Lab Report: Voltage Regulator Design using LTSpice

V.L.S. Bhargav ; Lanka Kushwanth
Table Number: 3
Room Number: 114
Roll Number: 2025102061

October 7, 2025

PART A:

Aim:

The aim of this experiment is to design and analyze different voltage regulators digitally. Using a zener diode, LM7805, and LM317, their line regulation, load regulation.

Software Used:

1. LTSpice
2. WineHQ (for running LTSpice on Linux/Mac)

Procedure:

1. Install LTSpice.msi file from the official Website to install LTSpice. Also install Wine if you use Linux/Mac.
2. Get familiarized with the interface of LTSpice and use it to build basic circuits and analyze them.
3. Build a circuit to observe the voltage regulation phenomenon of zener diode by varying load resistance using a step function.
4. Analyze the difference between Voltage input and output by plotting both onto the graph using the tools in LTSpice.
5. Now vary the Voltage of the circuit by fixing the resistance.
6. Analyze the difference again using the graphs.
7. Using the reference circuit build a LTSpice model for LM7805 and LM317. Repeat the same process, observe the difference between the input and output Voltages.

Reference Circuit:

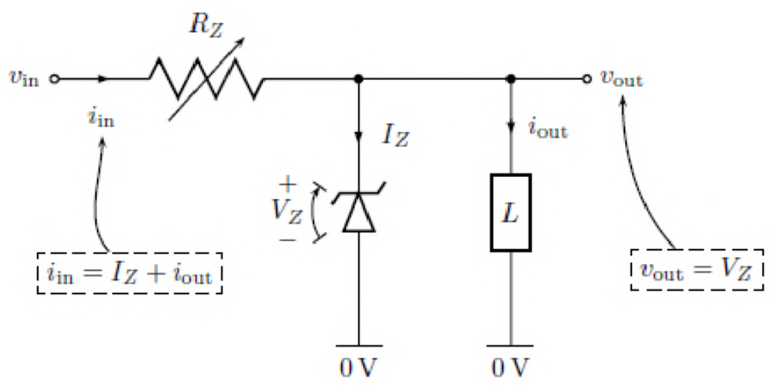


Figure 1: reference circuit for zener diode.

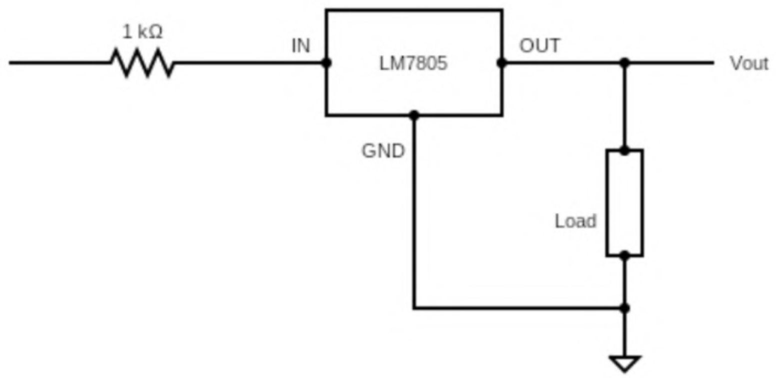


Figure 2: reference circuit for LM7805 IC - Load Regulation.

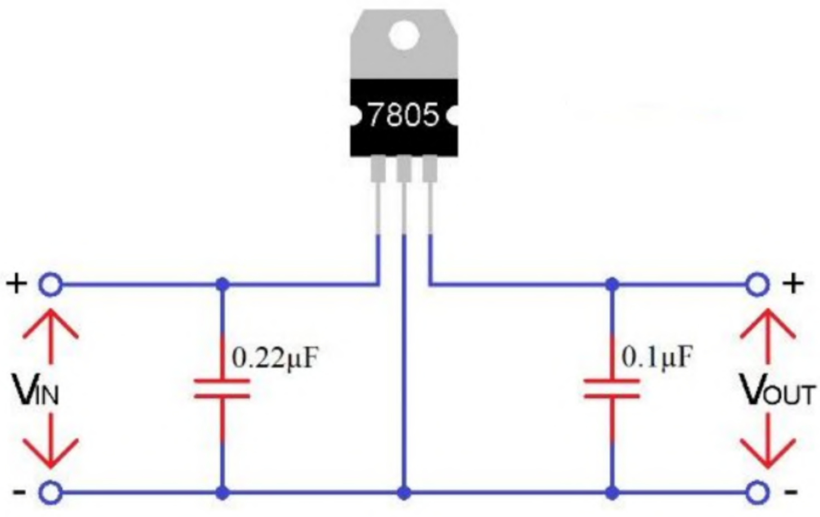


Figure 3: reference circuit for LM7805 IC - Line Regulation.

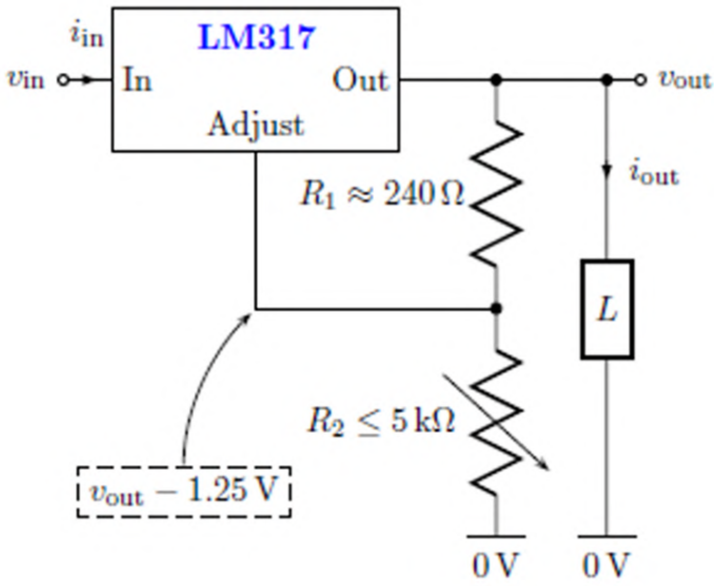
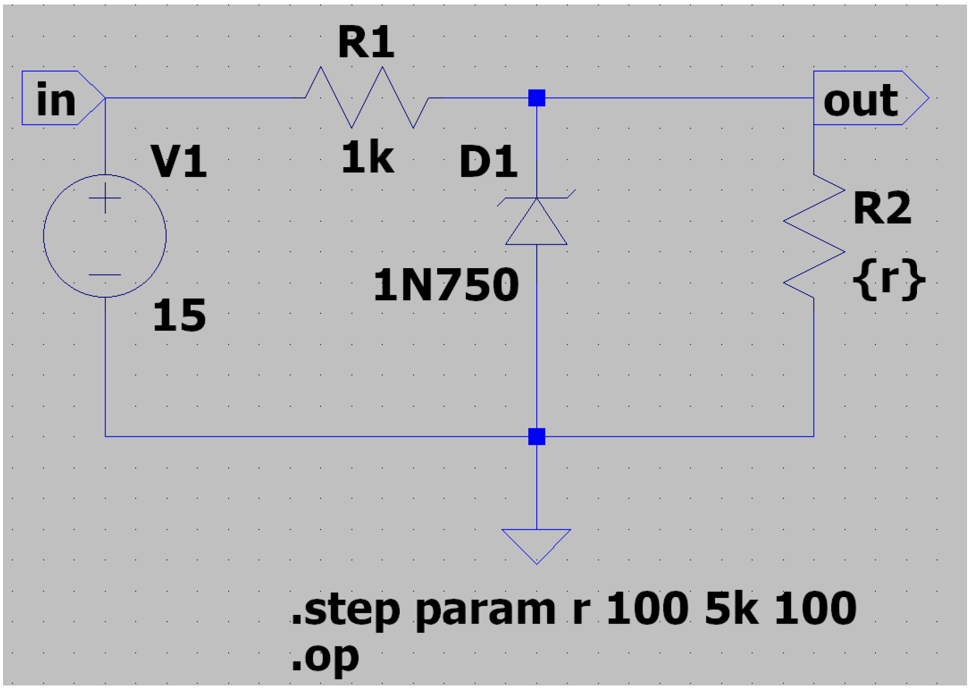


Figure 4: reference circuit for LM317 diode.

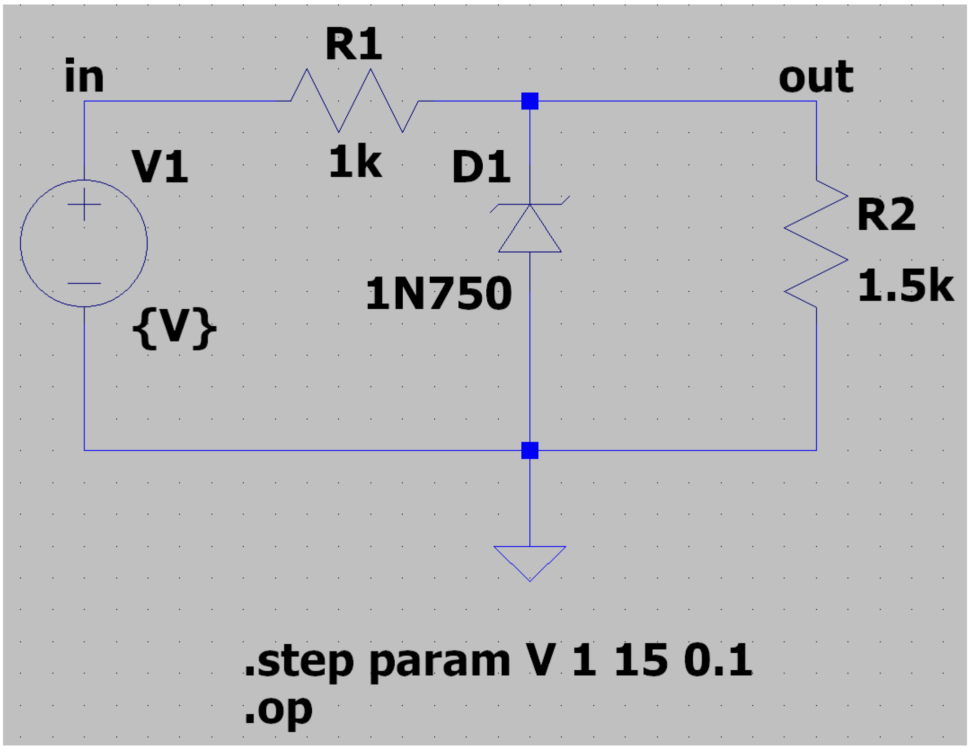
LTspice Circuit:

SPICE directives used:

1) .step param parameter... - this is used to increase a parameter in steps
2) .op refers to the DC Operating Point Analysis (its used to run the simulation)

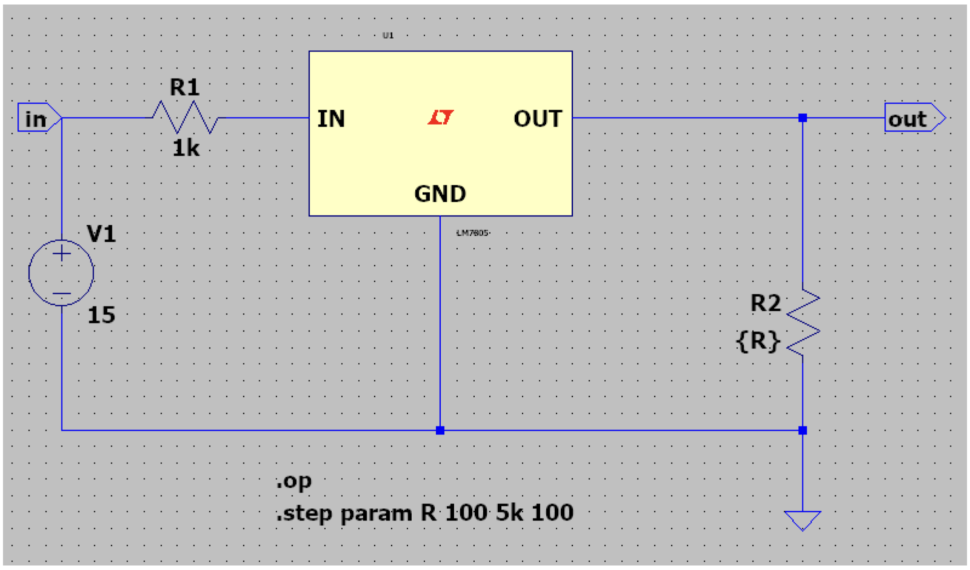


(a) LTspice schematic zener diode with variable resistance.

