HIGH CURRENT SOURCE-MEASURE UNIT BASED ON LOW COST DAQ

Georgi Todorov Nikolov

Faculty of Electronics and Technologies, Technical University of Sofia, Studenstki Grad, TU-Sofia, block 1, room 1366, 1797, Sofia, Bulgaria, e-mail: gnikolov@tu-sofia.bg

The development of a high current source-measure unit based on multifunctional low cost data acquisition board, graphical development environment and a circuit of voltage controlled current source is presented in this paper. Such development is motivated by capability of source-measure units to acquire data, generate I-V curves, and otherwise characterize various device performances. As a part of proposed development some considerations concerning high current sources are presented and some aspects of circuit design are treated. Because the circuit traditionally is used only as current generator, in this paper is suggested innovative approach to use this current source as voltage generator. The approach consists basically in implementation of software loop that continuously calculate resistance of device under test and control the output voltage. The developed virtual system can be used for circuit and device evaluation, where a DC signal must be applied to a device under test and the response to that signal must be measured.

Keywords: Device characterization, LabVIEW, Source-Measure Unit, Virtual Instruments, Voltage Controlled Current Source

1. INTRODUCTION

Generation and measurement of voltages and currents are essential to evaluating fundamental electric parameters. This is especially true in the field of semiconductors and electronic parts, in the field of sensors, and in the research of leading-edge technology, where highly accurate, high-speed, and convenient source and measurement devices are demanded [1]. A commercial DC Source-Measure Unit (SMU) is a convenient test tools for many materials and device measurement. SMU changes measurement topologies automatically i.e., switch between source voltage measure current and vice versa. For high impedance devices under test (DUT) an SMU can be configured to source voltage and measure current. When the investigated device or material has low impedance, more accurate results are achieved by sourcing current and measuring voltage. Furthermore the SMU has a current compliance function that can automatically limit the current level to prevent damage to the device or material under test. Similarly there is a voltage compliance function when the current is being sourced.

The many SMU models available provide a wide range of features, from simple units to specialized instruments for highly demanding applications. These instruments provide a fast, easy, and accurate method for characterizing a wide array of devices and materials. The disadvantage of manufactured models is their relatively high cost. It varies between fife and fifty thousand dollars [1, 2].

In this paper is suggested development of high current SMU based on new generation of portable low-cost modular data acquisition board (DAQ) and voltage controlled current source (VCCS) with grounded load. The DAQ is controlled by computer via USB, application programming interface DAQmx and graphical programming environment LabVIEW.

2. Hardware Design and Simulation

The block diagram of presented virtual system fulfilling source-measure functions is shown in fig.1. The system consists of computer platform, DAQ board and voltage controlled current source.

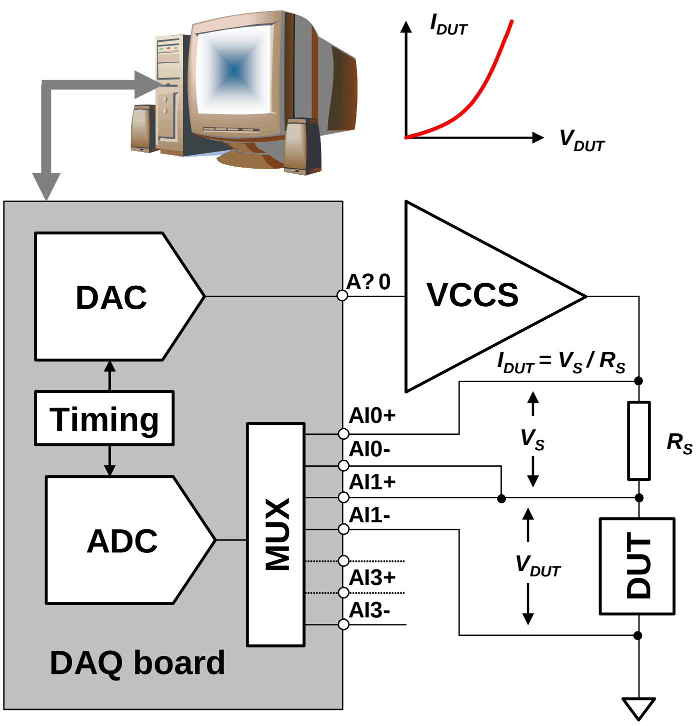

Fig. 1. Block diagram of virtual source-measure system

Computer platform can be any that is capable to drive DAQmx and LabVIEW. The second component of the designed virtual system is a modular multifunctional DAQ board. As the measuring part of the virtual system reported here, this device performs a number of tasks, including analog measurement, generation and timing.

