Lab 3: Transistor Characterization

1. Task:

Besides diodes, transistors are also commonly-used active device in analog circuits, such as operational amplifier. Transistors include two commonly used families: bipolar junction transistors (BJTs) and field-effect transistors (FETs).

If you open an existing SPICE model of transistor in LTspice, you will find 20 plus parameters including a variety of parasitic circuit elements and some process related parameters. It is time consuming and difficult for the application engineer to extract all these parameters. In most cases, the SPICE models will be provided by the manufacturers. The manufacturers also provide the component datasheet, which list the important parameters and figures, from which, the SPICE parameters, can be calculated.

In this task, you will get familiarize with BJT and MOSFET in terms of a) <u>output and/or transconductance characteristics</u>; and b) <u>key characteristic parameters such as DC current gain and early voltage for BJT, threshold voltage, the trans-conductance gain and channel width modulation factor for MOSFET.</u>

2. Pre-Lab:

<u>Characterize NPN BJT</u>:

BJTs come in two varieties: NPN and PNP, representing the semiconductor type of the three regions. The emitter (E) is very heavily doped compared to the base (B) and collector (C). This is an essential feature of the BJT – if the emitter and collector were switched around in a circuit, the BJT would not perform very well.

A BJT can be characterized by two parameters: DC current gain β and forward early voltage V_A. Based on the two parameters, all key parameters such as the transconductance g_m and output impedance needed for small signal analysis can be calculated.

$$r_o = \frac{V_A}{I_C} \tag{1}$$

<u>Characterize NMOS</u>:

Metal-Oxide-Semiconductor Field-effect transistors (MOSFETs) are so called as they rely on an electric field to modulate the conductance between the source (S) and drain (D) terminals. This electric field is controlled by the voltage on the gate (G) of the device. In normal operation, very little gate current flows in MOSFET. They come in two varieties – n-channel, and p-channel, signifying the type of the semiconductor forming the channel between the source and drain terminals.

The operation of a NMOS can be represented below:

- Saturation region: when $0 < (V_{GS} - V_{th}) < V_{DS}$

$$I_D = K_n (V_{GS} - V_{th})^2 (1 + \lambda V_{DS}) \tag{2}$$

- Linear region: when $V_{DS} < (V_{GS} - V_{th})$

$$I_D = 2K_n V_{DS}\left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right) \tag{3}$$

Based on (1) and (2), a NMOS can be characterized by three parameters: K_n, the threshold voltage V_{th}, and the channel length modulation factor λ. Once a DC bias is known, the key parameters in small signal analysis, such as transconductance g_m and output impedance r_o can be derived based on the three parameters.

$$g_m = \left.\frac{di_D}{dv_{GS}}\right|_{(V_{GS}, I_D)} = 2K_n (V_{GS} - V_{th}) = 2\sqrt{K_n I_D} = \frac{2I_D}{V_{GS} - V_{th}} \tag{4}$$

$$r_o = \frac{1}{\lambda I_D} \tag{5}$$

Normally, these values are either provided directly on the component datasheet, or can be derived from the relevant specifications on the datasheet. The specifications often come with the detailed test conditions. In this lab, you will get to know how to find out these parameters from datasheet and also how to verify it by test.

3. Hardware and Software

Table 1: List of hardware and software

Name	Qty	Description
PC	1	For NI ELVIS II test
NI ELVIS II	1	Hardware test platform
DMM	1	Digital Multimeter for current measurenment

Table 2: Component list

Name	Qty	Description
BC108 or 2N3904	1	BJT under test with datasheet
2N7000	1	NMOS under test with datasheet

4. Lab procedure and analysis:

4.1. Bipolar Transistors:

You will be given one of two BJTs (BC108 or 2N3904) with different packages. Note the label on the device and record it in your log book/report. You need to do this part of experiment for only one device.

Refer to the datasheet of the BJT given to you. Find out the type of the transistor and which leads correspond to the emitter, the base and the collector respectively. Although different packages are available, the assignment of the pins is the same for most BJTs.

Question:

If the datasheet is not available, how do you identify whether the BJT at hand is NPN or PNP? (Hint: two PN junctions in BJT.)

How do you differentiate the emitter from collector? Explain how these differences are related to the doping concentrations in the 3 regions.

