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Automated Measurement of Power MOSFET Device Characteristics Using USB Interfaced Power Supplies

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Automated Measurement of Power MOSFET Device Characteristics Using USB Interfaced Power Supplies

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Abstract

This paper describes use of USB interfaced multi-source DC power supplies to measure the I-V characteristics of high current, high power devices, specifically Power MOSFETs and Power Diodes. The LabVIEW GUI program we developed enables the user to run the measurement, automatically, over the user specified current and voltage ranges while protecting the device from excessive currents and overheating via current and power limits also specified by the user. The LabVIEW runtime window indicates the progress of the measurement time with a highlighted horizontal bar graph display and plots the drain I-V characteristics of the device in real time as the data is gathered. At the conclusion of the measurement an Excel compatible file is created for further evaluation, interpretation, graphing of the data, and for SPICE parameter extraction [1]. Power MOSFET devices, to measure their I-V characteristics under a PC's control, require a power supply with a minimum of two channels which can be controlled by a PC via a serial, or a GPIB, or a USB interface. Our experiments were conducted with a Keithley 2230-30-1 Triple Power Supply unit [8] which has a USB interface. Maximum measurement ranges of voltage and current are limited only by the power supply at hand, not by the software. Our power supply had three channels, Channels 1 and 2 rated at 0-30V, 1.5Amp maximum, and a Channel 3 rated at 0-6V, 5.0 Amp maximum.

The power diode version of the program also gives the option of semi-log plotting of the diode I-V data in real time for the user to estimate a PN-junction diode's forward ideality factor and its saturation current directly on the screen.

This is the first demonstration of using USB interfaced affordable power supplies instead of expensive source-measure units (SMU's) to measure the I-V characteristics of high-power semiconductor devices. Because of its simple and inexpensive hardware requirements, the system is perfectly suitable for use in the undergraduate electronics laboratories for instruction as well as being a tool in industrial and research laboratories for the product testing and characterization of high power semiconductor devices. The system can also adapted to measure the I-V characteristics of solar cells [2] and solar panels, and high-power Bipolar Junction Transistors (BJTs), as well.

1. Introduction

This paper describes the design, operation and use of a PC controlled automated measurement system for the testing and measurement of the I-V characteristics of high-current high-power

MOSFET devices by employing the new inexpensive USB interfaced triple-channel bench power supplies as opposed to a set of two expensive Source-Measure-Units (SMUs) [8, 9, 10, 11]. The paper also includes the results of such automated measurements taken on sample high-power MOSFETs and a discussion of the results.

In the past decade, with the invention and production of reliable, second-breakdown-free and inexpensive HEXFET Power MOSFETs, high-power high-current Bipolar Transistors (BJTs) have been replaced by the HEXFET power MOSFETs. In addition to the advantage that power MOSFET's, unlike BJTs, did not require a base current to turn on, they also behave like a simple resistor with an extremely low "On Resistance" for switching applications [3]. Such small on resistances delivered by these devices allows the MOSFET to work as a switch to power the load with minimum a power loss and helps high power circuits to achieve very high efficiencies whether it be energy conversion like DC-to-DC or DC-to-AC power converters, or DC motor controls or, stepper motor driver circuits. The fact that the gate current is almost zero makes these devices very suitable to be driven directly from microprocessor or microcontroller output at low voltages (typically 0-5 volts TTL level) with no need for a specialized power driver amplifier. That is why we are seeing them utilized in all digital power control projects, and also in Pulse-Width-Modulated (PWM) analog power control projects, as well. To name a few, robotics control, electric vehicle drive control, heating and ventilation applications, and alternative energy projects like wind power or solar power applications [4].

Measurement of a power MOSFET's I-V characteristics becomes important when the application and the circuit to be designed needs details of the characteristics, in particular if tight tolerances are dictated on the design, and more importantly, when a realistic SPICE model of the device is needed for an accurate simulation of the power system is to be performed prior to building and testing it under the risks of damage and high cost associated with the high power levels involved. Manufacturers provide data sheets of these devices with detail. Reference [5] gives an example of such a data sheet for a high-power high-current MOSFET. However, in most data sheets the emphasis is on the extreme values rather than the midrange operation where most applications operate the device at. This is particularly relevant when such a power MOSFET is driven at 0-5V TTL level the gate voltages provided by microprocessors in digital control applications and PWM based DC motor driver circuits, examples of which were mentioned above. That is why an in-house capability is needed to measure the I-V characteristics of these devices. Unfortunately the high cost of power semiconductor test equipment comprised of multiple units of Power SMUs [8, 9] is prohibitively high to have in a small design company, an R&D laboratory, or a university teaching/design laboratory.

This paper reports perhaps the first demonstration of using USB interfaced affordable power supplies instead of expensive source-measure units (SMU's) to measure the static I-V characteristics of high-power semiconductor devices. LabVIEW [6, 7] has been chosen to design and develop a GUI control system which is not only user friendly but also flexible and transportable with an executable runtime file which can run on any PC without requiring a

LabVIEW full program package to have been installed. Because of its simple and inexpensive hardware requirements, the system is perfectly suitable for use in the undergraduate electronics laboratories for instruction as well as being a tool in industrial and research laboratories for the product testing and characterization of high power semiconductor devices.

The system can also be adapted to measure the I-V characteristics of solar cells [2] and solar panels, and high-power Bipolar Junction Transistors (BJTs), as well.

In the following sections of the paper a description of the system will be given followed by a description of the LabVIEW control and the GUI window which provides options and ranges to be chosen by the user, and displays the measured device characteristics as the measurement proceeds. In the later sections, samples of measurement results, data saved and the device characteristics plotted will be shown together with the interpretation and discussion of these results.

