Amplifier Project

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Lab 2 Report

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Contents

List of Tables

List of Figures

1 Introduction

1.1 Purpose

The purpose of this lab is to investigate the use of BJTs as amplifier circuit elements [1]. First, the three basic configurations (CE, CC, and CB) are observed [1]. Then, by proper combinations and permutations, 2-transistor amplifier configurations can be studied for improved gain-bandwidth performance [1]. Finally, a specific configuration was required to be designed to meet or exceed a prescribed set of specifications [1].

1.2 Experiment Overview

In day 1, three different signle amplifier configurations and three different two-transsitor configurations were constrcuted and analyzed. Data were measured and the charactersitics of the amplifiers were verified. Then, useful parameters were calculated using the obtained measurements.

In day 2, a cascode amplifier design is constructed and tested. Data were measured to verify that the measured parameters values of the cascode amplifier matched with the assumptions and the theoretical calculations when analyzing the amplifier.

In day 3, more test measurments were done to verify the functionality of the designed cascode amplifier as well as to confirm that the design meet or exceed a prescribed set of specifications.

2 Background

The semiconductor device introduced in this course is the bipolar junction transistor. The three basic configurations of the BJT amplifier are the common-collector mode, common-base mode, and common-emitter mode. These configurations are used for voltage or current amplification. However, the various configurations can be combined to create two-transistor amplifiers which overcome the drawbacks of the single transistor amplifiers and provide more desireable characteristics analog designers seek.

3 Cascode Amplifier Design Project

3.1 Prelab

$$Z = 5 + 5 + 0 = 10$$

Design Requirements:

1. Mangnitude of voltage gain:

$$|A_v| = 12\sqrt{10+35} = 12\sqrt{45} = 80.50\ v/v \pm 10\% = (80.50 \pm 8.05)\ v/v$$

2. Load resistance:

$$R_L = 6(10+40)^2 = 6(50)^2 = 15\ k\Omega$$

3. The high frequency cutoff f_H is to be maximized. **It must exceed 1 MHz**.
4. The output voltage: V_{out} = approximately 2 V peak-peak without appreciable distortion.
   - To ensure this, the AC base-emitter voltage must be kept under 10 mV peak-peak for such an output.
5. No DC current may flow in R_L and no DC current may flow into or out of the signal generator.
6. The low frequency f_L **must be less than 200 Hz**.
7. The magnitudes of the input and output impedances at 1 kHz are to be determined by calculation and then measured.
8. Total circuit power **is not to exceed 50 m**W.
9. The transistors are all to be 2N3904.
10. Collector currents in the transistors are to be $1.0\ mA \pm 10\% = (1.0 \pm 0.1)\ mA$.
11. Power-supply voltages are to be **+15 volts**.
12. No adjustable components, e.g. trim-pots, will be allowed.
13. Additional design requirements:

$$\beta = 147.06$$

$$\alpha = 0.99 \approx 1$$

$$C_\mu = 4\ pf$$

$$C_\pi \approx 50\ pf$$

$$g_m = 40\ milli\ mhos$$

$$r_\pi = 3.313\ k\Omega$$

$$r_e = \frac{\alpha}{g_m} = \frac{0.99}{40\ milli\ mhos} = 24.75\ \Omega$$

Figure 1 below shows an example schematic of a cascode amplifier circuit.

