# Automated Semiconductor Device Measurement System for Temperature and Magnetic Field Characterization

**M.G. Guvench, M. Rollins, S. Guvench and M. Denton**
**University of Southern Maine**

## Summary

**This paper describes the design, operation and use of a PC controlled automated measurement system for I-V characterization of semiconductor devices. The system can do, in addition to full I-V characterization of semiconductor devices like diodes, transistors and integrated circuits, characterization of their behavior under varying temperature, radiation and magnetic fields. Therefore, the system is also suitable for measuring and characterizing magnetic, radiation and temperature sensors as well as the standard semiconductor devices.**

## 1. Introduction

Principles of automated measurement of bipolar and field-effect transistors by employing the standard IEEE-488 interfaced electronic test bench instruments available in undergraduate electronics laboratories and methodologies that can be used to extract their SPICE parameters from the acquired I-V data were described earlier[1,3]. However, limited dynamic range of such electronic test bench instruments, although excellent as teaching tools, cannot be relied on for higher level modeling work needed at senior or graduate level courses and in research, particularly if CMOS components are being modeled for analog VLSI chip design. In order to facilitate automated characterization of I-V characteristics of semiconductor devices with precise measurement of terminal and environmental variables a new measurement setup was designed. This setup employs "Source-Measure-Units" rather than standard digital DC ammeter-voltmeter combinations to achieve wider dynamic range and accuracy as well as precision. Source-Measure Units (SMU's) are combined instruments comprising of a source that can be held constant, or stepped, or swept upon instructions from a controller computer, and a digital meter to measure the complement of the current or voltage forced by its source. SMU's can be operated in two distinct modes: (1) as a voltage source forcing terminal voltage and an ammeter that measures the current drawn by a device connected as a load at the SMU's terminals, or (2) as a current source forcing the terminal current and a voltmeter combined with it that measures the voltage developed across the device connected at its terminals. If the SMU's source is stepped by a controller computer a single SMU will be sufficient to get a full I-V curve of a two terminal device, such as a PN junction diode. Multiple SMU's can be employed to get I-V characteristics of multi-terminal devices such as BJT's and FET's, and even logic gates and operational amplifiers. The purpose of this project was, while synchronizing multiple SMU's to measure multi-terminal devices, also to be able to vary the environmental factors such as the temperature or a magnetic field in order to determine the sensitivity of semiconductor devices and sensors to such factors.

## 2. The Measurement System

The system designed comprises of a 9-inch pole Magnion electromagnet capable of generating fields up to 2.5 Teslas driven by a 65 ADC power supply that can be controlled by an external voltage source, a Group-3 141D model digital tesla-meter, an Oxford Instruments ITC4 digital PID temperature controller, a wafer prober with a heated chuck, two Keithley 236 source-measure units and a Keithley 213 quad voltage source. Figure 1 illustrates schematically the measurement system built. With the exception of the PID temperature controller, which is RS-232 interfaced to the PC, all of the instruments are controlled via IEEE-488 bus by a Pentium class computer. In the figure two SMU's and a quad voltage source used were represented in a block named "Parametric Analyzer" for saving space.