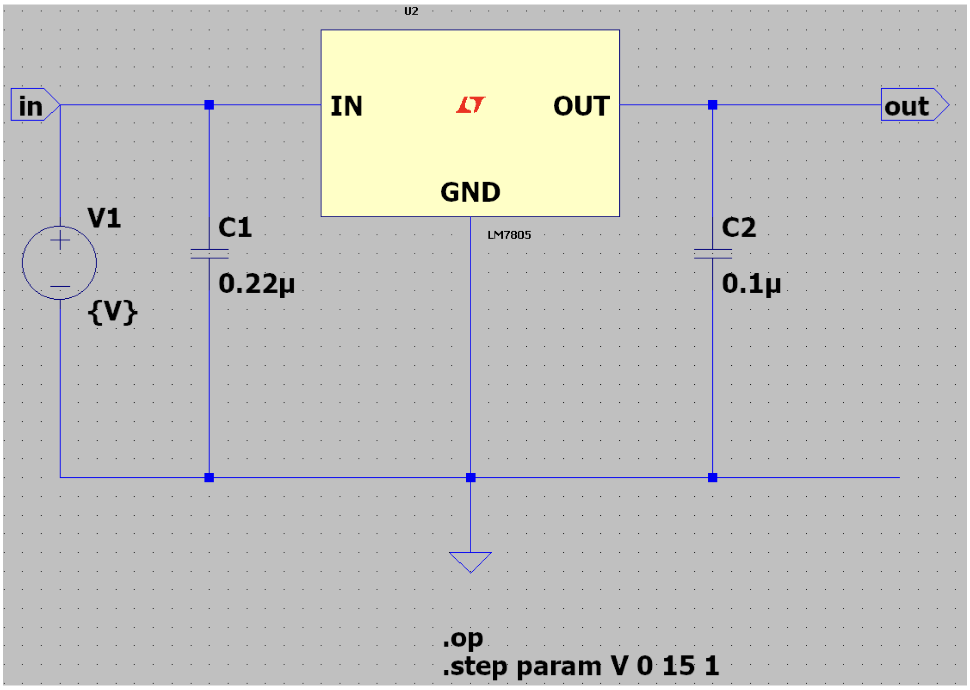


(b) LTspice schematic zener diode with variable voltage.

Figure 5: LTspice schematics for Zener diode circuits.

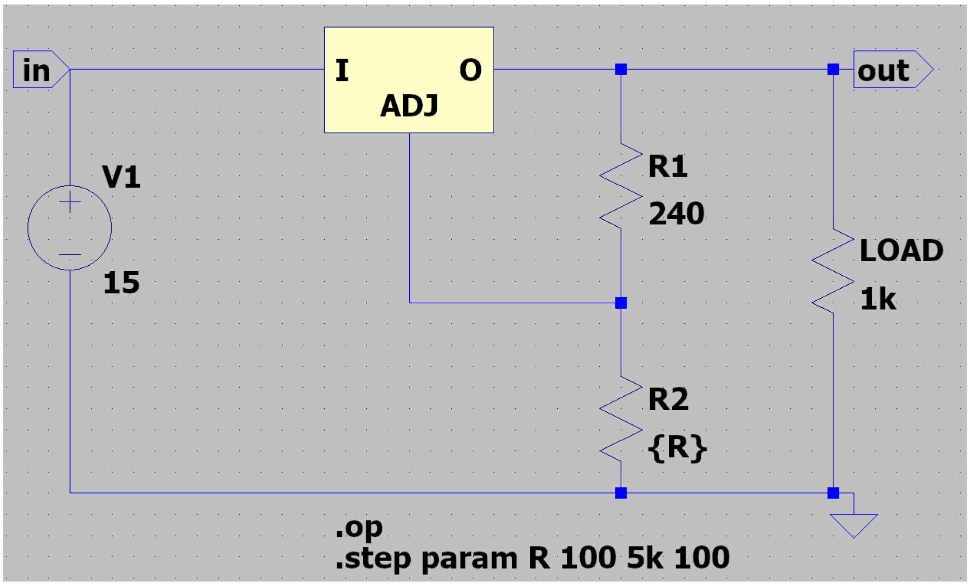


(a) LTspice schematic of LM7805 with variable resistance.

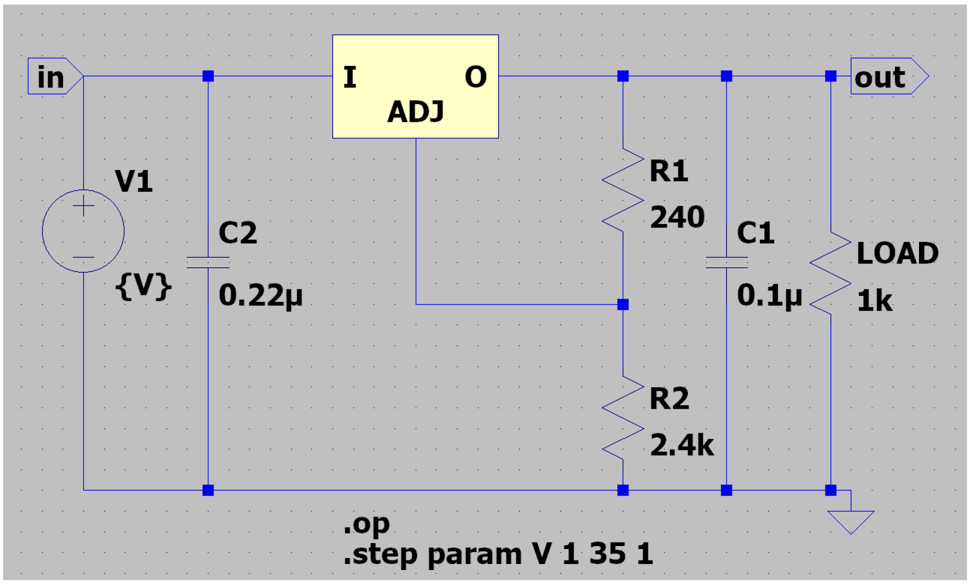


(b) LTspice schematic of LM7805 with variable voltage.

Figure 6: LTspice schematics for LM7805 regulator circuits.



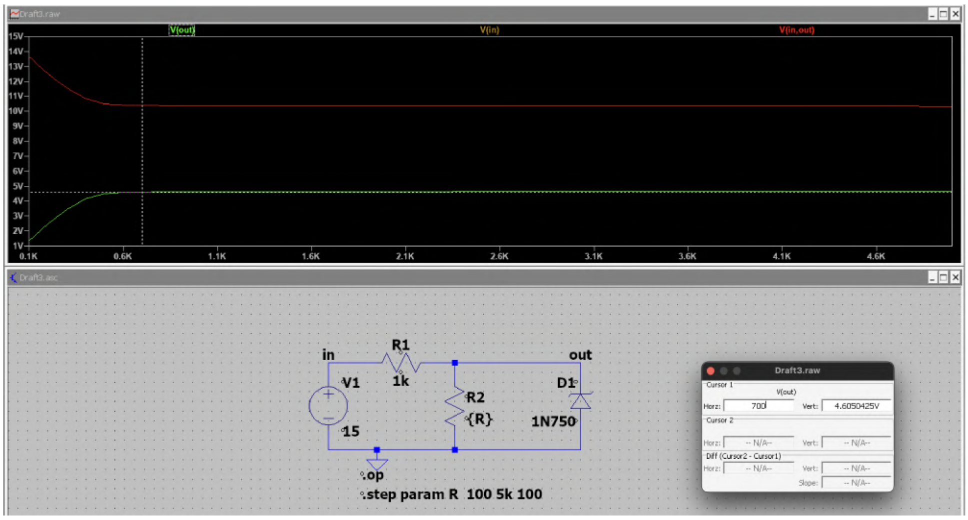
(a) LTspice schematic LM317 with variable resistance.



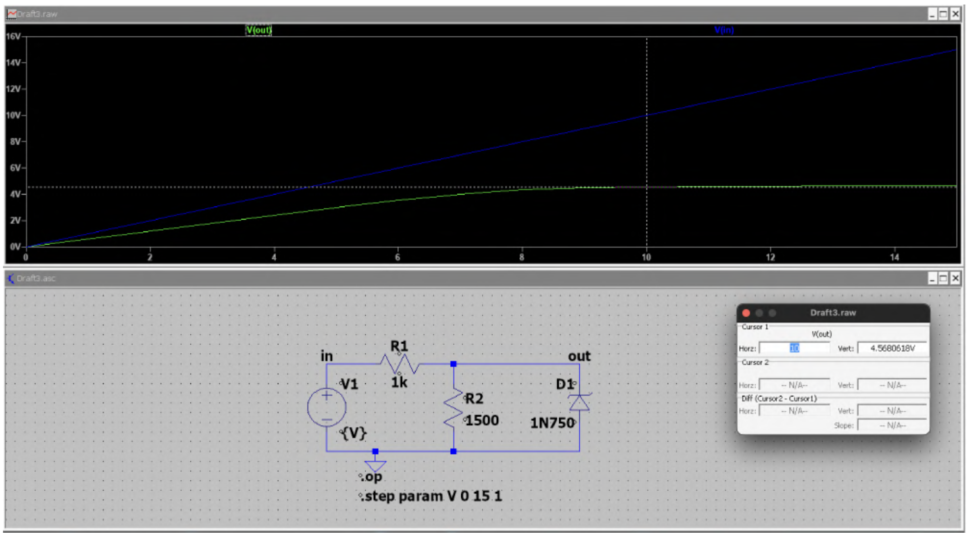
(b) LTspice schematic LM317 with variable voltage.

Figure 7: LTspice schematics for LM317 regulator circuits.

