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# **CMOS image sensor reaching $0.34 e^-_{\text{RMS}}$ read noise by inversion-accumulation cycling**

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# Abstract

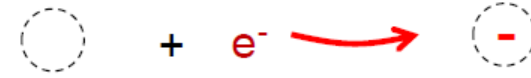
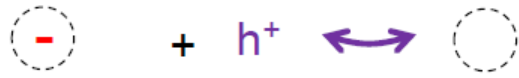
**This work presents the design and evaluation of a 0.18  $\mu\text{m}$  technology 16\*16 pixels prototype CMOS image sensor reaching a read noise below 0.34  $e^-_{\text{RMS}}$ .**

**This result is obtained by the combination of severe oversampling and the reduction of 1/f noise by inversion-accumulation cycling.**

- The principle
- Measurement&interpretation
- How far is photon counting
- Take home message

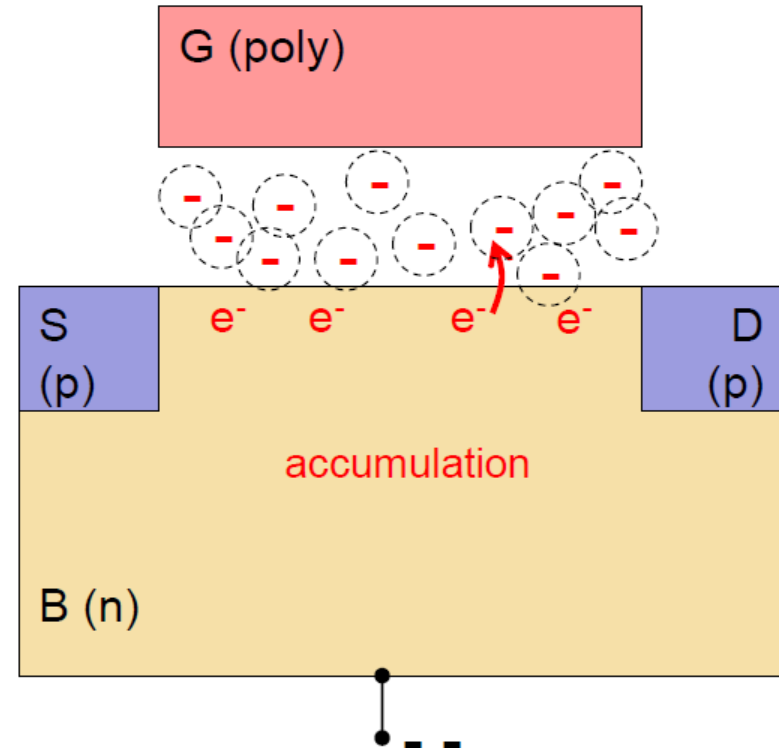
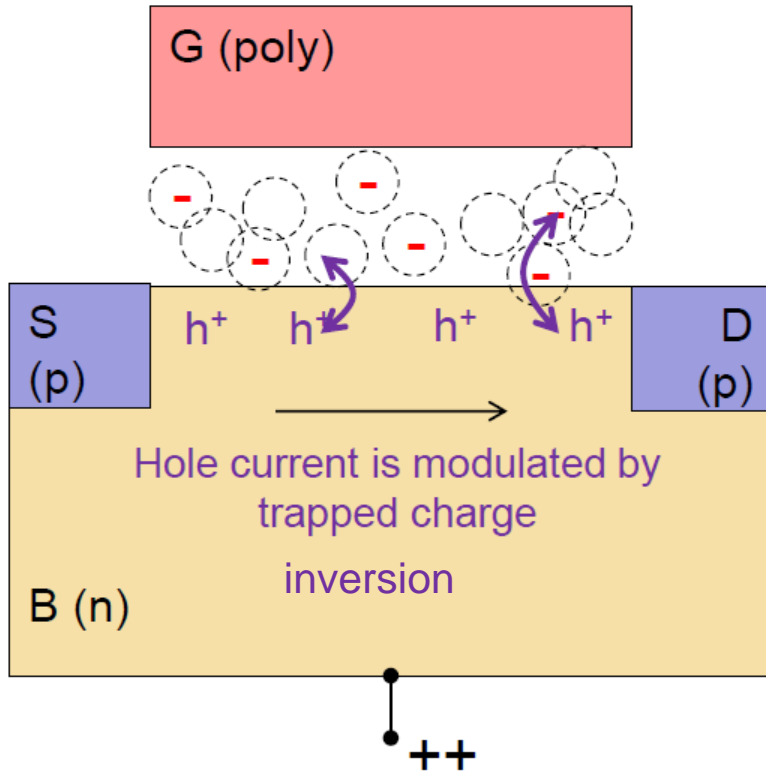
## The principle

