

LOW CURRENT MEASUREMENTS AT ALBA

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Abstract

High accuracy low current readout is an extensively demanded technique in 3rd generation synchrotrons. Whether reading from scintillation excited large-area photodiodes for beam position measurement or out of gold meshes or isolated metallic coated surfaces in drain-current based intensity monitors, low current measurement devices comprise an ubiquitous need both for diagnostics and data acquisition in today's photon labs. In order to tackle the problem of measuring from various sources of different nature and magnitude synchronously, while remaining flexible at the same time, ALBA has started a project to develop a 4 independent channel electrometer. It is based on transimpedance amplifiers and integrates high resolution ADC converters and an Ethernet communication port. Each channel has independently configurable range, offset and low pass filter cut-off frequency settings and the main unit has external I/O to synchronize the data acquisition with the rest of the control system.

INTRODUCTION

With around 110 channels distributed in 7 beamlines, current measurement based diagnostics are the most common in Alba photon labs.

The most extended method for low current readout relies on range-configurable transimpedance amplifiers that convert the currents generated in the different sources into voltages. Those voltages are later read out either by ADCs or converted to pulses by Voltage to Frequency Converters (VTFs) and counted in counter cards. Lately, also some solutions based on charge integrators are appearing in the market, but transimpedance amplifiers are still the most common battle horse when it comes to low current measurement.

The dynamic range of the aforementioned currents spans from 1mA to few pA with bandwidths below a few kHz.

Apart from the characteristics of the current signal, it's important to mention that a usual problem coming up while measuring such low currents is the appearance of noise coupled, most often, from the power network, either through the cables or any other element of the setup. While noise coupling reduction techniques like proper shielding are the most effective solution, preventing the noise appearance, one desirable feature of the subsystem in charge of the measurement, especially for slow varying signals, is the possibility of selecting low band pass filters that attenuate out-of-band noises.

The beamline control system reads these currents with acquisition times typically in the range of 1ms to 1s and quite often the acquisition window must be precisely synchronized with other elements in the lab environment.

The different diagnostic equipment come with channels arranged in different configurations, from typical single channel intensity monitors to dual or quad-channel in 1D or 2D X-ray beam position monitors.

Beyond pure current measurements, beamline scientists often face the need of automate the compensation of low-frequency drifts due to thermal load changes or mechanical instability in optical components as mirrors or monochromators. To do that, an output signal to steer piezoelectric actuators or stepper motors can be generated after processing the signal acquired from photodiodes or drained out of isolated metallic surfaces exposed to the X-rays.

In order to provide us with a general platform to confront all those applications having as common link the measurement of low currents the Electronics section in Alba Computing Division launched the AlbaEm project.

The main target of this project is to produce a modular, transimpedance amplifier based, 4 independent channel electrometer with Ethernet communication with the possibility of accepting I/O expansion boards.

In the next paragraphs we detail the characteristics of the designed solution and the current status of the project.

SYSTEM ARCHITECTURE

The system architecture was chosen to maximize modularity to simplify at the same time future upgrades of the different subsystems, troubleshooting and maintenance.

The platform can be divided in the following main parts: Microprocessor board, current amplifiers (up to 4 units), main, I/O board and front panel board (see Fig. 1).

Current Amplifiers

With a first typical bipolar transimpedance amplifier layout stage and a second voltage gain stage, the amplifier provides gains from $1E+4$ to $1E+10$ V/A for $\pm 10V$ output in 8 full ranges from 1mA to 100pA. In the first stage, specific circuitry provides input offset voltage adjustment down to $1\mu V$.

This first part feeds a second order low pass filter with 3dB cut-off frequency configurable to 100Hz, 10Hz and 1Hz. The filter can also be bypassed.

Finally, an output buffer stage allows polarity inversion and feeds both the upstream internal ADCs and a rear panel connector.

The analog ground is isolated from the equipment chassis to prevent ground loops and all the configuration is SPI based and stored in an onboard FLASH memory.

Microprocessor Board

The Electronics section in Alba Computing division has made extensive use of Rabbit microprocessor MiniCores

[1] in the past. These modules consist of small form factor PCBs with an embedded Rabbit microprocessor, flash and RAM memories and ethernet PHY. The microprocessor has a CISC architecture and supports different peripherals.

