Lab 1a: Zener Follower

• GOAL

The overall goal of Lab 1 is to demonstrate a linear voltage regulator to drive a 5V DC brushless fan (e.g. a computer fan). This is a two-week lab.

- Lab 1a is a simple power supply based on a Zener follower.
- Lab 1b explores improved power supply circuits using negative feedback to produce a stable output voltage.

Fig. 0: 5V DC brushless fan.

• OBJECTIVES

The objectives of Lab1a are the following:

1) Heat sink:
    a. Compute the smallest heat sink (largest θ_{SA}) needed for the pass transistor.
    b. Attach a heat sink to the power transistor.
2) Zener Diode:
    a. Measure the zener voltage and current versus input voltage (V_{IN} is between 12 to 15V).
    b. Compute the zener resistance and line regulation.
3) Zener Follower:
    a. Measure the power supply efficiency when driving a 5V fan.
    b. Make appropriate measurements to compute the line and load regulation.
    c. Better understand the pass transistor's properties.

• GENERAL GUIDELINES

1) Each student must design, build, and test his/her own circuits.
2) Students are allowed (even encouraged) to work together (e.g. share a test station). **However, you must make measurements and demo your own circuit!**
3) Do NOT use "Autoscale" on the scope! Buma will deduct 300 pts if he catches you doing this.
4) **Use neat wiring for your circuits! Starting in Lab 2, a messy circuit will cost you 10 pts**.
5) This lab (includes Lab1a and Lab1b) has a report. Each student must turn in his/her own lab report. See the course website for the template.

   Honor Code Compliance: **You must turn in your own work**! Blatant duplication of circuit analysis, design, simulations, and/or lab reports will result in ZERO points and possible reporting to the Honor Council.

PARTS AND MATERIALS

- Lab kit
- Benchtop power supply, multimeter, and probe box (contains banana cables, multimeter probes, etc.)
- Heat sink + mounting kit
- Zener diode: 1N4734A (5.6V)
- Transistor (TIP31A)
- Resistors:

Resistors:	22 ohm (red/red/black)	2 W (really thick resistor!)
	220 ohm (red/red/brown)	¼ W
	510 ohm (green/brown/brown)	½ W (sort of thick resistor)
	2.2 kohm (red/red/red)	¼ W

- 5V DC brushless fan

PART 1: HEAT SINK FOR PASS TRANSISTOR

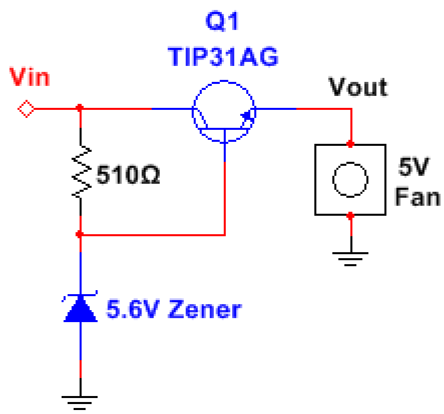

Fig. 1: Zener follower circuit.

Fig. 1 shows the circuit we had designed in class. A heat sink is required to keep the pass transistor Q1 reasonably cool. Remember that device lifetime is reduced by roughly 50% for every 10 °C increase in junction temperature!

How do we choose a heat sink? Our goal is to compute the maximum θ_{SA} that will keep the junction temperature T_J below a desired value. As explained in the Lab 1a tutorial, the main equation is:

$$T_J = T_A + P \cdot (\theta_{JC} + \theta_{CS} + \theta_{SA}) \qquad \text{Eqn. (1)}$$

- **<u>Task 1a</u>**: Compute the maximum allowable heat sink thermal resistance θ_{SA}. Use the following assumptions:
  - $T_J < 85$ °C NOTE: This is a very conservative value (i.e. a very safe operating temperature)
  - $T_A = 25$ °C NOTE: This is fine for an open air circuit (i.e. not in a small enclosure)
  - You can use the same power dissipation value from Lecture 01 (see notes)
  - Use the TIP31 data sheet to find θ_{JC}
  - Assume $\theta_{CS} = 0.5$ °C/W
  - Hint: You should get a value between 22 and 26 °C/W.

