CERN HSE Occupational Health & Safety and Environmental Protection unit

PulsRad 2022 Pulsed Radiation Measurement Workshop

Radiation Monitoring Front End ASIC - ACCURATE

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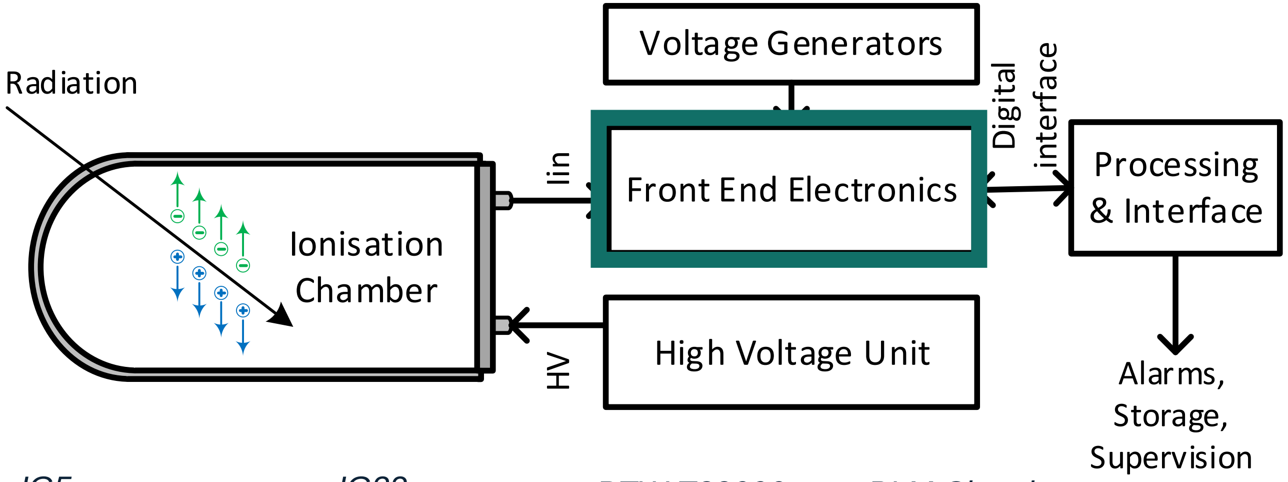
PulsRad - 1st Pulsed Radiation Measurement Workshop
December 5–8, 2022 – CERN,GENEVA

Overview

- Motivation for ASIC Development
- ASICs of RP
- Architecture of ACCURATE 2
- Characterization
- Results
- Conclusion

Radiation Monitoring System



IG5

IG32

PTW T32006

BLM Chamber

Challenges

Complex radiation environment
- Different chambers

Output current dynamic range
- > 9 decade

Current resolution
- Femtoampere

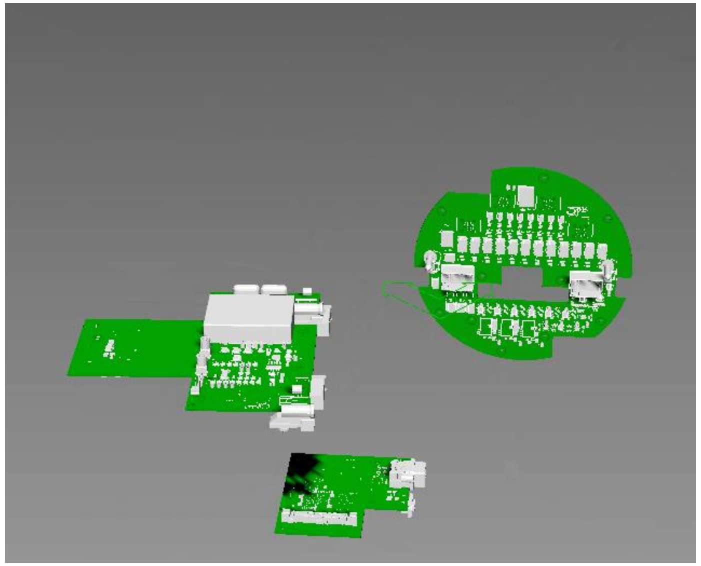
Complex input profile
- Pulsed or slow changing

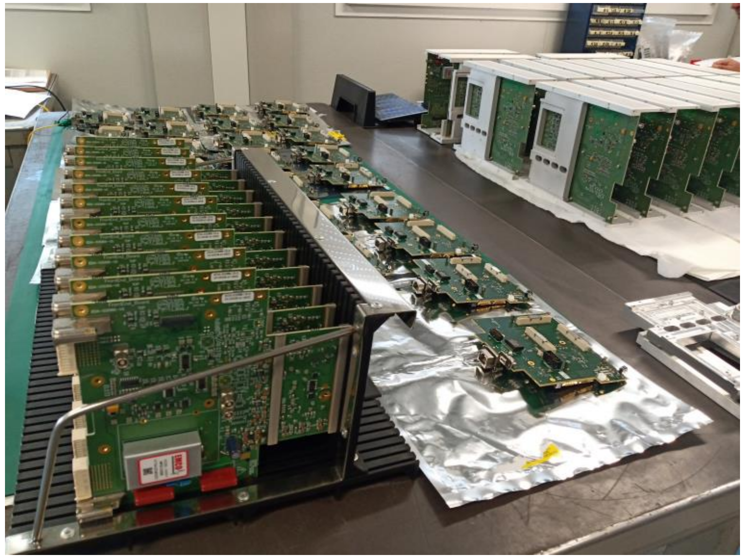
Design technology
- Available, robust, reliable, cheap, feasible

Why a dedicated ASIC(Application Specific Integrated Circuit)?

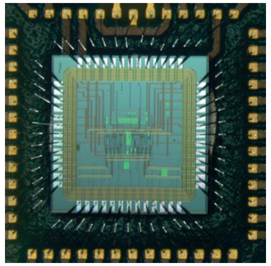
Existing solution

- Based on more than 3000 discrete components
- Difficulties in sourcing and mitigating obsolescence
- Complex assembly process
- Upgrade takes significant effort
- Dependent on critical components which are difficult to replace





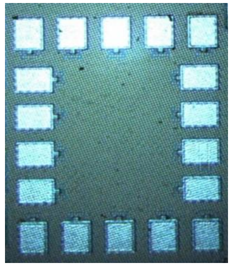
ASIC generations



UTOPIA 2

2016

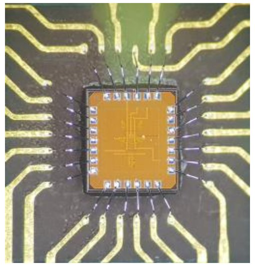
- AMS 350 nm
- 1 fA to 5 uA
- -50 fA leakage
- Resolution : 1 fA
- Charge collection for 100 nC pulse : 45%



ACCURATE 0

2018

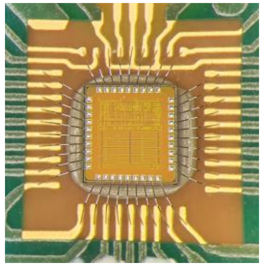
- GF 22 nm FDSOI
- 1 fA to 1 nA
- -240 fA leakage
- Resolution : 1 fA
- Technology Evaluation



ACCURATE 1

2019

- TSMC 130 nm
- 1 fA to 1 uA
- -7 fA leakage
- Resolution : 1 fA
- Technology and Architecture evaluation



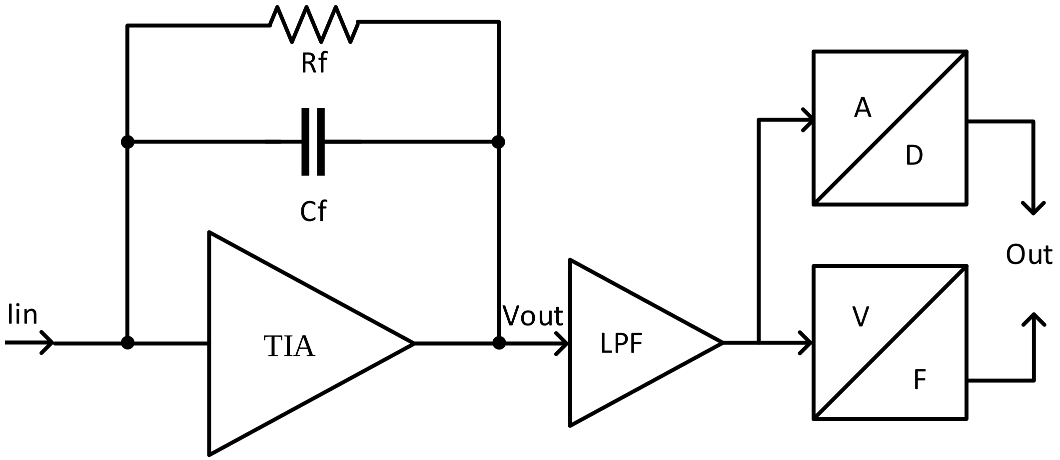
ACCURATE 2A, 2M

2021

- TSMC 130 nm
- 1 fA to 1 uA
- -7 fA leakage
- Resolution : 1 fA
- Technology and Architecture evaluation

