NORTHWESTERN POLYTECHNICAL UNIVERSITY

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SENSROC12: A high-count-rate low-noise front-end readout ASIC for Si-PIN-based personal dosimeter

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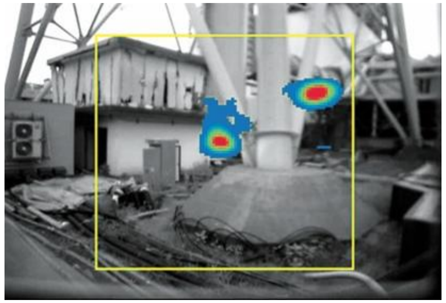
Outline

Introduction

- **Personal Dosimeter**
  - Ionization radiation of nuclear imaging in hospital and research in laboratories
  - military personal searching for nuclear materials
  - Occupational exposure in nuclear power plants



1. Main requirements
- Energy spectrum(±30%,^{137}Cs)
- Relative intrinsic error(±15%,^{137}Cs)
- Angular response(±20%,^{137}Cs)
- Energy range(48keV～7MeV)
- Dose(1μSv～1Sv)/Dose rate range(1μSv/h～1Sv/h)
- Temperature (-40-85℃)
- Low power dissipation

2. Other
- Waterproof，dropping and shock prevention
- electromagnetic radiation hardness
- Electrostatic protection

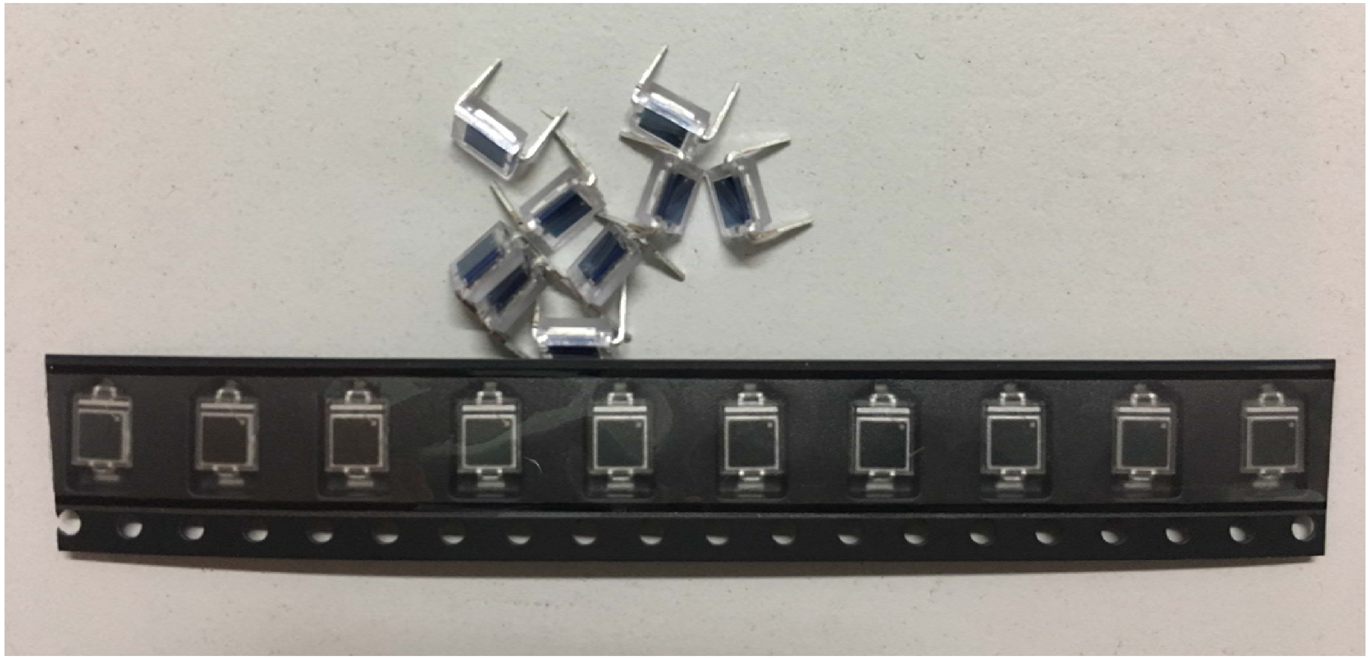
Introduction

Radiation Detectors

	PMT	APD	Silicon Photodiode	CZT,CdTe
Size	Bulky	Compat, thin	Compat, thin	Compat, thin
Gain	$10^6 \sim 10^7$	$10^2 \sim 10^3$	$10^2 \sim 10^3$	$10^2 \sim 10^3$
Noise	Low	moderate	Low	Low
Threshold Sensitivity	1 ph.e	10 ph.e	1 ph.e	--
Timing Resolution	~0.5 ns	~ 1ns	~ 0.5ns	~ 7 ns
Energy Resolution	~10 %	~13 %	~10 %	~4 % (0.2 ~ 20 keV)
Bias Voltage	800 ~1500 V	100~2000V	25 ~50 V	800~ 1500 V
Cost	$	$$	$$$($)	$$$

