ALCOR v3 update

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ALCOR day - 25.02.2025

ALCOR v3

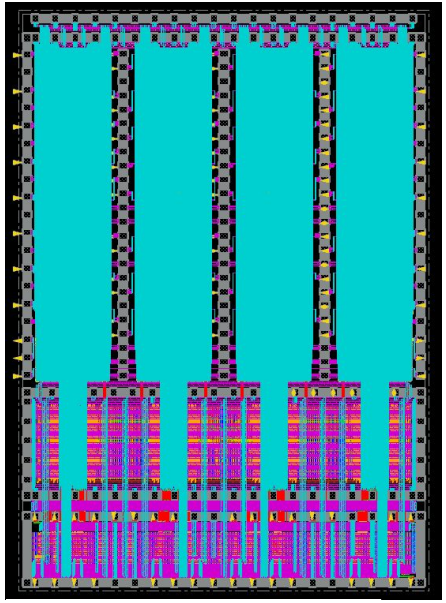
ALCOR v2: 32-channel wire bonded ASIC
ALCOR v3: 64-channel ASIC (8x8 matrix) inside BGA package (256 balls)

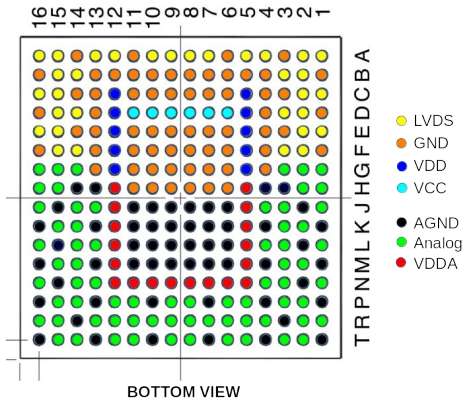
Operation of ALCOR at multiple of **EIC clock frequency** (98.52 MHz): digital logic → **394.08 MHz**

The ePIC detector will take data using a **streaming data acquisition system** with no traditional hardware trigger

Digital shutter: “inhibit” pixel digital logic to reduce data throughput

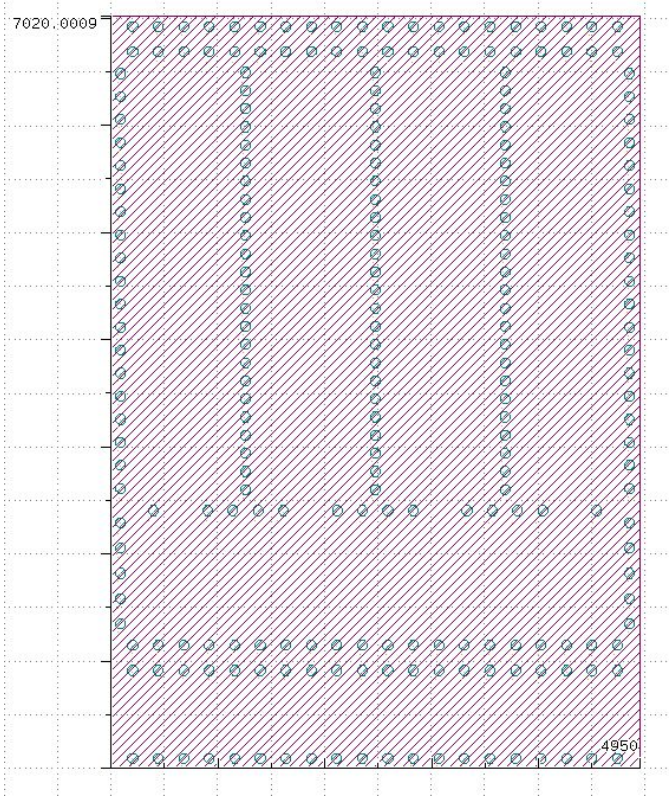
- ~10.2 ns bunch crossing, ~300 ps bunch length, select 2-3 ns → 3x-5x data reduction before ALCOR digitization
- Asynchronous digital shutter implemented in ALCOR v3 pixel logic with programmable delay to compensate offsets between the channels

