Reducing pixel-to-pixel disparities in Geiger mode avalanche photodiodes by using gated operation

E. Vilella*, A. Diéguez

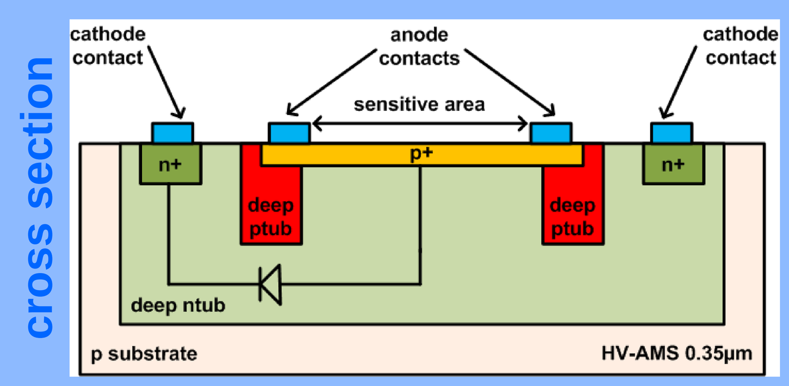
Department of Electronics – University of Barcelona (UB)

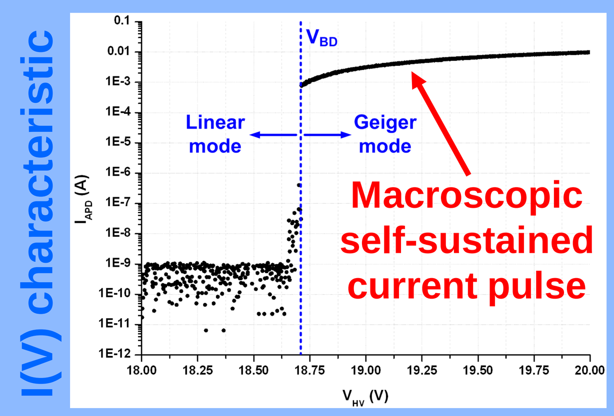
Martí i Franquès 1, 08028 – Barcelona, Spain

Geiger mode avalanche photodiodes (GAPDs)

A pn junction reverse biased above the breadkdown voltage (V_{BD}) that generates a macroscopic self-sustained current pulse when hit by impinging radiation

