Introduction

In this lab you will bias a Bipolar-Junction Transistor (BJT) in the active mode, and also tests a Common-Emitter (CE) amplifier. Moreover, you will learn a technique for experimental evaluation of the input and output resistances of an amplifier. For this lab, you will use the 2N3904 NPN BJT.

Pre-lab Assignment

P1. For the circuit of Figure 1, calculate node voltages V_B, V_C, and V_E, as well as the branch currents I_B, I_C, and I_E. Note that the resistances are different for different lab sections and, therefore, you must consult the document posted on D2L to determine the resistance values specific to your designated lab section. Otherwise, assume that $V_{cc} = 15V, \beta = 150, V_{BE,on} = 0.7V$, and $V_{CE,sat} = 0.3V$, and ignore the Early effect. Based on the calculated node voltages and branch currents, first establish that the transistor is in the active mode, and then determine the AC parameters g_m, r_e,and r_π. Complete Table 1. Show all of your work.

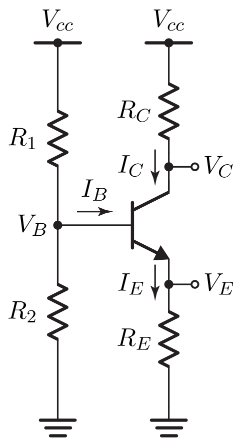

Figure 1: Transistor circuit.

Table 1: Quiescent voltages and currents, and AC parameters of the transistor circuit of Figure 1.

$V_B(V)$	$V_C(V)$	$V_E(V)$	$I_B(mA)$	$I_C(mA)$	$I_E(mA)$	$g_m(mS)$	$r_e(k\Omega)$	$r_\pi(k\Omega)$

P2. Using the results of P1, and assuming that $V_{cc} = 15V, R_S = 50\Omega$, and $R_L = 10k\Omega$, manually calculate the no-load voltage gain A_{vo}, voltage gain $A_v = v_o/v_i$, input resistance, R_i, and output resistance, R_o, of the Common-Emitter amplifier of Figure 2. Complete Table 2. Show all of your work.

P3. Simulate the Common-Emitter amplifier of Figure 2, assuming that the transistor is the 2N3904, $V_{cc} = 15V, R_S = 50\Omega, R_L = 10k\Omega, C_1 = C_2 = 10\mu F$, and $C_3 = 100\mu F$. Also, assume v_S to be a

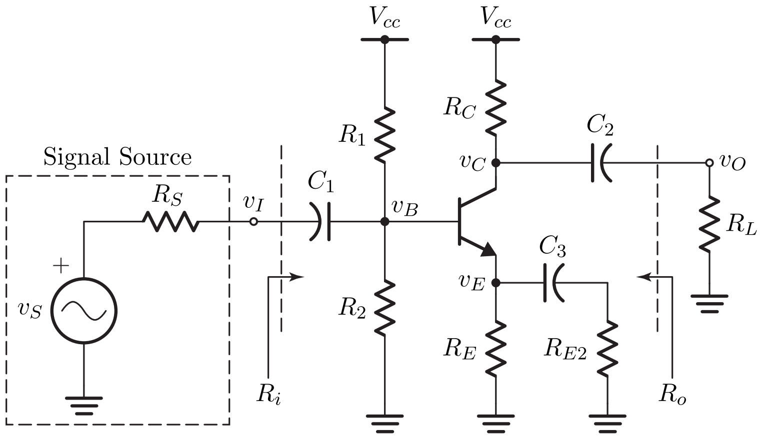

Figure 2: Common-emitter (CE) amplifier based on the circuit of Figure 1.

Table 2: Parameters of the Common-Emitter amplifier of Figure 2.

