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Multi-Channel Very-Low-Noise Current Acquisition System with On-board Voltage Supply for Sensor Biasing and Readout

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Abstract

This work describes a multi-channel electronic board for the acquisition and digitalization of current signals in the range from femto-amperes up to the tens of micro-amperes suitable in a wide range of applications for the readout of photodiodes. The electronic board includes a sensor bias generation circuit capable to drive large capacitive loads with good noise performances. The system also has user-configurable general-purpose pins for the control and actuation of external subsystems and provides both USB and UART interfaces for data transfer. The system features low power consumption in order to enable point-of-care applications.

1. Introduction

Lab-on-chip systems, also referred as micro-total-analysis systems, are increasingly becoming the target technology for many analytical applications as they offer very high performances in a compact, potentially-portable device \cite{1,2}. In order to meet these specifications, sensitive on-chip detection methods are required. Optical detection based on absorbance measurements \cite{3} or luminescence phenomena \cite{4,5} appears as one of the best candidates to accomplish this goal. In this cases, the transducer is typically a photodiode \cite{6,7,8,9}, and the output signal is a photocurrent proportional to the incident radiation intensity that may vary significantly according to the different target analytical applications. In order to achieve the best performances of such systems, proper readout electronics is needed. Its main requirements include: low noise readout in order to reach lower limits-of-detection (LOD), high dynamic range to cover the entire analytical interval and low power consumption to enable portable devices or point-of-care testing. In addition, features like transducer bias supply capability, flexible digital data interfaces as well as configurable general purpose digital inputs or outputs (GPIO) are almost mandatory to achieve a complete system. Typically, application-specific readout boards are developed to fulfil all the requirements but this impacts on the system costs as well as on the time required to achieve a complete demonstrator for an analytical application.

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Starting from these considerations our group developed a general purpose current readout board named SOPhIE which is the acronym for Simple Octal Photo-current Integration Electronics. SOPhIE is a eight-channel photocurrent readout electronic board that combines flexible selection of the current range, good noise performances, on-board sensor-bias voltage supply and configurable interfaces aiming at a high-performances general-purpose system suitable for different analytical applications.

2. System overview

The general architecture of the SOPhIE board is schematically depicted in Fig.1, while a picture of the SOPhIE board is reported in Fig.2a. A zero-insertion-force (ZIF) flex connector is used for interfacing the board with the sensors through a flex cable that e.g. can be directly bonded or glued on the sensor substrate. As an alternative ad-hoc interface boards can be used as shown in Fig.2b. Both sensor photocurrent and sensor bias voltage are routed through the ZIF connector.

The sensor front-end is the DDC118 Current-Input Analog-to-Digital Converter from Texas Instruments. This chip has eight identical input channels directly connected to the ZIF connector. Each channel has a dual-switched integrator for continuous signal integration with zero dead-time over a wide range of currents (from femto-amperes to the tens of micro-amperes). Signal range can be set both by acting on a network of feedback capacitors (to select up to eight different values for the integration capacitance) and by varying charge integration time. Thus, for a given...
signal range, circuit operation can be optimized for noise of speed performances. In order to achieve adequate noise performances, the board includes a low-noise sensor bias voltage generation circuit composed of a digital-to-analog converter followed by an operational amplifier suited for driving large capacitive loads that ensures correct operation also when working with large-area thin-film photosensors.

The driving signals for the front-end circuits are generated by a PIC18F4550 microcontroller from Microchip that also provides additional general purpose inputs and outputs that can be used to drive external devices as leds, pumps, motors or for synchronization with other systems. The microcontroller also provides the communication interfaces, both USB and UART, to a host device. The microcontroller firmware has been developed to achieve the best behaviour of the different devices, in terms of noise, speed and power consumption. In particular, critical routines have been developed in assembler in order to ensure correct timing of the controlled circuits for preventing disturbances on the analog signal path. Board power can be supplied either directly via the USB port or by an external unregulated AC/DC converter via an on-board voltage regulator. The USB power is filtered by a electro-magnetic-interferences (EMI) filter to generate the digital supply voltage. The analog supply voltage, used for the analog front-end circuits and voltage references, is derived from the digital supply after additional filtering and decoupling with ferrite beads. Additionally, in order to ensure the best noise performances particular care has been used in the printed circuit board layout phase, optimizing both component placement and line routing. A multi-platform Java graphical user interface has been developed to control all the acquisition parameters and to perform system calibration as well as data post-processing (storage and basic data analysis).

3. System characterization

System characterization has been performed in two stages. Initially, a Keithley 236 Source Measure Unit configured as current source, has been used to supply the input signal with a nominal resolution of 100 fA. Results reported here refer to the configuration with 50 fF integration capacitance and 800 ms integration time. In these conditions, the output standard deviation measured with a constant input current of 10 pA was 15 fA, as shown by the data reported in Fig.3a. This value corresponds to the practical noise limit of the used current source in our measurement setup. A similar results is achieved in the experiment reported in Fig.3b, where the input current ranges from 105.0 pA up to 105.9 pA with 100 fA steps proving the ability of the circuit to ensure low noise current sensing capabilities over a wide signal dynamic range.

The second stage of the system characterization has been performed by connecting at the input an array of sixteen hydrogenated amorphous silicon (a-Si:H) photodiodes. The photodiodes have been deposited on a glass substrate which has been inserted in the card edge connector of the interface board described in the previous section and shown in Fig.2b. A set of jumpers connects eight photodiodes of the array to the eight input channels of SOPHiE. The entire setup is enclosed in a light-shielded metal box that ensures dark conditions as well as effective EMI shielding. In order to generate an optical signal, a light emitting diode (LED) has been mounted inside the box and connected to one of the available GPIO signals for remote control though the Java system interface. In order to generate small signals, an infrared LED emitting at 700 nm has been chosen because typical a-Si:H photodiodes have low sensitivity.

![Graphs](image_url)

Figure 3. a) 10 pA signal acquired using 50 fF integration capacitance and 800 ms integration time. The measured standard deviation is 15 fA. b) Acquisition with input signal ranging from 105.0 pA to 105.9 pA with 100 fA steps. The measured standard deviation within each step is 15 fA.
Figure 4. a) Measured photodiode signal in dark and under IR LED irradiation. (raw data: initial 100 s, 5-sample moving average: after 100 s). b) and c) Histogram of the dark current calculated over raw data and averaged data, respectively.

at these wavelengths. For the experiment reported in Fig. 4a, the photodiodes have been biased at 25 mV reverse voltage and the readout has been done using the 50 pF integration capacitance and 200 ms integration time. The signal induced by the LED radiation is as low as 70 fA. The estimated total capacitive load at the output of the on-board bias circuit represented by the whole photodiode array was of larger than 10 nF. The capacitive load at each input channel of SOPhIE was around 50 pF. In these conditions, the measured standard deviation of the dark current is less then 40 fA. By using a n-sample adjacent averaging post processing filter the noise is reduced by a factor equal to the square root of n. As an example, using with 5-sample adjacent averaging a noise level decreases to 15 fA as shown by the histograms reported in Fig. 4b and c.

4. Conclusions

SOPhIE is a low-noise current acquisition system developed for the biasing and readout of photodiodes in analytical applications based on optical detection. Flexible selection of the readout speed and current range as well as the presence of configurable GPIO channels and USB and UART interfaces make SOPhIE a ‘general purpose’ system suitable for many applications.

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References