2. The Measurement System

Power MOSFET devices, to measure their I-V characteristics under a PC's control, require a power supply with a minimum of two independently variable DC source channels which can be controlled by a PC via a serial, or a GPIB, or a USB interface. Our experiments were conducted with a Keithley 2230-30-1 Triple Power Supply unit which has a USB interface, a fast, convenient and inexpensive interface. Our system's maximum measurement ranges of voltage and current are limited only by the power supply at hand, not by the software driving it. Since our power supply had three channels, Channels 1 and 2 rated at 0-30V, 1.5Amp maximum, and a Channel 3 rated at 0-6V, 5.0 Amp maximum the Power MOSFET measurements were limited to 0-30V at 1.5 Amp maximum or 0-6V at 5 Amps maximum. With other models available from Keithley Instruments [8] and others the system's measurement capability can be increased up to 72V and 5 Amps easily, without requiring any changes in the control software.

Figure 1 gives the photo of our hardware setup comprising of a Keithley 2230-30-1 triple channel USB interfaced power supply, the device, International Rectifier's IRF640N HEXFET NMOS Power Transistor in TO-220 package installed on a black, finned heat sink, with three soldered leads connecting the device to two of the three channels of the power supply. Actually, the heat sink seen in the picture has two such MOSFETs, one installed on the back, a second installed on the front side of the heat sink. The devices were bolted to the heat sink with thermal grease, "silicone heat sink compound," applied in between for good thermal contact. (The thermal grease is visible in the photo as the white smeared areas surrounding the transistor.) In this particular case the gate and source terminal pair was connected to Channel 1 of the power supply, and the drain and source terminal pair was connected to Chanel 3 while a short banana cable joined the negative terminals of the two channels to create a circuit common. Channel 3 was chosen for the drain in order to test the device at high currents up to 5 Amps which this

channel is able to supply. The PC which controlled the power supply is on the left and was not captured in the photo. The PC is a laptop operating in Windows 7 with LabVIEW'2015 installed. However, a run time executable version of the LabVIEW code developed allows the system to run on any PC without requiring the LabVIEW program to have been installed. Therefore, the setup is portable; it can be run from any PC, desktop or laptop, by simply installing the executable run time version of the code and plugging the USB cable to the power supply.

The photo was taken while the automated measurements were taking place as seen from the LED display panel on the power supply.

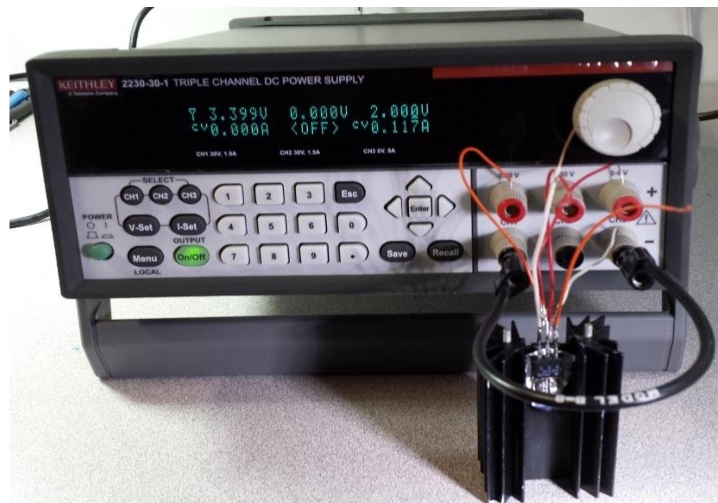


Figure 1. Power MOSFET Automated I-V Measurement Setup and Connections

(Channel 1 = VGS, Channel 2 = OFF, and Channel 3 = VDS)

Figure 2 shows the screen captured image of the LabVIEW window while the program is idling, ready for the user to pick and input the test parameters including the maximum current and maximum power limits needed to protect the device from overheating or getting damaged from excessive current during the test. At the beginning the program initializes, searches for the instruments connected and allows the user to pick the power supply to be used among the instruments the PC is connected to. Note that any combination of two channels out of the three can be selected. The GUI window design also includes bar graphs which display channel currents and channel powers delivered by each channel to the device for the user to monitor them visually. In addition, a larger green bar graph displays the progress of the test in relation to the expected time to completion.

On the right hand side of the front panel window, measured drain current is plotted as a function of the drain voltage. Since stepping of drain voltage is nested in the stepping of gate voltage multiple branches of drain I-V curves are generated, in real time as measurements progress, for

each value of gate voltage step. In Figure 1, the system is in idling mode, waiting for a start from the user. The drain I-V plots displayed are actually what was left from the previous run; it gets erased when the new run is started and evolves into a new plot as the measurement progresses.

