Lab 1b: Linear Voltage Regulator

• 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.

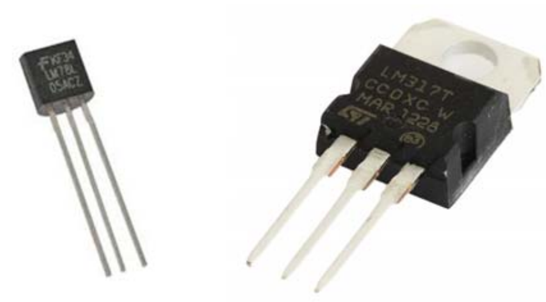


Fig. 0: (Left) 78L05 linear regulator (+5V @ 100 mA) (Right) LM317 adjustable linear regulator (1.5A)

• OBJECTIVES

The objectives of Lab1b are the following:

1) Zener follower with negative feedback:
   a. Modify the Lab 1a circuit to include an op amp and 10 kohm potentiometer.
   b. Make appropriate measurements to compute the line and load regulation.
2) 78L05 fixed voltage regulator IC:
   a. Make appropriate measurements to compute the line and load regulation.
   b. Observe the built-in thermal shutdown feature of the regulator IC.
3) LM317 adjustable voltage regulator IC:
   a. Observe the effects of bypass capacitors

• 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 and Lab 1a circuit
- Benchtop power supply, multimeter, and probe box (contains banana cables, multimeter probes, etc.)
- Heat sink + mounting kit
- Integrated circuits: Op amp (LF356)
  +5V fixed voltage regulator (78L05)
  Adjustable voltage regulator (LM317)
- Multi-turn potentiometers: 1 kohm (one) and 10 kohm (one)
- Resistors: 22 kohm (red/red/orange) ¼ W
- Capacitors: 0.1 μF (three), 1 μF (one), 10 μF (one), 100 μF (one), 470 μF (one)
- DC brushless fans: 5V (one), 12V (one)

• PART 1: ZENER FOLLOWER + NEGATIVE FEEDBACK

As we've seen in class (Lecture 02 notes), a more stable V_{OUT} is achieved by using negative feedback. The basic idea is to (1) sample a portion of V_{OUT} (2) subtract it from V_{REF} (3) amplify the difference to produce an error signal that adjusts the pass transistor to compensate for any mistakes in V_{OUT}. Nice!

- **Task 1a**: Add the op amp and 10 kohm potentiometer to your Lab 1a circuit:
  - Make sure the heat sink is tightly screwed to the TIP 31!
  - Use neat and color-coded wiring!
  - Let the load be the 2.2 kohm (red/red/red) resistor from last week's lab.
  - The op amp pin diagram is on the course website.
  - The 10 kohm potentiometer is explained in Fig. 1.

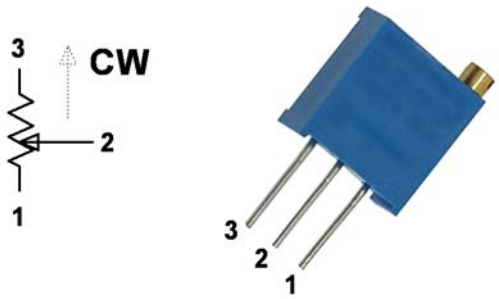


Fig. 1: The 25-turn 10 kohm potentiometer looks like this. The screw adjustment is the "bottom" of the potentiometer circuit symbol. Turn the screw clockwise (CW) to slide the wiper (2) towards the "top" (3).

- **Task 1b**: Find the potentiometer setting that produces V_{OUT} = 5V (+/- 0.020 V is OK).
  - Set the benchtop supply to be V_{IN} = 15V and 1.5A.
  - It helps A LOT if you don't have to hold both the multimeter probes and the screwdriver at the same time!
    - ➢ Wrap a wire around the red probe tip to allow insertion into the breadboard (see Fig. 2).

- The black probe can simply be inserted into the GND cable attached to the breadboard.

