ELEC 301 MINI PROJECT 3

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1. Objective

Familiarise and understand the characteristics of several multi-transistor amplifiers/circuits.

2. Introduction

Testing a cascode amplifier, an amplifier consisting of a common-base stage followed by a common-collector stage in cascade, an Op-Amp, and an AM modulator

3. Project-Questions

3.1 Part 1 (2N3904)

3.1. a

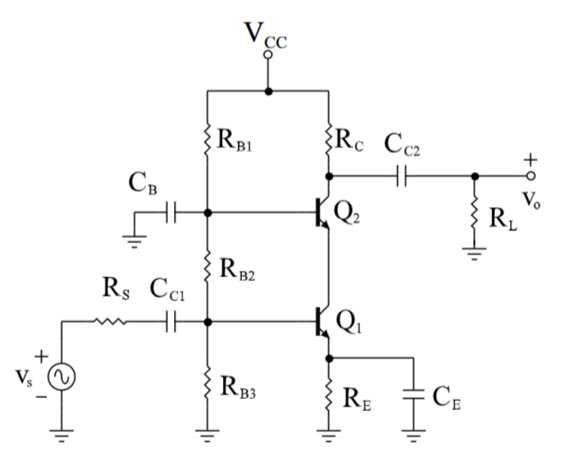


Figure 3.1.1 The Cascode Amplifier

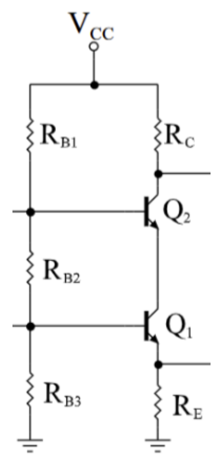


Figure 3.1.2 Biassing Cascode Amplifier

Calculation for biassing resistor values using the ¼ rule by setting

$$V_{C2} = \frac{3}{4}V_{CC} \quad V_{E2} = V_{C1} = \frac{1}{2}V_{CC} \quad V_{E1} = \frac{1}{4}V_{CC}$$

We yield the following voltage value

$$V_{C2} = 15V \quad V_{E2} = V_{C1} = 10V \quad V_{E1} = 5V \ V_{B2} = 10.7V \quad V_{B1} = 5.7V$$

As we want the maximum R_{Out} and keep the value in range, we choose $R_C = 2.4k\Omega$ as the standard resistor value. I used the $\beta = 100$ for this part of calculation from my previous mini project

$I_{C2} = \frac{V_{CC}-V_{C2}}{R_C} = 2.083mA$	$I_{E2} = I_{C1} = I_{C2} * \frac{\beta+1}{\beta} \approx 2.104mA$

$I_{B2} = \frac{I_{C2}}{\beta} \approx 20.833\mu A$	$I_{E1} = I_{C1}\frac{\beta+1}{\beta} \approx 2.125mA$
$I_{B1} = \frac{I_{C1}}{\beta} \approx 21.249\mu A$	$I_{RB1} = \frac{I_{E2}}{\sqrt{\beta}} \approx 210.383\mu A$
$I_{RB2} = I_{RB1} - I_{B2} \approx 189.134\mu A$	$I_{RB3} = I_{RB2} - I_{B1} \approx 168.304\mu A$

With all the current calculations, we found the corresponding resistors and converted them into standard values.

$R_E = \frac{V_{E1}}{I_{E1}} = 2352 \approx 2.4k\Omega$	$R_{B1} = \frac{V_{CC}-V_{B2}}{I_{RB1}} = 44198 \approx 43k\Omega$
$R_{B2} = \frac{V_{B2}-V_{B1}}{I_{RB2}} = 26373 \approx 27k\Omega$	$R_{B3} = \frac{V_{B1}}{I_{RB3}} = 33819 \approx 33k\Omega$

Small Signal Parameters

Transistor 2	Transistor 1
$R_{\pi 2} = \frac{V_T}{I_{B2}} = 1200 = 1.2k\Omega$	$R_{\pi 1} = \frac{V_T}{I_{B1}} = 1188 \approx 1.2k\Omega$
$g_{m2} = \frac{\beta}{R_{\pi 2}} = 0.0833S$	$g_{m1} = \frac{\beta}{R_{\pi 1}} = 0.0842S$

Capacitor values using OCTC and SCTC

		R_{Seen}
τ^{OC}_{Cc1}	$C_{C1} * (Rs + R_{B2} \vert\vert R_{B3} \vert\vert (R_{\pi 1} + (1 + \beta)R_E))$	$14k\Omega$
τ^{SC}_{Cc2}	$C_{C2} * (R_L + R_C)$	$52.4k\Omega$
τ^{SC}_{Ce}	$C_E * \frac{(Rs \vert\vert R_{B2} \vert\vert R_{B3} + R_{\pi 1}) \vert\vert R_E}{1+\beta}$	51Ω

Zero Calculation

$$\omega_{LZ} = \frac{1}{C_E * R_E} = \frac{1}{C_E * 2400}$$

By assuming we use the same coupling capacitor, and by our OCTC and SCTC test takes the dominant pole,

$$1200 = \sqrt{\left(\frac{1}{C_E * 51}\right)^2 - 2 * \left(\frac{1}{C_E * 2400}\right)^2}$$

