81/100

ELEC 301 MINI PROJECT 4

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1. Objective
2. Introduction
3. Project-Question
4. Reference

List of Figures

Figure 3.1.1 Bode Plot
Figure 3.1.2 Phase Plot
Figure 3.1.3 Oscillation at 10kHz
Figure 3.1.4 Low pass Circuit
Figure 3.1.5 Poles on Plane
Figure 3.1.6 Am = 2.5
Figure 3.1.7 Am = 3
Figure 3.1.8 Am = 3.5
Figure 3.2.1 29k Resistor
Figure 3.2.2 29.03k Resistor
Figure 3.3.1 The Feedback Circuit (In open loop)
Figure 3.3.2 Wave of Varying Rb2
Figure 3.3.3 Steady Bode and Phase plot
Figure 3.3.4 100K Rf Bode and Phase Plot
Figure 3.3.5 Varying Rf Bode and Phase Plot

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 A

Given information

$$H(s) = A_M \frac{\frac{1}{(RC)^2}}{s^2 + s(\frac{3-A_M}{RC}) + \frac{1}{(RC)^2}} \quad A_M = 1 + \frac{R_2}{R_1} \quad R = R_1 + R_2 = 10k\Omega$$

With given filter a 3dB frequency of 10kHz, and from the transfer function $\omega = \frac{1}{(RC)} = 2\pi f$

$$C = \frac{1}{R\omega} = \frac{1}{10k\Omega*(2\pi*(10kHz))} = 1.59nF$$

As we know from the 2nd order butterworth filter, the characteristic polynomial appears to be

$$s^2 + \sqrt{2} * s + 1$$

Thus, we can find the A_M

$$A_M = 3 - \sqrt{2} = 1.586$$

By solving equation of

$$R_1 + R_2 = 10k\Omega \text{ and } A_M = 1 + \frac{R_2}{R_1}$$

We got

$$R_1 = 6306\Omega\ and\ R_2 = 3693\Omega$$

Which is $R_1 = 6.2k\Omega\ and\ R_2 = 3.9k\Omega$ in standard value

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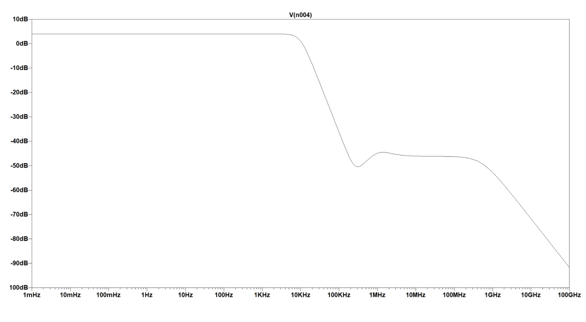

