Development of quad-channel high resolution digital picoammeter for beam diagnostics

Mauricio Donatti (*mauricio.donatti@lnls.br*), Fernando Cardoso, Lucas Tanio
Brazilian Synchrotron Light Laboratory (LNLS)

Introduction

High accuracy and high resolution low current measurements are a common demand for many beamlines attached to SIRIUS [1], the new 3 GeV 4th-generation Brazilian light source. Due to femtoampère resolution requirement and the need for a large number of diagnostic elements, a four-channel digital general-purpose current meter has been developed.

Fig 1. Assembled device

Main Features

- ✓ 4-channel current input
- ✓ 8 Selectable ranges from 250 pA to 2.5 mA full-scale
- ✓ Low-noise resolution: 3 fA/√Hz @ 5 sps
- ✓ Sampling rate up to 2 ksps @ 24 bits resolution
- ✓ 5V DC Jack Input
- ✓ TTL Trigger Input & Output
- ✓ 100M Ethernet link
- ✓ Auto range feature
- ✓ 4-channel analog output
- ✓ External bias capability (up to 400 V)

Digital Picoammeter Design Overview

Hardware design guarantees extremely low leakage on the current input stage employing guard ring tracks, planes, and metallic shielding driven by a guard buffer circuit, combined with PCB cut-outs and solder mask removal from sensitive region. Also, a careful cleaning process was developed to improve the circuit's accuracy.