Pros



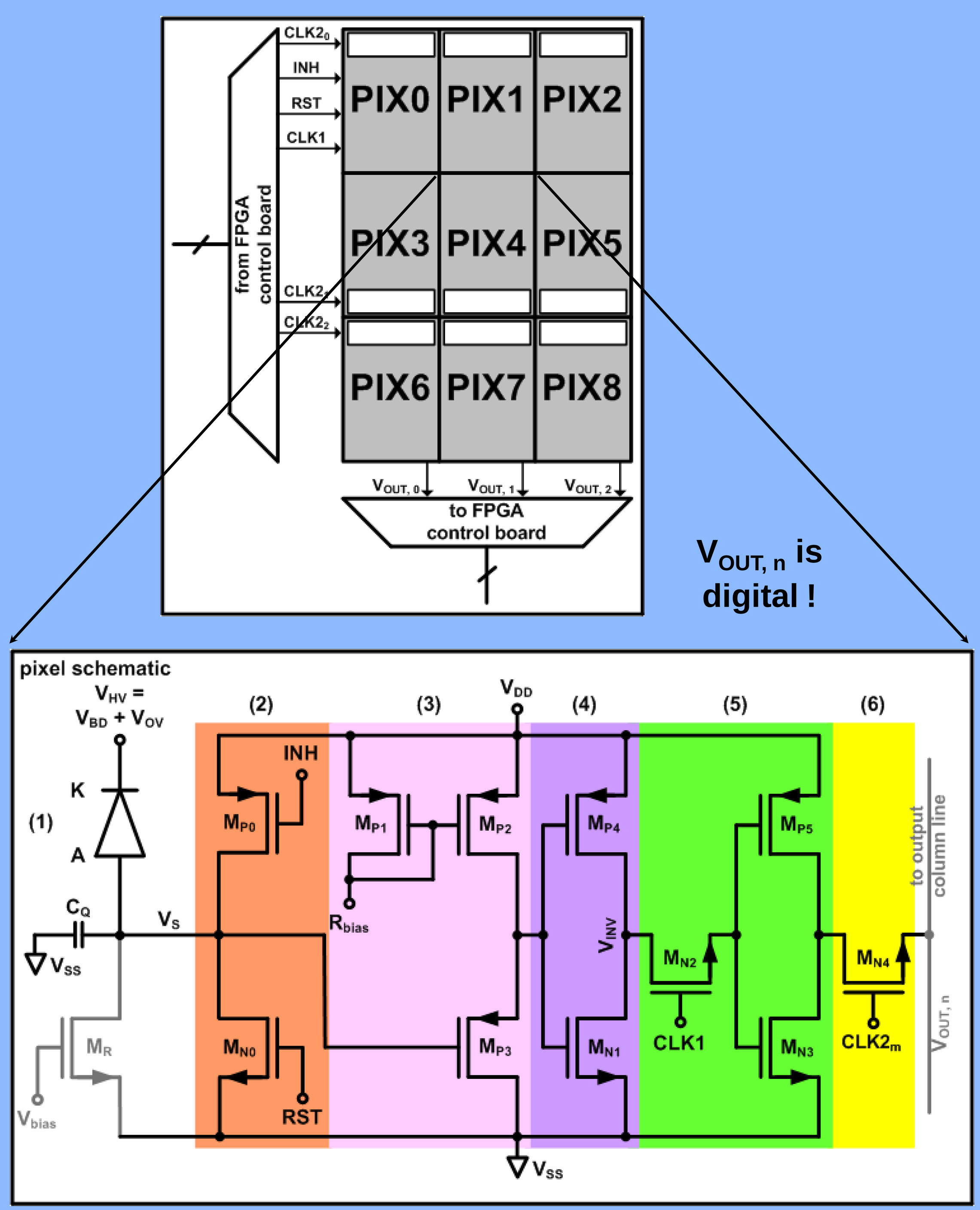


- \+ Ultra high sensitivity (virtually infinite gain)
- \+ No need for amplifiers
- \+ Picosecond rise times and short recovery periods
- \+ Possible single hit detection at each bunch crossing
- \+ Compatibility with standard CMOS technologies

Cons

- Presence of noise counts indistinguishable from real hits:
  - (a) Dark count rate (DCR). Spurious thermal/tunnel random pulses. Dependant on the doping profile (technology), quality of the process (sensor area), reverse bias overvoltage (V_{OV}) and temperature. Measured as dark counts/s (Hz).
  - (b) Afterpulses. Correlated pulses due to the random release of charges trapped during an avalanche. Dependant on the trap density, carriers involved in an avalanche and lifetime of these carriers.
- Irregular DCR distribution amongst the pixels of a detector due to variations of the cleanness during the fabrication process.
- Presence of dead pixels (pixels whose DCR is above the threshold value) due to punctual defects → Reduction of yield.

Array design and operation to reduce noise counts



Sensor and front-end electronics monolithically integrated in the same single die with HV-AMS 0.35µm

