Voltage Regulator Design using LTSpice

Objectives

1. Understand the working principles & use cases of voltage regulators (Line & Load Regulation)
2. Design a Voltage Regulator using a Zener diode in LTSpice.
3. Design a Voltage Regulator using LM7805 Spice Model in LTSpice.
4. Design a Voltage Regulator using LM317 Spice Model in LTSpice.
5. Check the noise performance of the above circuit designs.

Reading Exercise

Read about Zener diode: Link
Datasheets of LM7805, LM317 ICs and Zener diode.

Circuit Overview

Zener Diode Shunt Voltage Regulator

A simple voltage regulator circuit is shown below in Fig. 1. The input voltage is fed to a resistor connected to a shunt zener diode. A zener diode is a special type of diode that is operated in the reverse direction when it is used in a voltage regulator. When operated in reverse bias, the diode maintains a constant voltage across the diode irrespective of the diode current (provided the current is above the minimum breakdown current and below the maximum current rating).

The series resistor connected to the zener diode is used to limit the diode current. The load is connected

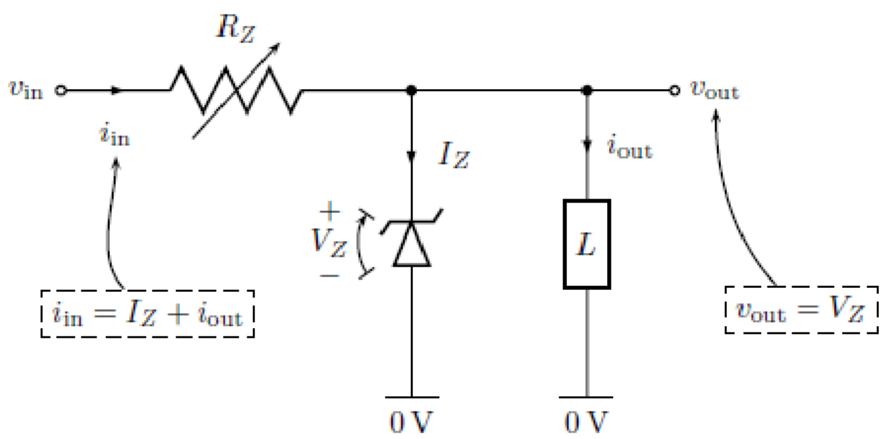

Figure 1: Zener diode shunt voltage regulator with load L.

in parallel to the zener diode so that the voltage across the diode remains constant irrespective of the value of the load. One problem with zener diode stabilizer circuits is that the diode can some times generate electrical noise on top of the DC supply as it tries to stabilize the voltage. Hence, a large value decoupling capacitor should be connected across the zener's output for additional smoothing. The following equations can be easily verified using KCL and KVL:

$$v_{out} = v_{in} - (I_Z + i_{out})R_Z = v_{in} - \left(I_Z + \frac{V_Z}{L}\right) R_Z \tag{1}$$

and so, for $v_{out} = V_Z$, R_Z must be chosen so that

$$R_Z = \frac{v_{in} - V_Z}{I_Z + i_{out}} = \frac{v_{in} - V_Z}{I_Z + \frac{V_{out}}{L}} = \frac{v_{in} - V_Z}{I_Z + \frac{V_Z}{L}} \tag{2}$$

LM7805 Fixed Voltage Regulator

The LM7805 is a fixed 5 V regulator. Since the output voltage is fixed, no external resistors are needed for setting the voltage.

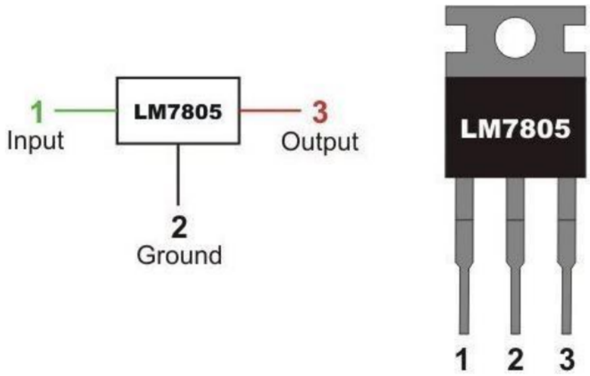

Figure 2: LM7805 voltage regulator

Line Regulation

Line regulation refers to the ability of a circuit to maintain constant (regulated) output voltage with change in the input voltage.

