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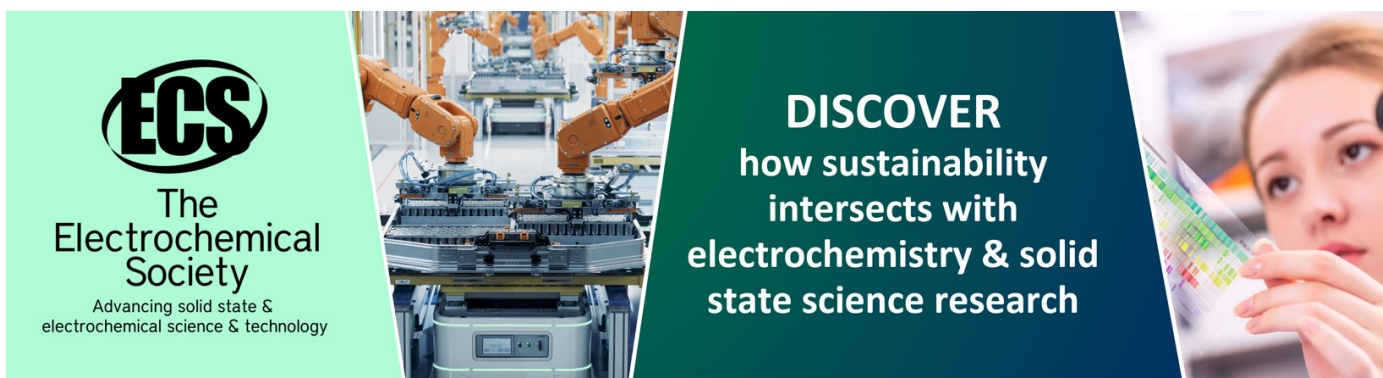
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Measurements of high impedance two-terminal device with SMU NI PXIe-4139*

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Abstract. To measure high-frequency and low-frequency impedance of betavoltaic power sources (it can be represented as two-terminal device), measurement stand was created. To measure high-frequency part need to inject external test signal through the current transformer with waveform generator and need to use external high-frequency current sensor, because of SMU PXIe-4139 current channel limitations.

Introduction

Two-terminal device impedance measurements is necessary in many scientific fields, such as: electrical impedance spectroscopy in the chemistry, electrochemistry and corrosion, frequency characteristics measurements in control systems research, impedance measurements in semiconductor devices, biological objects, etc.

The principles of impedance measurement are deeply investigated, the results are published in books [1-3]. The measurement methods are usually based on insertion of current oscillations to the main current of two-pole circuit and then voltage response measurement. This method used if the device under test (DUT) has a low resistance; in case of high internal resistance of DUT the insertion of voltage oscillations performs and then the current response measured. Generally, oscillations produces with special source, able to directly generate waveform to power DUT.

There are a lot of oscillations insertion methods, single-frequency and multifrequency methods are the most common. This methods with direct power waveform generation allow to measure the impedance in the low frequency part of spectra, right down to very low frequencies, about few uHz. For using these methods for high frequencies, high quality ADC required. ADC accuracy requirements are increased with reducing the level of currents or voltages, that is usual for high impedance devices.

To overcome this limitations, the second method of oscillations insertion can be used. It is to insert of oscillations with the current or voltage transformer, connected to the external generator. This method is usually applicable for input of high frequency oscillations.

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The high-frequency part of impedance spectra is very important for the parameters identification of equivalent circuit diagrams, because when impedance grows up, the time constants are shifted to the high-frequency region.

Using of modular devices allows to develop measurement procedure more flexible than with stand-alone devices. The advantages is in the creation of different synchronized working devices, implementation of complex measurement procedures and mathematical processing of the results. Modular SMU, produced by National Instruments, have one of the best capabilities nowadays in this class of devices. To significant disadvantages one can include lack of Linux support, the rest are solvable in principle.

Experimental

To measure static and dynamic characteristics of betavoltaic power sources, measurement stand based on SMU PXIe-4139 was created. Betavoltaic power source can be represented as double-pole circuit [4]. Because the generation current of the small area prototypes has a fairly low value (about a tens of nA), it was necessary to develop an effective method of impedance measuring of such devices, with the aim of SPICE model building to use in further calculations.