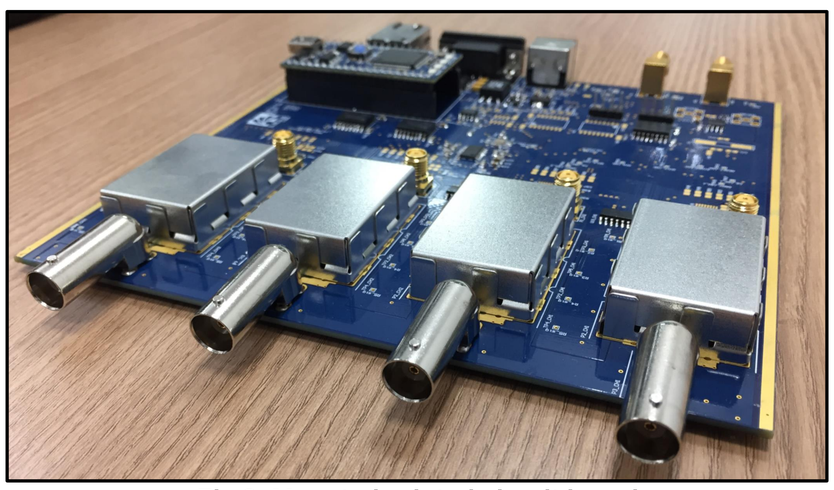


Fig 2. Mounted printed circuit board

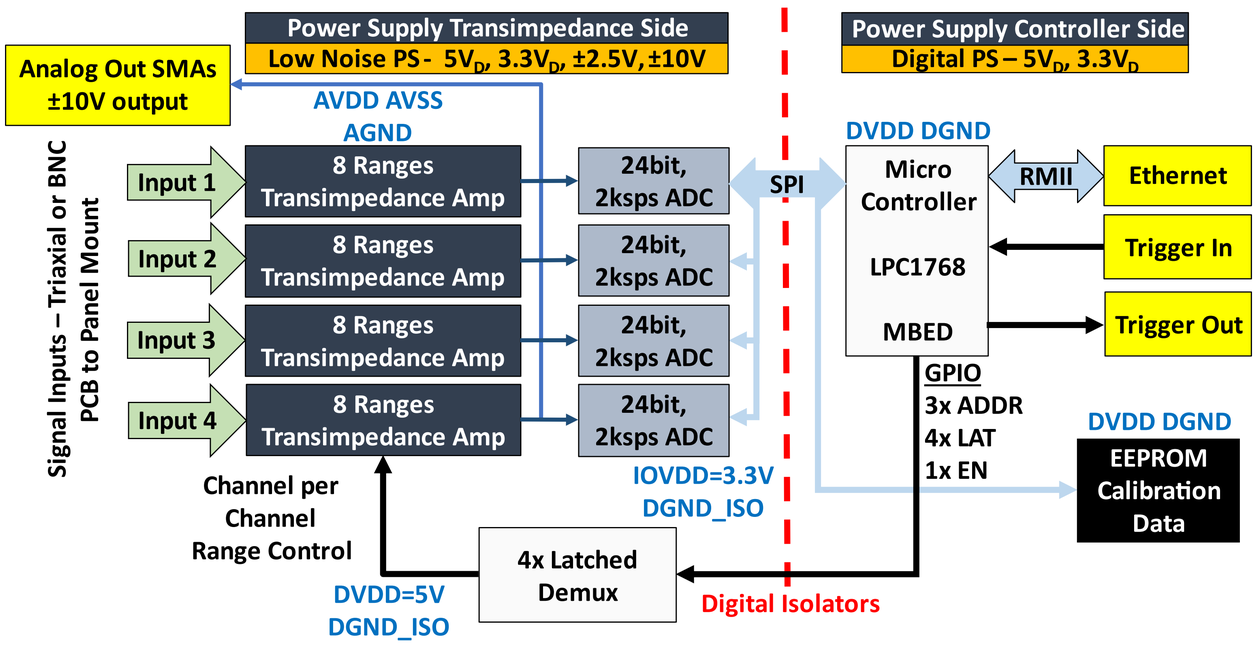


Fig 3. General block diagram

A wide dynamic range is implemented by means of a classical multirange transimpedance amplifier circuit [2], high insulation reed relays were used to select different high-precision gain resistors on the amplifier stage. The circuit is followed by floating 2 ksps, 24-bit Delta-Sigma analog-to-digital converters. The electronics is prepared to bias the connected device up to 400 V using an external HV power supply.

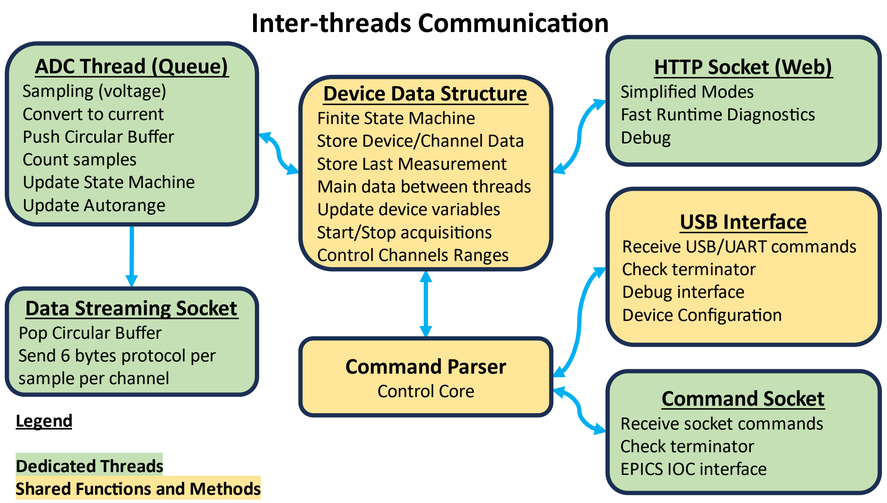


Fig 4. Firmware architecture

Range selection, ADCs configuration and digital data acquisition are managed by an ARM microcontroller. The data stream is sent through a 100 Mbps Ethernet link and can be external triggered. The firmware has been developed using MBED OS [3] and controls software compatible with EPICS [4] framework.

