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Department of Electrical, Computer, & Biomedical Engineering
Faculty of Engineering & Architectural Science

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Instructor:	Md Waselul Haque Sadid

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Assignment/Lab Title:	Common-collector (CC) Amplifier

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Due Date:	

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ELE 404: Electronics I
Common-Collector (CC) Amplifier

Introduction

In this lab you will construct a Common-Collector (CC) BJT amplifier and acquaint yourself with its very important property, namely, *buffering.* This lab also provides you with an opportunity to analyze and test a multi-stage amplifier (a two-stage amplifier, to be exact). For this lab, you will need two 2N3904 NPN BJTs.

Pre-lab Assignment

P1. Consider the CE amplifier of **Figure 1**, driving a load R_L. Assume that $R_1 = 12\ k\Omega$, $R_2 = 15\ k\Omega$, $R_C = 2.7\ k\Omega$, $R_E = 6.8\ k\Omega$, $R_{E2} = 220\ \Omega$, $V_{CC} = 15\ V$, $\beta = 150$, $V_{BE,on} = 0.7\ V$, and $V_{CE,sat} = 0.3\ V$. Also assume the capacitors to be short at the operating frequencies of interest. Then, manually calculate the DC (quiescent) currents and voltages of the amplifier, as well as the no-load voltage gain A_{vo}, voltage gain $A_v = v_o/v_i$ (with $R_L = 180\ \Omega$), voltage gain $A_{vs} = v_o/v_s$ (with $R_s = 50\ \Omega$ and $R_L = 180\ \Omega$), and output resistance R_o. Complete **Table P1**. Show all work.

$V_E = I_E \cdot R_E^{total} = (1.07 \cdot 7.02k\Omega) = 7.51V$

$V_C = V_{CC} - I_C R_C = 15 - 1.07mA \cdot 2.7 \approx 12.1V$

$A_{vo} \approx -\frac{R_C}{r_e + R_{E2}}$ where $r_e = \frac{25mV}{I_E} = 23.36\Omega$

$A_{vo} = \frac{-2.7K}{23.36+220} \approx -11.1$

$R_{out,eff} = R_C \| R_L = \frac{2.7K \cdot 180}{2.7k+180} \approx 167.6\Omega$

$A_v = -\frac{R_{out,eff}}{r_e + R_{E2}} \approx \frac{-167.6}{243.36} \approx -0.688$

$A_{vs} = A_v \cdot \frac{R_{in}}{R_{in}+R_S}$

$R_{in} = R_B (\beta(r_e + R_{E2})) = 6.67k \| 150 \cdot 243.36$
$= 5.7K$

$A_{vs} = -0.688 \cdot \frac{5.7K}{5.75K} \approx -0.681$

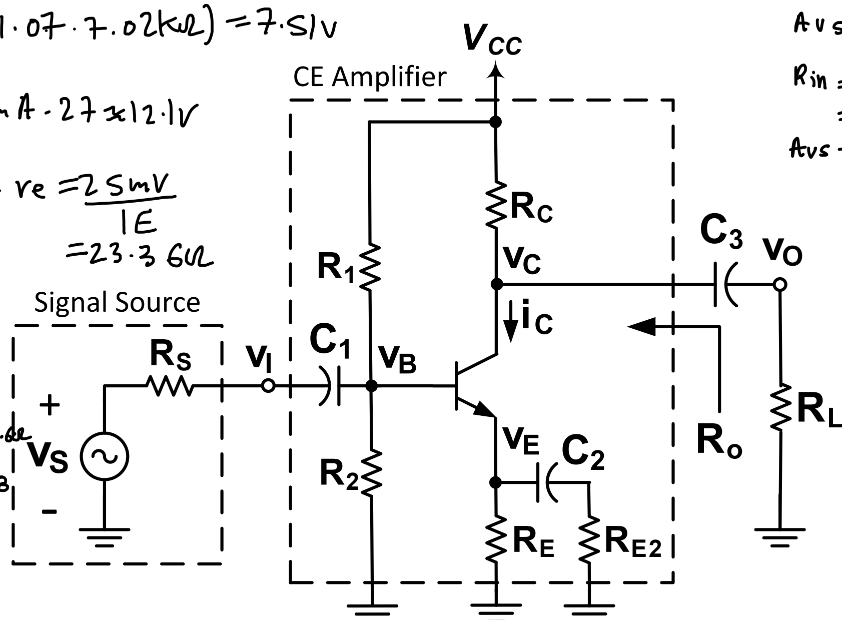


Figure 1. A Common-Emitter (CE) amplifier driving a load directly.

