Homework #1
ECE 363 (F19)
10 problems for 100 pts
Due Sep 20

A. Voltage References

1) Perform a "quick" analysis (e.g. assume 0.7V for a diode) to compute V_{REF} and current for each circuit in Fig. 1.

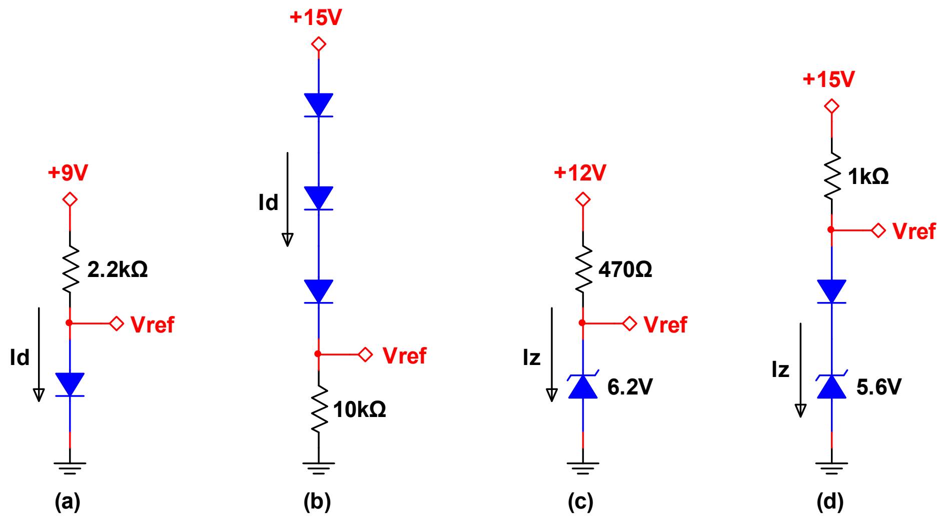

Fig. 1: Circuits to analyze for Problem 1.

2) In reality, the forward voltage of a diode is not always V_F = 0.7V. How to determine a more realistic value for V_F? We need to use the diode's data sheet! Fig. 2a shows the typical I-V curve for a 1N4148 diode. Notice that current is shown over a log scale, so the plot has a different shape compared to the sketch in the Lecture 01 notes (page 1.4).

   - Perform a "quick" analysis of the circuit in Fig. 2b to determine Id.
   - Use the I-V curve in Fig. 2a to find the diode voltage V_F corresponding to your Id value from part (a).
   - Use your "new" V_F value from part (b) to analyze the diode circuit to determine the "new" Id. In theory, you could repeat this procedure for finer accuracy, but it's usually not necessary when doing hand calculations.

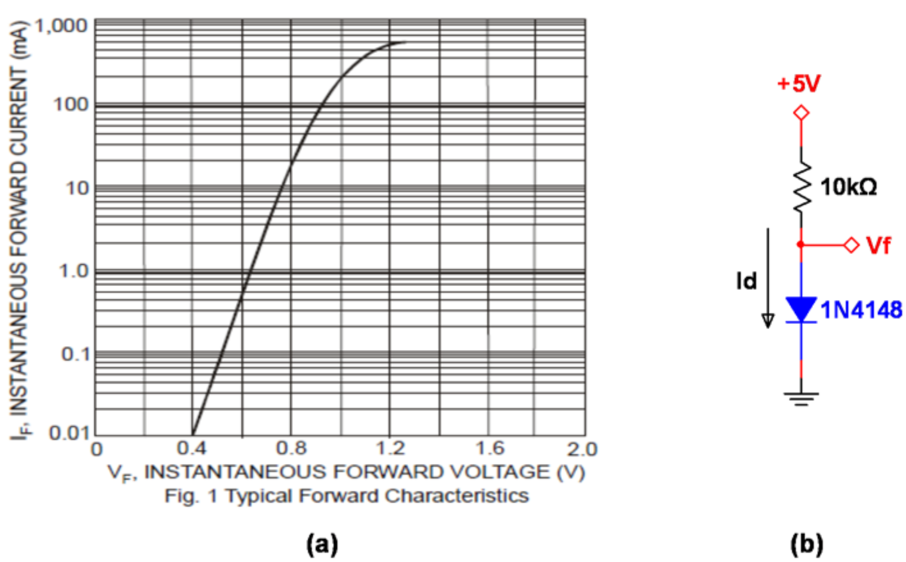

Fig. 2: Diode circuit and I-V curve from the 1N4148 datasheet.

