ECE-255
Final Exam

May/01/2012

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(Please print clearly)

Student ID: Solution

INSTRUCTIONS

- This is a closed book, closed notes exam. Calculators are allowed.
- Carefully mark your multiple choice answers on the scantron form. Work on multiple choice problems and marked answers in the test booklet will not be graded. Nothing is to be on the seat beside you.
- When the exam ends, all writing is to stop. This is not negotiable. No writing while turning in the exam/scantron or risk an F in the exam.
- All students are expected to abide by the customary ethical standards of the university, i.e., your answers must reflect only your own knowledge and reasoning ability. As a reminder, at the very minimum, cheating will result in a zero on the exam and possibly an F in the course.
- Communicating with any of your classmates, in any language, by any means, for any reason, at any time between the official start of the exam and the official end of the exam is grounds for immediate ejection from the exam site and loss of all credit for this exercise.

1. A silicon sample at room temperature has an intrinsic carrier concentration of $n_i = 10^{10}\ cm^{-3}$. It is doped with $N_A = 1\times10^{18}$ boron atoms/cm^3 and $N_D = 6\times10^{12}$ arsenic atoms/cm^3. The electron mobility is measured as μ_n – 1000 cm^2/V·s. What are the electron and hole concentration in this material and electron current density when an external field of E=100 V/cm is applied?
(q=1.6x10^{-19} C)

(1) p =1x10^{18} /cm^3; n =6x10^{12} /cm^3; j_n =9.6x10^{-2}A/cm^2
(2) p =1x10^{10} /cm^3; n =6x10^{12} /cm^3; j_n =1.6x10^{-4}A/cm^2
(3) p =6x10^{12} /cm^3; n =1x10^{18} /cm^3; j_n =1.6x10^{4}A/cm^2
✓ (4) p =1x10^{18} /cm^3; n =100 /cm^3; j_n =1.6x10^{-12}A/cm^2
(5) p –1x10^{18} /cm^3; n –100 /cm^3; j_n –1.6x10^{4}A/cm^2
(6) None of the above

$n + N_A = p + N_D$ $\qquad pn = n_i^2 \Rightarrow p = n_i^2/n$

$n + 10^{18} = 10^{20}/n + 6\times10^{12}$

$n^2 + 10^{18} n = 6\times10^{12} n + 10^{20}$

$n^2 + 10^{18} n - 10^{20} = 0 \Rightarrow n \sim 100\ /cm^3$

$p = n_i^2/n = 10^{20}/100 = 10^{18}\ /cm^3$

$J_n = q n \mu_n E = 1.6\times10^{-19} \times 10^2 \times 1000 \times (100)$

$= 1.6\times10^{-12}\ A/cm^2$

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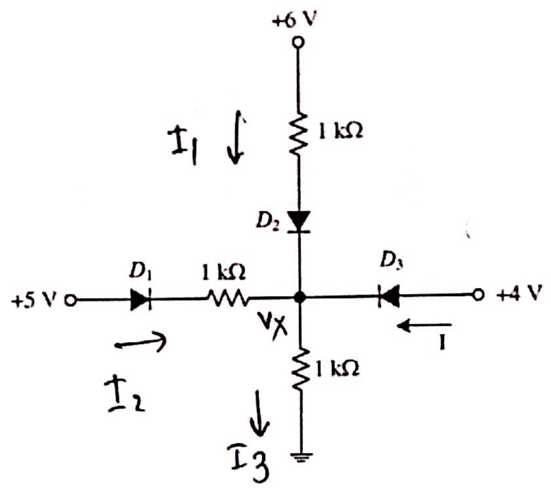
2. For the diode circuit below, determine the current, I (indicated in the graph), using the constant voltage model with Von =0.7V.



(1) I =0A
(2) I =0.3mA
(3) I =2.7mA
(4) I =3.3mA
(5) I =3.7mA
(6) None of the above

$V_x = 4 - 0.7 = 3.3V$

$$I_1 = \frac{6 - 0.7 - 3.3}{1K} = 2\,mA$$

$$I_2 = \frac{5 - 0.7 - 3.3}{1K} = 1\,mA$$

$$I_3 = \frac{V_x}{1K} = 3.3\,mA$$

$I_1 + I_2 + I = I_3 \Rightarrow I = 3.3 - (3)$

$= 0.3\,mA$

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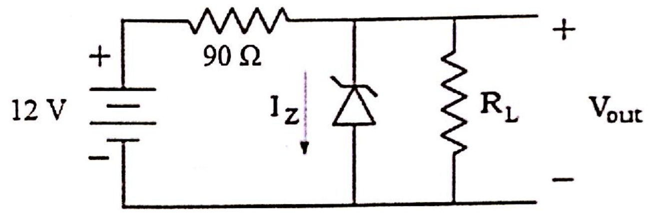
3. In the circuit below, the Zener diode has a breakdown voltage $V_{Z0} = 8.0$ V and a measurement has shown that $V_Z = 8.2$ V when $I_Z = 20$ mA. What is the value of V_{out} when R_L is infinitely large?



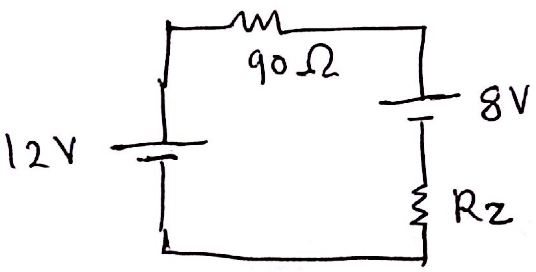
(1) V_{out} – 0 V
(2) V_{out} = 8.2 V
(3) V_{out} = 8.8 V
✓(4) V_{out} = 8.4 V
(5) V_{out} = 8.0 V
(6) None of the above

