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Extending Capability of Modular Source - Measure Units using Virtual Technique

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Abstract - **For test engineers, device developers and manufacturers, the new generation of Source-Measure Units (SMUs) can provide unique combination of sourcing and measuring instruments with either power and precision. This paper discuss ways to combine virtual techniques with multiple SMU channels from modular instruments to achieve voltage and current levels that are higher than the published direct current and voltage specifications of a single unit. In addition the examples discussed here show that by using instrument driver and graphical programming environment, the functionality of SMU can be extended.**

Keywords – **Automated Measurements, Graphical Programming, Source-Measure Units, Virtual Instrumentation.**

I. INTRODUCTION

Semiconductor devices and materials continue to occupy a great deal of technological position in the market. These devices are very important for various applications from computers, digital cameras, electronic entertainment systems, cell-phones to electronic instrumentation for medical purposes and environmental monitoring. In order to asses the device reliability and material quality, it is important to have accurate and easy to use electrical characterization techniques. The electrical characterization of semiconductor devices can be used to determine resistivity, mobility, carrier concentration, contact resistance, etc. Many important device and materials parameters can be extracted from the current-voltage (I-V) measurement. The current-voltage characteristic curves or simply I-V curves of a semiconductor device are a set of graphical curves which are used to define the relationship between the current flowing through a device and the applied voltage across its terminals. These characteristics are generally used as a tool to determine the basic parameters of a device but can also be used to mathematically model its behaviour within an electronic circuit simulators.

Most appropriate instruments for current-voltage characteristic measurements are so called Source-Measure Units (SMUs). This units, are source and measurement resources for applications requiring high accuracy, high resolution and measurement flexibility. These measurement instruments combine a programmable power source with the measurement functions of a digital multimeter. The SMU is a device that can work as a current source or as a voltage source and at the same time measuring the current or voltage across those terminals.

Usually the output power of Source-Measure Units are limited to 10 W. But in many cases, the broad use of power semiconductors required to characterize power devices with more output power. On the other hand, many parametric measurements require some sort of pulsed measurement capability. There are a number of factors driving this need, such as many physical effects, the use of novel smart materials, etc. It is very difficult to create a universal solution that satisfies all of mentioned requirements.

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This paper describes some virtual techniques that can be used to extend capabilities of SMUs. The new capabilities can be obtained by using the instrument driver and graphical programming environment. In the paper is considered the methods of extending the voltage or current range of modular SMUs and driving these units in pulse mode of operation. In order to proof the rightness of suggested methods the current vs voltage characteristics of low resistance value resistor are measured and applied.

II. MODULAR SOURCE-MEASURE UNITS

As it was previously mentioned the SMU can force voltage or current and simultaneously measure voltage or current. Every unit has three basic modes of operation - voltage source, current source and common. In common mode the SMU works as 0V voltage source and cannot perform any measurement.

Source -Measure Units have the ability to specify a compliance setting. When the SMU is in voltage source mode, the setting is current compliance and when it is in current source mode the settings is voltage compliance. When the SMU reaches compliance, it works appropriately as a constant current source or voltage source. The compliance feature prevents device damage by disable the measured value to exceed the specified compliance.

For a primary sweep measurement it is needed to specify three parameters - start, stop and step. The source-measure unit will begin with the sweep variable at the start value, and then it will increment the variable by step value. This process of incrementing by the step value and measuring continues until the sweep variable reaches specified stop value. Another sweep setup parameters, are direction and linear or logarithmic increment. The last parameter allows to specify the sweep steps are spaced linearly or logarithmically. In the case of a logarithmic sweep usually 10, 25 or 50 points per decade can be selected.

In addition, for sweep measurements some SMU can be forced in voltage pulse or current pulse mode to prevent device self-heating.

In general the minimum pulse width is 500 μs, the maximum is 5 s, and a minimum duty cycle is 0.01% [3]
It is important to remember that when making pulsed measurements must be take a care that are not specifying any other measurement conditions that might conflict with the pulse settings.

The synchronized sweep function allows to configure an SMU to track the primary sweep source. For this type of measurement two additional parameters: must be specified - a ratio and an offset value. The SMU will perform a synchronized sweep measurement tracking the primary sweep variable by a value determined by the ratio. The offset parameter allows to have a direct current offset from the primary sweep variable. The synchronized sweep function has many uses, but two important ones are placing SMUs in series and parallel

Some SMUs support a list sweep function capability. This feature allows the measurement points to be specified by an user defined list created in a spreadsheet format.
The list sweep function adds a functionality to the basic sweep function. Instead of being used with constant linear or logarithmic steps, this function permits to specify the step points completely arbitrarily.

