ECSE331 Lab 5

MOSFETs and BJTs DC Characteristics

ECSE331

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ECSE331 Lab-5 Report

***Abstract* — This report will investigate the i-v characteristics of a MOSFET and a BJT transistor. The i-v transfer curve obtained at different temperatures for each will also be compared to better analyze their characteristics.**

I. INTRODUCTION

In this lab, students are required to build and use curve tracers for MOSFET and BJT to analyze their i-v characteristics. Students will also investigate the temperature effects on MOSFET and BJT. This lab will be using BS170 MOSFET and PN2222 BJT.

II. EXPERIMENT RESULTS

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

a). Measured V_t and i_D-v_{DS} characteristics at different gate voltages

In this part, we first constructed a curve tracer, as shown in Fig. 1.

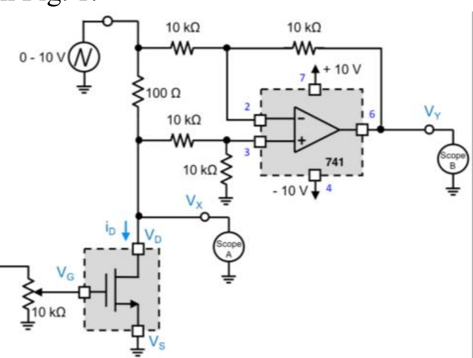

Fig. 1. Curve-trace set-up for measuring the MOSFET i-v characteristics

We first set the V_g to $0V$ and observed a drain current $i_D = 0A$ while the drain-source voltage v_{DS} sweeps from $0V$ to $10V$.

Then we adjusted the screw of the potentiometer so that i_D started to flow as shown in figure 2. We measured the gate voltage V_g at this point, and the measured V_g is the threshold voltage of this BS170 MOSFET. From its datasheet, we know that, theoretically, its threshold voltage is $2V$. Our measured threshold voltage, V_t, is $2.131V$, and it agrees with the theoretical value.

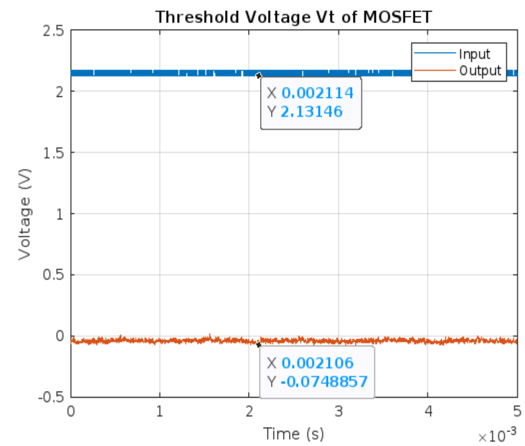

Fig. 2. Measured threshold voltage (V_t=2.1V)

Then we increased V_g from measured V_t (2.1V) to $5V$ with a step of $500mV$ (Fig. 2). When the gate voltage is increased to $2.5V$, the current line is no longer flat. By connecting two points, (8.7693, 0.0065) and (0.8987, 0.0053), we generated the function of the line cross it:

$$slope = \frac{1}{r_o} = \frac{0.0065 - 0.0053}{8.7693 - 0.8987} = 1.525 \times 10^{-4}$$

And hence:

$$i_D = 1.525 \times 10^{-4} v_{DS} + 5.163 \times 10^{-3}$$

By calculating the x-intercept point at this line, we can obtain the effective early voltage of this MOSFET:

$$V_A = \frac{-5.163\times10^{-3}}{1.525\times10^{-4}} = -33.86V$$

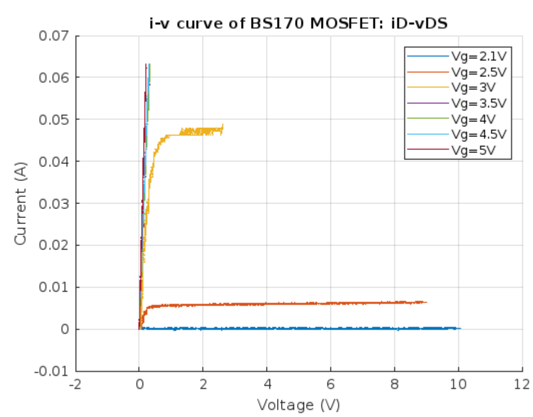

Fig. 3. i_D-v_{DS} characteristics of the BS170 MOSFET

When V_g is increased to above $3V$, the i_D-v_{DS} curve, as shown in Fig. 3, is vertical. BS170