Getting the standard capacitor value

$$C_E = C_{C1} = C_{C2} = 16\mu F \approx 22\mu F$$

30 uF -2 points

3.1. A, dc operating point

	V_C	V_B	V_E	I_C	I_B	I_E
Q1	10.69	6.14	5.47	$2.27mA$	$7.28\mu A$	$2.27mA$
Q2	14.57	11.37	10.69	$2.26mA$	$7.35\mu A$	$2.27mA$

3.1. B, Bode/Phase Plot and Poles Calculation

Using the R_{Seen} values from capacitor calculation above for ω_{L3dB}

ω_{Cc1}	$\frac{1}{C_{C1} * R^{Seen}_{C1}}$	3.2467 Rad/s
ω_{Cc2}	$\frac{1}{C_{C2} * R^{Seen}_{C2}}$	0.8674 Rad/s
ω_{Ce}	$\frac{1}{C_{Ce} * R^{Seen}_{Ce}}$	3214.2719 Rad/s
ω^{Z}_{Ce}	$\frac{1}{C_{Ce} * R_E}$	18.9394 Rad/s
ω_{L3dB}	$\sqrt{\omega^2_{Cc1} + \omega^2_{Cc2} + \omega^2_{Ce} - 2(\omega^{Z}_{Ce})^2}$	3317.5 Rad/s = 528.78 Hz

~~wrong result~~   -2 points

Using the formula sheet of 2N3904, we found that $C_\pi = 25pF$ and $C_\mu = 2pF$. By applying Miller theorem and redrawing the circuit we end up with the diagram below.

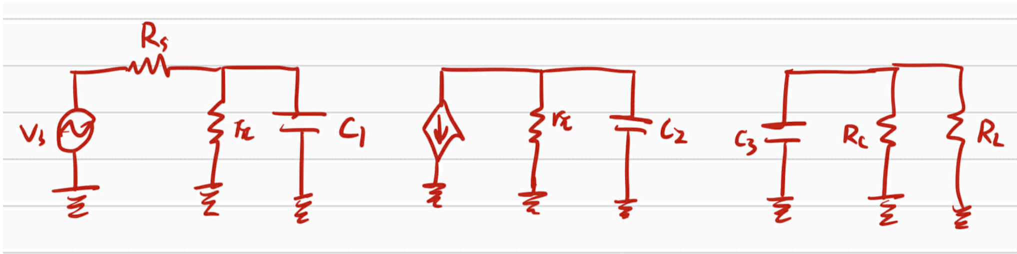


Figure 3.1.3 High Frequency Model

$$C_1 = C_{\pi 1} + 2C_{\mu 1} \qquad \omega_{H1} = \frac{1}{C1*(R_s||R_\pi||R_{B2}||R_{B3})} = 720.7\ M\ Rad/s$$

$$C_2 = C_{\pi 2} + 2C_{\mu 2} \qquad \omega_{H2} = \frac{1}{C1*(\frac{R_\pi}{1+\beta})} = 2902.3\ M\ Rad/s$$

$$C_3 = C_{\mu 2} \qquad \omega_{H3} = \frac{1}{C1*(R_L||R_C)} = 218.3\ M\ Rad/s$$

$$\omega_{H3dB} = \sqrt{(\frac{1}{\omega_{H1}})^2 + (\frac{1}{\omega_{H2}})^2 + (\frac{1}{\omega_{H3}})^2}^{\,-1} = 208.416\ Rad/s = 33.17\ MHz$$

