A front-end ASIC for ionising radiation monitoring with femto-amp capabilities

Evgenia Voulgari[1,2], Matthew Noy[1], Francis Anghinolfi[1], Daniel Perrin[1], François Krummenacher[2], Maher Kayal[2]
[1]CERN, CH 1211 Geneva , [2]EPFL-STI-EE, Station 11, CH - 1015 Lausanne

Abstract

An ultra-low leakage current Application Specific Integrated Circuit (ASIC) called UtoPia (Ultralow Picoammeter) has been designed and fabricated in AMS 0.35 μm CMOS, in order to be used as the front-end for ionising radiation monitoring at CERN. It is based on the topology of a Current to Frequency Converter (CFC) and demonstrates a wide dynamic range of 8.5 decades without range changing. Due to a design aimed at minimising input leakage currents, input currents as low as 10 fA can be measured.
Keywords: radiation monitoring, ultra-low leakage current, femto-amperes

Introduction

The obligation to protect people from unjustified exposure to ionising radiation requires that ambient radiation be monitored.

Radiation detector: Ionisation chambers

State of the art:

Several read-out systems with wide Dynamic Range of more than 5 decades.
But I_{min}= 300 fA* (typically among existing systems)
Limitation: Ultra-low leakage currents in the input of the ASIC

•Required radiation measurement: 50 nSv/h to 0.1 Sv/h

•Typical conversion factor for γ rays: 1.2e-6 A/Sv/h

•Required input current for a specific detector: 60 fA to 120 nA

* Flemming, H. A Successor for the GSI Charge to Frequency Converter Module, 2004.

Specifications of the front-end ASIC

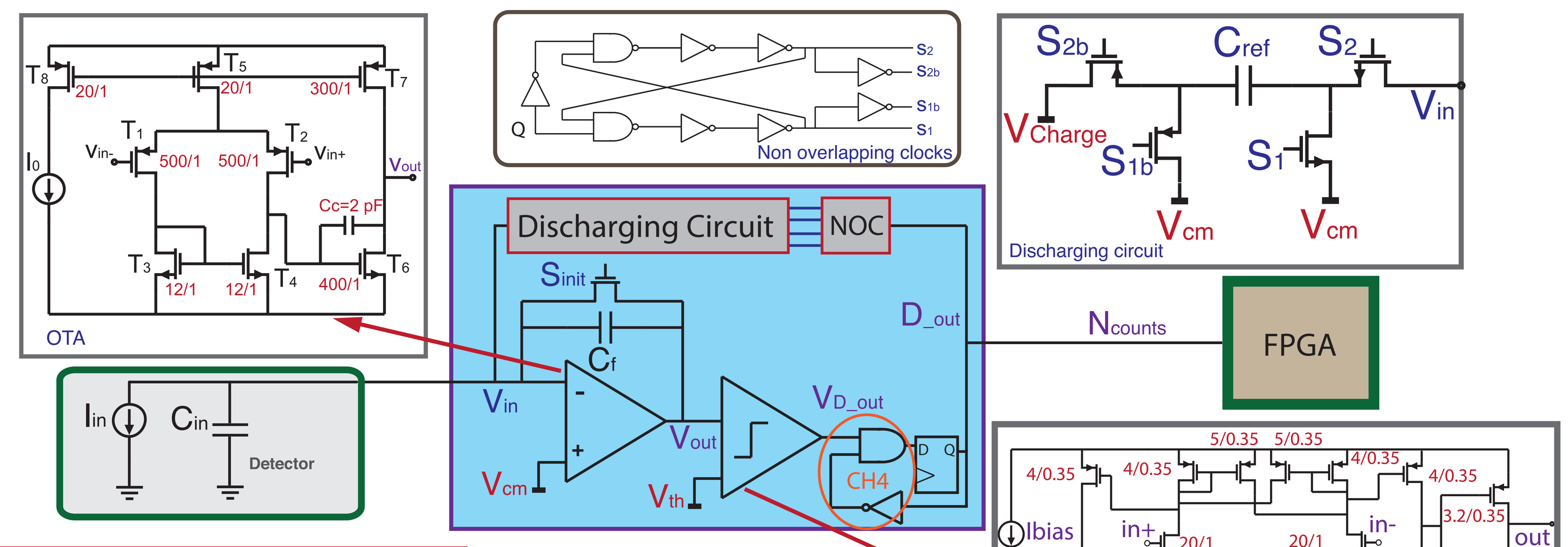
Input current polarity	Negative
Dynamic range for constant input current	$60fA$ to $250nA$
Maximum pulsed input current	$1.72\mu A$
Charge per pulse	$5nC$
C_{in}	$9pF, 65pF$
Measurement time window	$100ms$
Linearity error	$\pm 5\%$
Temperature range	-15°C to 55°C

