Electronic Circuits

ELEC 301

Mini-Project 3

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2020-11-20

Part 1 The Cascode Amplifier

A. DC Operating Points

According to the SPICE model of 2N3904 in *Circuitmaker*, the β of 2N3904 is **300**.

The required parameters of the cascode amplifier are marked below:

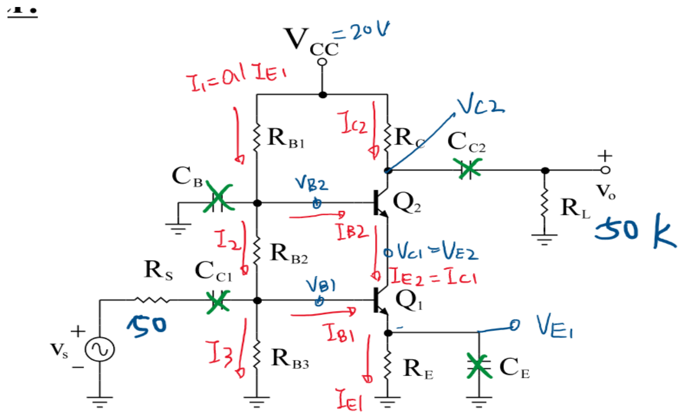


Figure 1. The Cascode Amplifier with the needed parameters.

To find R_{B1}, R_{B2} and R_{B3}, the $1/4^{th}$ rule is applied:

$$V_{B2} = (1/2)*V_{cc} + 0.7 = 0.50 * 20 + 0.7 = 10.7 \text{ V}$$
$$V_{B1} = (1/4)*V_{cc} + 0.7 = 0.25 * 20 + 0.7 = 5.7 \text{ V}$$
$$V_{C2} = (3/4)*V_{cc} = 0.75 * 20 = 15 \text{ V}$$
$$V_{C1} = V_{E2} = (1/2)*V_{cc} = 0.5 * 20 = 10 \text{ V}$$
$$V_{E1} = (1/4)*V_{cc} = 0.25 * 20 = 5 \text{ V}$$

For the circuit in **Figure 1**, the R_C is R_{out} which is 2.5 kΩ ± 250Ω. To convert it to standard resistor value, **R_C = 2.4 kΩ** is used. The currents are calculated:

$$I_{C2} = (V_{cc} - V_{C2}) / R_C = (20 - 15) / 2.4\text{k} = 2.083 \text{ mA}$$
$$I_{B2} = I_{C2} / \beta = 2.083 / 300 = 6.944 \ \mu\text{A}$$
$$I_{C1} = I_{E2} = I_{C2} + I_{B2} = 2.083 \text{ mA} + 6.944 \ \mu\text{A} = 2.090 \text{ mA}$$
$$I_{B1} = I_{C1} / \beta = 2.090 / 300 = 6.966 \ \mu\text{A}$$
$$I_{E1} = I_{C1} + I_{B1} = 2.090 \text{ mA} + 6.966 \ \mu\text{A} = 2.097 \text{ mA}$$
$$I_1 = I_{E1}/\beta^{0.5} = 2.097 / 17.32 = 0.1211 \text{ mA}$$
$$I_2 = I_1 - I_{B2} = 0.1211 \text{ mA} - 6.944 \ \mu\text{A} = 0.1141 \text{ mA}$$
$$I_3 = I_2 - I_{B1} = 0.1141 \text{ mA} - 6.966 \ \mu\text{A} = 0.1072 \text{ mA}$$

The gm can be obtained by divided I_C by VT: gm1 = 0.0836 ℧, and gm2 = 0.08332 ℧. Then, rπ can be obtained by divided β by gm: rπ1 = 3.589 kΩ → 3.6 kΩ (standard), and rπ2 = 3.6 kΩ → 3.6 kΩ (standard).

The values of the resistors are calculated based on these currents and converted to the standard values:

$$R_{B1} = (V_{cc} - V_{B2}) / I_1 = (20 - 10.7) / 0.1211\text{ mA} = 76.815\text{ k}\Omega \rightarrow \boxed{\mathbf{75\text{ k}\Omega}}$$

$$R_{B2} = (V_{B2} - V_{B1}) / I_2 = (10.7 - 5.7) / 0.1141\text{ mA} = 43.811\text{ k}\Omega \rightarrow \boxed{\mathbf{43\text{ k}\Omega}}$$

$$R_{B3} = V_{B1} / I_3 = 5.7 / 0.1072\text{ mA} = 53.191\text{ k}\Omega \rightarrow \boxed{\mathbf{51\text{ k}\Omega}}$$

$$R_C = (Vcc - Vc2) / Ic2 = (20 - 15) / 2.083\text{ mA} = 2.4\text{ k}\Omega \rightarrow \boxed{\mathbf{2.4\text{ k}\Omega}}$$

$$R_E = V_{E1} / I_{E1} = 5 / 2.097\text{mA} = 2.384\text{ k}\Omega \rightarrow \boxed{\mathbf{2.4\text{ k}\Omega}}$$

C_B is a large capacitance so at low frequency it is shorted, and $R_{BB} = R_{B2}//R_{B3}$. According to the formulas in ELEC301 Cascode Note [1], the low frequency poles are calculated:

$$\omega_{Lp}^{CC1} = [C_{C1} * (R_S+R_{B2}||R_{B3}||(r\pi1+(1+\beta)*R_E))]^{-1} = [C_{C1}*22.653\text{ k}\Omega]^{-1}$$

$$\omega_{Lp}^{CE} = [C_E * R_E//((r\pi1+R_{B2}||R_{B3}||R_S)/(1+\beta))] = [C_E * 12.065\ \Omega]^{-1}$$

$$\omega_{Lp}^{CC2} = [C_{C2} * (R_L + R_C)]^{-1} = [C_{C2} * 52.4\text{ k}\Omega]^{-1}$$

There is one zero that is not at 0. $\omega_{Lz} = 1/(R_E*C_E)$. From above, the resistance seen by the C_E is the smallest so that the dominant low-frequency pole is located at $[C_E * 12.065\ \Omega]^{-1}$. The resistance seen by C_{C1} and C_{C2} are enormous compared to the C_E, thus these poles are too far away from the dominant pole, so they are negligible to calculate the ω_{L3dB} which is given: ω_{L3dB} = 500 Hz = 500 * 2π = 3141.59 rad/s.