Table P1. Quiescent and AC parameters of the CE amplifier of **Figure 1**.

$V_C[V]$	$V_E[V]$	$I_C[mA]$	$A_{vo}[V/V]$	$A_v[V/V]$ $R_L = 180\ \Omega$	$A_{vs}[V/V]$ $R_L = 180\ \Omega$ $R_s = 50\ \Omega$	$R_o[k\Omega]$

12.1	7.51	1.07	-11.1	-0.688	-0.681	2.7

P2. Now consider the two-stage amplifier of **Figure 2**, in which the **CE amplifier** of **Figure 1** is not directly connected to the load, but it **drives the load through a Common-Collector (CC) amplifier**. Thus, **the CC amplifier acts as a buffer** between the CE amplifier and the load. That is, it makes the load appear much larger to the CE amplifier, to not bring down the output voltage of the CE amplifier, while its own voltage gain is close to (albeit smaller than) unity. Then, repeat the analysis of **Step P1** for the amplifier chain of **Figure 2**. Assume the same parameters as those you assumed in **Step P1**, with the addition that $R_{E3} = 1.2\ k\Omega$. Complete **Table P2**. Show all the work.

$A_{vo(total)} = A_{vo(CE)} \cdot A_{vo(CC)} = -11.1 \cdot 0.98 = -10.88$

$A_{vs} = -10.88 \cdot \frac{5.7k}{5.75k} = -10.77$

$V_{C}' + V_{BE} = 7.51 + 0.7 = 8.21V$

$I_{E2} = \frac{8.21}{1.2K} = 6.84mA$

$I_{C2} = 6.84mA \cdot \frac{\beta}{\beta+1} = 6.81mA$

$V_{E2} = 8.21V$

$R_o = r_e \| R_{E3} \| R_L = 3.65 \| 1.2K \| 180 = 3.5\Omega$

$A_{vo} = \frac{R_L}{R_L + r_e}$

$r_e = \frac{25mV}{I_{E2}} = 3.65\Omega$

$A_{vo(CC)} = \frac{180}{180 + 3.65} = 0.98$

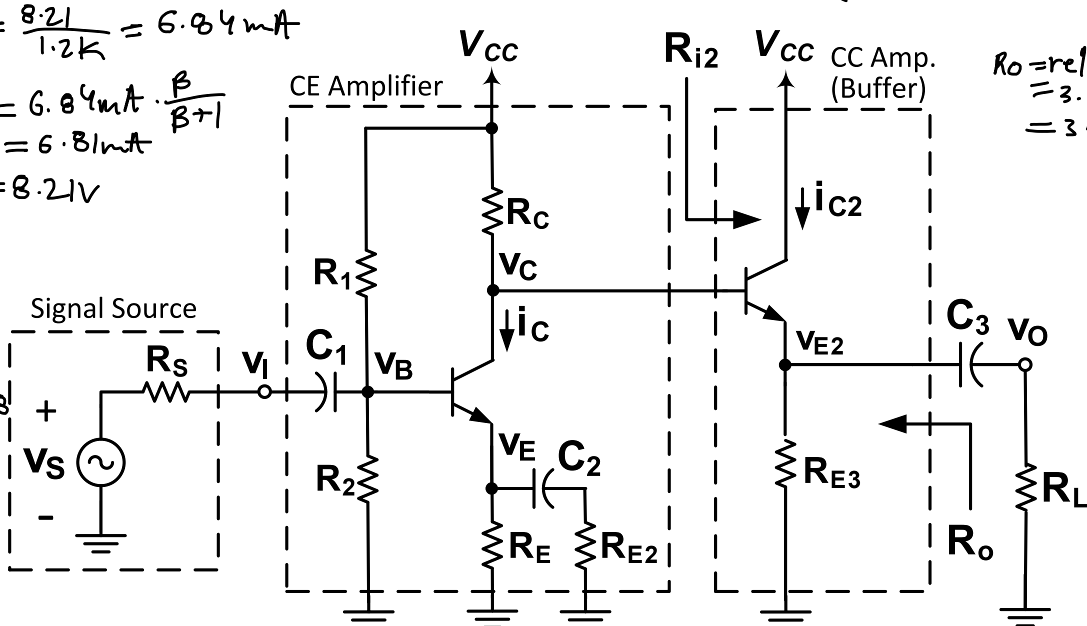
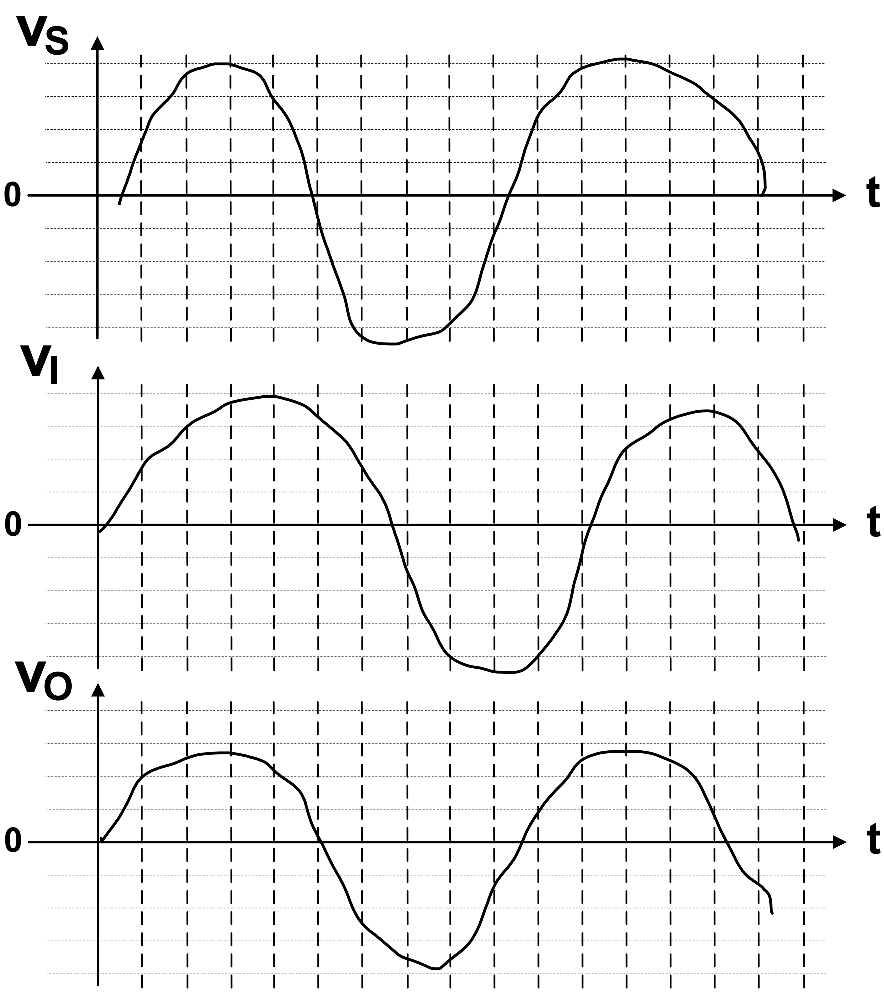


Figure 2. Common-Emitter (CE) amplifier of Figure 1 driving a buffered load.