Utopia ASIC Architecture

Topology:

Current to Frequency Converter (CFC) Synchronous but also Asynchronous (CH4)

- *The input current I_{in} is integrated in C_f until V_{th} is reached*
- *A discharging circuit injects charge Q_{ref} in the input*
- *If the V_{out} remains above the threshold the discharging circuit injects again (CH4)*
- *An FPGA counts how many times Q_{ref} is injected in a measuring time window T_w (1)*



$$I_{in} = \frac{N_{counts} Q_{ref}}{T_w} \quad (1)$$

Cin	9 pF, 65 pF
Cf	1 pF
Cref	1 pF
fclk	10 MHz

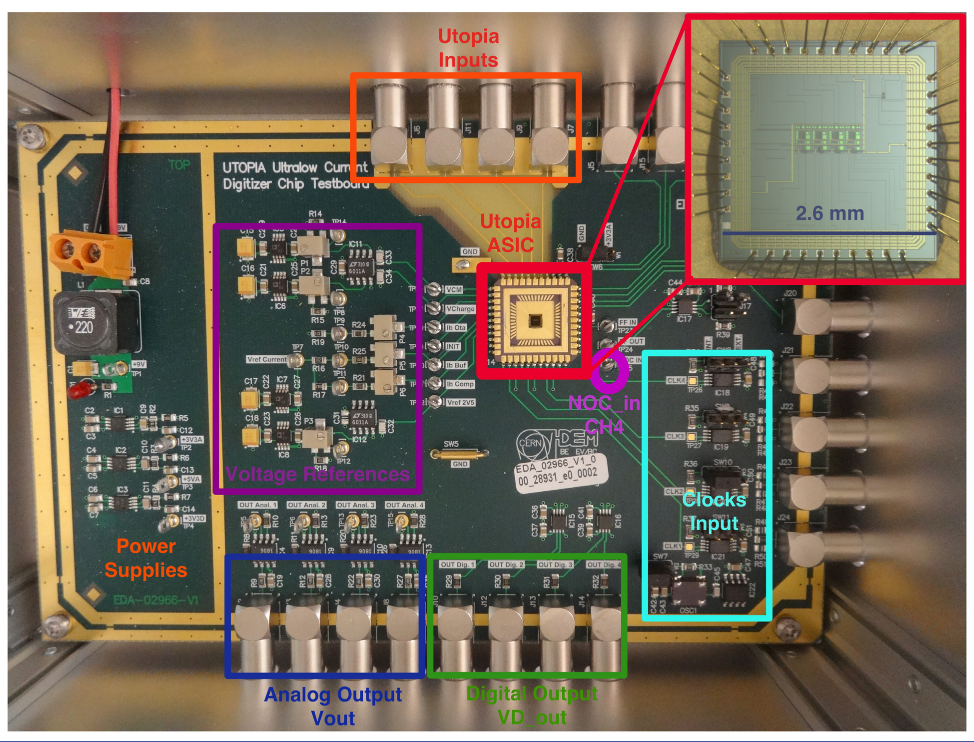
Circuit Design

AMS 0.35μm CMOS C35B4C3 4M/2P/HR/5V IO technology
Ceramic 44 CQFJ package

•OTA: two-stage Miller amplifier with pMOS inputs
•Comparator: internal positive feedback and hysteresis
•Discharging circuit: stray insensitive switched capacitor circuit

