NAME: ____

GEORGIA INSTITUTE OF TECHNOLOGY
School of Electrical and Computer Engineering

ECE 4430	Second Exam	Closed Book and Notes
Fall 2002	October 30, 2002	

General Instructions:

1. Write on one side of the paper. (1 Pt.)

2. Put answers to all questions in the spaces provided on the test. (1 Pt.)

3. Show all work for full credit on questions requiring calculations. No credit will be given for answers alone, without supporting work.

4. Problems and questions are weighted as indicated. The maximum score is 100 points.

5. If you need more paper (provided in class), remove the staple from the exam and, when finished, arrange the test in order. Place the extra pages with supporting work in the test behind the page where the problem appears and indicate accordingly. Staple the entire test together so that there are no loose pages. (1 Pt.)

TEST SCORE: ____________________________________ / 100

I certify that I have neither given nor received any assistance while taking this test from anyone.

____ (Signature) (1 Pt.)

☐ Place a check mark in the box if you observed any suspicious actions while taking this test.

Formula Sheet: Equations/Constants that you may, or may not, need are listed below:

$K' = 50\ \mu A/V^2$ (unless otherwise stated in the problem)
$K_n = K'W/L$
$\lambda = 0.01\ V^{-1}$ (unless otherwise stated in the problem)
$V_{TO} = 0.7$ V (unless otherwise stated in the problem)
$\gamma = 0.5\ V^{1/2}$ (unless otherwise stated in the problem)
$2\varphi_F = 0.6$ V (unless otherwise stated in the problem)
$I_{D\text{-}Triode} = (K_n/2)\ [2(V_{GS} - V_{TN})V_{DS} - V_{DS}^2]$
$I_{D\text{-}Sat} = (K_n/2)\ (V_{GS} - V_{TN})^2\ (1 + \lambda V_{DS})$
$V_{TN} = V_{TO} + \gamma\ [\text{sqrt}(2\varphi_F - V_{BS}) - \text{sqrt}(2\varphi_F)]$
$r_{o\text{-}MOS} \approx 1 / (\lambda I_{DS})$
$g_{m\text{-}MOS} = \text{sqrt}[2I_{DS}K_n]$
$V_{ds\text{-}sat} = \text{sqrt}(2I_{DS}/K_n)$
$g_{mb\text{-}MOS} = \eta g_{m\text{-}MOS}$
$\eta = \gamma \div 2\ \text{sqrt}(2\varphi_F - V_{BS})$

$V_t = kT/q \approx 26$ mV and $I_S = 1E\text{-}15$ A (unless otherwise stated in the problem)
$I_{Diode} = I_S\ [\exp(V_D/V_t) - 1]$

$$C_j = \frac{C_{j0}}{\left(1 - \frac{v_D}{\psi_o}\right)^m}$$

→ $0.33 \le m \le 0.5$

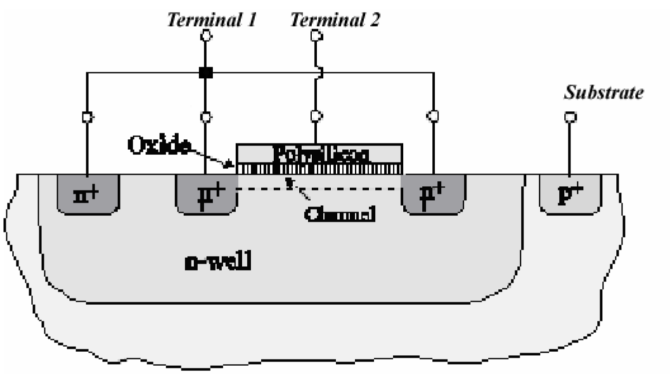
$V_A = 100$ V (unless otherwise stated in the problem)
$\beta_F = 50$ (unless otherwise stated in the problem)
$I_{CE} = I_S\ [\exp(V_{BE}/V_t) - 1]\ [1 + V_{CE}/V_A]$
$r_{o\text{-}NPN} = V_A / I_{CE}$
$g_{m\text{-}NPN} = I_{CE}/V_t$

