Pixel Design of Gain-Boosted Event-Based Vision Sensor to Control Event Noise and Latency at Low Illuminance

Masahiro Tsukamoto, Yusuke Sato, Futa Mochizuki, Hirotsugu Takahashi, Kazuyoshi Yamashita, Atsumi Niwa, Tetsuji Yamaguchi, Hayato Wakabayashi, Yusuke Oike

Sony Semiconductor Solutions Corporation, Kanagawa, Japan

Outline

- Background

- Experiments
  - -Dominant factors of pixel noise
  - -Parameters controlling the LGT noise
  - -Extending the concept to the gain-boosted EVS

- Measurement results

- Summary

Outline

- Background

- Experiments
  - -Dominant factors of pixel noise
  - -Parameters controlling the LGT noise
  - -Extending the concept to the gain-boosted EVS

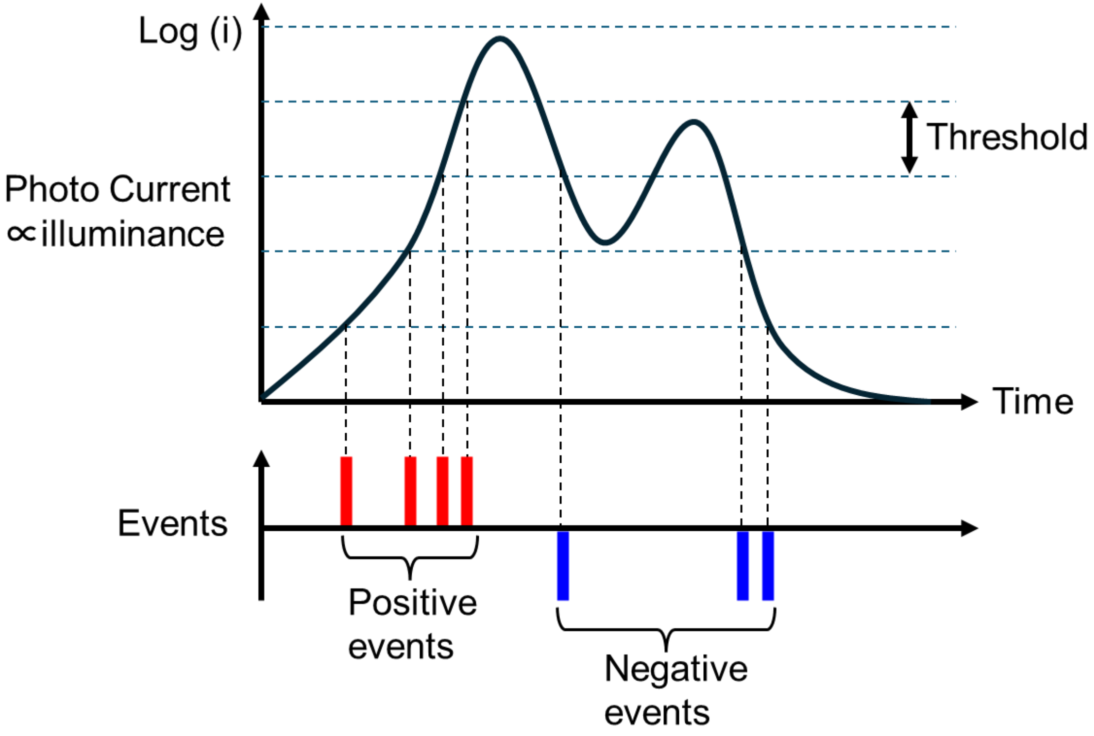
- Measurement results

- Summary

Background

- Event-based Vison Sensor (EVS) detects changes in brightness
- EVS advantages : Low power consumption, High-speed detection, etc

