

# 3EJ4 Lab2

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## Part I:

**Q1. (10 Points)** (1) Based on the simulation data obtained in Step 1.2, what are the  $V_{o,min}$ , and  $I_o$  of the current sink? Use the measurement data obtained in Step 1.10 to verify the  $V_{o,min}$  and  $I_o$ . (2) Based on the simulation data obtained in Step 1.2 and the measurement data obtained in Step 1.10, what are the ranges of the simulated and measured output resistance  $R_o$  of the current sink for  $V_{CC}$  larger than  $V_{o,min}$ ?

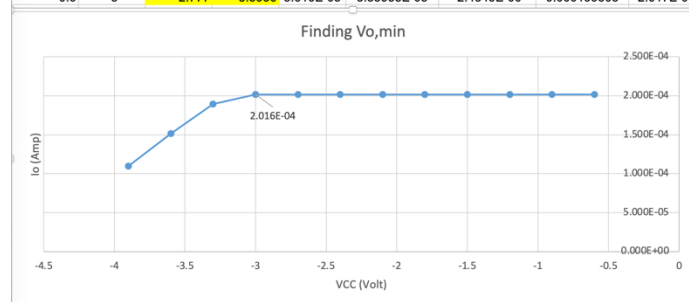
(1): 

VCC	IC	VE	Ro
-3	1.85E-04	-3.490808	7.19E+06

, the  $V_{o,min} = -3V$  and  $I_o = 1.85 \times 10^{-4} A$ .

VCC	VEE	CH1 (VB)	CH2 (VE)	IR1	IR2	IB = IR1 - IR2	IE	IC = IE - IB
Volts	Volts	Volts	Volts	Amps	Amps	Amps	Amps	Amps
-3.9	-5	-3.3836	-3.987	4.406E-05	2.80625E-05	1.59948E-05	0.000125682	1.097E-04
-3.6	-5	-3.106	-3.717	4.044E-05	3.28819E-05	7.56076E-06	0.000159181	1.516E-04
-3.3	-5	-2.8596	-3.4716	3.723E-05	3.71597E-05	7.46528E-06	0.000189628	1.896E-04
-3	-5	-2.7774	-3.3946	3.616E-05	3.85868E-05	-2.42274E-06	0.000199181	2.016E-04
-2.7	-5	-2.7774	-3.3942	3.616E-05	3.85868E-05	-2.42274E-06	0.000199231	2.017E-04
-2.4	-5	-2.7776	-3.3944	3.617E-05	3.85833E-05	-2.41667E-06	0.000199206	2.016E-04
-2.1	-5	-2.7778	-3.395	3.617E-05	3.85799E-05	-2.41059E-06	0.000199132	2.015E-04
-1.8	-5	-2.777	-3.3956	3.616E-05	3.85938E-05	-2.4349E-06	0.000199057	2.015E-04
-1.5	-5	-2.777	-3.3952	3.616E-05	3.85938E-05	-2.4349E-06	0.000199107	2.015E-04
-1.2	-5	-2.7774	-3.3942	3.616E-05	3.85868E-05	-2.42274E-06	0.000199231	2.017E-04
-0.9	-5	-2.7776	-3.3942	3.617E-05	3.85833E-05	-2.41667E-06	0.000199231	2.016E-04
-0.6	-5	-2.777	-3.3936	3.616E-05	3.85938E-05	-2.4349E-06	0.000199305	2.017E-04

The verified result from the Step 1.10.  
The corresponding  $I_o(I_c)$  is  $2.016E-04$ .



(2):

Simulated result ranges of  $R_o$ :  $7.19E+06$  to  $7.69E+07$  ohm.

Experimental result ranges of  $R_o$ : Neglect the negative resistance values because the uncertainty of circuit behaviors, the experimental ranges should between the range of  $2.68E+06$ ohm and  $6.05E+06$ ohm.

**Q2. (10 Points)** What are the values of  $V_{o1}$  and  $V_{o2}$  obtained in Step 1.5? Check the  $Q$ -points of  $Q_2$  under these two conditions and explain/justify the results obtained qualitatively.

