NATIONAL UNIVERSITY *of* SINGAPORE

Department of Electrical and Computer Engineering

EE2021 – Devices and Circuits

Homework 4 Solutions

<u>Homework 4:</u>

You have to submit the homework assignment (Q.1) in hardcopy in class on <u>Wednesday 8 April 2015</u>.

Unless otherwise stated, you may use the tables of the amplifier configurations and equivalent resistances in your lecture notes in your solutions to the questions.

Q.1

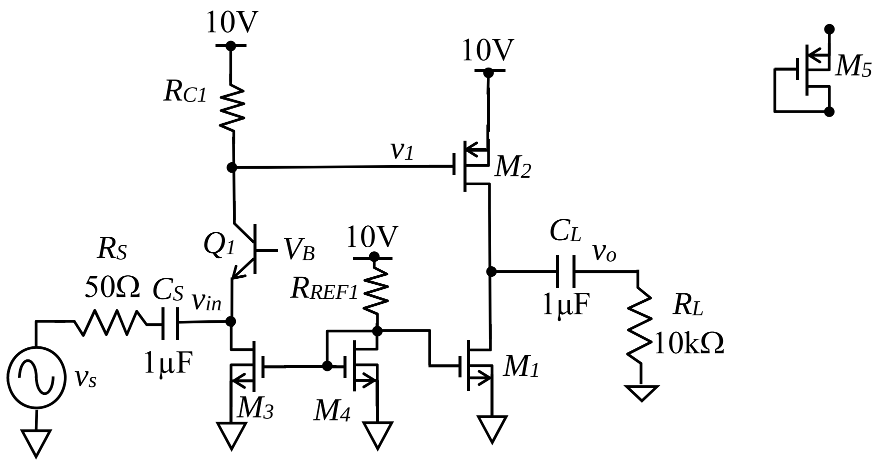

Fig. Q1

In the two-stage amplifier circuit shown in Fig. Q1, assume that the npn BJT, the NMOS transistors and the PMOS transistors have the following device parameters:

- V_A = 100 V and β = 100 for the BJT, Q_1;
- K_n = 2m A/V^2, V_{THN} = 1 V, λ_n = 0.001V^{-1} and no body effect for the NMOS transistors, M_1, M_3 and M_4.
- K_p = 2m A/V^2, V_{THP} = -1 V, λ_p = 0.001V^{-1} and no body effect for the PMOS transistors, M_5 and M_2.

Further assume that R_{REF1} is chosen such that M_1, M_3 and M_4 each has a drain current of 1 mA. (You are not required to find R_{REF1}.)

(i) Identify the configuration of each stage of the multi-stage amplifier.

[2 marks]

(ii) Estimate the small signal parameters of M_2, i.e. $g_{m,M2}$, and $r_{o,M2}$ and the small signal parameters of Q_1, i.e., $g_{m,Q1}$, $r_{\pi,Q1}$, $r_{o,Q1}$.

[3 marks]

(iii) Design R_{C1} to ensure that M_2 has the same current as M_1 assuming these transistors are operating in the saturation region.

[2 marks]

(iv) Estimate the overall gain, i.e., v_o/v_s.

[6 marks]

(v) What is the minimum V_B value allowed such that M_3 is operating in the saturation region?

[4 marks]

(vi) If R_{C1} is replaced with M_5, would it create any biasing issue? Would the overall gain be larger or smaller?

[3 marks]

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1. (i) Identify the configuration of each stage of the multi-stage amplifier.

Common base - Common Source

(ii) Estimate the small signal parameters of M_2, i.e. $g_{m,M2}$, and $r_{o,M2}$ and the small signal parameters of Q_1, i.e., $g_{m,Q1}$, $r_{\pi,Q1}$, $r_{o,Q1}$.

$I_{C,Q1} \approx I_{E,Q1} = I_{D,M3} = I_{D,M1} = I_{D,M2} = 1$ mA.

$$g_{m,Q1} = \frac{I_C}{V_T} = \frac{1\text{ mA}}{0.025\text{ V}} = 40\text{ mA/V}.$$

$$r_{\pi,Q1} = \frac{\beta}{g_m} = \frac{100}{0.04} = 2.5\text{ k}\Omega.$$

$$r_{o,Q1} = \frac{V_A}{I_C} = \frac{100}{1\times10^{-3}} = 100\text{ k}\Omega.$$

$$g_{m,M2} = 2\sqrt{K_p I_{D,M2}} = 2\sqrt{2\times10^{-3}\times1\times10^{-3}} = 2.83\text{ mA/V}.$$

$$r_{o,M2} = \frac{1}{\lambda_p I_D} = \frac{1}{0.001\times1\times10^{-3}} = 1\text{ M}\Omega.$$

(iii) Design R_{C1} to ensure that M_2 has the same current as M_1 assuming these transistors are operating in the saturation region.

$$I_{D,M2} = K_p\left(\left|V_{GS,M2}\right| - \left|V_{THP}\right|\right)^2 = 1\ \text{mA}$$

$\Rightarrow \left|V_{GS,M2}\right| = 1.71\ \text{V} = I_{C,Q1}R_{C1}$ (The other solution, 0.293 V is rejected as it is less than the magnitude of the threshold voltage.)

