

# MICRO-523: Optical Detectors

Week Twelve: Advanced SPAD cameras – Exercises

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Based on MICRO-523, P.-A. Besse, 2023

TAs: Samuele Bisi, Kodai Kaneyasu

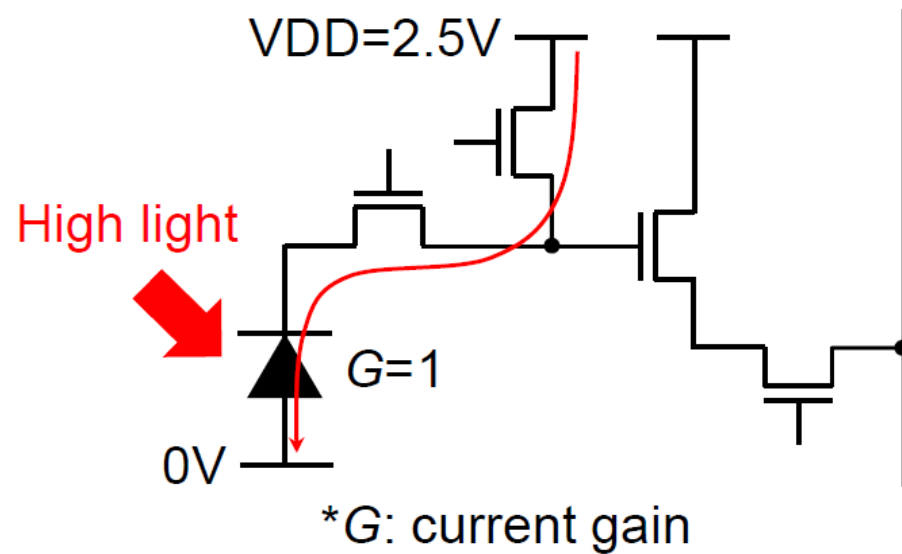
The logo of the École polytechnique fédérale de Lausanne (EPFL), consisting of the letters 'EPFL' in a bold, red, sans-serif font.

# Reminder: Exercise 11.2: SPAD camera power consumption

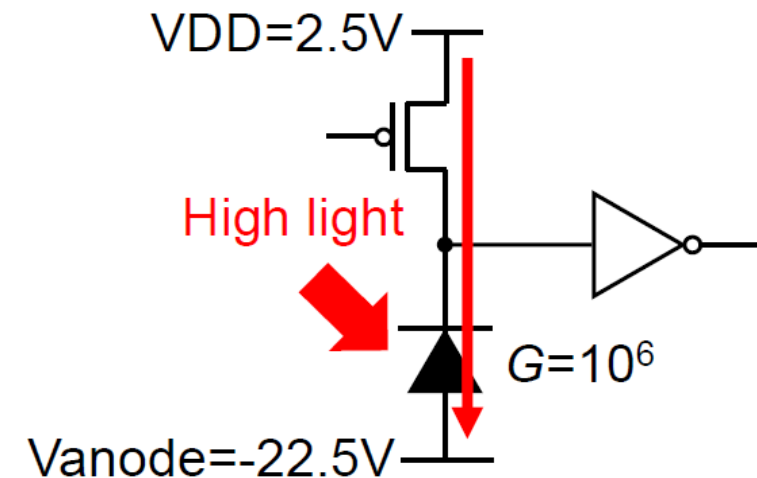
K. Morimoto, Image Sensors Europe 2024

- **Assumption:  $N_{\text{pix}}=3\text{Mpixel}$ ,  $Q_{\text{sat}}=20\text{k}$ , Frame rate=60fps**

