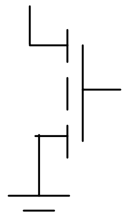
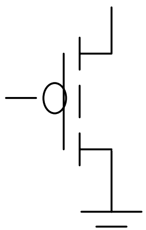
3D Range Sensor using time of flight method

By Martin Krämer

NMOS





PMOS

Motivation

- proof of concept of an 3D Range Sensor
- finding the difficulties

There was no prior knowledge of the light source and the characteristic of the Photo Diode

1. Concept of Time of Flight (ToF) method
   - Handling of background light
2. Concept of the Sensor and its building blocks
   - Photo PN-Diode
   - Source Follower
   - CDS Stage
3. One Readout Cycle
   - Timing of the different Clocks
4. Multiply Readout
5. Layout
6. Conclusion

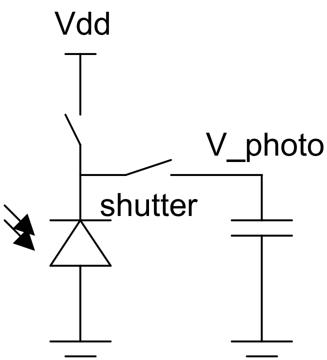
Concept of Time of Flight method (1)

Basic Idea: Measure the time of flight of an light pulse and calculating the distance

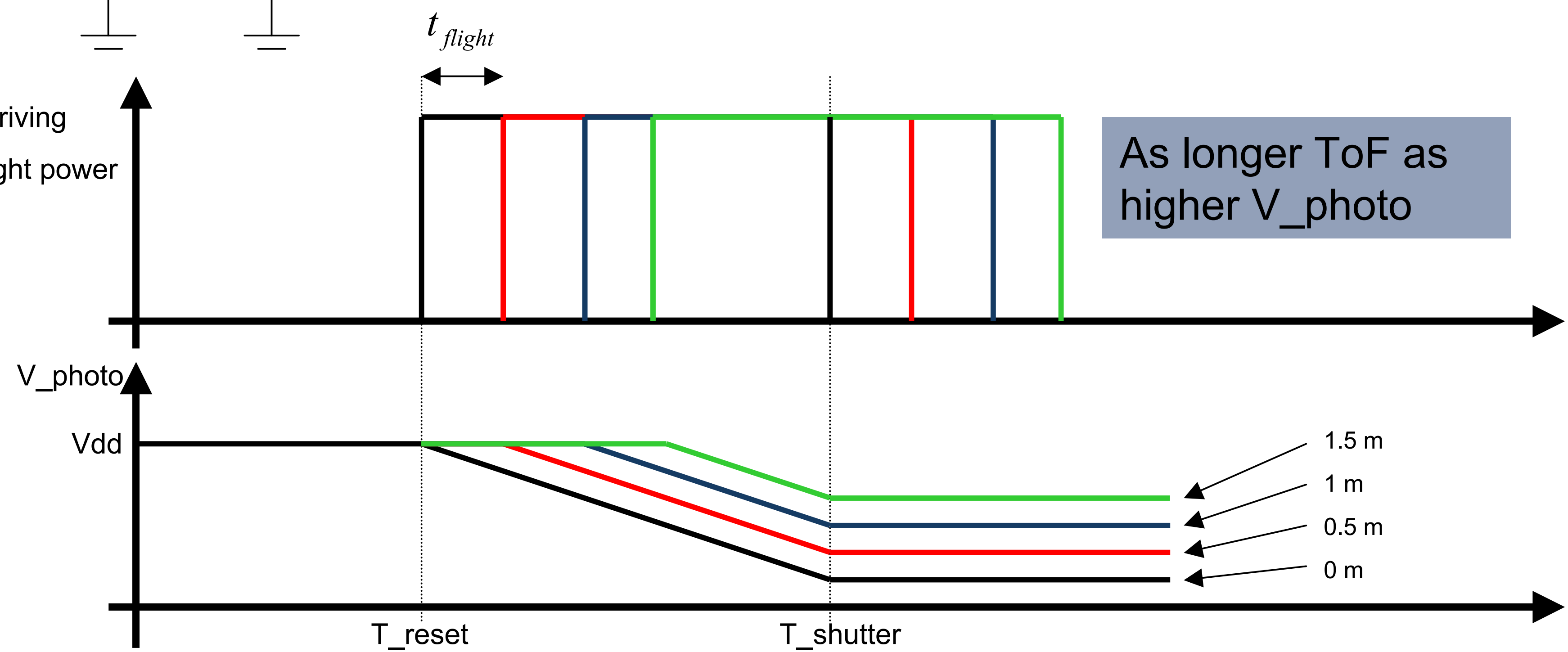
Challenge : Speed of light is very fast, for example in 3.33 ns the light traveled 1m. We must detect ns !

sed on: “Entwicklung von optischen 3D CMOS-Bildsensoren auf der Basis der Pulslaufzeitmessung“ by Elkhalili, O. (PhD thesis)

Concept of Time of Flight method (2)



The photo current discharge the capacitance until the shutter close. The background light is ignored.



As longer ToF as higher V_photo

sed on: “Entwicklung von optischen 3D CMOS-Bildsensoren auf der Basis der Pulslaufzeitmessung“ by Elkhalili, O. (PhD thesis)

Concept of Time of Flight method (3)

What about the background light?

Background light causes also a photo current, thus discharge also the capacitor.

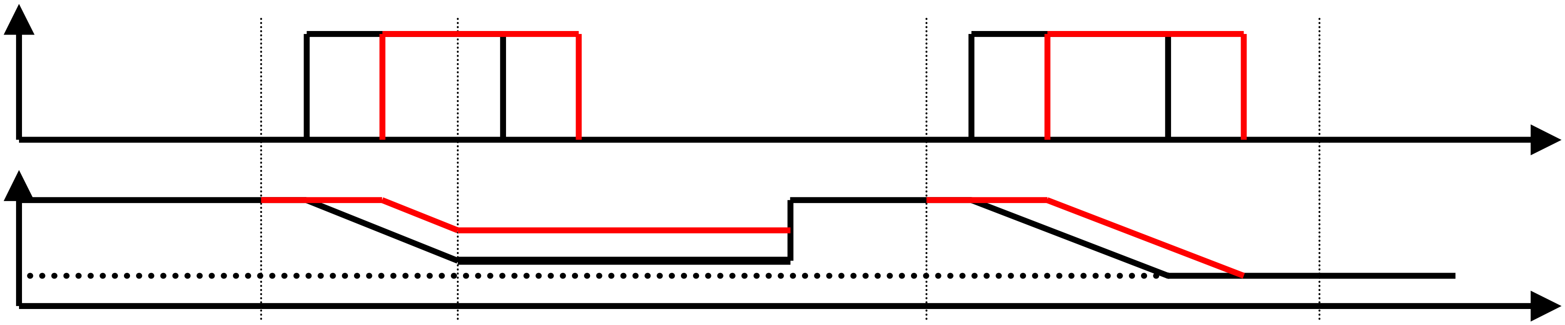
Making two measurements, one with the light source and one with only the background light. Assuming that the measurements are fast, thus the background light is constant.

Now we can subtract them and we get the correct output voltage.

sed on: “Entwicklung von optischen 3D CMOS-Bildsensoren auf der Basis der Pulslaufzeitmessung“ by Elkhalili, O. (PhD thesis)

Concept of Time of Flight method (3)

What about intensity variation of the light pulse?

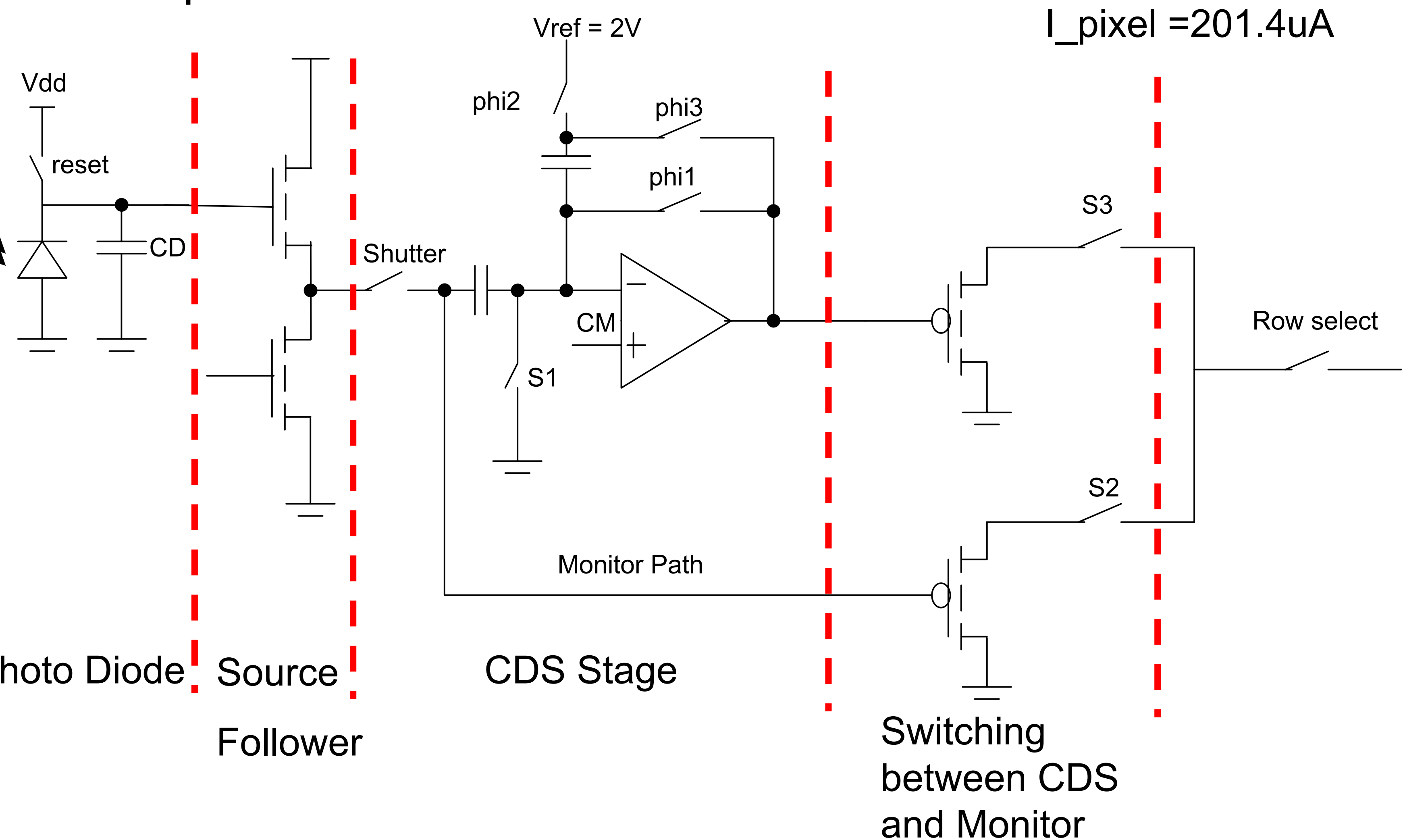


Making two measurements, one with normal short shutter Time (T_pulse) and one with a long shutter time.

