Chapter 50
Sophie: A General Purpose Sub-Picoamps Current Readout Electronics

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SOPhIE is a eight-channel photocurrent readout electronic board that combines flexible selection of the current range (from femtoamps to hundreds of nanoamps), good noise performances and on-board sensor-bias voltage supply. Adjustable integration times allow digitizing up to 20 ksample/s with a resolution of 20 bit/sample. USB and UART data interfaces as well as eight additional general-purpose inputs and outputs pins are externally available. The noise level of the measured current, achieved when the board is connected to an array of hydrogenated amorphous silicon photodiodes, is less than 40 fA working at 5 sample/s and with a full-scale range of 1 nA. These features make SOPhIE suitable for low-level current sensing in lab-on-chip applications.

50.1 Introduction

Many sensing applications rely on the measurement of low-level currents, in the range of femtoamperes up to microamperes, produced by a transducer [1]. In the case of analytical devices, the transducer is often a thin film photodiode [2] that detects the radiation emitted by a chemiluminescent process [3, 4] or by the stimulated emission of a naturally fluorescent substance [5, 6] or a fluorescently labeled analyte [7]. Photodiodes are also used to detect the variation of an incident radiation source in absorption measurements [8]. In all the cases there is the need to reveal small current variations with a good signal to noise ratio. According to

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these considerations, we developed SOPhIE (Simple Octal Photo-current Integration Electronics): a eight-channel photocurrent readout electronic board that combines flexible selection of the current range, good noise performances and on-board sensor-bias voltage supply.

50.2 System Description and Characterization

The circuit is built around the DDC118 *Current-Input Analog-to-Digital Converter from Texas Instruments* [9] used as low-noise sensor front-end. The chip has eight identical input channels each including a dual-switched integrator. It performs continuous signal integration (zero dead-time) over a wide range of currents (from femtoamps to hundreds of nanoamps) with adjustable integration times that allow digitizing up to 20 ksample/s with a resolution of 20 bit/sample. The timing and control signals are generated by a PIC18F4550 microcontroller from Microchip that also provides the communication interfaces, both USB and UART, to the host device. The microcontroller controls also a low noise Digital-to-Analog converter followed by an operational amplifier suited for driving large capacitive loads for the generation of the photodiode reverse bias voltage. Eight additional general purpose inputs and outputs (GPIO) pins are externally available for driving external hardware as pumps, radiation sources or reading digital alarms or analog sensors as humidity or temperature sensors. The microcontroller firmware has been developed to achieve the best behavior of the different devices, in terms of noise, speed and power consumption. On-board voltage regulator and electro-magnetic-interference (EMI) filter allow to supply the board either from the USB port or with an external unregulated AC/DC converter. A careful layout has been carried out in order to ensure optimal noise performances as well as a compact printed circuit board as shown in Fig 50.1.

Circuit characterization has been first performed using a Keithley 236 SMU as current source. Using 50 pf integration capacitance and 800 ms integration time (full-scale range equal to 250 pA) the output standard deviation measured with a constant input current of 10 pA was 15 fA, which is compatible with the noise level of the current source used for the tests. In Fig. 50.1 (right) the results achieved using the same parameters with an input current ranging from 105.0 pA up to 105.9 pA with 100 fA steps are shown.

50.3 Practical Application Example

In order to test the board in practical operating conditions, the readout circuit has been connected to an array of 30 thin film hydrogenated amorphous silicon photodiodes deposited on a glass substrate [10, 11]. The glass chip has been inserted in a card edge connector placed on an ad-hoc developed adapter board that has been