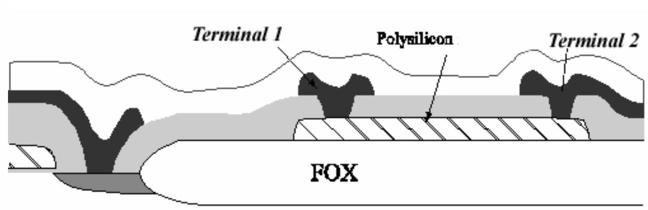
$CMRR = |A_{dm}| / |A_{cm}|$

$Z_{miller\text{-}in} = Z / (1 - k)$
$Z_{miller\text{-}out} = Z\ k / (k - 1)$

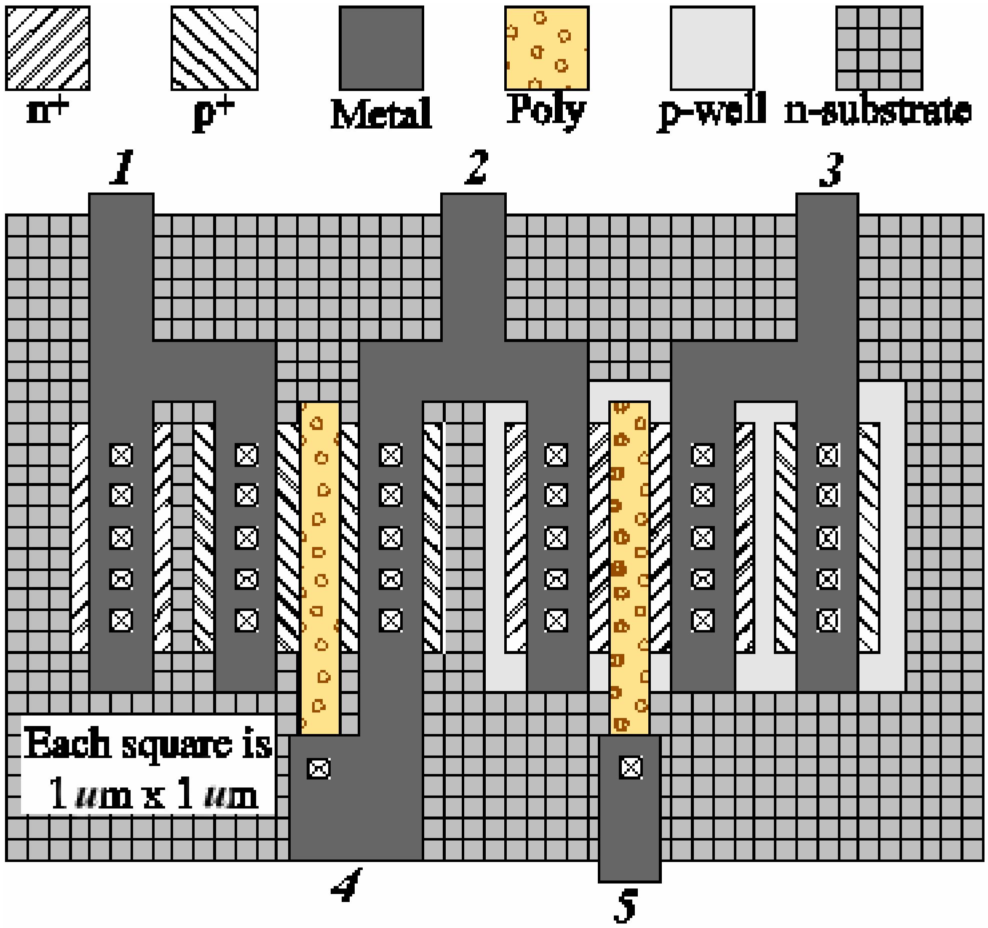
Fabrication – Part A (30 Points)

1. Draw the schematic (label the terminals) and identify the devices of the figures shown below, as they would be used (be specific – base-emitter diode of lateral NPN, accumulation-mode MOS capacitor, etc.). (10 pts)