Simulation Plots:

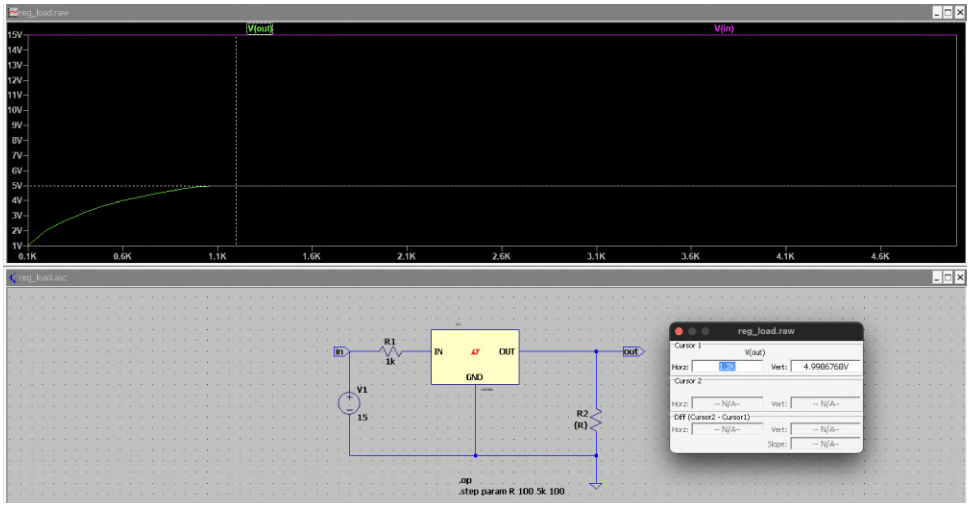


(a) Simulation output plot from LTspice for load regulation of zener diode.

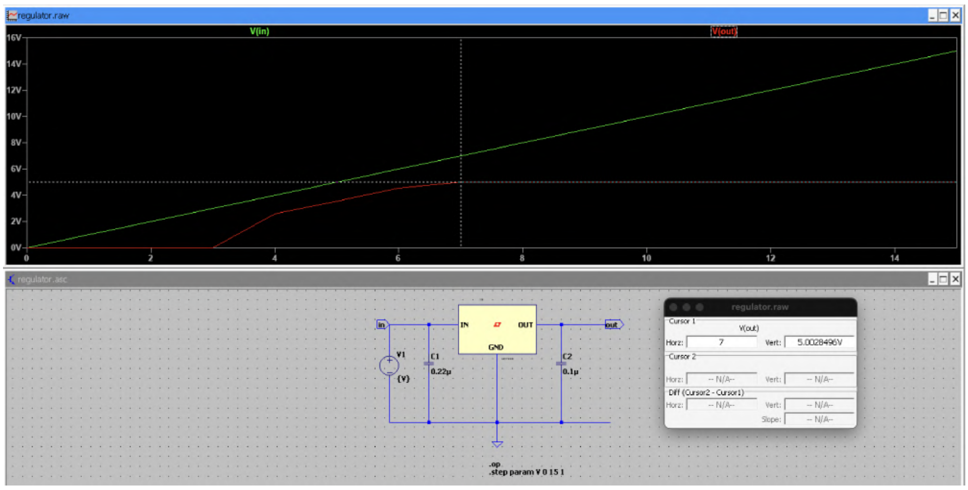


(b) Simulation output plot from LTspice for voltage regulation of zener diode.

Figure 8: Simulation plots for Zener diode.

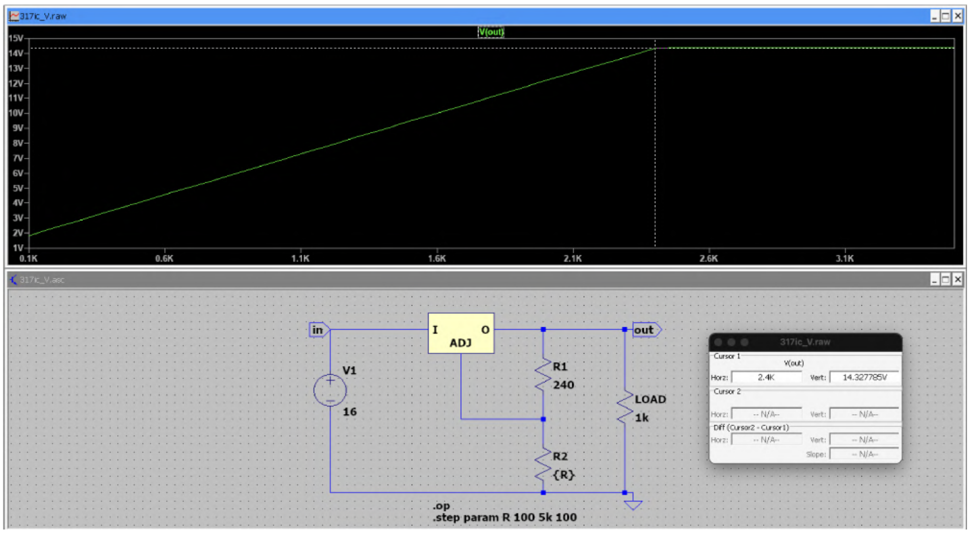


(a) Simulation output plot from LTspice for load regulation of LM7805 IC.

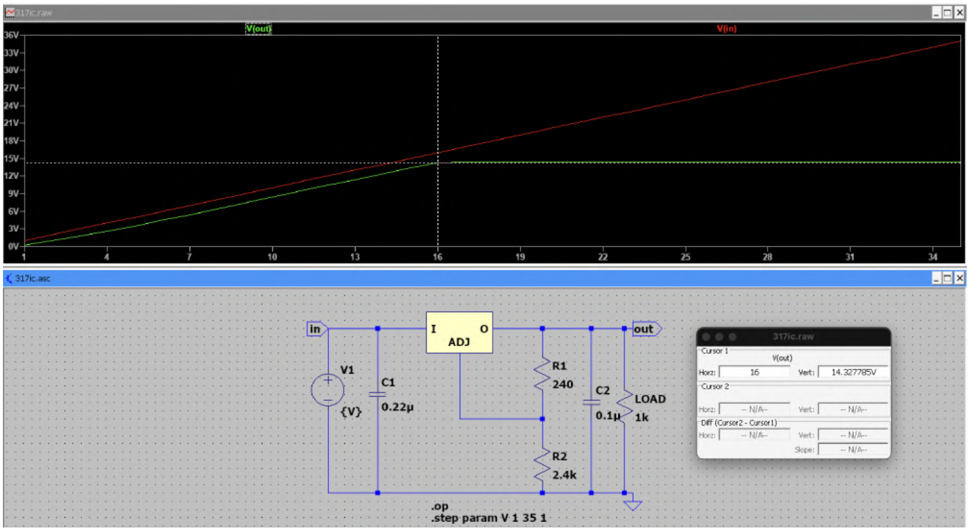


(b) Simulation output plot from LTspice for line regulation of LM7805 IC.

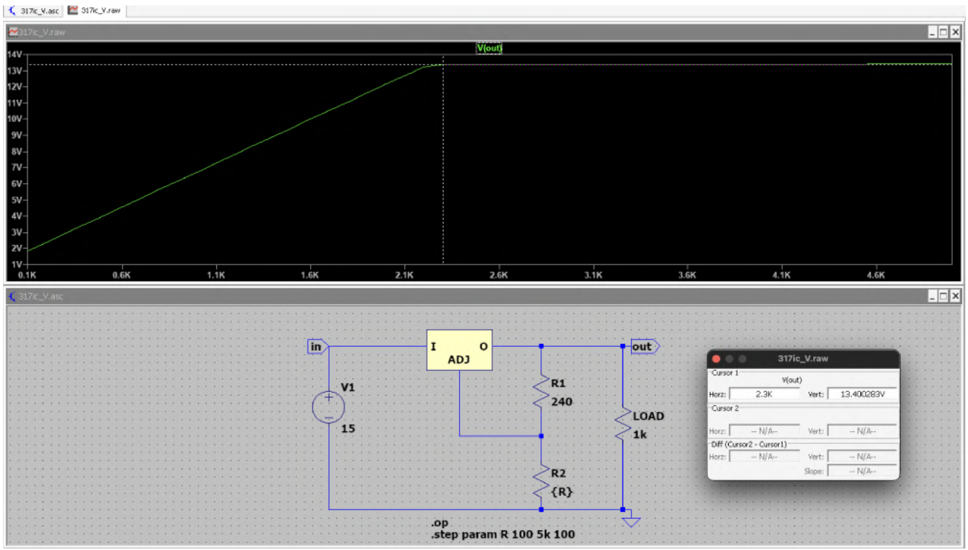
Figure 9: Simulation plots for LM7805 regulator.



(a) Simulation output plot from LTspice for load regulation of LM317 IC.



(b) Simulation output plot from LTspice for line regulation of LM317 IC.



(c) Simulation output plot from LTspice for load regulation of LM317 IC with different voltage.

Figure 10: Simulation plots for LM317 regulator.

Observations:

Key Points:

- An asymptote of the Zener diode while changing resistance is observed at $\approx 4.7\,\text{V}$.
- An asymptote of the Zener diode while changing voltage is also observed at $\approx 4.7\,\text{V}$.
- Similarly, for the LM7805 IC, the line and load regulation have asymptotes converging to $\approx 5\,\text{V}$.
- In the case of the LM317 IC, the asymptotes converge to different voltages depending on the input voltage.
  1. In Fig. 15 and Fig. 16, the voltage value is $\approx 14.33\,\text{V}$ for an input of $16\,\text{V}$.
  2. Whereas in Fig. 17, the output voltage is $\approx 13.4\,\text{V}$ for an input voltage of $15\,\text{V}$.

Analysis:

- Upon varying the series resistance and input voltage for the 1N750 Zener diode, the output voltage was observed to stabilize at $\approx 4.7\,\text{V}$, indicating the point of voltage regulation.
- For the LM7805 IC, both line and load variation tests showed that the output consistently settled around $\approx 5\,\text{V}$, confirming its fixed-voltage regulation characteristic.
- In the case of the LM317 IC, the output voltage was found to depend on the input voltage as well as the resistor configuration used in the feedback network.
  1. From the simulation corresponding to Fig. 15 and Fig. 16, the regulated output voltage was observed to reach $\approx 14.33\,\text{V}$ when the input voltage was $16\,\text{V}$ in both load and line regulation.
  2. From Fig. 17, with an input voltage of $15\,\text{V}$, the output voltage was observed to stabilize near $\approx 13.4\,\text{V}$ for load regulation and similar changes can be made in line regulation to get same result.

Explanation:

- The 1N750 Zener diode maintains a nearly constant voltage once the reverse bias voltage reaches its breakdown region. This occurs due to the Zener breakdown effect, where the diode conducts in reverse while clamping the voltage at its Zener voltage ($\approx 4.7\,\mathrm{V}$), providing stable regulation.

- The LM7805 IC uses an internal voltage reference and feedback network to maintain a fixed output of $5\,\mathrm{V}$, regardless of variations in input voltage (as long as the input is at least $\approx 2\,\mathrm{V}$ above the output) or load current. This demonstrates both line and load regulation capabilities.

- The LM317 is an adjustable regulator whose output voltage depends on the resistor divider network between its output and adjustment pins. The output voltage is given by:

$$V_{\text{out}} = V_{\text{ref}} \left(1 + \frac{R_2}{R_1}\right) + I_{\text{adj}} R_2$$

  where $V_{\text{ref}} \approx 1.25\,\mathrm{V}$ and $I_{\text{adj}} \approx 50\,\mu\mathrm{A}$.

