ECSE 331
Laboratory No. 5
MOSFETs And BJTs DC Characteristics

Objective:

Investigate the i-v characteristics of a MOSFET and BJT transistor. Design a resistor biasing network to establish the DC operating point of a transistor.

Equipment Required:

1. NI Elvis-II$^+$ test instrument
2. PC with ELVIS-II$^+$ software installed
3. Heat Gun
4. Aerosol Freeze Spray to cool diode
5. Hand-held thermal imager
6. Components:
    a. BS170 NMOS transistor
    b. 2N2222A npn transistor
    c. 10 kΩ potentiometer
    d. resistors: 100 Ω, 10 kΩ

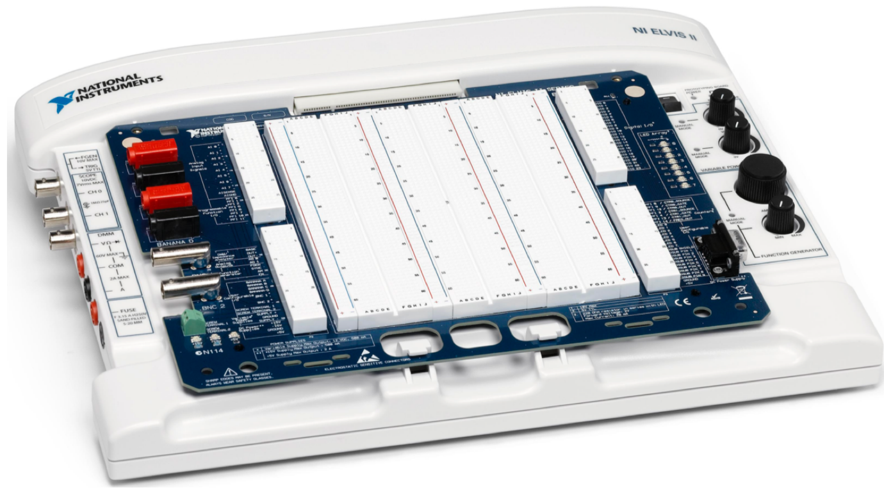
Description of the NI Elvis-II+ Test Instrument:

The National Instruments Educational Laboratory Virtual Instrumentation Suite (NI ELVIS-II$^+$) is a hands-on design and prototyping platform that integrates the 12 most commonly used instruments – including oscilloscope, digital multi-meter, function generator, bode analyzer, and more. It connects to a PC through a USB connection, providing quick and easy acquisition and display of measurements.

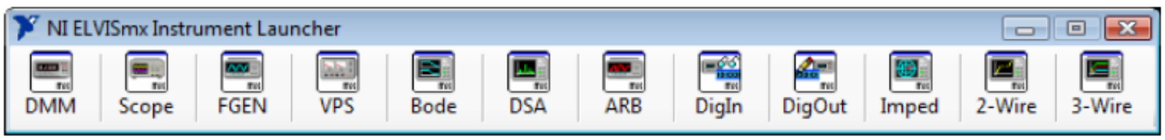
The National Instruments Educational Laboratory Virtual Instrumentation Suite consists of two main components:

1. The bench-top workstation (NI ELVIS-II$^+$), which provides instrumentation hardware and associated connectors, knobs, and LEDs as shown in Fig. 1(a). A prototyping board (breadboard) sits on top of the workstation, plugged into the NI ELVIS-II$^+$ platform, and offers hardware workspace for building circuits and interfacing experiments.
2. NI ELVIS-II$^+$ software, which includes soft front panel (SFP) instruments. Fig. 1(b) illustrates the PC screen view of the oscilloscope interface.

The Elvis-II$^+$ prototype board consists of 5 separate areas: four small prototype areas on the peripheral of the board, and a much larger central prototype area. The boards on the peripheral are used to interface to the internal data acquisition board of the Elvis-II$^+$ system. There are marking along the perimeter of the board indicating the connection. The student was introduced to this test bench back in Laboratory 1. The student should refer back to this lab for a detailed description of the



(a)



(b)

Fig. 1: (a) Elvis-II$^+$ instrumentation hardware with prototyping board, and (b) menu for various virtual instrument.

NI ELVIS-II$^+$ test system.

