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Report 1

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Abstract

In this experiment, the voltage regulation characteristics of a Zener diode and an IC 7805 voltage regulator were studied. Line regulation and load regulation were investigated by varying the input voltage and load resistance, respectively. The Zener diode was observed to maintain a nearly constant output voltage equal to its breakdown voltage when operated in the breakdown region. The effect of an additional current limiting resistor on improving load regulation was also examined. The IC 7805 voltage regulator was found to provide a stable output voltage of approximately 5.0 V over a wide range of input voltages and load conditions, demonstrating superior regulation performance compared to the Zener diode regulator.

Contents

1 Introduction

Voltage regulation is a fundamental requirement in electronic circuits to ensure stable and reliable operation of active and passive components. Practical power supplies are subject to fluctuations due to variations in input voltage (line variations) and changes in load current (load variations). Voltage regulators are designed to minimize these effects and provide a nearly constant output voltage.
This experiment investigates two widely used voltage regulation techniques: (i) shunt regulation using a Zener diode and (ii) series regulation using an integrated circuit regulator, IC 7805. The performance of these regulators is analyzed in terms of line regulation and load regulation.

1.1 Aim

The objectives of the experiment are:

- To investigate line regulation and load regulation using a Zener diode as a shunt voltage regulator.
- To study the use of IC 7805 voltage regulator.
- To compare the regulation performance of a Zener diode regulator with that of IC 7805.

1.2 Components and Instruments

The following components and instruments are used:

1. Power supply : ±15 V
2. $R_S = R_C = 2.2$ kΩ (2 Nos.)
3. Load resistance $R_L = 1.0$ kΩ potentiometer, 1.0 W
4. Zener diode : 1 No. with $V_Z = 2.7$ V or 3.9 V or 5.1 V
5. LM7805 IC : 1 No.
6. Breadboard : 1 No.
7. Two DT-830D multimeters for current measurements and one 8007 multimeter with probe for voltage measurements
8. Single strand wires : 6 Nos.

2 Theory

Voltage regulation is the process of maintaining a constant output voltage despite variations in input voltage (line variations) and load current (load variations). In practical electronic systems, unregulated power supplies suffer from fluctuations due to changes in mains voltage, temperature, and load conditions. These fluctuations can severely affect the performance and reliability of electronic circuits.
This experiment studies two voltage regulation techniques:

1. Shunt voltage regulation using a Zener diode
2. Series voltage regulation using the integrated circuit IC 7805

2.1 Zener Diode

A Zener diode is a specially designed semiconductor diode that allows controlled operation in the reverse breakdown region. Unlike ordinary diodes, which are damaged when operated beyond their breakdown voltage, Zener diodes are designed to operate safely and stably in this region.

2.1.1 Construction of Zener Diode

A Zener diode is constructed from a heavily doped *p*-*n* junction. The high doping concentration on both sides of the junction results in:

- A very thin depletion region
- A strong electric field across the junction even at low reverse voltages

The thickness of the depletion layer determines the breakdown voltage of the diode. By controlling the doping concentration during fabrication, Zener diodes with precise breakdown voltages (typically from 2 V to 200 V) can be manufactured.

2.1.2 Breakdown Mechanism

When a Zener diode is reverse biased, it initially conducts a very small leakage current. As the reverse voltage increases, breakdown occurs due to one of the following mechanisms:

1. **Zener Breakdown**

   For Zener diodes with breakdown voltage below approximately 5 V, breakdown occurs due to the *Zener effect*. The strong electric field across the thin depletion layer enables electrons to tunnel directly from the valence band of the *p*-region to the conduction band of the *n*-region. This is a quantum mechanical tunneling process.

2. **Avalanche Breakdown**

   For breakdown voltages above approximately 5 V, avalanche breakdown dominates. In this mechanism, charge carriers gain sufficient kinetic energy from the applied electric field to ionize lattice atoms upon collision, generating additional electron–hole pairs. This results in a chain reaction, causing a sudden increase in current.

In practical Zener diodes, both mechanisms may coexist, but one dominates depending on the breakdown voltage.

