ECE-255 Final Exam
December 13, 2013

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(Please print clearly)

Student ID: Solution

INSTRUCTIONS

- This is a closed book, closed notes exam.
- Clearly mark your multiple choice answers in the scantron.
- 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.

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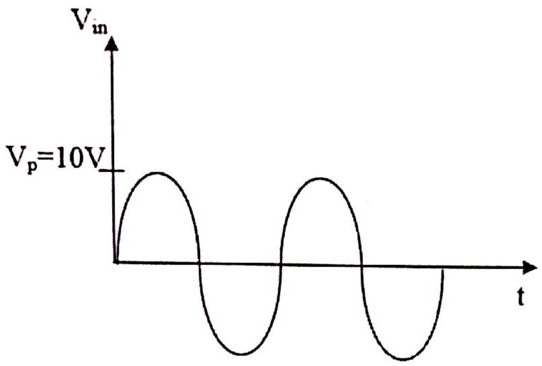
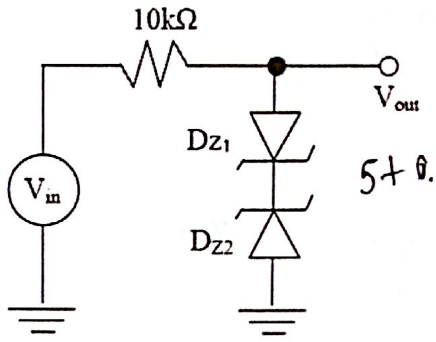
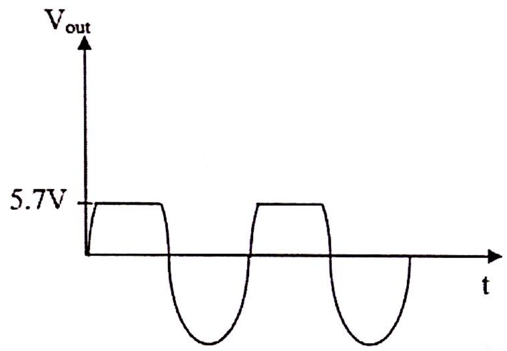
1) For the circuit shown below, if a sinusoidal wave with a peak voltage of 10 V is applied to the input, which one of the curves represent the output voltage? (V_{on}=0.7V, V_Z=5V)



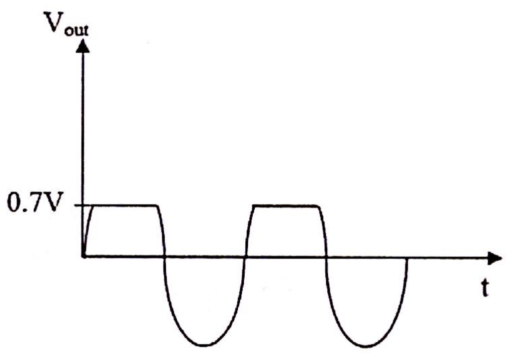


5+0.7 = 5.7V

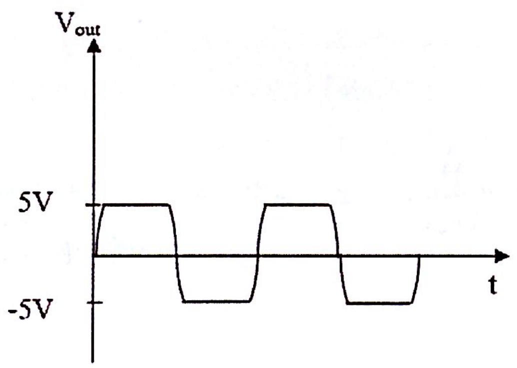
(1)



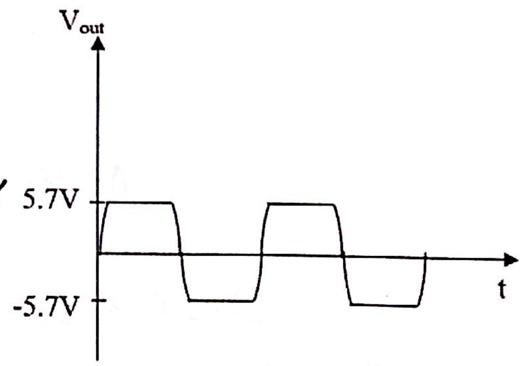
(2)



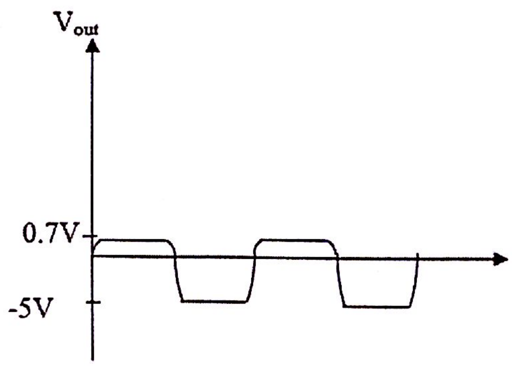
(3)



✓ (4)



(5)



(6) None of these

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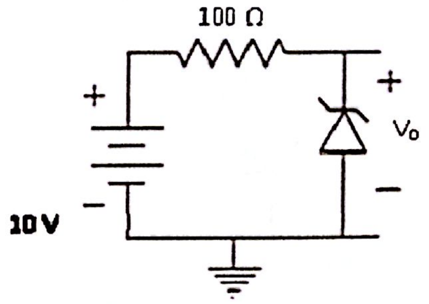
2) The Zener diode in the circuit has an equivalent resistance $R_Z = 20\ \Omega$. From the diode data sheet we find that if the voltage across the Zener diode is 6.4 V at $I_Z - 20$ mA. Determine the output voltage V_{out}.