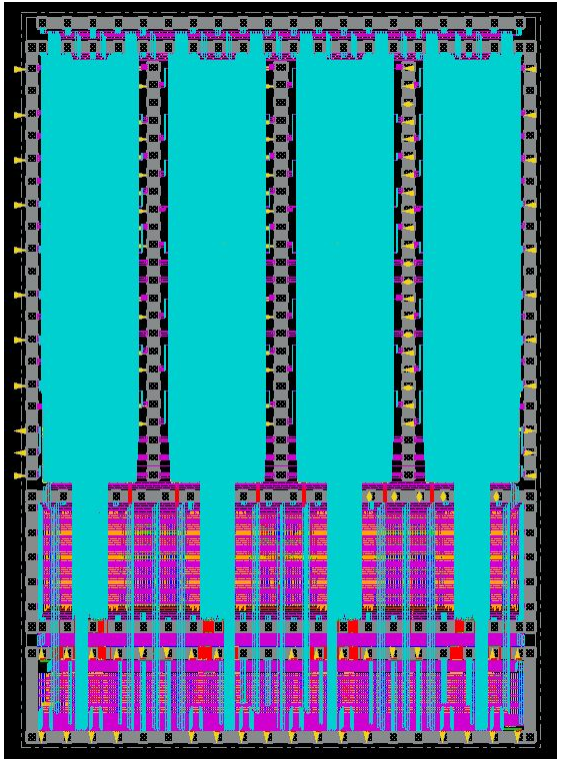




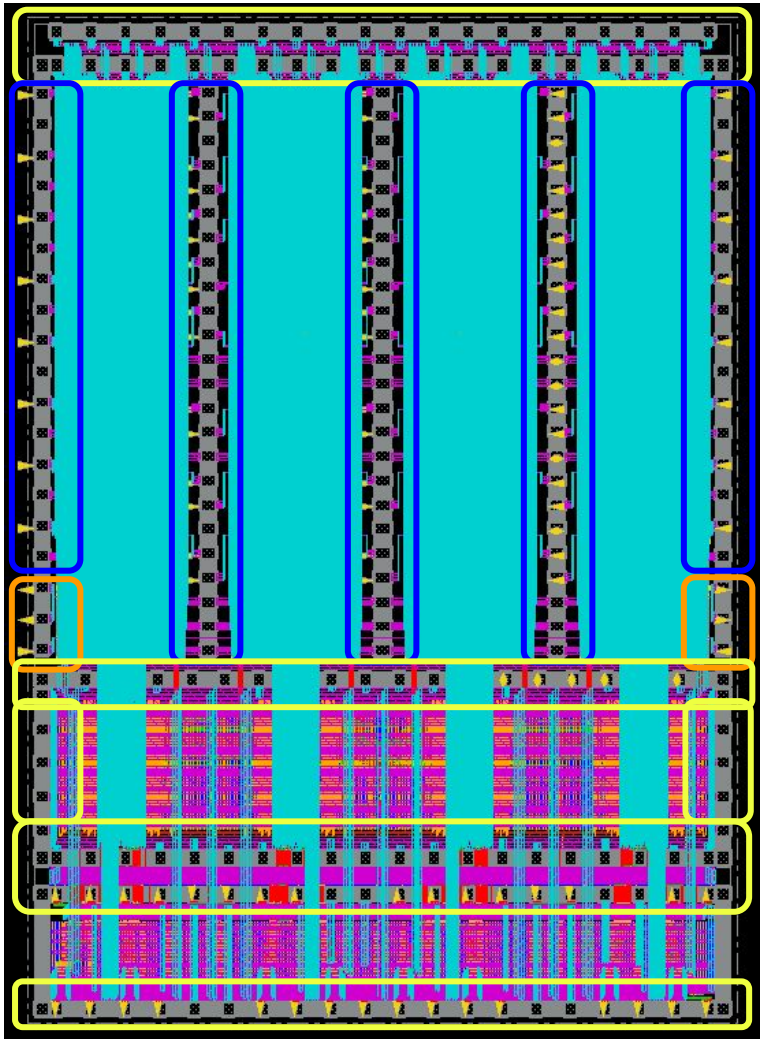
ALCOR-64

- ALCOR-64:
  - 7.02mm x 4.95mm
- 234 PAD
- Bump pads pitch:
  - ~170 µm (Analog IN)
  - ~215 µm





ALCOR-64



Analogue power supply

Pixel input + analogue power supply

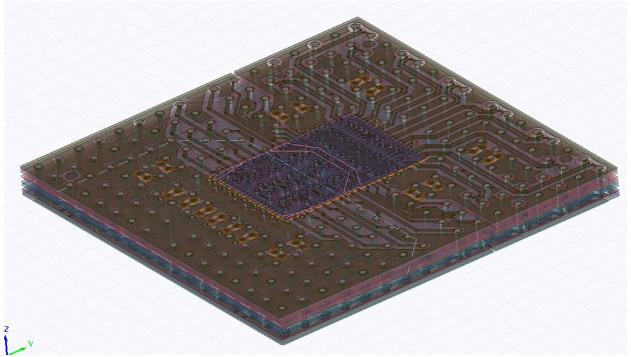
Bias Vref (2) + debug outputs (4)