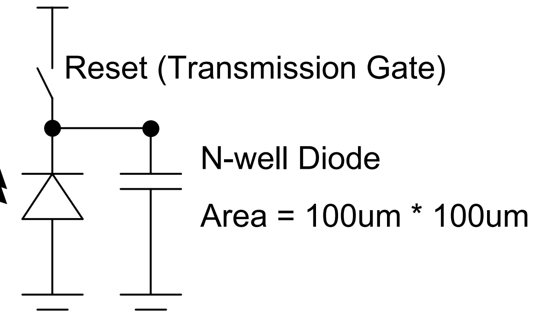
The arriving light power is canceled. We need for the distance measurement 4 measurements.

sed on: “Entwicklung von optischen 3D CMOS-Bildsensoren auf der Basis der Pulslaufzeitmessung“ by Elkhalili, O. (PhD thesis)

Concept of Sensor

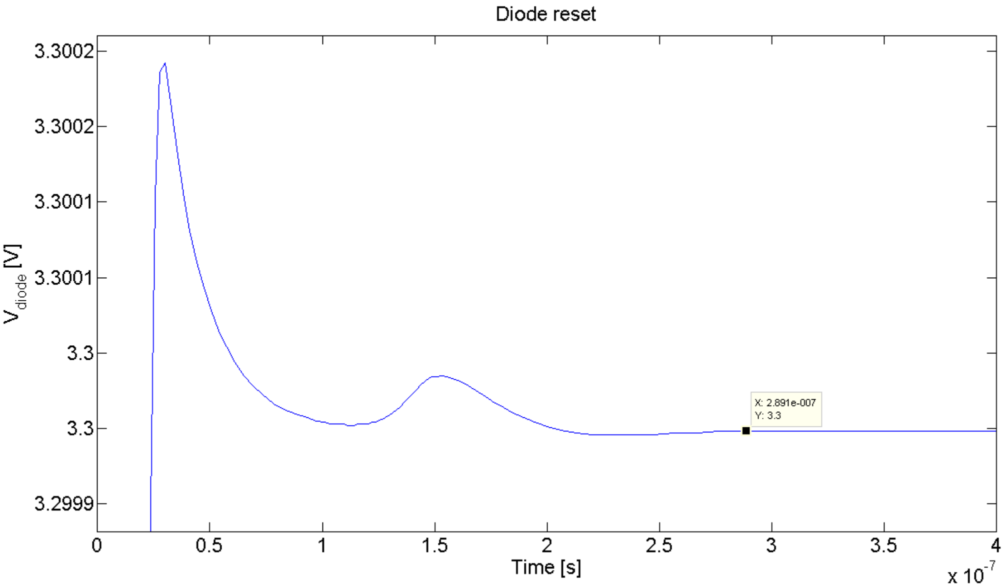


PN Diode



Using a LASER with a wave length around 900 nm as light source. Because this light is not visible for the human eye.

The NWD is deeper in the substrate, thus 900nm can reach this better then shorter wave lengths, because of absorption.



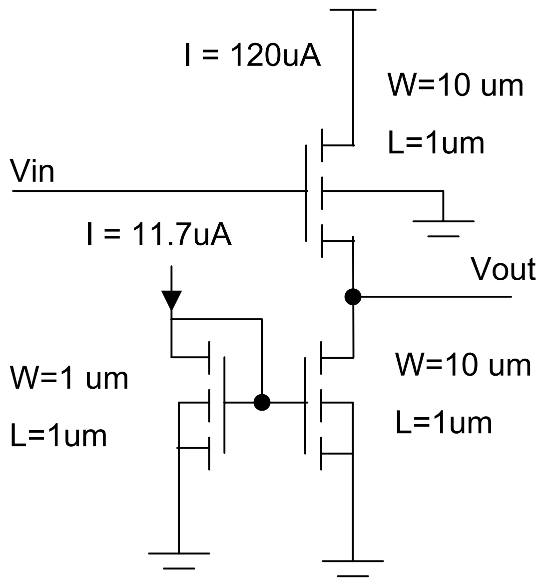
Reset time from 0V to Vdd=3.3 V is 298 ns. I gave 2 us reset time

Assumptions:

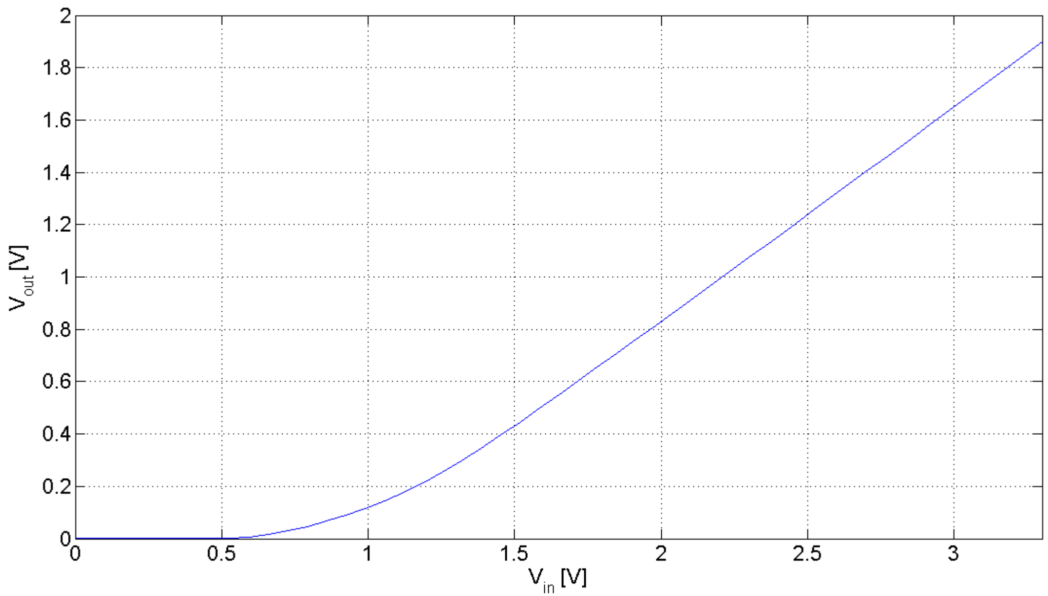
I_LASER= 2 nA

I_background = 300pA

NMOS Source Follower

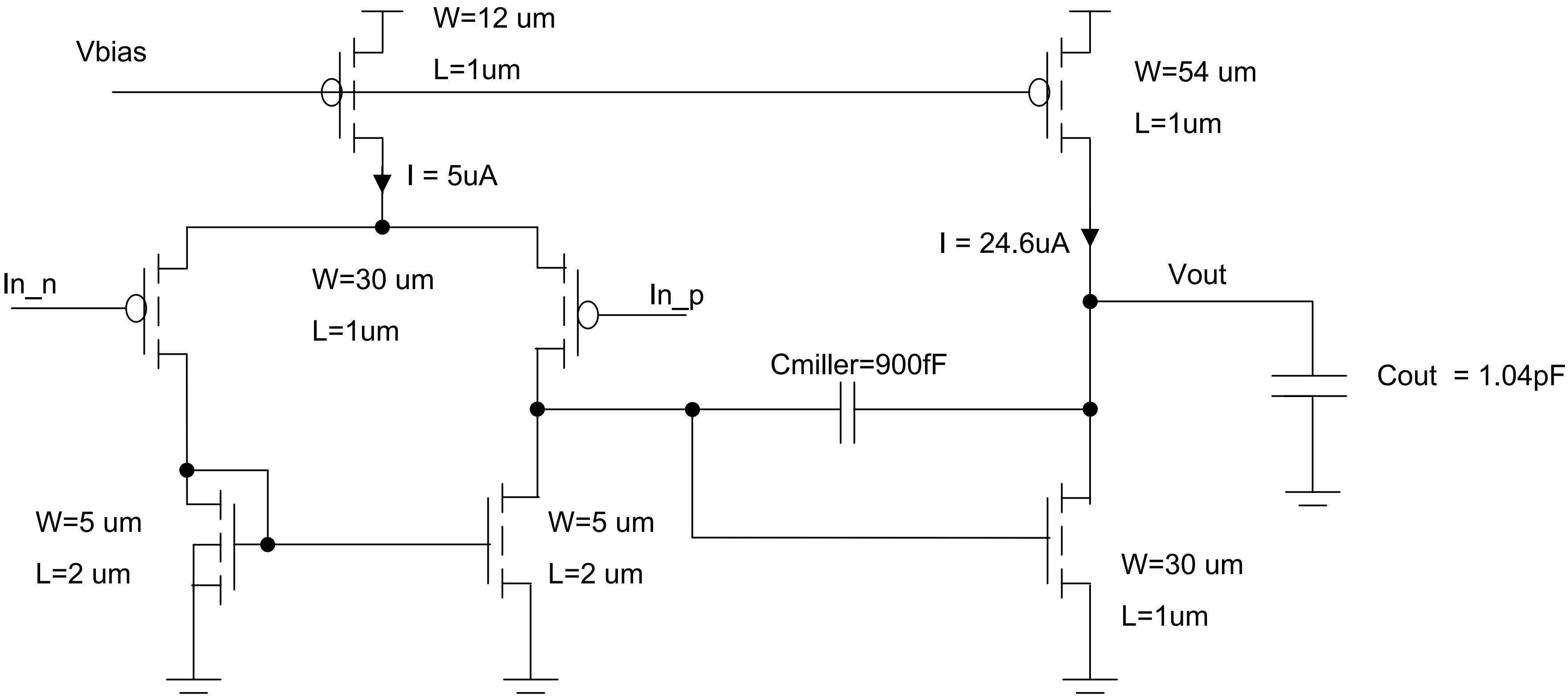


Vbs is not zero for the input transistor, this leads to a higher Vth and this gives us this big Voltage drop of 1.4 V. Also we have a Voltage gain of 0.8.