Image of detection and event output

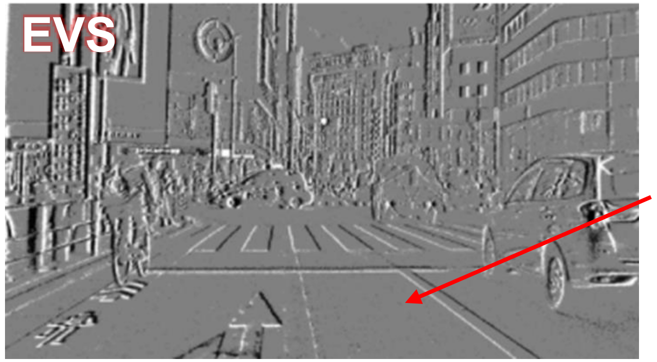


Application

Background

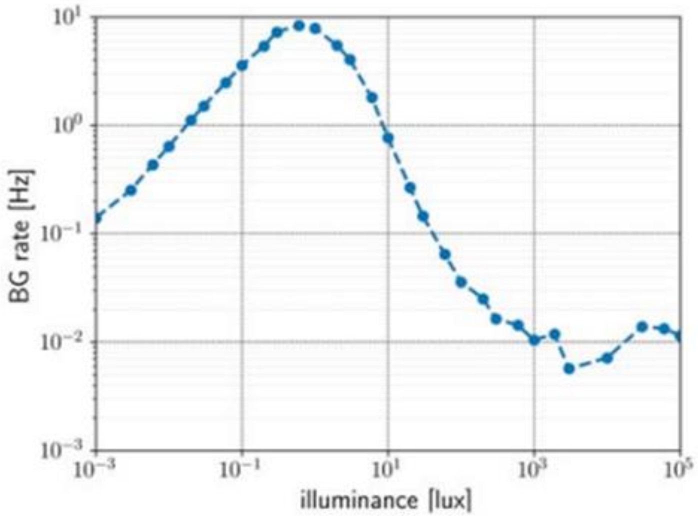
- **The significant issues of EVS : Background rate (BGR)**
- **Design guidelines for controlling BGR is required.**

The images captured by EVS and CIS



False events detection, called background rate (BGR)

Measurement results of BGR vs illuminance [1]



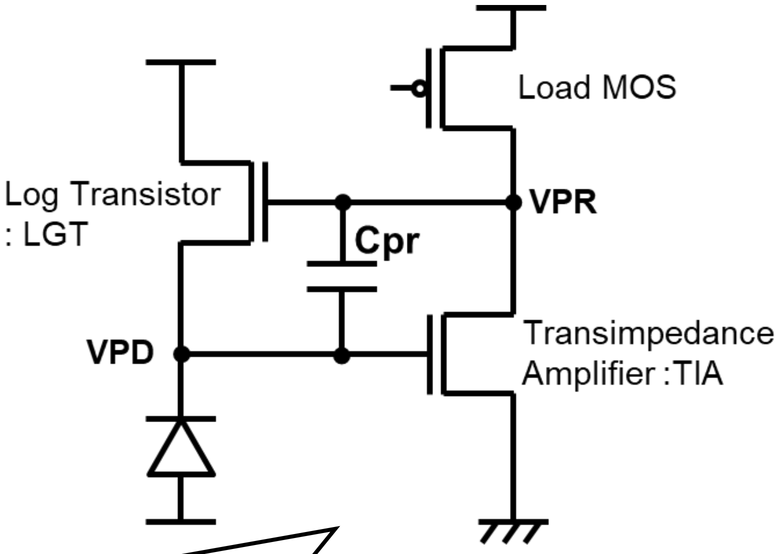
BGR is worst at low illuminance due to the pixel noise

[1] T. Finateu et al., “A 1280 x 720 back-illuminated stacked temporal contrast event-based vision sensor with 4.86 µm pixels, 1.066geps readout, programmable event-rate controller and compressive data-formatting pipeline”, ISSCC 2020.

Background

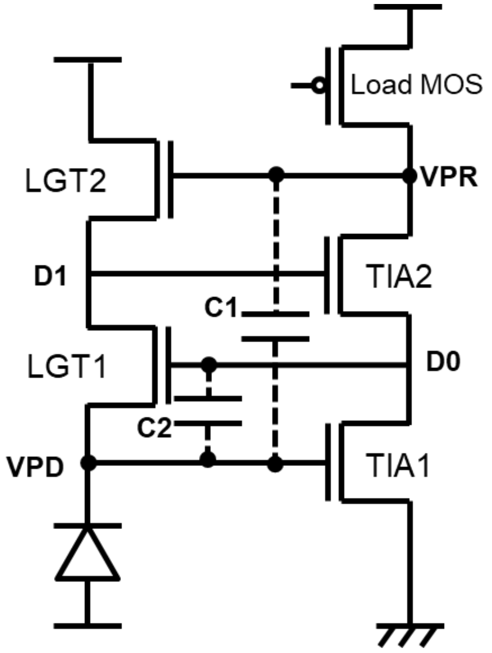
Design guidelines for gain-boosted EVS pixel is need to be established

