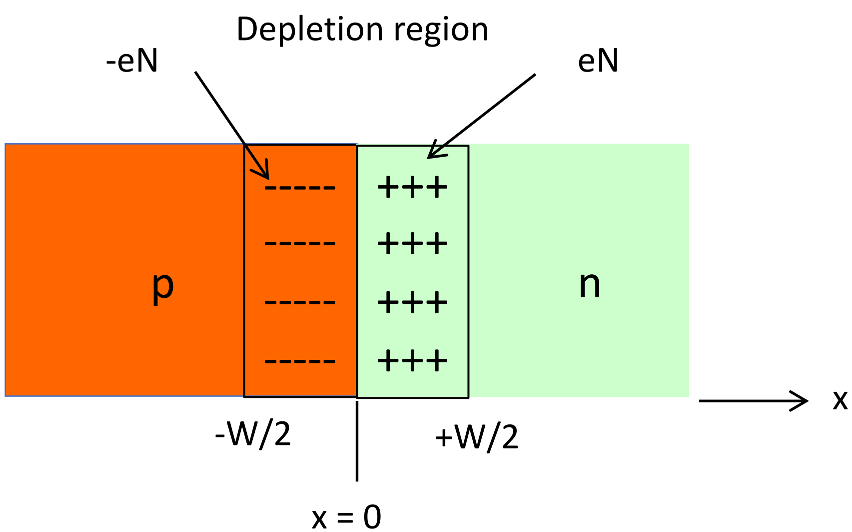
Physics 525 Semiconductor Physics Problems

1. (20 pts) The figure shows a pn junction. Assume the acceptor density $N_A = N$ and the donor density $N_D = N$. In the depletion region the ionized donors and acceptors are exposed and account for the nonzero charge density. The depletion region ends abruptly at ± W/2. Make the following assumptions:



i. The total charge density is zero outside the depletion region.

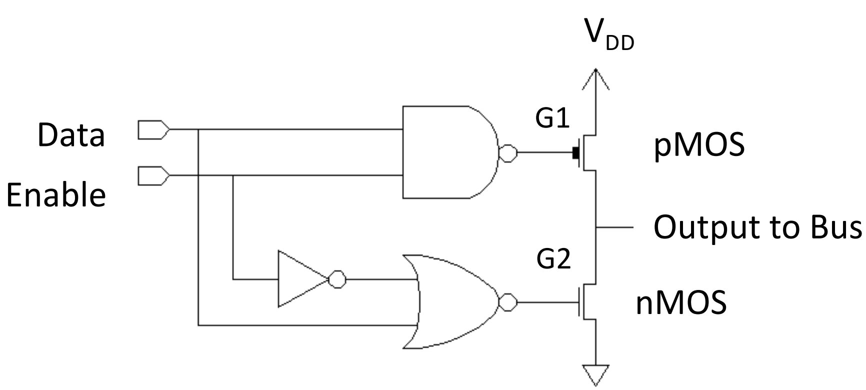
ii. Silicon has a dielectric constant $\epsilon = 11.8\,\varepsilon_0$.

iii. The junction has a cross-sectional area *A* and the voltage varies only along the *x* direction.

iv. The built-in potential difference from –W/2 to W/2
Is given by,

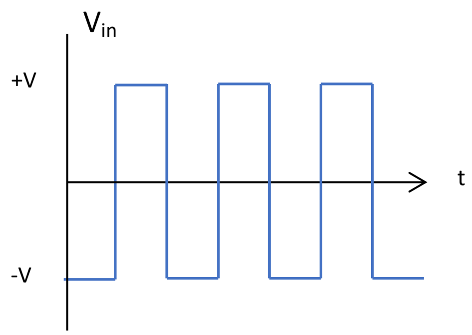
$$\Delta V_{built-in} = \frac{k_B T}{e} \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

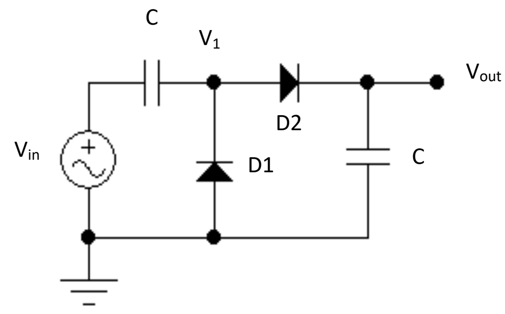
Solve Poisson's equation for the voltage V(x) and find the depletion layer width W. Show that it agrees with the expression in the notes. Find W for N = $10^{15}/\text{cm}^3$.