# MOSFET 1/f noise: the “McWorther model”

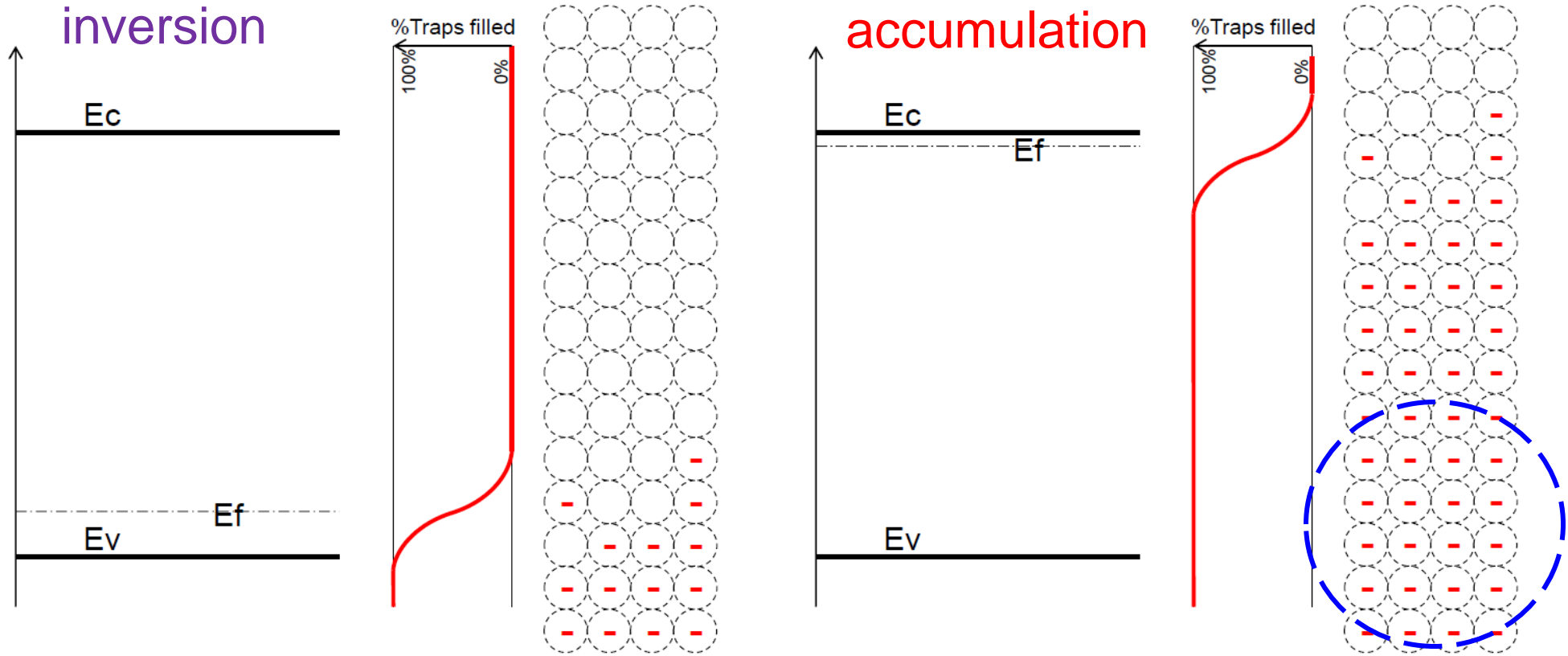


Filled oxide state + hole  $\rightleftharpoons$  empty oxide trap

Empty oxide state + electron  $\rightleftharpoons$  filled oxide trap



# Fermi statistics of interface states



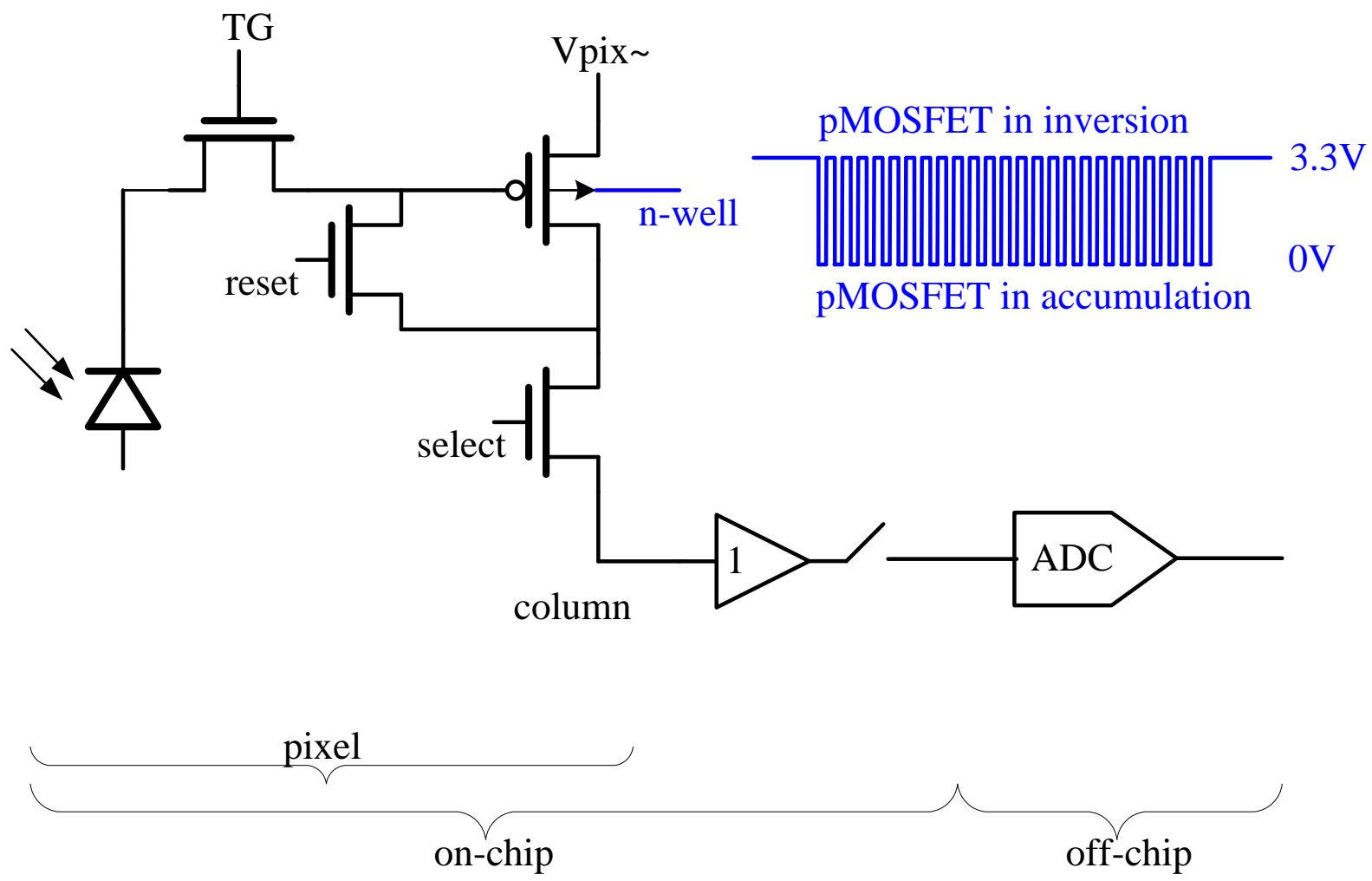
Population of trapping/emission time constants  
Each of them is one RTS