25 M rad/s -2 points

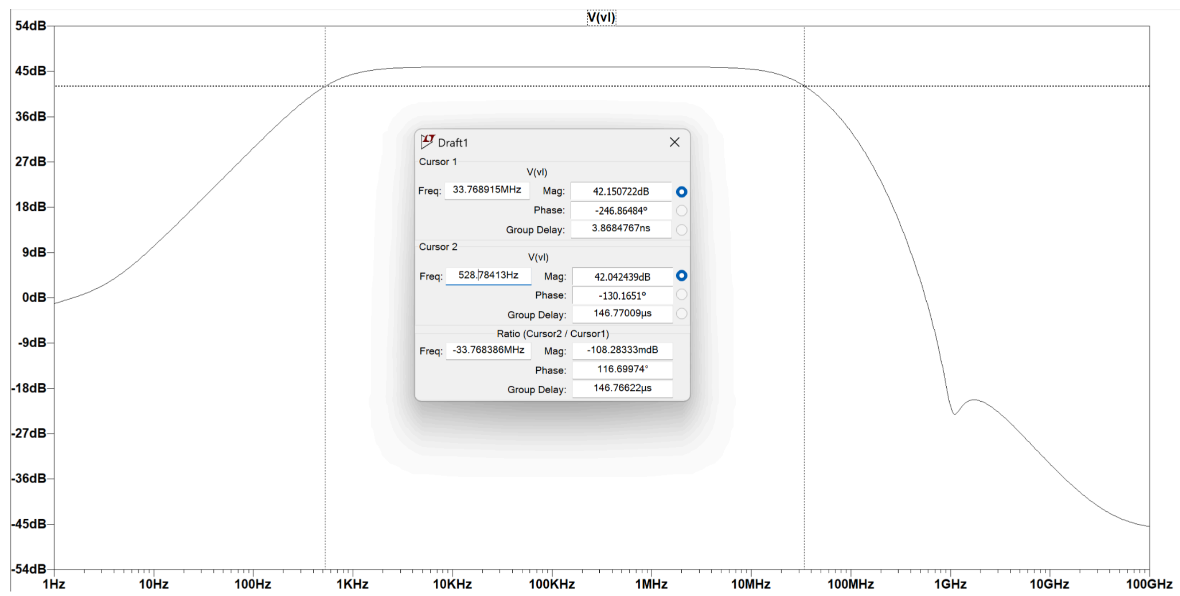


Figure 3.1.4 Bode Plot Q1

Bode Plot

axis numbers are not visible   -1 point

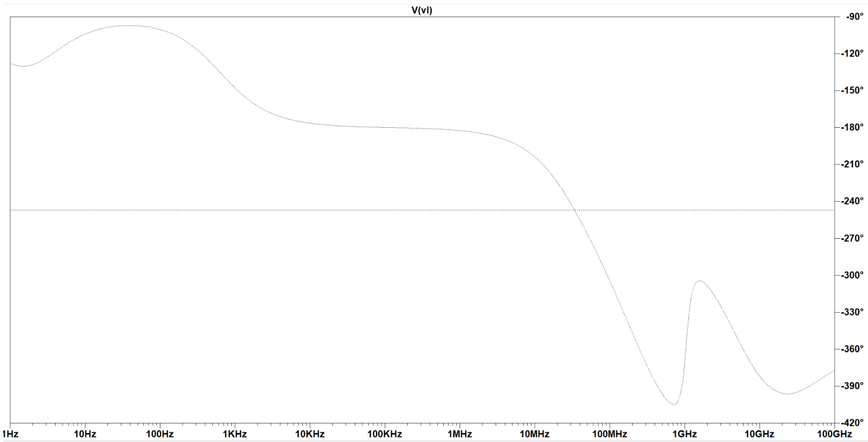


Figure 3.1.5 Phase Plot Q1

Phase Plot

3.1. C, Mid-Band

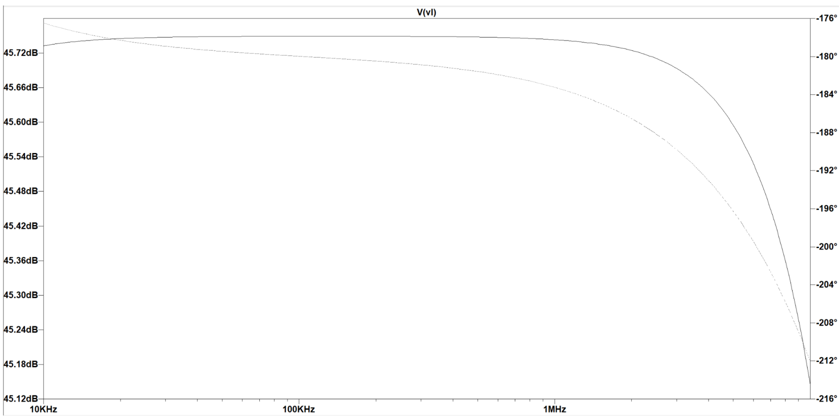


Figure 3.1.6 Mid-Band Plot Q1

By running the simulation and measure the $\frac{V_o}{V_S}$, we found that

$$A_{Gain} = 10^{\frac{45}{20}} = 194\frac{V}{V}$$

3.1. D, Input impedance

	Simulated	Calculated
Input Impedance	$2.878k\Omega$	$1.11k\Omega$

To make the input impedance to meet the requirement of 3.5**$k\Omega$**. We have to add the extra resistor to input, 3.5k-2.878k, a standard resistor 680**Ω**. After this resistor is added, the upon calculation will hold true and make the correct calculation.

3.2 Part 2 (2N2222A)

I used $\beta = 166.66$ for this part of calculation from my previous mini project

3.2. a

Biasing Capacitor with ⅓ Rule

V_{C1}	V_{B1}	V_{E1}	V_{C2}	V_{B2}	V_{E2}
$2V_{CC}/3$	$V_{E1} + V_{BE}$	$V_{CC}/3$	V_{CC}	$2V_{CC}/3$	$V_{B2} - V_{BE}$
8V	4.7V	4V	12V	8V	7.3V

Current Calculation

Using the small signal model to determine the R_{in} and R_{Out}

$$R_{In} = \frac{r_\pi}{1+\beta}||R_{E1}$$

$$R_{In} = \frac{\beta}{1+\beta}\frac{V_T}{I_{C1}}||\frac{V_{E1}}{I_{E1}}$$

$$R_{In} \approx \frac{V_T}{I_{E1}}$$

With $R_{In} = 50$ $I_{E1} = 0.5mA$

I_{C1}	I_{B1}	I_{E1}	I_{Rb1}	I_{Rb2}	I_{B2}	I_{E2}
$\frac{I_{E1}*\beta}{\beta+1}$	$\frac{I_{C1}}{\beta}$	$0.5mA$	$0.1I_{E1}$	$I_1 - I_{B1}$	$\frac{I_{E2}}{\beta+1}$	$\frac{V_{E2}}{R_{E2}}$
$0.497mA$	$2.982\mu A$	$0.5mA$	$50\mu A$	$47.02\mu A$	$25.49\mu A$	$4.27mA$

Then consider the R_{Out} and combined circuit characteristic equations

$$R_{Out} = \frac{R_{C1}}{1+\beta} + \frac{V_T*R_{E2}}{V_{E2}}||R_{E2} = 50$$

$$R_{C1} = \frac{4}{I_{C1}+I_{B2}} = \frac{4}{I_{C1}+\frac{1}{1+\beta}*\frac{7.3}{R_{E2}}}$$