Logarithmic EVS pixel



Previous studies on EVS pixel are mostly based on this pixel [2,3,4]

Gain-boosted EVS [5]



Gain-boosted EVS is proposed in the reference [5].
This EVS pixel has high current–voltage conversion gain and superior EVS characteristics

[2] A. Suess et al., "Physical modeling and parameter extraction for event-based vision sensors", IISW 2023.
[3] X. Mou et al., "Joint Parameter estimation for event-based vision sensor characterization", EI 2024.
[4] C. Posch et al., "Sensitivity and uniformity of a 0.18μm CMOS temporal contrast pixel array", ISCAS 2011.
[5] B. Son et al., "A 640×480 dynamic vision sensor with a 9μm pixel and 300Meps address-event representation", ISSCC 2017.

Outline

- Background

- Experiments
  - -Dominant factors of pixel noise
  - -Parameters controlling the LGT noise
  - -Extending the concept to the gain-boosted EVS

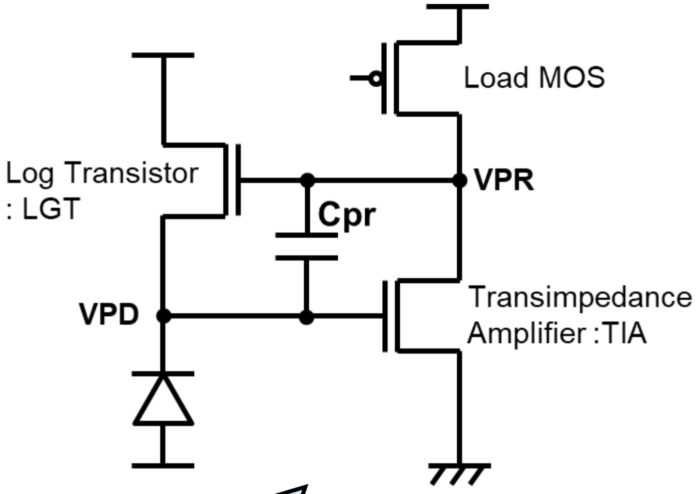
- Measurement results

- Summary

Experiments

This study was conducted in the following

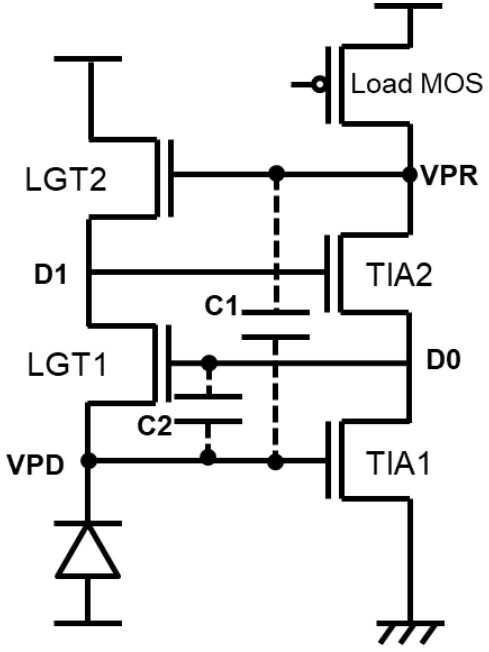
1. Investigation of the dominant noise factor based on the logarithmic EVS (Left figure)
2. Deriving the parameters controlling the dominant noise component.
3. Extending the concept to the gain-boosted EVS
4. Confirming the validity of the approach by measuring some sample of devices.