2.1.3 V–I Characteristics of Zener Diode

The voltage–current characteristics of a Zener diode consist of three distinct regions:

1. **Forward Bias Region:** The diode behaves like a normal silicon diode with a forward voltage drop of approximately 0.7 V.
2. **Reverse Leakage Region:** A small reverse current flows due to thermally generated minority carriers.
3. **Reverse Breakdown Region:** Once the reverse voltage reaches the breakdown voltage V_Z, the current increases sharply while the voltage across the diode remains nearly constant.

This nearly constant voltage region is exploited for voltage regulation.

2.2 Zener Diode as a Voltage Regulator

A Zener diode can be used as a shunt voltage regulator by connecting it in reverse bias across the load, along with a series resistor R_S. The series resistor limits the current through the diode and absorbs variations in input voltage.

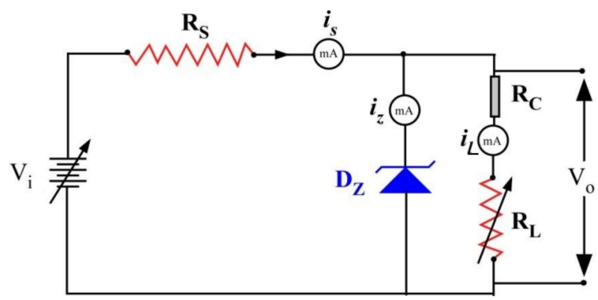

Figure 1: Zener diode shunt voltage regulator circuit.

Applying Kirchhoff's Current Law:

$$i_S = i_Z + i_L \tag{2.2.1}$$

where,

$$i_S = \frac{V_i - V_Z}{R_S} \qquad \text{and} \qquad i_L = \frac{V_Z}{R_L}$$

2.2.1 Line Regulation Using Zener Diode

In line regulation, series resistance, R_S and load resistance, R_L are fixed, only input voltage, V_i is varied. Output voltage, V_o remains the same at V_Z and i_L remains constant as long as the input voltage is maintained above a minimum value. Thus,

$$\delta i_Z = \delta i_S \qquad \text{[Using Eq.(2.2.1) at constant } i_L\text{]}$$

Thus when load R_L is fixed and input voltage V_i varies then Zener current i_Z and total current i_S change in a way to maintain i_L and hence V_o constant. Any change in V_i appears across the series limiting resistance R_S.

2.2.2 Load Regulation Using Zener Diode

In load regulation, input voltage, V_i remains constant and the load resistance, R_L is varied. Output voltage remains same, as long as the load resistance is maintained above a minimum value. Since the voltage V_Z across the Zener remains constant, i_S is independent of load. Hence in this case

$$\delta i_Z = -\delta i_L \qquad \text{[Using Eq.(2.2.1) at constant } i_S\text{]}$$

Thus Zener current changes with change in load current due to change in R_L but output remains constant at V_Z.

2.3 IC 7805 Voltage Regulator

The IC 7805 is a three-terminal linear voltage regulator, designed to provide a fixed stable output voltage of 5 V when the input voltage is in the range from 7.2 V to 32 V. The maximum current the load can draw is about 1 A.

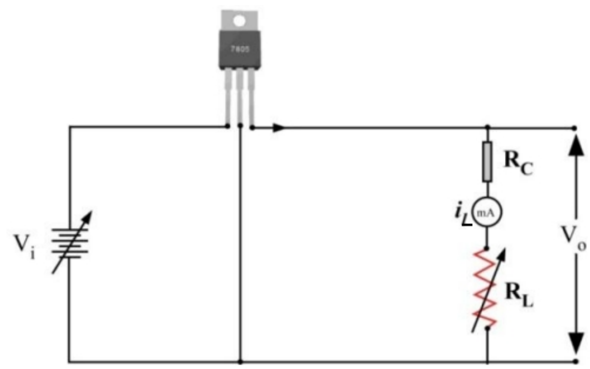

Figure 2: IC 7805 voltage regulator circuit.