ω_{L3dB} = 3141.59 rad/s = $\sqrt{[CE * 12.065\ \Omega]^{\wedge}(-2) - 2*(2400*CE)^{\wedge}(-2)}$ → $\boxed{\mathbf{C_E = 26.382\ \mu F}}$. Then coupling capacitors **C_{C1} and C_{C2} are picked to be the same value with C_E.** The designed circuit and the measured DC operating points are shown below:

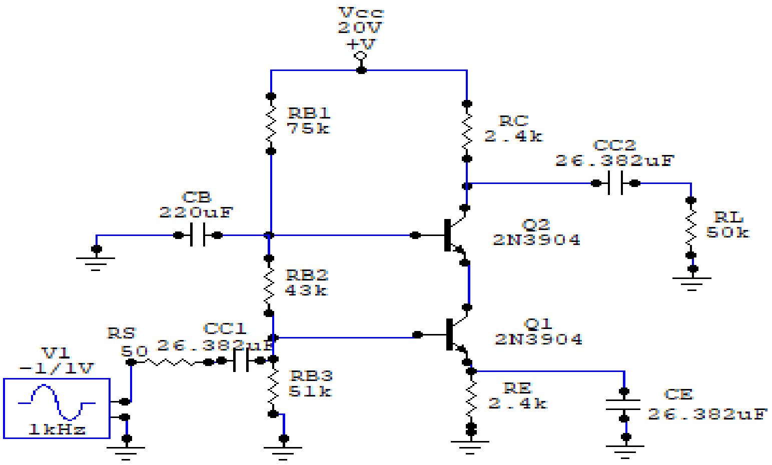


Figure 2. The Cascode Amplifier with the designed values.

Table 1. The measurements of DC operating points.

	I_C (mA)	I_B (μA)	I_E (mA)	V_C (V)	V_B (V)	V_E (V)
Q1	1.878	14.44	1.893	9.542	5.200	4.537
Q2	1.864	14.23	1.878	15.530	10.20	9.542

B. The Locations of the ω_{L3dB} and ω_{H3dB}

As shown in **A**, for the low-frequency capacitors, $\omega_{Lp}^{CC1} = [C_{C1}*22.653\ k\Omega]^{-1} = 1.673$ rad/s ; $\omega_{Lp}^{CE} = [C_E * 12.065\ \Omega]^{-1} = 3141.701$ rad/s ; $\omega_{Lp}^{CC2} = [C_{C2} * 52.4\ k\Omega]^{-1} = 0.723$ rad/s. The low-frequency zero is $\omega_{Lz} = 1/(2.4k * C_E) = 15.794$ rad/s. The ω_{L3dB} is then obtained:

$$\omega_{L3dB} = \sqrt{\omega Lp1^2 + \omega Lp2^2 + \omega Lp3^2 - 2 * \omega Lpz^2} = 3.142\ k\ rad/s = \boxed{\mathbf{500.0048\ Hz}}$$

To find the ω_{H3dB}, the circuit is converted to the small-signal model, and the Miller Theorem is applied. The miller gain is found by $V1/V\pi1 = -1$. The small-signal $C\pi$ and $C\mu$ can be calculated using the formula from MP2 [2] and the SPICE model parameters. $C\pi1 = 42.44$ pF, $C\pi2 = 42.33$ pF; $C\mu1 = 1.86$ pF, $C\mu2 = 1.75$ pF. The converted circuit is below ($R_{BB} = R_{B2}//R_{B3}$):

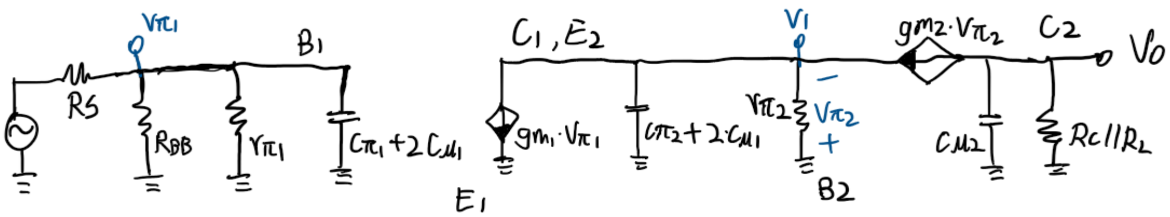


Figure 3. The small-signal model after the Miller Theorem is applied.

$$\tau 1 = (RS||RBB||r\pi 1) * (C\pi 1+2C\mu 1) = 2.271\ ns$$
$$\tau 2 = (r\pi 2/301) * (C\pi 2+2C\mu 1) = 0.551\ ns$$
$$\tau 3 = (RC||RL) * C\mu 2 = 4.008\ ns$$

The ω_{H3dB} can be calculated by $(\tau 1^2 + \tau 2^2 + \tau 3^2)^{-1/2} = 215.554$ Mrad/s = $\boxed{\mathbf{34.307\ MHz}}$

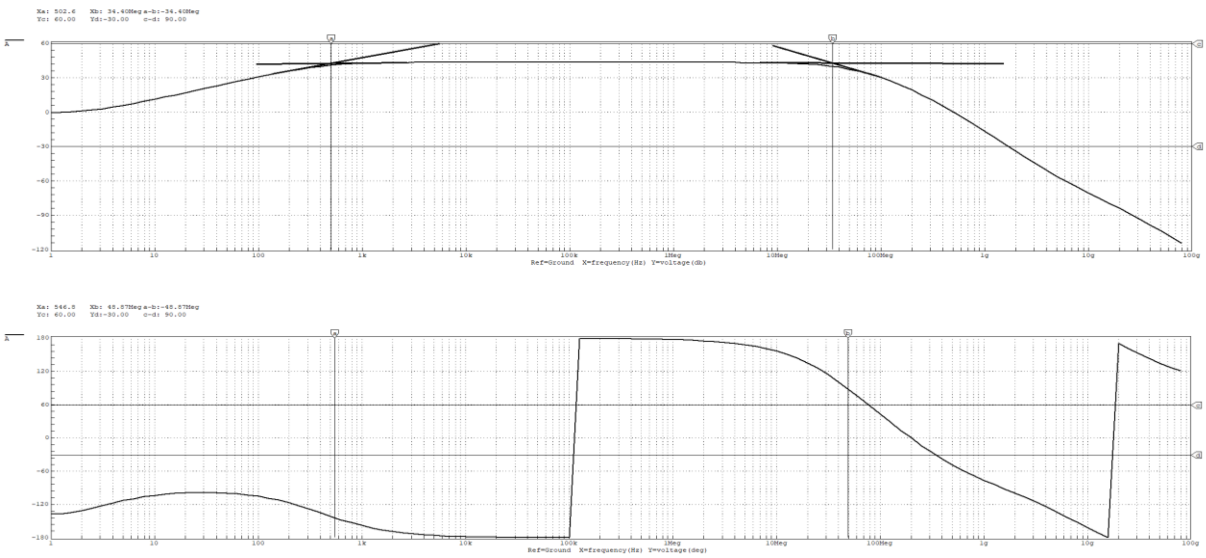


Figure 4. The Bode and Phasor plot of the circuit.