Reference charge

$$Q_{ref} = C_{ref} V_{charge} - C_{ref} V_{in}(t) \quad (2)$$



Summary of UtoPia Characteristics

Technology	AMS 0.35μm
Power Supply	$3.3V$
Clock	$10MHz$
Die Size	$2.6mm$ x $2.6mm$
Polarity	Negative with this biasing
Gain A_0 OTA	$86dB$
GBW OTA	$100MHz$
Phase margin ϕ OTA	$62deg$
Q_{ref}	$1pC$

Design for Ultra-low Leakage

Minimum Current:

$$I_{min} = \frac{Q_{ref}}{T_w} \quad (3)$$

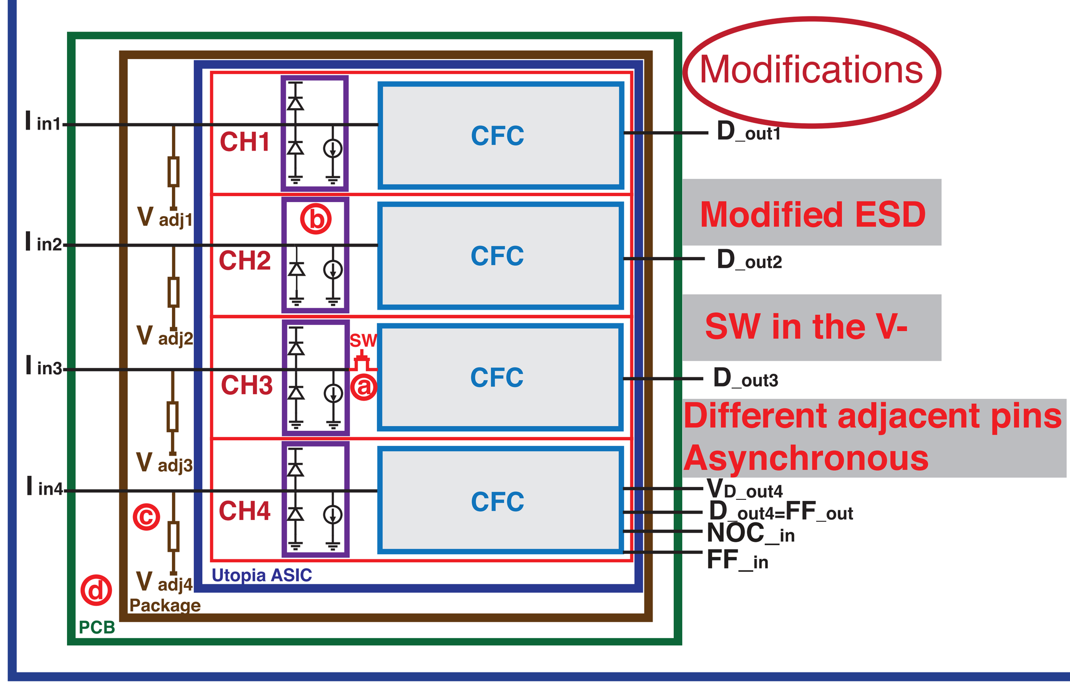
Q_{ref}= 1 pC, T_w=100 ms, I_{min}= 10 pA

For measuring lower:

•The measurement time T_w can be increased
•Averaging for better resolution

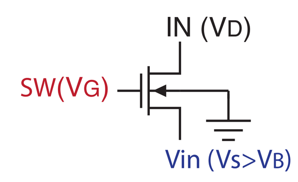
But I_{min} is limited by the sum of the leakage currents

4 channels of UtoPia



(a) Subthreshold leakage current minimisation:

$$V_{TS} = V_{T0} + \gamma\left(\sqrt{\phi_o + V_{SB}} - \sqrt{\phi_o}\right) \quad (4)$$



The V_{cm} is at a different potential relative to the bulk ($V_{in}= V_{cm}+V_{off}$)

