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Noise Analysis of a Serial Multiple Sampling in Back-Illuminated CMOS Image Sensor

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1. Abstract

We have developed a 1/2.3-inch 10.3Mpixel back-illuminated CMOS image sensor (BI-CIS) with a serial multiple sampling. This sensor has achieved the RMS random noise of 1.3e-. The Row Temporal Noise (RTN) is analyzed by considering the transfer function in the system level and the developed model is verified by the experimental result under each sampling time.

2. Introduction

The demand for low-noise (for capturing a clear image in low-light conditions) CMOS image sensors is still increasing. The correlated multiple sampling is well-known as a noise reduction technique [1]. Some papers present the noise reduction characteristics but they have not mentioned the influence of row temporal noise [2]. This paper presents a BI-CIS with a serial multiple sampling which is realized in the column ADC block without any processing digital block and analyzes the RTN behavior.

3. Block diagram

This sensor consists of a pixel array, the column parallel single-slope ADCs and the LVDS interface. Four pixels share a floating diffusion and one vertical signal lines are assigned to each pixel column. This sensor includes a 12b analog-to-digital converter and a 12b serial LVDS interface to enable a data-rate up to 576MHz.The column counter has a 14bit ripple counter to realize the average processing by a serial multiple sampling.

4. Measurements

The measured noise characteristic of the serial multiple sampling is shown in Fig. 1. The sensor achieves 1.3e-rms random noise at 24dB. The serial multiple sampling can reduce not only a circuit noise but also a pixel noise. The circuit noise improvement ratio is better than the pixel noise one because the dominant circuit noise source is not frequency dependent noise but a thermal noise.

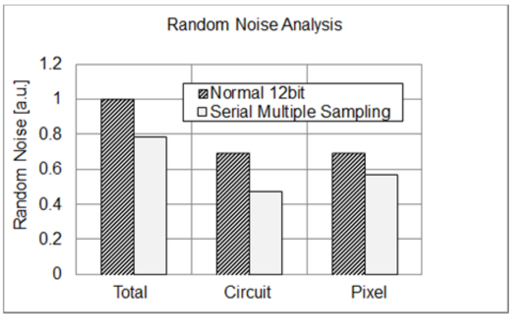

Fig.1 Random noise component

5. Row temporal noise analysis

The RTN comes from the simultaneity of the AD conversion. The reference voltage circuit (DAC) and pixel circuit become the noise factors. Total noise ($\overline{V_n^2}$) is respectively given by eq. (1) (2).

$$\overline{V_n^2} = \overline{V_{nPIX}^2} + \overline{V_{nDAC}^2} \qquad (1)$$

$$\overline{V_n^2} = \int_0^{\infty} \{Sn1(f)|H_{PIX}|^2 + Sn2(f)|H_{DAC}|^2\}\, df \qquad (2)$$

Sn1 and Sn2 are noise power spectral density of pixel noise component and DAC's. H_{PIX} and H_{DAC} are total system transfer function of pixel supply and DAC, respectively [3]. As for pixel power supply the decoupling capacitor (C_{PIX}) operates as a low pass filter and the noise is reduced by an amplifier transistor output resistance. Therefore H_{PIX} can be expressed as eq. (3).

$$H_{PIX}(\omega) = \frac{G_{SF}}{1+\left(\frac{\omega}{\omega c}\right)^2} * H_{CMP}(e^{-j\omega t}) * H_{CDS}(e^{-j\omega t}) \qquad (3)$$

Here, H_{CMP} is a comparator's transfer function and H_{CDS} is a correlated double sampling transfer function. G_{SF} is the transfer gain by an amplifier transistor. On the other hand, H_{DAC} is described as below for eq. (4).

$$H_{DAC}(\omega) = H_{CMP}(e^{-j\omega t}) * H_{CDS}(e^{-j\omega t}) \qquad (4)$$

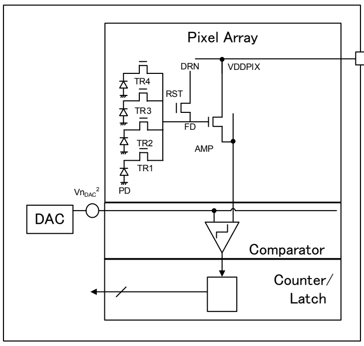

Fig. 2 Block diagram related with RTN

To calculate the transfer function, the normal readout timing (Correlated Double Sampling) and serial multiple timing diagram (Correlated Multiple Sampling) are described in Fig. 3. The difference between P1 and P2, P1 and D1 and D1 and D2 are defined as ΔS, ΔT and ΔD. The CDS transfer function of normal readout is described as below [4].

$$H_{CDS}(e^{-j\omega t}) = \mathrm{e}^{\mathrm{i}\omega(\mathrm{t}+\Delta\mathrm{T})} - \mathrm{e}^{\mathrm{i}\omega\mathrm{t}}$$

$$= \mathrm{e}^{\mathrm{i}\omega\mathrm{t}}\mathrm{e}^{\mathrm{i}\omega\Delta\mathrm{T}} * j * 2\sin(\omega\Delta T/2) \qquad (5)$$

In addition to that, the serial correlated multiple sampling is calculated by using the same methodology.

$$H_{CMS}(e^{-j\omega t})$$

$$= \mathrm{e}^{\mathrm{i}\omega(\mathrm{t}+\Delta\mathrm{T}+\Delta\mathrm{D})} + \mathrm{e}^{\mathrm{i}\omega(\mathrm{t}+\Delta\mathrm{T})} - \mathrm{e}^{\mathrm{i}\omega(\mathrm{t}+\Delta\mathrm{S})} - \mathrm{e}^{\mathrm{i}\omega\mathrm{t}} \qquad (6)$$

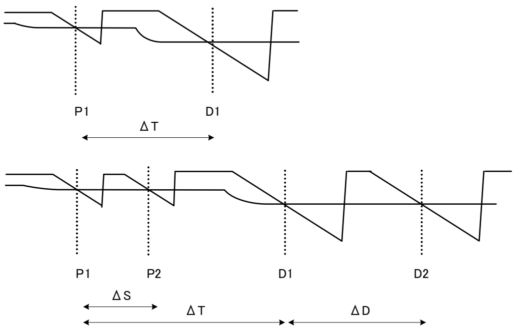

Fig.3 Serial multiple sampling timing

As show in Fig. 4, the sampling interval dependency and comparison of change rate between measurement value and calculation one has a good correlation. From this estimated value the analysis and validity of serial multiple sampling are confirmed. This result indicates the importance of shortening the sampling interval[5].

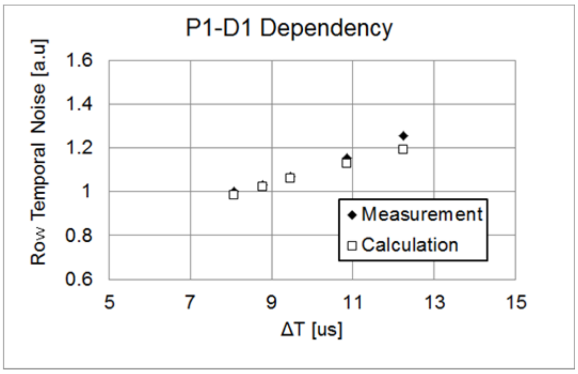

Fig.4 RTN of ΔT dependency

6. Conclusion

In conclusion, this paper presents a BI-CIS which achieves the RMS random noise of 1.3erms- with serial multiple sampling. Moreover, the RTN analysis considered transfer function can be verified by the correlation result of sampling interval.

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