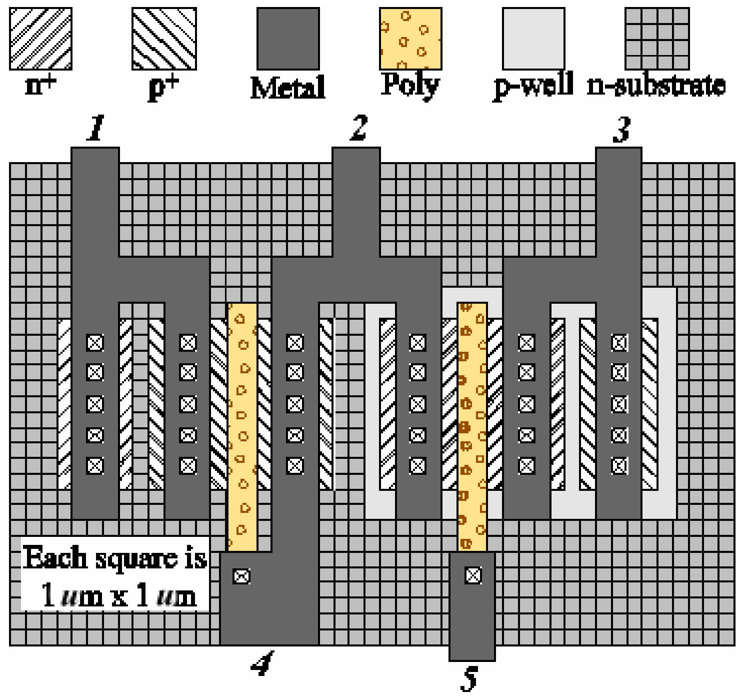




2. Use the layout shown below to answer the following questions.



(a) Draw the corresponding schematic. (5 pts)



(b) Which terminal(s) (1, 2, 3, 4, or 5) is(are) more than likely connected to the positive power supply?

__________________________ (2 pts)

Why? ____

____ (2 pts)

(c) Which terminal(s) is(are) more than likely connected to the negative power supply?

__________________________ (2 pts)

Why? ____

____ (2 pts)

(d) Which terminal(s) is(are) more than likely the input(s) of the circuit?

__________________________ (2 pts)

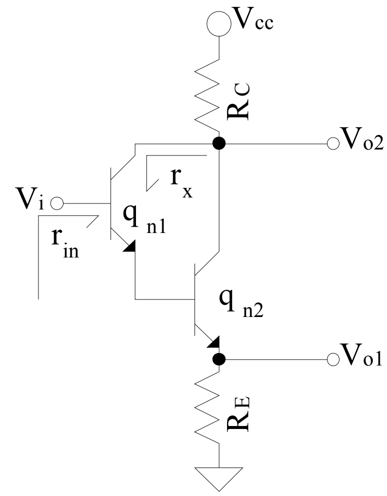
(e) What specific capacitor components (e.g., $C_{db\_sidewall}$, C_{db_bottom}, $C_{gs\_overlap}$, $C_{gs\_saturation}$, etc.) do you expect to be present on terminal 5? (5 pts)

Single and Two Transistor Amplifiers – Part B (25 Points)

1. Circle the single transistor amplifiers that produce a non-inverting transfer function. (6 pts)

CC CB CE CD CG CS

2. For the circuit shown and using small signal parameters (e.g., r_π, g_m, β, etc.), (a) derive input resistance r_{in} and the transfer function from V_i to V_{o1} (i.e., V_{o1}/V_i) –assume V_A is infinite (r_o is infinite).



(10 pts)

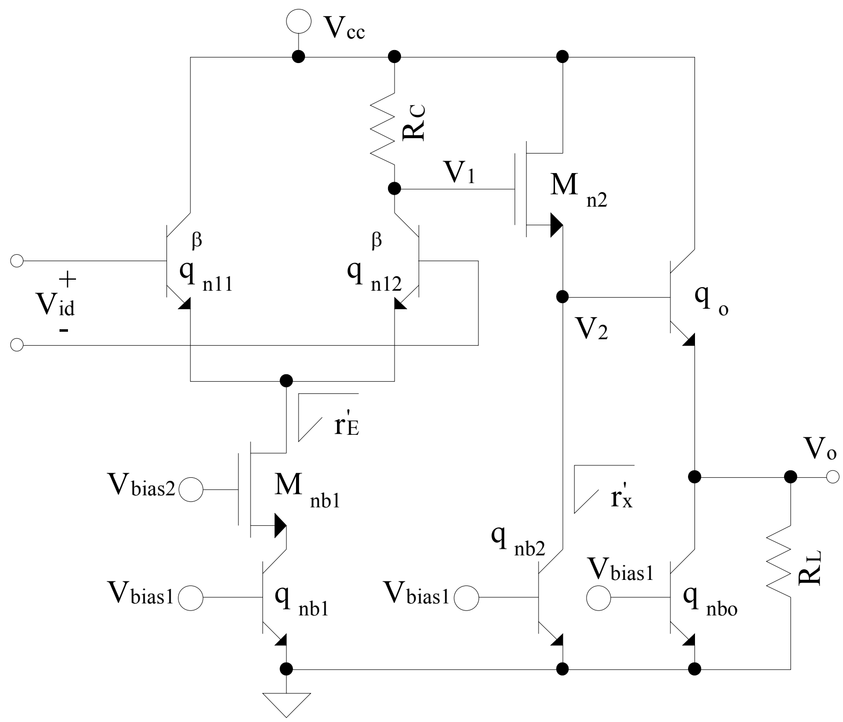
(b) The gain from V_i to V_{o2} (i.e., V_{o2}/V_i) is ***greater than / less than / equal to*** V_{o1}/V_i. (2 pts)

