ECE-255
Exam II
March 5, 2019

Name: <u>For Discussion in Class</u>
(Please print clearly)

Student ID: ________________

Division 1 (TuTh):____ Division 2 (MWF): ______

INSTRUCTIONS

- This is a closed book, closed notes exam. **Only the Texas Instruments TI-30X IIS scientific calculator is allowed.**
- Carefully mark your multiple-choice answers on the scantron form. If you need to change an answer on the scantron form, erase previous answer completely. 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. **All incidents will be reported to the Dean of Students.**
- 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 rejection from the exam site and loss of all credit for this exercise. **All incidents will be reported to the Dean of Students.**

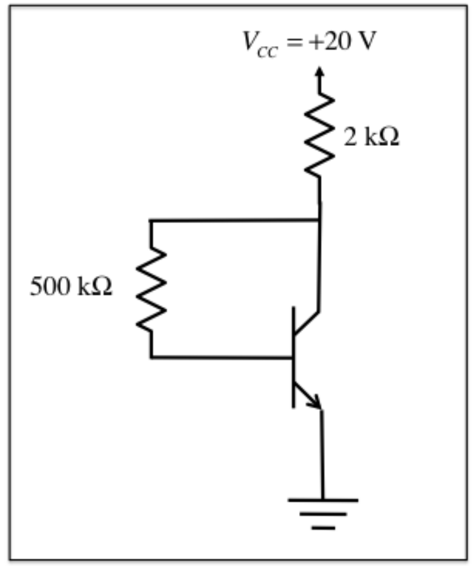
Problems Q1-Q10 consider BJTs and related circuits.

Q1. A transistor is biased in the active region so that $\alpha = 0.95$ and $g_m = 38$ mS. What is the value of r_π ?

(1) 0.5 kΩ (2) 1.0 kΩ (3) 1.5 kΩ
(4) 2.0 kΩ (5) 2.5 kΩ (6) 3.0 kΩ
(7) 3.5 kΩ

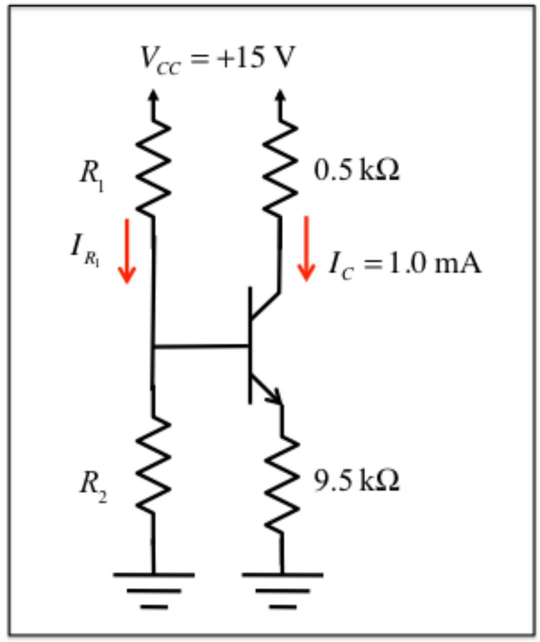
Q2. For the circuit below, the current through the 500 kΩ resistor is 0.037 mA. Determine the small signal transconductance. Assume $\beta = 20$, $V_{BE} = 0.7$ V, and $V_T = 0.026$ V.

(1) 10.2 mS (2) 17.3 mS (3) 28.5 mS
(4) 37.3 mS (5) 0 mS (6) 38.9 mS
(7) 43.2 mS



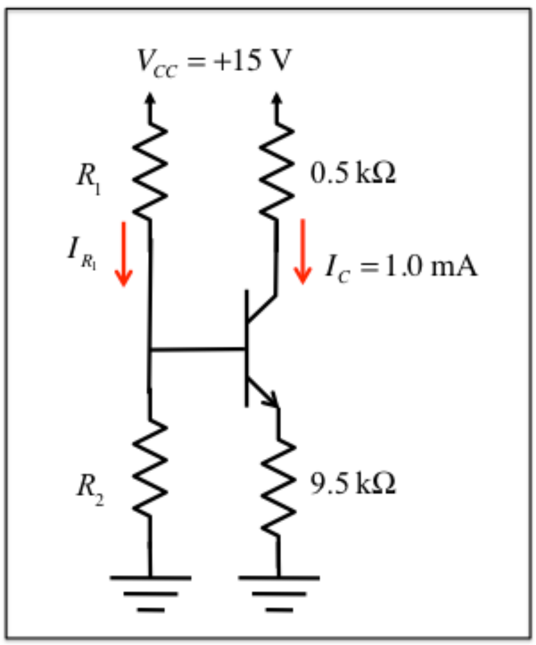
Q3. For the circuit below, I_{R1} = 10 I_B. Choose R_1 so that $I_C = 1$ mA. Assume $\beta = 100$ $V_{BE} = 0.7$ V, and $V_T = 0.026$ V. Note that you can solve this problem without knowing R_2.

