Integrated Circuits for Physics Experiments

Microelectronic Group

Integrated Circuits for Physics Experiments

Outline

- Motivations
- ScalTech Project: Why 28nm technology?
- A Rail-to-Rail Input Chopper Instrumentation Amplifier
- IC-PIX28: Integrated Chip for PIXel read-out
- A Resistance-to-Frequency Interface for High DR Resistive Sensors

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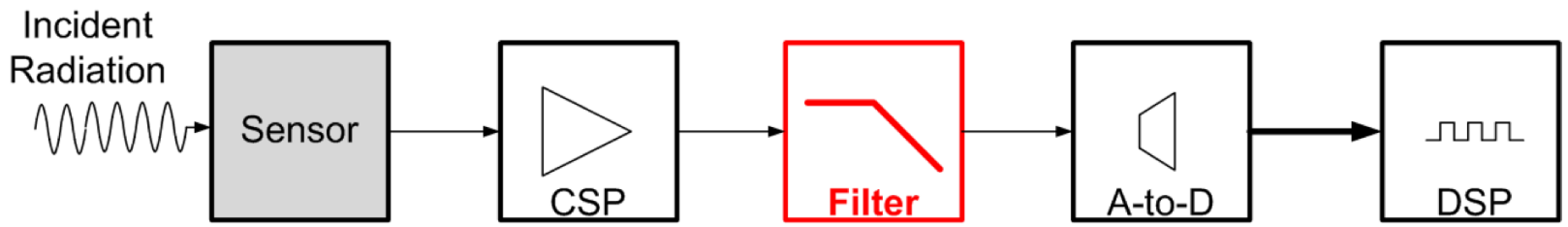
Motivations

Design of integrated electronic interfaces for physics experiments



High-Energy-Physics Systems – Typical Blocks Scheme

- Typical Acquisition Path Blocks:
  - Charge-Sensitive-Preamplifiers
  - Analog Filters
  - Amplifiers
  - Analog to Digital Converters
  - Digital Signal Processing

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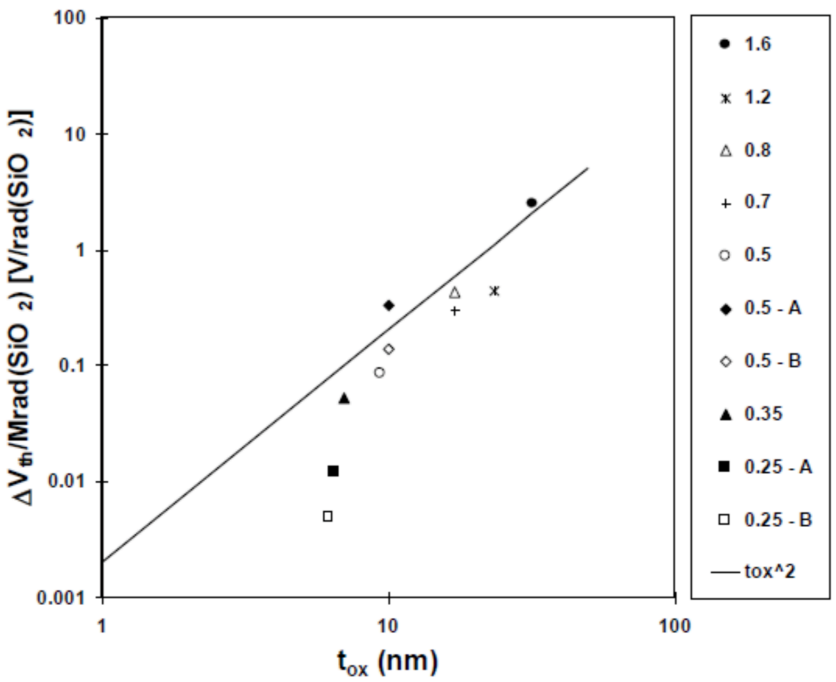
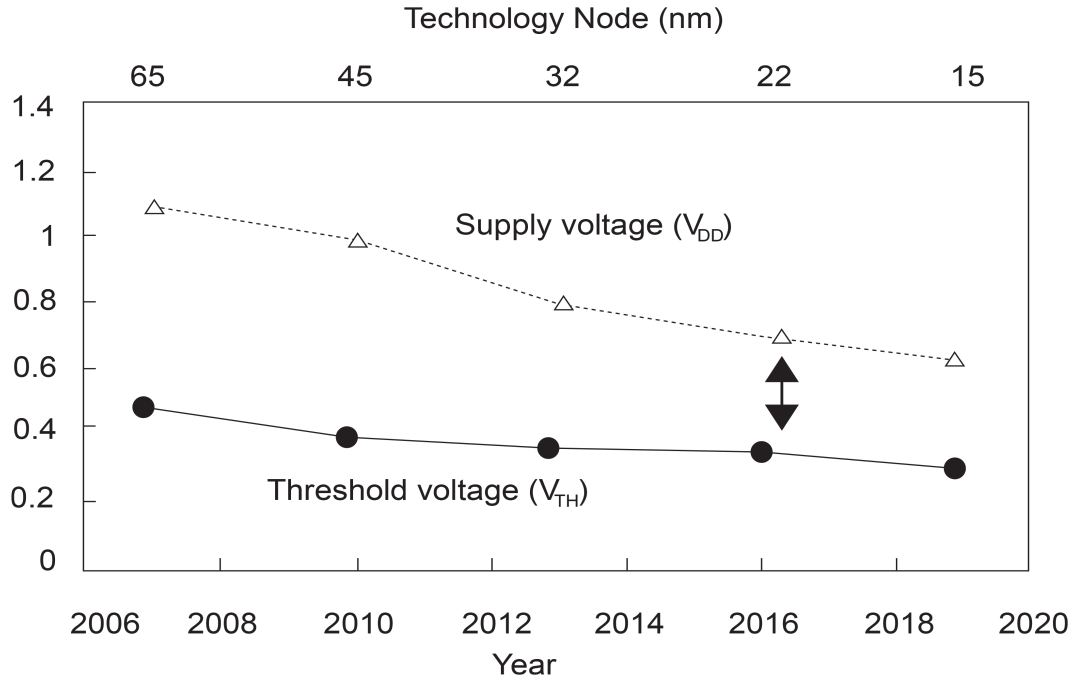
Scaltech Project
Why 28nm technology?