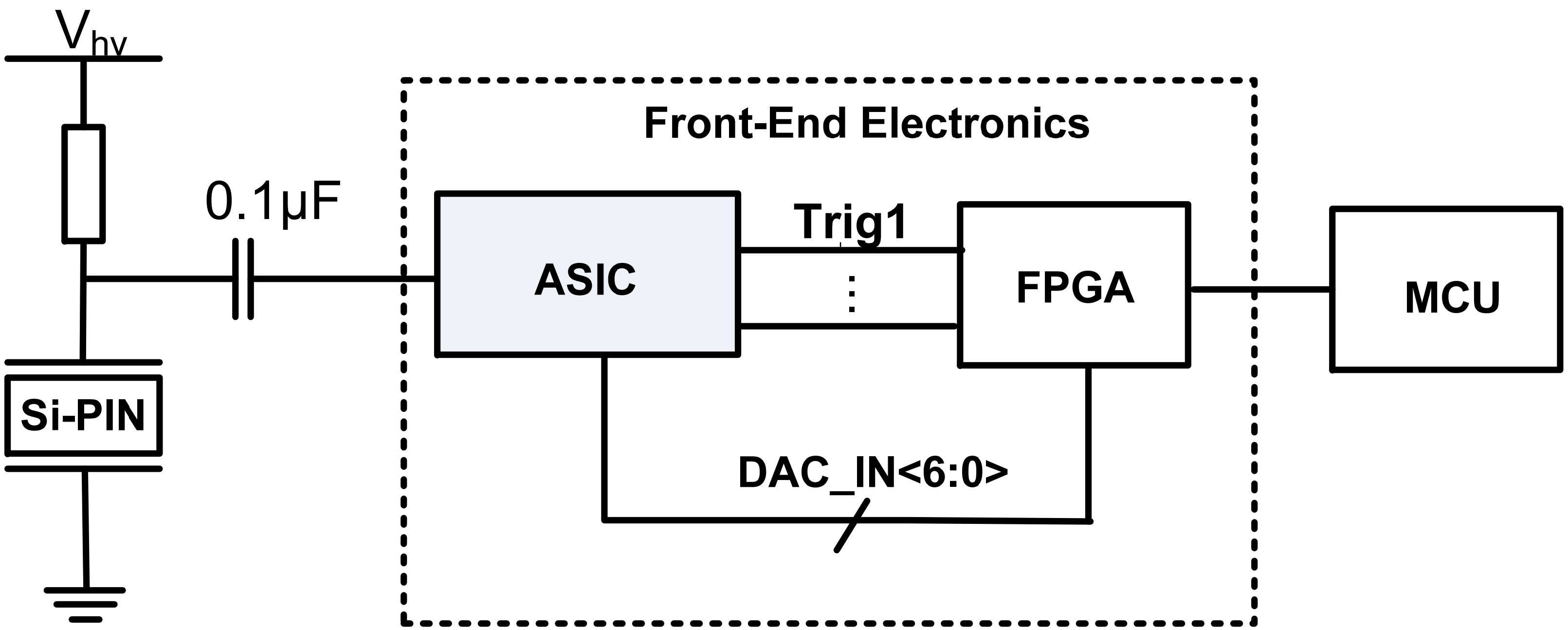
Introduction

- **Proposed detector → Si-PIN detector**
  - Each dimension: 5.4 mm × 4.3 mm × 3.2 mm;
  - Radiant sensitive area: 7.5 mm^2
  - Detector capacitance: ~20 pF
  - High radiant sensitivity
  - Fast response times