(1) 0 k (2) 25 k (3) 50 k
(4) 75 k (5)100 k (6) 125 k
(7) 150 k

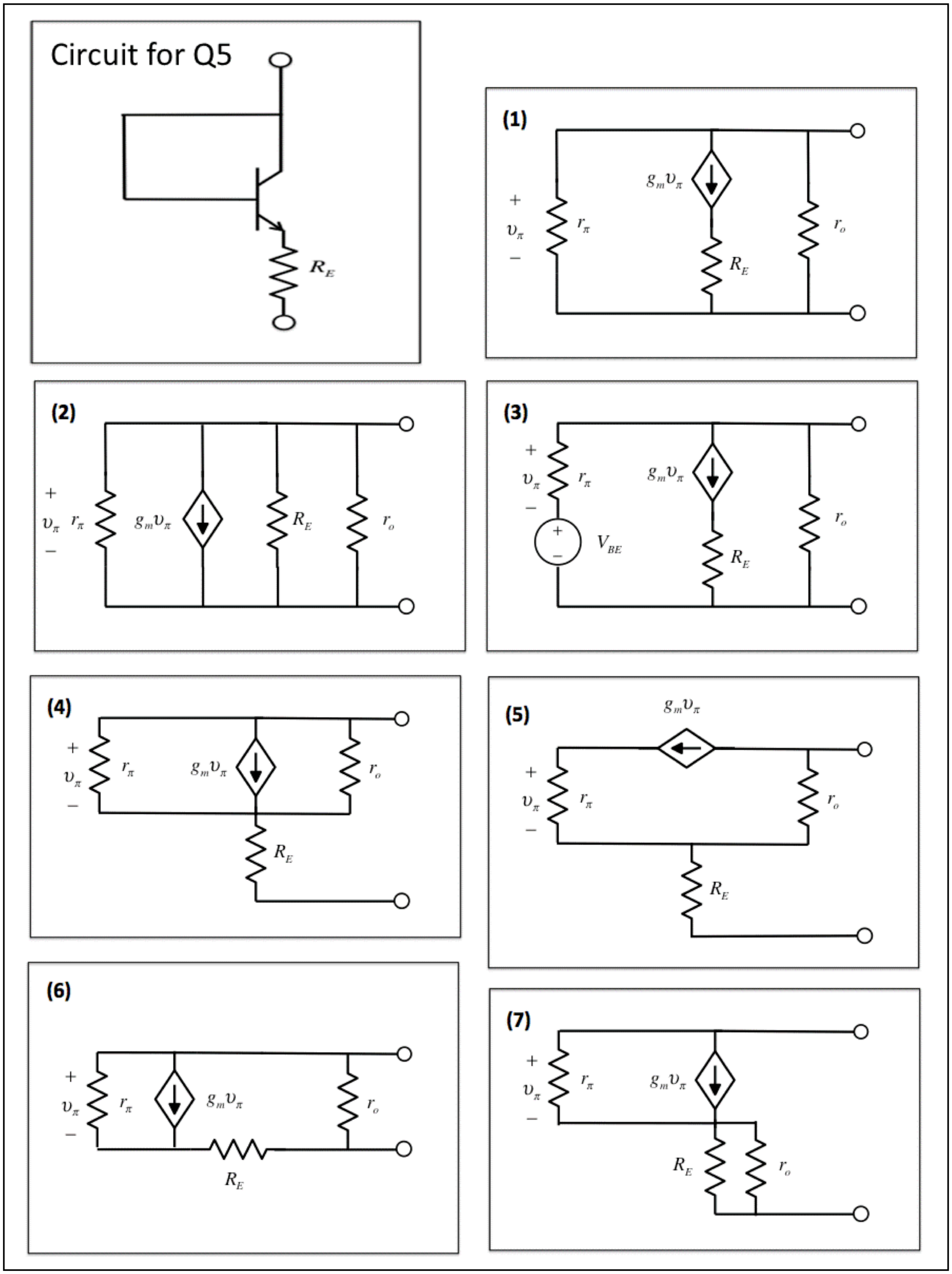


Q4. For the circuit considered in Q3, suppose that the value of β increases by 2x. Which of the following best describes the change in DC bias conditions? You should assume that the transistor remains in (forward) active mode.

(1) I_B decreases by ~ 2x, and I_C decreases by ~ 2x.
(2) I_B decreases by ~ 2x, and I_C remains ~ constant.
(3) I_B decreases by ~ 2x, and I_C increases by ~ 2x.
(4) I_B increases by ~ 2x, and I_C decreases by ~ 2x.
(5) I_B increases by ~ 2x, and I_C remains ~ constant.
(6) I_B increases by ~ 2x, and I_C increases by ~ 2x.
(7) I_B remains ~ constant and I_C increases by ~ 2x.



