An lpGBT sub-system for environmental monitoring and control of experiments

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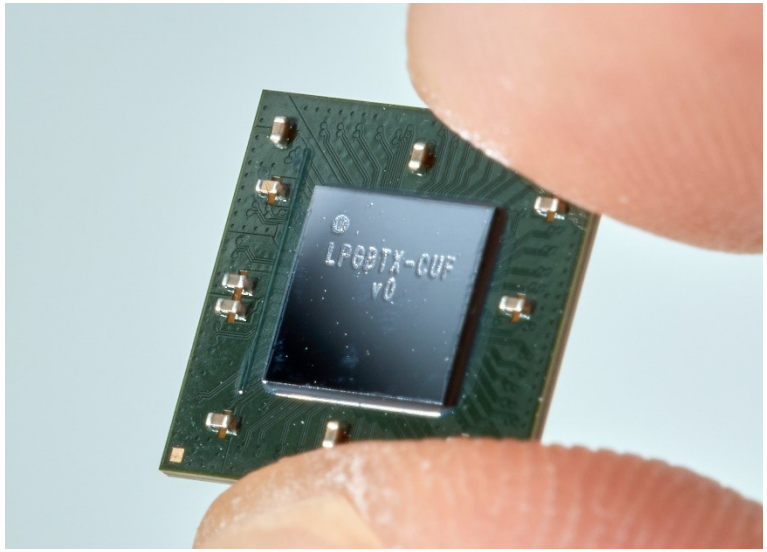
Topical Workshop on Electronics for Particle Physics (TWEPP-19)
2-6 September 2019, Santiago de Compostela, Spain

This work was supported by the European Union Horizon 2020 Research and Innovation programme under Grant Agreement no.654168 (AIDA-2020) and by the Polish Ministry of Science and Higher Education under Contract No. 3501/H2020/2016/2

Agenda

- lpGBT environmental monitoring sub-system
  - Introduction, architecture, design of key blocks
- Measurements of monitoring sub-system
  - Setup, ADC results, DAC results, reference voltage generator
- X-ray Irradiation studies
  - Setup, example results
- Summary

lpGBT – Not only for communication



Capable of
- 5.12 or 10.24 Gbps (for uplinks)
- 2.56 Gbps (for downlinks)

Enables the implementation of RadTol
- DAQ links
- Trigger links (constant latency)
- Experiment control [slow control] links

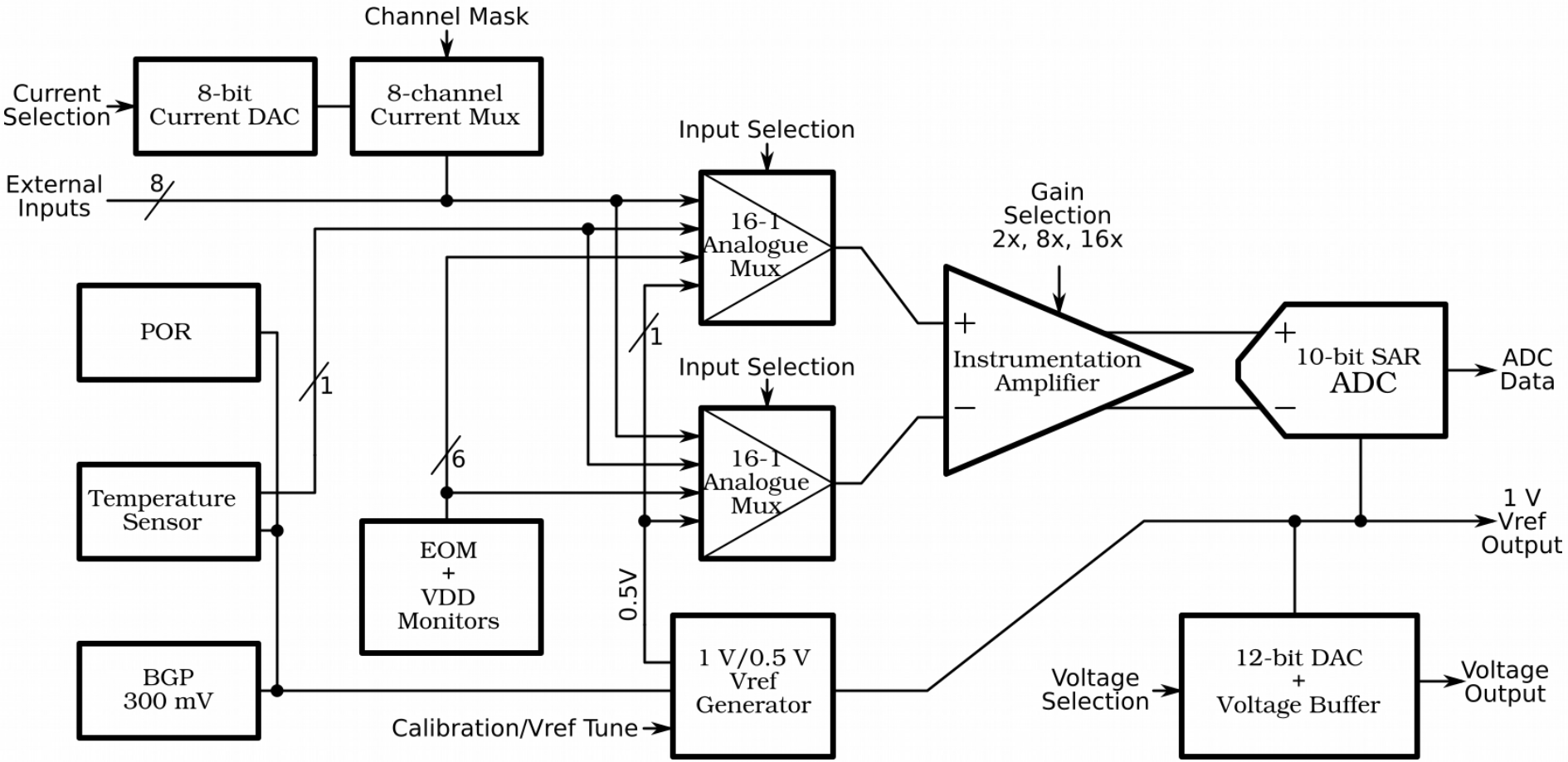
Implements Control and Monitoring Functions
- Three I2C Masters
- 16 – bit General Purpose I/O port
- Output reset pin
- 10 – bit ADC (8 multiplexed inputs)
- 8 – bit voltage DAC
- 8 – bit current DAC
- Temperature sensor

This presentation

Analogue features

Designed for radiation hardness
- Total Ionizing Dose (TID): 200 Mrad
- Extensive SEU protection (TMR, FEC)

lpGBT environmental monitoring sub-system

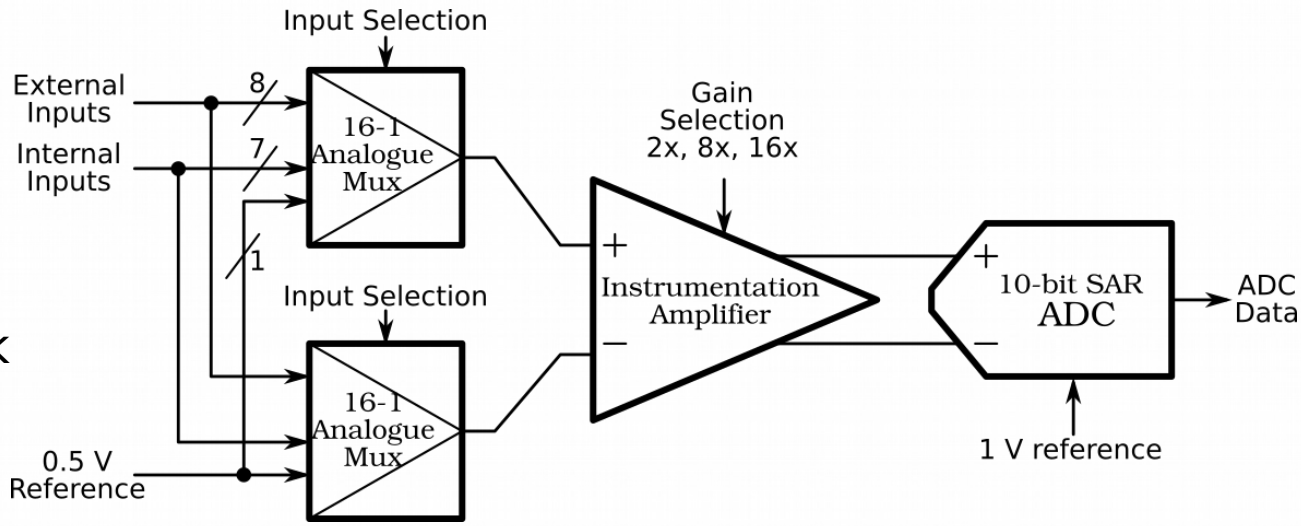


Block diagram of monitoring sub-system

ADC core and Instrumentation Amplifier

Main components:

- 10-bit ADC core
- Instrumental amplifier with resistive feedback
- 2 analogue multiplexers



Gain & Input ranges:

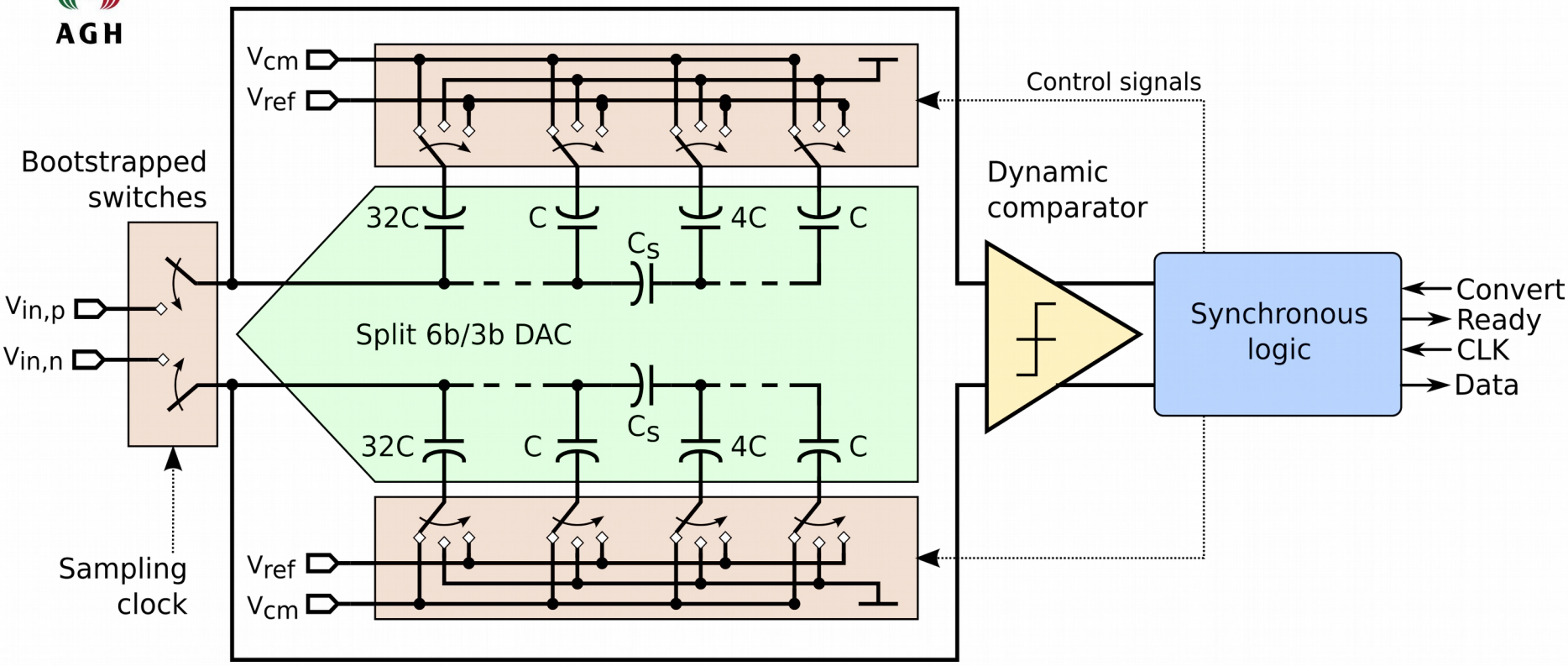
Gain	Single-ended	Differential*
2	0 - 1 V	+/- 500 mV
8	350 - 650 mV	+/- 150 mV
16	430 - 570 mV	+/- 70 mV

*differential input common mode: 0.4 – 0.9 V

Important features:

- 8 external inputs
- 7 inputs for internal signal monitoring (temperature, power supply voltages, ...)
- 0.5 V reference signal for single ended operation

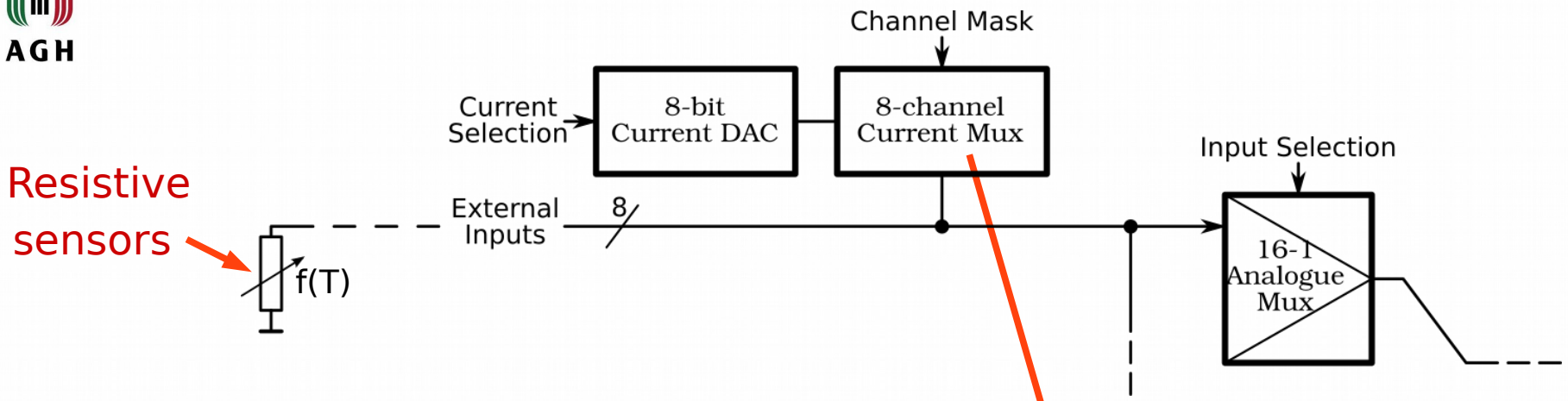
10-bit ADC - core architecture



Important features:

- Differential segmented/split DAC with MCS switching scheme – ultra low power consumption
- Dynamic comparator – no static power consumption
- Fully triplicated synchronous logic

Biasing current on the analogue input

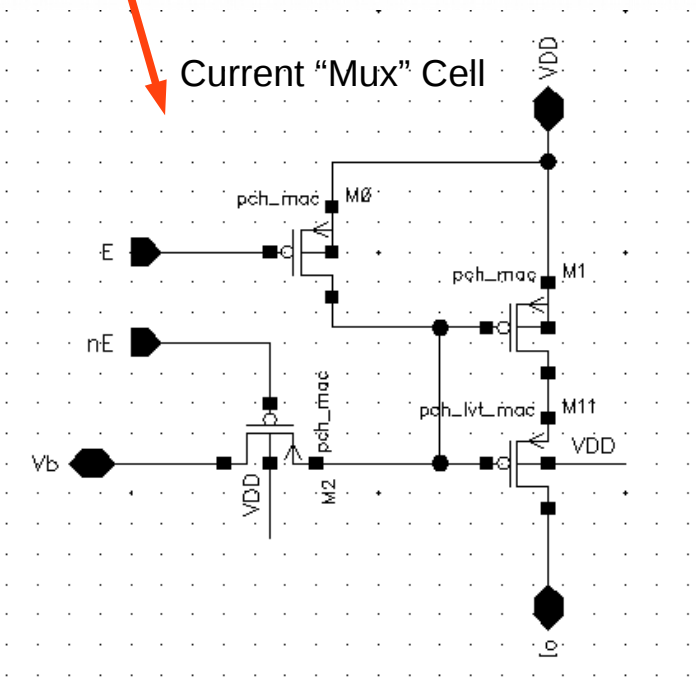


8-bit current DAC:

- One channel
- Current range 0 – 900 uA (LSB ~3.5 uA)
- Current reference from BGP

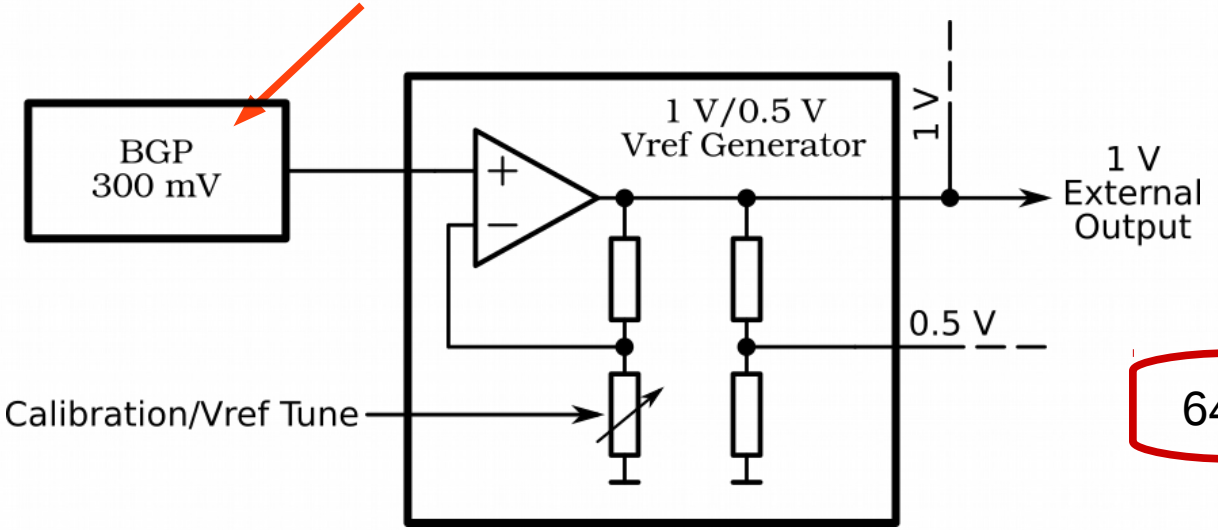
8-channel current “Mux/Switch”:

- Current can be applied to the external inputs
- The same current for all channels



Reference Voltage Generator

BGP provided by Stefano Michelis



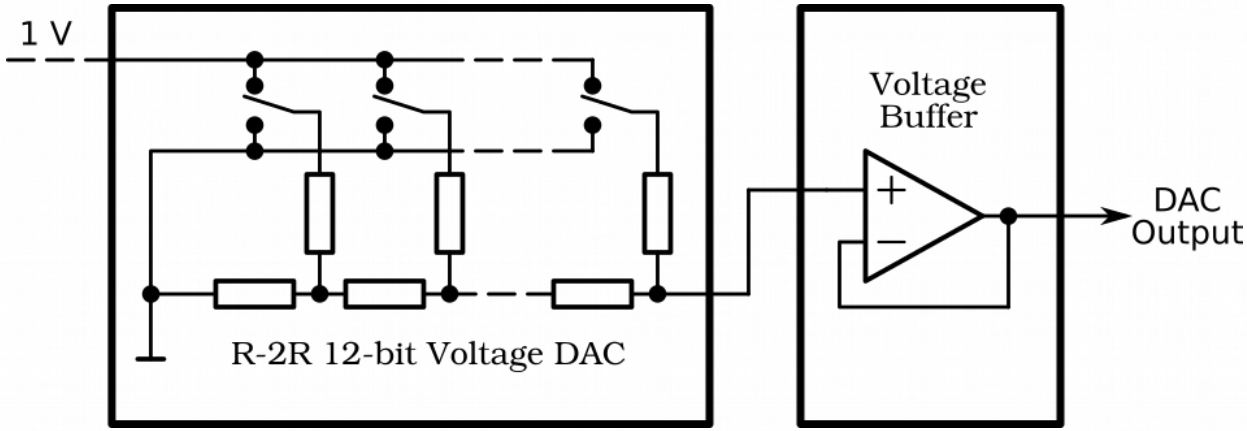
$$V_{ref} = V_{bgp} \cdot \left(1 + \frac{R_f}{R_{adj}}\right)$$