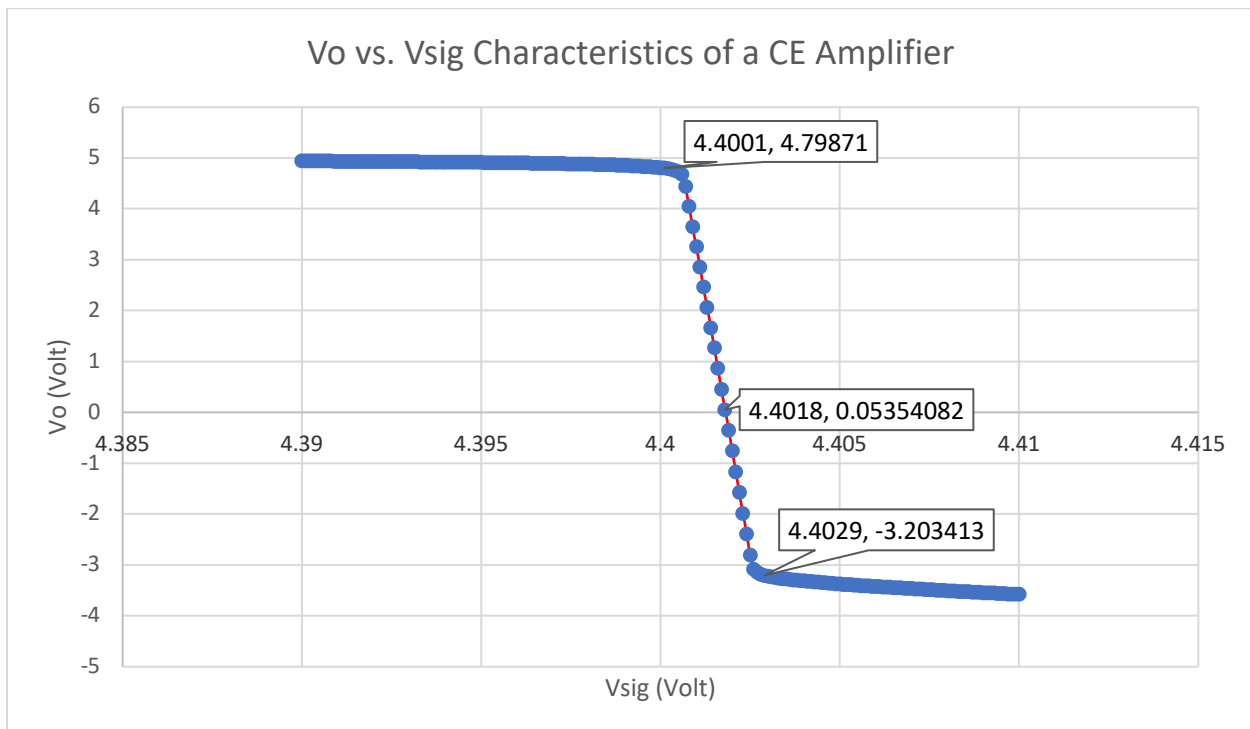
$V_{o1} = 4.94029V$        $V_{o2} = -3.57892V$

Vo1 (V)	Vo2 (V)
4.94029	-3.57892

Explain/justify: As the value of Vo1 and Vo2 obtained from Step 1.5, the value of Vo1 is pushing towards the saturation region of 5V. Since there is a huge jump from Vo1 to Vo2, which can conclude that Vo2 is in the cut-off region.

**Q3. (15 Points)** Based on the simulation data obtained in Step 1.6, (1) plot the simulated DC  $V_o$  vs.  $V_{sig}$  characteristics. Discuss/justify the simulated characteristics. (2) For the circuit to work as an amplifier, find the DC input range for  $V_{sig}$  and the output voltage range for  $V_o$ . (3) Find the  $V_{sig}$  value and its corresponding collector current  $I_{C2}$  that results in  $V_o \approx 0$  V. (4) Based on the measurement data obtained in Step 1.16, plot the measured DC  $V_o$  vs.  $V_{sig}$  characteristics.