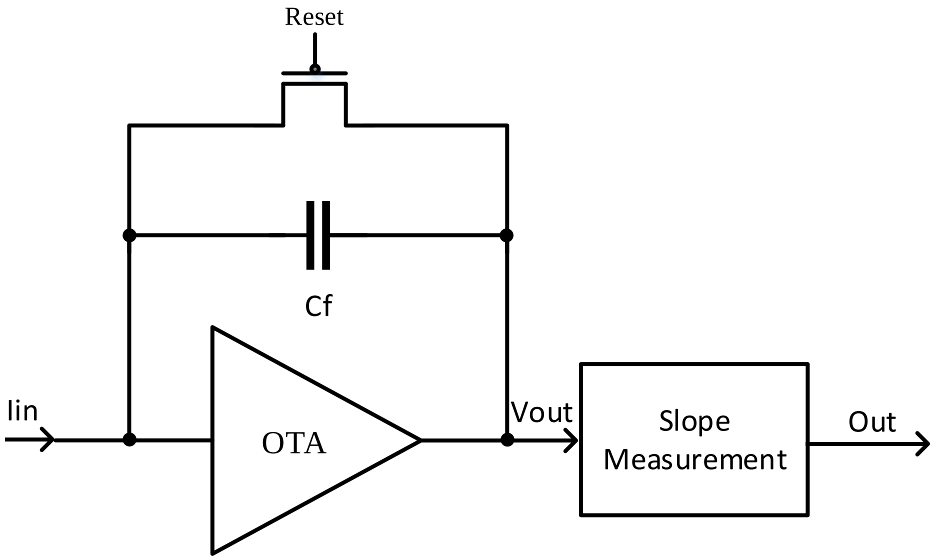
Low current measurement - Approaches

Voltage domain measurement



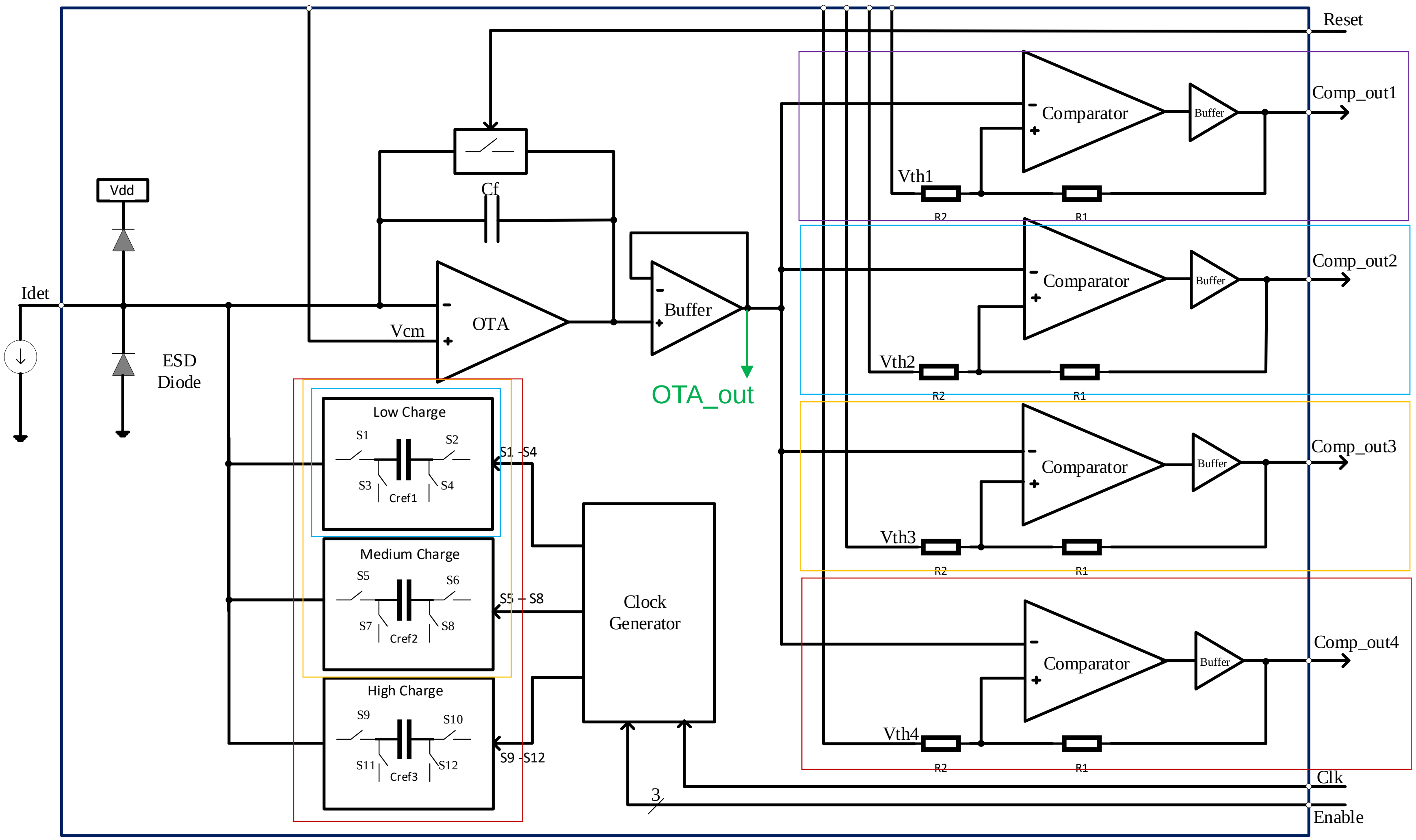
Current converted to voltage which is then measured

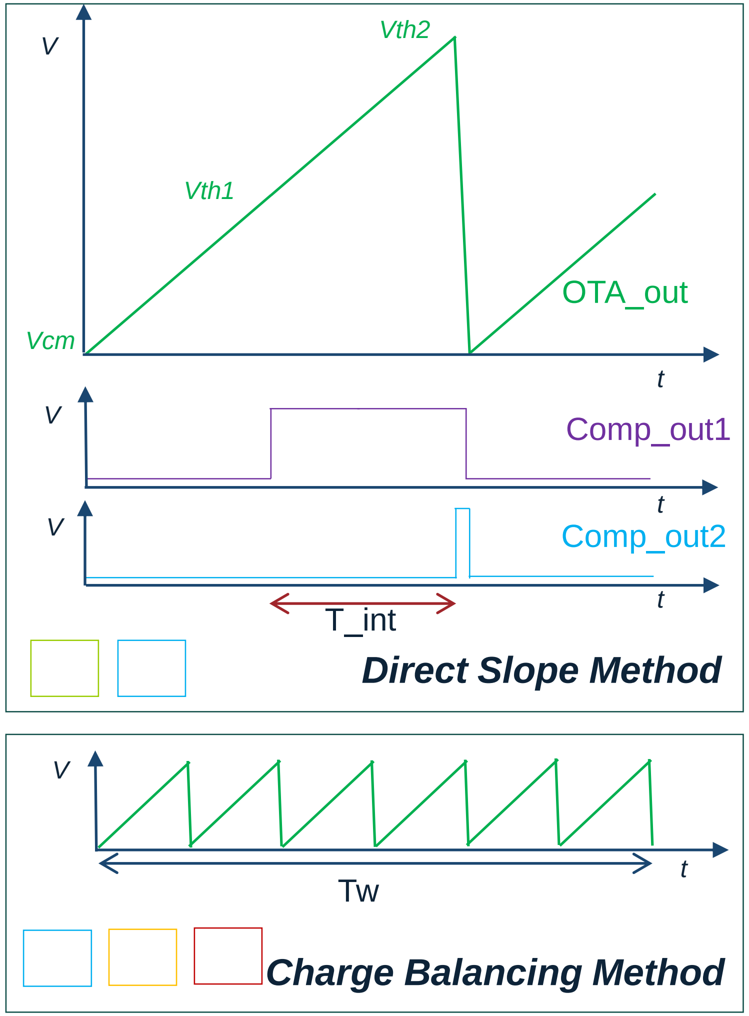
Direct current measurement



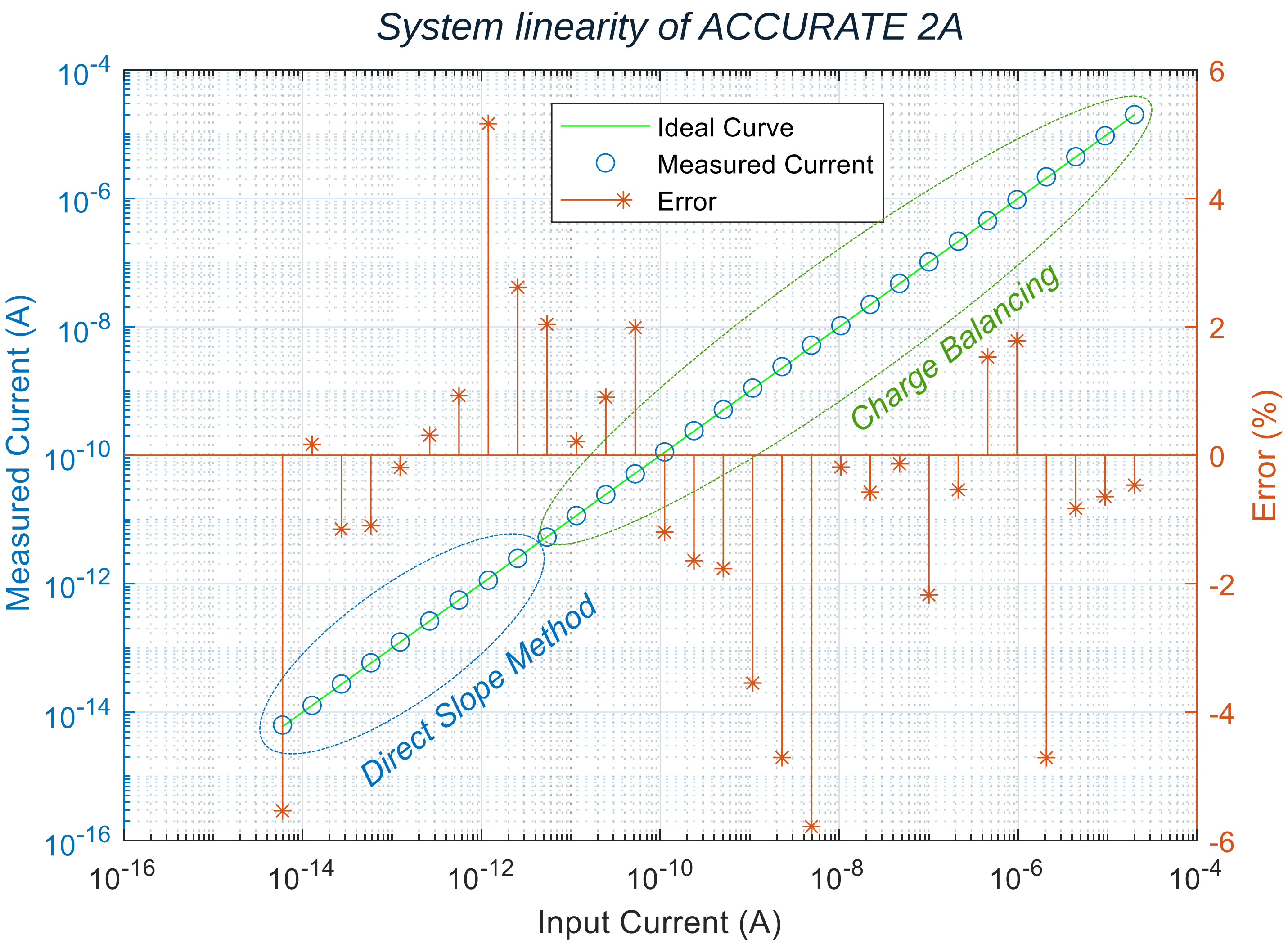
Current is integrated, the slope of which is measured to estimate current

