PHYSICS 536

Experiment 6: Transistor Characteristics

A. Introduction

This experiment will illustrate the characteristics of BJTs and J-FETs and the voltage gain of a basic amplifier. Before beginning work refer to GIL section 10 for instructions for testing transistors and transistor lead configuration. We will use by-pass capacitors for this experiment; refer to GIL section 13. Other useful resource material is given in GIL sections 3.2, 4.3, 12, and 14.

1. **Bias Equations:** For a common-emitter BJT (Figure 1) the relevant biasing equations are:

$$I_c = (1\text{ mA})e^{(V_{be} - 650mV)/25mV} \quad (6.1)$$

$$v_{be} = 650\text{mV} + 25\text{mV}\ \ln(I_c / 1\text{ mA}) \quad (6.2)$$

$$|V_{ce}| = |V_p| - |I_c| \times R_L \quad (6.3)$$

For a common-emitter J-FET the biasing equations are:

$$I_d = I_{dss}(1 - V_{gs}/V_T)^2 \quad (6.4)$$

$$V_{gs} = V_T[1 - (I_d / I_{dss})^{1/2}] \quad (6.5)$$

$$|V_{ds}| = |V_p| - |I_d| R_L \quad (6.6)$$

Figure 1

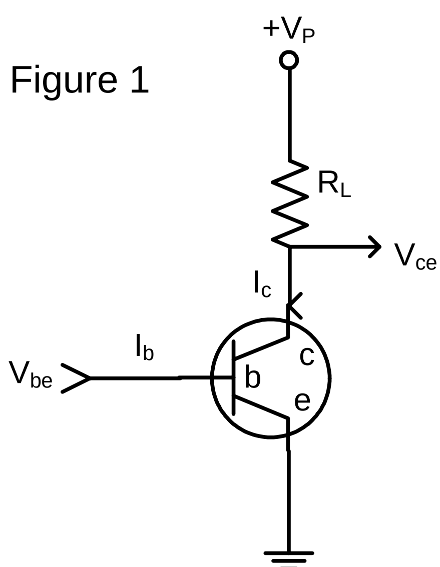
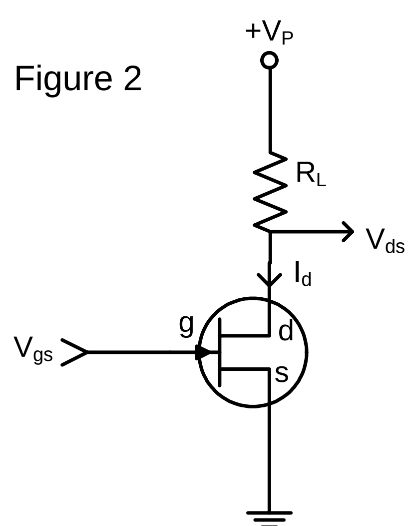


Figure 2



2. Gain Equations Some characteristics of transistors can be illustrated by analogy with diodes. For a diode in the current conducting regime the slope of the curve in the exponential I-V relationship is the transconductance, the reciprocal of the resistance. Accordingly, the transconductance is the derivative of the collector current as a function of the voltage across the base-emitter junction. In many instances it is useful to think of an equivalent resistance rather than a transconductance. For BJTs an approximation is

$$r_m = \frac{25(\Omega - \text{mA})}{I_c} + 1\Omega . \tag{6.7}$$

For J-FETs the equivalent resistance is given by

$$r_m = \frac{V_T}{2\sqrt{I_{dss} I_d}} \tag{6.8}$$

The voltage gain is given by

$$v_o / v_i = -\frac{(r_c \parallel R_L)}{r_m} \tag{6.9}$$

The minus sign indicates that the amplifier inverts the output signal.

3. **Current Control** The collector current is given by the equation

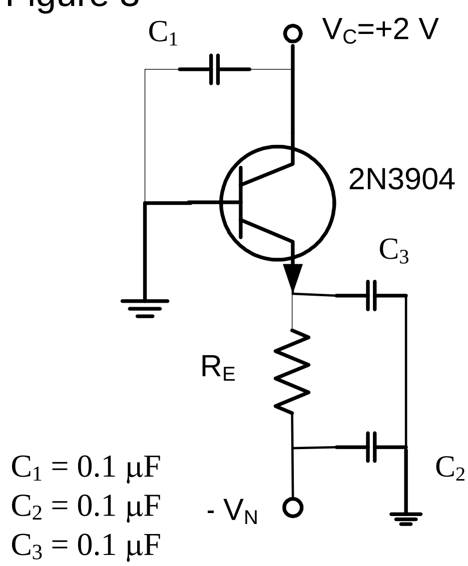
$$I_c = h_{fe} I_b \tag{6.10}$$

A typical value for h_{fe} is 100, but it can be between 20 and 700 in special purpose transistors.