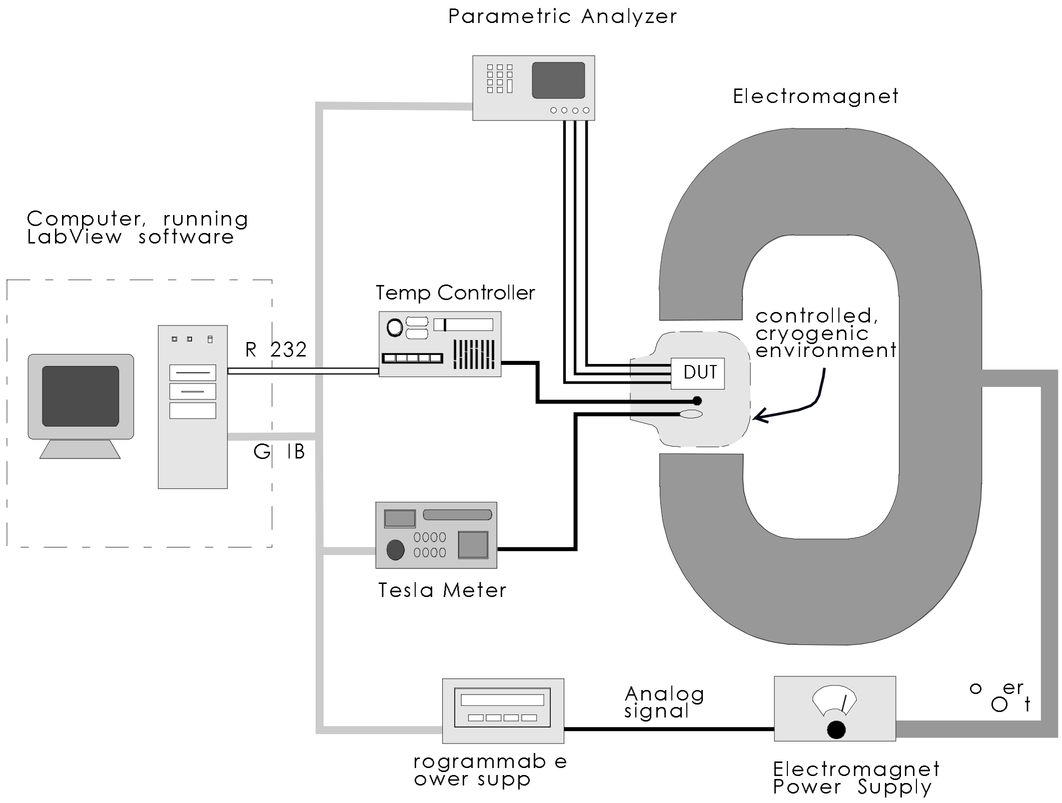


*Figure 1: System Schematic*

To facilitate a user friendly graphical interface National Instruments' LabView was chosen to create a virtual instrument and its programmable controller. The graphical interface controller is used to program and automate the measurement process.

Figure 2 gives a flow diagram representation of the routine the LabView master controller dictates on the hardware. Figure 2 shows only one SMU loop in which SMU is operated and stepped as voltage source. Actually, two SMUs are utilized whose operations constitute two interpenetrating loops, one for the input the other for the output terminals of the 3- or 4-terminal device being measured. The SMUs can be chosen to operate either as a voltage-source-current-measure or current-source-voltage-measure mode, therefore facilitating all four possible combinations of modes of operation. For BJT measurements the SMU No.1 is set to operate as a current source (to deliver constant base current steps) and SMU No.2 is set to operate as a voltage source to supply the collector-emitter voltage and measure the collector current the transistor passes in response to each ($I_B$,$V_{CE}$) value. For Field-Effect-Transistors, JFETs or MOSFETs, the SMU No.1 is set to operate as a current source to deliver the constant gate voltage steps needed and SMU No.2 is set to operate as a voltage source to supply the drain-source voltage and measure the drain current the FET is passing in response to each ($V_{GS}$,$V_{DS}$) value. Figure 4 gives the graphical user interface window our program displays for setting the SMU modes and addresses as well as the step values, ranges and maximum allowed limits (compliance's).

It is to be noted that the electromagnet's magnetic field cannot be set directly from its power supply. Instead, the DC current controlled via a voltage control input is supplied to the coils and sets the value of the field. PC control of this current is achieved through an IEEE-488 interfaced voltage source (Keithley Instruments Model 213 Quad Voltage Source) which generates the controlling voltage needed by the electromagnet's power supply. Figure 4 gives the graphical user interface window our program displays for stepping the magnetic field. The IEEE-488 interfaced Tesla meter continuously monitors the magnetic field and passes it on the controller. When the field reaches and settles at its new step value within 1%, the program initiates a full I-V measurement cycle involving SMU's and controlled voltage sources. At each bias point, the magnetic field is measured and recorded along with the I-V data.

For stepping the temperature the onboard closed-loop PID control capability of ITC4 Temperature Controller is used where the set temperature is the instantaneous value of the temperature steps controlled by the LabView program. Better than 0.2 degree control is achieved at all temperatures.

