Homework 2 **ECE 302H: Introduction to Electrical Engineering**

I include time estimates for each problem. A problem may take you more or less time, but if you spend more than half of the allotted time on a problem and aren't making progress, it's time to ask for help!

(Do not forget the Professionalism Project Unit A, which is a separate assignment due at the same time as this one.)

Problem 2.1 – Equivalent Circuits (1h)

Apply a test voltage (or current) and calculate the resulting current (or voltage) to prove the common scenarios below. Sketch the IV characteristic of each circuit. These will help you build intuition and are also worth memorizing.

a) An equivalent circuit for a voltage source V_s in parallel with a resistor R is a voltage source alone. What is the value of the voltage source?
b) An equivalent circuit for a current source I_S in series with a resistor R is a current source alone. What is the value of the current source?
c) An equivalent circuit for two resistors R_1 and R_2 in series is a single resistor. What is the value of the resistor? If $R_1 \gg R_2$, what is the combined resistance approximately equal to?
d) An equivalent circuit for two resistors R_1 and R_2 in parallel is a single resistor. What is the value of the resistor? If $R_1 \gg R_2$, what is the combined resistance approximately equal to?
e) An equivalent circuit for a voltage source V_S in series with a resistor R is a current source in parallel with a resistor. What are the values of the current source and resistor? What are the open-circuit voltage and short-circuit current of this important circuit?
f) An equivalent circuit for a current source I_S in parallel with a resistor R is a voltage source in series with a resistor. What are the values of the voltage source and resistor? What are the open-circuit voltage and short-circuit current of this important circuit?

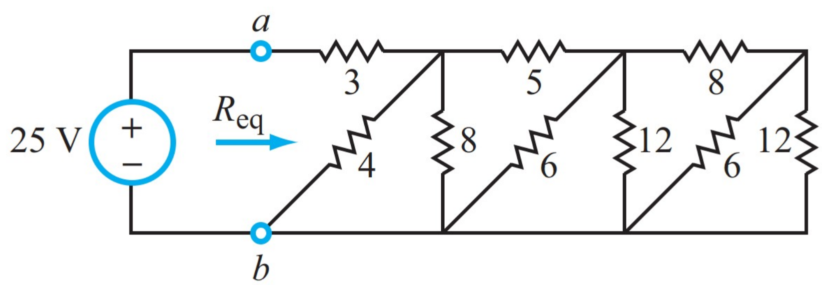
Problem 2.2 – Series and parallel; voltage, current, and power (0.25h)

You have four resistors of value R and power rating P (meaning each resistor is allowed to dissipate up to P). Please describe two ways that you could use the resistors to create an object with the same resistance R but quadruple the power rating. Draw the circuit for each approach.

I include time estimates for each problem. A problem may take you more or less time, but if you spend more than half of the allotted time on a problem and aren't making progress, it's time to ask for help!

Problem 2.3 – Resistor equivalent circuit exercise – adapted from Ulaby 2.40 (0.5h)

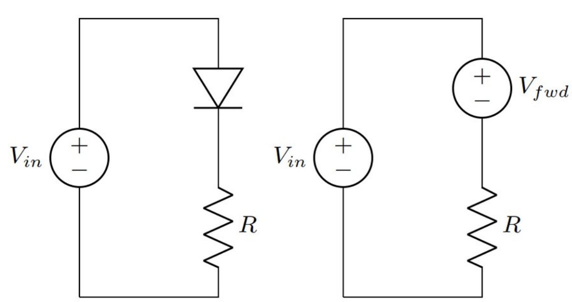
Find R_{eq} and use it to solve for the voltage across and current through each component.



Problem 2.4 – Solving Single-Loop Circuits (0.5h)

Most modern lighting – from small notification lights to lighting whole rooms – is done with light-emitting diodes (LEDs). An LED is like any diode – it only allows current to flow in one direction. When current is flowing, the diode can be modeled as having a constant voltage drop. A circuit with a diode is shown in the Figure, along with the same circuit with the diode replaced by its constant-voltage-drop model.

a) Use Kirchoff's laws to explain why it is necessary to include a resistor in the circuit (even if it is merely the parasitic resistance of the wires) in order to analyze the circuit. In real life, if you plugged a voltage source Vin directly into the LED, what bad thing would happen?
b) Calculate the current that flows as a function of Vfwd and R.
c) Look up the datasheet for the Wurth Electronik 151031SS06000 AlGaAs "Super Red" LED at this url: https://www.we-online.com/catalog/en/WL-TMRC. What is the typical luminous intensity of the LED? What level of current does that correspond to?
d) Let Vin be a microcontroller general purpose input/output (GPIO) pin which can output 5 V. Assume the forward voltage drop of the LED to be 2.2 V. Now look on the datasheet for a graph that shows luminous intensity as a function of current. Choose a resistor value R such that the diode produces 45 milli-candelas (mcd) of luminous intensity.



I include time estimates for each problem. A problem may take you more or less time, but if you spend more than half of the allotted time on a problem and aren't making progress, it's time to ask for help!

Problem 2.5 – Circuit Tradeoffs (1.5h)

Let us explore an amplifier based on a MOSFET. The MOSFET is a transistor with three terminals, the (D)rain, the (S)ource, and the (G)ate. The MOSFET acts like a "dependent current source" whose current is not fixed but rather depends on some other voltage or current in the circuit. In this case, the MOSFET current is proportional to its gate-source voltage vgs (the voltage difference between its gate and its source).

[Hint – remember that all ground symbols are connected; remember to do KVL around each mesh and KCL at each non-ground node; remember that you can still do KVL around meshes with open circuits. Treat open circuits like circuit elements whose element law is $i=0$]

a) Consider the first circuit in the Figure, with only a MOSFET and a drain resistor RD. Use the equivalent circuit on the right to calculate the gain of the amplifier, which is vout/vin.
b) The quantity gm is known as the "transconductance" of the transistor ["conductance" because it has units of A/V just like a regular conductance, "trans-" because a voltage in one place is related to a current in a different place]. The transconductance gm is usually a large value but not necessarily a reliable value from part to part or across temperature. How different will the amplifier gain be if gm changes by a factor of 2?
c) Now consider the second circuit in the Figure. This circuit has an additional resistor connected to the MOSFET's source pin. This amplifier is said to have "source degeneration." Calculate the gain for this amplifier. Is the gain larger or smaller than the gain of the first circuit?
d) We mentioned that gm is usually large. What is the approximate gain of the amplifier assuming gm is very large?
e) Consider gm to be large but not well-controlled – using your answer to the previous part, how does the gain vary if gm varies by a factor of two?
f) Write a few sentences discussing the tradeoff between the first circuit and the second circuit.

I include time estimates for each problem. A problem may take you more or less time, but if you spend more than half of the allotted time on a problem and aren't making progress, it's time to ask for help!