After the follower comes a capacitor, the big current is for speed

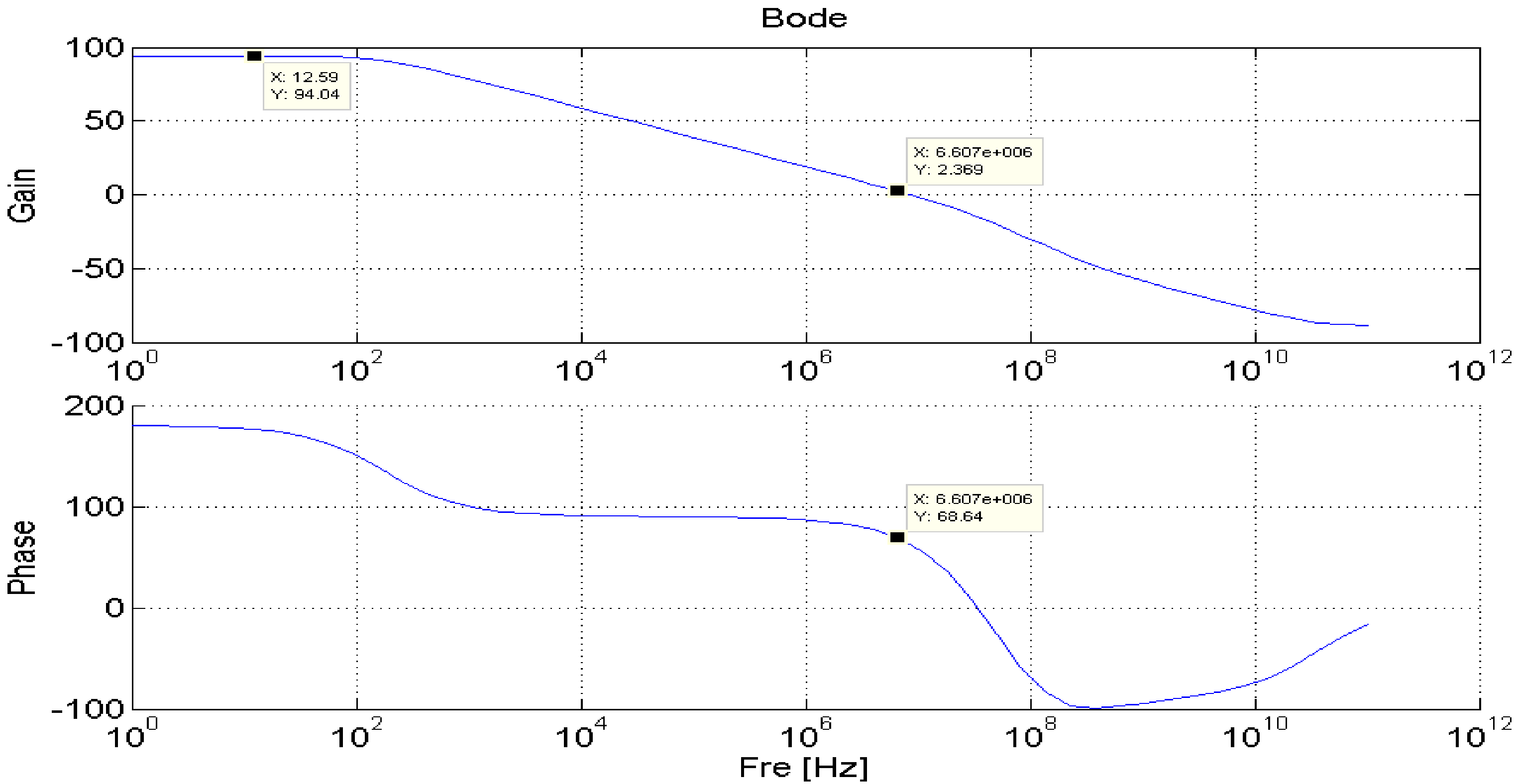
CDS Stage (Miller OTA)



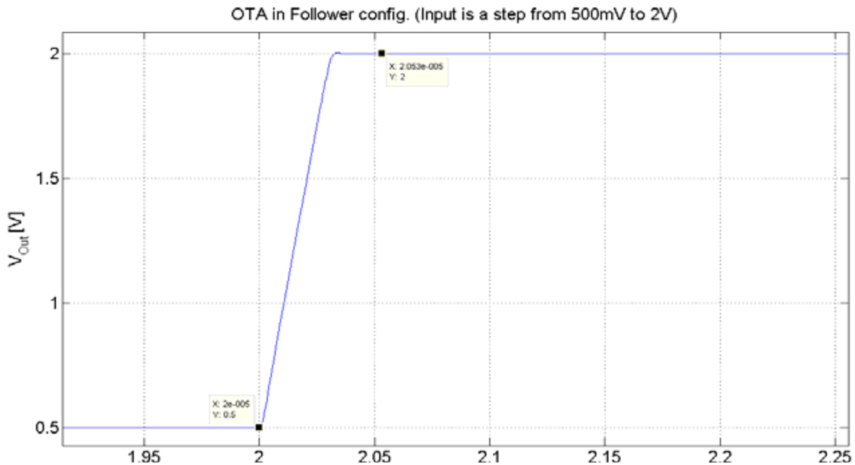
All PMOS Bulks connected to VDD and all NMOS Bulks connected to GND

CDS Stage (Miller OTA)

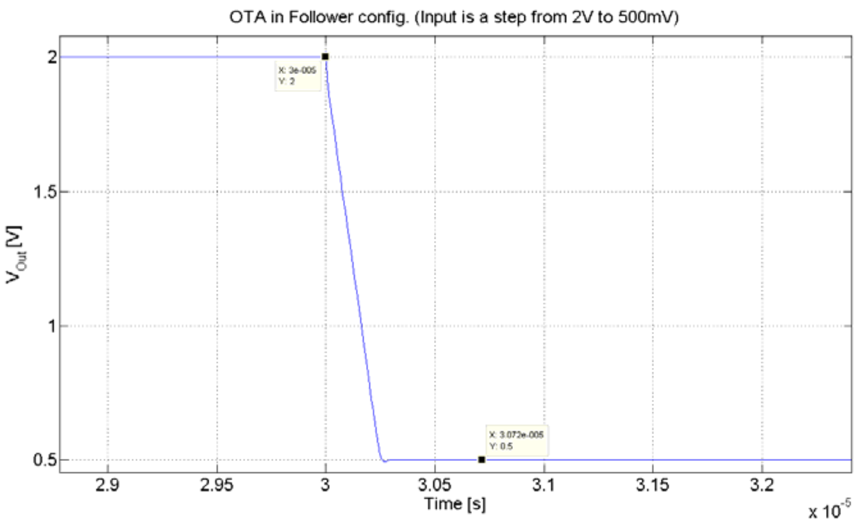
Gain = 94 dB, PM = 62° (1.4 pF at output), GBW = 9.05MHz and I_all = 33.7uA



CDS Stage (Miller OTA)

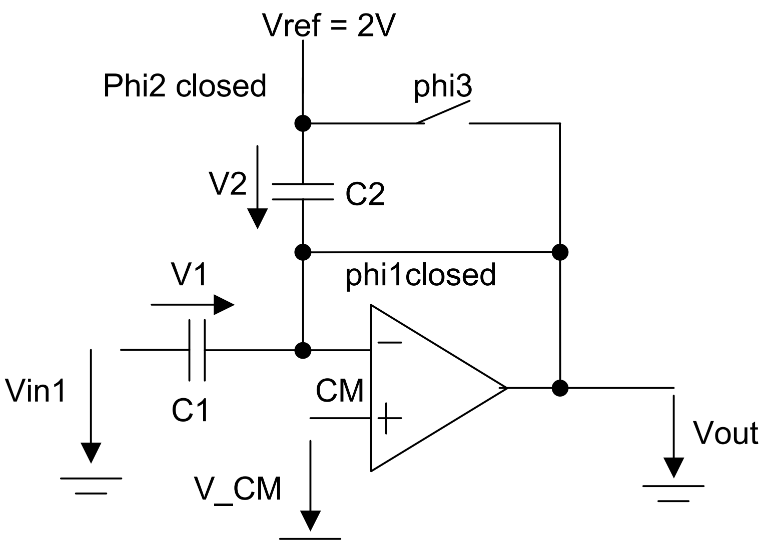


Settling time up = 530ns



Settling time down = 720ns

CDS Stage (Phase 1)

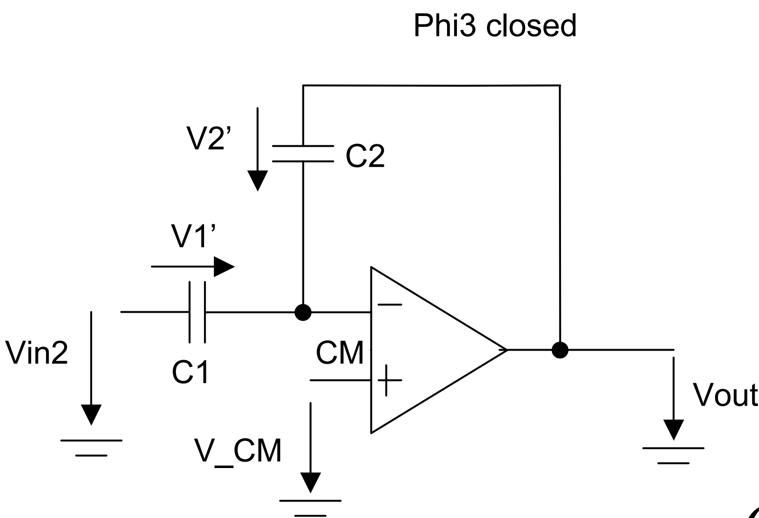


All switches are transmission gates, with w=1.3um and l=0.35um

$$V_1 = V_{in} - V_{CM} \Rightarrow Q_1 = C_1 (V_{in1} - V_{CM})$$

$$V_2 = V_{ref} - V_{CM} \Rightarrow Q_2 = C_2 (V_{ref} - V_{CM})$$

CDS Stage (Phase 2)



$$V_{1'} = V_{in2} - V_{CM} \Rightarrow Q_{1'} = C_1(V_{in2} - V_{CM})$$

$$\Delta Q_1 = Q_{1'} - Q_1 = C_1(V_{in2} - V_{in})$$

$$Q_{2'} = Q_2 - \Delta Q = C_2(V_{ref} - V_{CM}) - C_1(V_{in2} - V_{in}$$

$$V_{2'} = \frac{Q_{2'}}{C_2} = V_{ref} - V_{CM} - \frac{C_1}{C_2}(V_{in2} - V_{in})$$