As shown in **Figure 4**, the measured ω_{L3dB} is $\boxed{\textbf{510.7 Hz}}$ and the ω_{H3dB} is $\boxed{\textbf{38.88 MHz}}$. The deviation of ω_{L3dB} is 1.96%, and the deviation of ω_{H3dB} is 11.8%. The model can be described as acceptable since the errors are not significant.

C. Various Amplitude of the Input Signal

From **Figure 4**, the mid-band bandwidth is from 510 Hz to 39 MHz. Therefore, **50 kHz** is chosen for the generator. The oscilloscope is used to measure the output signal. The diagram that represents the relationship between Vs and Vo is below:

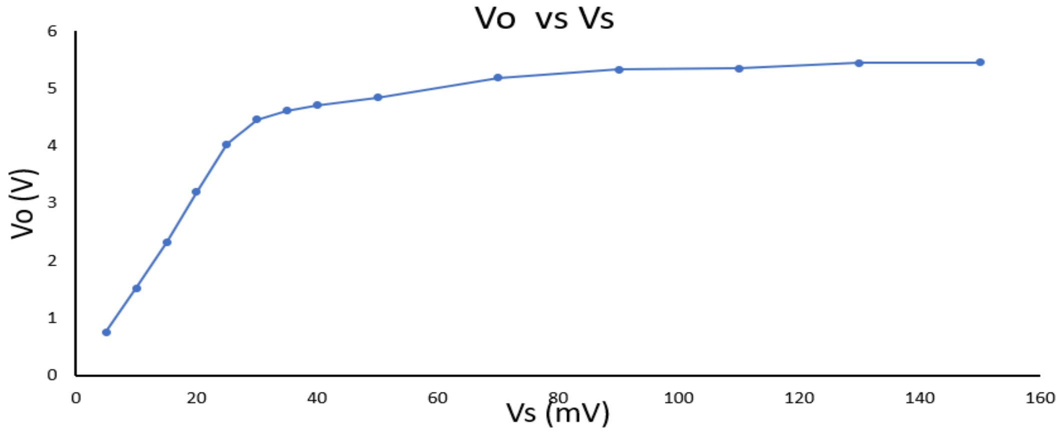


Figure 5. The relationship between Vo and Vs under 50 kHz.

As shown in **Figure 5**, in the linear region (the amplitude of Vs = 5 mV – 50 mV), the gain $\mathbf{A_v}$ = $\boxed{\textbf{155.322}}$, which is greater than the requirement: minimum A_v= 50.

D. The Input and Output Impedance

To measure the input impedance, the 50 Ω resistor is removed, and the probe of the Oscilloscope is located at the right node of C_{C1}. The frequency is set to be 10 kHz, and the amplitude of the voltage is 20 mV. To ensure the input impedance mees the requirement (Zin > 5 kΩ), a **30 Ω resistor is connected to the emitter** of Q1. The peak to peak voltage and peak to peak current are measured respectively: Vin = 0.02V ; Iin = 3.834 µA. The measured input impedance is equal to Zin = Vin / Iin = $\boxed{\textbf{5217 Ω.}}$

For the output impedance, the input generator is shorted, and the RL is removed. Another identical generator is connected to the load terminals with a small resistor (1 µΩ) in series to measure the current. The circuit is below:

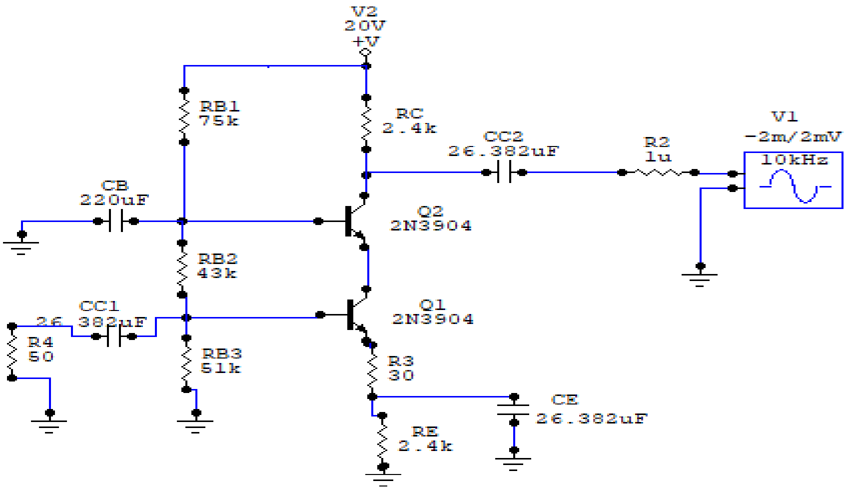


Figure 6. The circuit to calculate the output impedance.

The probe of the Oscilloscope is located at the right node of R_2 with the same frequency and the amplitude of the voltage in **Figure 2**. The peak to peak voltage and peak to peak current are measured respectively: Vout = 0.04V ; Iout = 16.65 µA. The measured output impedance is equal to Zout = Vout / Iout = $\boxed{\textbf{2.402 k}\Omega\textbf{,}}$ which is ±250Ω around 2.5 kΩ, so it is reasonable.

Part 2 Cascaded Amplifiers – The CB followed by CC

A. Design the Circuit

The common-base/common-collector repeater is converted to the small-signal model at mid-band frequency. All low-f capacitors are shorted, and all high-f capacitors are opened.