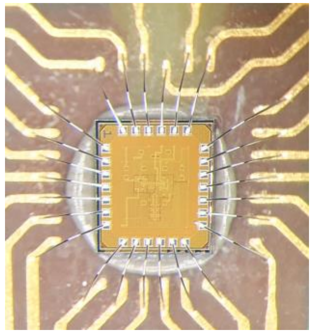
ACCURATE 2A system architecture

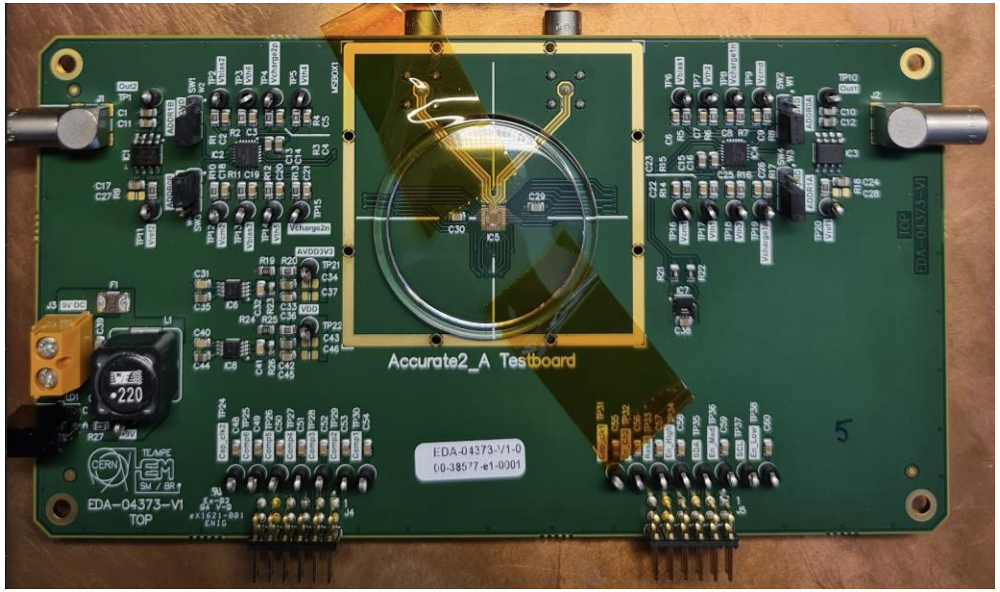




Combined output & characteristics of ACCURATE 2A

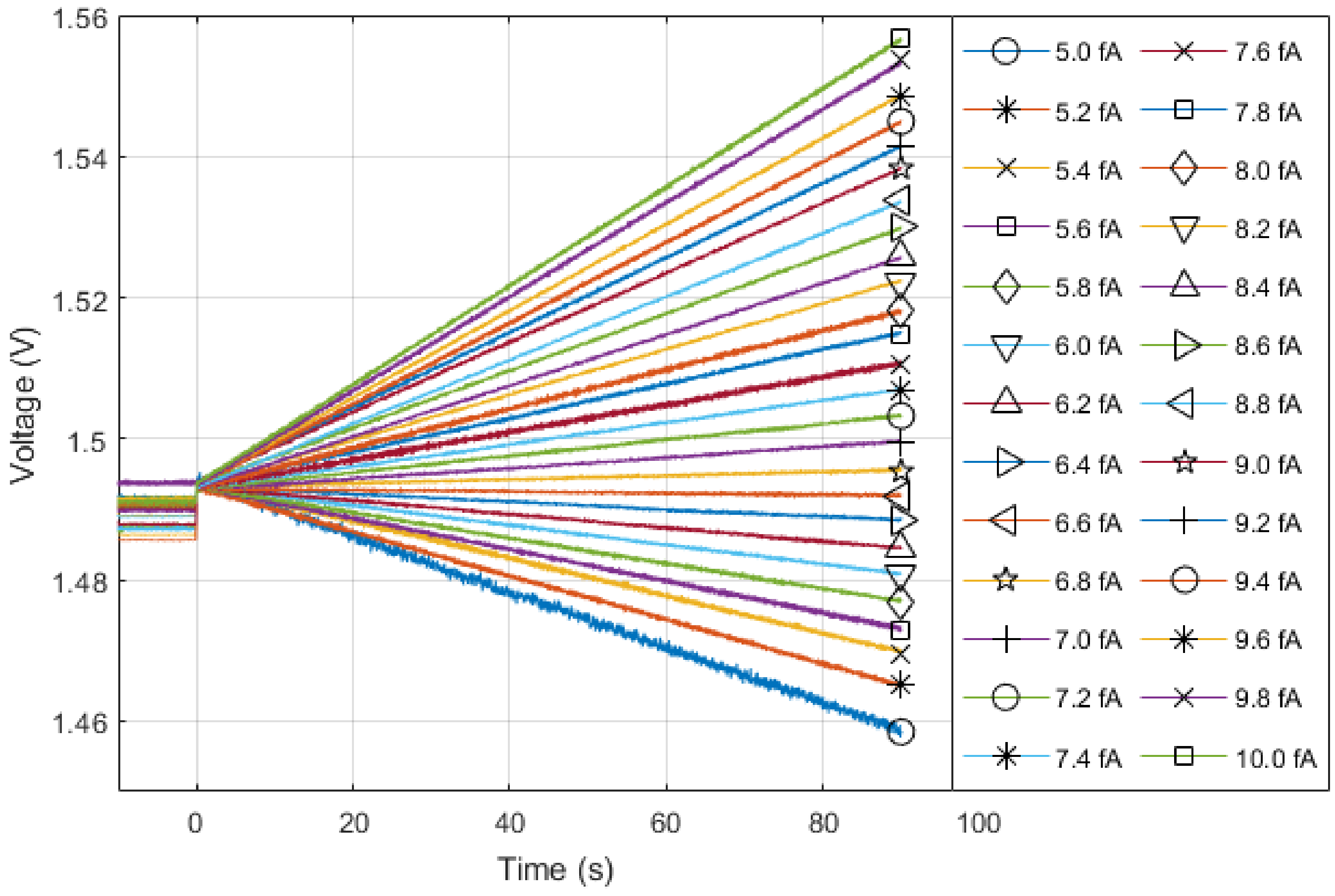






Sub-femtoampere sensitivity

Integrator output of ACCURATE 2A for input current swept with 200 aA resolution



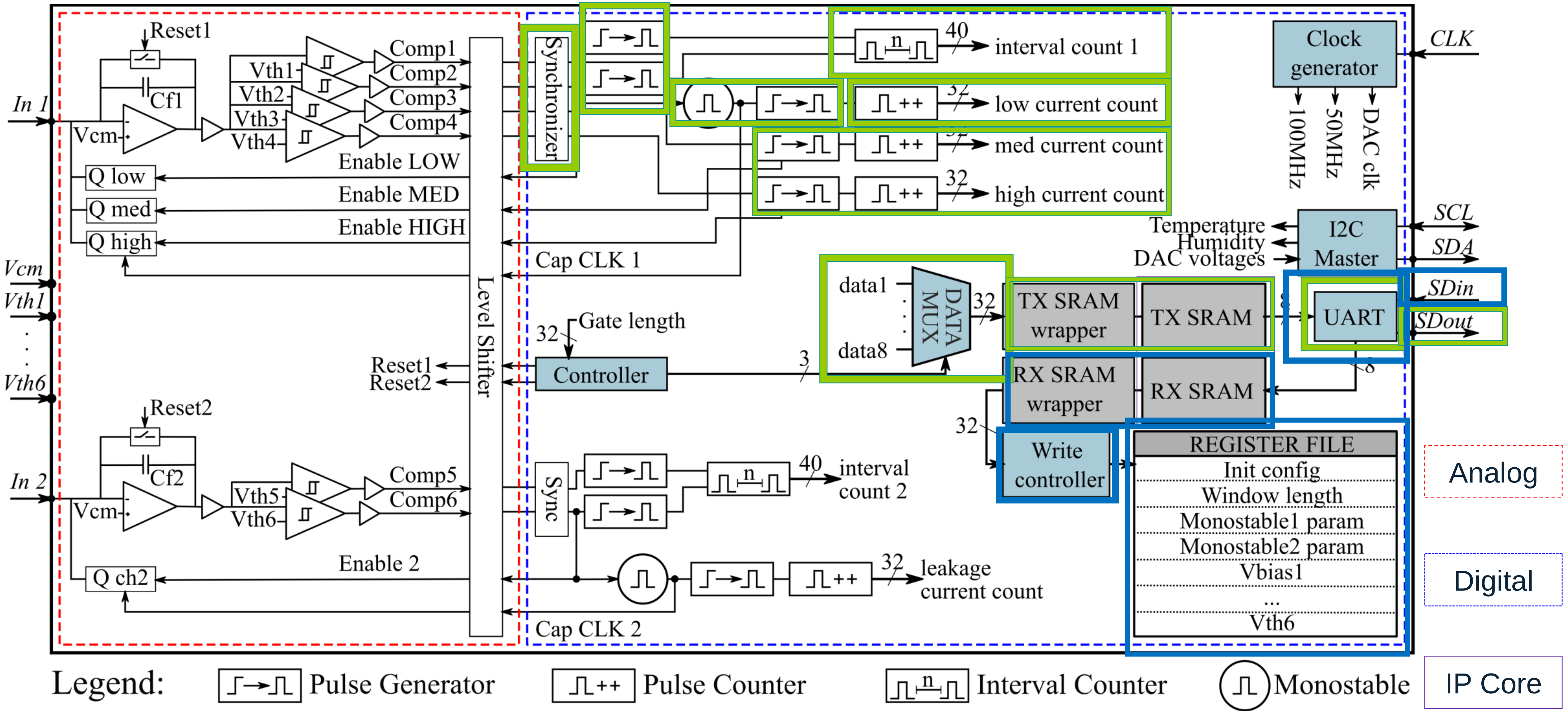
- Optimal value of feedback capacitance
- Low leakage thick gate transistors

- Guarding in layout and PCB using common mode voltage

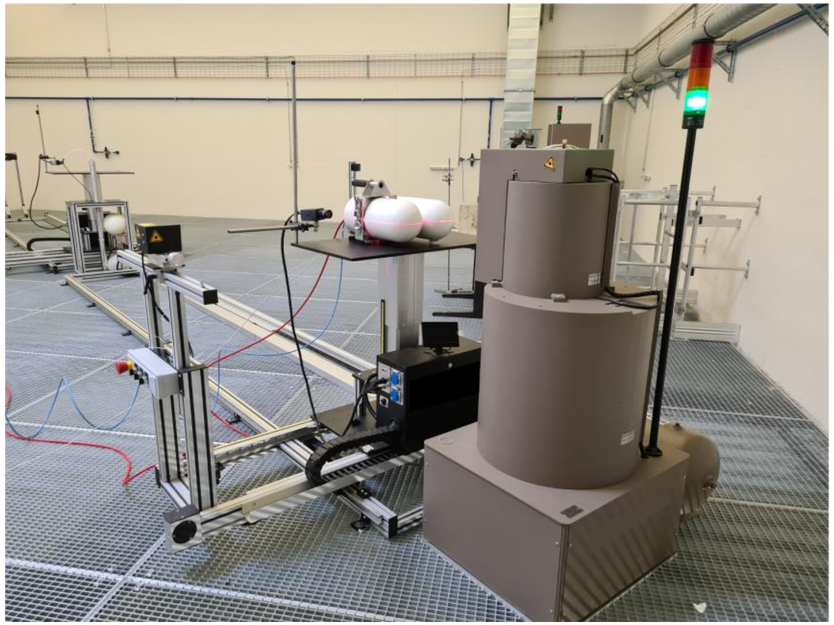
- PCB design with minimal noise coupling
- Series switches optimized for leakage
- EMC shielding
- Special cables with low leakage
- Characterization in controlled environment

❖ Achieved a sensitivity of 200 aA (1250 electrons per second)