(1) V_{out} =6.4V (2) V_{out} =6.0V

(3) V_{out} =6.67V (4) V_{out} =5.33V

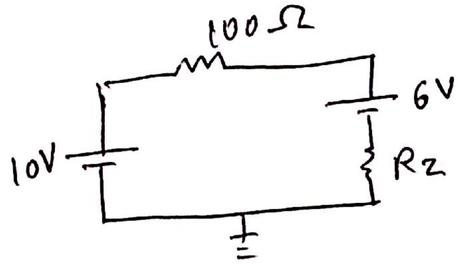
(5) V_{out} =10 V (6) None of the above



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

$$6.4 = V_{Z0} + 20(20)\ \text{mV}$$

$$V_{Z0} = 6.4 - 0.4 = \underline{6\ V}$$



$$\frac{10-6}{100+20} = I_Z = \frac{4}{120} = 0.033\ A$$

$$V_o = 6 + I_Z R_Z$$
$$= 6 + (0.033)(20)$$
$$= 6.67V$$

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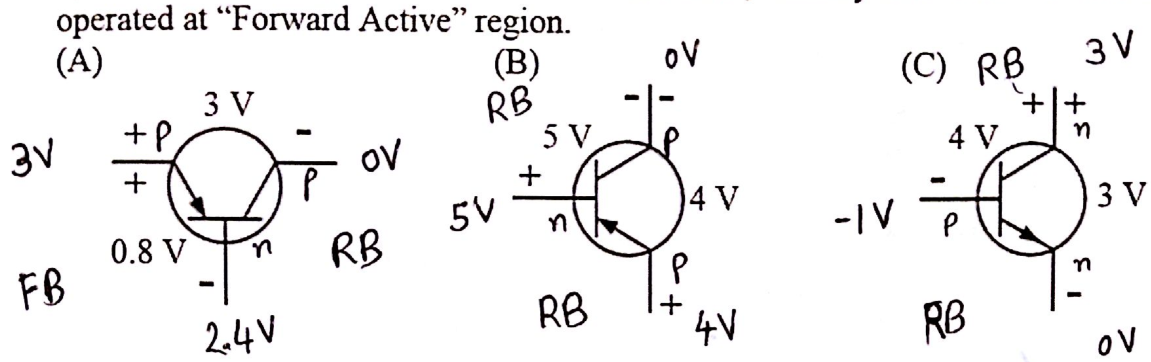
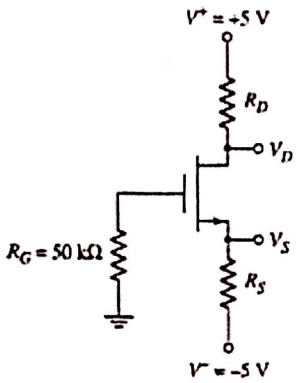
3) For the three bipolar transistors shown below, identify which one or two devices are operated at "Forward Active" region.



Which device or devices are operated at "Forward active regions"?

(1) A
(2) C
(3) B
(4) A and B
(5) B and C
(6) None of the above.

4) MOSFET circuit:



<u>Circuit Values:</u>
$I_D = 2.5$ mA
$R_D = 1$ kΩ
$R_S = 1$ kΩ

<u>MOSFET Values:</u>
$V_{TN} = 1.5$ V
$k_n' = 1$ mA/V^2
$\lambda = 0$ V^{-1}

(a) Determine the MOSFET's DC drain-to-source voltage, V_{DS}. (b) What is the (W/L) ratio required for the MOSFET to satisfy the above biasing conditions?

(1) -4V;10.0 (2) 5V;2.5 (3) 3V;2.5
(4) 4V;2.0 (5) 5V;5.0 (6) None of the above

$V_G = 0$ V, $V_D = 5 - I_D R_D = 5 - (2.5)(1) = 2.5$ V

$V_S = -5 + I_D R_S = -5 + (2.5)(1) = -2.5$ V

$\underline{V_{DS} = 5\text{ V}}$

$V_{GS} = 2.5\text{V} > V_{tN} = 1.5\text{V}$ $V_{DS} > V_{GS} - V_{tn}$ (sat^n)

$I_D = \frac{1}{2} k_n' \frac{W}{L} (V_{GS} - V_{tn})^2$

$2.5(2) = \frac{W}{L}(1)^2 \Rightarrow \underline{\frac{W}{L} = 5}$

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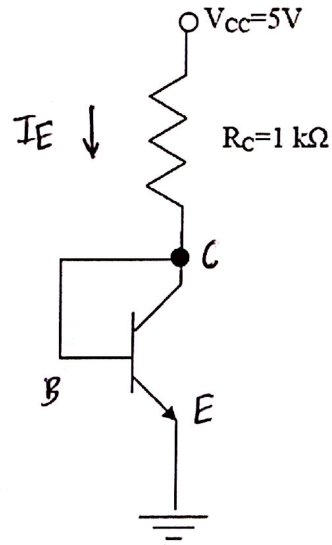
5) For the bipolar circuit shown below, I_C?

$\beta=80$, $V_{BE}(on)=0.7$, $V_T=25$ mV



(1) 4.3mA (2) 28.7µA (3) 2.87mA ✓(4) 4.25mA
(5) 0.425mA (6) None of the above

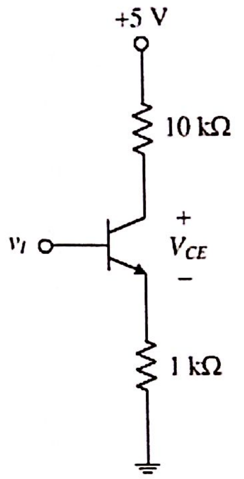
$V_C = V_B = 0.7V$

$V_C = V_B$ (ensures FA region)

$I_E = \frac{5-0.7}{1} = 4.3$ mA

$I_C = \alpha I_E = \frac{\beta}{\beta+1} I_E = \frac{80}{81}(4.3) = 4.25$ mA

6) Find the value of V_{CE} in the BJT circuit shown below for v_I =0V.



BJT Values:

$\beta = 200$
$V_{BE\ ON} = 0.7$ V
$V_{CE\text{-}SAT} = 0.1$ V
$V_A = \infty$ V
$V_T = 26$ mV

(1) 0V	(2) 0.1V	(3) 0.7V
(4) 1.3V	(5) 5V ✓	(6) None of the above

$V_I = 0V$

If transistor is ON, $V_{BE} = 0.7V \Rightarrow V_E = -0.7V$

But then direction of current is into the Emitter which is not possible. so transistor is off. No current.

$V_E = 0V, \quad V_C = 5V \Rightarrow V_{CE} = 5V$

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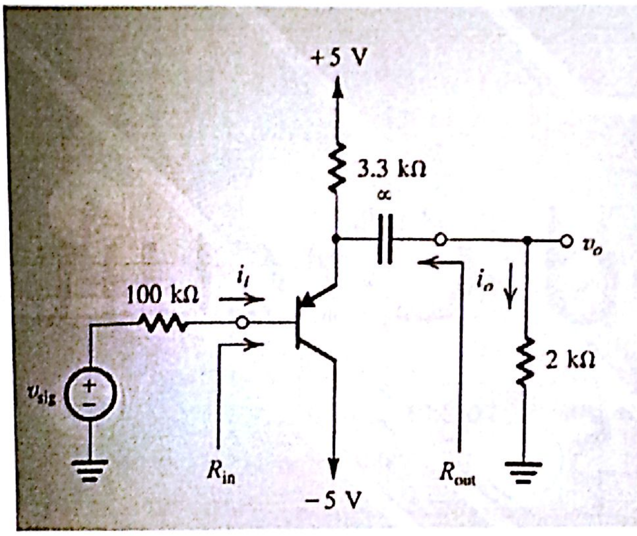
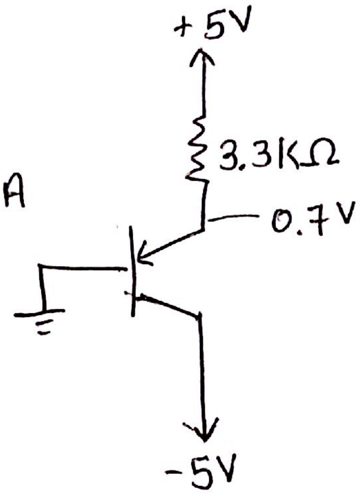
7) The value of g_m in the BJT transistor shown below is? Assume β=50, V_{BE}(on)=0.7, V_T–25 mV.



