11/22/2019

ECSE 331: Electronics

Laboratory Report No. 4

McGill University

Chang Zhou (260779060)
Siyu Wang (260779031)
Haoran Du (260776911)

MOSFETs and BJTs DC Characteristics

Chang Zhou, Siyu Wang, Haoran Du

***Abstract*—The purpose of laboratory experiment was to explore the functions and characteristics of MOSFETs and BJTs. In the first part of this laboratory, the I-V characteristics of the MOSFET was found and drawn for different gate voltages, then the transconductance g_m of the circuit was found. In the second part, the behavior of the MOSFET was studied at various temperatures. The same experiment was also conducted on the BJT transistor.**

***Index Terms*—MOSFET, BJT, transistors**

I. Introduction

THE goal of this laboratory was to test and explore the behavior of different transistors by drawing their I-V diagrams using the NI Elvis-II test instrument. More specifically, the I-V curve for the MOSFET and BJT transistors were drawn using the data taken with the NI Elvis instrument. A resistor network was designed to find the DC operating point of the transistors. Finally, the effect of temperature on the operation of the transistors was tested.

II. Experiments Procedures and Result

A. MOSFET I_D-V_{DS} Characteristics Using a Curve Tracer

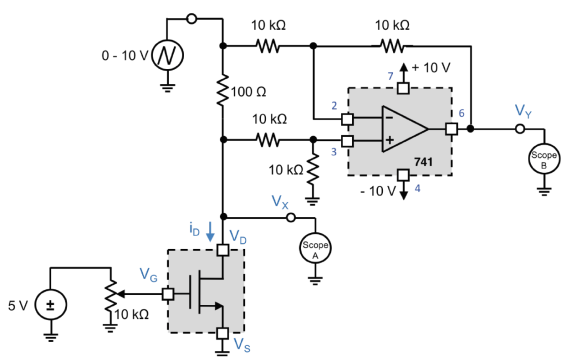

Fig. 1. Circuit digram for I-V characteristic used in part A.

The above circuit shown in Fig. 1 was constructed to measure V_{DS} and I_D and trace the I-V curve. This experiment was repeated multiple times with different gate voltages V_g. A sawtooth waveform going from $1\,\mathrm{V}$ to $10\,\mathrm{V}$ was applied.

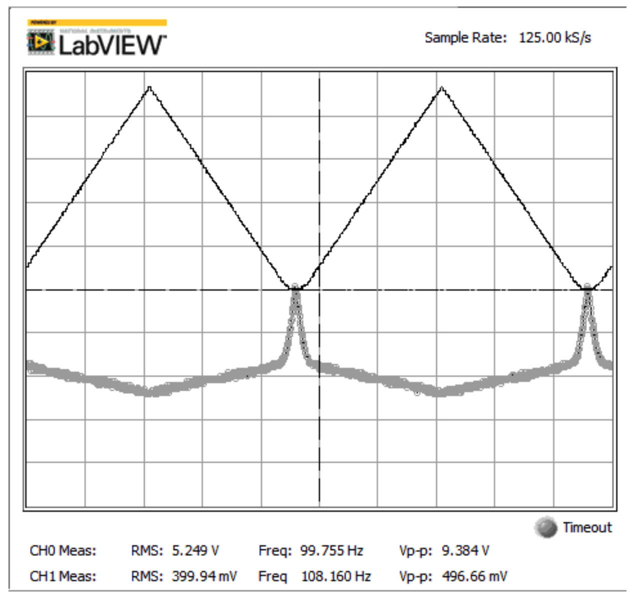

Fig. 2. V_D as a function of V_{in} when $V_g = 0$.

Next, in the same circuit, the gate voltage V_g was increased to $3.1\,\mathrm{V}$, $3.6\,\mathrm{V}$, $4.1\,\mathrm{V}$, $4.6\,\mathrm{V}$ and $5.1\,\mathrm{V}$. For each case in the $1\,\mathrm{V}$ to $5\,\mathrm{V}$ gate voltage range, the I-V curve was constructed using the data collected with the Oscilloscope. Below are some of the results.

