Linear-Logarithmic Two-Transistor Active Pixel Sensor with Variable Dynamic Range

Sung-Hyun Jo, Myunghan Bae, Byoung-Soo Choi, Pyung Choi, Jang-Kyoo Shin

School of Electronics Engineering, Kyungpook National University, Korea
jkshin@ee.knu.ac.kr

ABSTRACT

In this paper, we present a linear-logarithmic two-transistor active pixel sensor (APS) with variable dynamic range. The proposed APS is composed of two-transistor with a shared reset transistor for shrink pixel size and wide dynamic range (WDR) characteristics. The select transistor can be eliminated by changing the pulse signal through the drain node of the source follower. The proposed APS uses a gate/body tied metal oxide field-effect transistor type photodetector (GBT-PD) for high sensitivity. Also, we applied the negative feedback structure, which offers significant advantages and allows obtaining WDR without complex circuitry. The sensitivity of the proposed APS is 8.23 V/lux•s in the linear region and 0.32 mV/lux•s in the logarithmic region, while its combined dynamic range reaches 112.1 dB. The sensor was fabricated by using the 0.18 μm 1-poly 6-metal CMOS process and its performance was evaluated.

Keywords: CMOS image sensor, wide dynamic range, MOSFET type photodetector

1 INTRODUCTION

Image sensor technology has progressed from advanced semiconductor technology. The complementary metal–oxide–semiconductor (CMOS) process offers the capability of integrating smart functions on imagers in a single chip [1-4]. As CMOS technology scales down, the pixel size is reduced for higher resolution sensors; thus, creating high-performance CMOS image sensors has become more difficult. A lower saturation level due to the small supply voltage and a higher noise level due to mismatch of the device cause the dynamic range to become a very significant problem n. The dynamic range of image sensors is defined as the ratio of the saturation signal level to the noise level. Natural scenes have a very wide range of illumination with light intensities varying over the 100 dB range or wider. To capture natural scenes with such a dynamic range, an imager with wide dynamic range (WDR) is required. However, the dynamic range of current commercial cameras without applying a special technique is limited to less than 60 dB. Various approaches have been developed to acquire WDR images [6-10]. Logarithmic sensors may extremely widen their dynamic range in the high-illumination region by compressing the image signal. However, the conventional logarithmic technique that operates in the sub-threshold region suffers from low sensitivity at low light intensity [11-12].

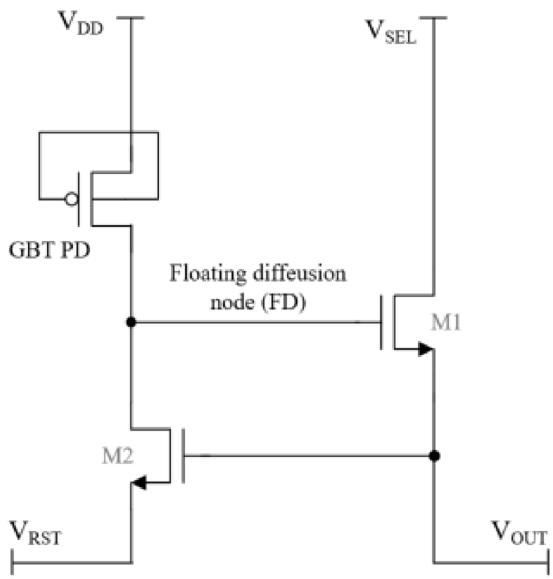
In this work, we developed linear-logarithmic two-transistor active pixel sensor (APS) with variable dynamic range. The proposed APS uses a gate/body tied MOS field-effect transistor type photodetector (GBT-PD) for high sensitivity [13-15]. Also, we applied the negative feedback structure, which offers significant advantages and allows obtaining WDR without complex circuitry [16]. The proposed APS using an output voltage feedback structure that allows a significant extension of the dynamic range while maintaining high sensitivity at low illumination. The negative feedback structure of the proposed APS is provided by a very simple design and WDR function.