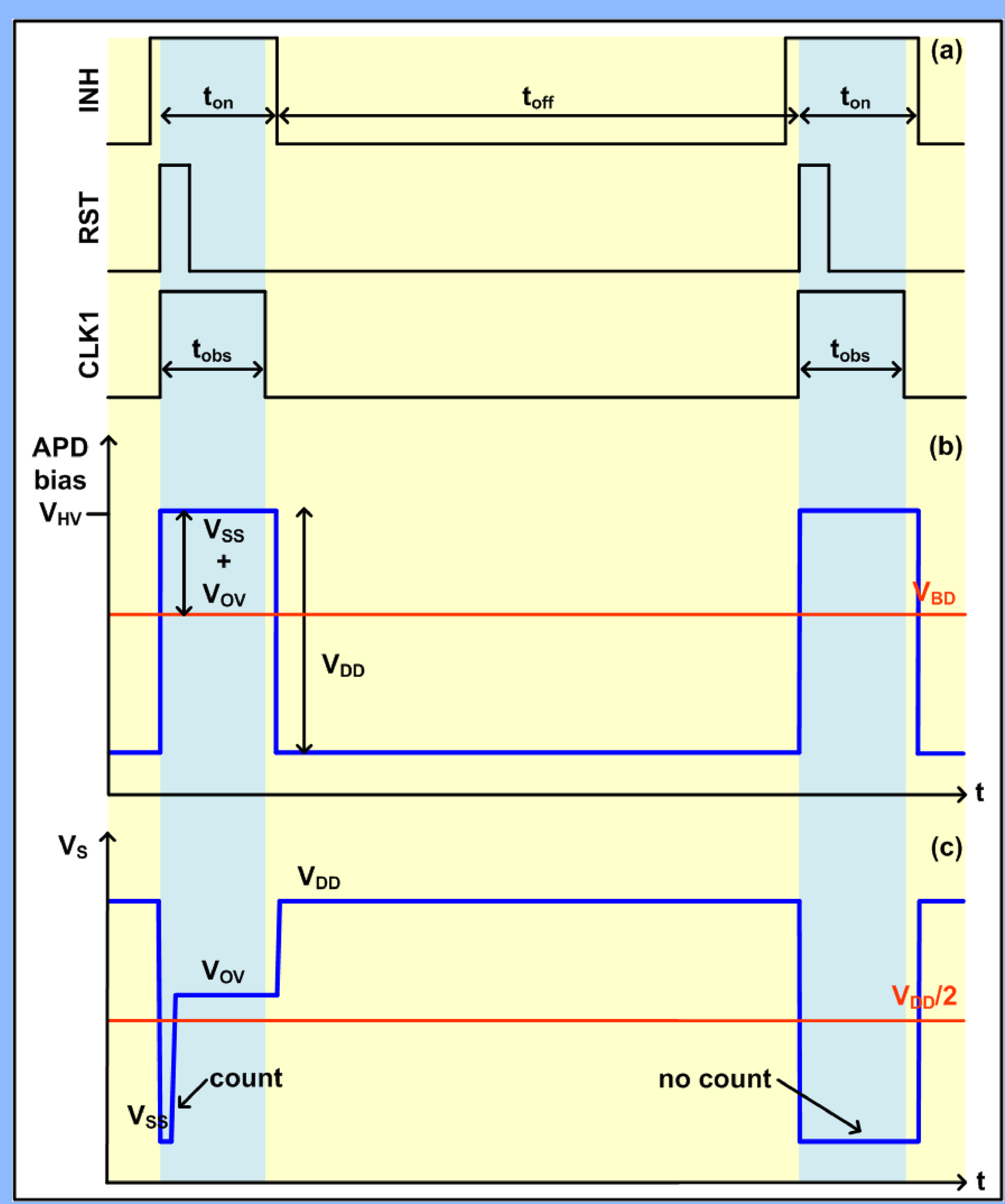
Strategies implemented to reduce the noise:

- (a) Gated acquisition. The sensor is active only for short adjustable periods of time (t_{on}) in the nanosecond range while $V_{HV} > V_{BD}$. The sensor is inactive (t_{off}) during the interbunch and the intertrain periods.
- (b) Low reverse bias overvoltage operation (V_{OV}). Allowed by the level-shifter.

