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A New Integrated Multi-Pathogen In Situ Detection Platform Using Electrochemical Impedance Spectroscopy †

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Abstract: Scientists are always searching for inventions and developing new methods for the detection of pathogenic bacteria in drinking water. Some of those techniques are based on electrochemical reactions, performed by a device called potentiostat. For in situ analysis, there is a high demand for hardware efficient instruments with a customized set of requirements including Electrochemical Impedance Spectroscopy (EIS) measurements. Therefore, we developed the 'EcoStat' device. As outcome of further developments, we demonstrate the successful implementation of an EIS feature and a multiplexing unit to achieve a detection platform for multiple pathogens. We present results performed on a simplified Randles Cell model.

Keywords: potentiostat; *Escherichia coli*; *Legionella pneumophilia*; Cyclic Voltammetry; Electrochemical Impedance Spectroscopy; Randles Cell

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1. Introduction

Many research groups focus on developing electrochemical methods to detect water pathogens such as *Escherichia coli*, *Legionella pneumophilia*, etc. [1]. These methods involve potentiostat technology resulting in a demand for integrated, specialized and hardware efficient in situ devices. Therefore, we developed and built the 'EcoStat' potentiostat with the PC interface 'Potcon' [2]. In our previous work we showed the Cyclic Voltammetry (CV) capability of this instrument for environmental analysis [3]. Here, we present an extended version of the potentiostat to additionally perform EIS measurements, which widens the application field and the range of detectable pathogens. Together with an analog multiplexer a multi-pathogen in situ detection platform was designed.

2. Principle of Operation

In Figure 1, a block diagram of the EcoStat device is shown. In CV mode, the digital waveform synthesizer produces a triangular shaped signal with ramps in a defined scan rate. The voltage between the Reference Electrode (RE) and Working Electrode (WE) is set to this ramp voltage by adjusting the Counter Electrodes (CE) voltage. This is performed by a digital PID controller [2]. In the newly implemented EIS mode, a two electrode setup is used. The complex impedance of the sample is measured as a function of frequency. Therefore, the waveform synthesizer works as NCO (Numeric Control Oscillator) which produces a sinusoidal signal. Its frequency can be stepped from 10 Hz to 1 kHz, which is applied at one of the EIS cells electrodes. One frequency step sustains about one second. The amplitude and phase shift of the electrode current relative to the applied voltage is measured and the complex impedance can be calculated.

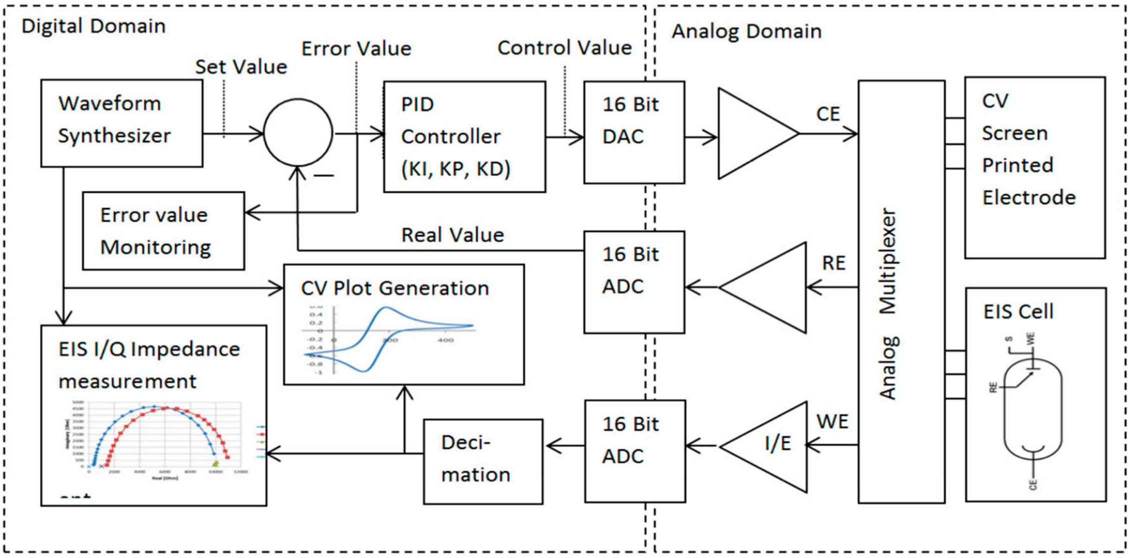

Figure 1. Block diagram of the multiple pathogen detection platform comprising the EcoStat device.