- Pros:
  - Radiation Hardness (to check with measurements)
  - Higher integration
  - Higher processing rate & more speed

- Cons:
  - Lower V_{DD} to v_{th} ratio
  - Lower signal swing
  - Lower SNR
  - Higher PVT variations

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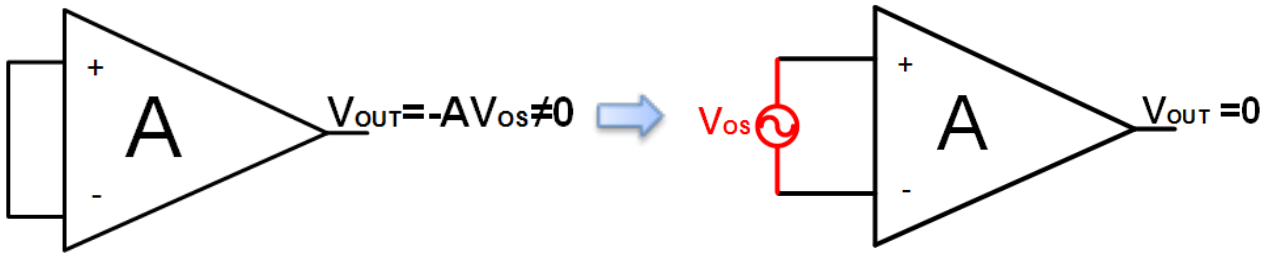
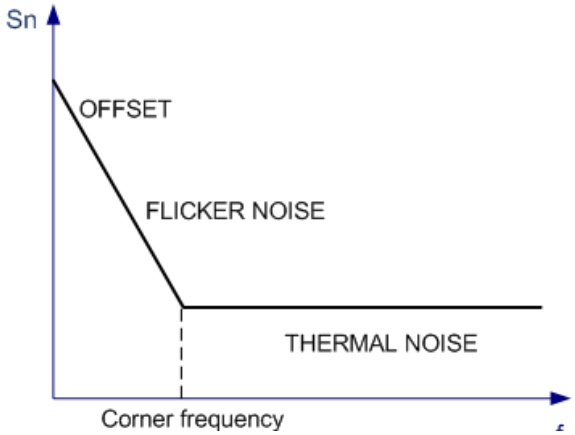
A Rail-to-Rail Input Chopper Instrumentation Amplifier

Offset & 1/f noise definition

- **Offset** is the signal that needs to be applied to the input to make the amplifier output equal to zero
  - Systematic offset
    - due to asymmetric paths
  - Random offset
    - due to mismatch i.e. random variations of identical designed devices
    - threshold voltage VTH and drain current ID mismatches



