

EECS 40, Fall 2007
Prof. Chang-Hasnain

Homework #10

Due at 5 pm in 240 Cory on Thursday, 12/6/07

Total Points: 100

- Put (1) your name and (2) discussion section number on your homework.
- You need to put down all the derivation steps to obtain full credits of the problems. Numerical answers alone will at best receive low percentage partial credits.
- No late submission will be accepted except those with prior approval from Prof. Chang-Hasnain.

1. Solar cells and photodetectors (35 points)

1. What happens over time to the resistance of silicon when very intense radiation is applied to it?

The radiation generates holes and electrons in the silicon. This raises the probability that electrons are in the conduction band and holes in the valence band. Therefore, the resistance drops.

2. For a PN-junction under reverse bias (no radiation), what is the source of current?

There is only a very small current due to diffusion.

3. What happens to an electron-hole pair in the intrinsic region of a photodiode, and why? (Assume no external voltage is applied, and then comment on the role external voltage would play).

The pair is in a stable condition. It needs energy to separate the electron from the hole. There is a small probability that this happens due to the thermal energy in the device. If radiation is applied, the energy is used to separate the pair. Then there is a free electron and a free hole. They move in a random direction until they recombine again with another free carrier. If an external voltage is applied, the electrons tend to move toward the +pol and the holes towards the -pol. This is due to the electric field. The directed effect is called drift.

4. What happens when red light is shined on Aluminum Arsenic? What about violet light?

The energy of the red light is too low to excite the Aluminum Arsenic because it is less than AIAs's band gap. Therefore, the number of free charge carriers is not increased. Violet light rays have higher energy and will be absorbed by the AIAs and therefore increase the number of free charge carriers.

5. Suppose you know the amount of incident light, so that $I_D = f(V_D)$ (see second figure below). Write down the equation you would solve to find the operating point that maximizes power. Then write the resistor you would choose in terms of v_{opt} and $f(V_{opt})$ in order to achieve this operating point.

$$dP/dV = d/dV(f(V) \cdot V) = 0$$

Solve for this to find v_{opt}

$$R = v_{opt} / f(V_{opt})$$

6. Suppose you have a number of curves, each corresponding to a different amount of incident light, and you are trying to maximize the amount of power generated. What would it mean if the curves ever intersected? What does this tell us about our ability to determine the amount of incident light (assuming we knew the curve for every value of incident light)?

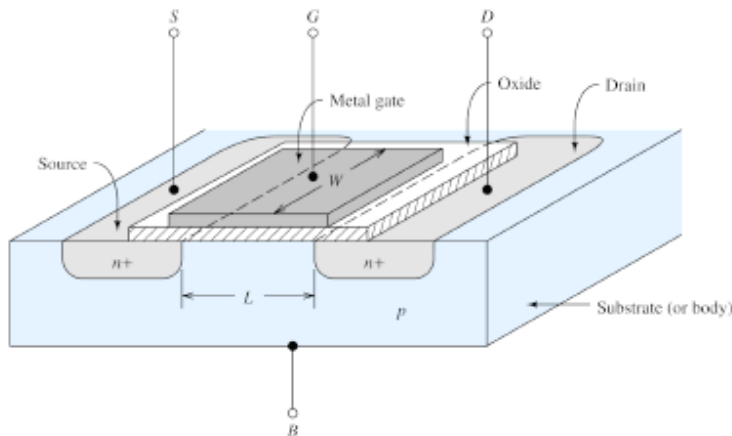
The curves intersecting means that for different amount of incident light you get the same output voltage & current. That shouldn't happen. So we can always determine the amount of incident light uniquely, assuming we can measure precisely.

2. Analysis of an Amplifier (65 pts)

Amplifiers are essential building blocks in analog circuits and can be found in almost all electronic devices. Amplification requires the usage of nonlinear devices such as bipolar junction transistors (BJT) or metal oxide semiconductor field effect transistors (MOSFET). In this homework, you will fully analyze an amplifier based on a MOSFET. Before starting with this homework, you may want to read chapter 12 of the textbook.

• Geometry of a MOSFET (10 pts)

- a. Sketch the model of an n-channel MOSFET. Clearly identify which regions are n and p doped. Also, mark the terminals. (5 pts)



- b. Explain the principal operation of the MOSFET. Is the charge through the channel transported by holes or electrons?

For NMOS, as the gate-body voltage increased above a certain positive value (called threshold voltage V_{to}), a thin layer of electrons is formed at the oxide-Si interface. This layer is called the inversion layer, which forms a bridge to conduct electrons from source to drain. As the channel is n-type, with electrons as the conducting carriers, this type of MOSFET is called N-MOSFET. Current can flow from the drain, through the channel, and out the source if a drain to source voltage, V_{DS} , is applied. You may notice that the terms "source" and "drain" seem to be backwards. This is because they are the source and drain of *carriers*, which in the case of a NMOS are electrons.

For PMOS you have a negative voltage (relative to the body) applied at the gate, so holes congregate at the interface. These conduct.

- **II Large Signal Model of MOSFET (25 pts)**

- c. In which modes can a MOSFET be operated. In which mode is the MOSFET a good amplifier?

