Impedance measurement set-up based on off-the-shelf PXI modules

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Abstract. As bioimpedance measurements are being done in an increasing variety of measurands and environments, measurement equipment must be flexible in use and easy to handle for the researcher. Measurement equipment used today is excellent for a range of uses, but it is often bulky, heavy, and not very flexible. A new compact and flexible measurement set-up based on off-the-shelf modules is described. The system is based on commercially available PXI-modules, one module that may be custom made, and custom software. The basis of the system is a PXI chassis with a power supply unit. The chassis is equipped with a controller module running software controlling the system, a signal generator, and a multi-channel digitizer. All of this is commercially available. Both a custom made and a commercially available impedance interfaces were used. A LabVIEW program is controlling the measurement system, and provides a user interface. The LabVIEW program handles necessary signal conditioning and calibration. The measurement system is capable of doing frequency response measurements at frequencies up to 15 MHz. In addition to the two normal voltage pick-up electrodes used in four-electrode measurements, this system has the possibility to use 5 extra voltage pick-up electrodes. This simplifies exploration of segmental impedance, anisotropy, reciprocity, etc.

1. Introduction

Impedance measurements are done by measuring voltage across, and current through a sample at several frequencies, and then calculate the complex impedance using Ohm’s law. This method needs some refinements to be practical for measuring impedance in biological materials. Dedicated frequency response analyzer systems typically use 2, 3, or 4 electrodes to reduce effect of the electrode interfaces, and to provide a method for volume selectivity [1]. To be able to pick out even very small signals at the frequencies of interest a method called lock-in amplification is used. Instruments with these features tend to be physically large, heavy, and they tend to have limited flexibility when it comes to signal processing [2]. To increase areas where bioimpedance measurements are possible, and to enhance bio-impedance measurement signal processing there is a need for a compact and flexible instrumentation platform.

2. Materials and method

2.1. System overview.
The measurement system is made as a PXI system. The system consists of a compact chassis that provides the physical housing of the measurement system, and power supply [3]. A controller module
is used to control the system (CTRL). The controller is a PXI-module containing a PC that is running
MS Windows and LabVIEW. These parts form the instrument infrastructure.

The instrument is made of one signal source providing an arbitrary voltage waveform (DAC), a
multi-channel voltage digitizer (ADC), and an impedance interface. The signal source and the voltage
digitizer are commercially available as PXI-modules. The impedance interface is not commercially
available as a PXI-module, so two alternatives were used: One custom made, which can be used in the
PXI chassis, and one commercially available non-PXI.

Figure 1: a) Complete impedance measurement system in a PXI chassis, b) impedance interface. The impedance
interface may be placed either inside or outside the PXI chassis.

2.2. About PXI.
PXI is a standard for modular PC-based instrumentation systems. A typical system consists of a PXI
chassis equipped with power-supply and cooling plus one or more modules [4].

2.3. Of-the-shelf PXI modules.
The off-the-shelf modules used in this particular case are:
- NI PXI-1031: A general-purpose 4-slot chassis for PXI.
- NI PXI-8183: A PXI-controller, which is a PC-module that fits in the PXI-chassis.
- NI PXI-5402: A 20 MHz arbitrary waveform signal source.
- NI PXI-5105: A 60 MS/s multichannel digitizer with simultaneously sampled inputs.
All PXI parts used are from National Instruments.

2.4. Commercially available external impedance interface.
The Solartron 1294 impedance interface was used. One basic configuration of this device is shown in
figure 1 b). The IIF-part in figure 1 a) is on the outside of the PXI box in figure 1 a) when the external
impedance interface is used.

2.5. Custom-made impedance interface.
The custom-made impedance interface in figure 1 b) has several functions necessary to use the
measurement system as a four-electrode measurement system.

The top signal path is not doing any signal processing, but passes the stimulus voltage through.
The bottom signal path is a current-to-voltage converter and a buffer. The return current from the
signal source is converted to a voltage in this path, and the resulting voltage is buffered by a buffer
with 50 $\Omega$ output impedance. The buffered signal is fed to the voltage digitizer.
The two signal paths in the middle are voltage pick-up signal paths. The input signal is connected
to a unity-gain input buffer with very high input impedance. The output of this buffer is fed to a buffer
with 50 $\Omega$ output impedance. The signal from the input buffer is connected to another buffer that
drives the shield of the input coaxial cable. This gives us a driven-shield solution that presents a
reduced parasitic capacitance load to the input signal. The two buffers used in the driven-shield path
must have very low accumulated phase shift for the intended measurement bandwidth (15 MHz).
Several RC-filters are placed in the signal paths to ensure stability and to optimize signal quality.