Investigation of
(1) Dominant factor of pixel noise
(2) Parameters controlling the dominant factor

(3) Extending the concept
(4) Confirmed by measurements

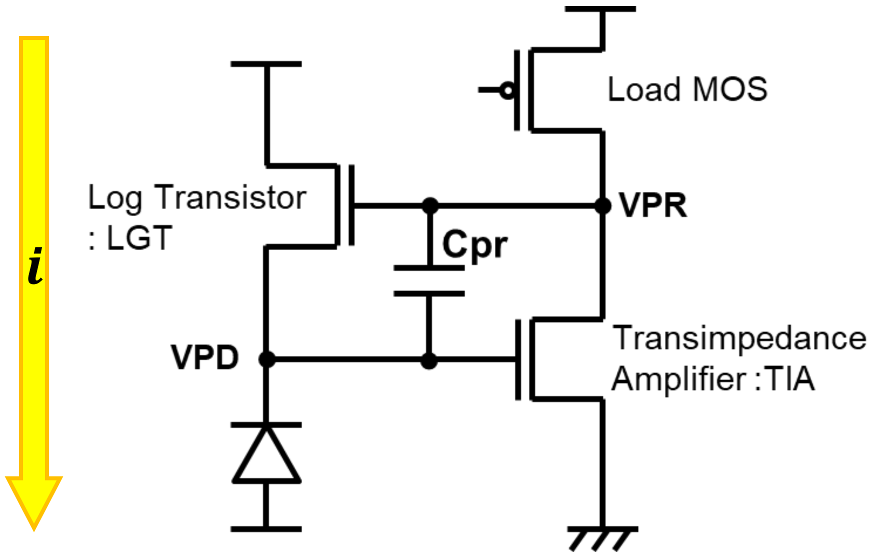
Gain-boosted EVS



Experiments

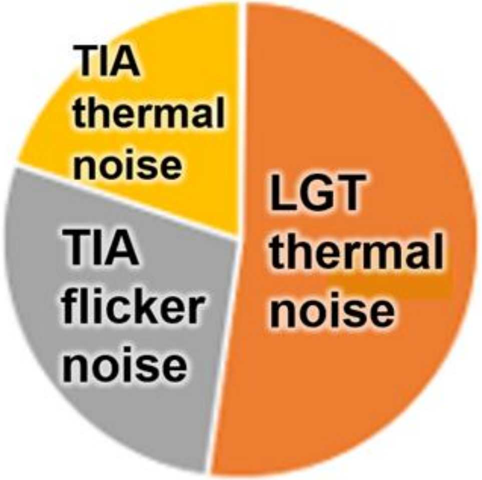
1. Dominant factor of pixel noise

LGT thermal noise is the dominant component in EVS pixel.



At low illuminance, photo current is very small.
It is limited by the size of photodiode.

Result of SPICE Sim



\# Define
The contribution rate of $\boldsymbol{R_m}$ to the mean square is quantified by the following formula

$$\frac{R_m{}^2}{R_1{}^2 + R_1{}^2 + \cdots + R_n{}^2}$$

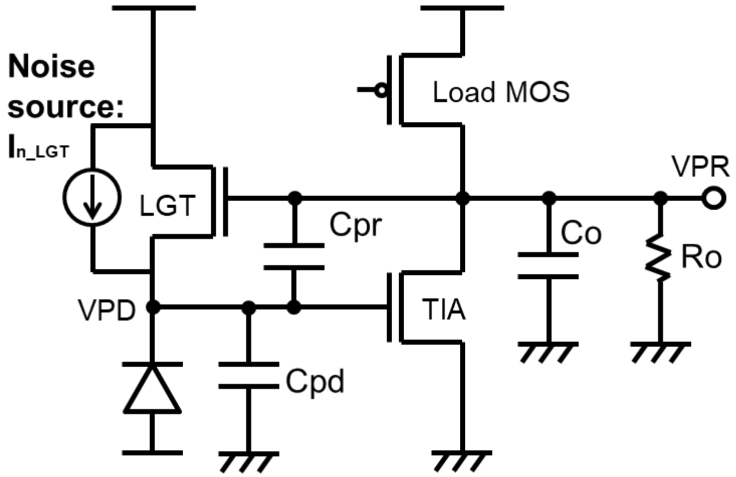
To optimize the pixel noise, controlling the bandwidth of LGT noise is necessary.

