TIIMM-1: Pixel Analog Design

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Contents

STRONG – TIIMM: strategy & requirements

The TIIMM

The TIIMM (Tracking and Ions Identifications with Minimal Material budget) project in STRONG aims to create a new class of instrument combining precision tracking and energy loss measurement in conditions where minimizing the crossed material is mandatory.

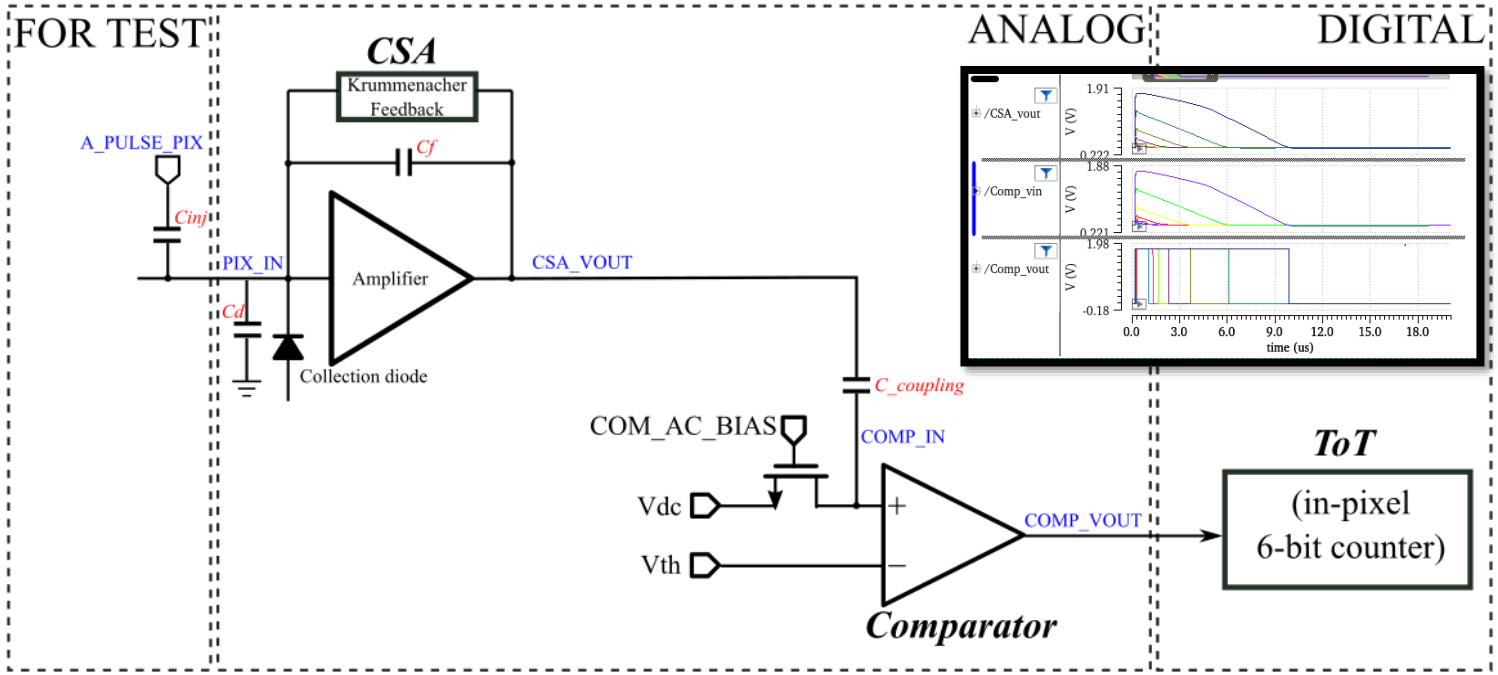
TIIMM-prototype expectations

-TIIMM-prototypes target to establish a pixel architecture allowing to digitize in-pixel the charge collected.

- Prominent difficulty is the dynamic range: signal equivalent charge from 500 e^- to 500 ke^- (possibly reduced to 100-200 ke^- by charge sharing among pixels
- Pixel pitch should be as small as possible, at least smaller that current hybrid-pixel sensors (50 µm pitch).
- 2 to 3 prototypes should help optimize the resolution on the collected charge and the dynamic range
- Prototypes do not investigate the sensor read-out architecture.