Using the two equation we yield

$$R_{C1} = 7655\Omega = 7.5k\Omega \; R_{E2} = 1707\Omega = 1.8k\Omega$$

And complete the table of I_{B2} and I_{E2}

For the rest of resistors,

$$R_{E1} = \frac{V_{E1}}{I_{E1}} = 8k\Omega \quad R_{B2} = \frac{V_{B1}}{I_{RB2}} = 100k\Omega \quad R_{B1} = \frac{V_{CC}-V_{B1}}{I_{RB1}} = 146k\Omega$$

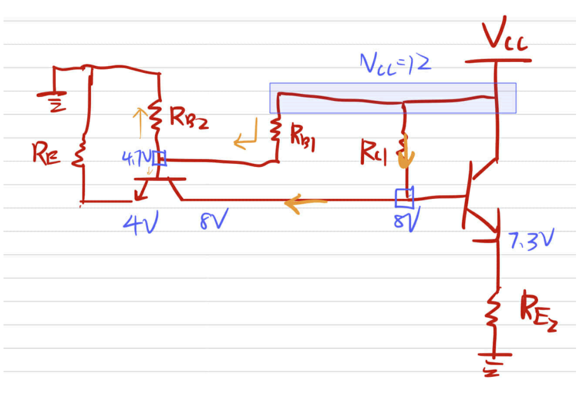


Figure 3.2.1 Biassing Circuit Model

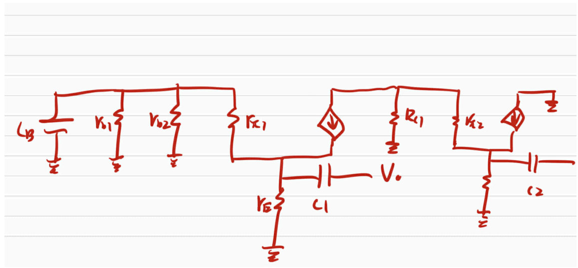


Figure 3.2.2 Small Signal Model

For Capacitor calculation

With the condition of $C_1 = C_2$ using the input resistance 50

$$\omega_{L3dB} = \sqrt{\left(\frac{1}{C*50}\right)^2 + \left(\frac{1}{C*50}\right)^2} = 1000(2\pi)$$

$$C_1 = C_2 = 4.5\mu F = 4.7\mu F$$

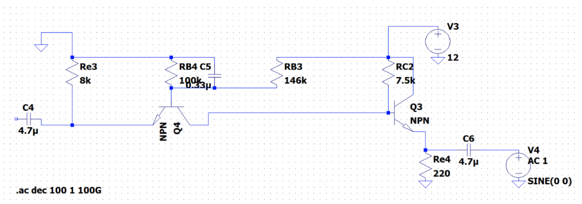
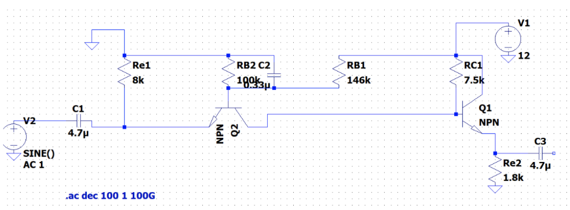
And based on the pole distribution law, the next pole will located 1 decade below the previous pole,

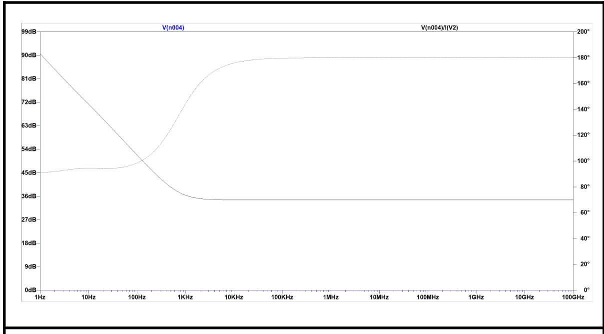
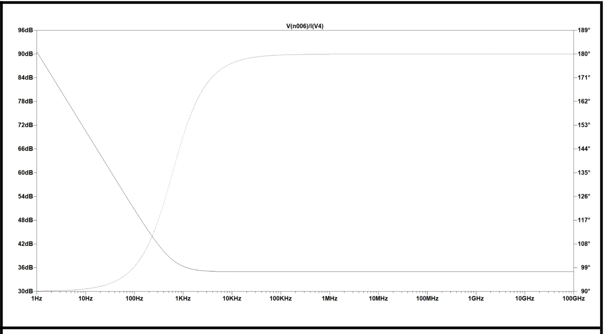
$$\omega_{CB} = \frac{1}{4.5\mu*50*10} = 444\,rad/s$$

$$444.4 = \frac{1}{C_B*(R_{B1}||R_{B2}||R_{\pi 1})}$$

$$C_B = 0.33\mu F$$

3.2. B

Rin	Rout
 Figure 3.2.3 Rin Circuit Model	 Figure 3.2.4 Rout Circuit Model

	
$53.5\,\Omega$	$56\,\Omega$

For Rout, we adjust the output resistor to 220 to met the specification

And for the midband gain, we set the frequency to 100KHz and find $A_M = 130\frac{V}{V}$