Figure 3.1.1 Bode Plot

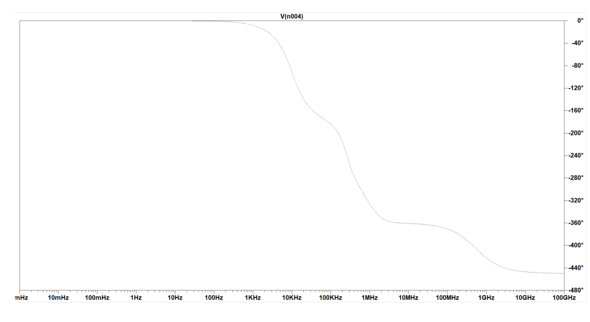

Figure 3.1.2 Phase Plot

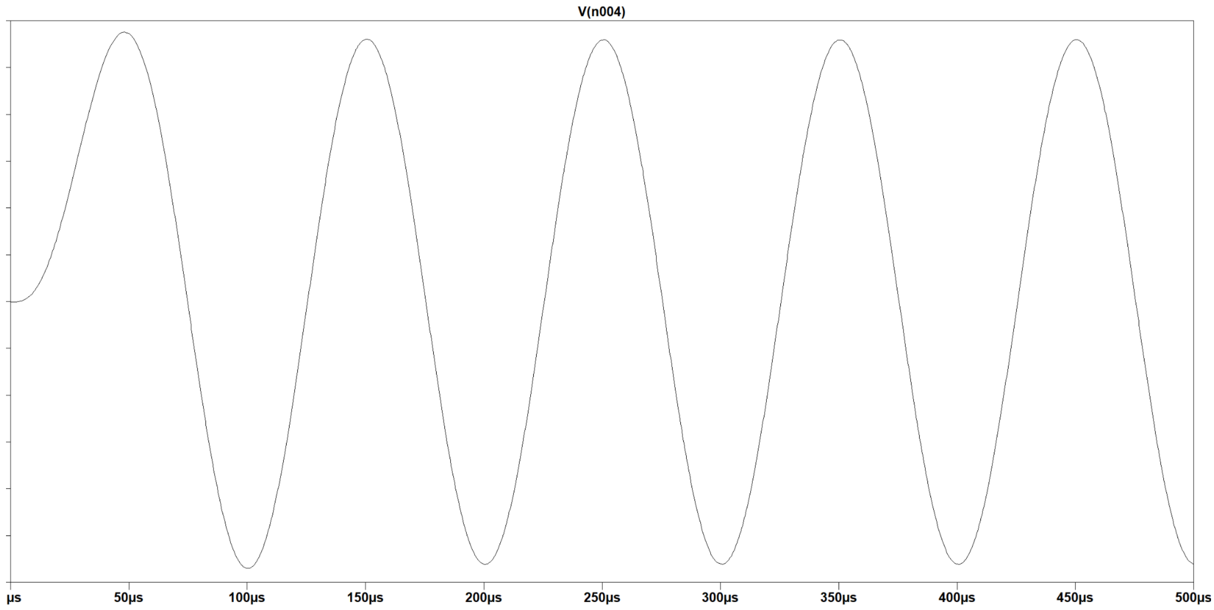

Figure 3.1.3 Oscillation at 10kHz

At what value of AMdoes your circuit start t

2^{nd} Order Low Pass Filter

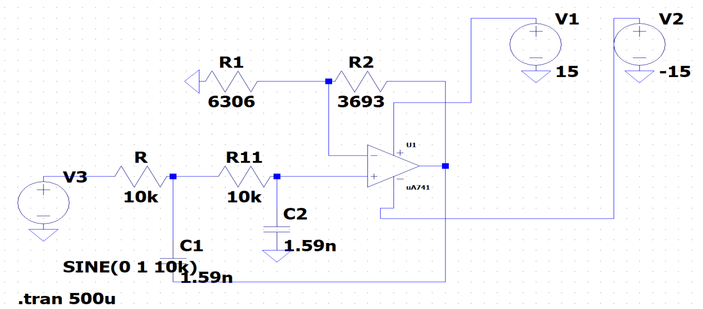

Figure 3.1.4 Low pass Circuit

Pole's Location

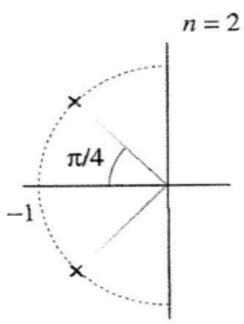

Figure 3.1.5 Poles on Plane

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Root Locus Plot		

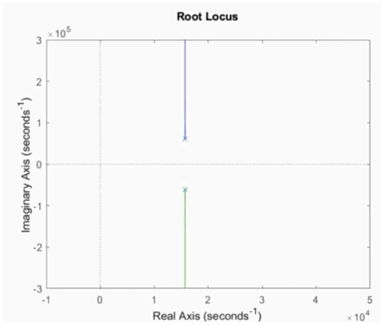