$A_{vo}(V/V)$	A_v for $R_L = 10k\Omega(V/V)$	$R_i(k\Omega)$	$R_o(k\Omega)$

1-kHz symmetrical sinusoidal voltage. Choose the magnitude of v_S in such a way that v_o features the maximum possible swing without noticeable distortion. Although doable by trial and error, this can be done systematically by first calculating the maximum permissible swing of v_o, and then dividing that swing by A_v, in order to find the maximum permissible swing of v_I. The swing of v_S is then close to that of v_I, since R_S is typically much smaller than R_i. Present the waveforms of v_S, v_I, and v_o for approximately three cycles (periods) as Graph P3. Make sure that v_I and v_o are in-phase (in terms of their zero-crossings). Otherwise, check your simulation model and parameters. Also, verify that your manual calculation of A_v (reported in Table 2) agrees with the gain indicated by the waveforms of Graph P3. Otherwise, check your calculations and/or simulation model.

P4. It is useful and a common practice to represent an amplifier (irrespective of its internal circuitry, number of transistors, etc.) with a two-port equivalent circuit such as the one shown in Figure 3 below. Thus, the input port of the amplifier is assumed to effectively appear to the outside world as R_i, the input resistance of the amplifier. Also, the output port of the amplifier is viewed from the outside world as a Thevenin circuit whose Thevenin voltage $A_{vo}v_i$ is a magnified copy of the input voltage, where the magnification factor A_{vo} is the open-circuit (or no-load) voltage gain of the amplifier, and whose Thevenin (or series) resistance, R_o, is the output resistance of the amplifier.

Now, consider the circuit of Figure 4 in which an amplifier represented by the two-port box of Figure 3 drives a test load, $R_{t,out}$ and is fed by a signal source whose Thevenin voltage and resistance are v_s and R_s, respectively. However, the signal source is not directly connected to the input port of the amplifier, but through another test resistor, $R_{t,in}$, as Figure 4 illustrates. Prove that the input resistance of the amplifier can be found from

$$R_i = R_{t,in}\left(\frac{v_i}{v_t - v_i}\right)$$

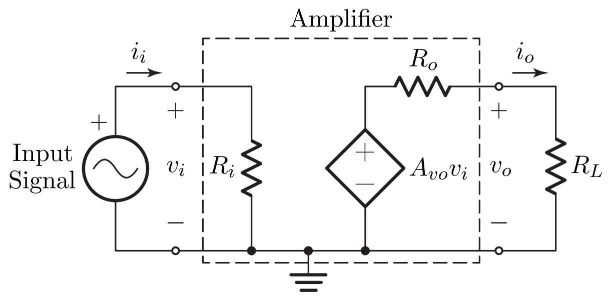

Figure 3: Two-port representation of an amplifier.

Also, prove that the output resistance of the amplifier, R_o, can be found from

$$R_o = R_{t,out}\left(\frac{A_{vo}v_i}{v_o} - 1\right)$$

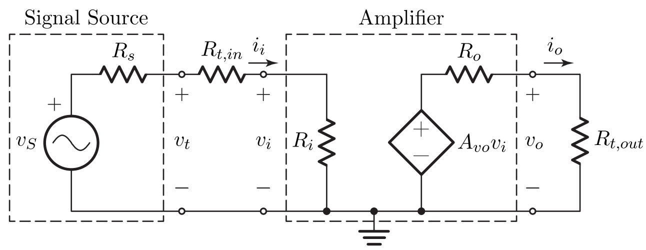

Figure 4: An amplifier energizing a test load, $R_{t,out}$, through a signal source in series with a test resistance, $R_{t,in}$.

Experiment and Results

E1. Construct the transistor circuit of Figure 1, using the BJT 2N3904 as the transistor. Figure 5 helps you identify the pins of the transistor. Set your bench-top power supply to ensure that the supply voltage is $V_{cc} = 15V$. Then, using your multimeter in the DC voltage measurement mode, measure node voltages V_B, V_C, and V_E. Then, using the resistances and measured voltages, calculate the device currents I_B, I_C, and I_E. Complete Table 3.

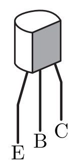

Figure 5: Terminals of the NPN BJT 2N3904

E2. Use the circuit that you built in E1 as a kernel and evolve it to the Common-Emitter amplifier of Figure 2 with $R_L = 10k\Omega$. Use 10-μF electrolytic capacitors as the coupling capacitors C_1 and

Table 3: Measured terminal voltages and currents of the BJT in the circuit of Figure 1.