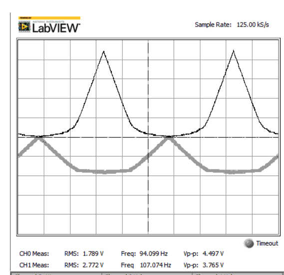

Fig. 3. $V_g = 3.1\,\mathrm{V}$.

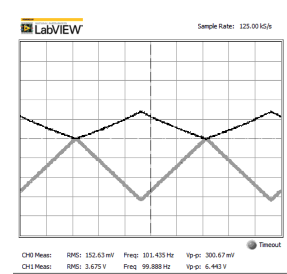

Fig. 4. $V_g = 3.6\,\mathrm{V}$.

Also, it is observed that when V_g is greater than $2\,\mathrm{V}$, we start to see the behavior of the MOSFETs. When Vin is about to reach than $2\,\mathrm{V}$, which is around the threshold voltage according to the Manufacturers data sheet, I_D saturates.

This work is the report of the laboratory section of course ECSE 331 offered at McGill University.

C. Zhou is with the Department of Electrical and Computer Engineering, Faculty of Engineering, McGill University, H3A 0E9 Montreal, QC, Canada (email: chang.zhou2@mail.mcgill.ca).

S. Wang is with the Department of Electrical and Computer Engineering, Faculty of Engineering, McGill University, H3A 0E9 Montreal, QC, Canada (email: siyu.wang5@mail.mcgill.ca).

H. Du is with the Department of Electrical and Computer Engineering, Faculty of Engineering, McGill University, H3A 0E9 Montreal, QC, Canada (email: haoran.du@mail.mcgill.ca).

To find the transconductance g_m, of our device the following formula:

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

Next, applying the circuit in Fig. 1, we obtained the following results:

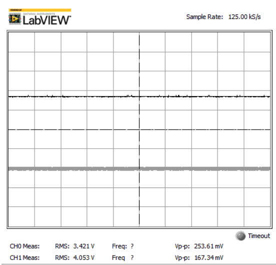

Fig. 5. Applying 3.1 V V_{GS}.

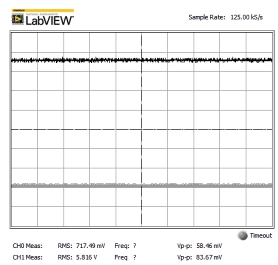

Fig. 6. Applying 3.3 V V_{GS}.

From Fig. 5 and Fig.6, hence,

$$\begin{aligned} g_m &= \frac{\Delta i_D}{\Delta v_{GS}} \\ &= \frac{58\,\mathrm{mA} - 41\,\mathrm{mA}}{3.3\,\mathrm{V} - 3.1\,\mathrm{V}} \\ &= 0.085\,\mathrm{S} \end{aligned}$$

The equivalent small-signal model of MOSFET is presented in Fig. 7:

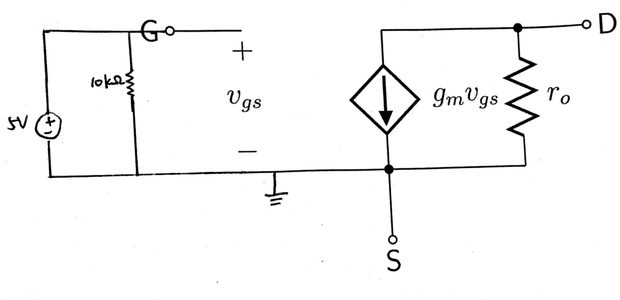

Fig. 7. Equivalent small-signal model of MOSFET for low-frequency operation.

The hybrid-pi model was used in the above model, where we define

$$r_0 = \frac{V_A}{I_D} \tag{1}$$

B. MOSFET Temperature Effects

The MOSFET's I_D-V_{DS} curve was measured using the circuit in Fig. 1 at different temperatures. In theory, the current conducted at a higher temperature a fixed V_{DS} will be larger than that at a lower temperature. In the lab, the following results are obtained at room temperature.