TIIMM-1

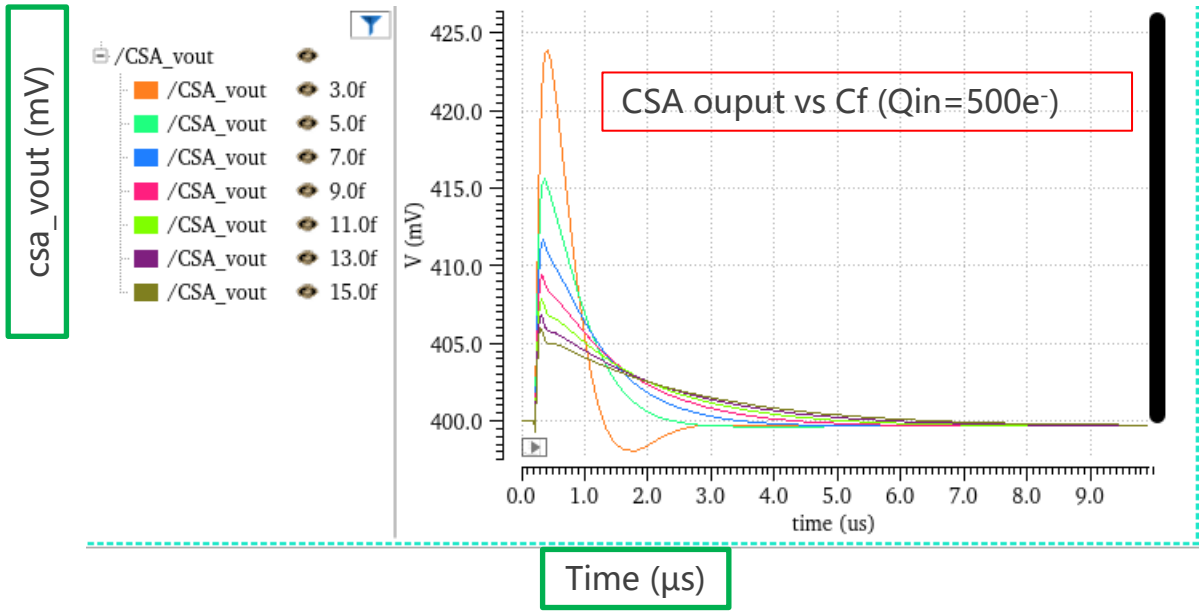
- ✓ CMOS Monolithic Active Pixel Sensor
- ✓ Design in TowerJazz 180 nm process
- ✓ Matrix: 32 (rows) * 16 (columns)
- ✓ Pixel pitch: ≤ 40 μm
- ✓ Analog part in pixel: optimization for better performance
- ✓ Digital part in pixel: use the same readout structure in TIIMM-0
- ✓ The charge is digitized over 6 bits (ToT).

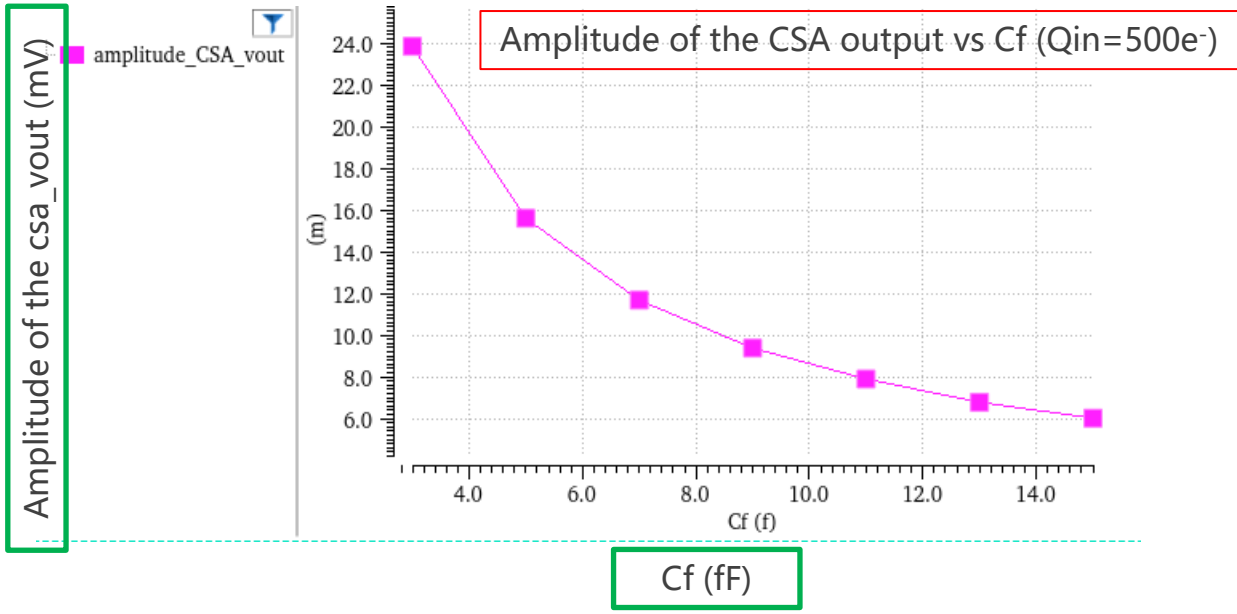


1. AC coupling structure (C_coupling).
2. Optimization of the CSA.
3. Keep the digital readout structure.
4. Remove the 4-bit trimming DAC and the DAC configuration part.

- 《C_{inj}: injection Capacitor, for test》
- 《C_d : detecter Capacitor》
- 《C_f : feedback Capacitor》

