

Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science

6.002 – Electronic Circuits
Spring 2002

Final Exam

Name: _____

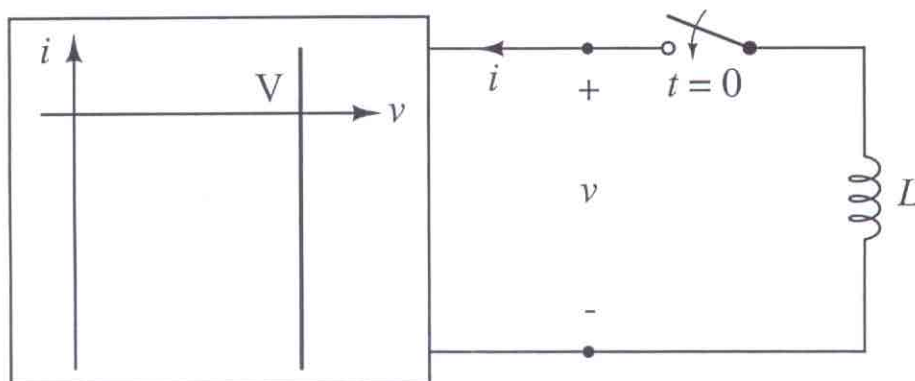
Instructor:	Mur-Miranda	Sussman	Wilson	Baldo
Time:	9 10	10 11	11 12	1 2

- Please put your name in the space provided above, and circle the name of your recitation instructor and the time of your recitation.
- Do your work for each question within the boundaries of the question. When finished, put your answer to each question in the corresponding answer box that follows the question.
- You may use one double-sided page of notes while taking this exam. Calculators are allowed.
- Final grades in 6.002 will not be given out by phone or by e-mail. Rather, they should be available through WEBSIS by May 23. You may review and take back your final exam on or after May 23.
- Good luck!

Problem 1 – 25%

This problem involves determining the transient response of four networks as they are connected to a load through a switch that closes at $t = 0$. In each case, the terminal behavior of the network is described graphically. For each case, graph the terminal current i and the terminal voltage v that results during the transient that follows the closure of the switch. Clearly label the axes of both graphs, and clearly label both transients with their analytical expressions.

(1A) The load is an inductor having inductance L and no initial current.



$i(t)$



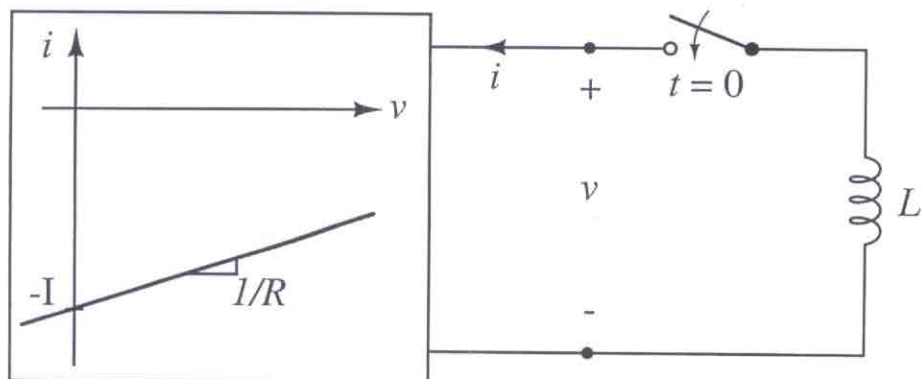
t

$v(t)$



t

(1B) The load is an inductor having inductance L and no initial current.



$i(t)$



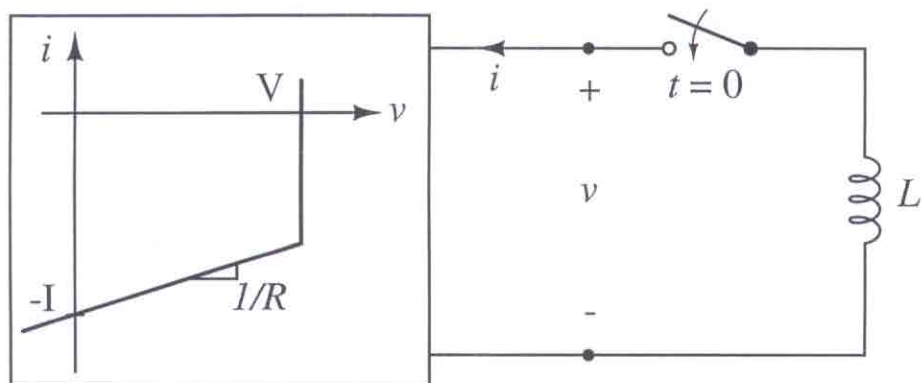
t

$v(t)$



t

(1C) The load is an inductor having inductance L and no initial current.