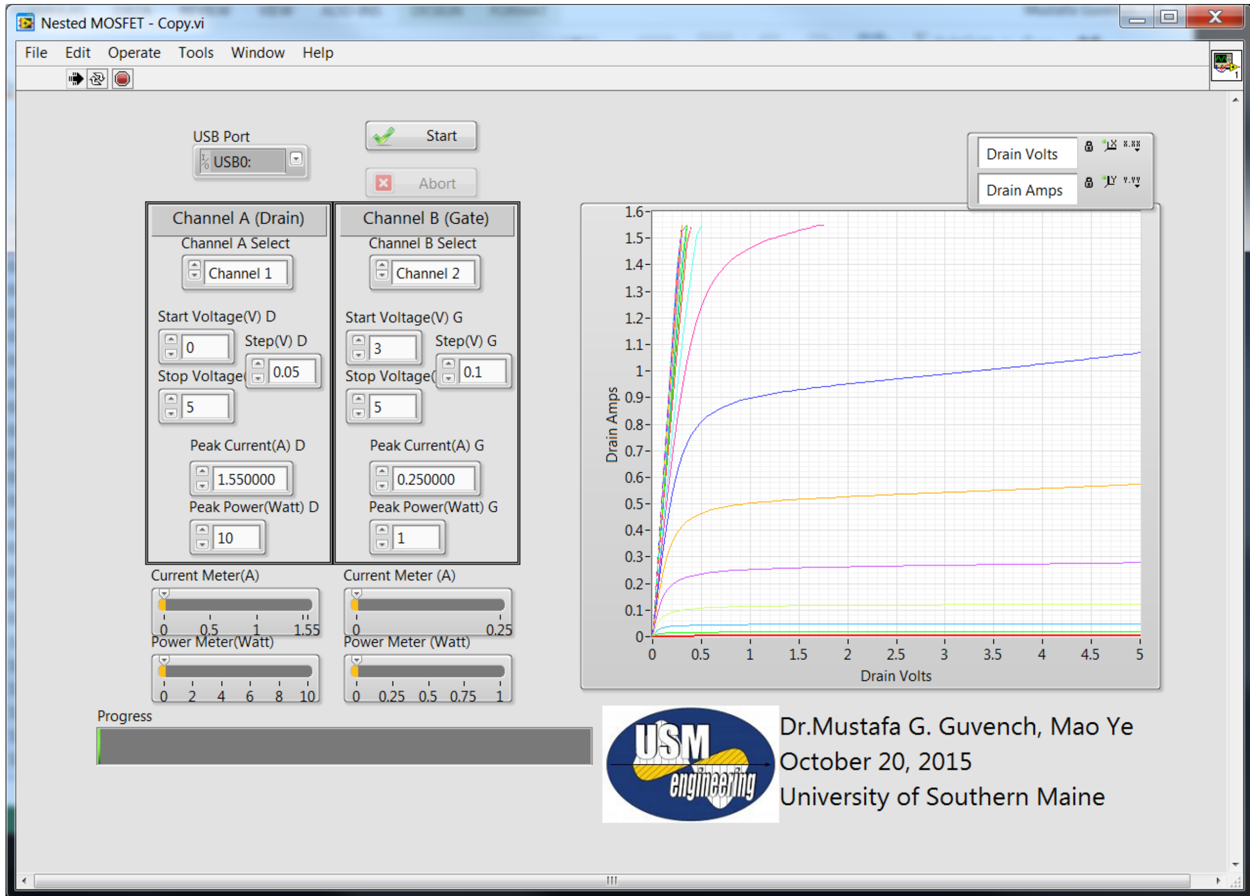


Figure 2. The GUI Front Panel of LabVIEW Window

(The program is running on idle, displaying the previous test's setup values and the plotted results, and ready for the new values to be entered for the next I-V test run.)

The LabVIEW code developed is illustrated in Figures 3a, 3b, and 3c where sections of the block diagram of the code are copied for the experienced reader to see and analyze. Basically, section A (shown in Figure 3a) contains program, PC-interface and instrument initializations, and display and input settings for the user inputted measurement parameters like voltage steps, ranges of voltages applied, the current and power limit values, etc.. Section B communicates with the power supply and controls stepping of channel voltages which have to be stepped in two nested loops. Section C is in charge of creating an Excel compatible data file to collect and save the measurement results and create the I-V plot on the front panel while checking the conditions for maximum current and maximum power limits if they are reached, and creating a warning window if these conditions are violated. Figure 4 gives a screen captured copy of the front panel window. It clearly shows the progress bar graph advancing and current and power bar graphs

displaying the current values of the channel currents and powers being delivered to the MOSFET’s Drain and Gate terminals. At the same time, the Drain I-V data is displayed in graphical form, built in real time for the user to follow measurement results as the test progresses.

In Figure 5 the same measurement’s front panel window is given, this time captured after a maximum current limit is reached. Shown as insert is the small warning window the code generated to warn the user. It waits for input from the user to continue or abort the test. The latter option, i.e. a decision to abort, is more relevant if the maximum power limit is encountered which, if continued, may lead to a thermal run away. The LabVIEW code can easily be modified to employ the third unused power supply channel to actually monitor the device’s temperature with a temperature sensor such as a calibrated thermistor which passes current in proportion to temperature. Once a set point current (corresponding to a set point of temperature) is passed through the thermistor the LabVIEW code added would abort the test and protect the device from thermal damage.