$V_Z = V_{Z0} + I_Z R_Z$

$8.2 = 8 + 20(R_Z)$

$\Rightarrow R_Z = 0.2/20 = 10\,\Omega$

When R_L is ∞, No current through R_L



$4 = I(90+10) = I(100)$

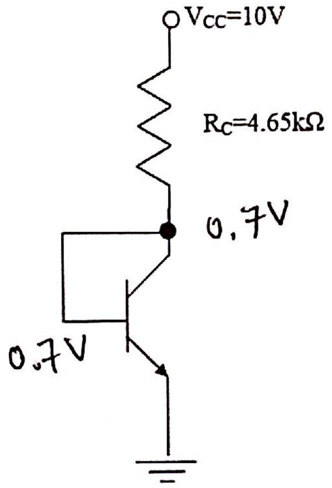
$I = 40$ mA

$V_{out} = V_{Z0} + I_Z R_Z$

$= 8 + (40(10)/1000)$

$= 8 + 0.4 = \underline{8.4\text{V}}$

4. Determine the collector current, Ic, for the following BJT circuit.
β_F=99, V_{BE}(on)=0.7V.



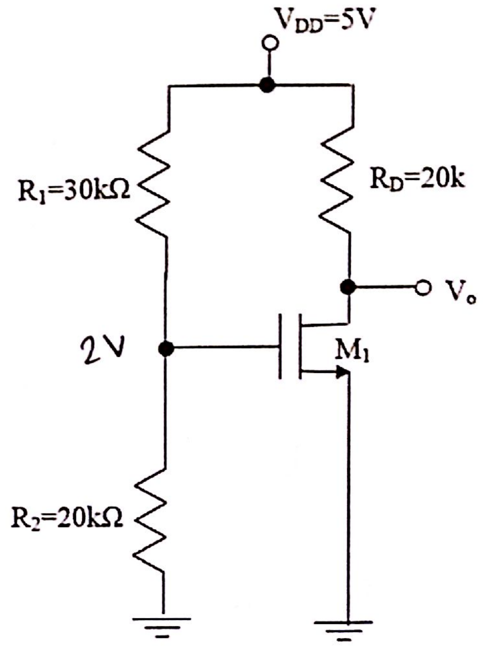
$$I_E = \frac{10-0.7}{4.65} = \frac{9.3}{4.65} = 2\ mA$$

$$I_C = \alpha I_E = \frac{99}{100}(2) = 1.98\ mA$$

(1) Ic –2mA
(2) Ic –1.98mA ✓
(3) Ic =2.15mA
(4) Ic =0.02mA
(5) Ic =1.435mA
(6) None of the above

5. For the MOS circuit shown below, what is the output voltage, V_o?
$\lambda=0$, $V_{TN}=1V$, $K_N=0.3\ mA/V^2$

✓(1) $V_o=2V$
(2) $V_o=2.5V$
(3) $V_o=3V$
(4) $V_o=3.5V$
(5) $V_o=4V$
(6) None of the above



$V_G = \frac{20}{20+30}(5) = 5\left(\frac{2}{5}\right) = 2V$

$V_{GS} = 2V > V_{tN}$

$V_{GS} - V_{tN} = 1V$

assuming sat^n $\quad I_D = \frac{1}{2}K_N(V_{GS}-V_{tN})^2$

$= \frac{1}{2}(0.3)(1)^2 = 0.15\ mA$

$V_o = 5 - I_D R_D = 5 - 20(0.15) = 5-3 = 2V$

$V_{DS} = 2V > V_{GS} - V_{tN}$

confirmed sat^n

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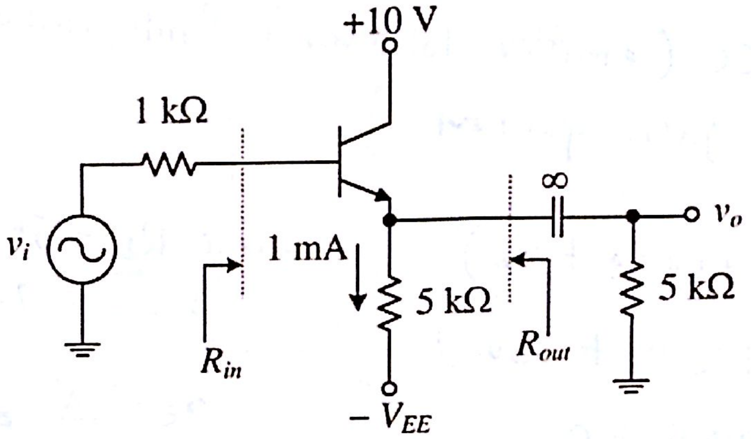
6. Determine the voltage gain, input resistance and output resistance (both are indicated in the graph) of the amplifier circuit shown below.
β_o −80, V_A −∝, V_T −25mV.

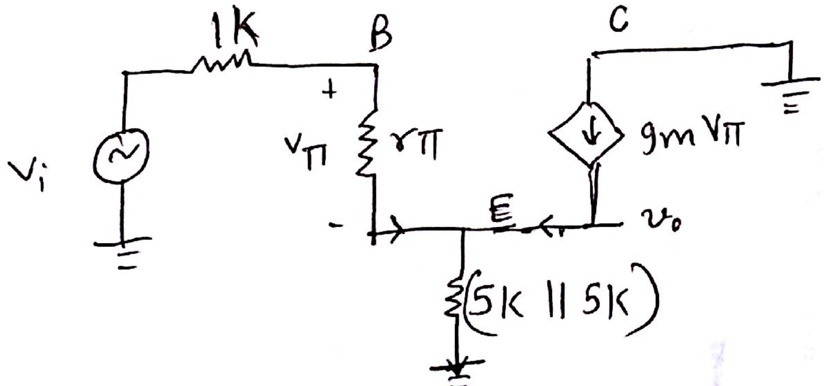


(1) $A_v \approx 1$; $R_{in} = 204.5k\Omega$; $R_{out} \approx 37\Omega$
(2) $A_v \approx 100$; R_{in} −20kΩ; $R_{out} \approx 37\Omega$
(3) $A_v \approx -100$; $R_{in} = 2k\Omega$; $R_{out} \approx 2.5k\Omega$
(4) $A_v \approx 1$; $R_{in} = 400k\Omega$; $R_{out} \approx 25\Omega$
(5) $A_v \approx 100$; R_{in} −1kΩ; $R_{out} \approx 5k\Omega$
(6) None of the above ✓

$I_C = \alpha I_E$
$= \frac{80}{81}(1)$
$= 0.99\ mA$
$\sim 1\ mA$

$g_m = I_C / V_T = \frac{1}{25} = 40\ mA/V$

$r_\pi = \frac{\beta}{g_m} = \frac{80}{40} = 2K\Omega$



$\frac{V_\pi}{r_\pi} + g_m V_\pi = \frac{v_o}{2.5K}$

$\left(\frac{1}{r_\pi} + g_m\right)\left(\frac{v_i - v_o}{1 + 1K/r_\pi}\right) = \frac{v_o}{2.5K}$