All traps relevant for  
RTS and 1/f noise are  
filled:  
Long term memory is  
lost

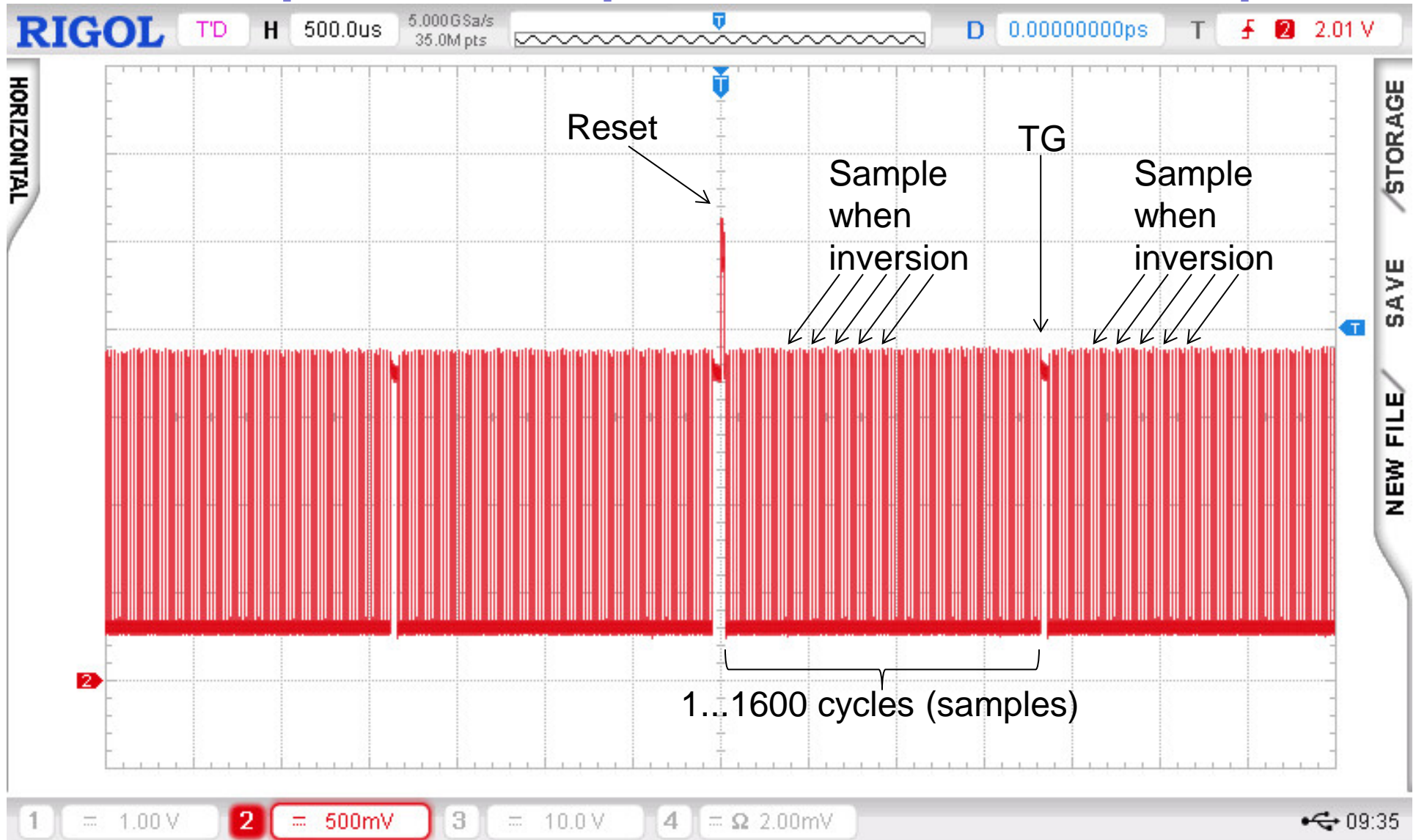
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# Measurement &interpretation