(1):

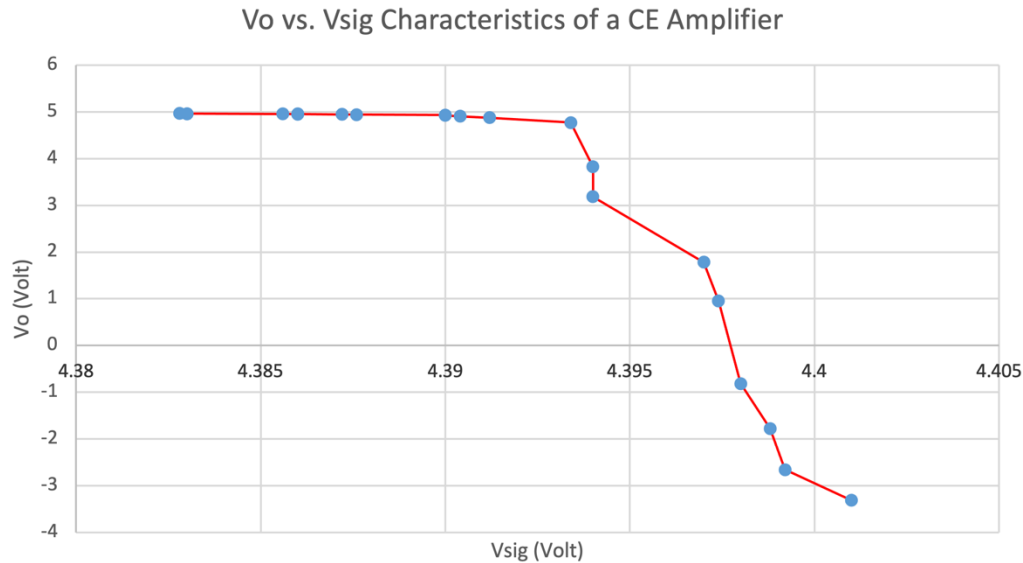


**Discuss/justify:** As the graph shown above, there are three regions plotted of the CE Amplifier, the upper bond shows an approximately horizontal line is the saturation region of the Q-point which means the transistor is fully on, the lower bond shows an approximately horizontal line is the cut-off region of the Q-point which means the transistor is fully off, the linear line between the upper bond and lower bond is the active region of the Q-point which can amplify upper and lower part of the input signal.

(2): For the circuit to work as an amplifier, the DC input range for  $V_{sig}$  is 4.4001 to 4.4029, and the output voltage range for  $V_o$  is 4.79871 to -3.203413

(3):  $V_{sig} = 4.4018V$  and  $I_c = -0.000184882$ , when  $V_o \approx 0V$ .

(4):



**Q4. (10 Points)** (1) Based on the simulation data obtained in Step 1.7, what are the magnitude (in dB) and phase of intrinsic voltage gain  $A_{vo}$  at low frequency (i.e., 100 Hz) and the upper 3-dB frequency  $f_{3dB}$  (i.e., the frequency at which the amplitude become  $1/2 = 0.707$  of its low-frequency value, or the phase changes  $45^\circ$ ) of this CE amplifier? (2) Verify the voltage gain  $A_{vo}$  using the measurement data obtained in Steps 1.18 and 1.19. (3) Increase the frequency of W1 to the upper 3-dB frequency  $f_{3dB}$  obtained from the simulation, check the value of  $A_{vo}$ , and see if it is about 0.707 of its low-frequency value obtained at 100 Hz. Provide WaveForms screenshots of your measurement results.