It is well known that is possible to use the positive and negative inputs of an operational amplifier to make a high impedance current source (current pump) using a conventional operational amplifier [3, 4]. The basic circuit of voltage controlled current source or so called improved Howland current pump is shown in fig. 2. This circuit can put out both positive and negative output current (and zero current) into various loads. The pump operation is based on utilizing both negative and positive feedbacks around the operational amplifier. The load is connected to the positive loop. Current through the load is defined by equation:

$$I_{out} = -\frac{V_{in}}{R_S}\frac{R_2}{R_1} \qquad (1)$$

In presented circuit of VCCS, each feedback resistor may have a relatively high value (100 kΩ or higher), but the value for R_S should be relatively small. This condition improves the efficiency of the Howland current pump, as smaller voltage is wasted across R_S and smaller current is wasted through R_4 and R_3. The improved Howland current pump is often used for testing other devices. They can be used to force currents into sensors and various materials in experiments, or in production test. They can bias up diodes or transistors, or set test conditions [3].

Almost any op-amp can be used in a Howland current pump. However, if a wide output current range is required, a high current amplifier, running on ±4 amperes (or more) may be needed.

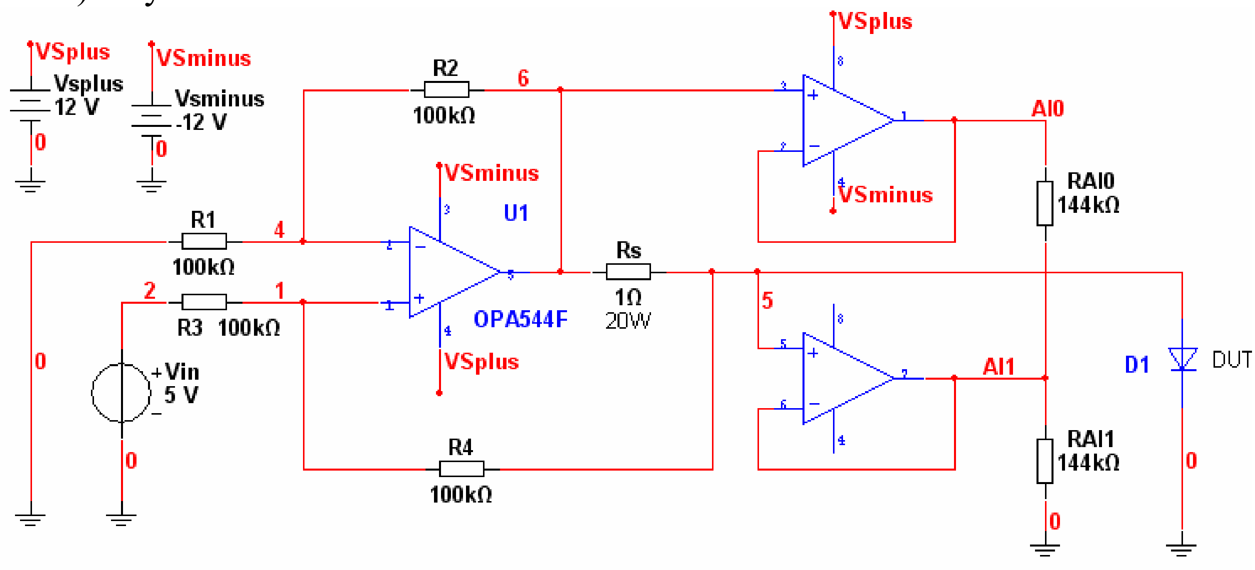

Fig. 2. High current voltage controlled current source

The circuit of the high current VCCS used in presented development is shown in fig. 2. For high current generation the operational amplifier from Texas Instruments OPA 544 with 4 ampere output current is selected [5]. The resistors values are chosen following the considerations and recommendation from design methodology presented in reference [4]. The voltage followers are needed because of relatively low input impedance of selected DAQ (144 kΩ for USB DAQ 6009 labeled as RAI0 and RAI1 in fig. 2). The important requirements for operational amplifiers used as voltage followers are low input offset voltage and high input impedance. If more sophisticated (and more expensive) DAQ is selected the followers are unnecessary.