3.2. C

After plotting the bode plot by adding the output resistance and adjusting the capacitors value, we ends up with

$$f_{L3dB} = 830Hz$$
$$f_{H3dB} = 3.5MHz$$

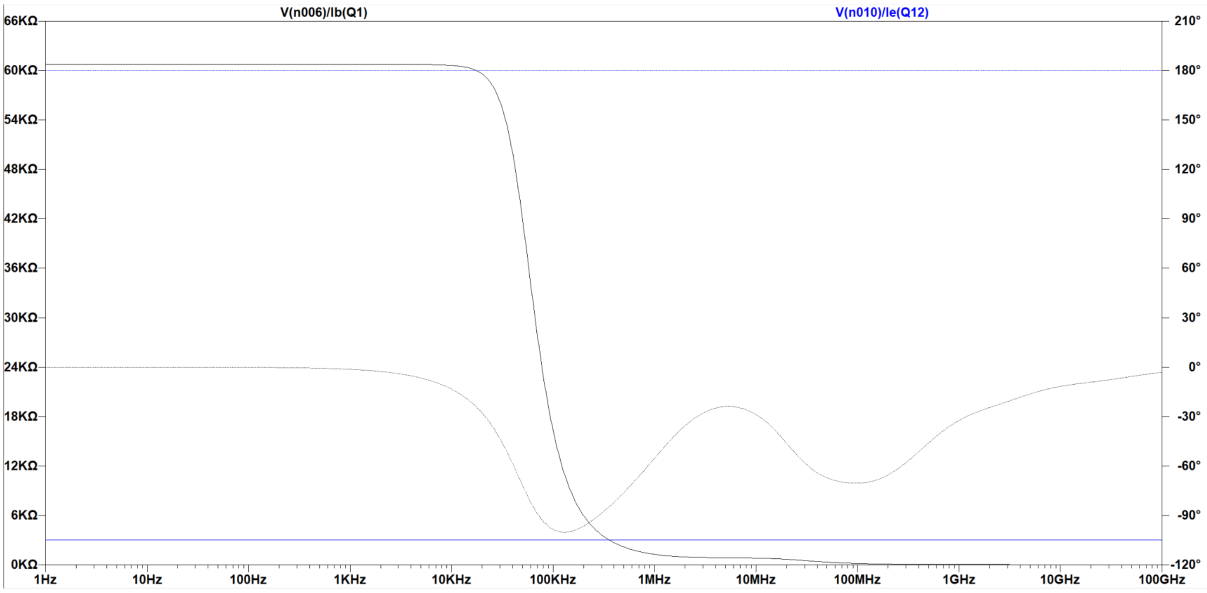


Figure 3.2.5 Q2 Bode Plot

3.2 Part 3

A)

I. Bode Plot

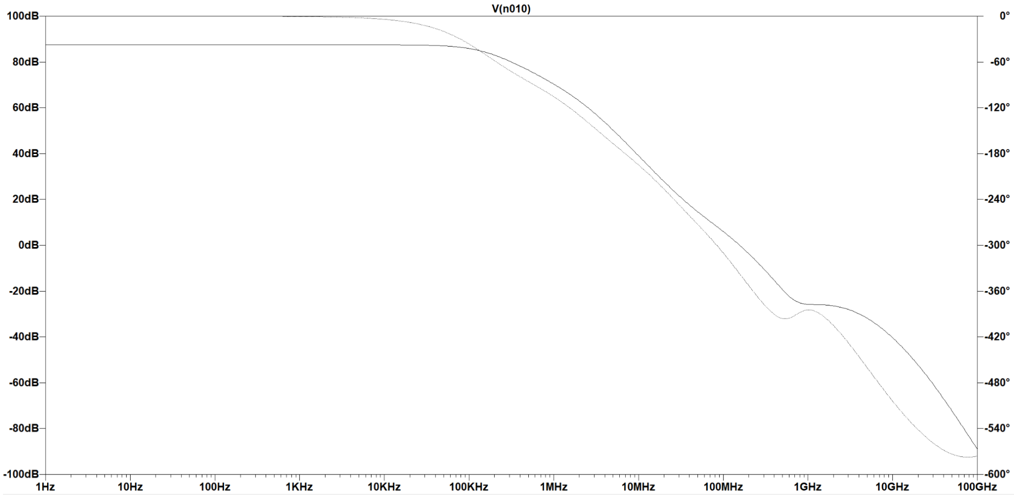


Figure 3.3.1 Q3 Bode Plot

II. Am = $87.5dB = 10^{87.5/20}$=$23713.737\frac{V}{V}$

11.8 K -2 points

B)