Practical Information for the Student:

In performing this experiment, you will construct several building blocks of modern transistor circuits. On doing so, keep the following points in mind:

1. In the figures, more positive voltages are always shown closer to the top of the page, so that current flows in the circuit from top to bottom.
2. Keep all connecting leads as short as possible and pushed down to the surface of the circuit board. You want to avoid a "*rat's nest*" of wiring whereby unwanted coupling capacitances and series inductances are created. These parasitics can prevent your circuit from working correctly.
3. Use different color wires in your circuit. The standard convention is red for positive supply voltages, blue for negative supply voltages and black for ground. Use colors that are different than these for signals. If you use a single color for everything, your circuit should still work. However, the debug process will be much more difficult if something goes wrong. It is important for the student to understand that when asked to design a circuit it is not limited to just the arrangement and component selection for the circuit but also to the fact that the design may not work the first time it is assembled. In general, all design will require at least two iterations before one can declare success!
4. In understanding circuits, as well as designing them, keep in mind that that there are two *interleaved* problems: the dc design, which establishes the operating points, and the ac

design, which is responsible for how the circuit responds to signals. The student must design both problems at the same time; if you make a change to one, be sure that you haven't changed the other.

Write-Up Requirements:

A good laboratory report should contain a **brief** description of what the experiment was about, including circuit diagrams, and what you did, your data, your results, and anything else called for in the assignment, such as questions inserted in the laboratory. Answers to these questions require observations that need to be made at the time you do the experiment.

The laboratory report should be written using the IEEE paper style consisting of a double-column single-space format, and must adhere to the following:

1. Title page - Title of the assignment/project, authors' name, and course name.
2. Abstract - Abstract of the assignment/project report.
3. Introduction
4. Main body of the assignment/project report including figures.
6. Conclusions
7. References
8. Appendices

Procedure:

I. MOSFET i_D-v_{DS} Characteristics Using a Curve Tracer

In a similar manner to that which was performed for the diode in Laboratory 4, here the student will extend the use of the curve tracer to one that can sweep the MOSFET drain-source voltage v_{DS} while measuring its drain current i_D for different gate voltages.

The student will recall that the curve tracer apparatus consists of the function generator generating a triangular voltage waveform and a current probe constructed from a differential amplifier with a 100-Ω sense resistor. The A and B channels of the oscilloscope will then enable one to display the drain current as a function of the drain-source voltage. The function generator and the oscilloscope can be found in the Elvis-II$^+$ test system.

Construct the circuit shown in Fig. 2 using the 741 op-amp and the BS170 NMOS transistor. The BS170 is a single packaged device. The pin-outs for this IC are shown in Fig. 3. The student should already be familiar with the pinouts of the 741 from previous experiments.

Using the NMOS transistor, connect the drain terminal to the function generator, connect the wiper of a 10-kΩ potentiometer to the gate terminal operating with 5 V across its main terminals, and connect the source terminal to ground as shown in Fig. 2. Set the function generator feature to generate a saw-tooth waveform over a 0 V to +10 V signal range. Connect the V_X node to channel A of the oscilloscope and the V_Y to channel B of the oscilloscope. As the voltage V_Y is 100-times larger than the current, either scale the input by a factor of one-hundred, or simply keep track of the y-axis units and adjust any plot accordingly. Set the oscilloscope to plot channel A versus B, so that an i_D-v_{DS} characteristic will appear on your screen. Beginning with the gate voltage set to 0 V, observe that the drain current i_D is zero while the drain-source voltage v_{DS} sweeps from 0 to 10 V. Next, adjust the screw of the potentiometer so that the drain current i_D begins to flow. According to the manufacturers data sheet the threshold voltage is approximately 2 V. *Measure the gate voltage at which this point and record it. This voltage is the threshold voltage V_t of the MOSFET.* Next, increase the gate voltage in increments of 500 mV until the gate voltage reaches 5 V, and capture the i_D-v_{DS} characteristics. *In your report, combine all the curve traces into a single plot and observe the overall behavior. What is the effective Early voltage of your device?*

In this next test, set the gate voltage to 3 V by adjusting the potentiometer and the drain voltage to 5 V. This will require that the saw tooth signal source be replaced with a DC variable voltage source. Once complete, measure the gate voltage and drain current, and record these results. Next, adjust the gate voltage by approximately 100 mV. Again, measure the gate voltage and drain current, and record these results. Compute the transconductance g_m of your device using the following formula:

$$g_m = \frac{\Delta i_D}{\Delta v_{GS}}$$

Draw the equivalent small-signal model of your MOSFET for low-frequency operation.