$i(t)$



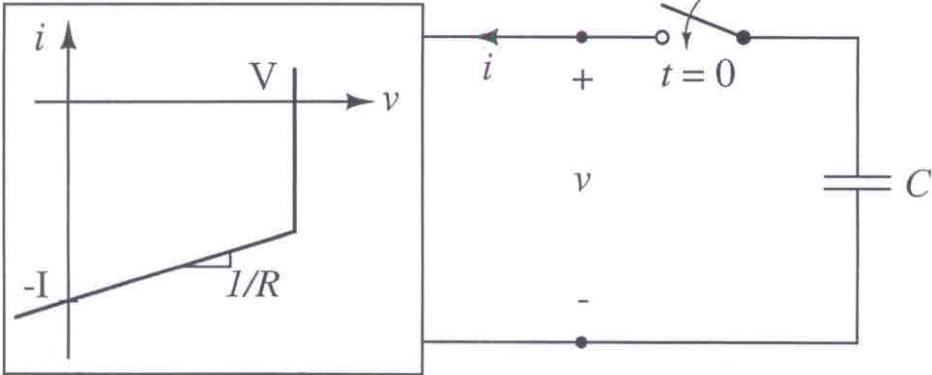
t

$v(t)$



t

(1D) The load is a capacitor having capacitance C and no initial voltage.



$i(t)$



t

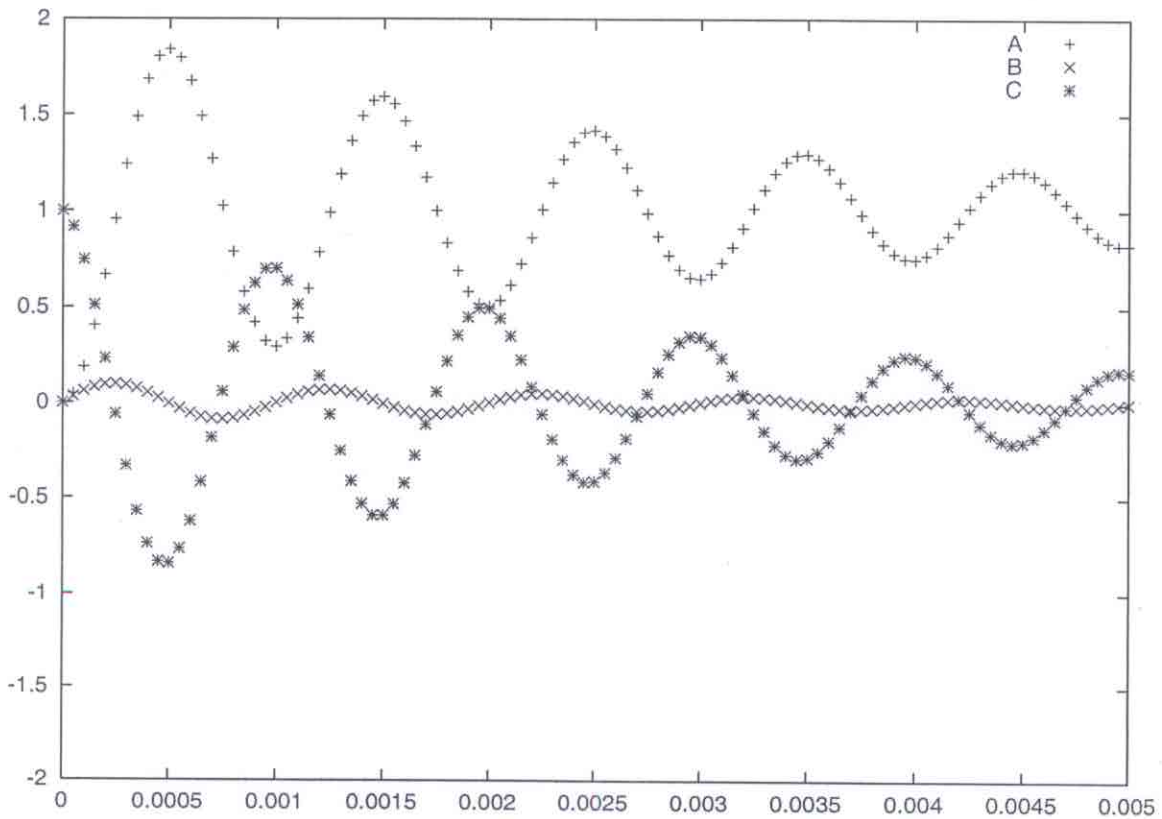
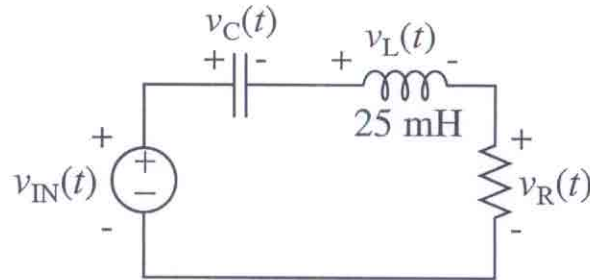
$v(t)$