2.3.1 Internal Construction

The IC 7805 contains:

- A precision Zener voltage reference
- An error amplifier
- A series pass transistor
- Feedback network
- Current limiting and thermal protection circuits

2.3.2 Operating Principle

The regulator operates using negative feedback. Any deviation in output voltage is detected by the error amplifier, which adjusts the conduction of the series pass transistor to restore the output voltage to 5 V.The IC requires a minimum input voltage (dropout voltage) of approximately 7.2 V to maintain regulation. The maximum input voltage to get the stable output of 5 V is 32 V.

2.3.3 Line Regulation Using IC 7805

For a fixed load, variations in input voltage do not significantly affect the output voltage due to active feedback control, resulting in excellent line regulation.

2.3.4 Load Regulation Using IC 7805

The IC maintains constant output voltage over a wide range of load currents, up to approximately 1 A, making it superior to Zener-based regulators.

3 Line Regulation Using Zener Diode

3.1 Observation Table

Sr. No.	Load Resistance R_L (Ω)	Input Voltage V_i (V)	Series Current i_S (mA)	Zener Current i_Z (mA)	Output Voltage V_o (V)
1	2200	0.00	0.00	0.00	0.00
2	2200	0.46	0.09	0.00	0.29
3	2200	1.09	0.21	0.00	0.67
4	2200	1.55	0.29	0.00	0.94
5	2200	2.09	0.40	0.00	1.29
6	2200	2.52	0.48	0.00	1.54
7	2200	3.15	0.60	0.00	1.94
8	2200	3.57	0.67	0.00	2.17
9	2200	4.08	0.78	0.01	2.51
10	2200	4.51	0.87	0.01	2.77
11	2200	5.17	0.99	0.01	3.17
12	2200	5.62	1.08	0.02	3.44
13	2200	6.16	1.18	0.02	3.77
14	2200	6.76	1.31	0.03	4.13
15	2200	7.02	1.36	0.04	4.28
16	2200	7.68	1.51	0.08	4.64
17	2200	8.00	1.59	0.11	4.78
18	2200	8.82	1.85	0.28	5.07
19	2200	9.02	1.91	0.33	5.12
20	2200	9.50	2.13	0.52	5.22
21	2200	10.05	2.33	0.70	5.29
22	2200	10.55	2.55	0.90	5.34
23	2200	11.07	2.77	1.11	5.37
24	2200	11.88	3.15	1.54	5.41
25	2200	12.67	3.50	1.82	5.44
26	2200	13.42	3.86	2.18	5.46
27	2200	14.44	4.35	2.66	5.47
28	2200	15.26	4.74	3.05	5.48

Table 1: Line Regulation Using Zener Diode

3.2 i_Z vs. i_S Plot

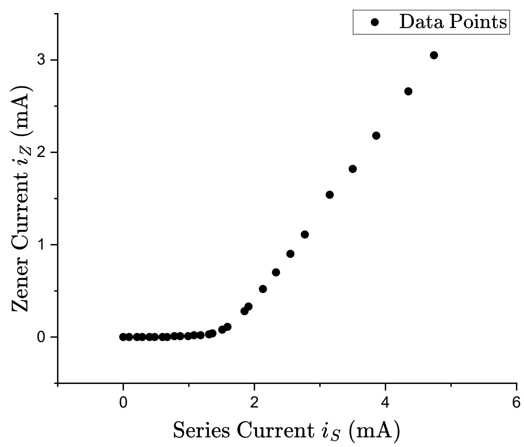

Figure 3: Zener Current i_Z (mA) vs Series Current i_S (mA)

3.2.1 Discussion

The graph shows that initially the Zener current remains nearly zero for small values of series current, indicating that the Zener diode is not in the breakdown region. After reaching the breakdown voltage, the Zener current increases linearly with the series current. This linear region confirms that any change in series current produces a proportional change in Zener current while the load current remains constant. Thus, the relation $\delta i_Z = \delta i_S$ is verified, demonstrating proper line regulation of the Zener diode beyond the breakdown region.