## CMOS imager (4T pixel)



## SPAD imager (passive recharging)



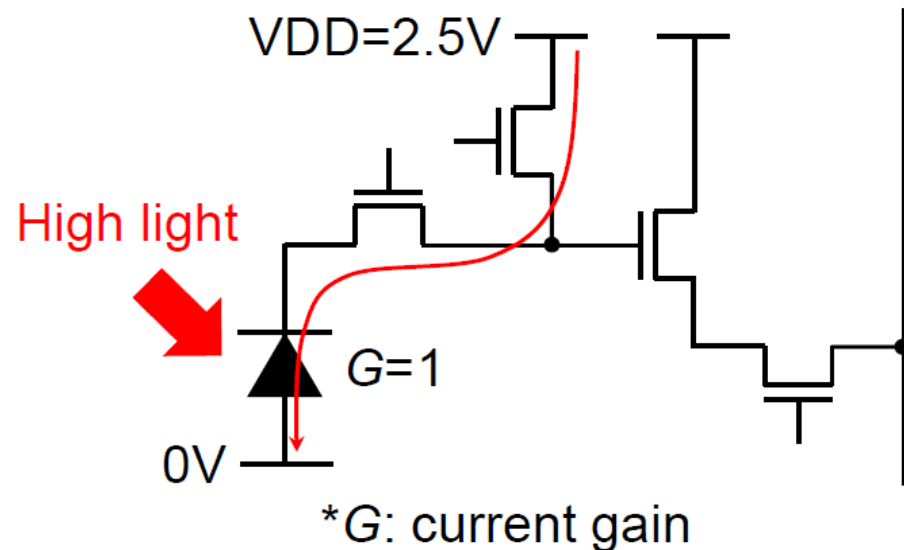
*How can the power consumption of a SPAD-based camera operating at high illumination be reduced from the architectural point of view?*

# Reminder: Exercise 11.2: SPAD camera power consumption

K. Morimoto, Image Sensors Europe 2024

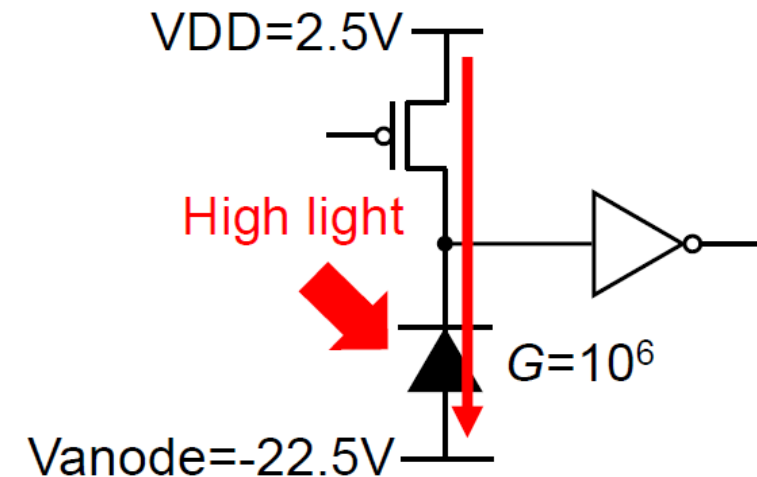
## ■ Assumption: $N_{\text{pix}}=3\text{Mpixel}$ , $Q_{\text{sat}}=20\text{k}$ , Frame rate=60fps

### CMOS imager (4T pixel)



- $V = 2.5\text{V}$
- $I = N_{\text{pix}} \times Q_{\text{sat}} \times G \times 60\text{fps} = 0.58\mu\text{A}$
- $P = VI = 1.4\mu\text{W}$

### SPAD imager (passive recharging)

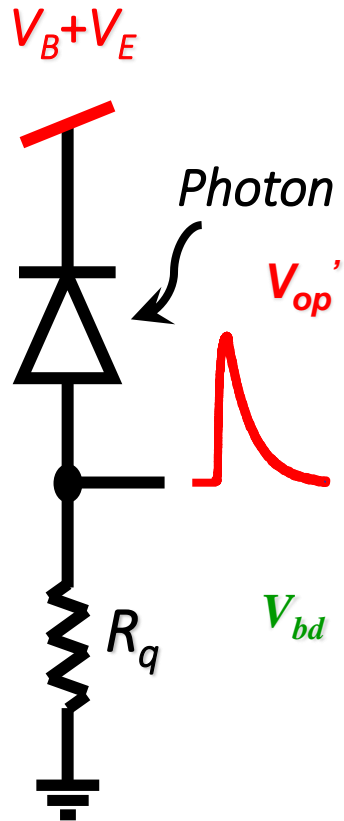


- $V = 25\text{V}$
- $I = N_{\text{pix}} \times Q_{\text{sat}} \times G \times 60\text{fps} = 0.58\text{A}$
- $P = VI = 14\text{W}$