I. Differential input impedance, 60.66kΩ

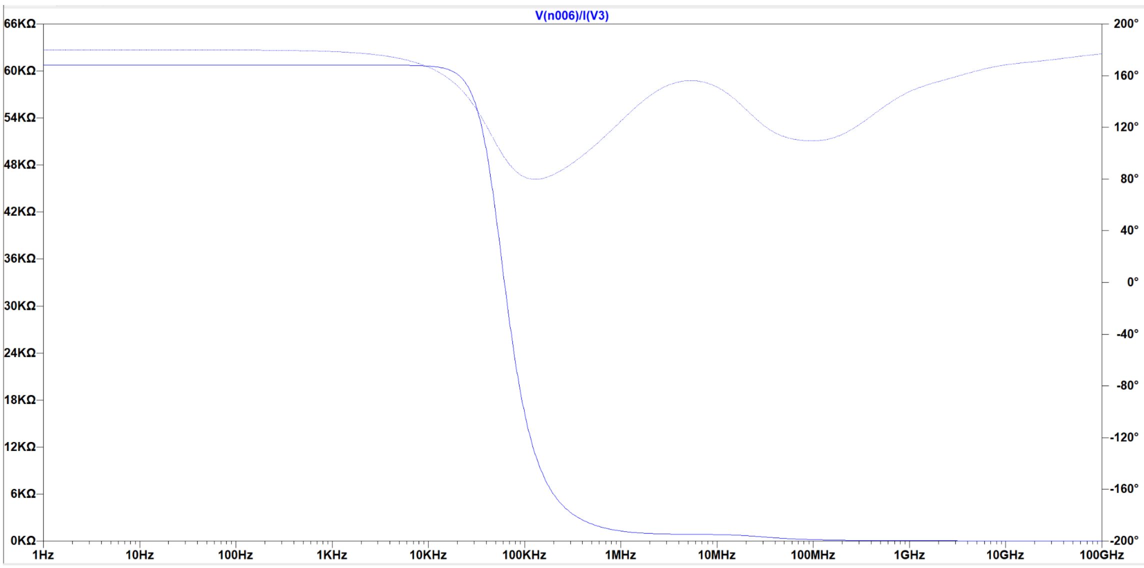


Figure 3.3.2 Rin Plot

II. Output impedance after measurement is 3kΩ

C)

I.

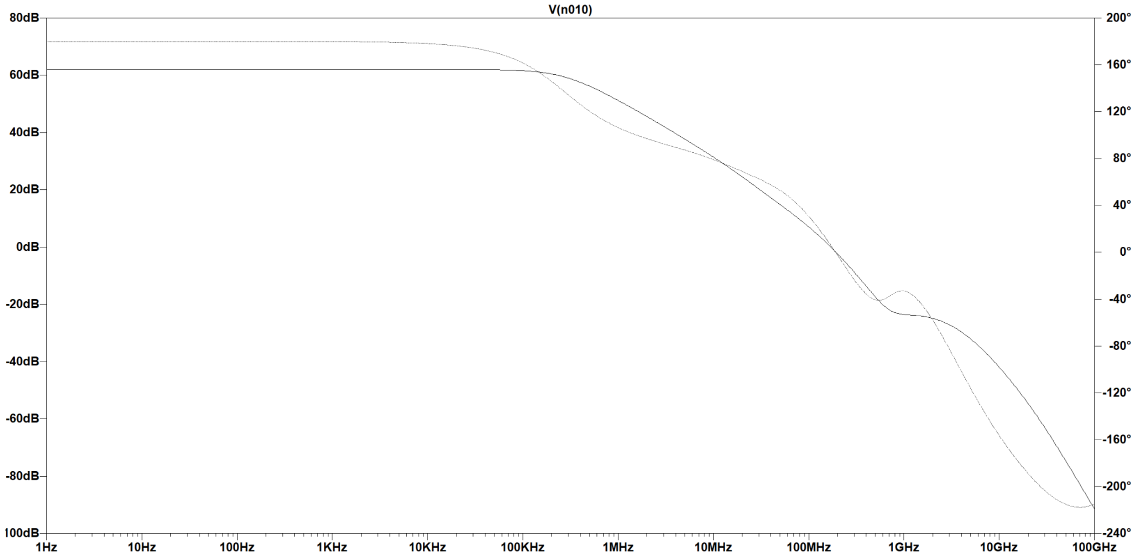


Figure 3.3.3 Q3 New Bode Plot

II.

$$\text{CMRR} = \frac{A_D}{A_M} = \frac{62.5}{87.5} = 0.714$$

wrong result -2 points

D)