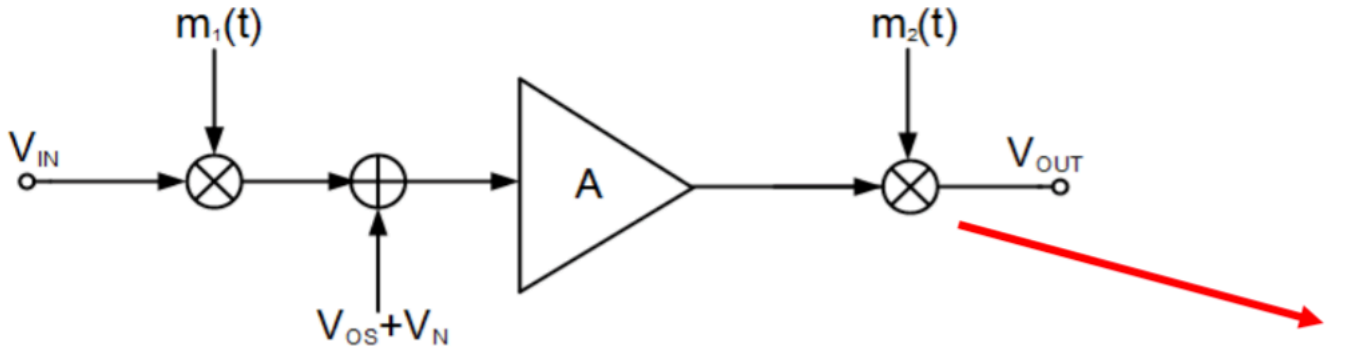
- **Flicker (1/f) noise** energy is due to charge trapping in the discontinuity of the MOS gate oxide
  - Characterized by a large time constant
  - Concentrated at low frequency

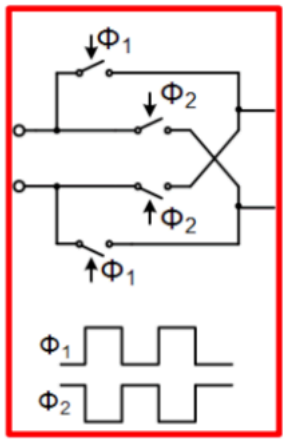


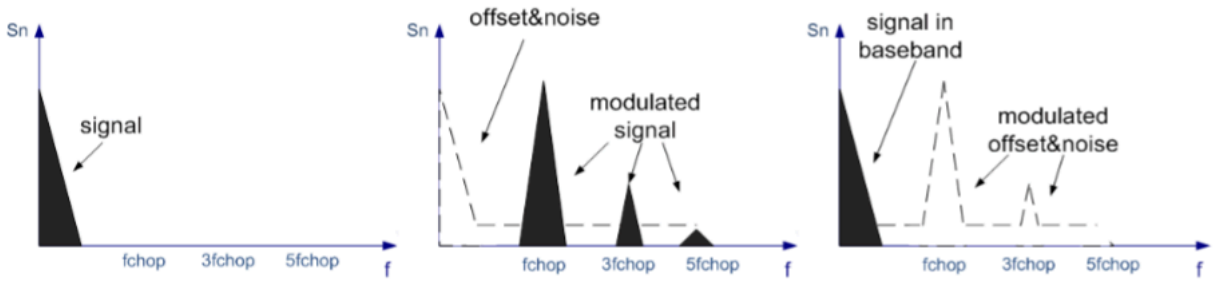
A Rail-to-Rail Input Chopper Instrumentation Amplifier

Chopping Technique

- Signal is modulated, amplified and then demodulated again
- Offset & 1/f noise are modulated once → shifted to high frequency
- $m_i(t)$ is a square wave signal with period $T_{chop}=1/f_{chop}$
- Modulator is a polarity reversing switch



