Due in the "EE 105 box" near 125 Cory Hall by 5pm on Friday 8/31/2012.

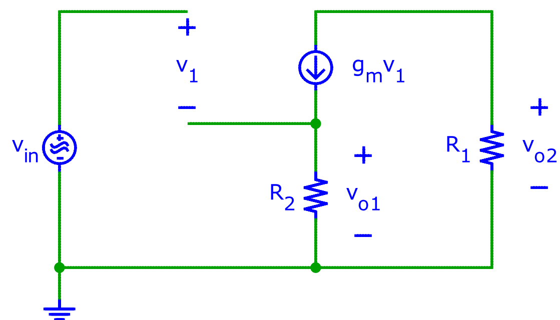
Read Chapters 1 and 2 in B. Razavi: Fundamentals of Microelectronics

Review

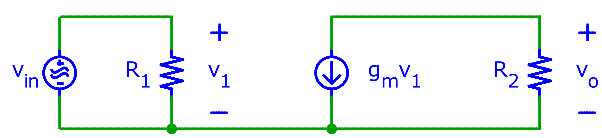
1. A 16 Megapixel digital camera chip capable of operating 1000 frames per second (i.e. 1000 frames are recorded each second). How many analog-to-digital converters (ADCs) are required to operate in parallel if a single ADC requires 6.9 ns to convert the output from one pixel of the camera chip?

2. The peak output from a microphone is 2.7 mV. Calculate the voltage gain in dB (deci-Bel) required to produce a 6.3 V peak input for a headset.

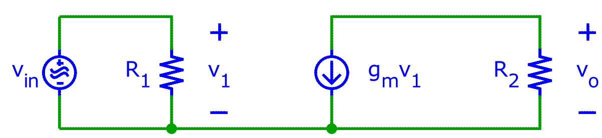
3. Calculate v_{o1}/v_{in} and v_{o2}/v_{in} for $g_m = 4.9\,\text{mS}$, $R_1 = 9.8\,\text{k}\Omega$, $R_2 = 44\,\text{k}\Omega$. We'll recognize this seemingly arbitrary circuit later in the course as the small signal model of a transistor amplifier.



4. Find the value of g_m such that $-v_o/v_{in} = 3.6$ for $R_1 = 21\,\text{k}\Omega$, $R_2 = 1.8\,\text{k}\Omega$. The circuit represents an important transistor configuration.



5. Draw the Thévenin and Norton equivalents for the port labeled v_o and calculate the component values. Use $g_m = 1.3\,\text{mS}$, $R_1 = 84\,\text{k}\Omega$, $R_2 = 38\,\text{k}\Omega$.



Semiconductors

6. a) Calculate the intrinsic carrier density n_i of Silion at $T = 280\,\text{K}$.
   b) Calculate the temperature T at which the intrinsic carrier density has twice the value calculated in part (a).

7. A bar of intrinsic Silicon has a length $L = 1.3\,\text{cm}$ and a cross-section $A = 1.2\,\text{mm}^2$.
   a) Calculate the resistance R of the bar across its length at 20C and at the extremes of the MILSPEC temperature range (-55C and +125C). Use $\mu_n = 1350\,\text{cm}^2/\text{Vs}$ and $\mu_p = 480\,\text{cm}^2/\text{Vs}$. You may assume (incorrectly, to simplify the problem) that mobility is constant independent of temperature and ignore the effect of velocity saturation.
   b) Use the Silicon bar to design a thermostat with an output that goes high (near the supply) when the temperature is above 70 degrees Farenheit, and is low otherwise. In addition to the Silicon bar the following components are available: ideal operational amplifiers, voltage comparators (operates like an ideal operational amplifier with the output voltage limted by the supplies), ideal resistors (value does not depend on temperature), and constant voltage sources. Draw a complete circuit diagram and calculate the values for all components (resistors, sources). This problem has many solutions, use your creativity to find one that minimizes the number of components required.

8. A bar of Silicon has a length $L = 2.6\,\text{cm}$ and a cross-section $A = 2.3\,\text{mm}^2$.
   a) Calculate the doping density N_A that results in a resistance $R = 1.4\,\text{k}\Omega$ across the length of the bar. Is this a practical result, i.e. is is possible to dope Silicon at this level?
   Use $\mu_n = 1350\,\text{cm}^2/\text{Vs}$ and $\mu_p = 480\,\text{cm}^2/\text{Vs}$. Ignore the effect of velocity saturation.
   b) At what temperature would an undoped (i.e. intrinsic) Si bar exhibit the same resistance R? How practical is this?
   You may assume (for simplicity) that the mobility is not a function of temperature.

9. A bar of intrinsic Silicon has a length $L = 1.6\,\text{cm}$ and a cross-section $A = 2.6\,\text{mm}^2$. Plot the average velocity in [mph] (so you can relate it to speeds you are familiar with; you may also use [km/h]) of electrons as a function of the voltage applied across the length of the bar. Use $\mu_o = 1350\,\text{cm}^2/\text{Vs}$ and $v_{sat} = 10^7\,\text{cm/s}$.
   Submit an accurate plot that is to scale. Preferably use a program such as Matlab (available on the instructional machines), Octave, MathCad, or Excel for your plot (preferred). Alternatively you may use cross-hatched paper and draw the graph by hand (use a ruler!) accurately and to scale (tedious technique that was popular before computers came into existence).

10. A diode is forward biased with a constant voltage V_D. Suppose you want to increase the diode current I_D tenfold, by how much do you need to increase V_D? Use $T = 300\text{K}$. The result is independent of I_s.
   Let's use this simple result to gain insight into important circuit problems:
   a) Light-emitting diodes (LEDs) exhibit similar exponential I/V characteristics. They are the reason why LEDs generally cannot be driven by a voltage source (the current would be extremely sensititive to voltage variations, potentially resulting in burnout). Driving the LED with a current source avoids this problem. Unfortunately the outputs of digital circuits (often the control signals for LEDs) are typically voltage and not current sources. Insertion of a simple circuit element between the digital output and the diode solves the problem. What cricuit element is used and why does it reduce the current variation?
   b) The voltage corresponding to a tenfold change of current is also relevant in MOS transistors where it is called "subthreshold slope" S and specified in [mV/decade]. Transistor operation is governed by similar physics as diodes: turning the transistor "off" only reduces current flow but does not completely interrupt it. In large chips, the remaining current substantially adds to power dissipation. Finding transitors with higher "subthreshold slope" (lower values of S) is a topic of intense research and will determine our future ability to improve the performance of integrated circuits.
   Suppose a future computer consists of 10^{10} transistors controlled by 0.5 V (the supply voltage) and 0 V, respectively, in the "on" and "off" state. Assuming that in the "on" state, a transistor conducts $I_{on} = 1\,\text{mA}$. Because of the non-zero value of S, a (small) current flows even when the transistor is off, i.e. the control voltage is zero. The resulting power dissipation is called "leakage

power" and is consumed even if the circuit is not performing any computation. Engineers spend significant effort on minimizing leakage. Why?

i. What is the maximum permitted leakage current I_{off} per transistor that results in no more than 5 mW leakage power dissipation for the entire computer when all transistors are turned off?

ii. What value of S is required to meet this requirement for I_{off}? Unfortunately, diodes with such a low value of S do not exist. Because reducing S is such an important problem, researchers at Berkeley and elsewhere are trying to build novel devices with smaller values of S.
Hint: the math in this problem is trivial; you do not need exponential functions!