Lab 3

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ELECENG 3EJ4

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<u>Part 1</u>: Common-Collector (CC) Amplifier/Emitter Follower

Q1.

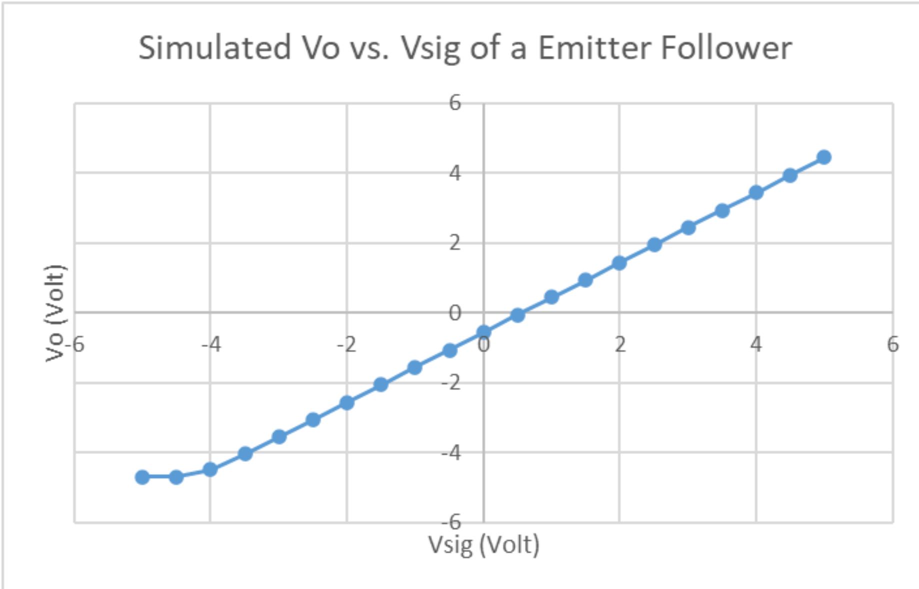

Figure 1: V_o vs V_{sig} graph from simulation

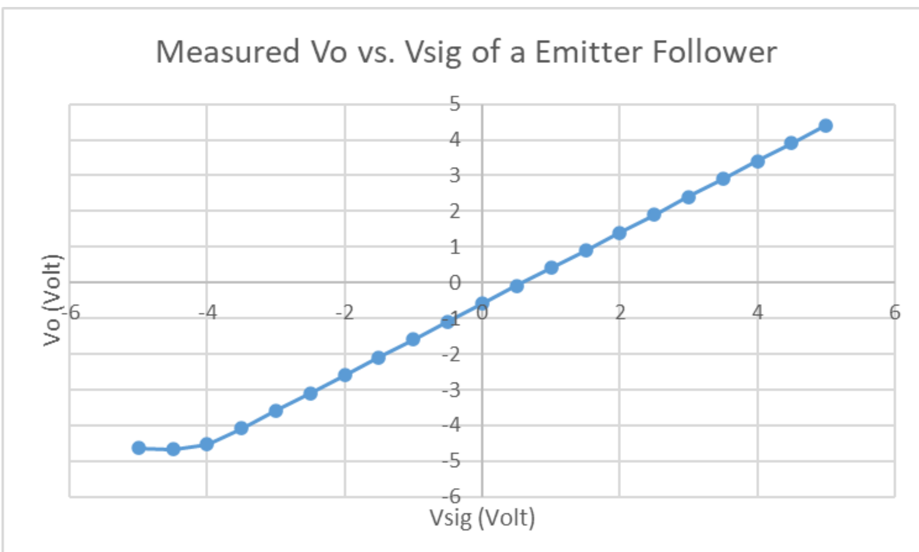

Figure 2: V_o vs V_{sig} graph from AD2 measurements

(1) The V_o vs V_{sig} characteristics of the simulated and measured data were almost identical. They both have an upward trend. As V_{sig} increases, V_o increases linearly. This makes sense because V_{sig} is voltage at the base and V_o is voltage at the emitter, so the voltage difference V_{sig} - V_o must equal $V_{BE,on}$. As V_{sig} increases, V_o must increase to stay in the active region. This is the characteristic of an emitter follower.