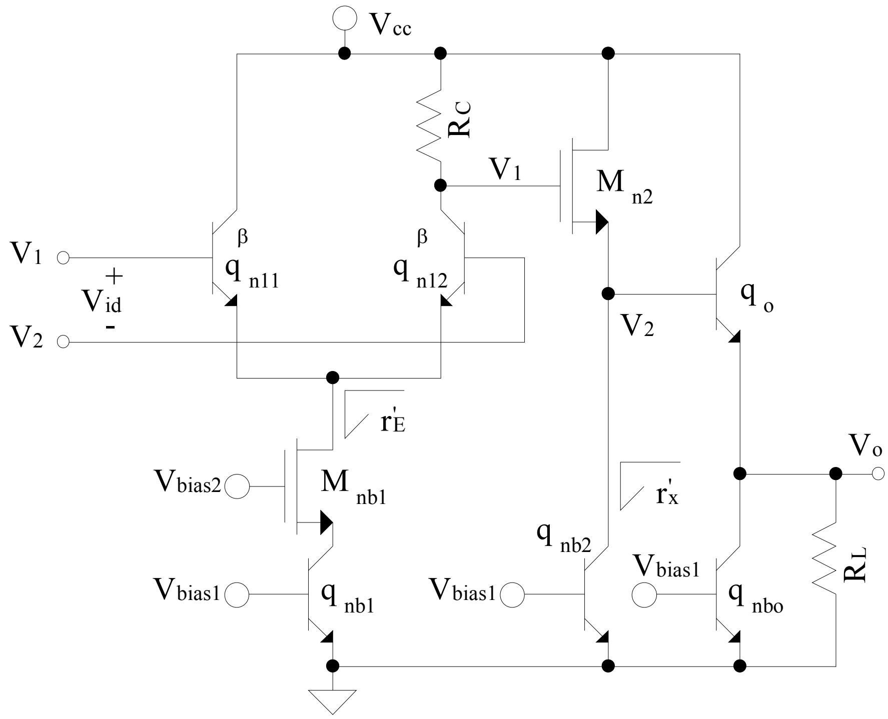
(c) ***True / False***: V_{o1} is in phase with V_{o2}. (2 pts)

(d) Derive the resistance looking into the collector of q_{n1} (r_x)? (5 pts)

Differential Amplifiers – Part C (41 Points)

1. For the circuit shown and using small signal parameters (e.g., r_π, g_m, etc.) and labels shown (assume β and r_o are infinite), (a) derive the differential-mode gain of the circuit ($A_{dm} = V_o/V_{id}$) assuming the gain from V_1 to V_o is unity ($V_o/V_1 = 1$), (b) derive the common-mode gain ($A_{cm} = V_o/V_{cm}$) using r_E' for the resistance looking into the drain of M_{nb1}, and (c) calculate the common-mode rejection-ratio performance of the circuit. (25 pts)





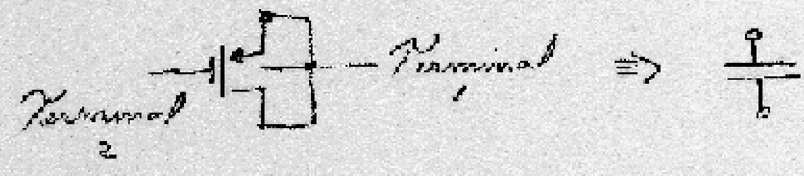
2. Which devices have been used as current sources or sinks? ______________________________ (6 pts)

3. Of those, which one(s) exhibit(s) the lowest V_{min}? ______________________________ (6 pts)

4. Which one(s) has(ve) the best output resistance performance? ___________________________ (4 pts)

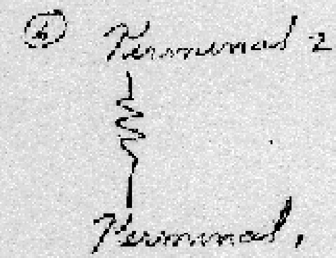
Second Exam - 4430 - Fall 2002

Part A. (1) (a)