3) Choose the appropriate resistor R (value and power rating) for a voltage reference that uses a 5.6V Zener in series with a diode (see Fig. 3). The power supply V_S can vary from 10 to 15V. For this problem, you can assume the diode and zener always have $V_F = 0.7V$ and $V_Z = 5.6V$, respectively. However, make sure the Zener has no less than 10 mA of current.

NOTE: It turns out this combination of components is very stable with temperature (e.g. < 0.1% per °C). This is because the 5.6V Zener has the OPPOSITE temperature coefficient compared to the diode. You can buy a component that combines these two (e.g. 1N821).

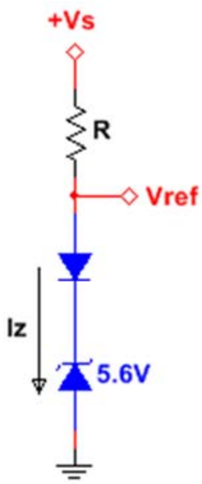

Fig. 3

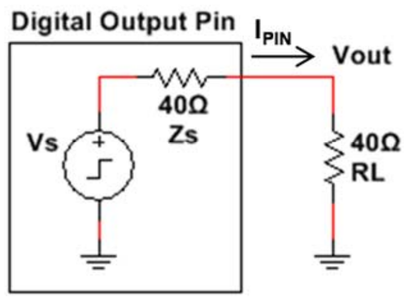

Fig. 4a

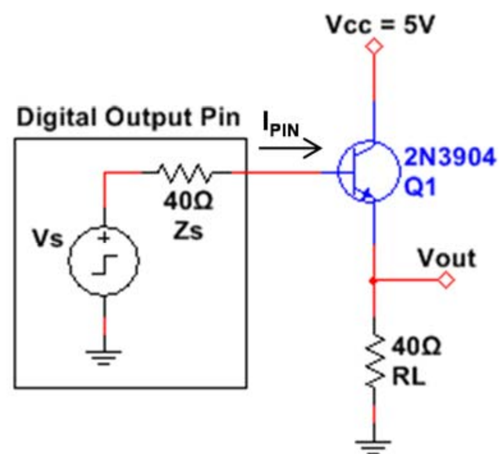

Fig. 4b

B. Emitter Follower Analysis (all data sheets on course website)

4) The digital output of a microcontroller (e.g. Arduino) typically produces 0 or 5V, but only if the output current is less than a certain value (e.g. less than 40 mA). The output voltage will drop at higher currents. ☹

Consider Fig. 4a, where the digital output pin is modeled as an ideal source $V_S = 5V$ in series with an output impedance $Z_S = 40$ ohm. Suppose we want to connect a $R_L = 40$ ohm load to the digital output pin of a microcontroller. It is desirable for $V_{OUT} \geq 4V$ and $I_{PIN} \leq 40$ mA.

(a) Compute the voltage V_{OUT} and current I_{PIN} coming out of the digital output pin.

(b) Is V_{OUT} acceptable?

Emitter follower to the rescue! As shown in Fig. 4b, a 2N3904 transistor is used for Q1. **Appendix #1 in the Lecture 01 notes discusses how to use the datasheet plots to find "typical" and "worst-case" transistor parameters.**

(c) Perform a "quick" analysis (e.g. assume $V_{BE} = 0.7V$ and $\beta = 100$) to determine if V_{OUT} and I_{PIN} are acceptable. Hint: Use KVL around the loop of V_S, Z_S, V_{BE}, and R_L.

(d) Compute V_{OUT} and I_{PIN} using **typical** 2N3904 parameters. Assume room temperature (T = 25°C) for all parameters.

(e) Are V_{OUT} and I_{PIN} acceptable under "worst-case" 2N3904 parameters?