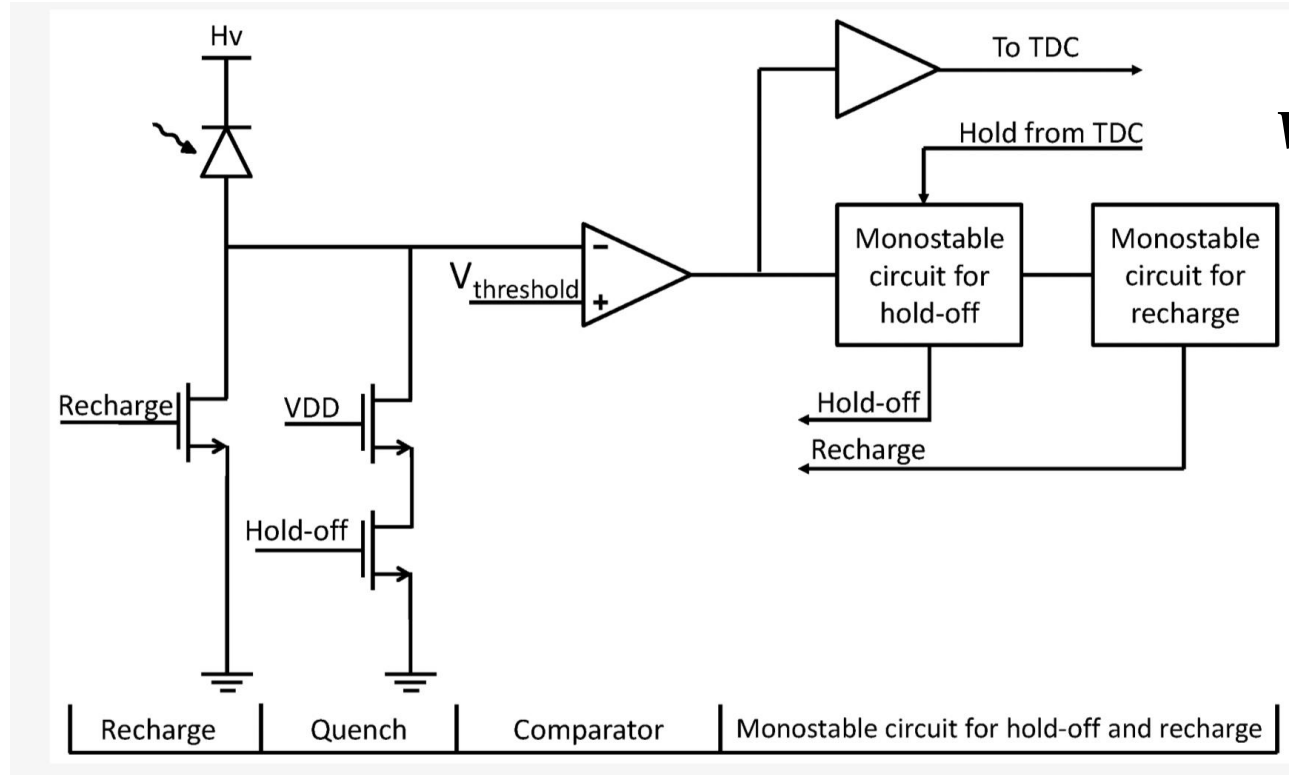
**$10^7 \times$  higher power!**

# 12.1 Active vs Passive