To achieve high output voltage it is possible to combine SMUs in series. Because usually channel on the SMU is an isolated output, it can be cascaded in series with other channels to generate higher output voltages. For series connection, the output voltage is the sum of the voltages of the individual output and the current is the current of any one output. Each of the individual outputs must be programmed to obtain the total output voltage. Obviously, care should be taken that the output voltage of each unit does not exceed the maximal channel to earth ground specification listed in documentation.

If it is needed to create a constant current source with higher voltage levels than a SMU can provide, it is possible to use two SMU channels in series with first one configured in voltage mode and the second configured in current mode. By this configuration, the combined supply still operates in constant current mode, because the current level is maintained by the second SMU operating in current mode.

Combining SMUs in parallel in current force mode seems to be relatively easy. According Kirchhoff’s current law, the sum of the currents entering a node is equal to the sum of the currents leaving the node.. For parallel connection, the output current is the sum of the currents of the individual output and the voltage is from each of the outputs. [1]. However, the usefulness of such parallel connection is limited when SMUs are in voltage mode of operation [3]. When two SMUs in parallel are programmed at the same voltage level, low variations in the circuitry prevent their voltage levels from being exactly the same. Because more of SMUs are four-quadrant supplies these minor variations could cause one channel to attempt to control another. One SMU output may begin to sink the current provided by the other SMU instead of being directed to the output. This situation can be avoided by using diodes on the output of each channel to guide the current in one direction. To cancel out the voltage drop that will appear across the diode, remote sense can be connected directly across the DUT terminals.

The U2722A is USB Modular Source Measure Unit with a three channels 20V/120mA; It can operate in a 4-quadrant operation and can be programmed for voltage and current, and measure signals down to pico amperes. In four-quadrant operation, it is capable to source or sink current with both polarities of output voltage. The channels could be connected in series for higher voltage or in parallel for higher current. But many of the functions listed above, such as pulsed sweep, synchronized sweep, list sweep etc. are not supported by hardware of U2722A. In next chapters are considered a ways to establish such functionality by virtual methods.

III. Instrument Driver

Recently almost all measurement instruments support remote control by a personal computer. Usually this is accomplished by sending commands from a development environment to the instrument. In more cases this commands are in ASCII format, according Standard Commands for Programmable Instruments (SCPI). While these commands are in most cases well documented, it is very difficult to understand how the commands interact, especially in large measuring systems.

Instrument driver is a set of software routines that simplifies remote instrument control. It provides a higher level interface and a more abstract view of the measurement device that is easier to understand.
In addition instrument drivers provide a common framework, so that a software engineer can move quickly, between different instruments without having to learn new commands.

The modern instrument drivers define an abstraction layer using Virtual Instrument Software Architecture (VISA). This software architecture provides a standard communication driver to handle all forms of instrument interfaces, whether the bus is RS-232, USB, GPIB, VXI, PXI or Ethernet. When an instrument is opened, a VISA session identifier is created to uniquely identify that measuring instrument. Because instrument drivers also encapsulate the SCPI commands, data is exchanged in string format for message-based instruments.

Virtual instrument software architecture is an integral part and an accepted standard of LabVIEW. In this graphical programming environment is defined an internal design model of instrument driver [9]. All user accessible software components are organized into a modular hierarchy based on measuring instrument functionality.
The structure of LabVIEW instrument drivers is shown in the Fig. 1.

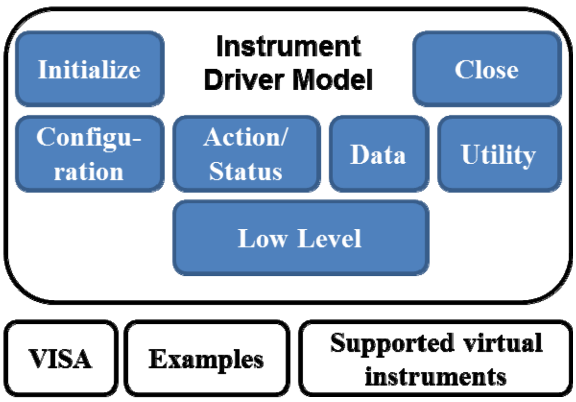


Fig. 1. The structure of LabVIEW instrument drivers

For test engineers, the model provides a structural instrument driver model. Once an user understands one instrument driver, he can apply that knowledge to other LabVIEW instrument drivers.