64 values, 6-bit tunning

Important features:

- Reference based on Bandgap ~300 mV
- Adjustable Reference Voltage (to be adjusted during production testing)
- 1 V and 0.5 V outputs available
- 1 V external output with high current driving capability

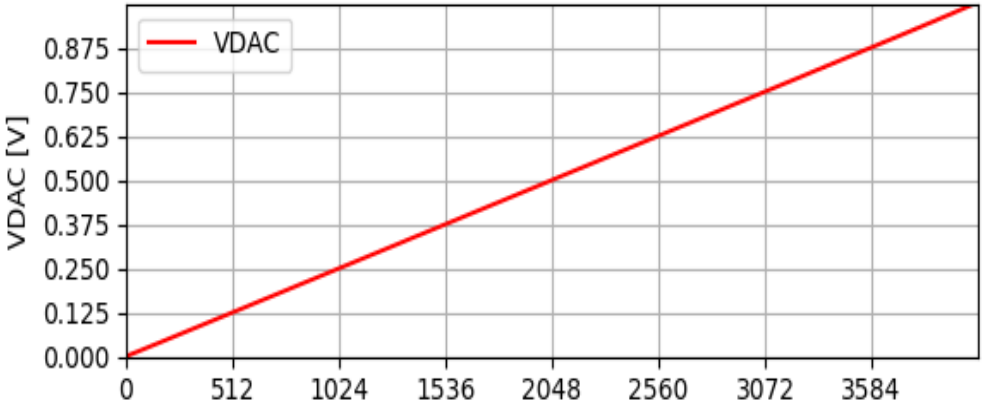
Voltage DAC architecture



Macro cell provided by Tomas Benka and Miroslav Havranek (RD53)

Important features:

- 8-bit Voltage DAC (12-bit control)
- R-2R architecture
- Voltage buffer at the output
- 0-1 V output dynamic range



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Measurements Setup

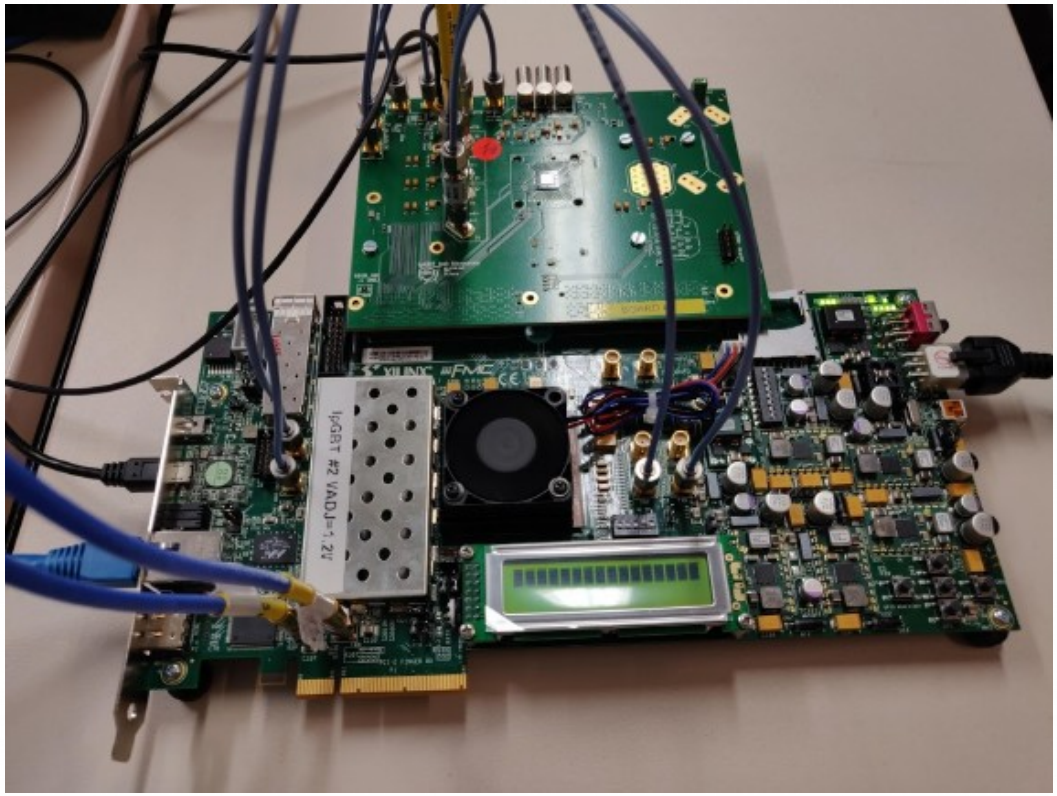
On-board equipment:

- 16- bit DAC

  (AD5686BCPZ), INL < 2 LSB
- 16-bit ADC

  (AD7682BCPZ), INL < 1.5 LSB)
- 1.2 V Reference

  (ADR3412ARJZ), accuracy < 0.1%

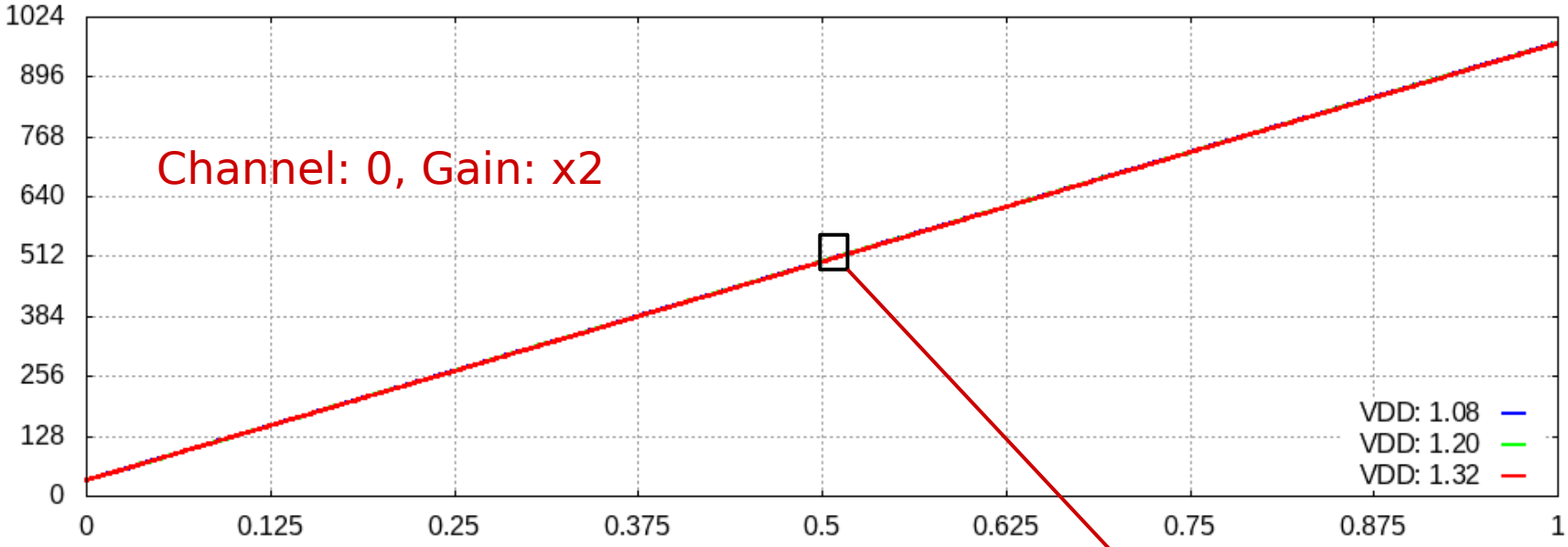


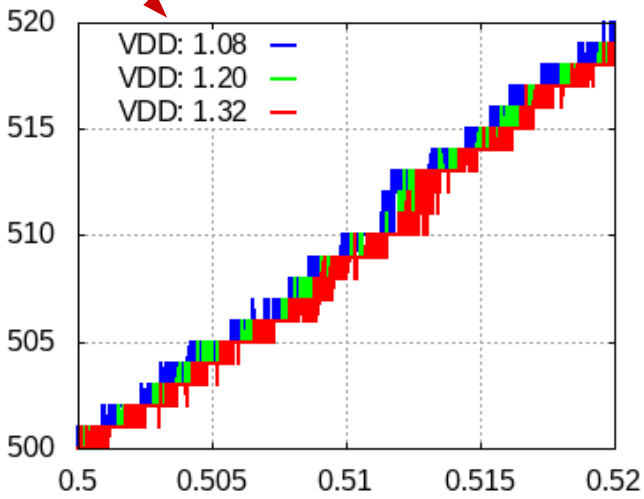
Dedicated FPGA-based measurement system, for more details see

“LpGBT Tester: an FPGA based test system for the lpGBT ASIC”

by J. Mendez et al.