$\frac{(40.5)}{1.5}(v_i - v_o)(2.5) = v_o$

$\frac{v_i - (V_\pi + v_o)}{1K} = \frac{V_\pi}{r_\pi}$

$v_i - V_\pi - v_o = \frac{1K}{r_\pi} V_\pi$

$v_i - v_o = V_\pi\left(1 + \frac{1K}{r_\pi}\right)$

$\Rightarrow 67.5(v_i - v_o) = v_o$

$\Rightarrow 67.5 v_i = 68.5 v_o$

$\Rightarrow \frac{v_o}{v_i} = 0.985$

This is CC (emitter follower) Configuration. You can directly guess gain ≈ 1

$R_{in} = (\beta + 1)(r_e + R_L)$ where $R_L = 5K \parallel 5K = 2.5 K\Omega$

$= (81)(25 + 2500)$

$= 204.5 \ K\Omega$

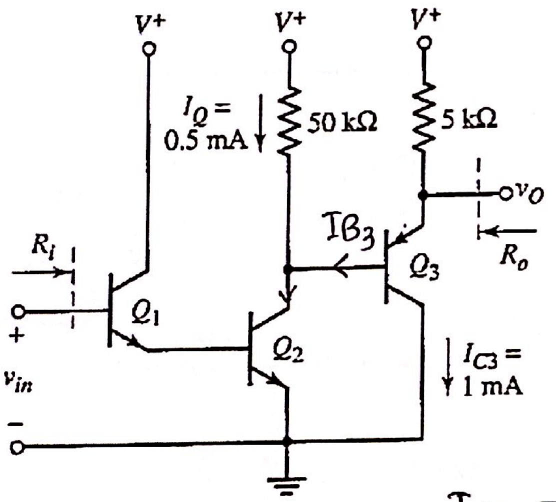
$r_e = \frac{\alpha}{g_m} \approx 1/g_m = 25\ \Omega$

$R_{out} = r_e \parallel 5K\Omega$

$= \frac{\alpha}{g_m} \parallel 5K\Omega$

$= 25\Omega \parallel 5K\Omega \approx 25\ \Omega$

7. Determine the input resistance, R_i, for the amplifier circuit below (currents for Q_2 and Q_3 are indicated in the figure, and it needs to be calculated for Q_1). Assume β_0–100, V_A–∞, V_{BE}(on)–0.7V, V_T–25mV for all BJTs, and V+–5V.



$$I_{B3} = \frac{I_{C3}}{\beta} = \frac{1}{100} = 0.01 \text{ mA}$$

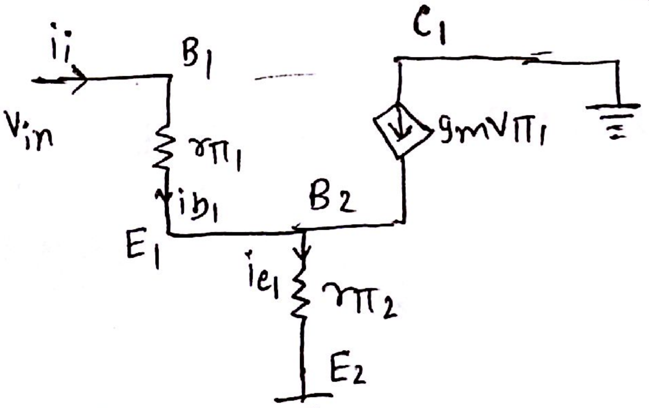
$$I_{C2} = 0.5 + 0.01 = 0.51 \text{ mA}$$

(1) ≈ 500kΩ
(2) ≈ 5kΩ
(3) ≈ 250kΩ
(4) ≈ 1.5MkΩ
(5) ≈ 1MΩ
(6) None of the above

$$\boxed{R_i = r_{\pi 1} + (\beta+1) r_{\pi 2}}$$

$$I_{E1} = I_{B2} = I_{C2}/\beta = 5.1 \ \mu A$$

$$I_{C1} = \alpha I_{E1} \approx 5.1 \ \mu A$$



$$r_{\pi 1} = \frac{\beta}{g_{m1}} \qquad g_{m1} = \frac{I_{C1}}{V_T} \Rightarrow r_{\pi 1} = \beta \frac{V_T}{I_{B1}}$$

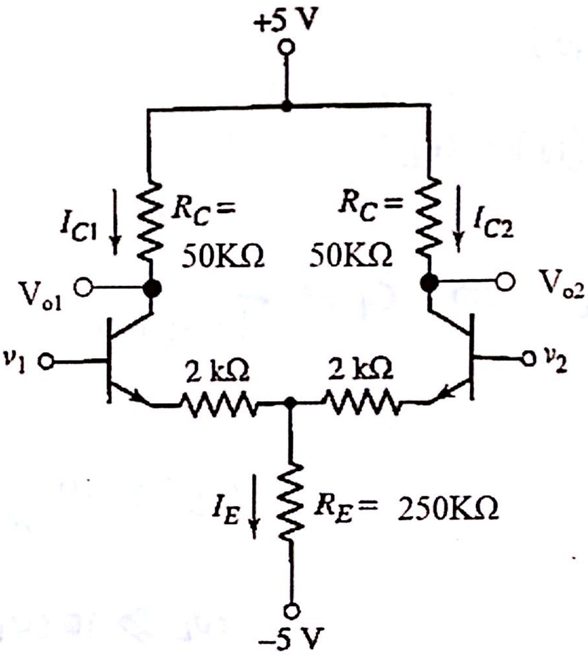
$$= \frac{25}{5.1} \times 100 \times 10^3$$

$$= 490 \text{ k}\Omega$$

$$r_{\pi 2} = \frac{V_T}{I_{B2}} = \frac{25}{5.1} \times 10^3 = 4.9 \text{ k}\Omega$$

$$R_i = 490 + (101)\, 4.9 \approx 490 + 490 \approx 980 \text{ k}\Omega$$

8. What are the common-mode gain ($|Av_c|$) and differential mode gain ($|Av_d|$) for the circuit shown below? Assuming β_0>>1.