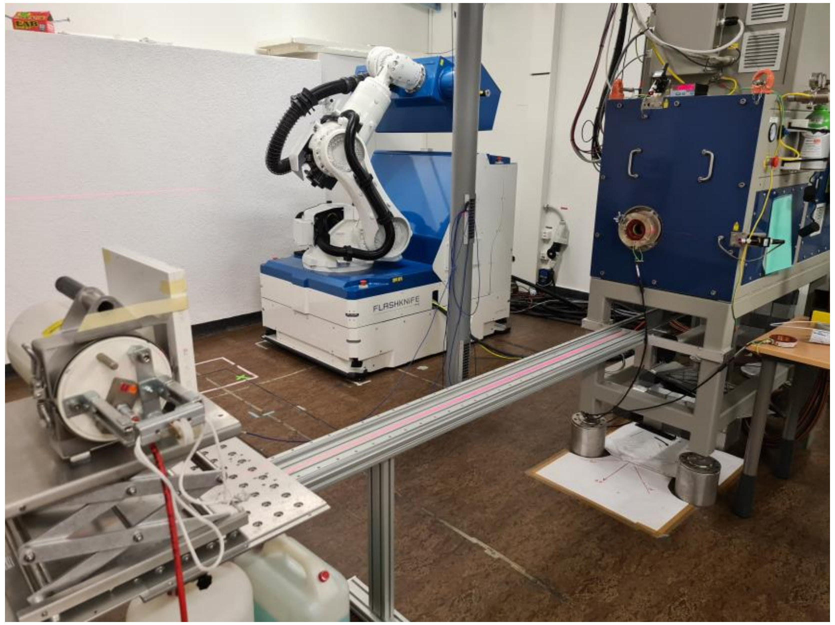
ACCURATE 2M system architecture



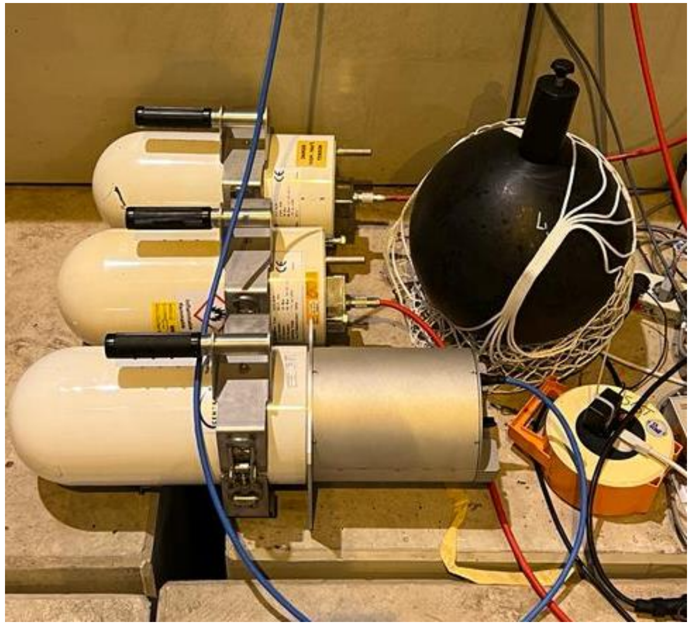
ACCURATE 2 Characterisation



ACCURATE @CalLab, CERN



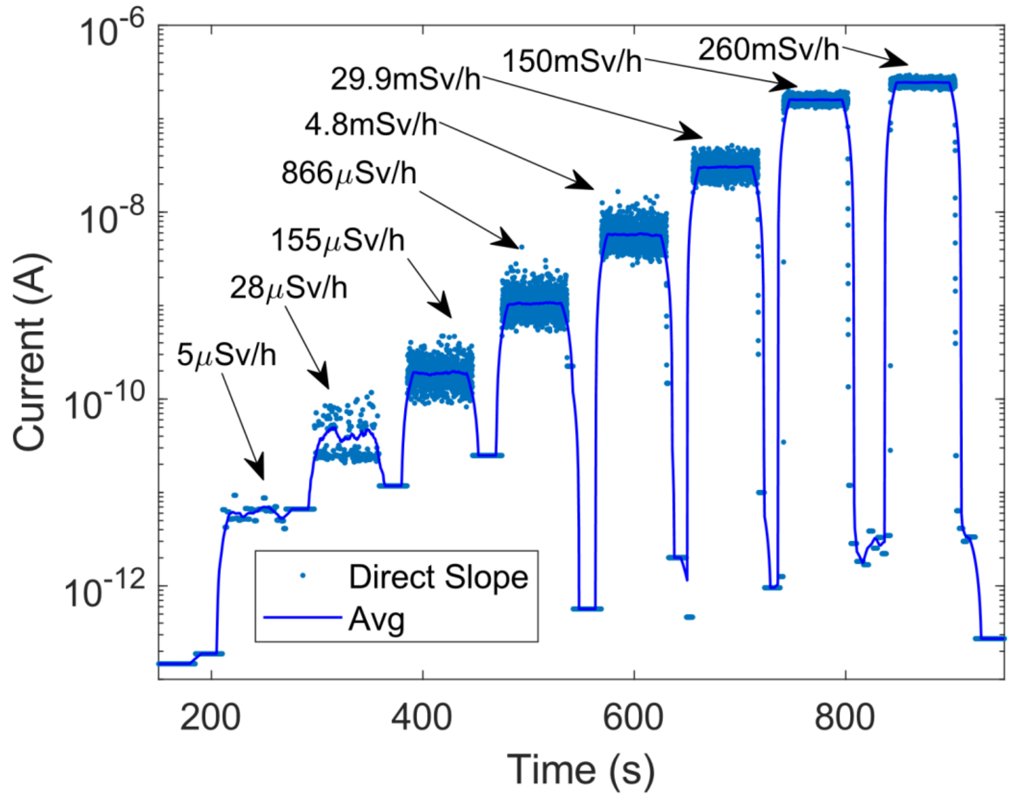
ACCURATE@CHUV – Flash Therapy



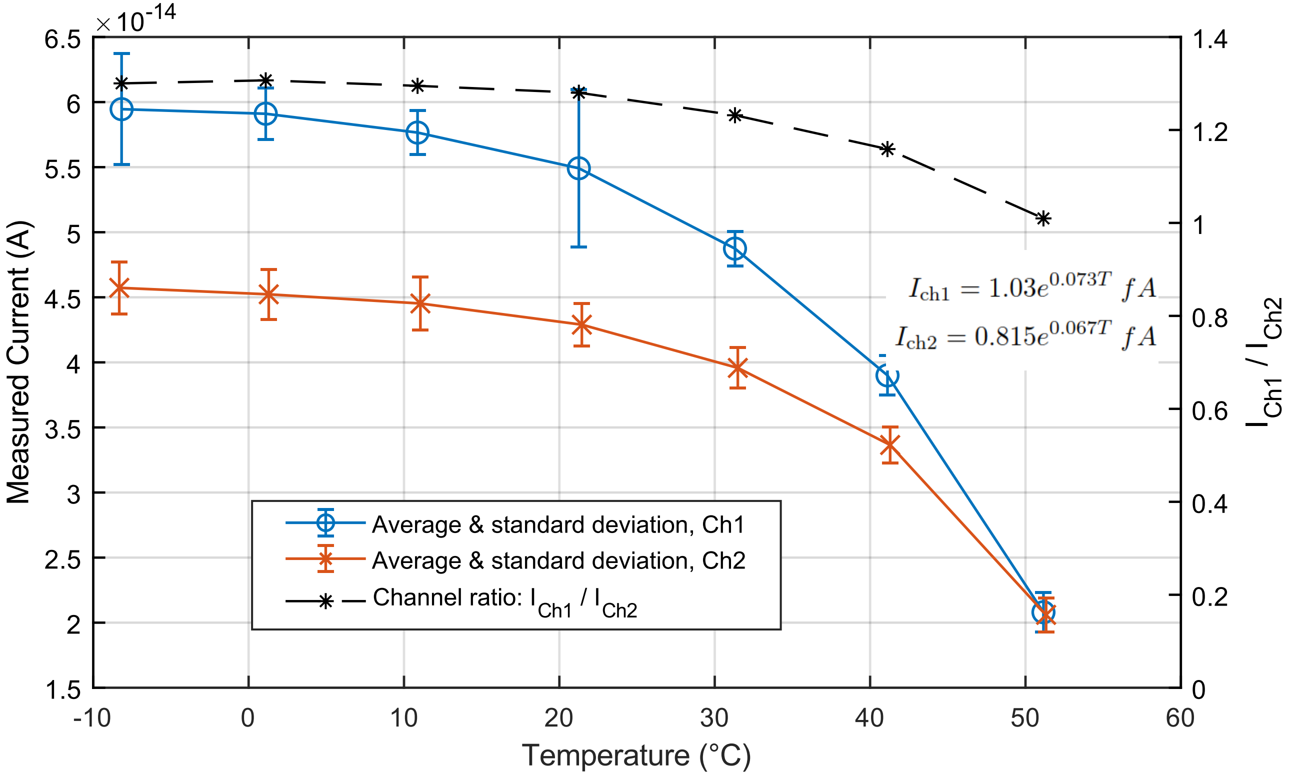
ACCURATE@GSI

ACCURATE 2 Characterisation Results

Current measured by ACCURATE 2M with IG5 chamber for different dose rates



Current measured by two channels of ACCURATE 2M for temperatures from −10°C to 50°C with an input current of −50 fA



PSAIF : Proton Synchrotron - Antiproton collector Irradiation Facility

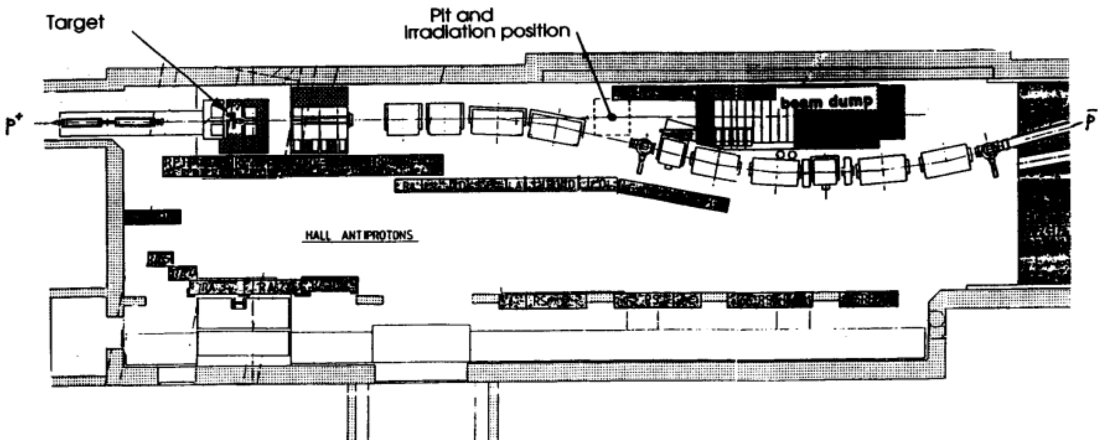
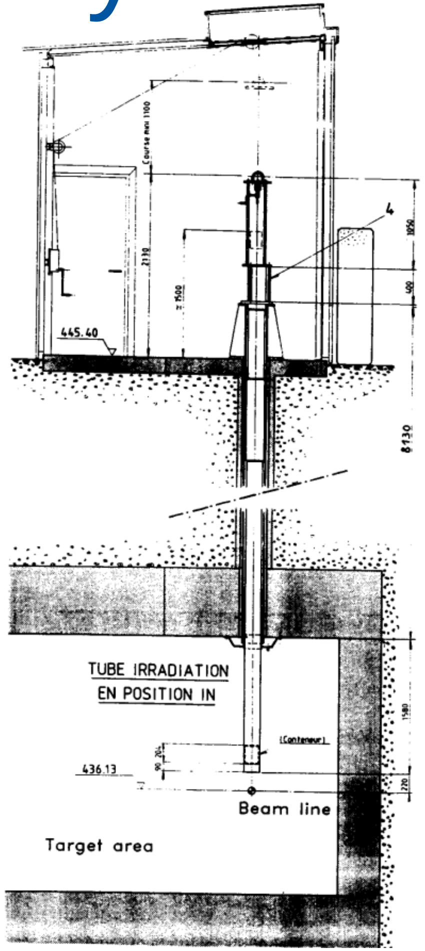


Fig. 1a. ACOL target area.



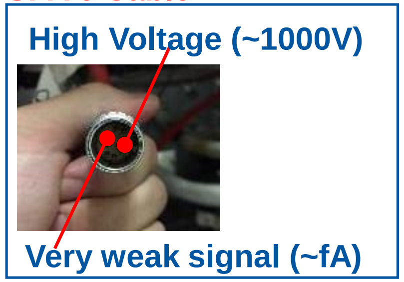
PSAIF Pit

- Target hit by 26 GeV protons from Proton Synchrotron (PS)
- Spill length of 500 ns and repetition rate of 90 -110 s cycle length
- Radiation field dominated by photons
- Facility allows to place an ionisation chamber at different depth to vary the input radiation level
- Pit has a depth of around 8 m and the position can be adjusted using a pulley arrangement

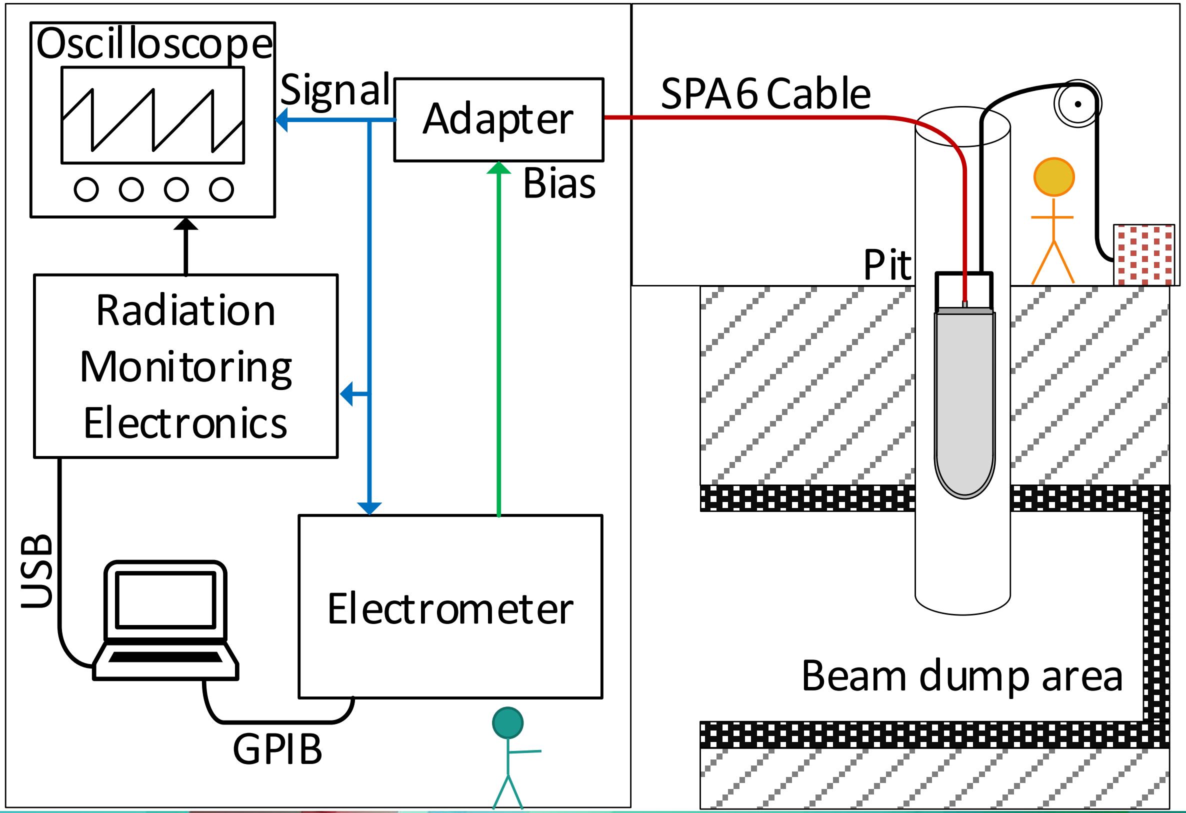
Measurement Setup

- Ionisation chamber output is bought out using a custom made SPA6 cable
- The High voltage voltage for the chamber is also passed through the same cable
- The measurement electronics placed in an adjacent room with safe radiation levels
- Output generated recorded sequentially with oscilloscope, electrometer and ASIC based front end electronics
- MATLAB based software records the data from all instruments