t

Problem 2 – 25%

This problem concerns the second-order circuit shown below. The inductance L is 25 mH, as indicated. The input v_{IN} steps from 0 V to 1 V at $t = 0$. Prior to the step neither the inductor nor the capacitor store any energy. Three voltage waveforms that correspond to v_C , v_L and v_R are also graphed below, although they are not labeled as such. Their common horizontal axis is marked in seconds, and their common vertical axis is marked in volts.



(2A) The three voltage waveforms are labeled "A", "B" and "C". Identify which waveform is which voltage.

A:	B:	C:
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(2B) What is the *approximate* value of the capacitance C ?

$C \approx$

(2C) What is the *approximate* value of the resistance R ? Hint: $e^{-0.7} \approx 1/2$, and $e^{-1.6} \approx 1/5$.

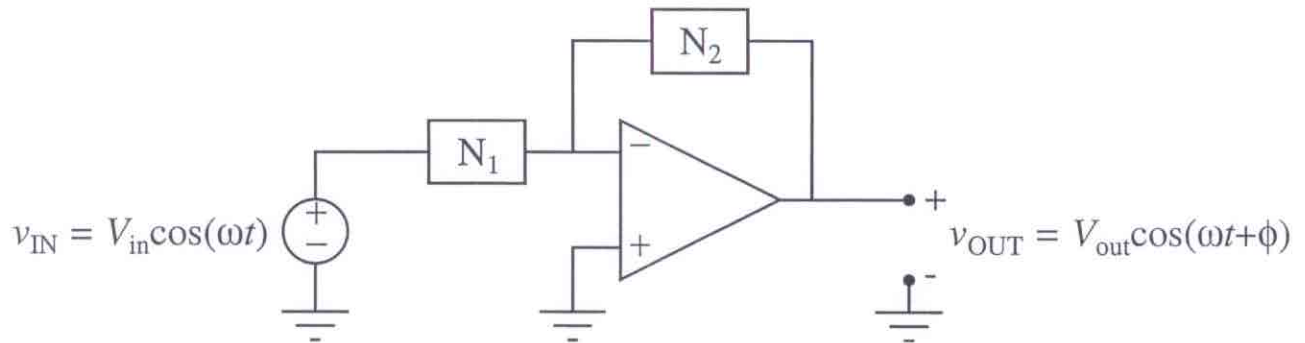
$R \approx$

(2D) Indicate the validity of the following statements by circling "T" for "True" or "F" for "False" as appropriate.

T	F	The transient oscillatory period increases with increasing L .
T	F	The transient oscillatory period increases with increasing C .
T	F	The transient rate of decay increases with increasing R .
T	F	The transient rate of decay is independent of C .
T	F	The transient rate of decay is independent of L .
T	F	The quality factor satisfies $Q < 5$.

Problem 3 – 25%

This problem concerns the op-amp filter shown below; note the definitions of the sinusoidal-steady-state input and output voltages, v_{IN} and v_{OUT} , respectively. Networks N_1 and N_2 are single-port networks that contain only capacitors inductors and resistors. Assume that the op-amp is ideal.

