ECE/ENGRD 2100 – Spring 2019 | Issued: January 23, 2019, 10 am
Prelab 1 | Due: January 29, 2019, 12:20 pm

Prelab Problem 1.1: Voltage and Current Dividers

(a) Derive expressions for V_{out} and I_{in} for the voltage divider shown in Fig. P1(a), write your answer in terms of V_{in}, R_1 and R_2.

(b) Derive an expression for I_{out} and V_{in} the current divider shown in Fig. P1(b), in terms of I_{in}, R_1 and R_2.

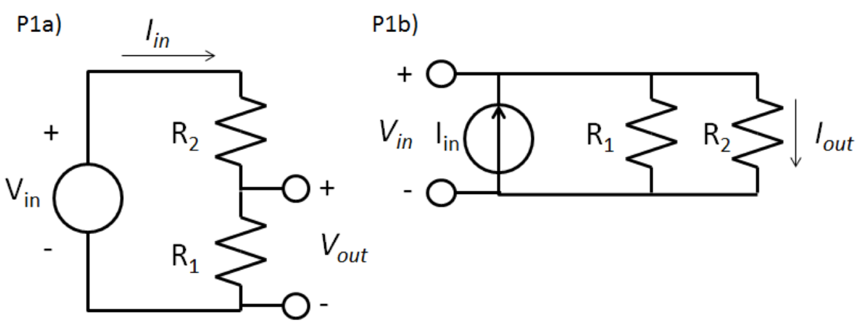


Fig. P1: Voltage and current divider circuits

Prelab Problem 1.2: Modeling the Diode I-V Relationship

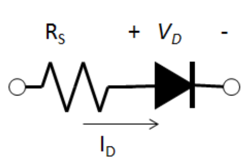
The general diode equation is given by:

$$I_D = I_o\left[exp\left(\frac{qV_D}{\eta kT}\right) - 1\right] \qquad \text{(Eq. p2)}$$

(a) Derive an approximate expression for the diode's "small signal" conductance, $\boldsymbol{g_D} = \frac{\boldsymbol{dI_D}}{\boldsymbol{dV_D}}$ in terms of the diode current itself, assume a modest forward-bias such that $V_D \gg \frac{kT}{q}$.

(b) Derive an expression for the ideality factor (η) as a function of the diode current $\boldsymbol{I_D}, \boldsymbol{g_D}$, physical constants, and temperature.

(c) Derive an expression for the voltage across a real diode as a function of diode current when a parasitic resistance (R_s) is included in the diode model as shown below. The resistance is in series with an ideal diode described by equation p2 (hint: determine V_D as a function of I_D from equation p2, and noting the diode and resistor are in series and hence share the same current, add the voltage drop due to the resistor). Plot the resulting I-V curve using the following values: I_0 = 250x10^{-12} A (250 pA), R_s = 8 Ω, $\frac{kT}{q}$ = 0.026 V, and η = 1. Make two plots, one for current ranging from 0-1mA, and the second for current ranging from 0-100 mA. Under what condition does the series resistor begin to dominate the I-V characteristics of the diode?



$$V_D = \frac{\eta kT}{q} ln\left(\frac{I_D}{I_o} + 1\right)$$

Prelab Problem 1.3: LED Problem

Three LEDs (one red, one green, one blue) have the I-V curves shown. Your goal is to design a circuit where each LED is supplied with a unique current using a single 4 V power supply (the currents have been chosen to generate approximately equal light intensity as perceived by the human eye).