Introduction

- **Proposed front-end electronics**



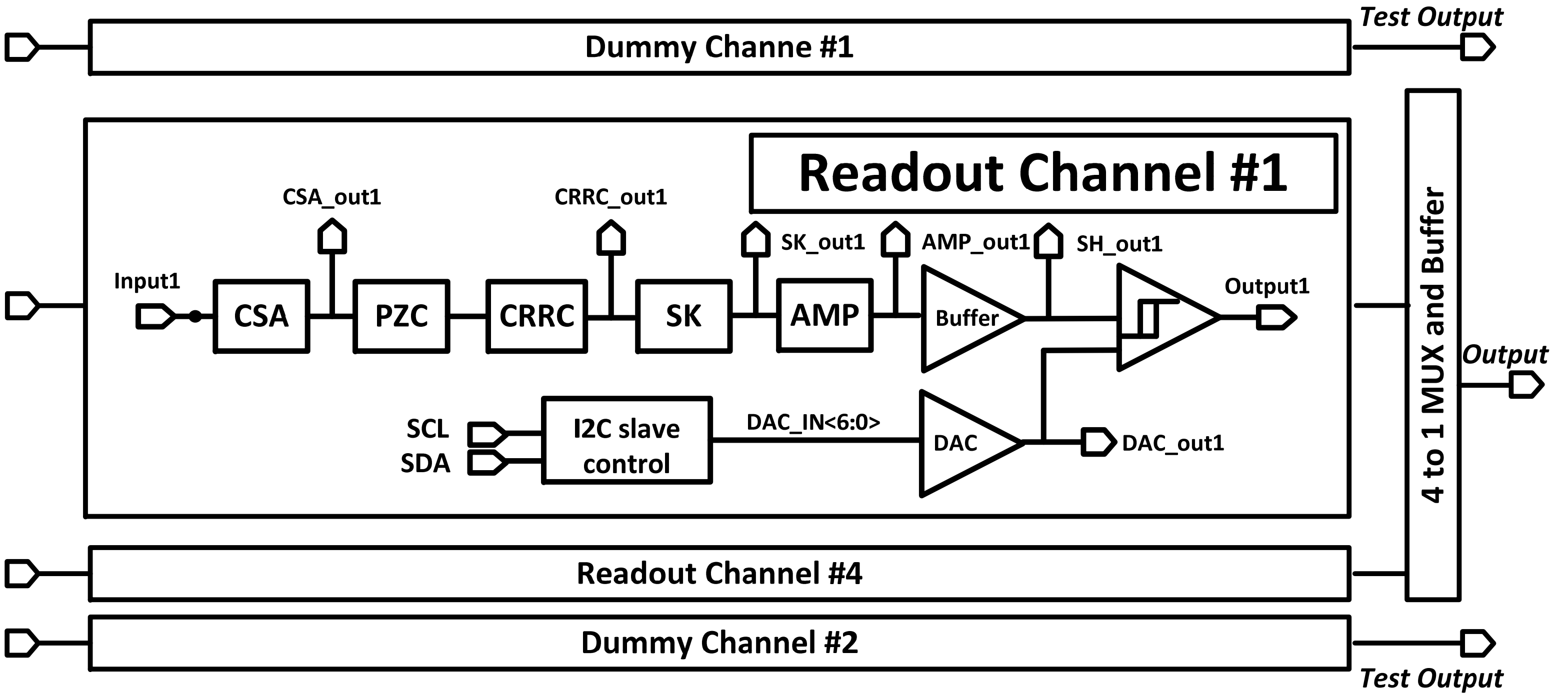
Introduction

ASIC requirement

Power Voltage	+/- 1.65V
Bias Voltage	5 V
Detector Capacitance	20 pF
Input Charge Range	0.2 fC ~ 15 fC
Shaping Time	<1 μs
Gain	> 60 mW/fC
ENC	<100 e^-@0 pF
Counting Rate	1 MCPS
Static Power Dissipation	1 mW/channel (not include DAC and discrimination) 1.2 mW/channel (include DAC and discrimination)