- **Task 1b**: Attach the heat sink using the "heat sink mounting kit"
  - We are using a 20 °C/W heat sink, which is slightly larger (physically) than necessary.
  - Fig. 2 shows how the heat sink should be mounted to the "TO-220" package of the transistor.
  - Remember to apply a THIN layer of thermal paste to both the heat sink AND the transistor!
    - There is only one tube of thermal paste, so remember to share!
    - NOTE: The thermal paste fills in tiny air gaps to ensure good thermal conduction.
  - You can consult Buma's breadboard for guidance.

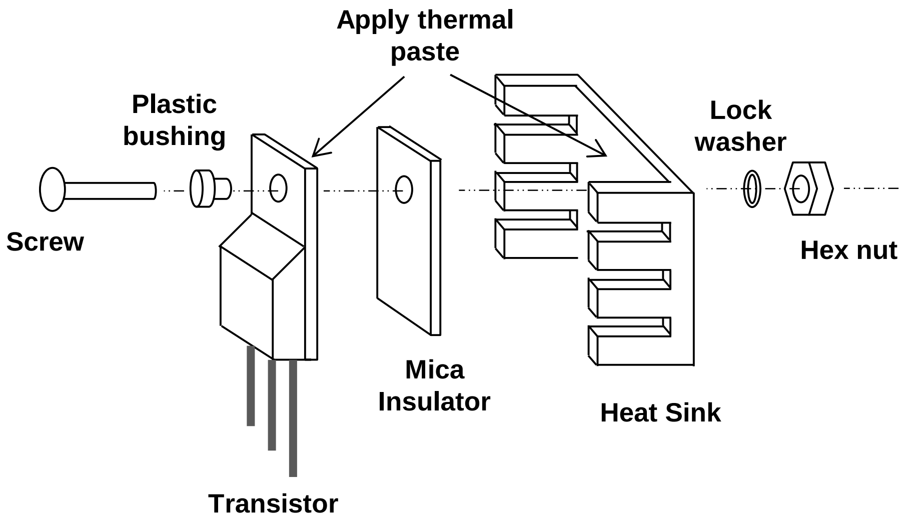

Fig. 2: Remember to apply a thin layer of thermal paste to the "back" of the transistor and "front" of the heat sink!

PART 2: ZENER DIODE

A zener diode is a decent voltage reference, but it MUST be operated along the steep part of the I-V curve (see Lecture 01 notes). For this class, we'll use 10 mA as a minimum acceptable I_Z. This is not a universally accepted value, but it's a reasonable rule of thumb for many zeners.

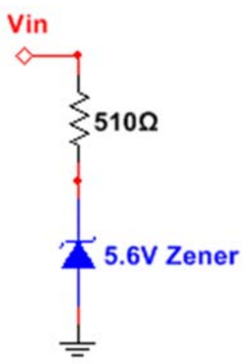

Fig. 3: Zener voltage reference

- **Task 2a:** Build the zener voltage reference (Fig. 3). Some comments:
  - You must use NEAT and COLOR-CODED wiring on your breadboard:
    - RED = $+V_{IN}$ (from benchtop power supply)
    - BLACK = GND
    - YELLOW = everything else
  - On the zener, the black band is the cathode (the "crooked" line of the zener symbol).

- Do NOT cram your circuit into a tiny space on the breadboard!
  - It is difficult to measure current in a crowded circuit.
  - You can consult Buma's breadboard for an example.

- **Task 2b**: Measure V_Z and I_Z for V_{IN} = 12V and 15V to complete Table 1.
  - Use the multimeter to do this.
  - Set the benchtop supply current limit to 0.75A.
  - Make sure you use the correct settings (e.g. voltage range) to give the most accurate measurements!
  - To measure current, remember that you must "break" the circuit and place the multimeter probes between the break points!

Table I: Zener Measurements

V_{IN}	V_Z	I_Z
12V		
15V		

- **Task 2c**: Data analysis
  - Compute the Zener resistance: $R_Z = \Delta V_Z/\Delta I_Z$
    - It should be less than 10 ohms.
    - How does your experimental value compare with the "Z_{ZT}" value in the 1N4734A data sheet?
      - The "Z_{ZT}" is the zener impedance at the test current I_{ZT}.
    - Remember that the slope of the I-V curve is $1/R_Z$. A steep slope (small R_Z) is good for a zener!
  - Compute the following: Line Regulation = $(V_{Z,HIGH} - V_{Z,LOW})/(V_{Z,LOW})$ x 100%
    - It should be less than 1%, which is pretty good.
    - NOTE: It turns out zeners in the 5.6V range are better than other values (e.g. 20V) in terms of zener resistance and line regulation.