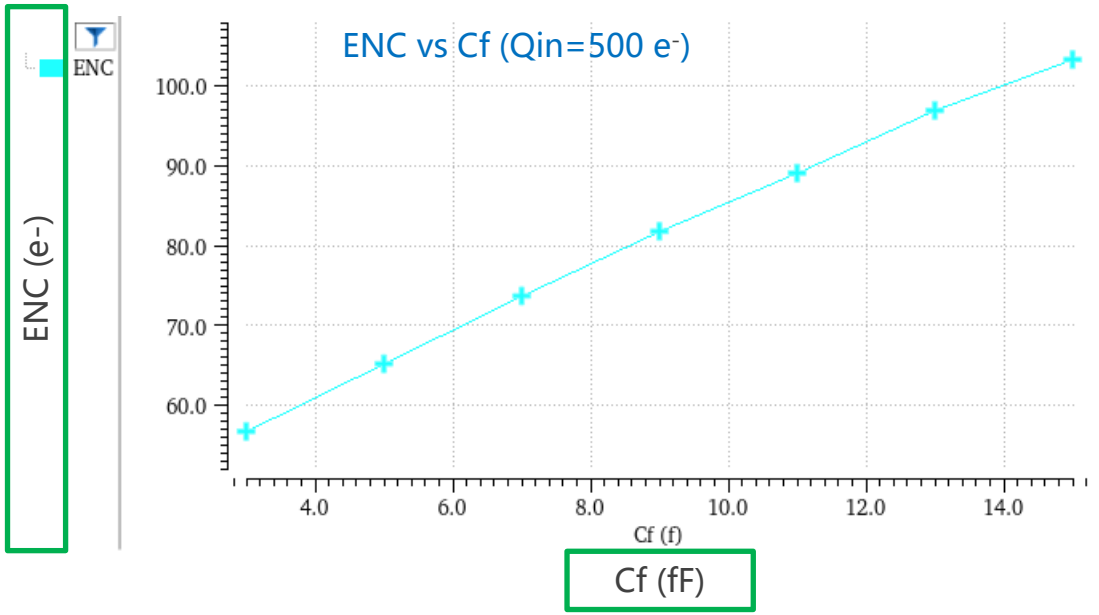
TIIMM-1: CSA performance vs Cf

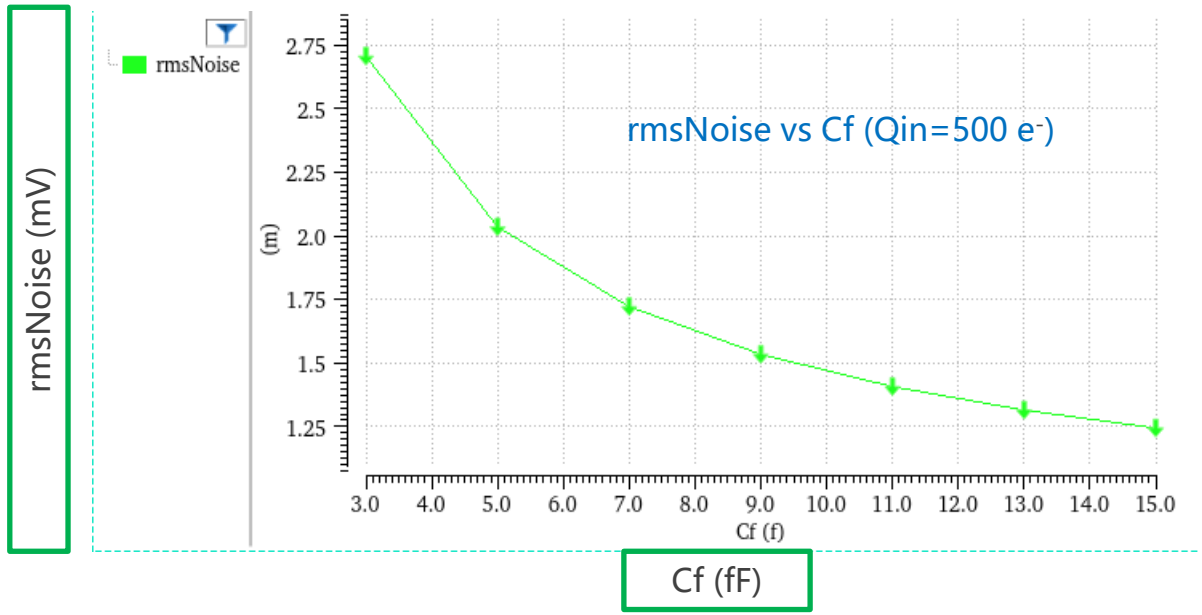




- Cf changes from 3 fF to 15 fF
- The Amplitude of the CSA output decreases with the Cf

TIIMM-1: CSA performance vs Cf

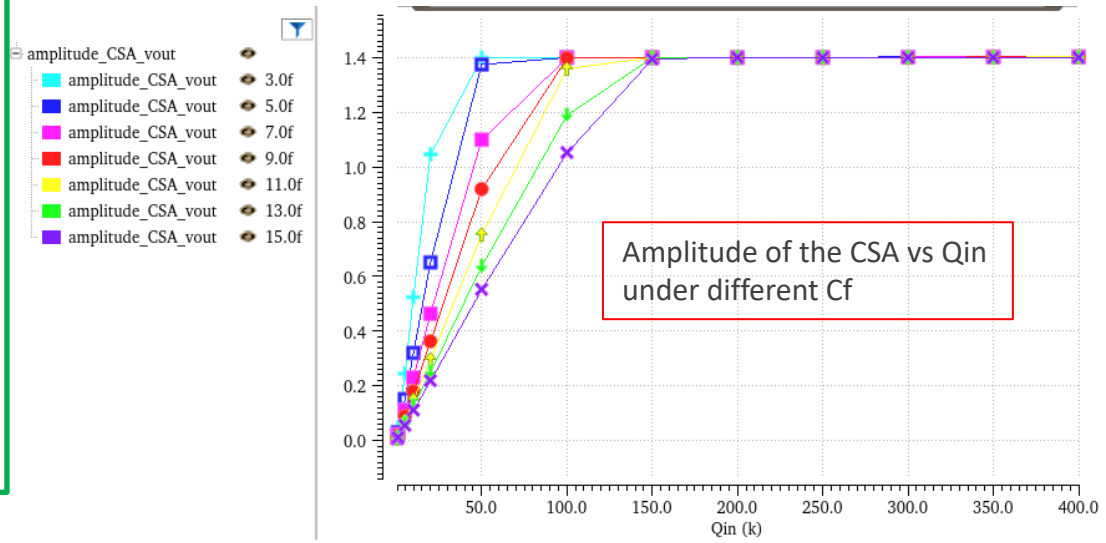




- Cf changes from 3 fF to 15 fF
- The ENC is about 55 e- @Cf=3fF
- The ENC is about 105 e- @Cf=15fF