Readout techniques for Si-PIN detectors

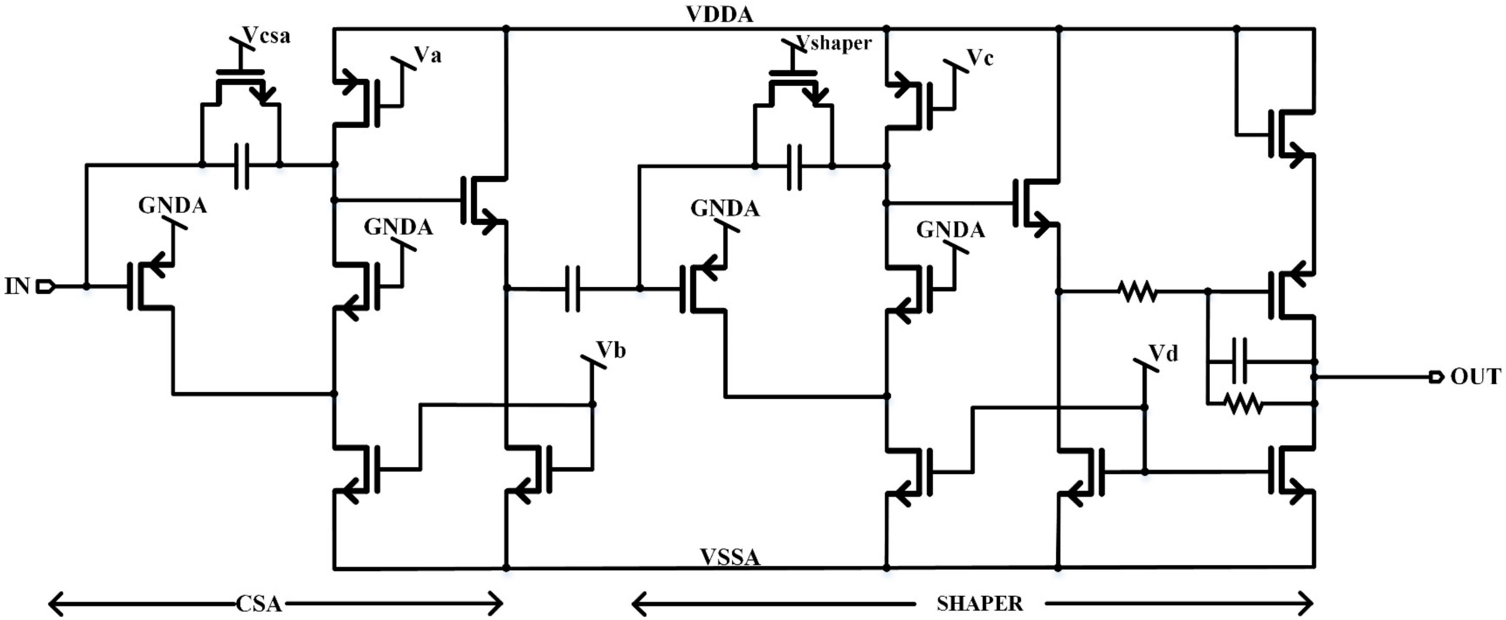
- Proposed topology



- Main features
  - Preamplifier: charge sensitive amplifier + PZC
  - Pulse shaper: CR-RC + SK + AMP(positive output)
  - Discriminator: high speed comparator + DAC(threshold adjustment)

Readout techniques for Si-PIN detectors

- **Proposed schematic of readout circuit**



- **Main Features**
  - Input stage: PMOS + cascode

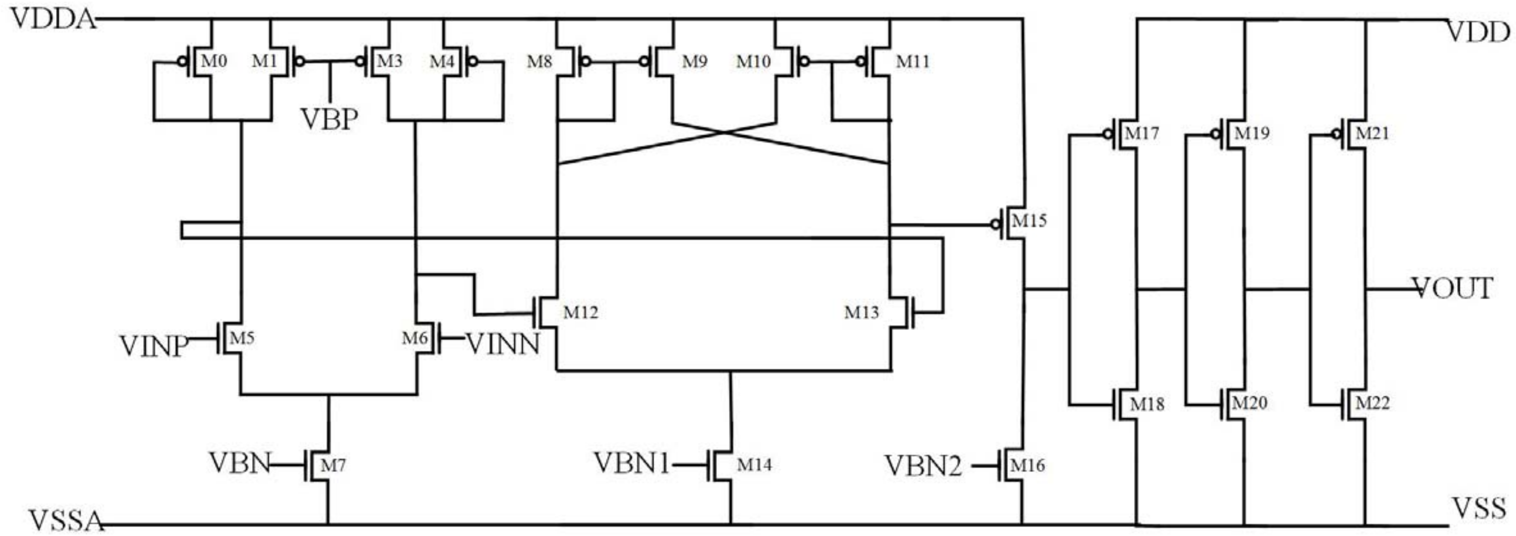
$$H(s) = -\frac{V_{OUT}(s)}{i_D(s)} \approx -\frac{1}{sC_F + \frac{1}{R_F}}$$