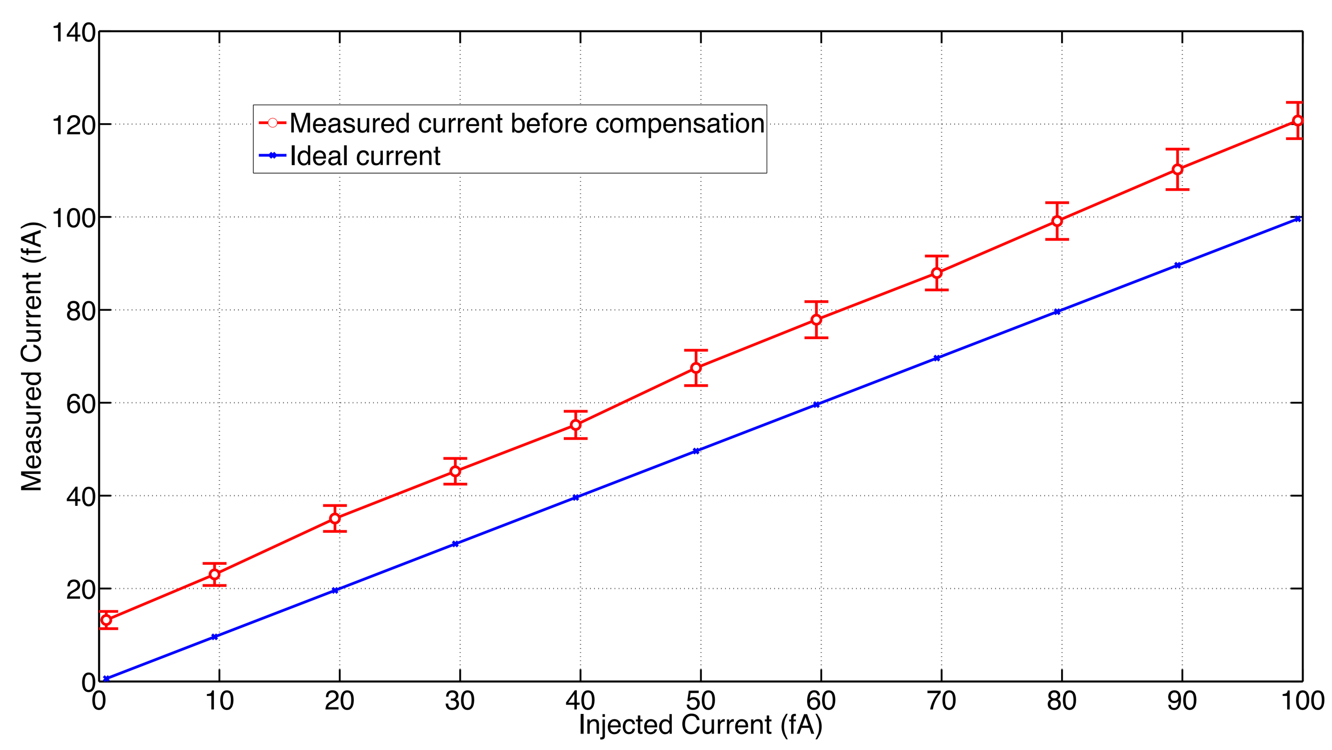
(b) ESD protection leakage current:
•Measurement over long time periods and subtraction of the offset
•V_{cm} change, changes polarity of leakage

(c) Package leakage due to adjacent pins:
Worse in CH4 that is adjacent to V_{DD} (+120 fA)
New bonding further from V_{DD} (+14 fA)

(d) PCB leakage:
Negligible, no ground plane under the inputs

fA Range Measurements

High precision current source (Keithley 6430), climatic chamber: constant temperature and humidity