Experiments

2. Parameters controlling the LGT noise bandwidth

The capacitance between the input and output of EVS pixel, which corresponds to C_{pr} is design parameter

EVS pixel circuit model added LGT noise



g_m	Transconductance of LGT
G_m	Transconductance of TIA
I_{n_LGT}	Noise of LGT
V_{PR}	Output node voltage of pixel
V_{PD}	Input node voltage of pixel
C_{pr}	Capacitance between the input and output
C_{pd}	Total capacitance of the input node excluding C_{pr}
C_o	Total capacitance of the output node excluding C_{pr}

$$\begin{cases} g_m(V_{PR}-V_{PD})+I_{n\_LGT}-sV_{PD}C_{pd}-sC_{pr}(V_{PD}-V_{PR})=0 \\ G_mV_{PD}+sV_{PR}C_o+\dfrac{V_{PR}}{R_o}+sC_{pr}(V_{PR}-V_{PD})=0 \end{cases}$$

The cutoff frequency is calculated from the transfer function of I_{n_LGT}

$$\omega \approx \frac{g_m}{\underline{C_{pr}+\dfrac{C_{pd}}{(1+G_mR_o)}}} \approx \frac{g_m}{C_{pr}}$$

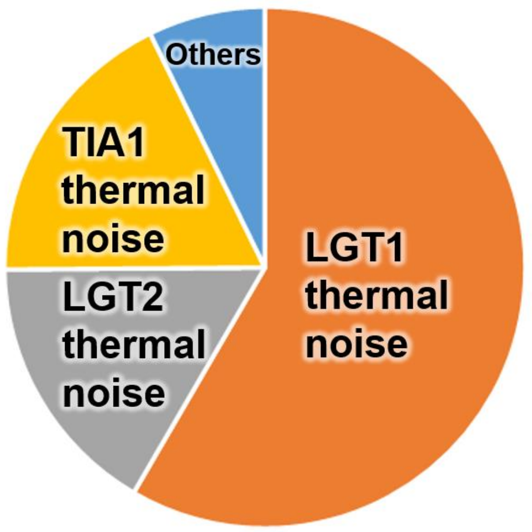
C_{pr} appears to be larger than C_{pd}. (**Miller effect**)
→ C_{pr} contributes significantly to the noise band of the LGT

Experiments

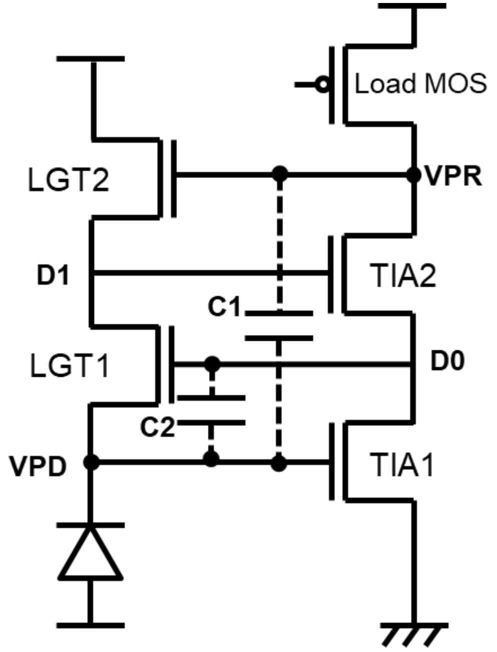
3. Extending the concept to gain-boosted EVS

In gain-boosted EVS, C_{pr} is defined by $C_1 + \frac{C_2}{2}$

Result of SPICE Sim



The contribution rate of each transistor noise at low illuminance for a gain-boosted EVS.



C_{pr} that determines the LGT1 noise band is defined following.

$$C_{pr} \approx C_1 + \frac{C_2}{2}$$

The coefficient is determined by considering the difference in the Miller effect between C_1 and C_2 .