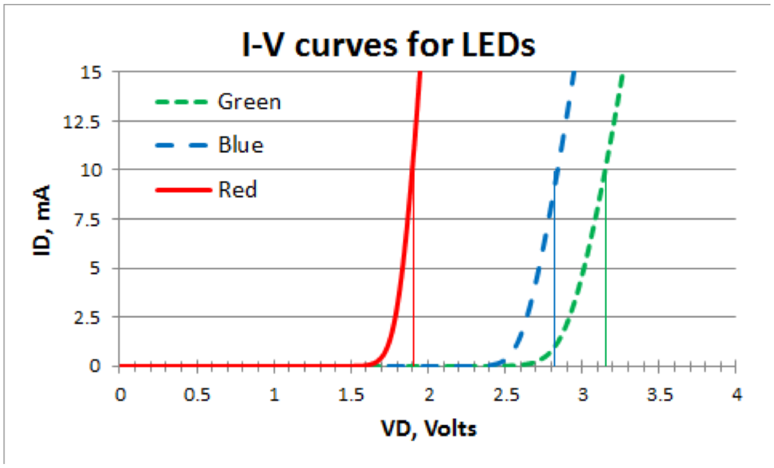


Fig. P3a: I-V curves for the 3 LEDs in problem 1.3

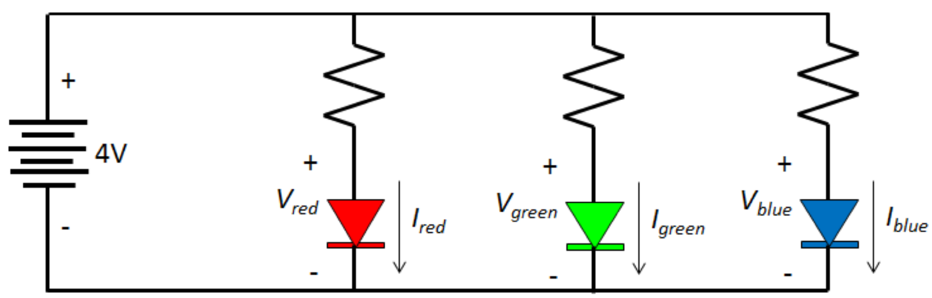


Fig. P3b: circuit for problem 3b and c: find the values of the three resistors shown.

(a) Approximately what voltage must each diode have across it (V_{red}, V_{green}, V_{blue}) to provide the following currents: I_{red}=10 mA, I_{green}= 2.5 mA, I_{blue} = 5 mA (extract this from Fig. P3a: try to be precise to ±100 mV).

(b) In order to provide each of these currents when supplied from a single, 4V power supply, each LED can be placed in series with a distinct resistor to provide the required voltage when supplying the required current, as diagrammed in Fig. P3b. Based on part (a) what, approximately, must this resistance be for each LED? Hint: apply Kirchoff's Voltage Law for each diode-resistor-battery loop to find what voltage is across each resistor for the LED voltages (V_{red}, V_{green}, V_{blue}) from part (a), and then compute what each resistor must be to provide the required current to its respective LED.

(c) What will be the total power consumed by this circuit? How much power will be dissipated in the resistors? What percentage of power supplied to the circuit is actually delivered to the LEDs?

Prelab Problem 1.4: Solar Cell Problem

Here again we will use the diode equation (eq. p2), but now to model the Silicon Solar Cell which we will test in the lab. For parameter values in the diode equation assume: $I_0 = 250\ \text{pA}$, $\eta = 1$, and $\frac{kT}{q} = 26$ mV. A solar cell is modelled as a diode with a parallel current source. The current through the source is directly proportional to the incident solar flux.

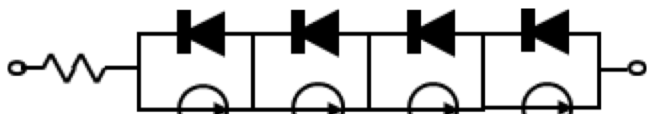


Fig. P4. Model of our solar cell: current sources are all equal in value, proportional to incident light intensity.

(a) The solar cell we will use is actually 4 diodes in series, as shown below. Derive an expression for the current through the complete 4 diode cell as a function of applied voltage (assume there is no light shining on the cells so the current sources are off).

(b) With no external light incident on the cells, add a 16-Ω series resistance and plot the solar cell's I-V curve (representing operation in the dark) on a linear scale. Compute the current as a function of the voltage applied across the resistor-diode sequence. Generate this plot in MATLAB or another math program (not by hand). *Hint: compute V as a function of I as in problem 1.2c, and use this to generate a plot of the IV curve.*

(c) Plot on the same graph (as part a) the illuminated diode I-V curve. Model the photocurrent as an independent current source (caused by illumination of the solar cell) of 50 mA across each diode.

   i. To set this up, consider the following: if the cell is not connected to an external circuit, the 50 mA current simply flows through the diode, and the voltage across the diode is determined by the equation you derived in Problem 1.2c, i.e., there will be a voltage generated across the diode by this solar current.

   ii. If there is an external resistor connected, then some of the 50 mA current can flow into the load and deliver energy (the solar cell mode). So modify your expression for diode voltage by including the 50 mA term in the diode equation, then write the equation for the total voltage drop across the 4 diodes, including that due to the series resistance, as sketched in Fig. P4. Once again, you want to compute voltage as a function of ideal diode current (including photocurrent in your model) and then add in the voltage associated with the resistance. Plot current as a function of applied voltage.

(d) On a separate graph plot the power versus voltage curve for the illuminated solar cell in part b. This is simply a product of the diode voltage and diode current. It can be positive or negative depending on the external circuit. Where (at what voltage) does the delivered power maximize?

(e) Make a final plot of the illuminated diode I-V curve (linear scale) and graphically illustrate the determination of the short circuit current, the open circuit voltage, the best operating point, and the resulting fill factor (fill factor is defined as the power under optimal bias divided by the product I_{sc} x V_{oc}: both can be represented graphically by boxes).