Pixel schematic legend:

- (1) Sensor size is 20µm x 100µm
- (2) Inhibition and reset transistors to control GAPD bias (gated acquisition)
- (3) Level-shifter to allow V_{OV} operation
- (4) Inverter for sensor readout ($V_{Th} = V_{DD}/2$)
- (5) Dynamic latch for in-pixel storage after t_{obs} (controlled by CLK1)
- (6) Pass gate for row selection and off-chip readout during t_{off} (controlled by CLK2)

Waveforms for gated acquisition



Experimental results

Advantages

Gated acquisition:

- \+ Elimination of afterpulses (leaving long enough t_{off})
- \+ Reduction of the probability to detect dark counts with short t_{obs} of a few ns. The DCR is still the same!
- \+ No erroneous results
- \+ No sensor blindness
- \+ No loss of sensitivity (no dead pixels)
- \+ Increase and uniformization of the detector performance amongst the different pixels
- \+ Extended range of detectable signals
- \+ Reduction of the amount of data to be saved
- \+ Synchronization of sensor operation with expected signal arrival

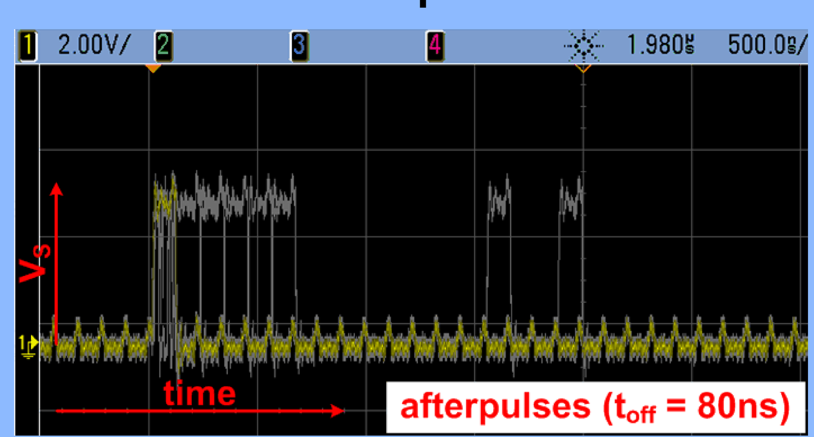
In addition, to apply our gating pulse…

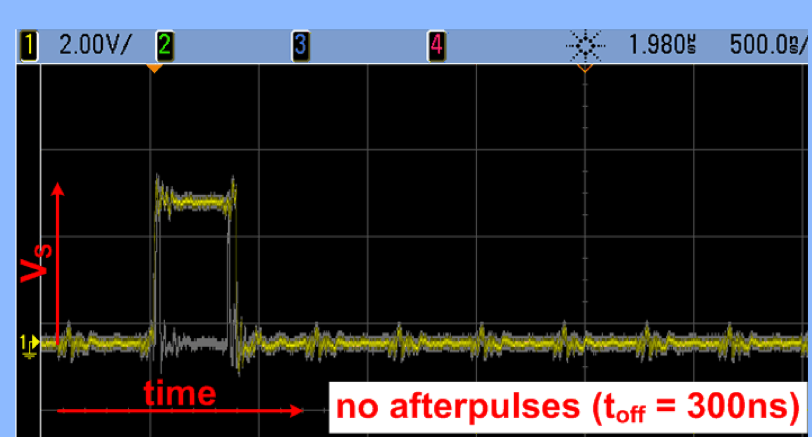
- \+ No AC coupling is needed
- \+ No sinusoidal voltages are required

Low reverse bias overvoltage operation (V_{OV}):

- \+ Reduction of the dark count rate (tested values $0.5V < V_{OV} < 1.5V$)

