**NANYANG TECHNOLOGICAL UNIVERSITY**

**SEMESTER 2 EXAMINATION 2018-2019**

**EE2002 – ANALOG ELECTRONICS**

April / May 2019 | Time Allowed: 2½ hours

**INSTRUCTIONS**

1. This paper contains 5 questions and comprises 9 pages.
2. Answer ALL questions.
3. All questions carry equal marks.
4. This is a closed book examination.
5. Unless specifically stated, all symbols have their usual meanings.
6. A List of Formulae is provided in Appendix A on pages 7 to 9.

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1. (a) For the non-ideal Op-Amp in negative feedback shown in Figure 1(a) on page 2, derive the expression for the output voltage $v_{OUT}$ in terms of all or some of the following variables $v_1$, $v_2$, $V_{IO}$, $I_+$, $I_-$, $R_1$, $R_2$, $R_3$, $R_4$, $R_5$, $R_6$ and $R_7$, assuming that the output is in the linear range of operation.

**Note:** *Parallel resistance of $R_a$ and $R_b$ can be written as $R_a // R_b$ without expanding it.*

(11 Marks)

Note: Question No. 1 continues on page 2.



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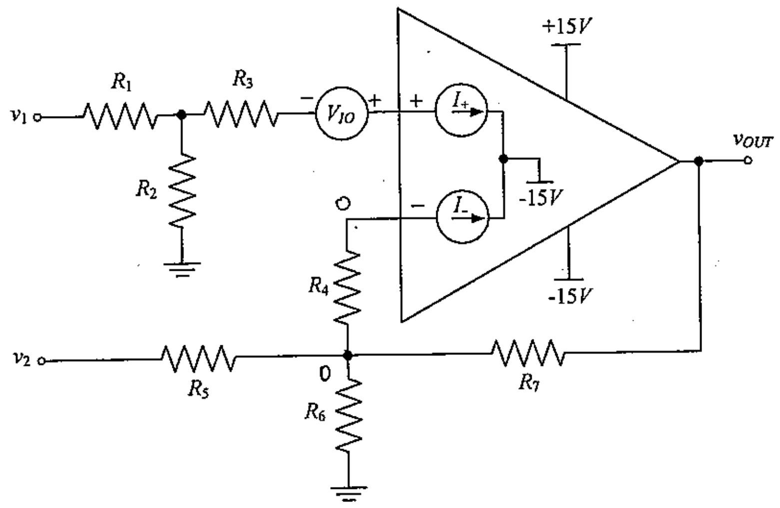


**Figure 1(a)**

(b) In Figure 1(b), the empirical junction diode equation is:

$$V_D = n\ V_T\ ln\ [I_D/I_S]$$

for the identical diodes $D_1$ and $D_2$ where $n = 1$, $V_T = 26$ mV and $I_S = 6 \times 10^{-17}$ A at room temperature. The resistors $R_1 = R_2 = 8$ kΩ , $R_4 = 5$ kΩ , $R_3 = 20$ kΩ and the DC voltage source $V_S = 10$ V. Find the DC quiescent operating point or Q-point ($I_D$ , $V_D$) of the diodes $D_1$ and $D_2$ (to 3 decimal places in μA and V, respectively).

(9 Marks)

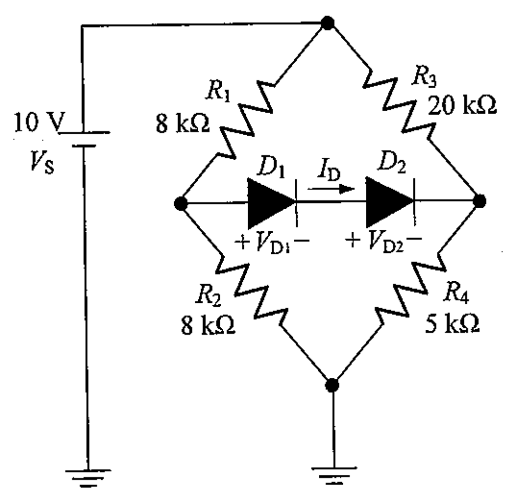


**Figure 1(b)**

2. For the amplifier shown in Figure 2, the MOSFET transistor has $V_{TN}$ = 1 V, $K_n = 200\ \mu A/V^2$ and $\lambda = 0.01\ V^{-1}$. All the capacitors $C_G$, $C_D$ and $C_S$ in the circuit are assumed to have infinite capacitance.

(a) Find the Q-point of the transistor. (6 Marks)

(b) Draw the small signal equivalent circuit. Determine the voltage gain $A_v = \frac{v_o}{v_i}$ and current gain $A_i = \frac{i_o}{i_i}$ of the amplifier.

(10 Marks)

(c) Determine the maximum amplitude of the input signal $v_i$ for small-signal operation.