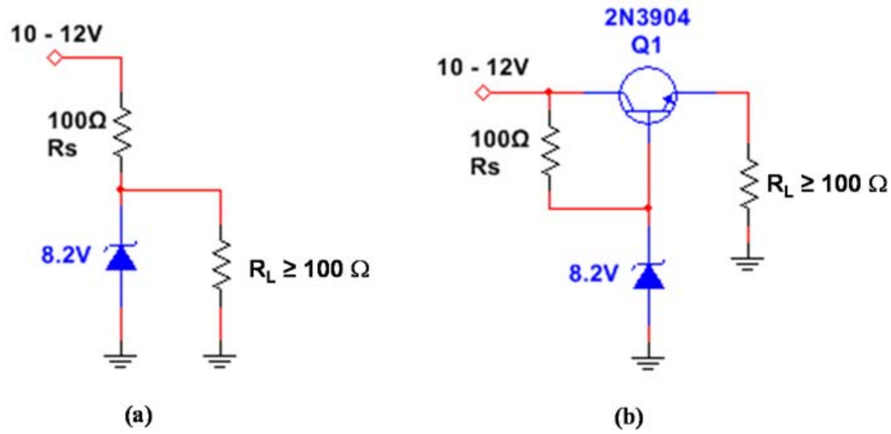

Fig. 5: (a) Zener directly connected to load. (b) Avoiding drop-out by using a Zener follower as a voltage buffer.

5) The output voltage of any DC power supply is based on an internal "voltage reference", which is typically a zener diode. The main thing with a zener diode is to make sure it has enough current I_Z to avoid drop-out! In ECE 248, we assumed zener regulation is maintained if $I_Z > 0$ mA. That is not very realistic. **In this course, we'll use $I_Z \geq 10$ mA as a more reasonable criterion for zener regulation**. There is no universally accepted rule for the minimum value of I_Z. Such ambiguity is often the case in the real world!

   Suppose we want an 8.2V zener to drive loads with $R_L \geq 100$ ohm. The supply voltage varies from 10 to 12V.

   (a) In Fig. 5a, does the zener diode maintain regulation under worst-case supply and load conditions?

   (b) In Fig. 5b, perform a "quick" analysis (assume $V_{BE} = 0.7$V and $\beta = 100$) to determine if the zener diode maintains regulation under worst-case supply and load conditions.

   (c) Suppose Q1 is a 2N3904 transistor. Does Q1 need a heat sink? **Assume "typical" transistor parameters (you need to use the datasheet plots)**.

   (d) We obviously want to avoid drop-out (I_Z too low) but we also want to avoid *burn-out* (I_Z too high)! Suppose the zener diode has a power rating of 1W. Is our zener OK?

6) If you need to control a large current with a very tiny current, use a Darlington! A brief review of Darlington transistors is in Appendix #3 of the Lecture 01 notes (see course website). The main thing to remember is that $V_{BE} \approx 1.4$V and $\beta \approx 2500$ for a Darlington!

   Fig. 6 shows a zener regulator consisting of a 12V zener, a TIP120 Darlington, and a load $R_L \geq 10$ ohm.

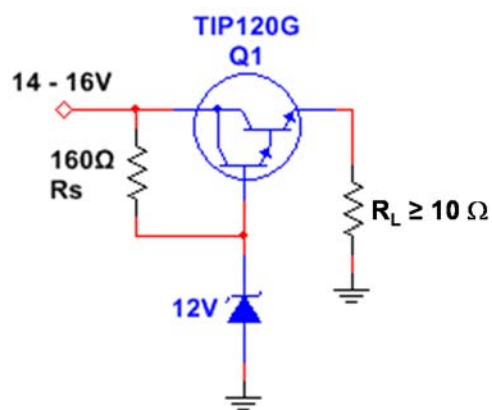

Fig. 6: The extra high current gain of a Darlington is useful for high load currents.

   - Perform a "quick" Darlington analysis ($V_{BE} = 1.4$V, $\beta = 2500$) to determine if the zener diode maintains regulation under worst-case supply and load conditions.
   - Assuming "quick analysis" conditions, compute the junction temperature T_J to show why Q1 very much needs a heat sink. Hint: You should find that T_J is over 350°C! Whoa.
   - You have a selection of heat sinks with sink-to-ambient thermal resistance θ_{SA} = 5, 10, 15, and 20 °C/W. Which heat sink is the best choice? Assume the case-to-sink thermal resistance is θ_{CS} = 0.5°C/W (see Appendix #4 in the Lecture 01 notes for heat sink formulas). Assume T_A = 25 °C and that we want T_J < 85°C.

7) When choosing a transistor without a heat sink, we want the device's power rating to be over twice the actual power dissipation (i.e. 2X safety factor). However, the power rating depends on the ambient temperature T_A! Most data sheets show the power rating for T_A = 25 °C, which is OK if the device is in the open air. In many situations, the circuit is inside an enclosure without a fan (e.g. smartphone), so the ambient temperature of the transistor can easily exceed T_A = 40 °C! This reduction (also called "derating") of the device's power rating is important.