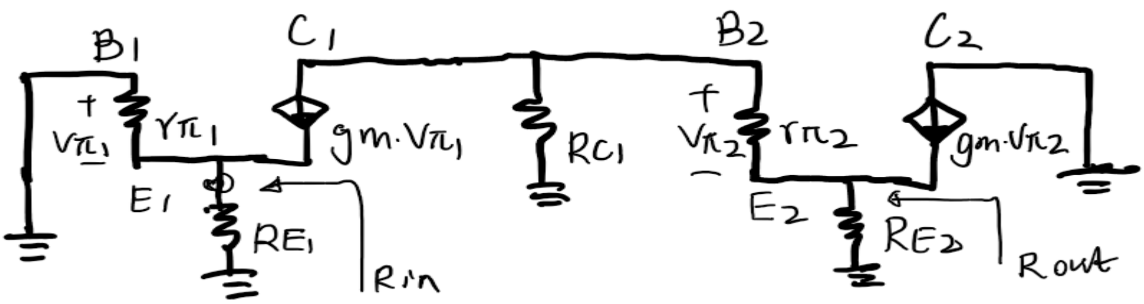


Figure 7. The small-signal model of the repeater at mid-band.

$$Rin = r\pi 1/(1+\beta)||R_{E1} = \beta * V_T/[(1+\beta)*I_{C1}] \;||\; R_{E1} = \alpha * V_T/I_{C1} \;||\; R_{E1} = V_T/I_{E1} \;||\; V_{E1}/I_{E1}$$

$$Rin = (V_T*V_{E1}/I_{E1}^2) / ((V_T+V_{E1})/I_{E1}), \text{ since } V_T \text{ is so small that } V_{E1}/(V_T+V_{E1}) \approx 1$$

$$Rin = 50\ \Omega \approx V_T/I_{E1} = 25\ mV / I_{E1} \rightarrow I_{E1} = 0.5\ mA$$

To find the resistance of each resistor, the circuit is converted to DC circuit, and the 1/3rd rule is applied:

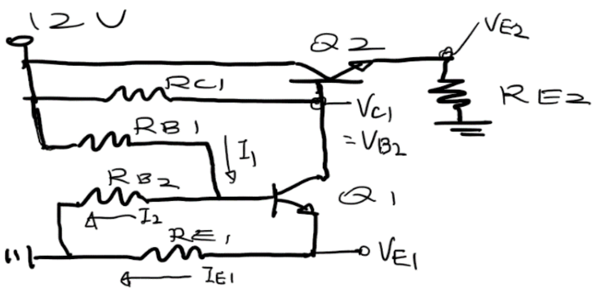


Figure 8. The DC circuit of the repeater.

According to the 1.3rd rule, $V_{E1} = V_{cc}/3 =$ **4 V**; $V_{B1} = V_{E1} + 0.7 =$ **4.7 V**; $V_{B2} = V_{C1} = (2/3)*Vcc$ = **8 V**; $V_{E2} = V_{C1} - 0.7$ V = **7.3 V** ; $I_1 = 0.1*I_{E1} =$ **0.05 mA**; $I_{B1} = I_{E1}/(1+\beta) =$ **1.66 μA** ; $I_2 = I_1 - I_{B1}$ = 0.05 mA – 1.66 μA = **0.04834 mA** ;

The resistances can be calculated:

$$R_{B1} = (12 - 4.7) / 0.05 \text{ mA} = \boxed{\mathbf{146\ k\Omega}}$$

$$R_{B2} = 4.7 / 0.04834 \text{ mA} = \boxed{\mathbf{97.228\ k\Omega}}$$

$$R_{E1} = 4 / 0.5 \text{ mA} = \boxed{\mathbf{8\ k\Omega}}$$

From **Figure 7**, $R_{out} = [(R_{C1}+r\pi2)/(1+\beta)] \parallel R_{E2} = 50\Omega$. The R_{E2}, I_{E2} and R_{C1} are obtained (Process is in **Appendix**).

$\boxed{R_{E2} = \mathbf{7.0\ k\Omega}}$ $\quad I_{E2} = 1.074$ mA $\quad \boxed{R_{C1} = \mathbf{8.00\ k\Omega}}$

$r\pi1 = 15.05$ kΩ $\quad r\pi2 = 7.1$ kΩ $\quad gm1 = 0.02$ $\quad gm2 = 0.042$

In order to find the capacitance, the circuit under the low frequency is below:

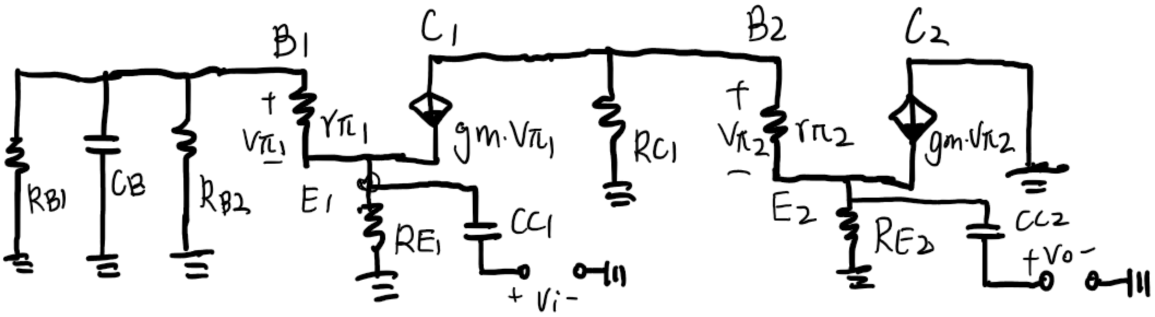


Figure 9. The repeater circuit under the low frequency.

Since all the three capacitors are low-frequency capacitors, the short-circuit test is applied (See process in **Appendix**). The resistance seen by C_{C1} and C_{C2} are 48.69 Ω and 49.80 Ω respectively (approximated to 38.4 Ω), and 11964.64 Ω for CB. Therefore, C_{C1} and C_{C2} contributes the dominant pole. Assume C_{C1} and C_{C2} have the same capacitance, the value is calculated:

$$(1000\text{Hz} * 2\pi)^2 = (1/C_{C1}*48.69)^2+(1/C_{C1}*49.80)^2 \rightarrow \boxed{\mathbf{C_{C1} = C_{C2} = 4.59\ \mu F}}$$

The location of the low-frequency pole can be calculated:

$$\omega = 1/(49.1 * 4.59\mu F) = 4442.88 \text{ rad/s}$$

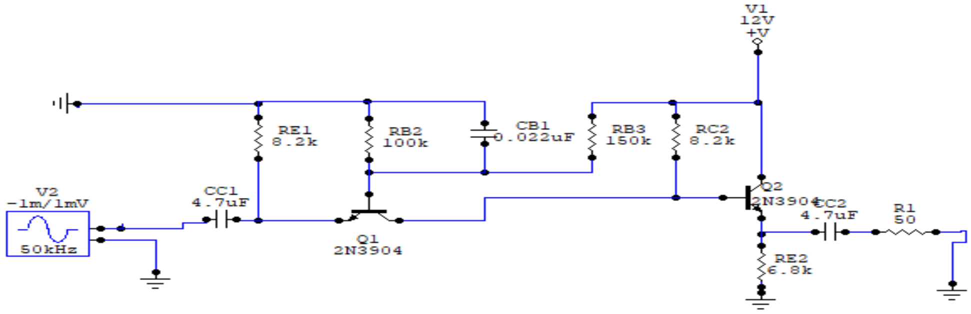
Since the pole of C_B dose not contribute to the dominant pole, the location is at least one decade below the dominant pole. To make C_B is as small as possible, set ω_{CB} is one decade below the dominant. Thus, $\omega_{CB} = 444.288$ rad/s $= (11964.64\Omega * C_B)^{-1} \rightarrow \boxed{\mathbf{C_B = 0.19\ \mu F}}$.