TIIMM-1: CSA performance vs Cf

Amplitude of the CSA_vout (V)

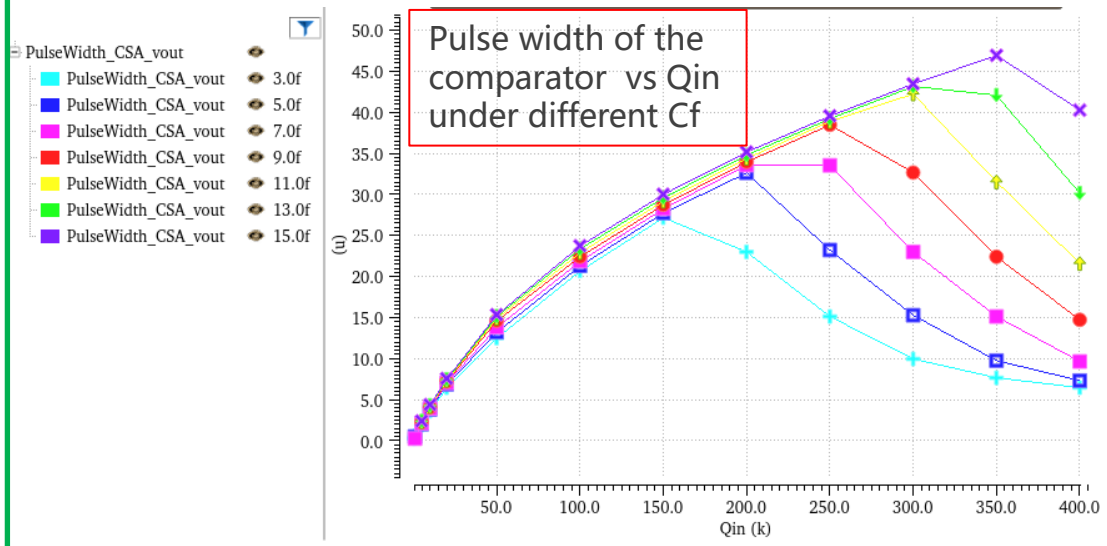


Qin (ke-)

- Cf changes from 3 fF to 15 fF

- The amplitude of the CSA output is linear with Qin= 0~50k e- @Cf=3fF
- The amplitude of the CSA output is linear with Qin= 0~150k e- @Cf=15fF

Pulse width of the CSA (µS)



Qin (ke-)

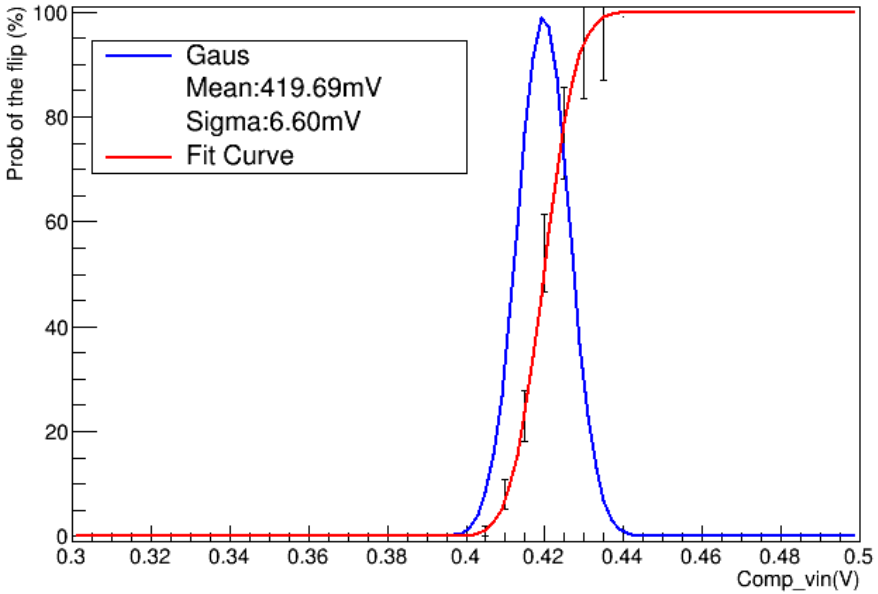
- Cf changes from 3 fF to 15 fF

- The pulse width of the CSA output is linear with Qin= 0~150k e- @Cf=3fF
- The pulse width of the CSA output is linear with Qin= 0~350k e- @Cf=15fF