- For $R_1 = 240\,\Omega$ and $R_2 = 2.4\,\mathrm{k}\Omega$, the expected voltage is:

$$V_{\text{out}} \approx 1.25 \left(1 + \frac{2400}{240}\right) = 13.75\,\mathrm{V}$$

  including $I_{\text{adj}} R_2$, resulting in $\approx 13.9\,\mathrm{V}$, which matches simulation results.

- When the input voltage is $15\,\mathrm{V}$, the regulator approaches its dropout limit (minimum voltage difference required for regulation), causing the output to drop slightly to $\approx 13.4\,\mathrm{V}$. Increasing the input to $16\,\mathrm{V}$ restores full regulation, giving $\approx 14.3\,\mathrm{V}$ as observed in the simulation.

Conclusion:

- The Zener diode circuit successfully demonstrated voltage regulation at $\approx 4.7\,\mathrm{V}$ through the Zener breakdown effect, maintaining a nearly constant voltage regardless of load or input variations.

- The LM7805 IC exhibited stable regulation at $\approx 5\,\mathrm{V}$, confirming its fixed-output capability under both line and load changes.

- The LM317 adjustable regulator produced output voltages dependent on the resistor configuration and input voltage, following the theoretical formula:

$$V_{\text{out}} = V_{\text{ref}} \left(1 + \frac{R_2}{R_1}\right) + I_{\text{adj}} R_2$$

- Simulation results closely matched the expected theoretical values, verifying the correct operation and regulation principles of all three regulators.

- Thus, the experiment successfully demonstrated the working, comparison, and regulation behavior of Zener diode, LM7805, and LM317 voltage regulators.

PART B:

Aim:

To analyze the noise performance of a voltage regulator circuit with and without capacitive filtering, and to observe the effect of capacitors on noise in the output voltage.

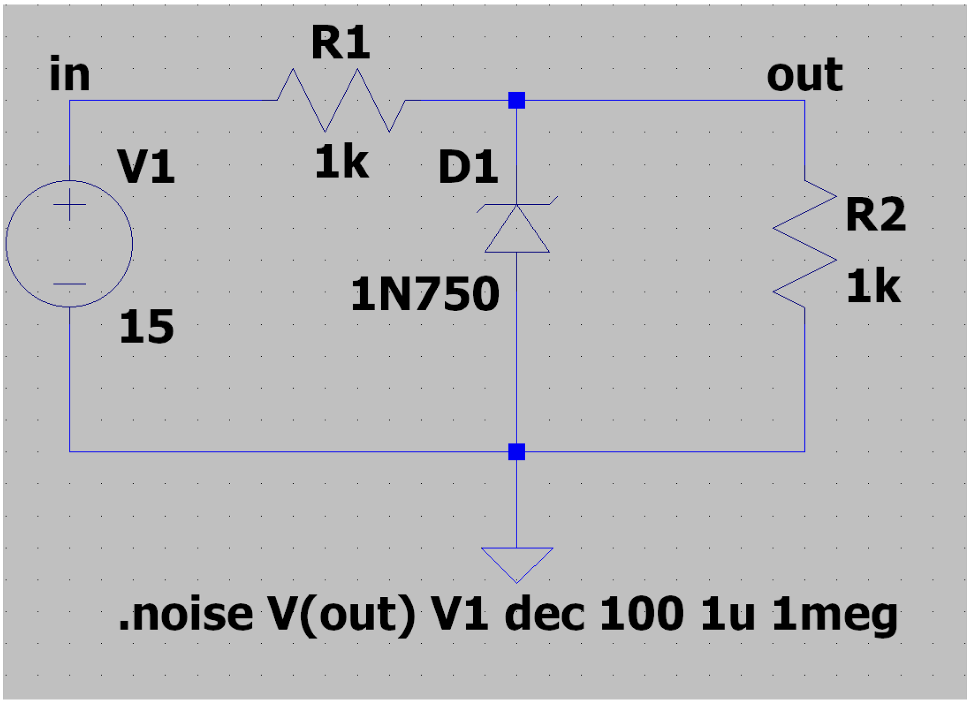
Procedure:

1. Add a load resistor to the circuit and run a transient simulation to see the DC output waveform without any filtering capacitor.
2. Write down or note the voltage values you see from this unfiltered output.
3. Now, add a capacitor in parallel with the load resistor. This capacitor helps smooth out the DC output (acts as a filter).
4. Run the transient simulation again with the capacitor and observe how the output waveform changes compared to the first one.
5. Connect other voltage regulator LM7805 and LM317 and watch how it reduces noise in the output voltage.

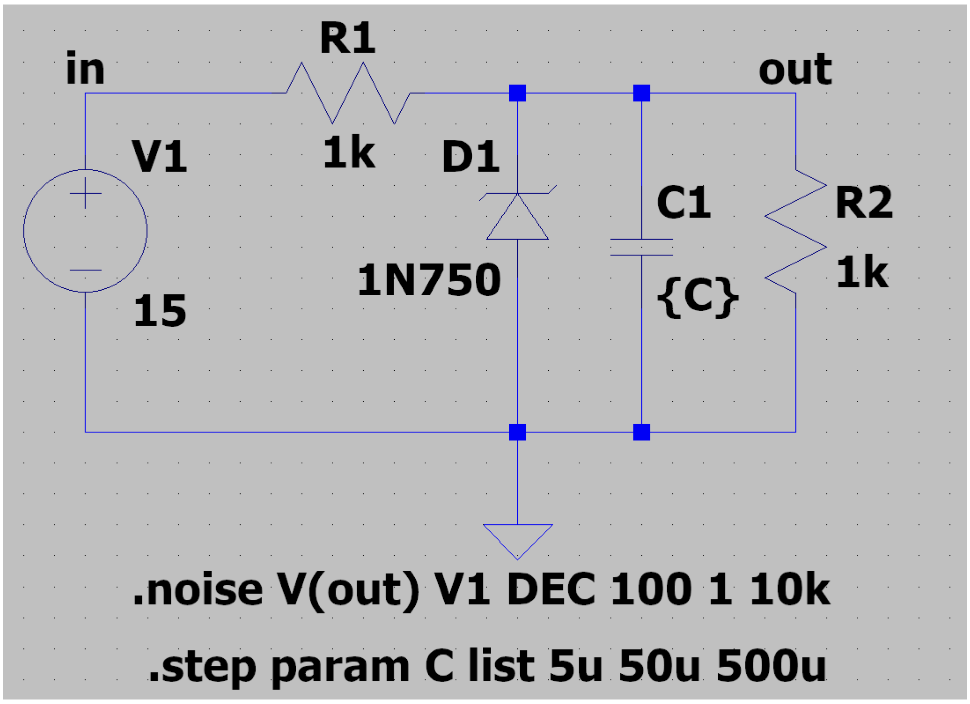
LTspice Circuit:

SPICE directives used:

1) .step param parameter... - this is used to increase a parameter in steps
2) .noise V(out) V1 ... - this is used to generate a noise for the frequency of given range.

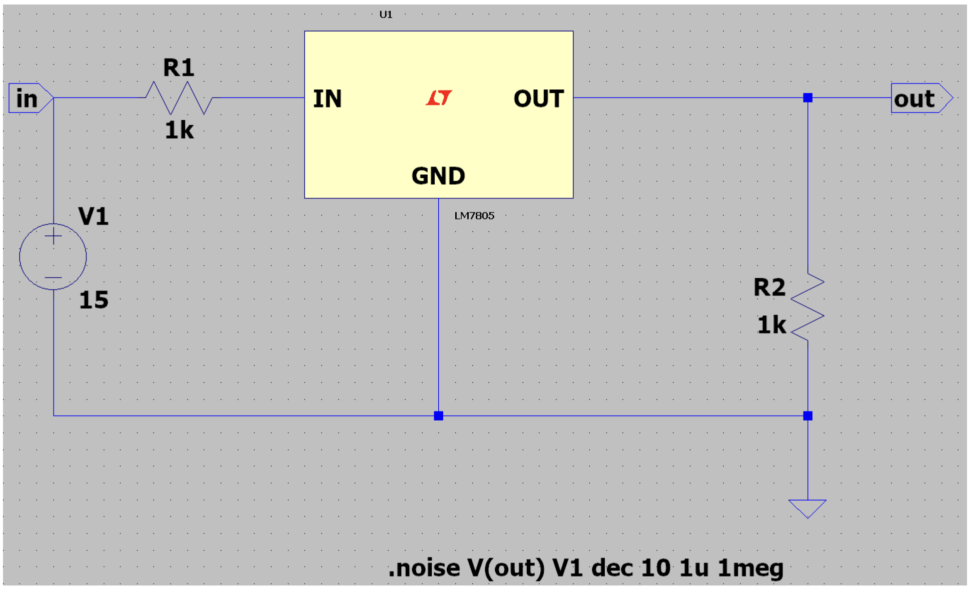


(a) LTspice schematic circuit without capacitor (Zener).

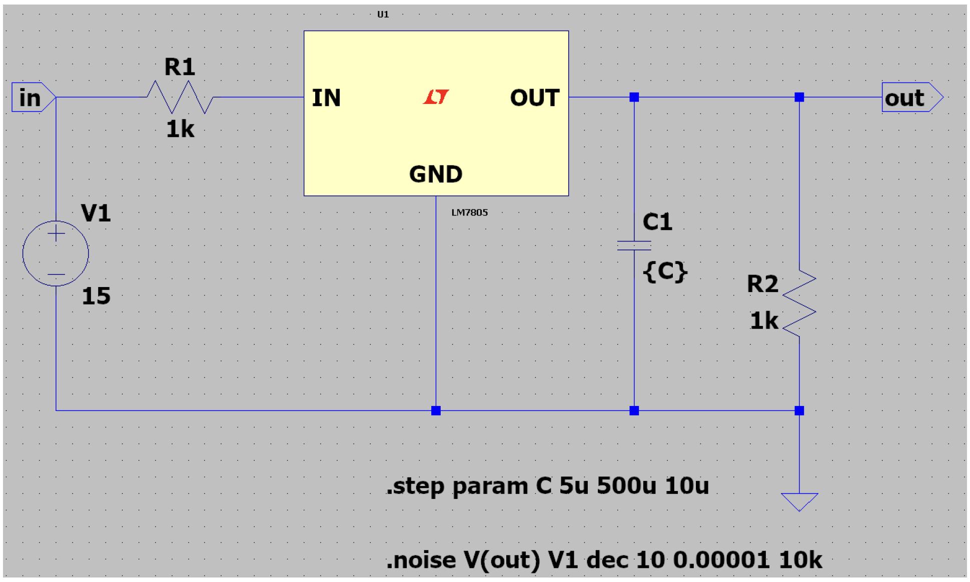


(b) LTspice schematic of rectifier circuit with capacitor (Zener).

Figure 11: Noise analysis circuit for Zener diode.

