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An Economical and Convenient Experiment Setup for Electrode Investigation

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Abstract— **Electrodes are among the critical components of neural stimulation devices. Investigating electrode properties like electrode impedance, charge injection capacity, and electrode corrosion limits plays an important role in electrode development. There are many commercial devices available for this purpose. Although useful, these devices are usually expensive and often offer more functions than required. We propose a versatile setup, composed of a LabVIEW program, a National Instruments multifunctional board, and a circuit built of discrete commercial elements. The system offers basic functions used in electrochemical investigation like current and voltage injection, cyclic voltammetry, and impedance spectroscopy. It offers the functionalities of both a potentiostat and an arbitrary waveform generator. It has already been applied elsewhere [1, 2].**

I. INTRODUCTION

Electrode parameter analysis is essential for the development of neural stimulation devices. The instruments used to measure the electrochemical properties of the electrodes include arbitrary waveform generators and potentiostats. These devices are usually expensive and have functionalities beyond what is needed in many practical electrode studies. Examples include [3] and [12]. Commercial arbitrary waveform generators used in electrochemical studies have current outputs whose voltage can swing as high as ±60V [3]. Such high voltages are usually not necessary in neural stimulation devices. In [4], the outputs of our stimulator chip could not exceed ±2V. In [5], the output driver of the stimulation chip had 0V and 5V supply connections. Neural stimulation devices in [6], [7], and [8] have output driver supply voltages of 10V and the ones in [9] and [10] have output driver supply voltages of ±2.5V, respectively. The corresponding output voltages can never exceed these boundaries. Furthermore, it is desirable to adjust the maximum clamp voltage of the current signal outputs of an arbitrary waveform generator (AWG):

- Electrode stability and lifetime depend more on the absolute electrode potential rather than on the voltage drop on the electrode's Helmholtz capacitance [2][11].
- Electrode damage can be investigated using different voltage boundaries for higher output currents. This alleviates the decision of what maximum supply voltage is allowable for the output drivers of the stimulation chip.

To the author's knowledge, there is no AWG available which is capable of limiting the output currents and voltages to adjustable values at the same time.

Commercial potentiostats have many functions and the ability to handle electrochemical cells with as high as 4 electrodes. They have usually computer interface software which is installed on a laptop or a PC and onboard microprocessor and memory like [12]. But they are usually expensive and many are able to handle only one output channel.

Using 3 or 4 electrode arrangements enhances the accuracy because it abolishes the effect of potential fluctuations of the counter electrode on the measurements. These fluctuations are due to high currents flowing from the working to the counter electrode. But in many practical experiments, like impedance spectroscopy, the currents involved are relatively low, so a two electrode arrangement (working and counter electrodes) is enough. In applications concerning not very large electrodes (for example, iridium electrodes with an area of 100 μm x 100 μm), cyclic voltammetry can be performed with a 2 electrode arrangement (in this example, the corresponding current is less than 3.5 μA according to our measurements). For materials with lower charge injection capacity per unit area like TiN and platinum, the cyclic voltammetry measurement accuracy is even higher for a given area using a 2 electrode arrangement, compared to iridium.

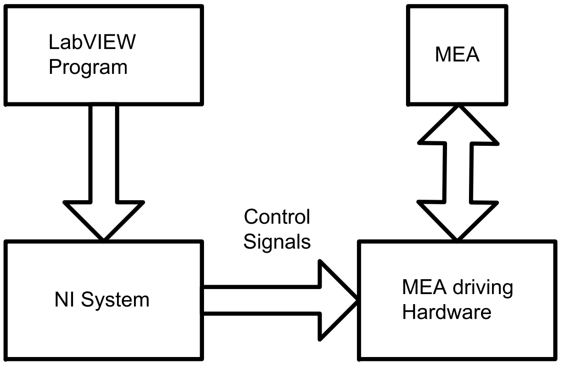


Fig. 1. Block diagram of the system as was used in [1].

