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Architecture of Compact Electrochemical Measurement Instrument

Vojtech Dvorak, Marek Bohrn, Lukas Fujcik, Jiri Haze, Vilem Kledrowetz, Michal Pavlik

Department of Microelectronics, Brno University of Technology,
Technicka 10, 616 00, Brno, Czech Republic
(email: dvorak@phd.feec.vutbr.cz, bohrn@feec.vutbr.cz, fujcik@feec.vutbr.cz,
haze@feec.vutbr.cz, kledrowetz@feec.vutbr.cz, pavlik@feec.vutbr.cz,)

Abstract: The paper presents system overview and description of an architecture of a low-power, low-noise electrochemical measurement instrument. The design drivers for the instrument were to make a small and portable instrument for an on-field measurement utilizing common voltammetry techniques together with a high precision laboratory instrument with a high variability of generated potential functions for experimental electrochemical techniques to measure biochemical processes.

Keywords: ASIC, electrochemical measurement, FPGA, polarography, potentiostat, voltammetry

1. INTRODUCTION

The voltammetry is a group of electrochemical techniques widely used to analyze a chemical compound – an analyte. An electrical potential changed in a time is applied on the analyte via electrodes and the corresponding current through the analyte is measured. The purpose of the voltammetry is to determine a concentration of components in the analyte and to characterize a chemical reactivity of the analyte (Wang(2006)).

Different measurement techniques are utilized in the voltammetry. Each technique is suitable to analyze different properties of the analyte. The Linear Sweep Voltammetry is basic technique of the voltammetry. In this technique, the applied potential is linearly changed in time (either rising or falling potential ramp, see Fig. 1a) and current is continuously measured and saved for further analysis. The graphic interpretation of a result of the Linear Sweep Voltammetry is voltammogram where current is shown as a function of a potential.

A composition of the measured analyte is obtained from peaks in the voltammogram. More accurate result can be achieved when rising and falling voltage ramps are periodically applied on analyte. This technique is called the Cyclic Voltammetry (Bard and Faulkner (2001) and Wang (2006)).

Various forms of the pulse voltammetry were developed to increase speed of a measurement compared with the linear sweep voltammetry. In general, all pulse voltammetry techniques have some common properties. Pulses are generated with a defined potential step and a defined setup time. The resulting current through the analyte can be measured continuously (chronoamperometry). A different approach is to measure the current through the analyte at a defined time before the end of the current potential pulse (sampled-current voltammetry) and the dependency of the measured current on the applied potential is observed. Some of the most important pulse voltammetry techniques are according (Bard and Faulkner (2001)) are Staircase Voltammetry (Fig. 1b), Normal Pulse Voltammetry (Fig. 1c), Squarewave Voltammetry (Fig. 1d) and Differential Pulse Voltammetry (Fig. 1e).

The AC Voltammetry is a technique to analyze electrical properties of an analyte. In this technique, an AC potential modulated on a changing potential is applied on analyte and current is measured and evaluated. The typical characteristic of the applied potential in the AC Voltammetry technique is depicted in Fig. 1f. The amplitude of the modulated AC potential has to be small enough to avoid any electrochemical changes in the analyte (i.e. reduction or oxidation), typically in the order of magnitude of millivolts (Bard and Faulkner (2001)). The underlying changing potential can be a potential ramp or stairs of DC potentials.

The Electrochemical Impedance Spectroscopy is a technique similar to the AC Voltammetry in the way that small AC potential is applied on an analyte. Underlying potential is hold constant and the frequency of AC signal is changed in time, typically in the range from 10^{-4} to 10^{6} Hz (Bard and Faulkner (2001)).

The Polarography can be understood as a subclass of the Voltammetry. All techniques described in this section can be utilized in polarographic measurements. Mercury drop electrodes are utilized in polarography instead of solid state electrodes used for voltammetry techniques. There are two types of mercury electrodes - Dropping Mercury Electrodes (DME) and Static Mercury Drop Electrodes (SMDE) (Bartek et al. (2010)).