  - Pulse shaper: cascode CR-RC + simplified SK

$$H(s) = -\frac{sR_2C_1}{(1+sR_1C_1)(1+sR_2C_2)}$$

Readout techniques for Si-PIN detectors

- **Proposed hysteresis discrimination**



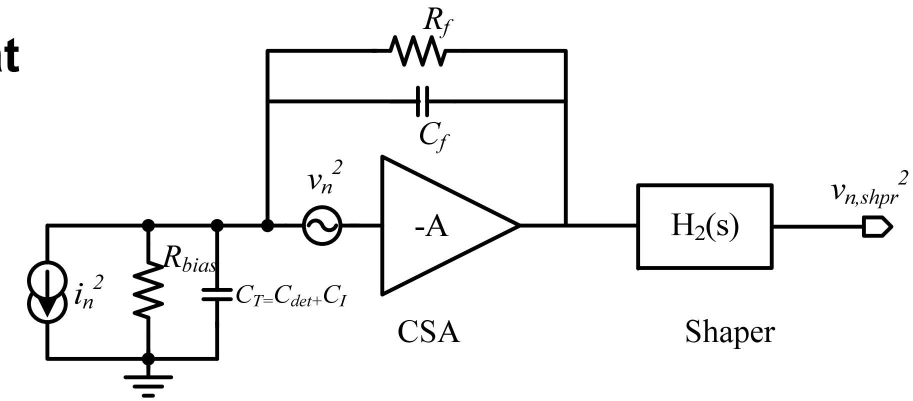
- **Main Features**
  - **Hysteresis voltage → 5mv**
  - **Three stage cascade structure**
  - **Isolate analog/digital power supplies**

Readout techniques for Si-PIN detectors

- **The power spectral density of current noise and voltage noise at the input of CSA**

$$\overline{i_n^2} = 2qI_{det} + \frac{4kT}{R_{bias}} + \frac{4kT}{R_f}$$

$$\overline{v_n^2} = 4kT\frac{\gamma_n}{g_{m1}} + \frac{K_f}{C_{ox}^2}\frac{1}{WL}$$



- **The output noise of shaper**

$$\overline{v_{n,shpr}^2} = \frac{1}{C_F^2}\left[\frac{t_p}{8}\left(2qI_{det} + \frac{4kT}{R_{bias}} + \frac{4kT}{R_f}\right) + (C_F + C_T)^2\left(\frac{4kT\gamma_n}{8t_p g_{m1}} + \frac{K_f}{2C_{ox}^2}\frac{1}{WL}\right)\right]$$

The equivalent noise charge is

$$ENC = \frac{\sqrt{\overline{v_{n,shpr}^2}}}{v_{shpr,\max}(Q_{in} = 1 \quad electron)}$$

Readout techniques for Si-PIN detectors

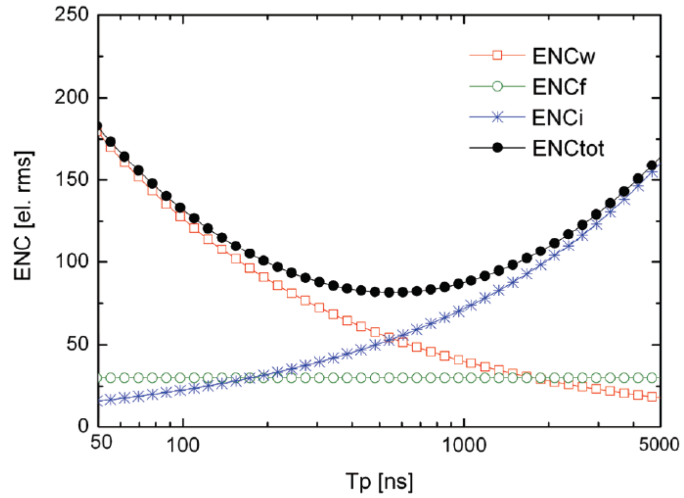
- The ENC can be calculated as

$$ENC = e\sqrt{\frac{t_p}{8}\left(2qI_{\det} + \frac{4kT}{R_{bias}} + \frac{4kT}{R_f}\right) + (C_F + C_T)^2\left(\frac{4kT\gamma_n}{8t_p g_{m1}} + \frac{K_f}{2C_{ox}^2}\frac{1}{WL}\right)}$$

- The ENC can be divided into three parts according to the current noise source, the voltage noise source and the 1/f noise source.

$$ENC^2 = ENC_i^2 + ENC_v^2 + ENC_f^2$$

$$\begin{cases} ENC_i^2 = 0.462t_p\left[qI_{\det} + 2kT\left(\frac{1}{R_{bias}} + \frac{1}{R_f}\right)\right] \\ ENC_v^2 = 3.696\frac{(C_F + C_T)^2}{t_p}\frac{kT\gamma_n}{g_{m1}} \\ ENC_f^2 = 3.696(C_F + C_T)^2\frac{K_f}{C_{ox}^2}\frac{1}{WL} \end{cases}$$