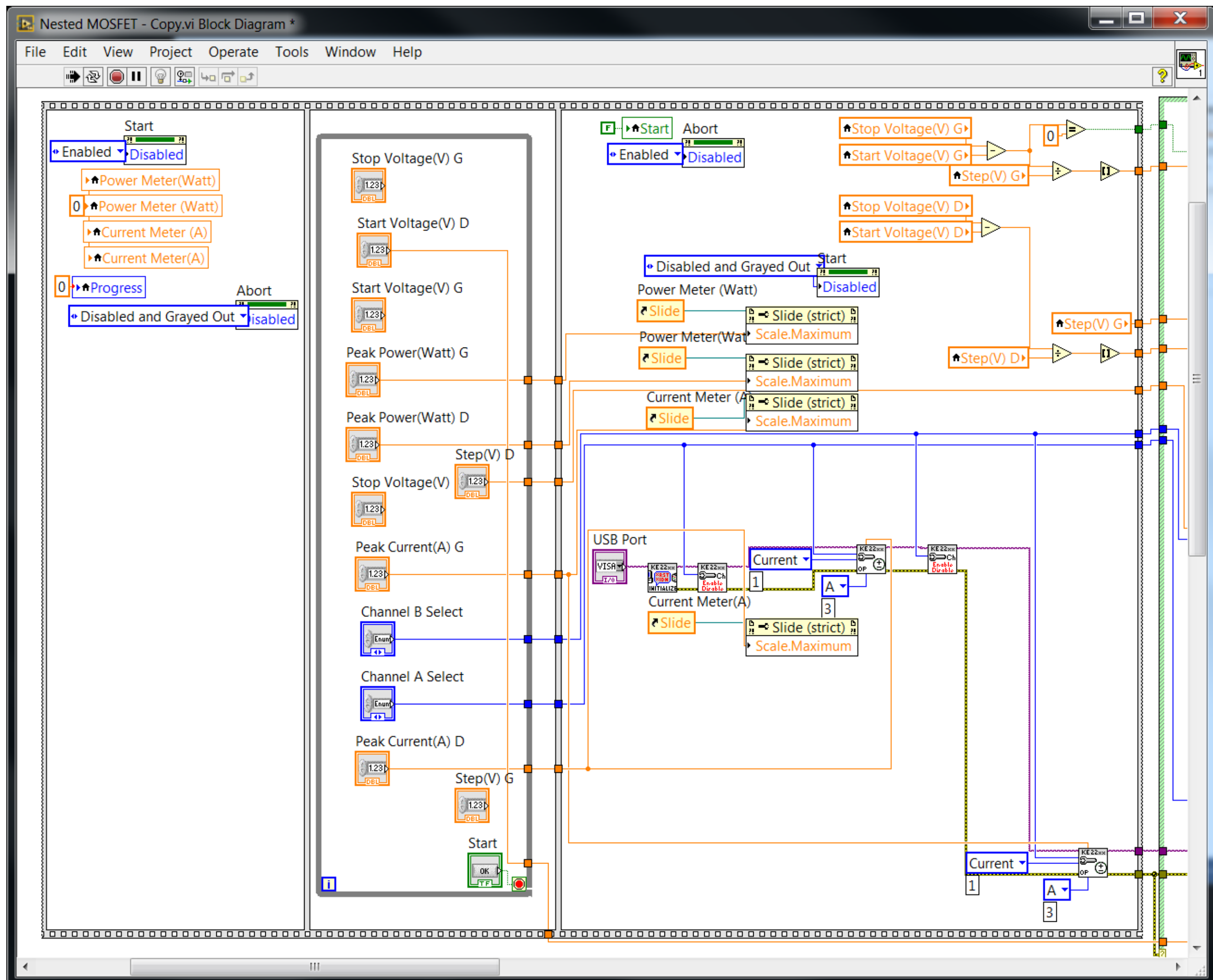
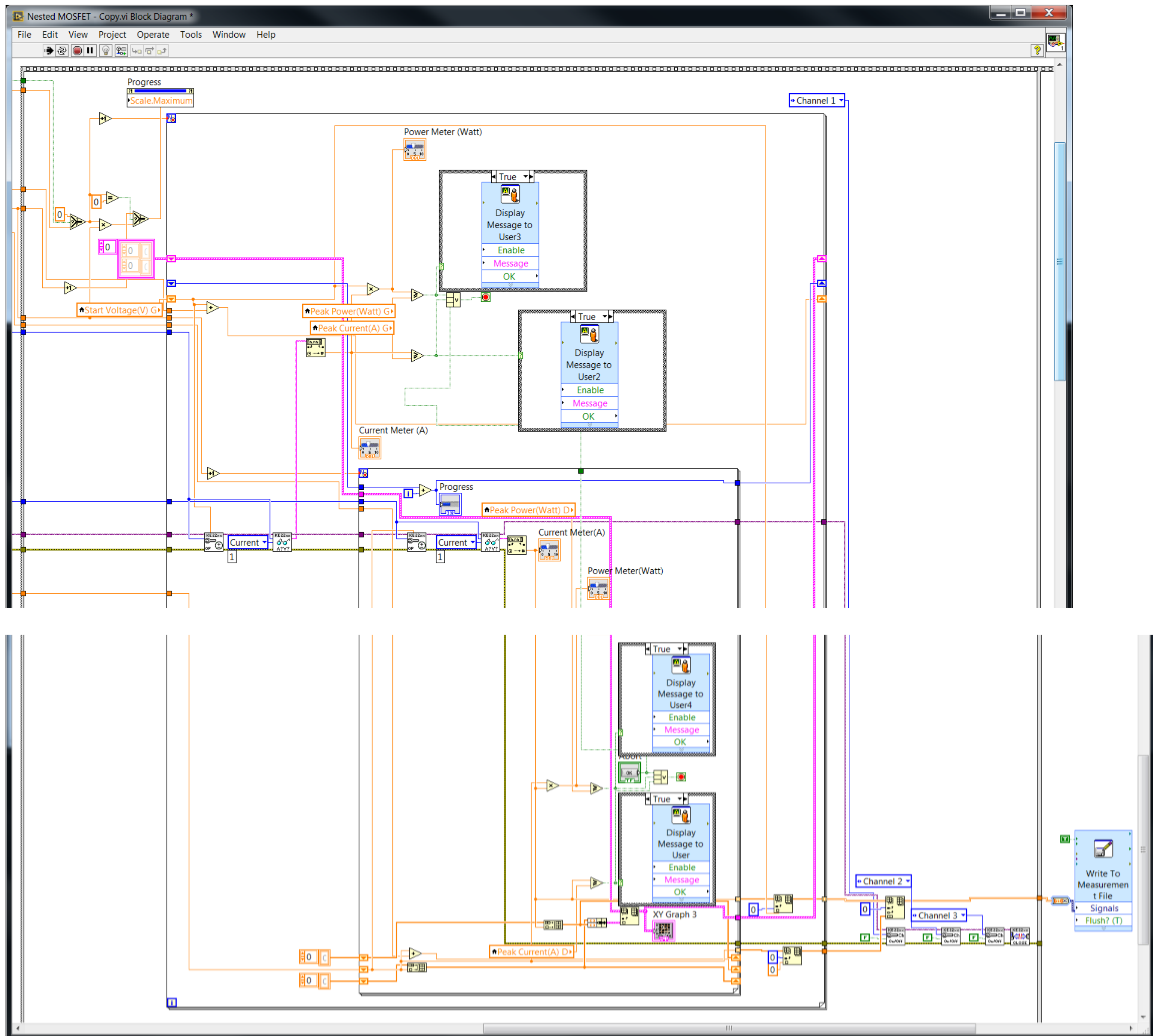


Figure 3a. The Block Diagram of the LabVIEW code (Part A: Initialization and User Definition of Measurement Parameters, Ranges of Voltage Steps and Maximum Current and Power Limits)



Figures 3b&3c. Block Diagram of the LabVIEW code (Part B (shown in top half): communicates with the power supply and controls stepping of channel voltages which have to be stepped in two nested loops within the limits allowed, and Part C (bottom half): collects data and creates plots.)

