TIIMM-0/1: Test and design report

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Contents

STRONG – TIIMM: strategy & requirements

The TIIMM

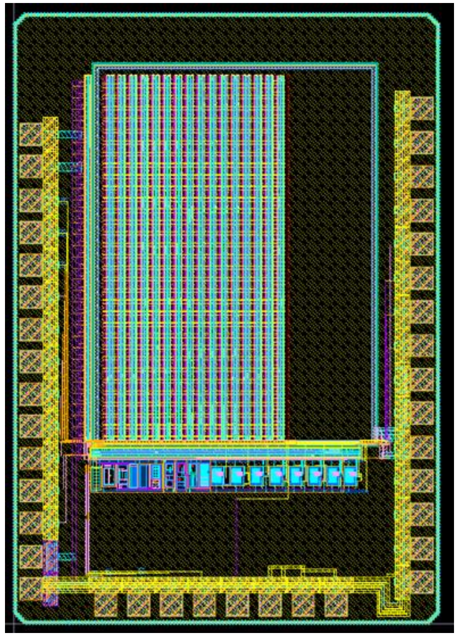
The TIIMM (Tracking and Ions Identifications with Minimal Material budget) project in STRONG aims to create a new class of instrument combining precision tracking and energy loss measurement in conditions where minimizing the crossed material is mandatory.

TIIMM-prototype expectations

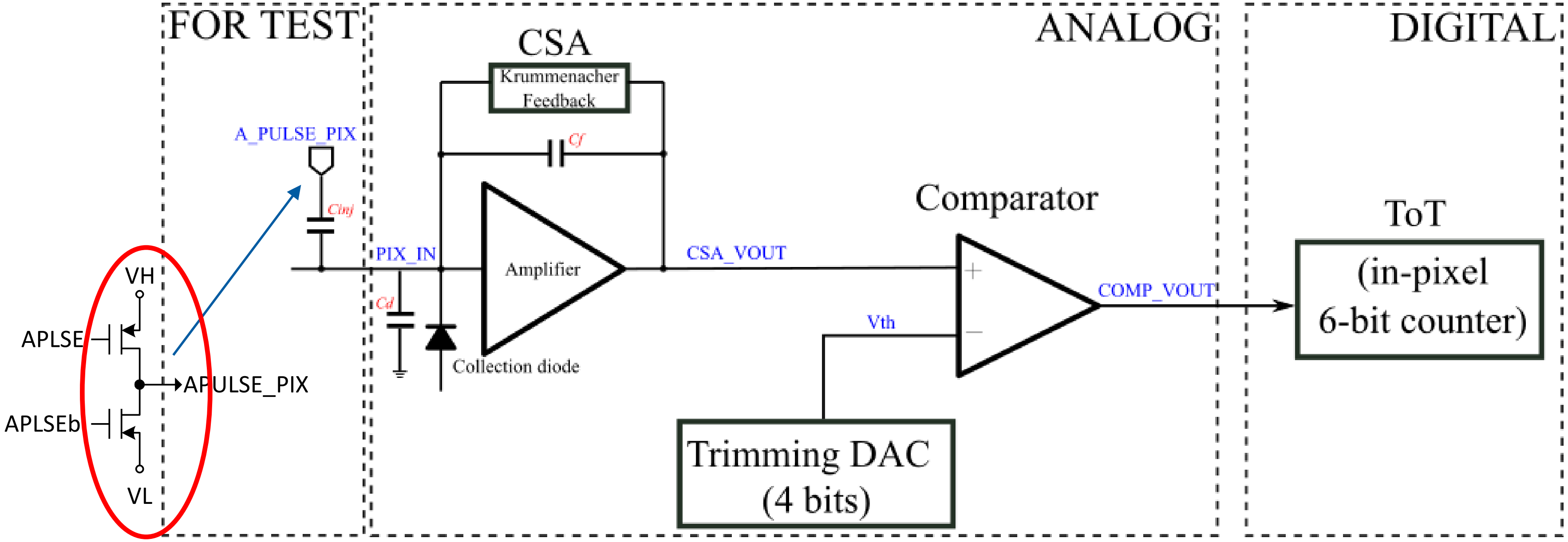
-TIIMM-prototypes target to establish a pixel architecture allowing to digitize in-pixel the charge collected.