(2) Based on the simulation data, we can see that I_{E2} starts to be constant at -0.185mA when V_{sig} > -2.5V. This is also where the voltage difference V_{sig} - V_o equal $V_{BE,on}$ of the transistor, which is 0.553V. So for the simulation, the range for V_{sig} is -2.5V < V_{sig} < 5V,

and the range for V_o is -3.053V < V_o < 4.447V. Based on the measured data, we can see that $V_{BE,on}$ of the transistor is equal to 0.594V, and V_{sig} - V_o is equal to 0.594V when V_{sig} > -2.5V. So the range for V_{sig} is -2.5V < V_{sig} < 5V, and the range for V_o is -3.096V < V_o < 4.406V.

For both simulation and measurement, It should be noted that $V_{BC} = V_{sig} - 5V$ should be less than $V_{BC,on}$ to stay in the active region, so the actual maximum for V_{sig} is $5V + V_{BC,on}$, and the actual maximum for V_o is $V_{sig} - V_{BE,on} = 5V + V_{BC,on} - V_{BE,on}$.

(3) For the simulation, V_{sig} = 0.553V gives $V_o \approx 0V$. For the measurement, V_{sig} = 0.594V gives $V_o \approx 0V$.

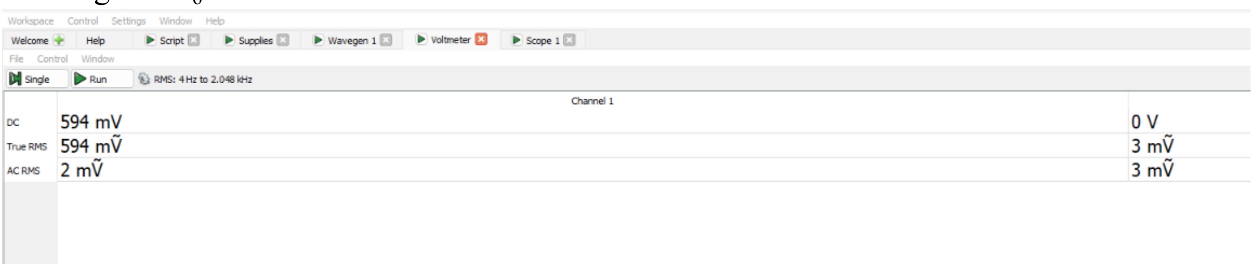

Figure 3: V_{sig} value when V_o = 0

Q2.

The simulated A_{vo} at low frequency (100 Hz) is 0 dB with a phase of -8.47e-5 degrees. The measured A_{vo} at 100 Hz is 0.6 dB with a phase of 9.8 degrees.

1	Frequency	M(V(Vo))	P(V(Vo))	Av = 20*log(|Vo|/1mV)
2	Hz	Volts	Degrees	dB
3	100	0.001	-8.47E-05	0.00

Figure 4: Simulated numbers from PSpice

1	ΔC1 (V) = Vsig(Peak2Peak)	ΔC2 (V) = Vo(Peak2Peak)	Voltage Gain Av (dB)
2	0.0011138	0.0011985	0.6
3			