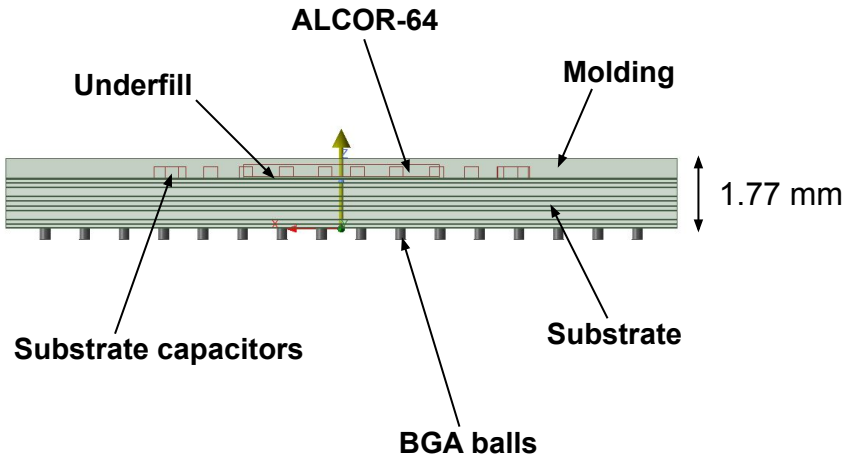
Digital core power supply

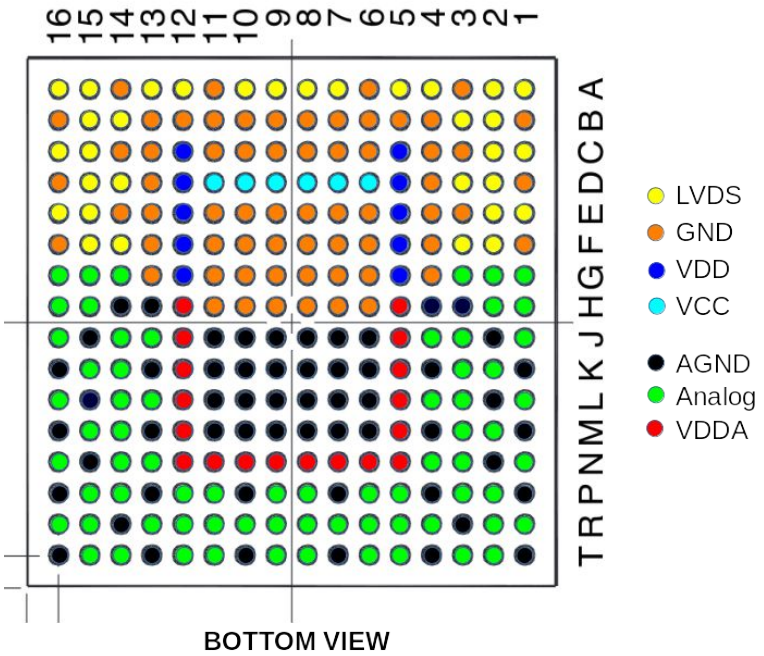
Digital IO power supply and signals

ALCOR-64 BGA package

- BGA 256 (16 x 16)
- Size: 17 mm x 17 mm
- Ball pitch: 1 mm