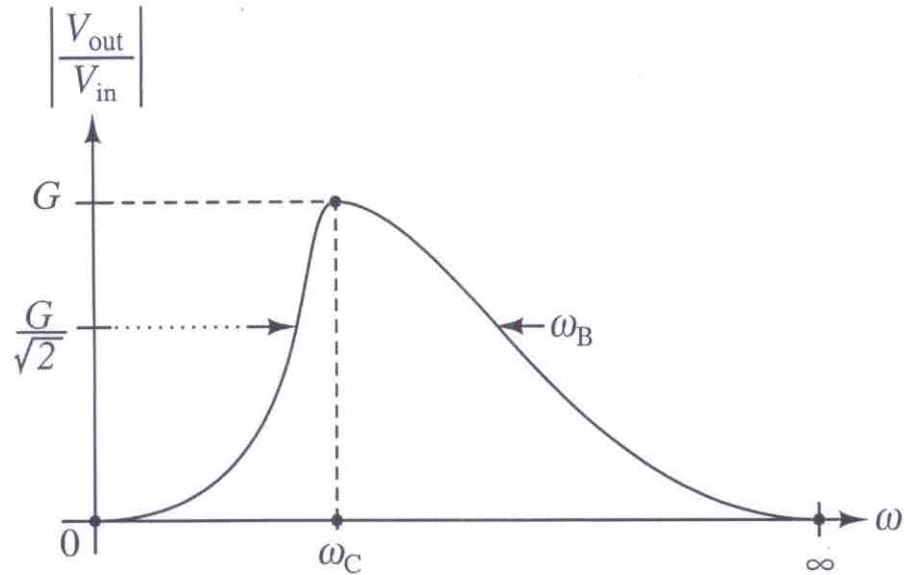


- (3A) Let N_1 have the frequency-dependent impedance $Z_1(\omega) = Z_{R1}(\omega) + jZ_{I1}(\omega)$, where Z_{R1} and Z_{I1} are the real and imaginary parts of Z_1 , respectively. Similarly, let N_2 have the frequency-dependent impedance $Z_2(\omega) = Z_{R2}(\omega) + jZ_{I2}(\omega)$. For this case, find V_{out} and ϕ as functions of V_{in} , Z_{R1} , Z_{I1} , Z_{R2} and Z_{I2} .

$V_{out} =$

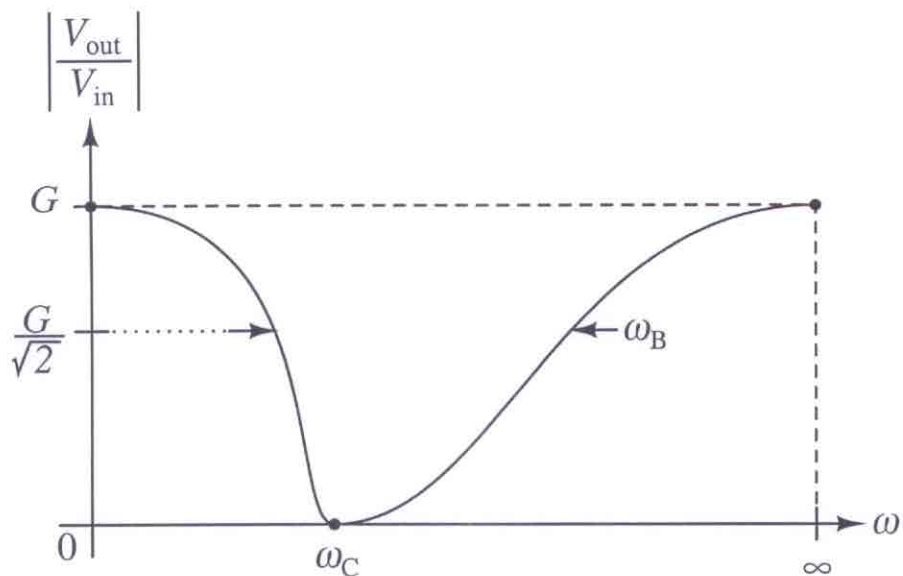
$\phi =$

- (3B) Suppose that N_1 is a single resistor having resistance R . Further, suppose that N_2 contains one capacitor having capacitance C , one inductor having inductance L , and one resistor having resistance βR . For this case, design N_2 so that the filter provides the band-pass gain magnitude $|V_{\text{out}}/V_{\text{in}}|$ defined graphically below. That is, draw the topology of N_2 , and specify C , L and β in terms of R , and the filter parameters G , ω_B and ω_C . Hint: the function $X^2/(X^2 + Y^2)$ equals $1/2$ when $X = \pm Y$.



	$C =$
Topology:	$L =$
	$\beta =$

- (3C) Repeat the previous part, but design N_2 instead so that the filter provides the band-stop gain magnitude defined graphically below. Again, draw the topology of N_2 , and specify C , L and β in terms of R , and the filter parameters G , ω_B and ω_C .