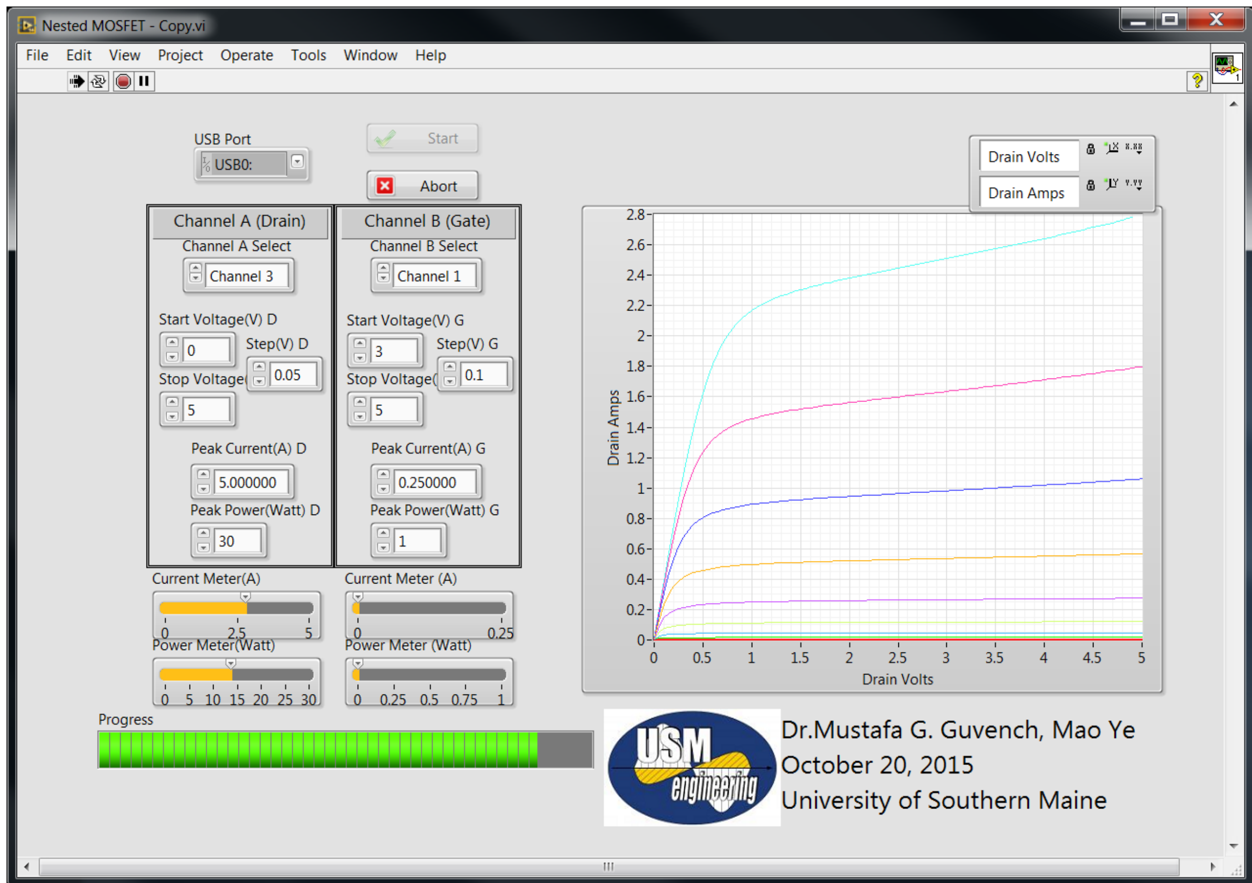


Figure 4. The GUI Front Panel of LabVIEW Window

(The program is running in normal mode, stepping Ch 1– Gate Voltage once for each loop of Ch 3 – Drain Voltage, and plotting the Drain Current in real time. Green bar graph shows progress in time while yellow bar graphs show the current and the power the device is encountering on the two channels.)