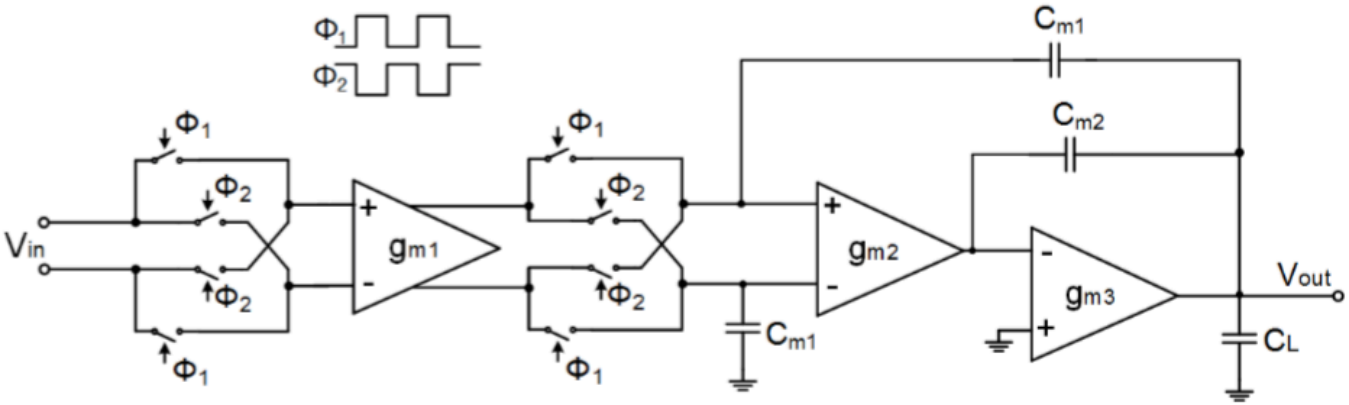




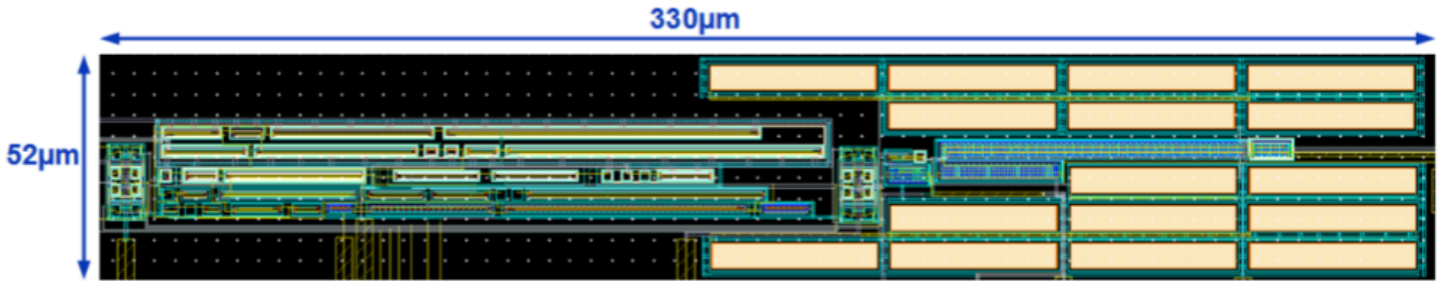
A Rail-to-Rail Input Chopper Instrumentation Amplifier

Circuit Schematic and Layout

- Design of an instrumentation amplifier (IA) characterized by:
  - High gain
  - Low offset
  - Low flicker noise



- Typical dynamic offset cancellation technique: **Chopping technique**
- Three-stage chopper instrumentation amplifier
  - Thanks to chopping operation, offset and flicker noise are reduced
  - Scaled technology → Amplifier working in sub-threshold region



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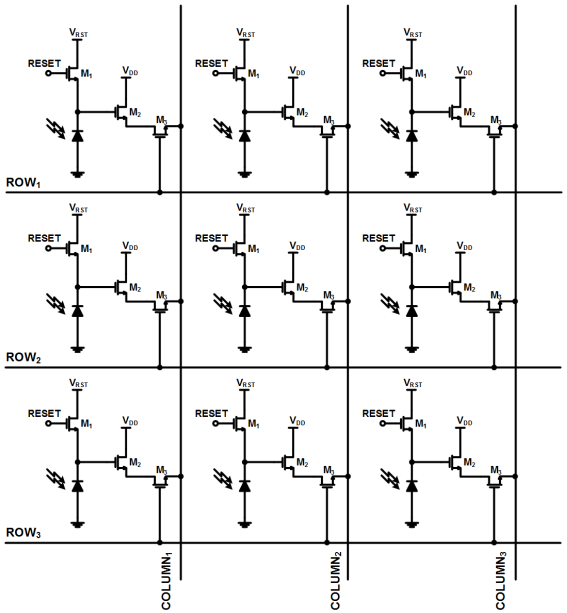
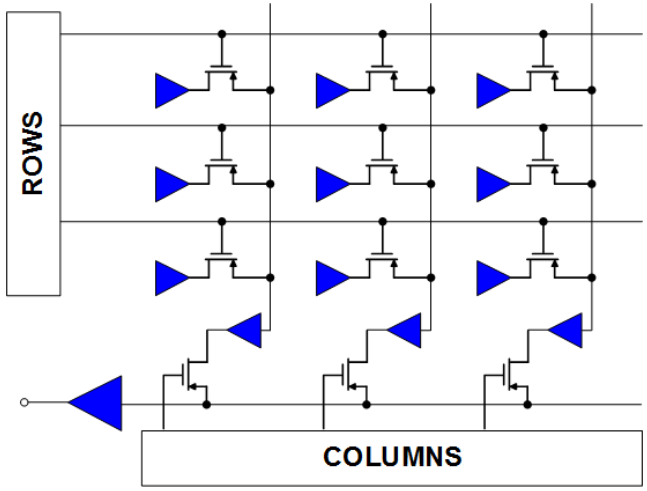
IC-PIX28: Integrated Chip for PIXel read-out