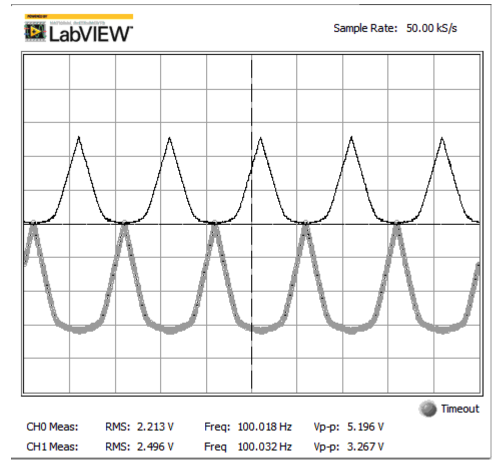

Fig. 8. MOSFET's I_D-V_y at room temperature: 31 °C.

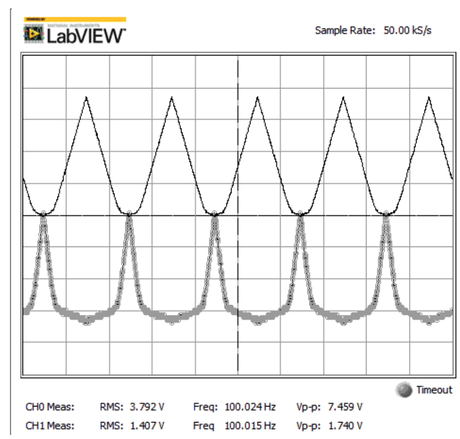

Fig. 9. MOSFET's I_D-V_y at −18 °C.

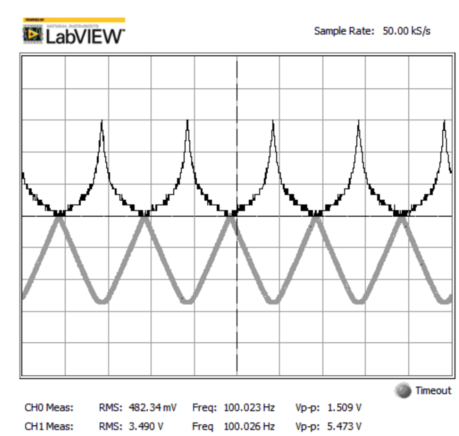

Fig. 10. MOSFET's I_D-V_y at 47 °C.

By comparing the three graphs, we see that for 31 °C and 47 °C, the values and the graph are very similar. For −18 °C, I_D is smaller at the same V_{DS}. It could be explained by the fact that at lower temperatures, there are less free electrons and holes available to conduct current. Similarly, as the temperature increases, there would be more thermally generated holes and free electrons, which increases its conductivity.

C. BJT I_C-V_{CE} Characteristics Using a Curve Tracer

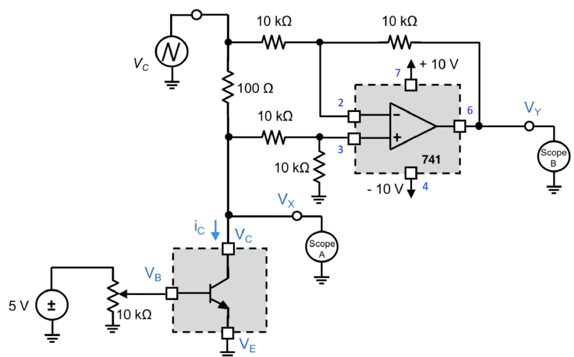

Fig. 11. Circuit diagram to find I_C-V_{CE} for the BJT.

To analyze the behavior of I-V characteristic of the BJT, we built the circuit in Fig. 11 and plot the curve for different values of V_{in}, which is a sawtooth waveform that varies from 1 V to 10 V. We obtained the follwoing results:

1) :

V_{CE} (unit: V)	V_Y (unit: V)	I_C (unit: A)
0	0	0
1	0	0
2	0	0
$\vdots$	$\vdots$	$\vdots$
8	0	0
9	0	0
10	0	0

When the base voltage V_B is below 650 mV, the results are somewhat similar to the table shown above and as shown in Fig. 12, which is zero current flowing.

2) : When the base voltage V_B is increased to 700 mV, we start to get the result as shown in Fig. 13.