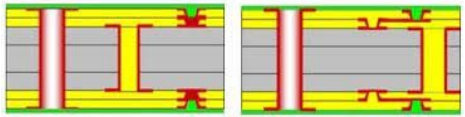




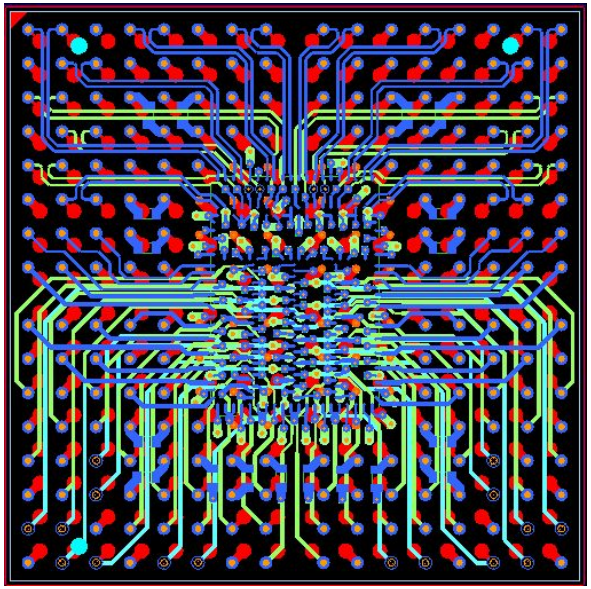


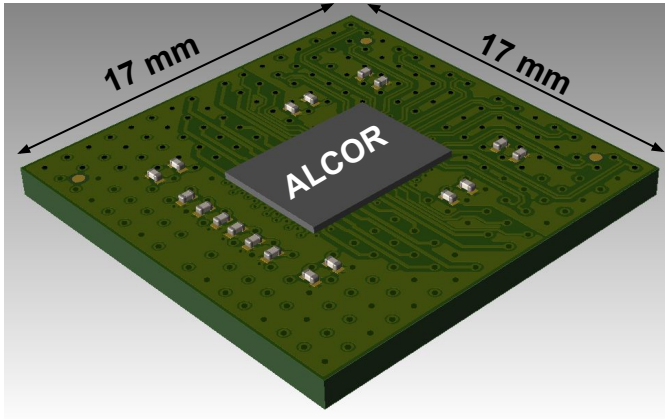
ALCOR BGA substrate

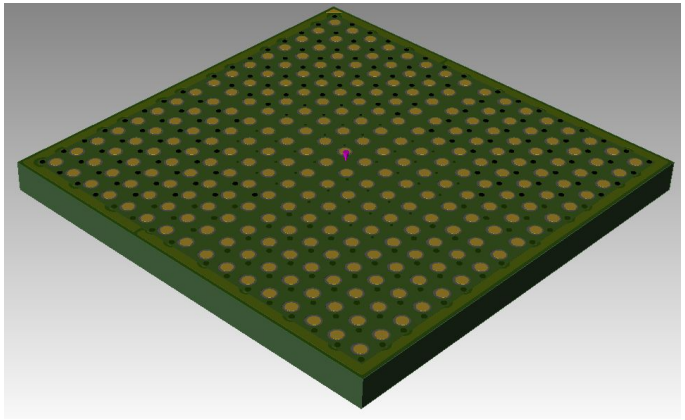
- BGA 256 Ball 17x17mm 1mm-pitch
- BT-Epoxy
- 10 Layer (2+N+2)
- Tick 1.27 mm