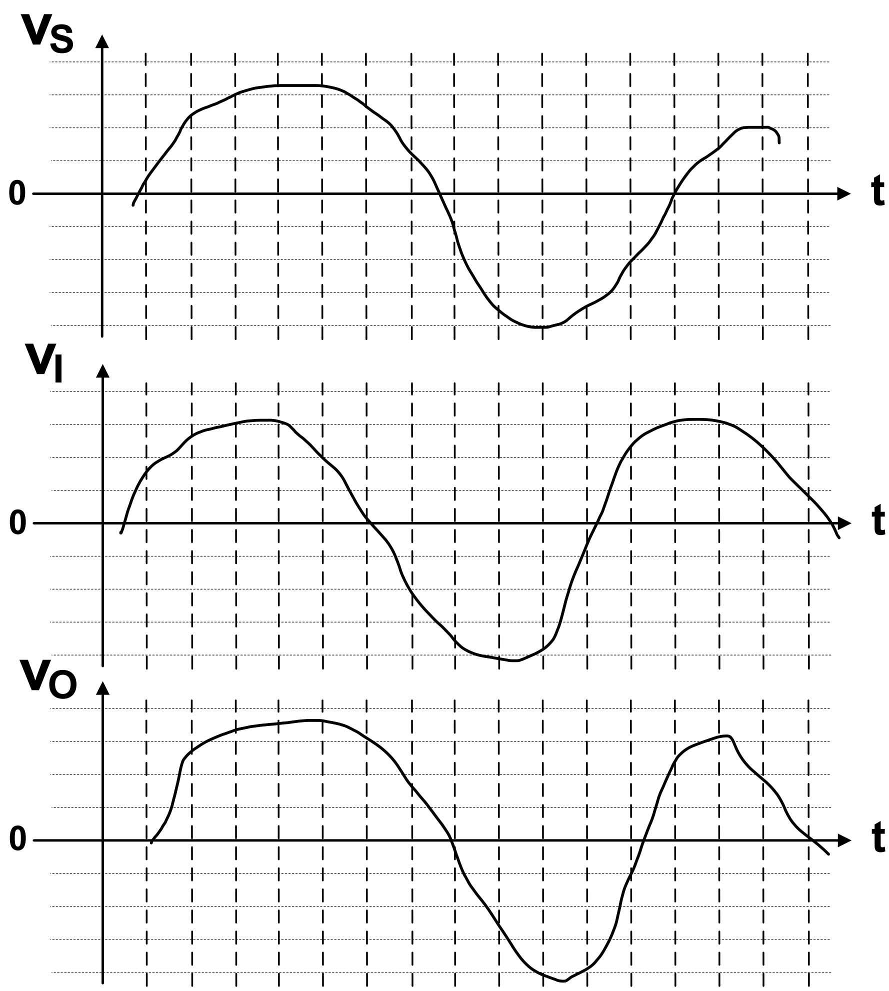
Table P2. Quiescent and AC parameters of the two-stage amplifier of **Figure 2**.

$V_C[V]$	$V_E[V]$	$I_C[mA]$	$V_{E2}[V]$	$I_{C2}[V]$	$A_{vo}[V/V]$	$A_v[V/V]$ $R_L = 180\ \Omega$	$A_{vs}[V/V]$ $R_L = 180\ \Omega$ $R_s = 50\ \Omega$	$R_o[k\Omega]$
12.1	7.51	1.07	8.21	6.81	-10.88	-10.88	-10.77	0.0035

P3. Simulate the CE-CC two-stage amplifier of **Figure 2**, assuming the 2N3904 as the transistors, $V_{CC} = 15\,V$, $R_S = 50\,\Omega$, $C_1 = 10\,\mu F$, and $C_2 = C_3 = 100\,\mu F$. Also, assume v_S to be a **1-kHz symmetrical sinusoidal voltage**. However, choose its magnitude in such a way that, with no load (for the purpose of simulation, use $R_L = 100\,k\Omega$ as an infinite load resistance), v_O has a peak-to-peak swing of 2.0 volts. Then, present the waveforms of v_S, v_I, and v_O, for three cycles, for $R_L = 100\,k\Omega$, as **Graph P3(a)**. Next, repeat the simulations but with $R_L = 180\,\Omega$, and present the waveforms as **Graph P3(b)**. In both simulations, 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 calculations of the gains (reported in **Table P2**) agree well with the gains indicated by the simulated waveforms. Otherwise, check your calculations and/or your simulation model.