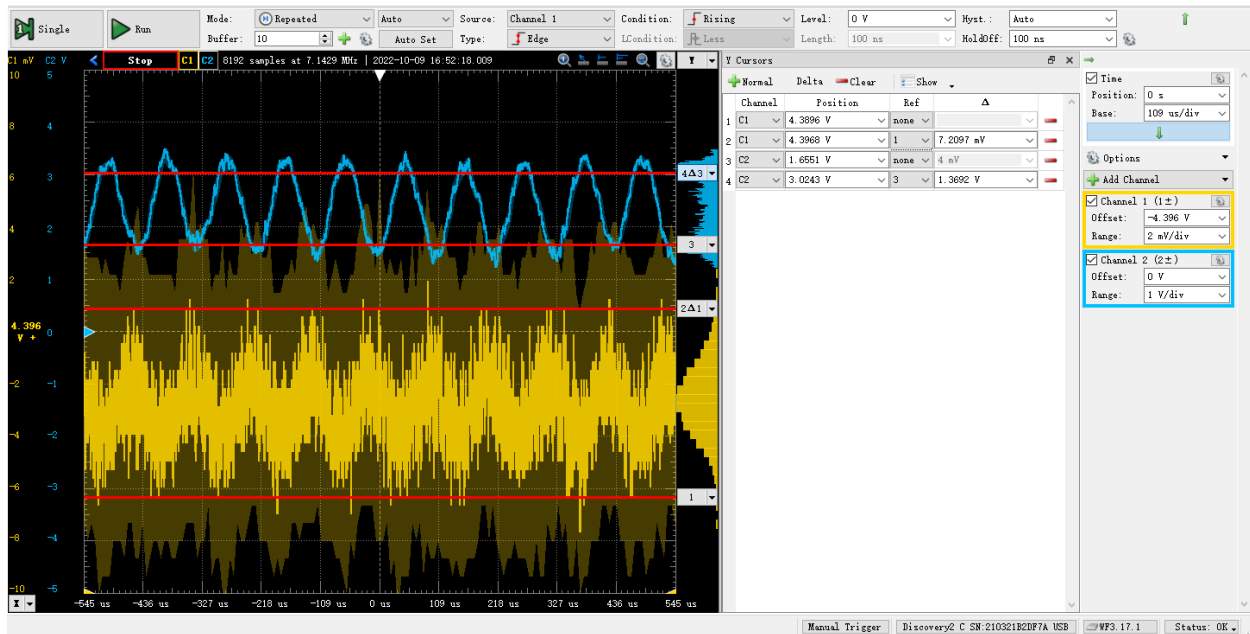
(1): The magnitude (in dB) and phase of intrinsic voltage gain  $A_{vo}$  at low frequency (i.e., 100 Hz) is, 72.14662238dB and 179.5968243deg. The upper 3-dB frequency  $f_{3dB} = 9128.428949Hz$ .

(2):

$\Delta C1$ (V)	$\Delta C2$ (V)	Gain $A_v$ (dB)
2.41E-03	2.5596	60.5

It is close enough to the simulation result.

(3): WaveForms screenshot result:



The gain of Avo is equal to  $=20 \cdot \text{LOG}_{10}(1.3692/7.21\text{E-}03) = 45.6$  which is approximately equal to  $0.707 \cdot 60.5 = 42.7735$  the gain of low frequency.

## Part2:

**Q5. (15 Points)** Based on the simulation data obtained in Step 2.2, (1) what are the voltages of  $V_o$  and  $V_E$ , and  $I_{C2}$  of  $Q_2$  when  $V_{CM} = 0\text{V}$ , (2) what is the input common-mode range (i.e., the voltage range of  $V_{CM}$  to maintain the same out voltage), and (3) what determines the upper and lower bounds of the input common-mode range? (4) Based on the measurement data obtained in Steps 2.7 and 2.8, verify the common-mode range by experimental data.