(a) What is the 2N3904's power rating at T_A = 25, 50, and 75 °C without a heat sink?

(b) A TIP31 can easily handle 750 mW at T_A = 25 °C. But can it do so at T_A = 75 °C without a heat sink?

For this course, we'll choose a heat sink by requiring $T_J < 85$ °C, which is comparable to a cup of scalding hot coffee! This produces similar results to the "2X safety factor" approach (e.g. what we use for a transistor WITHOUT a heat sink). If your calculation produces a NEGATIVE value for θ_{SA}, this is obviously impossible and a heftier transistor is required!

(c) A transistor must dissipate 15W. Can a TIP31 do this with a heat sink for T_A = 40 °C? Assume θ_{CS} = 0.5°C/W. Show all work!

(d) Can a MJE3055 dissipate 15W at T_A = 40 °C? If so, compute the minimum heat sink (i.e. maximum θ_{SA}) required.

C. Emitter Follower Design (all data sheets on course website)

8) Design a zener follower (see Fig. 8) for a load rated at 6V @ 50 mA. The input voltage V_S is 7 to 9V. Some design constraints:

- Output voltage: The load is OK between 5.5 to 6.5V
- Zener: Choose from 4.7, 5.1, 5.6, 6.2, 6.8, or 7.5V
- Transistor: Choose from 2N3904, TIP31, MJE3055

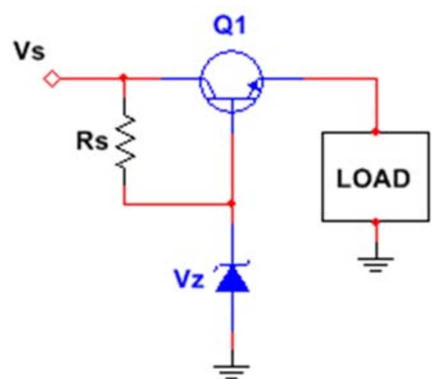

Fig. 8: Circuit for Problem 8.

(a) Using "quick" analysis assumptions (V_{BE} = 0.7V and β = 100), determine the appropriate zener diode. Show all work!

(b) Determine the appropriate transistor using "quick" analysis parameters (assume T_A = 25 °C). You MUST explain why you chose one transistor and not the other two.

NOTE: Remember that you want to choose a transistor of appropriate size. As a circuit designer, you do not want your components to be larger or more expensive than necessary!

(c) Choose the appropriate 5% standard value for Rs, and determine if a ¼ W, ½ W, or 1 W rating is needed.

9) You are asked to design a power supply for a 6V DC motor. The input voltage V_S comes from a supply that can vary from 9V to 11V. Normally, you would use a DC-DC converter chip for this. Unfortunately, there seems to be a world-wide shortage of such ICs. You decide to use a zener regulator with a Darlington, due to the potentially large motor current (see below).

- Here are the design constraints:

- Output voltage: must be within +/- 5% of 6V.
- Motor: The motor has a "no-load" current of 150 mA and a "stall" current of 1A. Don't design for the no-load current, because that assumes the motor is not connected to anything – NOT useful! Let's design the power supply to provide 50% of the stall current.
- Zener: The zener must either be 6.2, 6.8, 7.5, or 8.2V.
- The Darlington transistor can either be a KSP13, TIP120, or TIP140.
- T_A = 40 °C (circuit is in an enclosure, where the air gets warm)

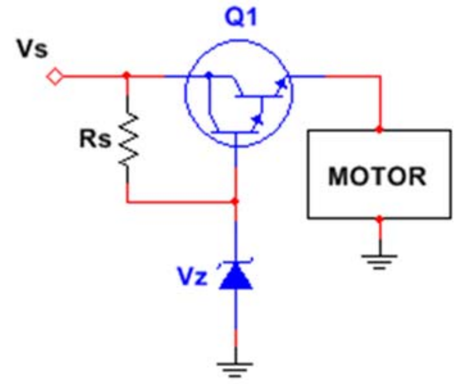

Fig. 9: Darlington zener follower.

(a) Using "quick" analysis assumptions, determine the appropriate zener diode. Show all work!

(b) Perform a "quick" analysis to determine the appropriate transistor. If you need a heat sink, leave those calculations for part (c). You MUST explain why you chose one transistor and not the other two.