B. Ebers-Moll Model of BJT Characteristics

The exponential I-V relation, used for diodes, provides a quantitative description of BJTs called the Ebers-Moll-Model. The transistor current in this circuit is controlled by the resistor in series with the emitter. The sum of the voltages across the collector-base junction, the base-emitter junction, and the emitter resistor, is constant and equal to the voltage across terminals CN. The emitter resistor, R_E, creates a voltage drop effectively lowering the voltage across the base-emitter junction

Figure 3



until V_{be} has the value needed to permit the resistor current to flow into the emitter. The current is determined by the voltage across R.

$$I_c \approx I_e = (V_e - V_n)/R \tag{6.11}$$

Both voltages in this equation are magnitudes. V_n is a fixed voltage source, and $V_e \approx -0.65V$ because the emitter-base junction is forward biased. Therefore, I_c is controlled by R. In this part of the experiment, you will calculate and measure V_{be} for different values of I_c.

Although the voltage across the base-collector junction is small, there still is enough heat generated at the collector when I_c is 1mA or greater to raise the transistor temperature and affect the V_{be} measurement. Therefore, you should read V_{be} quickly and turn off the power supply as soon as you can so the transistor will be at room temperature for the next measurement.

Three bypass capacitors are used in the circuit. The capacitors C_1 and C_2 should always be included, even if they are not shown on the circuit diagram. Other capacitors, such as C_3, will be specified when they are needed. In this circuit, C_3 is included so that stray AC signals will not affect the DC measurement of V_{be}.

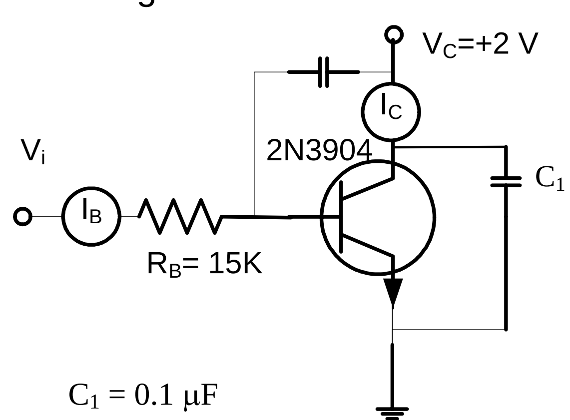
1) Measure V_{BE} as a function of current. The 2N3904 transistor can operate effectively for currents ranging from 100 μA to 100 mA. Measure V_{BE} for collector currents of 1 μQ, 100 μA, and 10 mA. To obtain these specific collector currents use resistors having resistances of 10M, 100K, and 1K respectively. Use the digital meter for your measurements. Refer to the GIL for suggestions on connections.

The value of V_{BE} observed may deviate from that predicted by approximately 30mV. Why in your opinion are your measurements slightly different from predictions?

C. Base Current Control

The collector current (I_c) is controlled by the base current (I_b) in the following circuit. The meters must be inserted in series with the current; refer to GIL GI-2.2. A large resistor is included in series with V_i to form a current source, which supplies I_b. I_b is small so set the scale accordingly. Set the scale on the meter measuring the collector current as needed. The capacitor

Figure 4



across the collector prevents oscillation that can be caused by the long leads going to the meter. The current gain, h_{fe}, depends on I_c. Specific examples can be seen in the specification sheets in the textbook.

2) Use V_i to adjust I_b and obtain the specified values of I_c. Calculate h_{fe} from the observed I_b and I_c.

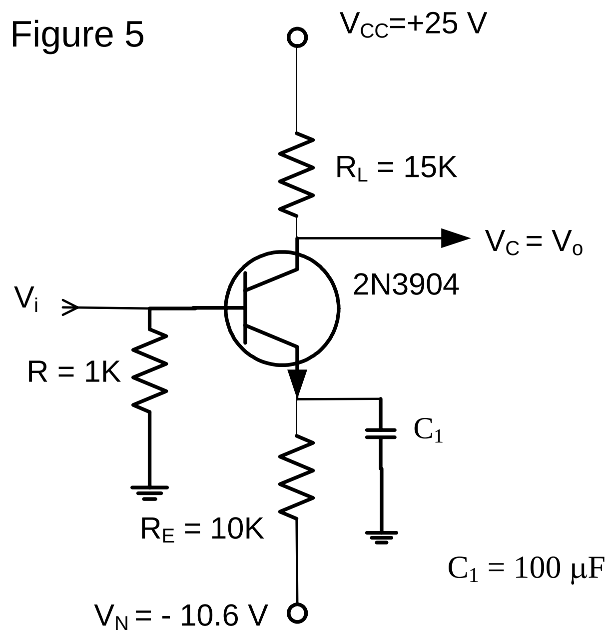
D. Basic Gain Measurement

The purpose of this section is to measure the DC bias conditions and the gain for this basic amplifier. Connect the capacitor with proper polarity.