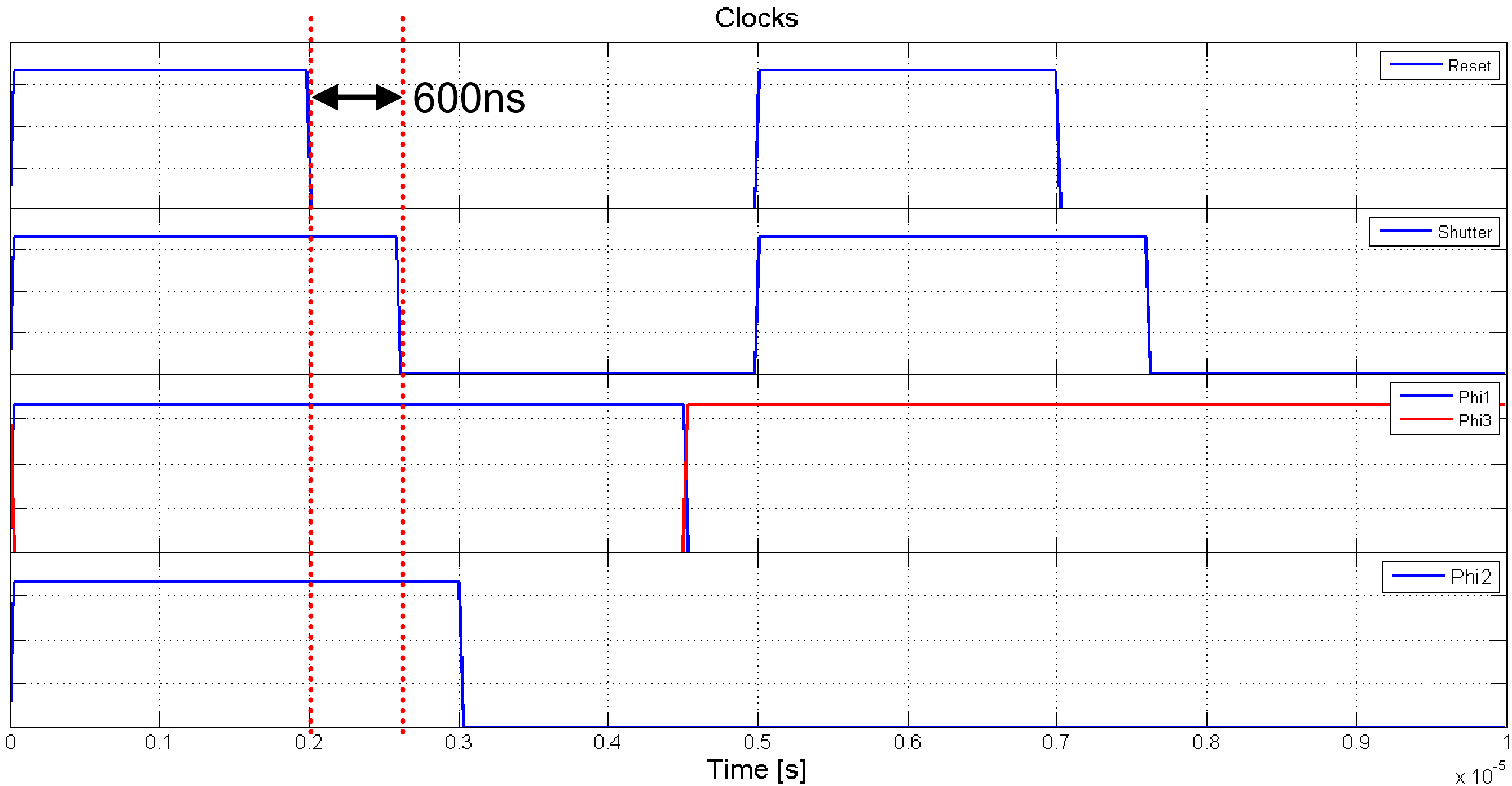
$$V_{out} = V_{2'} + V_{CM} = V_{ref} - \frac{C_1}{C_2}(V_{in2} - V_{in})$$