II. MOSFET Temperature Effects

In this part of the laboratory, you will measure the temperature effects of the MOSFET that you used in part A of this experiment. This will require access to a hot-air blowgun, a can of freeze spray (spray-on liquid Nitrogen) and a hand-held thermal imager. These are available in the microelectronics laboratory in Rm 4090 of the Trottier building.

For this step, return to the curve tracer set-up involving the BS170 NMOS transistor shown in Fig. 2. Remember to reconnect the saw tooth waveform signal to the drain of the MOSFET and set to a 0 – 10 V sweep. Display the i_D-v_{DS} characteristic for the MOSFET using your oscilloscope for a gate voltage of 3 V. Use the hand-held thermal imager and determine the temperature of the MOSFET. Record your i_D-v_{DS} characteristic at this temperature. Now, using the can of freeze spray, blow the freeze-spray coolant directly onto the MOSFET, while at the same time exercising its i-v characteristic. Measure the temperature of the MOSFET using the hand-held thermal imager and record this information along with the i_D-v_{DS} characteristics. Now, repeat this procedure but this time use the hot-air blowgun, blow hot air onto the MOSFET. Avoid heating up the op-amp circuit. This will raise the temperature of the MOSFET. Measure the temperature of the MOSFET and record this information along with the i_D-v_{DS} characteristics. Compare the three plots taken at the three different temperatures. *How do they compare? How do you expect the i_D-v_{DS} characteristics to change with temperature? Provide an explanation with supporting theory. Can you suggest a method in which to reduce the changes in MOSFET behavior as a function of temperature?*

III. BJT i_C-v_{CE} Characteristics Using a Curve Tracer

In this part of your laboratory you will investigate the i_C-v_{CE} characteristics of the 2N2222A npn transistor. Using your curve-tracer circuit, place the BJT into the test port as shown in Fig 4. The pin-outs for this device is shown in Fig. 5. Set the base voltage using the 10-kΩ potentiometer so that it is 0 V. Set the saw tooth waveform output from the function generator to produce a signal that varies between 0 V to 10 V. Observe the i_C-v_{CE} characteristic on the oscilloscope in the same manner described in part I of this experiment. You should see a flat line represent zero collect current. Next, increase the base voltage by steps of about 50 mV to no more than 750 mV – approximately two turns of the screw adjustment control of the potentiometer. Be aware that the BJT is extremely sensitive to this voltage, so take care with this step. Capture the i_C-v_{CE} characteristics corresponding to each of these base voltage settings. *In your report, combine about ten traces into a single plot and observe the overall behavior. What is the effective Early voltage of your device?*

In this next test, set the base voltage to 650 mV by adjusting the potentiometer and the collector voltage to 5 V. This will require that the saw tooth signal source be replaced with a DC programmable source. Once complete, measure the base voltage and collector current, and record these results. Next, adjust the base voltage to 700 mV . Again, measure the base voltage and collector current, and record these results. Compute the transconductance g_m of your device using the following formula:

$$g_m = \frac{\Delta i_C}{\Delta v_{BE}}$$

Draw the equivalent small-signal model of your BJT for low-frequency operation.

IV. BJT Temperature Effects

For this step, return to the curve tracer set-up involving the BJT shown in Fig. 4. Remember to reconnect the saw tooth waveform signal to the collector of the BJT and set to a 0 – 10 V sweep. Display the i_C-v_{CE} characteristic for the MOSFET using your oscilloscope for a base voltage of 700 mV. Use the hand-held thermal imager and determine the temperature of the BJT. Record your i_C-v_{CE} characteristic at this temperature. Now, using the can of freeze spray, blow the freeze-spray coolant directly onto the BJT, while at the same time exercising its i-v characteristic. Measure the temperature of the BJT and record this information along with the i_C-v_{CE} characteristics. Now, repeat this procedure but this time use the hot-air blowgun, blow hot air onto the BJT. Avoid heating up the op-amp circuit. This will raise the temperature of the BJT. Measure the temperature of the BJT and record this information along with the i_C-v_{CE} characteristics. Compare the three plots taken at the three different temperatures. *How do they compare? How do you expect the i_C-v_{CE} characteristics to change with temperature? Provide an explanation with supporting theory.*

This concludes this lab.