Introduction

- **Applications:**
  - **➔ Physics Experiments**
  - **➔ Photography**
    - **CMOS Active Pixel Sensors (APSs)**
      - Each pixel cell performs
        - Photon to Electron conversion
        - Charge to Voltage conversion
      - Sensor and read-out electronic are on-chip
        - More compatibility
        - More accuracy
        - More complex
    - **Input Charged particles:**
      - 0.1fC ÷ 6fC (very small charges)
    - **Conventional Pixel Structures:**
      - Matrix of n-rows and m-columns
      - Higher pixel cells to increase the resolution
      - Pixel cell smaller, low power and faster



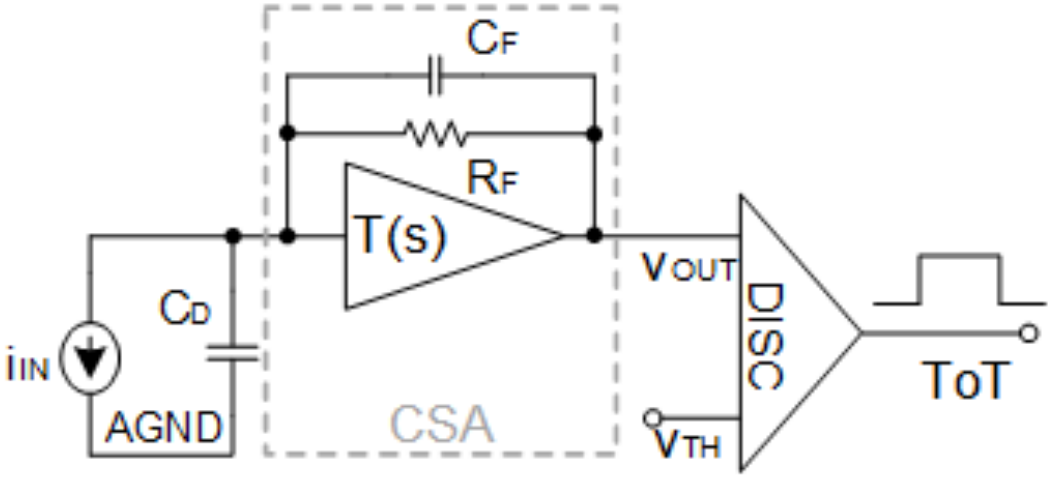


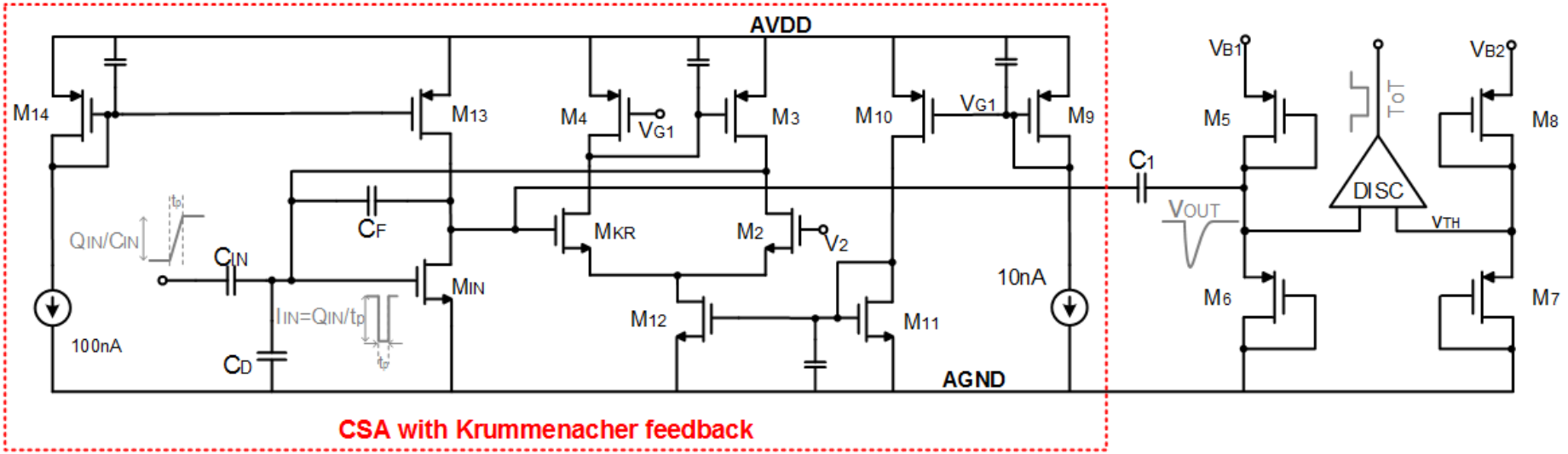
IC-PIX28: Integrated Chip for PIXel read-out