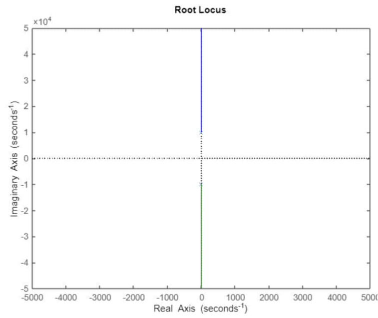
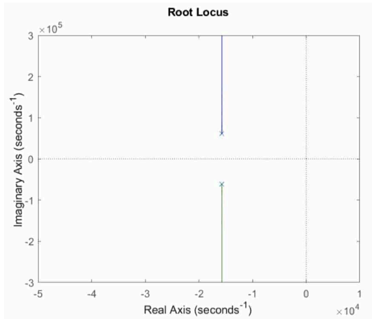
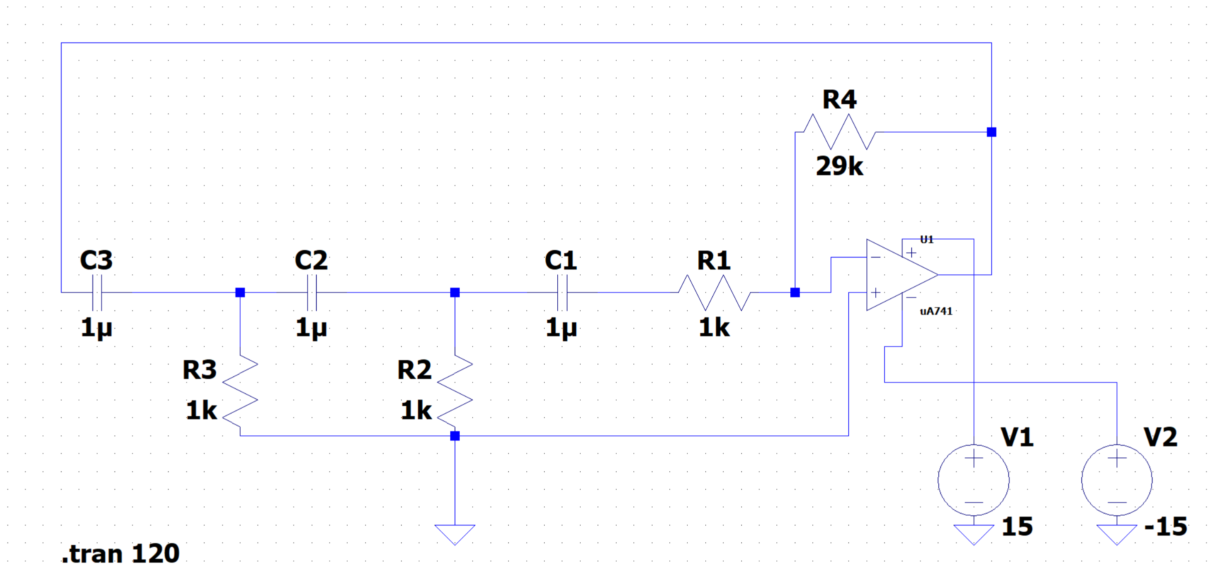

		

Figure 3.1.6 Am = <3 (2.5)	Figure 3.1.7 Am = 3	Figure 3.1.8 Am = >3 (3.5)

3.2 Part A



By running the simulation, we found that the breakdown occurs when the value of 29R resistor becomes 29.02k. Rather than the flat continuous voltage, it leads to a sudden breakdown

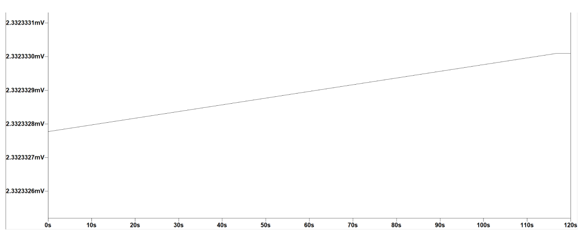
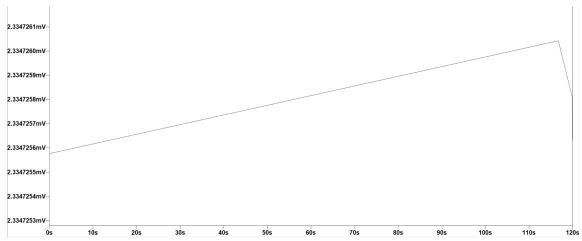
	