Figure 5: Measured numbers from AD2

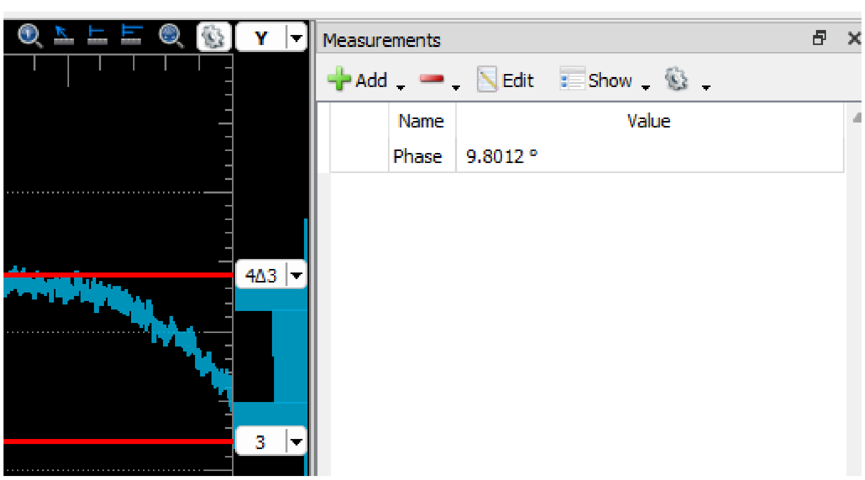

Figure 6: Phase from AD2 measurement

<u>Part 2</u>: Differential Amplifier with Current Mirror (CM) Load

Q3.

(1) Expression for I_o as a function of I_{REF}:

According to textbook, equation for I_o as a function of I_{REF}, taking the early effect into account is:

$$I_o = \frac{I_{REF}}{1+2/\beta}\left(1+\frac{(V_E - V_o) - V_{EB}}{V_A}\right)$$

$$I_o = \frac{I_{REF}}{1+2/\beta}\left(1+\frac{(V_E - V_o - V_E + V_B)}{V_A}\right)$$

$$I_o = \frac{I_{REF}}{1+2/\beta}\left(1+\frac{V_B - V_o}{V_A}\right)$$

(2) When I_{REF} is 0.1 mA, I_o is 0.104 mA. The ratio I_o/I_{REF} is 1.04. When I_{REF} is 1 mA, I_o is 0.975 mA. The ratio I_o/I_{REF} is 0.975.

	A	B	C	D	E	F
1	IREF	Io	Vin	Vo	VEC(Q1) = VEB(Q1)	VEC(Q2)
2	Amps	Amps	Volts	Volts	Volts	Volts
3	0.0001	0.000104	4.423166	-3.961	0.58	8.96

Figure 7: Simulation data from Step 2.2 when I_{REF} is 0.1mA

	A	B	C	D	E	F
1	IREF	Io	Vin	Vo	VEC(Q1) = VEB(Q1)	VEC(Q2)
93	0.001	0.000975	4.341335	4.746068	0.66	0.25
94						

Figure 8: Simulation data from Step 2.2 when I_{REF} is 1mA

(3) From the simulation data, we can see that as I_{REF} and I_o increases, the ratio I_o/I_{REF} gets smaller. This makes sense because as I_o and I_{REF} increases, V_o increases, and according to the theoretical equation, as V_o increases I_o decreases. Based on data from lab 1, the

PNP-BJT 2N3906 has the characteristics $\beta = 123$ and $V_A = 143V$. Using these values for $I_{REF} = 0.1mA$ ($V_o = -3.961V$, $V_B = V_{in} = 4.423166V$), the theoretical value of $I_o = 0.1042mA$, and for $I_{REF} = 1mA$ ($V_o = 4.746V$, $V_B = V_{in} = 4.341335V$), the theoretical value of $I_o = 0.981mA$. These values are almost identical to the simulated results.

Q4.

(1) Based on the simulation data, R_{in} looking from V_{in} toward the collector of Q1 is 389.12 ohms, and current gain A_i is 1.04 A/A.