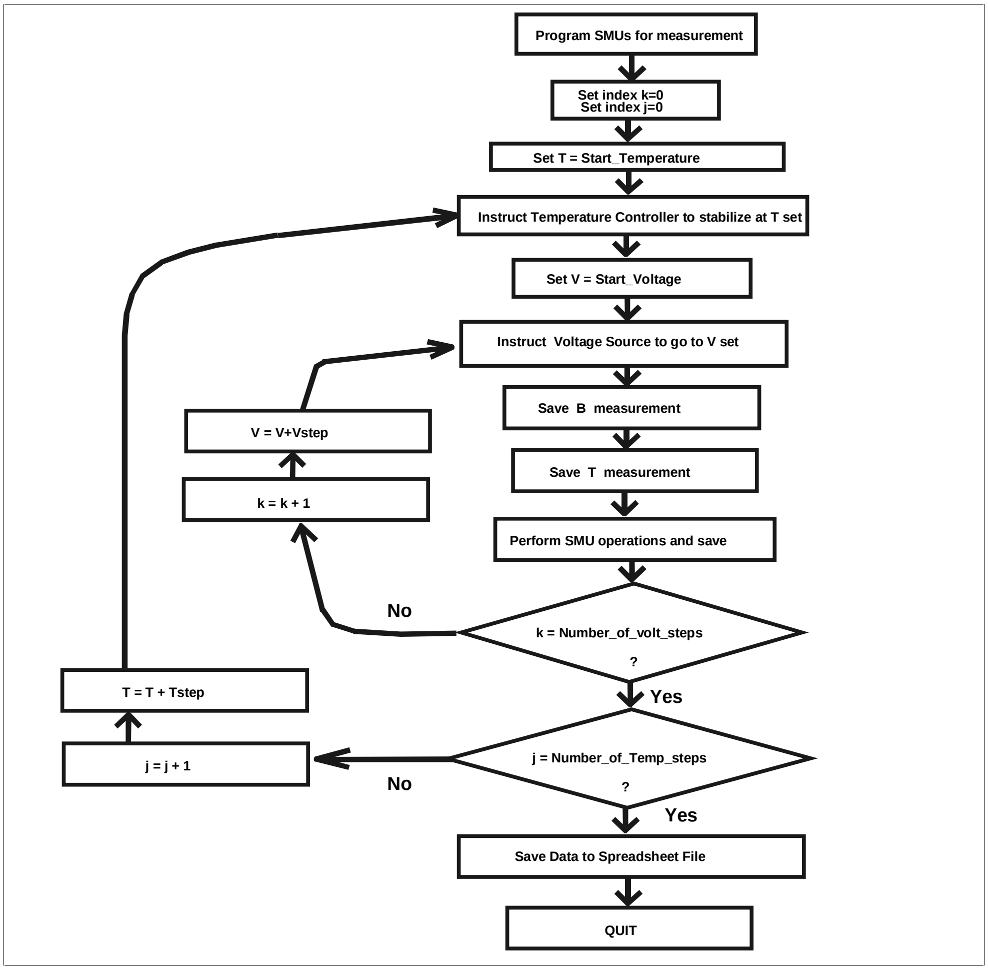
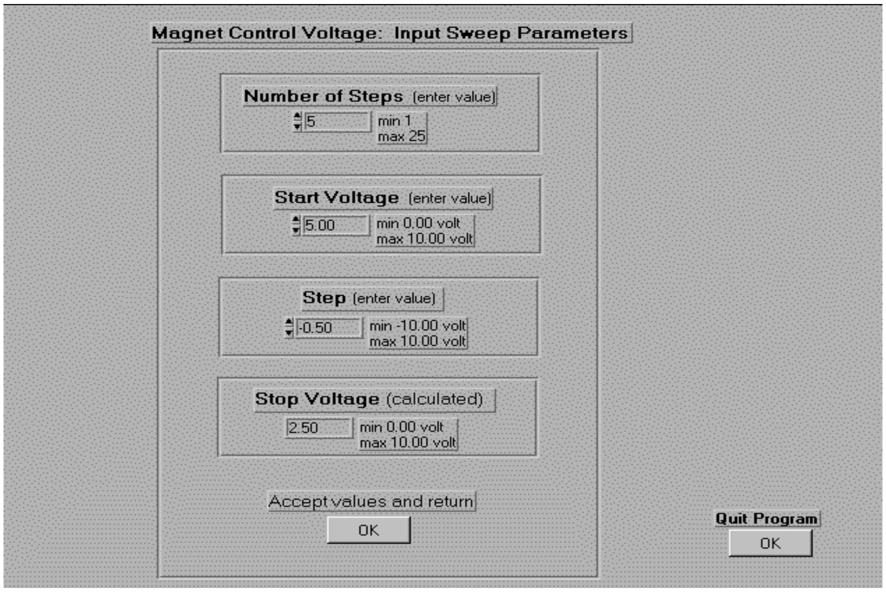