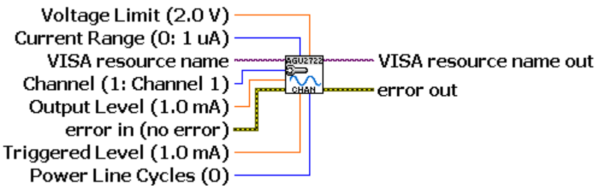
The LabVIEW instrument driver‘s functions for remote control of modular SMU Agilent U2722 are summarized in Table 1.

TABLE 1. AGILENT U2722 LABVIEW INSTRUMENT DRIVER

INITIALIZATION Initialize.vi

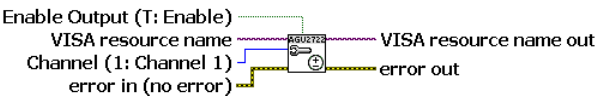
Establishes communication with the instrument and optionally performs an instrument identification query and/or an instrument reset. It also places the instrument in a default state needed for other instrument driver operations. Therefore, call this VI before calling other instrument driver VIs for this instrument. Generally, you need to call the Initialize VI only once at the beginning of an application.

CONFIGURATION Configure Channel.vi



Configures the output mode and characteristics of each channel. This function is polymorphic and configures the channel to output in source current or source voltage mode.

CONFIGURATION Configure Output.vi

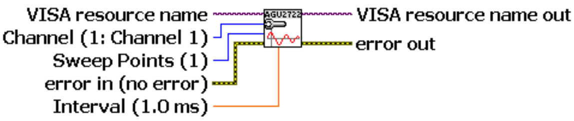


Configures the output state for the specified channel.

CONFIGURATION Configure Power Line.vi

Configures the characteristics of power line.

CONFIGURATION Configure Sweep.vi

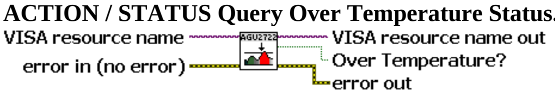


Configures how the instrument measures multiple points.

CONFIGURATION Trigger.vi

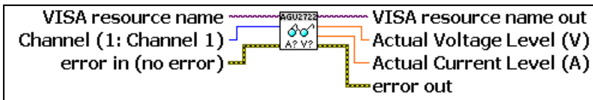
Configures the trigger source.

ACTION / STATUS Query Over Temperature Status.vi



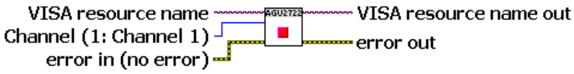
Returns the status of over voltage temperature protection.

DATA Read Output (Single or Multiple).vi



Returns the actual voltage level and actual current level for a desired channel. This function is polymorphic and returns single value or array of values.

LOW LEVEL Abort.vi



Aborts an acquisition and returns the instrument to the Idle state. You initiate an acquisition with the Initiate VI. Use this VI only with other low-level VIs. The high-level VIs automatically incorporate this functionality. This VI does not check the instrument status.

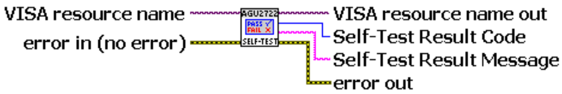
LOW LEVEL Initiate.vi

Initiates an acquisition. After you call this VI, the instrument leaves the Idle state and waits for a trigger. As at Abort.vi use this VI only with other low-level VIs.

UTILITY Reset.vi

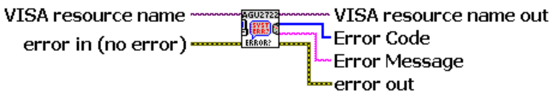
Resets the instrument and then sends a set of default setup commands to the instrument.

UTILITY Self-Test.vi



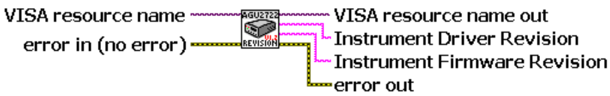
Runs the instrument's self-test routine and returns the test results.

UTILITY Error Query.vi



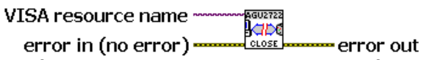
Queries the instrument for any errors in the instrument's error queue. It will continue to read errors until all errors have been read from the instrument. Any errors will be returned in the **error out** control.This VI is called automatically by most driver VIs so it is not usually necessary to call this in an application.

UTILITY Revision Query.vi



Queries the current instrument firmware revision and instrument driver revision.