The proposed system provides a 2 electrode arrangement for potentiostatic measurements. LabVIEW provides an easy way to design a suitable computer interface. The computer is interfaced to the electrode driving hardware via a National Instruments multifunctional board. The only processor involved is the computer CPU, which controls the whole experiment setup by LabVIEW. This minimizes the hardware cost and complexity. The system can handle 4 output channels at a time. If used as an AWG, it can limit the output currents to adjustable voltage boundaries.

We have used our setup to perform studies on microelectrode arrays (MEAs) [1, 2]. The system proved to be effective and handy throughout the experiments. The block diagram of the system together with MEAs is shown in Fig. 1 [1]. The electrode driving hardware is connected to the electrodes under test, while the counter electrode is connected to the system ground.

II. SYSTEM DESIGN

The system is controlled by a LabVIEW program running on a laptop. The connection to the experiment setup is through a PCMCIA card, an NI 6259 multifunctional board, and two SCC-68 connection blocks. The LabVIEW program generates the required voltage waveforms through the NI 6259 board. One of these is the quasi-arbitrary waveform shown in Fig. 2. This voltage is output to SCC-68 analog output pins. This signal is then fed to the periphery hardware as shown in Fig. 3.

The system has two modes. In one mode, it is used as a current signal generator (the mechanical switch connected to point A). The voltage output is used to generate an arbitrary current signal via the transconductance circuit shown in Fig. 3 and the output potential is limited by the voltage limiter. The discharge switch is controlled by a digital output from the NI system, to discharge the output electrodes on demand (Fig. 2).

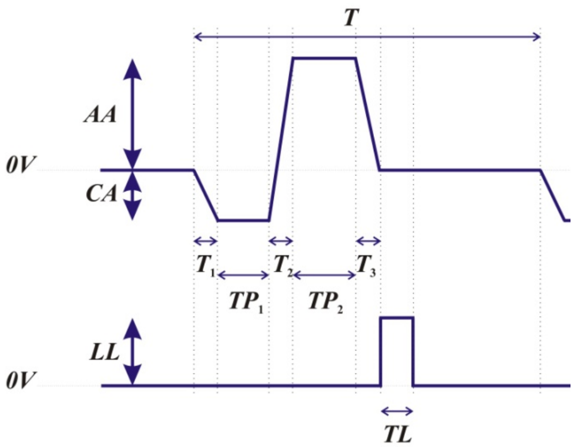


Fig. 2. Quasi-arbitrary voltage waveform, generated inside LabVIEW and used for the AWG hardware of the system (top). Digital signal used to turn the discharge switch on (bottom).

In the second mode, the system can be used as an arbitrary voltage signal generator while the switch is connected to point B. We can also perform cyclic voltammetry by adjusting the signal parameters from Fig. 2 properly ($T_1 = T_{P1} = T_{P2} = 0$) to get a triangular voltage and measuring the current through the current measurement resistor. In all the measurements, the electrodes under test are connected as in Fig. 3. The LabVIEW program can also produce a sine signal with varying frequency (0.01Hz to 100 kHz). The higher boundary of 100 kHz is due to the limitation of NI 6259 board output sampling rate and may be raised by using another NI board. The sine signal is output and the electrode current and voltage are measured by the analog inputs of the NI system. Signal processing implemented in the LabVIEW program extracts electrode impedance over varying frequency and makes impedance spectroscopy possible. In the following the circuit parts shown in Fig. 3 are explained.