(4 Marks)

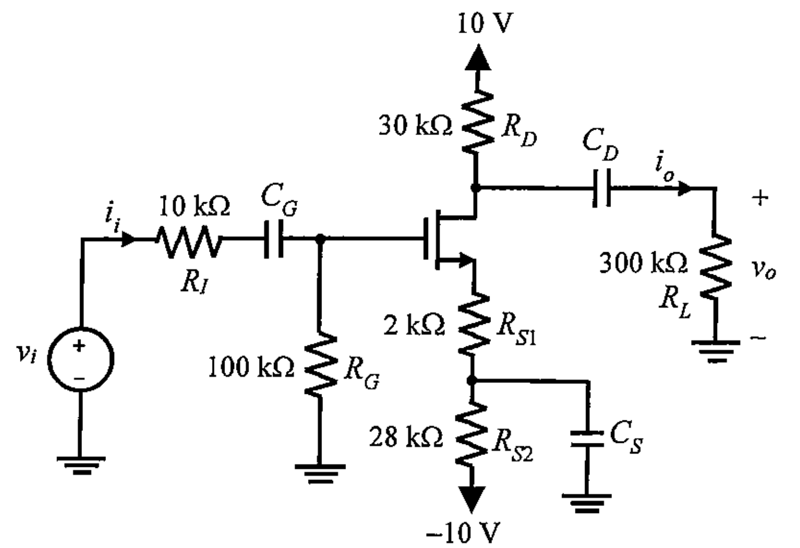


**Figure 2**



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3. In Figure 3, the DC operating point for BJT $Q_1$ is $I_{C1} = 170\ \mu A$ and $V_{CE1} = 4$ V, and the DC operating point for BJT $Q_2$ is $I_{C2} = 240\ \mu A$ and $V_{CE2} = 3$ V. Both $Q_1$ and $Q_2$ have $\beta = 100$, $V_A = 75$ V at the room temperature. Assume that all the capacitors have infinite values, and all the resistors have the values as indicated in Figure 3.

(a) Determine the voltage gain $A_v = \frac{v_o}{v_i}$ (9 Marks)

(b) Determine the input resistance $R_{in}$ and output resistance $R_{out}$ of the amplifier. (6 Marks)

(c) Determine the small-signal input signal range for $v_i$ of this amplifier. (5 Marks)

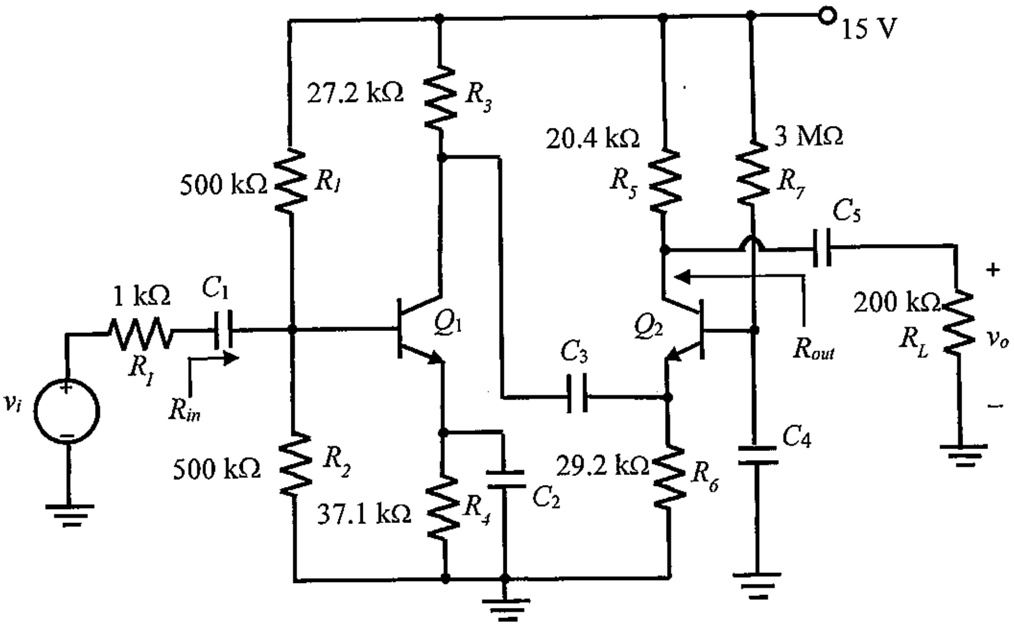


**Figure 3**

4. Consider the cascode current mirror circuit comprising PMOS transistors $M_1$-$M_4$ as shown in Figure 4. Assume all the transistors are identical and in saturation. Perform small-signal analysis, indicating clearly the $g_m$ and $r_o$ of the $i$-th transistor as $g_{m,i}$ and $r_{o,i}$. For example, the $g_m$ and $r_o$ for transistor $M_1$ should be written as $g_{m,1}$ and $r_{o,1}$, respectively.

(a) Draw the AC small signal model of the circuit and derive the expression for the output resistance $R_{out}$ in terms of the small signal parameters $g_m$ and $r_o$ of the MOSFET.

(10 Marks)

(b) Given that $I_{REF} = 200\ \mu A$, $K_p$ for the MOSFET is $100\ \mu A/V^2$, $|V_{TP}| = 0.5$ V and $\lambda = 0.01\ V^{-1}$ ,find the value of the output resistance $R_{out}$ based on the expression in part (a) if the drain of $M_2$ is connected to 0 V.

(5 Marks)

(c) Using the same MOSFET parameter values given in part (b), find the value of the maximum voltage on the drain of $M_2$ such that all the transistors are in the saturation region.