- 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-0



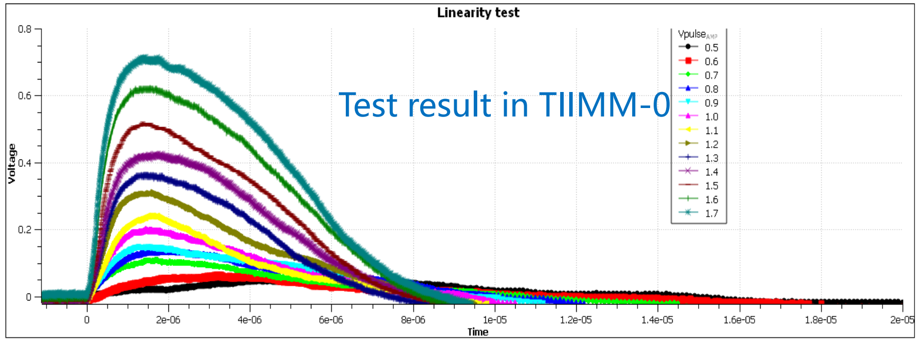
TIIMM0 sensor layout

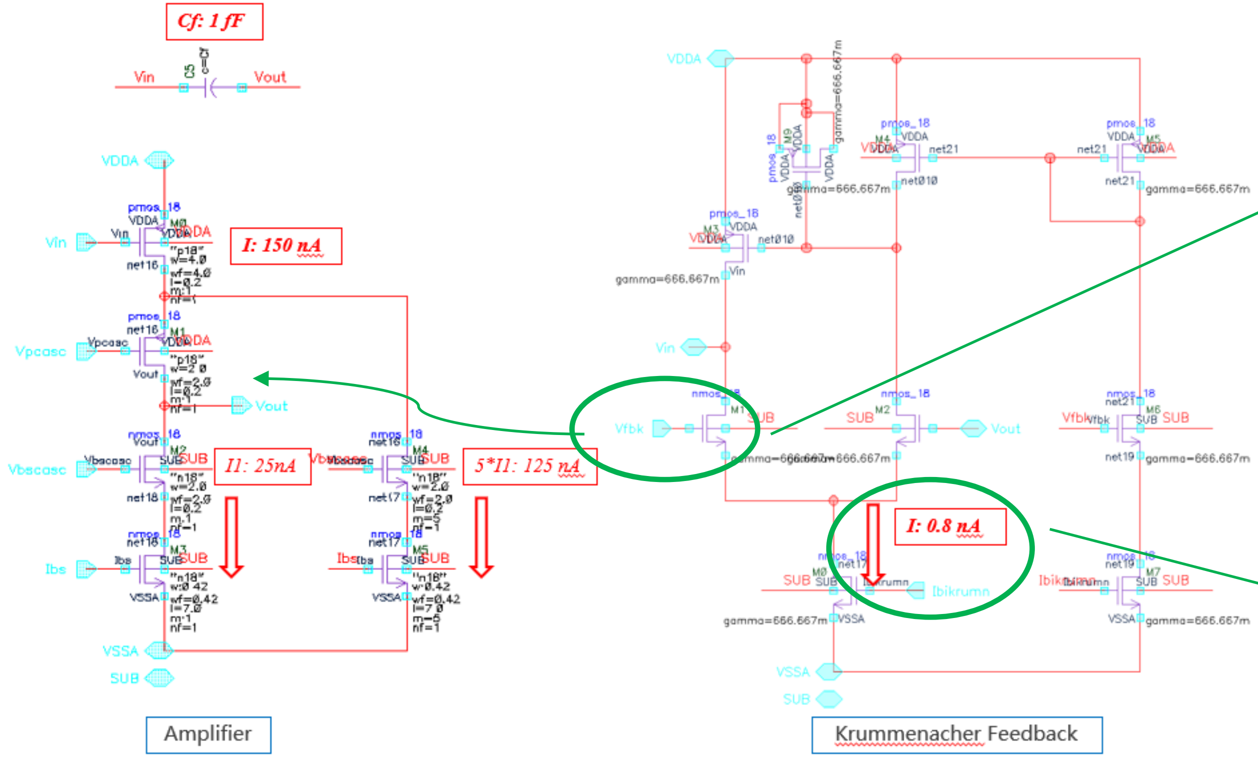


- **CMOS Monolithic Active Pixel Sensor**
- **Design in TowerJazz 180 nm process**
- **Submitted in March, 2020**
- **Chip area: 2.2 mm * 1.5 mm**
- **Matrix: 32 (rows) * 16 (columns)**
  (the last column has the analog output for test)
- **Pixel pitch: 40 µm**
- **Position and energy measurements**

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

TIIMM-0: test problems



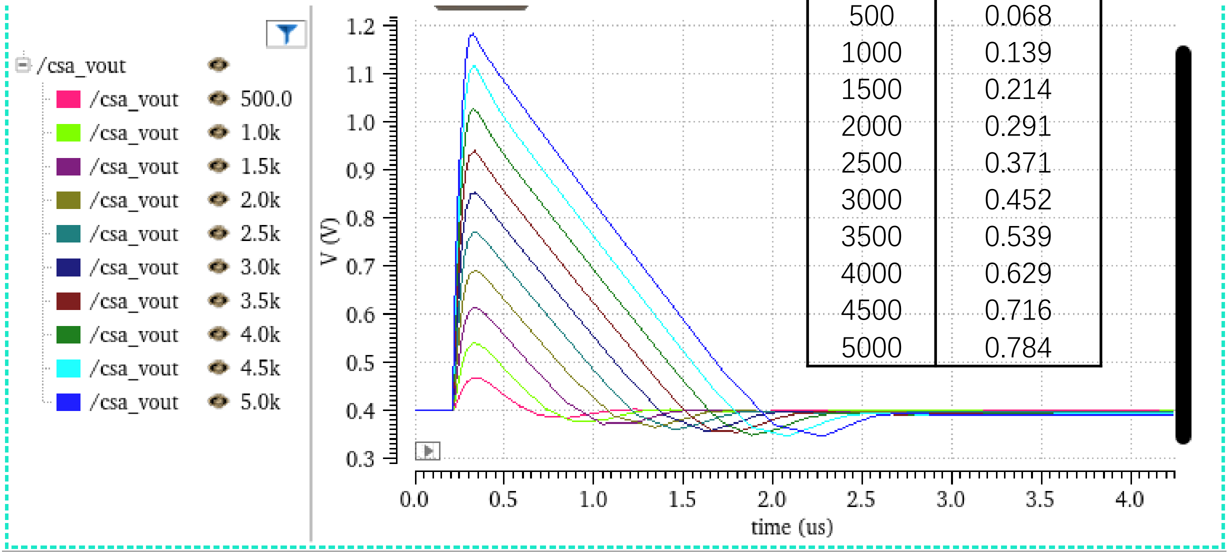


- The bias voltage Vfbk provide the baseline for the CSA output.
- The default value is 0.4 V.
- If we set this value at about 150 mV, the pulse width will be large and we can see the long overshot problem.
- The performance in the simulation is consistent with that in the test.
- In the following test, we increase the Vfbk at a large value.

- 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 pulse width is about 8 us (@VL=0.5V, VH=1.7V).

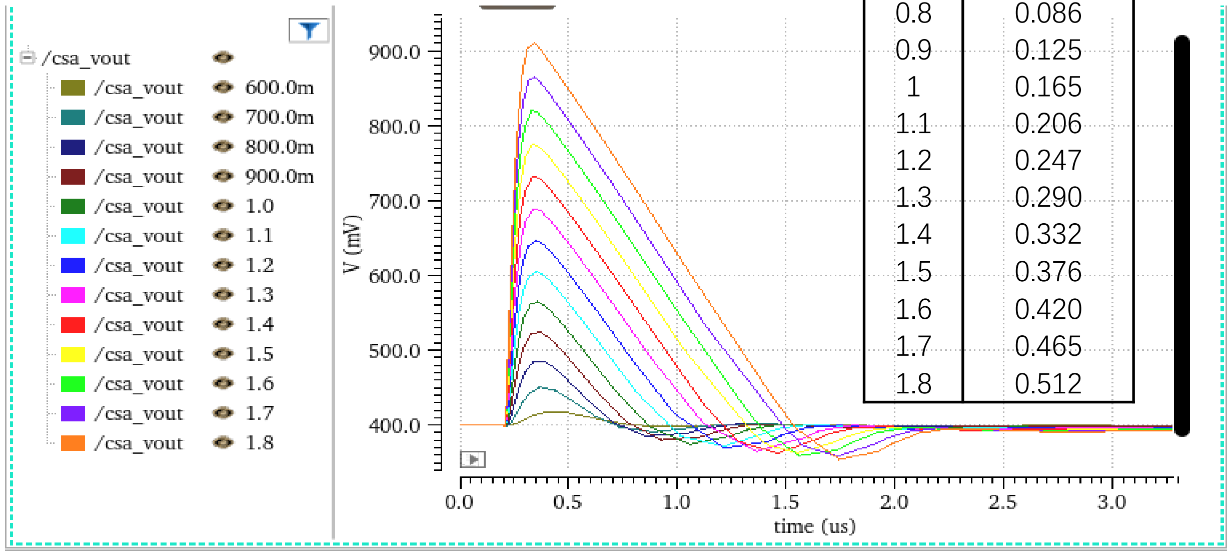
TIIMM-0: CSA simulation result @Ibikrumn=0.8nA