** P. Grybos. "Front-end Electronics for Multichannel Semiconductor Detector Systems", Warsaw, 2010

Readout techniques for Si-PIN detectors

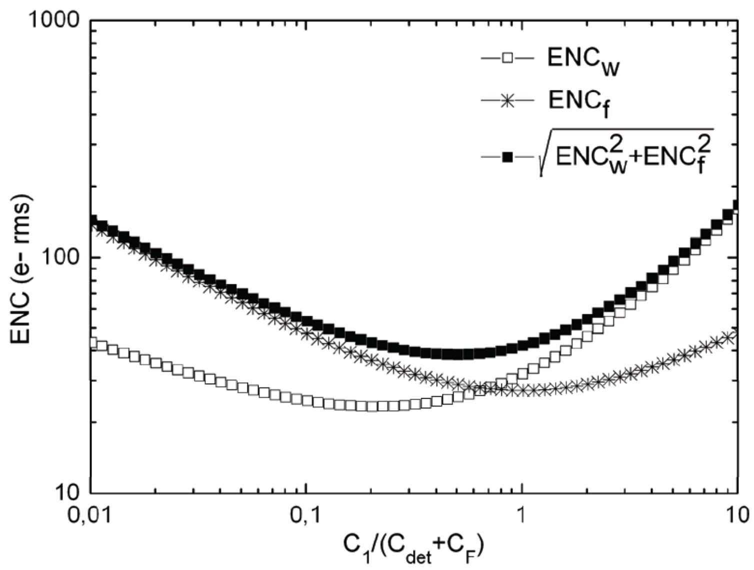
- **The minimum ENC$_v$ is obtained if**

$$C_I = \frac{C_{det} + C_F}{3} \qquad W_{1,opt} = \frac{C_{det} + C_F}{2C_{ox}L_{min} + 6C_{ov}}$$

- **The minimum of *ENC$_f$* is obtained if**

$$C_I = C_{det} + C_F$$

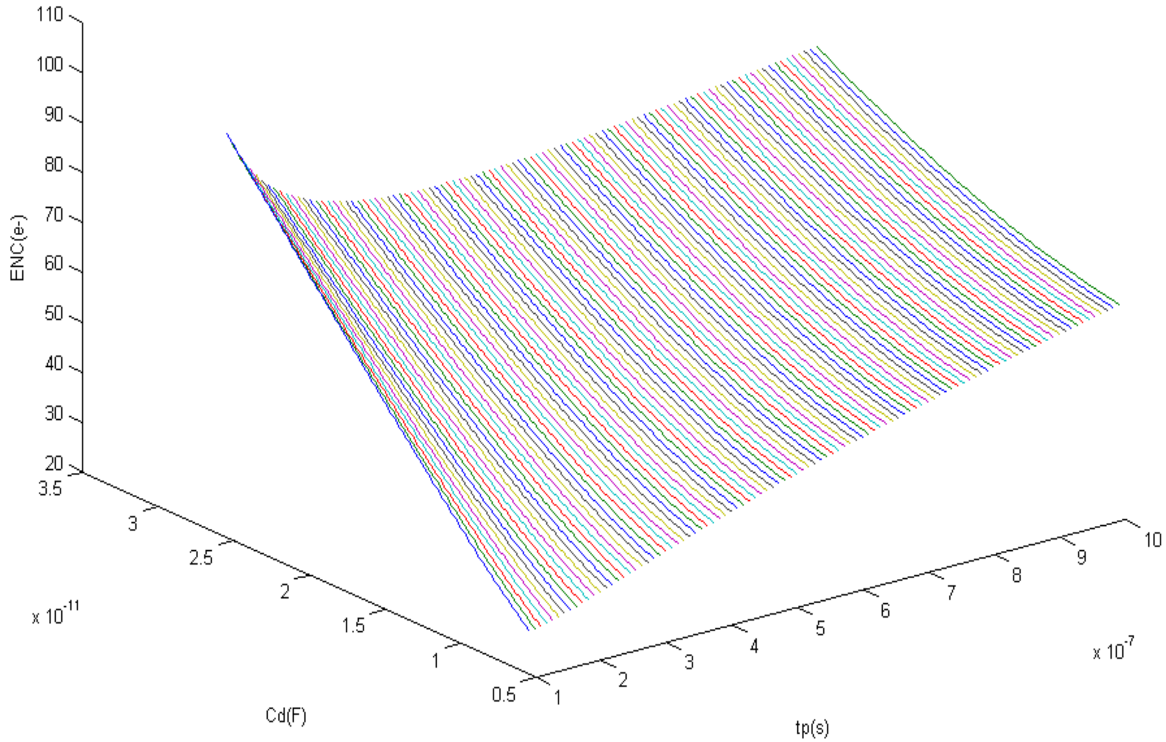
The optimum C_I is closer to $(C_{det} + C_F)/3$ for short peaking time.
When the peaking time is longer, $(C_{det} + C_F)$ is more appropriate.