MOS Capacitor

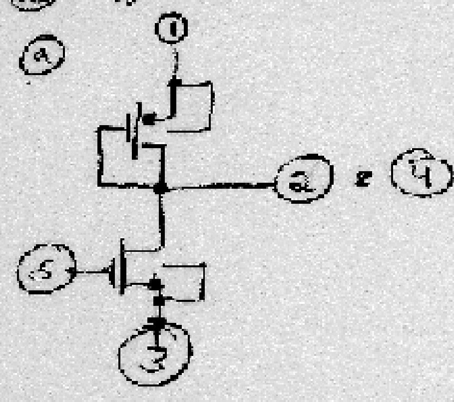
(b)



Polysilicon Resistor

(2) n-substrate, p-well Technology

(a)



(b) (1) ⇒ Reverse bias n-substrate junction diodes, thereby isolating all circuits sharing the same substrate

(c) (3) ⇒ Isolate p-well from substrate ⇒ reverse-bias p-well-substrate diode

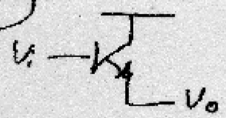
(d) (5)

(2)

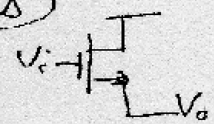
Part A (e) $C_S = C_{gs\text{-}saturation} + C_{gs\text{-}overlap} + C_{dg\text{-}overlap}$; $C_{gs\text{-}saturation} = \frac{2}{3} C_{ox}'' WL$

Part B

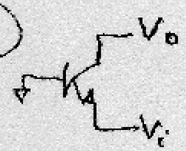
(1) CC



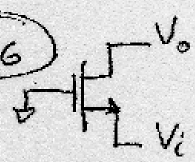
CD



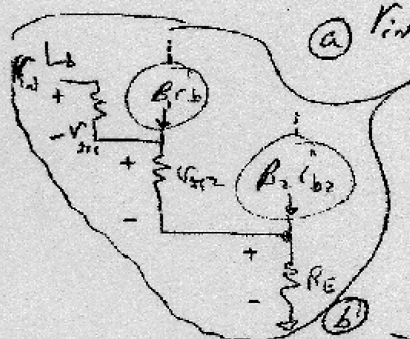
CB



CG



(2)



(a) $$r_{in} = \frac{V_t}{i_t} = \frac{i_b(r_{\pi 1}) + i_b(1+\beta_1) r_{\pi 2} + i_b(1+\beta_1)(1+\beta_2) R_E}{i_b}$$

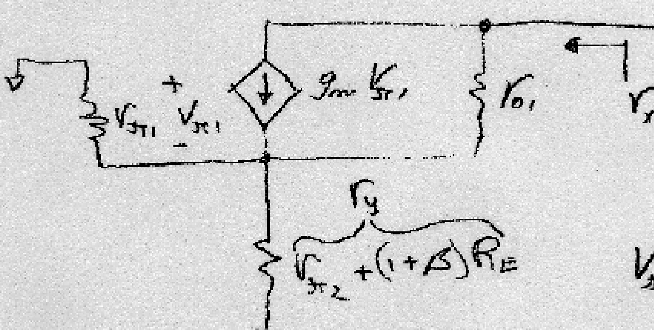
$$\approx r_{\pi 1} + (1+\beta_1) r_{\pi 2} + (1+\beta_1)(1+\beta_2) R_E$$

$$\frac{V_o}{V_i} = \frac{(1+\beta_1)(1+\beta_2) R_E \cdot i_b}{r_{in} \cdot i_b} = \frac{(1+\beta_1)(1+\beta_2) R_E}{r_{\pi 1} + (1+\beta_1) r_{\pi 2} + (1+\beta_1)(1+\beta_2) R_E}$$

(b) greater than

(c) False

(d)



$$r_x = \frac{V_t}{i_t} = \frac{(i_t - g_{m1} V_{\pi 1}) r_{o1} + i_t (r_y \,//\, r_{\pi 1})}{i_t}$$

$$V_{\pi 1} = -i_t (r_{\pi 1} \,//\, r_y)$$

$$\therefore r_x = \frac{\left[i_t + i_t g_{m1} (r_{\pi 1} \,//\, r_y)\right] r_{o1} + i_t (r_y \,//\, r_{\pi 1})}{i_t}$$

$$\therefore r_x = \left[1 + g_{m1} (r_y \,//\, r_{\pi 1})\right] r_{o1} + (r_y \,//\, r_{\pi 1}) \approx g_{m1} \left[\left(r_{\pi 2} + (1+\beta) R_E\right) // r_{\pi 1}\right] r_{o1}$$

(3)

Part B (1) (2) con't.