2+N+2 HDI PCB Structure







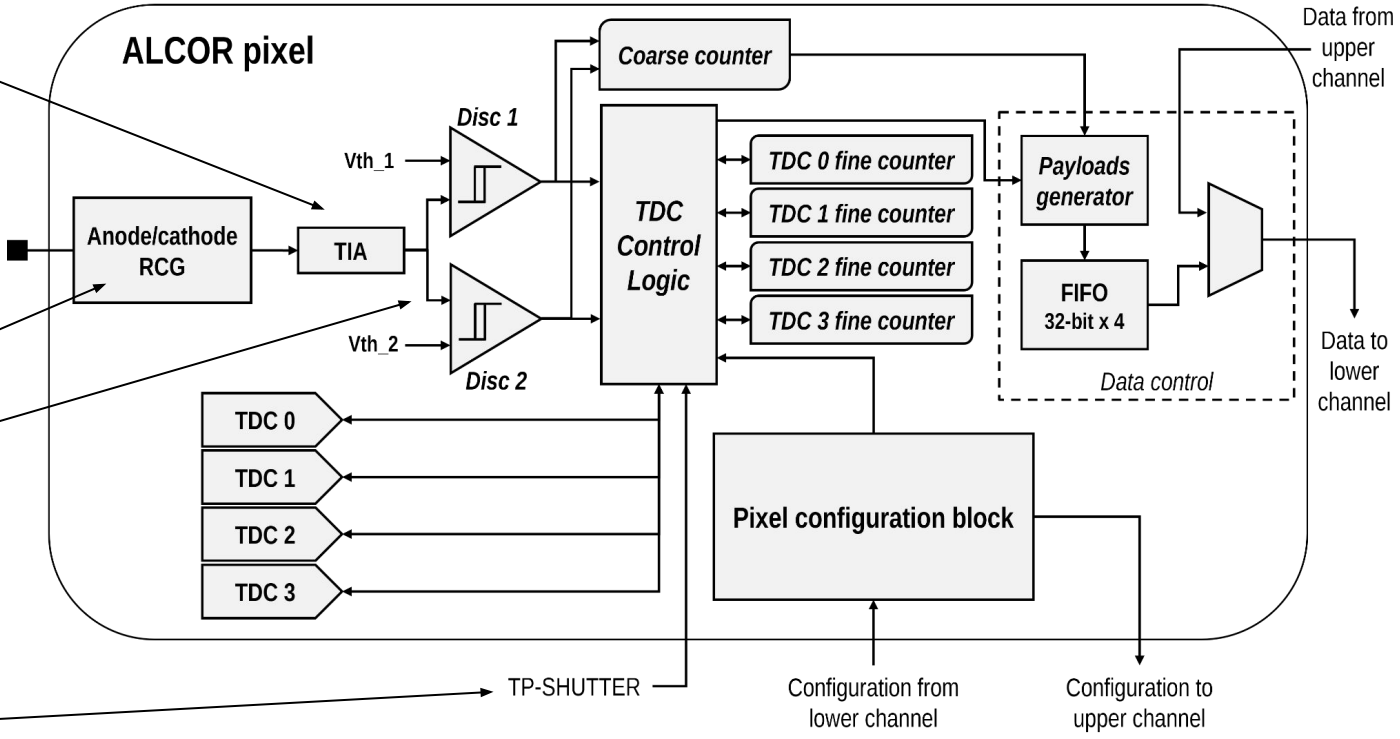
ALCORv3 - pixel architecture

Single TIA output stage coupled to 2 discriminators

RCG with **increased bandwidth**

Hysteresis discriminators

TP-shutter to TDC control logic to filter out-of-time dark-count signals



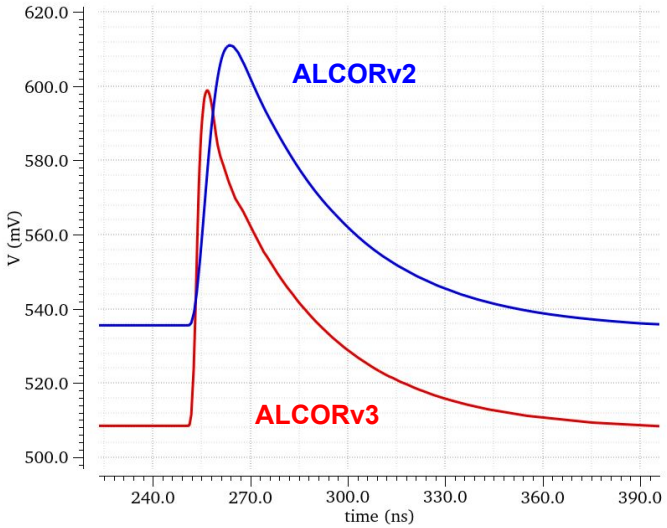
ALCOR v3 - Front-End

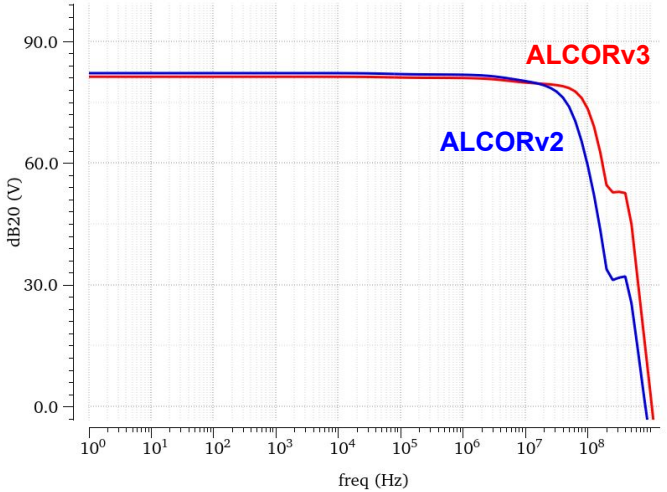
Increased amplifier bandwidth to improve time resolution

- CS amplifier bias transistor with source degeneration to reduce its noise contribution
- Common gate DC current partially subtracted before output stage