The EIS Feature is shown in detail in Figure 2. The current through the second electrode is converted into a voltage by a current to voltage (I/E) converter. This voltage is sampled by an Analog Digital Converter (ADC). Sample values are multiplied with the NCO signal with coherent phase (Inphase) and 90° delayed (Quadrature), and summed up into the corresponding 'integrate and dump' (I&D) registers. Then, the register values are sent to the personal computer. Further, the data are processed by the PotCon. Phase and absolute amplitude are calculated via the 2-argument arctangent function (ATAN2) and the Pythagorean Theorem. Its reciprocal values are representing the complex impedances. Then, the complex impedances over frequency are visualized in a Nyquist plot (Figure 3). By performing multiple measurements over a longer period, the impedance change over time can be analyzed. The impedance change over time in growth media can be used as an indicator for pathogen contamination and detection of specific microorganisms[1].

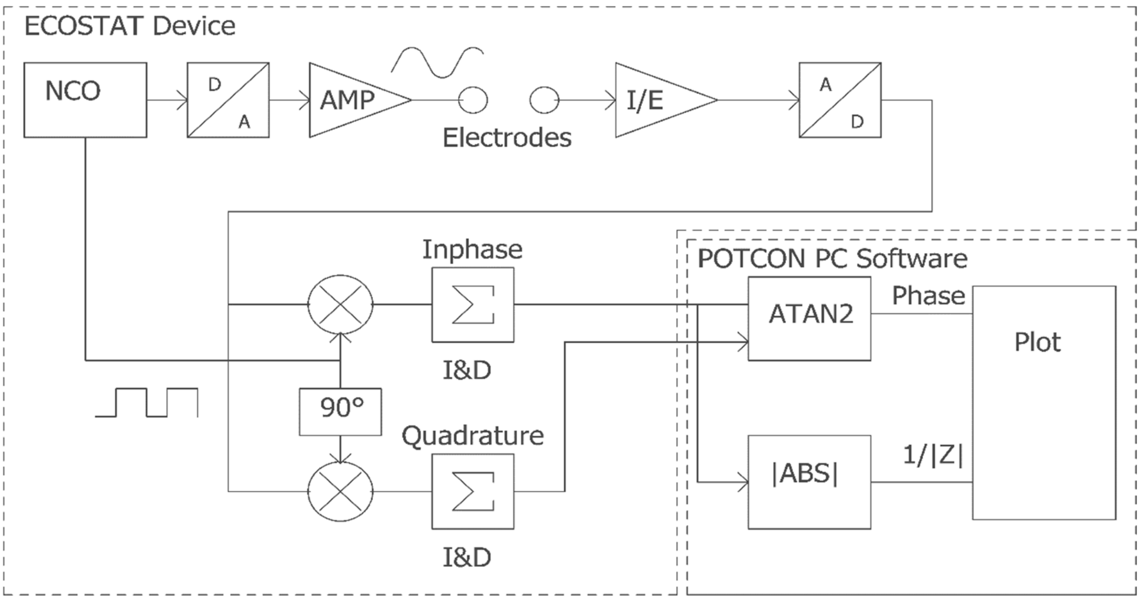

Figure 2. Detailed block diagram of the implemented EIS feature.

In Figure 3, a schematic of the multiplexing unit it shown. It is connected with the EcoStat device and can be easily extended by utilizing shift registers. Therefore, it enables the nearly parallel measurement of multiple cells.