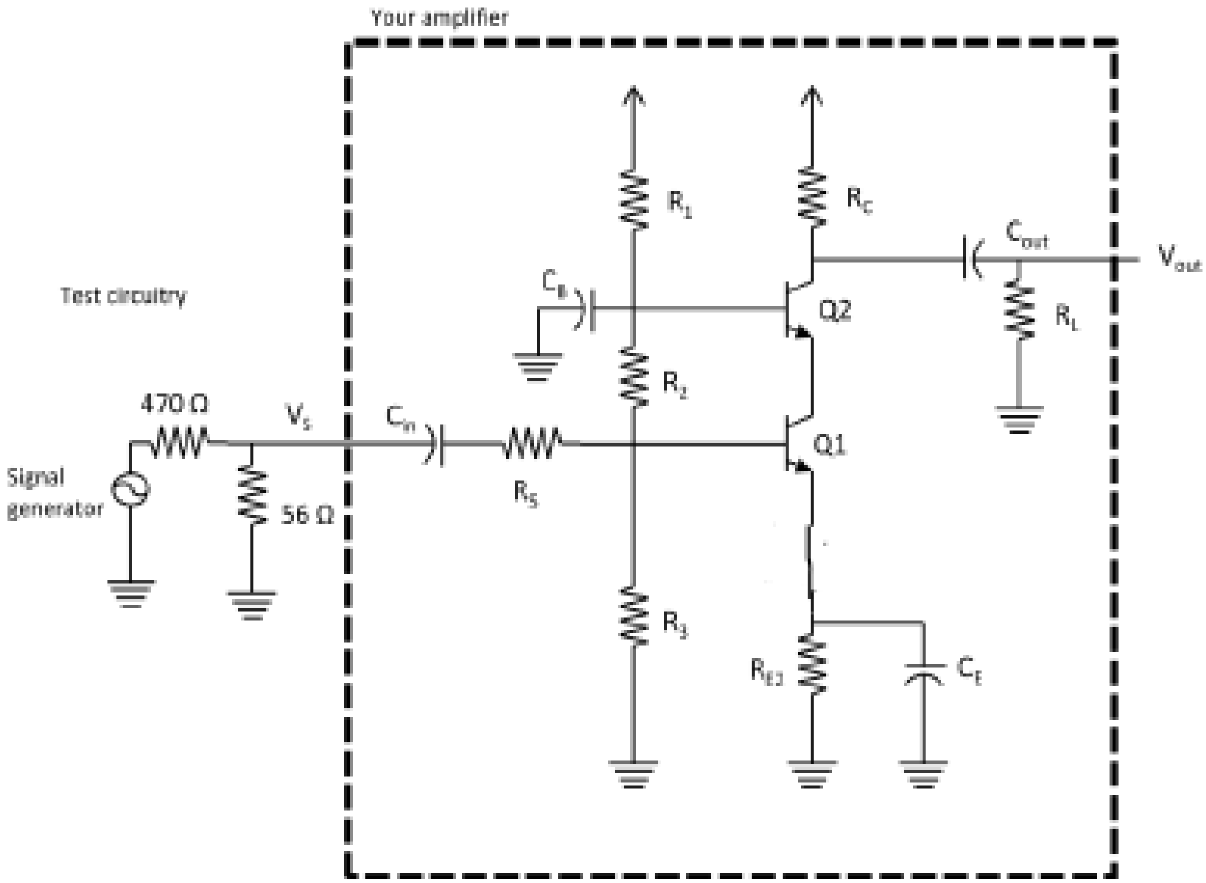

Figure 1: Schematic of Cascode Amplifier Circuit [1]

DC Analysis:

Assuming V_E is 20% of V_{CC}, we get the following:

$$\begin{aligned} V_E &= 0.2 * V_{CC} \\ &= 0.2 * 15\ V \\ &= 3\ V \end{aligned}$$

Assuming $V_{CE_1} = 2\ V$, we get the following:

$$\begin{aligned} V_{C_1} &= V_{E_1} + V_{CE_1} \\ &= 3\ V + 2\ V \\ &= 5\ V \end{aligned}$$

$$\begin{aligned} V_{C_2} &= \frac{V_{CC} + V_{C_1}}{2} \\ &= \frac{15\ V +\ 5\ V}{2} \\ &= 10\ V \end{aligned}$$

Based on these assumptions, we can calculate all of the followings:

$$\begin{aligned} R_{E_2} &= \frac{V_E}{I_E} \\ &= \frac{3\ V}{1\ mA} \\ &= 3\ k\Omega \end{aligned}$$

$$\begin{aligned} R_C &= \frac{V_{CC} - V_{C_2}}{I_{C_2}} \\ &= \frac{15\ V -\ 10\ V}{1\ mA} \\ &= 5\ k\Omega \end{aligned}$$

$$\begin{aligned} V_{B_1} &= V_{E_1} + 0.7\ V \\ &= 3\ V + 0.7 \\ &= 3.7\ V \end{aligned}$$

$$\begin{aligned} V_{B_2} &= V_{C_1} + 0.7\ V \\ &= 5\ V + 0.7 \\ &= 5.7\ V \end{aligned}$$

Given the values of I_C and β from Lab 1 report, we get the following:

$$\begin{aligned} I_{B_1} = I_{B_2} &= \frac{I_C}{\beta} \\ &= \frac{1\ mA}{147.06} \\ &= 6.8\ \mu A \end{aligned}$$

Assuming I_{BB} is ten times the sum of the base currents of both transistors, we get the following:

$$\begin{aligned} I_{BB} &= 10 * (I_{B_1} + I_{B_2}) \\ &= 10 * (6.8\ \mu A + 6.8\ \mu A) \\ &= 10 * (13.6\ \mu A) \\ &= 136\ \mu A \end{aligned}$$

Based on the previous calculations, R_1, R_2, R_3, can be calculated as follows:

$$\begin{aligned} R_1 &= \frac{V_{CC} - V_{B_2}}{I_{BB}} \\ &= \frac{15\ V -\ 5.7\ V}{136\ \mu A} \\ &\approx 68.40\ k\Omega \end{aligned}$$

$$\begin{aligned} R_2 &= \frac{V_{B_2} -\ V_{B_1}}{I_{BB} -\ I_{B_2}} \\ &= \frac{5.7\ V -\ 3.7\ V}{136\ \mu A -\ 6.8\ \mu A} \\ &\approx 15.5\ k\Omega \end{aligned}$$

$$\begin{aligned} R_3 &= \frac{V_{B_1}}{I_{BB} -\ I_{B_1} -\ I_{B_2}} \\ &= \frac{3.7\ V}{136\ \mu A -\ 6.8\ \mu A -\ 6.8\ \mu A} \\ &\approx 30.23\ k\Omega \end{aligned}$$

Figure 2 below shows an example schematic of the designed cascode amplifier circuit.