Graph P3(a). Source, input, and output voltage waveforms of the amplifier of Figure 2, with $R_S = 50\,\Omega$ and $R_L = 100\,k\Omega$.



Graph P3(b). Source, input, and output voltage waveforms of the amplifier of Figure 2, with $R_S = 50\ \Omega$ and $R_L = 180\ \Omega$.

Experiments and Results

E1. Construct the circuit of **Figure 3**, which is the circuit of **Figure 2** but divided into three sub-circuits, namely, the CE amplifier, the CC amplifier, and the load. Thus, it can be configured to either represent the CE amplifier of **Figure 1** or the two-stage amplifier of **Figure 2**.

Use the 2N3904 as the transistors (**Figure 4** helps you identify the pins of the transistor). Also, use the same resistances as those assumed in **Step P3** ($\boldsymbol{R_L = 180\ \Omega}$). Note that the capacitors are electrolytic and, therefore, need their polarities respected.

Set your bench-top power supply to ensure that the supply voltage is $V_{CC} = 15\ V$. However, do not interconnect the signal generator just yet. Then, **set the jumpers** as per **Table E1**, use your multimeter in the DC voltage measurement mode, and measure and record the node voltages. Based on the resistances and measured voltages, calculate the device currents. Complete **Table E1**.

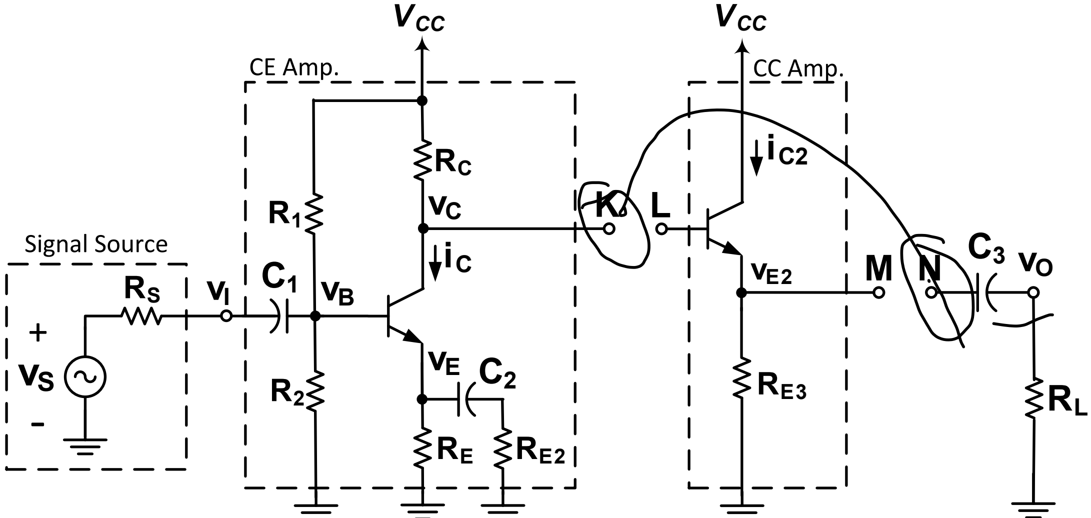


Figure 3. A circuit that can be configured to represent the CE amplifier of Figure 1 or the two-stage amplifier of Figure 2.

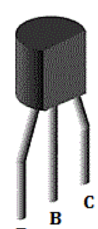


Figure 4. Terminals of the NPN BJT 2N3904.

Table E1. Quiescent parameters of CE amp. of Figure 1 and two-stage amp. of **Figure 2**.