(1) 16 mA/V
(2) 8 mA/V
(3) 32 mA/V
(4) 25 mA/V
(5) 64 mA/V
(6) None of the above

DC analysis,



$$I_E = \frac{5-0.7}{3.3} = \frac{4.3}{3.3} = 1.3\ mA$$

$$I_C = \alpha I_E = \frac{50}{51}(1.3) = 1.28\ mA$$

$V_{EC} > 0.2V \Rightarrow$ confirmed FA

$$g_m = I_C/V_T$$

$$= 1.28/25 = 51.2\ mA/V$$

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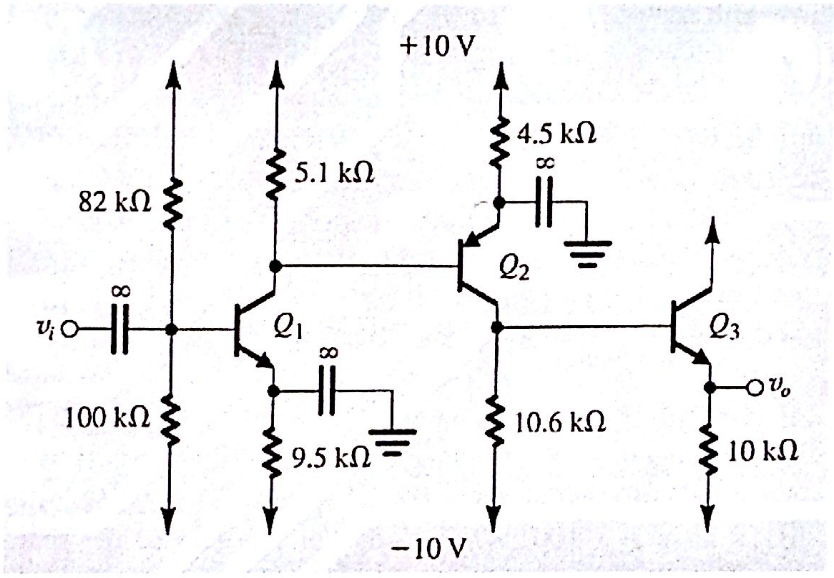
8) The multistage amplifier shown below has which of the following configuration:



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

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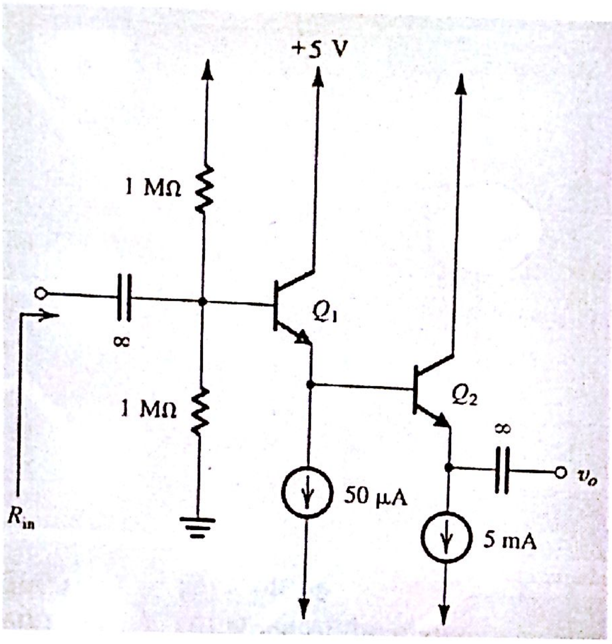
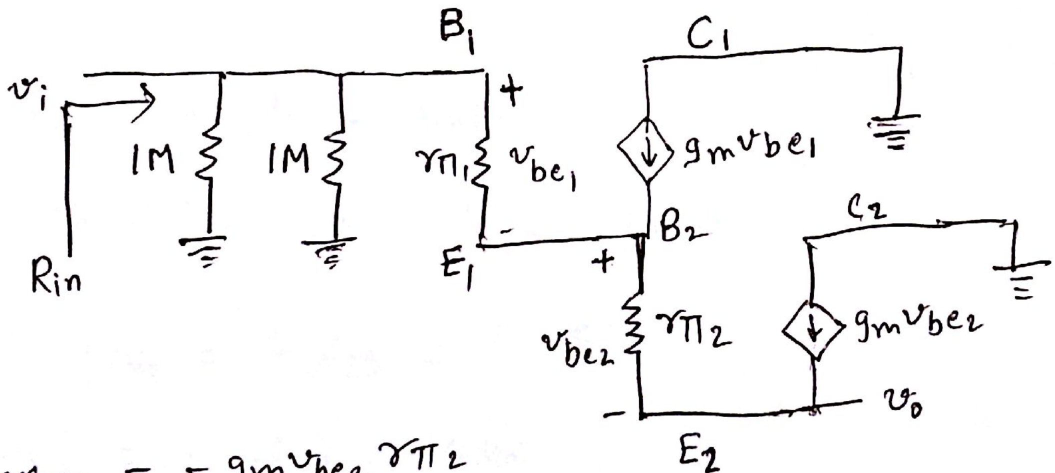
9) What is the input impedance of the two stage amplifier shown below? Assume β=100, V_{BE}(on)=0.7, V_T=25 mV.



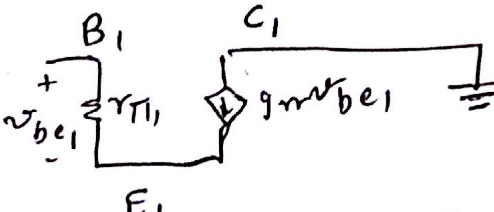
✓(1) ≈ 500kΩ (2) ≈ 75kΩ (3) ≈ 250kΩ (4) ≈ 65 kΩ
(5) ≈ 25 kΩ (6) None of the above