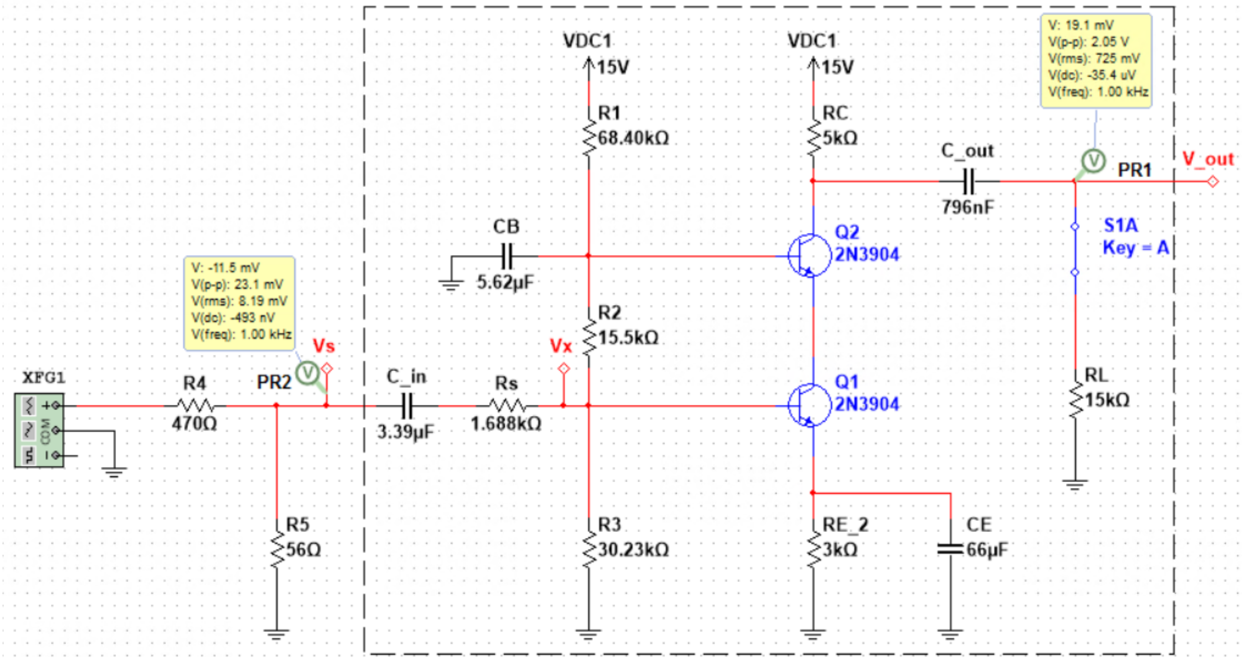

Figure 2: Schematic of The Designed Cascode Amplifier Circuit [1]

AC Analysis:

Figure 3 below shows the small signal model of the cascode amplifier project.

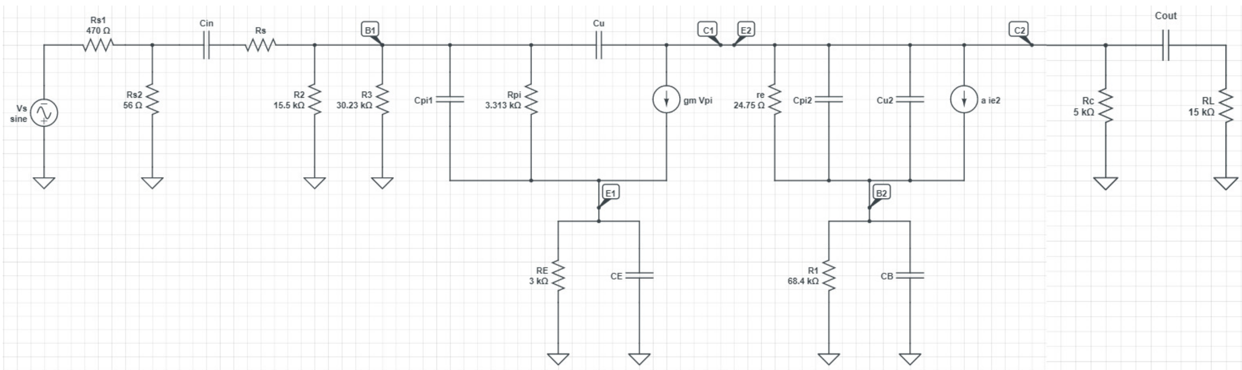

Figure 3: The Small Signal Model of The Cascode Amplifier Project

Step 1: A_v

$$|A_v| = 12\sqrt{10+35} = 12\sqrt{45} = 80.50\ v/v \pm 10\% = (80.50 \pm 8.05)\ v/v$$

The voltage gain is derived as follows:

$$\begin{aligned} A_v &= \frac{-\alpha i_{E_2}(R_C//R_L)}{V_\pi} * \frac{\frac{R_2//R_S//r_\pi}{R_{S_1} + R_S + [R_2//R_3//r_\pi]} * V_S}{V_S} \\ &= \frac{\alpha g_m \cancel{V_\pi}(R_C//R_L)}{\cancel{V_\pi}} * \frac{\frac{R_2//R_S//r_\pi}{R_{S_1} + R_S + [R_2//R_3//r_\pi]} * \cancel{V_S}}{\cancel{V_S}} \\ A_v &= \alpha g_m (R_C//R_L) * \frac{R_2//R_S//r_\pi}{R_{S_1} +\ R_S +\ [R_2//R_3//r_\pi]} \end{aligned}$$

By rearranging the previous equation for R_S, we get the following:

$$\begin{aligned} R_S &= \frac{[\alpha g_m (R_C//R_L)][R_2//R_3//r_\pi]}{A_v} - R_{S_1} - (R_2//R_3//r_\pi) \\ &= \frac{[(1)(40\ milli\ mhos)(5\ k\Omega//15\ k\Omega)][15.5\ k\Omega//30.23\ k\Omega//3.313\ k\Omega]}{80.50} - 470\ \Omega - (15.5\ k\Omega//30.23\ k\Omega//3.313\ k\Omega) \\ &= 1.688\ k\Omega \end{aligned}$$

Setp 2: R_{in}

$$\begin{aligned} R_{in} &= R_S + (R_2//R_3//r_\pi) \\ &= 1.688\ k\Omega + (15.5\ k\Omega//30.23\ k\Omega//3.313\ k\Omega) \\ &= 4.188\ k\Omega \end{aligned}$$

Setp 3: R_{out}

$$R_{out} = R_C = 5\ k\Omega$$

Assuming a low frequency, f_L, of **100 Hz**, and taking the design considerations below into account:

$$\begin{aligned} &\frac{1}{R_{C_E} C_E} \rightarrow 70\%\ of\ 2\pi f_L \\ &\frac{1}{R_{C_B} C_B} = \frac{1}{R_{C_{in}} C_{in}} = \frac{1}{R_{C_{out} C_{out}}} \rightarrow 10\%\ of\ 2\pi f_L \end{aligned}$$