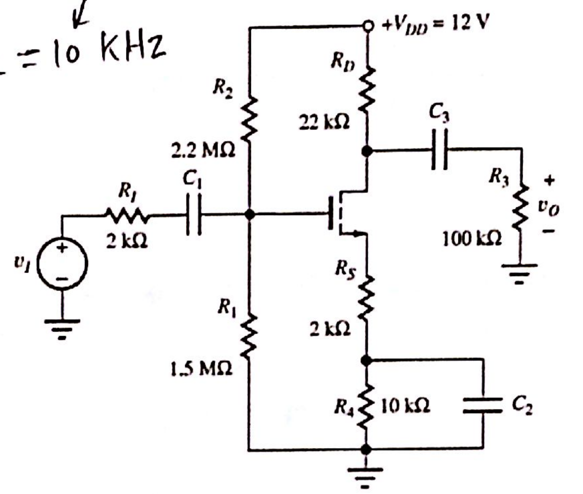
(1) $|Av_c| \approx 0.1$; $|Av_d| \approx 10$
(2) $|Av_c| \approx 0.1$; $|Av_d| \approx 33$
(3) $|Av_c| \approx 0.2$; $|Av_d| \approx 50$
✓(4) $|Av_c| \approx 0.1$; $|Av_d| \approx 25$
(5) $|Av_c| \approx 25$; $|Av_d| \approx 0.1$
(6) None of the above

For solution, look at Final Exam Fall 2013 : Q12

9. Choose the value of C_1 so that it can be neglected at frequencies larger than the low cutoff frequency, f_L = 10 kHz. We use □ □ 10 $\frac{□}{□□□}$ as the design rule.

$\rightarrow C_1 \geq 10 \frac{1}{\omega_L R_{1S}}$

$f_L = 10$ KHz



$\omega_L = 2\pi(10)$ Krad/s

(1) $C_1 > 79$ nF
(2) $C_1 > 72.3$ pF
(3) $C_1 > 106$ pF
(4) $C_1 > 0.0178$ nF
(5) $C_1 > 0.178$ nF ✓
(6) None of the above

$\omega_1 = \frac{1}{R_{1S} C_1}$

$\omega_1 << \omega_L$

$10\,\omega_1 \leq \omega_L$

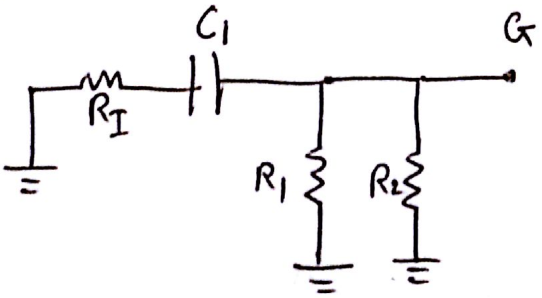
$\Rightarrow \frac{10}{R_{1S} C_1} \leq \omega_L$

$\Rightarrow C_1 \geq \frac{10}{\omega_L R_{1S}}$

$R_{1S} = (R_2 \parallel R_1) + R_I$
$= (1.5 \parallel 2.2)$ MΩ + 2KΩ
$= 0.891$MΩ + 2KΩ
$= 891.9 + 2 = 893.9$ KΩ

$C_1 \geq \frac{10}{2\pi(10) * 893.9 \cdot 10^6}$

$C_1 \geq 0.178$ nF



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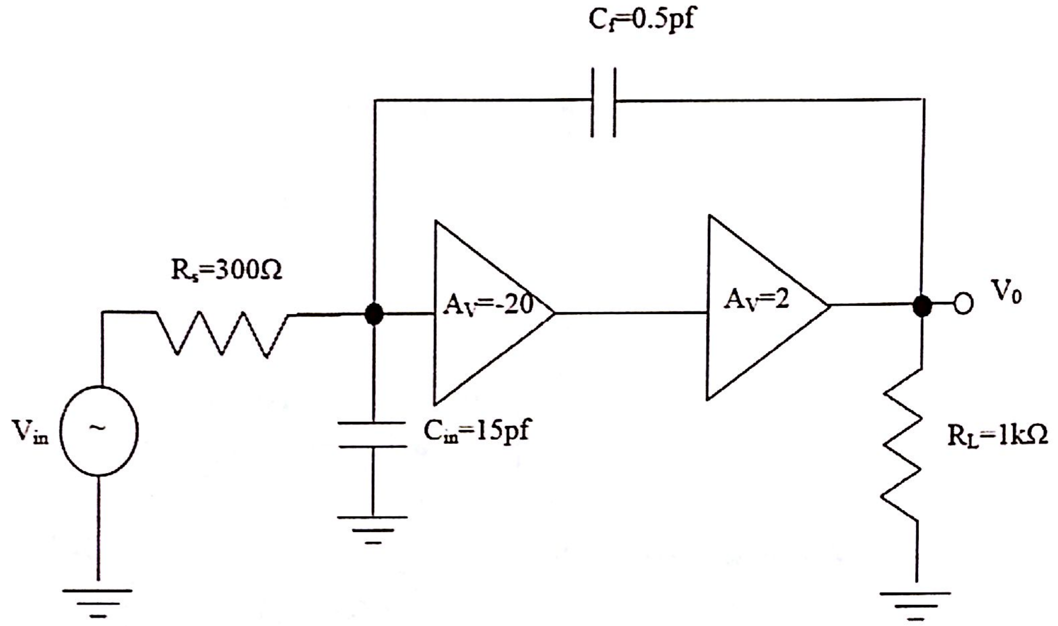
10. For the amplifier circuit shown below, calculate upper- cutoff frequency, f_H.