Qin/e-	Amplitude/V
500	0.068
1000	0.139
1500	0.214
2000	0.291
2500	0.371
3000	0.452
3500	0.539
4000	0.629
4500	0.716
5000	0.784



CSA ouput vs Qin

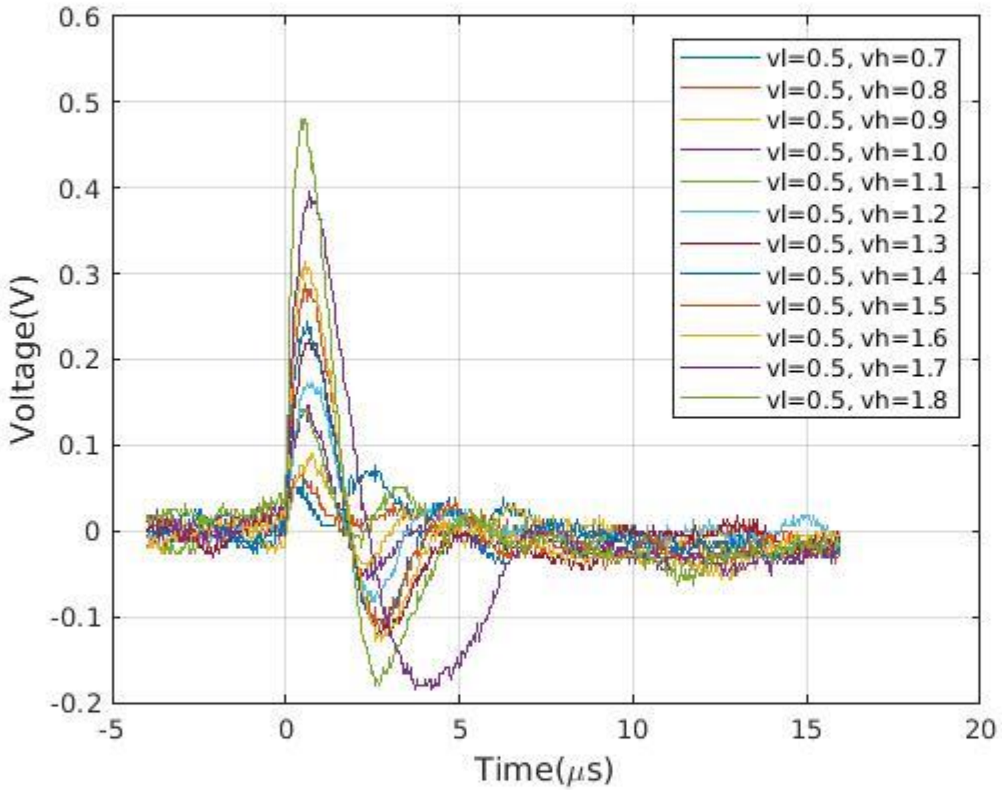
Vh/V	Amplitude/V
0.6	0.018
0.7	0.051
0.8	0.086
0.9	0.125
1	0.165
1.1	0.206
1.2	0.247
1.3	0.290
1.4	0.332
1.5	0.376
1.6	0.420
1.7	0.465
1.8	0.512



CSA ouput vs vh, vl=0.5V

From the simulation results, we can predict that Qin is about 3.5 ke- @vh=1.8V, vl=0.5V
The pulse width can reach 1.5 us (vh=1.8V, vl=0.5V) @ Ibikrumn=0.8 nA

TIIMM-0: test result vs vh @Ibikrumn=0x82

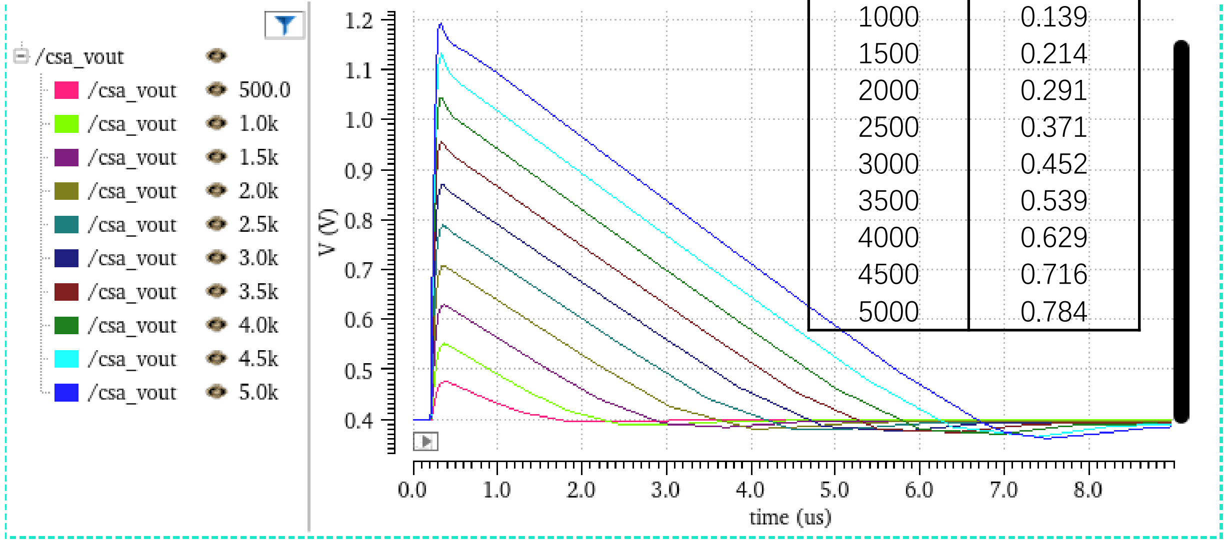


@Ibikrumn=0x82

- the pulse width is below 2 us.
- The overshot problem is obvious and it is difficult to see the linearity of the pulse width with vh.
- In the next test, we decrease the current of Ibikrumn to 0x20 to get a larger pulse width.