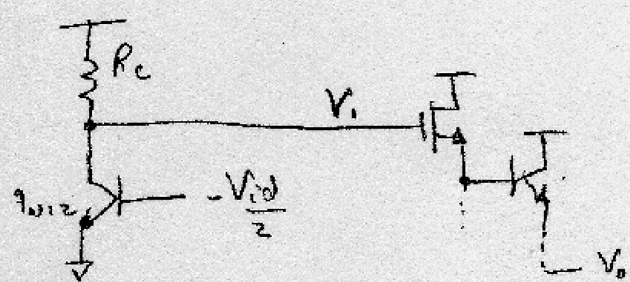
$$r_{\pi 1} = \frac{\beta}{g_{m1}} = \frac{\beta V_t}{I_{C1}} = \frac{\beta V_t}{I_{C2}}\beta = \beta r_{\pi 2}$$

$$g_{m1} = \frac{I_{C1}}{V_T} = \frac{I_{C2}}{\beta V_T} = \frac{g_{m2}}{\beta} \qquad r_{o1} = \frac{V_{A1}}{I_{C1}} = \frac{V_{A2}}{I_{C2}}\beta = \beta r_{o2}$$

$$\therefore\ r_x \approx \left(\frac{g_{m2}}{\beta}\right)\beta r_{o2}\left(\left[r_{\pi 2} + (1+\beta)R_E\right] \| \beta r_{o2}\right)$$

Part C

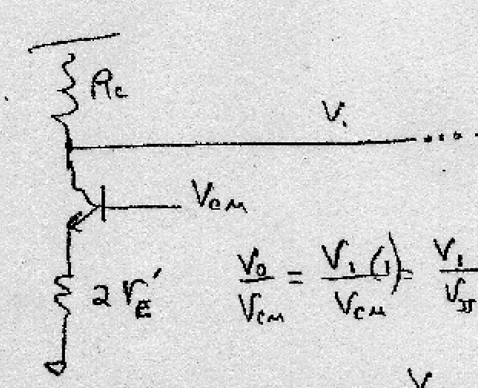
(a)



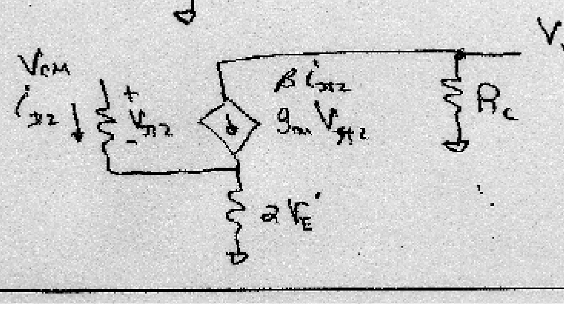
$$\frac{V_1}{V_{id}} = -\left(-\frac{g_m R_C}{2}\right)$$

$$\frac{V_o}{V_{id}} = \frac{V_1}{V_{id}}\,\frac{V_o}{V_1} = \frac{g_m R_C}{2}(1) = \frac{g_m R_C}{2}$$

(b)



$$\frac{V_o}{V_{cm}} = \frac{V_1(1)}{V_{cm}} = \frac{V_1}{V_{\pi 12}}\,\frac{V_{\pi 12}}{V_{cm}} = (g_m R_c)\left(\frac{\beta r_\pi}{\beta\left[r_\pi + (1+\beta)2r_E'\right]}\right)$$



$$= \frac{g_m R_c r_\pi}{r_\pi + (1+\beta)2r_e'}$$

$$\approx \frac{g_m R_c}{1 + \left(\frac{1+\beta}{r_\pi}\right)2r_e'}$$

Part c ⓒ

$$CMRR = \frac{|A_{dm}|}{|A_{cm}|} = \left(\frac{g_m R_C}{2}\right)\left(\frac{1 + \left(\frac{1+\beta}{r_\pi}\right) 2 r_e'}{g_m R_C}\right)$$

$$\approx \left(\frac{1+\beta}{r_\pi}\right) r_e' \approx g_m r_e'$$

Part c

② M_{Nb1} and q_{Nb1}

q_{Nb2}

q_{Nb0}

③ q_{Nb2}

q_{N0}

④ M_{Nb1} and q_{Nb1}.