Figure 3.2.1 29k Resistor	Figure 3.2.2 29.02k Resistor

-3

Use $f = \frac{1}{2\pi RC\sqrt{6}}$ for the frequency calculation and measuring the bode plot out while changing resistors and capacitors values gives us the following results.

C	$1\mu F$	$0.5\mu F$	$2\mu F$
R	$1k\Omega$	$0.5k\Omega$	$2k\Omega$
$f_{Calculate}$	65 Hz	260 Hz	16.2 Hz
$f_{Measured}$	65 Hz	259 Hz	16 Hz
Error	0 %	0.38 %	1.23%

At the operating frequency, the three RC filters introduce an attenuation factor of $\frac{1}{29}$. To achieve unity gain, the inverting amplifier's gain is set to 29, satisfying the Barkhausen criterion for sustained oscillations. When the circuit has unity gain, it results in a pair of complex conjugate poles lying on the imaginary axis, which explains the sustained oscillation. In some cases, it may be necessary to slightly increase the resistance (denoted as 29R) to compensate for OpAmp non-idealities. These non-idealities can shift the poles closer to the left half-plane, and adjusting the resistance helps move the poles closer to the imaginary axis to maintain stable oscillation.

3.3 Part A

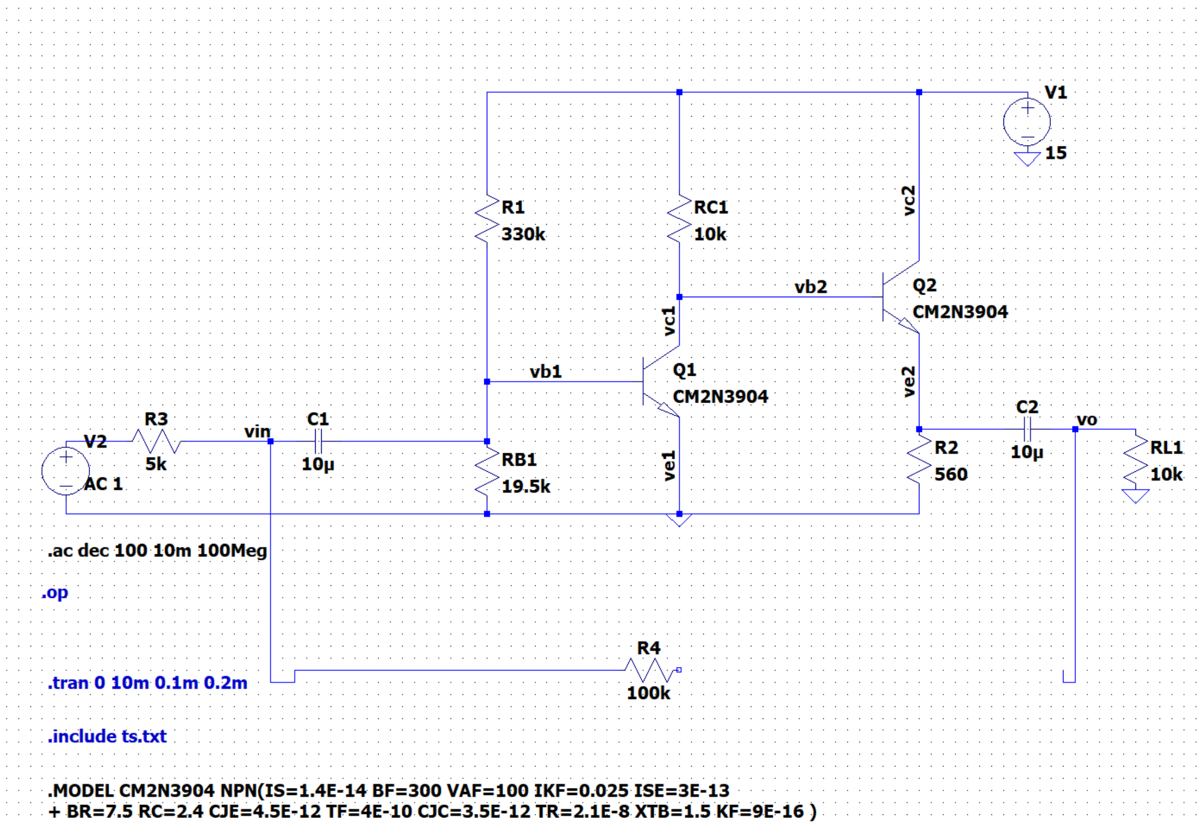


Figure 3.3.1 The Feedback Circuit (In open loop)

To begin with, we use the .step param on RB1 located on the image above to sweep and find the greatest open loop gain by opening the feedback circuit at the same time.

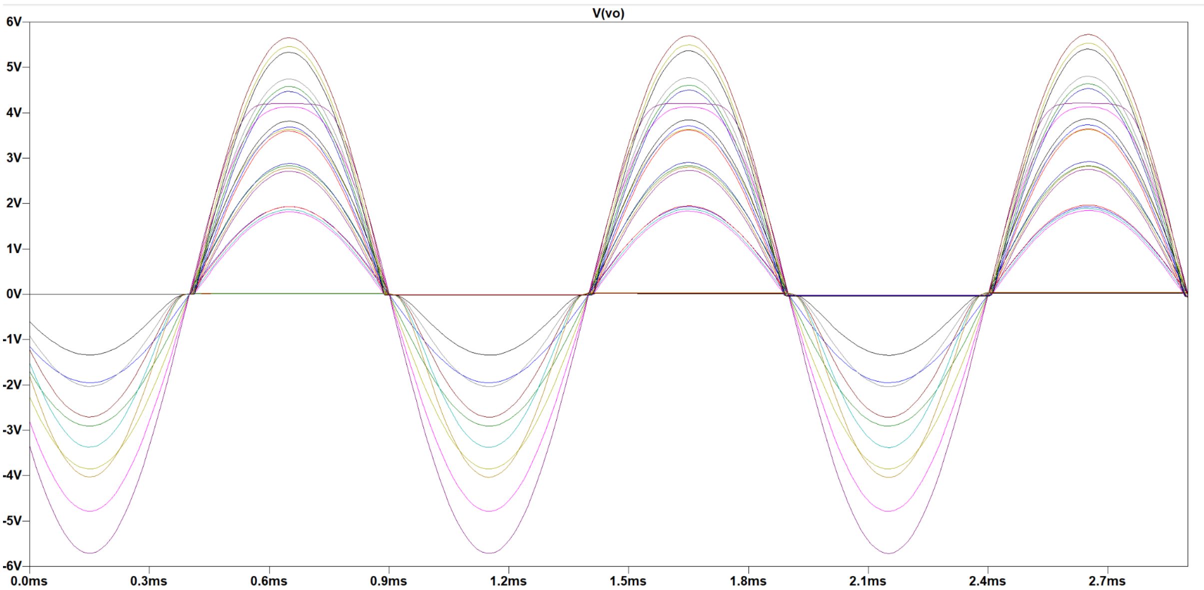


Figure 3.3.2 Wave of Varying Rb2

From the above plot, we found that the final value ends up around 19.5 kΩ

3.3.1 DC biassing points

	V_C	V_B	V_E	I_C	I_B	I_E	h_{fe}	g_m	r_π
Q1	1.9V	0.65V	0V	1.32mA	10.9uA	1.3mA	120	0.053	2.3k
Q2	15V	1.9V	1.1V	2.1mA	14.5uA	1.8mA	141	0.088	1.6k