*Figure 2: Flow Chart of LabView Program*

Figures 3 and 4 show the control windows initially displayed for graphical user interface.



Magnet Control Voltage: Input Sweep Parameters

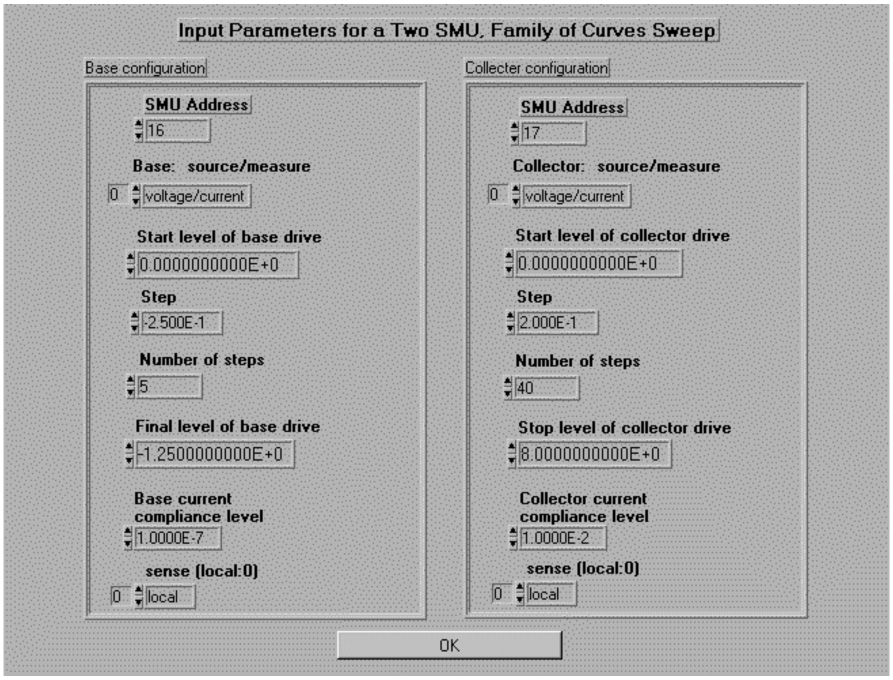
**Number of Steps** (enter value): 5 (min 1, max 25)

**Start Voltage** (enter value): 5.00 (min 0.00 volt, max 10.00 volt)

**Step** (enter value): -0.50 (min -10.00 volt, max 10.00 volt)

**Stop Voltage** (calculated): 2.50 (min 0.00 volt, max 10.00 volt)

*Figure 3: Magnetic Field Control Setup Window*



Input Parameters for a Two SMU, Family of Curves Sweep

Base configuration

**SMU Address**: 16
**Base: source/measure**: 0 voltage/current
**Start level of base drive**: 0.0000000000E+0
**Step**: -2.500E-1
**Number of steps**: 5
**Final level of base drive**: -1.2500000000E+0
**Base current compliance level**: 1.0000E-7
**sense (local:0)**: 0 local