(c) The available heat sinks have thermal resistances of θ_{SA} = 6, 12, 18, and 24 °C/W. Which heat sink is the best choice? Assume that T_J < 85°C and θ_{CS} = 0.5°C/W. Remember that T_A = 40 °C! Show all work!

(d) Using **"typical" parameters** for your choice of transistor from part (b), determine the appropriate resistor R_S. Choose a standard 5% value and a power rating of either ¼ W, ½ W, or 1W.

D. Emitter Follower with Feedback

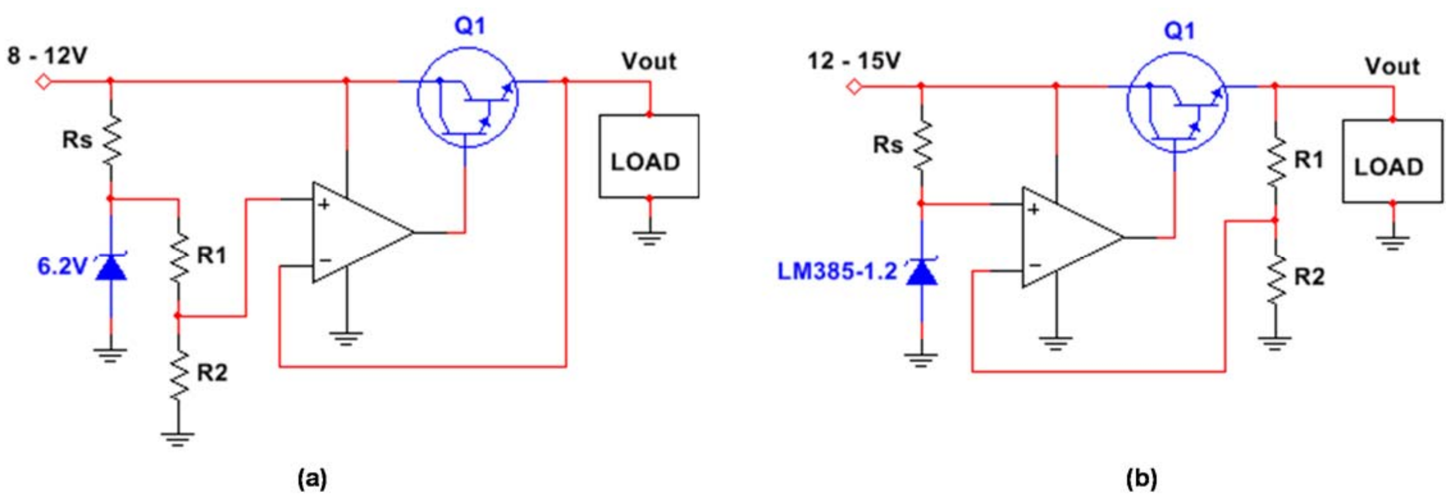

Fig. 10: Linear voltage regulator with (a) $V_{OUT} < V_{REF}$ (b) $V_{OUT} > V_{REF}$.

10) A voltage regulator uses negative feedback to stabilize the output voltage. A voltage divider is used to sample a portion of either V_{REF} or V_{OUT}, depending on whether V_{OUT} is smaller or larger than V_{REF}.

(a) In Fig. 10a, V_{REF} is a 6.2V zener while V_{OUT} = 5V (+/- 5% is OK). **Choose the standard 5% resistor values and power ratings (¼ W, ½ W, or 1W) for R_1, R_2, and R_S**. Keep in mind the following:

- The voltage divider should draw less than 1 mA (< 10% of the zener current) to ensure the zener is little affected by the divider.
- The zener should have at least 10 mA.

(b) In Fig. 10b, V_{REF} is an LM385-1.2 "bandgap voltage reference" that produces 1.235V while V_{OUT} = 9V (+/- 5% is OK). **Choose the standard 5% resistor values and power ratings (¼ W, ½ W, or 1W) for R_1, R_2, and R_S**. Keep in mind the following:

- Let the LM385-1.2 have about 1 mA (this is much lower than a conventional zener!).

  NOTE: The LM385-1.2 is really nice because it works even with only 10 uA of current! This makes it ideal for micropower (e.g. long battery life) applications.

- The voltage divider should draw about 1 mA. This is enough current to keep the pass transistor turned on but low enough to ensure the divider dissipates little power.