$v_{be_2} = - g_m v_{be_2} r_{\pi 2}$

$\Rightarrow v_{be_2} = 0$ $\Rightarrow$ No current through $r_{\pi 2}$

Now,



$v_{be_1} = 0$

$\Rightarrow$ No current through r_{π_1}

R_{in} = 1M || 1M = 500 KΩ

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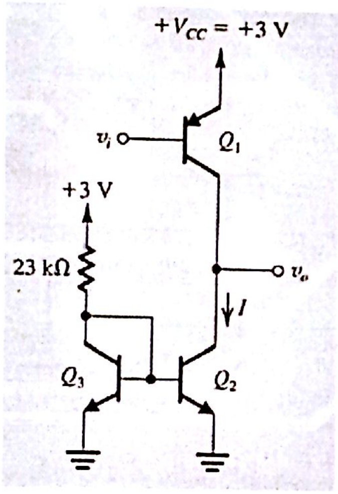
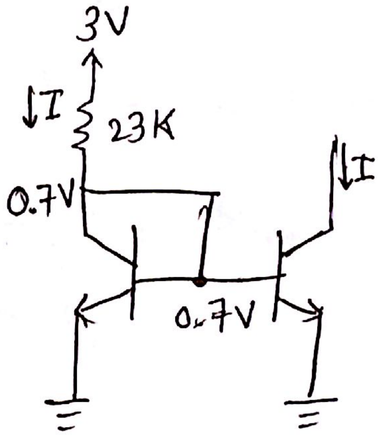
10) What is the gain (v_o/v_i) of the CE amplifier shown below, assume β=100 V_{BE}(on)–0.7, V_T–25 mV, and V_A–100V for all transistors (Hint: R_L is the total load resistance seen at the output node)



(1) ≈ -2000 (2) ≈ -4000 (3) ≈ 1 (4) ≈ -1000
(5) ≈ -500 (6) None of the above



Q_2 - Q_3 (Current Mirror)

$$I = \frac{3-0.7}{23K} = \frac{2.3}{23} = \underline{0.1\ mA}$$

Q_1 (CE) gain $\frac{v_o}{v_i} = -g_m R_L$

$$R_L = r_o(Q_2) = \frac{V_A}{I_C} = \frac{100}{0.1} = 1\ M\Omega$$

$$g_m = I_C/V_T = 0.1/25 = 4\ mA/V$$

$$v_o/v_i = -4(1) = -4000$$

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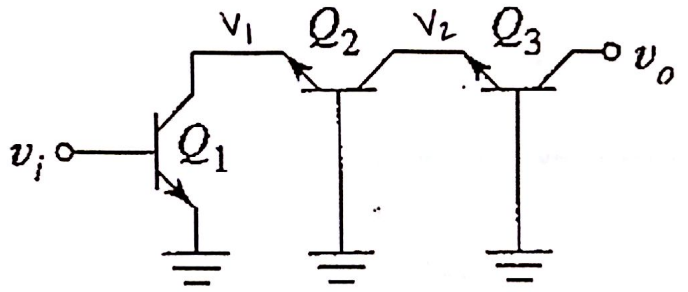
11) For the amplifier shown below known as double cascode, what is the gain |Av|? Q_2 and Q_3 both have twice the Early voltage as that of Q_1. But they all have the same β.
Note: $I_{c1}=I_{c2}=I_{c3}$, $g_m=g_{m1}=g_{m2}=g_{m3}$, $2r_{o1}=r_{o2}=r_{o3}$, $r_{\pi1}=r_{\pi2}=r_{\pi3}$
Assume $r_o >> 1/g_m$ for all three



(1) $g_m r_{o1}$ (2) $g_m^3 r_{o1}^3$ ✓(3) $2g_m r_{o1}$ (4) $g_m^2 r_{o1}^2$
(5) $4g_m r_{o1}$ (6) None of the above

Q_1 (CE) : $\frac{v_1}{v_i} = -g_m R_L$

$= -g_m(r_{o1} \parallel r_e) = -g_m(r_{o1} \parallel 1/g_m)$ (Q2)

$r_e = \alpha/g_m \approx 1/g_m$

since, $r_o >> 1/g_m$

$\frac{v_1}{v_i} = -g_m(1/g_m) = -1$

Q_2 (CB) : $\frac{v_2}{v_1} = g_m R_L$ here $R_L = r_e$ (Q3)

$= g_m(1/g_m) = 1$ $= 1/g_m$

Q_3 (CB) : $\frac{v_o}{v_2} = g_m R_L = g_m r_{o3}$

$\Rightarrow \frac{v_o}{v_i} = \frac{v_1}{v_i} \times \frac{v_2}{v_1} \times \frac{v_o}{v_2} = -1(1)(g_m r_{o3}) = -2 g_m r_{o1}$

$|Av| = 2 g_m r_{o1}$

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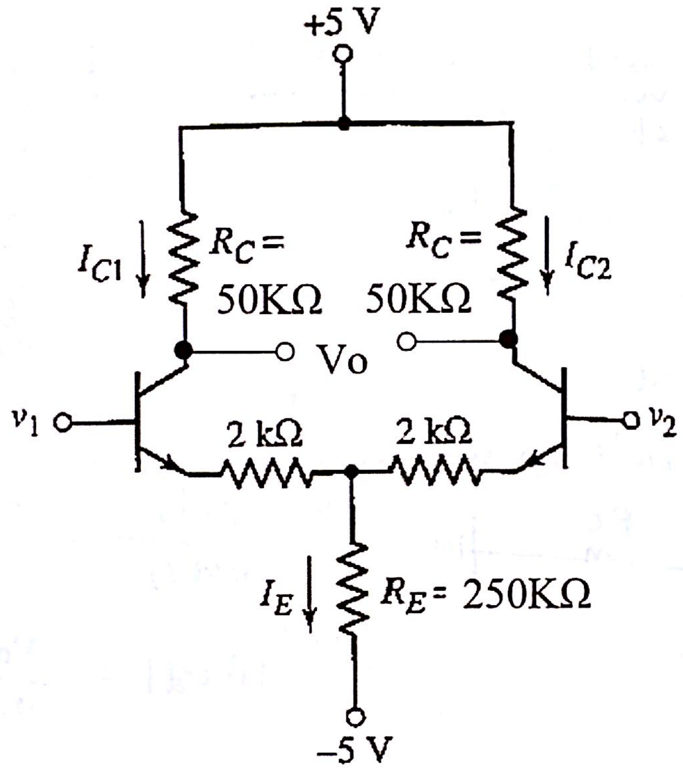
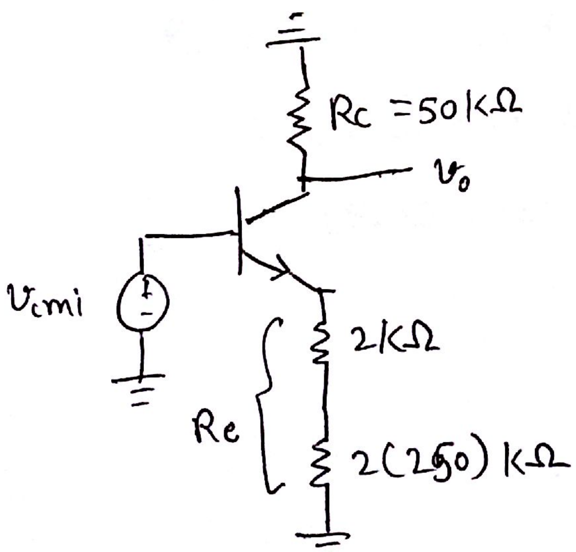
12) What is the common-mode gain ($|Av_c|$) for the circuit shown below? Assuming $\beta_0 >> 1$ and $r_o >> 1$. (hint: use the half circuit model; draw small signal model of BJT to calculate v_{oc}/v_{ic} at $v_{id}=0$; 2 kΩ resistor can be regarded as part of transistor or it's much smaller than 50 kΩ.)