Collecter configuration

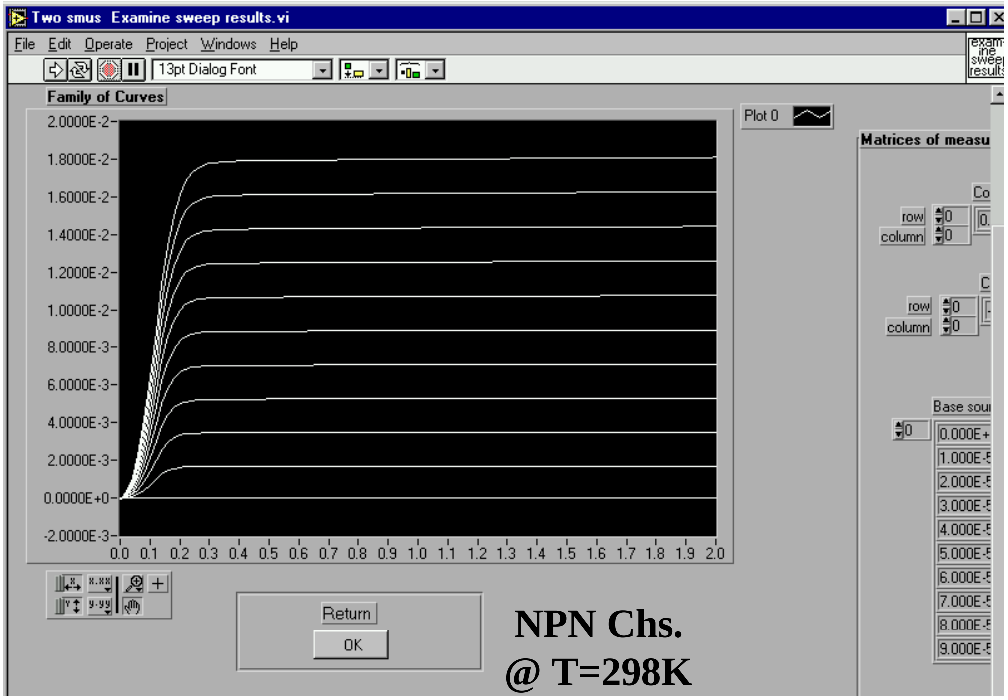
**SMU Address**: 17
**Collector: source/measure**: 0 voltage/current
**Start level of collector drive**: 0.0000000000E+0
**Step**: 2.000E-1
**Number of steps**: 40
**Stop level of collector drive**: 8.0000000000E+0
**Collector current compliance level**: 1.0000E-2
**sense (local:0)**: 0 local

*Figure 4: SMU Sweep/Step Setup Window*

## 3. Results

This semiconductor device measurement system allowed all operating parameters, including device currents, voltages, and temperature and magnetic fields to be stepped and responses to be measured and device data to be acquired automatically. The data is processed and either the results are displayed in graphical form during the test, or the data is saved into text files for use by other data processing or parameter extracting programs later.

Figure 5 gives an example of the I-V characteristics of a NPN transistor measured with this system. In one run I-V characteristics each similar to the one in Figure 5 are generated and displayed on the screen for each and every temperature and magnetic field step specified. The user has either the option of capturing the graph displayed at each temperature, magnetic field point, or the option of skipping the screen displays completely. The former gives the user the opportunity to see the characteristics of the device quickly and experiment with different measurement parameters and to build confidence in the integrity of the device and its connections, and the parameters chosen. The latter option is typically preferred to collect data in a single, unattended, long run with many steps in temperature, magnetic field or any other external variable the device is being tested under.



**NPN Chs.**
**@ T=298K**

*Figure 5: N-P-N Transistor I-V Characteristics Measured and Displayed on Screen*

Figure 6 gives an example of the I-V characteristics of an N-channel junction-field-effect-transistor measured with this system. The device was actually measured under stepped magnetic field and temperature conditions. The figure shows the first of the I-V characteristics displayed on the screen after the initial settings of zero magnetic field and room temperature. Figures 7 and 8 give the I-V characteristics measured, with data saved in text files, imported to a spreadsheet file, sorted and plotted in MS Excel for the N-channel JFET tested. Figure 7 shows the effect of the magnetic field, with thirteen different (initial plus twelve steps of) magnetic field settings ranging from 0 Tesla to 2.5 Teslas while operating the device at room temperature. It is observed that the JFET current decreases with the applied magnetic field in a nonlinear manner. This is attributed to magneto-resistance effect which is proportional to $B^2$[5]. Saturation of the electromagnet's core at field densities of about 2 Teslas creates the narrowing of the separation between the constant-VGS curves seen in Figure 7.