MOSFET is more conductive than CD4007 MOSFET, which was originally intended for use in the tested circuit. Too much voltage is being dropped on the current sense resistor, and hence we had the vertical i_D-v_{DS} curve.

b). Transconductance of the BS170 NMOS Transistor

The signal source was changed to a DC source around 9.5V so that the gate voltage can be set to 3V while the drain voltage is around 5V. Our gate voltage is set to $V_g = 3.051V$. The current $i_d = \frac{-V_y}{100} = \frac{3.948V}{100} = 0.03948\ A$. The measured result is shown in Figure 4. We then changed the gate voltage to 3.163V. The current $i_d = \frac{4.074V}{100} = 0.04074\ A$. The measured result is shown in Figure 5. We can then compute the transconductance $g_m = \frac{\Delta i_D}{\Delta V_{GS}} = \frac{0.04074-0.03948}{3.163-3.051} = 0.01125\ A/V$.

Moreover, with the early voltage calculated before, we can get the output resistance of the small-signal model. $r_o = \frac{V_A}{\Delta i_D} = \frac{34V}{0.00126} = 27k\Omega$. We can thus draw the small-signal model as shown in Figure 6.

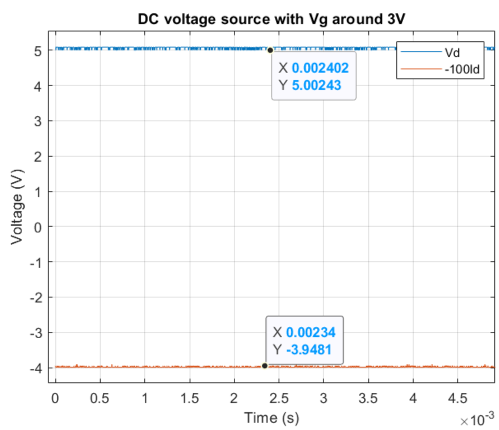

Fig. 4. Output and drain voltage when gate voltage is around 3V.

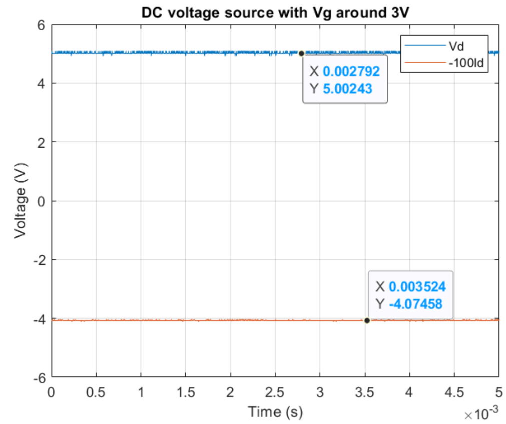

Fig. 5. Output and drain voltage when gate voltage is around 3.1V.

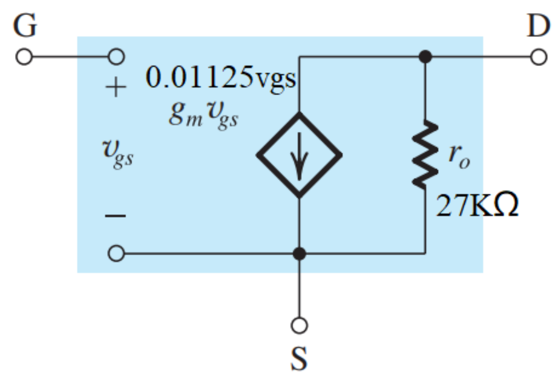

Fig. 6. Small Signal model of the MOSFET based on our measurements.[1]

B. MOSFET Temperature Effects

In this part, we used the same curve-tracer set-up as in part A. We recorded the i_D-v_{DS} characteristics of the MOSFET under three different temperatures and compared them to observe how the i_D-v_{DS} curve changes with temperature. We expected the drain current to increase as the temperature increases.