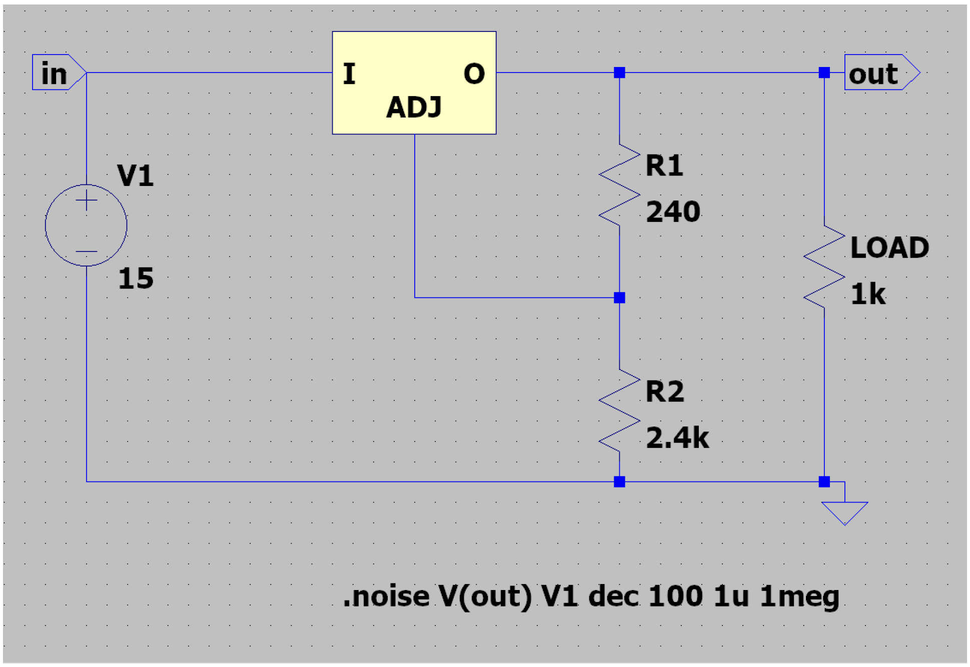


(a) LTspice schematic of circuit without capacitor filter (LM7805).

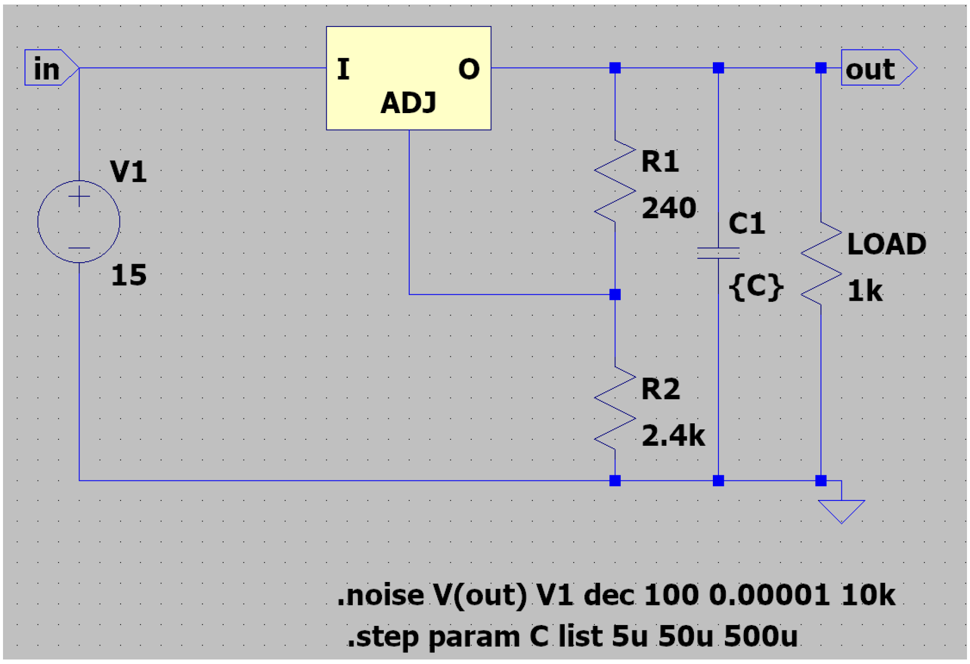


(b) LTspice schematic of rectifier circuit with capacitor filter (LM7805).

Figure 12: Noise analysis circuit for LM7805 regulator.



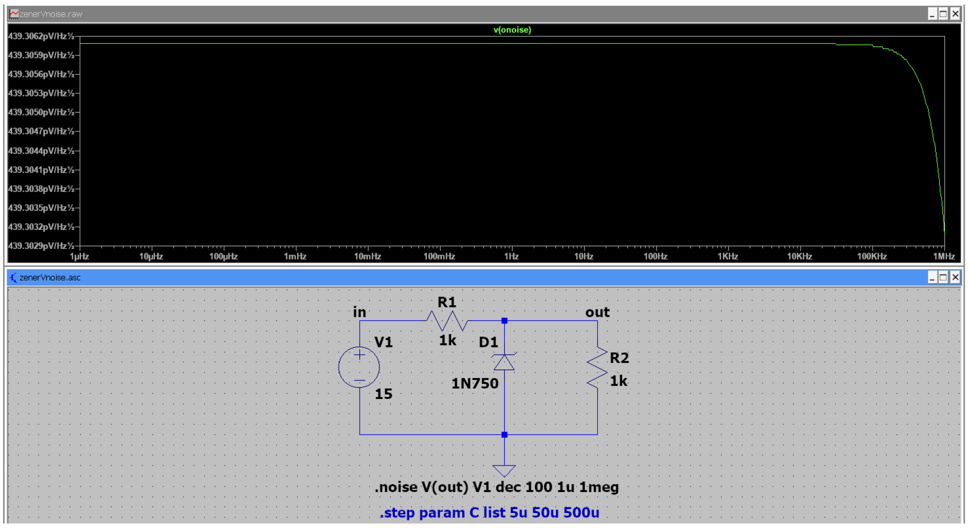
(a) LTspice schematic of circuit without capacitor filter (LM317).



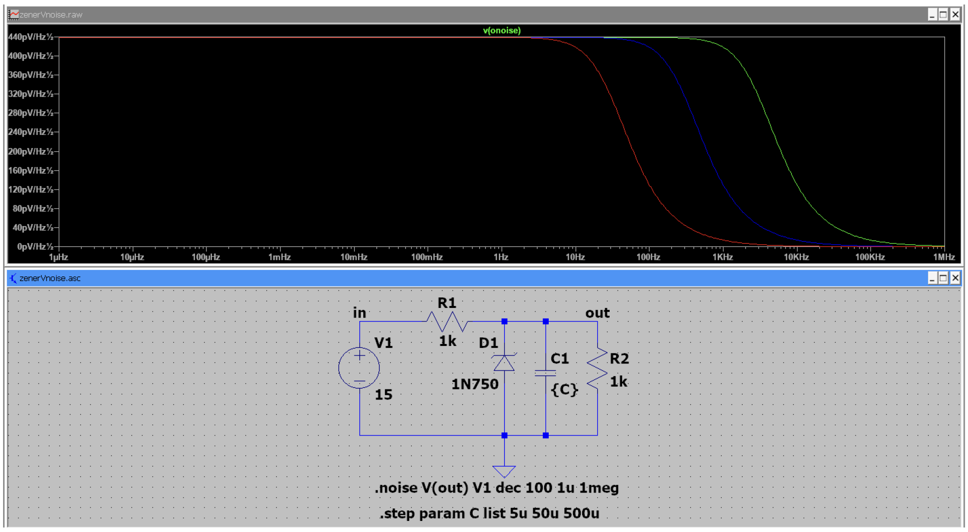
(b) LTspice schematic of rectifier circuit with capacitor filter (LM317).

Figure 13: Noise analysis circuit for LM317 regulator.

LTspice Simulation:

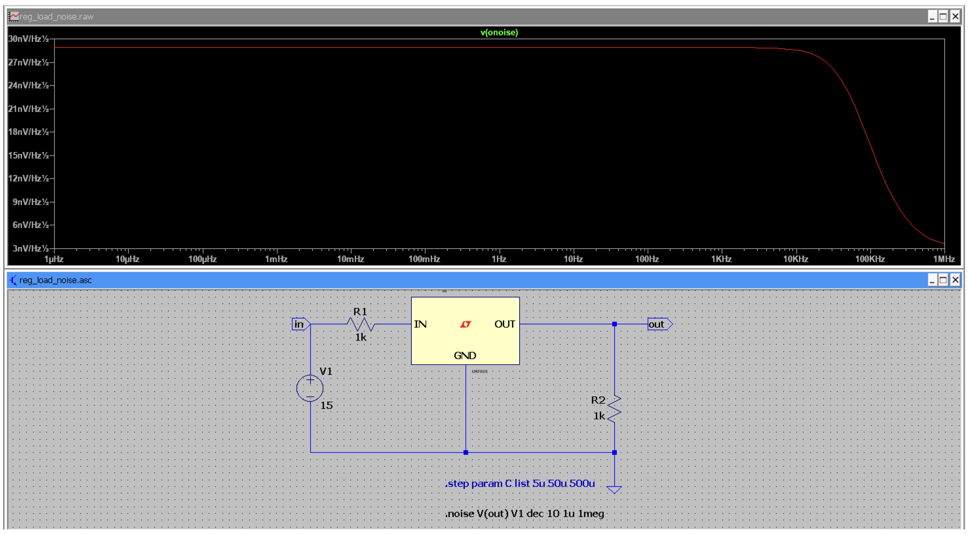


(a) LTspice simulation of circuit without capacitor (Zener).

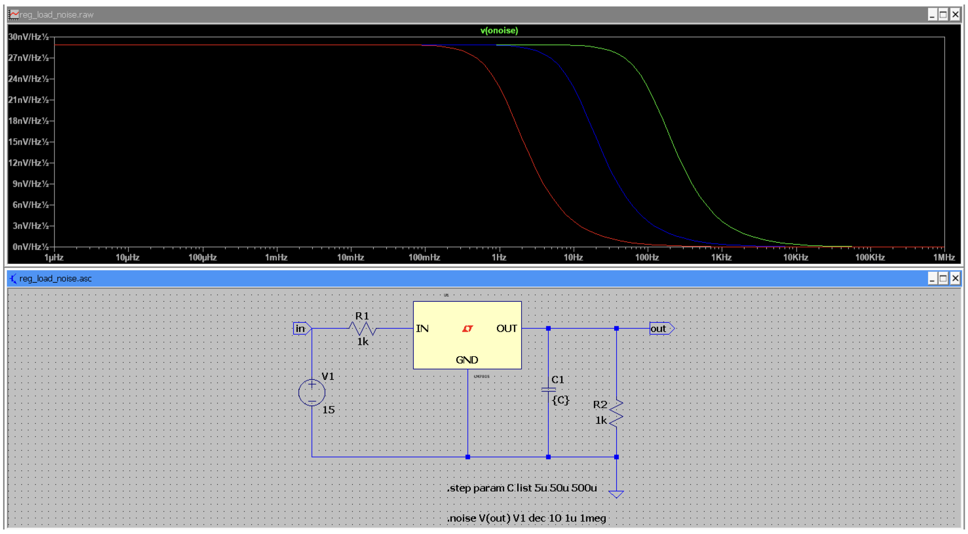


(b) LTspice simulation of rectifier circuit with capacitor (Zener).

Figure 14: Noise analysis circuit for Zener diode.