- Adjust the potentiometer with a screwdriver while observing V_{OUT}.
  - Make sure the multimeter's voltage range is set to give the most accurate measurement!
  - It takes about 25 turns to span the entire potentiometer range, so be patient!

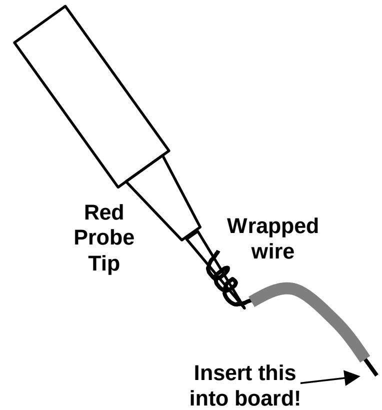


Fig. 2: Tightly wrap some wire around the red probe tip to allow insertion into the breadboard.

- **Task 1c**: Make the necessary measurements to complete Table 1A.
  - The load should be R_L = 22 ohm (red/red/black) (the real thick resistor)!
  - Compute ***line regulation***, which is defined as: $(V_{OUT,HIGH} - V_{OUT,LOW})/(V_{OUT,LOW})$ x 100%.
    - Line regulation describes V_{OUT} stability when subject to ***variable V_{IN}*** but ***constant load***.

Table 1A: Measurements for Line Regulation (RL = 22 ohm)

V_{IN}	15V	12V
V_{OUT}		

- **Task 1d**: Make the necessary measurements to complete Table 1B.

Table 1B: Measurements for Load Regulation (Vin = 15V)

R_L	2.2 kohm (red/red/red)	22 ohm (red/red/black)
V_{OUT}		

  - Compute ***load regulation***, which is also defined as: $(V_{OUT,HIGH} - V_{OUT,LOW})/(V_{OUT,LOW})$ x 100%.
    - Load regulation describes V_{OUT} stability when subject to ***constant V_{IN}*** but ***variable load***.
  - How does your experimental value compare to your Lab 1a measurement (Task 3d)?
    - It should be better than last week.

- **Task 1e**: Replace the load resistor with the 5V fan.
  - Measure V_{OUT} with a multimeter and make sure it is still 5V! ☺

- **Task 1f**: Unplug the fan when you are done. Leave your circuit on the board for the demo.

• PART 2: 78L05 FIXED VOLTAGE REGULATOR IC

In most projects, you are probably better off using a voltage regulator IC rather than building your own regulator with discrete components. These chips are really convenient since they also contain a bunch of protection circuitry such as: (A) current limiting (B) thermal shutdown (C) soft start during initial power up.