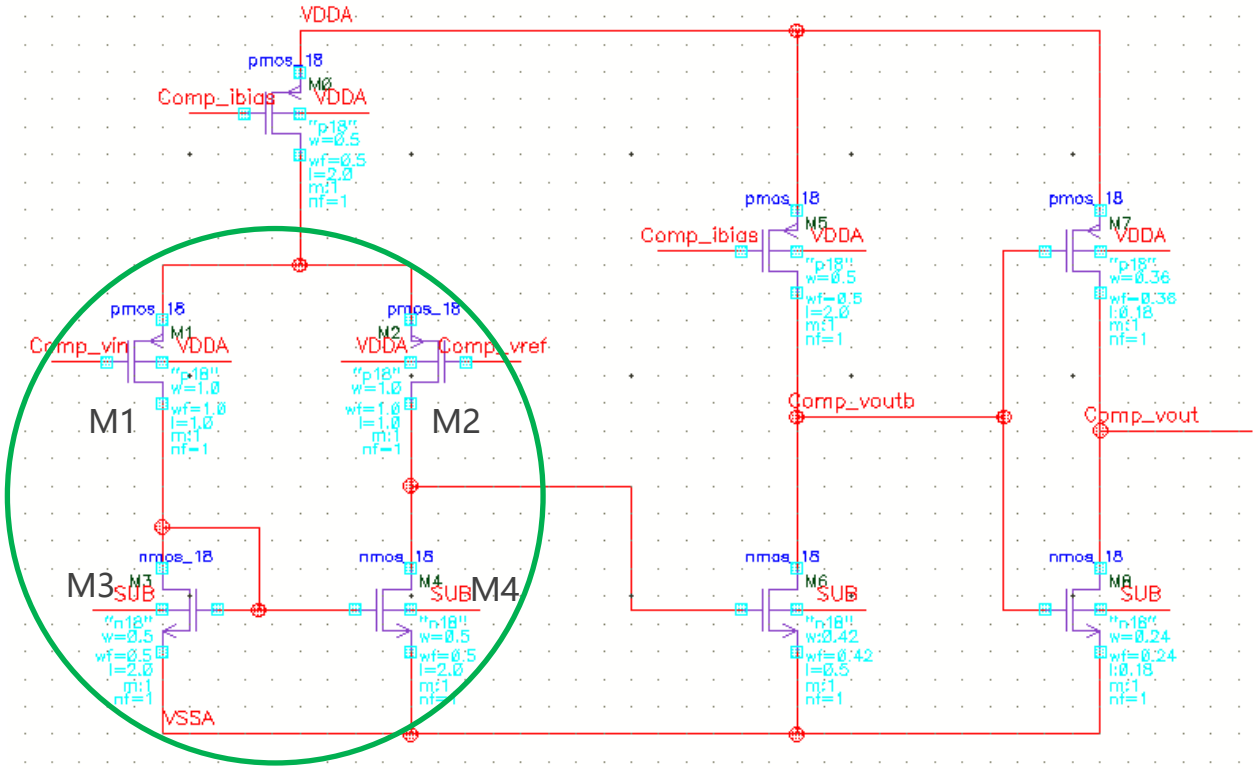
TIIMM-1: comparator offset simulation

Comp_vin/V	Prob of the flip(%)
0.40	0
0.405	1
0.41	8
0.415	23
0.42	54
0.425	77
0.43	93
0.435	97
0.44	99
0.45	100

Comp_vref=0.42V
In the Monte Carlo simulation , the number of points is100, we calculate the probability of the flips.



Comparator offset: 6.6 mV



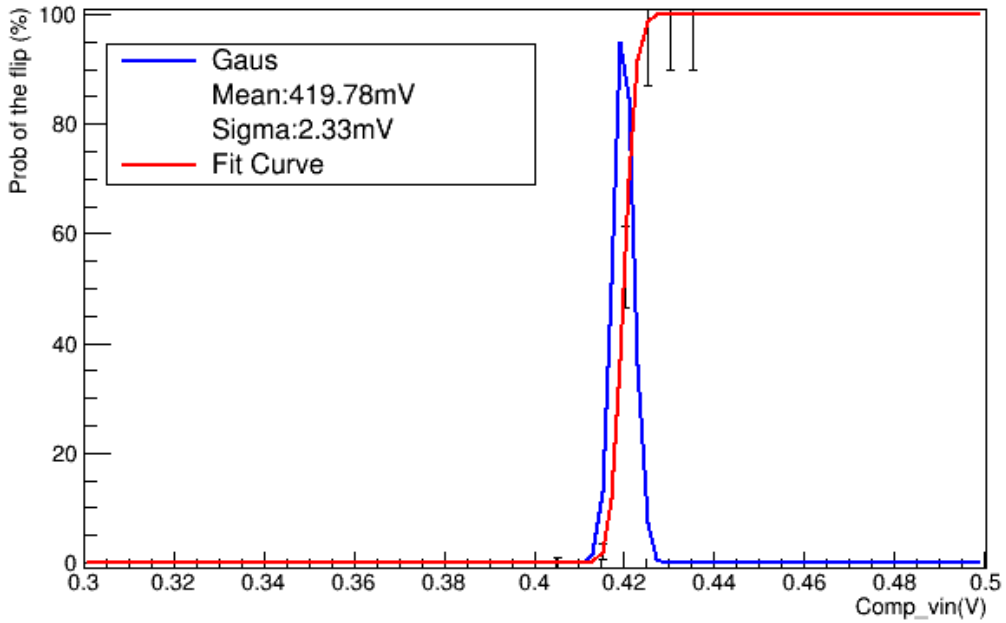
Comparator schematic in TIIMM-1

After simulation, we get the contribution of the transistors for the offset. The transistors M1~M4 contribute the most for the offset of the comparator.

TIIMM-1: comparator offset simulation

Change:
M1-M2 from 1/1 to 1/10
M3-M4 from 0.5/2 to 2/10

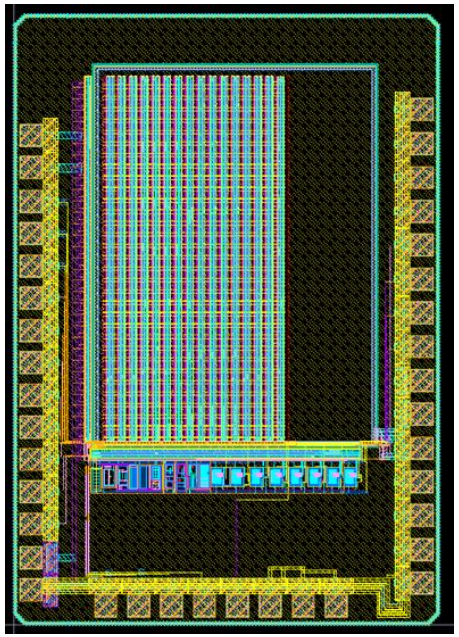
Comp_vin/V	Prob of the flip(%)
0.40	0
0.405	0
0.41	0
0.415	2
0.42	54
0.425	97
0.43	100
0.435	100
0.44	100
0.45	100