Measurement of static current-voltage characteristic is not a problem for this SMU model, which have an effective on-board protection from AC 50Hz power supply interference and the instrumental means of preventing (guarding) current leakage. The advices in [5] allow to build an effective system of low current measurements. The designed wiring diagram represented on figure 1.

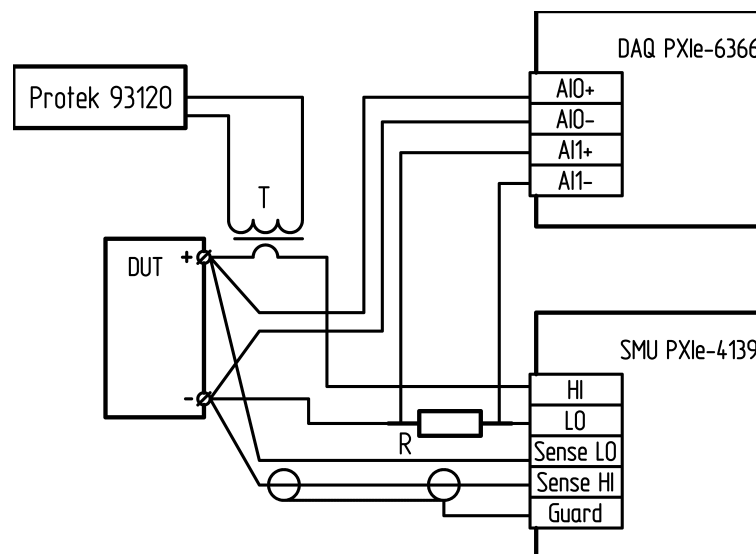


Figure 1. Wiring diagram of experiment.

While measuring low-frequency part of impedance, the insertion method of single-frequency oscillations was used, which realizes the following sequence for every point in a required frequency range:

1. Setting the DC operating point of the DUT.
2. Insertion of sinusoidal oscillations to the voltage of the DUT by the shape setting of SMU PXIe-4139 output signal. The oscillation amplitude shouldn't exceed the region of linearity, in order to the response signal must be also sinusoidal. This condition is satisfied if the nonlinear distortion coefficient of the signal response is not more than 5%.

3. Making current and voltage signals measurement.
4. Selection of the main harmonic amplitude of measured current and voltage, the impedance calculations for a given frequency point.

For the impedance measurement of the high frequency spectrum (10 kHz - 400 kHz) the above method can't be used, because the SMU's maximum sampling frequency is 100 kHz, and high-quality sine waveform requires at least 4 points on the period.

The desired signal is injected by an external generator with a current transformer with a variable transformation ratio. The rest of the measurement sequence is the same.

While impedance measuring as described way, the authors faced with feature of SMU PXIe-4139, not reflected in the documentation [6]. This was expressed as measured impedance overrotation, from the frequency of 100 kHz with a slope of +20 dB/decade, like as inductive component added. The influence of cables was checked on the test circuits, their effect was negligible at these frequencies.

To clarify the reasons of this effect, it was made an additional experiment. The meaning of experiment was in parallel current and voltage measuring with the second measuring system (multifunctional DAQ module PXIe-6366). The current sensor was a metallized heat-resistant lacquer resistors (russian MLT type), which do not have a reactive components up to frequencies of the 6 MHz (fig. 1).

The SMU configured to One-point voltage stabilization mode. After the source operation completes, the measurements of current and voltage channels were made. The AC 50Hz power supply frequency was filtered by second order filter. The SMU PXIe-4139 and DAQ PXIe-6366 measurements were synchronized. The start of the SMU measurement begins at the AI Start trigger from the DAQ board.

Results and discussion

The results revealed that the voltage channel measurements of SMU and DAQ are identical up to noise amplitude (see figure 2, for DAQ PXIe-6366 $F_s = 2\text{MS/s}$, for SMU PXIe-4139 $F_s = 900\text{kS/s}$).