PART 3: ZENER REGULATOR

A transistor is needed to buffer the zener from a power-hungry load. The zener only sees the small I_B, while the load is driven by the large I_E. However, transistor power dissipation impacts efficiency and device lifetime. Furthermore, transistor properties (e.g. current gain) are not perfectly constant but instead vary with I_C as well as temperature.

- **Task 3a:** Build the rest of the zener regulator (Fig. 4). Some comments:
  - You must still use neat and color-coded wiring.
  - Do NOT cram your circuit into a tiny space on the breadboard!
  - The TIP 31 pin diagram is on its datasheet (see course website).
  - The fan wiring is RED = V_{OUT} and BLACK = GND.
    - The fan wires a little flimsy, so be careful when you insert them into the breadboard.
  - Your circuit works when the fan turns on AND the benchtop power supply shows a current draw of roughly 0.25A.
    - The heat sink will get pretty warm after about 30 seconds of operation.

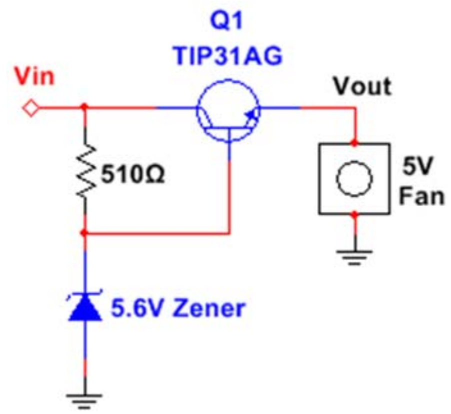

Fig. 4: The mighty Zener follower!

- **Task 3b**: Measure the efficiency of your zener regulator for V_{IN} = 12V and 15V.
  - To do this, make the necessary multimeter measurements and calculations to complete Table 2.
  - You should get an efficiency of roughly 40% for V_{IN} = 12V and 30% for V_{IN} = 15V.
  - Compute the following: Line Regulation = $(V_{OUT,HIGH} - V_{OUT,LOW})/(V_{OUT,LOW})$ x 100%
    - NOTE: Line regulation describes V_{OUT} stability for different V_{IN} but the SAME load.

Table II: Zener Follower Measurements

V_{IN}	I_{IN}	V_{OUT}	I_{OUT}	Computed Efficiency
12V				
15V				

- **Task 3c**: The transistor's V_{BE} decreases with temperature by approximately -2 mV/°C. The temperature dependence of V_{BE} is a real issue and must not be ignored in practical applications!
  - Set V_{IN} = 15V and turn off power to the breadboard.
  - Let the TIP31 transistor cool off for about 5 minutes.
  - Configure the multimeter to measure DC voltage (use the 2V range).
  - Measure the transistor's V_{BE} IMMEDIATELY after turning on power to the board! Enter this "cool" V_{BE} value into Table 3.
  - Keeping the multimeter probes on V_{BE}, you should see V_{BE} decrease as the transistor warms up.
  - After about 5 minutes, enter the "hot" V_{BE} value into Table 3.

Table III: "Cool" and "Hot" V_{BE} Measurements (Vin = 15V)

Cool V_{BE}	Hot V_{BE}

- **Task 3d**: The transistor's V_{BE} as well as its current gain depend on both temperature AND current. So annoying! We'll vary the load current by replacing the fan with different resistors.
  - Make the necessary multimeter measurements to complete Table 4.
    - Remember to use the proper multimeter settings to get the most accurate measurements!
  - Compute Load Regulation = $(V_{OUT,MAX} – V_{OUT,MIN})/(V_{OUT,MIN})$ x 100%
    - Load regulation measures V_{OUT} stability for the same V_{IN} but DIFFERENT load currents.

Table IV: Measurements for different load currents (Vin = 15V)

R_{LOAD}	V_{OUT}	I_{OUT}	I_B	Computed current gain
2.2 kohm				
220 ohm				
22 ohm				

• PART 4: CIRCUIT DEMO

- **Show Buma your working circuit in all its glory!**
  - The load should be the 5V fan.
  - Demonstrate that V_{OUT} is near 5V as V_{IN} is varied from 12 to 15V.
- **Show Buma the following data**:
  - Heat sink calculation
  - Computed zener resistance and line regulation (based on Table 1)
  - Computed efficiencies (based on Table 2)
  - "Cool" and "Hot" V_{BE} (Table 3)
  - Load regulation and Table 4

(End of Lab 1a)