

# Wide Range Current Amplifier with Data Acquisition System

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**Abstract** - Wide Range Current Amplifier (WRCA) with DAQ system is constructed and tested. The device consists of *I-V* converter, 24 bit  $\Sigma$ - $\Delta$  ADC, microcontroller ( $\mu$ C), personal computer (PC), feedback loop control and galvanic insulation units. Communication between the ADC,  $\mu$ C and the PC computer is realized over SPI and USB interface, respectively.

The data acquisition, control and processing are implemented on originally developed GUI software based on the Qt4 platform under the MSWindows operating system.

The device test was carried out by measurement of current-voltage (*I-V*) characteristics on test resistors in comparison with measurements, performed on commercial picoammeter Keithley 6487. In general the measurements followed a linear dependence which corresponds to the resistor behavior of the samples under study. A quantitative comparison between the constructed WRCA and the standard K6487 devices was carried out performing a linear regression analysis of the data measured.

It was found that for the measured current less than 10 pA the error in the slope calculated from WRCA measurement is 2 times higher than K6487 ones. The error in the slope from measurement with the WRCA in the range of 2 nA and 20 nA is an order of magnitude higher than K6487 one. The error in the slope determined from measurements with both devices for the ranges of 2  $\mu$ A, 200  $\mu$ A, 2 mA and 20 mA is comparable.

WRCA device constructed is proper for current measurements of samples, prototypes, and electronic devices with a satisfactory precision in the wide range of 10pA-20mA.

**Keywords** – Wide Range Current Measurement, Data Acquisition and Control

## I. INTRODUCTION

Nowadays the current-voltage measurements of semiconductor samples, prototypes and devices with nonlinear characteristics - photovoltaic cells, light-emitting diodes, field effect transistors, and sensors is growing

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extensively [1, 2, 3].

From the other side measurement of injection currents is necessary to give valuable information about the electronic properties of the materials especially for wide-gap semiconductors and insulators [4].

At low voltages current of about  $1 \times 10^{-13}$  is flowing through the sample but increasing 6-7 orders of magnitude, when conditions for charge carrier injection from the electrodes occur [5]. It is proved that the trap concentration and their distribution in energy could be extracted from the shape of the current-voltage (*I-V*) characteristic [6].

Measurement of low current in high impedance samples could not be implemented with conventional digital multimeters. For low-level signals, more sensitive instruments such as electrometers, picoammeters, and nanovoltmeters must be used [7]. A typical example of such device is the electrometer Keithley 6487.

Moreover some special precautions should be taken to prevent the noise and the influence of parasitic signals generated from sources with piezoelectrical, triboelectrical or electrochemical origin.

When measuring high resistive samples the time-constant plays also an important role. For example, a shunt capacitance of 100 pF (including the input cable) and a source resistance of 20 G $\Omega$  results in a RC time constant of two seconds. Ten seconds must be allowed for the measurement to settle to within 1% of the final value [8]. The long time measurement could be automated by a virtual instrument. A virtual instrument consists of an industry-standard computer or workstation equipped with powerful application software, cost-effective hardware such as plug-in boards, and driver software, which together perform the functions of traditional instruments [9]. With virtual instruments, engineers and scientists build measurement and automation systems that suit their needs exactly (user-defined) instead of being limited by traditional fixed-function instruments (vendor-defined).

This work aims to construct simple Wide Range Current Amplifier (WRCA) for characterization of semiconductor samples prototypes and devices based on DAQ system. It allows more flexible control and adjustment of the user-defined parameters. WRCA has another advantage of a galvanic separation between the modules decreasing the level of the parasitic current flow.

## II. DEVICE DESCRIPTION

### A. Hardware

WRCA with DAQ (Fig. 1.) consists of *I-V* converter, 24 bit ADC, reference voltage of 2.5 V, microcontroller

( $\mu\text{C}$ ), personal computer (PC), feedback loop control, galvanic insulation and a power supply units.