Figure 8 shows the I-V characteristics of the same JFET plotted from data taken at three different temperatures in an automated run. The narrow range of temperature and slow variation of drain current with temperature of the device tested made the bunches of three constant VGS curves obtained to remain distinguished from the other bunches of constant VGS curves. As expected, the JFET current decreases with temperature, a clear display of the fact that its temperature sensitivity is determined mostly by the negative temperature coefficient of its channel mobility. At VGS = 0 V, the JFET current has a temperature coefficient of about -0.3 %/C.

However, at low currents when operating close to its pinch-off, the temperature sensitivity of the current reverses its sign, indicating more dominant contribution of the temperature coefficient of its pinch-off voltage.

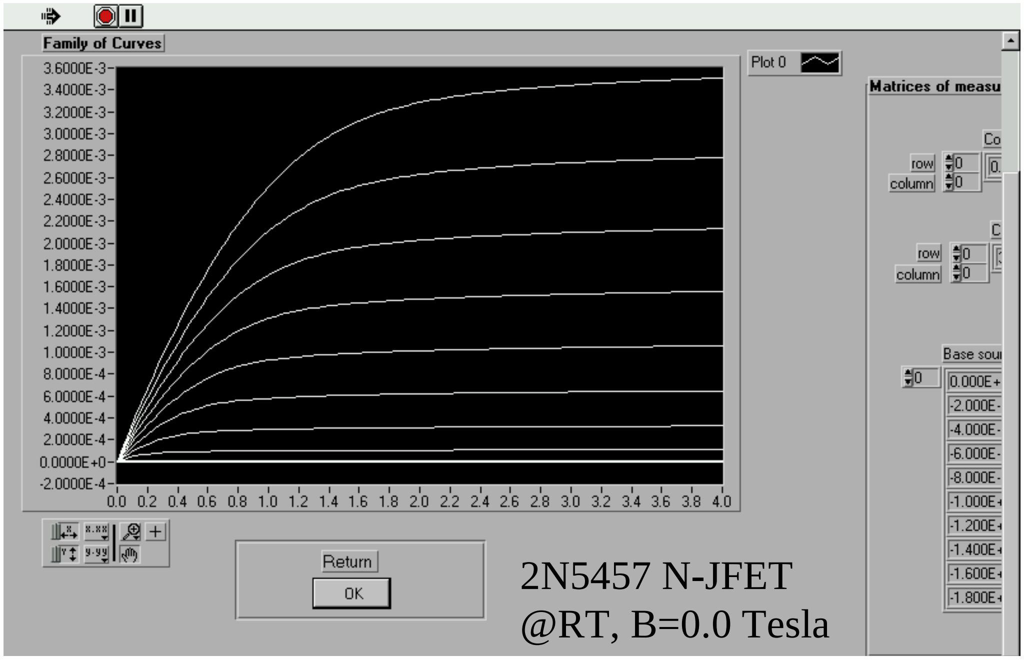


*Figure 6. JFET I-V Characteristics Measured and Displayed on Screen*

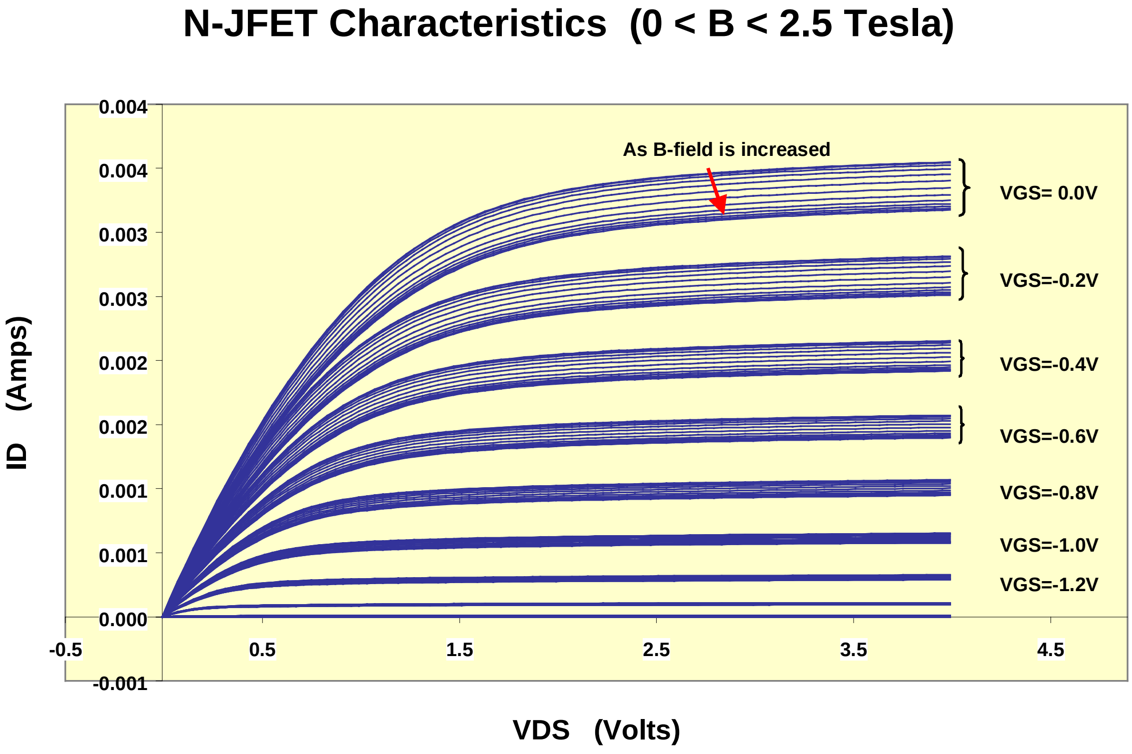


*Figure 7. Effect of B-Field on JFET Characteristics*

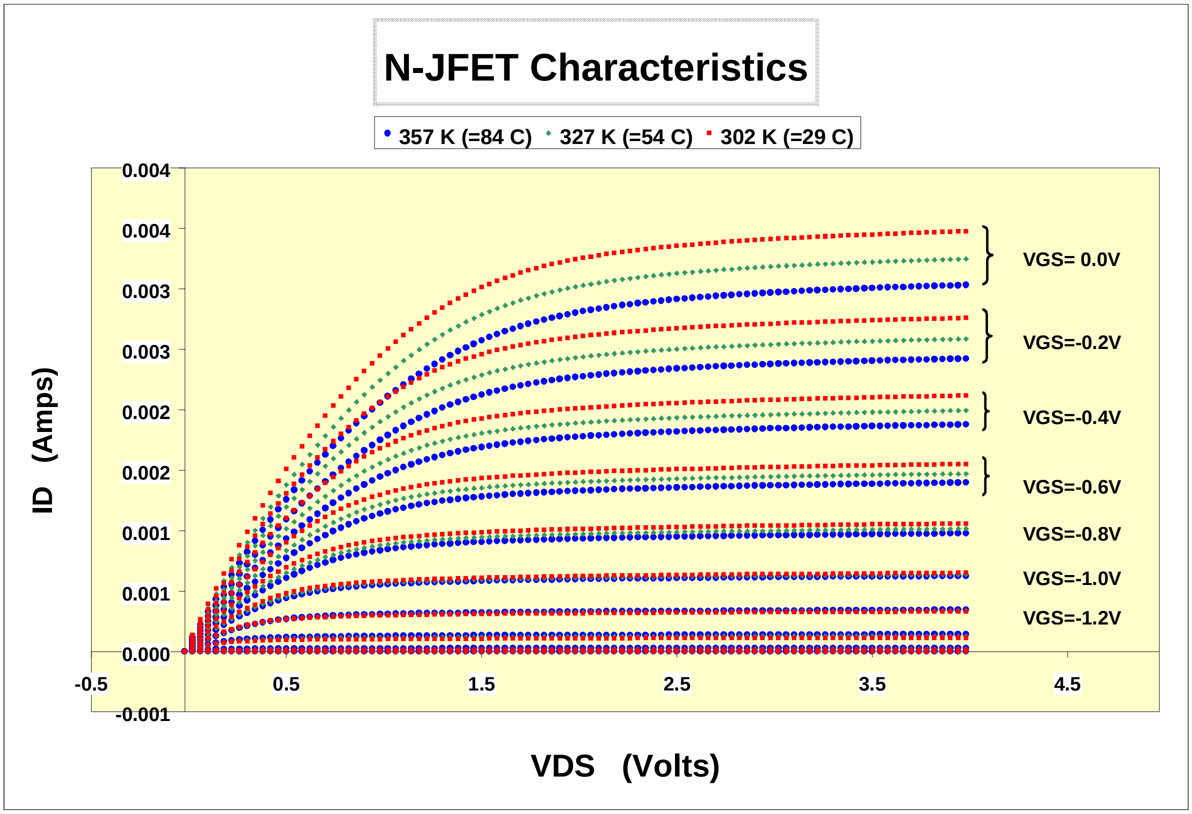


*Figure 8. Effect of Temperature on JFET Characteristics*

## 4. Conclusions and Remarks

The system was built and the programming was done as a part of senior electrical engineering capstone project at University of Southern Maine. It has been used in characterizing magnetic sensors and in SPICE modeling of MOSIS fabricated CMOS transistors and integrated circuits. In the presentation, the principles of operation and the details of the LabView programming particularly specific to the source-measure units will be given with more samples of device characteristics measured under varying magnetic field and temperature conditions. In addition, use of the setup in the characterization of CMOS devices and home made CMOS operational amplifiers will be shown.