Then, the capaciotrs can be calculated as follows:

$$\frac{1}{R_{C_{in}} C_{in}} = 0.1 * 2\pi f_L$$

$$\begin{aligned} R_{C_{in}} &= [R_{S_1}//R_{S_2}] + R_s + [R_2//R_3//r_\pi] \\ &= [470\ \Omega//56\ \Omega] + 1.688\ k\Omega + [15.5\ k\Omega//30.23\ k\Omega//3.313\ k\Omega] \\ &= 4.688\ k\Omega \end{aligned}$$

$$\begin{aligned} C_{in} &= \frac{1}{0.1 * (2\pi * 100\ Hz) * (4.688\ k\Omega)} \\ &\approx 3.39\ \mu F \end{aligned}$$

$$\frac{1}{R_{C_E} C_E} = 0.7 * 2\pi f_L$$

$$\begin{aligned} R_{C_E} &= R_E// \left[\frac{r_\pi + [[(R_{S_1}//R_{S_2}) + R_S]//R_2//R_3]}{1+\beta}\right] \\ &= 3\ k\Omega// \left[\frac{3.313\ k\Omega + [[(470\ \Omega//56\ \Omega) + 1.688\ k\Omega]//15.5\ k\Omega//30.23\ k\Omega]}{1+147.06}\right] \\ &= 34.21\ \Omega \end{aligned}$$

$$\begin{aligned} C_E &= \frac{1}{0.7 * (2\pi * 100\ Hz) * (34.21\ \Omega)} \\ &\approx 66\ \mu F \end{aligned}$$

$$\frac{1}{R_{C_B} C_B} = 0.1 * 2\pi f_L$$

$$\begin{aligned} R_{C_B} &= R_1//R_2//[r_e * (1+\beta)] \\ &= 68.40\ k\Omega//15.5\ k\Omega//[24.75\ \Omega * (1+147.06)] \\ &= 2.83\ k\Omega \end{aligned}$$

$$\begin{aligned} C_B &= \frac{1}{0.1 * (2\pi * 100\ Hz) * (2.83\ k\Omega)} \\ &\approx 5.62\ \mu F \end{aligned}$$

$$\frac{1}{R_{C_{out}} C_{out}} = 0.1 * 2\pi f_L$$

$$\begin{aligned} R_{C_{out}} &= R_C + R_L \\ &= 5\ k\Omega + 15\ k\Omega \\ &= 20\ k\Omega \end{aligned}$$

$$\begin{aligned} C_B &= \frac{1}{0.1 * (2\pi * 100\ Hz) * (20\ k\Omega)} \\ &\approx 796\ nF \end{aligned}$$

Step 4: Low Poles

$$\begin{aligned} \omega_{L_1} &= \frac{1}{2\pi R_{C_{in}} C_{in}} \\ &= \frac{1}{2\pi (4.688\ k\Omega)(3.39\ \mu F)} \\ &\approx 10\ Hz \end{aligned}$$

$$\begin{aligned} \omega_{L_2} &= \frac{1}{2\pi R_{C_E} C_E} \\ &= \frac{1}{2\pi (34.21\ k\Omega)(66\ \mu F)} \\ &\approx 70\ Hz \end{aligned}$$

$$\begin{aligned} \omega_{L_3} &= \frac{1}{2\pi R_{C_B} C_B} \\ &= \frac{1}{2\pi (2.83\ k\Omega)(5.62\ \mu F)} \\ &\approx 10\ Hz \end{aligned}$$

$$\begin{aligned} \omega_{L_4} &= \frac{1}{2\pi R_{C_{out}} C_{out}} \\ &= \frac{1}{2\pi (20\ k\Omega)(796\ nF)} \\ &\approx 10\ Hz \end{aligned}$$

$$\begin{aligned} \omega_L &= \omega_{L_1} + \omega_{L_2} + \omega_{L_3} + \omega_{L_4} \\ &= 10\ Hz + 70\ Hz + 10\ Hz + 10\ Hz \\ &= 100\ Hz \end{aligned}$$

Step 5: High Poles

$$\omega_{H_1} = \frac{1}{2\pi R_{2C_\mu + C_\pi}(2C_\mu + C_\pi)}$$

$$\begin{aligned} 2C_\mu + C_\pi &= 2(4\ pf) + 50\ pf \\ &= 58\ pf \end{aligned}$$

$$\begin{aligned} R_{C_\mu + C_\pi} &= [(R_{S_1}//R_{S_2}) + R_S]//R_2//R_3//r_\pi \\ &= [(470\ \Omega//56\ \Omega) + 1.688\ k\Omega]//15.5\ k\Omega//30.23\ k\Omega//3.313\ k\Omega \\ &= 1.17\ k\Omega \end{aligned}$$

$$\begin{aligned} \omega_{H_1} &= \frac{1}{2\pi(1.17\ k\Omega)(58\ pf)} \\ &= 2.345\ MHz \end{aligned}$$

$$\omega_{H_2} = \frac{1}{2\pi\ r_e\ (2C_\mu + C_\pi)}$$

$$\begin{aligned} 2C_\mu + C_\pi &= 2(4\ pf) + 50\ pf \\ &= 58\ pf \end{aligned}$$

$$\begin{aligned} \omega_{H_2} &= \frac{1}{2\pi(24.75\ \Omega)(58\ pf)} \\ &= 110.87\ MHz \end{aligned}$$

$$\omega_{H_3} = \frac{1}{2\pi R_{C_L + C_\mu}(C_L + C_\mu)}$$

$$\begin{aligned} C_L + C_\mu &= 0\ pf + 4\ pf \\ &= 50\ pf \end{aligned}$$

$$\begin{aligned} R_{C_L + C_\mu} &= R_C//R_L \\ &= 5\ k\Omega//15\ k\Omega \\ &= 3.75\ k\Omega \end{aligned}$$

$$\begin{aligned} \omega_{H_3} &= \frac{1}{2\pi(3.75\ k\Omega)(4\ pf)} \\ &= 10.61\ MHz \end{aligned}$$

$$\begin{aligned}\omega_H &= \left[\frac{1}{\omega_{H_1}} + \frac{1}{\omega_{H_2}} + \frac{1}{\omega_{H_3}}\right]^{-1} \\ &= \left[\frac{1}{2.345\ MHz} + \frac{1}{110.87\ MHz} + \frac{1}{10.61\ MHz}\right]^{-1} \\ &\approx 1.90\ MHz\end{aligned}$$