The  $I$ - $V$  converter (1) is based on the low offset and low noise chip LMP7721. The suggested OP has the advantage

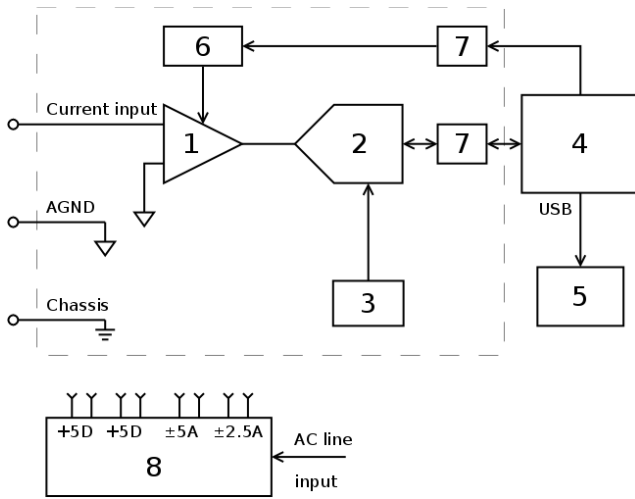


Fig. 1. Block diagram of the wide range current amplifier with DAQ system: 1 -  $I$ - $V$  converter; 2- 24 bit  $\Sigma$ - $\Delta$  ADC; 3 - Reference voltage; 4 - Microcontroller; 5 - Personal computer; 6 - Feedback loop control; 7 - Galvanic insulation; 8 - Power supply.

of low input offset current (in the range of fA), low offset voltage (about 50  $\mu\text{V}$ ) and could be purchased on a reasonable price.

24-bit  $\Sigma$ - $\Delta$  ADC (2) of type ADS1259 was chosen because its inputs accept true differential signals, possess internal 50 Hz filter, output pin for Data Ready notification, SPI interface and  $\Sigma$ - $\Delta$  modulation. For optimal work the  $\Sigma$ - $\Delta$  ADC was configured in a way that the input voltage is read on every conversion cycle and put of the output buffer of the SPI interface. In this way the  $\mu\text{C}$  needs only to read the SPI interface upon the Data Ready notification to acquire the new value. For this purpose the Data Ready output pin is connected to an external interrupt pin of the  $\mu\text{C}$ . The SPI interface is set to operate in full (3-wire) mode. An external reference voltage (3) of 2.5 V was provided by the ADR3425 chip. The clock frequency of 7.3268 MHz was generated by external quartz crystal oscillator. In this way a maximum conversion rate of 14400 SPS can be achieved. But because the ADC is set to use the 50 Hz filter the sample rate is fixed to 50 SPS. This is sufficient to provide one measurement every 20 ms.

The  $\mu\text{C}$  unit (4) is based on PIC18F4550 chip which has SPI and USB interfaces.  $\mu\text{C}$  operates with an external 20 MHz quartz oscillator. The USB interface operates in full (48 MHz) mode.

The data acquisition, control and processing are driven by originally developed GUI software based on the Qt4 platform under the MSWindows operating system.

The 6 range feedback loop control unit (6) is designed to provide accurate measurements from tens of picoampers to 20 mA. The reed relays of type COTO 9001-05-00 are with switching time of 300 ms.

Galvanic insulation units (7) are based on an PS2805 optocouple. The galvanic insulation prevents the mutual

parasitic influence between the digital and analog units reducing the noise and blocking the fluctuation currents.

The dashed line confines the units designed on the WRCA PCB. Special precautions are taken into account to provide a high insulation resistance and shielding of the input stages of the converter during the PCB design. Therefore the current input, AGND and chassis pins are connected to the sample via triax high insulation cable and connector.

#### A. Software

Block-diagram of the  $\mu\text{C}$  software is presented on Fig 2. After starting the  $\mu\text{C}$  initialization of the peripheral ports and the interfaces is taking place. It consists of setting the interrupt priority of the  $\mu\text{C}$ , configure which ports are outputs and which inputs and send commands for initializing the interfaces.

After the initialization the software enters an endless loop awaiting a command from the PC.

Upon receiving an USB interrupt, the command sent through the interface is read and the corresponding action is performed. Depending on the input command the  $\mu\text{C}$  can change the range of the WRCA, could perform offset calibration (this option is reserved for a future development), set the WRCA into Zero Check mode or send, the newest data from the ADC to the PC. The commands for the data acquisition are transferred to the ADC through the SPI interface.

