Name: ________ Solutions

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EE 40

Midterm 3

November 14, 2002

PLEASE WRITE YOUR NAME ON EACH ATTACHED PAGE

PLEASE SHOW YOUR WORK TO RECEIVE PARTIAL CREDIT

Problem 1: 10 Points Possible __________

Problem 2: 20 Points Possible __________

Problem 3: 10 Points Possible __________

Problem 4: 20 Points Possible __________

Problem 5: 20 Points Possible __________

Problem 6: 20 Points Possible __________

TOTAL: 100 Points Possible __________

Name:________Solutions

Problem 1: 10 Points

Fill in the blanks to correctly complete the sentences.

To improve conduction in silicon, atoms from other elements are incorporated into the lattice.

The addition of Group III elements creates ___p____ - type material.

For example, ______boron_______ is a Group III element that might be added to the silicon.

The addition of Group V elements creates ___n__- type material.

For example, ___phosphorus__ is a Group V element that might be added to the silicon.

The Group ____III_____ elements need one more electron in the outer shell to complete all four lattice bonds.

This lack of an electron is called a _____hole________.

When the two types of material are joined together, electrons cross the junction between the two materials to complete lattice bonds where needed.

The movement of free electrons from an area of greater concentration to lesser concentration, motivated by the need to complete lattice bonds, is called ____diffusion________________

This creates a layer without free charge carriers, called the ____depletion___________ layer.

The movement of electrons creates positive charge in the atoms the electrons have left behind, and negative charge in the atoms which the electrons have joined. This creates a potential difference across the junction; the ____n_____ - type material is at higher potential.

This causes electrons to move across the junction towards the higher electric potential. This movement, due to attraction by positive potential, is called _______drift_____________.