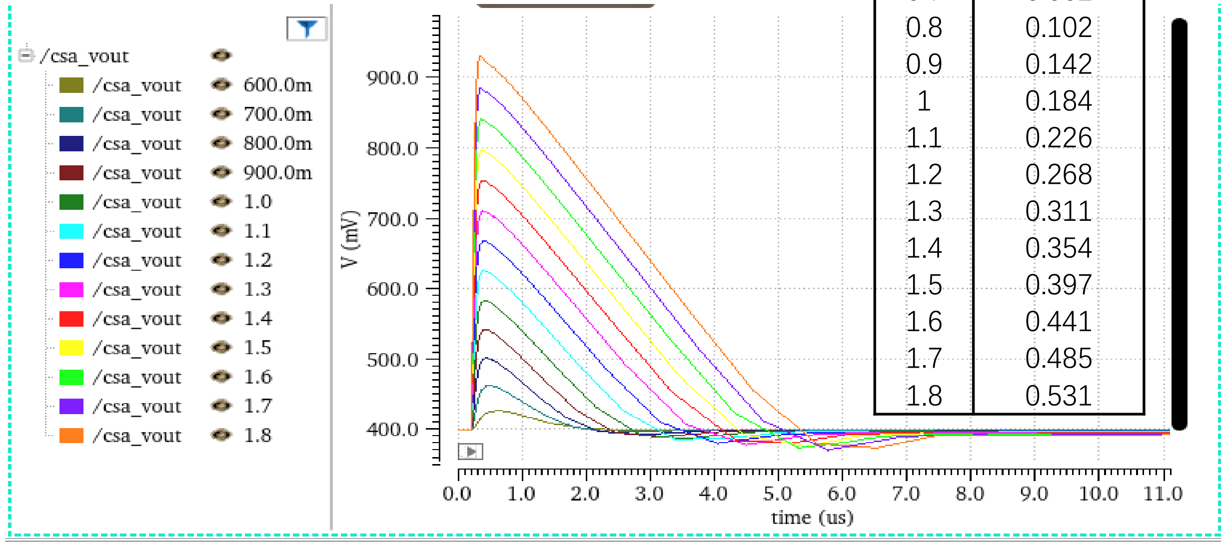
TIIMM-0: CSA simulation result @Ibikrumn=0.2nA

Qin/e-	Amplitude/V
500	0.068
1000	0.139
1500	0.214
2000	0.291
2500	0.371
3000	0.452
3500	0.539
4000	0.629
4500	0.716
5000	0.784



CSA ouput vs Qin

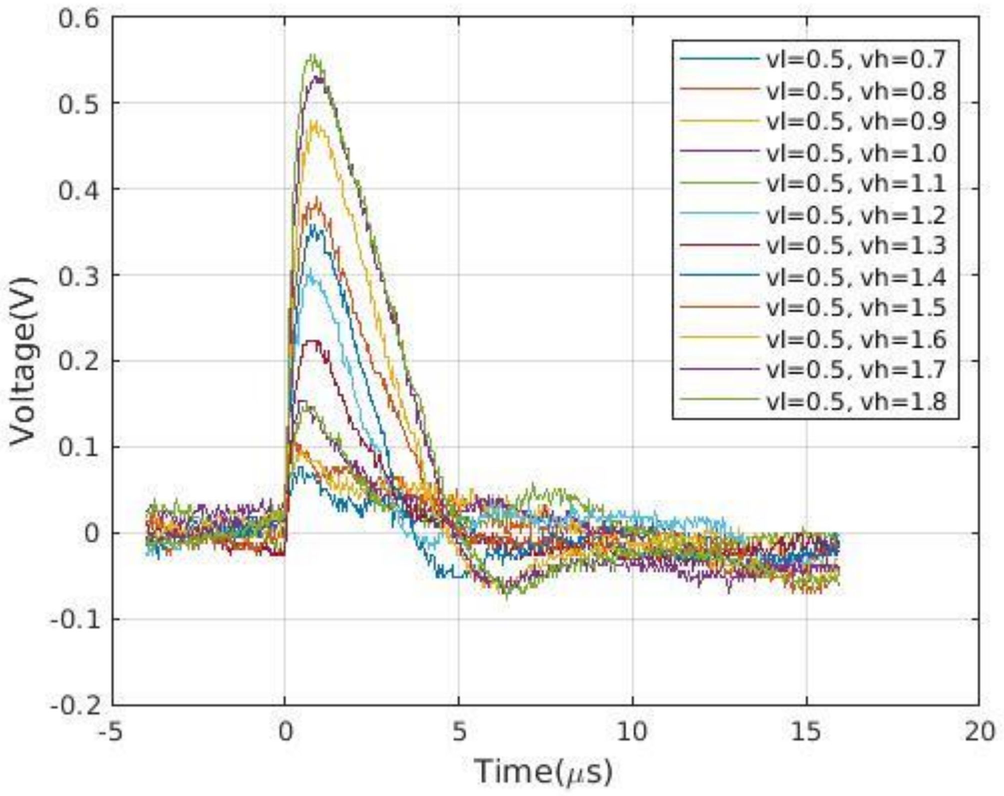
Vh/V	Amplitude/V
0.6	0.026
0.7	0.062
0.8	0.102
0.9	0.142
1	0.184
1.1	0.226
1.2	0.268
1.3	0.311
1.4	0.354
1.5	0.397
1.6	0.441
1.7	0.485
1.8	0.531



CSA ouput vs vh, vl=0.5V

- From the simulation results, we can predict that Qin is about 3.5 ke- @vh=1.8V, vl=0.5V
- The pulse width can reach 5 us (vh=1.8V, vl=0.5V) @ Ibikrumn=0.2nA

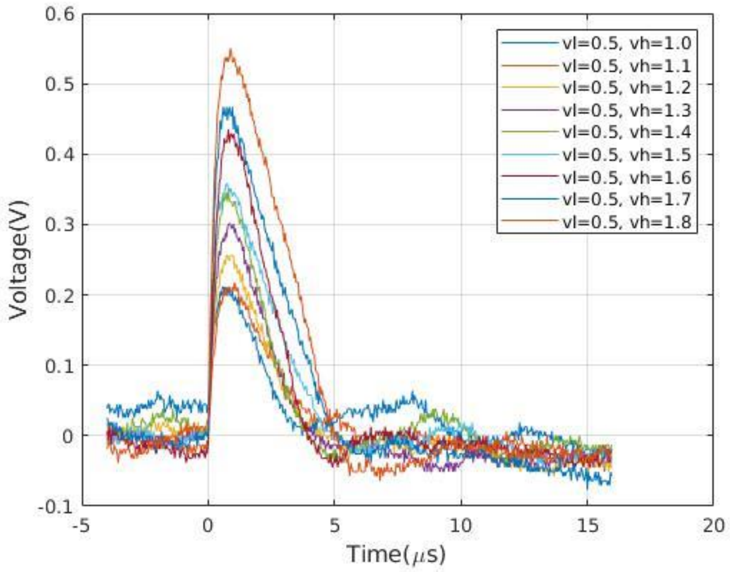
TIIMM-0: test result vs vh @Ibikrumn=0x20