n my circuit C2=320.952fF

and C1=1.047pF. The gain of the stage is A=3.26

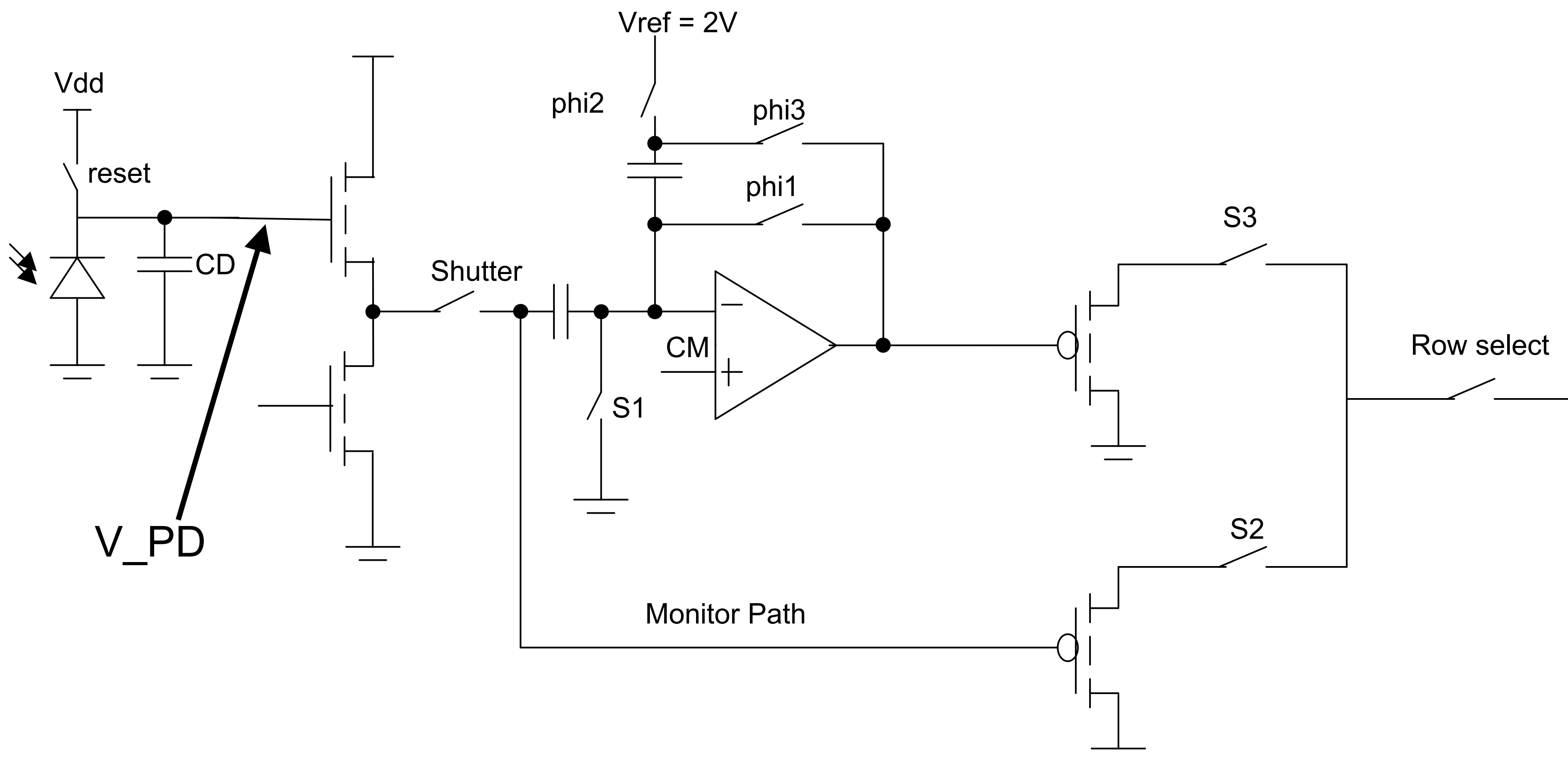
One measurement cycle

Clock timing



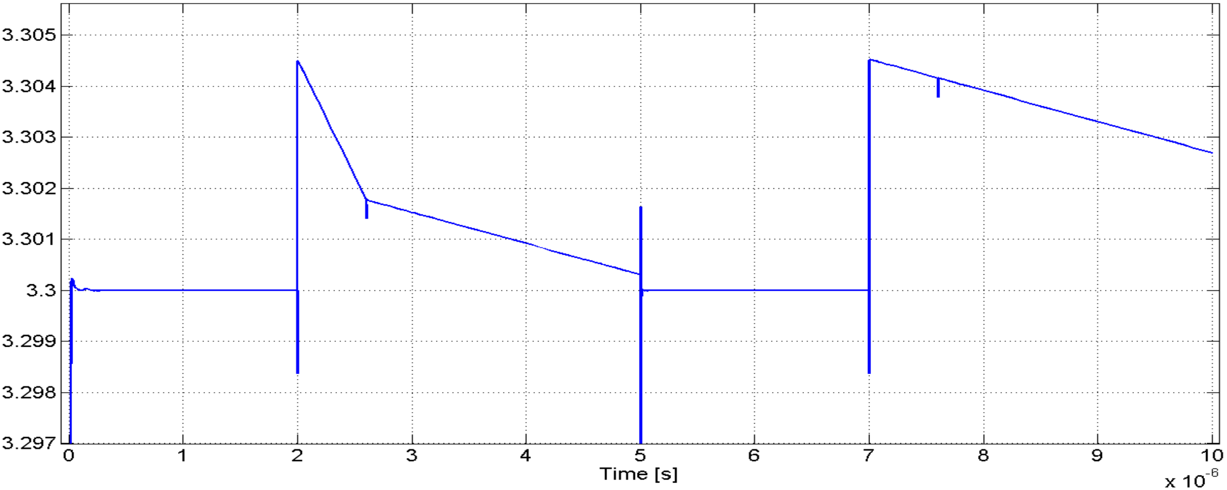
One measurement cycle

PD Voltage

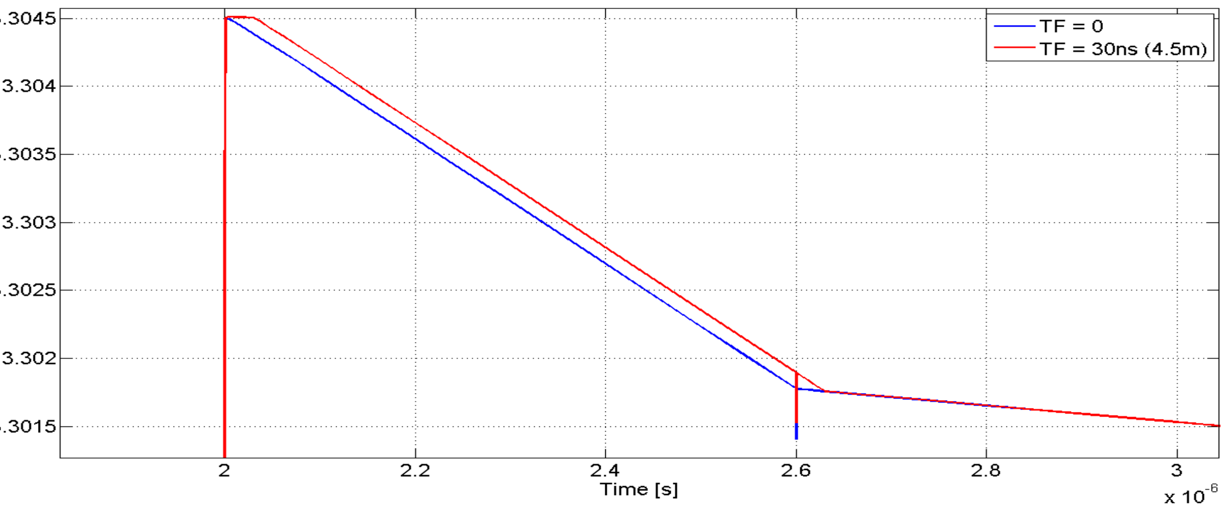


One measurement cycle

PD Voltage



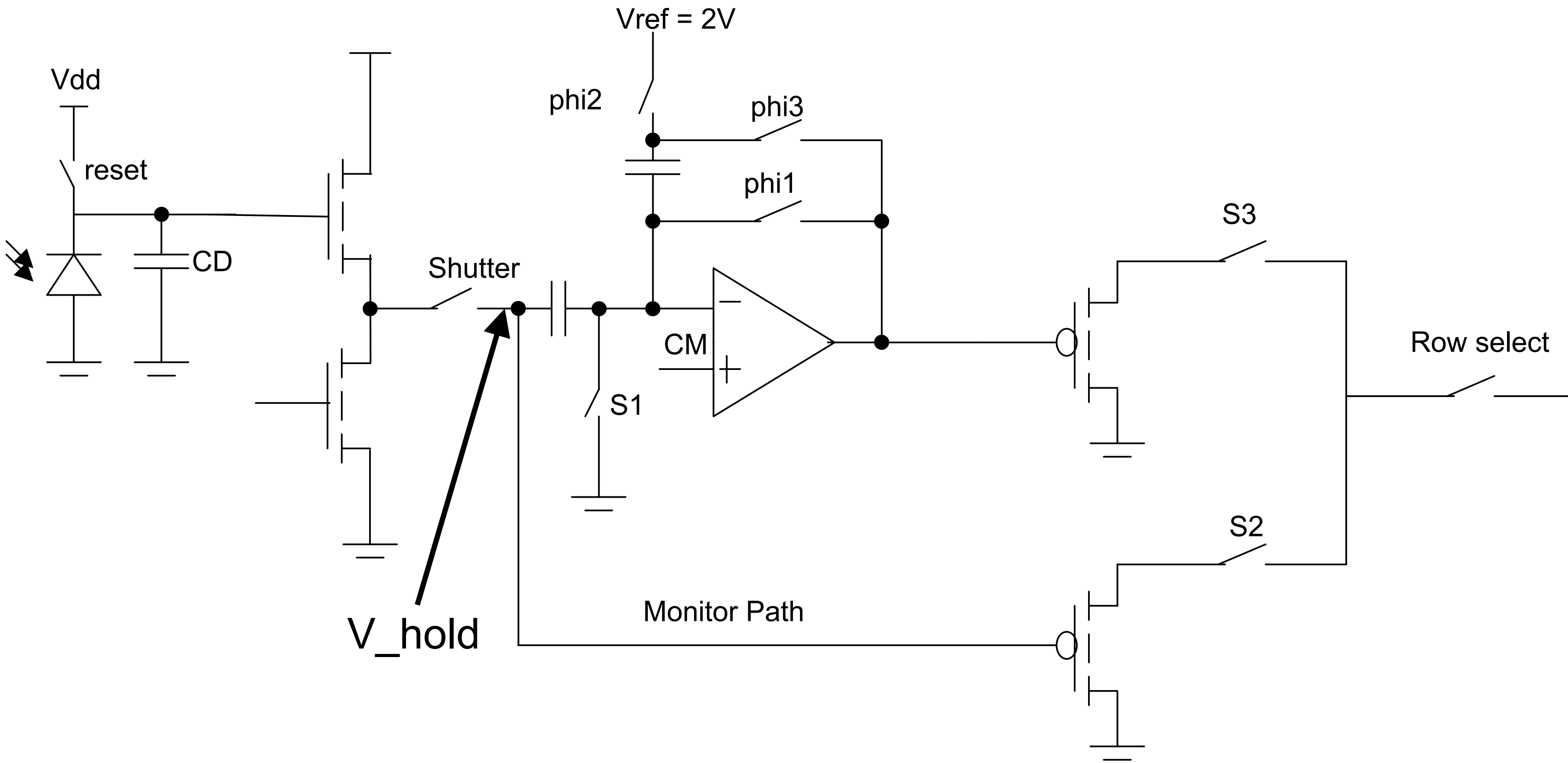
40mV step at 2us caused by charge injection and clock feed through



TF=0 to TF=30ns is the measurement borders

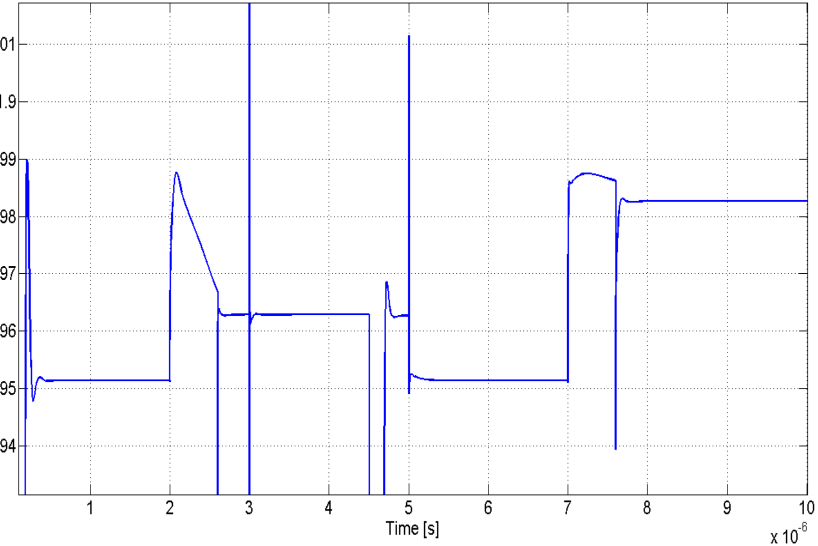
One measurement cycle

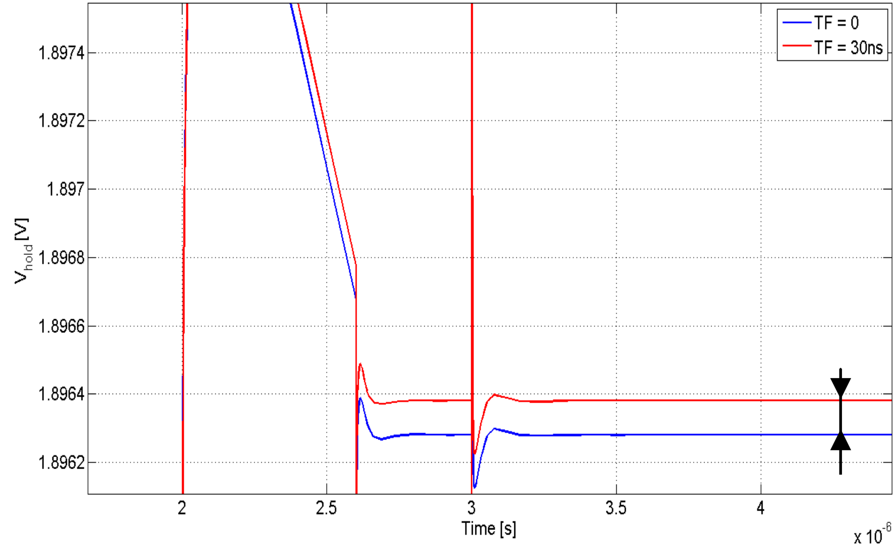
V_hold



One measurement cycle

Hold Voltage

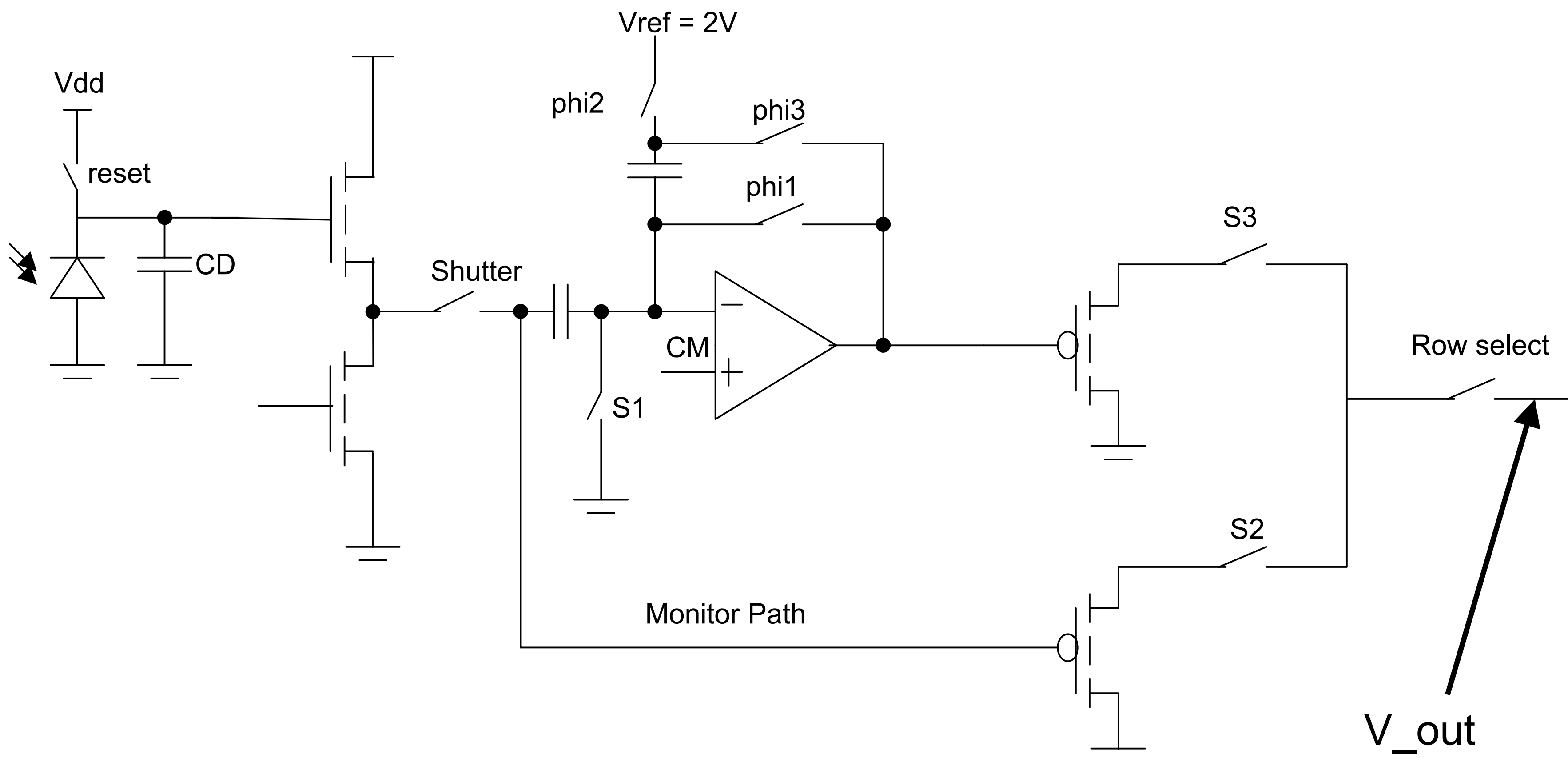




The difference between the Hold Voltages is 96 uV. This is really small. The range is from 0 to 4.5m (TF=30ns)

