2005, pp. 379-383.

[4] Kawai N., Kawahito S., "Measurement of low-noise column readout circuits for CMOS image sensors", *IEEE Trans. Electron Devices*, vol. 53, no. 7, Jul. 2006, pp. 1737-1739.