3) Measure the collector voltage and the gain. Use an input voltage of 10 mV at 2kHz. Observe the phase inversion.

(Assume that $r_c = 100K / I_c(\text{in mA})$)

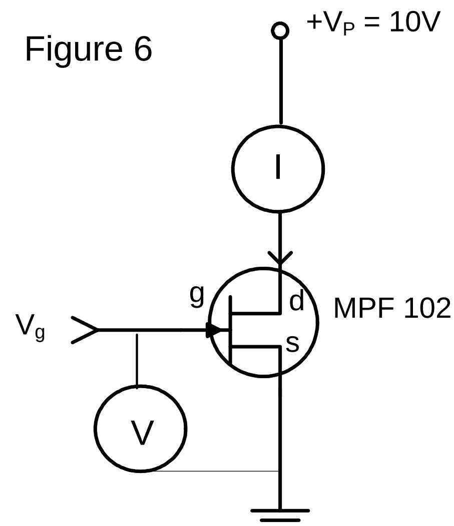
Figure 5



E. JFET Characteristics I_{dss} and V_T.

4) Measure I_{dss} by connecting the gate to common. Next, connect a power supply (V_g) and measure the V_g necessary to reduce I_d to $I_{dss}/100$. Calculate V_T from this V_g. Use this I_{dss} and V_T to predict the I_d for $V_g = 0.2V_T$ and $0.7V_T$. Measure I_d at these values of V_g and compare to your calculations. These measurements should demonstrate that our equation provides a good description of the $I_d - V_{gs}$ relation for a JFET.

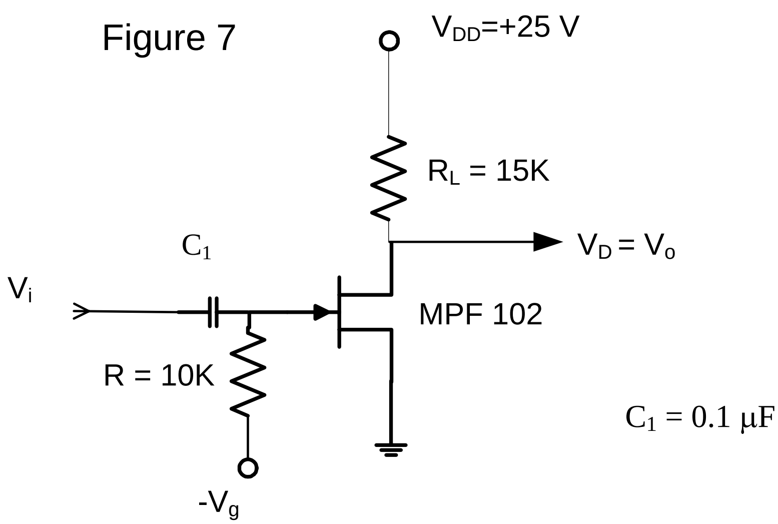
Figure 6



F. JFET Voltage Gain

5) Adjust V_g until V_d has the value that corresponds to $I_d \approx 1mA$. Calculate the expected gain using the parameters measured in step 8. Use $v_i = 100mV$ at $10KHz$ and measure v_o. Compare v_o / v_i to your calculation.

Figure 7



Physics 536
Experiment 7(A)

1.

$$V_n = -10.6V$$
$R = 10M$ provides $I_c = 1\mu A$
$R = 100K$ provides $I_c = 100\mu A$
$R = 1K$ provides $I_c = 10mA$

2.

$I_c = 1mA$ with $h_{fe} = 150$
$I_c = 30mA$ with $h_{fe} = 250$

3.

$$V_n = -10.6V \quad R_1 = 10K \quad R_L = 15K$$

4.

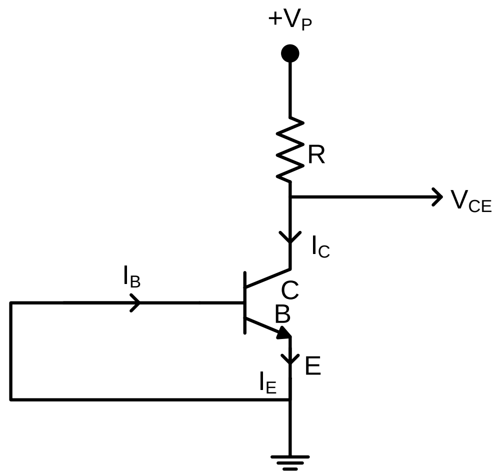
$$I_{dss} = 7mA \quad V_T = 2.5V$$

5.

$$I_{dss} = 7mA \quad V_T = 2.5V \quad R_L = 15K \quad I_d = 1mA$$

Initial Components
Transistors, 2N3904
Capacitors, 3 0.1µf
Resistors, 1K,100K, 10Meg

Transistors: MPF102 FET
Capacitor: 100µf
Resistors:1K, 10K, 15K, 100K, 10M



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