CLOSE Close.vi



Performs an instrument error query before terminating the software connection to the instrument.

IV. Experimental Results

Implementing the internal design structure shown in Fig. 1 and virtual instruments summarized in Table 1, a test engineer can combine instrument driver functions to create applications. The block diagram in the Fig. 2 shows how instrument drivers programmatically force the U2722 in pulsed mode of operation. In order to control pulse width function Time Delay is used. The linear sweep is controlled by start, stop and steps parameters. Actually parameter steps is the count terminal, that specifies the number of execution of the code inside the For Loop. As can be seen the block diagram consists from driver functions, build-in LabVIEW functions and VISA functions. With appropriate arrangement this functions build command strings and send them to the source-measure units. The VISA functions perform device management, communication, and error handling.

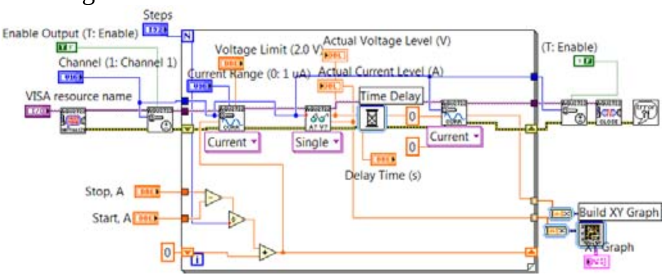


Fig. 2. Block diagram of VI for driving SMU in Pulsed mode of operation

The front panel of the created application is shown in the Figure 3. As a device under test the resistor with low lever resistance is used. Since a standard resistor does not have coherent self-heating or some electron trapping issues, the results of the measurements with linear sweep and pulsed sweep should be the same.

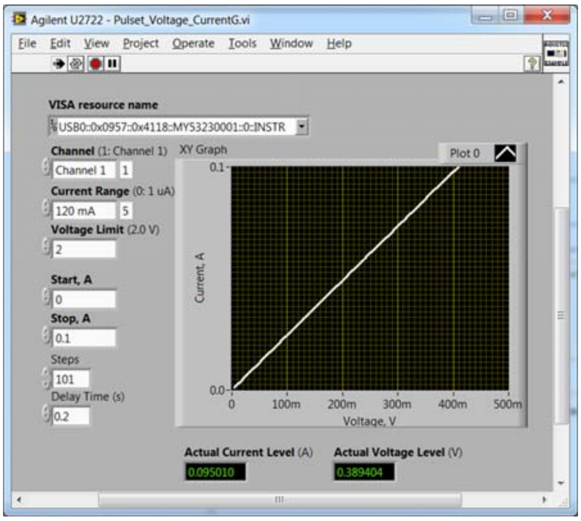


Fig. 3. Front panel of VI for SMU control

Figure 4 shows the block diagram of the instrument driver application for controlling two SMUs in parallel mode. As in previous diagram here is used driver functions, built-in LabVIEW functions and VISA functions. The specific code in Figure 4 placed below in Case structure send commands to second SMU. When the primary sweep reach the current limit of the first SMU the Case structure is changed in True and the second SMU going to drive in parallel mode. In such way the value of the output current is doubled.

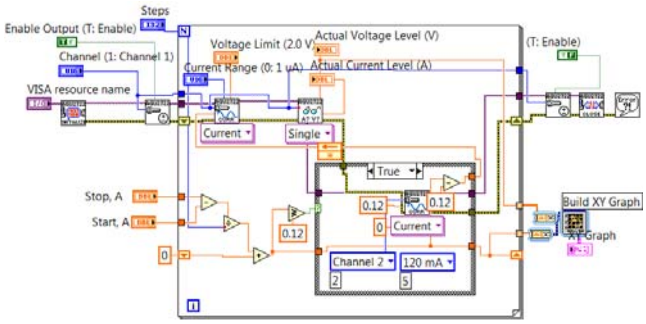


Fig. 4. Block diagram of VI for SMUs in parallel

V. Conclusion

In the presented paper a number of virtual techniques that can be used to extend capabilities of SMUs are described and considered. The new capabilities can be obtained by using the instrument driver and graphical programming environment. For example with two channels connected in parallel, it's possible to deliver twice the current to the tested device as would be possible using a single channel. In the paper is considered the method of driving the units in pulse mode of operation. In order to proof the rightness of suggested methods the current vs voltage characteristics of low resistance value resistor are measured and applied. The introduced methods can be implemented for characterizing many other electronic devices and circuits.

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