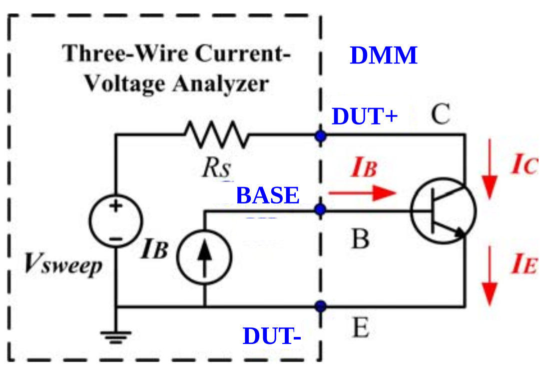


Figure 1: Circuit connection for measurement of BJT I–V characteristics

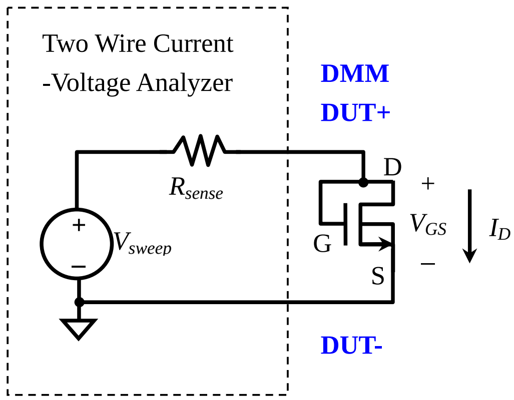
1. Connect the BJT with DMM connectors on the left side of the prototyping board: C-terminal to DUT+, B-terminal to BASE and E-terminal to DUT- as shown in Figure 1. Turn on the power bottoms at the rear side of workbench and the DAQ. Turn on the prototyping boarding power so that the three green LED indicators are on.

2. Firstly find out the specified DC current gain and its testing conditions on datasheet. Then set up the analyzer accordingly to measure the $I_C - V_{CE}$ curve.

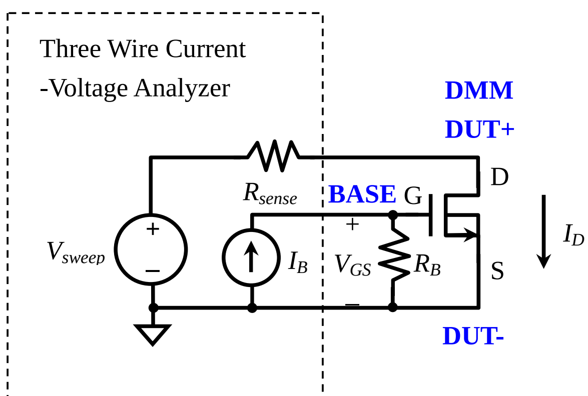
3. Find out the specified output admittance $=1/r_o$ and its test conditions on datasheet. Calculate forward early voltage based on equation (1) firstly. Then set up the analyzer accordingly to measure the $I_C - V_{CE}$ curve in order to find out the forward early voltage V_A.

4.2. MOSFET

You will be given a discrete NMOS (2N7000). Refer to the corresponding datasheet to identify the terminals (G, S&D). Make sure the substrate pin is connected to source pin during the lab. Note that the D&S terminals of the MOSFETs are not interchangeable due to its parasitic body diode between S&D.



(a) Measurement of $I_D - V_{GS}$ characteristics



(b) Measurement of $I_D - V_{DS}$ characteristics

Figure 2: Circuit connection for measurement of NMOS characteristics

1. Find out the gate threshold voltage V_{th}, transconductance g_m and output conductance $1/r_o$ on component datasheet and calculate K_n and λ. Device Model:______________

2. Connect the gate, drain and source terminal of an NMOS as shown in Figure 2 (a). Choose "Two Wire Current-Voltage Analyzer" from NI Instruments Launcher. Choose the proper range to make sure the readings are accurate and repeatable.

3. Connect the given NMOS to measure the $I_D - V_{DS}$ characteristics as shown in Figure 2 (b). Connect the D terminal to DMM DUT+, the S terminal to DUT-, and G terminal to BASE ports. Plot $I_D - V_{DS}$ curve.