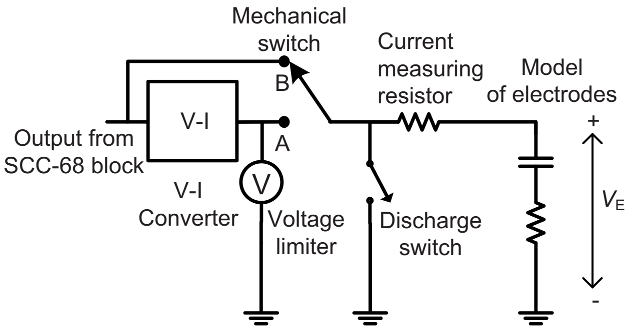


Fig. 3. The block-diagram of the hardware built to generate and measure current and limit output voltage.

a) The V-I converter:

This module converts voltage to current. The circuit is shown in Fig. 4. The output current is related to input voltage as:

$$I_{out} = \frac{V_{in}}{R}$$

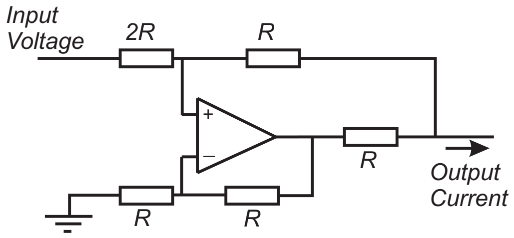
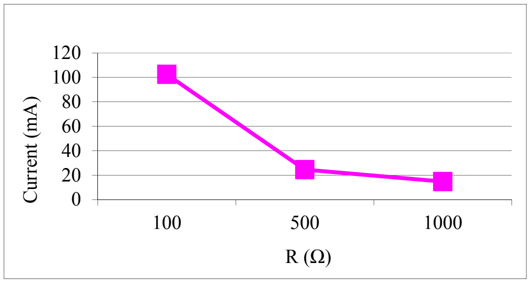


Fig. 4. The V-I converter

The V-I converter is designed to deliver 10mA maximum output current. Fig. 5 shows the op-amp output current versus R. This current is pulled out of the supply voltage and should be minimized to reduce losses and to maximize the number of hardware units supportable by a commercial DC power supply. To minimize the op-amp output current, R was set to $1k\Omega$. It is not possible to increase R further, because then an input voltage higher than 10V is required to deliver 10mA output current. This high voltage is not supported by NI 6259. R equal to $1k\Omega$ leads to a maximum output voltage swing of ±4.75V (output voltage swing of the op-amp used here: ±13V) for the output current of 10mA (Fig. 5, bottom). A higher output voltage swing is still possible with this circuit for output currents less than 10mA. If in an application this high output current is also necessary for the higher voltage swings, *R* must be reduced.



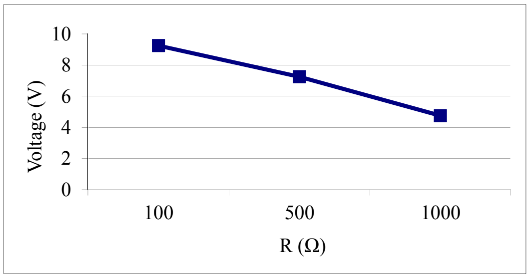


Fig. 5. Calculated op-amp output current versus *R* (top) and output voltage swing of the V-I converter (bottom)

The circuit transient response was measured using step input voltages and the circuit was proven to be stable.

b) The voltage clamp circuit:

This circuit is shown in Fig. 6. This clamp circuit limits the output voltage to the reference potentials set by the two trimming potentiometers. The voltage clamp can limit the output voltages to values adjustable between -10V and +10V. The op-amps were chosen to have a high slew rate, to assure that the voltage limits are not exceeded even for high output currents. The op-amps must also have a high input differential range to comply with their high input voltage differences.

The NI 6259 together with SCC-68 blocks provide 4 analog output channels. We built four hardware units as shown in Fig. 3 and connected them to the SCC-68 blocks. Thus our system has 4 output channels in total. To increase the number of output channels, one must apply another NI board with a higher number of analog output channels and use more hardware units, correspondingly.