3.3 V_o vs. V_i Plot

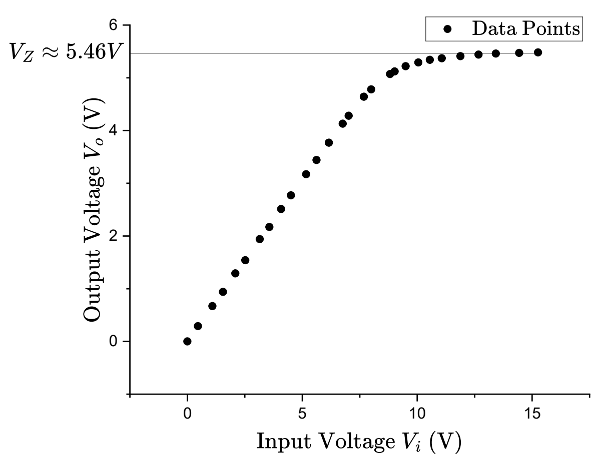

Figure 4: Output Voltage V_o (V) vs Input Voltage V_i (V)

3.3.1 Discussion

The breakdown voltage V_Z of the zener diode is found to be about 5.46 V. The graph shows that the output voltage initially increases with the input voltage until the Zener diode reaches its breakdown voltage. Beyond this point, the output voltage remains nearly constant despite further increase in input voltage. This constant voltage region corresponds to the Zener breakdown voltage V_Z. The graph thus verifies the voltage regulating action of the Zener diode under line regulation conditions.

4 Load Regulation Using Zener Diode

4.1 Observation Table (without R_C)

Sr. No.	Input Voltage V_i (V)	Load Resistance R_L (Ω)	Load Current i_L (mA)	Zener Current i_Z (mA)	Output Voltage V_o (V)
1	15.00	0.00	7.16	0.09	0.11
2	15.00	63.95	6.88	0.09	0.52
3	15.00	108.15	6.73	0.09	0.89
4	15.00	150.10	6.63	0.08	1.07
5	15.00	208.98	6.45	0.08	1.42
6	15.00	275.04	6.28	0.08	1.79
7	15.00	331.16	6.12	0.08	2.10
8	15.00	407.72	5.96	0.08	2.50
9	15.00	518.39	5.71	0.07	3.01
10	15.00	588.13	5.56	0.07	3.34
11	15.00	627.74	5.48	0.07	3.50
12	15.00	665.43	5.41	0.07	3.65
13	15.00	728.65	5.29	0.07	3.91
14	15.00	760.99	5.23	0.07	4.04
15	15.00	798.45	5.16	0.08	4.18
16	15.00	827.45	5.10	0.09	4.28
17	15.00	880.00	5.01	0.10	4.44
18	15.00	898.99	4.97	0.10	4.52
19	15.00	912.78	4.94	0.11	4.57
20	15.00	948.67	4.87	0.13	4.68
21	15.00	1019.07	4.72	0.19	4.87

Table 2: Load Regulation Using Zener Diode (without R_C)

4.1.1 i_Z vs i_L Plot and Discussion

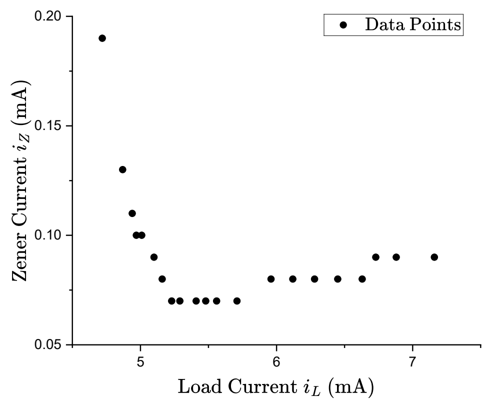

Figure 5: Zener Current i_Z (mA) vs Load Current i_L (mA)

The graph shows that the Zener current i_Z initially decreases with an increase in load current i_L, indicating an inverse relationship between the two currents. This behavior is expected since the input voltage is kept constant and the total current is shared between the Zener diode and the load.

However, beyond a certain value of load current, the Zener current does not continue to decrease smoothly. Instead, it shows a slight increase in discrete steps as the load current increases further. This step-like behavior may be attributed to non-ideal characteristics of the Zener diode, such as its finite dynamic resistance, along with measurement resolution and contact variations in the circuit. In the absence of the current limiting resistor R_C, the Zener diode operates close to the edge of its breakdown region, resulting in irregular current redistribution and poor load regulation.