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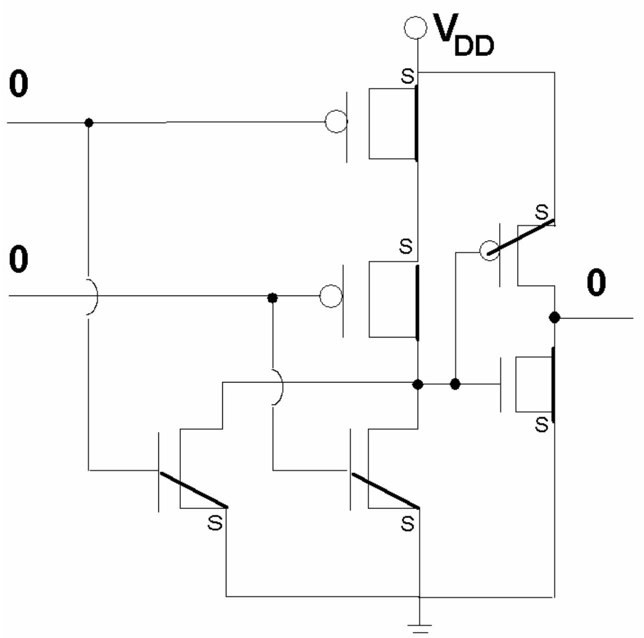
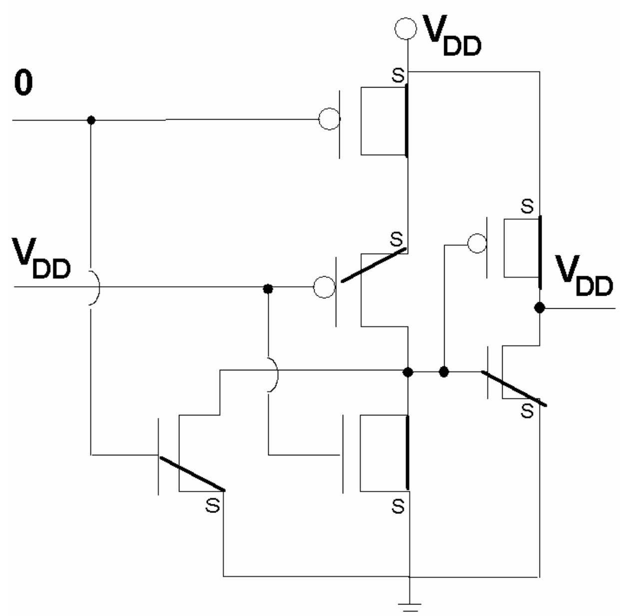
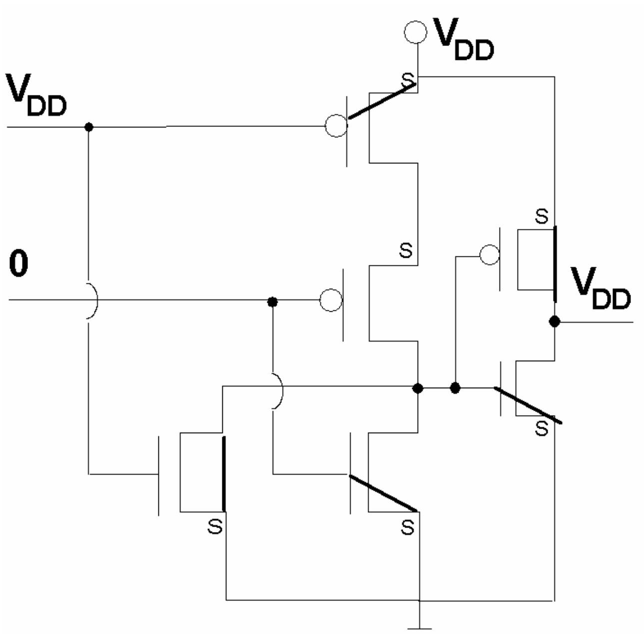
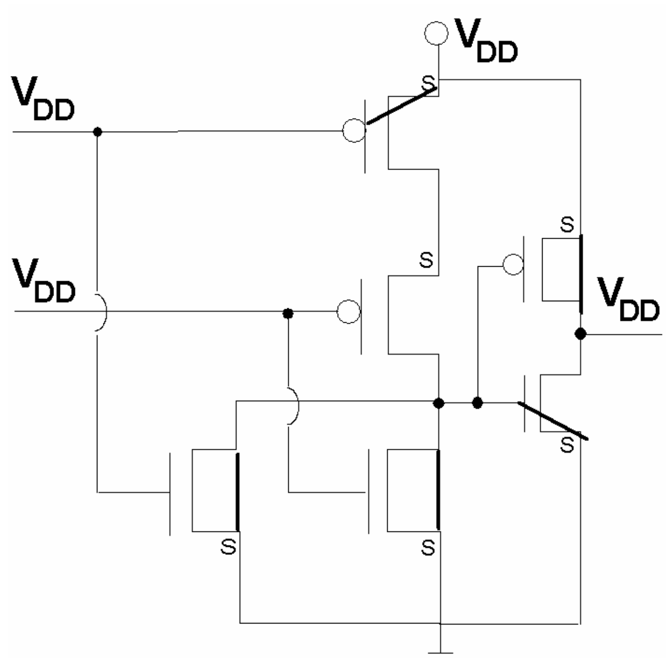
Problem 2: 20 Points

Determine the logical operation performed by the circuit below (copied 4 times for convenience):







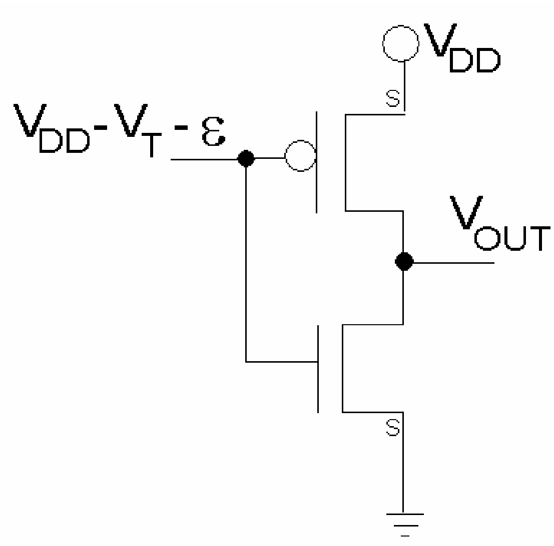


Name:_________Solutions

Problem 3: 10 Points

Consider the following circuit, with the input voltage just below $V_{DD} – V_T$. Here, the NMOS threshold voltage is V_T and the PMOS threshold voltage is $–V_T$. V_T is positive, and much smaller than V_{DD}. Assume that the transistors have matched I_D/V_{DS} characteristics.