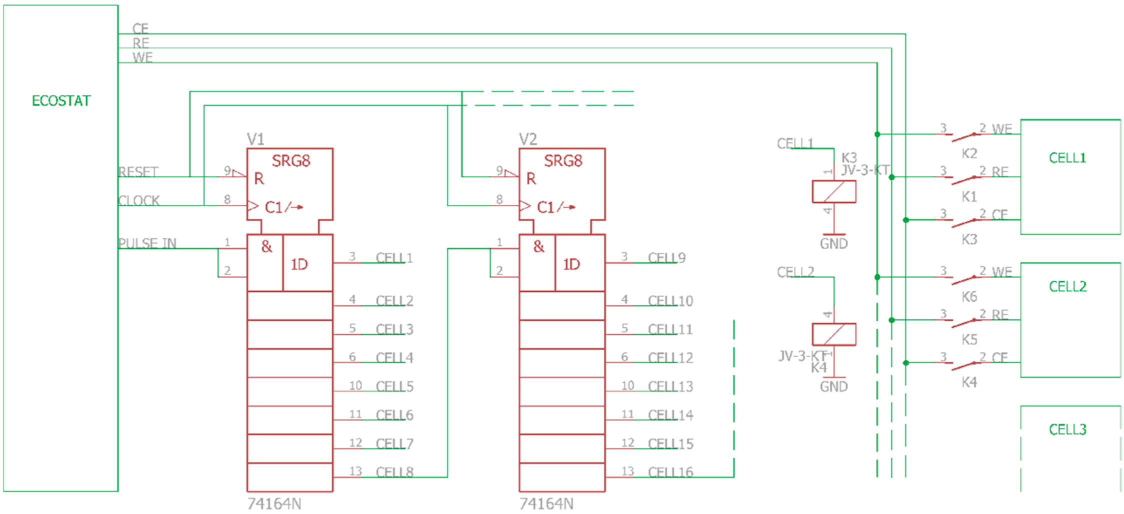

Figure 3. Schematic of the multiplexing unit as an extension of the EcoStat device.

3. Results

The EIS Feature was tested using a simplified Randles Cell Modell [4], which resembled a frequency dependent impedance. The complex impedance over frequency was visualized in a Nyquist plot. The theoretic outputs were known and plotted against the measurement results in Figure 4.

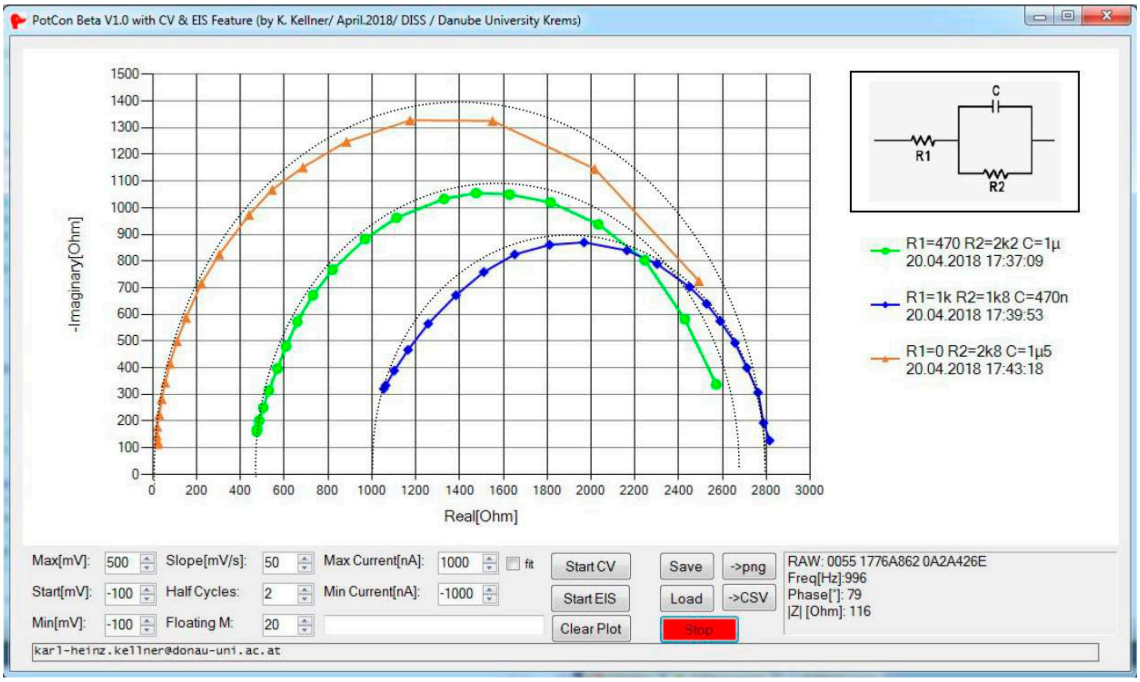

Figure 4. A demonstration of EIS, performed with the enhanced EcoStat device and presented with the PotCon GUI. The complex impedance Nyquist Plots of simplified Randles Cell under varying parameters are shown. Theoretical results are marked with dotted lines.

4. Conclusions and Outlook

A new, integrated multi-pathogen, in situ detection platform using Electrochemical Impedance Spectroscopy was successfully designed and constructed. CV and EIS measurements can now be performed with the same device (EcoStat). The EIS measurement function with frequencies ranging from 1 to 10 kHz could be successfully verified by using a simplified Randles Cell model. Additionally, automatic measurements on multiple cells can be achieved by implementing a multiplexer.

For the future, several improvements of the instrument are planned: A further increase of the frequency range should be achieved by minor hard- and software optimizations. A timing unit with a battery backup for long time measurements is already under construction. And finally, we are thinking about the development of a controlled heater for the incubation process of the microorganisms.

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Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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