2 OPERATIONAL PRINCIPLE

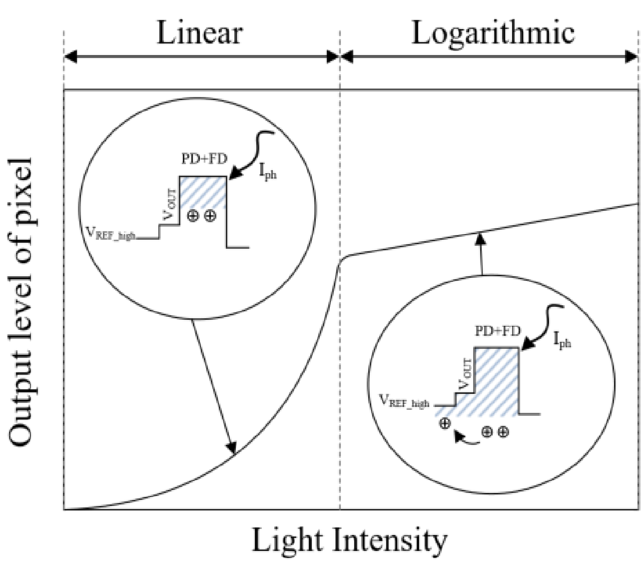
The proposed APS shows a simple and high-performance pixel structure using a standard CMOS process. It only comprises a two-transistor system with a shared reset/feedback transistor for WDR and a source follower transistor. The selection transistor can be eliminated by inducing the pulse signal through the drain voltage of the source follower. Figure 1 shows the schematic and light response characteristics of the proposed

APS. Aptina, a company specialized in CMOS imaging products, explored new pixel structures based on small pixel designs without using the selection transistor method. In our new approach, we combined the no-selection-transistor technique with a shared reset/feedback transistor. The shared reset/feedback transistor structure is advantageous to obtain pixel shrink and extended dynamic range.

Figure 2 shows the timing diagram of the proposed APS and direction of charge flows during each operation period. The proposed APS is similar to a conventional APS. The operation mode of the proposed APS is varied by controlling the turn-on time of the reset (T_{delay}) and high-level voltage of the reset transistor (V_{RST}). The amplifying photocurrent of the GBT-PD flows from V_{DD} to floating diffusion node, and the output voltage of the proposed APS increases, as shown in Fig. 2. As the output node is connected to the M1 gate, the proposed APS requires a negative reset voltage (V_{RST} = −0.6 V) for its reset operation. After the reset period, VRST is set to the fixed value of 0.4 V to extend the dynamic range. The M1 feedback transistor operates in the subthreshold region, and the output voltage of the proposed APS linearly increases until V_{OUT} – V_{RST} = $V_{threshold}$ (M2). After a certain charge accumulation period, M2 is gradually turned on because of the increased output voltage connected to the M1 gate. As the incident light intensity increases, the M1 gate voltage connected to the output voltage further increases. Consequently, the output voltage is not saturated because more electrons are accumulated in the channel.

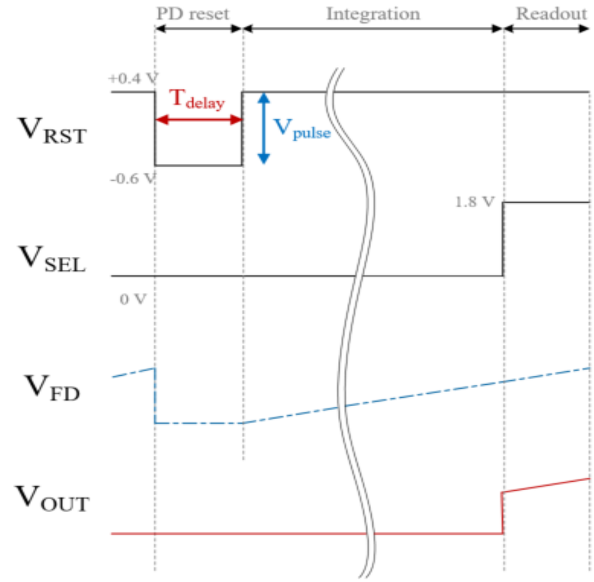


(a)

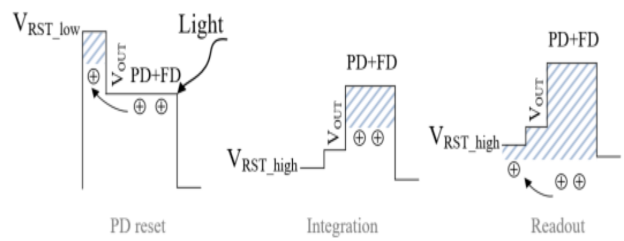


(b)

Fig. 1. (a) Schematic of the proposed APS; (b) light response characteristics of the proposed APS.