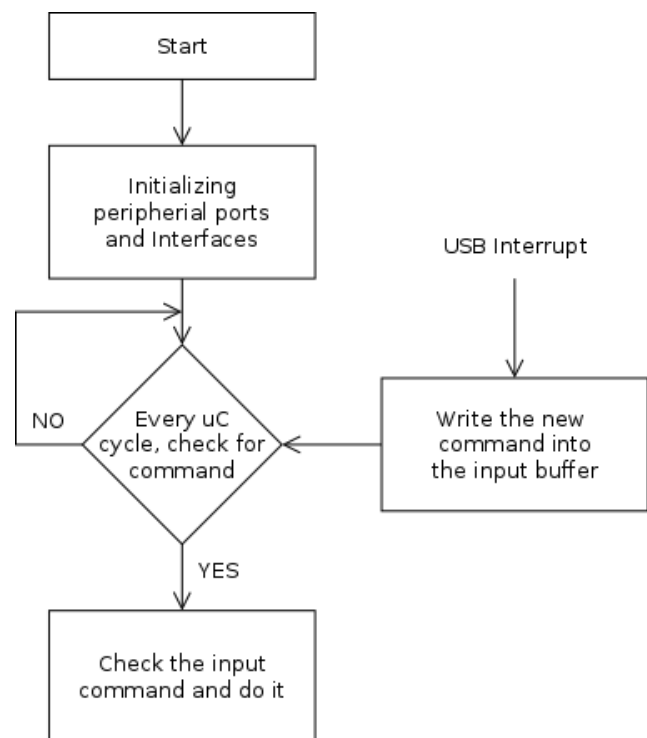


Fig. 2. Block diagram of the  $\mu\text{C}$  software

The purpose of the PC software is to set the parameters of the measurement (relaxation delay, voltage range, voltage step, etc), control buttons (start, stop, zero check, etc.), configuration options for the devices in use (range, current

limiting of the voltage source, sample rate, etc.), to be able to work with different devices and plot and record all data.

### III. DEVICE TESTS

The device test was carried out by a measurement of current-voltage ( $I$ - $V$ ) characteristics in comparison with a commercial picoamperemeter Keithley 6487 data,

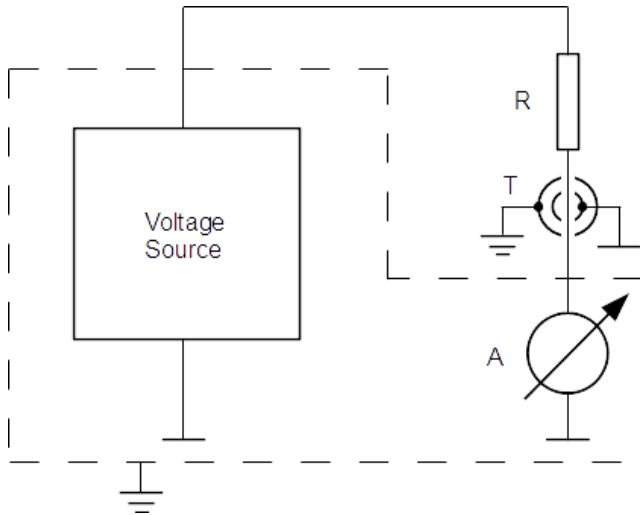


Fig. 3. Block diagram of the test measurement setup

according to the block diagram presented on Fig. 3. K6487 consists of a voltage source and electrometer (confined with a dash line on the figure). Three test resistors ( $R$ ) of 88 GOhms, 92 MOhms and 68 KOhms denoted hereafter as  $A$ ,  $B$  and  $C$ , respectively, were measured. The resistor under test was shielded and the shielding protection was connected to the chassis with the outer shell of the triax cable ( $T$ ). The middle shell of the triax cable was connected