B. Wire up the Circuit and Measure the min band voltage gain

The calculated values of the resistors and the capacitors are replaced by the standard resistor and capacitor values.

Table 2. The calculated and standard values of the resistors and the capacitors

	R_{B1}, kΩ	R_{B2}, kΩ	R_{E1}, kΩ	R_{E2}, kΩ	R_{C1}, kΩ	C_{C1}, µF	C_{C2}, µF	C_B, µF
Calculated	146	97.228	8.0	7.0	8.00	4.59	4.59	0.19
Standard	150	100	8.2	6.8	8.2	4.7	4.7	0.18



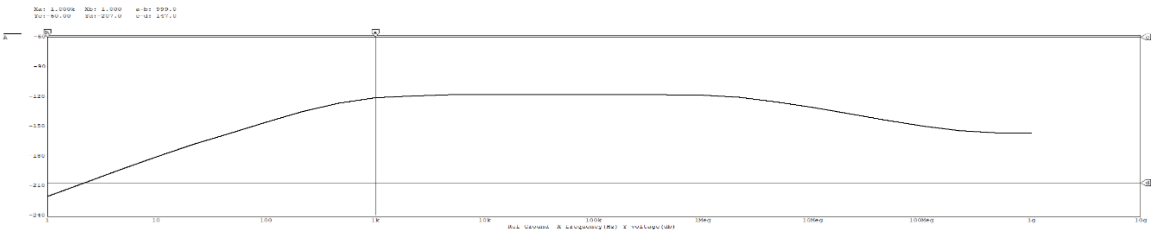


Figure 10. The designed circuit and the Bode plot.

To make sure the ω_{L3dB} is around 1000 Hz, the original C_B is replaced by $\boxed{\textbf{0.022 µF}}$.

The same method in **Part I.D** is used to measure the input and out impedance. To make both input and output impedance is 50 ± 5Ω, the RB2 is replace by **120 kΩ**, and the RE2 is replaced by **1.0 kΩ**.

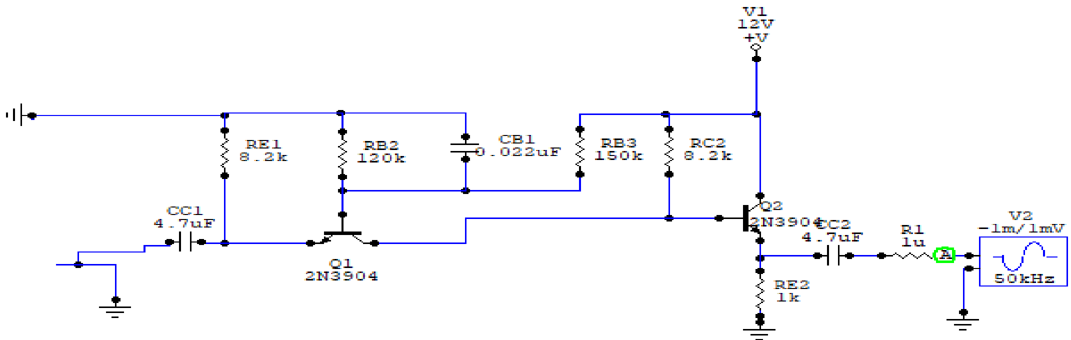


Figure 11. The adjusted designed circuit.

The amplitude of voltage is 1mV. The Z_{in} and Z_{out} are calculated by divided the voltage by current. $\boxed{Z_{in} = 50.57\ \Omega}$, and $\boxed{Z_{out} = 54.66\ \Omega}$. Both are in 50 ± 5Ω.

To measure the mid band voltage gain, the probe of the oscilloscope is used to apply the transient analysis. The ou which is 144.5 mV. The input terminal is connected to a -1mV/+1mV generator. Therefore, A_M is calculated:

$$A_M = Vo / Vs = 148 \text{ mV} / 1\text{mV} = \boxed{144.5}$$

C. Adjust the low frequency capacitors

After two impedances of 50 Ω are connected to the input and the output respectively, the Bode and Phasor plots are obtained:

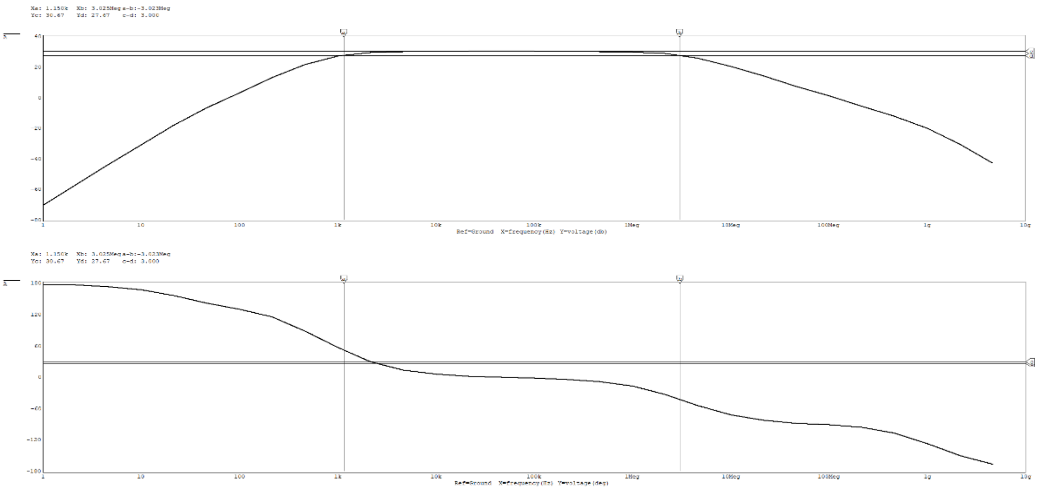


Figure 12. The Bode and Phasor plots of the circuit.