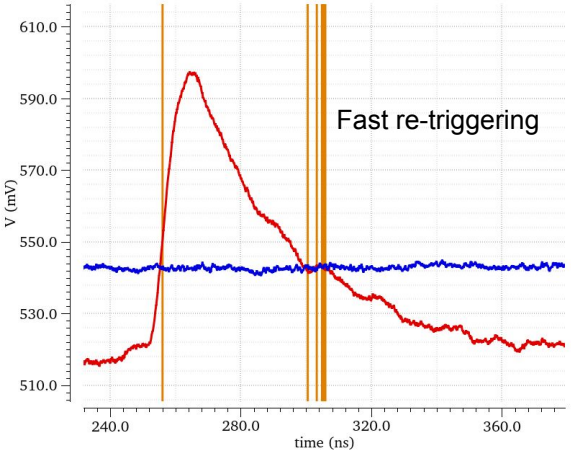
Transient simulation results

- slope: 10 MV/s → 24 MV/s
- rise time: 12.7 ns → 6.4 ns
- ampl: 76 mV → 86 mV
- rmsNoise: 1.4 mV → 2.2 mV
- jitter: 140 ps → 92 ps





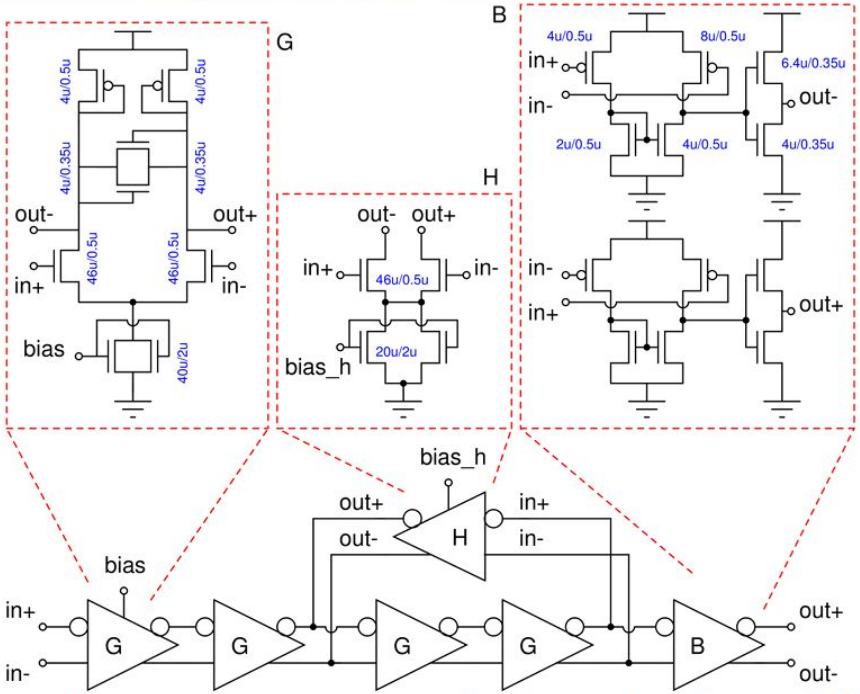
ALCORv2 transient noise sim



- ALCOR LE discriminator derived from design where it was coupled with CFD

➢ Added hysteresis to avoid re-triggering on slow tail with low thresholds
  - PCR3: enable/disable + 2-bit DAC

Fast multistage comparators



Very fast comparators are obtained by cascading low-gain cells. Full CMOS levels generated only in the last stage.

A. Rivetti

Shutter mixed-signal simulation

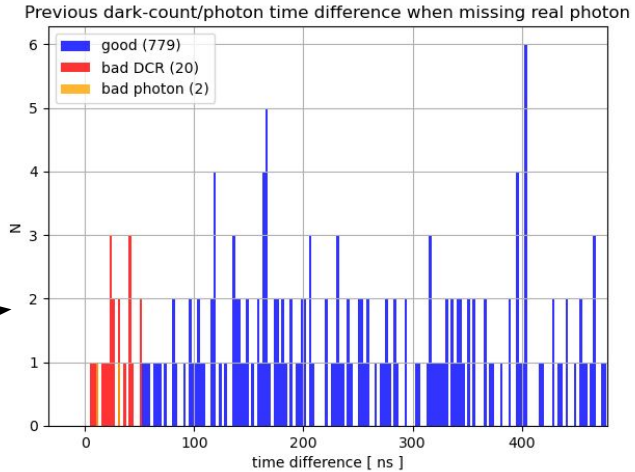
Shutter: periodic test-pulse (width = 2.5 ns)

Spectre netlist simulates different SiPM SPADs:

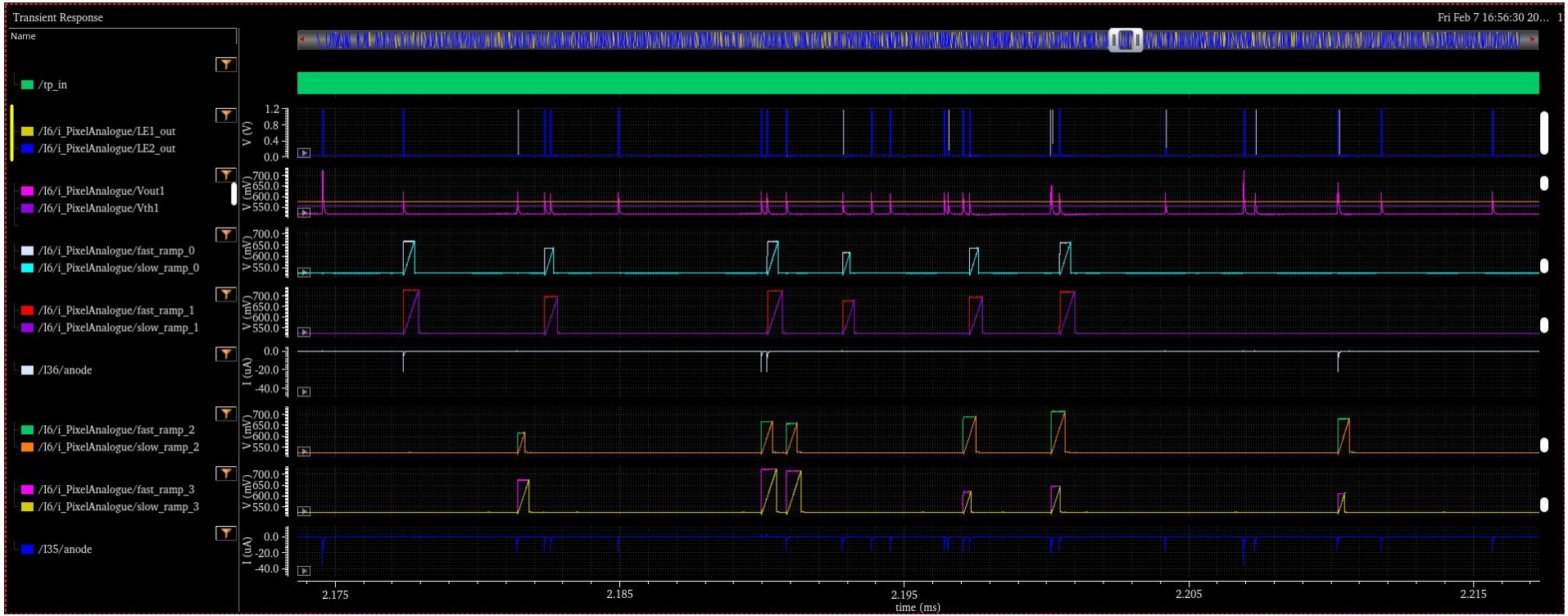
- Each **SPAD** is modeled with a current pulse generator, each with a different period
- **Real photons**: current pulse generators are synchronized with the shutter signal
- **Dark-count signals**: current pulse generators are not synchronized

Decode data, calibrate TDCs (from DCR asynchronous signals), extract ToA, compare with input netlist to evaluate shutter efficiency:

```
Total simulation time = 19532690.640 ns
Total number of dark counts = 10006
Dark count rate = 512.269 kHz
Dark counts cut by shutter: 8411
Dark counts passed through shutter: 1595
Shutter cut: 84.06%
Good events: 842
Missing events: 22
Efficiency: 97.45%
```



Shutter mixed-signal simulation (SlewRate mode)



Shutter efficiency vs DCR (mixed-signal sim)