	A	B	C	D	E	F	G
1	Frequency	M(V(Vin))	P(V(Vin))	M(I(V2))	P(I(V2))	R11 = h11 = v1/i1@v2=0 (Ohm)	Ai = h21 = i2/i1@v2=0 (A/A)
2	Hz	Volts	Degrees	Amps	Degrees	Ohm	A/A
3	100	0.000389118	-0.000369428	1.04E-06	179.9995855	389.12	1.04
4	110	0.000389118	-0.000406371	1.04E-06	179.9995443	389.12	1.04
5	120	0.000389118	-0.000443313	1.04E-06	179.9995031	389.12	1.04
6	130	0.000389118	-0.000480256	1.04E-06	179.9994619	389.12	1.04
7	140	0.000389118	-0.000517199	1.04E-06	179.9994208	389.12	1.04
8	150	0.000389118	-0.000554142	1.04E-06	179.9993796	389.12	1.04
9	160	0.000389118	-0.000591084	1.04E-06	179.9993384	389.12	1.04
10	170	0.000389118	-0.000628027	1.04E-06	179.9992972	389.12	1.04
11	180	0.000389118	-0.00066497	1.04E-06	179.999256	389.12	1.04
12	190	0.000389118	-0.000701913	1.04E-06	179.9992148	389.12	1.04
13	200	0.000389118	-0.000738856	1.04E-06	179.9991736	389.12	1.04
14							

Figure 9: Measurements from Step 2.5

(2) Based on simulation data, output impedance R_o looking into collector of Q2 is 1.58e+6 ohms or 1.58 Mohms.

	A	B	C	D	E	F	G	H
1	Frequency	M(V(Vin))	P(V(Vin))	M(I(V2))	P(I(V2))	h12 = v1/v2@i1=0	h22 = i2/v2@i1=0	Ro = 1/(h22 - 1/RL)
2	Hz	Volts	Degrees	Amps	Degrees	V/V	S	Ohm
3	100	7.05E-13	89.99031688	1.01E-10	179.9999973	7.05E-07	1.01E-04	1.58E+06
4	110	7.75E-13	89.99112589	1.01E-10	179.9999973	7.75E-07	1.01E-04	1.58E+06
5	120	8.46E-13	89.99179385	1.01E-10	179.9999973	8.46E-07	1.01E-04	1.58E+06
6	130	9.16E-13	89.99235331	1.01E-10	179.9999973	9.16E-07	1.01E-04	1.58E+06
7	140	9.87E-13	89.99282752	1.01E-10	179.9999973	9.87E-07	1.01E-04	1.58E+06
8	150	1.06E-12	89.99323354	1.01E-10	179.9999973	1.06E-06	1.01E-04	1.58E+06
9	160	1.13E-12	89.99358414	1.01E-10	179.9999973	1.13E-06	1.01E-04	1.58E+06
10	170	1.20E-12	89.99388912	1.01E-10	179.9999973	1.20E-06	1.01E-04	1.58E+06
11	180	1.27E-12	89.99415606	1.01E-10	179.9999973	1.27E-06	1.01E-04	1.58E+06
12	190	1.34E-12	89.99439098	1.01E-10	179.9999973	1.34E-06	1.01E-04	1.58E+06
13	200	1.41E-12	89.99459868	1.01E-10	179.9999973	1.41E-06	1.01E-04	1.58E+06

Figure 10: Measurements from Step 2.6

(3) Linear two-port network with h-parameters: (Note: h12 is neglected)