What is the differential mode gain ($|Av_d|$) for the circuit shown below?
[Answers: first common-mode gain; second differential mode gain]



(1) ≈0.1 ; ≈25 (2) ≈0.1; ≈50 (3) ≈0.2; ≈ 50 (4) ≈0.2; ≈25
(5) ≈25; ≈0.1 (6) None of the below



Gain of ~~commo~~ CE with Re is

$$\frac{v_o}{v_{cmi}} = \frac{-g_m R_C}{1+g_m R_e}$$

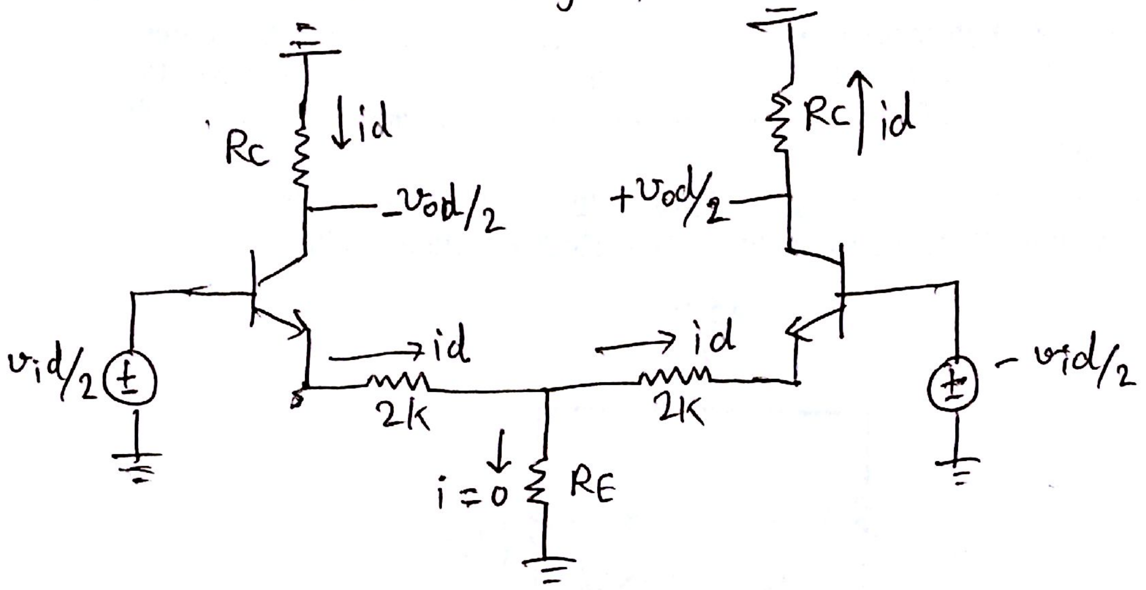
$$g_m = I_C/V_T = \beta I_B/V_T$$

$$g_m R_e >> 1 \Rightarrow \frac{v_o}{v_{cmi}} = -\frac{\cancel{g_m} R_C}{\cancel{g_m} R_e}$$

$$|Av_c| = \frac{R_C}{R_e} = \frac{50\,K}{2(250)K} \approx 0.1$$

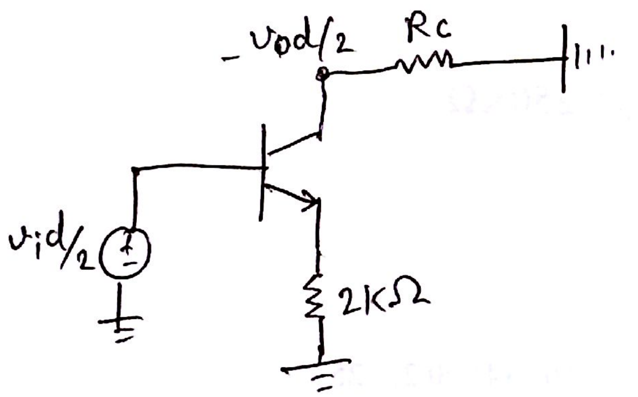
2K is neglected in front of 500K.

For the differential gain,



$$A_d = v_{od}/v_{id}$$

Differential Half circuit



$$-\frac{v_{od}/2}{v_{id}/2} = \frac{-g_m R_c}{1+g_m R_e}$$

$$|A_{vd}| = \frac{v_{od}}{v_{id}} \approx \frac{R_c}{R_e}$$

$$\approx \frac{50}{2} \approx 25$$

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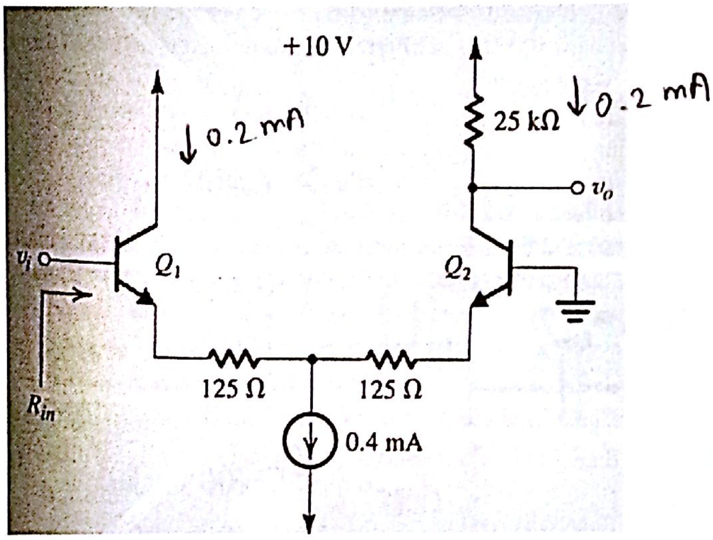
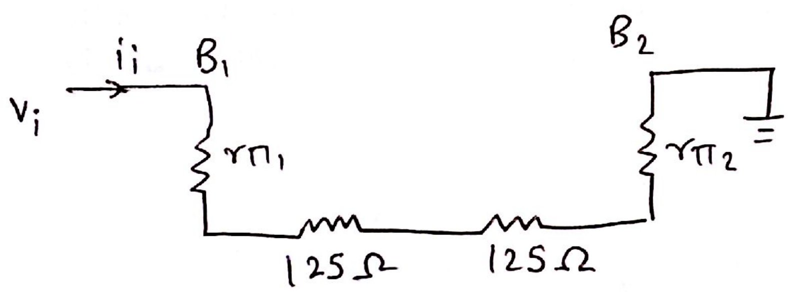
13) What is the differential mode input impedance of the amplifier shown below? assume β–100, V_{BE}(on)–0.7, V_T–25 mV, and V_A–100V.