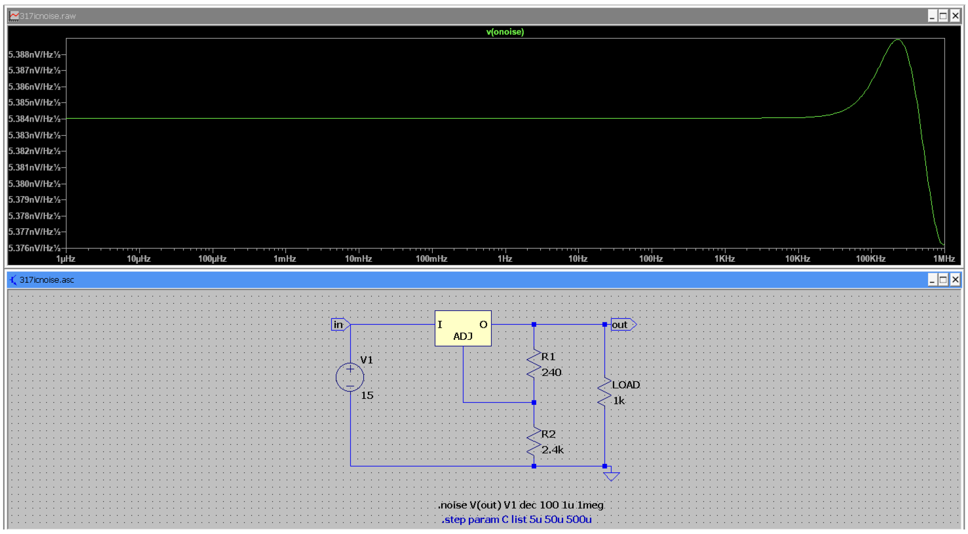


(a) LTspice simulation of circuit without capacitor filter (LM7805).

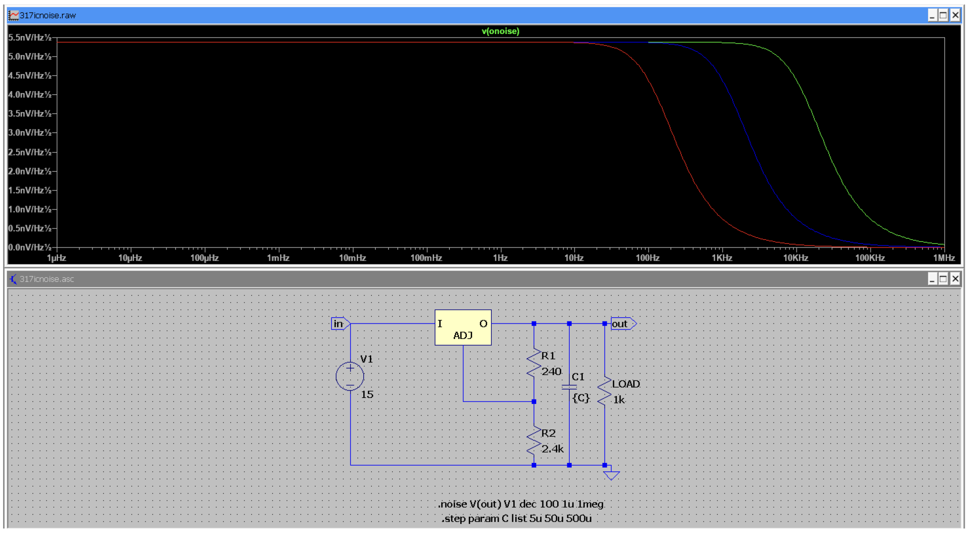


(b) LTspice simulation of rectifier circuit with capacitor filter (LM7805).

Figure 15: Noise analysis circuit for LM7805 regulator.



(a) LTspice simulation of circuit without capacitor filter (LM317).



(b) LTspice simulation of rectifier circuit with capacitor filter (LM317).

Figure 16: Noise analysis circuit for LM317 regulator.

Observations

- Each simulation demonstrates the frequency response (output noise voltage spectral density) for different regulator configurations, with some images displaying curves in multiple colors that correspond to different capacitor values (5µF, 50µF, and 500µF), as indicated by the simulation script in each schematic.
- For circuits with no output capacitor, the noise spectra show higher output noise across the frequency spectrum.
- Adding and increasing the output capacitance shifts the filter cutoff frequency lower, which enhances noise filtering at lower frequencies.

Analysis

- **1N750 Zener Diode (with and without capacitor):**
  - With no capacitor, the noise spectral density is relatively flat up to a certain frequency, then falls off at higher frequencies.
  - Adding capacitors produces a multi-colored plot where higher capacitance values lower the cutoff frequency and improve noise suppression at those frequencies (red: 500µF, blue: 50µF, green: 5µF).
- **LM7805 Linear Regulator (with and without capacitor):**
  - The single-color plot for no output capacitor shows a relatively high and flat noise spectral density over a wide frequency range, eventually rolling off as bandwidth limits take over.
  - Adding output capacitors generates three distinct curves, all beginning at similar noise levels but diverging at lower frequencies; the highest capacitance (red: 500µF) gives the greatest suppression (lowest cutoff), and the lowest (green: 5µF) the highest cutoff.
- **LM317 Adjustable Regulator (with and without capacitor):**
  - Without a capacitor, the noise spectral density remains high over a broad frequency range, with a peak at high frequency due to bandwidth limitations.
  - With increasing capacitance (5µF, 50µF, and 500µF), the cutoff frequency drops (red<blue<green; 5µF is highest cutoff, 500µF is lowest), suppressing noise more effectively at lower frequencies.

Capacitor Value and Color Mapping

- In each set of swept-capacitor simulations:
  - Green curve: 5µF (highest cutoff frequency, least noise suppression at lower frequencies)
  - Blue curve: 50µF (mid-range cutoff, improved suppression)
  - Red curve: 500µF (lowest cutoff, best noise suppression at lower frequencies)

Explanation

- The inclusion of an output capacitor creates a low-pass filter with the load resistor, filtering high-frequency noise from the regulator or reference output.
- As capacitance increases, the -3dB cutoff frequency, given by

$$f_c = \frac{1}{2\pi RC},$$

  decreases, resulting in better noise suppression across a wider part of the spectrum, particularly at mid-to-high frequencies.
- The simulation results confirm that greater capacitance leads to lower output noise across the usable frequency band for all regulator types examined.

Conclusion:

- Simulation results for noise spectral density and voltage regulation closely aligned with theoretical predictions, confirming the proper operation and noise-filtering effects of all regulator configurations tested.
- Overall, the study successfully demonstrated the voltage regulation characteristics, noise behavior, and filtering benefits of the Zener diode, LM7805, and LM317 regulators, including the impact of output capacitors on noise reduction.

References:

- Lab manual / class notes
- Engineering Circuit Analysis by William Hayt et al.
- Signals and Systems by V.A. Oppenheim et al.

Lab Report 4: Voltage Regulator Design on Breadboard

V.L.S. Bhargav ; Lanka Kushwanth
Table Number: 3
Room Number: 114
Roll Number: 2025102061

07-10-2025

Aim:

To design, implement, and analyze different types of voltage regulators on a breadboard, including:

- Zener diode shunt voltage regulator
- Fixed 5V regulator using LM7805
- Adjustable voltage regulator using LM317

and to study the line and load regulation characteristics of these circuits.

Components Used:

1. Zener diode (4.7V or 5.6V)
2. Resistors (various values)
3. Potentiometer (2k or 5k)
4. LM7805 voltage regulator IC
5. LM317 adjustable regulator IC
6. Breadboard
7. Connecting wires
8. Digital Multimeter (DMM)
9. DC Power Supply
10. Load resistors (10kΩ and variable)

Procedure:

Part A: Zener Diode Shunt Regulator

1. Connect the Zener diode circuit as shown in Figure 1.
2. Use an input voltage of 15V.
3. Refer to the diode datasheet and note the Zener voltage (V_Z) and Zener current (I_Z).
4. Calculate the biasing resistor using:

$$R_Z = \frac{V_{in} - V_Z}{I_Z + \frac{V_Z}{L}}$$

   where $L = 10k\Omega$ is the load.

5. Now select a resistor value R more than Rz (calculated).
6. Measure the output voltage using the DMM.
7. Record V_{out} for load values ranging from $L = 200\Omega$ to $L = 10k\Omega$ also try measuring without load ($L = \infty$)
8. Note the input current (i_{in}) in all cases.

Part B: Adjustable Regulator (LM317)

1. Connect the LM317 circuit as shown in Figure 3.
2. Use input $V_{in} = 15V$ and aim for output $V_{out} = 10V$.
3. Use the formula:

$$V_{out} = 1.25\left(1 + \frac{R_2}{R_1}\right)$$

4. Implement $R_1 \approx 240\Omega$ and calculate R_2 accordingly, or use a potentiometer for tuning.
5. Adjust the potentiometer until the measured output reaches approximately 10V.
6. Record:
   - V_{out} with load ($10k\Omega$)
   - V_{out} with no load ($L = \infty$)
   - Input current (i_{in})
   - Voltage between Output and Adjust pins (expected $\approx 1.25V$)

Part C: Fixed Regulator (LM7805)

1. Build the LM7805 circuit as shown in Figure 2.
2. For **Line Regulation:**
   - Vary input voltage (V_{in}) from 0V to 15V in at least five steps.
   - Record the corresponding output voltage (V_{out}).
3. For **Load Regulation:**
   - Keep $V_{in} = 15V$ constant.
   - Vary load resistance (R_L) in at least five steps.
   - Record V_{out} for each R_L.

Circuit Diagrams:

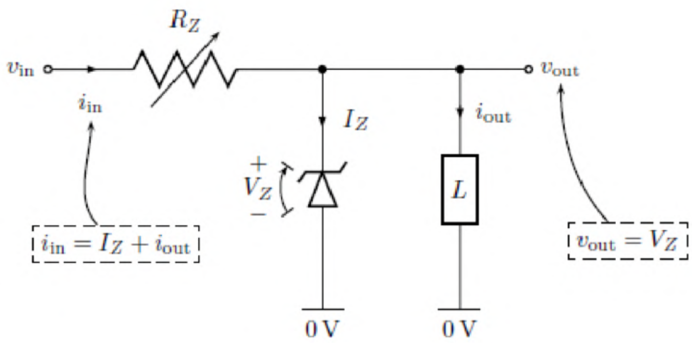
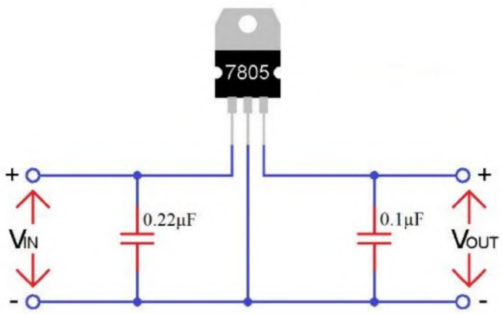
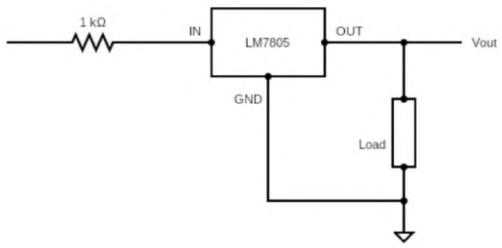


Figure 1: Zener diode shunt voltage regulator circuit.



(a) LM7805 Line Regulation Circuit



(b) LM7805 Load Regulation Circuit

Figure 2: Fixed 5V voltage regulator using LM7805 for (a) line and (b) load regulation.