We demonstrate the validity of this concept, by preparing samples with different C_{pr}

Outline

- Background

- Experiments
  - -Dominant factors of pixel noise
  - -Parameters controlling the LGT noise
  - -Extending the concept to the gain-boosted EVS

- Measurement results

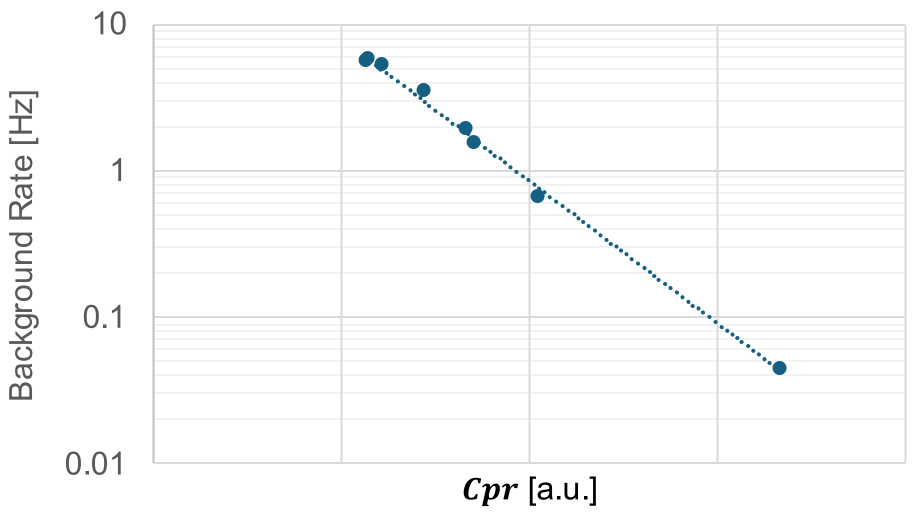
- Summary

Measurement results

BGR can be controlled by adjusting the C_{pr}, defined as $C_1 + \frac{C_2}{2}$

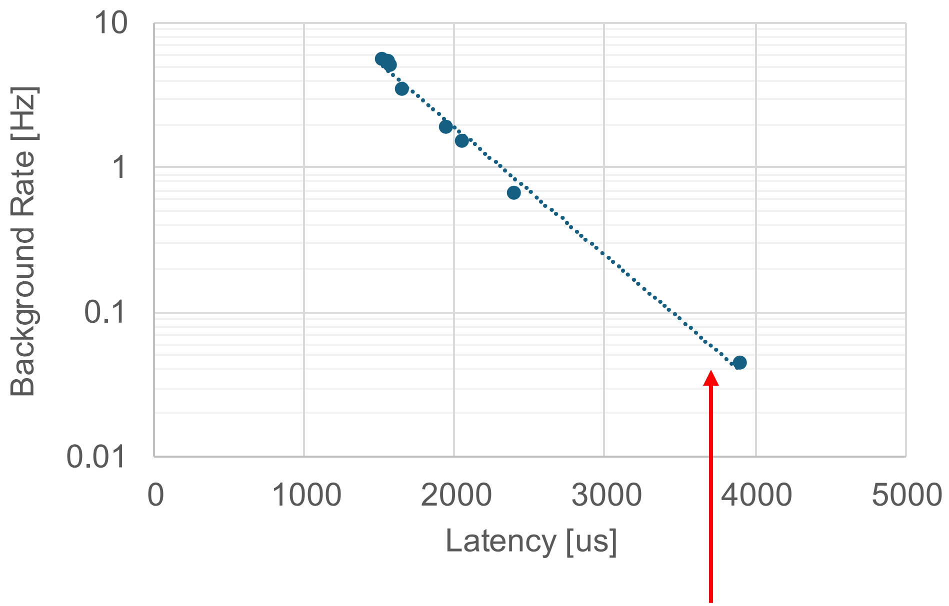
Optimizing C_{pr} is crucial, considering trade-off between BGR and Latency