** P. Grybos. “Front-end Electronics for Multichannel Semiconductor Detector Systems”, Warsaw, 2010

Readout techniques for Si-PIN detectors

- **Noise analysis**



Cf = 50 fF

Cd = 20 pF

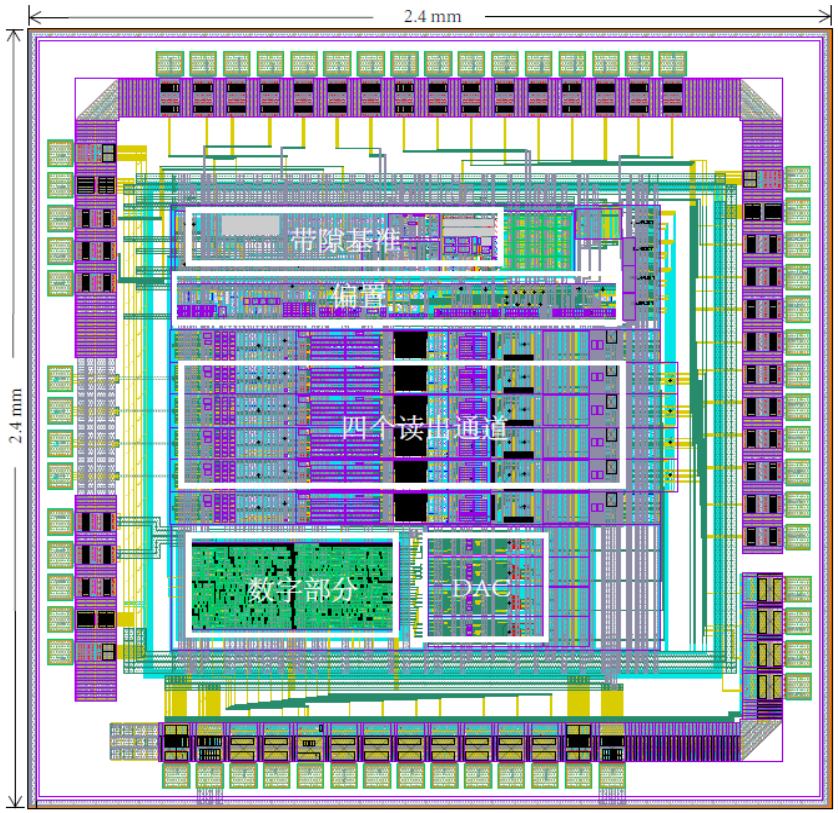
W = 3000 μm

L = 400 nm

I_D = 400 μA

T_p = 250 ns

Experimental results and Discussions



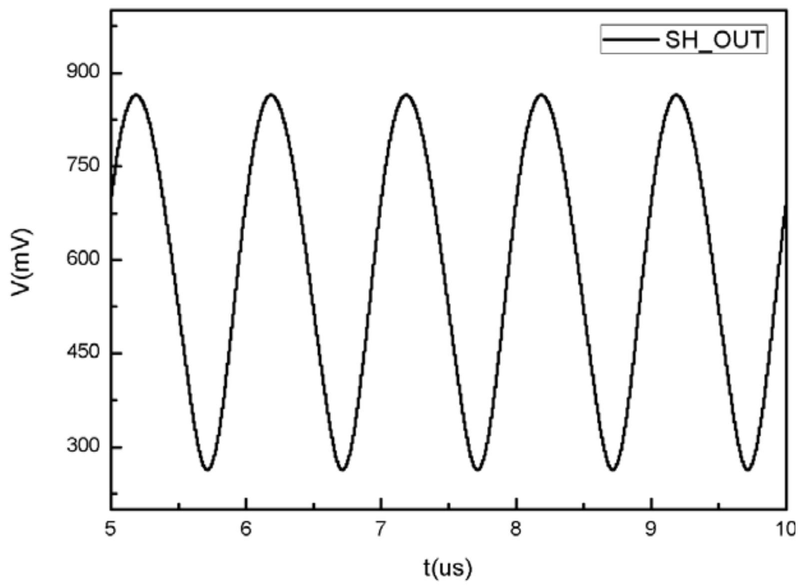
ASIC Layout

Process	CMOS 0.35μm 3.3V
Channel numbers	4
Die size (mm^2)	2.4 ×2.4
Power Diss.	1 mW/Ch.
Dynamic Range	0.2 fC ~ 16 fC
Non-linearity	< 3%
Gain	65 mV/fC
ENC	85 e @ 0 pF
Count Rate	1 MCPS
Peak Time	~ 0.5 us
Applications	Personal dosimeter and Portable spectrometer