.....

The project was partially funded by National Semiconductor and Fairchild Semiconductor Corporations.

## 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, pp.879-884.

[2] Marcy, D. and Sturm, J., “Teaching Systems Through Integrated Circuit Fabrication,” s1526, ASEE’97, Milwaukee,1997.
[3] Guvench, M.G., “Automated Measurement of MOS Capacitance and Determination of MOS Process Parameters in The MicroFabrication Laboratory” Proc. of ASEE, s2659, No.5, Milwaukee, 1997.
[4] Jenkins, T. and Kolesar E., “Laboratory Experiments in Integrated Circuit Fabrication,” Proc. A.S.E.E., v.1, pp.949-971, 1993.
[5] Guvenc, M.G., "Finite Element Analysis of Magnetotransistor Action," IEEE Trans. on Electron Devices, vol. ED-35, No.11, pp.1851-1860, November 1988.
[6] Wells, L.K. and Travis, J., “LabVIEW For Everyone, Graphical Programming,” Prentice-Hall, 1997.
[7] LabVIEW is a product of National Instruments, Austin, Texas, www.natinst.com.

## MUSTAFA G. GUVENCH

Mustafa G. Guvench received his B.S. and M.S. degrees in Electrical Engineering from M.E.T.U., Ankara in 1968 and 1970, respectively. He did further graduate work at Case Western Reserve University, Cleveland, Ohio between 1970 and 1975 and received M.S. and Ph.D. degrees in Electrical Engineering and Applied Physics. He is currently a full professor of Electrical Engineering at the University of Southern Maine. Prior to joining U.S.M. he served on the faculty of M.E.T.U., Ankara and Gaziantep campuses, Turkey and at the University of Pittsburgh. His