Ryerson University

Department of Electrical & Computer Engineering

ELE 404

Common-Emitter (CE) Amplifier

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 transistor circuit of **Figure 1**, calculate the 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 know the resistance values specific to your designated lab section**. Otherwise, assume that $V_{CC} = 15\ V$, $\beta = 150$, $V_{BE,on} = 0.7\ V$, and $V_{CE,sat} = 0.3\ V$, and ignore the Early effect. Based on the calculated node voltages and branch currents, first establish the fact that the transistor is in the active mode and then determine the AC parameters g_m, r_e, and r_π. Complete **Table P1**. Show all the work.

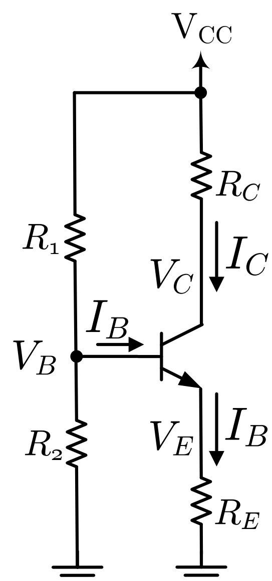


Figure 1. Transistor circuit.

Table P1. 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 **Step P1**, and assuming that $V_{CC} = 15\,V$, $R_S = 50\,\Omega$, and $R_L = 10\,k\Omega$, 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 (CE) amplifier of **Figure 2.** Complete **Table P2**. Show all the work.

Table P2. Parameters of the CE amplifier of **Figure 2**.

$\boldsymbol{A_{vo}[V/V]}$	$\boldsymbol{A_v[V/V]}$ **for** $\boldsymbol{R_L = 10\ k\Omega}$	$\boldsymbol{R_i[k\Omega]}$	$\boldsymbol{R_o[k\Omega]}$