Overall, the inverse relation $\delta i_Z = -\delta i_L$ is only approximately satisfied in this configuration.

4.1.2 V_o vs R_L Plot and Discussion

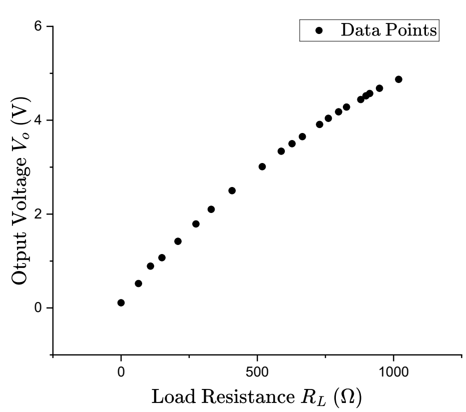

Figure 6: Output Voltage V_o (V) vs Load Resistance R_L (Ω)

At low values of R_L, the output voltage remains small due to the large load current, which prevents the Zener diode from operating in the breakdown region. As the load resistance increases, the load current decreases and the output voltage increases accordingly. At higher values of R_L, the curve shows a tendency toward saturation, indicating that the Zener diode is approaching its breakdown region. However, the output voltage does not become completely constant and remains slightly below the breakdown voltage. This suggests that the Zener diode has not fully entered the breakdown region within the measured range of load resistance. The absence of the current limiting resistor R_C restricts proper voltage regulation, resulting in incomplete saturation of the output voltage, so V_Z cannot be obtained reliably.

4.2 Observation Table (With $R_C = 2.2$ kΩ)

Sr. No.	Input Voltage V_i (V)	Load Resistance R_L (Ω)	Load Current i_L (mA)	Zener Current i_Z (mA)	Output Voltage V_o (V)
1	15.00	0.00	2.47	2.34	5.46
2	15.00	64.10	2.36	2.35	5.46
3	15.00	143.48	2.30	2.41	5.46
4	15.00	166.67	2.28	2.43	5.46
5	15.00	211.71	2.22	2.49	5.46
6	15.00	262.67	2.17	2.54	5.46
7	15.00	279.62	2.11	2.60	5.46
8	15.00	336.53	2.08	2.64	5.46
9	15.00	453.66	2.05	2.66	5.46
10	15.00	495.05	2.02	2.69	5.46
11	15.00	532.66	1.99	2.72	5.46
12	15.00	589.74	1.95	2.76	5.46
13	15.00	640.625	1.92	2.79	5.46
14	15.00	668.42	1.90	2.81	5.46
15	15.00	711.23	1.87	2.84	5.47
16	15.00	766.30	1.84	2.87	5.47
17	15.00	827.78	1.8	2.91	5.48
18	15.00	881.36	1.77	2.94	5.48
19	15.00	936.78	1.74	2.97	5.48
20	15.00	1011.76	1.70	3.01	5.48
21	15.00	1023.67	1.69	3.02	5.48

Table 3: Load Regulation Using Zener Diode (With R_C)

4.2.1 i_Z vs i_L Plot and Discussion

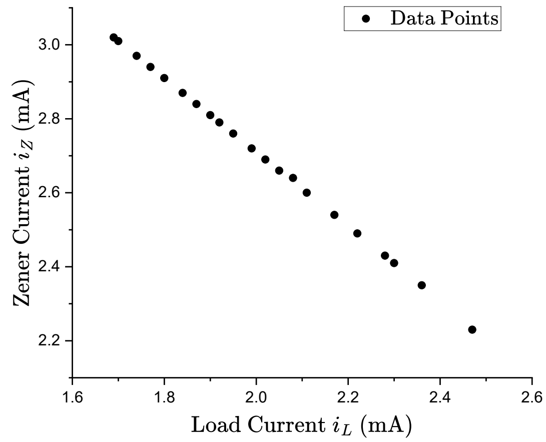

Figure 7: Zener Current i_Z (mA) vs Load Current i_L (mA)

With the inclusion of the current limiting resistor R_C, the graph again shows an inverse relationship between Zener current and load current, confirming $\delta i_Z = -\delta i_L$. Compared to the case without R_C, the graph is smoother and more linear, indicating improved regulation. The presence of R_C helps maintain the Zener diode within its breakdown region over a wider range of load currents.