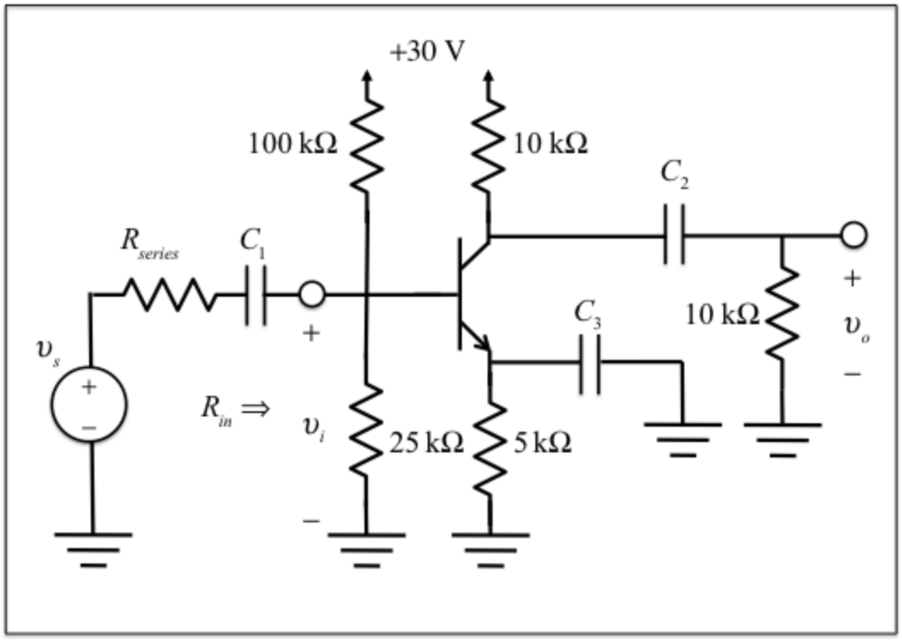
Q5. For the circuit below, select the proper small signal equivalent circuit.



Problems Q6-Q9 consider the circuit below, which has a transistor with β = 200 and V_{BE} = 0.6 V. The circuit is biased so that I_C = 1.05 mA. For this transistor, $g_m = 40.4$ mS, $r_\pi = 5\ \text{k}\Omega$, and $r_o = \infty\ \Omega$.

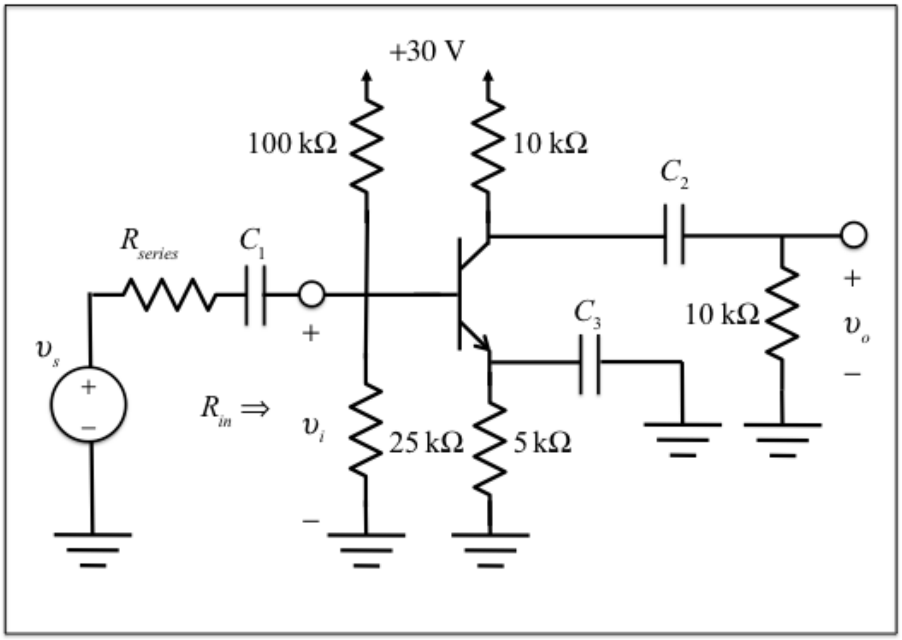
Q6. What kind of amplifier is this?

(1) Common source
(2) Common emitter
(3) Common gate
(4) Common base
(5) Common drain
(6) Common collector
(7) Cascode



Q7. For the circuit above, what is the voltage gain, $A_{v_i} = v_o / v_i$? You may assume that the capacitors are short circuits at the signal frequency. As shown in figure, v_i is to the right of C_1.