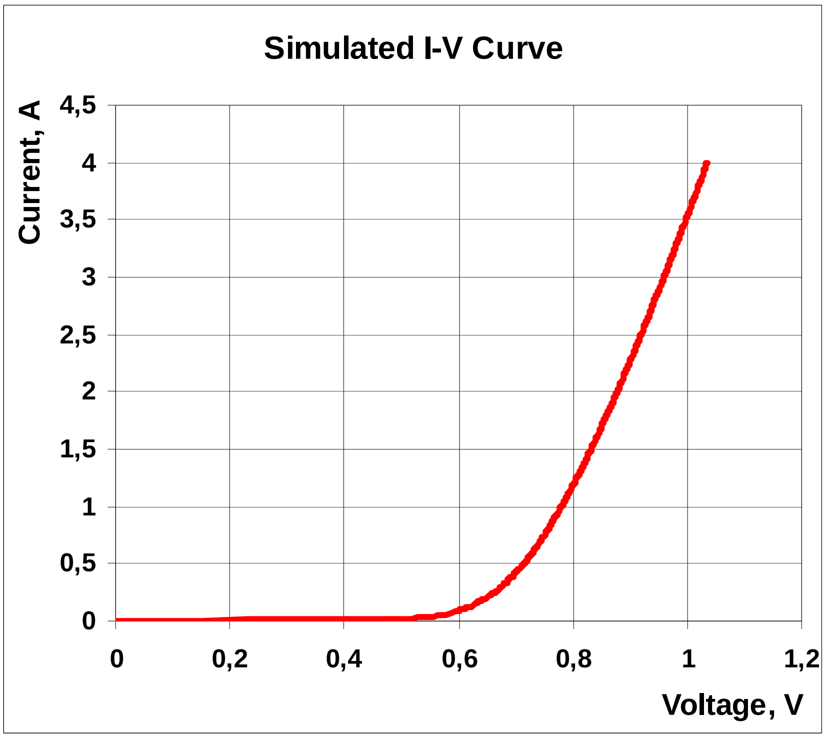

Fig. 3. Simulated I-V curve of power diode

Voltage difference between nodes AI0 and AI1 divided to sensing resistor R_S from fig. 2 will give current flowing into device under test. On the other hand the voltage in node AI1 will give the voltage across DUT. If these voltages are measured in sequence and after ordinary mathematical division then the I-V curve of DUT can be achieved.

To illustrate capability of designed circuit to drive high currents into loads the number of simulations is done. As DUT a power diode is selected and simulated I-V curve of this diode is shown in fig. 3.

3. SOFTWARE DESIGN AND OPERATION MODES

The leading software environment for data acquisition and instrument control is LabVIEW [6]. With this graphical language, users can acquire, analyze, and present real-world data from plug-in data acquisition boards, modular PXI instruments, traditional GPIB instruments or devices controlled via serial interfaces [7]. Because LabVIEW is commonly used to characterize circuit prototypes in design labs this software environment is used in presented development.

One of the more power features of LabVIEW is the build in connection with DAQmx data acquisition device drivers. DAQmx is a new type of drivers that saves development time and improves the performance of data acquisition applications [6]. One of the ways DAQmx saves development time is by providing an application programming interface that requires only a small number of functions to expose. This means that all of the functionality of a multifunction device is programmed with the same set of functions. In LabVIEW, this is possible because polymorphic software component accepts multiple data types for one or more input and output terminals. Another significant feature of the DAQmx architecture is measurement multithreading which means that multiple data acquisition operations can occur simultaneously.

The developed software that controls presented virtual source-measure system is shown in fig. 4. The DAQmx functions is placed in upper part of the while loop.

The first one is ***Create Virtual Channel*** function that creates a virtual channel and adds it to a task. It can also be used to create multiple virtual channels and add all of them to a task. Second function is ***Write*** that writes samples to the specified generation task. Each instance of the DAQmx ***Write*** function has an auto start input to determine if the function will implicitly start the task if it has not already been explicitly started. In this development the ***Write*** function is configured to write one samples of analog output data for iterations of while loop. A two ***Read*** functions follow that read samples from the specified acquisition task. First of them reads voltage difference between sense resistor and the second read the voltage across investigated device or material.

The last one function is the DAQmx ***Clear Task*** that clears the specified task. If the task is currently running, the function first stops the task and then releases all of its resources. For continuous operations, the ***Clear Task*** function should be used to stop the actual acquisition or generation.