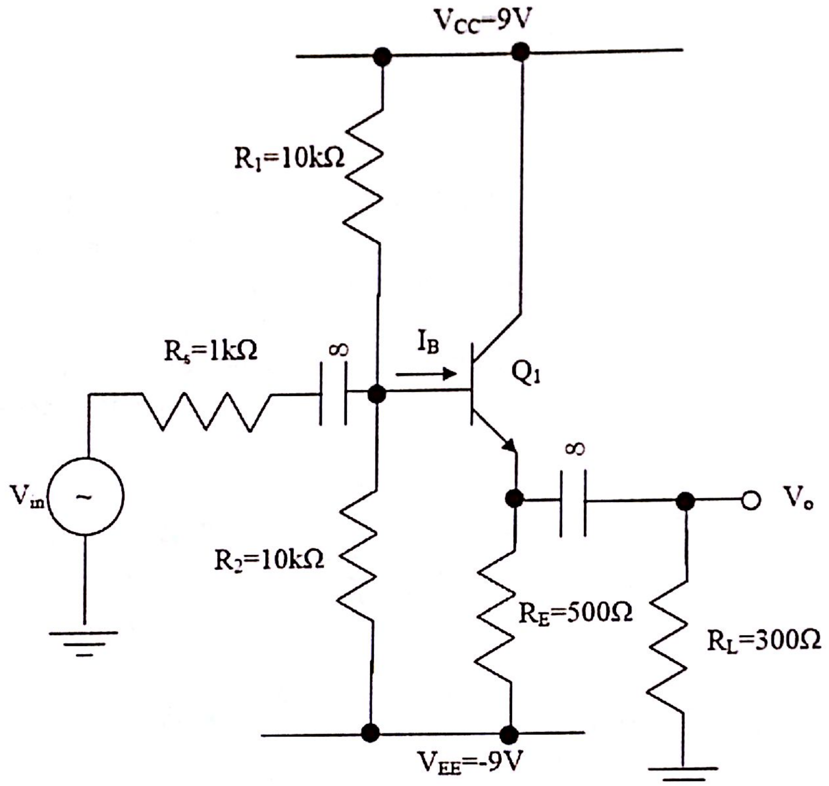


(1) ~94MHz
(2) ~15MHz ✓
(3) ~35MHz
(4) ~50MHz
(5) ~10MHz
6) Non of the above

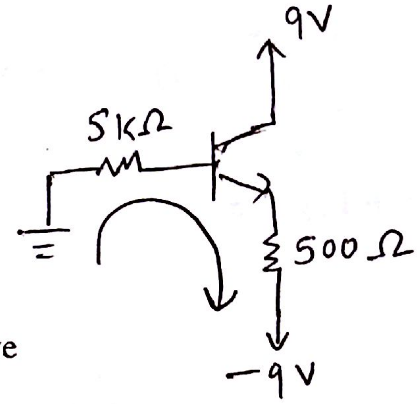
For Solution look at

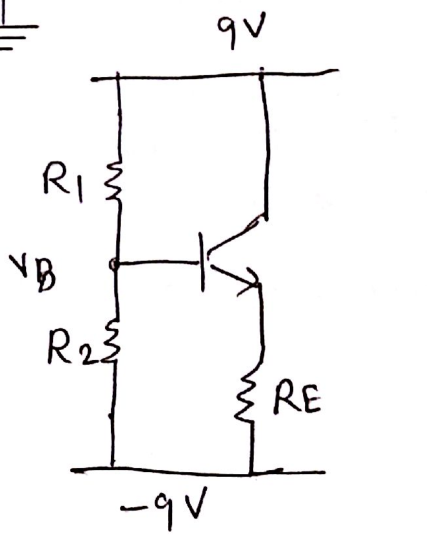
Final Exam Fall 2013 : Q 20

11. For the amplifier circuit shown below I_B=?
Assume β=180, $V_A=\infty$, and $V_{BE}(on)$=0.7V



(1) ~87μA ✓
(2) ~182μA
(3) ~7.3μA
(4) ~1.4mA
(5) 100μA
(6) None of the above





$$V_{th} = 18\left(\frac{R_2}{R_1+R_2}\right) - 9$$

$$= 18\left(\frac{10}{20}\right) - 9 = 0V = V_B$$

$$R_{th} = R_1 \parallel R_2 = 5K\Omega$$

$$-9 + I_E(500) + 0.7 + I_B(5K) = 0$$

$$\Rightarrow 8.3 = [(\beta+1)(500) + 5000]\, I_B \Rightarrow I_B = 86.9\ \mu A$$

12. Mid-band gain (A_{mid}), lower cutoff frequency (ω_L), and higher cutoff frequency (ω_H) for the amplifier transfer function given below are

$$A_v(s) = \frac{4\times10^8 s^2}{(s+1)(s+2)(s+1000)(s+2000)}$$

(1) A_{mid}=4x10[8], ω_L=2 rad/s, ω_H=1000 rad/s
(2) A_{mid}=200, ω_L=1 rad/s, ω_H=816.5 rad/s
(3) A_{mid}=400, ω_L=2.24 rad/s, ω_H=1000 rad/s
(4) A_{mid}=200, ω_L=2.24 rad/s, ω_H=2000 rad/s
✓(5) A_{mid}=200, ω_L=2.24rad/s, ω_H=894 rad/s
(6) None of the above

$$A_v(s) = \frac{4\times10^8 s^2}{(s+1)(s+2)\,10^3(1+s/1000)\,2\times10^3(1+s/2000)}$$

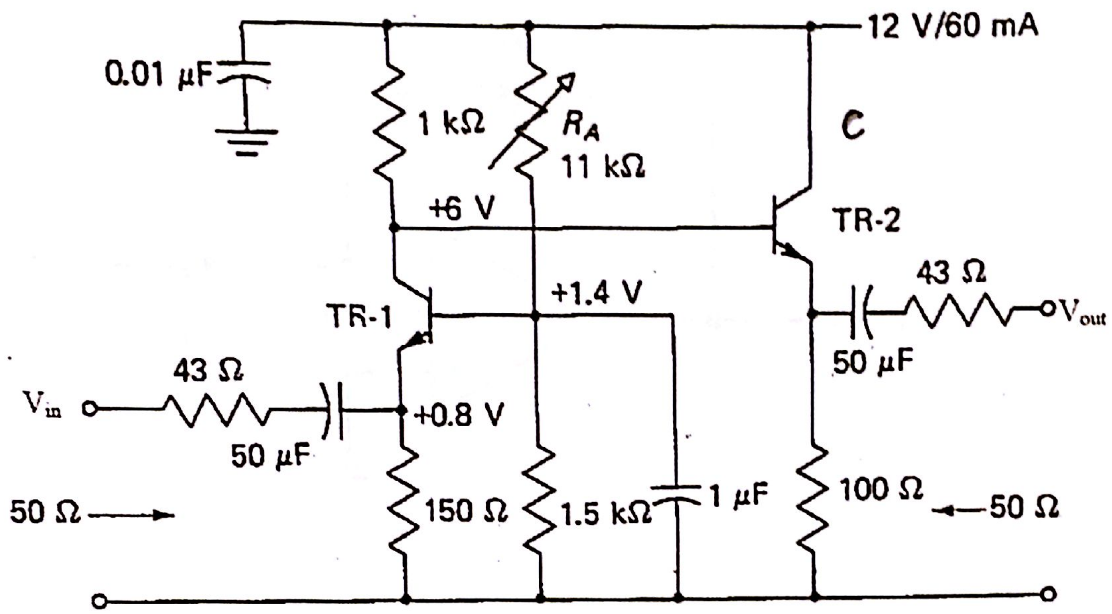
$$= \frac{4\times10^8}{2\times10^6} \cdot \frac{s^2}{(s+1)(s+2)} \cdot \frac{1}{(1+s/1000)(1+s/2000)}$$