(a)

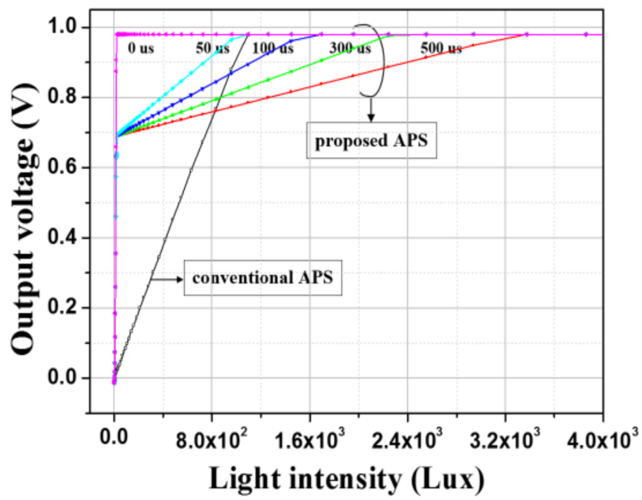


(b)

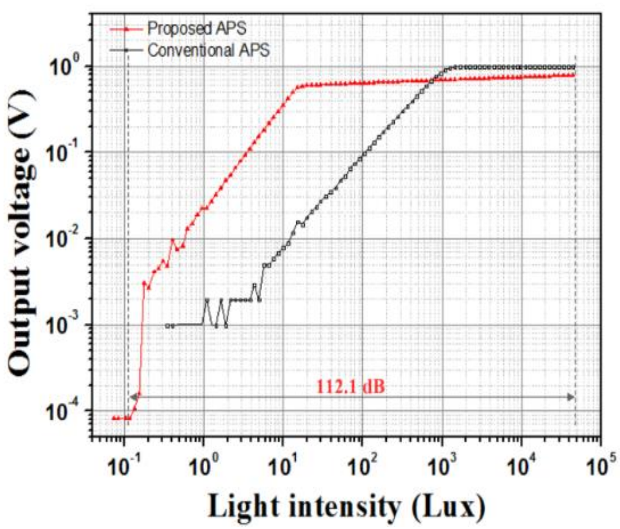
Fig. 2. (a) Timing diagram and (b) conceptual diagram of the proposed APS.

3 RESULTS AND DISCUSSION

Figure 3 shows the variation of the output voltage of the proposed APS as a function of turn-on of the reset and high-level voltage of reset. In Fig. 3a, the proposed APS has variable sensitivity by controlling turn-on time of reset (Tdelay). In low illumination region (under 1 lux), the proposed APS has high-sensitivity because of GBT PD. And, the sensitivity of the proposed APS is changed turn-on time (0 us, 50 us, 100 us, 300 us, 500 us) of the reset. As the Tdelay is longer, the output voltage of the proposed APS is not saturated because draining charge of the floating diffusion node increase. In Fig. 3b, the proposed APS has significant WDR characteristics due to negative feedback structure. The sensitivity of the proposed APS is 8.23 V/lux•s in the linear region and 0.32 mV/lux•s in the logarithmic region, while its combined dynamic range reaches 112.1 dB.



(a)



(b)

Fig. 3. Variation of the output voltage of the proposed APS (a) as a function of turn-on time of the reset (T_{delay}); (b) as a function of high-level voltage of reset (V_{pulse}).

4 CONCLUSIONS

We presented linear-logarithmic two-transistor APS with variable dynamic range. The negative feedback structure of the proposed APS provides WDR with a very simple design. The sensor has a two-transistor APS with a shared reset/feedback transistor for WDR and a source follower transistor. The selection transistor is eliminated by transmitting the pulse signal through the drain voltage of the source follower. The shared reset/feedback transistor provides smaller pixel size and WDR without complex circuitry. The proposed APS has a gate-controlled resistor (M2) for extending the dynamic range of the proposed APS. The feedback current of M2 is gradually increased as the illumination level is increased. For this reason, the dynamic range of the proposed APS is significantly extended, to 112.1 dB.

ACKNOWLEDGEMENTS

This work was supported by the Center for Integrated Smart Sensors funded by the Ministry of Education, Science and Technology as a Global Frontier Project (CISS-2013M3A6A6073718), the BK21 Plus project funded by the Ministry of Education, Korea (21A20131600011), and the Integrated Circuit Design Education Center (IDEC) in Korea.

REFERENCES

[1] Kartikeya Murari, Ralph Etienne-Cummings, Nitish Thakor, and Gert Cauwenberghs, "Which Photodiode to Use: A Comparison of CMOS-Compatible Structures", IEEE Sensors Journal, Vol. 9, No. 7, pp. 752-760, 2009.