(5 Marks)

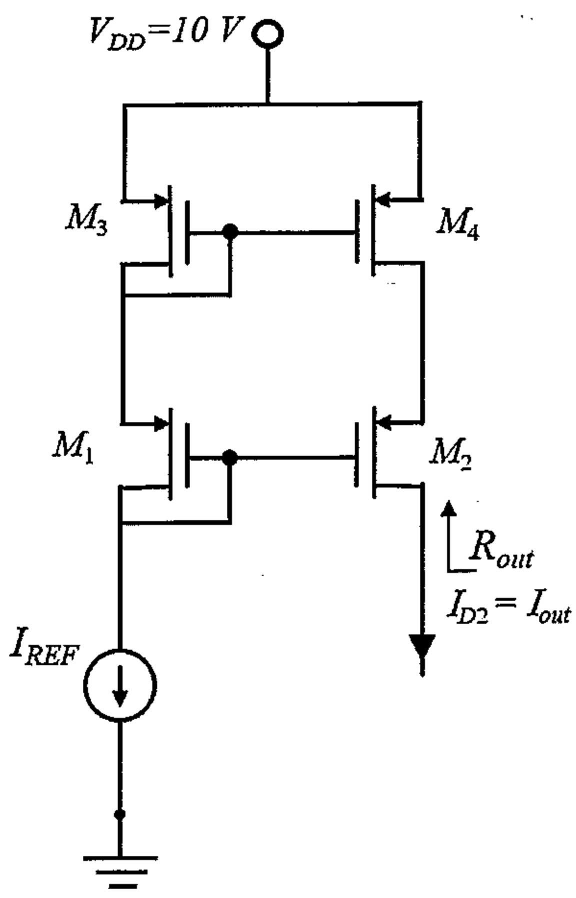


**Figure 4**



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5. Observe that the circuit shown in Figure 5 is a cascade of two identical Op-Amp gain stages. Assume the Op-Amps are ideal.

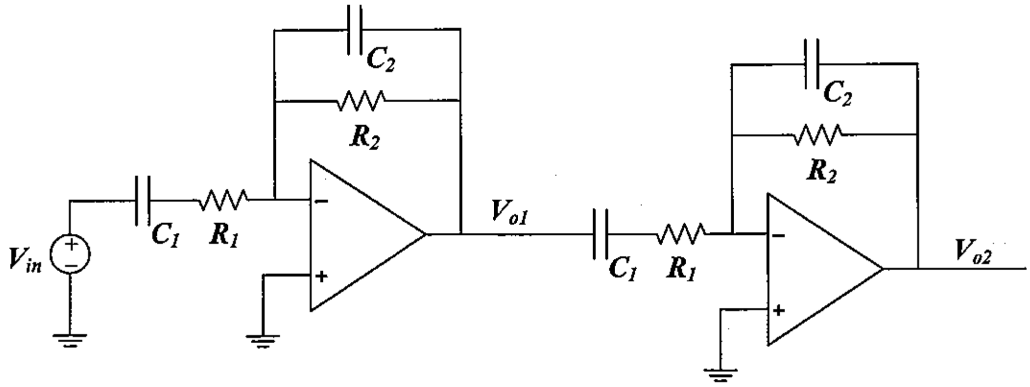



**Figure 5**

(a) Considering only the first stage in this part, derive the first stage transfer function $V_{o1} / V_{in}$, in terms of $R_2$, $C_2$, $R_1$ and $C_1$.

(6 Marks)

(b) Given that $R_2 = 10\ \text{k}\Omega$, $C_2 = 10\ \text{nF}$, $R_1 = 1\ \text{k}\Omega$, $C_1 = 10\ \mu\text{F}$, draw the Bode plot for the transfer function $|V_{o1} / V_{in}|$ derived in part (a). Clearly mark the slopes (in dB/decade) for all the regions in the plot, and indicate the lower cut-off angular frequency $\omega_L$, upper cut-off angular frequency $\omega_H$, and the maximum gain $A_0$ achieved at angular frequency $\omega = 1000$ rad/sec.

(8 Marks)

(c) Now, consider the cascade of both stages in Figure 5, with a transfer function $|V_{o2} / V_{in}|$. Use the SCTC and OCTC methods to find the new values of $\omega_L$ and $\omega_H$ for the cascade $V_{o2} / V_{in} = (V_{o1} / V_{in})^2$.