$A_{mid} = 200$

$\omega_L = \sqrt{1^2+2^2} = \sqrt{5} = 2.24$ rad/s

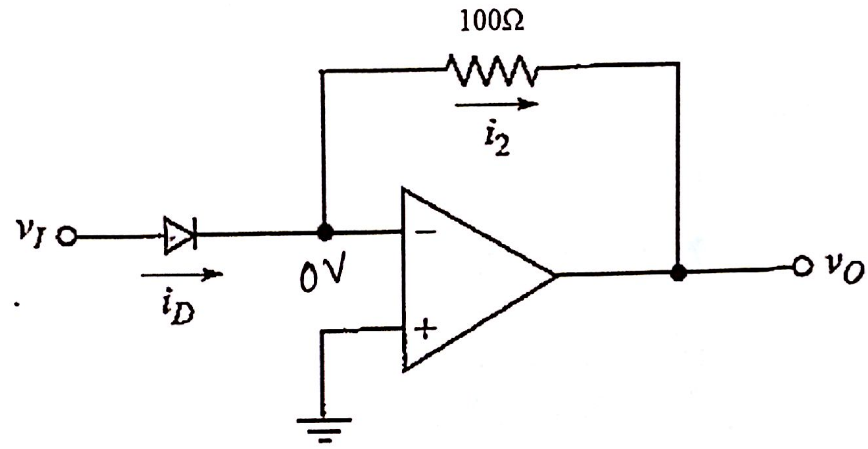
$\omega_H = \dfrac{1}{\sqrt{\frac{1}{10^6}+\frac{1}{4\times10^6}}} = 894$ rad/s

13. What is the configuration of the multi-stage amplifier shown below?



(1) CB-CC
(2) CE-CC
(3) CB-CB
(4) CC-CC
(5) CB-CE
(6) None of the above

14. What is V_o? if V_i=0.725V and $I_s=10^{-14}$A (Assume V_T=25mV)



(1) 0V
(2) -0.725V
(3) -3.9V ✓
(4) -0.1V
(5) -2.5V
(6) None of the above

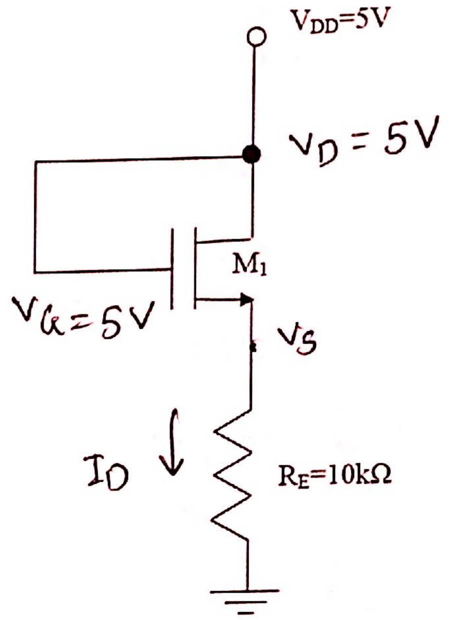
$I_D = I_S\, e^{(V_D/V_T)} \Rightarrow i_D = 10^{-14}\, e^{(0.725/0.025)}$

$= 3.93 \times 10^{-2}$ A

$i_2 = i_D = -\frac{v_o}{100} = 3.93 \times 10^{-2} \Rightarrow v_o = -3.93$ V

15. For the MOS circuit shown below, I_D=?

V_{TN}=1V, K_N=0.1 mA/V²



(1) 0.1mA
(2) 0.4mA
(3) 0.5mA
✓(4) 0.2mA
(5) 1mA
(6) None of the above

$I_D = \frac{1}{2} K_n (V_{GS} - V_{TN})^2$ $\qquad V_S = I_D R_E$

$I_D = \frac{1}{2}(0.1)(5 - I_D R_E - 1)^2$ $\qquad V_G = V_D \Rightarrow$ satn region

$= \frac{1}{2}(0.1)(4 - I_D R_E)^2$

$\Rightarrow I_D = 0.2\,mA$ $\qquad V_S = 2V,\ V_{DS} = 3V$

~~$V_{GS} - V_{tN} = 3$~~

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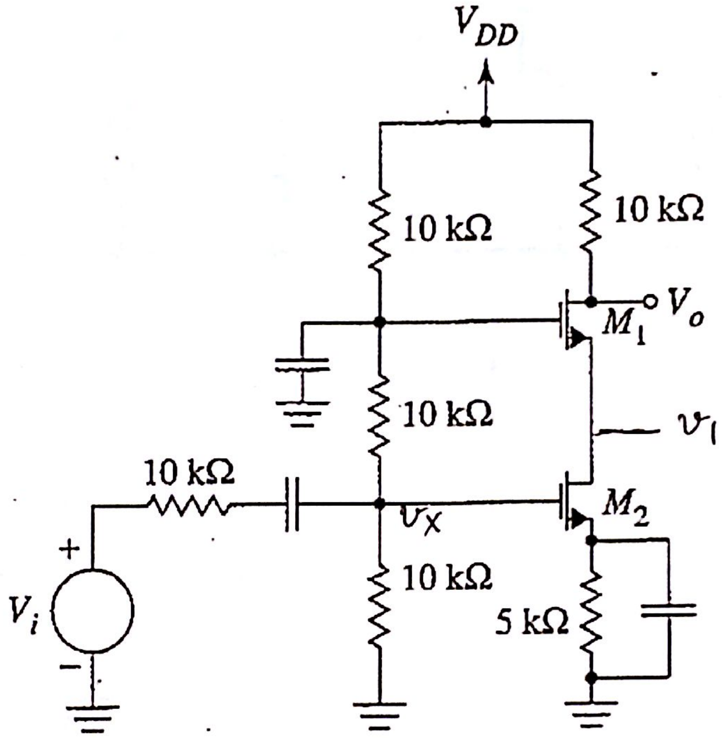
16. Figure below shows a cascode MOSFET, what is the mid-band gain ($A_v = V_o/V_i$)? Assume g_m=2mA/V and λ=0 for both transistors