- Shutter width = 2.5 ns
- Input rate = 20 kHz
- Sim time = 20 ms

Ongoing: digital simulations (with improved DCR and photons signals model) to verify shutter distribution for the whole ALCOR chip and provide better statistics

```
Total simulation time = 19989730.664 ns
Total number of dark counts = 811
Dark count rate = 40.571 kHz

Dark counts cut by shutter: 650
Dark counts passed through shutter: 161
Shutter cut: 80.15%

Good events: 409
Missing events: 1
Efficiency: 99.76%
```

```
Total simulation time = 19962950.756 ns
Total number of dark counts = 1604
Dark count rate = 80.349 kHz

Dark counts cut by shutter: 1309
Dark counts passed through shutter: 295
Shutter cut: 81.61%

Good events: 413
Missing events: 3
Efficiency: 99.28%
```

```
Total simulation time = 19427451.802 ns
Total number of dark counts = 3082
Dark count rate = 158.641 kHz

Dark counts cut by shutter: 2546
Dark counts passed through shutter: 536
Shutter cut: 82.61%

Good events: 388
Missing events: 2
Efficiency: 99.49%
```

```
Total simulation time = 19996870.504 ns
Total number of dark counts = 6325
Dark count rate = 316.299 kHz

Dark counts cut by shutter: 5286
Dark counts passed through shutter: 1039
Shutter cut: 83.57%

Good events: 412
Missing events: 7
Efficiency: 98.33%
```

```
Total simulation time = 19532690.640 ns
Total number of dark counts = 10006
Dark count rate = 512.269 kHz

Dark counts cut by shutter: 8411
Dark counts passed through shutter: 1595
Shutter cut: 84.06%

Good events: 842 (was 40 kHz)
Missing events: 22
Efficiency: 97.45%
```

ALCOR v3 registers

ECCR (4 → 8, one for each column)

- **Pol** (moved from PCR, propagated along the pixel column)
- **Shutter column/sector delay** (4-bit)

PCR3

- Offset1 [15:13]
- OpMode [12:9] - Pixel operation mode
- Offset2 [8:6] → **Disc hysteresis [8:6]**
- Gain [5:4]
- Gain2 [3:2] + Pol[1] + unused[0] → **Shutter pixel delay [3:0]**

Power consumption (I/Os)

LVDS tx: 8 Tx, SDO, clk_out (10)

- DVDD = 1.2 V → 0 uA (static), 30 uA (average), 0 uA (off) — P = 0.036 mW
- DVDDIO = 2.5 V → 4.2 mA (static), 5.5 mA (average), 620 uA (off) — **P = 14 mW**
  - I_{out} = 3.58 mA
  - I_{fb} = 260 uA
  - I_{bias} = 268 uA
  - I_{Rfb} = 25 uA

LVDS rx: reset, clk, tp, SDI, SS, SCLK (6)

- DVDD = 1.2 V → 0 uA (static), 220 uA (average) — P = 0.264 mW
- DVDDIO = 2.5 V → 1.7 mA (static), 1.8 mA (average) — **P = 4.5 mW**
  - I_{bias} = 300 uA + 470 uA + 560 uA + 360 uA

P_{tot} (10 Tx + 6 Rx) = 10 · 14 mW + 6 · 5 mW = **170 mW**

Power consumption (analogue)

Front-End

- AVDD = 1.2 V → 4.4 mA (cg = boost = 15) **P = 5.3 mW**
  - I_{amp} = 3.2 mA (I_{cg}= 86 uA, I_{boost}= 2.6 mA, I_{sub} = 110 uA, I_{mirror} = 50 uA, I_{out}= 190 uA)
  - $I_{bias/tp}$ = 185 uA
  - I_{disc} = 975 uA (+200 uA on DVDD when commuting)
  - I_{dig_buffer} = 0.170 uA

TDC (4 for each pixel)

- AVDD = 1.2 V → 190 uA (single TDC) + 30 uA (bias) **P = 0.950 mW**
- DVDD = 1.2 V → 5 uA (average, single TDC) P = 0.024 mW

Bias_EoC (4 sectors, same as ALCOR v2.1)

- AVDD = 1.2 V → 17 mA (cg = boost = 15) **P = 21 mW**

P_{tot} = 64 · (5.3 mW + 1 mW) + 21 mW = **425 mW** (360 mA) **4 debug output buffers to be added**

ALCOR v2.1 measurements

ALCOR FE-DUAL measurements

- cg=boost=0 I_{ana} = 280 mA I_{dig} = 240 mA
- cg=boost=5 I_{ana} = 324 mA I_{dig} = 240 mA
- cg=boost=10 I_{ana} = 373 mA I_{dig} = 240 mA
- cg=boost=15 I_{ana} = 411 mA I_{dig} = 240 mA
- cg=boost=20 I_{ana} = 440 mA I_{dig} = 240 mA
- cg=boost=25 I_{ana} = 461 mA I_{dig} = 240 mA
- cg=boost=30 I_{ana} = 477 mA I_{dig} = 240 mA

ALCOR v2 has slightly higher I_{ana} due to:

- **Periphery:** EoC bias manages 32 channels, in ALCOR v3 same circuit manages 64 channels (17 mA *vs* 34 mA)
- **Pixel:** FE and discriminator in ALCOR v3 have slightly lower *nominal bias* (0.5 mA / pixel → 32 mA / ALCOR), only one TIA output stage