Determine the most likely mode of operation for each transistor.



PMOS:

$V_{GS(P)} = V_{DD} – V_T – \varepsilon – V_{DD} = -V_T - \varepsilon$

$V_{GS(P)}$ is near threshold, so transistor is barely turned on => shallow curve => small I_D

NMOS:

$V_{GS(N)} = V_{DD} – V_T – \varepsilon$

$V_{GS(N)}$ is well above threshold, so transistor is fully turned on => steep curve

small I_D (from PMOS) and steep curve => $V_{DS(N)}$ small => **NMOS in triode**

$V_{DS(N)}$ small => $V_{DS(P)}$ not small => **PMOS in saturation**

Name:________ Solutions

Problem 4: 20 Points

Consider the following circuit. Find V_{OUT} when V_{IN} is 3.7 V.

NMOS:

$V_{T(N)} = 1$ V

$\lambda = 0$

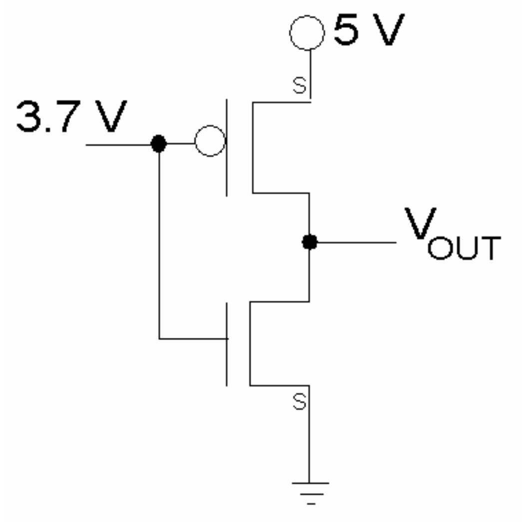
$I_{DSAT(N)} = 10^{-3}(V_{GS(N)}-V_{T(N)})^2$ A

PMOS:

$V_{T(P)} = -1$ V

$\lambda = 0$

$I_{DSAT(P)} = -10^{-3}(V_{GS(P)}-V_{T(P)})^2$ A



$I_{D(P)} + I_{D(N)} = 0$

$V_{DS(N)} – V_{DS(P)} = 5$ V

Guess that PMOS is in saturation and NMOS is in triode (basically situation from Problem 3).

PMOS:

$I_{D(P)} = I_{DSAT(P)}(1+\lambda V_{DS(P)}) = -10^{-3}(V_{GS(P)}-V_{T(P)})^2 = -10^{-3}(5 - 3.7 - -1)^2 = -9 \times 10^{-5}$ A

NMOS:

$I_{D(N)} = 2\ I_{DSAT(P)}\ (V_{GS(N)}-V_{T(N)}-V_{DS(N)}/2)V_{DS(N)}\ /\ (V_{GS(N)} – V_{T(N)})^2 = 2 \times 10^{-3}\ (3.7 – 1 – V_{DS(N)}/2)V_{DS(N)}$

$= -10^{-3}\, V_{DS(N)}^2 + 5.4 \times 10^{-3}\ V_{DS(N)}$

$= -I_{D(P)} = 9 \times 10^{-5}$

Roots of $-10^{-3}\, V_{DS(N)}^2 + 5.4 \times 10^{-3}\ V_{DS(N)} - 9 \times 10^{-5}$: $V_{DS(N)} = 5.383$ V and 0.017 V