$V_B(V)$	$V_C(V)$	$V_E(V)$	$I_B(mA)$	$I_C(mA)$	$I_E(mA)$

C_2, and a 100-μF electrolytic capacitor as the bypass capcaitors C_3. Be careful with the polarity of the capcaitors. Commonly, it is the negative terminal of the capacitor that is identified by a marking on the case of the capacitor. On the schematic, the negative terminal corresponds to the curved plate of the capacitor's symbol (see Figure 2).

Set Channel 1 and Channel 2 of your oscilloscope to the DC-coupled mode and use them to monitor voltages v_i and v_o, respectively. Then, set the signal generator to produce a 1-kHz symmetrical sinusoidal signal with the magnitude you found in P3. Again, use the maximum input signal magnitude that produces an undistorted (or sinusoid-looking) output voltage. As long as the amplifier works fairly linearly, that is, as long as the output voltage waveform looks like a sinusoid, your subsequent measurements will be valid. If the output signal appears to be distorted, or even worse, clipped, reduce the signal amplitude until this is no longer the case. Capture the waveforms of v_i and v_o for approximately three cycles, and present the waveforms as Graph E2. If the waveforms are noise by chance (for example due to their small magnitudes) use the oscilloscope's "Acquire" button and adjust the settings to capure the "Average" of the waveforms.

Next, set the multimeter to the AC voltage measurement mode and measure the rms values of v_i and v_o. Then, press the "dB" button on the multimeter to measure v_i and v_o in dB. From the measurements, determine the voltage gain $A_v = v_o/v_i$ in both V/V and dB. Remember that the value of a voltage V in dB is defined as $V(dB) = 20\log(V/V_R)$ where V_R is a reference voltage (for example, $0.7746V$ rms) identified by the datasheet of the multimeter. THe voltage gain in dB is therefore simply the output voltage measured in dB minus the input voltage in dB, i.e., $A_v(dB) = 20\log(V_o/V_i) = 20\log(V_o/V_R) - 20\log(V_i/V_R)$.

Record the measured values of v_i and v_o, as well as the corresponding voltage gains (in V/V and dB) in Table 4.

Table 4: Input and output AC voltages and gain of the Common-Emitter amplifier with $R_L = 10k\Omega$.

$V_i(V)$ rms	$V_o(V)$ rms	$A_v(V/V)$	V_i(dB)	V_o(dB)	A_v(dB)

Remove the $10-k\Omega$ load and repeat the AC voltage measurements used for Table 4. These measurements will give us the no-load voltage gain A_{vo}. Complete Table 5.

Table 5: Input and output AC voltages and gain of the Common-Emitter amplifier with $R_L = 10k\Omega$.

$V_i(V)$ rms	$V_o(V)$ rms	$A_v(V/V)$	V_i(dB)	V_o(dB)	A_v(dB)

E3. Now, we will measure the input resistance of the Common-Emitter amplifier built in E2, using the method discussed in P4. Set the multimeter in the AC voltage measurement mode to measure voltages in terms of their rms values. Then, bring the 10-$k\Omega$ load back into the circuit. Next, insert a test resistance, which we called $R_{t,in}$ in P4, between the output terminal of the signal generator and the input terminal of the amplifier (refer to Figure 4). Choose the value of $R_{t,in}$ such that it is close to the value of R_i that you expect the amplifier to have (based on the analysis you did in P2). For instance, if you calculated R_i to be about $7k\Omega$, then $R_{t,in}$ should also be of the same order of magnitude (e.g., a few $k\Omega$). Measure voltages v_t and v_i, and based on the measured values, calculate R_i. Complete Table 6.

Table 6: Parameters of the Common-Emitter amplifier for determining its input resistance.

