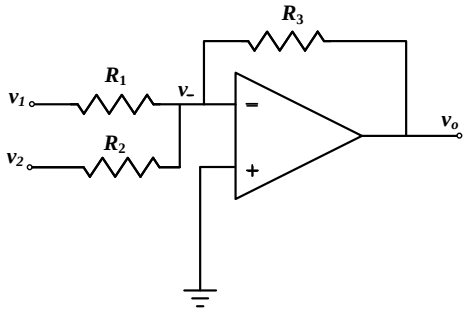
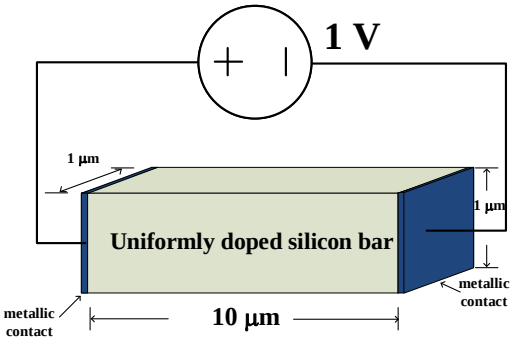
1. (24 points) Difference Amplifier
Given an ideal amplifier circuit as illustrated in the figure below. $R_1 = 2\ k\Omega$, $R_2 = 10\ k\Omega$, $R_3 = 51\ k\Omega$, $v_1(t) = (0.01sin3770t)V$, and $v_2(t) = (0.05sin10000t)V$.

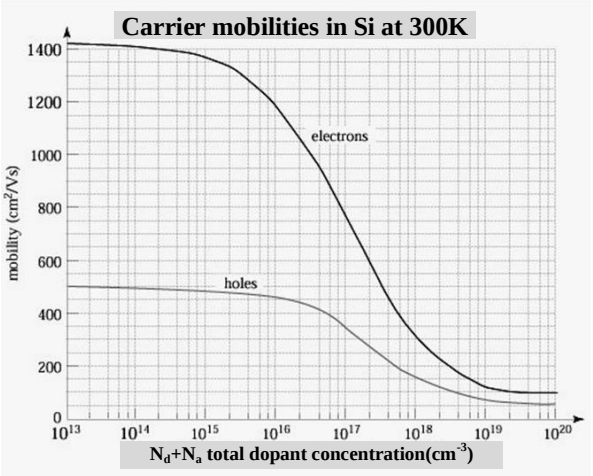


   (a) (6 points) Write an expression for the output voltage $v_o(t)$.
   (b) (6 points) Write an expression for the voltage appearing at the inverting input v_-.
   (c) (6 points) What is the input resistance at terminal v_1?
   (d) (6 points) What is the output resistance at terminal v_o?

2. (18 points) DC Imperfections
A particular inverting amplifier with a nominal gain of $-100\ V/V$ uses an imperfect op amp in conjunction with 100 $k\Omega$ and 10 $M\Omega$ resistors. The output voltage is found to be $+9.31V$ when measured with the input open; and $+9.09V$ with the input grounded.
   (a) (6 points) Plot the circuit configuration. Mark the input port v_i, the output port v_o, as well as the values of resistances.
   (b) (6 points) What is the bias current of this amplifier? In what direction does it flow?
   (c) (6 points) Estimate the value of the input offset voltage.

3. (18 points) Semiconductor Basics
Consider a Si bar of length $10\mu m$ and cross-sectional area $1\mu m^2$, **uniformly doped with** $10^{18}cm^{-3}$ **arsenic**, maintained at $T = 300K$. 1 Volt is applied across its length, as shown below:



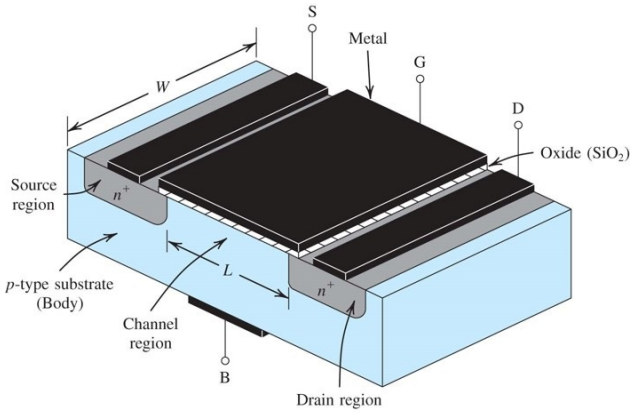


(a) (6 points) What are the electron and hole concentrations, n and p, in this silicon bar?

(b) (6 points) Estimate the resistance of this silicon bar.

(c) (6 points) Qualitatively (no calculations required), how would the resistance of this silicon bar change if it were to be **additionally doped with** $2 \times 10^{18} cm^{-3}$ **boron** ? Explain briefly.

4. (18 points) MOSFET
An NMOS transistor is featured with following parameters: $W = 20\mu m$, $L = 0.25\mu m$, $t_{ox} = 6nm$, $\mu_n = 460 cm^2/(V \cdot s)$, and $V_t = 0.5V$.

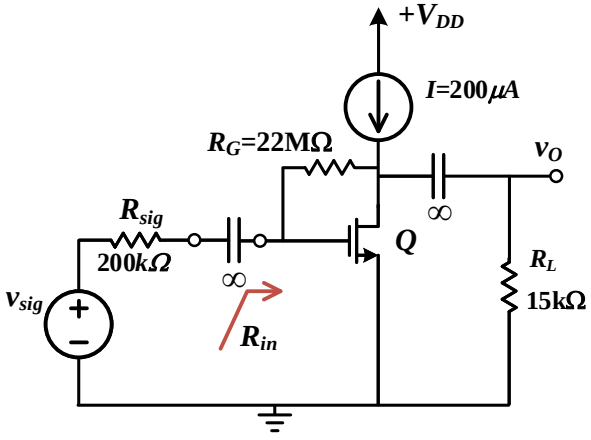


(a) (6 points) Calculate C_{ox} and k'_n.

(b) (6 points) Calculate V_{OV}, V_{GS}, and $V_{DS,min}$ needed to operate the transistor in the saturation region with a DC $I_D = 0.5mA$.

(c) (6 points) Assume v_{DS} is very small, find the values of V_{OV} and V_{GS} required to cause the device to operate as a 100Ω resistor.

5. (22 points) Transistor Amplifier
The figure below shows a discrete circuit amplifier. the NMOS transistor has $V_t = 0.8V$, early voltage $V_A = 20V$, and operate with $V_D = 1V$.



(a) (8 points) Calculate g_m and r_o.

(b) (6 points) Calculate R_{in} and the voltage gain v_o/v_{sig}.

(c) (6 points) What do V_D and the voltage gain v_o/v_{sig} become if I is increased to $1mA$?