Table 1 below shows the calculated and designed values of the components used to construct the cascode amplifier circuit.

Table 1: Calculated and Designed Component Values of The Cascode Amplifier

Component	**Design Value**
R_{S_1}	470 Ω
R_{S_2}	56 Ω
R_S	1.688 kΩ
R_1	68.40 kΩ
R_2	15.5 kΩ
R_3	30.23 kΩ
R_C	5 kΩ
R_L	15 kΩ
R_E	3 kΩ
C_{in}	3.39 pf
C_E	66 μf
C_B	5.62 μf
C_{out}	796 nf

3.2 Experiment

Table 2 below shows few simulated measurements that were used to calculate variables in Table 3. Note the I_{out} was ***calculated*** using the measured V_o and R_L, and not **directly** measured.

Table 2: Simulated Measurements

Variable	V_s (mV)	$V_s - V_x$ (mV)	V_o (V)	$V_o^{'}$ (V)	I_{out} (mA)	I_{in} (μA)
Simulated Results	23.082	8.39	2.034	2.71	0.1356	4.99

Table 3 below shows a comparison between the calculated and simulated results of the cascode amplifier.

Table 3: Calculated, Approximated, and Simulated Results of The Cascode Amplifier

Variable	**Calculated Results**	**Simulated Results**
A_v	(80.5 ± 8.05) v/v	88.12 v/v
R_{in}	4.188 kΩ	4.625 kΩ
R_{out}	5 kΩ	4.98 kΩ
f_L	100 Hz	71 Hz
f_H	1.90 MHz	6.2 MHz

Table 4: Measured Data to Calculate The Voltage Gain at Different Frequencies

f (Hz)	Vs (V)	Vo (V)	Av	20 Log (Av) (dB)
1	0.011708	0.000654	0.055892	-25.0529536
1.122018	0.011707	0.000835	0.071319	-22.93589211
1.258925	0.011707	0.001068	0.091265	-20.79393267
1.412538	0.011706	0.001371	0.117154	-18.62486252
1.584893	0.011705	0.001766	0.15088	-16.42738694
1.778279	0.011704	0.002282	0.19495	-14.20153079
1.995262	0.011703	0.002957	0.252667	-11.94903377
2.238721	0.011702	0.003842	0.328334	-9.673677991
2.511886	0.011701	0.005002	0.42749	-7.38147985
2.818383	0.011699	0.006518	0.557142	-5.080687533
3.162278	0.011697	0.008492	0.725976	-2.781553112
3.548134	0.011695	0.011046	0.944508	-0.495886913
3.981072	0.011693	0.014325	1.225118	1.763559185
4.466836	0.01169	0.018494	1.581941	3.983804241
5.011872	0.011688	0.023733	2.03057	6.152359607
5.623413	0.011686	0.030237	2.587581	8.257879182
6.309573	0.011683	0.038203	3.269897	10.29068054
7.079458	0.011681	0.047822	4.094071	12.24310811
7.943282	0.011679	0.059276	5.075593	14.10973616
8.912509	0.011676	0.072725	6.228325	15.88742497
10	0.011674	0.088308	7.564188	17.57524641
11.22018	0.011673	0.106141	9.093154	19.17429074
12.58925	0.011671	0.126321	10.82351	20.68736401
14.12538	0.011669	0.148928	12.76232	22.11859081
15.84893	0.011668	0.174034	14.91583	23.47294975
17.78279	0.011666	0.201705	17.28976	24.75578171
19.95262	0.011665	0.231997	19.88913	25.97231616
22.38721	0.011663	0.264949	22.71762	27.12725698
25.11886	0.011661	0.300573	25.77644	28.22445745
28.18383	0.011659	0.338829	29.06264	29.26670095
31.62278	0.011656	0.379605	32.56714	30.25559332
35.48134	0.011653	0.422693	36.27257	31.19156639
39.81072	0.01165	0.467764	40.15129	32.07399015
44.66836	0.011646	0.514355	44.1641	32.90138821
50.11872	0.011642	0.561866	48.26	33.67174634
56.23413	0.011638	0.609579	52.37749	34.38289366
63.09573	0.011634	0.656692	56.44768	35.03292126
70.79458	0.011629	0.702374	60.39895	35.62058847
79.43282	0.011624	0.745836	64.16275	36.14565877
89.12509	0.011619	0.786394	67.67926	36.60911258