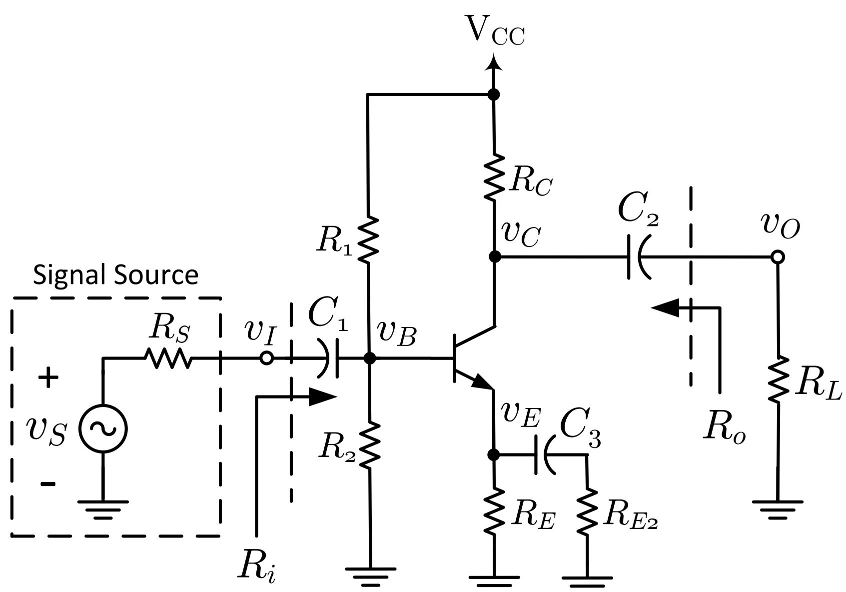
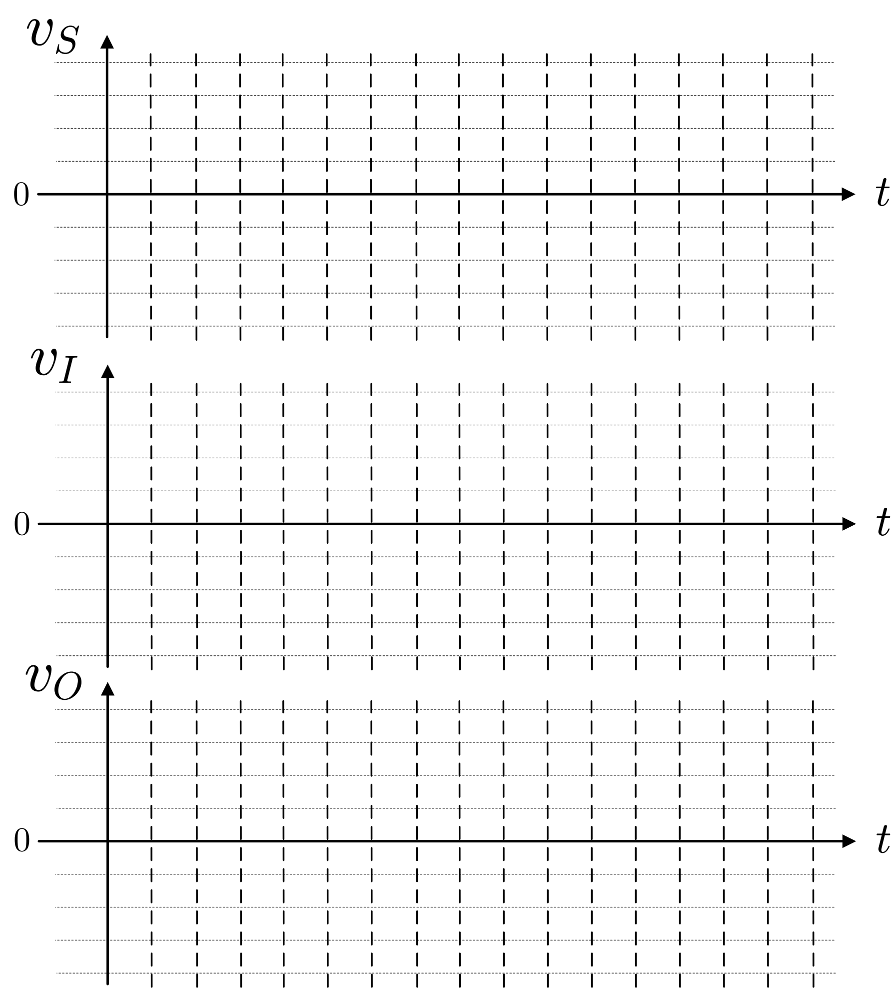


Figure 2. Common-Emitter (CE) amplifier based on the circuit of Figure 1.

P3. Simulate the CE amplifier of **Figure 2**, assuming that the transistor is the 2N3904, $V_{CC} = 15\ V$, $R_S = 50\ \Omega$, $R_L = 10\ k\Omega$, $C_1 = C_2 = 10\ \mu F$, and $C_3 = 100\ \mu F$. Also, assume v_S to be a 1-kHz symmetrical sinusoidal voltage. Choose the magnitude of v_S in such a way that v_O features the maximum 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 the mentioned swing by A_v, 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 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 P2**) agrees well with the gain indicated by the waveforms of **Graph P3**. Otherwise, check your calculations and/or your simulation model.



Graph P3. Source, input, and output voltage waveforms of the CE amplifier of Figure 2, with $R_S = 50\ \Omega$ and $R_L = 10\ k\Omega$.

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 a resistance, R_i, the input resistance of the amplifier. Also, the output port of the amplifier is viewed from the outside 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. For further information see Chapter 1, Section 1.5, Sedra-Smith textbook, 6th or 7th Editions.

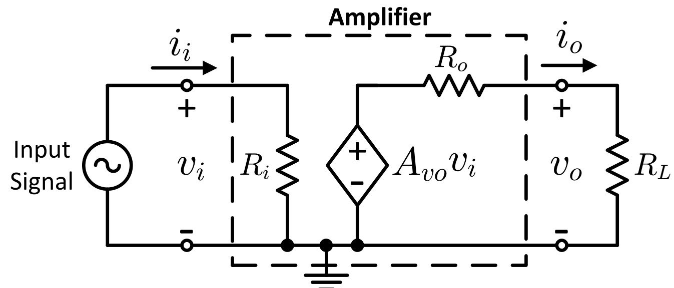


Figure 3. Two-port representation of an amplifier.