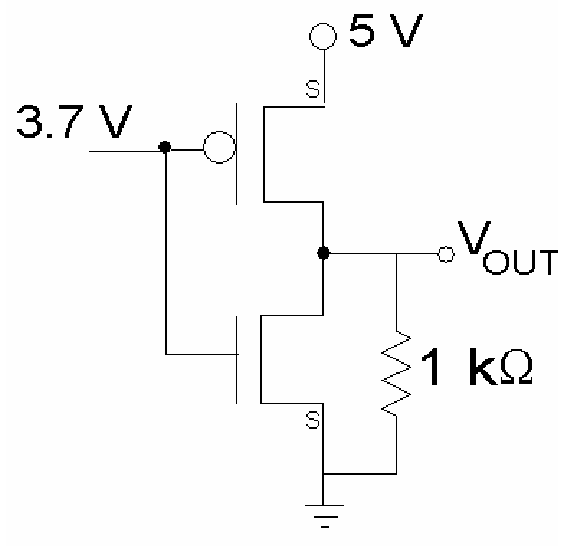
$V_{DS(N)} = 5.383$ V impossible, so $V_{DS(N)} =$ **0.017 V = V_{OUT}**

$V_{DS(N)} = 0.017$ V agrees with triode mode & $V_{DS(P)} = 0.017 – 5 = -4.983$ V agrees with saturation

Name:_________Solutions

Problem 5: 20 Points

Consider the following circuit. Find V_{OUT} when V_{IN} is 3.7 V.



NMOS:

$V_{T(N)} = 1$ V

$\lambda = 0$

$I_{DSAT(N)} = 10^{-3}(V_{GS(N)}-V_{T(N)})^2$ A

PMOS:

$V_{T(P)} = -1$ V

$\lambda = 0$

$I_{DSAT(P)} = -10^{-3}(V_{GS(P)}-V_{T(P)})^2$ A

$I_{D(P)} + I_{D(N)} + V_{DS(N)} /1000 = 0$

$V_{DS(N)} - V_{DS(P)} = 5$ V

Guess that PMOS is in saturation and NMOS is in triode (keep guess from Problem 4).

PMOS:

$I_{D(P)} = I_{DSAT(P)}(1+\lambda V_{DS(P)}) = -10^{-3}(V_{GS(P)}-V_{T(P)})^2 = -10^{-3}(5 - 3.7 - -1)^2 = -9 \times 10^{-5}$ A

NMOS:

$I_{D(N)} = 2\ I_{DSAT(P)}\ (V_{GS(N)}-V_{T(N)}-V_{DS(N)}/2)V_{DS(N)} / (V_{GS(N)} - V_{T(N)})^2 = 2 \times 10^{-3}\ (3.7 - 1 - V_{DS(N)}/2)V_{DS(N)}$

$= -10^{-3}\, V_{DS(N)}^2 + 5.4 \times 10^{-3}\ V_{DS(N)}$

$= -I_{D(P)} - V_{DS(N)} /1000 = 9 \times 10^{-5} - 10^{-3}\ V_{DS(N)}$

Roots of $-10^{-3}\, V_{DS(N)}^2 + 6.4 \times 10^{-3}\ V_{DS(N)} - 9 \times 10^{-5}$: $V_{DS(N)} = 6.386$ V and 0.014 V

$V_{DS(N)} = 6.386$ V impossible, so $V_{DS(N)} =$ **0.014 V = V_{OUT}**

$V_{DS(N)} = 0.014$ V agrees with triode mode & $V_{DS(P)} = 0.014 - 5 = -4.986$ V agrees with saturation