ADC – Basic results



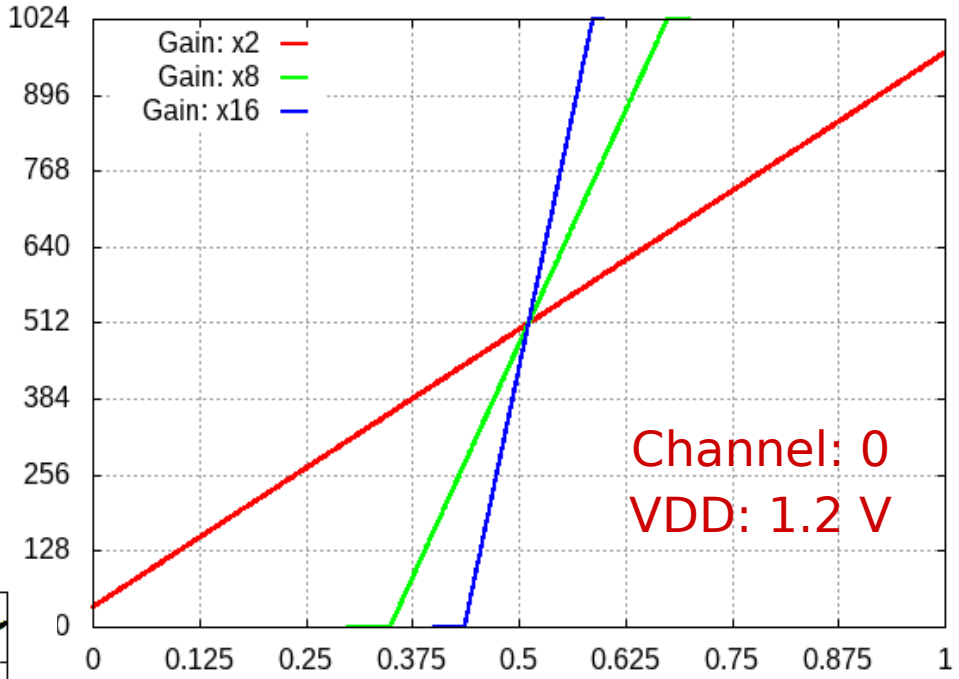


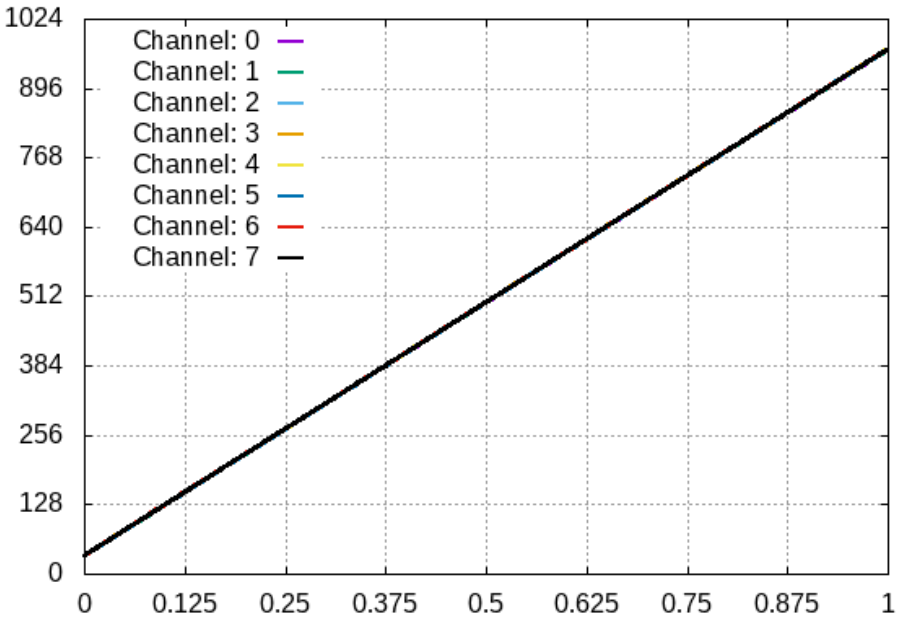
- ADC Core, input multiplexers and instrumentation amplifier fully functional
- Very good linearity (INL, DNL next slides)
- Effect of ADC power supply negligible

ADC – Linearity for different gains

Input ranges [V]:

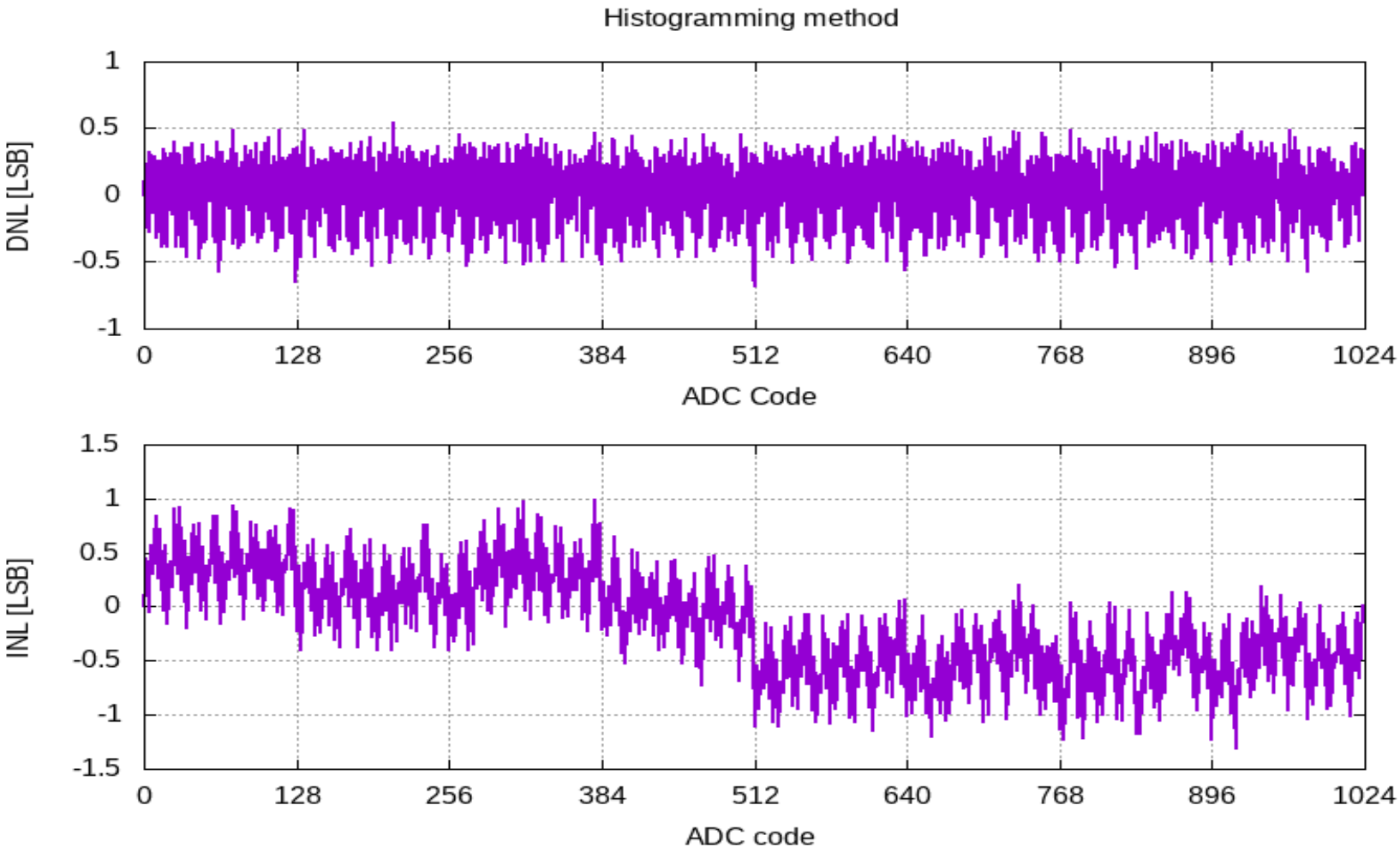
x2: [-0.043; 1.046]
spec: [0 - 1]
x8: [0.345; 0.668]
spec: [0.375, 0.625]
x16: [0.432; 0.582]
spec: [0.4375, 0.5625]





- Instrumentation amplifier fully functional
- Input multiplexer fully functional, no noticeable difference between channels