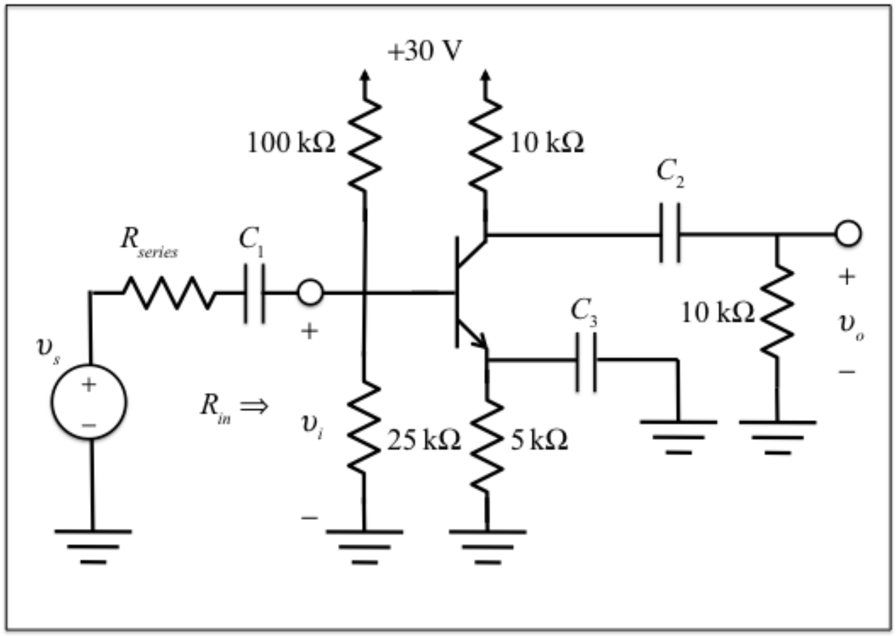
(1) +12 (2) -67 (3) +67
(4) -202 (5) +202 (6) -401
(7) +401



Q8-Q9 use same circuit as Q6-Q7 (repeated below); $g_m = 40.4$ mS, $r_\pi = 5\,\text{k}\Omega$, $r_o = \infty\,\Omega$).

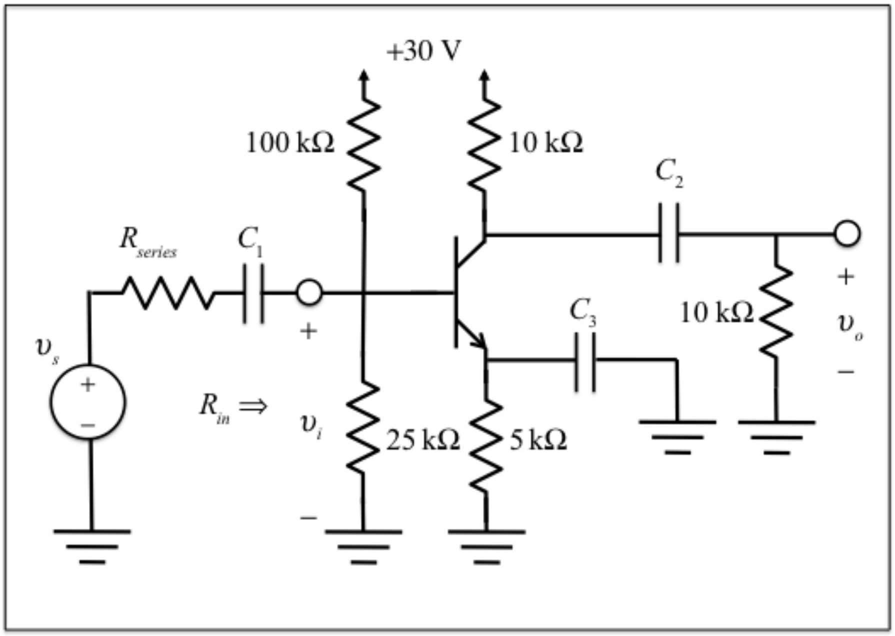
Q8. What is the input resistance, R_{in}, at the indicated position?

(1) 25 kΩ
(2) 20 kΩ
(3) 5 kΩ
(4) 4 kΩ
(5) 3 kΩ
(6) 2 kΩ
(7) 1 kΩ



Q9. If the capacitor, C_3 (lower right) is removed, approximately what is the magnitude of the new input resistance of the circuit?

(1) 5 kΩ
(2) 10.2 kΩ
(3) 19.6 kΩ
(4) 22.3 kΩ
(5) 100 **kΩ**
(6) 1000 kΩ
(7) 1200 kΩ



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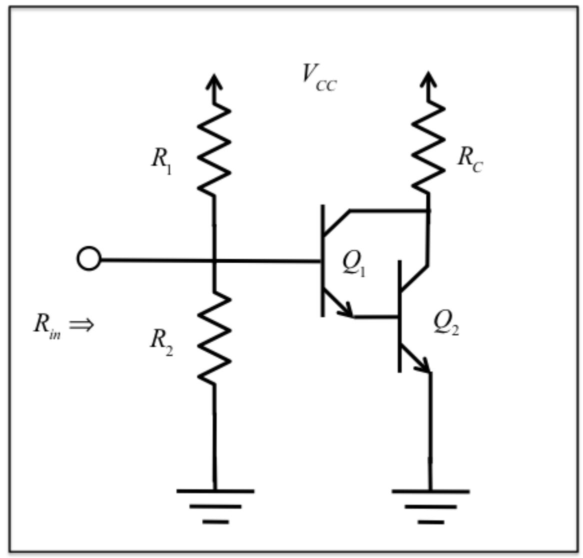
Q10. For the circuit below, what is the small signal input resistance, R_{in}, at the indicated location?