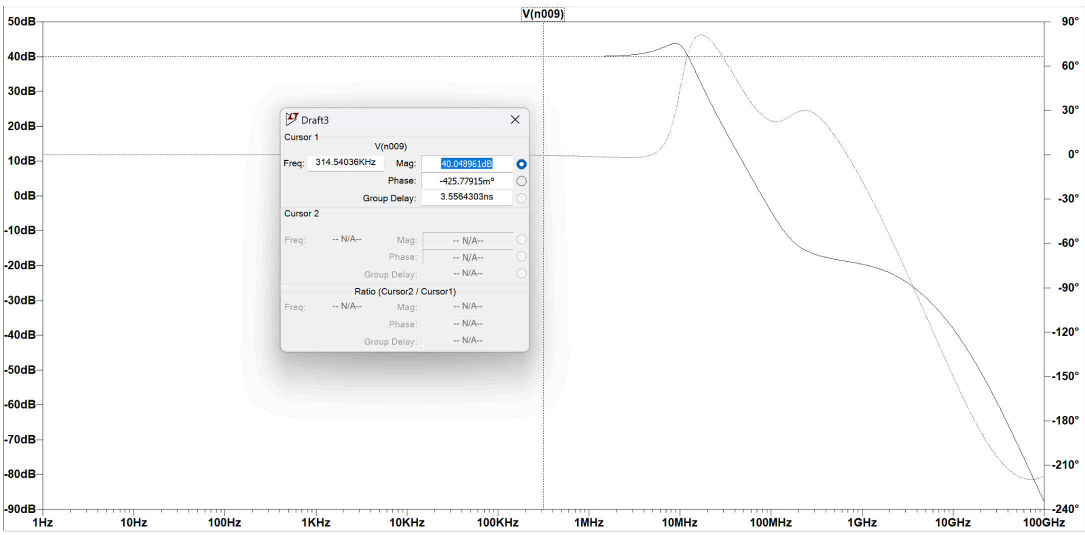


Figure 3.3.3 New Bode Plot

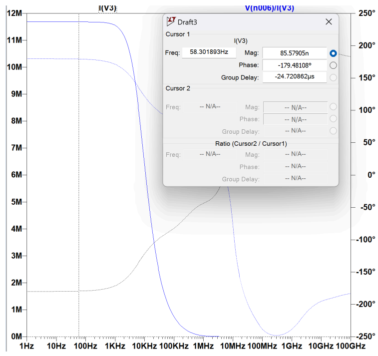
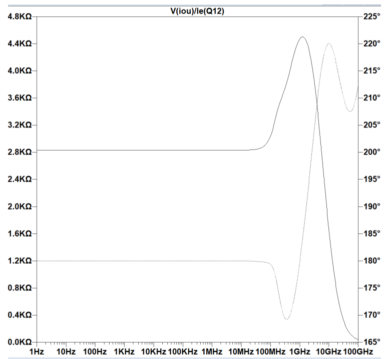
$$A_M = 40.09dB = 101.04\frac{V}{V}$$

E)

With the voltage varied, we found that as it goes from 1mV to around 170mV, the maximum voltage will start making the signal distortion occur.

axis numbers are not visible -1 points

F)