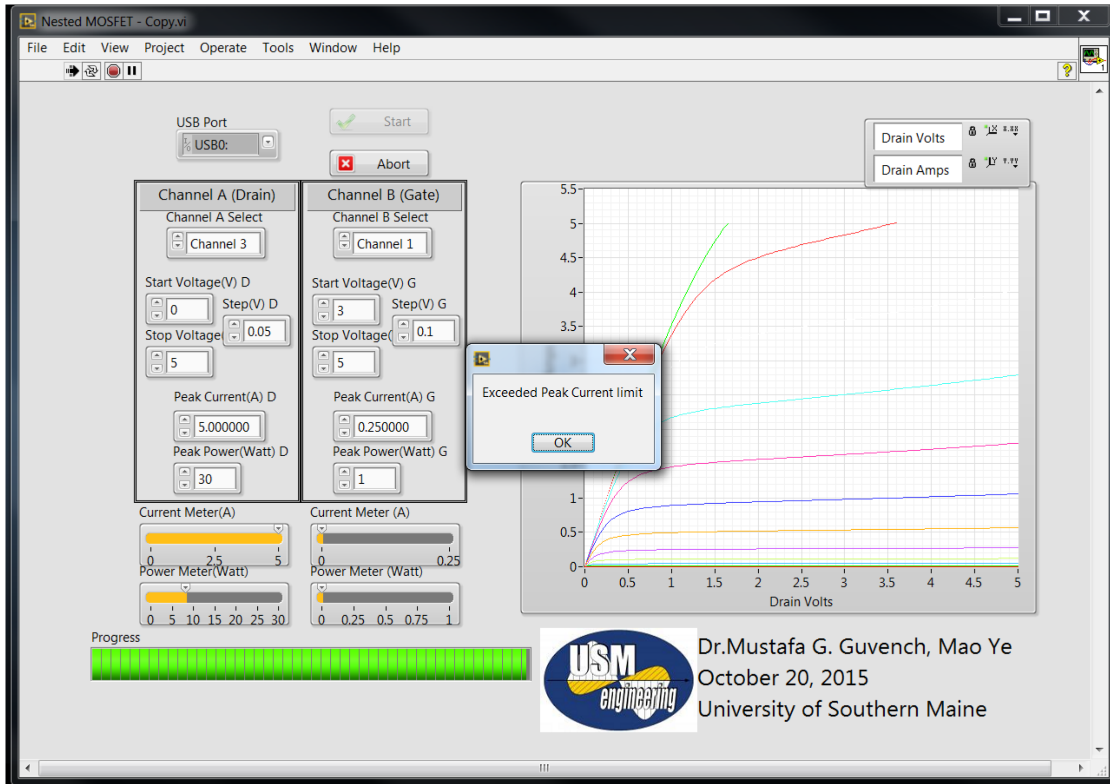


Figure 5. The GUI Front Panel of LabVIEW Window

(The program is running in normal mode, stepping Ch 1 – The Gate Voltage once for completion of each loop of Ch 3 – the Drain Voltage, and plotting the Drain Current in real time. Ch 3-Drain current has encountered maximum drain current condition which was set at 5 Amps, the program halts, pops up a small window and alerts the user of the situation. Note that Ch 3 – Drain current bar graph is at its maximum.)

IRF640 IV-5LV.xlsx - Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Untitled	Untitled 1	Untitled 2	Untitled 3	Untitled 4	Untitled 5	Untitled 6	Untitled 7	Untitled 8	Untitled 9	Untitled 1(	Untitled 1:	Untitled 1:
2	VDS	VGS=3	VGS=3.1	VGS=3.2	VGS=3.3	VGS=3.4	VGS=3.5	VGS=3.6	VGS=3.7	VGS=3.8	VGS=3.9	VGS=4	VGS=4.1
3	0	0.000006	0.000273	0.000784	0.000964	0.001544	0.003188	0.003694	0.003473	0.004186	0.003955	0.009035	0.006357
4	0.05	0.00126	0.003665	0.00987	0.024189	0.051141	0.090016	0.131285	0.164563	0.186454	0.197896	0.201353	0.200975
5	0.1	0.001371	0.004538	0.012598	0.032518	0.074387	0.144969	0.232522	0.309955	0.361762	0.389329	0.399638	0.400275
6	0.15	0.001494	0.004634	0.013699	0.036033	0.085371	0.176248	0.30549	0.43507	0.526306	0.57538	0.595539	0.597219
7	0.2	0.001616	0.004832	0.013915	0.037993	0.091635	0.194596	0.35491	0.537235	0.677687	0.754983	0.78663	0.791518
8	0.25	0.001663	0.005024	0.014304	0.039538	0.095733	0.20655	0.387983	0.617053	0.813581	0.927017	0.974069	0.984638
9	0.3	0.001709	0.00512	0.014758	0.040463	0.098986	0.215176	0.411047	0.677372	0.932291	1.08964	1.15669	1.17268
10	0.35	0.001772	0.005209	0.015142	0.04141	0.101083	0.22128	0.428152	0.722636	1.03294	1.24218	1.3342	1.35813
11	0.4	0.001766	0.005274	0.015417	0.041575	0.103312	0.226706	0.441434	0.7566	1.11596	1.38295	1.50648	1.54031
12	0.45	0.001752	0.005337	0.015602	0.042647	0.104764	0.230679	0.451535	0.783377	1.184	1.51084	1.67215	1.72004
13	0.5	0.001775	0.005444	0.01575	0.042805	0.106163	0.233914	0.459537	0.804234	1.23831	1.62509	1.83055	1.89473
14	0.55	0.001771	0.005507	0.015876	0.043117	0.107156	0.236672	0.466451	0.820755	1.28215	1.72589	1.98129	2.06586

sheet1

Figure 6. The Excel Output File with Data Generated During the Test in Figures 4 and 5

The LabVIEW code is designed to create an Excel compatible file and save all the measurement I-V data there for plotting the data later and further analysis. Figure 6 gives a screen capture of the Excel data which is ordered from top to bottom for increasing values of stepped VDS voltage. VDS stepped voltage values constitute the first column in that spreadsheet. The other columns give the measured Drain currents listed in corresponding order as the VDS values listed in the first column. These columns have at the top the value of the VGS gate voltage at which the data in the column were measured. This organization of the data can easily be transformed into an X-Y scatter plot which comes out directly in the standard form of MOSFET Drain I-V Characteristics. The Drain I-V plot created in Excel is shown in Figure 7.