(1) $R_{in} = r_{\pi 1} + r_{\pi 2}$

(2) $R_{in} = r_{\pi 1} + (\beta + 1) r_{\pi 2}$

(3) $R_{in} = R_1 \| R_2$

(4) $R_{in} = (R_1 \| R_2) + r_{\pi 1} + r_{\pi 2}$

(5) $R_{in} = (R_1 \| R_2) + r_{\pi 1} + (\beta + 1) r_{\pi 2}$

(6) $R_{in} = (R_1 \| R_2) \| r_{\pi 1} \| r_{\pi 2}$

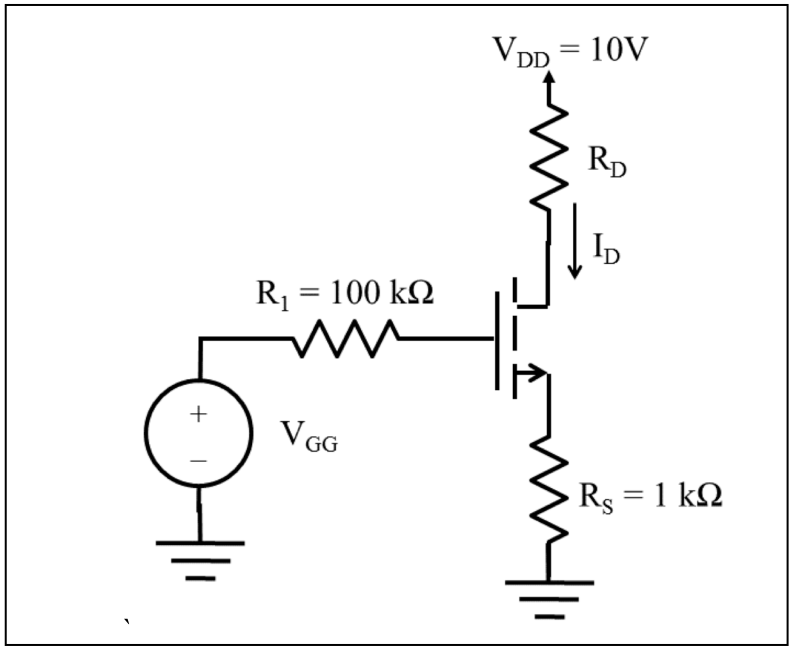
(7) $R_{in} = (R_1 \| R_2) \| \left(r_{\pi 1} + (\beta + 1) r_{\pi 2}\right)$

Problems Q11-Q19 consider MOSFETs and related circuits.

Q11 - Q12 refer to the DC MOSFET circuit shown in the figure. The MOSFET has V_{Tn} = 1V and λ = 0. The MOSFET operates in the saturation region and is biased at V_{GS} = 3V and drain current (I_D) = 1 mA.

Q11. What is the maximum value of R_D for which the transistor operates in saturation?

(1) 0.7 kΩ
(2) 0.8 kΩ
(3) 1.2 kΩ
(4) 2 kΩ
(5) 6 kΩ
(6) 7 kΩ
(7) 8 kΩ



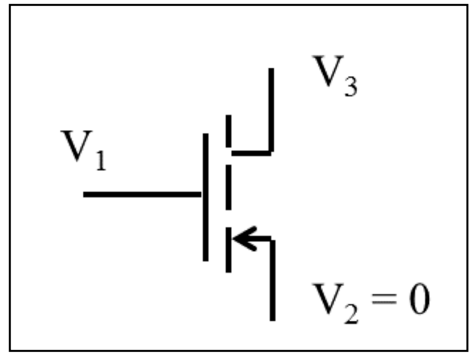
Q11 - Q12 refer to the DC MOSFET circuit shown in the figure. The MOSFET has V_{Tn} = 1V and λ = 0. The MOSFET operates in the saturation region and is biased at V_{GS} = 3V and drain current (I_D) = 1 mA.

Q12. The electron mobility (μ_n) is 1000 cm^2/Vsec and the W/L ratio is 5. What is the oxide capacitance per unit area (in nanofarads/cm^2)?