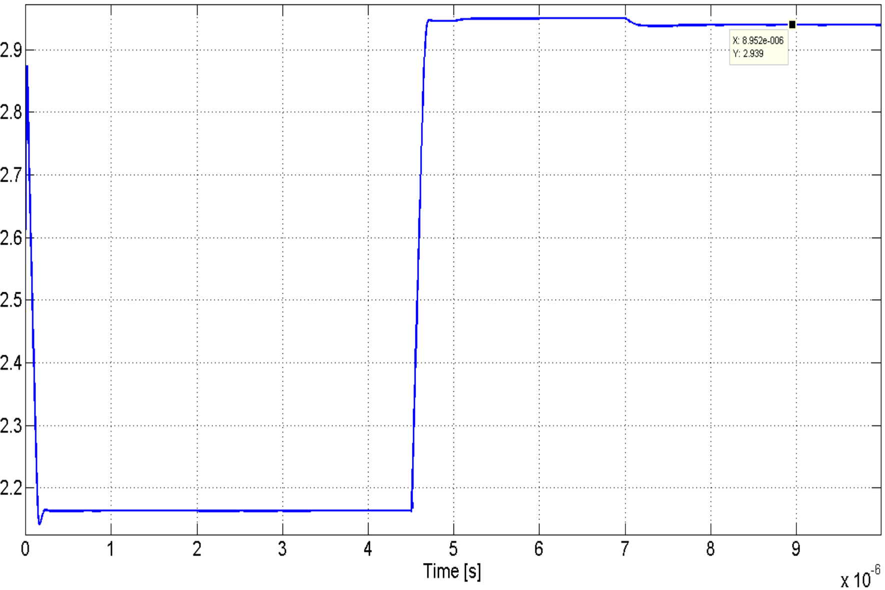
One measurement cycle

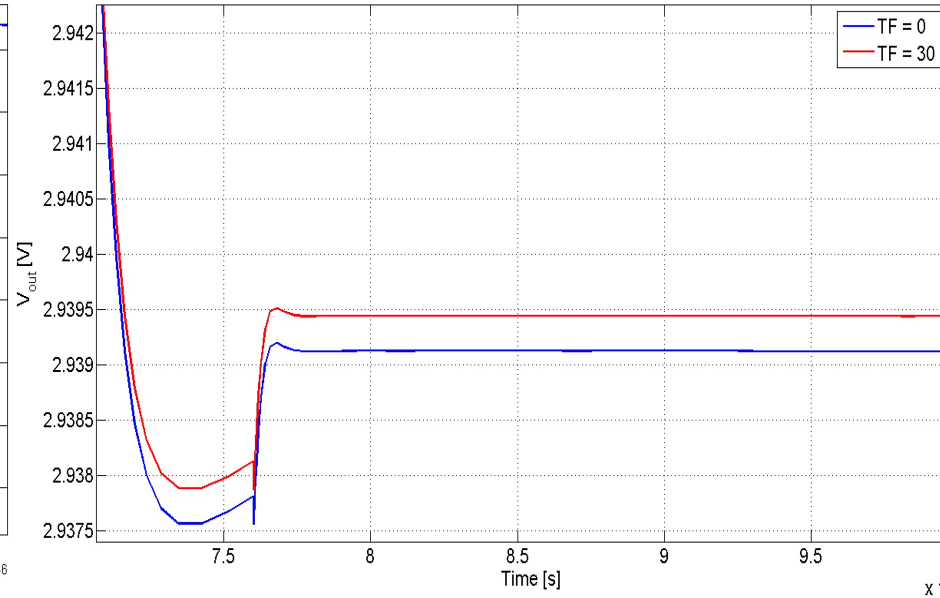
V_out



One measurement cycle

Hold Voltage





After the CDS stage, the difference between the Output Voltages is 321 uV.
This is a gain of 3.343 (from calculation 3.26)

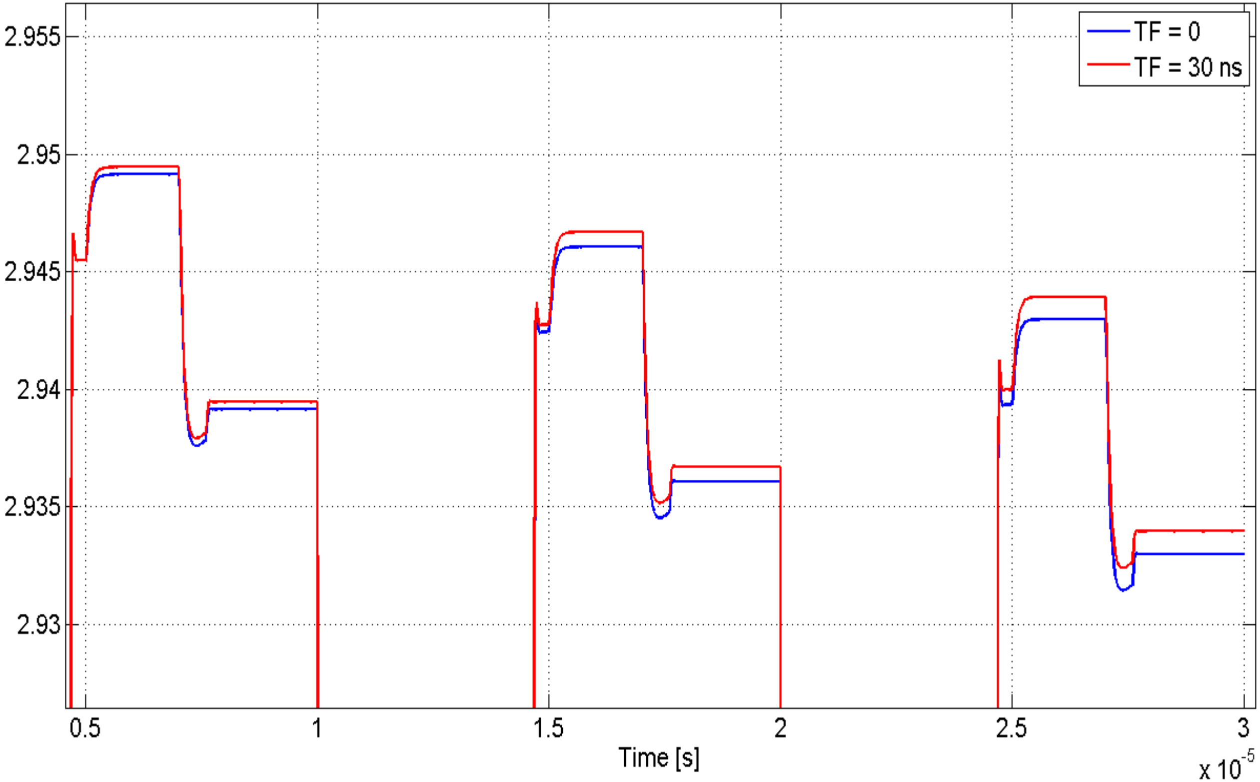
Multiple Readout

321 uV is not much for a range from 0 to 4.5m

But there is a possibility in the CDS stage for more gain. The Output Voltage is stored on C2, this output voltage can be used as new reference Voltage. Thus we can subtract often, we only have to make sure that the distance and the light situation doesn't change.