Prototype of one Channel

Output signals:

- Charge Sensitive Amplifier (CSA)
  - ➔ Charge to Voltage conversion
- Discriminator (DISC)
  - ➔ Voltage to Time conversion
  - ➔ Arrival time and amount of charge information





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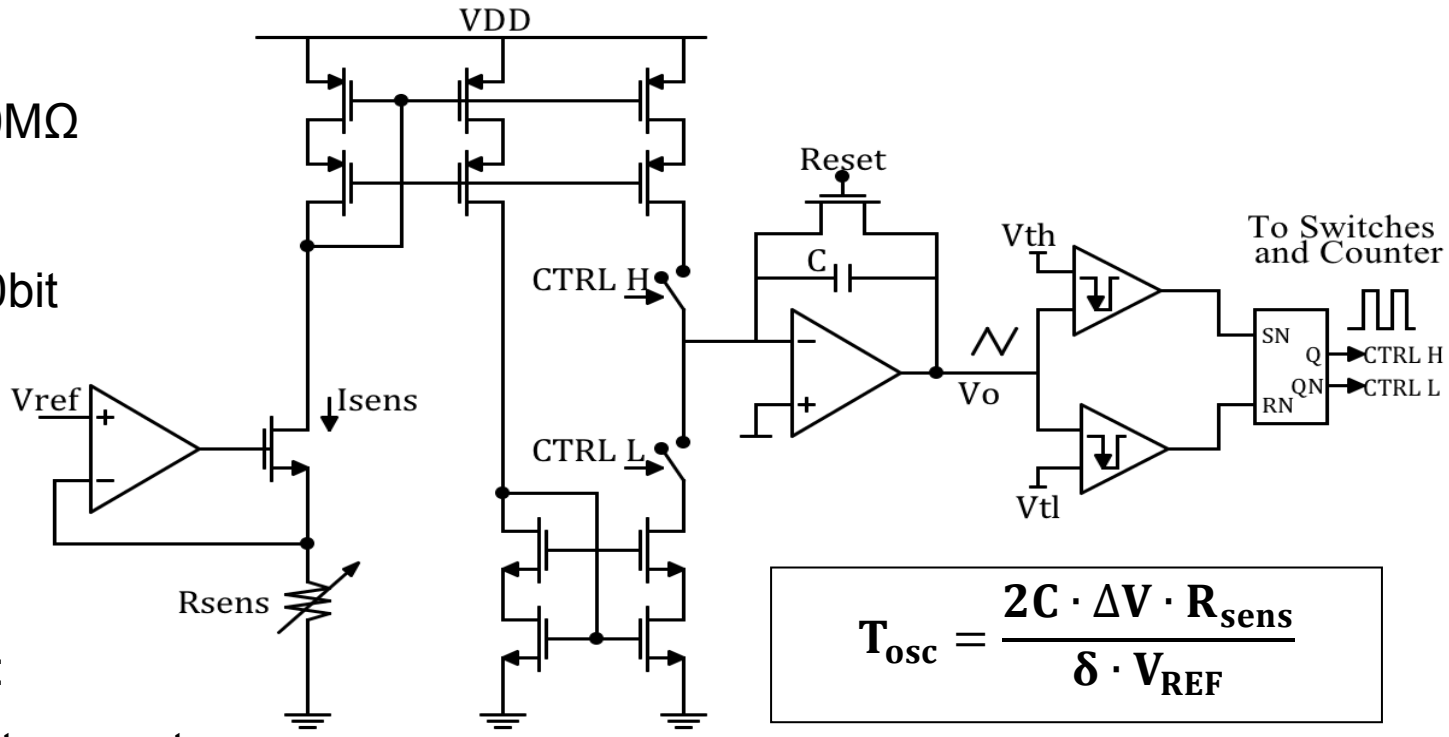
A Resistance-to-Frequency Interface for High Dynamic Range Resistive Sensors