As shown in **Figure 12**, the low-frequency cut-in point is 1.015 kHz, and the high-frequency cut-off point is 3.025 MHz. To meet the specification (low-frequency cut-in <1000 Hz), the capacitor C_B is adjusted to $\boxed{\textbf{0.033 μF}}$. The new low-frequency cut-in point is about $\boxed{\textbf{936.5 Hz}}$, which meets the requirement.

Part 3 The Differential Amplifier

A. Wire up the Circuit

The differential amplifier includes a current mirror, a ±15V power supply, 2N3904 transistors and 10 kΩ collector resistor to make the $I_{E1} = I_{E2} \approx 1$ mA. The wired-up circuit is below:

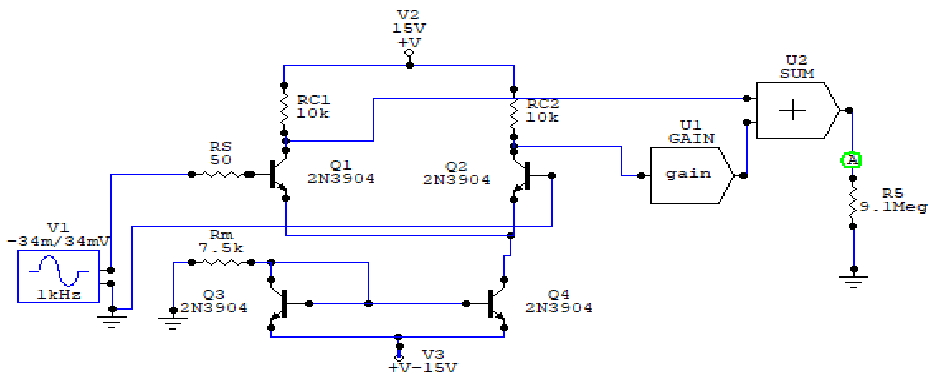


Figure 13. The circuit of the differential amplifier.

Since both I_{E1} and I_{E2} are 1 mA, the I_o is 2mA, and the I_{REF} is 2 mA. Therefore, a 7.5 kΩ resistor Rm is connected in the mirror. To simplify the calculation, the load is chosen very big (9.1MΩ) compare to other resistors. Therefore, RL can be treat as open in the following calculation.

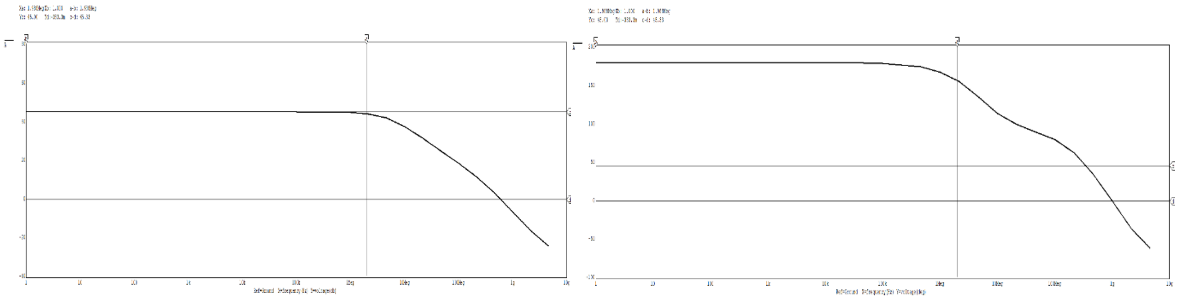


Figure 14. The Bode (left) and the Phasor (right) plots of the differential amplifier.

As shown in **Figure 14**, the $\boldsymbol{\omega_{H3dB}}$ **=** $\boxed{\textbf{4.430 MHz}}$. To get the differential gain, the one of the mid-band frequencies, 1 kHz is chosen. The amplitude of the input voltage is set to 10 mV. The oscilloscope is used to measure the output voltage (the amplitude is 3.534 V). The gain $|A_M|$ = Vo / Vs = 3.534 V / 0.01V = $\boxed{\textbf{353.4}}$.

B. Calculate the differential gain and f_{H3dB}

The gm and the miller gain are calculated from the small-signal model (see **Appendix**), gm = 0.0399S, and k = -398.671. The $C\pi$ and $C\mu$ are calculated by the formula in MP2 [2], $C\pi$ = 24.96 pF, and $C\mu$ = 1.85 pF. After the Miller theorem is applied, the circuit is below:

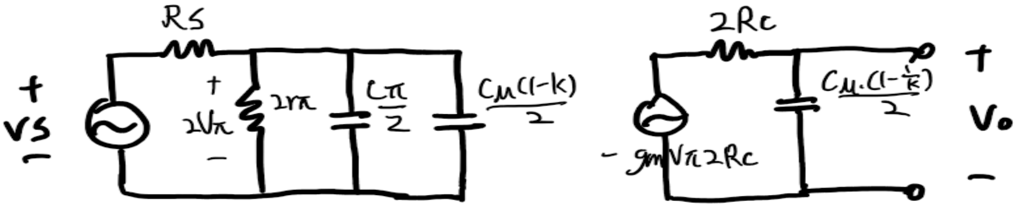


Figure 15. The circuit after applying the Miller theorem

The method in ELEC301 ch14 note [3] is used to calculate the ω_{HP}. (See **Appendix** for the process)

τ_{HP1} = 1.905 * 10-8 s $\qquad\qquad$ τ_{HP2} = 1.855 * 10-8 s

ω_{H3dB} = 37616890.7519 rad/s = $\boxed{\textbf{5.987 MHz}}$

To get the $|A_M|$, Vo = -gm*Vπ*2*R_C and Vπ = 0.5*2*rπ*Vs/(R_S+2*rπ). Putting Vπ into Vo, the $|A_M|$ is obtained (see **Appendix** for process):

$$\boxed{\mathbf{|A_M| = 397.677}}$$

The measured and calculated ω_{H3dB} are 4.430 MHz and 5.986 MHz respectively. The estimation is not very accurate. The deviation may be caused by the Miller transformation. On the other hand, the measured gain is 353.4 which is comparable to the calculated gain (397.677). Therefore, the estimation of the mid-band gain can be described as accurate.