$R_{t,in}(k\Omega)$	$V_t(V)$ rms	$V_i(V)$ rms	$R_i(k\Omega)$

E3. Next, replace the input resistance by a short link, to bring the amplifier back to the configuration of E2. Then, replace the 10-$k\Omega$ load resistance with a test resistance, which you called $R_{t,out}$ in P4, whose value is of the same order of magnitude as the value that you expect for R_o (based on your manual calculations from P2). Then, record the no-load and loaded rms output voltages of the amplifier. Based on the measured values, calculate R_o and complete Table 7.

Table 7: Parameters of the Common-Emitter amplifier for determining its output resistance.

$R_{t,out}(k\Omega)$ (i.e., the load)	$V_o(V)$ rms without load (i.e., $A_{vo}v_i$)	$V_o(V)$ rms with load	$R_o(k\Omega)$

Conclusion

Answer the following questions based on the various aspects of the lab. Questions must be *fully answered* and you must demonstrate that you have full understanding of the concepts observed in this lab to achieve full marks.

C1. Compare the calculated and measured quiescent (DC) voltages of the CE amplifier, and calculate the percent error from the following expression:

$$e_{\%} = \frac{\text{theoretical value} - \text{measured value}}{\text{measured value}} \times 100$$

Complete Table 8 and comment on the magnitude of, and reasons for, the errors.

Table 8: Theoretical and measured values of the small-signal resistance of the diode.

	$V_B(V)$	$V_C(V)$	$V_C(V)$
Calculated values (from P1)			
Measured values (from E1)			
Percent error, $e_{\%}$			

C2. Compare the calculated and measured AC parameters of the Common-Emitter amplifier, and calculate the percent errors. Complete Table 9. Comment on the magnitudes of, and reasons for, the errors.

Table 9: Theoretical and measured values of the small-signal resistance of the diode.

	$A_v(V/V)$	$A_{vo}(V/V)$	$R_i(k\Omega)$	$R_o(k\Omega)$
Calculated values (from P1)				
Measured values (from E1)				
Percent error, $e_{\%}$				

C3. Based on the measured results, calculate the current gain A_i and power gain A_p of the Common-Emitter amplifier. The current gain is defined as the ratio of the output current, i_o to the input current i_i (see Figure 3 and Figure 4 to identify those currents). Also, the power gain is defined as the ratio of the power that the amplifier delivers to the load to the power that the amplifier draws from the signal source, i.e., through its input port. Therefore, $A_p = A_v A_i$.

C4. Explain the effect of resistance R_{E2} of the Common-Emitter amplifier on:

- The voltage gain,
- The input resistance,
- The output resistance, and
- The maximum magnitude of v_i before the output voltage exhibits distortion.

TA Copy of Results

Table 10: Measured terminal voltages and currents of the BJT in the circuit of Figure 1.

$V_B(V)$	$V_C(V)$	$V_E(V)$	$I_B(mA)$	$I_C(mA)$	$I_E(mA)$

Table 11: Input and output AC voltages and gain of the Common-Emitter amplifier with $R_L = 10k\Omega$.

$V_i(V)$ rms	$V_o(V)$ rms	$A_v(V/V)$	V_i(dB)	V_o(dB)	A_v(dB)

Table 12: Input and output AC voltages and gain of the Common-Emitter amplifier with $R_L = 10k\Omega$.

$V_i(V)$ rms	$V_o(V)$ rms	$A_v(V/V)$	V_i(dB)	V_o(dB)	A_v(dB)

Table 13: Parameters of the Common-Emitter amplifier for determining its input resistance.

$R_{t,in}(k\Omega)$	$V_t(V)$ rms	$V_i(V)$ rms	$R_i(k\Omega)$

Table 14: Parameters of the Common-Emitter amplifier for determining its output resistance.

$R_{t,out}(k\Omega)$ (i.e., the load)	$V_o(V)$ rms without load (i.e., $A_{vo}v_i$)	$V_o(V)$ rms with load	$R_o(k\Omega)$

Student Name	Pre-lab (/20)	Set-up (/10)	Data Collection (/10)	Participation (/5)