3.3.2 Open Loop Response

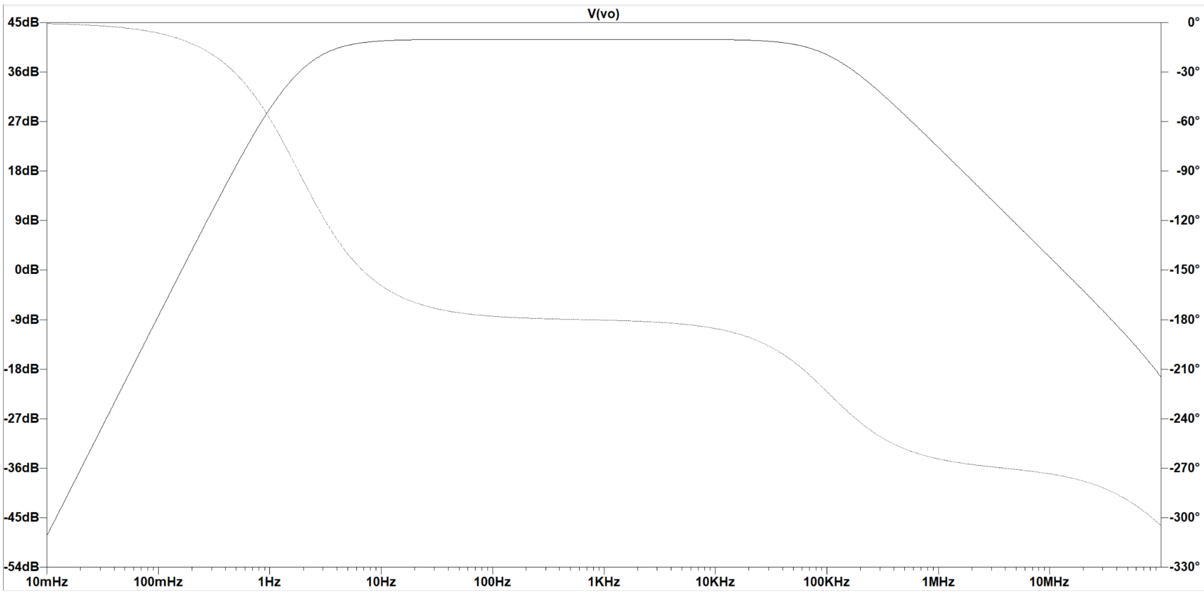
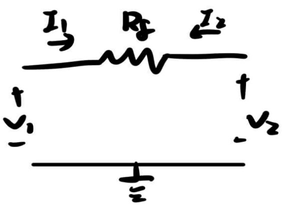


Figure 3.3.3 Steady Bode and Phase plot

ω_{L3dB}	ω_{H3dB}	A_M	R_{in} measured	R_{Out} measured
2.89Hz	88.4kHz	42.22	2.42kΩ	65.2Ω

With the closed loop condition, we use shunt-shunt topology with Y parameter to solve for the variables and gain using Rf = 100kΩ

	$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$

$$y_{11} = \frac{I_1}{V_1}|_{V2=0} \; y_{12} = \frac{I_1}{V_2}|_{V1=0} \quad y_{22} = \frac{I_2}{V_2}|_{V1=0}$$

$$y_{11} = \frac{1}{R_f} \; y_{12} = \frac{-1}{R_f} \quad y_{22} = \frac{1}{R_f}$$