Results

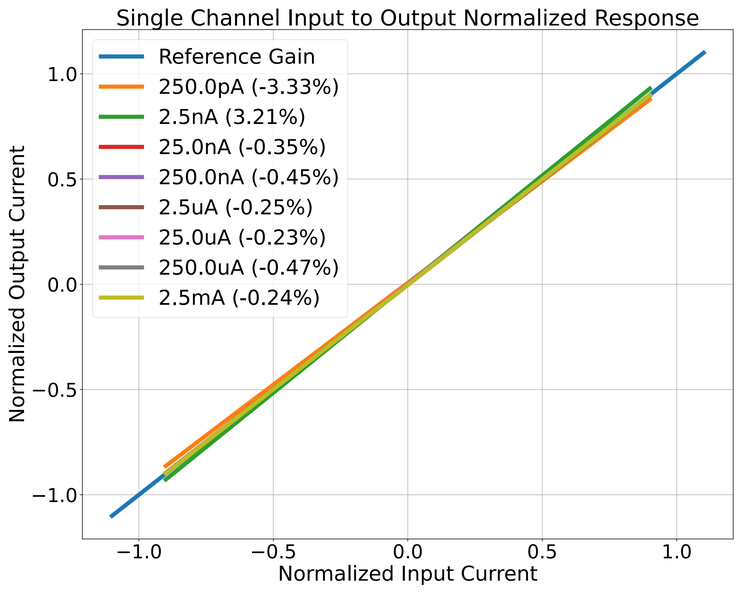
The characterization results show that the achieved gain, temperature stability, accuracy, and noise performance are competitive to similar commercial solutions.

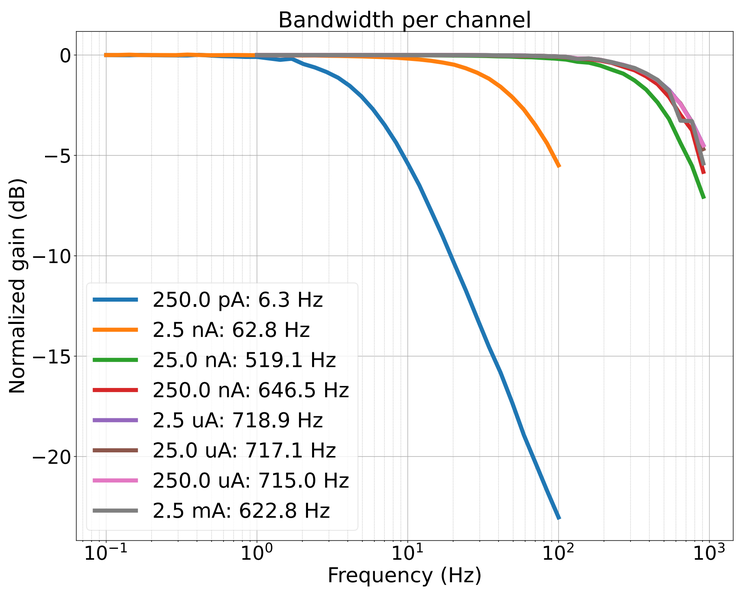
Analog bandwidth for higher currents around 700 Hz has been reached, as much as necessary for general beamlines current measurements.

Measured noise is around feedback resistors Johnson noise values for the first low current ranges (250 pA, 2.5 nA, 25 nA full-scale) and dominated by analog front-end voltage noise for higher current ranges.

Gain deviation without calibration is around 10% for lower currents and 0.1% for higher measurements, so individual calibration has been performed to compensate production deviations between ranges, channels and devices.

Each device is tested individually, and calibration results are stored into EEPROM. Future tests will be performed to evaluated long term calibration variations, specially for lower current measurements, strongly affected by humidity and dust effects at board and integrated circuits pads.