(1) 50 kΩ (2) 250 Ω (3) 25 kΩ ✓(4) 25.25 kΩ
(5) 12.625 kΩ (6) None of the above



$r_{\pi_1} = r_{\pi_2} = \beta / g_m$

$g_m = I_C / V_T$

$= \dfrac{0.2}{25}$

$= 0.008$ A/V

$r_\pi = 100 / 0.008$

$= 12.5$ kΩ

$R_{in} = r_{\pi_1} + r_{\pi_2} + 250\ \Omega$

$= 2(12.5)$ kΩ $+ 250\ \Omega$

$= 25.25$ kΩ

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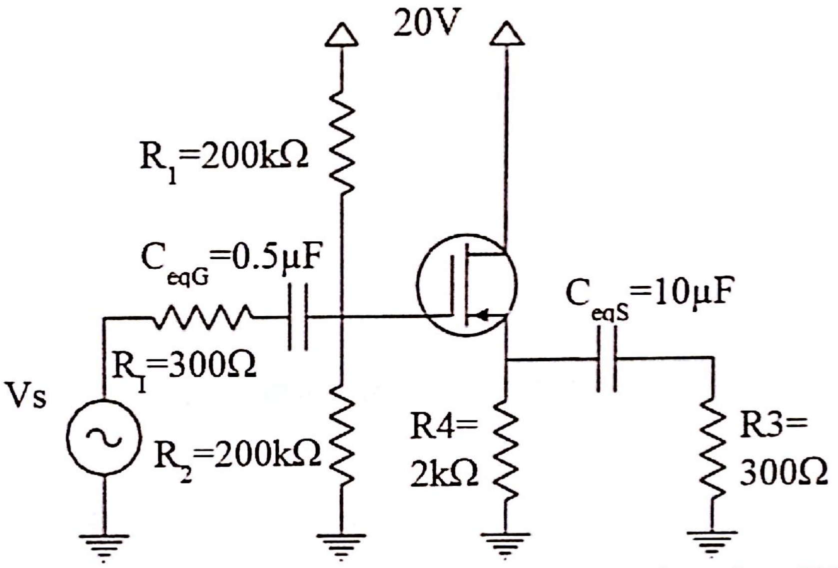
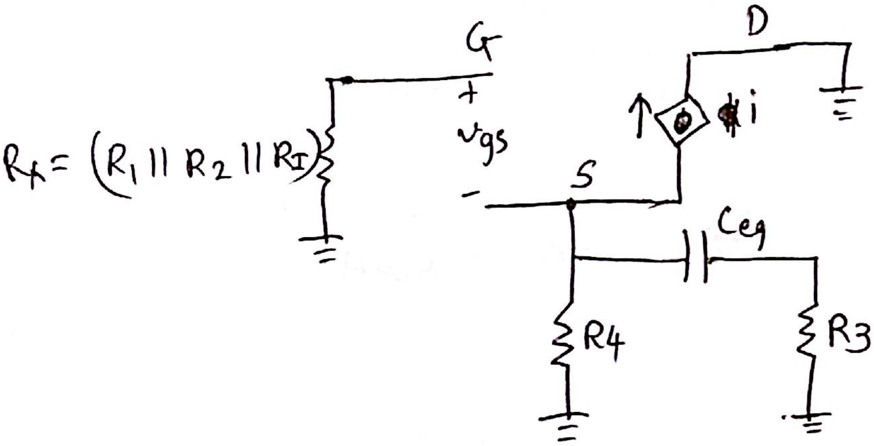
14) For the common drain amplifier shown below, the transconductance of the MOSFET is $g_m = 10mS$. Due to the high impedance at the output, the low cut-off frequency, ω_L, is dominated by the output pole: $\omega_L \approx \omega_{out} \approx \frac{1}{R_{eqs}C_{eqs}}$

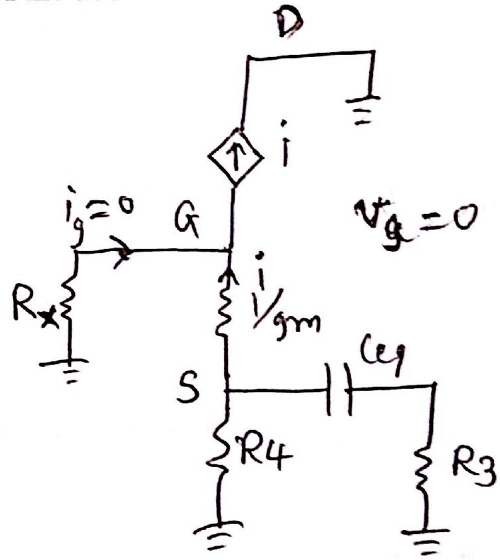


R_{eqs} is the equivalent resistance "looking into" the output capacitor, C_{eqs}. What is the value of R_{eqs}?

(1) $R_{eqs} = 395.2\Omega$ ✓
(2) $R_{eqs} = 300.0\Omega$
(3) $R_{eqs} = 260.9\Omega$
(4) $R_{eqs} = 75.0\Omega$
(5) $R_{eqs} = 360.9\Omega$
(6) None of the above

π Model





$$R_{eqs} = (R4 \| 1/g_m) + R3$$
$$= 2K \| 1/10m + 300$$
$$= 0.0095K + 300\,\Omega = 395.2\,\Omega$$

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15) Find A_{mid} for this transfer function.

$$A_v(s) = \frac{10^{10} s^2 (s+1)(s+200)}{(s+3)(s+5)(s+7)(s+100)^2(s+300)}$$

(1) 1
(2) 10^{10}
(3) $2\text{x}10^{12}$
(4) $3.33\text{x}10^5$
(5) $6.67\text{x}10^5$
(6) None of the above

~~Compare with low frequency gain expression~~

$$Av(s) = 10^{10}\left(\frac{s^2(s+1)}{(s+3)(s+5)(s+7)}\right)\left(\frac{(s+200)}{(s+100)^2(s+300)}\right)$$

$$= 10^{10} \frac{s^2(s+1)}{(s+3)(s+5)(s+7)} \frac{200(1+s/200)}{(100)^2(1+s/100)^2\, 300(1+s/300)}$$

$$= \frac{10^{10}\ 20\cancel{0}}{10^4\ 30\cancel{0}} \frac{s^2(s+1)}{(s+3)(s+5)(s+7)} \frac{(1+s/200)}{(1+s/100)^2(1+s/300)^2}$$