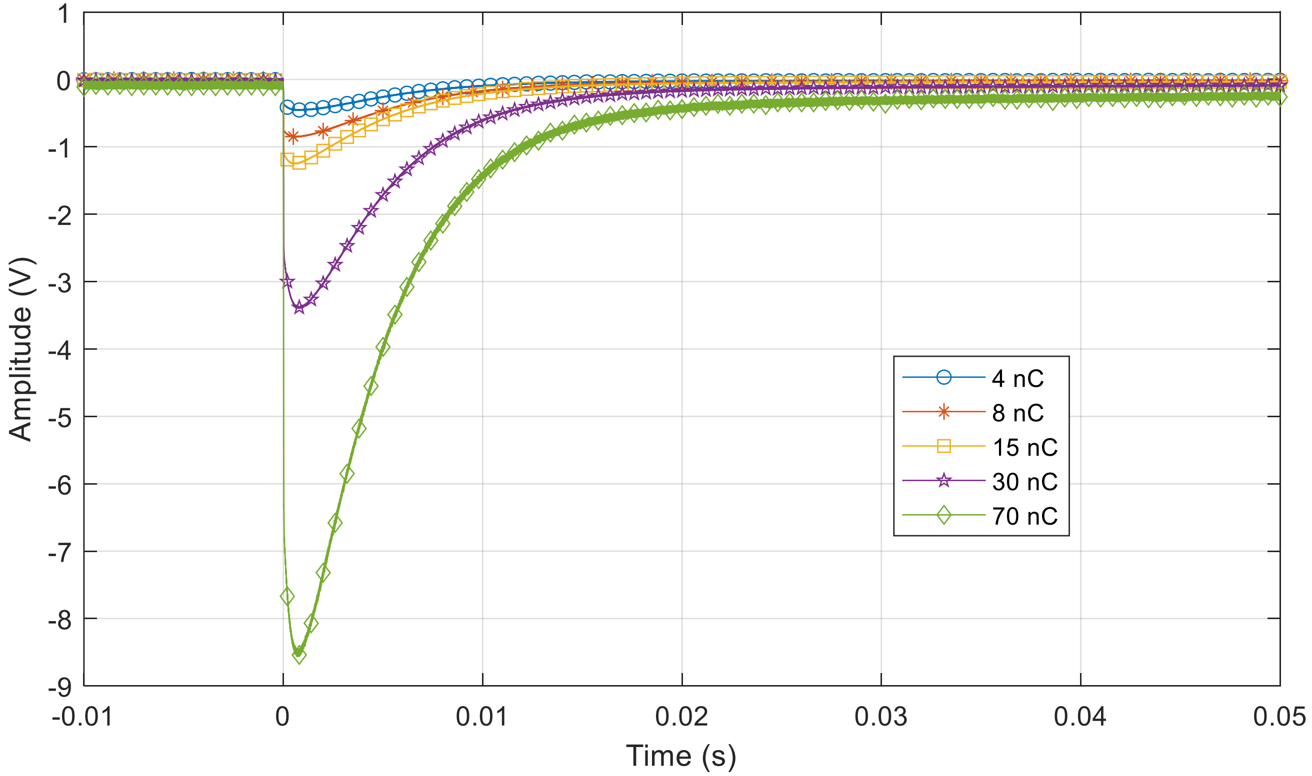
SPA 6 Cable



PSAIF measurement setup



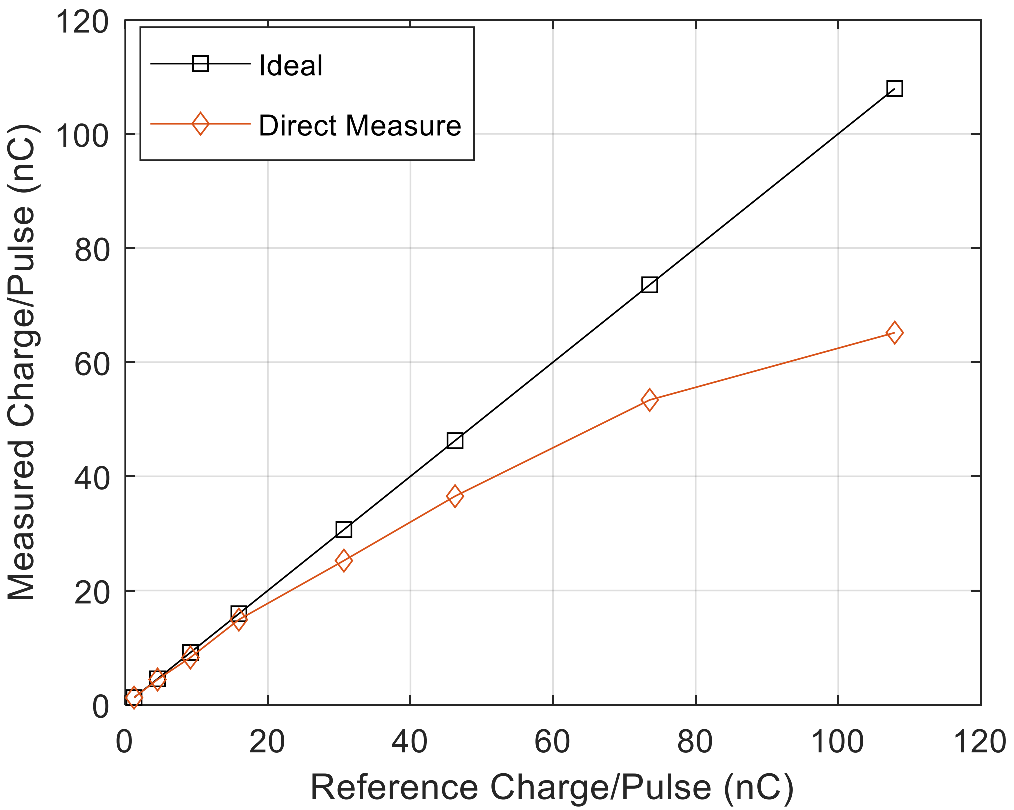
Measurements by oscilloscope



Ionization chamber Output recorded by oscilloscope with input impedance of 1 MΩ//16 pF

- Output of chamber recorded directly using an oscilloscope with input impedance 1 MΩ//16 pF
- To determine the shape of the discharge from the ionisation chamber
- Area under the curve proportional to total charge –> Hence used to ascertain the accuracy of electrometer which is used as reference

Charges measured by ACCURATE ASIC



Pulsed charge measured by ACCURATE ASIC in comparison to electrometer

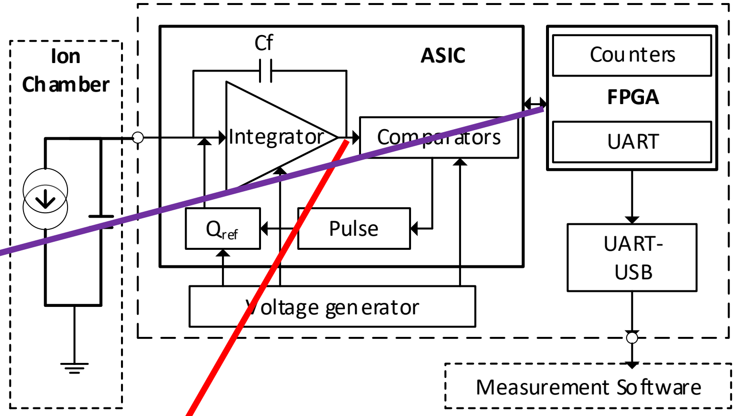
- For each position of the ionisation chamber within the pit, couple of pulses were recorded. The recorded charges were normalised with the proton intensity,

- The normalised charges measured by electrometer was used as reference and that measured by ACCURATE was compared.

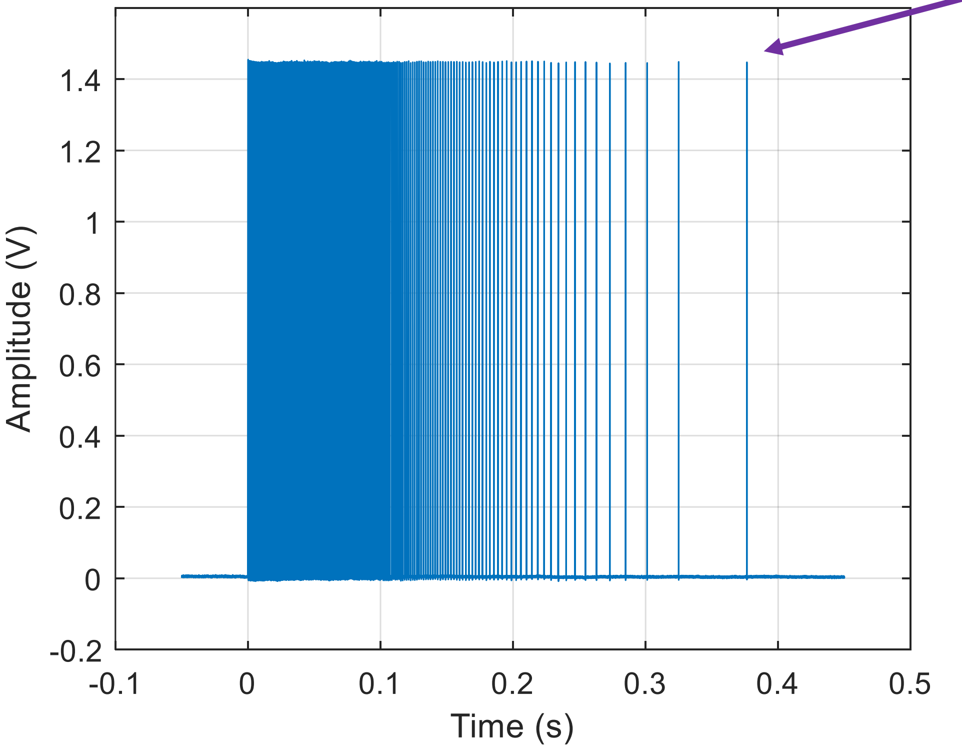
- As the charges increased, the deviation in both the measured charges increased.