Elimination of afterpulses



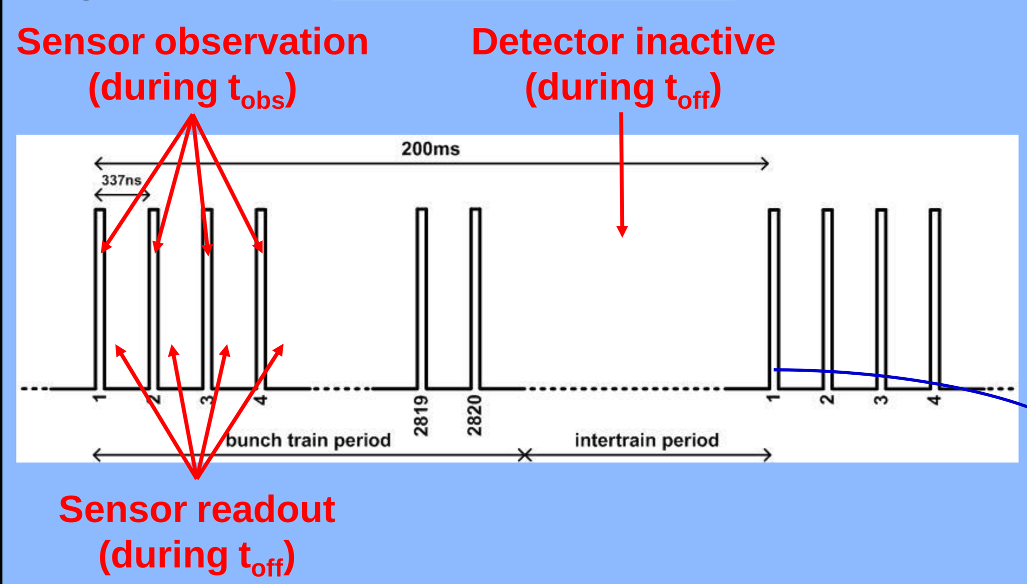


Experimental conditions

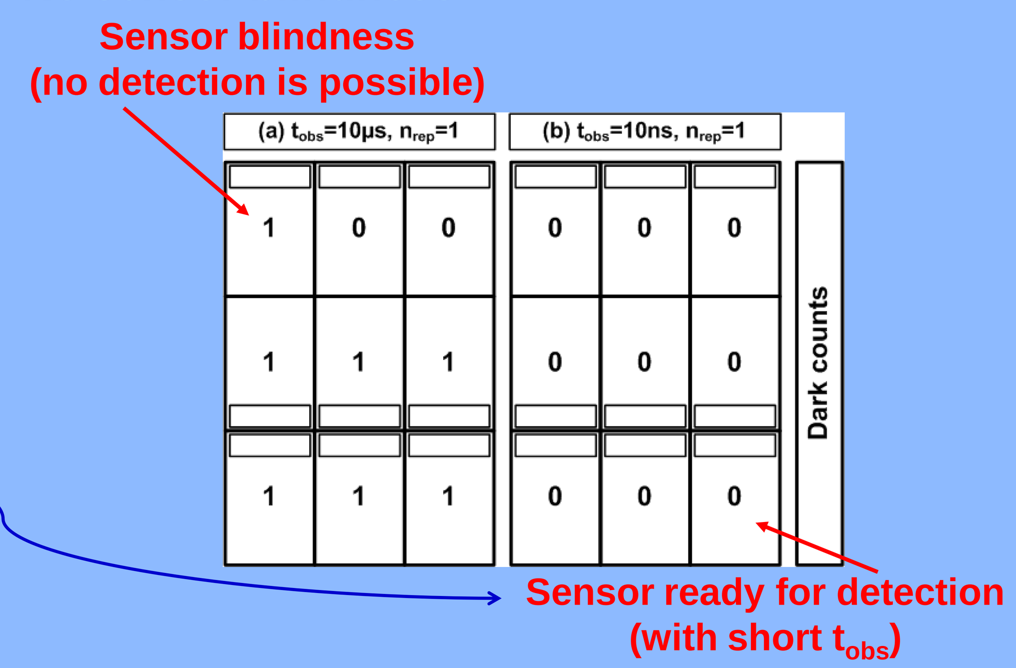
V_{OV} = 1.0V

T = 25ºC

Sensor synchronization with expected signal arrival. ILC beam structure:



No sensor blindness



*Corresponding author. E-mail address: evilella@el.ub.es

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