100	0.011615	0.823523	70.90228	37.01320421
112.2018	0.011611	0.85689	73.80199	37.36136151
125.8925	0.011607	0.886358	76.36562	37.65795764
141.2538	0.011603	0.911972	78.59598	37.90800632
158.4893	0.0116	0.933917	80.50852	38.11683694
177.8279	0.011598	0.952483	82.12774	38.2897978
199.5262	0.011595	0.968019	83.48355	38.43201795
223.8721	0.011593	0.980898	84.60811	38.54824019
251.1886	0.011592	0.991492	85.53348	38.6427227
281.8383	0.011591	1.000147	86.28989	38.71919826
316.2278	0.011589	1.007182	86.90481	38.78087632
354.8134	0.011589	1.012873	87.40246	38.83047338
398.1072	0.011588	1.017462	87.80374	38.87025986
446.6836	0.011587	1.02115	88.12633	38.90211406
501.1872	0.011587	1.024108	88.38506	38.92757723
562.3413	0.011587	1.026475	88.59216	38.9479058
630.9573	0.011586	1.028366	88.75768	38.9641186
707.9458	0.011586	1.029876	88.8898	38.97703835
794.3282	0.011586	1.03108	88.99515	38.98732719
891.2509	0.011586	1.03204	89.0791	38.99551659
1000	0.011586	1.032803	89.14595	39.00203223
1122.018	0.011585	1.033411	89.19915	39.00721445
1258.925	0.011585	1.033895	89.24148	39.01133506
1412.538	0.011585	1.03428	89.27514	39.01461083
1584.893	0.011585	1.034585	89.30191	39.01721453
1778.279	0.011585	1.034828	89.32318	39.01928377
1995.262	0.011585	1.035022	89.34009	39.02092806
2238.721	0.011585	1.035175	89.35353	39.02223455
2511.886	0.011585	1.035297	89.36421	39.02327254
2818.383	0.011585	1.035394	89.3727	39.02409715
3162.278	0.011585	1.035471	89.37944	39.02475218
3548.134	0.011585	1.035532	89.38479	39.02527244
3981.072	0.011585	1.035581	89.38904	39.0256856
4466.836	0.011585	1.035619	89.39242	39.02601364
5011.872	0.011585	1.03565	89.3951	39.026274
5623.413	0.011585	1.035674	89.39722	39.02648055
6309.573	0.011585	1.035694	89.39891	39.02664427
7079.458	0.011585	1.035709	89.40024	39.02677388
7943.282	0.011585	1.035721	89.4013	39.02687628
8912.509	0.011585	1.03573	89.40213	39.02695691

10000	0.011585	1.035738	89.40278	39.02702008
11220.18	0.011585	1.035744	89.40328	39.02706915
12589.25	0.011585	1.035748	89.40367	39.02710672
14125.38	0.011585	1.035751	89.40396	39.02713481
15848.93	0.011585	1.035754	89.40416	39.02715489
17782.79	0.011585	1.035755	89.4043	39.02716806
19952.62	0.011585	1.035756	89.40437	39.02717499
22387.21	0.011585	1.035756	89.40438	39.02717608
25118.86	0.011585	1.035755	89.40433	39.02717136
28183.83	0.011585	1.035754	89.40422	39.02716059
31622.78	0.011585	1.035752	89.40404	39.02714321
35481.34	0.011585	1.035749	89.40379	39.02711827
39810.72	0.011585	1.035744	89.40344	39.02708446
44668.36	0.011585	1.035739	89.40298	39.02703997
50118.72	0.011585	1.035732	89.40239	39.02698244
56234.13	0.011585	1.035723	89.40163	39.0269088
63095.73	0.011585	1.035711	89.40067	39.02681513
70794.58	0.011585	1.035696	89.39944	39.02669644
79432.82	0.011585	1.035678	89.3979	39.02654642
89125.09	0.011585	1.035655	89.39595	39.02635708
100000	0.011585	1.035625	89.39349	39.02611834
112201.8	0.011585	1.035588	89.3904	39.02581749
125892.5	0.011585	1.035541	89.3865	39.02543853
141253.8	0.011585	1.035482	89.38159	39.0249613
158489.3	0.011585	1.035408	89.3754	39.0243604
177827.9	0.011585	1.035315	89.36762	39.02360389
199526.2	0.011585	1.035198	89.35782	39.02265157
223872.1	0.011585	1.03505	89.34549	39.02145283
251188.6	0.011585	1.034864	89.32997	39.01994404
281838.3	0.011585	1.03463	89.31045	39.01804515
316227.8	0.011585	1.034336	89.28588	39.01565553
354813.4	0.011584	1.033965	89.25498	39.0126487
398107.2	0.011584	1.0335	89.21611	39.00886575
446683.6	0.011584	1.032914	89.16725	39.00410715
501187.2	0.011584	1.032179	89.10583	38.99812255
562341.3	0.011583	1.031255	89.02867	38.99059807
630957.3	0.011583	1.030094	88.93179	38.98114062
707945.8	0.011582	1.028638	88.81022	38.96925857
794328.2	0.011582	1.026813	88.65779	38.95433809
891250.9	0.011581	1.024528	88.46688	38.93561438