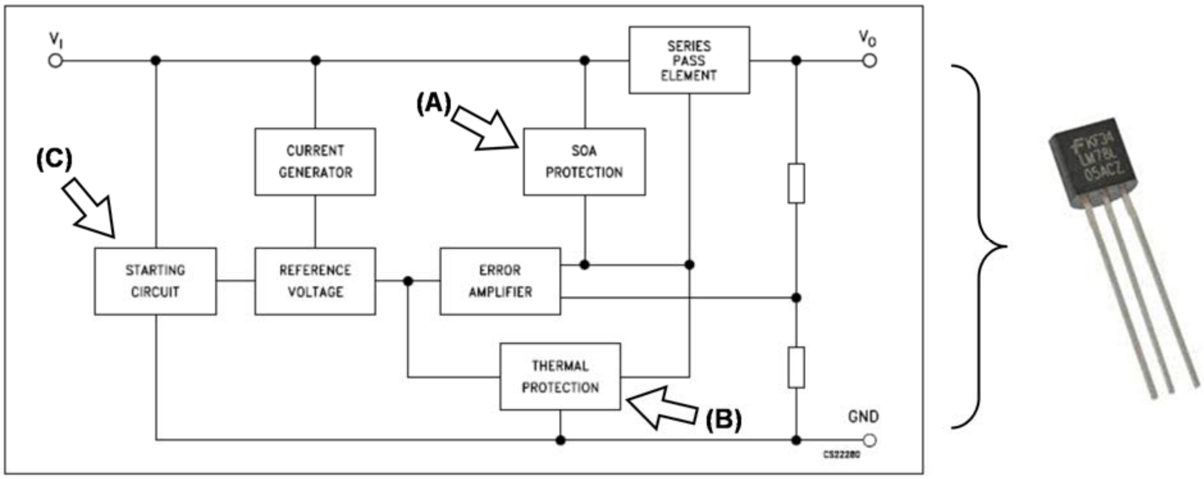


Fig. 3: Block diagram of a typical linear voltage regulator IC. These chips typically include protection circuitry for (A) Safe operating area (SOA) to limit current (B) Thermal shutdown if the device overheats (C) soft start to avoid excessive inrush currents during initial power up.

- **<u>Task 2a:</u>** Install the 78L05 regulator, which produces a fixed +5V output (max = 100 mA). Some comments:
  - This is a SEPARATE circuit from your zener follower + feedback, so build it on a different part of your breadboard.
  - You must use NEAT and COLOR-CODED wiring on your breadboard:
  - The 78L05 pin diagram is on the course website.
    - ➢ As always, the pin locations on the circuit diagram (Fig. 4) are NOT the same as the actual component. Check the datasheet!
  - Initially use V_{IN} = 15V and R_L = 220 ohm (red/red/brown).
  - When you turn on your circuit, confirm that V_{OUT} = 5V with the multimeter.

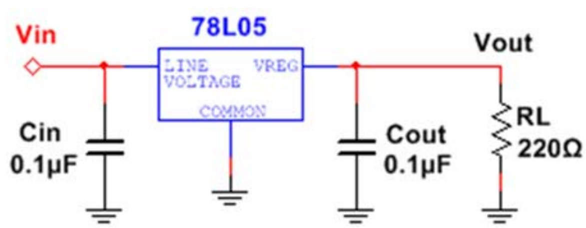


Fig. 4: +5V power supply using a 78L05 regulator IC. Cin and Cout are bypass capacitors to filter out any voltage spikes that approach the input and output pins.

- **<u>Task 2b</u>**: Make the necessary measurements to complete Table 2A.
  - Use your data to compute ***line regulation*** for the 78L05 regulator.

Table 2A: Measurements for Line Regulation (RL = 220 ohm)

V_{IN}	15V	12V
V_{OUT}		

- **Task 2c**: Make the necessary measurements to complete Table 2B.
  - We are using larger R_L (smaller load currents) because the 78L05 is only rated to 100 mA.
  - Use your data to compute the ***load regulation***.

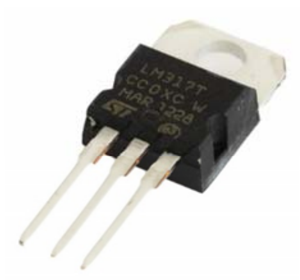
Table 2B: Measurements for Load Regulation (Vin = 15V)

R_L	22 kohm (red/red/orange)	220 ohm (red/red/brown)
V_{OUT}		

- **Task 2d**: Observe thermal shutdown of the regulator using the multimeter.
  - Insert the thick 22 ohm resistor as the load and watch V_{OUT} steadily drop as the regulator heats up.
  - When the voltage reaches a fairly steady value (after about one minute), **record this result**.
    - V_{OUT} should drop to roughly 2.5V.
    - The chip will be pretty HOT!
  - Suppose the regulator could produce $V_{OUT} = 5V$ into a $R_L = 22$ ohm load. Estimate the junction temperature by using $T_J = T_A + P \cdot \theta_{JA}$.
    - Assume $T_A = 25°C$ and $P = I_{OUT} (V_{IN} - V_{OUT})$
    - See the 78L05 datasheet to find θ_{JA} (the TO-92 package)
    - You should get a ridiculously high temperature, which is why thermal shutdown is such a useful feature!
  - V_{OUT} should go back up (above 4V) if we can cool off the regulator. How to do this? You can either (1) grip the regulator chip with the wire stripping tool (firm, but not too tight) (2) blow air on it (e.g. use your mouth).
    - Record the highest V_{OUT} you can achieve by cooling the regulator.