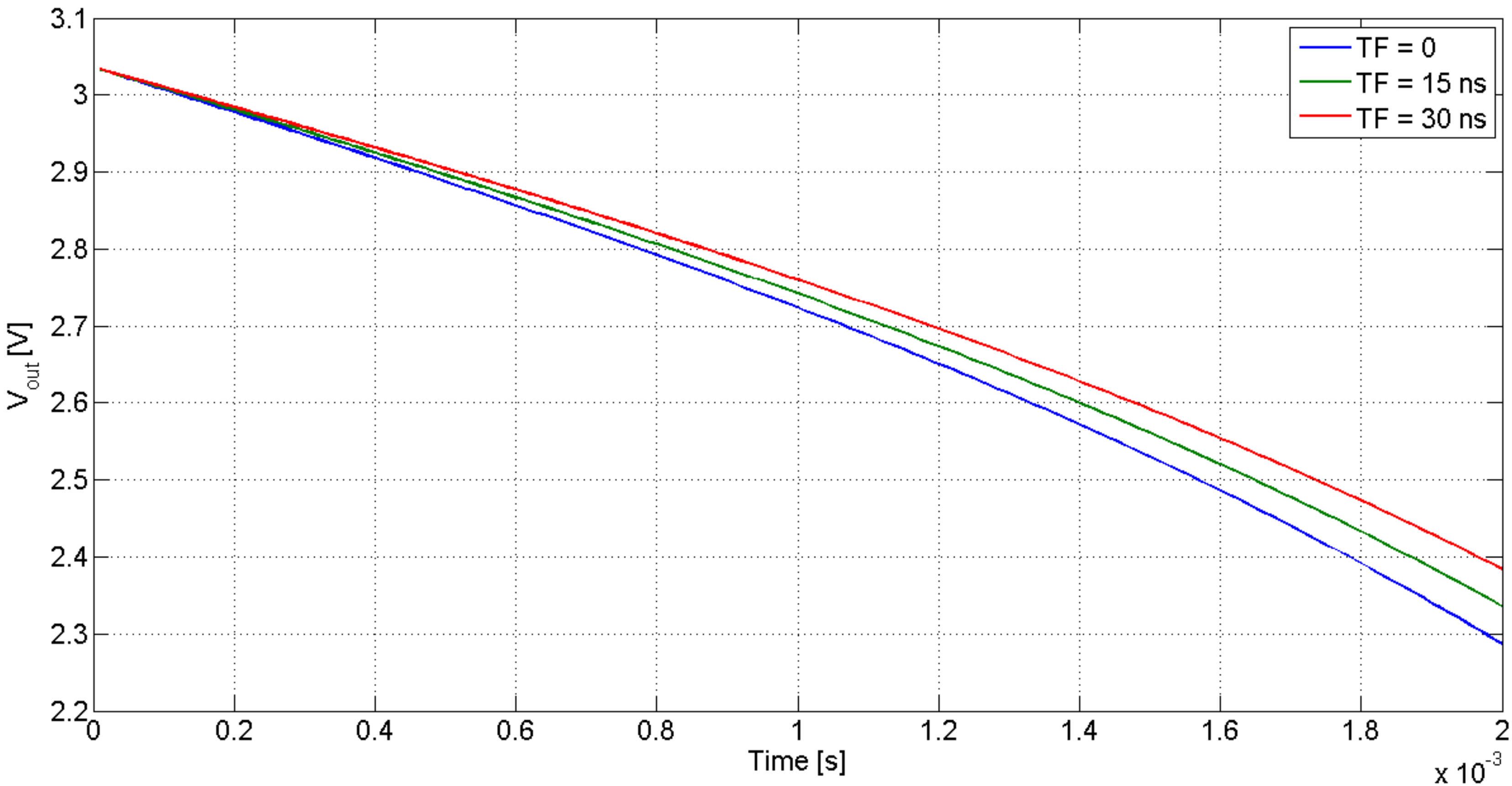
Multiple Readout

3 Cycles



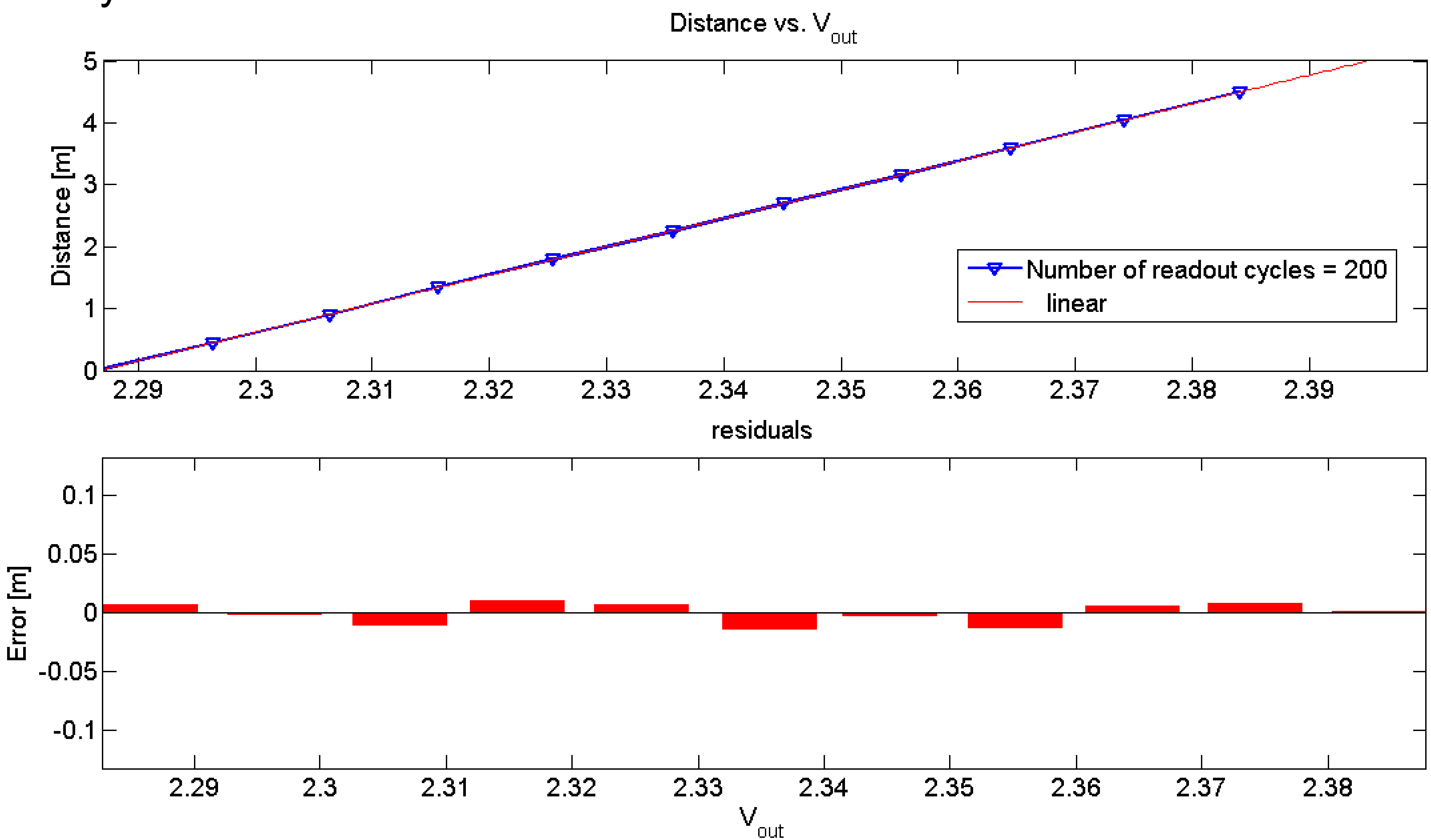
After 3 cycles we have a Voltage difference of 959uV. This is a gain of 2.987