# Pixel and readout circuit



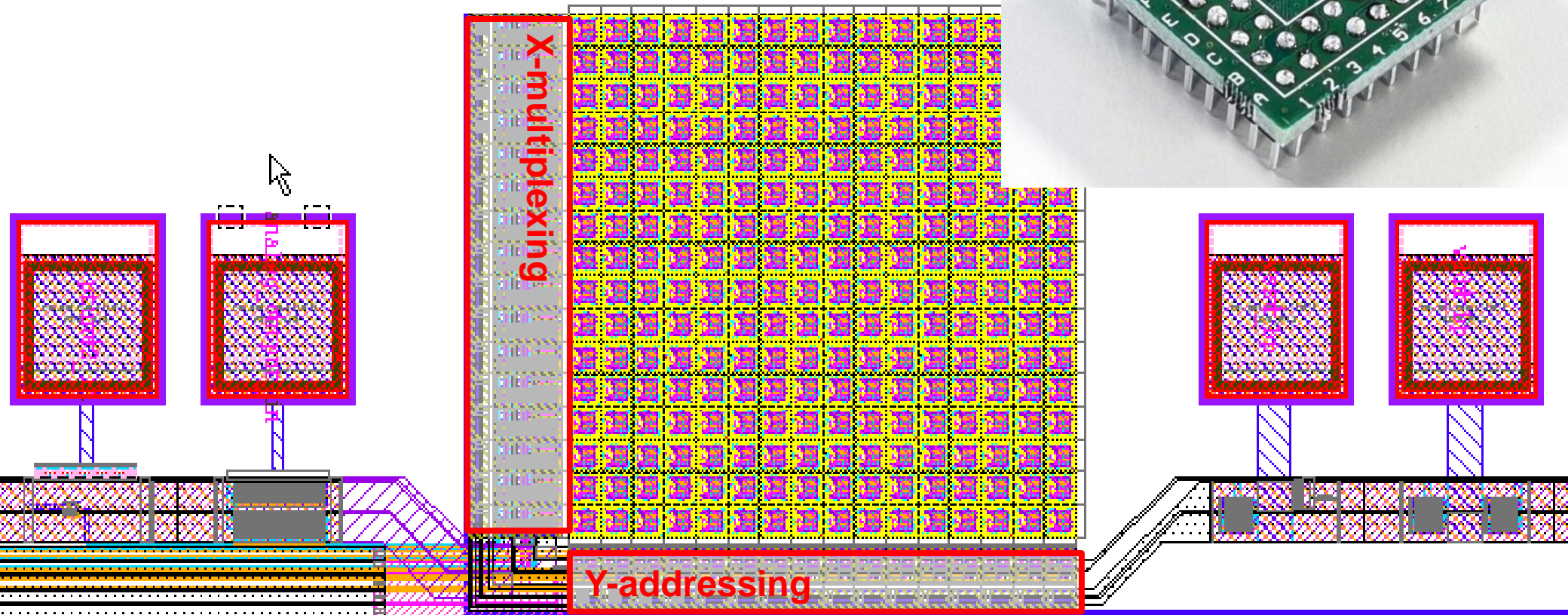
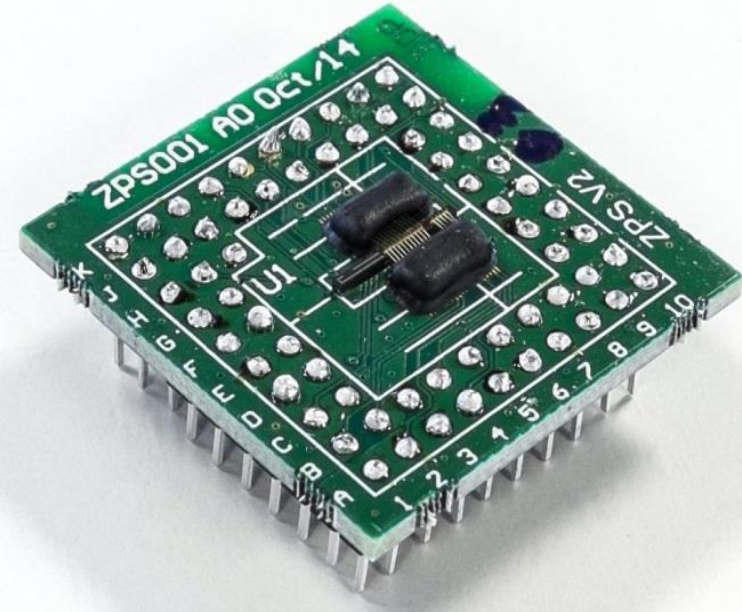
# Actual pixel output on oscilloscope