We set the gate voltage to $3V$. We started by measuring and recording its i_D-v_{DS} curve at 25℃ (Fig. 7). Then we blew the freeze-spray coolant to the MOSFET and recorded its i_D-v_{DS} curve at -3℃ (Fig. 8). Finally, we heated the MOSFET up to 60℃ and recorded its i_D-v_{DS} curve at 60℃ (Fig. 9).

To better compare the i_D-v_{DS} curve change, we superimposed them on one plot (Fig. 10). We observed that, at the same gate voltage and drain-to-source voltage, i_D would increase as the temperature increases. This is the same as our expectation.

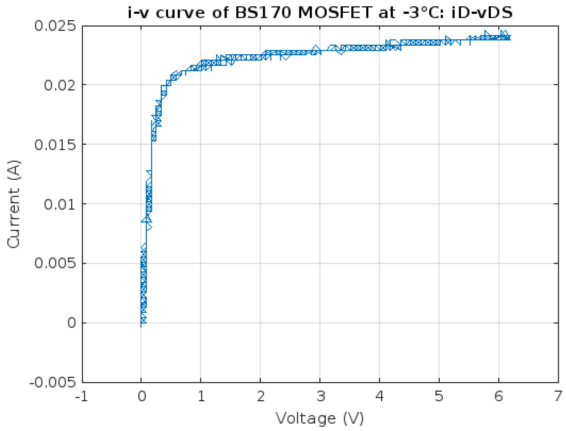

Fig. 7. i_D-v_{DS} curve of BS170 MOSFET at low-temperature

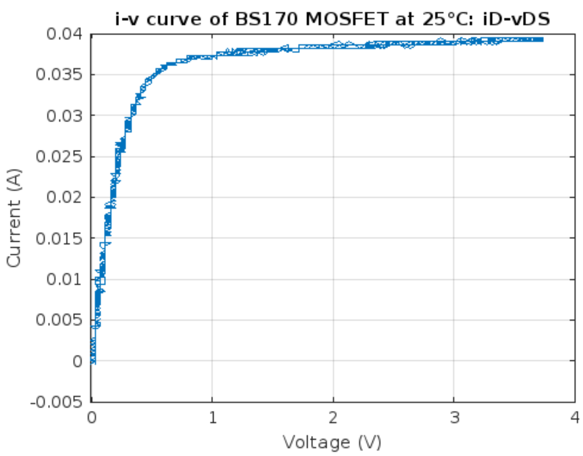

Fig. 8. i_D-v_{DS} curve of BS170 MOSFET at room-temperature

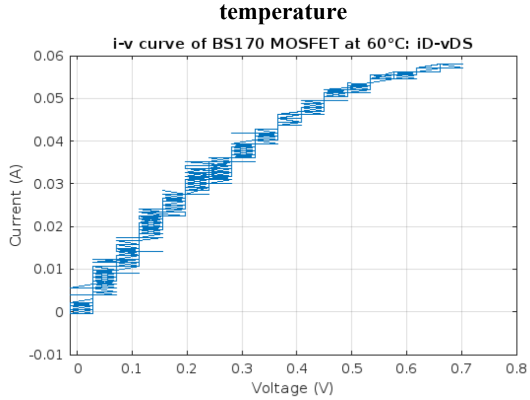

Fig. 9. i_D-v_{DS} curve of BS170 MOSFET at high-temperature

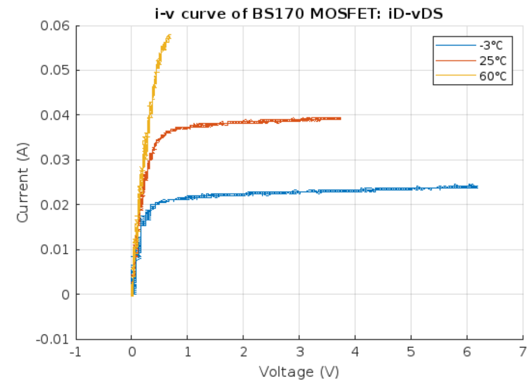

Fig. 10. Superimposed i_D-v_{DS} curves of BS170 MOSFET at three different temperatures

Our measured result also agrees with the theoretical result. The drain current depends on two factors: mobility(μ) and threshold voltage(V_t). Both the mobility and the threshold voltage will decrease as the temperature decreases. The drain current will decrease as mobility decreases, while it will increase as threshold voltage decreases. In our case, the change in threshold voltage has a dominant effect on the drain current [2]. Hence, theoretically, the drain current of our MOSFET will increase as temperature increases.