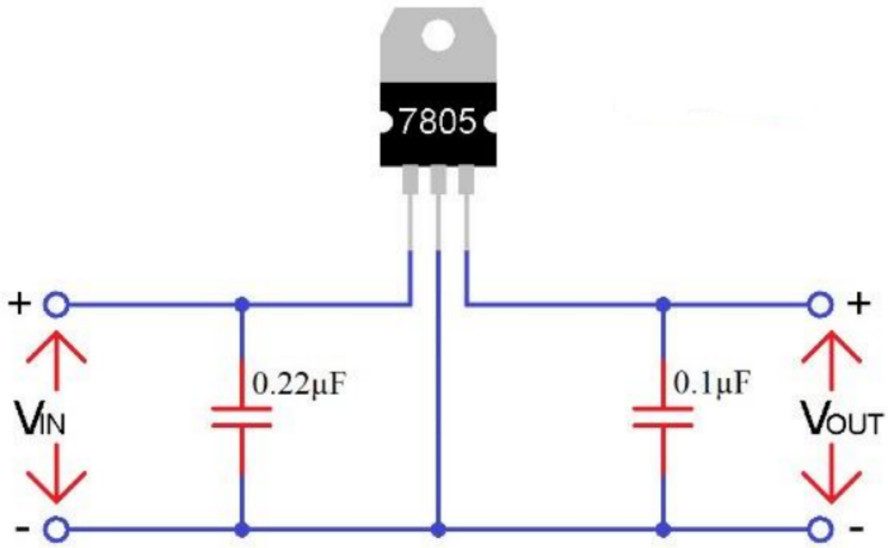

Figure 3: LM7805 Line Regulation

Load Regulation

Load regulation refers to the ability of a circuit to maintain constant (regulated) output voltage with change in the load resistance.

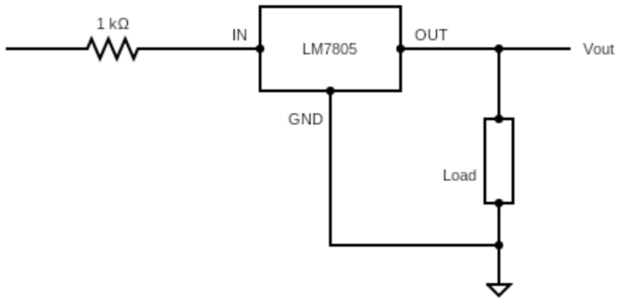

Figure 4: LM7805 Load Regulation

LM317 Adjustable Voltage Regulator

The LM317 is a three-terminal adjustable positive series voltage regulator. It maintains a constant 1.25 V potential difference between its 'OUT' and 'ADJUST' pins. An external resistor divider (R_1 and R_2) uses this internal reference to set a desired output voltage. LM317 adjustable series voltage

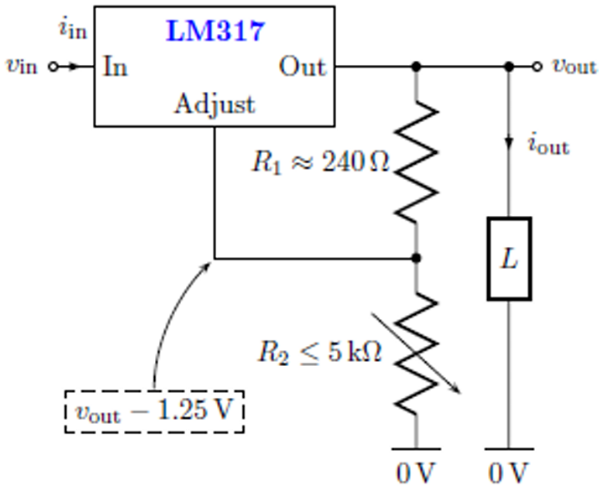

Figure 5: Using variable resistor divider

regulator with load L. Use 40V > (vin − vout) > 3V. The output voltage is determined by the formula:

$$v_{out} = 1.25V \times \left(1 + \frac{R_2}{R_1}\right) \tag{1}$$

Lab Exercise

1. Draw the Zener regulator circuit (Figure 1.) in LTSpice. Use a 15 V DC input, a 1 kΩ series resistor, and a 5 V Zener diode. Connect a load resistor R_L across the diode.
2. Use a '.step' command with a '.op' analysis to vary the load resistance R_L from 100 Ω to 5 kΩ and note how the output voltage is changing. (Load Regulation)
3. Use a '.step' command with a '.op' analysis to vary the DC input voltage from 0 V to 15 V and note how the output voltage is changing. (Line Regulation)
4. Replace the Zener circuit with the SPICE model for an IC7805 regulator (Figure 2.). Repeat the test from step 2 & 3. Compare the load regulation (change in output voltage vs. load) and line regulation (change in output voltage vs. input) of the two circuits.
5. Replace the Zener circuit with the SPICE model for an IC317 regulator (Figure 5.). Repeat the

test from step 2 & 3. Compare the load regulation (change in output voltage vs. load) and line regulation (change in output voltage vs. input) of the two circuits.

6. Turn off source excitation and perform a noise analysis (‘.noise‘) on the output node of the regulator (Zener / LM7805 / LM317) circuit up to 10 kHz.
7. Add a smoothing capacitor in parallel with the load. Rerun the noise analysis, stepping the capacitor value (e.g., 5 µF, 50 µF, 500 µF), and observe the effect on the output noise.