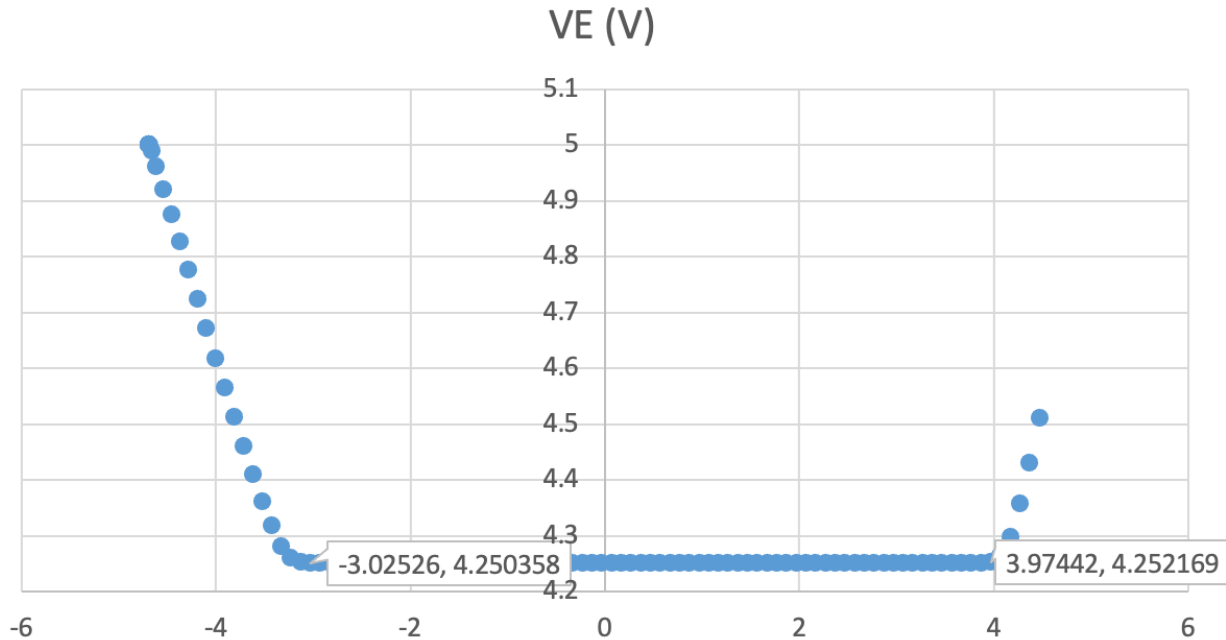
(1):  $V_o = -0.5253805$ ,  $V_E = 4.249999$ ,  $I_{C2} = 9.09093 \cdot 10^{-5}$  when  $V_{cm} = 0\text{V}$ .

$V_o$ (V)	$V_E$ (V)	$I_{C2}$ (A)	$V_{cm}$
-0.5253805	4.249999	9.09093E-05	-1.027E-15

(2): The input common-mode range of  $V_{cm}$  to stay constant is between  $-2.5\text{V}$  to  $4.5\text{V}$ .

$V_o$ (V)	$V_E$ (V)	$I_{C2}$ (A)	$V_{cm}$
-3.02526	4.250358	9.0865E-05	-2.5

$V_o$ (V)	$V_E$ (V)	$I_{C2}$ (A)	$V_{cm}$
3.97442	4.252169	9.0646E-05	4.5

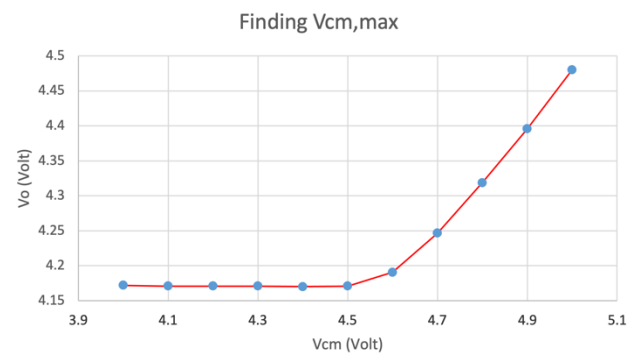


(3): what determines the upper and lower bounds of the input common-mode range?

The common-mode input voltage  $V_{cm}$  will determine the upper and lower bounds of the range which will keep  $V_{ov}$  the same as long as  $Q1$  &  $Q2$  are in saturation region which is the flat line as shown. When there is not sufficient  $V_{cm}$  supplies to meet the saturation condition of BJTS, it will act as an amplifier and shows an active region (linear increase or decrease line) from the graph.

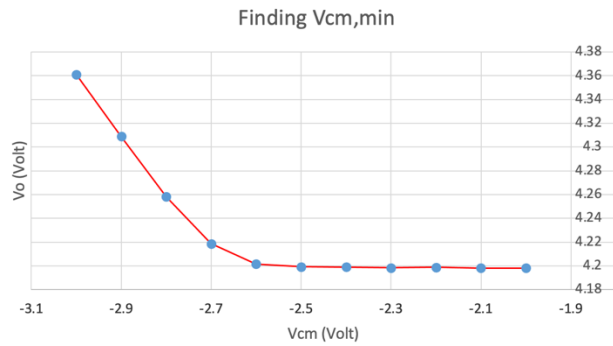
(4): Steps 2.7:

W1 Setting Volts	Channel 1 (VE) Volts	Channel 2 (Vo) Volts	IC2 = (5 V - Vo)/8.25 kohm Amps
4	3.395	4.172	1.00E-04
4.1	3.4922	4.171	1.00E-04
4.2	3.5936	4.171	1.00E-04
4.3	3.694	4.171	1.00E-04
4.4	3.7926	4.1702	1.01E-04
4.5	3.8934	4.171	1.00E-04
4.6	3.99	4.1906	9.81E-05
4.7	4.091	4.2466	9.13E-05
4.8	4.188	4.3188	8.26E-05
4.9	4.286	4.3956	7.33E-05
5	4.383	4.48	6.30E-05



Steps 2.8:

W1 Setting Volts	Channel 1 (VE) Volts	Channel 2 (Vo) Volts	IC2 = (5 V - Vo)/8.25 kohm Amps
-2	-2.6024	4.1982	9.72E-05
-2.1	-2.7048	4.1982	9.72E-05
-2.2	-2.803	4.1988	9.71E-05
-2.3	-2.904	4.1984	9.72E-05
-2.4	-3.002	4.1992	9.71E-05
-2.5	-3.103	4.1994	9.70E-05
-2.6	-3.2044	4.2016	9.68E-05
-2.7	-3.301	4.2188	9.47E-05
-2.8	-3.402	4.2582	8.99E-05
-2.9	-3.499	4.309	8.38E-05
-3	-3.5978	4.361	7.75E-05



Both data confirmed the range of  $V_{cm}$ .

**Q6. (10 Points)** Based on the simulated data obtained in Step 2.3, what is the low-frequency voltage gain  $A_{cm}$  in dB for the common-mode signal?

The gain of  $A_{cm}$  is -86.90dB.

### Part3:

**Q7. (10 Points)** Based on the simulation data obtained in Step 3.2 and the description in Section 9.2.3 Large-Signal Operation of the textbook, (1) what is the input differential-mode range? (2) How do we determine the upper and lower bounds of the input differential-mode range?

(1):  $T=25\text{mV}$ ,  $T/2=12.5\text{mV}$ , The differential-mode range is from -12.5mV to 12.5mV.

(2): The input differential-mode range is determined by the range needed to make the amplification linear, if it is outside that range, the amplification is not linear anymore.

**Q8. (10 Points)** (1) Based on the simulation data obtained in Step 3.3, what is the voltage gain  $A_d$  in dB for the differential-mode signal? (2) Estimate its upper 3-dB frequency  $f_{3dB}$  (i.e., the frequency at which the amplitude becomes  $1/\sqrt{2} = 0.707$  of its low-frequency value or the phase changes  $45^\circ$ ) and calculate the gain-bandwidth product (GBW) in hertz (Hz). (3) Compare the upper 3-dB frequency  $f_{3dB}$  of this differential amplifier with that of the CE amplifier obtained in Q4. (4) Based on the measurement data obtained in Step 3.6, calculate the measured low-frequency differential voltage gain  $A_d$  in dB.

(1): The voltage gain  $A_d$  is 19.63dB.

(2): The upper 3-dB frequency is 5655555.22514252Hz. The calculated gain-bandwidth product (GBW) is calculated by  $10^{(16.59/20)} = 6.755392$ .

(3): The upper 3-dB frequency is  $f_{3dB} = 9128.428949\text{Hz}$  from question (4) by using the CE amplifier. The upper 3-dB frequency is  $5655555.22514252\text{Hz}$  from question (8) by using the differential amplifier. The difference is the CE amplifier is used in the low-frequency voltage amplifier and well-suited for voltage amplification so it also provides a higher gain than differential amplifier. The differential amplifier is used mainly to suppress noise, generally the open loop gain can be as high as 100dB at DC(zero Hz). The output gain decreases linearly as frequency increases down to “Unity Gain” or 1, at about 1MHz, that’s why the upper 3-dB frequency of differential amplifier is much higher than the CE amplifier.

(4): The measured low-frequency differential voltage gain  $A_d$  is 21.8dB.

**Q9. (10 Points)** Based on the simulation data, what is the common-mode rejection ratio (CMRR) of the amplifier in dB?

The common mode gain is -86.90dB.

The differential mode gain is 19.63dB.

The common-mode rejection ratio (CMRR) is  $|19.63\text{dB}/|-86.90\text{dB}| = 0.2258918297 \approx 0.2359$