• PART 3: LM317 ADJUSTABLE REGULATOR IC

The LM317 is an adjustable voltage regulator IC, which means it can be configured to produce an arbitrary V_{OUT} (although it must be less than V_{IN}). We'll configure the LM317 as a 12V power supply to drive a 12V fan (rated current = 0.71A). This is MUCH more powerful fan – hold on tight!



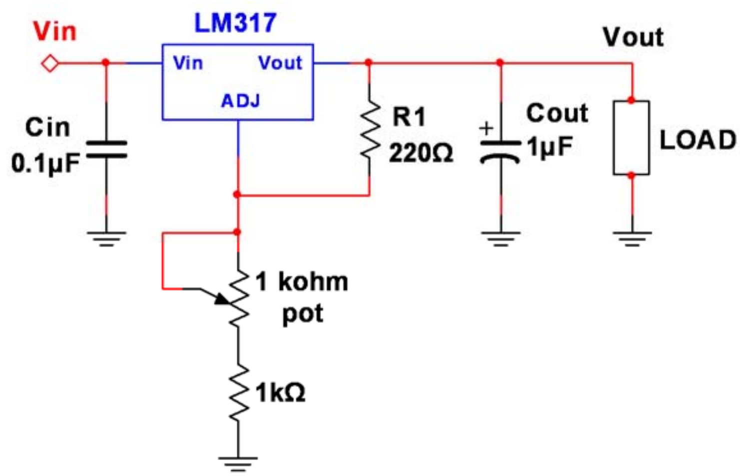


Fig. 5: LM317 adjustable regulator configured as a 12V power supply. Note that R2 is the combination of a 1kohm resistor in series with a 1 kohm potentiometer. The capacitors Cin and Cout are important to remove voltage spikes from Vin and Vout, respectively.

How does the LM317 work? It basically maintains 1.25V between the V_{OUT} and V_{ADJ} pins (see Fig. 5). Proper choice of R2 will produce the desired output according to $V_{OUT} = 1.25\ (1 + R2\ /\ R1)$. The LM317 data sheet suggests R1 = 240 ohm. This is not critical, so we will use R1 = 220 ohm (red/red/brown).

- **Task 3a:** Compute the proper value for R2 to get V_{OUT} = 12V.
  - We will make R2 by combining a 1 kohm resistor in series with a 1 kohm potentiometer (see Fig. 5).
    - This "combo" approach is a very common technique to get fine control over a resistance value.

- **Task 3b**: Suppose V_{IN} = 15V and the load is the 12V fan. This means V_{OUT} = 12V and I_{OUT} = 0.71A. Estimate the junction temperature by using $T_J = T_A + P \cdot \theta_{JA}$ and assume T_A = 25°C.
  - Assume the regulator's power dissipation is $P \approx I_{OUT}\,(V_{IN} - V_{OUT})$
  - See the LM317 datasheet to find θ_{JA} (the TO-220 package)
  - You should get a pretty toasty temperature, which is why a heat sink is a good idea!

- **Task 3c**: Estimate the junction temperature assuming a 20 °C/W heat sink.
  - Assume T_A = 25°C, $P = I_{OUT}\,(V_{IN} - V_{OUT})$, and θ_{CS} = 0.5°C/W.
  - See the LM317 datasheet to find θ_{JC} (the TO-220 package)
  - You should find that T_J remains fairly cool, which is good!

- **Task 3d**: Attach a heat sink to the LM317.
  - Use the same procedure as last week!
  - Make sure the heat sink is firmly bolted onto the LM317!
    - This squeezes out any excess thermal paste, which is important for good heat transfer.