- Sensor range: 100Ω-10MΩ (100dB)
- equivalent precision: 10bit
- Max Current: 500μA



$$T_{osc} = \frac{2C \cdot \Delta V \cdot R_{sens}}{\delta \cdot V_{REF}}$$

- Architecture Overview:
  - Voltage to current converter
  - Integrator
  - Comparators
  - Switches and Control Logic
  - Digital Output Counter

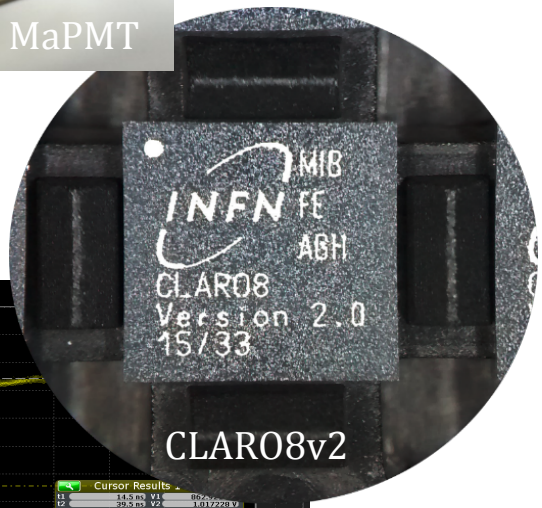
- Key Features:
  - Low Offset Opamp
  - Low Voltage, High linearity mirrors
  - fast Integrator and CT comparators
  - insensitive to Thermal noise

LHCb e CUORE

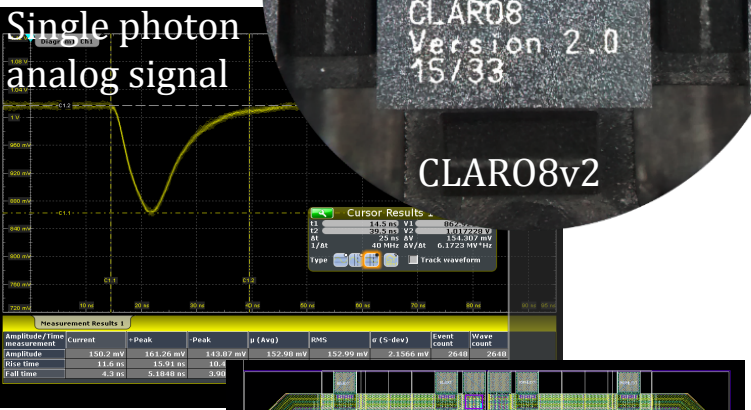
Gruppo Elettronica Analogica

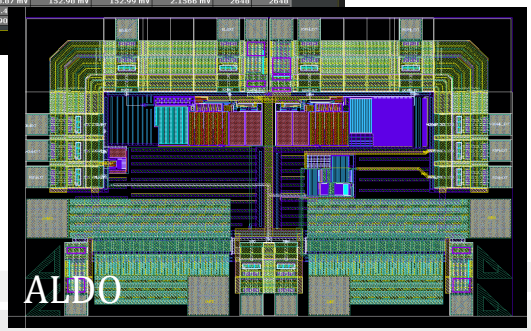
LHCb – Fisica delle alte energie


MaPMT



CLARO8v2




ALDO

L'esperimento

- LHCb è l'esperimento dedicato allo studio della fisica del quark beauty e della violazione della simmetria CP