(1) -20
(2) -400
(3) -2
(4) -100
(5) -6.67 ✓
(6) None of the above

M_2 (CS)

$$\frac{v_1}{v_X} = -g_m R_D = -g_m\left(\frac{1}{g_m}\right) = -1$$

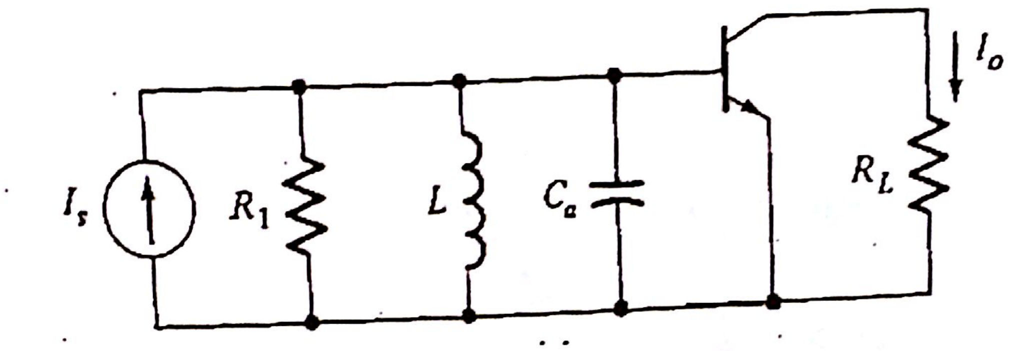
↓ input imp. of M_1

M_1 (CG) $\quad \frac{v_o}{v_1} = g_m R_D = g_m(10K) = 20$

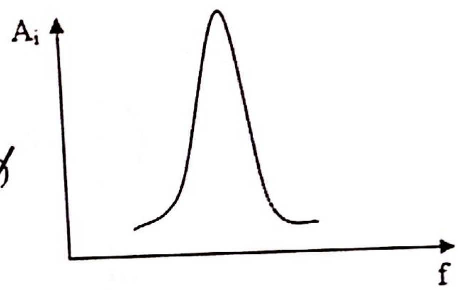
$$\frac{v_X}{v_i} = \frac{(10K \parallel 10K)}{(10K \parallel 10K) + 10K} = \frac{5K}{15K} = \frac{1}{3}$$

$$A_v = \frac{v_o}{v_i} = \frac{v_1}{v_X}\,\frac{v_X}{v_i}\,\frac{v_o}{v_1} = (-1)(20)\left(\frac{1}{3}\right) = -6.67$$

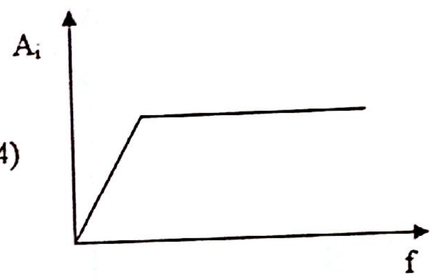
17. Which one of the current gain (A_i) frequency response curves belong to the amplifier shown below?



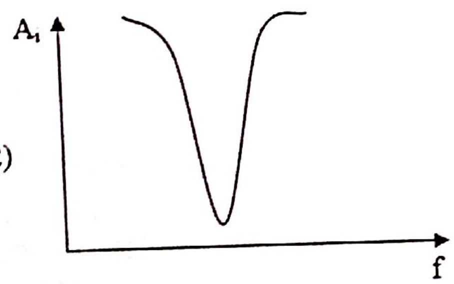
(1)



(4)

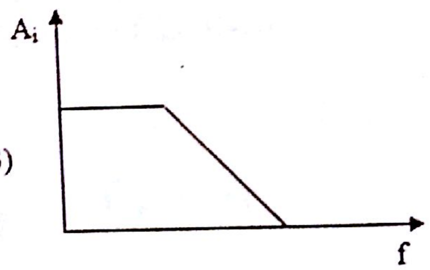


(2)



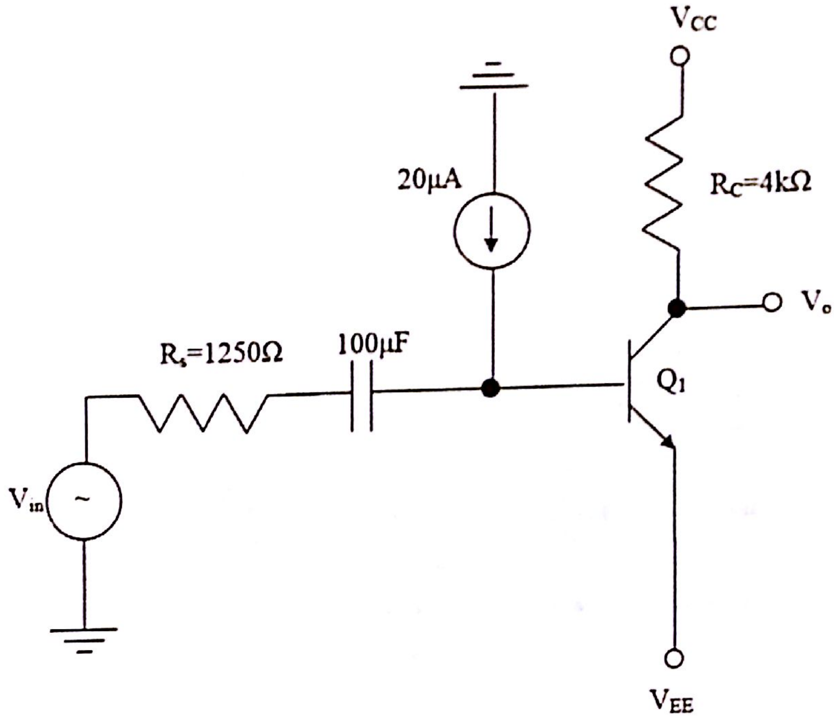
(5) Circuit cannot provide any current gain

(3)



(6) None of the above

18. For the amplifier circuit shown below estimated value of f_L is? For BJT assume $\beta=150$, $V_A=75V$, $V_{BE}(on)=0.7$, $V_T=25$ mV.