ADC – static measurements

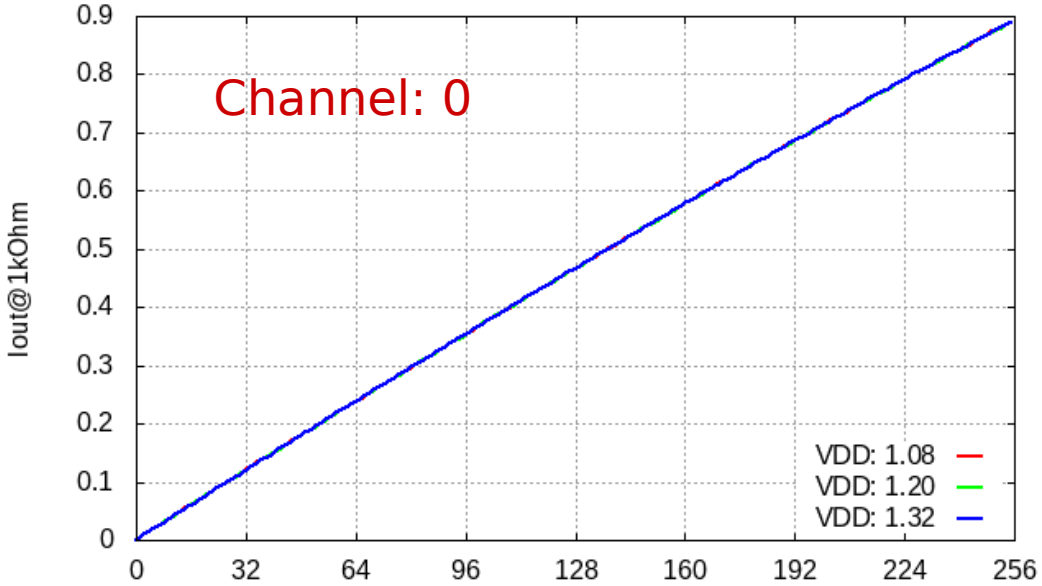


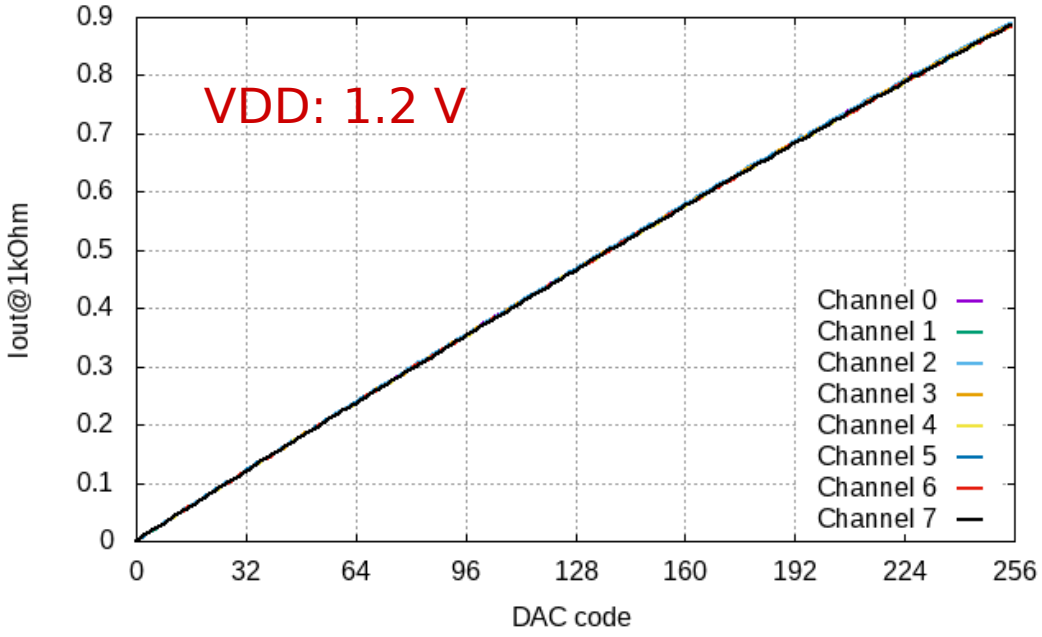
- DNL around +/-0.5LSB
- INL around +/-1LSB
- No missing codes

Current DAC and current multiplexer are fully functional

- DNL better than +/- 0.5 LSB
- Almost no power supply dependence (difference at maximum current better than 0.02%)
- All channels are almost identical

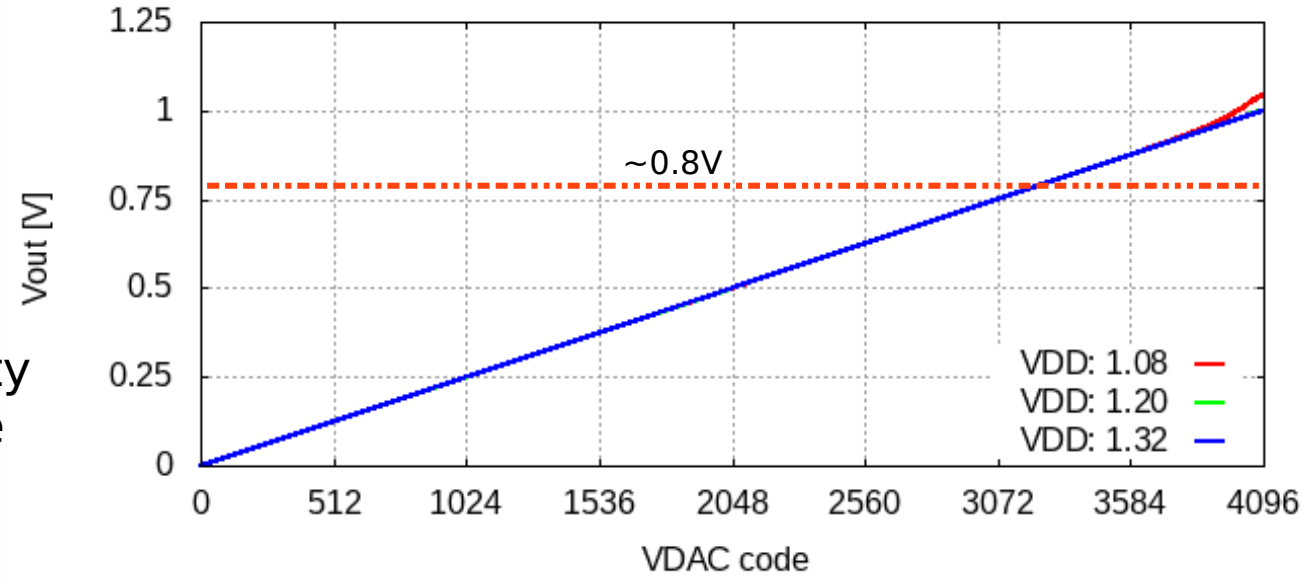
Current measured using 1 kΩ shunt resistor (the same resistor for all channels) – typical case for PT1000 temperature sensors

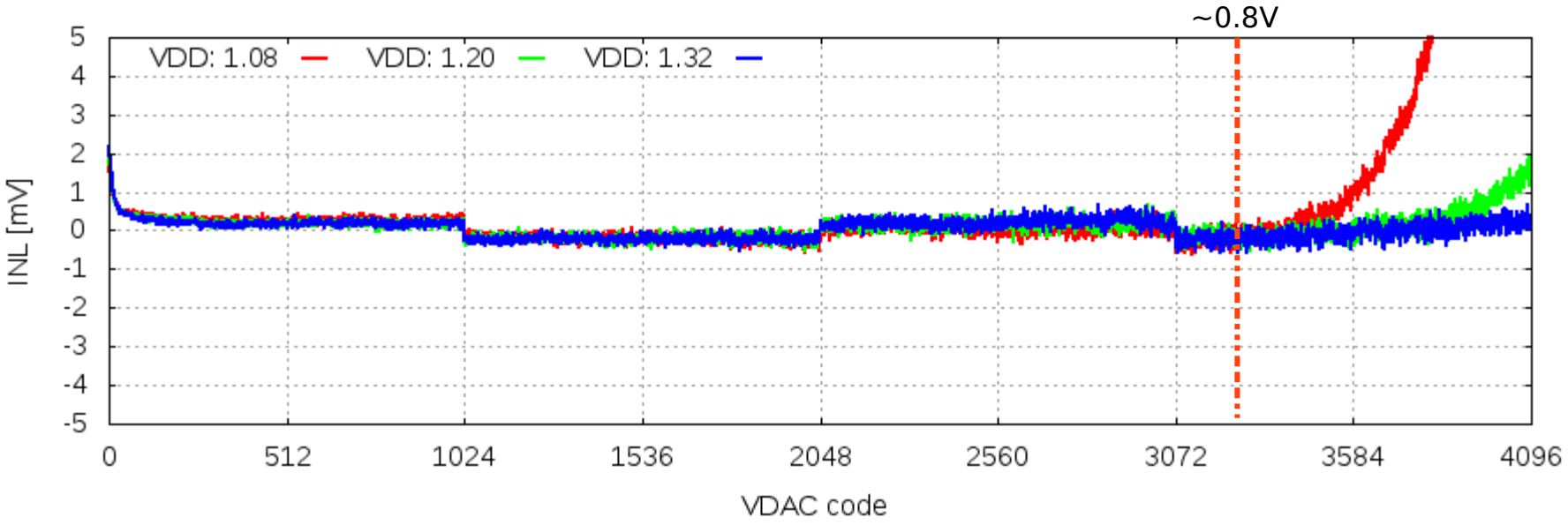




8-bit Voltage DAC

- Voltage DAC and output buffer are functional
- DAC integral linearity in most of the range is +/-0.5 LSB (8-bit)