# Layout and CoB

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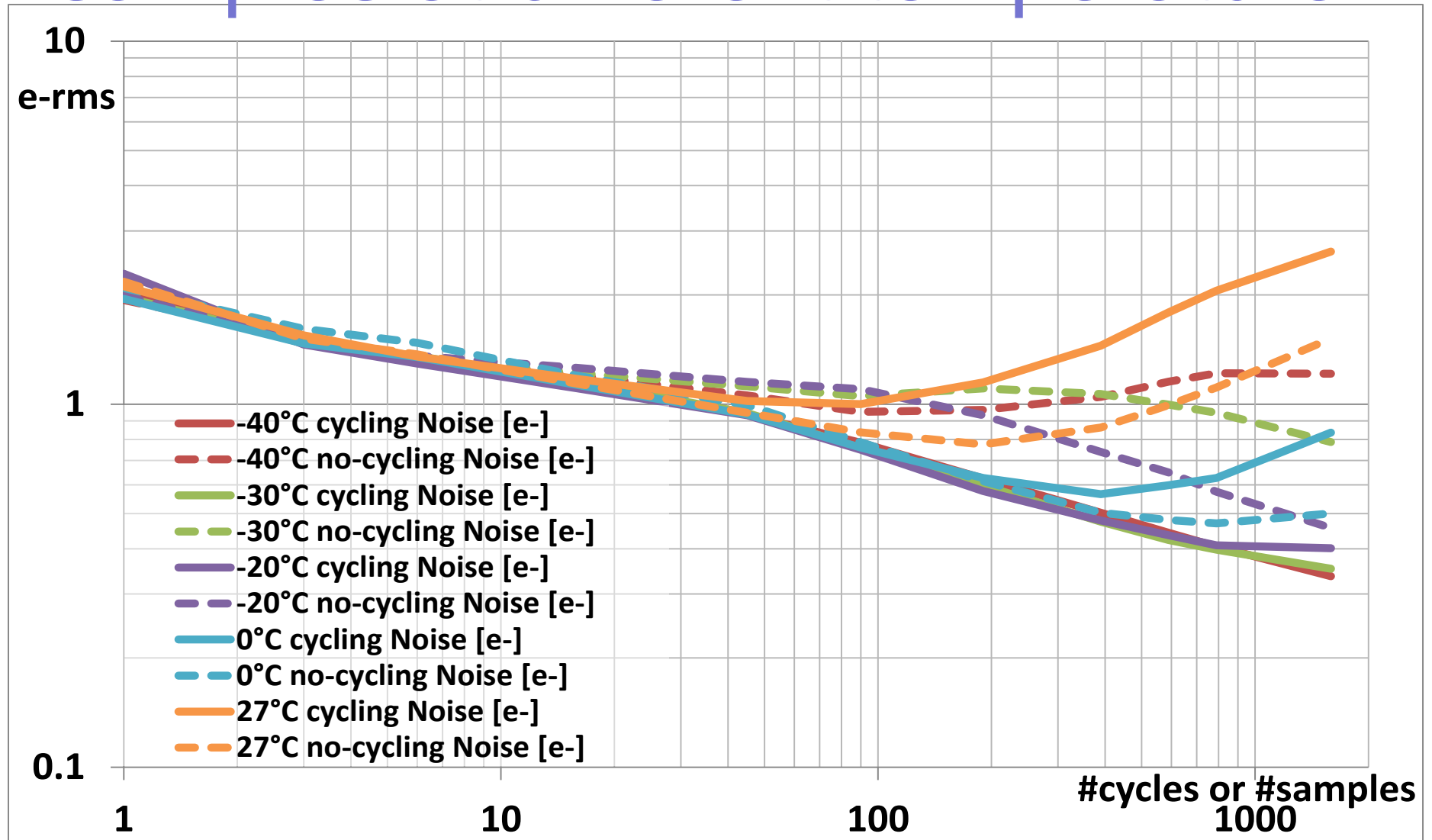


# ZPS2 nominal operation caeleste conditions and key features

Technology	180nm CMOS, 3.3V option
Pixels	16x16
Pitch	25 $\mu$ m
Pixel type	4T CTIA with pMOSFET
Interface	Direct Analog
N-well amplitude	Between 0V and 3.3V
CVF <sub>@output</sub>	402 $\rightarrow$ 392 $\mu$ V/e- (-40 $\rightarrow$ +27 $^{\circ}$ C) +/-3%~+/-1%