Topology:	$C =$
	$L =$
	$\beta =$

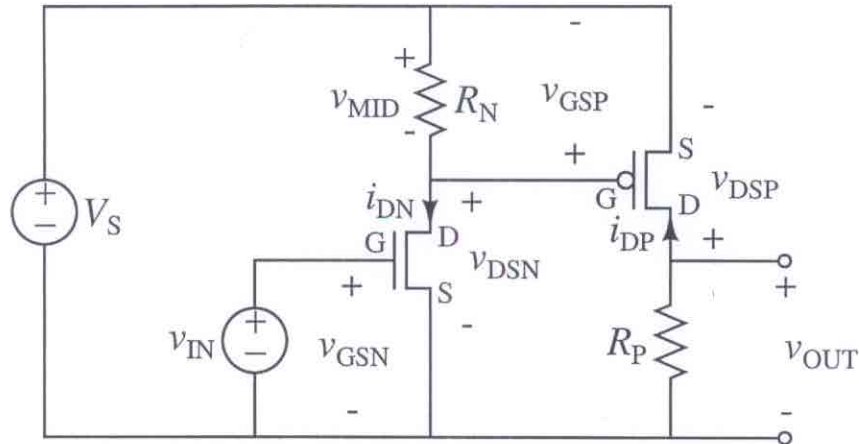
- (3D) Let N_1 be a single resistor having resistance R . Suppose that for a specific N_2 , $V_{\text{out}}(\omega)$ and $\phi(\omega)$ are determined to be the specific functions $\bar{V}_{\text{out}}(\omega)$ and $\bar{\phi}(\omega)$, respectively. Determine the $V_{\text{out}}(\omega)$ and $\phi(\omega)$ that would result if a capacitor having capacitance C were placed in parallel with the resistor that is N_1 . Express the result in terms of R , C , ω , $\bar{V}_{\text{out}}(\omega)$ and $\bar{\phi}(\omega)$.

$$V_{\text{out}} =$$

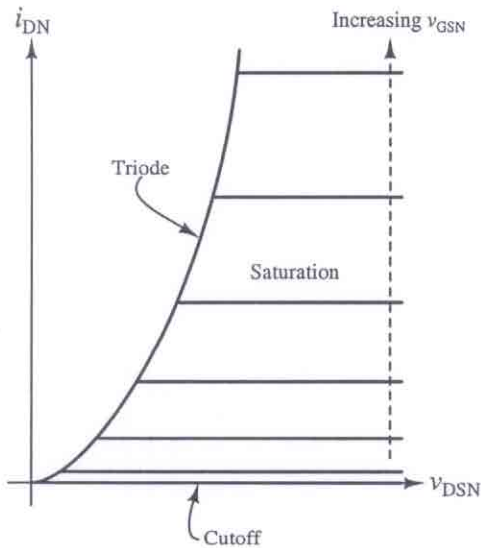
$$\phi =$$

Problem 4 – 25%

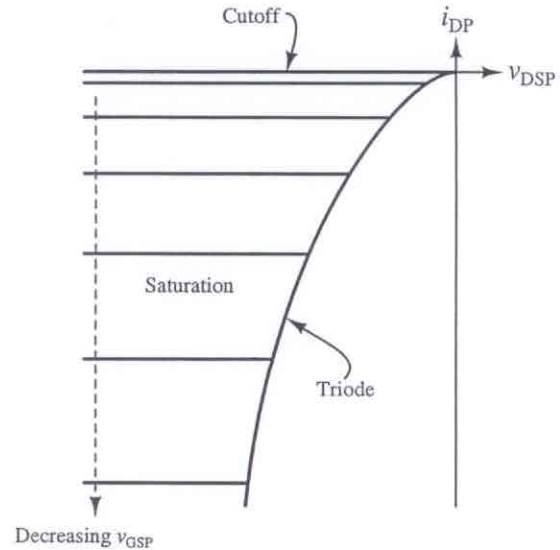
This problem concerns the MOSFET amplifier shown below. The amplifier is constructed with one n-channel MOSFET, one p-channel MOSFET and two resistors. The MOSFET characteristics are also shown below. Note that the operation of each MOSFET in its triode region is simplified; each triode region is compressed onto a quadratic curve. Also note that K_N , K_P and V_{TN} are all positive, while V_{TP} is negative.