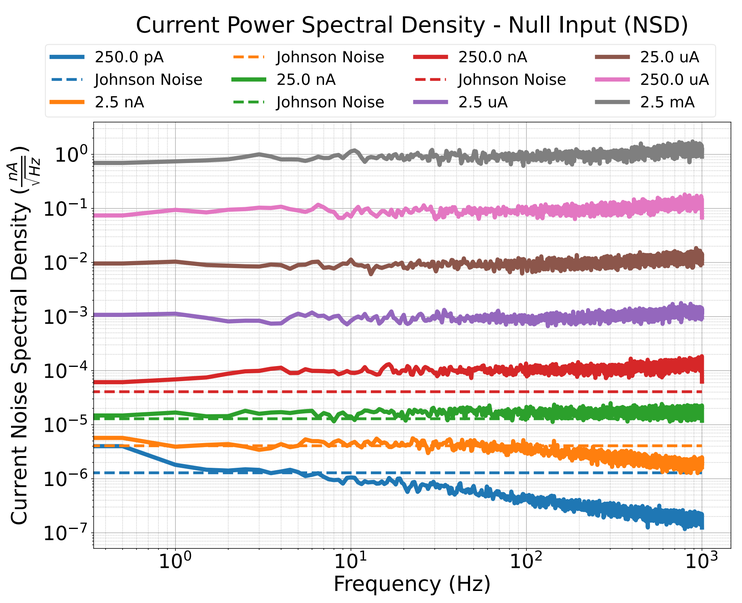


Fig 5. Single channel overall performance (gain, bandwidth, noise)

Conclusion

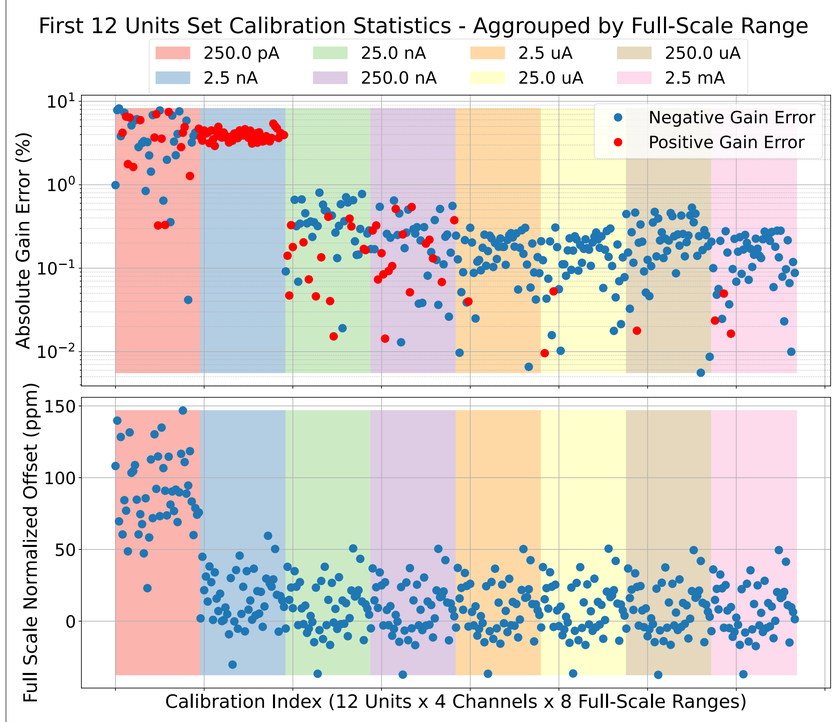


Fig 6. Calibration results

The device was able to measure hundreds of pA with intrinsic noise of units of fA (RMS) for low bandwidth measurements. All obtained results satisfy Sirius beamlines requirements. For many particle physics applications, the designed device could be an excellent low-cost multichannel solution. The first batch is already in use at Sirius and future works can be dedicated to long-term deviations.

Acknowledgments

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References

[1] L. Liu, X. R. Resende, and F. H. de Sá, A New Optics for Sirius, in IPAC'16. doi:10.18429/JACoW-IPAC2016-THPMR013

[2] L. Y. Tanio, F. H. Cardoso, M. M. Donatti, A multirange low noise transimpedance amplifier for Sirius beamlines, in IPAC'21. doi: 10.18429/JACoW-IPAC2021-WEPAB330

[3] MBED platform, *https://os.mbed.com/*

[4] Epics Controls, EPICS Documentation, *https://docs.epics-controls.org/en/latest/*

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