Amplifier	Jumpers	$V_C\ [V]$	$V_E[V]$	$I_C[mA]$	$V_{E2}[V]$	$I_{C2}[mA]$
CE (Figure 1)	**None**	11.865	7.606		--	--
Two-Stage (Figure 2)	**K-L**	12.000	7.604		11.154	

E2. Now, **remove both jumpers**. Then connect the signal generator, and measure v_C by your multimeter in the AC voltage measurement mode. **Set the signal generator such that the meter reads about 0.71 V (rms) for v_C.** This corresponds to a peak-to-peak swing of 2 V, which you must confirm by the oscilloscope. The oscilloscope must also **confirm that v_C is sinusoidal and distortion-free**. Once the above are all confirmed, **measure and record the rms value of v_I.** For all subsequent steps, you must make sure that v_I is set to this value. Note that these aforementioned measurements correspond to no-load operation of the CE amplifier of **Figure 1**. Calculate A_{vo} based in them. Record all values in **Table E2**.

Table E2(a). No-load AC voltages and gain of the CE amplifier of **Figure 1**.

Amplifier	Jumpers	$v_I\ [Vrms]$	$v_C[Vrms]$	$v_{E2}[Vrms]$	$v_O[Vrms]$	$A_{vo}[V/V]$
CE	**None**	6.3×10^{-3}	0.71359	--	--	

Next, establish the **K-N** jumper, and repeat the measurements (***Note:*** $R_L = 180\ \Omega$). Make sure that v_I is unchanged with respect to its value in **Table E2(a)**. Also, make sure that the voltages are sinusoidal, regardless of their magnitudes. The measured values correspond to loaded operation of the CE amplifier of **Figure 1**. Complete **Table E2(b).**

Table E2(b). Loaded AC voltages and gain of the CE amplifier of **Figure 1**.

Amplifier	Jumpers	$v_I\ [Vrms]$	$v_C[Vrms]$	$v_{E2}[Vrms]$	$v_O[Vrms]$	$A_v[V/V]$
CE	**K-N**	6.4×10^{-3}	0.457	--	0.457	

E3. Now, **remove K-N** jumper, but **establish K-L** jumper. Repeat the AC voltage measurements, and complete **Table E3(a)**. This configuration corresponds to no-load operation of the two-stage amplifier of **Figure 2**. Again, make sure that v_I is unchanged with respect to its value in **Table E2(a)**, and that the voltages are sinusoidal.

Table E3(a). No-load AC voltages and gain of the two-stage amplifier of **Figure 2**.

Amplifier	**Jumpers**	v_I $[Vrms]$	$v_C[Vrms]$	$v_{E2}[Vrms]$	$v_O[Vrms]$	$A_{vo}[V/V]$
Two-stage	**K-L**	6.3×10^{-3}	0.705	0.705	--	

Next, also establish the **M-N** jumper, repeat the measurements (***Note:*** $R_L = 180\ \Omega$), and complete **Table E3(b)**. Once again, make sure that v_I is unchanged with respect to its value in **Table E2(a)** and that the voltages are sinusoidal**.** Further, capture the waveforms of v_I and v_O for three cycles, and save the captured waveforms as **Graph E3**. Note that this experiment corresponds to loaded operation of the two-stage amplifier of **Figure 2**.

Table E3(b). Loaded AC voltages and gain of the two-stage amplifier of **Figure 2**.

Amplifier	**Jumpers**	v_I $[Vrms]$	$v_C[Vrms]$	$v_{E2}[Vrms]$	$v_O[Vrms]$	$A_v[V/V]$
Two-stage	**K-L, M-N**	6.3×10^{-3}	0.6583	0.644	0.642	

Conclusions and Remarks

C1. Compare the calculated and measured quiescent voltages for the CE amplifier of **Figure 1**, and complete **Table C1(a).** Calculate the percent error from the following expression:

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

Repeat the comparison for the two-stage amplifier of **Figure 2**, and complete **Table C1(b)**. Comment on the magnitude of errors, and provide reasons for discrepancies, if any.

Table C1(a). Calculated and measured (DC) voltages of the CE amplifier of **Figure 1**.