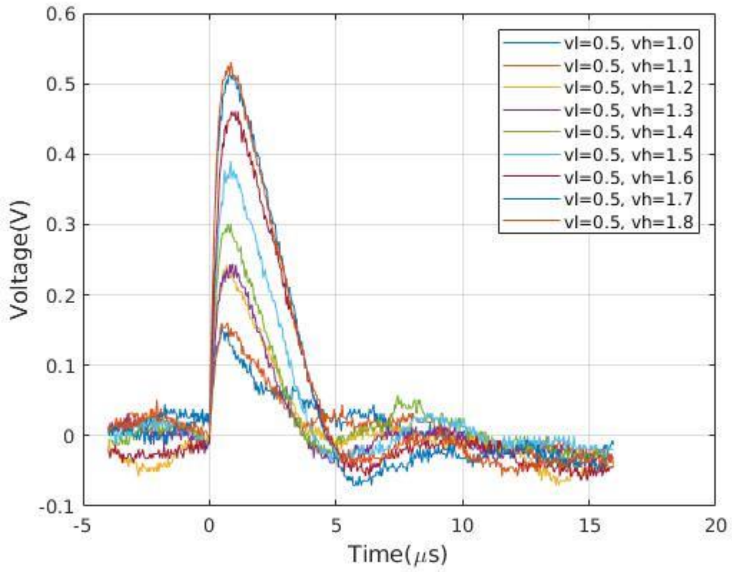


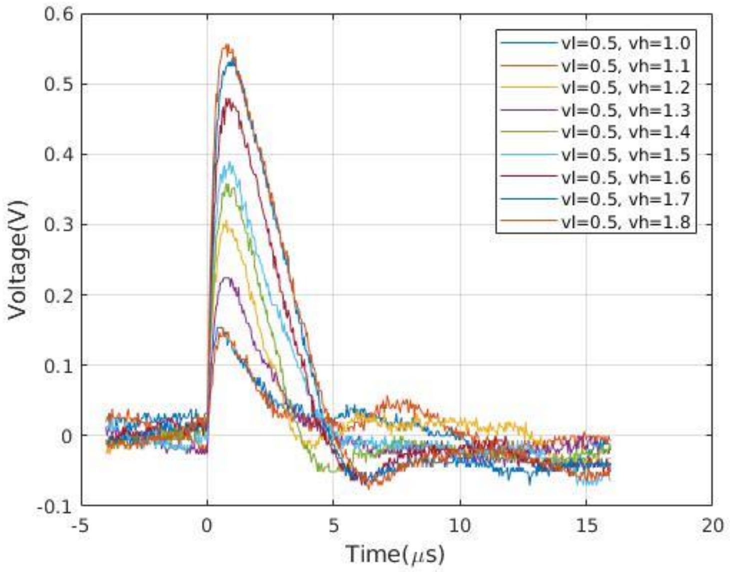
@Ibikrumn=0x20

- the pulse width is below 5 us.
- The overshot problem is better than the previous one.
- The pulse width is almost the same at some different points.

TIIMM-0: CSA output vs Vh

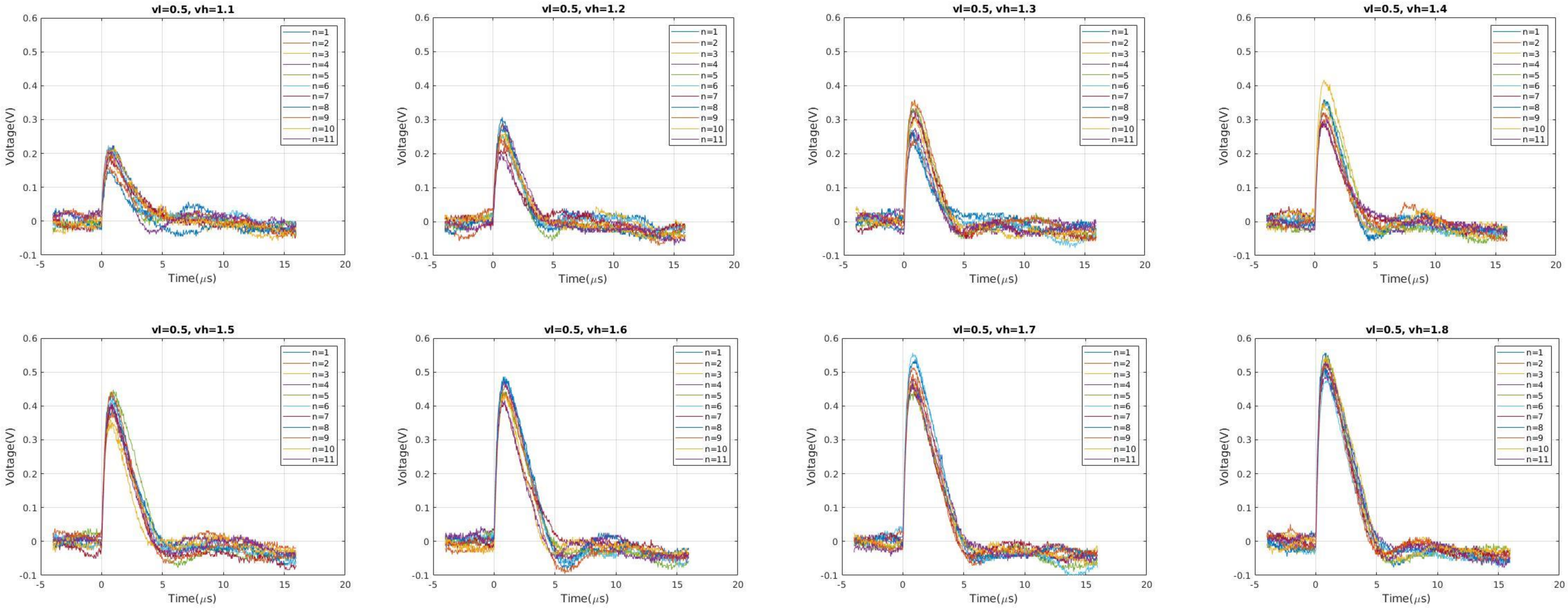






- In this test, Ikrumm=0x20, so the pulse width is larger, can reach 5 us.
- The 3 pictures above are from 3 tests at different time.
- The pulse width is almost the same at different vh sometimes.

TIIMM-0: 11 plots of CSA output at same vh



We can see that the dispersion of the amplitude and pulse width of the CSA output is large in the test result.