We neglect $y_{21} = \frac{I_2}{V_1}|_{V2=0}$ since it is usually small and find feedback gain using the open loop gain $A = R_s Am$ and $\beta = y_{12} = 10\mu S$

$$A_f = \frac{A}{1+\beta A}$$

And the adjusted value with feedback is listed simply as

$$A = \frac{V_o}{I_S} = \frac{V_o}{Vs/Rs} = \frac{10^{\frac{42.05}{20}}}{1/5000} = -633k\frac{V}{A}$$

$$A_f = \frac{633k}{1-10^{-5}*-633k} = -86.36k\frac{V}{A}$$

Frequency at 3dB point

$$f_{L3dB} = \frac{2.89}{1+10^{-5}*633k} = 0.394\ Hz$$

$$f_{H3dB} = (1 + 10^{-5} * 633k) * 88.4k = 648\ kHz$$

Resistors after the feedback implemented

$$R_{inNEW} = \frac{2.42k}{1-10^{-5}*-633k} = 330\Omega$$

$$R_{outNEW} = \frac{65.2}{1-10^{-5}*-633k} = 8.89\Omega$$

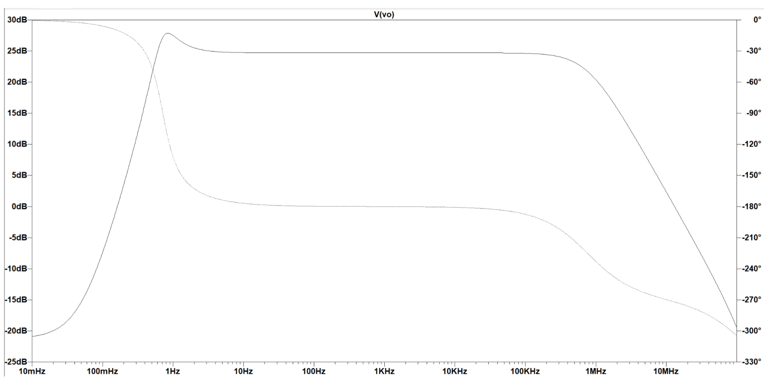


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Figure 3.3.4 100K Rf Bode and Phase Plot