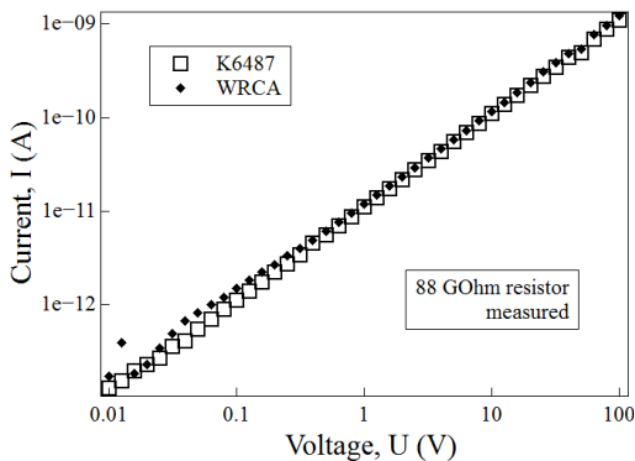


Fig. 4. Current- Voltage characteristic measured in the low current range

to the analog ground, whereas the inner wire of the triax cable connects the resistor ( $R$ ) and the amperemeter ( $A$ ). The measurement was performed applying the voltage in a logarithmic scale over 4 decades (0.01÷100 V) using the

K6487 voltage source. After performing the test with the standard K6487 device, the triax was only unplugged and connected to the WRCA input connector. The measurement was repeated with the same voltage source over the same measuring range setting the same hardware and software configuration.

The data from the low current range of measurement ( $10^{-13}$  ÷  $10^{-9}$  A) acquired from both K6487 and WRCA are plotted on Fig. 4 in log/log scale. In general the measurement follows a linear dependence which corresponds to the resistor behavior of the measured sample. Every point on the graph presents an average result from 5 measurements. For seek of clarification every second point on the graph is omitted.

At the beginning of the graph (tenths and units of picoamperes), the measurement performed with the WRCA device differs slightly from the straight line obtained from the standard K6487 instrument. This deviation could be related to the increased noise of the measurement and the input offset of the WRCA. It should be mentioned here that no special precautions to compensate the input offsets are taken into account. A hardware unit and a software correction algorithm for the compensation of the input offset as well are under development, and will not be discussed.

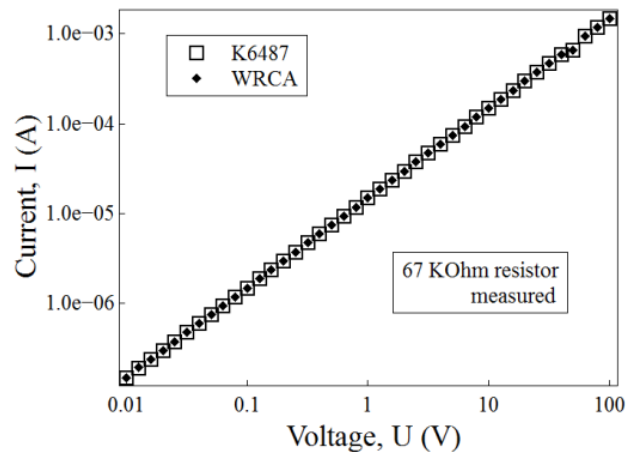


Fig. 5. Current-Voltage characteristic measured in the higher current range

In the range of tens of picoamperes and higher the measured data from the WRCA approach the standard K6487 ones. In the range of nano, micro and miliamperes (Fig. 5.) the measured WRCA data are with an agreement with the standard K6487 ones.

A quantitative comparison between measurement with the constructed WRCA and the standard K6487 device was carried out performing a linear regression analysis of the measured data. For this purpose the measured data for every operating range of the constructed device was replotted in an inverse dependence, i. e. the voltage vs. the current applied. The data are fitted with a linear regression according to the equation:

$$U = O+RI,$$

where  $U$  is the voltage applied on the test sample,  $I$  is the measured current and  $R$  is the resistance of the resistor which corresponds to the slope of  $U$  vs.  $I$  dependence. The

intercept  $O$  could be related to the noise, the input offset of the constructed device or other artifacts of the measurement.

Calculated in this way slope and the intercept (given in brackets) for every range of the constructed device are presented in Table 1.

The calculated slope and the intercept are presented with their standard deviation, determined from the linear regression.