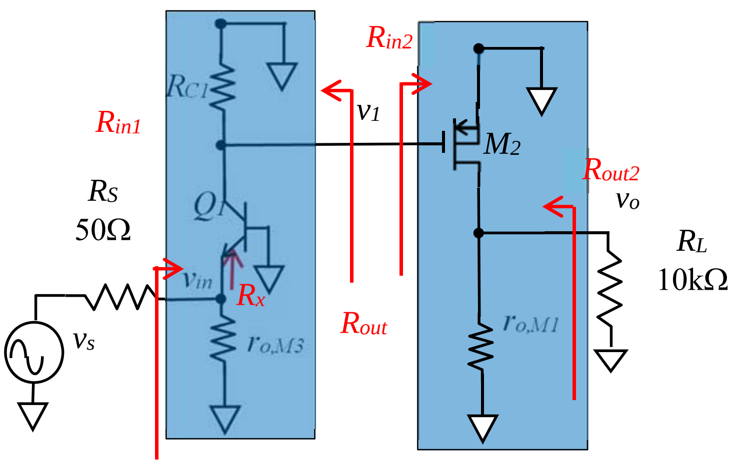
R_{C1} = 1.71 kΩ

(iv) Estimate the overall gain, i.e., v_o/v_s.

Note :

- Students are not required to draw the circuits shown below, nor state the values of the two-port parameters as given below. If they could get the answer to the overall gain correct, they get full (6) marks. However, if they do not get the answer, then these circuits, or parameter values, if given correctly, will earn partial credits as shown.
- Some of the answers below are calculated after making approximations. Students may calculate the values without using approximations. They should be marked correct in those cases. Anyway, the answers would not be different by more than 10%.

AC Equivalent Circuit :



Two port network prameters :

For CB Amplifier, $G_{m1} = -g_{m,Q1}$ = -40 mA/V,

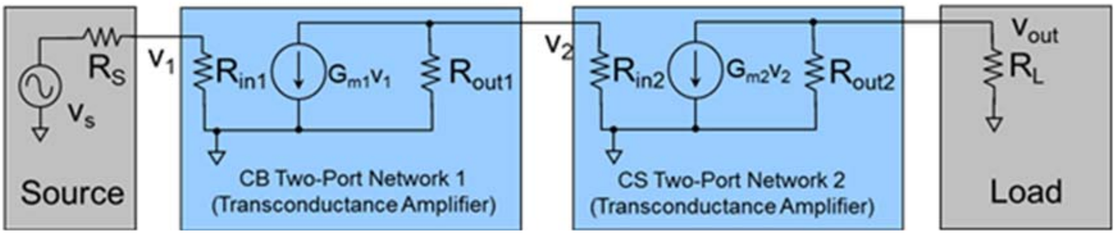
For CS amplifier, $G_{m2} = g_{m,M2}$ = 2.83 mA/V,

$R_{in2} = \infty$,

$$R_{out1} = r_{o,Q1}\left\{1 + g_{m,Q1}\left[\left(r_{\pi,Q1} + R_S\right) // r_{o,M3}\right]\left(\frac{r_{\pi,Q1}}{r_{\pi,Q1} + R_S}\right)\right\} // R_{C1} \approx R_{C1} = 1.71\ \text{k}\Omega$$

$$R_{in1} = \left[\frac{1}{g_{m,Q1}} \times \frac{r_{o,Q1} + R_C}{r_{o,Q1} + R_C/\beta} \right] // r_{o,M3} \approx \frac{1}{g_{m,Q1}} = 25\,\Omega$$

$R_{out2} = r_{o,M2} // r_{o,M1} = 500$ kΩ.



$$\frac{v_o}{v_s} = \frac{v_1}{v_s} \times \frac{v_2}{v_1} \times \frac{v_o}{v_2}$$

$$= \frac{R_{in1}}{R_S + R_{in1}} \times \left[-G_{m,Q1}\left(R_{out1} // R_{in2}\right) \right] \times \left[-G_{m,M2}\left(R_{out2} // R_L\right) \right]$$

$$\approx \frac{\frac{1}{g_{m,Q1}}}{R_S + \frac{1}{g_{m,Q1}}} \times g_{m,Q1} R_{C1} \times \left(-g_{m,M2} R_L \right)$$

$$= \frac{25}{50 + 25} \times 40 \times 10^{-3} \times 1.71 \times 10^{3} \times \left(-2.83 \times 10^{-3} \times 10 \times 10^{3} \right)$$

$$= 0.33 \times 68.4 \times (-28.3) = -638.8$$

(v) What is the minimum V_B value allowed such that M_3 is operating in the saturation region?

$$I_{D,M3} = K_n \left(V_{GS,M3} - V_{THN} \right)^2 = 1\text{ mA}$$

For M_3 to operate in saturation, the minimum drain-source voltage,

$$V_{DSsat,M3} = V_{GS,M3} - V_{THN} = \sqrt{\frac{I_{D,M3}}{K_n}} = 0.707\text{ V}.$$

$V_{E,Q1} = V_{DSsat,M3} = 0.707$ V

Minimum $V_{B,Q1} = V_{E,Q1} + 0.7 = 1.407$ V.

(vi) If R_{C1} is replaced with M_5, would it create any biasing issue? Would the overall gain be larger or smaller?

Biasing would not be an issue as the M_5 will produce the V_{GS} needed for 1 mA to flow through it.

The small signal resistance of M_5 (diode connected resistor) is

$$\frac{1}{g_{m,M5}} = 353\,\Omega\,.$$

As this value is less than RC1, the gain would be smaller.