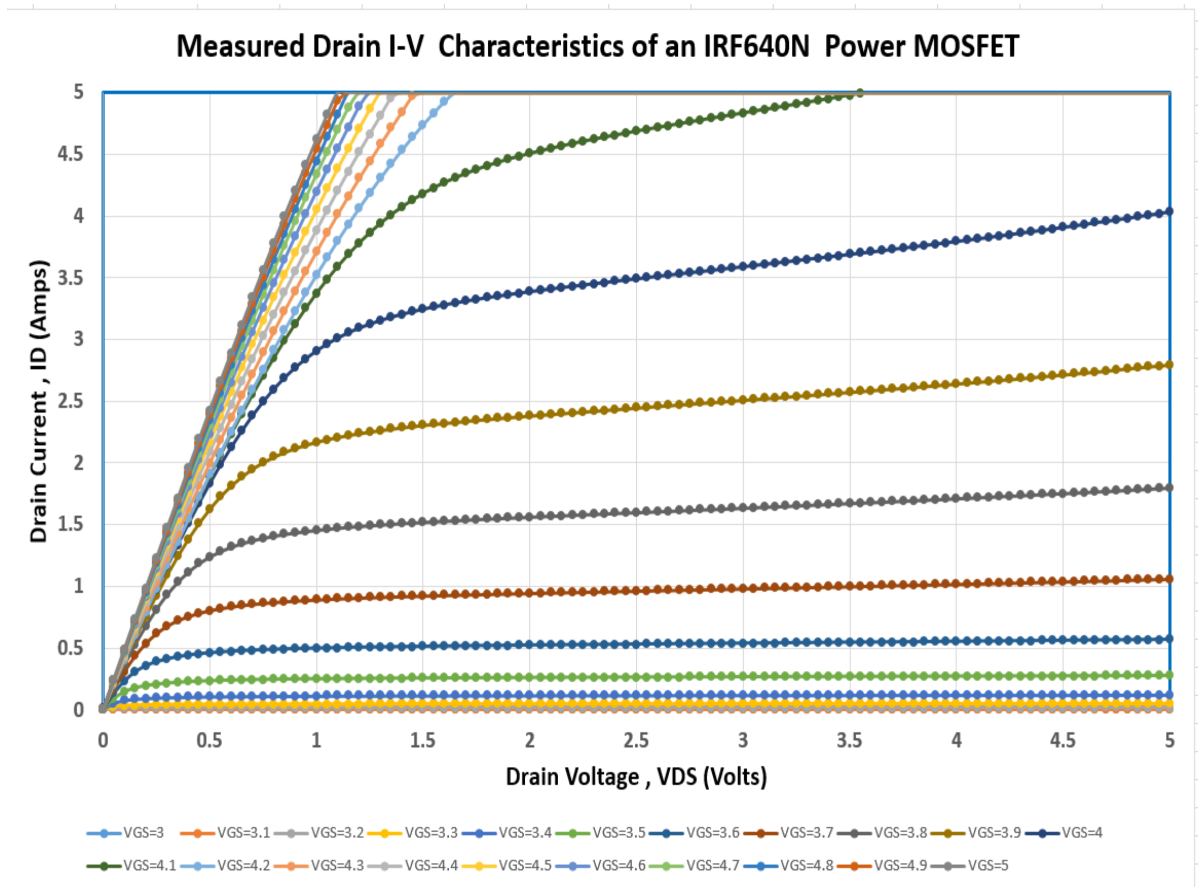


Figure 7. Excel Plotted Drain I-V Characteristics of the Power MOSFET from the Data Saved (Stepped VGS values listed in the legends run from 3.0V through 5.0V in 0.1V increments)

Note that this plot directly reveals one of the most important parameters of this Power MOSFET, namely, RON, the "On Resistance" of the device. Looking at the straight line with the highest slope one easily determines RON of this device with a gate VGS = 5 volts to be 1.1V/5Amp = 0.22 ohms. The manufacturer claims this device to yield RON = 0.15 at VGS =10 volts. Our measurement gives more relevant value for the application examples we gave earlier, like

microprocessor driven Power MOSFET which have to operate at a maximum TTL level digital output of 5 volts on its gate, proving the importance of being able to do these measurements in house, rather than relying on the manufacturer's data sheets which give the parameter measured at 10 Volts which is irrelevant for most applications.

In Figure 7, from the slope of the I-V branches, one can easily determine the SPICE parameter, LAMBDA = 1/15V. This is a parameter never specified in the manufacturer's data sheets.