2.6. Software.
The software part of the system is based on the graphical programming language LabVIEW from
National Instruments.
The software generates stimuli, process the measured signals, and produce desired presentation of the results. The front panel of a measurement program is shown in figure 2.

3. Results

3.1. Simulation results.
The custom-made impedance front-end has been simulated to verify performance. The most important signal paths are the voltage pick-ups and the current to voltage converter. Since the driven-shield signal path forms a loop that can be unstable, it was simulated.

![Figure 3: Solid lines: modulus, dashed lines: phase. a) Transfer function for voltage pick-up (blue lines) and current-to-voltage converter (red lines), b) transfer function for potentially unstable feedback-loop (blue lines) and transfer function for driven shield circuit (red lines).]

The Bode plots for the signal paths for the measurement signals are shown in figure 3 a).

Figure 3 b) shows that the loop gain is less than 0 dB at all frequencies, and that the driven-shield circuit has a phase shift less than 36° and less than 3.6 dB attenuation for all frequencies up to 15 MHz.

3.2. Measurement results.
A simplified measurement system was made using PXI modules and a Solartron 1294 impedance interface. The LabVIEW instrument in figure 2 controlled the PXI system. A comparison of the new PXI-based system and the Solartron 1260+1294 combination was done on a known test-circuit. Figure 4 shows results at 13 frequencies.

![Figure 4: Solid lines: modulus, dashed lines: phase. a) Modulus and phase for calculated and measured impedances, b) Measurement error for PXI (blue) and Solartron (red).]

4. Discussion

4.1. Flexibility.
The system is very flexible with regards to several properties: a) hardware choices, b) excitation set-up, and c) signal processing.

It is possible to expand the measurement by adding one or more voltage pick-ups. This makes it possible to explore several properties like anisotropy and segmental impedance simultaneously using more than two voltage pick-up electrodes. The impedance front-end can be replaced by similar front-ends offering different properties such as galvanic isolation, current-limiting, controlled-current stimuli, etc.

Since custom-made software defines the excitation, it is possible to define arbitrary waveforms for excitation. It is also possible to use any frequency-hopping or waveform-hopping scheme. It is also possible to use specialized waveforms such as those used by pacemakers. Such flexibility is not common in a frequency response analyzer like the Solartron 1260 [2].

It is possible to tailor the interface to most needs. Post-processing of the measurements can be done. Examples of post-processing are harmonic distortion analysis, noise analysis, linearity analysis, and comparison with existing data.

4.2. Simulation results.
The simulations shows that a) the feedback loop formed by the driven shield network and coaxial cable is stable, b) the phase shift in the circuits driving the shield has low enough phase shift to reduce capacitance seen by the voltage electrode, and c) there are no abrupt changes in gain or phase. The last point is important since it means that it is possible to calibrate the system by measuring the impedance of a reference over the relevant frequency range.

It is crucial for the driven-shield concept that the phase shift in the buffers driving the shield is as close to 0° as possible. Simulation shows that a phase shift of less than 36° is obtained for frequencies up to 15 MHz.

4.3. Measurement results.
The measurements show that the new PXI-based system is slightly poorer than the Solartron 1260+1294-combination in performance on the test-circuit. It is expected that this error can be reduced by software optimization (filters, lock-in, etc.).

4.4. Performance.
Measurement time can be reduced compared to available instruments due to the flexibility of the new measurement system. The cost of reduced measurement time may be increased programming time. Reduced measurement time may be especially useful when doing measurements in vivo.

Since the current and voltages are digitized and available, it is possible to utilize techniques such as lock-in, digital filtering, noise analysis, and harmonic distortion analysis.

5. Conclusions
A PXI-based impedance measurement system is useful since it is compact and flexible when looking at both hardware and software, and the first measurements demonstrates performance comparable to existing equipment. The presented system gives the scientist an opportunity to build an instrument that can be tailored to several specific tasks.

References
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