C. Various the Input Signal

From **Figure 14**, the mid-band bandwidth is from 1 Hz to 4.487 MHz. Therefore, **1 kHz** is chosen for the generator. The oscilloscope is used to measure the output signal. The diagram that represents the relationship between Vs and Vo is below:

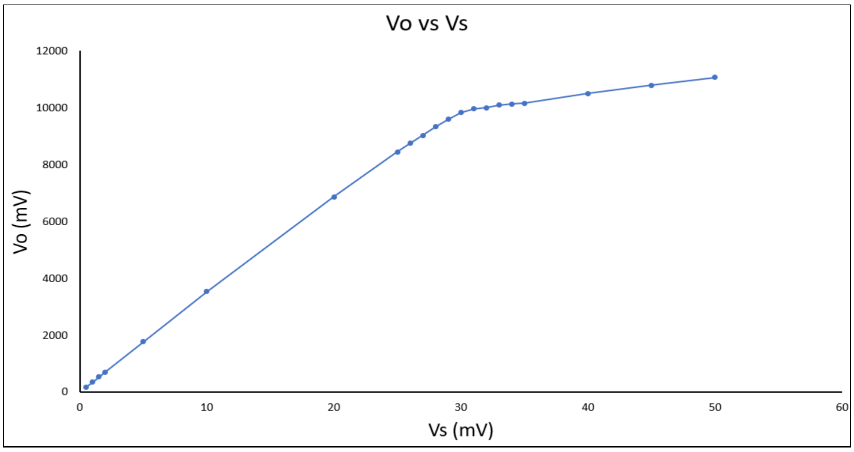


Figure 16. The relationship between Vs and Vo

As shown in **Figure 16**, the Vo(Vs) is linear until the Vs is 30 mV. Therefore, the maximum input signal for which the output is linear is $\boxed{\textbf{Vs = 30 mV}}$.

Part 4 The AM Modulator

A. The Differential Output

The circuit is wired up as required with a 50mVp, 1kHz generator and a 9.1 MΩ load. The output signal is measured using the oscilloscope.

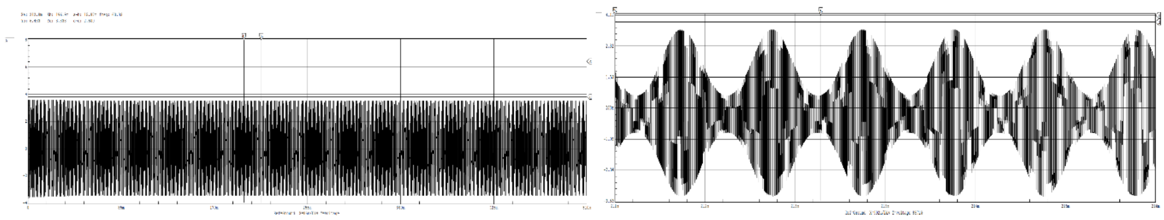


Figure 17. The plot of Vo vs Vs

The left plot is the output signal from 0s to 0.5s. Then right graph is the zoomed in plot to show the pattern clearer. As shown in the figure, the output signal is sinusoid.

B. Various the Input Signal

When the amplitude of the input signal is 10 mV, the peak of the output signal is 2.415 V. When the peak of the input signal is 100 mV, the peak of the output signal is 4.561 V. The input signal then is varied between 10 mV and 100 mV. The amplitude of the output signal rises with the increase of the amplitude of the input signal. The data of different input and output signals are recorded.

Table 3. The amplitude of the input and out signal

In (mV)	10	20	30	40	50	60	70	80	90	100
Out (V)	2.415	2.683	3.033	3.300	3.567	3.933	4.167	4.502	4.489	4.488

When measuring these points, the first distorted output signal appears at Vin = 90 mV. Thus, the maximum undistorted input signal is between 80 mV and 90 mV. After measuring the input signal from 80 mV to 90 mV, it is observed that **84 mV** is largest input signal that results in an undistorted output signal.

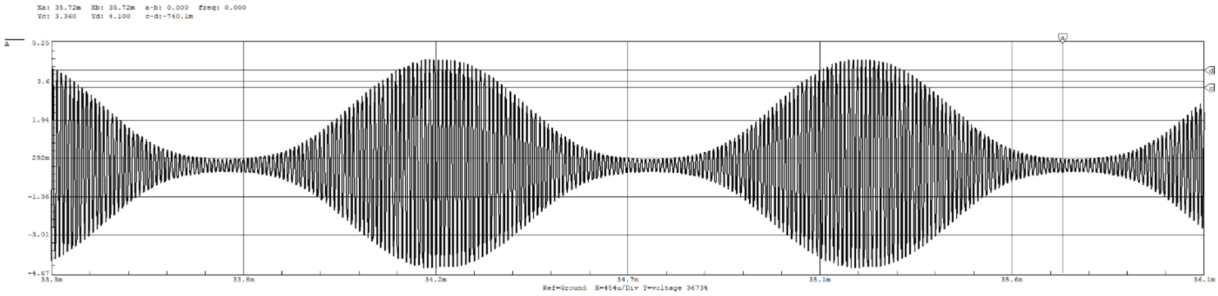


Figure 17. The zoomed plot of Vo vs Vs at Vi = 84 mV, 1kHz

C. Square-Wave Input Signal

The generator is set to be square-wave input with the amplitude of Vi = 50 mV and 1 kHz. The amplitude of output signal is 3.335 V. The input signal then is varied between 10 mV and 100 mV. It is observed that as the amplitude of the input signal increases, the amplitude of the output sign rises. The corresponding amplitudes of the output signals are recorded.

Table 4. The amplitude of the input and out signal

In (mV)	10	20	30	40	50	60	70	80	90	100
Out (V)	2.19	2.575	2.866	3.05	3.335	3.9	4.167	4.17	4.17	3.967

After measuring multiple times, it is found that when the amplitude of the input signal is 80 mV, the output signal starts to distort. Therefore, the maximum input signal that results in an undistorted output signal is around **78 mV**.