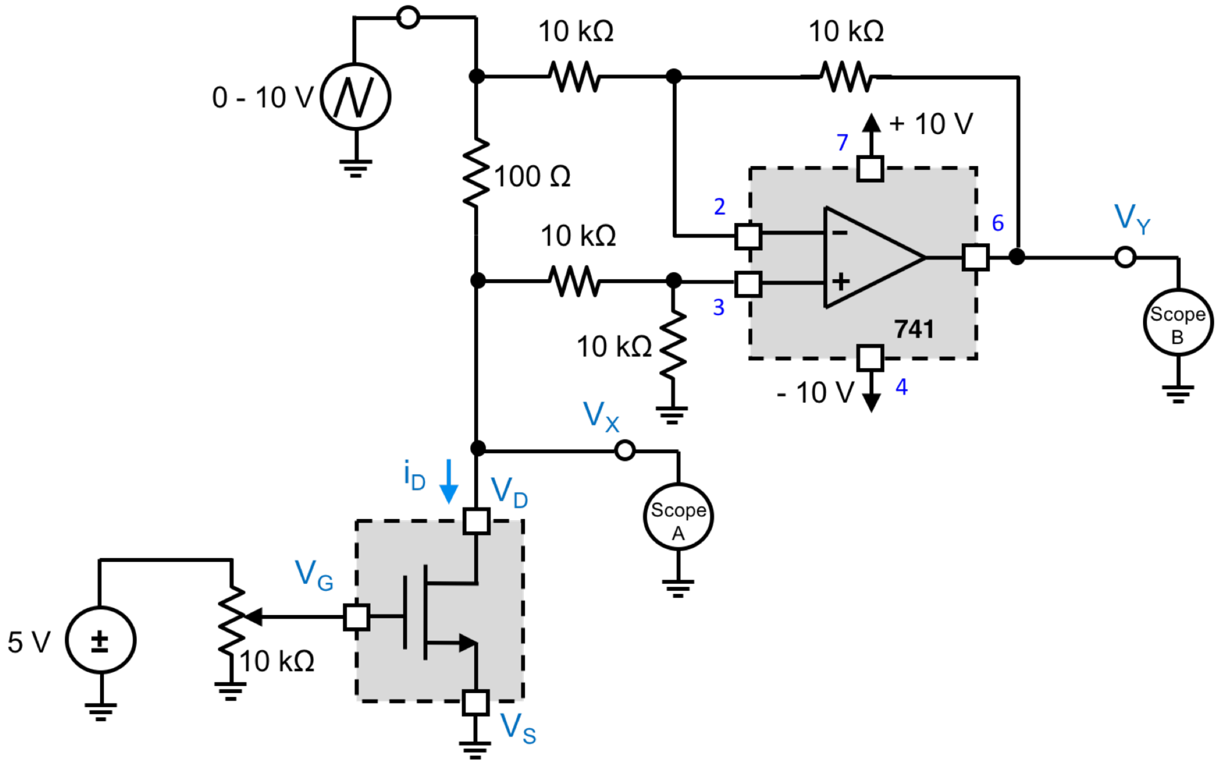


Fig. 2: Curve-trace set-up for measuring the MOSFET i-v characteristics.

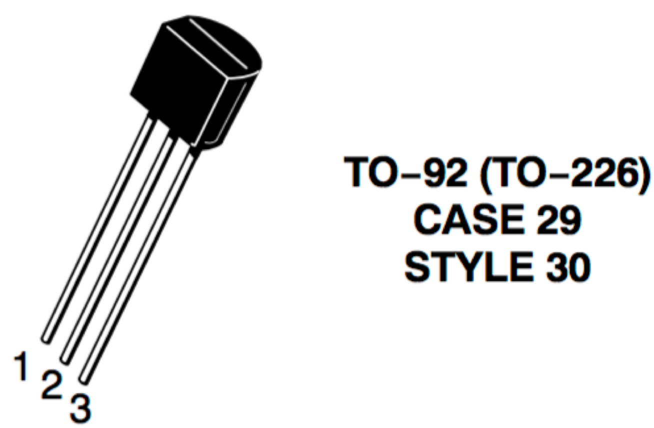


Fig. 3: Pin out for the BS170 NMOS transistor.
(Pin 1: Drain, Pin 2: Gate, Pin 3: Source).