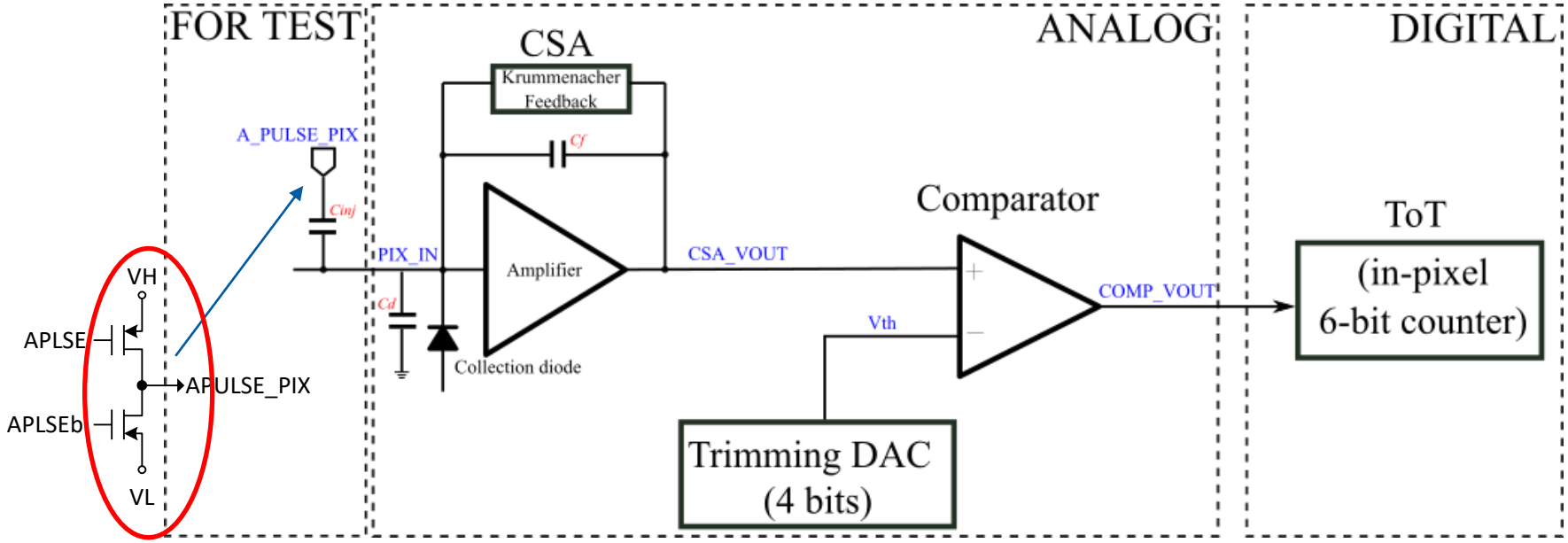
Comparator offset: 2.33 mV

To reduce the offset from 6.6 mV to 2.33 mV, the transistor area is more than 10 times larger than the last one.

