Voltage Regulator Design

Zener Diode Shunt Voltage Regulator

When an ideal diode is reverse biased, it conducts no current. The depletion layer at the reverse biased pn junction acts like an insulator. Like any real insulator, it can suffer breakdown when the applied potential is sufficiently high. A Zener diode has been specially built so that its depletion layer breaks down (safely) at low voltages. At breakdown, the diode presents very little incremental resistance to current flow, and so it can act like a good voltage reference.

Simple Zener Regulator Circuit

The circuit in Figure below maintains $\sim V_Z$ on its output by reverse biasing the Zener diode with $\sim I_Z$ current.

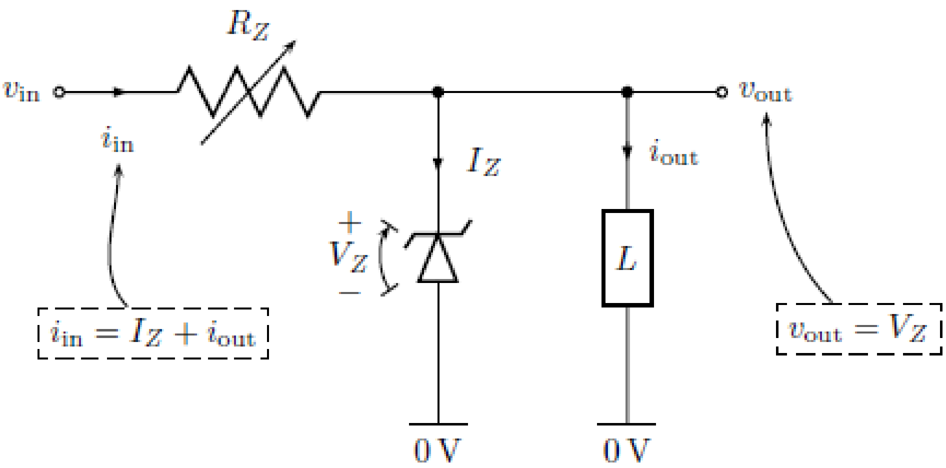


Figure 1: Zener diode shunt voltage regulator with load L.

Typical V_Z, I_Z, and "on" resistance R_{on} for Zener diodes can be noted from datasheet.

The resistor R_Z both biases the Zener diode and limits the output current i_{out}. That is,

$$i_{in} = I_Z + i_{out} \quad \text{.................................... (1)}$$

$$V_{in} - i_{in} \cdot R_Z = V_Z$$

$$i_{out} = \frac{V_{in} - V_Z}{R_Z} - I_Z$$

$$V_{out} = V_Z \quad \text{.. (2)}$$

where L is the typical load (e.g., ~10 k) and V_{out} is the desired output. As the load L moves off the typical load, the current through the Zener diode will change. A very small L will rob the Zener of so much current that it will move out of its Zener operation range. At that point, the output V_{out} will drop far below V_Z as the circuit reduces to a R_Z–L voltage divider.

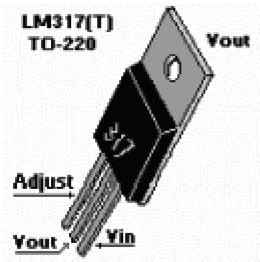
Zener Regulator Laboratory Procedure:

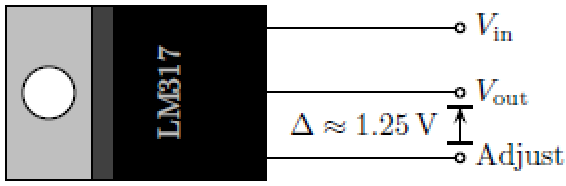
1. Design (i.e., choose components for desired output) and build the regulator.
   - Lookup your Zener diode's I_Z and V_Z in the datasheet
     – Using a 4.3V Zener diode will simplify later calculations.
     – Make sure you have the right Zener diode.

   ∗ Diode part numbers (e.g., 1N5229) are written in very small text that is "word-wrapped" around the outside of the glass diode package. Rotate diode to read the text.
   - Use input vin = 15V.
   - Use output vout = V_Z.
   - Using equation 2, calculate the R_Z needed to properly bias your Zener diode.
     – Use IZ from datasheet
     – Assume a typical load of 10 k.
2. Verify proper regulator output, but DO NOT TUNE the regulator.
   - Use a 10 k load.
   - Use your digital multimeter to measure the output.
     – If output is far from expected V_Z, make sure you calculated biasing resistor R_Z correctly.
   - For your report, refer to equation 1 and discuss how R_Z should be changed to tune the output (e.g., increase it or decrease it).
3. With no load (i.e., L = ∞, an open circuit), record the i_{in} current measured by the power supply as the no-load quiescent current, which is the additional current required to operate the regulator with no load.