TABLE 1. COMPARISON OF THE LINEAR REGRESSION ANALYSIS DATA FOR THE REFERENCE AND THE CONSTRUCTED DEVICES

range	R	K6487 value [Ohm]	WRCA value [Ohm]
200pA ( $<10\text{pA}$ )	A	$9.1\pm 0.018\times 10^{10}$ ( $2\pm 6\times 10^{-4}$ )	$8.5\pm 0.049\times 10^{10}$ ( $2\pm 0.2\times 10^{-2}$ )
200pA ( $>10\text{pA}$ )	A	$9.1\pm 0.003\times 10^{10}$ ( $1\pm 0.3\times 10^{-2}$ )	$8.7\pm 0.088\times 10^{10}$ ( $-0.7\pm 7\times 10^{-3}$ )
2nA	B	$8.9\pm 0.001\times 10^7$ ( $3\pm 6\times 10^{-5}$ )	$8.9\pm 0.02\times 10^7$ ( $4\pm 6\times 10^{-4}$ )
20nA	B	$8.9\pm 0.002\times 10^7$ ( $2\pm 0.8\times 10^{-3}$ )	$8.9\pm 0.05\times 10^7$ ( $-1\pm 0.5\times 10^{-3}$ )
2 $\mu\text{A}$	B	$8.9\pm 0.02\times 10^7$ ( $3\pm 6\times 10^{-5}$ )	$8.9\pm 0.02\times 10^7$ ( $3\pm 6\times 10^{-5}$ )
200 $\mu\text{A}$	C	$6.8\pm 0.0008\times 10^4$ ( $8\pm 6\times 10^{-4}$ )	$6.8\pm 0.0008\times 10^4$ ( $8\pm 7\times 10^{-4}$ )
2 mA	C	$6.8\pm 0.02\times 10^4$ ( $9\pm 6\times 10^{-4}$ )	$6.8\pm 0.01\times 10^4$ ( $6\pm 7\times 10^{-4}$ )
20 mA	C	$6.8\pm 0.001\times 10^4$ ( $-8\pm 6\times 10^{-2}$ )	$6.8\pm 0.002\times 10^4$ ( $-7\pm 1\times 10^{-2}$ )

The values for the resistor calculated from the WRCA and K6487 measurements differ each other which could be referred to the lower accuracy and higher noise of the WRCA measurement. For the measured current less than 10 pA the error in the slope calculated from WRCA measurement is 2 times higher than K6487 ones. This could be expected as the WRCA device is working on its limit range. It should be added here that the standard error of the slope, determined from K6487 measurement is at least 6 times higher than the corresponding error, determined from the other ranges. It should be connected with the noise presented in the measured data as no special precautions for measurement in the picoampere range concerning shielding, grounding and guarding are taken into account. The intercept calculated from WRCA measurement in the same range is also determined with higher standard error because the limit of the WRCA device.

Considering the slope, taken from measurement with the standard K6487 device in the range from 200 pA to 20 mA it could be seen that the error for the subranges of 2  $\mu\text{A}$  and 20 mA is an order of magnitude higher. This is related to an artifact in the K6487 voltage source. The error in the slope from measurement with the WRCA in the range of 2 nA, 20 nA and 2 mA is an order of magnitude higher than K6487 one. The error in the slope determined from measurements with both devices for the ranges of 2  $\mu\text{A}$ , 200  $\mu\text{A}$ , 2 mA and 20 mA is comparable.

In general it could be pointed out that the standard error calculated from measurements with WRCA device is higher than that, calculated from K6487 device. It could be concluded that the constructed WRCA device could measure currents with a satisfactory precision in the wide range of 10pA $\div$ 20mA. The measurement in the range of tenths and units of picoamperes could be improved introducing hardware and software compensation of the input offset. The device could be used for a wide range  $I$ - $V$  measurement of organic electronic samples, prototypes and devices.

#### IV. CONCLUSION

Wide range current amplifier with data acquisition system was constructed and tested. Test measurements of resistors are carried out with both the constructed device and the K6487 reference device.

It could be concluded that the constructed WRCA device could measure currents with a satisfactory precision in the wide range of 10pA $\div$ 20mA.

#### ACKNOWLEDGMENTS

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