TIIMM-0



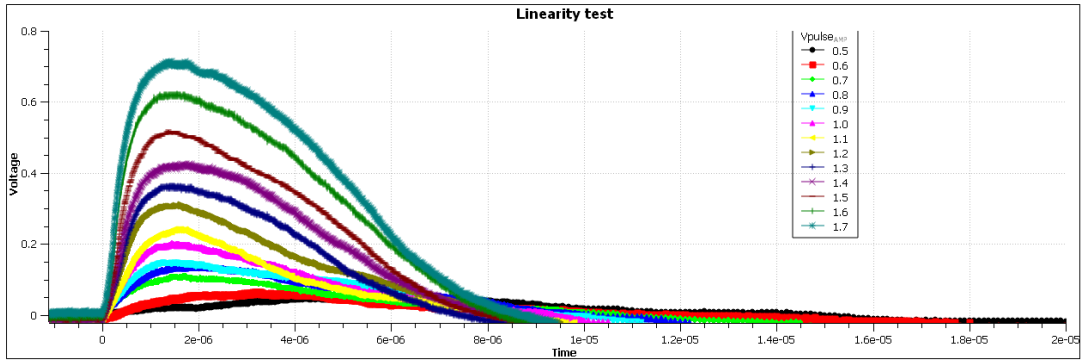
TIIMM0 sensor layout



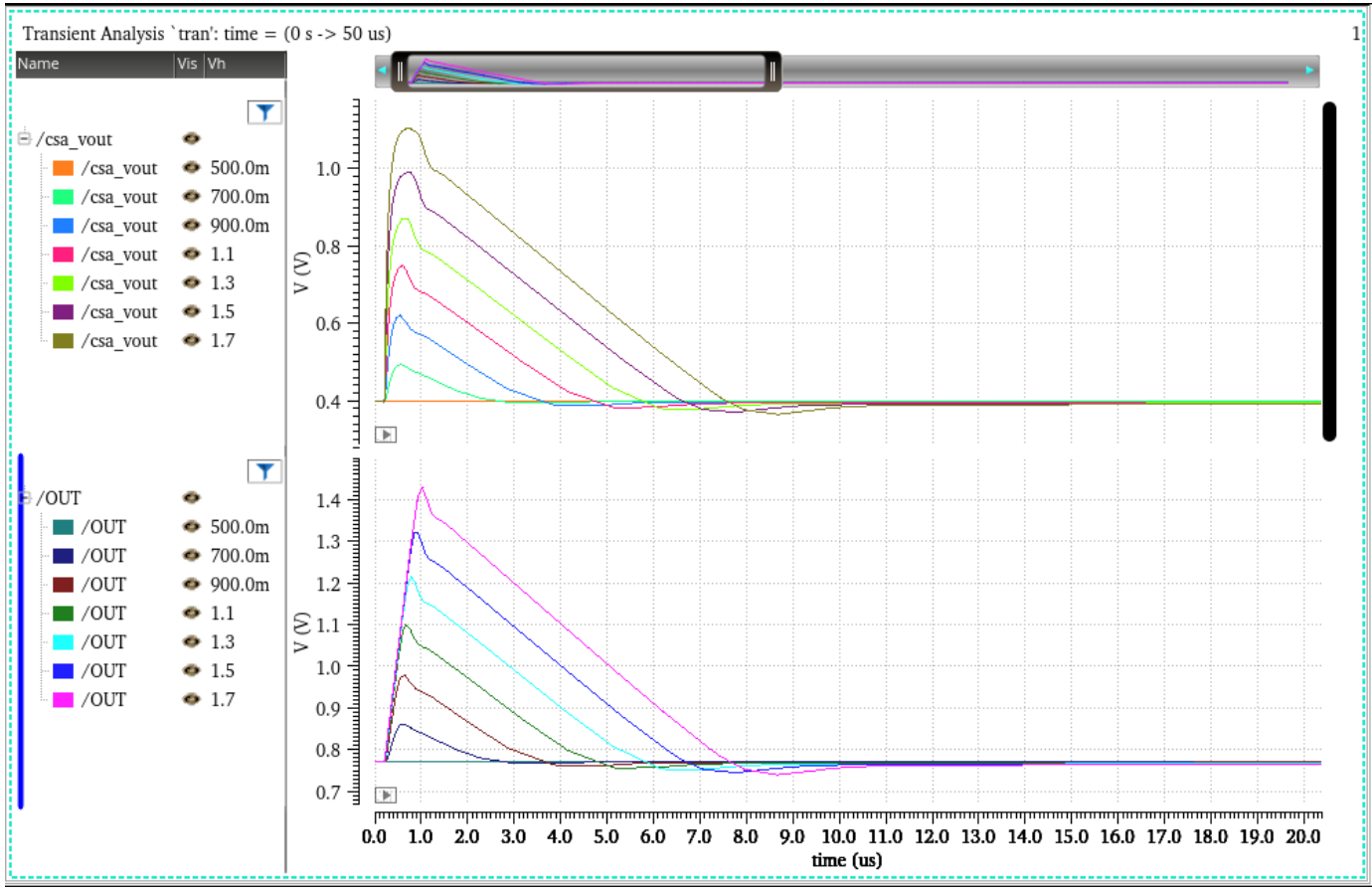
- **CMOS Monolithic Active Pixel Sensor**
- **Design in TowerJazz 180 nm process**
- **Submitted in March, 2020**
- **Chip area: 2.2 mm * 1.5 mm**
- **Matrix: 32 (rows) * 16 (columns)**
  (the last column has the analog output for test)
- **Pixel pitch: 40 µm**
- **Position and energy measurements**

- **TOT (6 bits)** – 6 bits register in pixel
- **Trimming DAC (4 bits) -** for threshold adjustment
- **Possibility to mask pixels**