- **Task 3e**: Build the circuit in Fig. 5. Some comments:
  - This is a SEPARATE circuit from the previous two circuits.
  - You must use NEAT and COLOR-CODED wiring on your breadboard:
  - The LM317 pin diagram is on the course website
    - Be careful with which pin is V_{IN}, V_{OUT}, and V_{ADJ}!
  - Initially use V_{IN} = 15V and R_L = 2.2 kohm (red/red/red).
  - Just like in Task 1b, adjust the potentiometer until you obtain V_{OUT} = 12V (+/- 0.02V is OK).

- **Task 3f**: Observe V_{OUT} using the scope. You will need to configure the scope in the following manner:
  - Turn on the scope. If the red "Rmt" appears on the screen, press "Force Trig" to get rid of it.
  - Press "Default" to reset the scope.
  - The scope settings should be:
    - HORIZONTAL: Scale = 2 ms/div.
    - CH1: Probe = 1X, Scale = 2V/div, Offset = -10V (this is below the bottom of the screen)
    - TRIGGER: Level = 11V
  - DO NOT PRESS AUTOSCALE! Buma will deduct 1,234 points if he catches you.
  - You should observe a nice flat horizontal line at 12V.

- **Task 3g**: Record a snapshot of V_{OUT} when the load is the 12V fan.
  - The fan is strong and pretty loud, so make sure you don't blow things away.
  - The benchtop supply should show a current draw of roughly 0.75A when the fan is on.
  - The scope waveform should have a lot of spikes (see Fig. 6).
    - You may need to adjust the scope trigger to get a nice steady waveform.

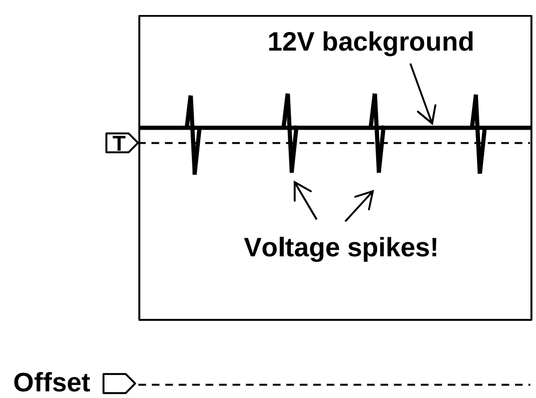


Fig. 6: Your V_{OUT} waveform for the 12V fan should contain voltage spikes. Note that the -10V DC offset will actually be BELOW the bottom of the screen!

- These voltage spikes are due to current spikes produced by the fan!
  - Like many electromechanical devices, DC brushless fans are complicated loads!
- Use MATLAB to record a scope snapshot.

- **Task 3h**: How to reduce these spikes? Try replacing Cout with 10 uF, then 100 uF, and finally 470 uF.
  - Think about why the larger Cout produces a smoother waveform.
  - Use MATLAB to record a scope snapshot with Cout = 470 uF.

PART 4: CIRCUIT DEMO

- **Zener follower + negative feedback:**
  - **Show Buma your regulator circuit with the 5V fan.**
    - Demonstrate that V_{OUT} is near 5V as V_{IN} is varied from 12 to 15V.
    - Show Buma your line regulation and load regulation values.
    - Unplug the 5V fan when you are done.
- **78L05 voltage regulator IC**
  - **Show Buma your regulator IC with the 2.2 kohm resistor as the load**.
    - Demonstrate that V_{OUT} is near 5V as V_{IN} is varied from 12 to 15V.
    - Show Buma your line regulation and load regulation values.
    - Show Buma your temperature calculation and result from the cooling experiment.
- LM317 adjustable regulator IC
  - **Show Buma your regulator IC with the 12V fan as the load and Cout = 1 uF.**
    - Buma will reset the scope. You must dial in the proper settings to display the fan voltage.
      - Do NOT press Autoscale! Buma will deduct 2,345 points if he catches you doing this.
    - Show Buma your two MATLAB plots of the fan voltage.

(End of Lab 1b)