(6 Marks)

**Appendix A**

## List of Selected Formulae (with the usual notations)

### Op-Amps:

Closed-Loop Negative Feedback Inverting Gain, $A_{VCL} = \frac{v_o}{v_i} = -\frac{R_f}{R_i}$ Figure (a)

Closed-Loop Negative Feedback Non-Inverting Gain, $A_{VCL} = \frac{v_o}{v_i} = \left(1 + \frac{R_f}{R_i}\right)$ Figure (b)

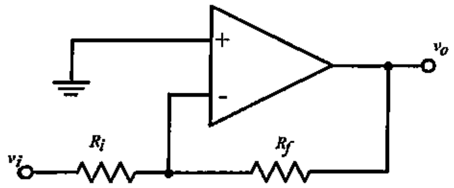



Figure (a)

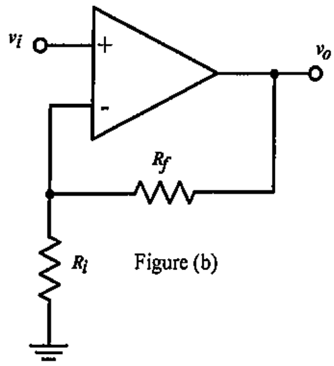
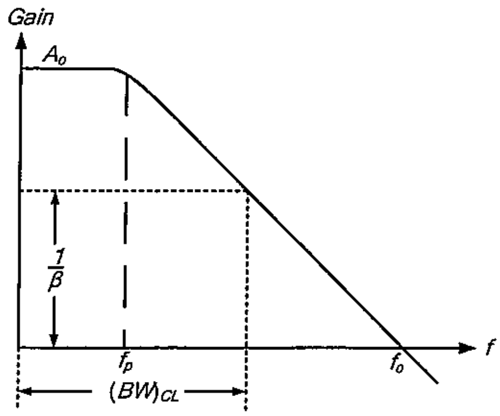



Figure (b)

Op-Amp's Slew Rate, $SR \geq \left|\frac{dv_o}{dt}\right|_{\max} = A_{VCL}\omega a_m = A_{VCL} a_m 2\pi f$ ,

where $v_i = a_m \sin(\omega t)$, $v_o = A_{VCL} v_i$, $v_o = A_{VCL} a_m \sin(\omega t)$ and $\left|\frac{dv_o}{dt}\right| = A_{VCL}\omega\, a_m \cos(\omega t)$

Op-Amp's frequency response: $A_{VOL}(jf) = \frac{A_o}{\left(1 + \frac{jf}{f_p}\right)}$




Gain-Bandwidth Product: $A_o f_p = f_o = \frac{1}{\beta}(BW)_{CL}$

where $\frac{1}{\beta} = \frac{R_f + R_i}{R_i}$

$t_r = \frac{0.35}{(BW)_{CL}}$

### Diodes:

$v_D \approx nV_T \ln\left(\frac{i_D}{I_S}\right)$ or $i_D \approx I_S e^{\left(\frac{v_D}{nV_T}\right)}$

where $e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \ldots\ldots\ldots$

Diode conductance: $g_D = \frac{1}{r_D} = \frac{I_D}{nV_T}$

**BJT in Forward Active Region:**

Ignore early effect: $i_C = I_S \exp\left(\frac{|v_{BE}|}{V_T}\right)$

With early effect: $i_C = I_S \exp\left(\frac{|v_{BE}|}{V_T}\right)\left(1+\frac{|v_{CE}|}{V_A}\right)$

where $I_s$: Saturation current,
$V_T$: Thermal voltage, assume 25 mV at room temperature,
$V_A$: Early voltage.
For npn transistor, $|v_{BE}| = v_{BE}$ and $|v_{CE}| = v_{CE}$;
For pnp transistor, $|v_{BE}| = v_{EB}$ and $|v_{CE}| = v_{EC}$.

**Small-signal model parameters of BJT:**

$g_m = \frac{I_C}{V_T}$, $r_\pi = \frac{\beta}{g_m}$ and $r_o = \frac{V_A + |V_{CE}|}{I_C} \approx \frac{V_A}{I_C}$

where $I_C$ : DC collector current at Q-point
$V_{CE}$: DC collector-emitter voltage at Q-point

Criterion for small-signal operation of BJT: $|v_{be}| \le 0.2V_T$

**MOSFET in Saturation Region:**

Criterion: $V_{DS} \ge V_{GS} - V_{TN}$ for NMOS;
$|V_{DS}| \ge |V_{GS}| - |V_{TP}|$ for PMOS

where $V_{TN}$, $V_{TP}$: Threshold voltage,
$V_{DS}$: DC drain-source voltage,
$V_{GS}$: DC gate-source voltage.

Ignore channel-length modulation effect: $i_D = \frac{K_n}{2}(v_{GS} - V_{TN})^2$ for NMOS,
$i_D = \frac{K_p}{2}(|v_{GS}| - |V_{TP}|)^2$ for PMOS.

With channel-length modulation effect: $i_D = \frac{K_n}{2}(v_{GS} - V_{TN})^2(1+\lambda v_{DS})$ for NMOS,
$i_D = \frac{K_p}{2}(|v_{GS}| - |V_{TP}|)^2(1+\lambda|v_{DS}|)$ for PMOS.

where $\lambda$: channel length modulation parameter,

For NMOS $K_n = K_n'\left(\frac{W}{L}\right)$ and $K_n' = \mu_n C_{ox}$; For PMOS $K_p = K_p'\left(\frac{W}{L}\right)$ and $K_p' = \mu_p C_{ox}$.