	$\boldsymbol{V_C[V]}$	$\boldsymbol{V_E[V]}$	$\boldsymbol{V_{E2}[V]}$
Calculated values (from Table P1)			---
Measured values (first column, Table E1)			----
Percent error, $e\%$			----

Table C1(b). Calculated and measured (DC) voltages of the two-stage amplifier of **Figure 2**.

	$\boldsymbol{V_C[V]}$	$\boldsymbol{V_E[V]}$	$\boldsymbol{V_{E2}[V]}$
Calculated values (from Table P2)			
Measured values (second column, Table E1)			
Percent error, $e\%$			

C2. Compare the calculated and measured voltage gains of the CE amplifier of **Figure 1**, and calculate the percent errors. Complete **Table C2(a)**. Repeat the analysis for the two-stage amplifier of **Figure 2**, and complete **Table C2(b).** Comment on the magnitudes of errors and provide reasons for discrepancies.

Table C2(a). Calculated and measured voltage gains of the CE amplifier of **Figure 1**.

	$\boldsymbol{A_v[V/V]}$	$\boldsymbol{A_{vo}[V/V]}$
Calculated Values (from Table P1)		
Measured Values (from Table E2(a) and Table E2(b))		
Percent Error, $e\%$		

Table C2(b). Calculated and measured voltage gains of the two-stage amplifier of **Figure 2**.

	$\boldsymbol{A_v[V/V]}$	$\boldsymbol{A_{vo}[V/V]}$
Calculated Values (from Table P2)		
Measured Values (from Table E3(a) and Table E3(b))		
Percent Error, $e\%$		

C3. Based on the measured and calculated results, explain how the CC stage (that is the buffer) in the two-stage amplifier has enabled us to drive a heavy load ($R_L = 180\ \Omega$) while maintaining a good overall voltage gain. Give your viewpoint another angle by calculating the resistance that the CC stage presents to the output of the CE stage in the two-stage amplifier of **Figure 2** (that is R_{i2}) both with and without the load, and comparing it with R_L (that is, the load that the CE amplifier of **Figure 1** sees).

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Table E1. Quiescent parameters of CE amp. of Figure 1 and two-stage amp. of **Figure 2**.

Amplifier	Jumpers	$V_C\ [V]$	$V_E[V]$	$I_C[mA]$	$V_{E2}[V]$	$I_{C2}[mA]$
CE (Figure 1)	**None**	11.865	7.606		--	--
Two-Stage (Figure 2)	**K-L**	12.000	7.609		11.154	

Table E2(a). No-load AC voltages and gain of the CE amplifier of **Figure 1**.

Amplifier	Jumpers	$v_I\ [Vrms]$	$v_C[Vrms]$	$v_{E2}[Vrms]$	$v_O[Vrms]$	$A_{vo}[V/V]$
CE	**None**	6.3×10^{-3}	0.71359	--	--	

Table E2(b). Loaded AC voltages and gain of the CE amplifier of **Figure 1**.

Amplifier	Jumpers	$v_I\ [Vrms]$	$v_C[Vrms]$	$v_{E2}[Vrms]$	$v_O[Vrms]$	$A_v[V/V]$
CE	**K-N**	6.4×10^{-3}	0.457	--	0.457	

Table E3(a). No-load AC voltages and gain of the two-stage amplifier of **Figure 2**.

Amplifier	Jumpers	$v_I\ [Vrms]$	$v_C[Vrms]$	$v_{E2}[Vrms]$	$v_O[Vrms]$	$A_{vo}[V/V]$
Two-stage	**K-L**	6.3×10^{-3}	0.705	0.705	--	

Table E3(b). Loaded AC voltages and gain of the two-stage amplifier of **Figure 2**.

Amplifier	Jumpers	$v_I\ [Vrms]$	$v_C[Vrms]$	$v_{E2}[Vrms]$	$v_O[Vrms]$	$A_v[V/V]$
Two-stage	**K-L, M-N**	6.3×10^{-3}	0.6583	0.644	0.642	

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	Partner's Name	Set-Up (out of 10)	Data Collection (out of 10)	Participation (out of 5)
1	Hamza Malik	✓	✓	✓
2	Ryan Tsang	✓	✓	✓