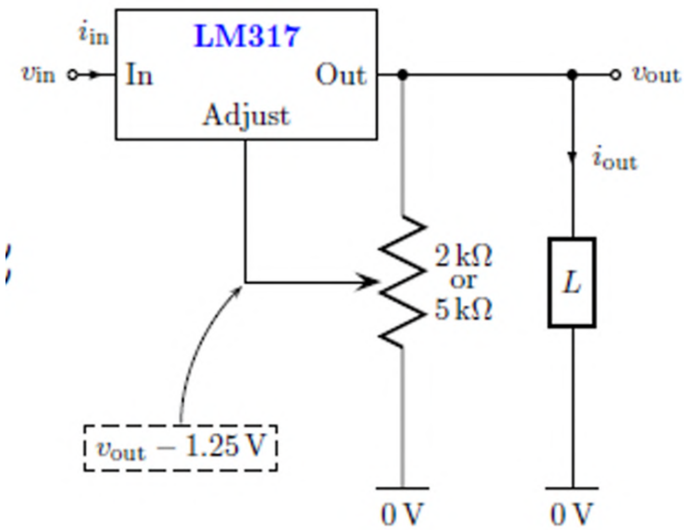
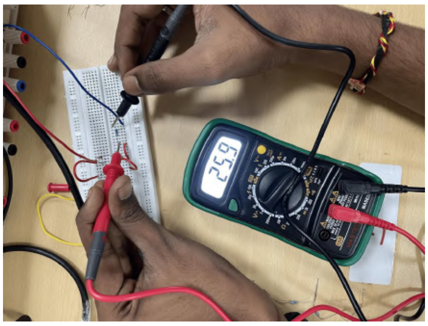


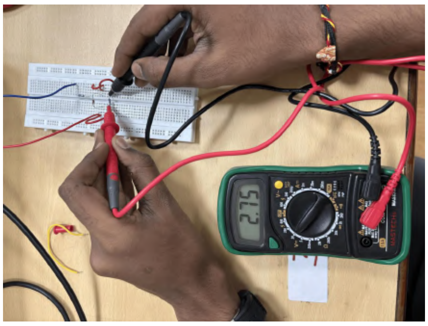
Figure 3: Adjustable voltage regulator using LM317.

Observation:

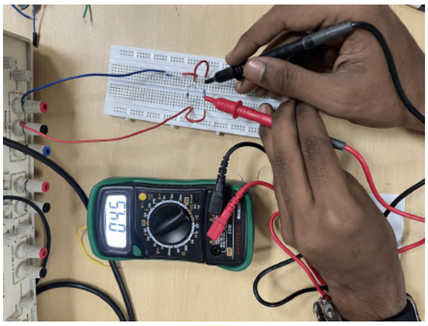
Zener Regulator Output:



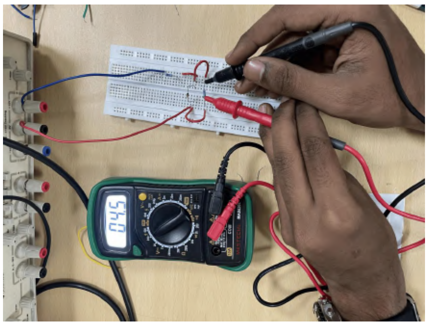
(a) Input (Case 1)



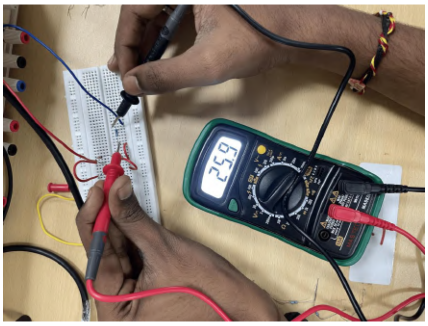
(b) Output (Case 1)



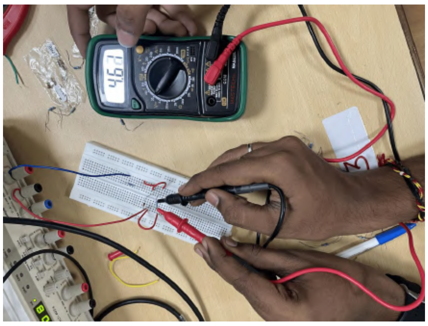
(c) Input (Case 2)



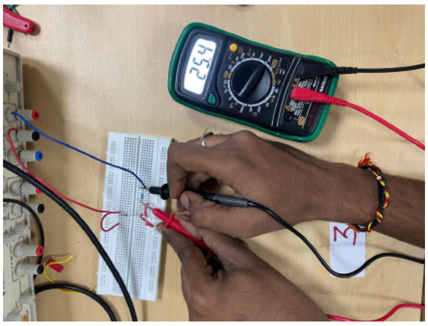
(d) Output (Case 2)



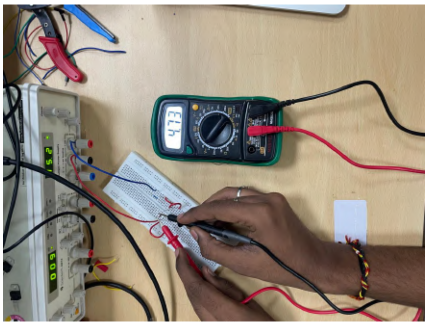
(e) Input (Case 4)



(f) Output (Case 4)



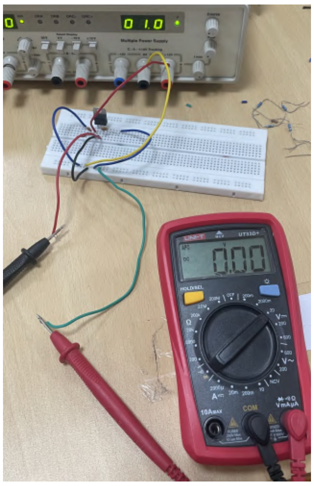
(g) Input (Case 5)



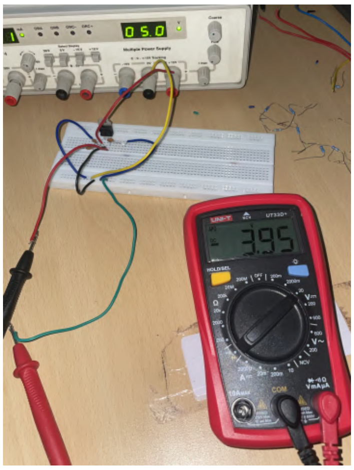
(h) Output (Case 5)

Figure 4: Experimental waveforms for Zener diode voltage regulator.

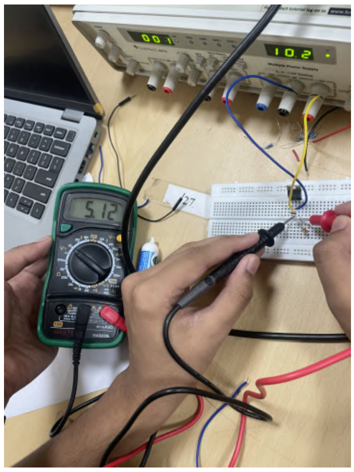
LM7805 Line Regulation:



(a) Line Regulation Setup 1



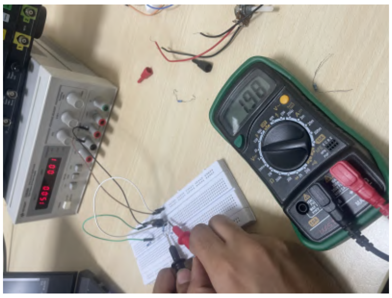
(b) Line Regulation Setup 2



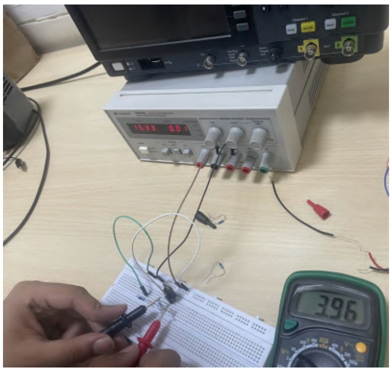
(c) Line Regulation Setup 3

Figure 5: LM7805 Line Regulation experimental setups.

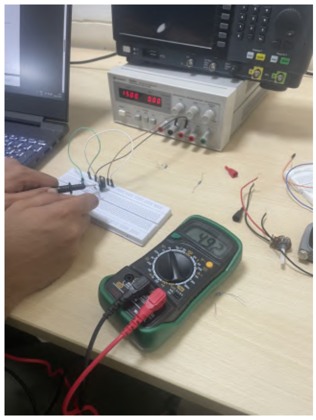
LM7805 Load Regulation:



(a) Load Regulation Setup 1



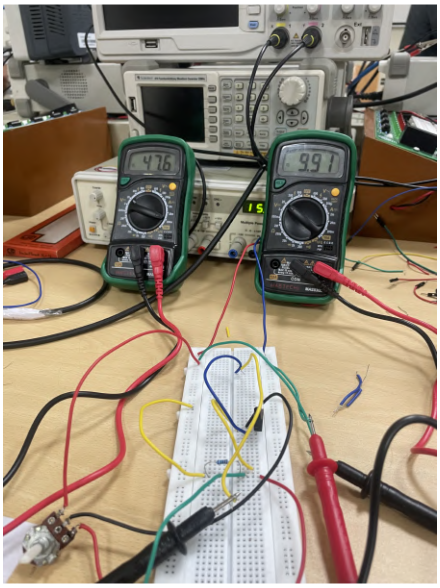
(b) Load Regulation Setup 2



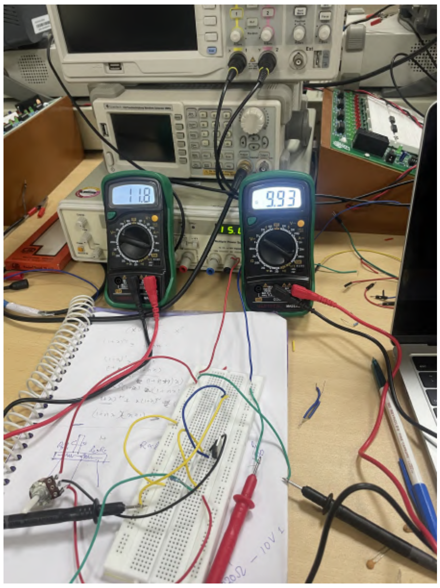
(c) Load Regulation Setup 3

Figure 6: LM7805 Load Regulation experimental setups.