MOSFET can be operated in cutt-off ($V_{GS} < V_{to}$), triode ($V_{GS} > V_{to}$ and $v_{DS} < v_{GS} - V_{to}$), or saturation ($V_{GS} > V_{to}$ and $v_{DS} > v_{GS} - V_{to}$). MOSFET is a good amplifier in saturation mode.

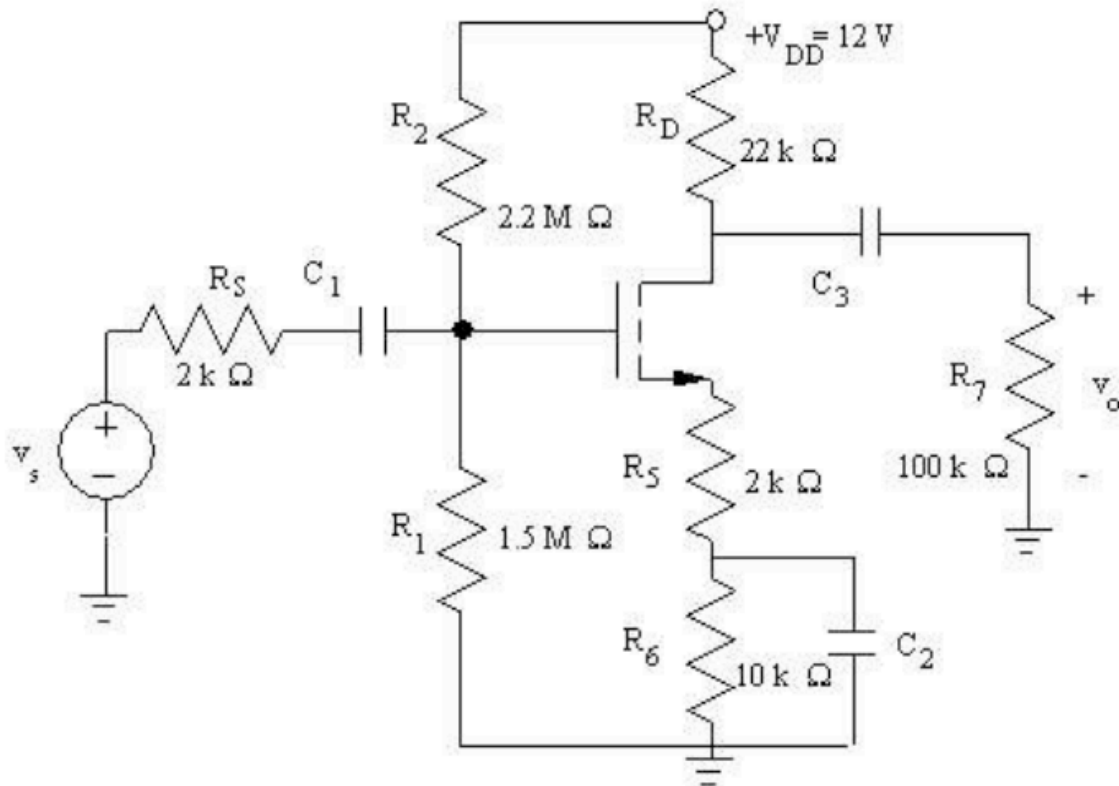
The analysis of an amplifier is usually divided into the DC analysis and the AC analysis. For both analyses, we have draw equivalent circuits. We will first consider DC equivalent circuits.

- d. In DC equivalent circuits, capacitors, coils, AC voltage sources, and AC current sources may be replaced by DC equivalents. Fill out the following table:

circuit element	DC equivalent	Explanation
Coil	short	$V = L di/dt$, so in steady state where i is constant $V=0$.
Capacitor	open	Capacitor will charge until in steady state; then no current flows.
AC current source	open	AC current source does not allow the flow of a DC current, hence open circuit. (Or think of using

		superposition).
AC voltage source	short	DC voltage across an AC voltage source is 0, so short. (Or think of using superposition.)

In the following we will analyze the following single stage amplifier circuit:



- e. Draw the DC equivalent circuit for the given circuit. The source v_s is an AC voltage source.

We open all capacitors. R_s and R_7 become useless and V_s does not affect the circuit. Thus the DC equivalent contains R_1 , R_2 , R_D , R_5 , R_6 and the MOSFET hooked up to V_{DD} .

Aim of the DC analysis is to calculate the Q-point of the transistor, i.e. the voltage between drain and source and the current through the channel. The Q-point can then be used to calculate the transconductance and the drain resistance of the MOSFET which is needed for the small signal analysis.

- f. Calculate the voltage between the drain and the source as well as the voltage between the gate and the source. Further, calculate the current through the channel of the MOSFET. In which mode is the MOSFET biased? The transistor is an n-channel type. For this complete exercise,

use the typical values of an MOSFET as given in the table on page 581 of the textbook, and assume $K = 1 \text{ mA/V}^2$.