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, R_i, of the amplifier can be found from

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

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

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

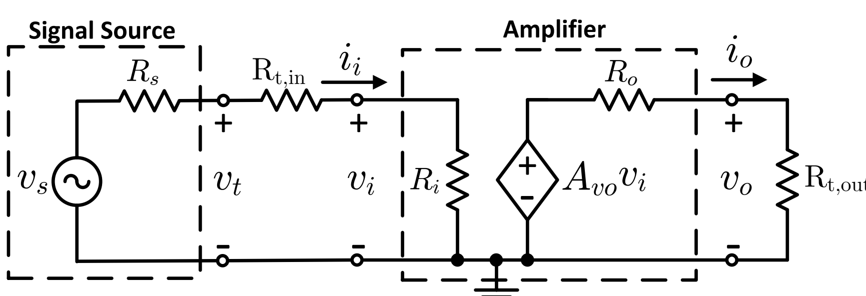


Figure 4. An amplifier energizing a test load, $R_{t,out}$, through a signal source in series with a test resistance, $R_{t,in}$.

Experiments 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 $V_{CC} = 15\,V$. Then, using your multimeter in the DC voltage measurement mode, measure the node voltages V_B, V_C, and V_E. Then, using the resistances and the measured voltages, calculate the device currents I_B, I_C, and I_E. Complete **Table E1**.

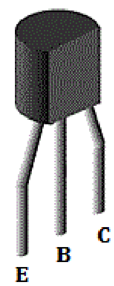


Figure 5. Terminals of the NPN BJT 2N3904.

Table E1. Measured terminal voltages and currents of the BJT in the circuit of **Figure 1**.

$V_B\,[V]$	$V_C[V]$	$V_E[V]$	$I_B[mA]$	$I_C[mA]$	$I_E\,[mA]$

E2. Use the circuit you built in **Step E1** as the kernel and evolve it to the CE amplifier of **Figure 2**, with $R_L = 10\ k\Omega$. Use 10-μF electrolytic capacitors as the coupling capacitors C_1 and C_2, and a 100-μF electrolytic capacitor as the bypass capacitors C_3. Be careful with the polarity of the capacitors. Commonly, it is the negative terminal of the capacitor that is identified by a marking on the case of the capacitor. Schematically, 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 Step P3.** The idea is that you should go for the maximum input signal magnitude that results in an undistorted (or sinusoid-looking) output voltage. As long as the amplifier works fairly linearly, that is, as long as its output voltage waveform looks very much 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 about three cycles, and save the captured waveforms as **Graph E2.** If the waveforms are noisy by any chance (for example, due to their small magnitudes), use the oscilloscope's "Acquire" button to capture 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 of 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, 0.7746 V rms) identified by the datasheet of the meter. The voltage gain in dB is therefore simply the output voltage 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 the corresponding voltage gains (in V/V and dB) in **Table E2(a)**.

Table E2(a). Input and output AC voltages and gain of the CE amplifier, with $R_L = 10\ k\Omega$.

$\boldsymbol{V_i\ [Vrms]}$	$\boldsymbol{V_O[Vrms]}$	$\boldsymbol{A_v[V/V]}$	$\boldsymbol{V_I[dB]}$	$\boldsymbol{V_O[dB]}$	$\boldsymbol{A_v\ [dB]}$

Remove the 10-$k\Omega$ load and repeat the AC voltage measurements used for **Table E2(a)**. These measurements will give us the no-load voltage gain, A_{vo}. Complete **Table E2(b)**.

Table E2(b). Input and output AC voltages and gain of the CE amplifier, with $R_L = \infty$.