Multiple Readout

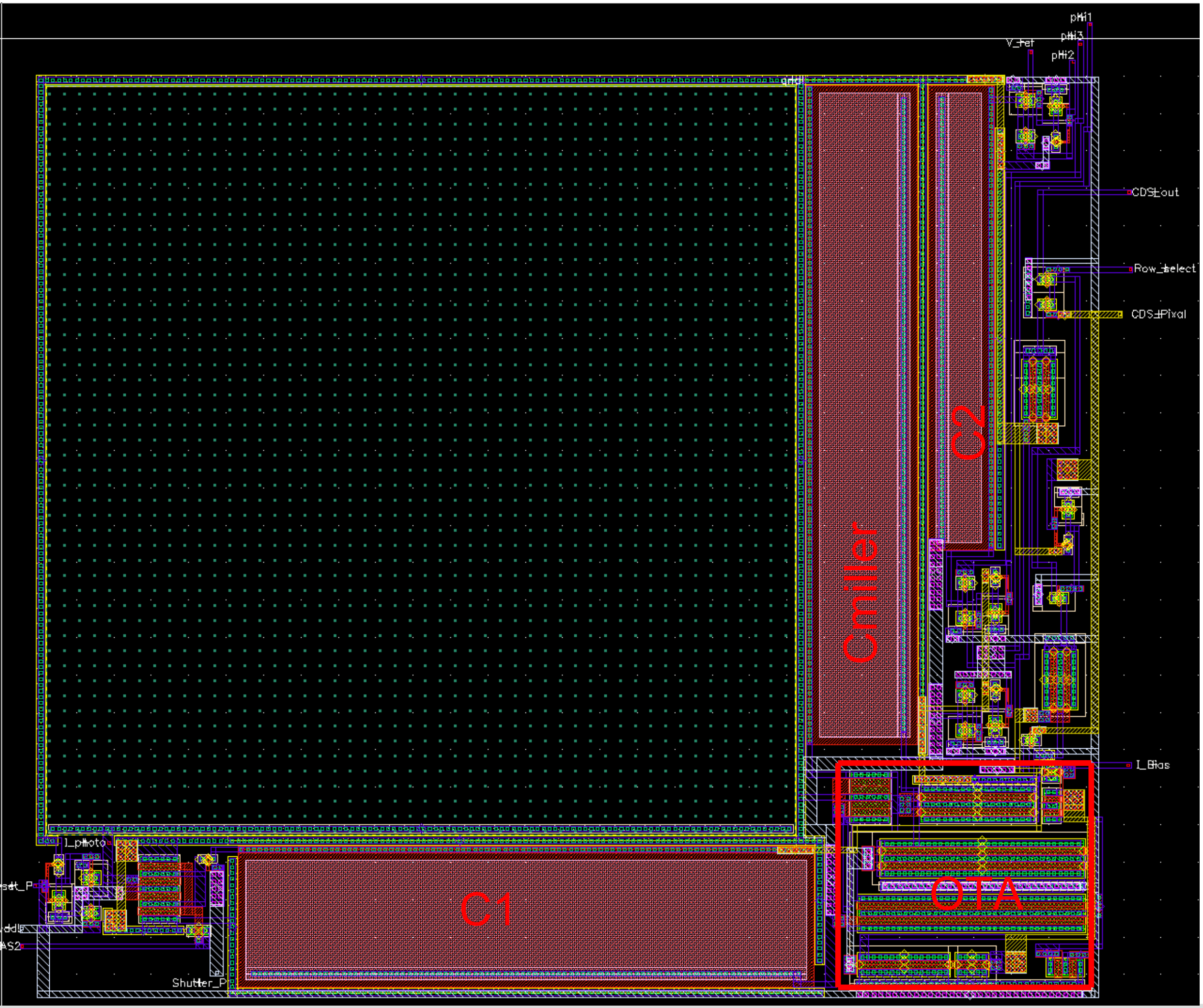


Multiple Readout

200 Cycles



Layout

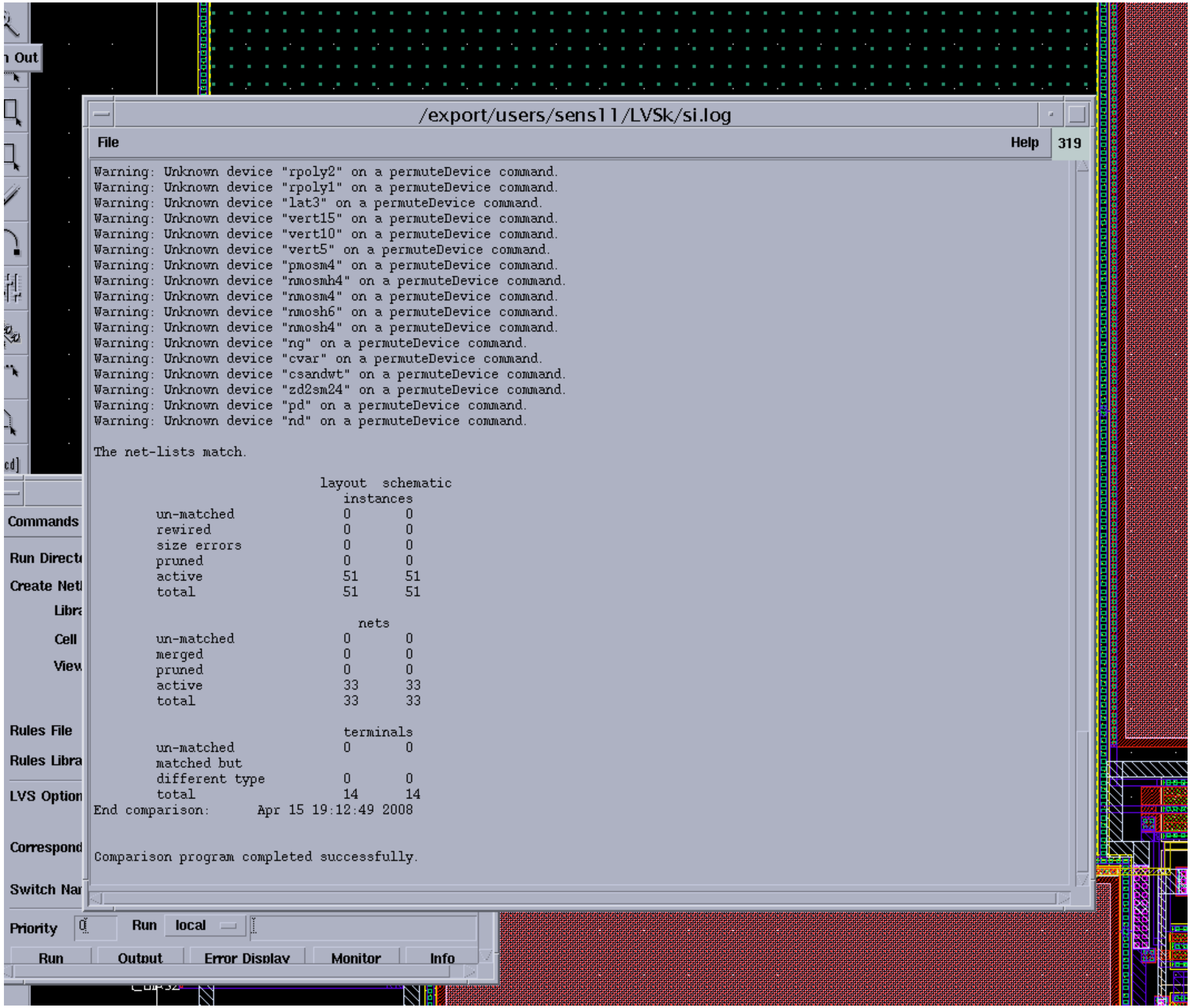


W=142.5 um

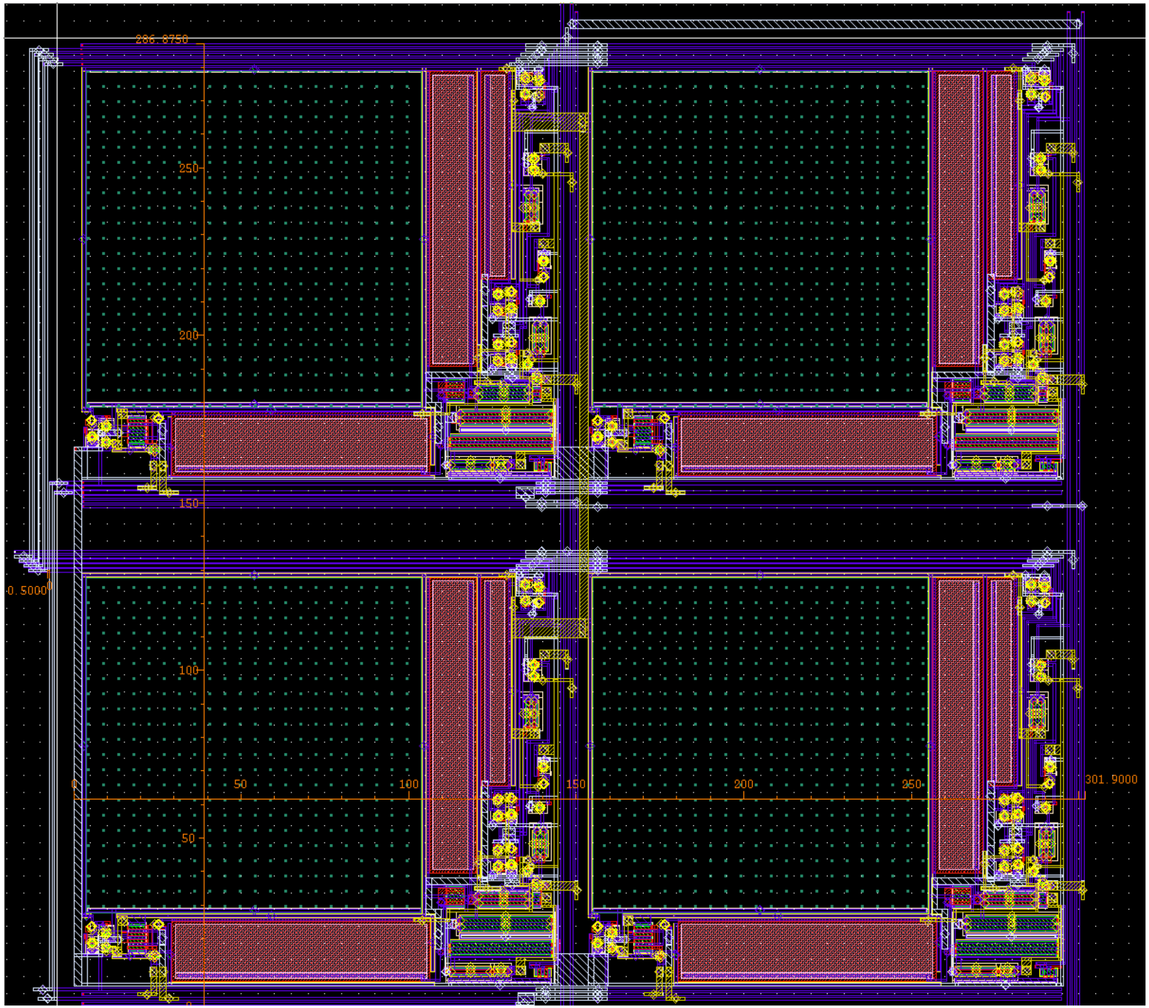
L=123.1 um

Fill factor = 57%

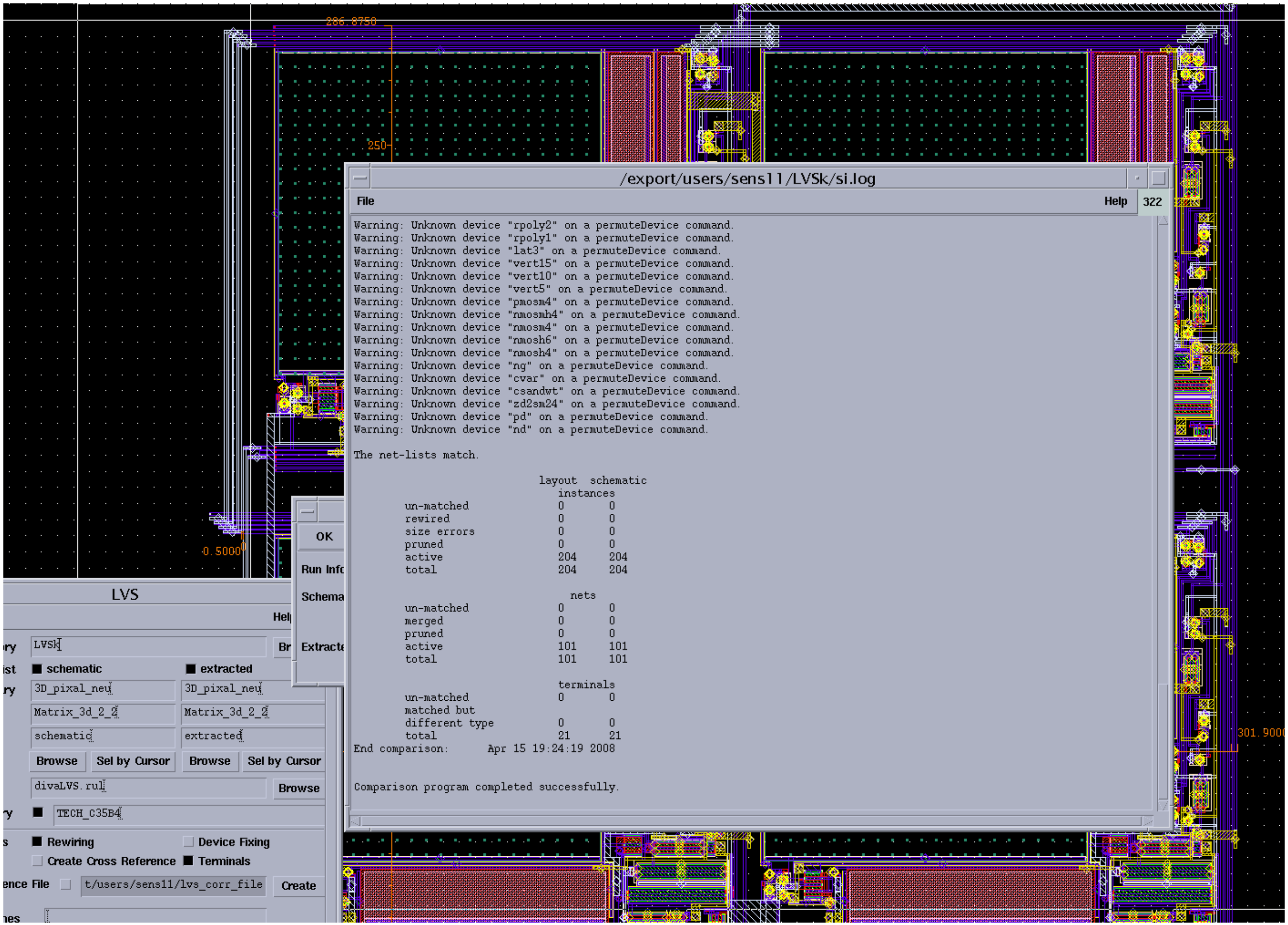
Layout Pixel LVS



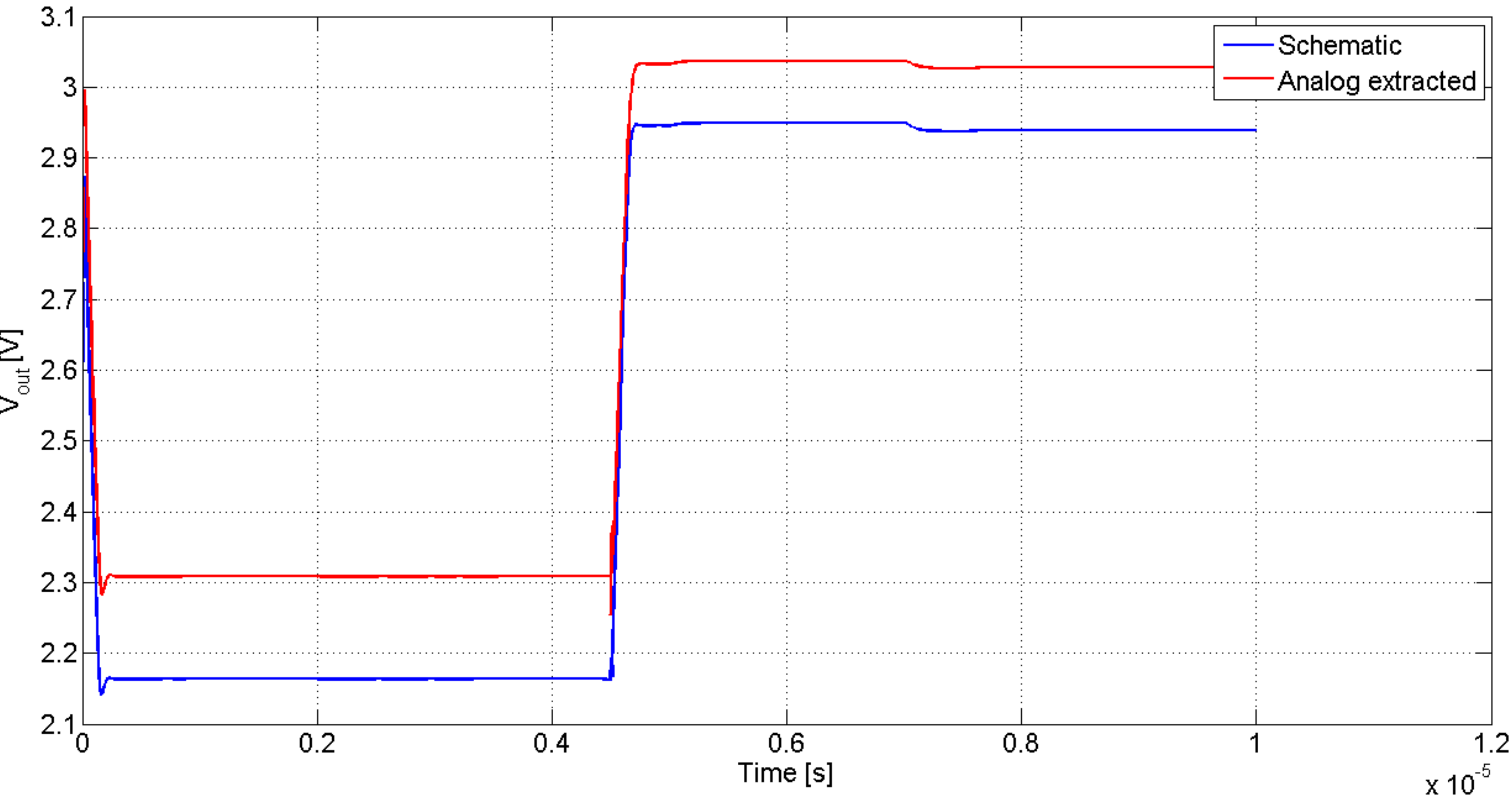
Layout 2*2 matrix



Layout 2*2 matrix LVS



Analog Extracted one cycle



Conclusion

- It Is possible
- But the concept needs a high precision circuit, this means it cost area and current
- It is absolutely necessary for the design to know the light source and the PD
- In this study the noise was neglected, it is also absolutely necessary to make a noise analysis. It is one of the biggest error factors because of the low voltage differences

Ref: “Entwicklung von optischen 3D CMOS-Bildsensoren auf der Basis der Pulslaufzeitmessung“ by Elkhalili, O. (PhD thesis)