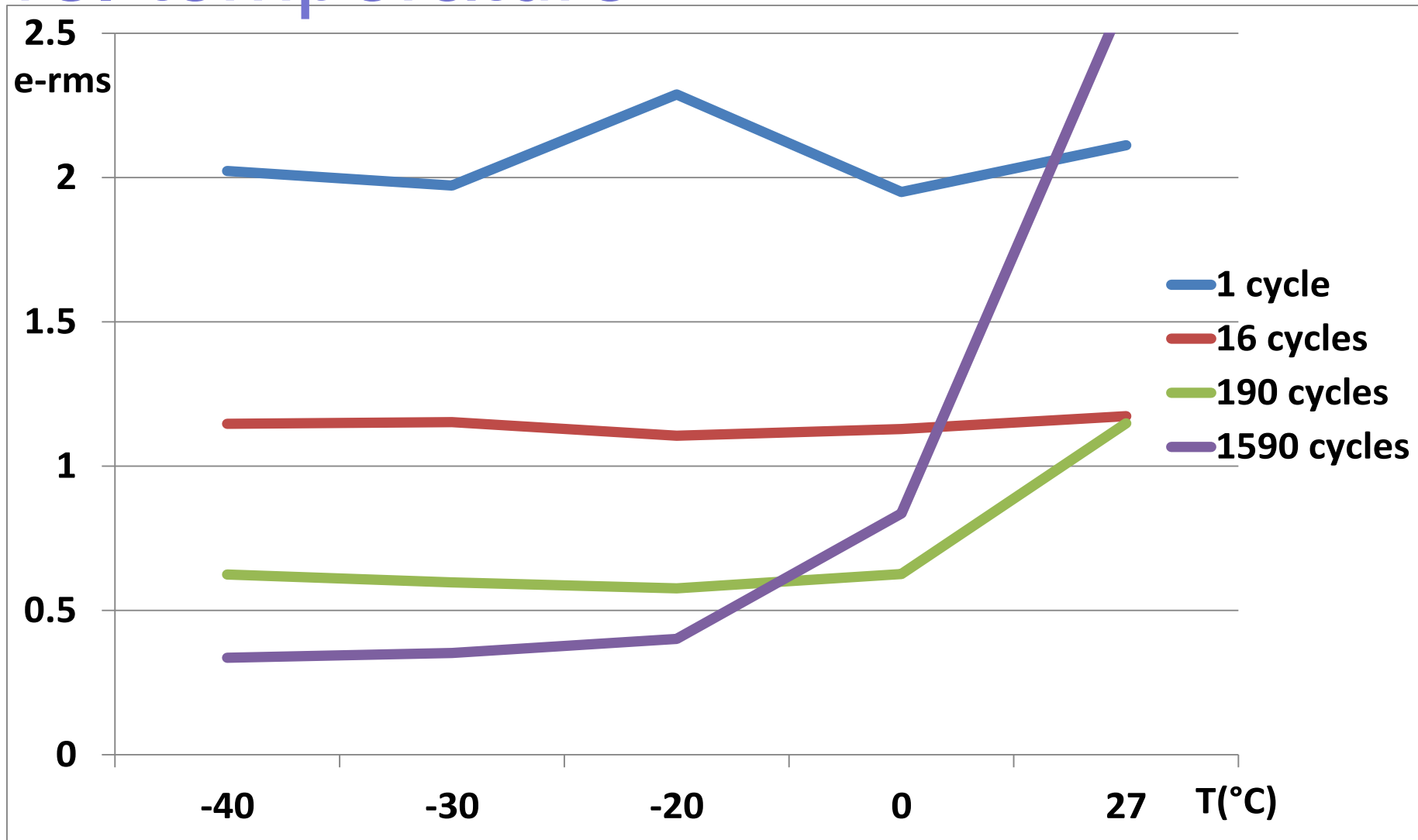
Operation Temperature	-40 $\rightarrow$ +27 $^{\circ}$ C
Sample Frequency	50kHz
Illumination Condition	Dark
Accumulation time / Inversion time	16
CDS	Digital
#Oversamples or #Cycles	1 $\rightarrow$ 1600
Acquisition System	Caeleste in-house