research interests and publications span the field of microelectronics including I.C. design and semiconductor technology and its application in sensor development, finite element and analytical modeling of semiconductor devices and sensors, and electronic instrumentation and measurement.

## MARK E. ROLLINS

Mark Rollins graduated from the University of Southern Maine with B.S. degree in Electrical Engineering in 1997. He has worked for National Semiconductor, Incon and Enercon. He is currently working as an R&D engineer at Sensor Research and Development. His interests are software development, programmable controllers, and automated measurements and instrumentation.

## SERPIL GUVENCH

Serpil Guvench received her B.S. and M.S. degrees in Physics from Ankara University, Turkey. She also holds a M.S. degree in Electrical Engineering and Applied Physics from Case Western Reserve University, Cleveland, Ohio. She worked as a member of research staff at CWRU, University Hospitals in Cleveland, Atomic Energy R&D Center in Ankara, Montefiore Hospital in Pittsburgh, and taught at M.E.T.U., Gaziantep Campus, Turkey. Her research experience and interests include applications of ultrasound in medicine, semiconductor devices, glucose sensors, and currently analog integrated circuits.

## MICHAEL S. DENTON

Michael Denton graduated from University of Southern Maine with B.S.degree in Electrical Engineering in 1999. While attending USM he held various technical and engineering positions at Maine Yankee Nuclear Power station. After graduation he has joined IEA (Industry & Energy Associates) as design engineer. His interests are measurement and instrumentation and power plant safety and design.