TIIMM-0: CSA with Analog buffer simulation

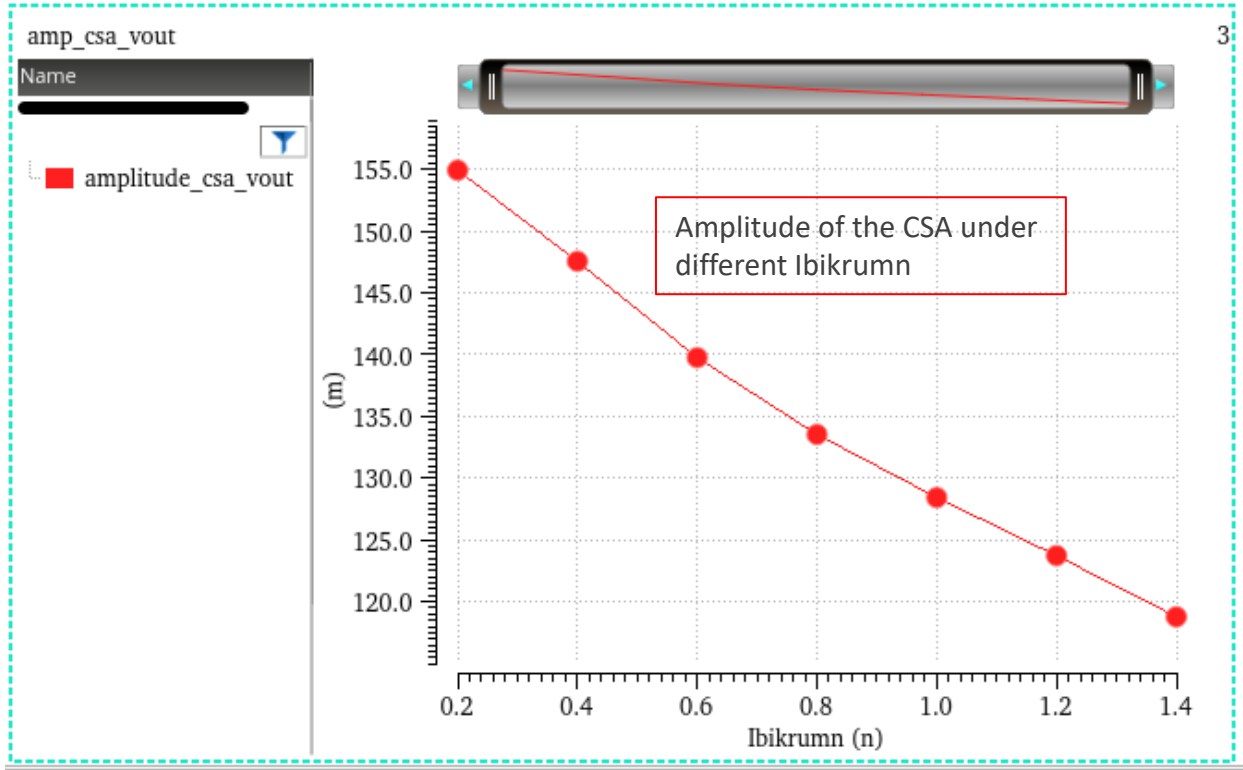


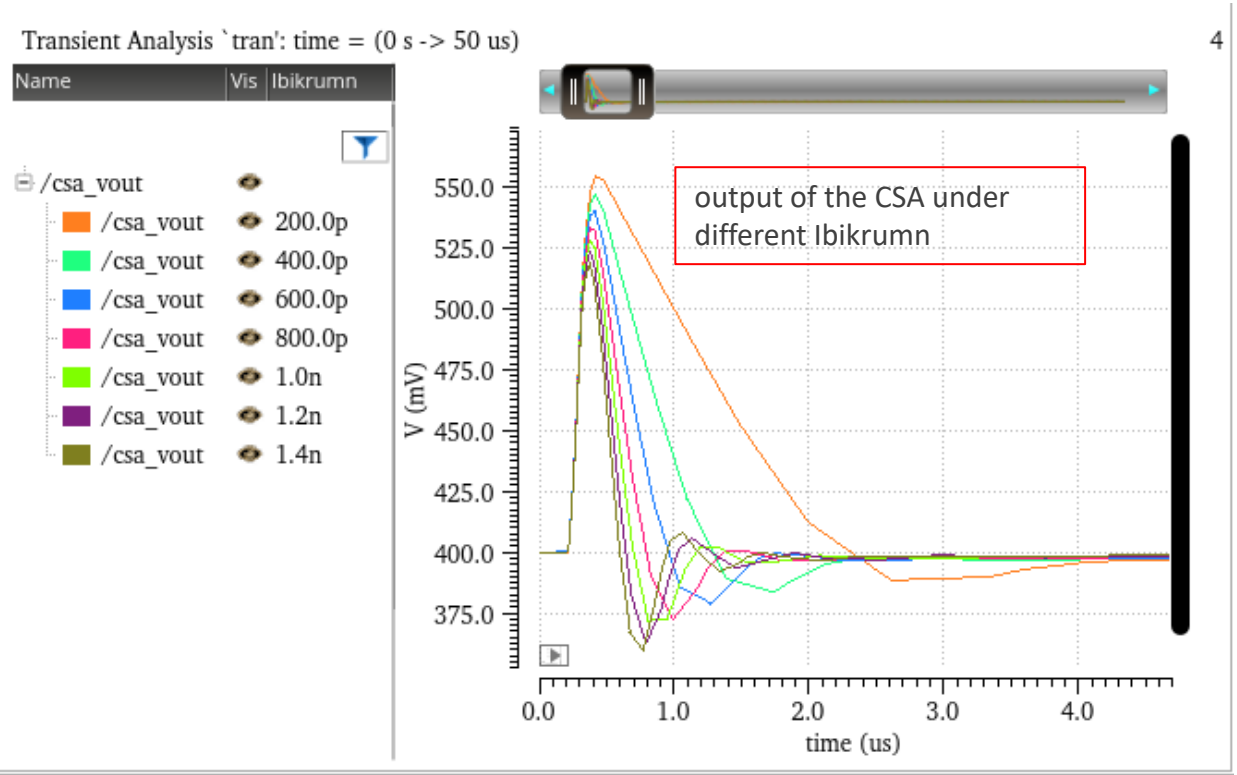
Test result in TIIMM-0



The bias current Ibikrumn in the Krumn feedback circuit influences the pulse width of the CSA a lot. The default value is 0.8nA.
And if we set this value at 0.16nA, the output will be like the picture above, the pulse width is about 8 us (@VL=0.5V, VH=1.7V), which is similar to the result we got in the test.

TIIMM-0: CSA with Analog buffer simulation





The bias current Ibikrumn in the Krumn feedback circuit influences both the gain and pulse width of the CSA.
With the increase of the Ibikrumn, the gain will decrease a little.
The default value is 0.8nA.

Summary

- Cf changes from 3 fF to 15 fF: the ENC is about 55 e- (@Cf=3fF) and 105 e- (@Cf=15fF)
- The amplitude of the CSA output is linear with Qin= 0~50k e- (@Cf=3fF) and linear with Qin= 0~150k e- (@Cf=15fF)
- The pulse width of the CSA output is linear with Qin= 0~150k e- (@Cf=3fF) and linear with Qin= 0~350k e- (@Cf=15fF)
- The offset of the comparator could be reduce from 6.6 mV to 2.33mV by increasing the transistors M1-M2 from 1/1 to 1/10 and M3-M4 from 0.5/2 to 2/10.
- In TIIMM-0, the bias current Ibikrumn in the Krumn feedback circuit influences the pulse width of the CSA a lot. We can get similar results in the simulation as that in the test by set this value at 0.16nA(default value is 0.8nA)

Thanks!