n-Channel MOSFET



p-Channel MOSFET



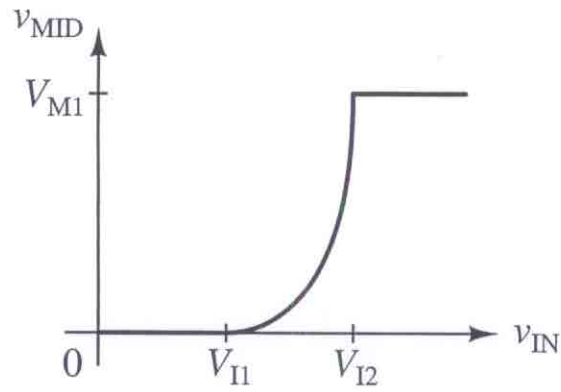
$$i_{DN} = \begin{cases} 0 & v_{GSN} - V_{TN} \leq 0 & \text{(Cutoff)} \\ \frac{K_N}{2}(v_{GSN} - V_{TN})^2 & 0 \leq v_{GSN} - V_{TN} < v_{DSN} & \text{(Saturation)} \\ \frac{K_N}{2}v_{DSN}^2 & 0 \leq v_{DSN} \leq v_{GSN} - V_{TN} & \text{(Triode)} \end{cases}$$

$$i_{DP} = \begin{cases} 0 & -v_{GSP} + V_{TP} \leq 0 & \text{(Cutoff)} \\ -\frac{K_P}{2}(-v_{GSP} + V_{TP})^2 & 0 \leq -v_{GSP} + V_{TP} < -v_{DSP} & \text{(Saturation)} \\ -\frac{K_P}{2}v_{DSP}^2 & 0 \leq -v_{DSP} \leq -v_{GSP} + V_{TP} & \text{(Triode)} \end{cases}$$

- (4A) Assume that the n-channel MOSFET operates in its saturation region. Determine v_{MID} as a function of v_{IN} .

$$v_{\text{MID}} =$$

(4B) The dependence of v_{MID} on v_{IN} can be summarized by the figure shown below. Determine the parameters V_{I1} , V_{I2} and V_{M1} in the figure.

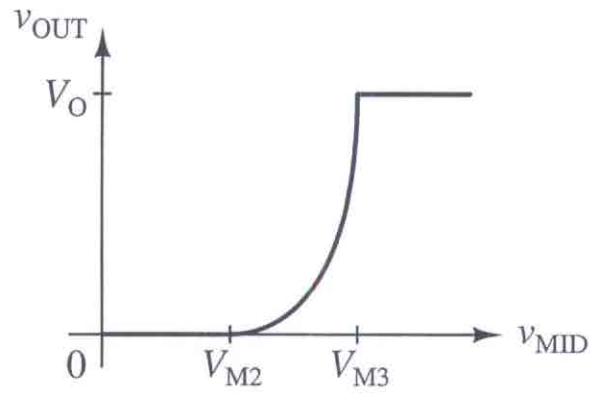


$V_{\text{I1}} =$	$V_{\text{I2}} =$	$V_{\text{M1}} =$
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- (4C) Assume that the p-channel MOSFET operates in its saturation region. Determine v_{OUT} as a function of v_{MID} .

$$v_{OUT} =$$

(4D) The dependence of v_{OUT} on v_{MID} can be summarized by the figure shown below. Determine the parameters V_{M2} , V_{M3} and V_{O1} in the figure.



$V_{M2} =$

$V_{M3} =$

$V_O =$

- (4E) To achieve a wide operating range for v_{OUT} it is desirable for the p-channel MOSFET to enter its triode operating region before the n-channel MOSFET does. Which of the following design constraints is necessary to guarantee this operation? Circle the correct constraints.

Constraints: $V_{M1} < V_{M2} < V_{M3}$ $V_{M2} < V_{M1} < V_{M3}$ $V_{M2} < V_{M3} < V_{M1}$

- (4F) Assuming that both the n-channel MOSFET and the p-channel MOSFET operate in their saturation regions. Determine v_{OUT} as a function of v_{IN} .

$v_{OUT} =$

- (4G) Let $v_{IN} = V_{IN} + v_{in}$ and $v_{OUT} = V_{OUT} + v_{out}$ where V_{IN} and V_{OUT} , and v_{in} and v_{out} , are the large and small-signal components of v_{IN} and v_{OUT} , respectively. Assume that both MOSFETs operate in their saturation regions, at bias points established by V_{IN} . In this case, determine the linearized small-signal gain of the amplifier, v_{out}/v_{in} , evaluated at V_{IN} .

$$v_{out}/v_{in} =$$