Measurements of current with SMU showed, that sine amplitude was decreases from 100 kHz with the slope of -20 dB/decade, compared with DAQ current measurements.

The measured ratio of signal from the internal current sensor of the SMU to the external current sensor for different sampling frequency are shown at figure 3.

A detailed SMU documentation study did not give any information on the detected effect and means of extending this effect. Perhaps there is internal digital filtering (as the shape of Bode plot looks like) in the control loop of the SMU PXIe-4139.

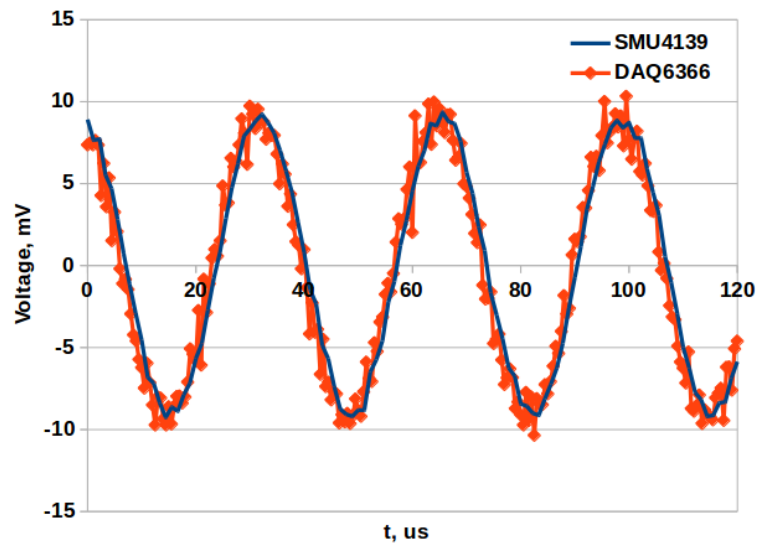


Figure 2. Voltage channel measurements of SMU PXIe-4139 and DAQ PXIe-6366.

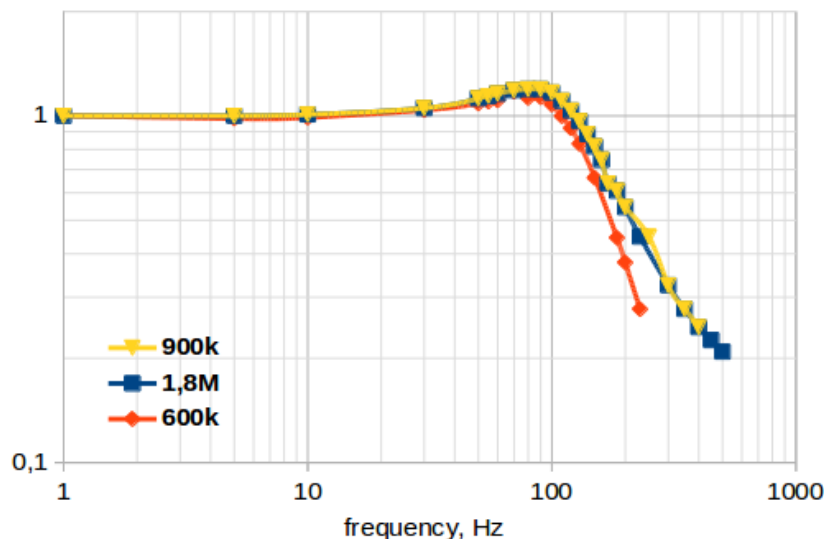


Figure 3. Ratio of signal from SMU internal current sensor to external current sensor for different sampling frequency.

Conclusion

Using of modular SMU gives wide possibilities for creation of measuring systems for specific needs, in particular for measuring the impedance characteristics in the range DC-400kHz. The low-frequency part of impedance spectra can be measured with the method of direct power waveform generation of the SMU PXIe-4139 output. High-frequency part can be measured with injection of external test signal through the current transformer with waveform generator. In the last case, for adequate current measurement we should use an external HF current sensor (resistive or transformer type). Also in this case SMU can be used only to set the operating point of the DUT.

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