V_{CE} (unit: V)	V_Y (unit: V)	I_C (unit: mA)
0	0.5	5
1	1.5	15.3
2	2	15.3
$\vdots$	$\vdots$	$\vdots$
5	1.61	16.1
6	1.69	16.9
7	1.66	16.6

As it can be seen from the graphs and tables, at low gate voltages, the value of I_C is very small. When the gate voltage is increased to around 710 mV, we see that the current starts to increase to around 15 mA.

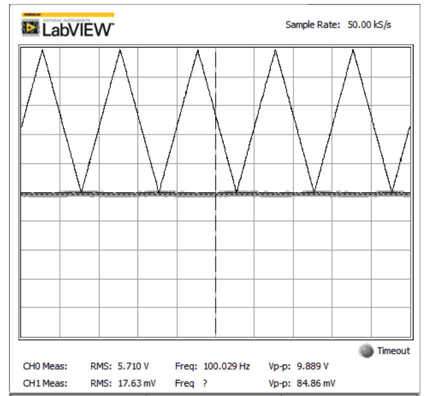

Fig. 12. BJT is in switched off mode.

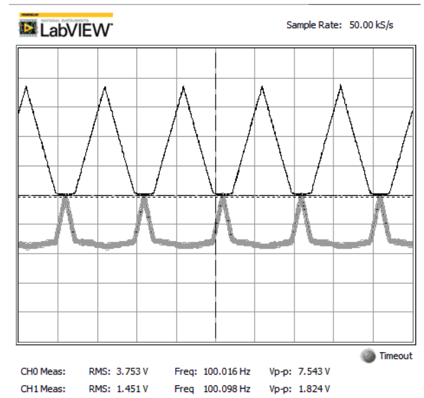

Fig. 13. Base voltage is increased to 700 mV.

3) Computing the Transconductance of BJT: Now, as required, the base voltage V_B is set to be 650 mV. The result as shown in Fig. 14.

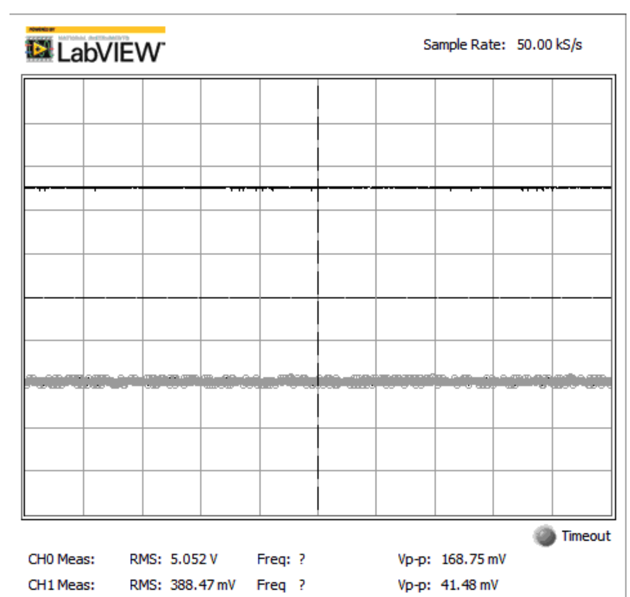

Fig. 14. Base voltage is set to 650 mV.

From Fig. 14, I_C is measured to be $3\,\mathrm{mA}$. Next, we set base voltage V_B to be $700\,\mathrm{mV}$. The measuring result is shown in Fig. 15.

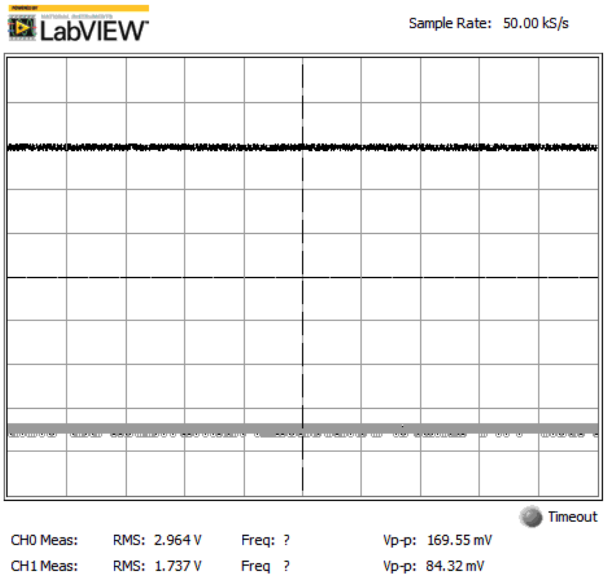

Fig. 15. Base voltage is set to $700\,\mathrm{mV}$.