Amid = 0.67×10^6

low freq. Response

high freq. Response

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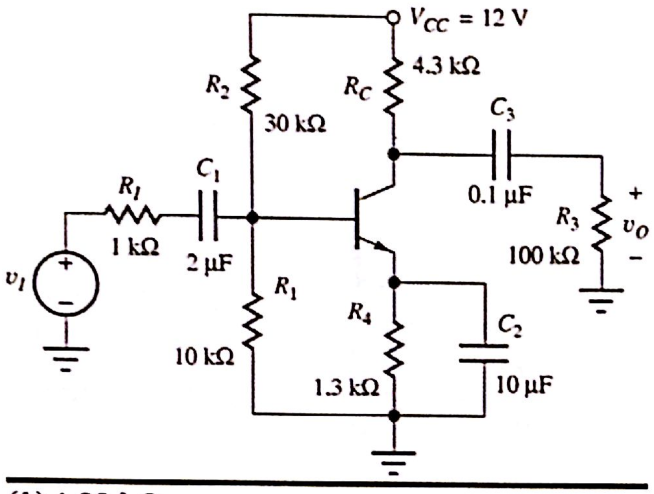
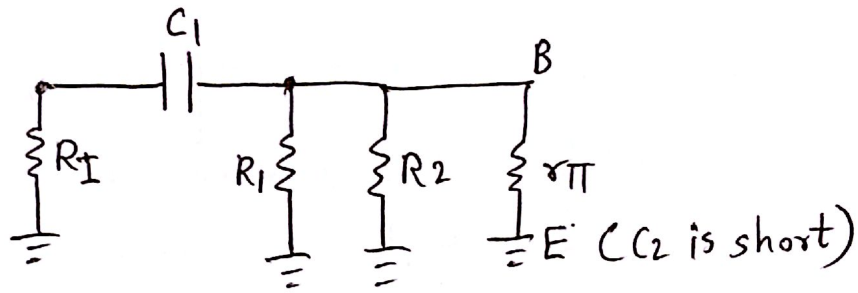
16) Short circuit time constant method is an important technique to determine the low cut-off frequency using equation: $\omega_L \cong \sum_{i=1}^{3} \frac{1}{R_{iS} C_i}$. For the circuit below, what is the R_{1S} for the BJT base related loop? Here r_π=1.51 kΩ and β_0=99 and r_0=46.8 kΩ.



(1) 4.88 kΩ
(2) 3.044 kΩ
(3) 7.095 kΩ
(4) 8.095 kΩ
(5) 2.26 kΩ ✓
(6) None of the above



$R_{1S} = R_I + (R_1 \parallel R_2 \parallel r_\pi)$
$= 1K + (10K \parallel 30K \parallel 1.51K)$
$= 1K + 1.26K = 2.26\,k\Omega$

$R_{1S} C_1 = 2.26 \times 2\ ms = 4.52\ ms = 0.00452\ s$

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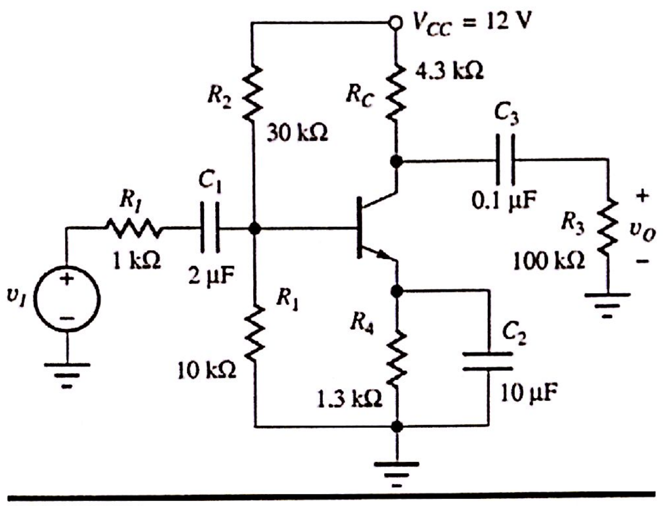
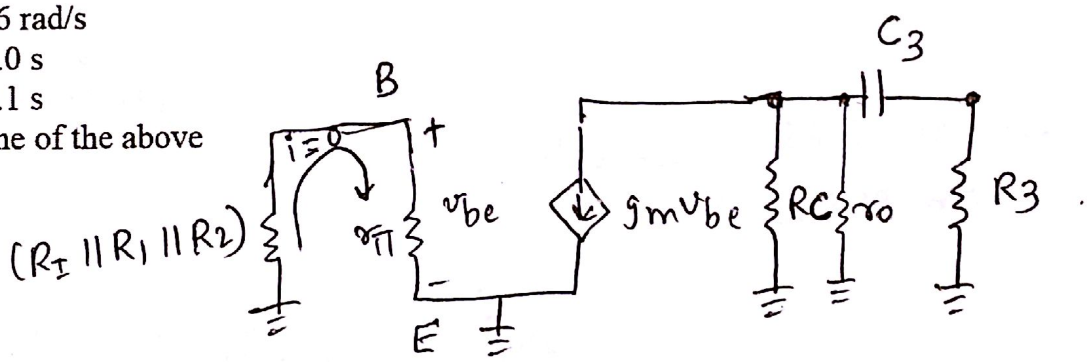
17) Short circuit time constant method is an important technique to determine the low cut-off frequency using equation: $\omega_L \cong \sum_{i=1}^{3} \frac{1}{R_{iS} C_i}$. For the circuit below (the same as in Problem 16), what is the time constant for the BJT collector related loop? Here $r_\pi = 1.51$ kΩ, $\beta_0 = 99$, and $r_0 = 46.8$ kΩ.



$v_{be} = 0$

(1) 96.1 rad/s
(2) ~ 0.01 s ✓
(3) 0.96 rad/s
(4) ~ 1.0 s
(5) ~ 0.1 s
(6) None of the above

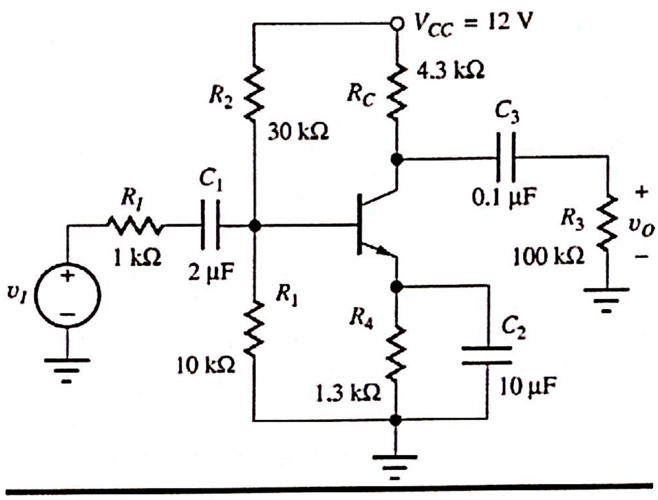


$$R_{3S} = (R_C \| r_o) + R_3$$
$$= (4.3 \| 46.8)K + 100K$$
$$= 102.2 \, k\Omega$$