	Input	Output
Bode Plot		
Value	85.579n	2.8k

3.2 Part 4

A

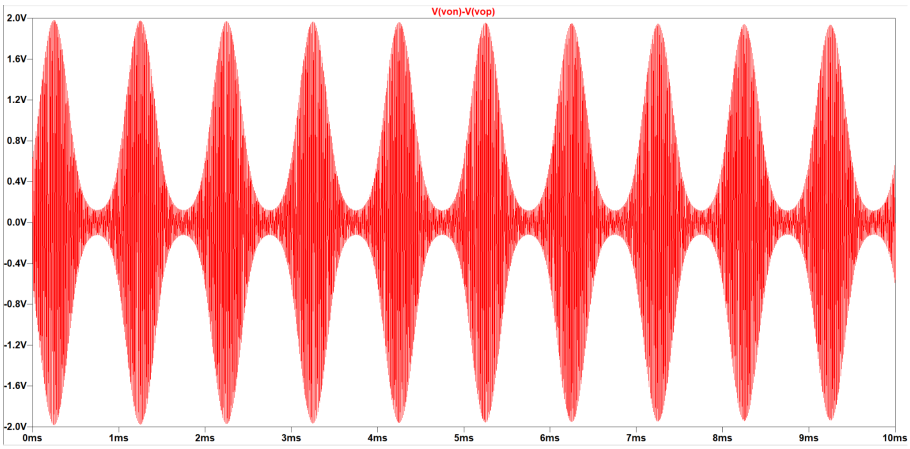


Figure 3.4.1 50mVp, 1kHz differential output

B

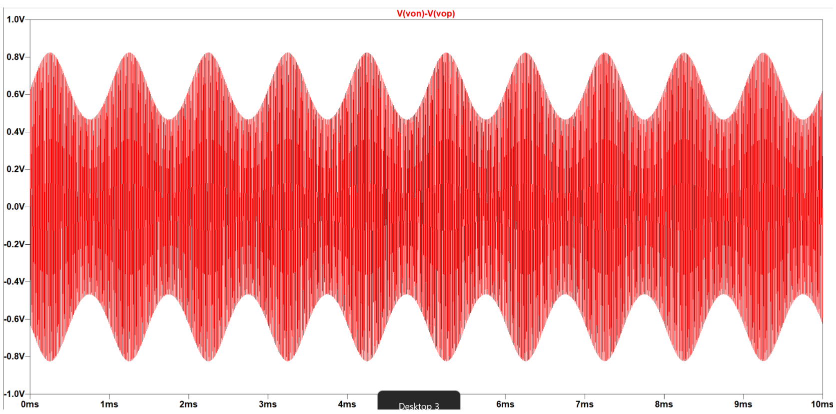


Figure 3.4.2 10mVp, 1kHz differential output

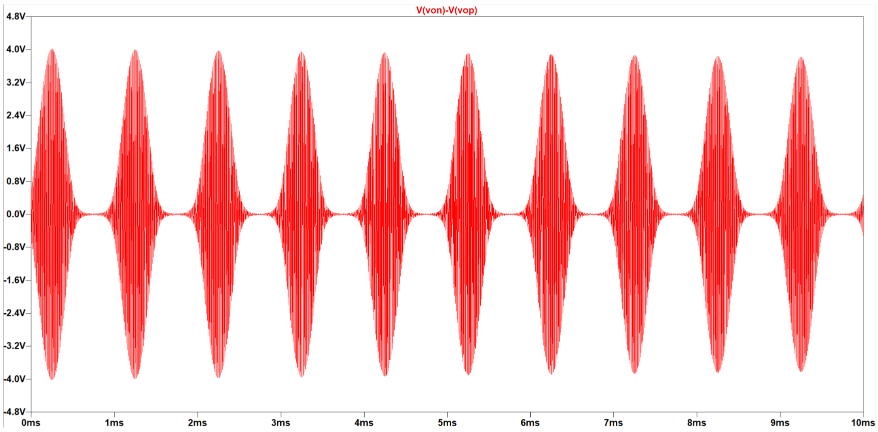


Figure 3.4.3 100mVp, 1kHz differential output

C

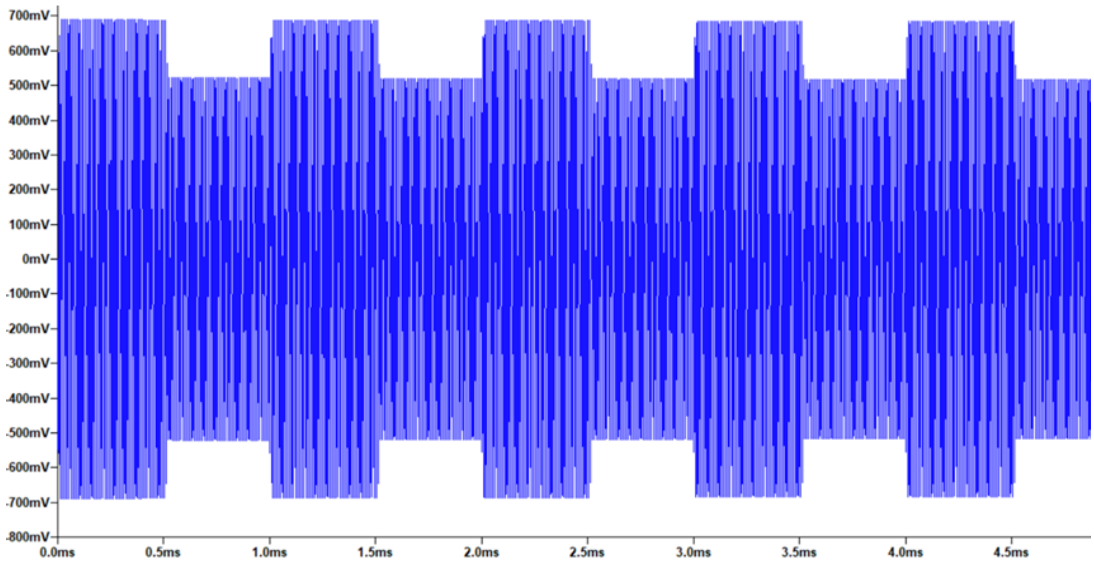


Figure 3.4.4 10mVp, 1kHz differential output

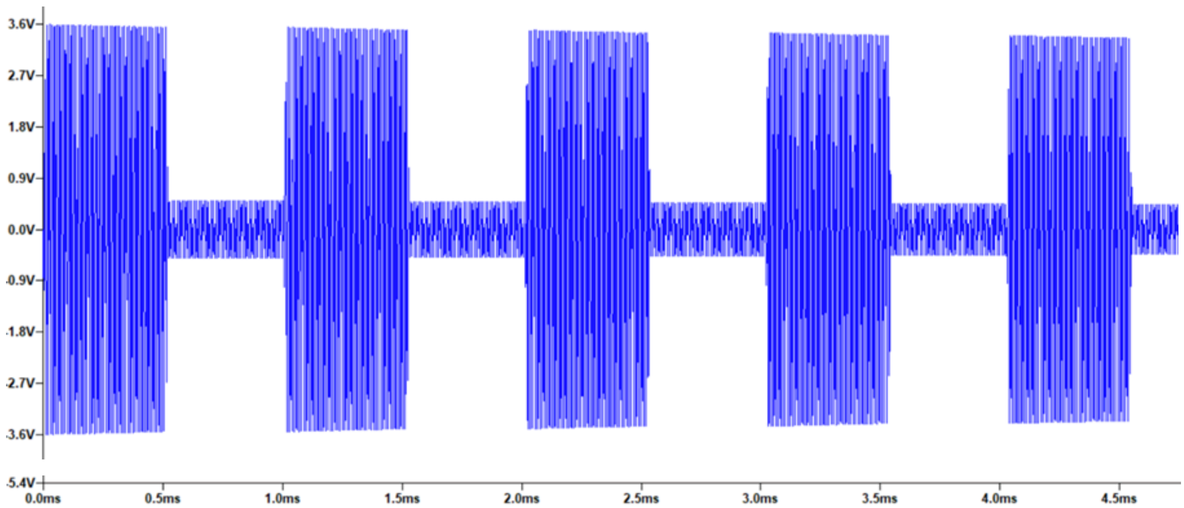


Figure 3.4.5 100mVp, 1kHz differential output

Under the 10mVp case, the modulated envelope is relatively low in amplitude, and the carrier signal is faintly visible resulting in a less distinct envelope. And with 100mVp cases, the envelope is more obvious than the 10 mVp case, but some distortion might be observed if the signal begins approaching over-modulation.

4. Conclusion

In this inquiry, we explored the construction and biassing of cascade amplifiers, cascode amplifiers, and the operation and characteristics of operational amplifiers (op-amps). We learned that a cascode amplifier combines the advantages of a common-emitter and a common-base configuration, providing high input impedance, significant gain, and immunity to the Miller effect at high frequencies. We also covered how to bias a circuit using the 1/4 rule and how to adjust parameters to meet specific design requirements. Additionally, we discussed the application of cascade amplifiers as repeaters in signalling systems and practice/design with specification given.

5. References

1. ELEC 301 Course Notes
2. A. Sedra and K.Smith, "Microelectronic Circuits", 8th (or higher) Ed., Oxford University Press, New York.
3. LTSPICE User's Tutorial
4. 2N2222A datasheet
5. 2N3904 datasheet