Electronic Supplementary Information

Fuel cell-powered microfluidic platform for lab-on-a-chip applications: Integration into an autonomous amperometric sensing device

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Electronics definition

(i) General description

The electronics module in the self-powered microfluidic platform features two main blocks: powering and instrumentation. The powering part delivers the necessary voltage to drive the instrumentation, whereas the instrumentation block controls a three-electrodes electrochemical cell working in amperometric configuration.[1]

All selected components have been chosen to reduce the power consumption of the system. The total consumption of the circuit is around 900 μW with all the integrated circuits working at the nominal voltage of 3 V. Figure 1 presents the circuit architecture, in which the powering block is depicted at the top and the instrumentation block with the electrodes configuration at the bottom.

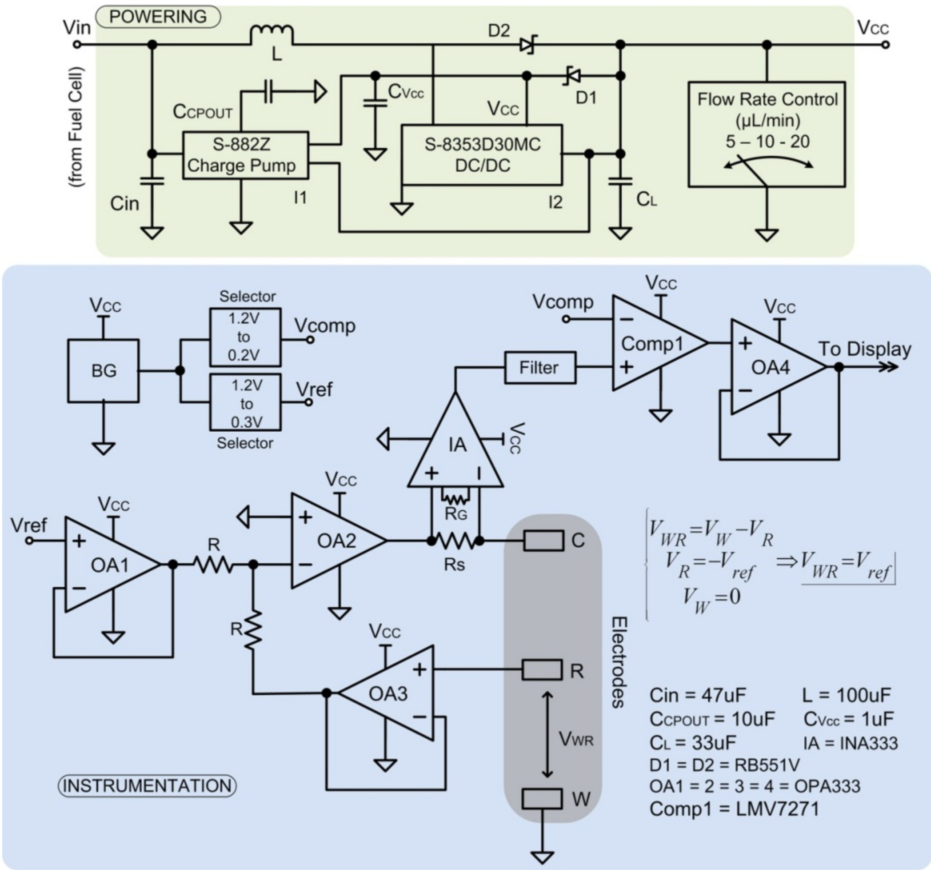

Fig. S1 General architecture of the implemented electronics.

Electronic Supplementary Material (ESI) for Lab on a Chip

(ii) Powering Block

The powering block generates a nominal power of 1.5 mW @ 3 V with a minimum input voltage (Vin) of 186 mV and 10 mA from the Fuel Cell in the steady state operation. This module is based on the combination of an S-8827 charge pump (I1) and the S-8353D30MC step-up DC-DC converter (I2) from Seiko Instruments.