To reduce the thermal effect on MOSFET, we can maintain the external temperature by placing the entire system into a thermostatic chamber.

C. I-V Characteristics of the BJT

a). i_C-v_{CE} characteristics at different base voltages

In this part, we reconstructed the curve tracer circuit shown in Figure 11 to measure the I_C-V_{CE} curve of the BJT.

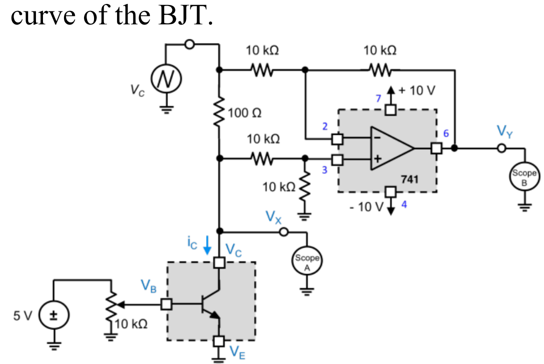

Fig.11. Curve tracer to measure I_C-V_{CE} characteristics of the 2N2222A NPN-BJT

We increased the base voltage from 50mV to about 750mV by steps of about 50mV. Figure 12 shows the superimposed I-V curves. To make it clearer to see, we only kept 9 voltages in our plots. We can clearly see that when the base voltage turns to around 650 mV, the current started flowing. Early voltage is the voltage value at which the I_C-V_{CE} linear curve (in the active region) intersects the x-axis.

By plugging in two points (2.68199, 0.00189533) and (5.99446, 0.00214423), we can determine the current

$i_c = 0.00007514 * V_{CE} + 0.0016938.$

We can thus calculate the early voltage:

$V_A = \frac{-0.0016938}{0.00007514} = -22.54V.$

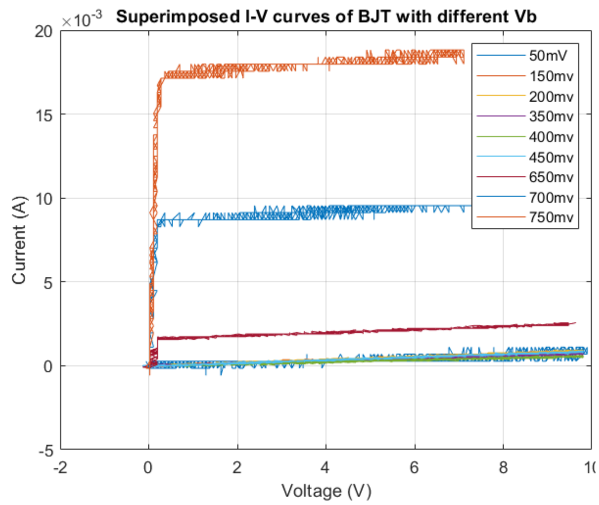

Fig.12. Superimposed I-V plots of the BJT with nine different base voltages.

b). Transconductance of the PN2222 BJT Transistor

We then set the base voltage to 650mV with the collector voltage equal to 5V. We measured the base voltage $V_B = 652mV$. The collector current $i_C = \frac{-V_y}{100} = \frac{0.306V}{100} = 0.00306\,A$. Our measured result is shown in Fig. 13.

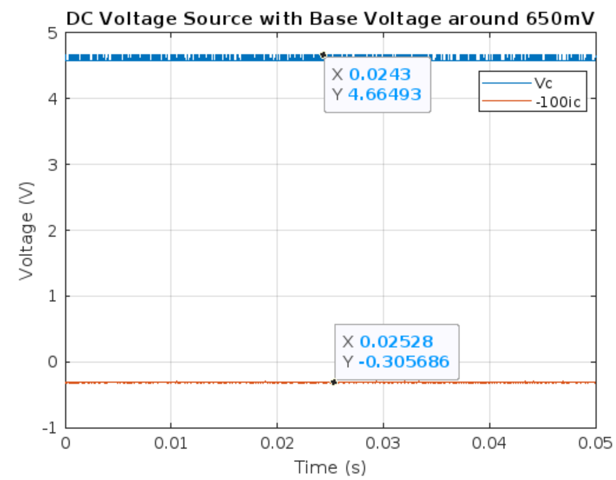

Fig. 13. Output and collector voltage when the base voltage is around 650mV.