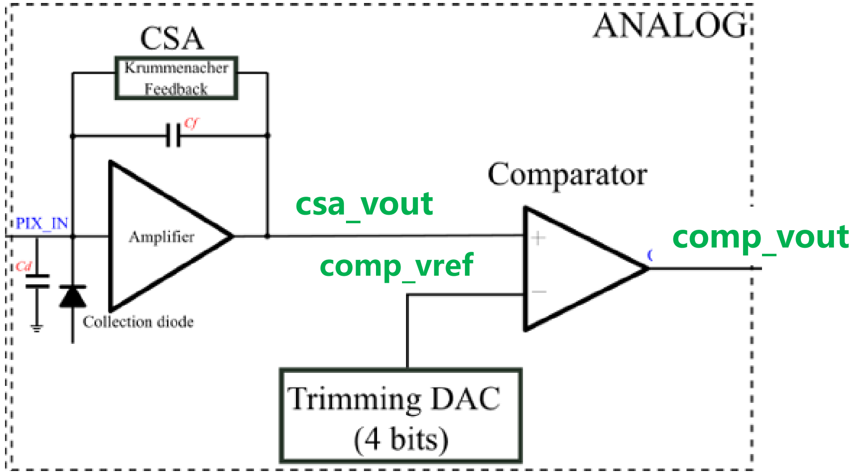
TIIMM-0: Performance of the analog pixel

csa_vout	Qin/ke-	0.5	1	2	5	10	50	100	200
	Mean/ns	296	473.9	845.5	1818	3117	8994	12590	2144
	Sigma/ns	80.94	175.4	339.3	736.8	1247	2785	3040	388.3
	Sigma/Me	27.34%	37.01%	40.13%	40.53%	40.01%	30.97%	24.15%	18.11%

When the Qin is over 100 ke-, for example, @200 ke-, the pulse width decreases with Qin.

- (TIIMM-0 Schematic Simulation)Pulse width of CSA output from Monte Carlo Simulation, Pulse width spread vs Qin(500 e-~200k e-)

threshold: baseline of CSA output + 20mV



csa_vout	Qin/ke-	0.5	1	2	5	10	50	100	200
	Mean/ns	395.8	490.1	751	1434	2208	6274	9810	4083
	Sigma/ns	85.03	115.4	228.2	474	749.1	2023	2882	840.8
	Sigma/Me	21.48%	23.55%	30.39%	33.05%	33.93%	32.24%	29.38%	20.59%

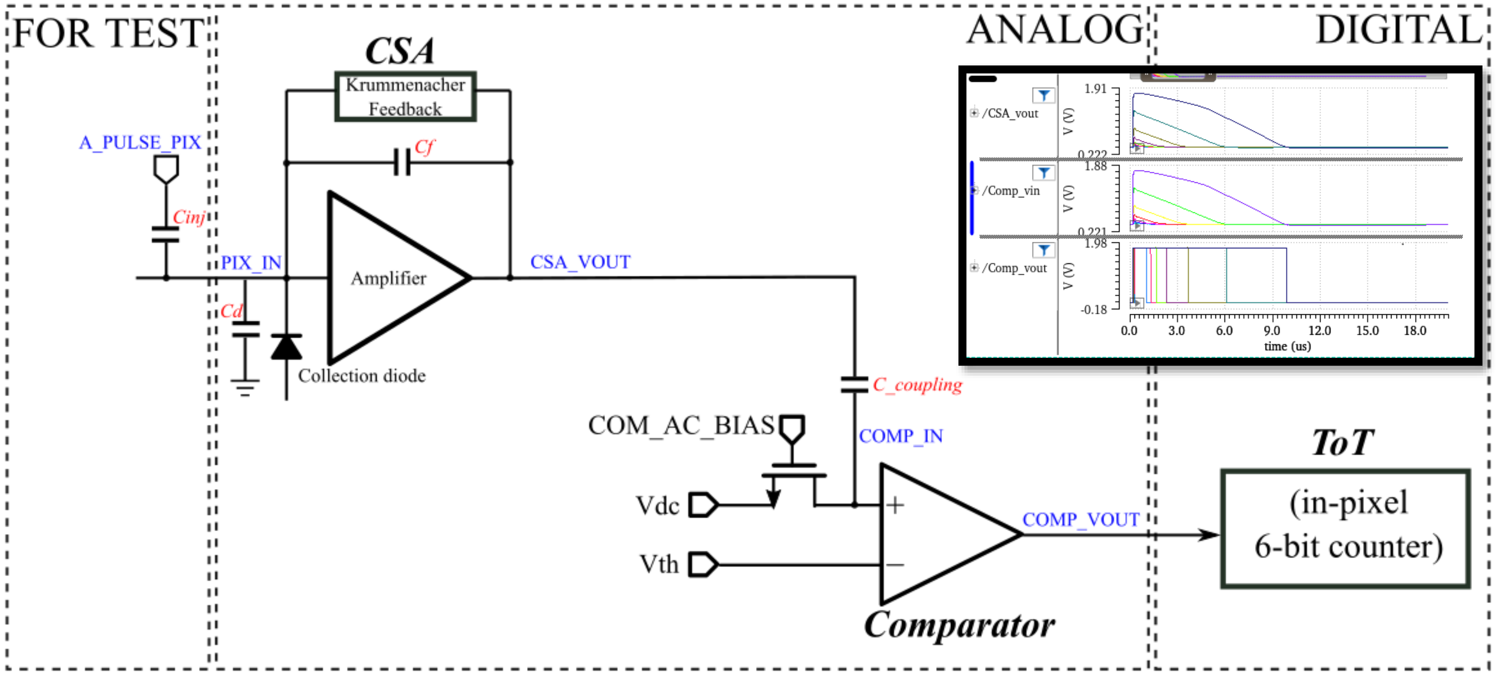
- (TIIMM-0 Layout Simulation)Pulse width of CSA output from Monte Carlo Simulation, Pulse width spread vs Qin(500 e-~200k e-)

threshold: baseline of CSA output + 20mV

Note:
The spread of the baseline of CSA is large.
Sometimes the baseline is much higher/lower than the comp_vref , so there are some calculation mistakes in the Monte Carlo simulation for the pulse width of the comp_vout. Therefore, only the result of pulse width spread of CSA is given.

TIIMM-1

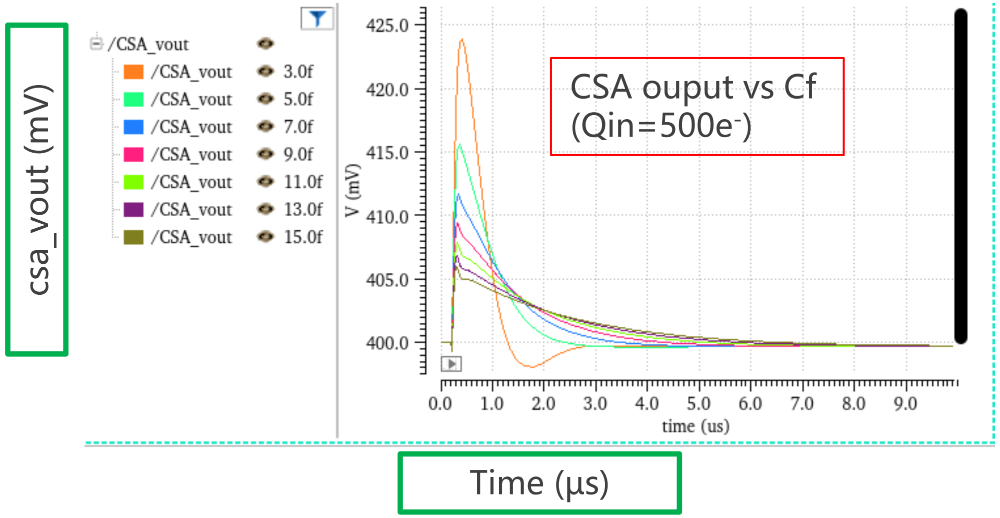
- ✓ CMOS Monolithic Active Pixel Sensor
- ✓ Design in TowerJazz 180 nm process
- ✓ Matrix: 32 (rows) * 16 (columns)
- ✓ Pixel pitch: ≤ 40 μm
- ✓ Analog part in pixel: optimization for better performance
- ✓ Digital part in pixel: use the same readout structure in TIIMM-0
- ✓ The charge is digitized over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