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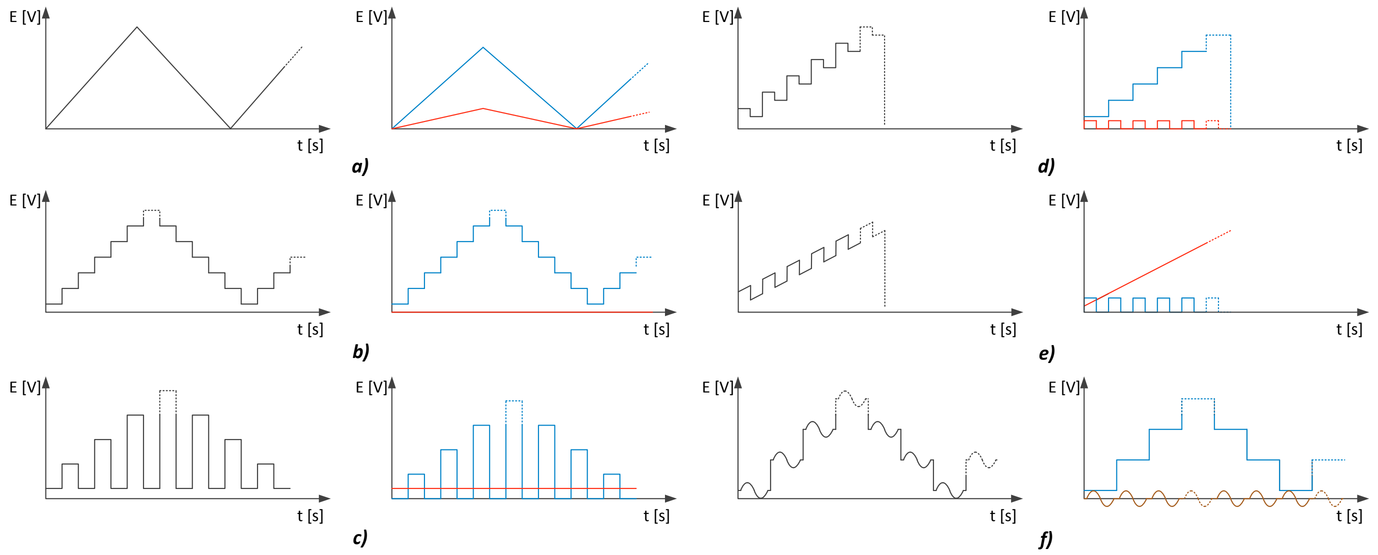

Fig. 1 : Basic voltammetry techniques utilized in the measurement instrument; left waveforms – time diagram of applied potential; right waveforms – waveforms generated by Pulse Generators and Harmonic Generator; a) Linear Sweep Voltammetry b) Staircase Voltammetry c) Normal Pulse Voltammetry d) Squarewave Voltammetry e) Differential Pulse Voltammetry f) AC Voltammetry

2. ARCHITECTURE OVERVIEW

The architecture of the measurement instrument proposed in this paper was developed to fulfil requirements on high accuracy of a measurement, high variability of generated potential functions and portable design of the instrument.

A measurement setup is composed of three parts: the measurement instrument, a commanding PC with a dedicated software and special electrodes for measurement of specific properties of an analyte. Details about the most common electrodes for each technique described in section 1 can be found in Bard and Faulkner (2001) or Wang (2006).

A simplified block diagram of the measurement instrument is in Fig. 2. The instrument consists of two main parts with a different level of a generated noise. A high-noise area of the instrument contains support circuitry provides a high speed communication with the commanding PC via USB bus, powering of the device and batteries charging. This part of the instrument is powered from the external power supply or directly from the USB bus. When a measurement is not in progress, the batteries are charged from the external power supply or from the USB bus.

The measurement core of the instrument is implemented in a low-noise area. This low-noise area is galvanically insulated from the high-noise area to prevent noise propagation. Several techniques were utilized to suppress a generation of a noise in the low-noise area during a measurement. The most important technique is powering of the measurement core from batteries during the whole measurement. This concept provides several advantages. The most important advantage is that the power source of the low-noise area does not produce any intrinsic noise.

An additional advantage resulting from the concept of the battery powering of the measurement core is lower requirements on the power supply of the high-noise area. There are dedicated batteries and voltage regulators for both the digital and the analog part of the measurement core to suppress noise injection from the digital circuitry to the analog parts through the power supply line.

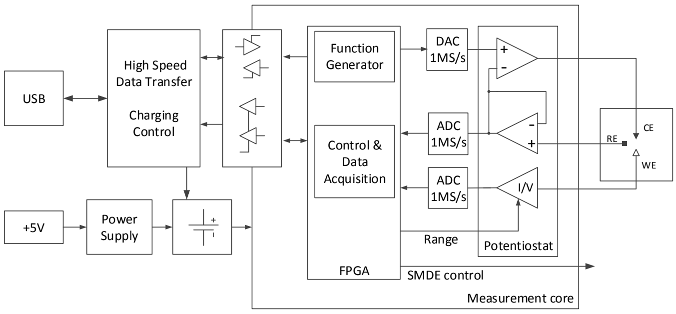

Fig. 2: Block diagram of the measurement instrument

The measurement core is composed of an analog signal processing chain, a control & data acquisition part and a function generator. The control & data acquisition part and the function generator are implemented in a low-power FPGA to provide an additional suppression of noise generated by the digital circuitry.

The analog signal processing chain of the measurement core consists of the high precision 20-bits DAC AD5791 to convert output of the Functional Generator implemented in the FPGA, two 18-bits ADCs LTC-2328-18 and a low-noise potentiostat implemented in a custom ASIC.