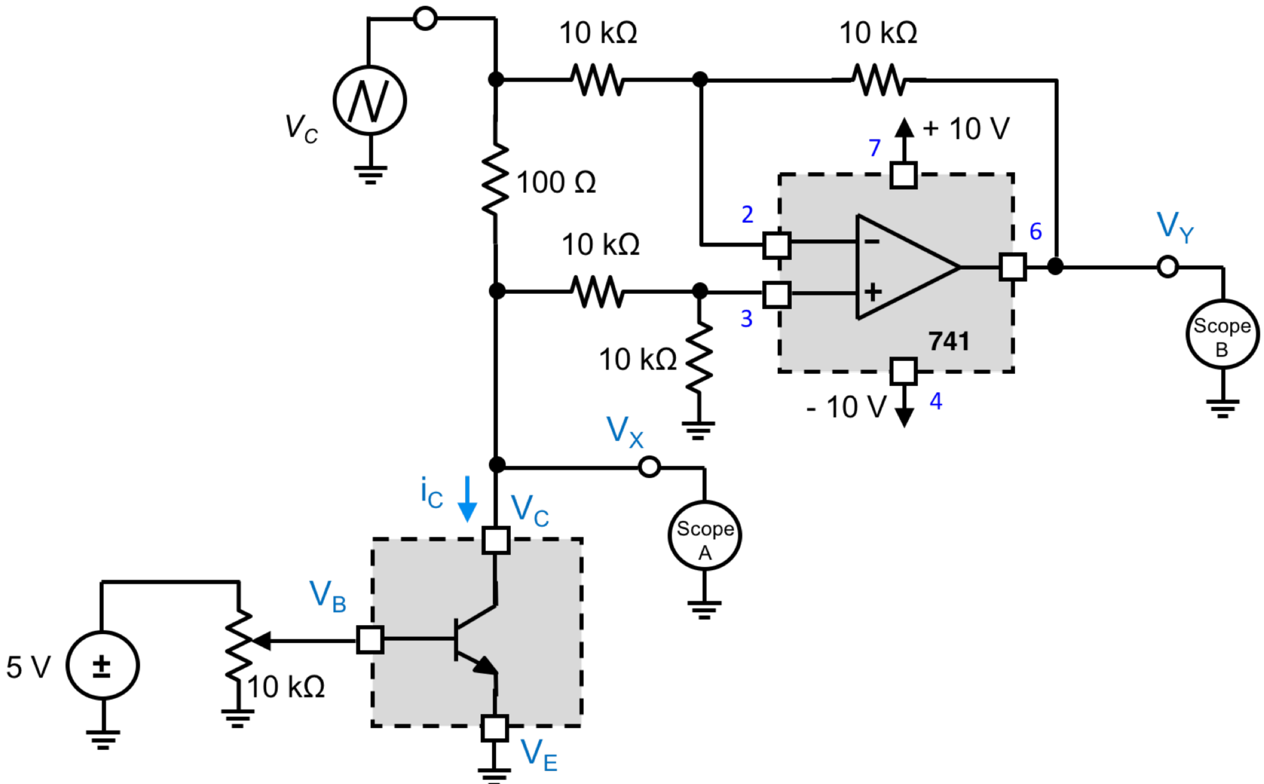


Fig. 4: Curve-trace set-up for measuring the BJT i-v characteristics.

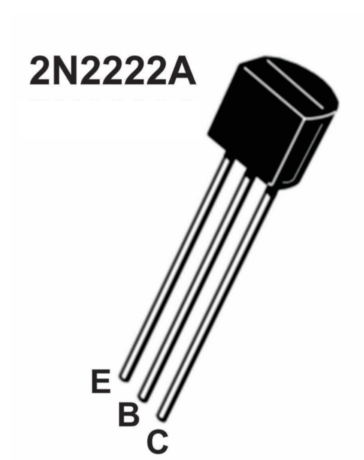


Fig. 5: Pin out for the BJT