2. (5 pts) The circuit on the left is used as a *tri-state* output. It acts like a digitally controlled switch. When Enable = 1 the switch is closed and whatever is on the Data input (logic 1 or logic 0) can be sent to the data bus. When Enable = 0 the switch is open so the bus is disconnected from the tri-state circuitry. Explain how it works.

3. (15 pts) The diode circuit shown below is a *charge pump*. For simplicity, assume that the input is a square wave that oscillates between +V and –V. Treat the diodes as perfect switches: zero resistance for any forward bias voltage and infinite resistance for any reverse bias voltage.



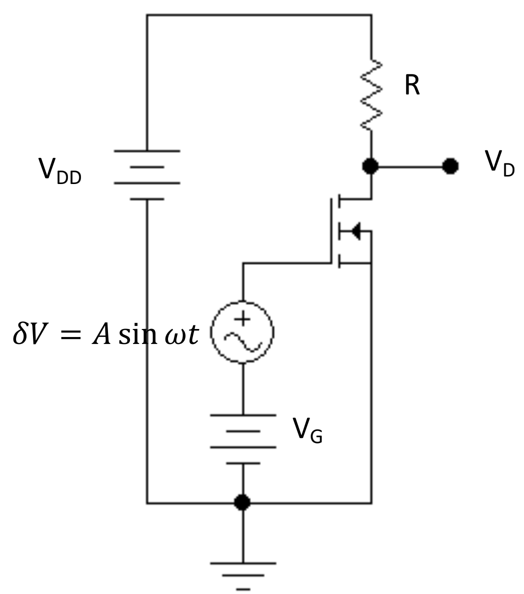


Assume that when V_{in} = -V, D1 is a short circuit and D2 is an open circuit and when V_{in} = +V, D2 is a short circuit and D1 is an open circuit. Find and plot V_{out} for the first 3 cycles of V_{in} and explain how V_{out} eventually approaches 2V. Hint: use a combination of Kirchoff's voltage law and charge conservation.

4. (10 pts) We've seen how MOSFETs are used for digital logic circuits but they are also used in analog electronics. The circuit on the right is used to amplify a small sinusoidal signal $\delta V = A \sin \omega t$. The voltage at the drain V_D consists of a constant (DC) part V_D^0 and a sinusoidal part $\delta V_D = G\delta V$ where *G* is the voltage gain of the amplifier. V_{DD} drives current through the MOSFET channel and V_G determines the MOSFET current. Assume that the MOSFET operates in its saturation region where,

$$I_{DS} = \kappa \, (V_{GS} - V_{Th})^2$$

The schematic diagram shows that $V_{GS} = V_G + \delta V$. Assume $\kappa = 2 \, x \, 10^{-3}$, R = 10^3 Ohms, V_{DD} = 10 V, V_G = 3 V and V_T = 2 V. By expanding the voltages and currents to lowest order in δV , find V_D^0 and the gain *G*. The ground symbol represents 0 Volts.



5. (20 pts) Consider the following Boolean expressions:

$$(X+Y)\cdot\left(\overline{X\cdot Y}\right),\ \overline{X\cdot Y+\bar{X}\cdot\bar{Y}},\ (X+Y)\cdot\left(\bar{X}+\bar{Y}\right),\ X\cdot\bar{Y}+\bar{X}\cdot Y$$

a. Show that all 4 expressions are equivalent.

b. Assuming that X and Y are the logical inputs, what logical operation does this correspond to?

c. Make an XOR gate using only NOR gates.

d. Boolean multiplication is distributive over addition. That is,

$$A\cdot(B+C)=A\cdot B+B\cdot C$$

Prove that Boolean addition is distributive over multiplication,

$$A+B\cdot C=(A+B)\cdot(A+C)$$

6. (5 pts) Use a truth table that includes inputs a, b, A, B, C, D to show how the multiplexer works.