**MOSFET in Triode Region:**

Criterion: $V_{DS} < V_{GS} - V_{TN}$ for NMOS;
$|V_{DS}| < |V_{GS}| - |V_{TP}|$ for PMOS

Ignore channel-length modulation effect:

$$i_D = K_n\left(v_{GS} - V_{TN} - \frac{v_{DS}}{2}\right)v_{DS} \text{ for NMOS,}$$

$$i_D = K_p\left(|v_{GS}| - |V_{TP}| - \frac{|v_{DS}|}{2}\right)|v_{DS}| \text{ for PMOS.}$$

With channel-length modulation effect:

$$i_D = K_n\left(v_{GS} - V_{TN} - \frac{v_{DS}}{2}\right)v_{DS}\left(1+\lambda v_{DS}\right) \text{ for NMOS,}$$

$$i_D = K_p\left(|v_{GS}| - |V_{TP}| - \frac{|v_{DS}|}{2}\right)|v_{DS}|\left(1+\lambda|v_{DS}|\right) \text{ for PMOS.}$$

**Small-signal model parameters of MOSFET**

For NMOS: $g_m = \sqrt{2K_n I_D\left(1+\lambda V_{DS}\right)} \approx \sqrt{2K_n I_D}$ and $r_o = \dfrac{\frac{1}{\lambda} + V_{DS}}{I_D} \approx \dfrac{1}{\lambda I_D}$

For PMOS: $g_m = \sqrt{2K_p I_D\left(1+\lambda |V_{DS}|\right)} \approx \sqrt{2K_p I_D}$ and $r_o = \dfrac{\frac{1}{\lambda} + |V_{DS}|}{I_D} \approx \dfrac{1}{\lambda I_D}$

where $I_D$ : DC drain current at Q-point
$V_{DS}$: DC drain-source voltage at Q-point

Criterion for small-signal operation:
For NMOS: $|v_{gs}| \le 0.2\left(V_{GS} - V_{TN}\right)$
For PMOS: $|v_{gs}| \le 0.2\left(|V_{GS}| - |V_{TP}|\right)$
where $V_{GS}$ : DC gate-source voltage at Q-point.

**Frequency Response: OCTC and SCTC**

1. **Disable** all independent sources (voltage sources → Short Circuit; current sources → Open Circuit); **Do not** remove or "disable" dependent sources!
2. **Identify** capacitors contributing to the frequency of interest, i.e., lower of higher cut-off.

**higher cut-off**

3. **Idealise** irrelevant capacitors by **short circuit** (because at high f, cap → short)
4. For each contributing capacitor $C_i$, set all other capacitors (other than the one you are looking at) **removed** (i.e. **Open Circuits**) and determine the resistance, $R_i$ seen by $C_i$
5. Higher cut-off frequency is estimated as:

$$\omega_{H-3\text{dB}} \approx \frac{1}{\sum_i C_i R_i}$$

**lower cut-off**

3. **Idealise** irrelevant capacitors by **open circuit** (because at low f, cap → open)
4. For each contributing capacitor $C_i$, set all other capacitors (other than the one you are looking at) **removed** (i.e. **Short Circuits**) and determine the resistance, $R_i$ seen by $C_i$
5. Lower cut-off frequency is estimated as:

$$\omega_{L-3\text{dB}} \approx \sum_i \frac{1}{C_i R_i}$$

END OF PAPER

# EE2002 PYP Solution

2018/2019 S2



1a.

$$V_{out} = V_{out}|_{V_1} + V_{out}|_{V_2} + V_{out}|_{V_{IO}} + V_{out}|_{I+} + V_{out}|_{I-}$$

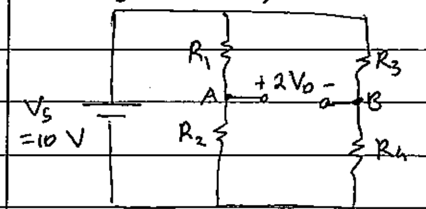
$$= V_1\left(1+\frac{R_7}{R_5//R_6}\right)\left(\frac{R_2}{R_1+R_2}\right) + V_2\left(-\frac{R_7}{R_5}\right) + V_{IO}\left(1+\frac{R_7}{R_5//R_6}\right)$$

$$+ I_+\left(-\left((R_2//R_1)+R_3\right)\right)\left(1+\frac{R_7}{R_5//R_6}\right) + I_-\left(R_4+R_7\right)$$

$$= \left(1+\frac{R_7}{R_5//R_6}\right)\left(V_1\left(\frac{R_2}{R_1+R_2}\right) + V_{IO} - I_+\left((R_2//R_1)+R_3\right)\right) - V_2\left(\frac{R_7}{R_5}\right)$$

$$+ I_-\left(R_4+R_7\right)$$

1b. Finding $V_{TH}$,




At node A,

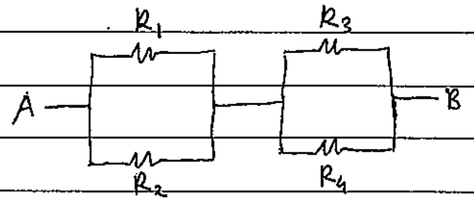
$$V_A = V_s\left(\frac{R_2}{R_1+R_2}\right) = \frac{1}{2}\cdot 10\,V = 5\,V$$