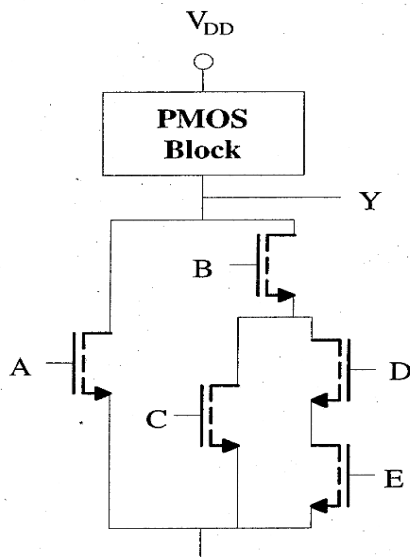
Using Voltage divider equation we find $V_G = R_1 / (R_1 + R_2) * 12 = 4.9 \text{ V}$.

Use $V_{GS} = V_G - 12\text{k}\Omega I_D$ and $I_D = K (V_{GS} - V_{to})^2$ to find $\{V_{GS} \rightarrow 0.386725\}$, $\{V_{GS} \rightarrow 1.52994\}$. IF $V_{GS} = 0.3867$, it is below threshold and our assumptions don't hold, thus $V_{GS} \rightarrow 1.52994$. $I_D = K (V_{GS} - V_{to})^2 = 0.280836 \text{ mA}$. We can finally back out $V_{DS} = 12 - 34\text{k}\Omega * 0.28 \text{ mA} = 2.462 \text{ V}$.

- We can see that this satisfies the conditions for saturated mode, which validates our assumption. i.e. $V_{GS} > V_{th}$ and $V_{DS} > V_{GS} - V_{th}$

IV CMOS Logic Gates (30 pts)

Apart from the application in amplifier circuits, MOSFETs are also the most important building blocks of logic circuits. A modern graphical processing unit, for instance, contains more than 120 million transistors. Apart from the already discussed diode logic, there exists logic gates which are based on BJTs. Further, there exists logic exclusively using n-channel MOSFETs or p-channel MOSFETs. Our focus, however, will be on the so called CMOS, which uses both types of MOSFETs.

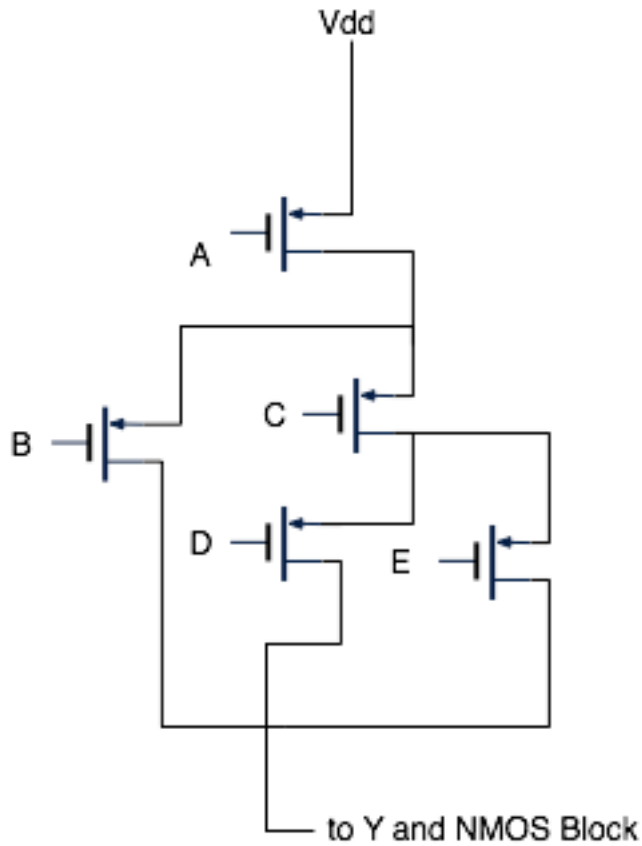


3. Given is NMOS block of a function implementing a boolean function. (15 pts)

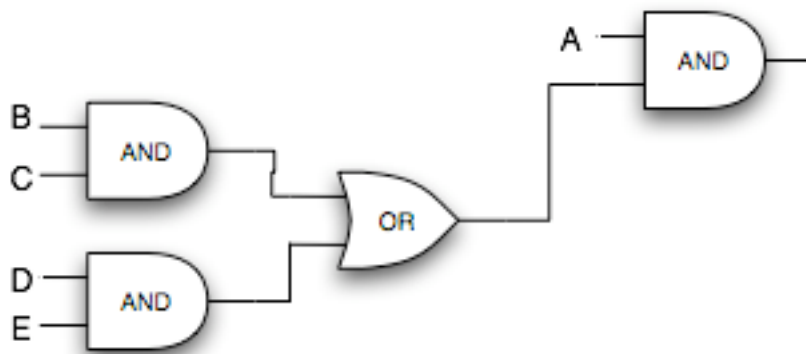
a) What boolean function is implemented?

$$Y = \text{not}(A + B(C + DE))$$

b) Draw the PMOS part of the circuit.



4. Construct a circuit which implements $Y = A \cdot (B \cdot C + D \cdot E)$ (15 pts)



The CMOS equivalent is also an acceptable answer.