Measurement time:
T_w=600 s

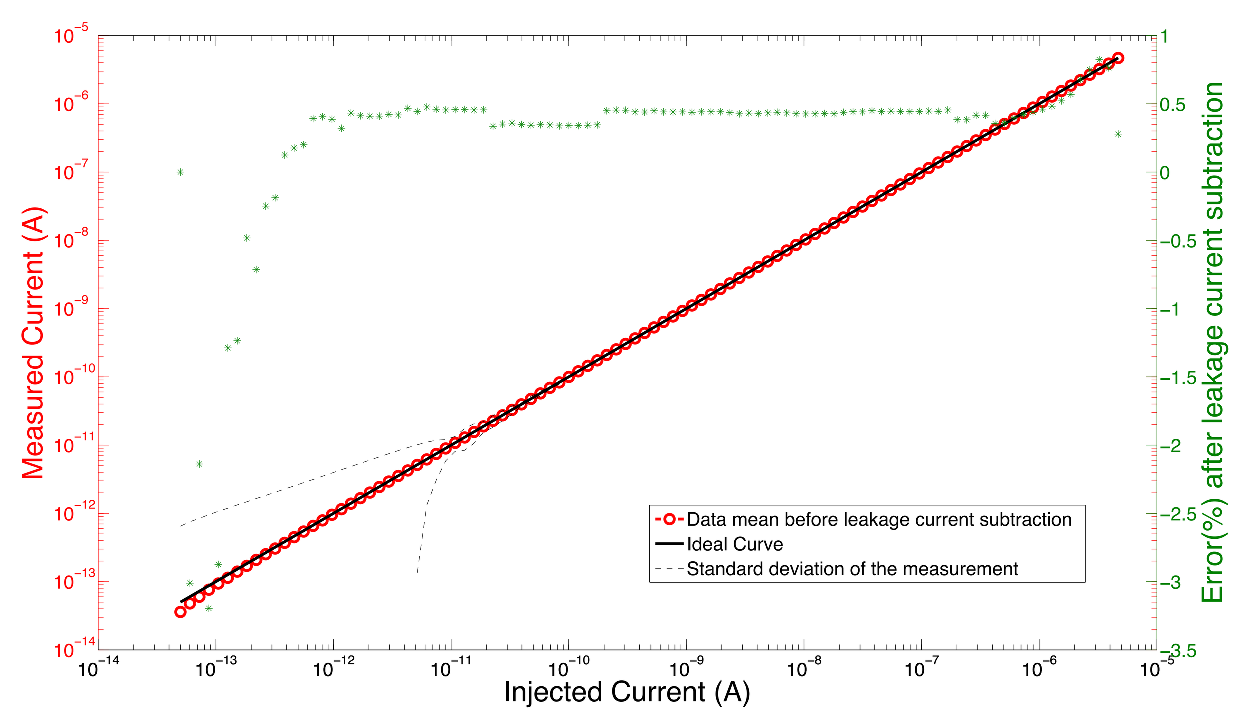
•Resolution increases
•Averaging to get non zero counts

Leakage current:
CH1, V_{cm}=1.62 V
to decrease the sum of the leakage currents

Offset of 12 fA
(same polarity)

Dynamic Range Measurements

Near the upper limit, noise on the signal pushed the system into saturation.
For robustness, a control system was added to CH4 to re-inject Q_{ref} if V_{out} >V_{th}.



I_{max}=5 μA

$$I_{max} = \frac{Q_{ref}}{2 \cdot T_{clk}} \quad (5)$$

Leakage current:
CH4, V_{cm}=1.5 V
Offset of 14 fA
(opposite polarity)

Conclusions:

A very wide dynamic range CFC with fA capabilities for radiation monitoring is presented. Special care was given to the input of the ASIC in order to minimise the possible sources of leakage current and be able to measure down to 10 fA after averaging over sufficient time. The ASIC is expected to work mainly in the fA to nA range. It will be revised and include auto-calibration for long term stability. Two matched channels will operate in parallel with one connected to the detector, whereas the other will integrate the ESD protection leakage current that is the dominant leakage current source. The subthreshold and package leakage currents were eliminated by design.

evgenia.voulgari@cern.ch, TWEPP 2015, 28 September to 02 October, Lisbon