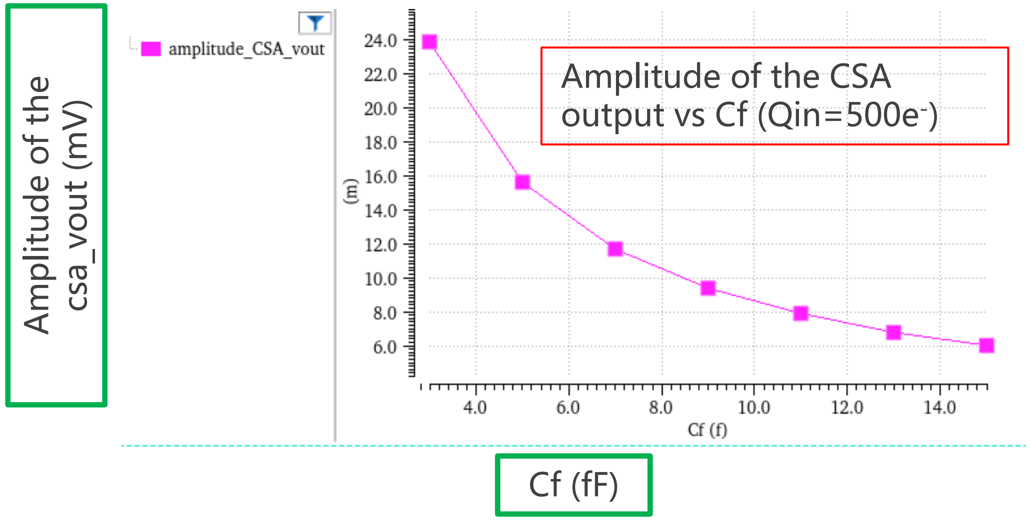


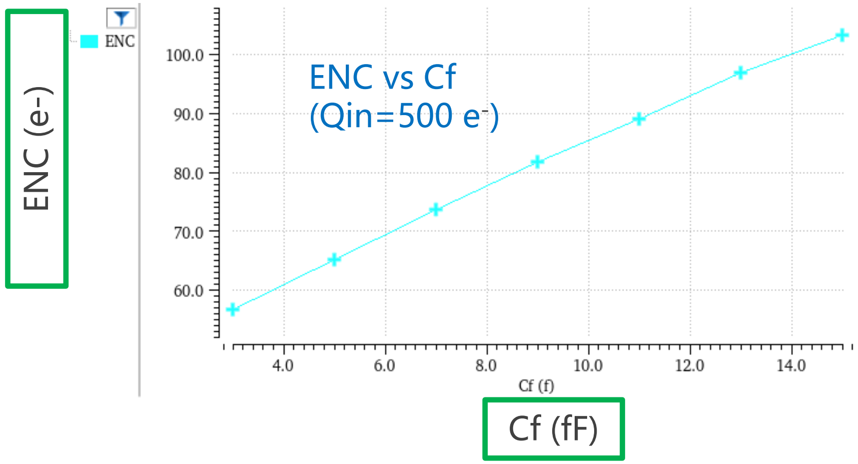
1. AC coupling structure (C_coupling).
2. Optimization of the CSA.
3. Keep the digital readout structure.
4. Remove the 4-bit trimming DAC and the DAC configuration part.