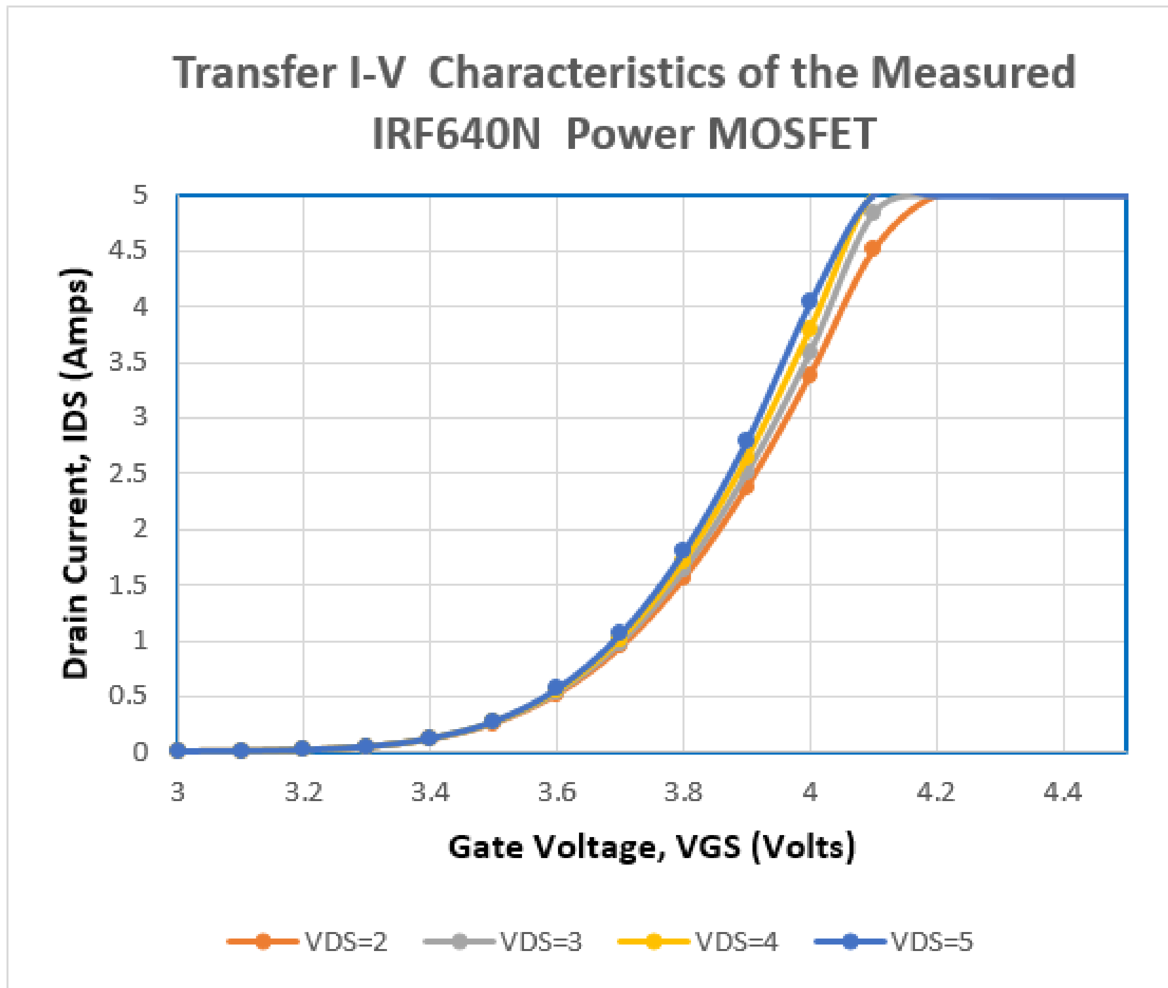


Figure 8. Excel Plotted Transfer Characteristics of the Power MOSFET from the Data Saved

The data collected and saved in Excel spreadsheet can also be used to plot the MOSFET's ID vs VGS Drain Transfer Characteristics. Figure 8 shows that plot for the IRF640N Power MOSFET we measured. From the curves generated it is clearly seen that this device turns on at a gate voltage, VGS = 3.3 volts. In the manufacturer's data sheets a vague value of VTO = 2 – 4 volts is given, too much spread for a good design. Whereas here we can clearly determine that the threshold voltage is actually 3.1 volts +/- 0.1 volt, quite precise value.

3. Conclusions, Remarks, Student Involvement and User Response

The system was built and the LabVIEW programming was written as a part of a faculty-directed senior design project at the University of Southern Maine. One highly motivated electrical engineering student (the co-author) worked on the project, focusing on learning the LabVIEW programming and developing the code. The project had the goal of creating a GUI user friendly program to measure the I-V characteristics of Power MOSFETs in the Electronics laboratory in an automated way while employing inexpensive, USB interfaced, multi-channel DC power supplies.

In the body of the paper we have demonstrated the simplicity of the hardware needed along with low cost implementation of it, excellent precision level of device current and voltage measurements achievable by employing inexpensive USB interfaced triple-channel benchtop power supplies to implement automated measurement of high power semiconductor devices. The Drain I-V curves plotted clearly showed the very low noise levels achievable.

Although the original need was for measuring power semiconductors, namely, the power MOSFETs, the range of the power supply at hand covers current, voltage and power levels of medium, even low power MOSFETs, JFETs, PN Junction diodes, Zener diodes. Therefore, the system developed can also be used to measure smaller power device characteristics, facilitating an undergraduate Electronics laboratory with an in-house device measurement and characterization capability. In that respect it will be an excellent educational tool. The plans are to introduce new experiments and demonstrations in the Electronics laboratory to enhance student learning of automated measurement as well as learning device characterization. Spring 2016 will be the first time this system will be introduced. Student response will be collected, evaluated and shared at the ASEE Annual Conference in New Orleans.

After the publication of this paper the authors plan to make copies of the run time version available to the public upon request.

References:

[1] Guvench, M.G., "SPICE Parameter Extraction from Automated Measurement of JFET and MOSFET Characteristics in the Computer-Integrated-Electronics Laboratory", Proc. of ASEE'94, vol.1, p.879-884.

[2] Guvench, M.G., Denis, A.M., and Gurcan, C. "Automated Measurement of I-V Characteristics of Large Area Solar Cells …," Proc. ASEE, s.2531, 2003

[3] Locher, R., "Power MOSFETs and their Applications", Fairchild Semiconductor Application Notes AN-558, https://www.fairchildsemi.com/application-notes/AN/AN-558.pdf

[4] "Power MOSFET Basics," A collection of application notes from power MOSFET manufacturers such as International Semiconductor, Fairchild Semiconductor, etc., http://www.tayloredge.com/reference/Electronics/Semiconductors/mosfetbasics.pdf

[5] IRF640 MOSFET Spec. Sheet, http://www.irf.com/product-info/datasheets/data/irf640n.pdf

[6] Essick, J., "Hands-on Introduction to LabVIEW for Scientist and Engineers," Oxford 2013

[7] LabVIEW is a product of National Instruments, Austin, Texas, www.ni.com

[8] Keithley Instruments' SMUs http://www.tek.com/keithley-source-measure-units and USB power supplies http://www.tek.com/dc-power-supply

[9] Keysight Technologies' SMUs http://www.keysight.com/en/pc-1862522/source-measure-units?nid=-33786.0&cc=US&lc=eng

[10] Fang, X., "Characterization and Modeling of SiC Power MOSFETs", Thesis, Ohio State University, December 2012. https://etd.ohiolink.edu/rws_etd/document/get/osu1354687371/inline

[11] Guvench, M.G., Rollins, M., Guvench, S., and Denton, M., "Automated Semiconductor Device Measurement System for Temperature and Magnetic Field Characterization," Proc. ASEE, s.2259, 2000.