- The relative error in measurement for charges around 100 nC was 40%

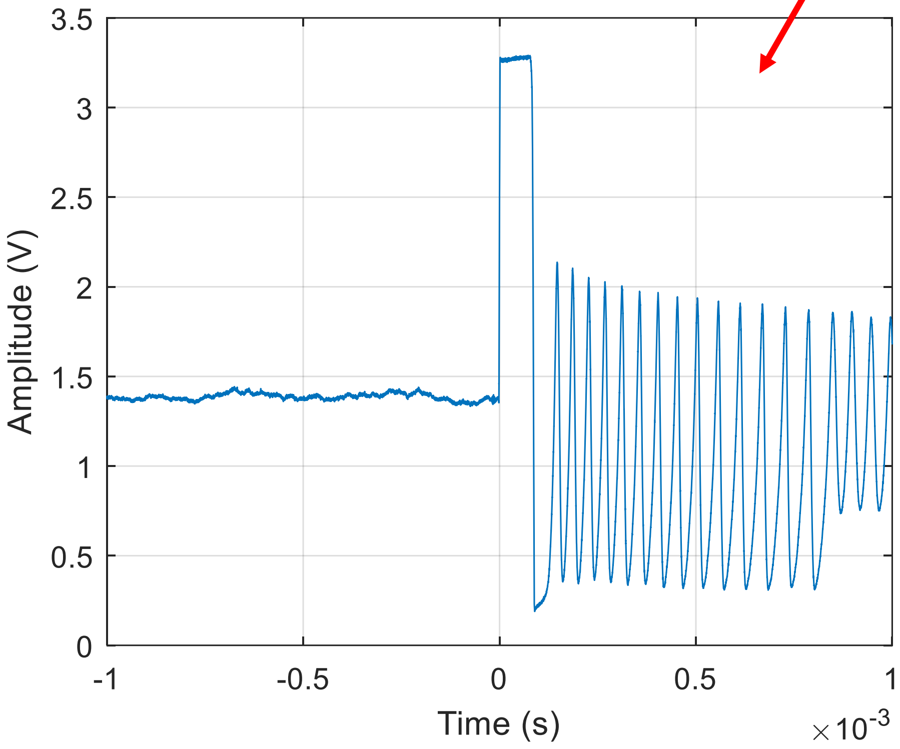
Reason for charge losses



Charge pulses generated by the ASIC for a pulse input



Output of the OTA in saturation

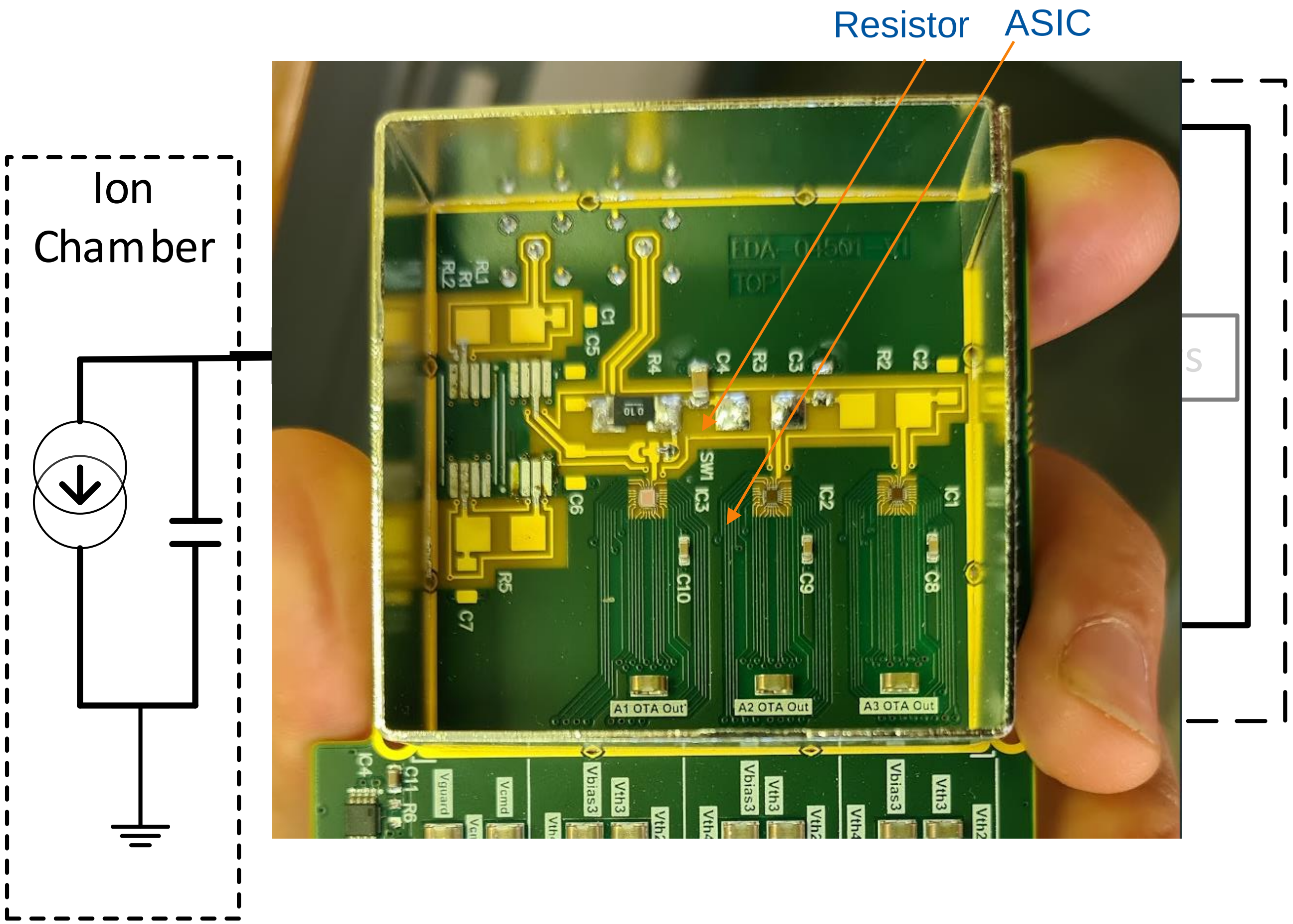


Reason for charge losses

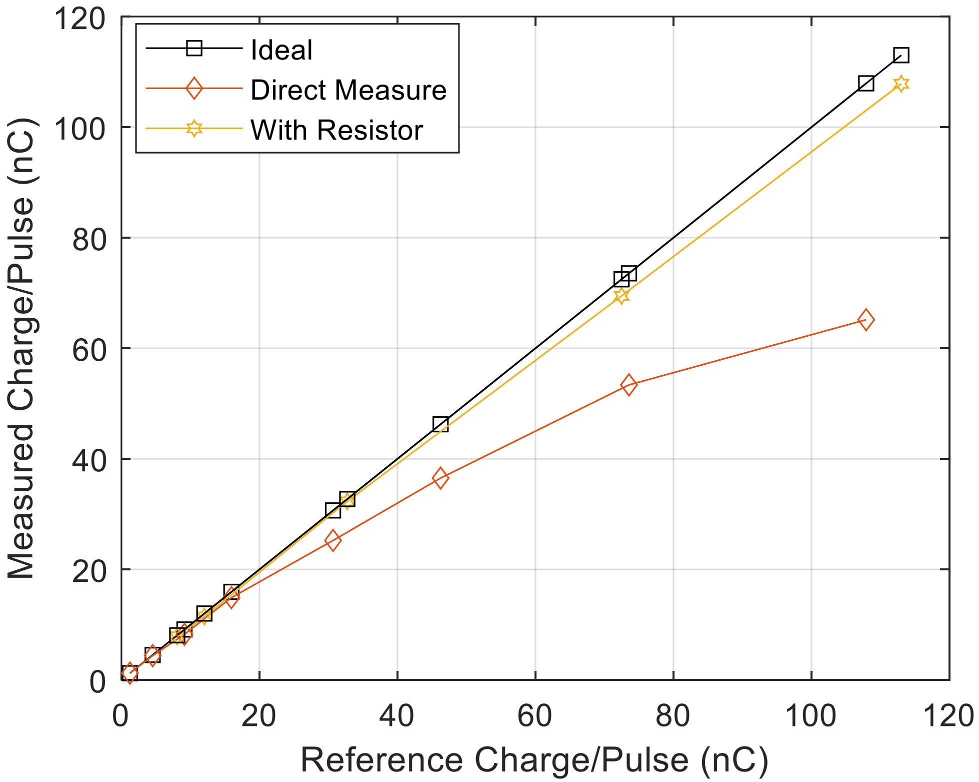
The speed of charge collection of the ASIC not fast enough compared to charge generation in the Ionization chamber

One possible solution

Slow down the discharge by increasing the **time constant** of the discharge path



Charge measurement with input resistor



Pulsed charge measured by ACCURATE ASIC with the series resistor

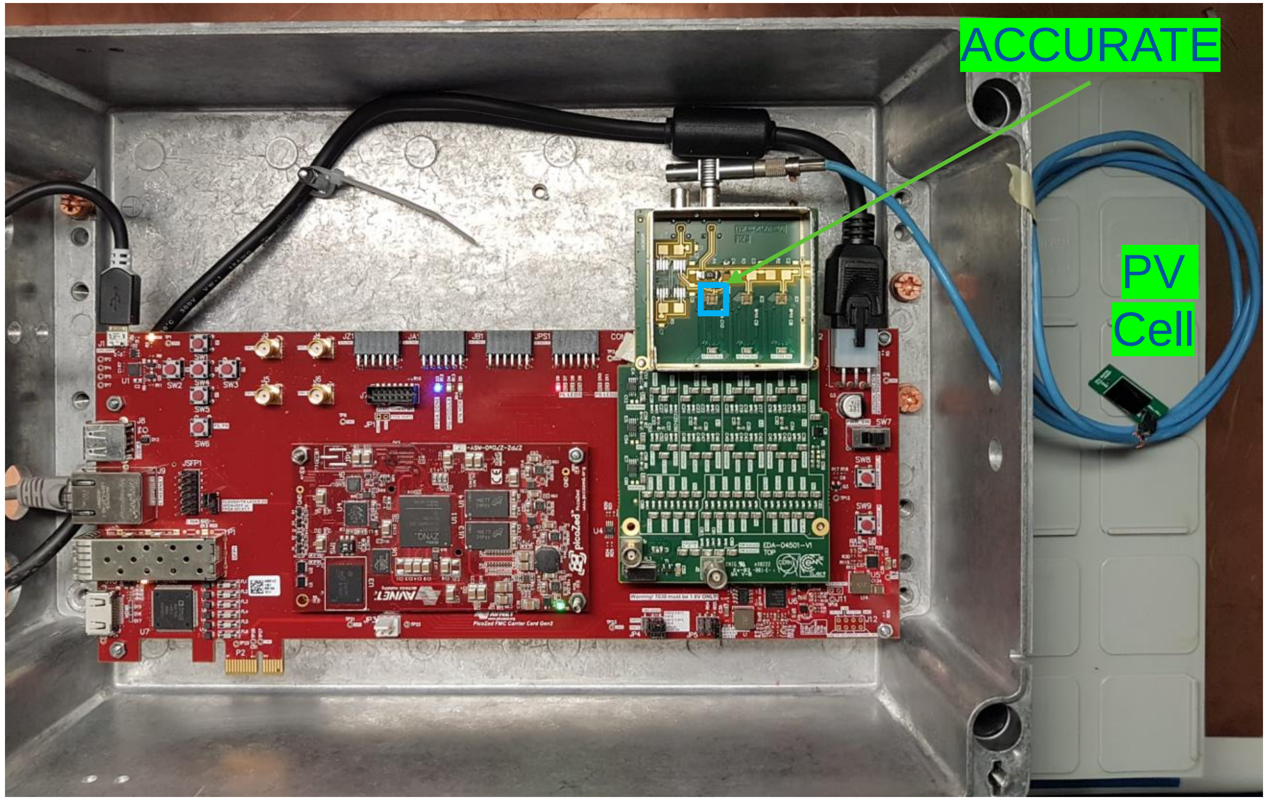
- Adding a 50 MΩ input resistor slows down the discharge
- Integrator does not saturate
- With the new configuration, ACCURATE ASIC measures all the charges within an accuracy of 10%