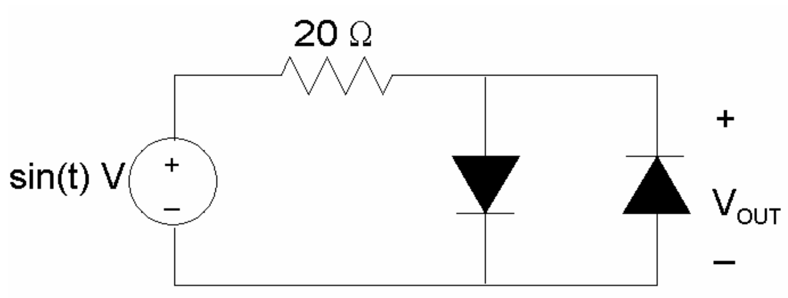
Name:________Solutions

Problem 6: 20 Points

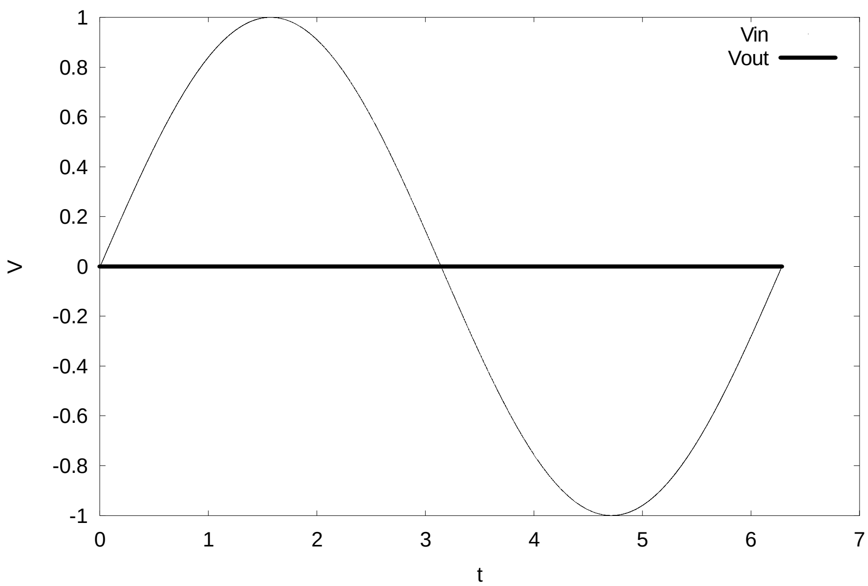
Sketch $V_{OUT}(t)$ for the diode circuit

a) using the ideal model
b) using the large-signal model
c) using the small-signal model.

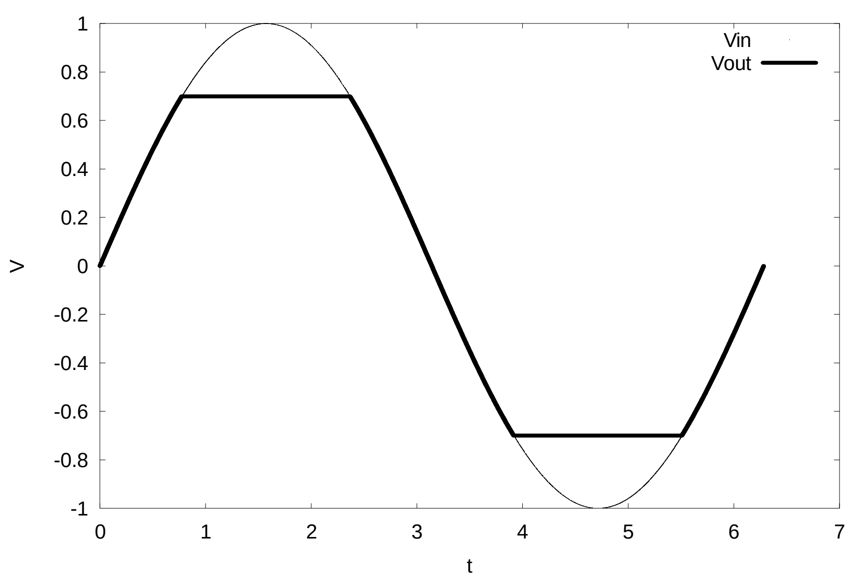
Provide enough detail to completely indicate the effect created by the circuit.



Ideal model: neither diode can accept positive forward voltage.



Large-signal model: each diode can accept any forward voltage up to 0.7 V, acting like open circuit. Above 0.7, a diode conducts current and resistor takes rest of input voltage.



Name:_________Solutions

Problem 6 Workspace

Small signal model: each diode acts as open circuit for forward voltage up to 0.6 V. Above 0.6, a diode conducts current through the 20 Ω resistor and its own 20 Ω resistance (part of its model). The difference between the input and 0.6 V is distributed across the 20 Ω resistors; thus the diode gets 0.6 V plus half the difference between 0.6 and the input voltage.