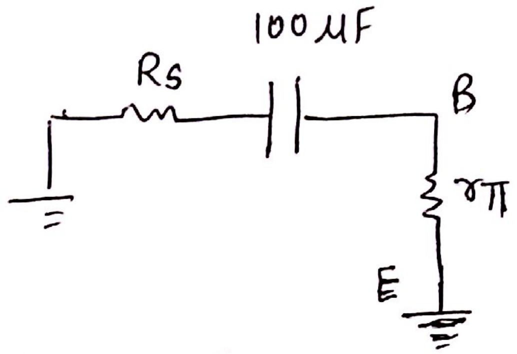
$I_B = 20\,\mu A$

$r_\pi = V_T / I_B$

$= 25/20$

$= 1.25\ K\Omega$

(1) ~1kHz
(2) ~10Hz
(3) ~ 0.64Hz ✓
(4) 0Hz
(5) ~2.5Hz
(6) None of the above



$R_{eq} = R_S + r_\pi$

$= 1.25\ K + 1.25 = 2.5\ K\Omega$

$f_L = \frac{1}{2\pi (R_{eq}) C} = \frac{\cancel{1000}\ 2}{2\pi (\cancel{2.5})(1\cancel{00})} = 0.64\ Hz$

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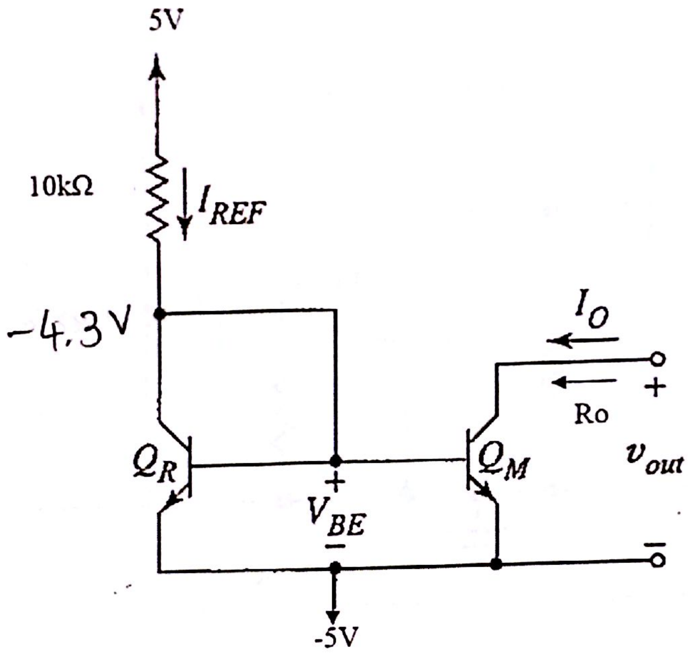
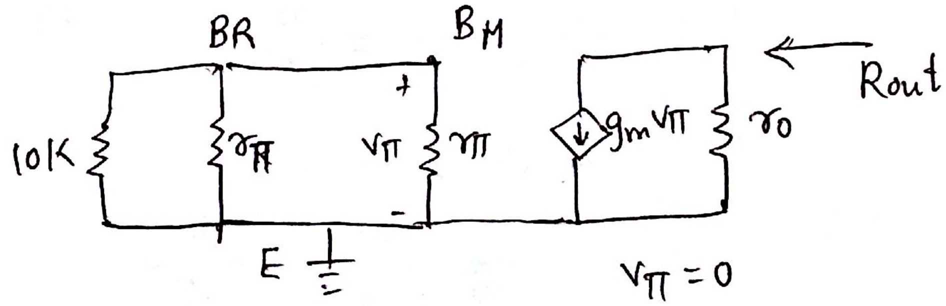
19. What is the value of output impedance (Ro) for the current mirror shown below? Assume β=∞, $V_{BE}(ON)=0.7V$, $V_A=75V$. Two transistors are identical



(1) 40 kΩ
(2) ∞
(3) 174 kΩ
(4) 81 kΩ ✓
(5) 500 kΩ
(6) None of the above

$I_o \doteq I_{Ref} = \frac{5+4.3}{10K}$

$= 0.93$ mA



$V_\pi = 0$

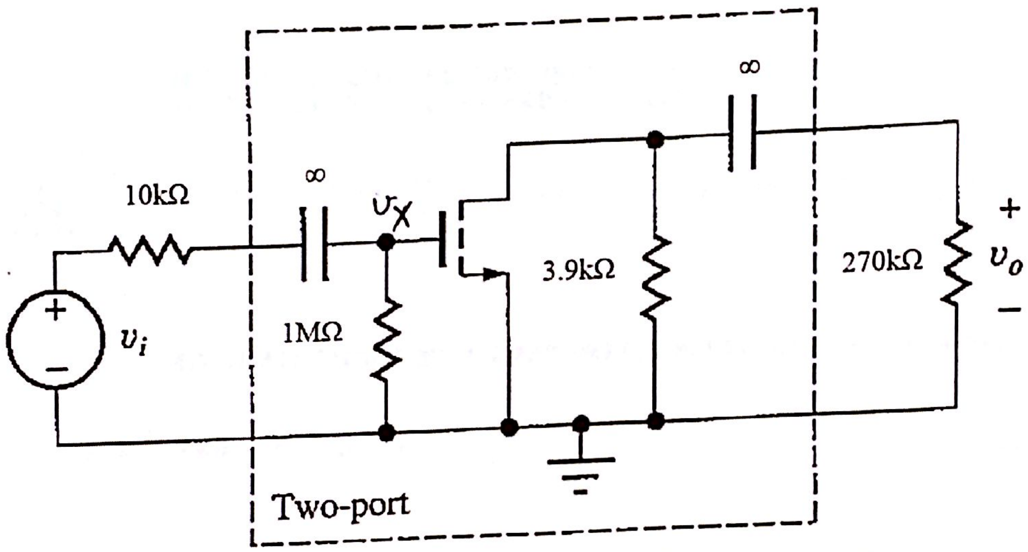
$R_{out} = r_o$

$= \frac{V_A}{I_C}$

$= 75/0.93$

$= 80.65$ KΩ

20. What is the voltage gain (v_0/v_i) for the amplifier below? Assume the MOSFET Q points are (2mA, 7.5V), K_n=1mA/V^2, and λ=0



(1) -7.8
✓(2) -7.61
(3) -540
(4) -25
(5) gain is zero since we ignored the channel length modulation
(6) None of the above

$g_m = \sqrt{2 K_n I_D}$
$= \sqrt{2(1)(2)}$
$= 2$ mA/V

CE

$\frac{v_o}{v_x} = -g_m (R_D \parallel R_L)$
$= -2(3.9 \parallel 270) = -7.69$

$\frac{v_x}{v_i} = \frac{1M}{1M + 10K} = 0.99$

$\frac{v_o}{v_i} = \frac{v_o}{v_x} \times \frac{v_x}{v_i} = -7.61$