Recharge

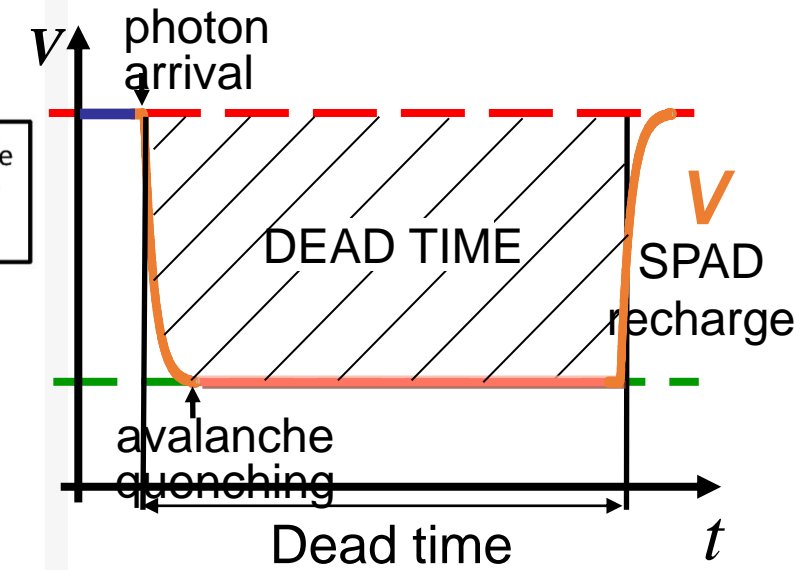
## Passive Recharge



## Active Recharge