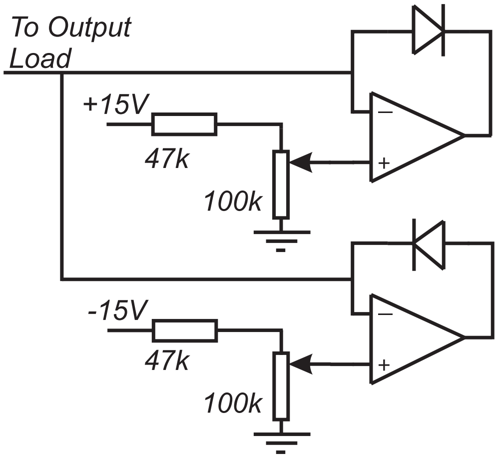


Fig. 6. Voltage clamp circuit

III. MEASUREMENT RESULTS

We have used the developed system in our previous studies [1, 2]. Fig. 7 shows the current injected into 16 electrodes in parallel and the corresponding measured electrodes potential. Both the current injection and the electrode current and voltage measurements are done by the system. The

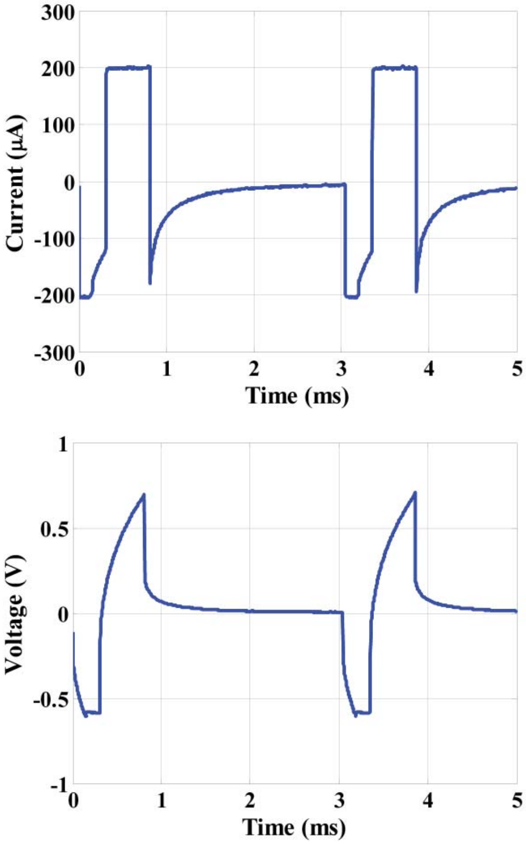


Fig. 7. Current generation and electrode current and voltage measurement by the system.

measurements are done by the analog inputs of NI 6259. The voltage boundaries were set to -0.6V and +0.8V in this example. The positive voltage limit of +0.8V is not reached as seen in the Figure. Fig. 8 shows the real-time charge injection calculation corresponding to the current of Fig. 7, done by the LabVIEW software. Here LabVIEW was used to integrate the current over time to calculate the injected charge. This curve can be used to calculate charge injection capacity for the electrodes.

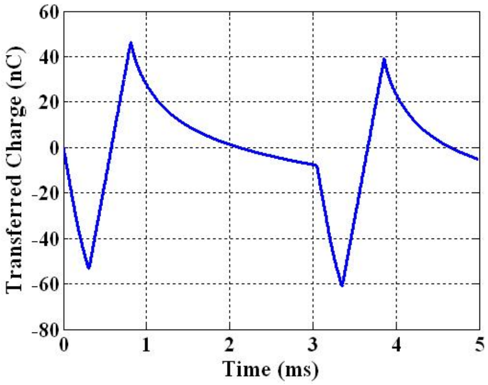


Fig. 8. Charge injection into the electrodes calculated from electrodes current in Fig. 7.

IV. CONCLUSION

An efficient and simple setup for electrode properties investigation, such as charge injection capacity, cyclic voltammetry, and impedance spectroscopy is introduced. The system can be used like a professional potentiostat and an arbitrary waveform generator in many practical electrochemistry investigations. Compared to a commercial potentiostat, the system can handle only a 2 electrode cell, opposed to as high as 4 electrodes. The potentiostatic functions of our system are useful only in the situations where the electrode currents are not high. Compared to a commercial AWG, the hardware is able to limit the output potentials to an adjustable window, which is an advantage. The system's implementation cost is low.

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