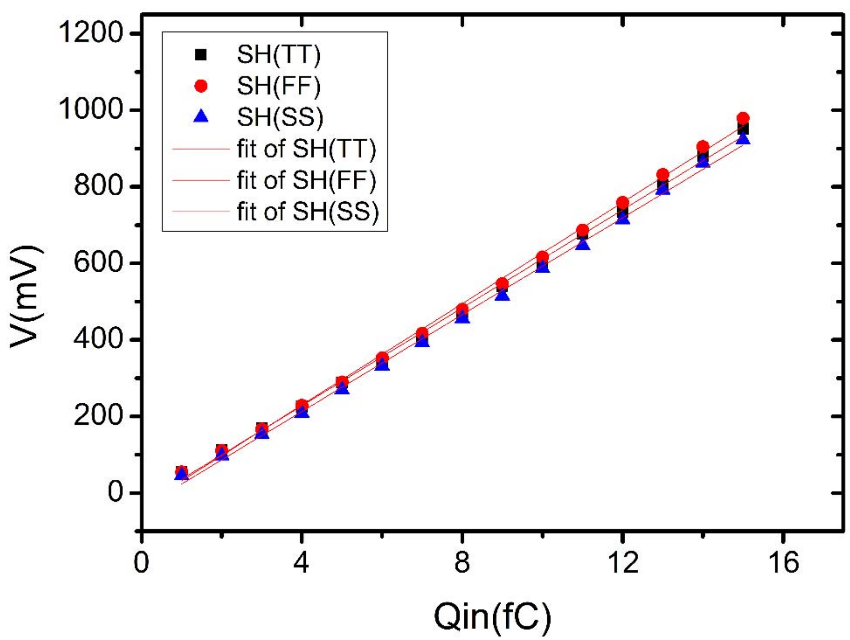
ASIC Overall Performance

Experimental results and Discussions

- **The maximum count rate is about 1MCPS.**
- **Input range → 0 ~ 16 fC; gain → 65 mV/fC (Typical)**



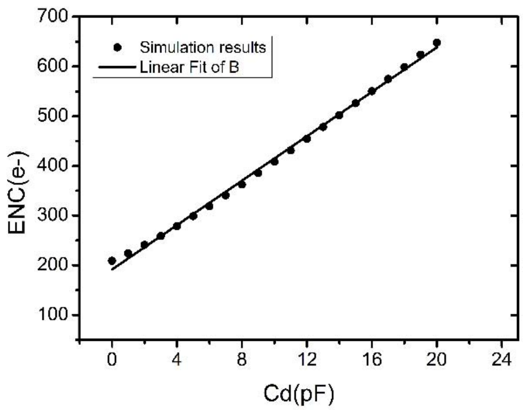
Output waveform



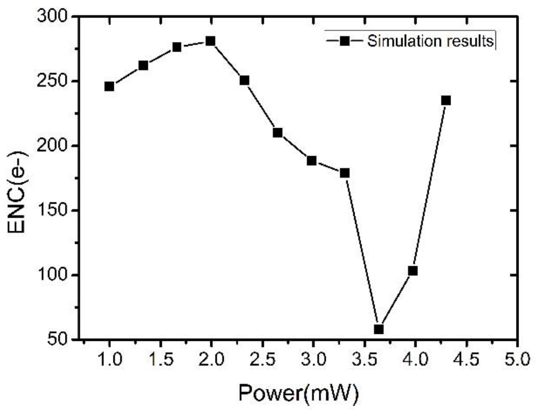
SH_out voltage VS. Qin

Experimental results and Discussions

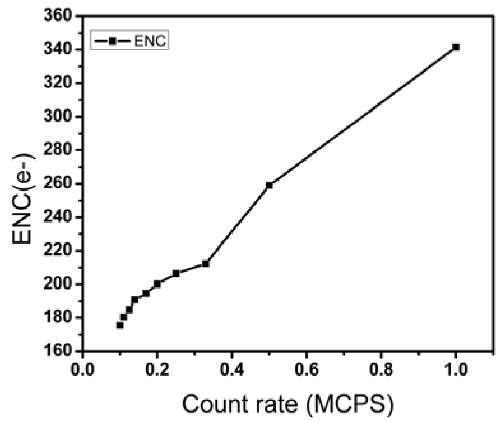
- **Noise performance**
  - ENC = 209 e- + 20 e- /pF(@ 1MCPS)



ENC vs. C_d



ENC vs. Power dissipation



ENC vs. Count rate

Experimental results and Discussions

Parameters	IDeF-X, 2009	2DASIC, 2009	STS-XYTER, 2013	IDE4184, 2015	This work
Process	CMOS 0.35μm	CMOS 0.35μm	CMOS 0.18μm	CMOS 0.35μm	CMOS 0.35μm
Channel numbers	32	16	128	128	4
Die size (mm^2)	2.8×6.4	2.95×2.95	10×6.5	8.04×7.37	2.4 ×2.4
Power Diss.	3mW / Ch.	0.15 mW / Ch.	3.1 mW / Ch.	90mW/ 128 Ch	1 mW/Ch.
Dynamic Range	0~8 fC	-12 fC ~+9 fC	-12 fC ~+9 fC	-25 fC	0.2 fC ~ 15 fC
ENC	33e+7 e/pF	88 e@ 0 pF	321 e@ 0 pF	130 e@ 0 pF	209 e + 20 e/pF
Count Rate	50 KCPS	30 KCPS	150 KCPS	92 KCPS	1 MCPS
FOM(ENC*Power Diss / Count Rate)	1.98	0.44	6.6	0.99	0.209

Conclusions and Perspectives

Conclusions for this presentation

- Proposed a novel front-end ASIC for Si-PIN-based personal dosimeter.
- An four-channel front-end readout prototype chip in 0.35 μm CMOS process.
- The simulation results show that the proposed ASIC can be employed for Si-PIN detector applications.
- Main experimental results include 1 mW/ch,200 e- (rms) @ 1 MCPS

Future work

- Performance evaluation of SENSROC12.
- Application verification in personal dosimeter system.

SENSROC12: A high-count-rate low-noise front-end readout ASIC for Si-PIN-based personal dosimeter

Thanks for your attentions.

Questions?