Time const $= R_{3S} C_3 = 102.2 \times 0.1$ ms $= 10.2$ ms $= 0.01$ s

~~97.85 rad/s~~

18) Short circuit time constant method is an important technique to determine the low cut-off frequency using equation: $\omega_L \cong \sum_{i=1}^{3} \frac{1}{R_{iS} C_i}$. For the circuit below (the same as in Problems 16 and 17), what is ω_L for the whole BJT related circuit if R_{2S} in the emitter loop is known as 23.3Ω? Here r_π=1.51 kΩ, β_0=99, and r_0=46.8 kΩ.



(1) 2300 rad/s
(2) 222 rad/s
(3) 96.1 rad/s
(4) 4513 rad/s
(5) 2.16 x 10^{-4} rad/s
(6) None of the above

$R_{2S} C_2 = 23.3 \times 10 \ \mu s$
$= 0.233 \ ms$

$$\omega_L = \frac{1}{R_{1S} C_1} + \frac{1}{R_{2S} C_2} + \frac{1}{R_{3S} C_3}$$
$$= \left(\frac{1}{4.52} + \frac{1}{0.233} + \frac{1}{10.2}\right) \times 10^3$$
$$= (0.22 + 4.3 + 0.098) \times 10^3$$
$$= 4618 \text{ rad/s}$$

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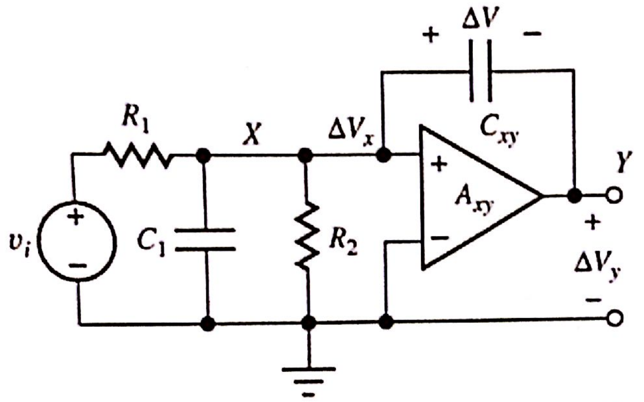
19) The circuit below highlights the so-called "Miller Effect". Determine the equivalent capacitance at the input and the output of this operational amplifier! Assuming C_{xy}=1μF, C_1=1μF and A_{xy}=-50.



1) C_{eq} (input)=1μF and C_{eq} (output)=1μF
2) C_{eq} (input)=52μF and C_{eq} (output)=1 μF ✓
3) C_{eq} (input)=50 μF and C_{eq} (output)=1 μF
4) C_{eq} (input)=51 μF and C_{eq} (output)=51 μF
5) C_{eq} (input)=52 μF and C_{eq} (output)=50 μF
6) None of the above

$$\frac{\Delta V_y}{\Delta V_x} = A_{xy} = -50$$

C_{xy} on input side $= C_{xy}(1+50) = 51 C_{xy} = 51\ \mu F$

$C_{eq}(\text{input}) = C_1 + C_{xy\,in}$

$= 1\ \mu F + 51\ \mu F$

$= 52\ \mu F$

C_{xy} on output side $= C_{xy}(1 + 1/50) \approx 1\ \mu F$

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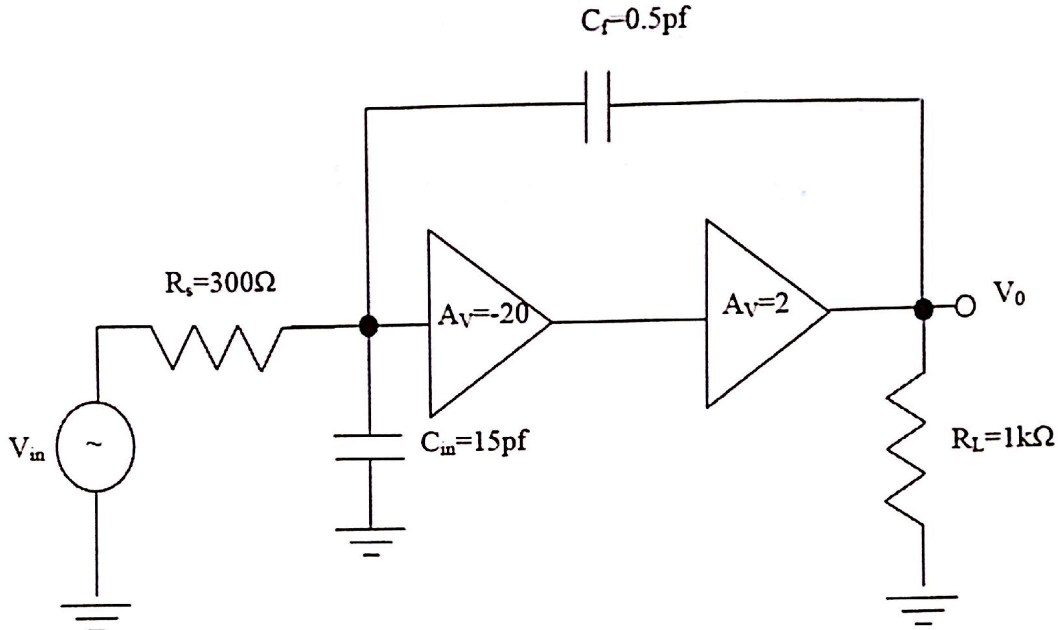
20) For the amplifier circuit shown below what is the high cutoff frequency f_H?



(1) ~94MHz (2) ~5MHz (3) ~35MHz ✓(4) ~15 MHz
(5) ~10MHz (6) None of the above

$A_{v_1} * A_{v_2} = A_v = (-20)(2) = -40$

$C_{f\,in} = 0.5(1+40) = 41 * 0.5 = 20.5$ pF

~~Cin~~ ≈ $C_{eq\,in} = C_{in} + C_{f\,in} = 15 + 20.5 = 35.5$ pF

$R_s C_{eq\,in} = 300 * 35.5 = 10.65$ ns ⇒ dominant pole

$C_{f\,out} = 0.5(1 + 1/40) \approx 0.5$ pF

$R_L C_{f\,out} = 1000 * 0.5 = 0.5$ ns → 318.5 MHz

∞ $f_H = \dfrac{1}{2\pi(10.65)\text{ ns}} \approx 15$ MHz

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