(1) 1
(2) 3
(3) 5
(4) 10
(5) 25
(6) 50
(7) 100

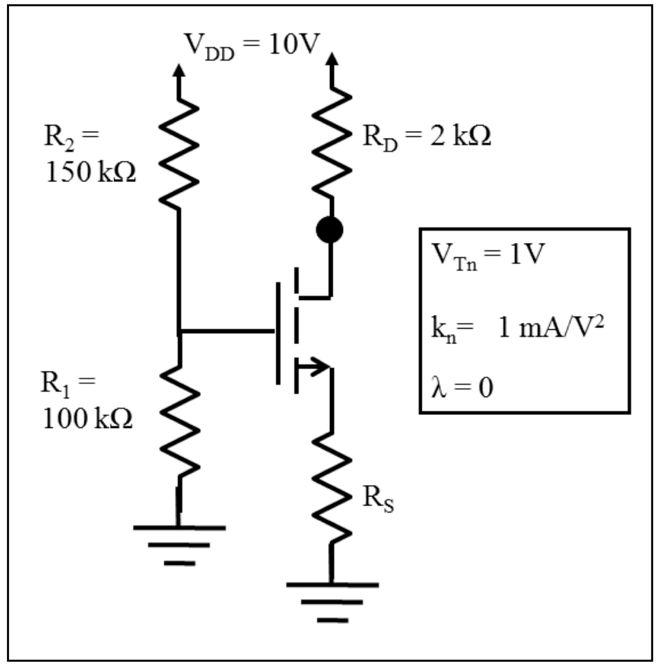
Q13. Consider an enhancement-mode PMOS transistor with $|V_{Tp}|$ = 0.25V. Which one of the following combination of voltages yields operation in the saturation region?

(1) V_1 = -1V, V_3 = -3 V
(2) V_1 = -1V, V_3 = 0 V
(3) V_1 = -1V, V_3 = +3 V
(4) V_1 = +1.5V, V_3 = +0.5 V
(5) V_1 = +1V, V_3 = -3 V
(6) V_1 = +1V, V_3 = +3 V
(7) V_1 = +3V, V_3 = +2 V



Q14.**Consider the MOSFET bias circuit shown in the figure. Suppose that we wish to achieve a bias point in saturation with I_D= 2 mA. What value of R_S is required?**

(1) 0.25 kΩ
(2) 0.5 kΩ
(3) 1.0 kΩ
(4) 1.5 kΩ
(5) 2.0 kΩ
(6) 3.0 kΩ
(7) 5.0 kΩ



Q15 and Q16 consider an NMOS transistor with $k_n = 1$ mA/V^2 and $\lambda = 0$. The transistor is operated at $I_D = 2$ mA. You are asked to find the parameters in the hybrid-π model.

Q15. What is the value of the transconductance?

(1) 0 mS
(2) 0.05 mS
(3) 0.1 mS
(4) 0.2 mS
(5) 0.5 mS
(6) 1 mS
(7) 2 mS

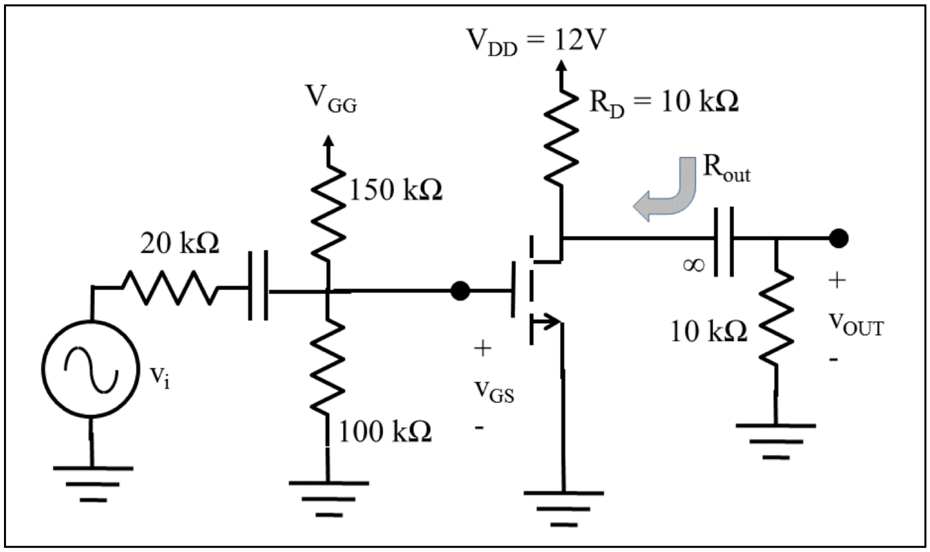
Q15 and Q16 consider an NMOS transistor with $k_n = 1$ mA/V^2 and $\lambda = 0$. The transistor is operated at $I_D = 2$ mA. You are asked to find the parameters in the hybrid-π model.

Q16. Now assume $\lambda = 0.02$. What is the value of r_o?