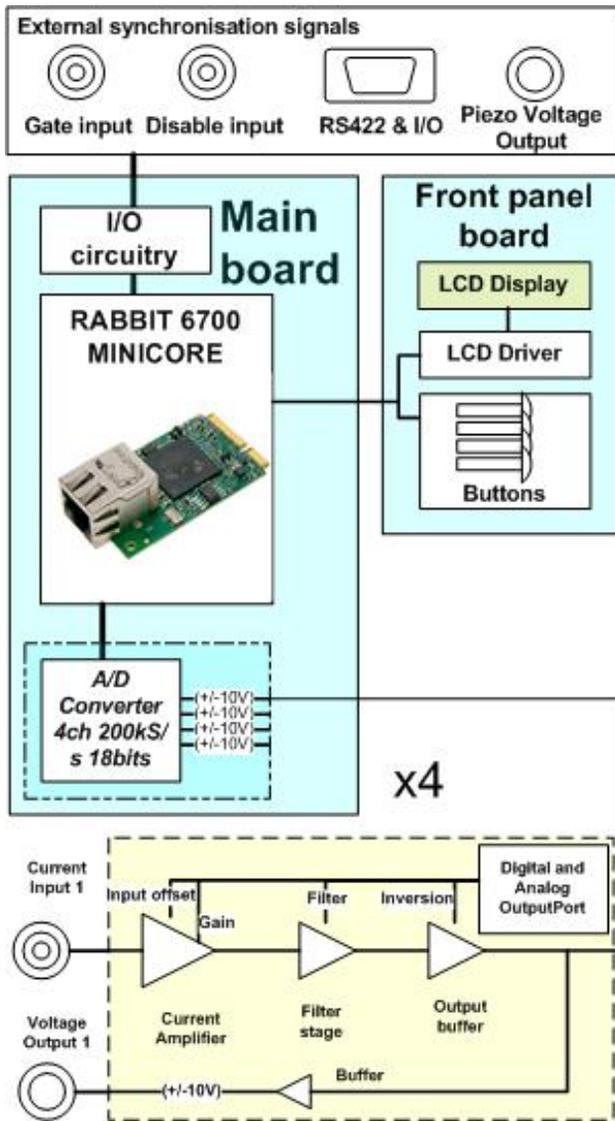


Figure 1: General system architecture.

The accumulated know-how and all the libraries developed for previous projects made the choice of one of these minicores the best option to minimize development time.

In the chosen MiniCore a 200MHz microprocessor is the central module. It has 1MB of RAM that can be used for data storage purposes. The microprocessor cares about the control and configuration of the rest of the subsystems either through SPI or its 8-bit external parallel bus. Communication is achieved via the onboard 10/100Mb Ethernet port.

Main Board

The main board hosts the rest of the boards and the ADCs and all the necessary gluing circuitry. Steered from the microprocessor board, a fast quad-channel 18bit bipolar ADC that can be run at sampling rates up to 200kHz carries out the data acquisition. With 1M Ω impedance inputs, an onchip 2nd order antialiasing filter and a configurable sinc digital output filter that helps to improve SNR and reduce data throughput unnecessary for low bandwidth, it fits perfectly the needs of an application like this.

I/O Circuitry

This subsystem contains the circuitry to adapt digital signal levels between the microprocessor and the exterior both for the synchronisation input signals and the output signals generated in applications where regulation of external actuators from current input signals is necessary.

Front Panel

Despite the electrometer is meant to be fully controlled remotely, a basic user interface will be available at the front panel so that it can be used as bench-top unit if necessary. The panel has an attached board carrying the minimum electronics to steer an LCD display and interface buttons to the microprocessor.

PROJECT STATUS

The first amplifier prototype was designed in November 2010 and first tested in January 2011. Thanks to the good results of the first amplifier prototype, the facility gave thumbs up to the project one month later. It was decided that it would be produced a number of electrometers for the beamline commissioning in October this year. Due to the strong schedule constraints, it was decided to mount in those electrometers a microprocessor and a 12bit ADC already used in another project. This board would be replaced later by the final one in the elements where the extra resolution would be required.

In the next paragraphs are described the performance of the designed amplifier and the acquisition board used for this first version of the device (see Fig. 2).



Figure 2: Low resolution electrometer rear panel.

Amplifier

The amplifier design has successfully reached the final stage. With up to 5 decades of noise free dynamic range, 3.2kHz bandwidth (1.5kHz for the last three ranges), filters providing extra out-of-band noise rejection, input offset voltage reduction down to 1 μ V (optimum for reading pA currents from large PIN diodes without saturating the amplifier output) and low drifts, it provides a very good foundation to add all the planned electrometer functionality (see Table 1).

In Table 1 are displayed the noises measured at the output of the amplifier and the correspondent SNR for each range and three different filter configurations. They were measured at constant input current of 10% of each range and a 20bit ADC. The output RMS voltage noise measured has been converted to current units to simplify the table interpretation.

Control and Signal Acquisition Boards

The work on the first prototype of the fast ADC main board is ongoing. In parallel, and based on a development for a previous inhouse project, the microprocessor and a 12bit ADC have been used to produce a lower resolution electrometer. This version, has been designed keeping it compatible with an upgrade to the future high-end ADC. That upgrade will just need the replacement of the main board with the one containing the new ADC, keeping chassis, amplifiers, microprocessor and firmware (with the evident exception of exchanging the low level library accessing the ADC by the new one).