The combination of the charge pump (I1) and the DC-DC converter (I2) allows the system to step up very low voltages of 0.3 volts (initial transient) using a minimum amount of energy. This is an essential point since the microfluidic platform is conceived as a self-powered system and the optimization of the energy is mandatory in order to expand the operation voltage range and lifetime of the system.

A minimum input voltage (V_{in}) of 300 mV coming from the fuel cell is necessary to start-up the power module, known as initial transient. Then, the steady state operation is achieved when the output voltage (V_{cc}) reaches the nominal voltage of 3 V. At this point, the input voltage (V_{in}) can be reduced until 180 mV without experimenting significant reduction of the nominal voltage. Below this point, it is not possible to pump the input energy and generate the nominal voltage to drive the instrumentation circuit.

Moreover, this circuit introduces extra functionality to the platform because it allows the possibility to control the rate of the injected fluid to be analyzed. The powering module includes a flow rate control circuit that controls the amount of current generated by the fuel cell and, subsequently, the sample flow rate.[2] Flow rates in the range of 5 to 20 µl/min can be selected through this module, which represents a fuel cell current between 5 to 20 mA.

(iii) Instrumentation Block

The instrumentation block is based on a potentiostat circuit formed by 3 amplifiers (OA1, 2 and 3) to control the voltage applied to the three electrodes sensor, Working (W), Reference (R) and Counter (C), and to measure the current generated in the Working electrode through an Instrumentation Amplifier (IA).[3] This circuit allows the application of different DC electrochemical methods such as amperometry and voltammetry.

Three main tasks define the potentiostat circuit. The first one consists on measuring the voltage difference between W and R electrodes (V_{WR}), avoiding the Reference electrode polarization. Secondly, it compares the measured potential (V_{WR}) to a reference voltage (V_{ref}) while the current flowing from the Counter to the Working electrodes (I_C) is modified in order to counteract the variations between the Reference voltage (V_{ref}) and the measured V_{WR}. Finally, the potentiostat measures the current flowing through the Counter electrode, which corresponds to the current generated at the Working electrode due to the electrochemical reaction of interest.

The sensor works in amperometric configuration. This consists on applying a constant DC voltage between the Reference and Working Electrodes while the current generated by the electrochemical reaction at the Working electrode is sensed. The measurement is done by the Instrumentation Amplifier (IA) and a series resistance connected with the Counter electrode that converts the current into a proportional voltage. Then, the voltage is filtered to avoid glitches and false detections. Finally, the filtered signal is compared with a reference signal (V_{comp}) using a Comparator (Comp1) to detect a specific amount of concentration of the measured specie. When the detection is positive, a signal is generated to activate the electrochromic display acting as an on/off alarm.

The electronics consists of three micropower Operational Amplifier (OPA333), one micropower Instrumentation Amplifier (INA333), one Voltage Reference (REF2912) and one Comparator (LMV7271), all from Texas Instruments. The instrumentation block was validated, as a first approach, with several variations of the Randles model.[3] Then, the circuit was tested and validated with a commercial screen printed electrode (DRP-550) by DropSens that was integrated into the microfluidic platform. The total power consumption of the electronics is around 900 µW, which ensures the proper operation of the platform even if the generated power from the power module is reduced from the nominal one.

References

1. L. R. F. Alley J. Bran, *Electrochemical Methods: Fundamentals and Applications*, John Wiley & Sons, 2001.
2. J. P. Esquivel, M. Castellarnau, T. Senn, B. Lochel, J. Samitier and N. Sabate, *Lab on a Chip*, 2012, **12**, 74-79.
3. J. Colomer-Farrarons and P. L. Miribel-Català, *A CMOS Self-Powered Front-End Architecture for Subcutaneous Event-Detector Devices: Three-Electrodes Amperometric Biosensor Approach*, Springer Science+Business Media B.V., 2011.