At node B,

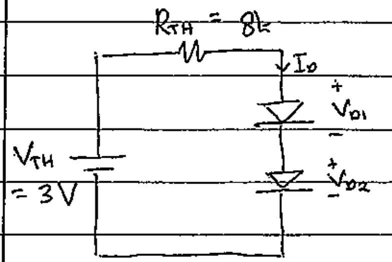
$$V_B = V_s\left(\frac{R_4}{R_3+R_4}\right) = \frac{5}{25}\cdot 10\,V = 2\,V$$

$$V_{TH} = V_A - V_B = 3\,V$$

Finding $R_{TH}$, voltage source becomes short circuit, then the circuit can be seen this way:




$$R_{TH} = R_1//R_2 + R_3//R_4$$
$$= 8k//8k + 20k//5k$$
$$= 8k\ \Omega$$




$$V_{D1} = V_{D2} = V_D$$

$$I_D = \frac{V_{TH} - 2V_D}{R_{TH}}$$

$$I_D = \frac{3 - 2V_D}{8k} \quad \ldots (1)$$

$$V_D = nV_T \ln\left(\frac{I_D}{I_S}\right) = 26\times10^{-3}\ln\left(\frac{I_D}{6\times10^{-17}}\right) \quad \ldots (2)$$

| | | | | | | |
|---|---|---|---|---|---|---|
| $V_D$ | 0.7 | 0.7497 | 0.7480 | 0.7481 | 0.7481 | 0.7481 |
| $I_D$ (in $\mu A$) | 200 | 187.5725 | 187.9895 | 187.9751 | 187.9756 | 187.9756 |

DC quiescent operating point: $\boxed{I_D = 187.976\ \mu A \quad V_D = 0.748\ V}$

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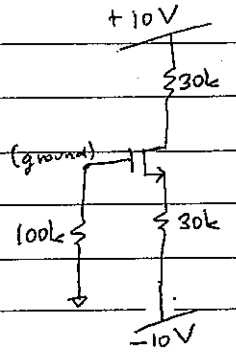
2a. Assume the NMOS is in saturation region,




$10 = V_{GS} + I_D(30k)$

$V_{GS} = 10 - (30k)(I_D) \; \ldots (1)$

$I_D = \frac{K_n}{2}(V_{GS} - V_{TN})^2 \; \ldots (2)$

Substitute (1) into (2),

$I_D = 100\mu\left(10 - (30k)I_D - 1\right)^2$

$0 = 9\times10^4 I_D^2 - 55 I_D + 8.1\times10^{-3}$

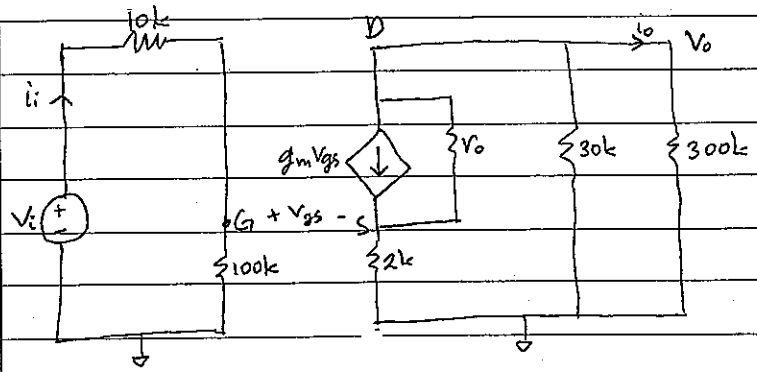
$I_D = 0.364\ mA$ or $\boxed{I_D = 0.248\ mA}$

$V_{GS} = -0.92\ V$ (not valid) $\quad \boxed{V_{GS} = 2.56\ V}$

$V_{DS} = 20 - I_D(30k + 30k)$

$\boxed{V_{DS} = 5.12\ V}$

2b.




$g_m = \sqrt{2K_nI_D}$

$= \sqrt{2(200\mu)(0.248m)}$

$= 3.15\times10^{-4}$

$r_o = \frac{1}{\lambda I_D} = \frac{1}{(0.01)(0.248m)} = 403.226\ k\Omega$

can be ignored since $r_o$ is large.