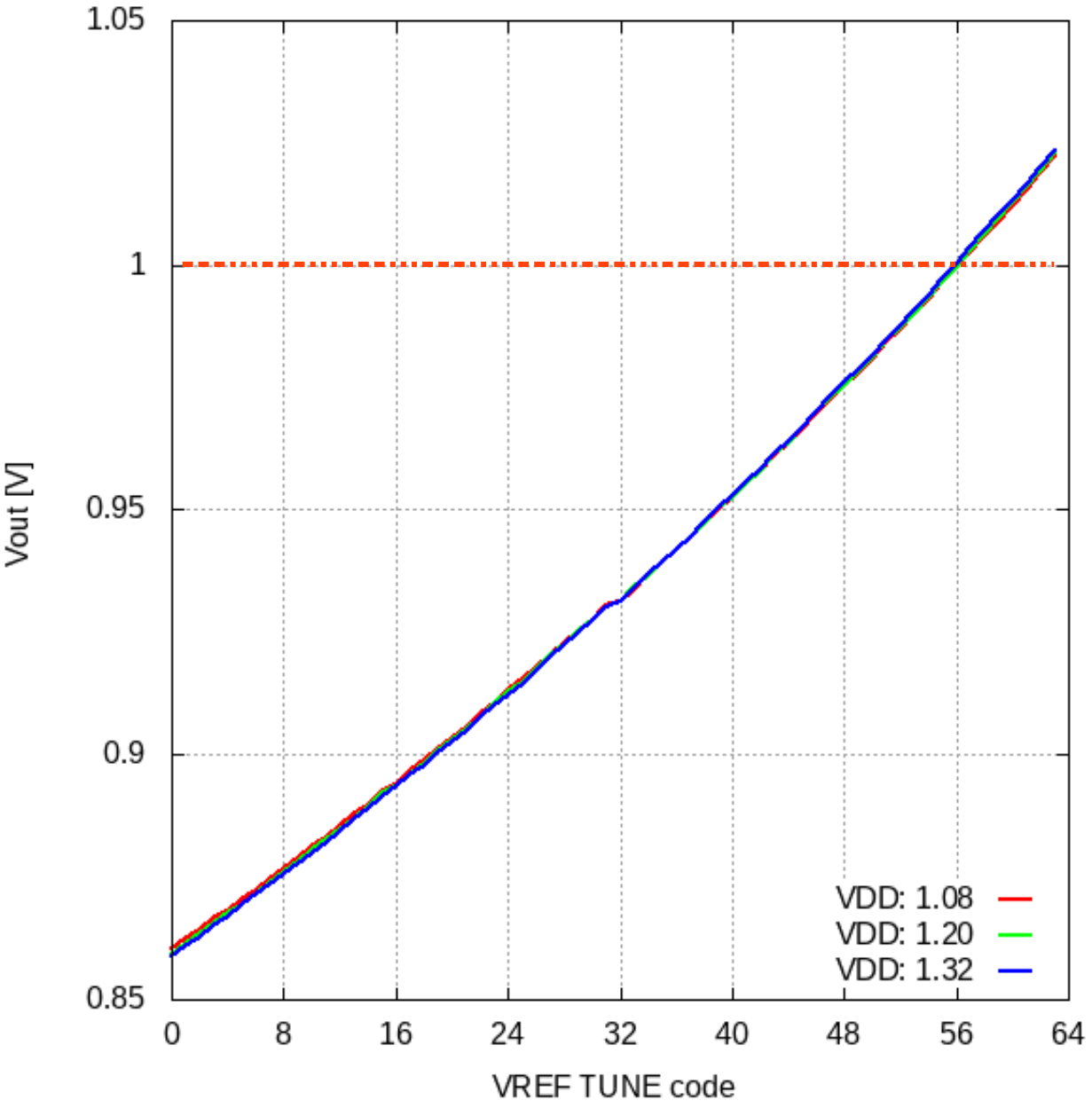




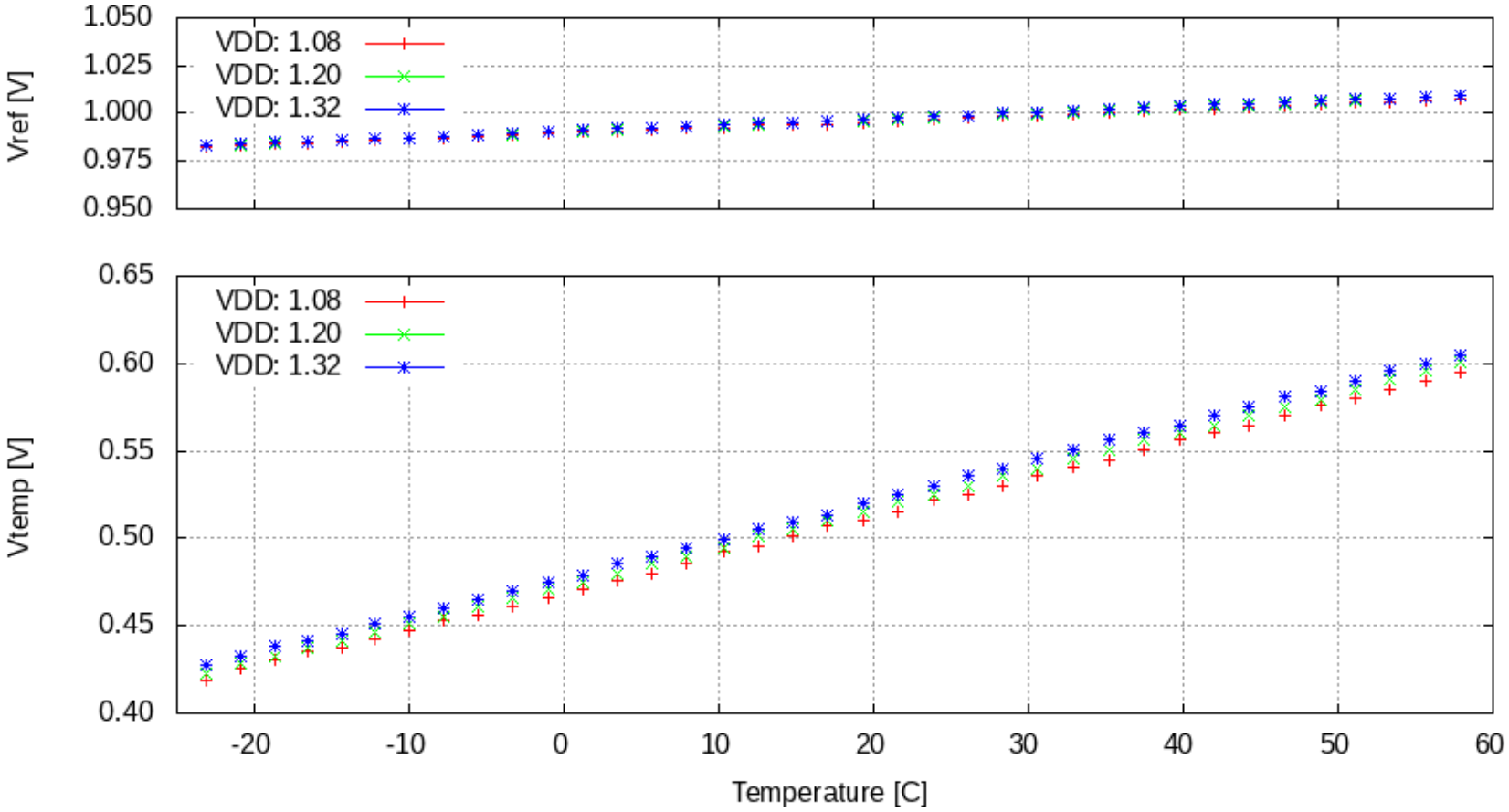
Reference Voltage Generator

Reference Voltage generator is fully functional

- Tuning range covers the nominal operating voltage (1 V)
- Range it is not well centered – probably the bandgap voltage is smaller than expected
- Almost no dependence on supply voltage (less than 0.15% for worst case – tune code 0)



Temperature measurements



- Reference voltage stability better than 300uV/℃
- Temperature sensor gain around 2.1 mV/℃ with INL better than +/- 2 mV (below 1℃)

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XRAY irradiation Setup

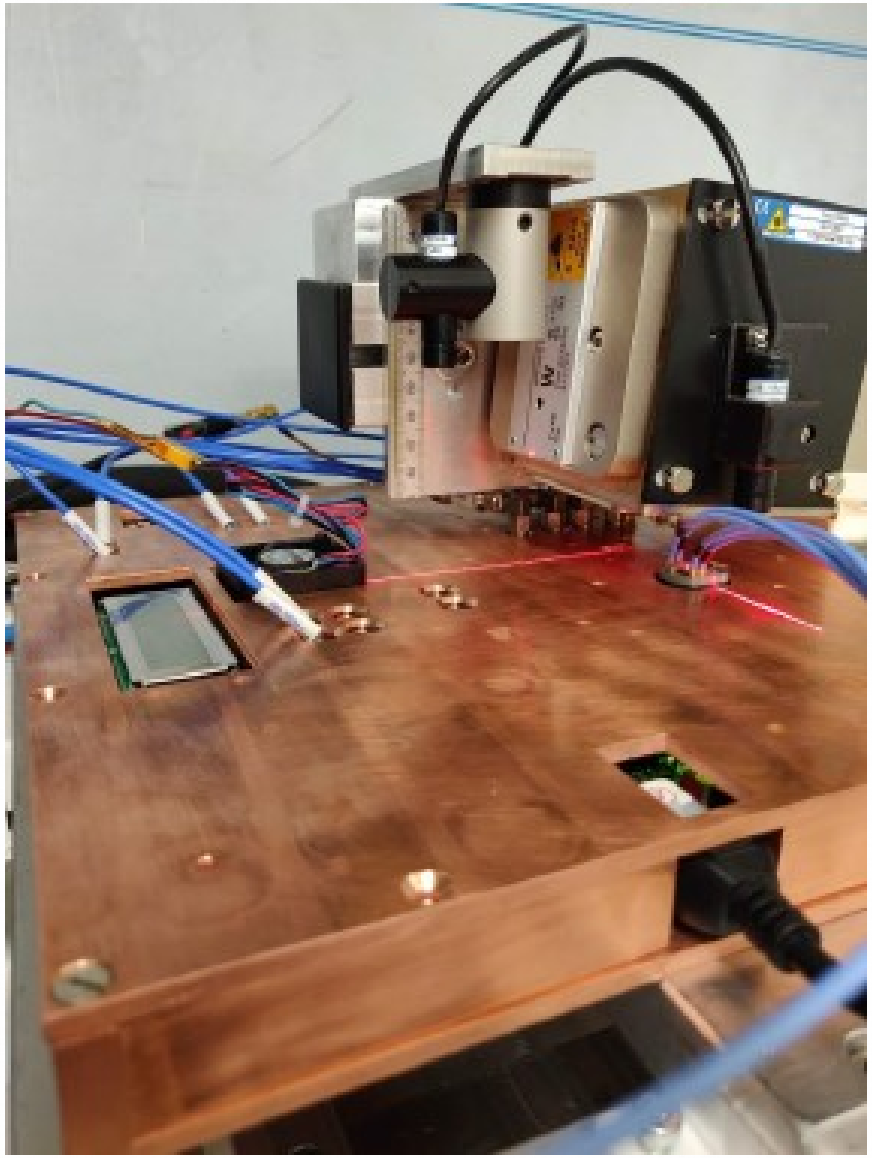
Obelix XRAY machine at CERN

Important features:

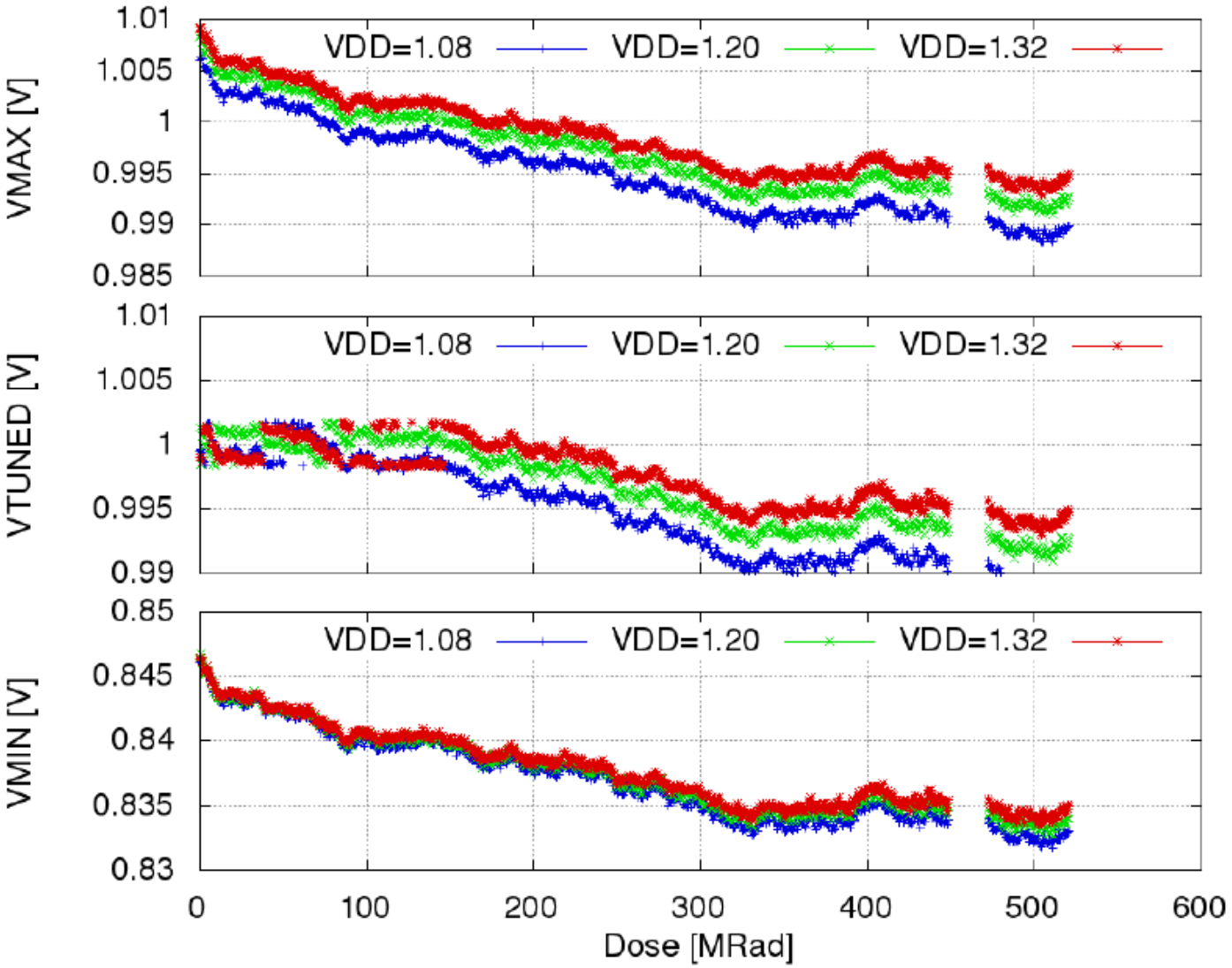
- 40 kV @ 50 mA
- Dose rate ~35 Mrad/h

Test conditions:

- Temperature: 10 ℃
- Run time : ~156 h
- Accumulated dose: ~520 MRad



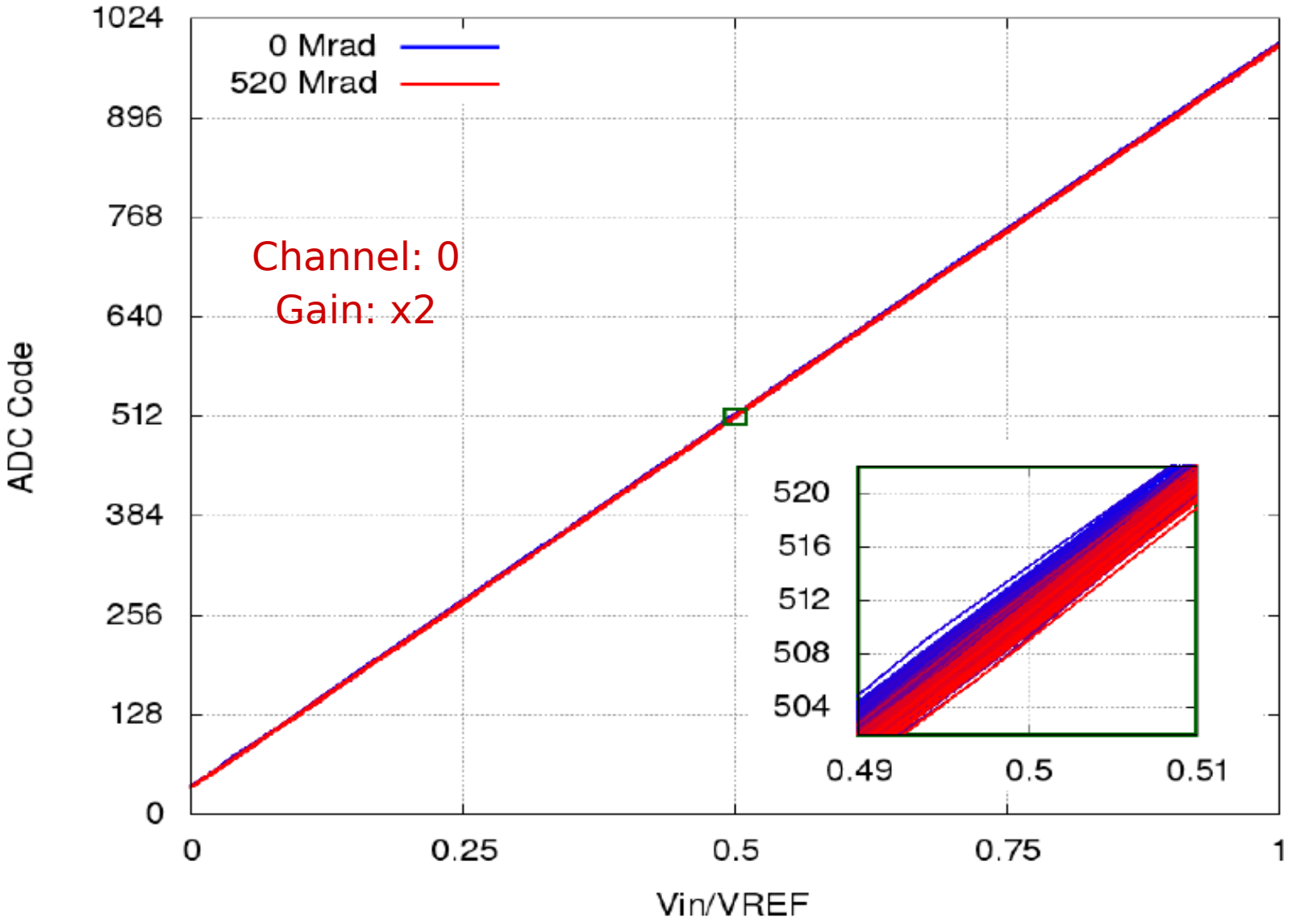
Reference Voltage vs irradiation



Voltage drops around 50uV/Mrad during irradiation

Tunning range is non sufficient above 150 MRad

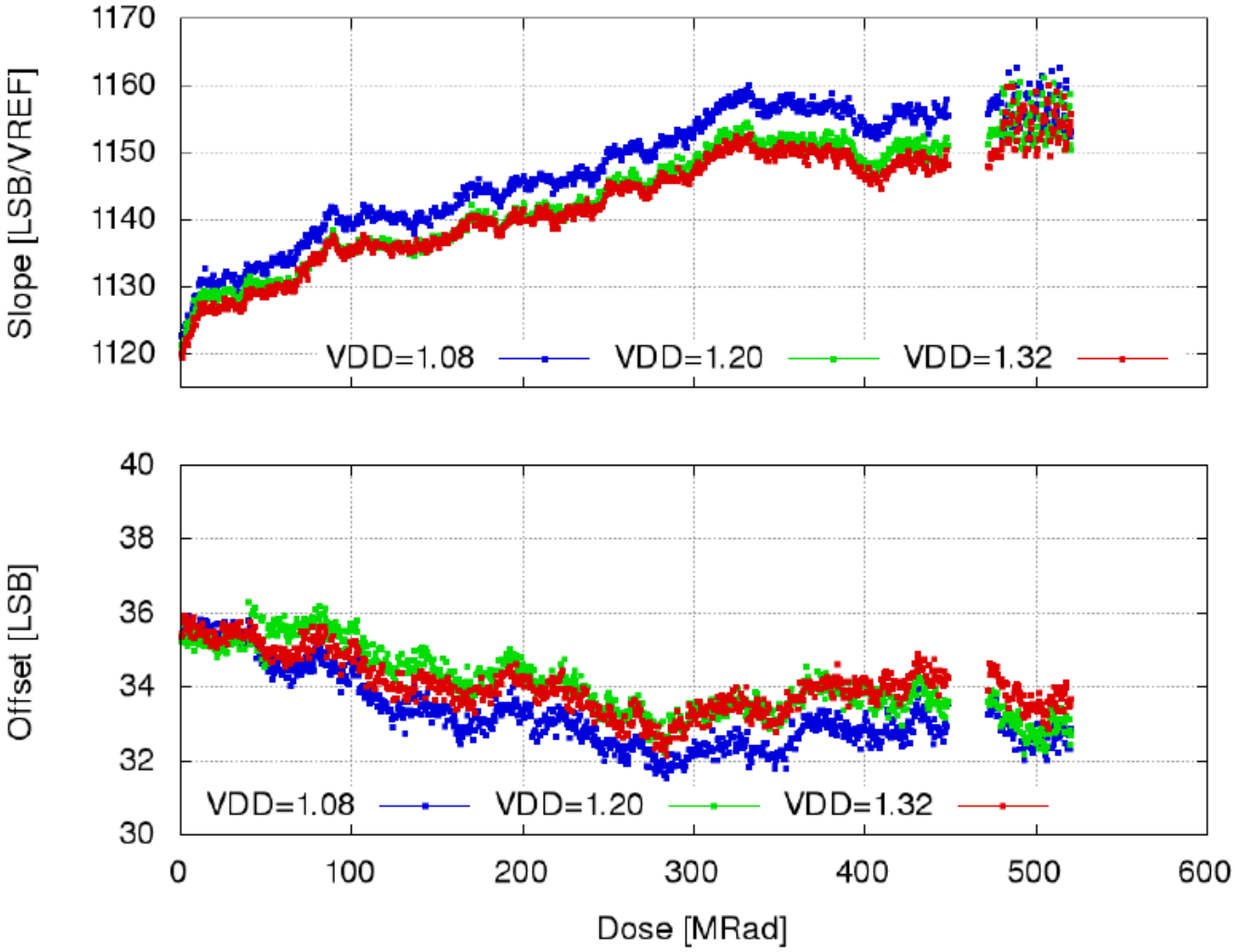
ADC linearity with irradiation



ADC linearity is very good up to 520 Mrad. No change during irradiation

ADC gain with irradiation

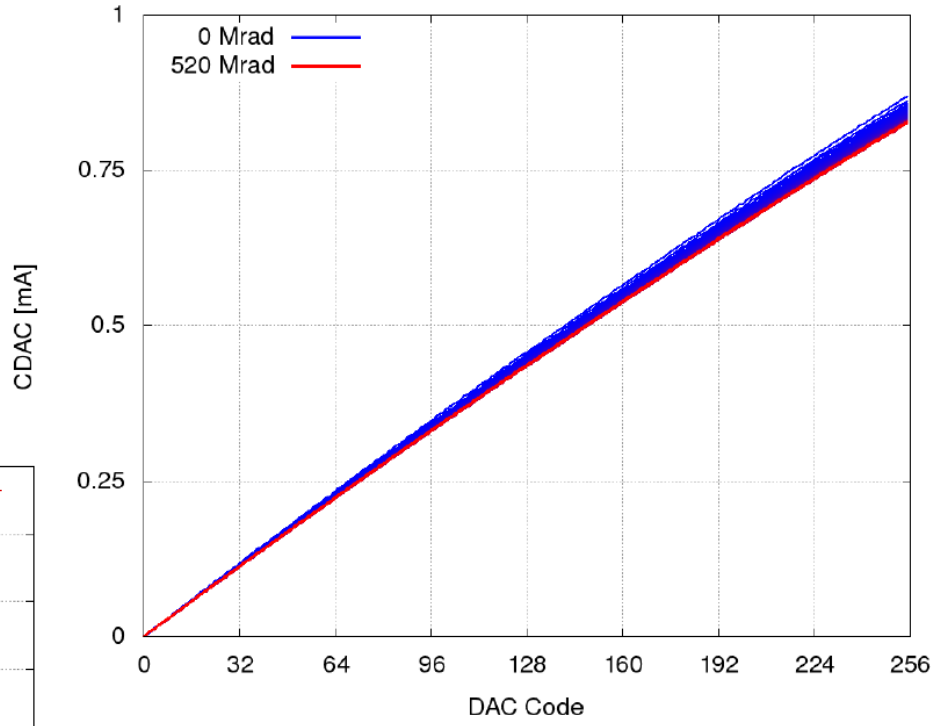
Channel: 0, Gain: x2

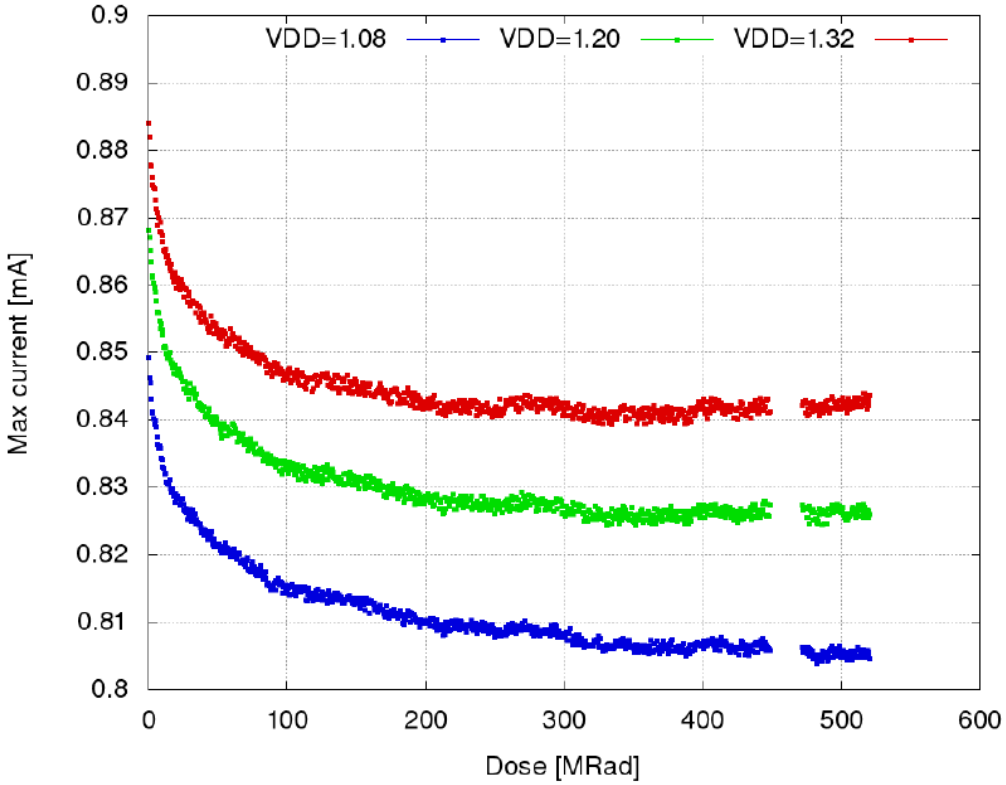


- Gain change up to ~4% at 520 MRad
- Offset change below 3 LSB up to 520 MRad

DAC current vs irradiation

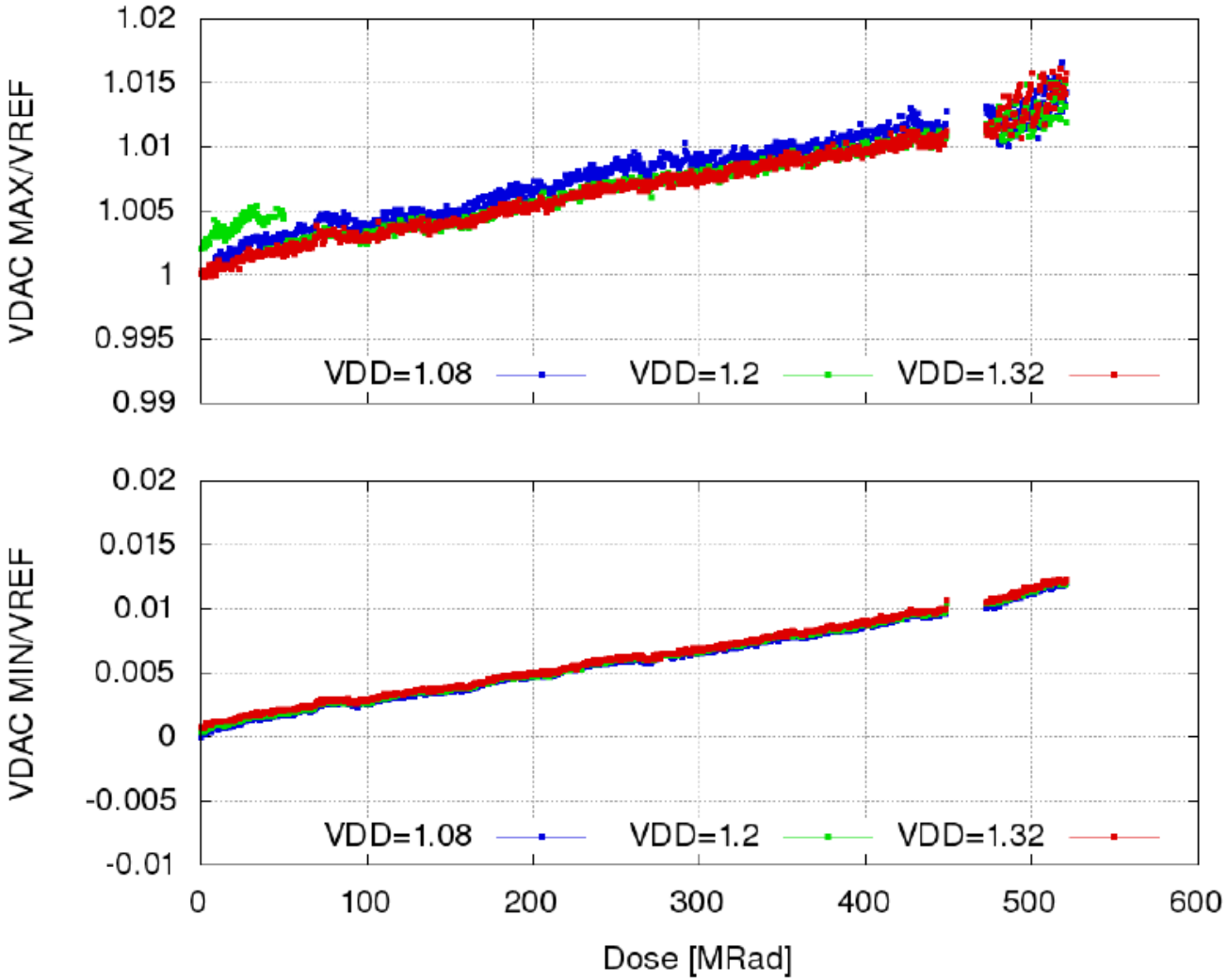
- Current DAC linearity not affected by radiation up to 520 MRad
- Gain slightly drops during irradiation





Maximum current drop less than 5%

Voltage DAC with irradiation



- Voltage DAC gain not affected by radiation
- Offset increases up to 1.5% at 520MRad

Summary

- A set of environment monitoring and stimulus functions were successfully integrated in the lpGBT:
  - 10- SAR ADC
  - 8-bit voltage DAC
  - 8-bit current DAC
  - Temperature Sensor
- All successfully tested for performance and for TID tolerance
- Remains to improve the tunability of the internal voltage reference

Thank you for attention