BGR at 0.3lux vs C_{pr} defined by $C_1 + \frac{C_2}{2}$



An exponential relationship between the BGR and C_{pr}

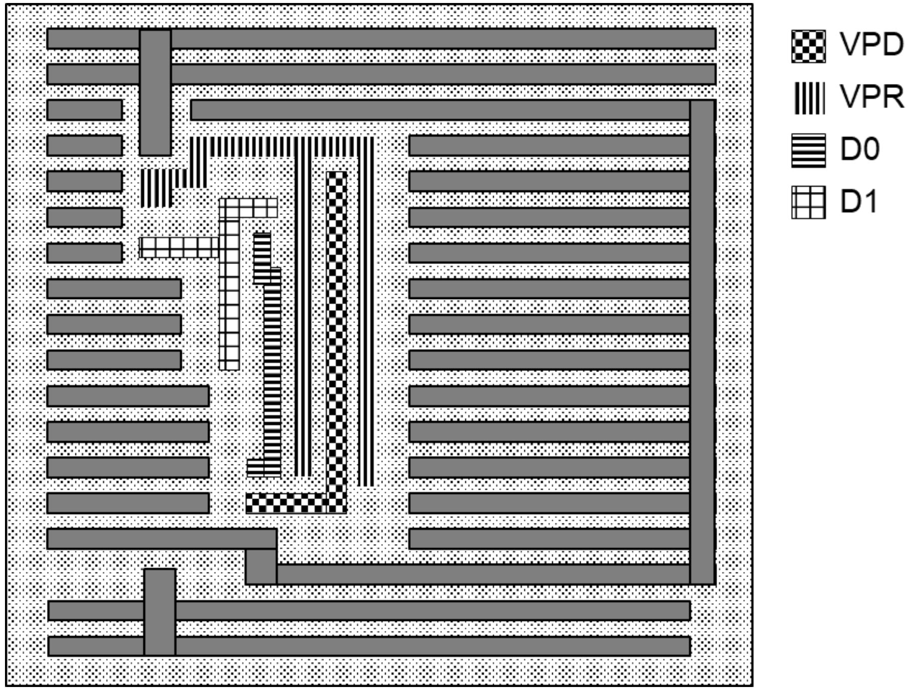
Trade-off relation between Latency and BGR



Designing a larger C_{pr} improves the BGR but worsens latency.

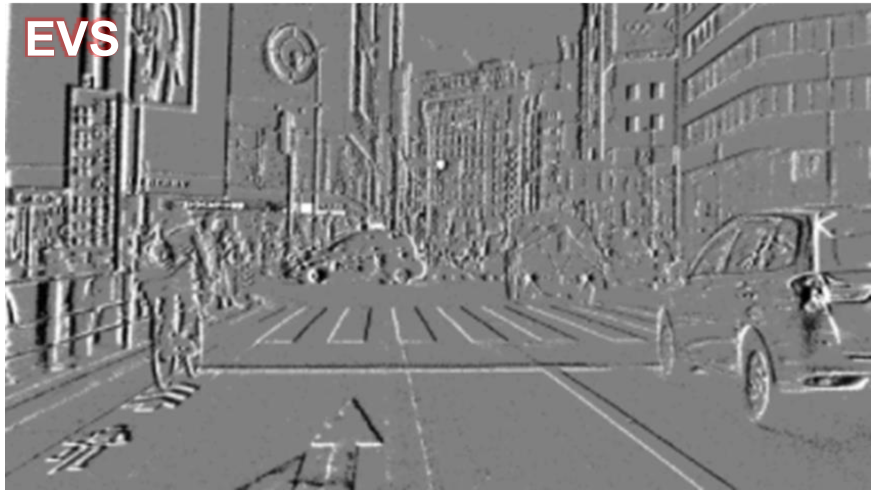
Layout and captured image

An example of layout for the 4.86-μm-pitch gain-boosted EVS pixel



C_{pr} **is optimally adjusted so that both the BGR and latency meet the required characteristics.**

Image captured by the EVS prepared in this study



Outline

- Background
- Experiments
  - -Dominant factors of pixel noise
  - -Parameters controlling the LGT noise
  - -Extending the concept to the gain-boosted EVS
- Measurement results
- Summary

Summary

- C_{pr} defined by $C_1 + \frac{C_2}{2}$ can control the BGR at low illuminance for a gain-boosted EVS pixel.

- The measurement of several samples with different C_{pr} designs showed the validity of the C_{pr} definition.

- C_{pr} should be optimally adjusted so that both BGR and latency meet the required characteristics, respectively.

- The required BGR and latency has been achieved by optimizing the layout of the 4.86-μm-pitch gain-boosted EVS pixel so that C_{pr} is the appropriate value.

Acknowledgments

This study has been conducted in collaboration with PROPHESEE.
The authors would like to thank PROPHESEE.