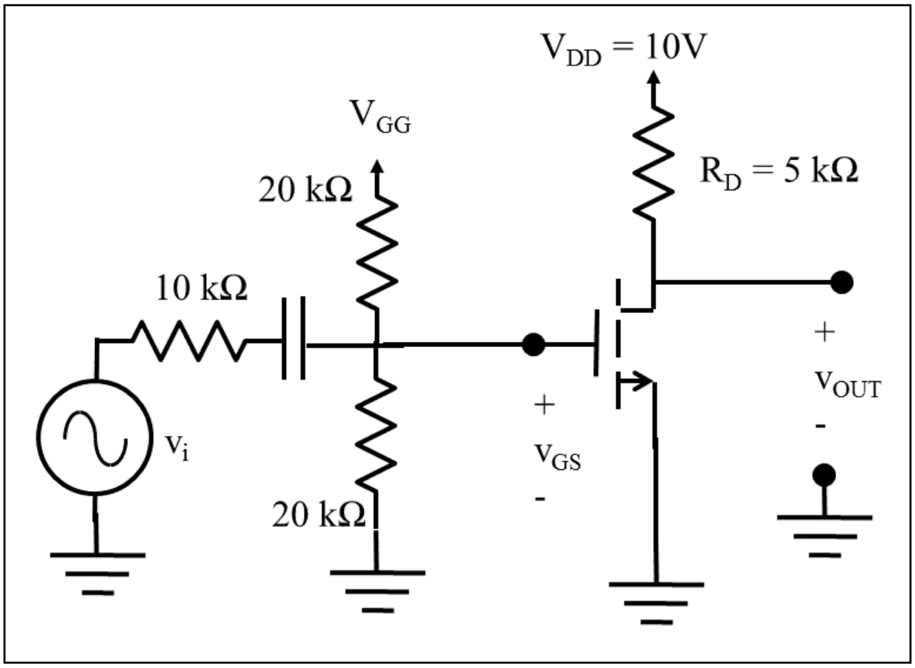
(1) 1 kΩ
(2) 5 kΩ
(3) 12.5 kΩ
(4) 25 kΩ
(5) 50 kΩ
(6) 100 kΩ
(7) 200 kΩ

Q17. Consider the MOSFET circuit shown below. The MOSFET operates in saturation regime. At the DC bias point, g_m = 2 mS and r_o = 30 kΩ. Note that v_i is an ac small-signal source. What is the value of R_{out} at the indicated location?

(1) 0.5 kΩ
(2) 4.3 kΩ
(3) 5 kΩ
(4) 7.5 kΩ
(5) 10 kΩ
(6) 20 kΩ
(7) 40 kΩ



Q18 – Q19 consider the MOSFET circuit shown below. The MOSFET operates in saturation regime. At the DC bias point, g_m = 2 mS and $r_o = \infty$ kΩ. Note that v_i is an ac small-signal source.



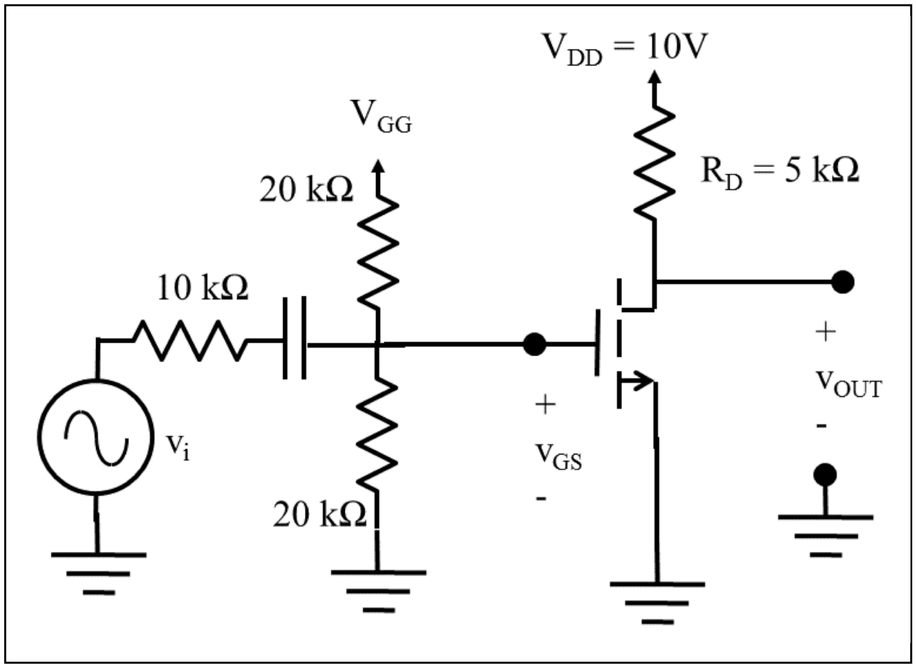
Q18. What is the magnitude of the small-signal voltage gain between the input and the gate of the MOSFET, v_{gs}/v_i?