1000000	0.01158	1.02167	88.22809	38.91213708
1122018	0.011579	1.018102	87.92988	38.88272914
1258925	0.011577	1.013657	87.55822	38.84593879
1412538	0.011575	1.008134	87.09621	38.79998467
1584893	0.011572	1.001293	86.52363	38.74269496
1778279	0.011569	0.992853	85.81677	38.67144286
1995262	0.011566	0.982492	84.94819	38.58308248
2238721	0.011561	0.969846	83.88698	38.47389163
2511886	0.011556	0.954521	82.59934	38.3395313
2818383	0.01155	0.936106	81.04975	38.17503413
3162278	0.011542	0.914197	79.20303	37.9748364
3548134	0.011534	0.888435	77.02707	37.73286774
3981072	0.011525	0.858543	74.49642	37.44270802
4466836	0.011514	0.824373	71.5963	37.09781123
5011872	0.011503	0.785954	68.32648	36.69178121
5623413	0.011491	0.743522	64.70433	36.21866646
6309573	0.011479	0.697528	60.76611	35.67322861
7079458	0.011467	0.64863	56.56617	35.05113598
7943282	0.011455	0.597647	52.17379	34.34904748
8912509	0.011444	0.545502	47.66822	33.5645796
10000000	0.011433	0.493155	43.13295	32.69618314
11220185	0.011424	0.441538	38.64997	31.74298309
12589254	0.011416	0.391506	34.29511	30.70464439
14125375	0.011409	0.343795	30.13462	29.58131416
15848932	0.011403	0.299011	26.22304	28.37366093
17782794	0.011398	0.257608	22.60215	27.08299458
19952623	0.011393	0.219898	19.30061	25.711419
22387211	0.01139	0.186045	16.3342	24.26195492
25118864	0.011387	0.156079	13.70657	22.73857643
28183829	0.011385	0.129908	11.41055	21.14613041
31622777	0.011383	0.107342	9.429899	19.49014101
35481339	0.011382	0.088112	7.741525	17.7765308
39810717	0.011381	0.0719	6.317791	16.01130546
44668359	0.01138	0.058364	5.12876	14.20024797
50118723	0.011379	0.047156	4.144125	12.34865632
56234133	0.011378	0.037944	3.334702	10.4611412
63095734	0.011378	0.030419	2.673464	8.54148535
70794578	0.011378	0.024304	2.13613	6.592555504
79432823	0.011377	0.019358	1.701425	4.616253819
89125094	0.011377	0.015371	1.35106	2.613495621
1E+08	0.011377	0.012169	1.069572	0.584203804

Using the data presented in Table 4, a plot of the voltage gain vs. frequency was generated as shown below in Figure 4.

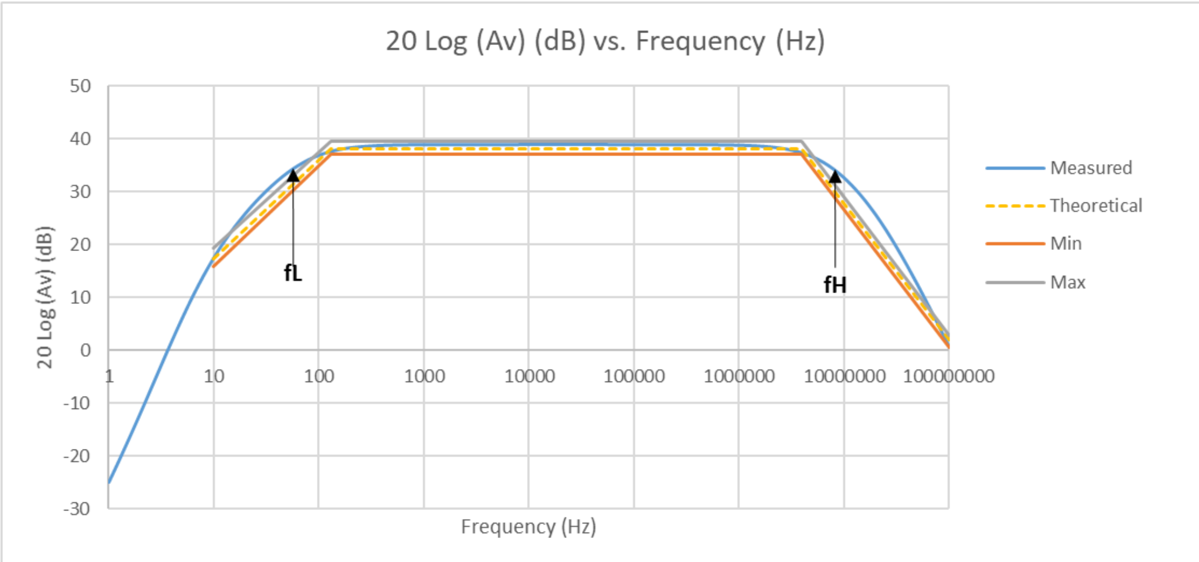

Figure 4: Voltage Gain vs. Frequency

Table 5 below shows the measured data of the gain as a function of the input peak-to-peak voltage swing.

Table 5: Measured Data of the Gain as a function of input peak-peak Voltage Swing

Vin (V)	Vout (V)	Av	20 Log (Av) (dB)
0.0105	0.934	88.95238095	38.98315154
0.0126	1.12	88.88888889	38.97694955
0.0147	1.31	89.11564626	38.99907922
0.0168	1.49	88.69047619	38.95753973
0.0189	1.68	88.88888889	38.97694955
0.021	1.86	88.57142857	38.94587299
0.0231	2.05	88.74458874	38.96283762
0.0253	2.22	87.74703557	38.86464907
0.0274	2.4	87.59124088	38.84921358
0.0295	2.58	87.45762712	38.8359538
0.0316	2.77	87.65822785	38.85585373
0.0421	3.65	86.69833729	38.76021537
0.0524	4.51	86.06870229	38.6969051
0.0632	5.3	83.86075949	38.47117583
0.0842	6.81	80.87885986	38.15670041
0.0946	7.48	79.06976744	37.96020923
0.105	8.03	76.47619048	37.67052492

Using the data presented in Table 5, a plot of the voltage gain vs. peak-to-peak voltage swing at the input was generated as shown below in Figure 5.