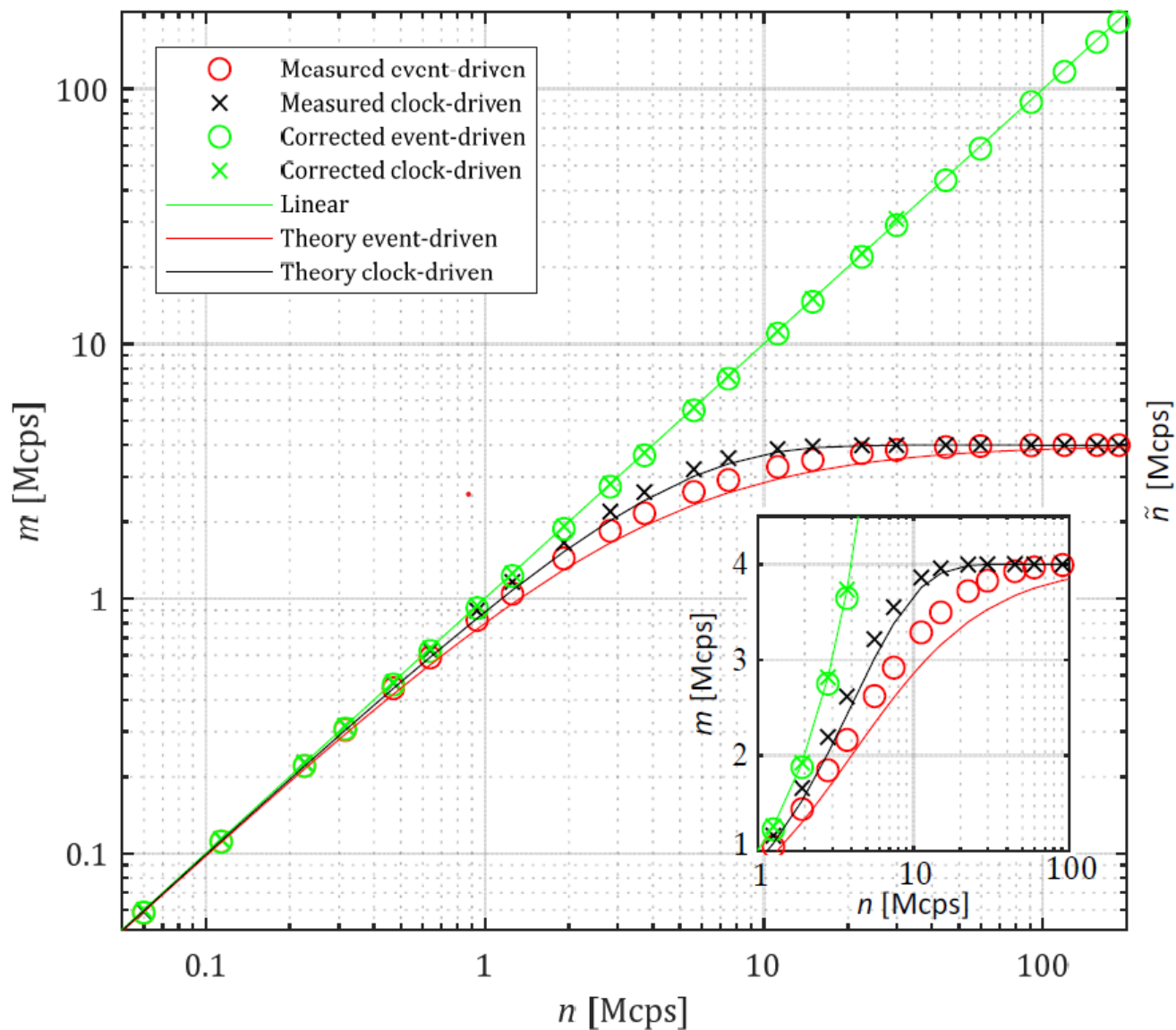
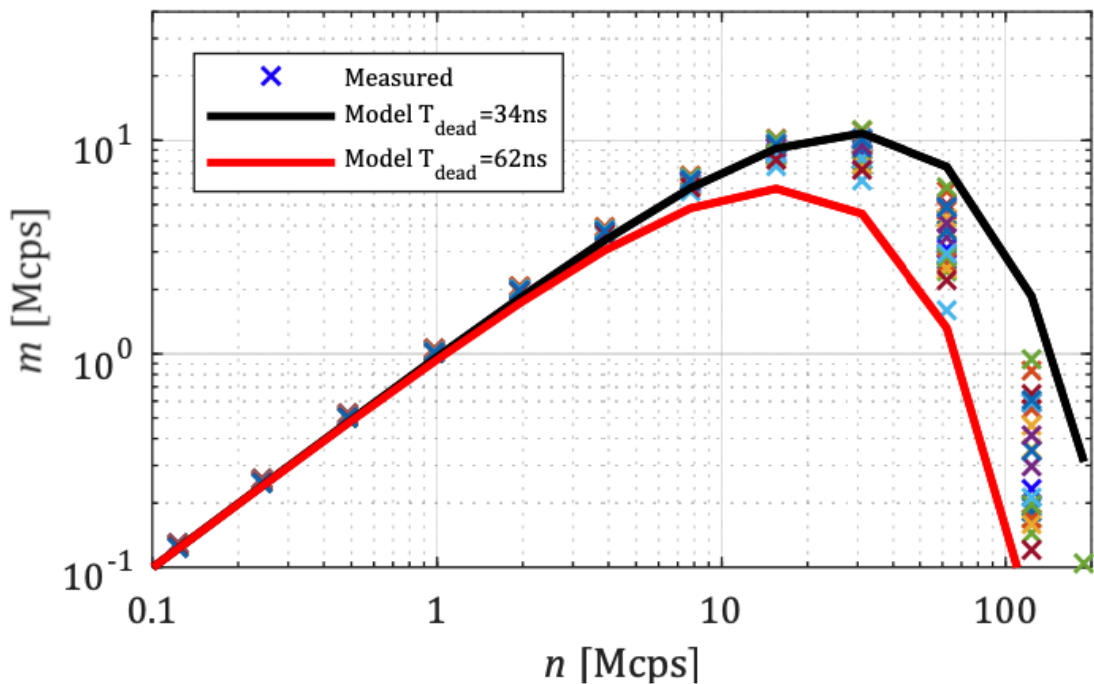
## Dead time control (hold-off)