$V_o = -(30k // 300k)\, g_m V_{gs}$

$V_o = 8.59(-V_g + V_s) \; \ldots (1)$

$V_s = (2k)(g_m V_{gs})$

$V_s = 0.63(V_g - V_s)$

$1.63\, V_s = 0.63\, V_g \; \ldots (2)$

$V_g = \frac{100k}{100k+10k} \cdot V_i = \frac{10}{11} V_i \; \ldots (3)$

Substitute (2) and (3) into (1), we get

$V_o = 8.59\left(-1 + \frac{0.63}{1.63}\right)\left(\frac{10}{11}\right) V_i$

$$\boxed{A_v = \frac{V_o}{V_i} = -4.79}$$

$V_o = i_o(300k)$ and $V_i = i_i(110k)$, hence

$$\frac{300k}{110k} \cdot \frac{i_o}{i_i} = -4.79$$

$$\boxed{A_i = \frac{i_o}{i_i} = -1.76}$$

2c. For small-signal operation, $|V_{gs}| \leq 0.2\,(V_{GS} - V_{TN})$

$|V_{gs}| \leq 0.312$ V

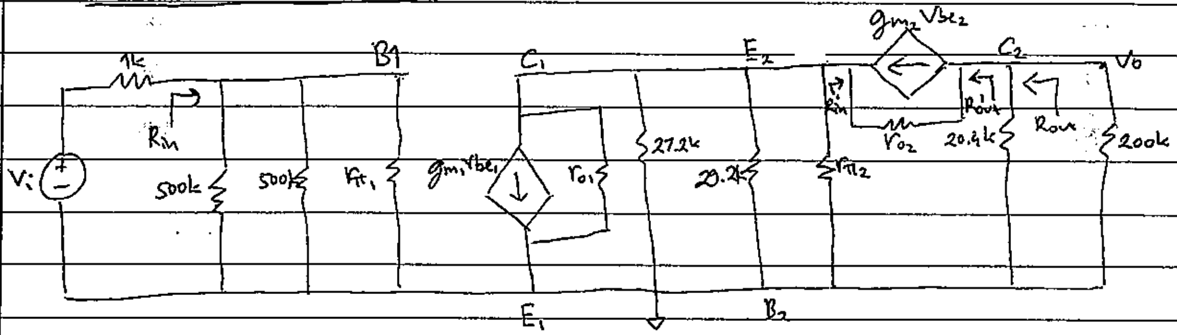
$|V_g - V_s| \leq 0.312$

$\left| V_g\left(1 - \frac{0.63}{1.63}\right)\right| \leq 0.312$

$\frac{10}{11}\left(1 - \frac{0.63}{1.63}\right)|V_i| \leq 0.312$

$$\boxed{|V_i| \leq 0.559 \text{ V}}$$

3a.




| | |
|---|---|
| $g_{m1} = 40I_{C1} = 6.8\times10^{-3}$ | $g_{m2} = 9.6\times10^{-3}$ |
| $r_{\pi1} = \frac{\beta}{g_{m1}} = \frac{100}{6.8\times10^{-3}} = 14.706\text{ k}\Omega$ | $r_{\pi2} = 10.417\text{ k}\Omega$ |
| $r_{o1} = \frac{V_A + \lvert V_{CE}\rvert}{I_C} = \frac{75+4}{170\mu} = 464.706\text{ k}\Omega$ | $r_{o2} = \frac{75+3}{240\mu} = 325\text{ k}\Omega$ |

Ignoring current through $r_{o2}$,

$V_o = -g_{m2}V_{be2}\,(20.4k // 200k)$

$\frac{V_o}{V_{e2}} = g_{m2}\,(20.4k//200k) \quad \ldots (1)$

$R'_{in} = \frac{V_{be2}}{g_{m2}V_{be2}} = \frac{1}{g_{m2}}$

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$V_{e2} = -\left(r_{o1} // 27.2k // 29.2k // r_{\pi 2} // \frac{1}{g_{m2}}\right) g_{m1} V_{be1}$

$\frac{V_{e2}}{V_{b1}} = -\left(r_{o1} // 27.2k // 29.2k // r_{\pi 2} // \frac{1}{g_{m2}}\right) g_{m1} \quad \ldots (2)$

$\frac{V_{b1}}{V_{in}} = \frac{500k // 500k // r_{\pi 1}}{(500k // 500k // r_{\pi 1}) + 1k} \quad \ldots (3)$

Multiply (1), (2), and (3)

$\frac{V_o}{V_i} = \frac{V_o}{V_{e2}} \cdot \frac{V_{e2}}{V_{b1}} \cdot \frac{V_{b1}}{V_{in}}$

$\boxed{A_v = 115.38}$

3b. $R_{in} = 500k // 500k // r_{\pi 1} = \boxed{13.89 k\Omega}$

Finding $R_{out}'$,

$V_x = i_x\left(r_{o1} // 27.2k // 29.2k // r_{\pi 2}\right) + \left(i_x - g_{m2} V_{be2}\right) r_{o2}$

$V_{be2} = -V_{e2} = -i_x\left(r_{o1} // 27.2k // 29.2k // r_{\pi 2}\right)$

$R_{out}' = \frac{V_x}{i_x} = r_{o1} // 27.2k // 29.2k // r_{\pi 2} + \left(1 + g_{m2}\left(r_{o1} // 27.2k // 29.2k // r_{\pi 2}\right)\right) r_{o2}$

$R_{out}' = 18.77 \ M\Omega$

$R_{out} = R_{out}' // 20.4k$

$\boxed{R_{out} = 20.38 \ k\Omega}$

3c. For small-signal operation of $Q_2$,

$|V_{be2}| \leq 0.005 \ V$

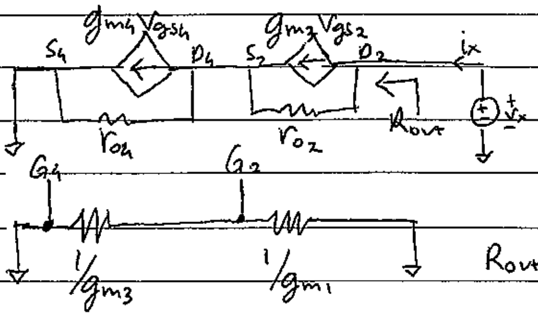
$\frac{V_{be2}}{V_{in}} = -\frac{V_{e2}}{V_{b1}} \cdot \frac{V_{b1}}{V_{in}}$ (refer to (2) and (3))

$V_{be2} = -0.649 \ V_{in}$

Substitute back to the range, we get

$\boxed{|V_{in}| \leq 7.7 \ mV}$

4a.