[2] Y. Maruyama and E. Charbon, "An all-digital, time-gated 128×128 SPAD array for on-chip, filter-less fluorescence detection", 16th International Solid-State Sensors, Actuators and Microsystems Conference (TRANSDUCERS), pp. 1180-1183, 2011

[3] N. Faramarzpour, M. J. Deen, S. Shirani, and Q. Fang, "Fully integrated single photon avalanche diode detector in standard CMOS 0.18μm technology", , IEEE Transactions on Electron Devices, Vol. 55, No. 3, pp. 760-767, 2008.

[4] J. Ota, T. Tokuda, K. Kagawa, M. Nunoshita, and S. Shiosaka, "Pulse modulation CMOS image sensor for bio-fluorescence imaging applications", , IEEE Procdeeing of Symposim Circuit and Systems, Vol. 4, No. , pp. 3487-3490, 2005.

[5] M. Bigasa, E. Cabrujaa,*, J. Forestb, J. Salvib, "Review of CMOS image sensors", , Microelectronics Journal, Vol. , No. 37, pp. , 433-451, 2010.

[6] S. Y. Lee, S. H. Seo, J. S. Kong, S. H. Jo, K. H. Choi, P. Choi, and J. K. Shin, "Dynamic range extension of the n-well/gate-tied PMOSFET-type photodetector with a built-in transfer gate", Journal of Sensor Science and Technology, Vol. 20, pp. 381-387, 2010.

[7] Masayuki Ikebe and Keita Saito, "A Wide-Dynamic-Range Compression Image Sensor With Negative-Feedback Resetting", IEEE Sensors Journal, Vol. 7, No. 5, pp. 897-904, 2007.

[8] Stephen O. Otim, Bhaskar Choubey, Dileepan Joseph, and Steve Collins, "Characterization and Simple Fixed Pattern Noise Correction in Wide Dynamic Range Logarithmic Imagers", IEEE Transactions on Instrumentation and Measurement, Vol. 56, No. 5, pp. 1910-1916, 2007.

[9] Graeme Storm, Robert Henderson, J. E. D. Hurwitz, David Renshaw, Keith Findlater, and Matthew Purcell, "Extended Dynamic Range From a Combined Linear-Logarithmic CMOS Image Sensor", IEEE Journal of Solid-State Circuits, Vol. 41, No. 9, pp. 2095-2106, 2006.

[10] G.G. Storm, J.E.D. Hurwitz, D. Renshaw, K.M. Findlater, R.K. Henderson, M.D. Purcell, "Combined Linear-Logarithmic CMOS Image Sensor", IEEE International Solid-State Circuits Conference (ISSCC), pp. 116-517, 2004.
[11] D. Park, J, Rhee and Y. Joo, "A Wide Dynamic-Range CMOS Image Sensor Using Self-Reset Technique", IEEE Electron Devices Letters, Vol. 28, pp. 890-892, 2007.
[12] S. Lee and K. Yang, "Sub-1-V Supply Self-Adaptive CMOS Image Sensor Cell With 86-dB Dynamic Range", IEEE Electron Devices Letters, Vol. 28, pp. 492-494, 2007.
[13] Joontaek Jung, Sung-Hyun Jo, Sang-Ho Seo1, Myunghan Bae, and Jang-Kyoo Shin, "Highly Sensitive Gate/Body-Tied P-Channel Metal Oxide Semiconductor Field Effect Transistor-Type Photodetector with an Overlapping Control Gate", Japanese Journal of Applied Physics, Vol. 51, pp. 02BG06, 2012.
[14] S. H. Seo, K. D. Kim, M. W. Seo, J. S. Kong, J. K. Shin and P. Choi, "Optical Characteristics of an N-Well/Gate-Tied PMOSFET-type Photodetector with Built-in Transfer Gate for CMOS Image Sensor", Sensors and Materials, Vol. 19, pp. 435-444, 2007
[15] Myunghan Bae, Sung-Hyun Jo, Byoung-Soo. Choi, Hee Ho Lee, Pyung Choi and Jang-Kyoo Shin, "Variable-Dynamic-Range Complementary Metal-Oxide-Semiconductor Image Sensor with Gate/Body-Tied Metal Oixde Silicon Field Effect Transistor-Type Photodetector Using Feedback Structure", Sensors and Materials, Vol. 28, pp. 13-19, 2016.
[16] Sung-Hyun Jo, Myunghan Bae, Byoung-Soo Choi, Sang-Ho Seo, Pyung Choi and Jang-Kyoo Shin, "Linear-Logarithmic Wide-Dynamic-Range Active Pixel Sensor with Negative Feedback Structure Using Gate/Body-Tied Photodetector with an Overlapping Control Gate", Sensors and Materials, Vol. 27, pp. 97-105, 2015.