# Read noise vs #cycles or caeleste #samples at different temperature



# Read noise (cycling) vs. temperature

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The principle

Measurement&interpretation

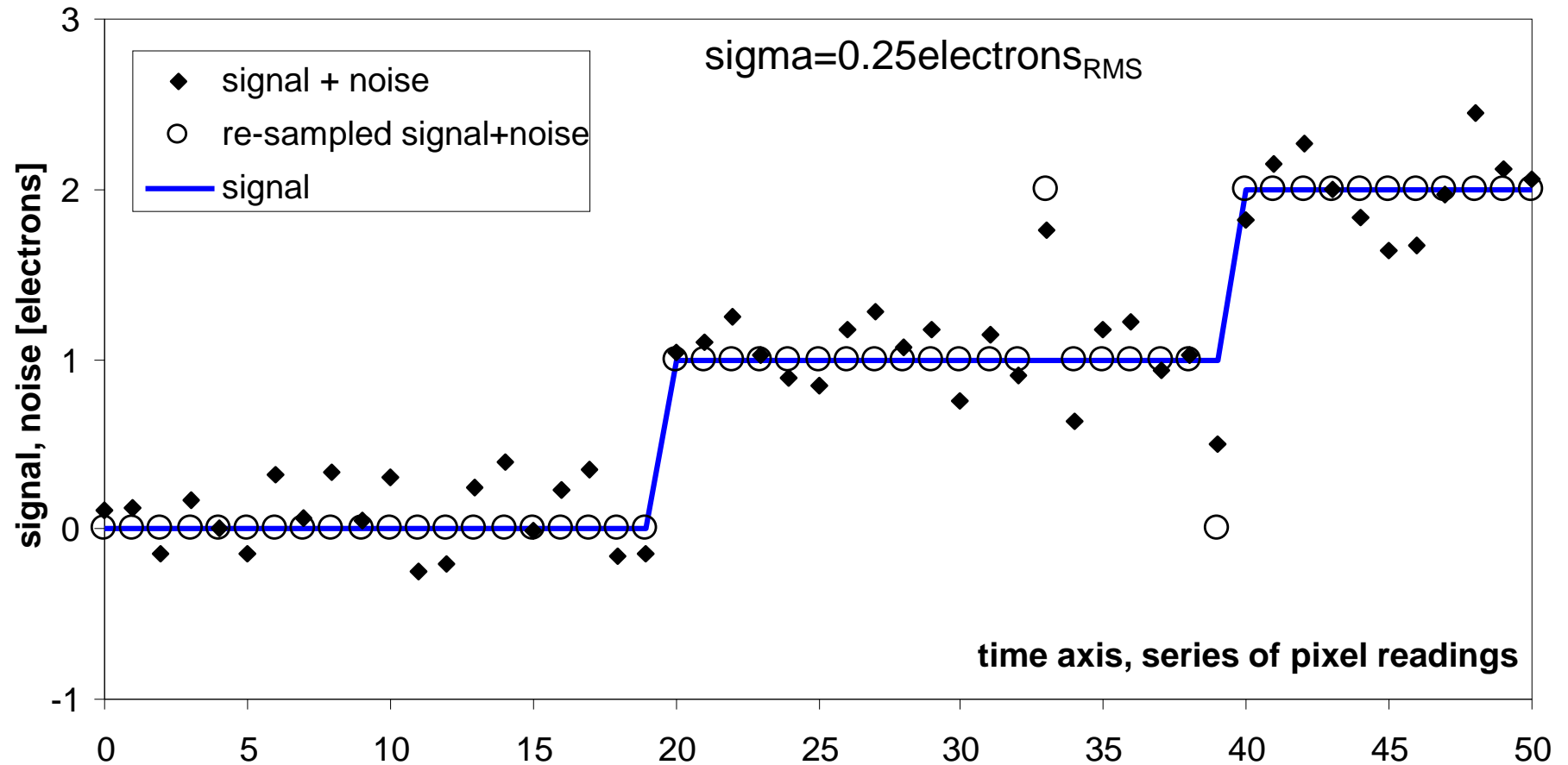
→ How far is photon counting

Take home message

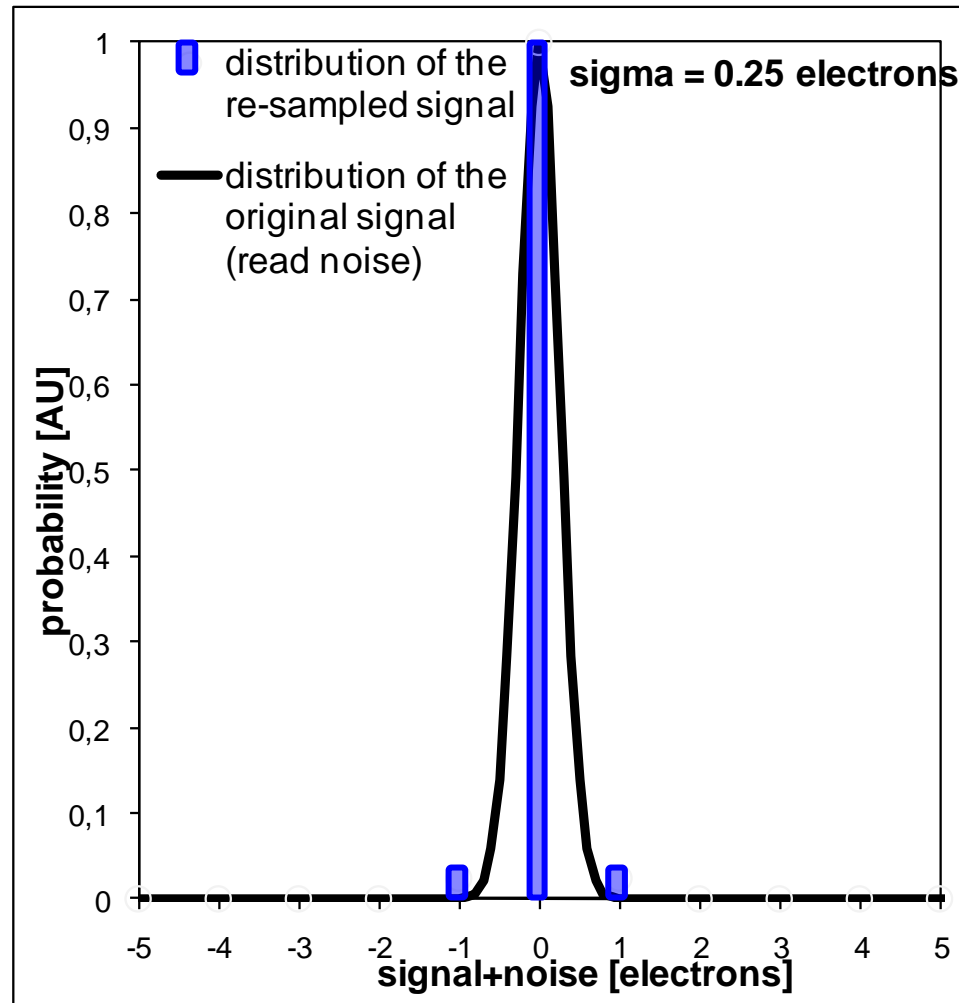
# How far is photon counting

## Excercise of thought

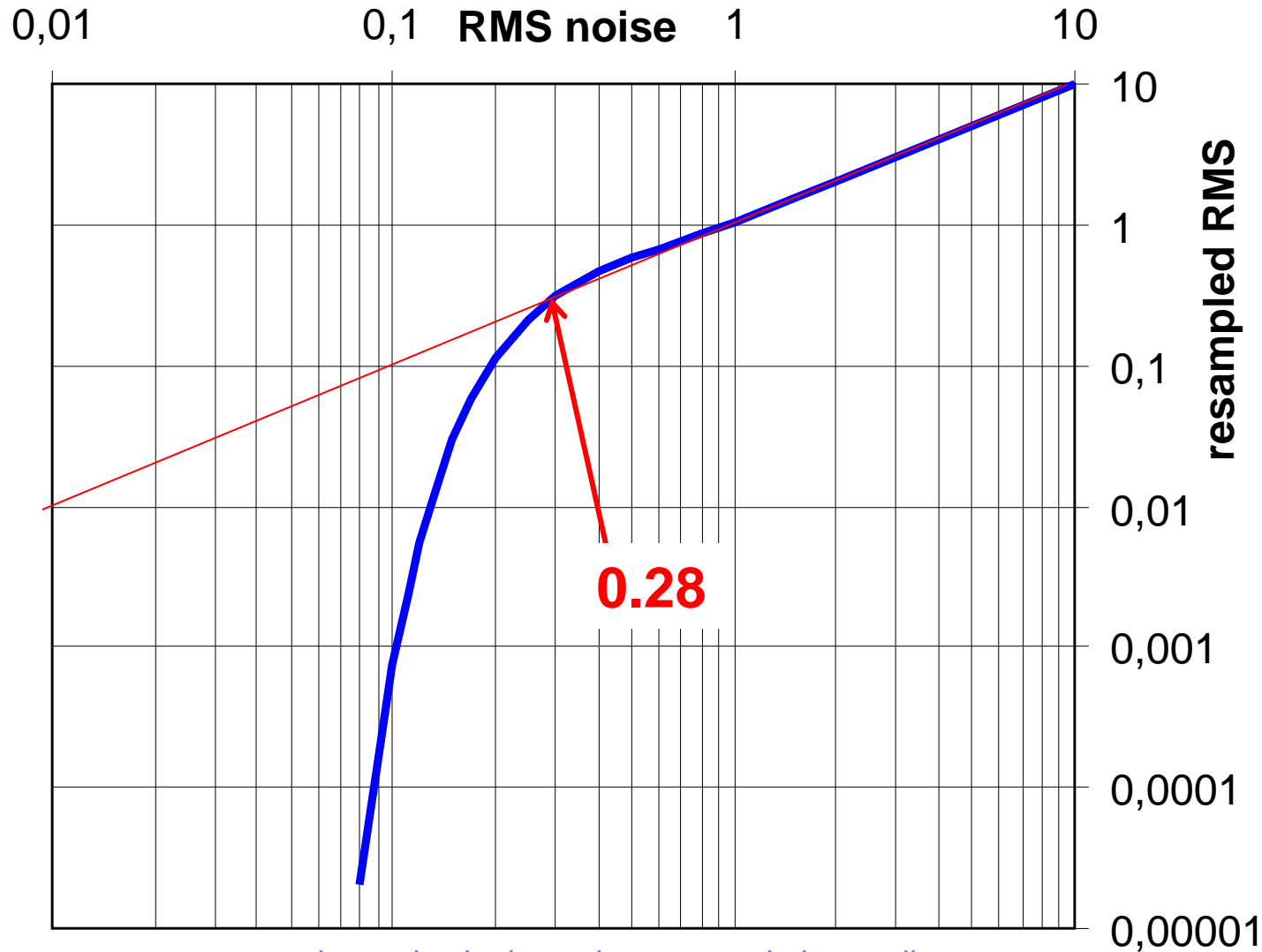
# The limit of “Photon Counting” accuracy



# The Gaussian distribution of 0.25 noise electrons



# The limit of “Photon Counting” accuracy





The principle

Measurement&interpretation

How far is photon counting

→ Take home message

# Take home message

## conclusions

# Take home



## Expected:

- ⇒ Clear effect of the inversion-accumulation cycling
- ⇒ Number of oversamples is limited by DCSN.

## Not expected:

- ⇒ Improvements factor is finite
- ⇒ McWorther model for  $1/f$  noise may be incomplete.

## Further improvements?

- ⇒ A higher number of cycles
- ⇒ Lower temperature
- ⇒ Thinner oxide MOSFETs.

⇒ JFETs and buried channel MOSFETs

Thank you!