# 12.1 Active vs Passive Recharge

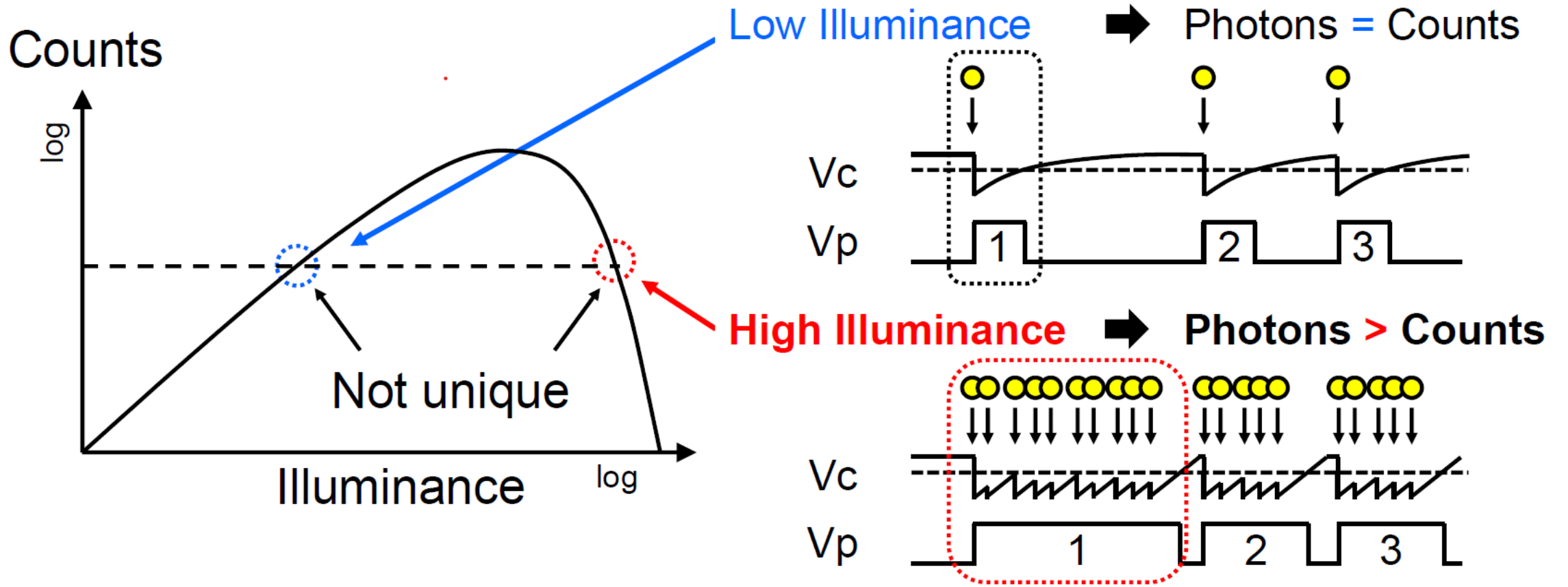
## Active Recharge

### Passive Recharge



Ivan M. Antolovic, *et al*, Dynamic range extension for photon c

# 12.1 Drawbacks of passive recharge



- Low & high illuminance could lead to the same counts

Y. Ota, et al., ISSCC 2022

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5.1: A 0.37W 143dB-Dynamic-Range 1Mpixel Backside-Illuminated Charge-Focusing SPAD Image Sensor with Pixel-Wise Exposure Control and Adaptive Clocked Recharging

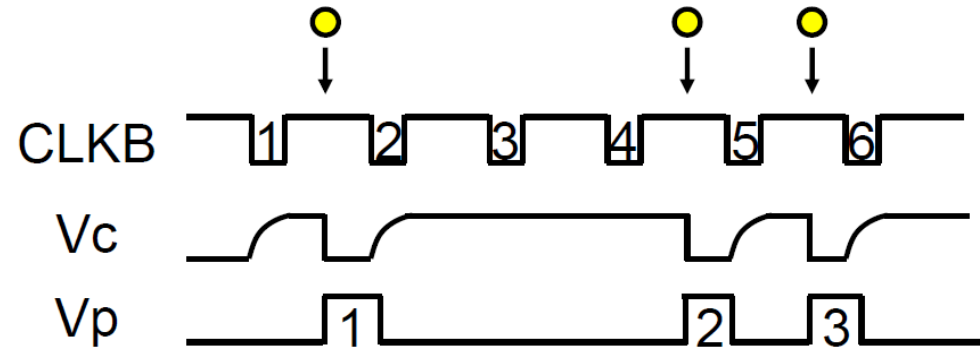
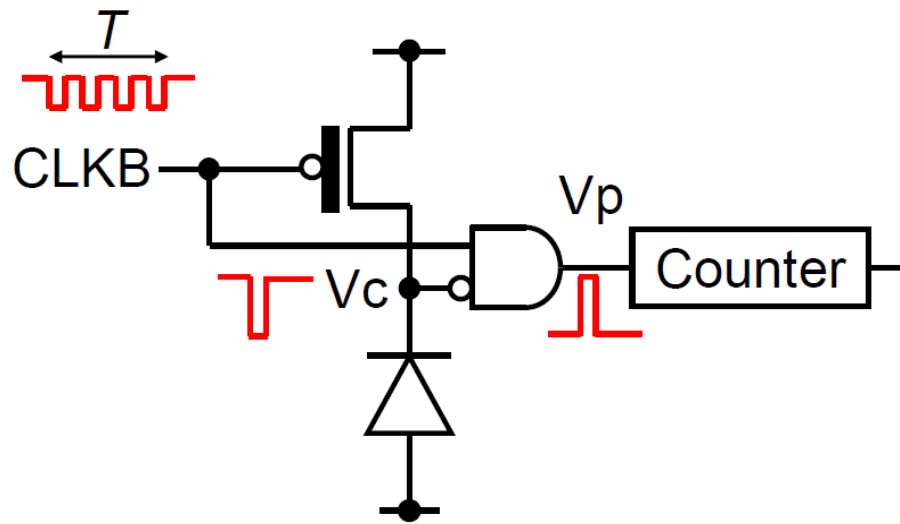
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# 12.1 Power Consumption Reduction Strategies