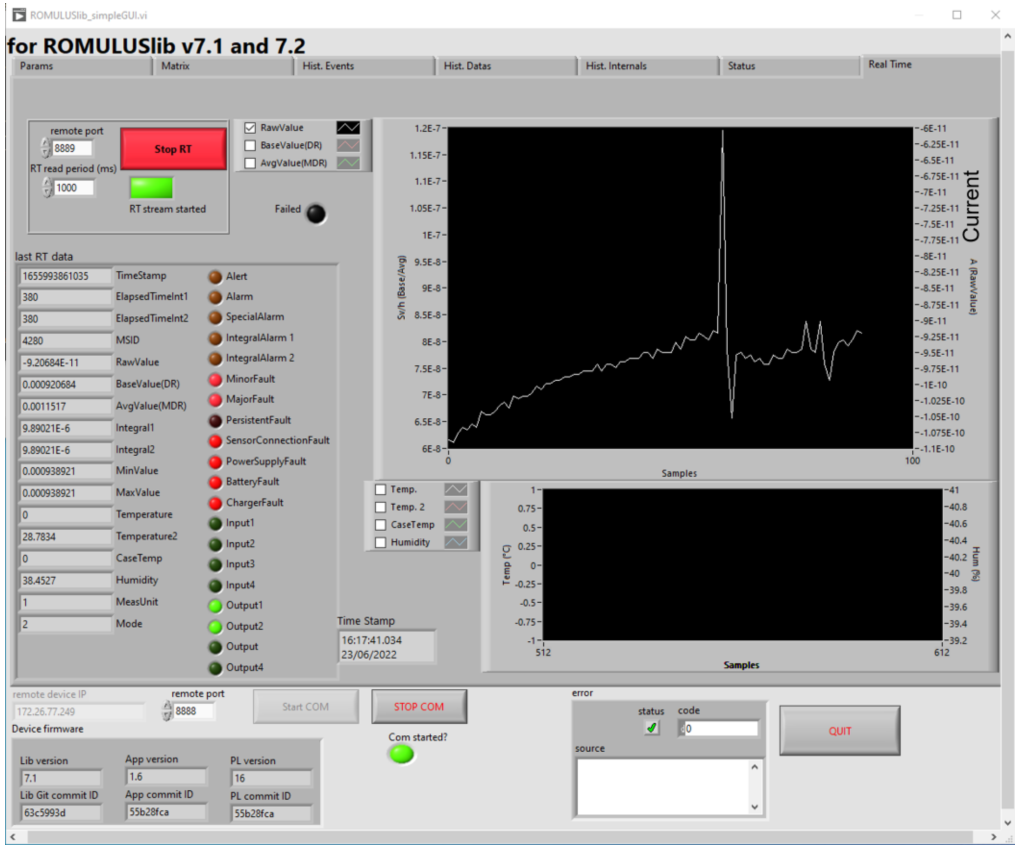
Drawback

- Add noise and reduce the performances for ultra-low current measurement

Beyond Radiation Monitoring

ACCURATE Interfaced with PV cell



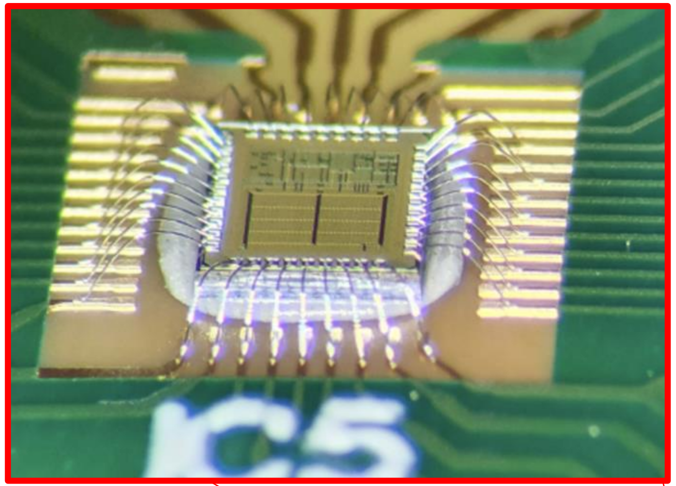


Conclusion

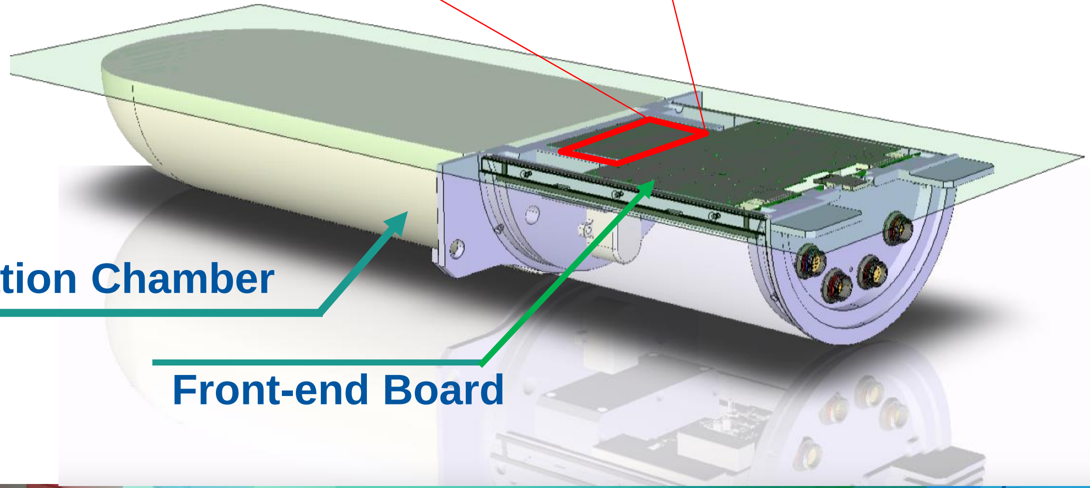
- ACCURATE: The first RP dedicated ASIC frontend electronics for ionization chamber
- When it is not controlled, the discharge time of ionization chamber can saturate any charge transfer front end electronics
- Adding a resistive impedance can increase the discharge time but also introduce a lot of noise
- Introducing resistor increases leakage current and compensation becomes cumbersome with variations in input bias voltage
- Calibrations to account for variations or a dual configuration for pulsed and environmental monitoring to be used
- Current version of the ASIC – ACCURATE 2 will be upgraded to new version ACCURATE 3 with integrated solution for improving the charge collection

Outlook

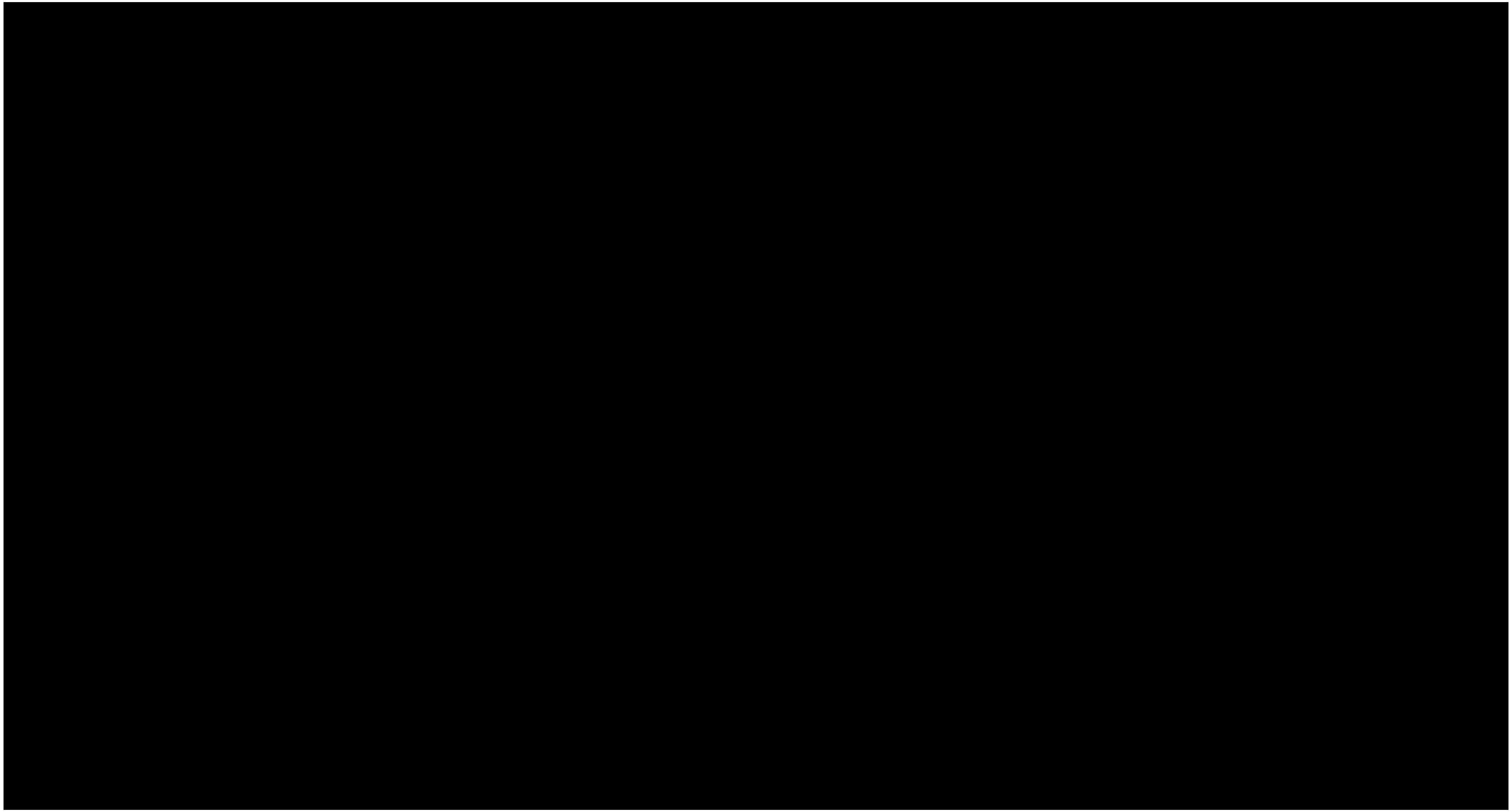
- ACCURATE 3 chip will be used to upgrade CROME electronics
- The first prototype combining CROME with ACCURATE 3 frontend is foreseen for 2025
- It would reduce our dependency to the market and reduce the complexity of CROME production process
- Interfacing ASIC with different kinds of sensors under study



Preparing for future with an integrated solution

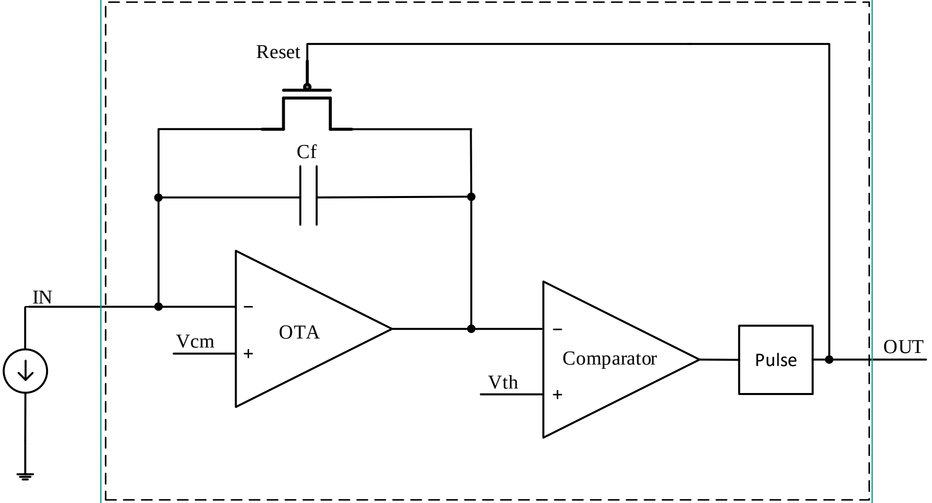


Thank you!

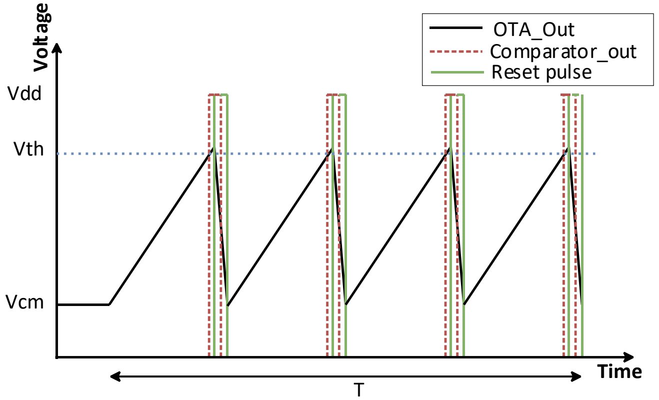


Direct current measurement topologies

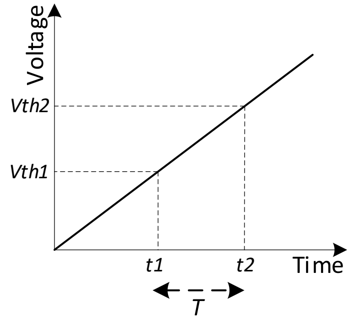
Reset Counting Method (RC)



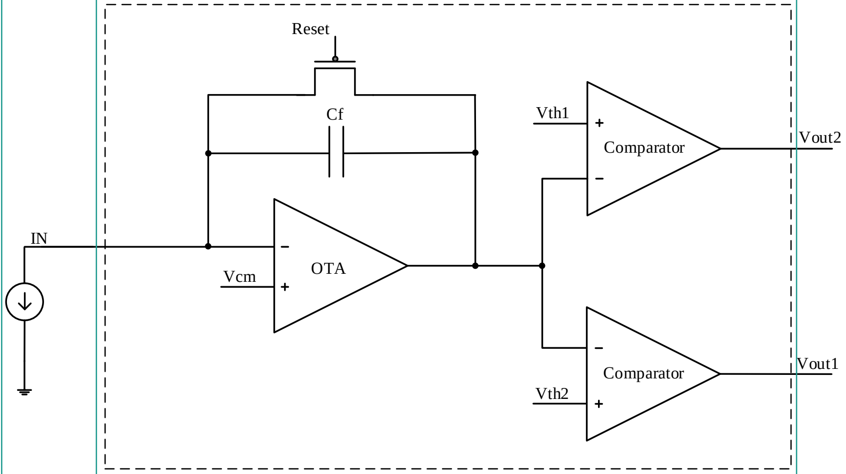
$$Iin = \frac{N * Cf * (Vth - Vcm)}{T}$$



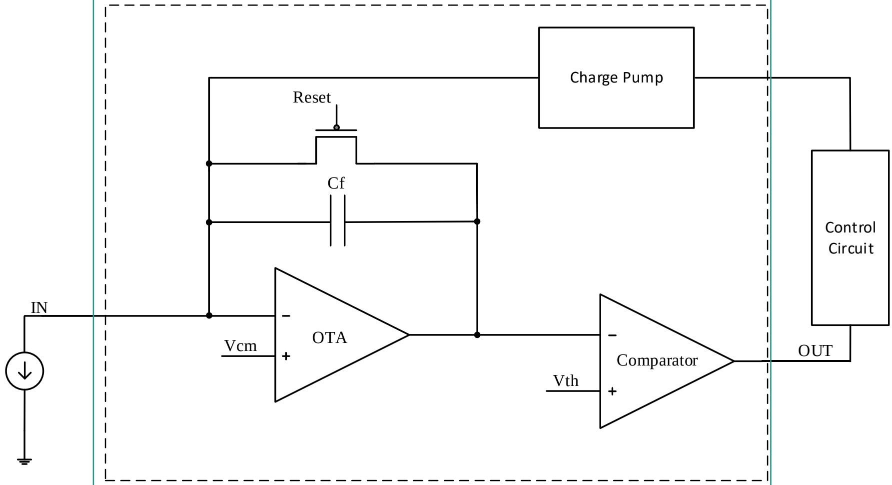
Direct Slope Measurement (DSM)