Table 1: RMS Output Noise in Current Units and SNR for the Different Range and Filter Configurations

Range	No filter		10Hz		1Hz	
	RMS	SNR(dB)	RMS	SNR(dB)	RMS	SNR(dB)
1mA	7nA	103	7nA	103	7nA	103
100 μ A	700pA	103	700pA	103	700pA	103
10 μ A	300pA	90	70pA	103	70pA	103
1 μ A	50pA	86	7pA	103	7pA	103
100nA	4pA	88	800fA	102	700fA	103
10nA	700fA	83	150fA	96	80fA	102
1nA	500fA	66	100fA	80	20fA	94
100pA	500fA	46	100fA	60	20fA	74

Performance

This model has a limited sampling rate of 1kHz and a maximum bandwidth of 500Hz (due to the presence of the antialiasing filter). While the 12bits resolution of this electrometer version's ADC and its internal noise are an evident performance penalty, its use as diagnostics according to commissioning plan will be most often for acquisitions in the 0.1s range where averaging improves the total system noise.

The total ADC subsystem noise was found to be 7mVrms (for a ± 10 V span) that averaged by 10 or 100 samples (acquisition times of 10ms or 0.1s for the fixed 1kHz sample rate) leaves good 4 decades of noise-free current measurement in each range (provided that the ADC is the noise limiting element for that range).

Functionality

In order to ease the integration of the electrometer in the beamline control system, the following features have been implemented:

- Digital filter averaging: A size configurable moving average filter can be enabled to low-pass filter the digitized currents.
- Buffered measurements: The electrometer saves in its memory a sequence of a software predefined number of acquisitions. This acquisition "points" are available to the beamline control system as soon as they are acquired. It is not necessary to wait till sequence acquisition end to get the values.
- Software triggered acquisitions: The electrometer averages current readouts at the maximum sampling rate during a preconfigured time window after a command arrival.
- Hardware triggered acquisitions: A TTL trigger signal accessible from the rear panel starts an acquisition for a preconfigured time window
- Hardware gated acquisitions: The TTL signal defines the beginning and the end of the acquisition time window.
- Events: A list of clients can be provided by software. When the electrometer finishes an acquisition it sends to those clients the acquired values via UDP. This feature reduces the need of polling and the amount of network traffic.
- Remote firmware update. New features can be added remotely via TFTP. This reduces the maintenance and firmware update times and simplifies the addition of new features.

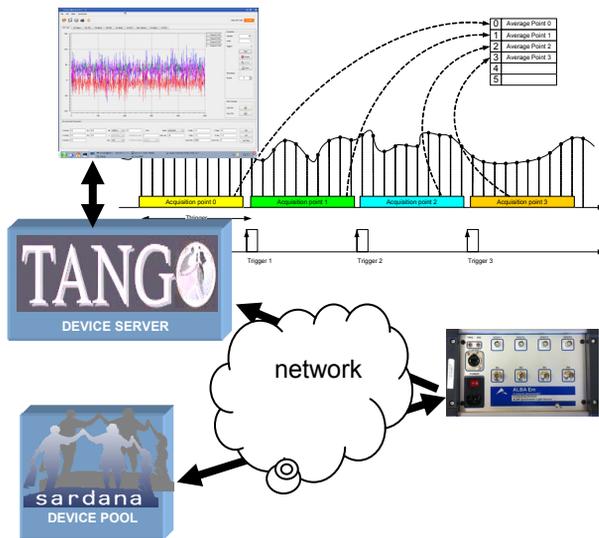


Figure 3: Integration in the beamline control system.

Integration in the Beamline Control System

The electrometer has been successfully integrated in SARDANA[2], the TANGO[3] based control system for instrumentation and data acquisition used at ALBA beamlines. In the current architecture, a python low level library to access the electrometer via UDP and a Sardana Pool Controller permit synchronization of measurements with other data acquisition in the beamline, while a TANGO Device Server acts as interface for GUIs (see Fig. 3).

SCHEDULE

The first amplifier prototype was designed in November 2010 and first tested in January 2011. In February of this year the project was finally approved and the first units with the 12 bit ADC were assembled and tested by May 2011. 25 electrometers were produced during summer for the beamline commissioning in October this year. During all this time the firmware has been steadily improved. The first fast ADC prototype is expected for February 2012. The implementation of functionality for optical equipment position regulation will come later.

CONCLUSIONS

AlbaEm is a living project. With very good results in the analog part of the design and an already mature

functionality, it can fulfill the scientist requirements for the October 2011 commissioning at the Alba beamlines.

The amplifier is considered to be the final one for general purposes, though other versions could be built in case more specific applications arise.

An acquisition system based in a 12bit ADC used in a previous inhouse project has been designed, implemented and tested. The units are prepared to be updated with just one part replacement wherever extra resolution is necessary. A fast 18bit ADC is expected to be ready the first quarter next year.

In less than one year, the team has been able to put together 25 units of a robust system that fulfills the basic needs for current based diagnostics. Currently, these 25 units are already installed in the 7 beamlines and ready for the first photon beams.

Moreover the high potential of the new updates should convert AlbaEm in a platform that will allow us to tackle all the future needs of the scientists at Alba beamlines.

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- [3] Tango. The object oriented distributed control system, <http://www.tango-controls.org>.