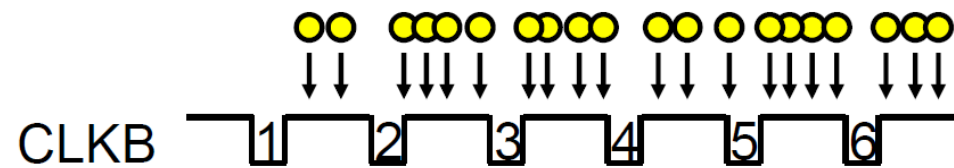
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- *How can the power consumption of a SPAD-based camera operating at high illumination be reduced from the architectural point of view?*
- *Hints for possible strategies:*
  - Reduce count for high illuminance. Example: employ active recharge.
  - Shut pixels off – how, when? Example: time to saturation.

# 12.1 Possible strategy 1: Clocked Recharging



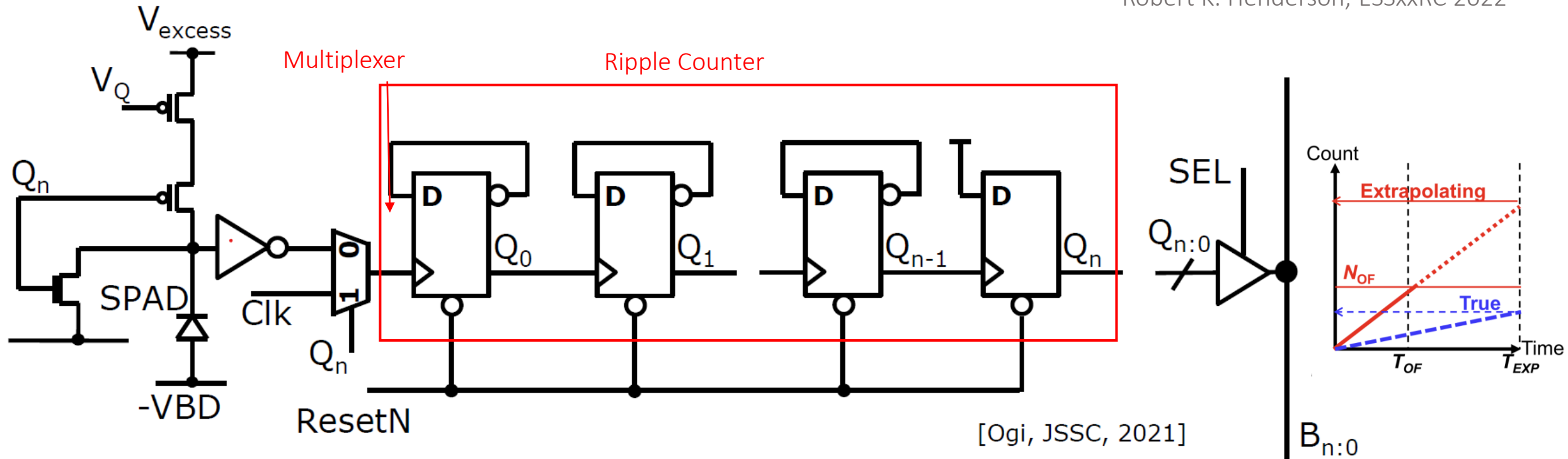
**High Illuminance** → CLKB pulses = Counts



Draw a graph with illumination (horizontal axis) vs Counts (vertical axis).

# 12.1 Possible strategy 2: Time to saturation HDR

Robert K. Henderson, ESSxxRC 2022



- ❑ All pixels initially count SPAD events
- ❑ When  $Q_n=1$  representing saturation the counter switches over to Clk AND the SPAD is inhibited saving power for the most active SPADs.
- ❑ If  $Q_n=1$  the  $Q_{n:0}$  count represents time from saturation allowing DR extension

**Draw a graph with SPAD Counts (horizontal axis) vs Power consumption (vertical axis).**