(1) 0
(2) 0.5
(3) 0.75
(4) 0.9
(5) 1
(6) 5
(7) 10

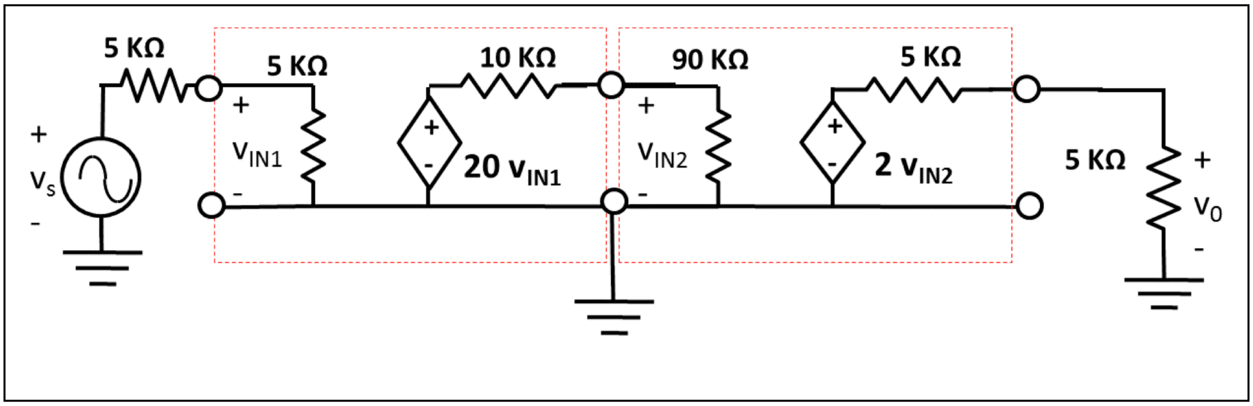
Q18 – Q19 consider the MOSFET circuit shown below. The MOSFET operates in saturation regime. At the DC bias point, g_m = 2 mS and r_o = ∞ kΩ. Note that v_i is an ac small-signal source.

Q19. What is the magnitude of the small-signal voltage gain between the gate of the MOSFET and the output, v_{out}/v_{gs}?

(1) 0.5
(2) 2
(3) 4
(4) 5
(5) 8
(6) 10
(7) 15



Q20. Consider the 2-stage amplifier shown in the figure below. Note that each amplifier stage is represented by an equivalent circuit (i.e. these are not equivalent circuits for transistors). Also note that each stage is characterized by an open-circuit voltage gain (controlled sources in figure are VCVS) and input/output resistances. What is the magnitude of the overall voltage gain (v_o/v_s)?



(1) 1
(2) 4.5
(3) 9
(4) 10
(5) 20
(6) 36
(7) 40

Extra Work Space

Equation Sheet: ECE-255 Spring 2019

$$np = n_i^2 \qquad \sigma = q\left(p\mu_p + n\mu_n\right) \qquad D_n/\mu_n = D_p/\mu_p = k_B T/q = V_T$$

$$J_n = qn\mu_n \mathcal{E} + qD_n\, dn/dx \qquad J_p = qp\mu_p \mathcal{E} - qD_p \frac{dp}{dx}$$

$$I_D = I_S\left(e^{V/V_T} - 1\right) \qquad r_d = V_T / I_D$$

NPN:

$$i_C = I_S e^{v_{BE}/V_T} \qquad I_S = A_E\left(\frac{qD_n n_i^2}{W_B N_A} + \frac{qD_p n_i^2}{W_E N_D}\right)$$

$$i_B = \frac{i_C}{\beta} \qquad i_C = \alpha i_E \qquad i_C = \beta i_B$$

$$g_m = \frac{I_C}{V_T} \qquad g_m r_\pi = \beta \qquad r_o \approx V_A / I_C \qquad r_e = r_\pi/(\beta+1) = \alpha/g_m \approx 1/g_m$$

NMOS:

$$V_{GS} > V_{tn} \qquad V_{DS} \le \left(V_{GS} - V_{tn}\right) \qquad I_D = k_n'\left(\frac{W}{L}\right)\left[\left(V_{GS} - V_{tn}\right)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$V_{GS} > V_{tn} \qquad V_{DS} > \left(V_{GS} - V_{tn}\right) \qquad I_D = \frac{k_n'}{2}\left(\frac{W}{L}\right)\left(V_{GS} - V_{tn}\right)^2\left(1 + \lambda V_{DS}\right) \qquad \lambda = \frac{1}{V_A}$$

$$k_n' = \mu_n C_{ox} \qquad C_{ox} = \varepsilon_{ox} / t_{ox}$$

$$g_m = \frac{I_D}{\left(V_{GS} - V_{tn}\right)/2} \qquad r_o \approx V_A / I_C$$

CE:	$A_{v_o} = -g_m R_C$	$R_{in} = r_\pi$	$R_o = R_C$
CE with emitter R:	$A_{v_o} = \frac{r_\pi}{r_\pi + (\beta+1)R_E}\left(-g_m R_C\right)$	$R_{in} = r_\pi + (\beta+1)R_E$	$R_o = R_C$
CS:	$A_{v_o} = -g_m R_D$	$R_{in} = \infty$	$R_o = R_D$
CS with source R:	$A_{v_o} = \frac{1}{1 + g_m R_S}\left(-g_m R_D\right)$	$R_{in} = \infty$	$R_o = R_D$