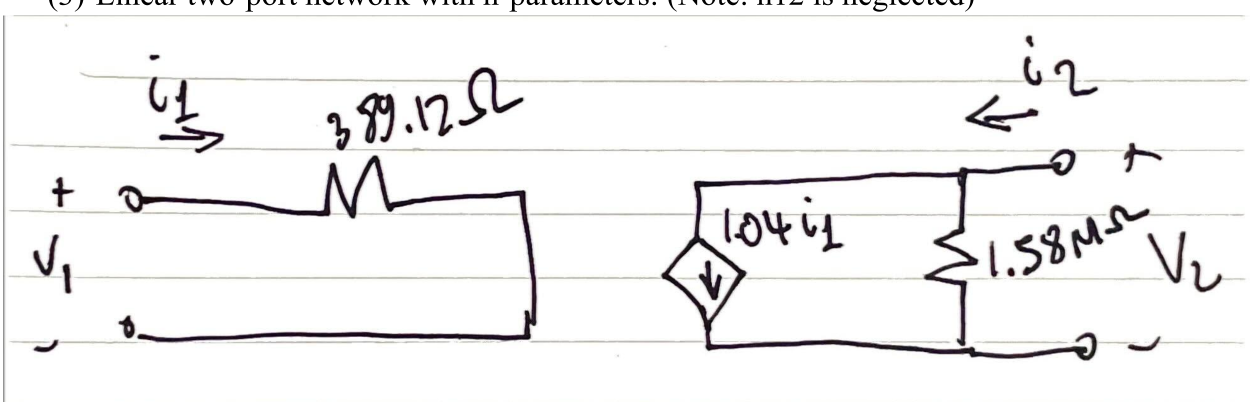

Figure 11: Linear two-port network for the current mirror

Part 3: Differential Amplifier with a Current Mirror (CM) Load

Q5.

(1) The voltage gain A_d for the differential mode signal is 70.07 dB.
(2) Yes, there was a mismatch in Step 3.6. I applied an offset voltage of 0.01025V to V_2.
(3) The measured gain was 56.8 dB, which is significantly lower than the simulated gain of 70.07 dB.

	A	B	C	D
1	Frequency	M(V(Vo))	P(V(Vo))	Ad = 20*log(|Vo|/2mV)
2	Hz	Volts	Degrees	dB
3	100	6.37860726	-0.51804511	70.07

Figure 12: Simulated data at 100 Hz from Step 3.2

	A	B	C
1	ΔC1 (V) = Vsig(Peak2Peak)	ΔC2 (V) = Vo(Peak2Peak)	Differential Voltage Gain Avd of a Single-Stage Differential Amplifier (dB)
2	1.2607E-03	1.7503	56.8
3			

Figure 13: Measured gain at 100 Hz

Q6.

The upper 3-dB frequency f_H is approximately 11,207 Hz.

	A	B	C	D	E	F	G
1	Frequency	M(V(Vo))	P(V(Vo))	Ad = 20*log(|Vo|/2mV)	GBW	GBW in Step 3.6, Lab 2	
207	10466.51211	4.633467232	-43.42611146	67.30			
208	10707.86705	4.583242224	-44.07880272	67.20			
209	10954.78757	4.53238499	-44.73198261	67.11			
210	11207.40201	4.48092768	-45.38531231	67.01			
211	11465.84168	4.428903778	-46.0384526	66.91			
212	11730.24089	4.376348003	-46.69106476	66.80			
213	12000.73707	4.323296193	-47.34281148	66.70			
214	12277.47083	4.269785188	-47.99335769	66.59			
215	12560.58599	4.215852707	-48.64237144	66.48			
216	12850.22971	4.161537222	-49.28952472	66.36			
217	13146.55253	4.106877827	-49.93449428	66.25			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			

Figure 14: Row 210 shows the upper 3-dB frequency

Q7.

The upper 3-dB frequency of this differential amplifier with a current mirror load is 11.2 kHz while the upper 3-dB frequency of a differential amplifier with a resistive load is 8.33 MHz, which is much higher than that of the differential amplifier with a current mirror load. This is because the current mirror load uses transistors as the load, which means at high frequencies, the load's functionality is affected by the internal capacitive effects while resistive loads are not affected at high frequencies.

Q8.

The GBW of the differential amplifiers with the current mirror load and resistive load are 3.57 * 10^7 Hz and 7.95 * 10^7 Hz, respectively.

E	F
GBW	GBW in Step 3.6, Lab 2
Hz	Hz
3.57E+07	7.95E+07

Figure 15: Gain bandwidth product calculated from simulated data on Excel