We then changed the base voltage to 706mV. The current $i_C = \frac{0.720V}{100} = 0.0072\,A$. The measured result is shown in Figure 14. We can then compute the transconductance $g_m = \frac{\Delta i_C}{\Delta V_{BE}} = \frac{0.0072-0.00306}{0.706-0.652} = 0.07667\,A/V$.

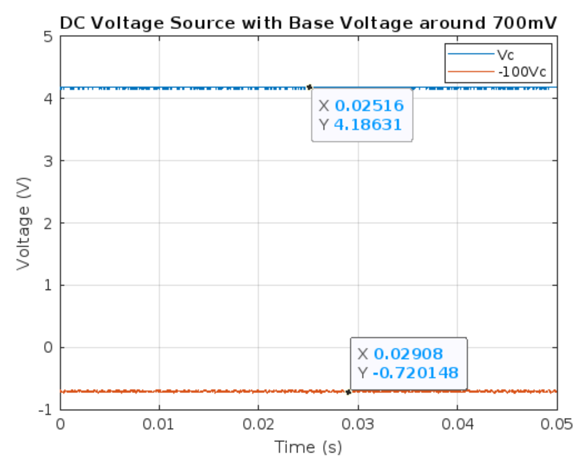

Fig. 14. Output and collector voltage when the base voltage is around 700mV.

With the early voltage calculated before, we can get the output resistance of the small-signal model:

$$r_o = \frac{V_A}{\Delta i_C} = \frac{22.54V}{0.00414} = 5.44k\Omega.$$

Assuming that β is 99, the input resistance can also be found.

$$r_\pi = \frac{\beta}{g_m} = \frac{99}{0.07667} = 1.29k\Omega$$

We can thus draw the small-signal model as shown in Figure 15.

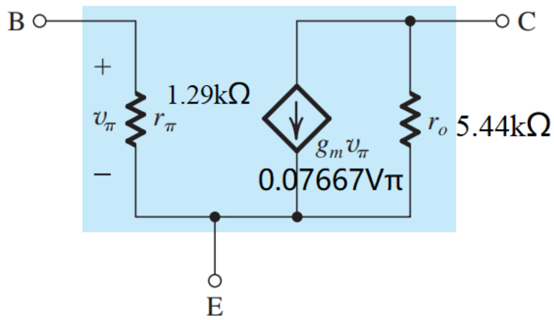

Fig. 15. Small Signal model of the BJT based on our measurements. [1]

D. BJT Temperature Effects

In this part, we used the same circuit as in part C. We repeated the same procedure in part B to cool down and heat up the BJT and recorded the i_C-v_{CE} curve at low (Fig. 16), high (Fig. 17), and room temperature (Fig. 18), respectively.

We expected the collector current i_C to increase with increasing temperature. From the superimposed plot (Fig. 19), we could clearly observe that at the same base voltage (700mV), i_C increases as temperature increases. This agrees with our expectation.

The collector current depends on the saturation current I_S, and I_S will increase with the temperature. Thus, theoretically, i_C will increase as temperature increases. This agrees with our measured result.