$V_{gs4} = 0$

$V_x = i_x(r_{o4}) + \left(i_x - g_{m2} V_{gs2}\right) r_{o2} \quad \ldots (1)$

$V_{gs2} = -V_{s2} = -i_x r_{o4} \quad \ldots (2)$

Substitute (2) into (1),

$R_{out} = \frac{V_x}{i_x} = r_{o4} + \left(1 + g_{m2} r_{o4}\right) r_{o2}$

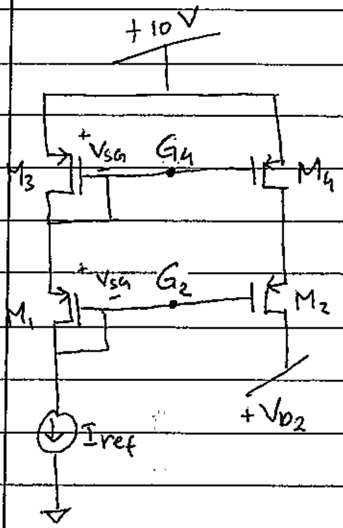
$\boxed{R_{out} = r_{o4} + r_{o2} + g_{m2} r_{o2} r_{o4}}$

4b. $r_{o2} = r_{o4} = \frac{1}{\lambda I_D} = \frac{1}{(0.01)(200\mu)} = 0.5\ M\Omega$

$g_{m2} = \sqrt{2 k_p I_D} = \sqrt{2(100\mu)(200\mu)} = 2\times10^{-4}$

$\boxed{R_{out} = 51\ M\Omega}$

4c.




For $M_2$ to be in saturation,

$V_{GS_2} < V_{TP}$

$|V_{DS_2}| \geqslant |V_{GS_2}| - |V_{TP}|$

At $G_4$ and $G_2$

$V_{G4} = 10 - V_{SG}$

$V_{G2} = 10 - 2V_{SG}$

$V_{SG}$ can be obtained from this equation:

$I_D = \frac{k_p}{2}\left(V_{SG} - |V_{TP}|\right)^2$

$V_{SG} = 2.5\ V$

Then $V_{G2} = 5\ V$.

$V_{SD2} \geqslant V_{SG2} - |V_{TP}|$

$-V_{D2} \geqslant -V_{G2} - |V_{TP}|$

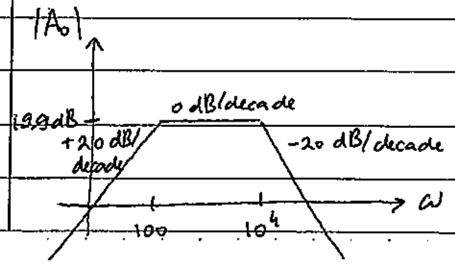
$V_{D2} \leqslant 5.5\ V$.

$\boxed{V_{D2\,max} = 5.5\ V}$

5a. $A_0 = \frac{V_{01}}{V_{in}} = -\frac{R_2 // \frac{1}{sC_2}}{R_1 + \frac{1}{sC_1}} = \frac{\frac{R_2}{1+sR_2C_2}}{\frac{1+sC_1R_1}{sC_1}} = \boxed{\frac{sR_2C_1}{(1+sR_2C_2)(1+sC_1R_1)}}$ ; $s = j\omega$

5b. $\left.\begin{array}{l}\omega_1 = 1/R_2C_2 = 10^4 \\ \omega_2 = 1/R_1C_1 = 100\end{array}\right\}$ $\omega_2 < \omega_1$, hence $\omega_L = \omega_2$, $\omega_H = \omega_1$.

When $\omega = 1000$ rad/sec, $\left|\frac{V_{01}}{V_{in}}\right| = 9.9 = 19.9$ dB.



Date No.

5c. Since the second stage is the exact copy of the first stage,

$$\frac{V_{o2}}{V_{o1}} = \frac{V_{o1}}{V_{in}}.$$

$$\frac{V_{o2}}{V_{in}} = \frac{V_{o2}}{V_{o1}} \cdot \frac{V_{o1}}{V_{in}} = \left(\frac{V_{o1}}{V_{in}}\right)^2$$

Previously, it is known that $\omega_H = \frac{1}{\sum \tau_{oc}} = \frac{1}{\tau_{oc}} = 10^4$ and $\omega_L = \sum \frac{1}{\tau_{sc}} = \frac{1}{\tau_{sc}} = 100$

Since $\tau_{oc}$ from stage 1 and stage 2 are the same (and so do $\tau_{sc}$),

$$\omega_H' = \frac{1}{\tau_{oc} + \tau_{oc}} = \frac{1}{\frac{1}{10^4} + \frac{1}{10^4}} = \boxed{5000}$$

$$\omega_L' = \frac{1}{\tau_{sc}} + \frac{1}{\tau_{sc}} = 100 + 100 = \boxed{200}$$

All the best! :)