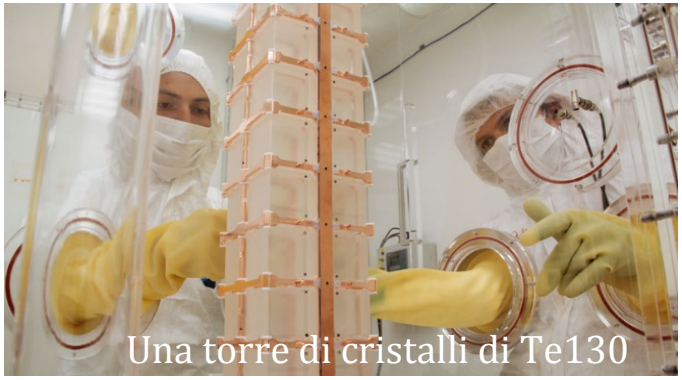
Rivelatore RICH

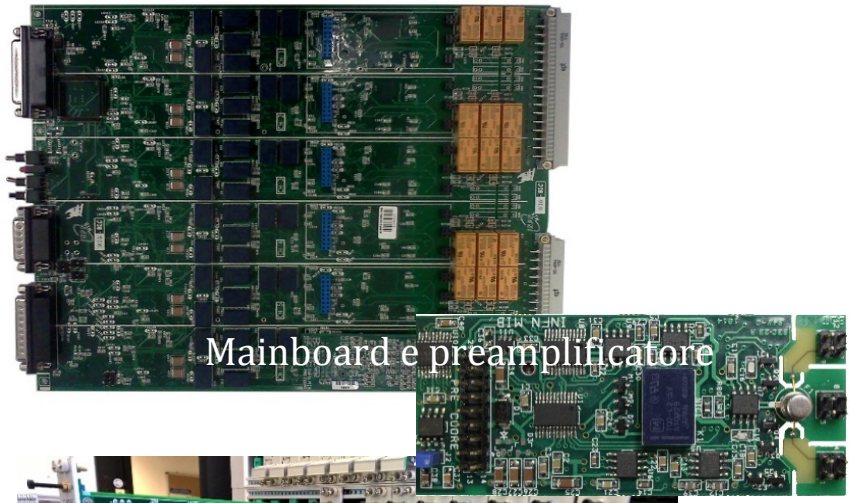
- I rivelatori RICH utilizzano l'effetto Cherenkov per misurare la velocità delle particelle e permetterne l'identificazione

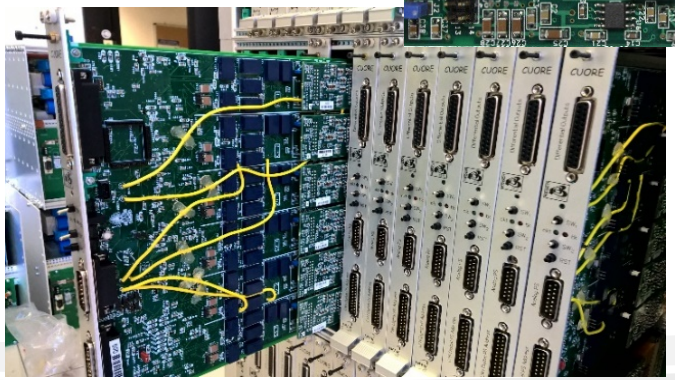
Le attività del gruppo di elettronica analogica per il rivelatore RICH di LHCb

- Studio dei tubi fotomoltiplicatori a pixel MaPMT (conversione fotone → segnale elettrico)
- CLARO: progettazione del circuito integrato di lettura dei segnali analogici provenienti dai fototubi (segnale elettrico analogico → segnale digitale binario)
- ALDO: progettazione del circuito integrato (regolatore lineare) per la gestione dell'alimentazione del CLARO
- Testbeam: campagne di test della catena opto-elettronica eseguite presso l'acceleratore SPS al CERN

CUORE – Fisica del neutrino


Una torre di cristalli di Te130


Mainboard e preamplificatore


1000 canali

L'esperimento

- CUORE è un esperimento dedicato allo studio del doppio decadimento beta senza neutrini nel Tellurio-130
- Sfrutta la tecnica bolometrica: vengono misurate piccolissime variazioni di temperatura dovute al rilascio di energia nei rivelatori mantenuti a T = 0.01 K
- L'elettronica deve essere estremamente stabile e precisa. Per questo si preferisce un'elettronica discreta

Le attività del gruppo di elettronica analogica a LHCb

- Progettazione e test di tutta la catena di lettura, alimentazione e comunicazione (preamplificatore, amplificatore, filtro antialiasing, alimentatori lineari e DCDC, hub di comunicazione, impulsatore)

Per altre informazioni sulle attività del gruppo di elettronica analogica passate pure per una chiacchierata

- Gianluigi Pessina – Reference professor – U1 3040
- Claudio Gotti – Postdoc – U2 3032
- Lorenzo Cassina – PhD student – U1 3041
- Paolo Carniti – PhD student – U1 3041

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Thank you for your attention