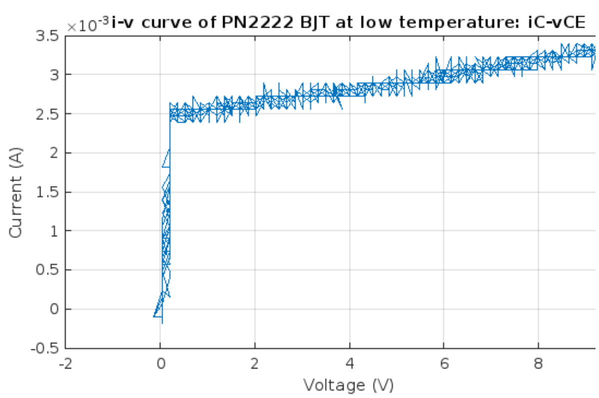

Fig. 16. i_C-v_{CE} curve of PN2222 BJT at low-temperature

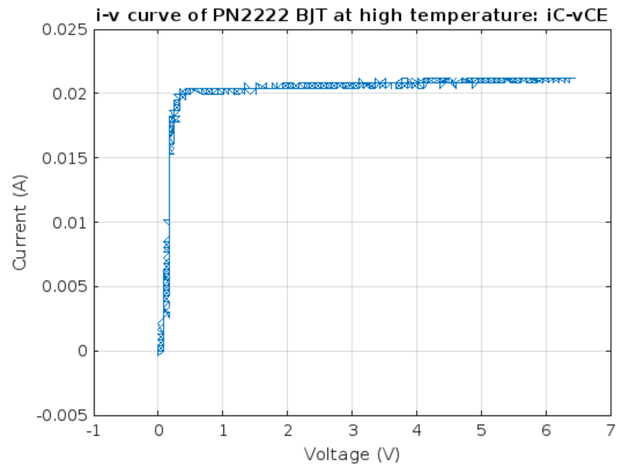

Fig. 17. i_C-v_{CE} curve of PN2222 BJT at high-temperature

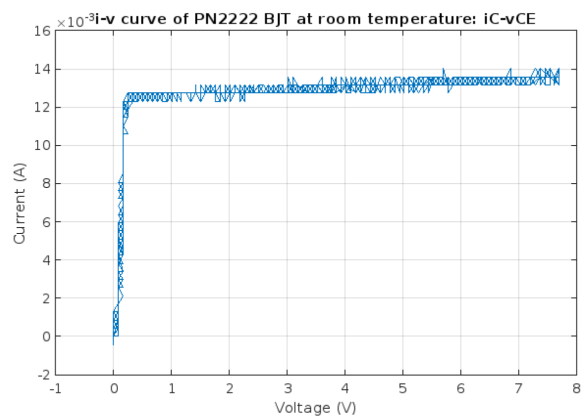

Fig. 18. i_C-v_{CE} curve of PN2222 BJT at room-temperature

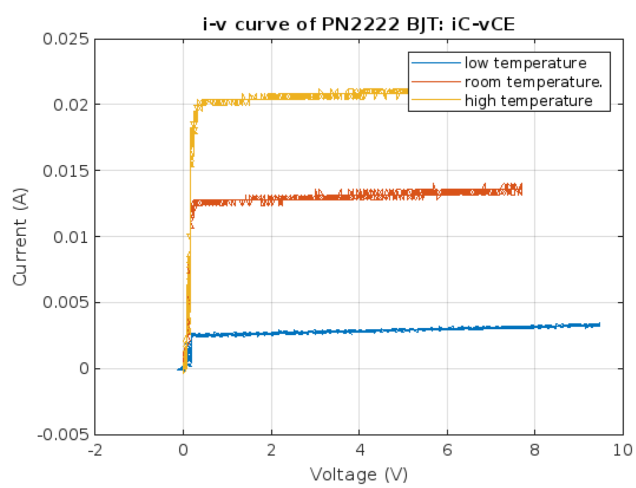

Fig. 19. Superimposed i_C-v_{CE} curves of the BJT at three different temperatures

CONCLUSION

In this lab, we investigated the i-v characteristics of BS170 NMOS and PN2222 BJT under different gate voltages and base voltages respectively. Based on the plots of their i-v curves, we observed the overall behavior of each, calculated the early voltage, and built the small signal model for each. We also explored their behaviors at different temperatures and found the drain current of BS170 NMOS and the collector current of PN2222 BJT will increase with temperature.

REFERENCES

[1]. A. S. Sedra and K. C. Smith, *Microelectronic Circuits,* 7th ed. New York, NY: Oxford University Press, 2014, pp. 289, 421, 422.

[2]. Media, O. (n.d.). *Effect of Temperature Inversion on Lower Nodes*. Embedded Computing Design. Retrieved March 29, 2023, from https://embeddedcomputing.com/technology/analog-and-power/power-semiconductors-wireless-charging/effect-of-temperature-inversion-on-lower-nodes#:~:text=The%20threshold%20voltage%20in%20a