3.3.3

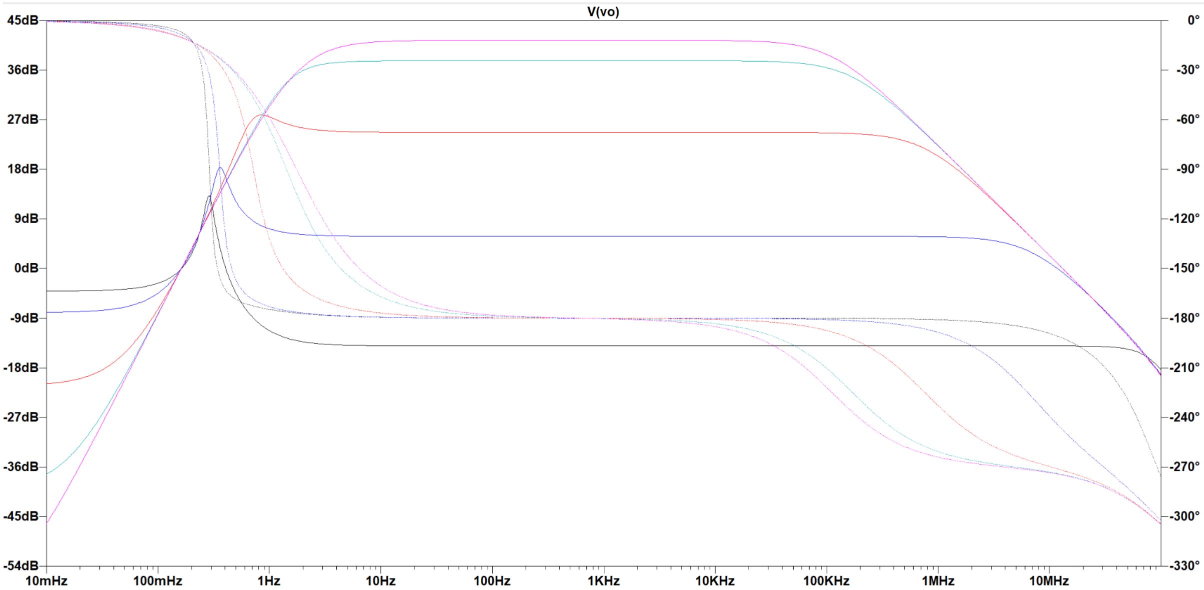

Figure 3.3.5 Varying Rf Bode and Phase Plot

Rewrite the feedback formula

$$A_f = \frac{A}{1+A\beta} \Rightarrow \beta = \frac{1}{A_f} - \frac{1}{A} = \frac{1}{A_{vf}{*}R_S} - \frac{1}{A}$$

R_f	$Measured\ A_{vf}$	$Calculated\ \beta$	$Measured\ \beta$
$1k\Omega$	-14.05	$-10^{-3}S$	$-1.005 * 10^{-3}S$
$10k\Omega$	5.86	$-10^{-4}S$	$-1.003 * 10^{-4}S$
$100k\Omega$	24.75	$-10^{-5}S$	$-1.002 * 10^{-5}S$
$1M\Omega$	37.85	$-10^{-6}S$	$-1.002 * 10^{-6}S$
$10M\Omega$	41.61	$-10^{-7}S$	$-1.01 * 10^{-7}S$

3.3.4

Determine the $R_{in}\ and\ R_{out}$ with 1kHz and running R_f in list and predict the feedback with

$$R_{if} = \frac{R_i}{1+A\beta} \Rightarrow 1 + A\beta = \frac{R_i}{R_{if}}$$

$$R_{of} = \frac{R_o}{1+A\beta} \Rightarrow 1 + A\beta = \frac{R_o}{R_{of}}$$

R_f	Measured R_{if}	Measured R_{of}	Feedback R_{if}	Feedback R_{of}	Predicted 1+$A\beta$
$10k\Omega$	26.2Ω	1.14Ω	96.6	55.7	65
$100k\Omega$	240.2Ω	8.71Ω	10.6	7.29	7.4
$1M\Omega$	1304Ω	38.4Ω	1.98	1.64	1.6

Following our simulation, we found out that As the value of R_f increases, the output feedback will be close to our predicted feedback following the above equation. And as the table displayed, the R_{of} is the one we use to estimate feedback instead of the R_{if}

3.3.5

By setting $R_f = \infty$ we will lead to $\beta = 0$, which has no feedback in the circuit leading the amplifier turns into an open loop with 1+$A\beta$ =1

R_C	A_V	β	$1 + A\beta$
$9.9k\Omega$	-126.1$\frac{V}{V}$	$-2.4 * 10^{-9}\frac{A}{V}$	1.003
$10k\Omega$	-126.62$\frac{V}{V}$	$-34 * 10^{-11}\frac{A}{V}$	1
$10.1k\Omega$	-127.2$\frac{V}{V}$	$3 * 10^{-9}\frac{A}{V}$	0.998

and with $100k\Omega$, we used the predicted feedback from previous part 1+$A\beta$ = 7.39

R_C	A_{Vf}	β	$1 + A\beta$
$9.9k\Omega$	-17.22$\frac{V}{V}$	$-11.0 * 10^{-6}\frac{A}{V}$	7.41
$10k\Omega$	-17.26$\frac{V}{V}$	$-10.02 * 10^{-11}\frac{A}{V}$	7.40
$10.1k\Omega$	-17.28$\frac{V}{V}$	$-9.01 * 10^{-9}\frac{A}{V}$	7.39

In your report compare this value with your expected value using the measured values of A ar

As seen from the above calculation and experiments with the smaller values of Rf, the intermediate frequency shows higher gain compared to the lower frequencies. This behavior can be attributed to the frequency dependence of the amplifier and the feedback network. At lower frequencies, the capacitive reactance is higher, which causes the circuit to produce a larger overall gain.

4. 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. Canvas Transistor Documents
5. 2N3904 datasheet