$\boldsymbol{V_i\ [Vrms]}$	$\boldsymbol{V_O[Vrms]}$	$\boldsymbol{A_{vo}[V/V]}$	$\boldsymbol{V_I[dB]}$	$\boldsymbol{V_O[dB]}$	$\boldsymbol{A_{vo}\ [dB]}$

E3. Let us now measure the input resistance of the CE amplifier built in **Step E2**, using the method discussed in **Step P4**. To that end, 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 you called $R_{t,in}$ in **Step P4**, between the output terminal of the signal generator and the input terminal of the amplifier (refer to **Figure 4**). Choose a value for $R_{t,in}$ that is close to the value of R_i you expect the amplifier to have (based on your analysis in **Step P2**). For instance, if R_i to be measured is expected to be about 7 kΩ, then $R_{t,in}$ should also be of the same order of magnitude (e.g., about a few kΩ). Measure voltages v_t and v_i, and based on the measured values, calculate R_i. Complete **Table E3.**

Table E3. Parameters of the CE amplifier for determining its input resistance.

$\boldsymbol{R_{t,in}}$ $[\boldsymbol{k\Omega}]$	$\boldsymbol{V_t[Vrms]}$	$\boldsymbol{V_i[Vrms]}$	$\boldsymbol{R_i[k\Omega]}$

E4. Next, replace the input test resistance by a short link, to bring the amplifier back to the state it had in **Step E2**. Then, replace the 10-$k\Omega$ load resistance with a test resistance, which you called $R_{t,out}$ in **Step P4**, whose value is of the same order of magnitude as the value you expect for R_O (based on your manual calculations in **Step 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 E4.**

Table E4. Parameters of the CE amplifier for determining its output resistance.

$\boldsymbol{R_{t,out}}$ $[\boldsymbol{k\Omega}]$ **(i.e., the load)**	$\boldsymbol{V_O[Vrms]}$ **without load (i.e., $\boldsymbol{A_{vo}v_i}$)**	$\boldsymbol{V_o[Vrms]}$ **with load**	$\boldsymbol{R_o[k\Omega]}$

Conclusions and Remarks

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

$$e\% = \frac{calculated\ value - measured\ value}{measured\ value} \times 100$$

Complete **Table C1** and comment on the magnitude of, and reasons for, the errors.

Table C1. Calculated and measured (DC) voltages in the transistor circuit of **Figure 1**.

	$\boldsymbol{V_B[V]}$	$\boldsymbol{V_C[V]}$	$\boldsymbol{V_E[V]}$
Calculated values (from Table P1)			
Measured values (from Table E1)			
Percent error, $e\%$			

C2. Compare the calculated and measured AC parameters of the CE amplifier, and calculate the percent errors. Complete **Table C2**. Comment on the magnitudes of errors and provide reasons for discrepancies.

Table C2. Calculated and measured ac parameters for the CE amplifier of **Figure 2**.

	$\boldsymbol{A_v[V/V]}$	$\boldsymbol{A_{vo}[V/V]}$	$\boldsymbol{R_i[k\Omega]}$	$\boldsymbol{R_o[k\Omega]}$
Calculated Values (from Table P2)				
Measured Values (from Tables E2, E3, and E4)				
Percent Error, $e\%$				

C3. Based on the measured results, calculate the current gain A_i and power gain A_p of the CE 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 CE amplifier on

- The voltage gain
- The input resistance
- The output resistance
- The maximum magnitude of v_i before the output voltage exhibits distortions.

TA Copy of Results

Table E1. 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 E2(a). Input and output ac voltages and gain of the CE amplifier, with $R_L = 10\ k\Omega$.

$V_i\ [Vrms]$	$V_O[Vrms]$	$A_v[V/V]$	$V_I[dB]$	$V_O[dB]$	$A_v\ [dB]$

Table E2(b). Input and output ac voltages and gain of the CE amplifier, with $R_L = \infty$.

$V_i\ [Vrms]$	$V_O[Vrms]$	$A_{vo}[V/V]$	$V_I[dB]$	$V_O[dB]$	$A_{vo}\ [dB]$

Table E3. Parameters of the CE amplifier for determining its input resistance.

$R_{t,in}\ [k\Omega]$	$V_t[Vrms]$	$V_i[Vrms]$	$R_i[k\Omega]$

Table E4. Parameters of the CE amplifier for determining its output resistance.

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

	Partner's Name	Pre-Lab (out of 20)	Set-Up (out of 10)	Data Collection (out of 10)	Participation (out of 5)
1					
2					