From Fig. 15, I_C is measured to be $20\,\mathrm{mA}$. Hence,

$$\begin{aligned} g_m &= \frac{\Delta i_c}{\Delta v_{BE}} \\ &= \frac{20\,\mathrm{mA} - 3\,\mathrm{mA}}{700\,\mathrm{mV} - 650\,\mathrm{mV}} \\ &= 0.34\,\mathrm{S} \end{aligned}$$

4) Small signal model of BJT at low frequency: The equivalent small-signal model of BJT is presented in Fig. 16:

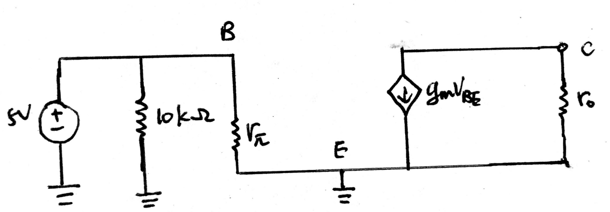

Fig. 16. Equivalent small-signal model of BJT.

The pi model was used in the above model since the emitter is connected to the ground.

$$\begin{aligned} r_0 &= \frac{V_A}{I_c} \\ r_\pi &= \frac{V_T}{I_B} \end{aligned}$$

D. BJT Temperature Effects

As seen in subsection II-C, as we increase the temperature, the current for a certain drain voltage increases. In theory, as the temperature increases, there are more free holes and electrons to carry the charges, thus the I_C-V_{CE} curve would shift up as the temperature increases. We obtained the following results:

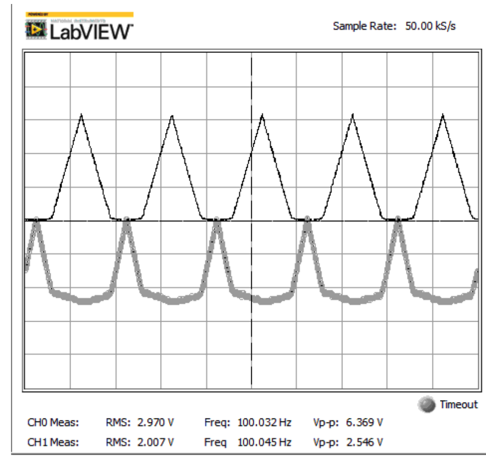

Fig. 17. BJT V_{DS}-V_Y at $22\,°\mathrm{C}$.

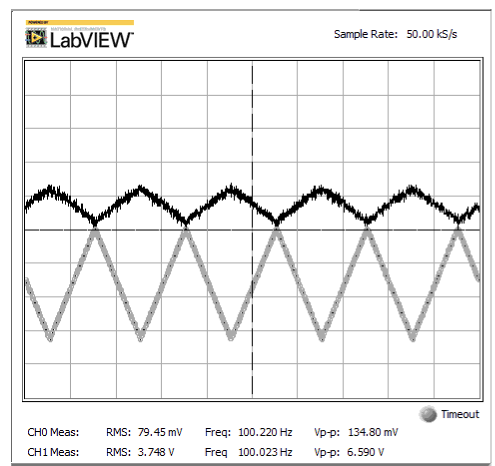

Fig. 18. BJT V_{DS}-V_Y at $45\,°\mathrm{C}$.

By comparing Fig. 17 and Fig 18, we see that for $22\,°\mathrm{C}$ and $45\,°\mathrm{C}$, at lower temperatures, there are less free electrons and holes available to conduct current, which yields to a worse conductivity.

III. Conclusion

To conclude, in this lab, the experiments overall confirmed what was learned in class, various circuits were built and the usefulness of the MOSEFT and BJT transistors were demonstrated. We saw in this lab that the conductivity of MOSFETs and BJTs are heavily affected by the temperature. Also, for different values of V_{DS}, the transistors behave differently. When V_{DS} is more than the overdrive voltage, then its current I_D is saturated.