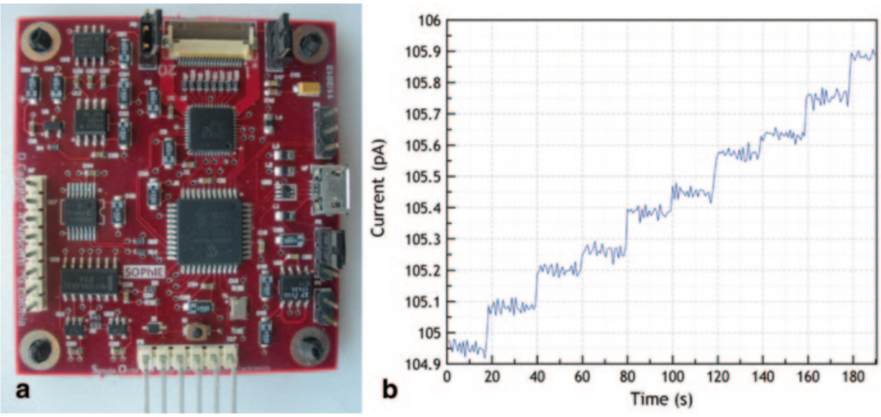

Fig. 50.1 *Left*: SOPhIE. Main specs include: continuous acquisition (no dead-time), range from femtoamps to microamps, integration time from 400 µs to 1 s, low noise bias supply (unlimited capacitive load), USB and UART interface, eight fully configurable GPIO pins, USB or external unregulated power supply, low power consumption, compact board size (70 × 70 mm^2). *Right*: electrical characterization results, the input current is sourced by a Keithley 236 Source Measure Unit. SOPhIE signal integration time is 800 ms and integration capacitance is 50 pF corresponding to a full-scale range equal to 250 pA

connected with a flex cable to the input connector of the SOPhIE board. A set of jumpers allows to connect eight photodiodes of the array to the eight input channels of SOPhIE. The photodiodes have been biased at low reverse voltage (25 mV) and the readout has been done using the 50 pF integration capacitance and 200 ms integration time with a resulting full-scale range of 1 nA. Due to the relatively large size of the thin-film photodiodes (2 × 2 mm^2), the estimated total capacitive load at the output of the on-board bias circuit, represented by the whole array, was larger than 10 nF [12]. The capacitive load at each input channel of SOPhIE was around 500 pF. In these conditions, the standard deviation of the measured dark current was less than 40 fA. By using a n-sample adjacent averaging post processing filter the noise can be reduced by a factor equal to the square root of n. As an example, using with 5-sample adjacent averaging, the measurement noise level decreases to about 15 fA. Figure 50.2 reports the results achieved using a 650 nm infrared light emitting diode to generate a photocurrent as low as about 75 fA. In the figure the raw data as well as the 5-sample adjacent averaging filtered values are reported, showing the ability of the circuit to detect low-level signals over a wide range.

50.4 Conclusions

We have presented a compact readout board, SOPhIE, that is suitable for current readout in lab-on-chip applications. Thanks to its flexibility in terms of readout speed and current range selection as well as to the additional features as low-noise

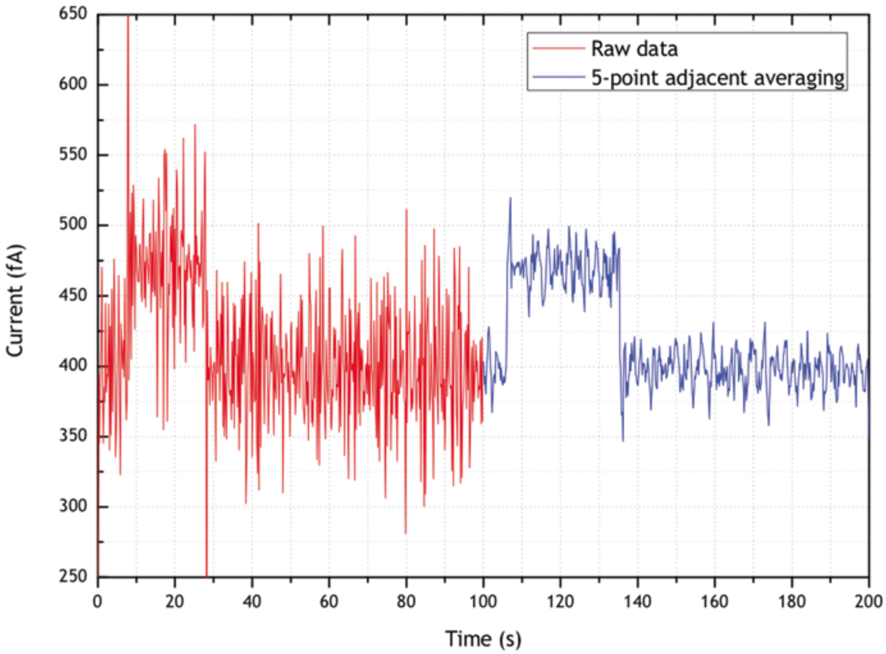

Fig. 50.2 Photodiode current acquired with SOPhIE with 50pF integration capacitance and 200 ms integration time (full-scale range equal to 1nA). The photocurrent signal is induced by a 650 nm LED. Up to 100 s the raw data, while after 100 s the 5-sample moving average are reported

bias voltage supply, USB and UART communication interfaces, additional GPIO channels and low power consumption, the board can be used for low-level current sensing applications not limited to photodiode readout.

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