L(Load)Ω	$v_{out}(V)$	i_{in} (mA)

LM317 Adjustable Positive Series Voltage Regulator

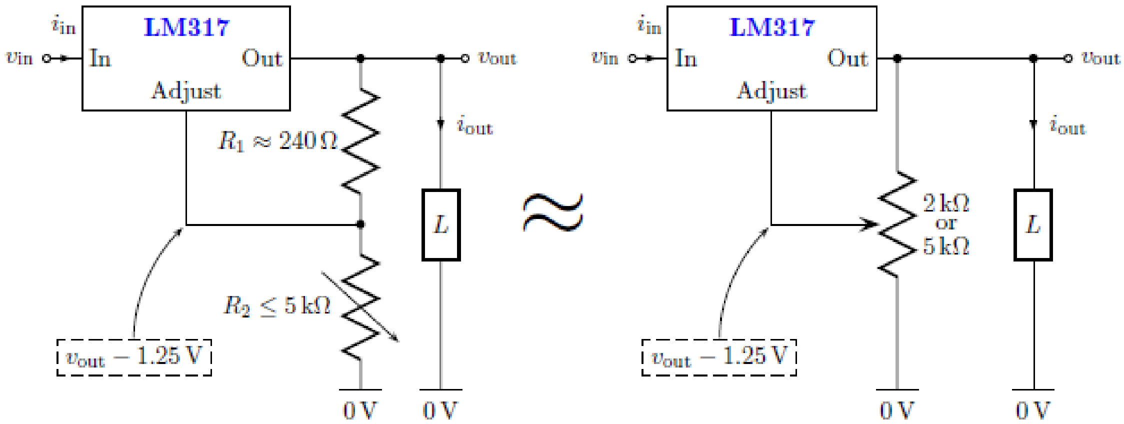




The two circuits in Figure 2 are identical. The LM317 maintains 1.25V potential difference between its "Out" and "Adjust" pins, and the voltage divider acts as a lever propping vout above the ground reference. The aim of this experiment is to understand the working and use cases of voltage regulators and potentiometers.

In Figure 2(a), the (temperature-independent) output is given by

$$v_{out} = (1.25) * \left(1 + \frac{R_2}{R_1}\right) \text{...} (3)$$



(a) Using variable-resistor divider. (b) Using potentiometer.

Figure 2: LM317 adjustable series voltage regulator with load L. Use 40V > (vin − vout) > 3V.

LM317 IC Regulator Laboratory Procedure:

1. Design (i.e., choose components for desired output) and build the regulator in Figure 2(a) or (b).
    - RESISTOR VALUES SHOWN in schematics reflect nominal potentiometer sizes.
    - Again, use input vin = 15V and output vout = 10V.
    - Use equation 3 to calculate the proper R1/(R1 + R2) ratio.
    - You have two implementation options.

        (i) From Figure 2(a), set $R_1 \approx 240$ and calculate R_2. Implement R_2 with a variable resistor made from adjacent legs of a 2 k or 5 k potentiometer.

        (ii) From Figure 2(b), adjust a 2 k or 5 k potentiometer for the right R_1/(R_1 + R2) ratio.

        While you should perform all calculations for your report, it may be easiest to skip calculations for now and tune 2 k or 5 k potentiometer until output reaches desired 10V.

A brief about Potentiometer: There are two types of resistors: fixed resistors and variable resistors based on the resistance value. Potentiometers are a type of adjustable resistor that has three pins. Now, the potentiometer is filled with resistive material and turning the knob changes the amount of this material and so the resistance of the material. Try exploring more stuff about potentiometer as it is an important equipment in lab experiments. For more Information: https://randomnerdtutorials.com/electronics-basics-how-a-potentiometer-works/#:~:text=Potentiometers%20can%20be%20used%20as,pin%20is%20the%20voltage%20output.

2. Tune regulator output by adjusting the R_1–R_2 divider (or potentiometer) until measured $v_{out} \approx 10V$.

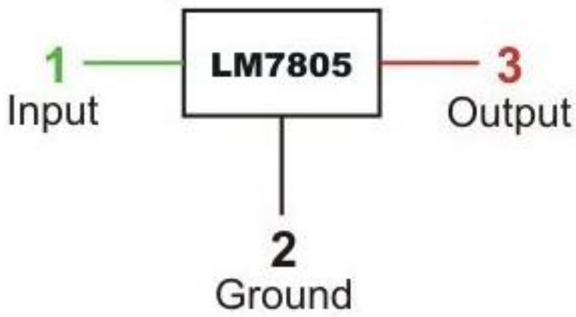
- Use a 10 k load.
- Use your digital multi meter (DMM) to measure the output.

3. Use your DMM to measure (and RECORD) the potential between the Output and Adjust pins. What is expected?

4. With no load (i.e., L = ∞, an open circuit), record the i_{in} current measured by the power supply as the no-load quiescent current, which is the additional current required to operate the regulator with no load. Try finding out a potential disadvantage of this kind of setup and how is it inefficient.

L(Load)Ω	$v_{out}(V)$	i_{in} (mA)

LM7805 Voltage Regulator



In Figure 2 replace LM317 with LM7805 and repeat the procedure.