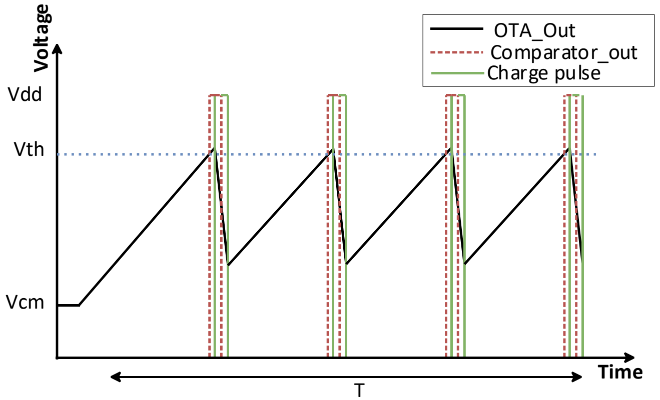
$$Iin = \frac{Cf * (Vth2 - Vth1)}{t2 - t1}$$



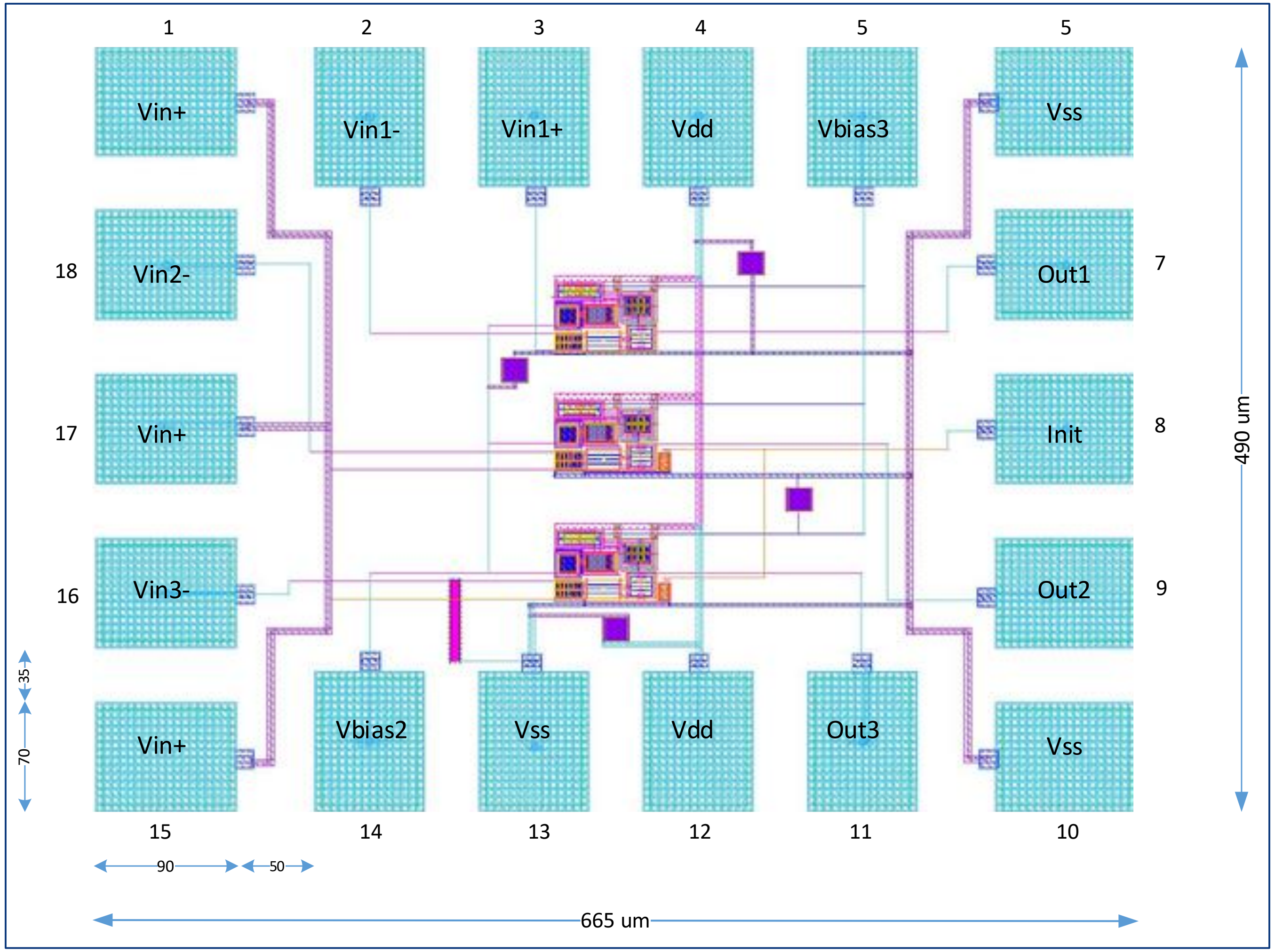
Charge Balancing Method(CB)

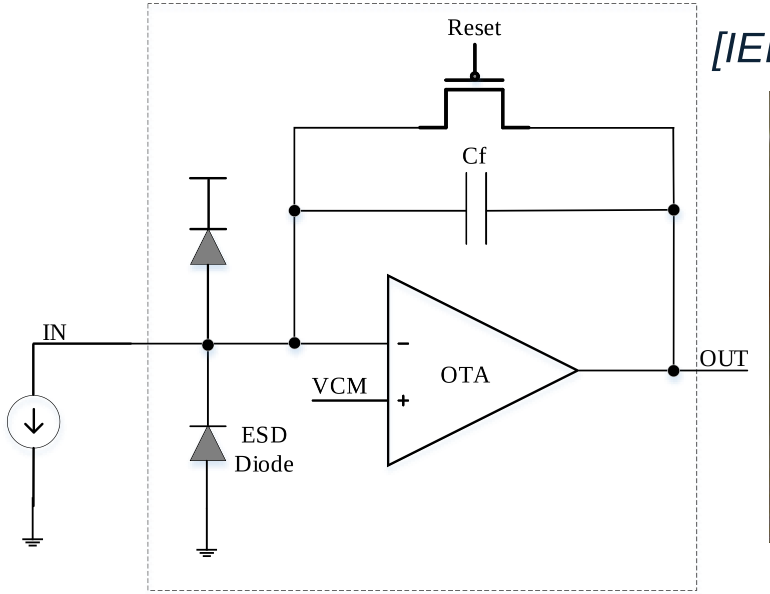


$$Iin = \frac{N * Qref}{T}$$



Technology demonstrator ASIC 1 – ACCURATE 0



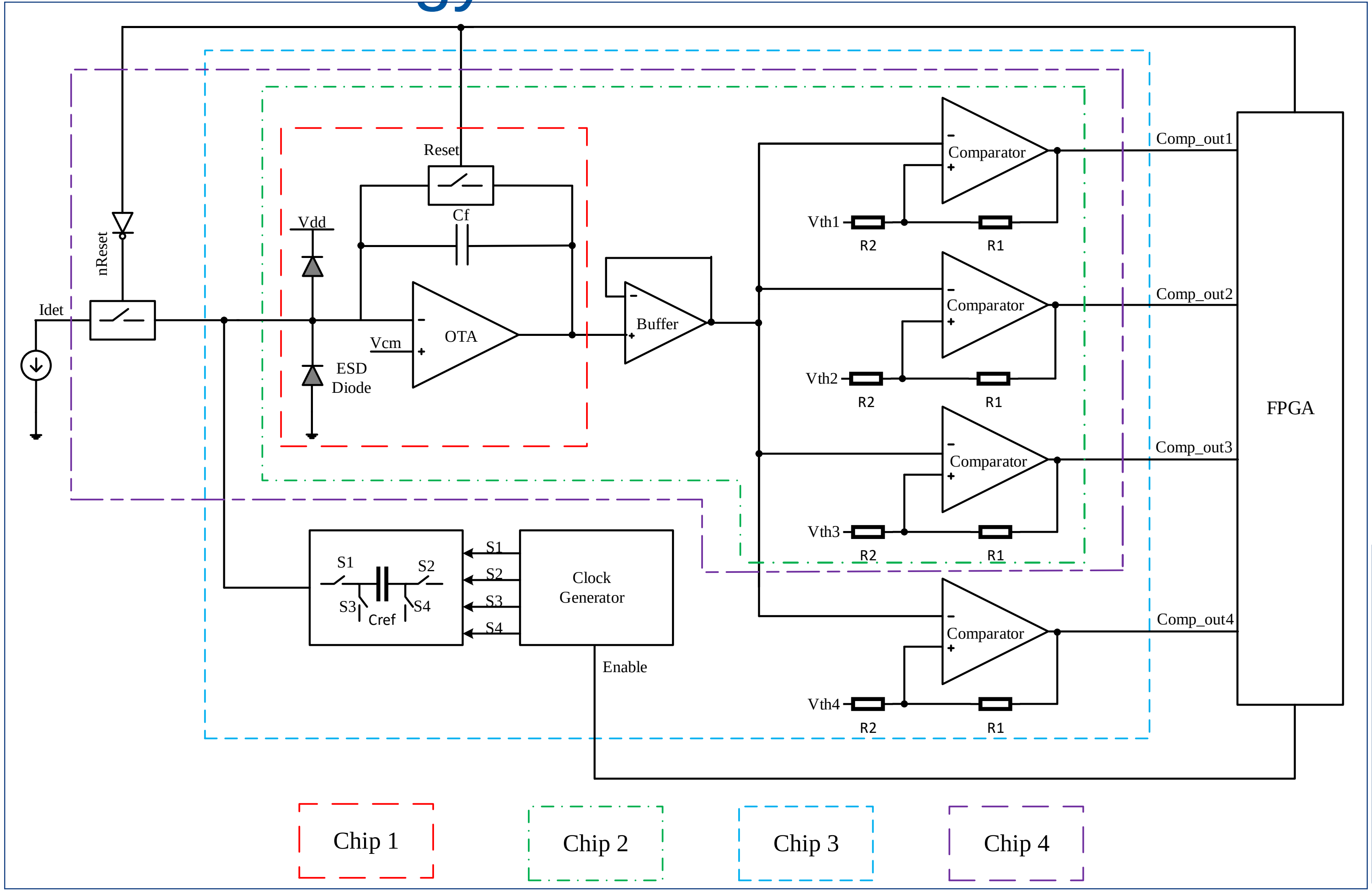


[IEEE S3S2019]

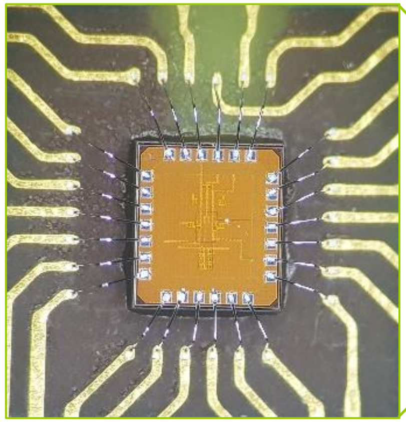
Primary objective: Technology evaluation for leakage currents

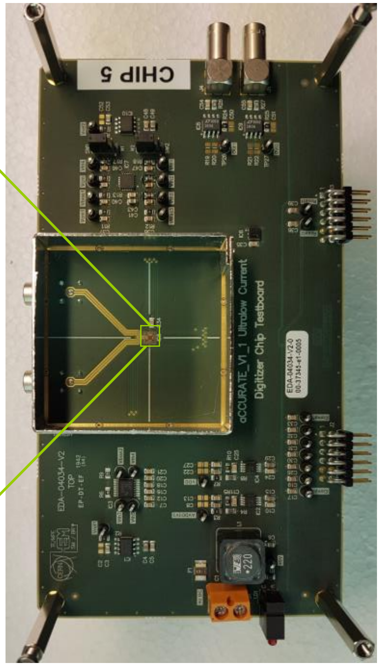
- Technology : GF 22FDX
- Measurement range : -1 fA to -1 nA
- Number of channels: 3

Technology demonstrator ASIC 2 – ACCURATE 1



[IEEE ACCESS 2021]





Primary objective: Technology evaluation - leakage currents

- Technology: TSMC 130 nm
- Measurement range: -1 fA to -1 μA
- Number of variants: 5
- Number of channels: 2

Comparison with state of the art

Year	Minimum Current Resolution	Maximum measurable Current	Methodology	Tech. node	Ref.
2013	550 aA	30 nA	Current amplifier	350 nm	Carminati 2013
2015	314 fA	250 µA	Sigma Delta ADC	180 nm	Pol 2015
2016	100 fA	16 µA	Sigma Delta ADC	500 nm	Li 2016
2017	1 fA	5 µA	Charge balancing	350 nm	Voulgari 2017
2017	470 fA	20 µA	SAR ADC	350 nm	Ghoreishizadeh 2017
2018	80 pA	12 µA	Charge balancing	350 nm	Fausti 2018
2021	**200 aA**	**20 µA**	**Charge balancing + Direct slope**	**130 nm**	**ACCURATE 2**