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

TIIMM-1: CSA performance vs Cf



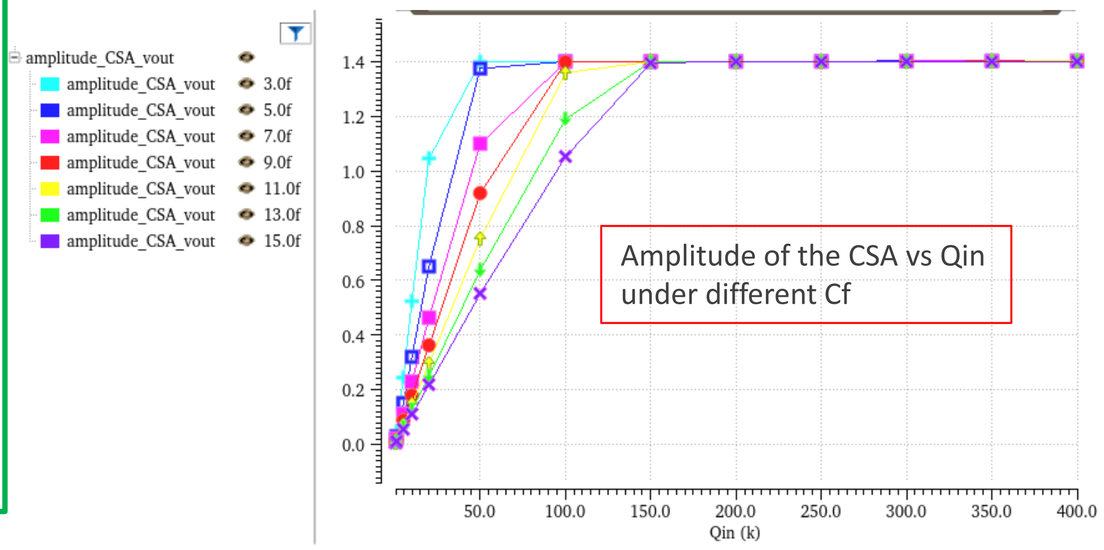


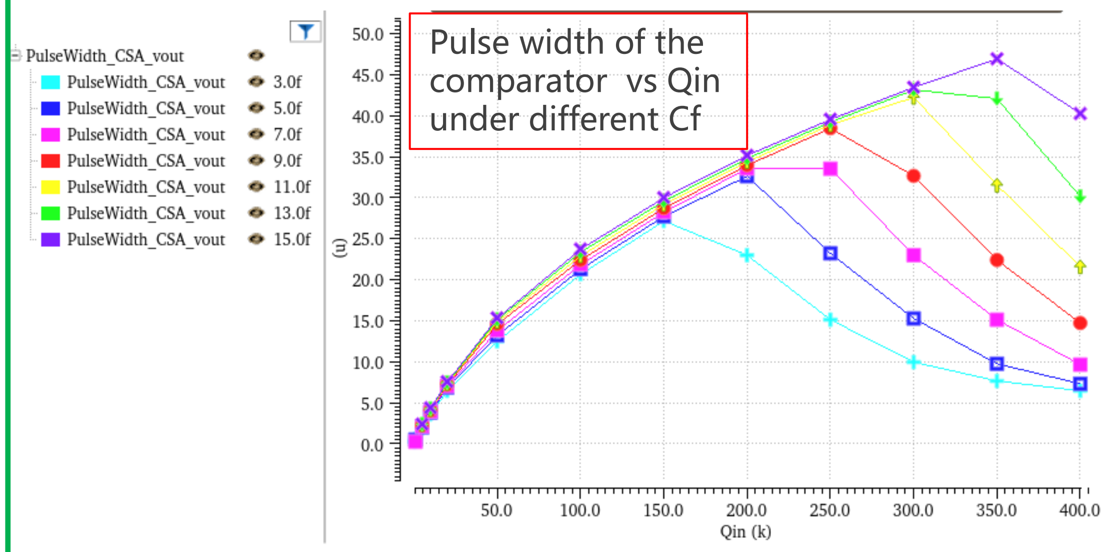


- Cf changes from 3 fF to 15 fF

- The Amplitude of the CSA output decreases with the Cf
- The ENC is about 55 e- @Cf=3fF
- The ENC is about 105 e- @Cf=15fF

TIIMM-1: CSA performance vs Cf





- 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

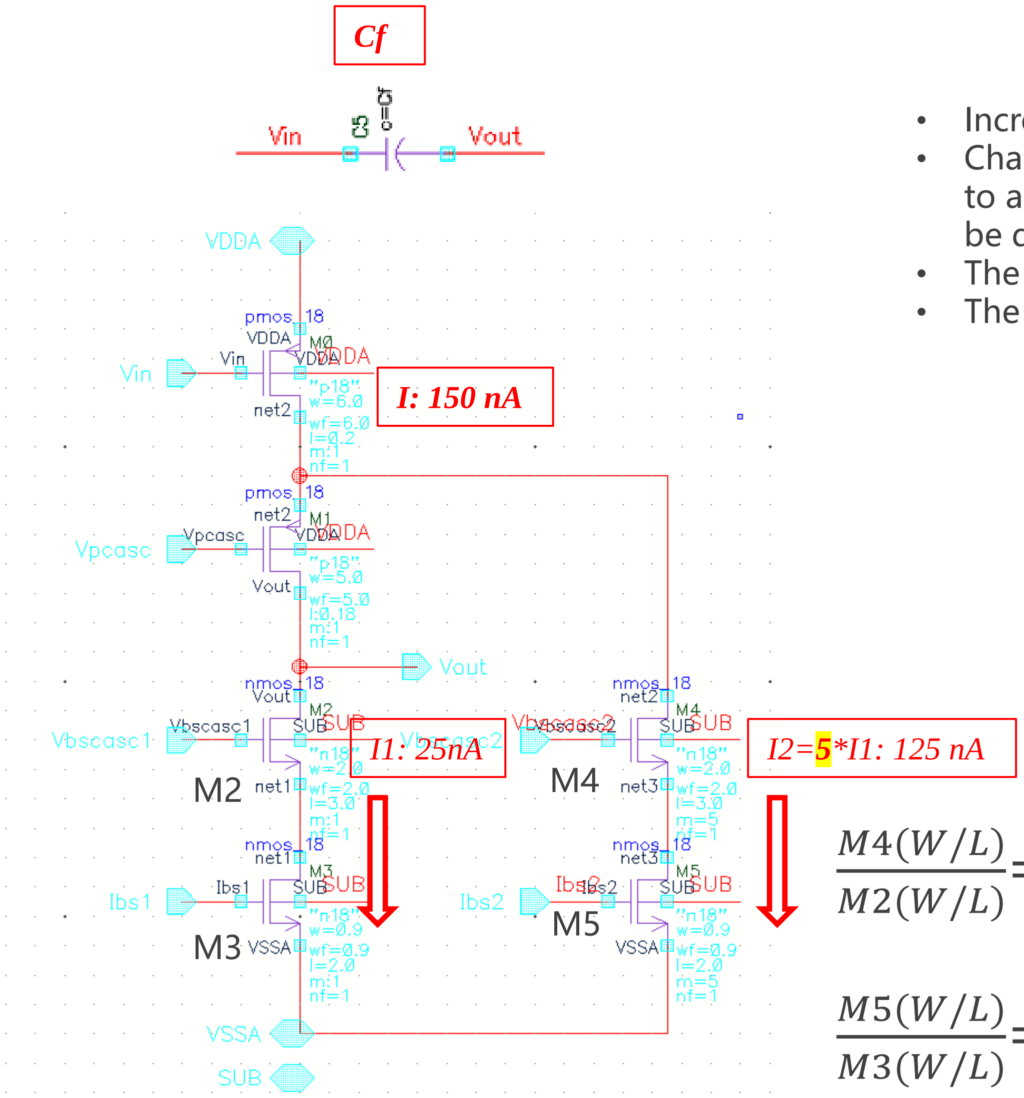
- Cf changes from 3 fF to 15 fF

- 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

Transient noise simulation (Noise vs Qin):

Qin/e-	500	5K	10K	20K	100K
Noise/mV	2.9	3.0	3.5	5.8	9.7

TIIMM-1: Analog pixel design



$$\frac{M4(W/L)}{M2(W/L)}=5$$

$$\frac{M5(W/L)}{M3(W/L)}=5$$

Amplifier

- Increase Cf: 3fF → 5fF or 7fF
- Change current source Ibs to 2 independent current sources Ibs1 and Ibs2 (need to add one current DAC) to provide the current I2. The area of M4 and M5 can be decreased under this situation.
- The basic performance shows no difference with the previous one.
- The layout of the pixel is under design

To get I2=5*I1: The transistor M4 and M5 has a large W (5 times of the W of M2 and M3), which consumes a large area.

Summary

- In TIIMM-0:

  The pulse width will increase when we decrease the bias current Ibikrumn in the Krumn feedback circuit.

  The pulse width will increase when we decrease the bias voltage Vfbk in the Krumn feedback circuit. And when Vfbk is about 150 mV, the overshot problem can last for a long time.
- In TIIMM-0, the pulse width has a large dispersion in the test results.
- For TIIMM-1, the capacitance Cf will be increased to 5 fF/7fF.
- In TIIMM-1, we will use two current DACs to provide the bias currents. Then, we can decrease the area of the amplifier for increasing Cf.

Thanks!