There are two operating modes of presented virtual system – "current source/ voltage measure" and "voltage source/current measure" mode. For each of modes are developed specific subVI for data manipulation. In current source mode the digital to analog converter generates voltage according equation:

$$V_{in} = I_{out} R_S \frac{R_1}{R_2}, \tag{2}$$

where I_{out} is desired output current and values of resistors is according fig. 2.

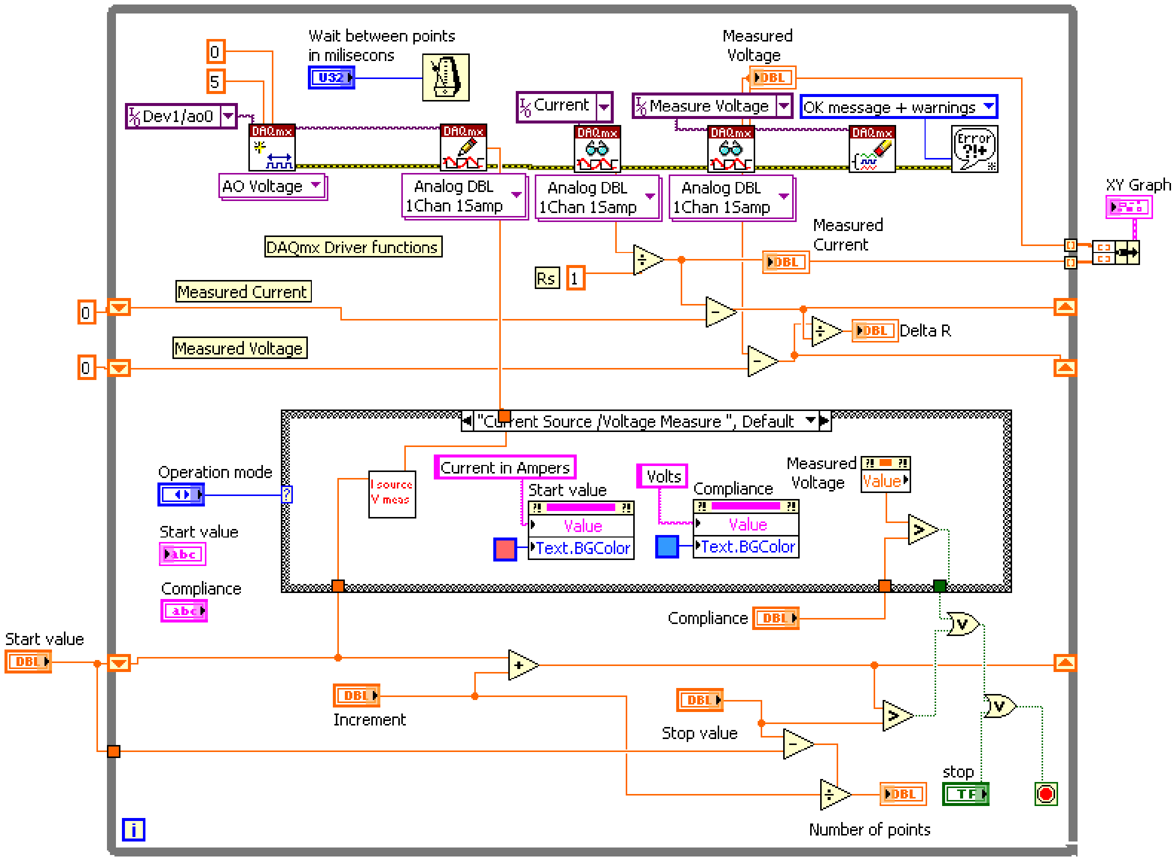

Fig. 4. Block diagram of developed software

In voltage source/current measure mode the generated from digital to analog converter voltage is:

$$V_{in} = \frac{V_{out}}{R_{DUT}} R_S \frac{R_1}{R_2}, \tag{3}$$

where V_{out} is desired output voltage and value of R_{DUT} is the resistance of device under test calculated in previous iteration of while loop.

The while loop stops if one of three events occurs – the source value reach desired value, the measure value reach compliance or the user push button "Stop".

4. Experimental Results and Application

In order to illustrate presented approach experimental results acquired from power diode (SY200) as a DUT are shown in fig. 5. The virtual SMU is used in current source/voltage measure mode. As can be seen from the fig. 5 a good agreement with simulated results from fig. 2 is achieved. There are some disturbances in the I-V curve caused by noise and limited resolution of ADC. Better results can be achieved with high resolution DAQ. Even if generated current is less than 1 A appropriate heat sinking is necessary because of thermal protection of the amplifier.