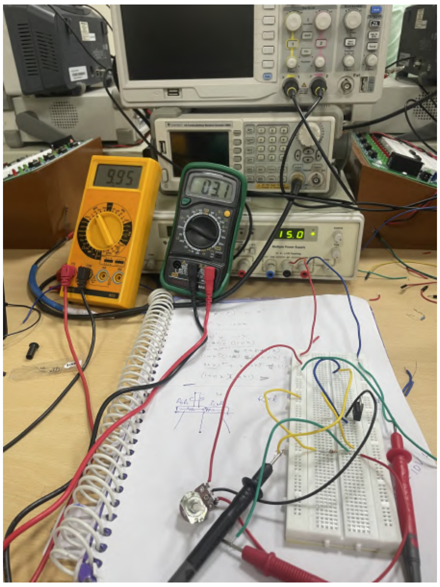
LM317 Adjustable Regulator:



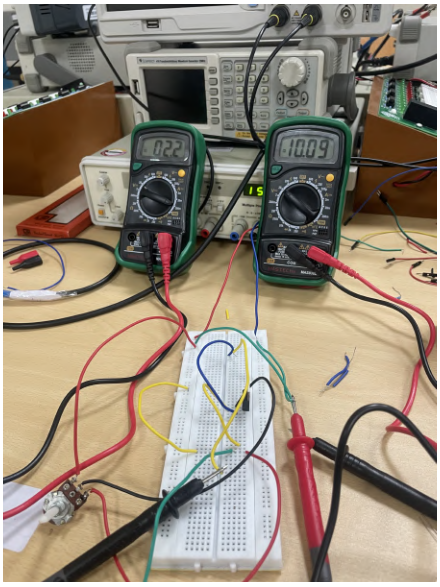
(a) LM317 Regulator Setup 1



(b) LM317 Regulator Setup 2



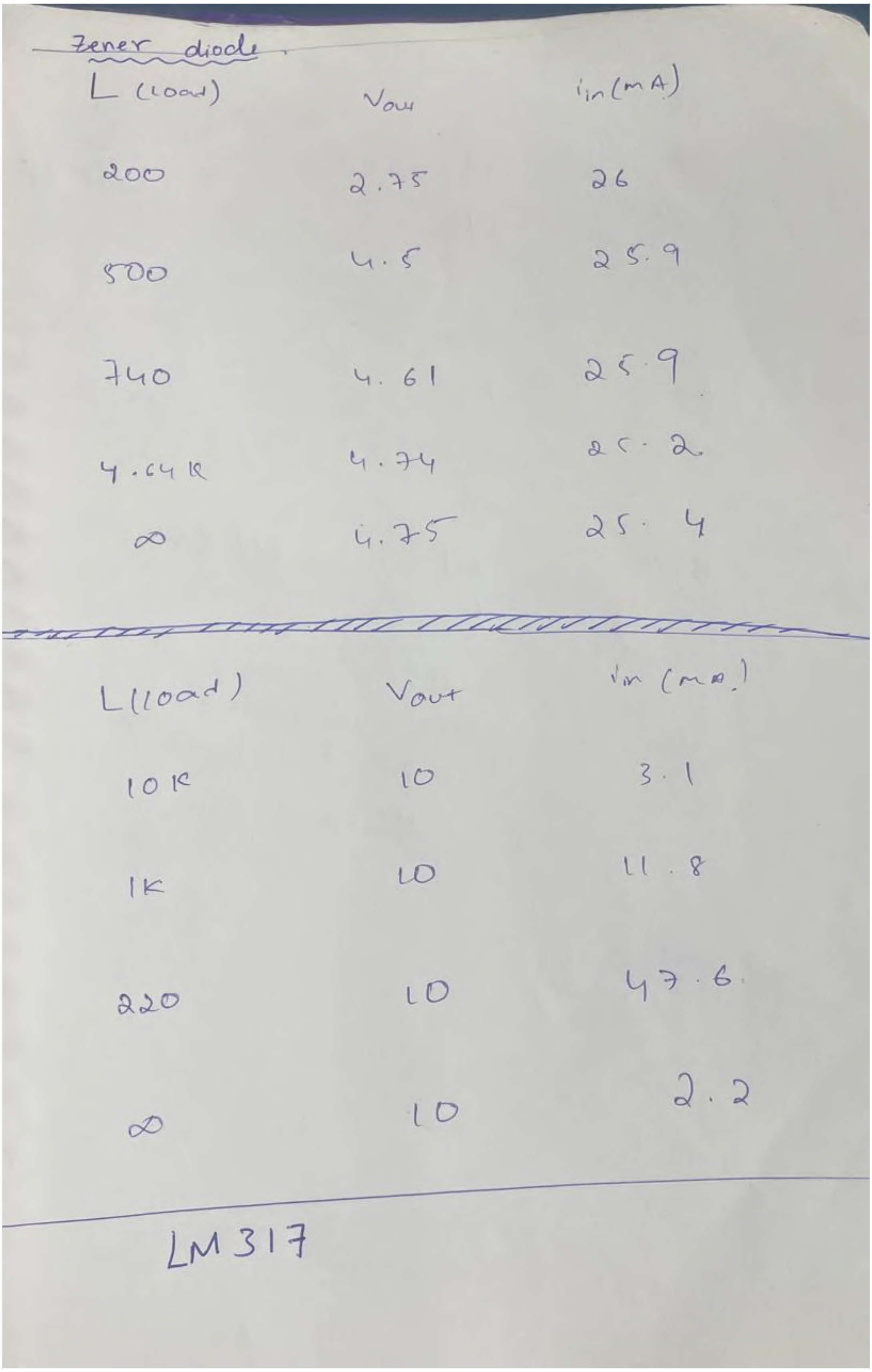
(c) LM317 Regulator Setup 3



(d) LM317 Regulator Setup 4

Figure 7: LM317 adjustable voltage regulator on breadboard.

Observation Tables:



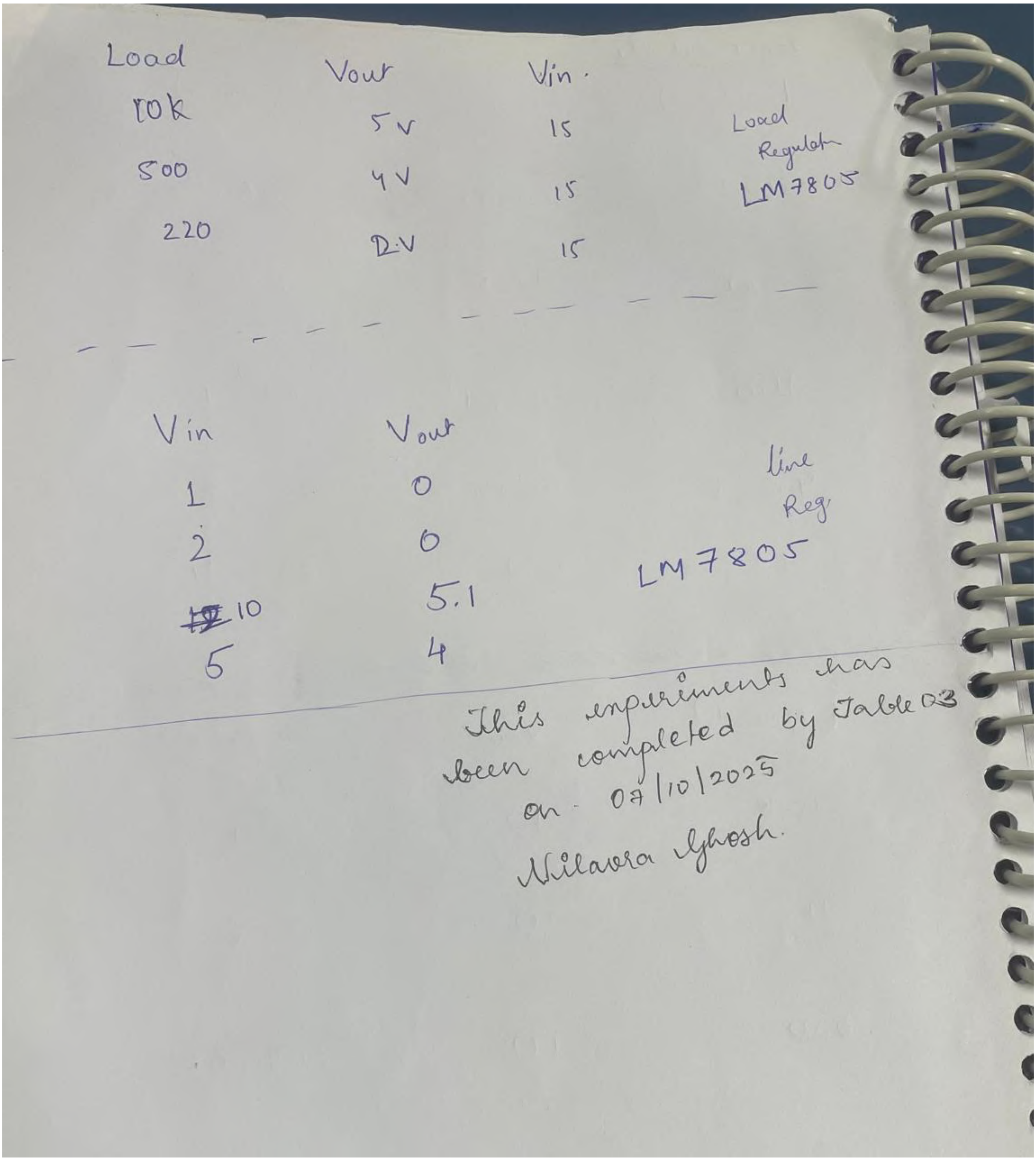
Zener diode.

L (load)	V_{out}	i_{in} (mA)
200	2.75	26
500	4.5	25.9
740	4.61	25.9
4.64k	4.74	25.2
∞	4.75	25.4

L (load)	V_{out}	i_{in} (mA)
10k	10	3.1
1k	10	11.8
220	10	47.6
∞	10	2.2

LM317

Figure 8: Observation Table 1: Zener and LM317 data.



Load	Vout	Vin
10k	5 V	15
500	4 V	15
220	2 V	15

Load Regulation
LM7805

Vin	Vout
1	0
2	0
~~12~~ 10	5.1
5	4

line Reg
LM7805

This experiments has been completed by Table 03 on 07/10/2025
Nilavra Ghosh.

Figure 9: Observation Table 2: LM780 data.

Explanation:

Zener Diode Regulator:

A Zener diode maintains a nearly constant voltage (V_Z) across itself when reverse biased in breakdown region. The biasing resistor R_Z limits current and ensures the Zener remains in its regulation region.

$$R_Z = \frac{V_{in} - V_Z}{I_Z + \frac{V_Z}{L}}$$

At light loads (large L), most current flows through the Zener. At heavy loads (small L), less current flows through the Zener, and regulation worsens.

LM7805 Fixed Regulator:

The LM7805 maintains a fixed 5V output irrespective of input voltage or load changes (within limits). **Line regulation** measures change in V_{out} with varying V_{in}, and **Load regulation** measures change in V_{out} with varying load R_L. Ideally, both are small, showing stable regulation.

LM317 Adjustable Regulator:

The LM317 provides a variable output set by the external resistor divider:

$$V_{out} = 1.25\left(1 + \frac{R_2}{R_1}\right)$$

It keeps about 1.25V between the output and adjust pins. By tuning R_2, a desired V_{out} is achieved. However, it requires a minimum voltage difference of $\approx 3V$ between input and output for proper operation.

Conclusion:

- Designed and implemented Zener, LM7805, and LM317 regulator circuits.
- Verified the regulation characteristics of each circuit.
- Observed that:
  - Zener diode gives basic regulation but less stability with varying load.
  - LM7805 provides excellent fixed 5V regulation.
  - LM317 allows adjustable voltage with good precision.
- Understood the concepts of line and load regulation.
- Minor deviations from theoretical values are due to component tolerances and measurement errors.

References:

- Lab manual: Voltage Regulator Design on Breadboard (Lab 4 Handout)
- Electronic Devices and Circuit Theory by Boylestad and Nashelsky
- LM7805 and LM317 datasheets