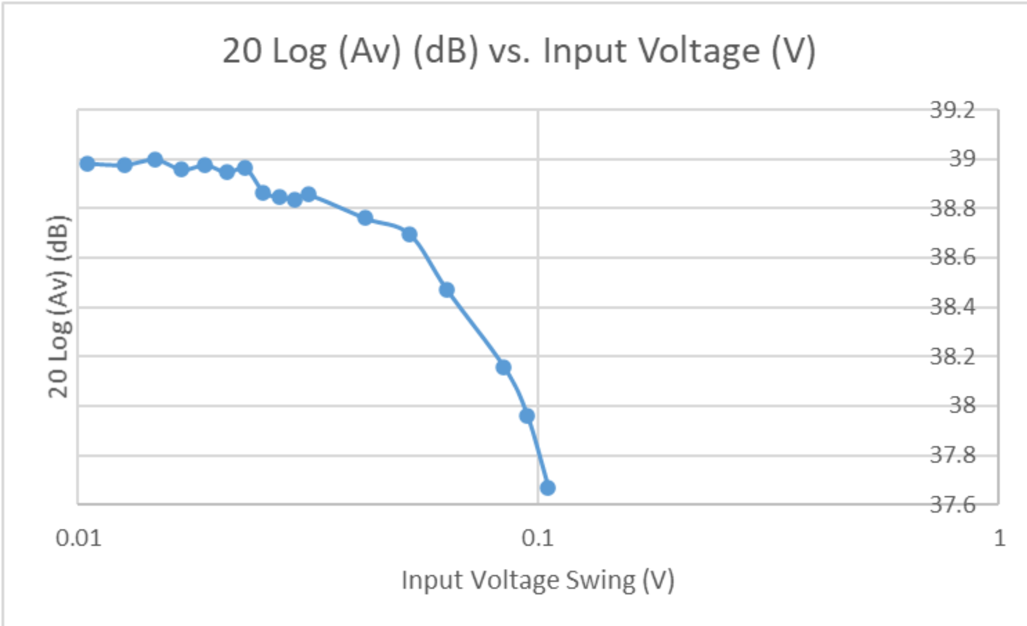

Figure 5: Voltage Gain vs. Input Voltage

Discussion

Amplifier Parameters

As shown in table 3, the achieved gain by the amplifier is 88.12 v/v. The theoretical gain of the amplifier is (80.05 ± 10%) v/v. This gain falls just into the range required for the gain as the maximum value required for the gain is 88.55 v/v. Although the measured gain of the amplifier falls within the acceptable range, it does not match the theoretical value exactly due to the assumptions that were made in order to compute the prelab calculations.

The measured input impedance is 4.625 kΩ while the theoretical input impedance is 4.188 kΩ. The cause of the difference between the theoretical and measured input impedance can be attributed to the value of R_S as the resistance value was calculated using the theoretical gain of 80.05 v/v.

The measured output impedance is 4.98 kΩ which is an exact match of the theoretical output impedance of 5 kΩ.

The measured low cutoff frequency is 71 Hz which meets the required specifications as it is below 200 Hz. An assumption of the low cutoff frequency of 100 Hz was made in order to compute the prelab calculations which turned out to be a very good assumption as the assumed value is fairly close to the measured one.

The measured high cutoff frequency is 6.2 MHz which also meets the required specifications as it is way above 1 MHz. However, the theoretical value of the high cutoff frequency is 1.90 MHz. The cause of the difference between the theoretical and measured high cutoff frequency can be attributed to the computation of the resistance values of the circuit that the capacitors see. It is possible that an error has been made while computing the resutls of the high cutoff frequency. However, the measured value of the high cutoff frequency still meets the required specifications of the amplifier design project

Another requirement of this amplifier is that the power dissipation of the circuit should not exceed 50 mW. The power dissipation calculations for the amplifier circuit can be done as follows:

$$\begin{aligned} P_{DC} &= V_{CC} * I_{CC} \\ &= V_{CC} * (I_C + I_{BB}) \\ &= 15\ V * (1\ mA + 136\ \mu A) \\ \therefore P_{DC} &= 17.04\ mW \end{aligned}$$

$$\begin{aligned} P_{ac} &= \frac{v_{o_{rms}}^2}{R_L} \\ &= \frac{\left(\frac{2\ V_{pk-pk}}{2\sqrt{2}}\right)^2}{R_L} \\ &= \frac{\left(\frac{2*2V}{2\sqrt{2}}\right)^2}{15\ k\Omega} \\ \therefore P_{ac} &= 0.13 mW \end{aligned}$$

$$\begin{aligned} P &= P_{DC} + P_{ac} \\ &= 17.04\ mW + 0.13\ mW \\ \therefore P &= 17.17\ mW \end{aligned}$$

$$\therefore \eta = \frac{P_{ac}}{P_{DC}} = \frac{0.133}{17.07} \approx 0.78\%$$

The computed total power dissipation, DC and AC, of the circuit is 17.17 mW which meets the required specifications as it is below 50 mW.

Voltage Gain vs. Frequency Plot

Figure 4 above shows a plot of the measured gain of the amplifier at various frequencies as well as the theoretical, minimum, and maximum gain that the amplifier is able to achieve based on the given specifications. Due to the fact that the measured gain value is very close to the maximum gain value, most of the data points lie along the maximum value line. However, most of the data points of the measured gain lie within the range between the minimum and maximum gain value indicating that the amplifier meets the required specifications.

Voltage Gain vs. Input Voltage Swing Plot

As shown in Figure 5 above, at low voltage input, the voltage gain remains fairly constant at around 38.9 dB. The point at which the gain differs from the low signal gain by 1 dB at an input voltage of 94.6 mV where the voltage gain is 37.9 dB as shown in Table 5 above.

4 Conclusion

The experiments done in this lab demonstrate the features and characteristics of three basic configurations (CE, CC, and CB) of a signle transistor amplifier. They hightlighted the various strengths and weaknesses of each configuration. Then, by proper combinations and permutations, 2-transistor amplifier configurations were constructed and studied for improved gain-bandwidth performance [1]. Finally, a specific configuration of a cascode amplifer was designed to meet or exceed a prescribed set of specifications [1] which presented a great experience with designing, building, and testing an analog circuit.

5 References

[1] “Lab 2: Amplifier Project” Carleton Univeristy, Ottawa, 2017.