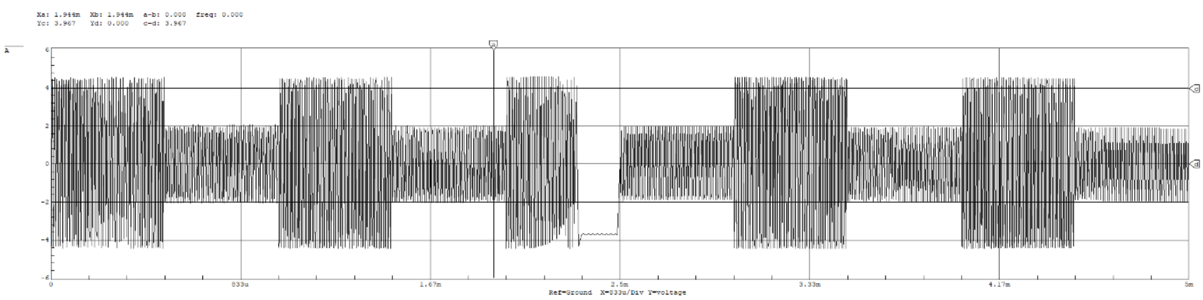


Figure 18. The distorted output signal when input = 80 mV.

How the AM Modulator works

In the small-signal model, the collector of a BJT is connected to a voltage-controlled-current source. The input voltage plays a significant role in this system. When the input voltage is sinusoid, the current is also sinusoid. There are two generators in the circuit. The high-frequency one is called carrier [4], and the low-frequency one is called input. The current goes through the load depends on both generators. Therefore, when the two different input voltage are multiplied (convolution) by each other, the amplitude of the output signal is modulated.

Conclusion

In Mini-Project 3, the fundamental knowledge of Amplifier is used to design a cascode amplifier and a cascaded amplifier (the common-base followed by the common-collector) that meet the given specification. The $1/4^{th}$ rule, $1/3^{rd}$ rule and the small-signal model are used to determine the resistors and the capacitors. The cut-in and cut-off frequencies of the cascode amplifier are found using transient analyses, and the input and output impedances are measured using the oscilloscope. In addition, a differential amplifier is designed using 2N3904 transistor and a current mirror. The mid-band gain and the high cut-off frequency are calculated and measured. The relationship between the Vo and Vs is investigated. It is found that the output is linear before the saturation point. Finally, the AM modulator is studied. The relationship between the amplitude of the output signal and the input signal is observed under the sinusoid input signal and square-wave input signal respectively. It is found that the output signal has a positive relation with the input signal. Moreover, when the input voltage exceeds the saturation point, the output signal will be distorted. The basic principle of the AM modulator is investigated and explained. In summary, this mini project provides the advanced knowledge of amplifiers, and visualizes the basic principle of AM modulator. This knowledge will be useful in the future career.

Reference

[1] ELEC 301 Cascode Amplifier Notes

[2] The Mini-Project 2. Author: Ruyi Zhou (myself)

[3] ELEC 301 Chapter 14 Notes

[4] Wikipedia: AM Modulation: *https://en.wikipedia.org/wiki/Amplitude_modulation*

Appendix

Part II :

$$R_{C1} = \frac{V_{CC} - V_{C1}}{I_{C1} + I_{B2}} = \frac{12-8}{\frac{0.5m \cdot 300}{301} + I_{B2}}$$

$$I_{B2} = I_{E2} \cdot \frac{1}{(\beta+1)} = \frac{7.3}{301 \cdot R_{E2}}$$

$$r_{\pi 2} = \frac{300 \cdot V_T}{I_{C2}} \quad r_{\pi 1} = \frac{300 \cdot V_T}{I_{C1}} = 15\,k\Omega$$

$$R_{out} = 50 = \frac{r_{\pi 2} + R_{C1}}{1+\beta} \parallel R_{E2}$$

By HP-Prime :

$$R_{E2} = 7\,k\Omega, \quad R_{C1} = 8\,k\Omega, \quad r_{\pi 2} = 7.1\,k\Omega$$

$$g_{m1} = \beta / r_{\pi 1} = 0.02, \quad g_{m2} = \beta / r_{\pi 2} = 0.042$$

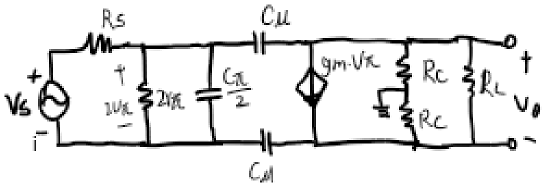
Time constant :

$$\tau_{CB}^{sc} = C_B \times [R_{B1} \parallel R_{B2} \parallel r_{\pi 1}] = C_B \times 11964.64\,\Omega$$

$$\tau_{CC1}^{sc} = C_{C1} \times \left[\frac{r_{\pi 1}}{(1+\beta)} \parallel R_{E1}\right] = C_{C1} \times 48.69\,\Omega$$

$$\tau_{CC2}^{sc} = C_{C2} \times \left[\frac{R_{C1} + r_{\pi 2}}{(1+\beta)} \parallel R_{E2}\right] = C_{C2} \times 49.80\,\Omega$$

Part III. b :



$$C_\pi = 24.96\,pF$$
$$C_\mu = 1.85\,pF$$

$$g_m = \frac{I_C}{V_T} = \frac{\alpha \cdot I_E}{V_T} = \frac{(300/301) \cdot 1mA}{25mA} = 0.0399\,S$$

$$\text{miller gain } k = \frac{V_o}{2V_\pi} = \frac{1}{\cancel{2V_\pi}} \cdot -g_m \cdot \cancel{V_\pi} \cdot 2R_C = -399$$

$$r_\pi = \beta / g_m = 7.518\,k\Omega$$

$$\tau_{HP1} = \left(\frac{C_\pi}{2} + \frac{C_\mu}{2}(1-k)\right)\underbrace{(2 r_\pi \parallel R_S)}_{49.834\,\Omega} = 1.905 \times 10^{-8}\,s$$

$$\tau_{HP2} = \frac{C_\mu}{2} \cdot \left(1 - \frac{1}{k}\right) \cdot 2R_C = 1.855 \times 10^{-8}\,s$$

$$\omega_{H3dB} = \left(\sqrt{\tau_{HP1}^2 + \tau_{HP2}^2}\right)^{-1} = 37616890.7519\,rad/s$$
$$= \boxed{5.987\ MHZ}$$

$$A_m = \frac{V_o}{V_s} = \frac{1}{V_s} \cdot -g_m V_\pi \cdot 2R_C \quad \& \quad V_\pi = \frac{1}{\cancel{2}} \cdot \frac{\cancel{2} r_\pi}{R_S + 2r_\pi} \cdot V_s$$

$$\therefore |A_m| = \left|\frac{-g_m \cdot r_\pi \cdot \cancel{V_s} \cdot 2R_C}{\cancel{V_s} \cdot (R_S + 2r_\pi)}\right| = 397.677.$$