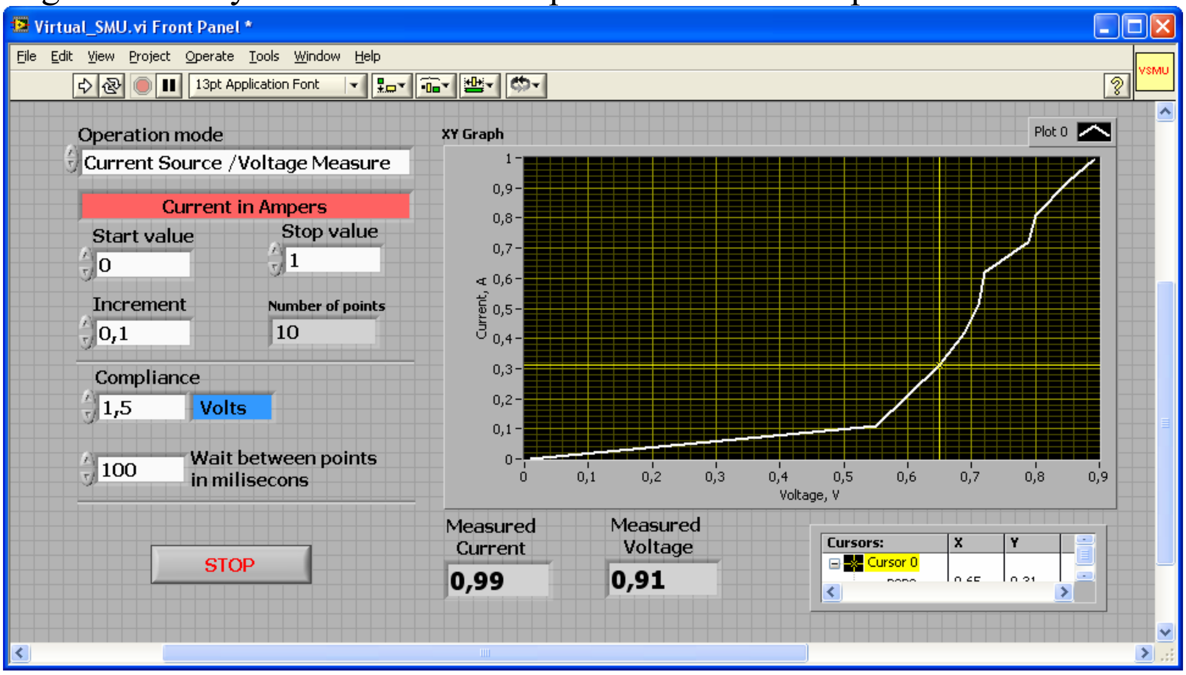

Fig. 5. Front panel of developed virtual system with experimental results

5. Conclusion

In the present paper, the design of a virtual system possessing capability of source measure unit has been discussed. The system has been designed and built using a voltage controlled current source, portable modular DAQ, application programming interface DAQmx and graphical programming environment LabVIEW. The developed system is portable and affordable since it is small and inexpensive. The experimental results show that the system is efficient and can be used for static characterization of power semiconductors, sensors and various materials.

This investigation has been carried out in the framework of the research projects 08014ни-3 and 08023ни-7/2008.

2. References

[1] Yokogawa, *Highly Accurate 2-Channel Voltage/Current Source Measure Unit GS820*, Bulletin 7656-00E, Yokogawa Electric Corporation, Japan 2008.

[2] Keithley Instruments, *Designing a Semiconductor Characterization System for an Undergraduate Fabrication Lab*, White Paper, Cleveland, Ohio, USA, 2004.

[3] Pease R., A., *A Comprehensive Study of the Howland Current Pump,* National Semiconductor, Application Note 1515, January 29, 2008

[4] Stoyanov I., Nikolov G. "Design of Voltage to Current Converter for Grounded Load" SIITME 2000 Bucharest, Romania, September 21-24 2000 pp.124-128

[5] Texas Instruments, *OPA544 High-Current Operational Amplifier*, Data Sheet, 2006.

[6] Travis, J., J. Kring, *LabVIEW for Everyone: Graphical Programming Made Easy and Fun,* Prentice Hall, 2006.

[7] Mitev, M. RS485 – transmitter-receiver controlling for various data speeds. Eleventh International Scientific and Applied Science Conference "Electronics ET'2002", book 4, p 78 - 83, Sozopol, September 25-27, 2002 (in Bulgarian).