4.2.2 V_o vs R_L Plot and Discussion

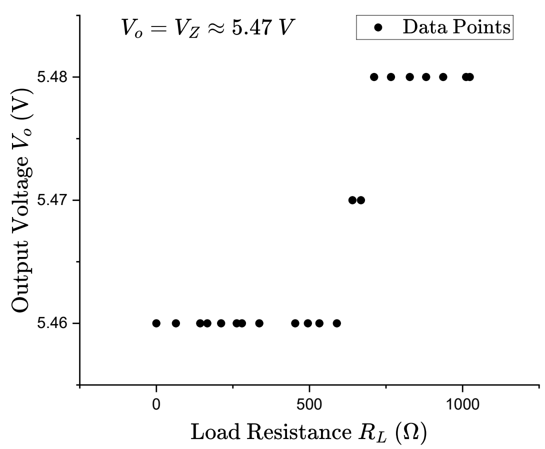

Figure 8: Output Voltage V_o (V) vs Load Resistance R_L (Ω)

The output voltage in the presence of R_C remains nearly constant in the range 5.46–5.48 V. Taking a representative value from this constant region, the breakdown voltage of the Zener diode is found to be $V_Z \approx 5.47$ V. The graph shows that the output voltage remains nearly constant over a wide range of load resistance values. This demonstrates effective load regulation due to the presence of the current limiting resistor R_C. The breakdown voltage V_Z of the Zener diode can be clearly identified from this graph, confirming stable voltage regulation under varying load conditions.

5 Line Regulation Using IC 7805

5.1 Observation Table

Sr. No.	Load Resistance R_L (Ω)	Input Voltage V_i (V)	Load Current i_L (mA)	Output Voltage V_o (V)
1	2200	0.00	0.00	0.00
2	2200	0.54	0.00	0.00
3	2200	1.04	0.00	0.00
4	2200	1.56	0.08	0.47
5	2200	2.00	0.58	1.27
6	2200	2.43	0.77	1.68
7	2200	2.92	0.98	2.07
8	2200	3.48	1.22	2.66
9	2200	3.99	1.42	3.12
10	2200	4.49	1.65	3.57
11	2200	4.99	1.87	4.06
12	2200	5.51	2.09	4.55
13	2200	6.01	2.26	4.91
14	2200	6.60	2.27	4.93
15	2200	6.98	2.27	4.93
16	2200	7.87	2.28	4.94
17	2200	8.50	2.28	4.95
18	2200	9.20	2.28	4.95
19	2200	10.01	2.29	4.97
20	2200	10.92	2.29	4.97
21	2200	11.80	2.29	4.97
22	2200	12.82	2.27	4.97
23	2200	13.73	2.29	4.97
24	2200	14.50	2.29	4.97
25	2200	15.28	2.30	4.98

Table 4: Line Regulation Using IC 7805

5.2 V_o vs V_i Plot

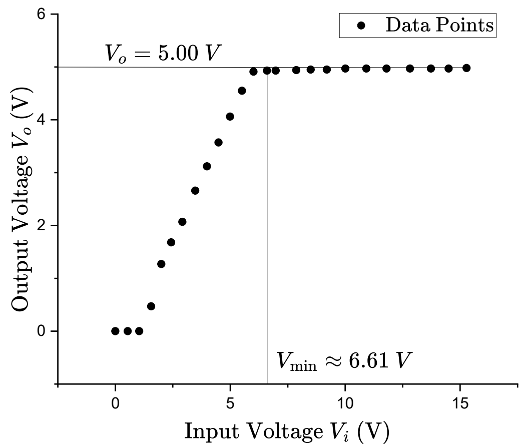

Figure 9: Output Voltage V_o (V) vs Input Voltage V_i (V)

5.2.1 Discussion

From the V_o vs V_i plot, the output voltage becomes constant at approximately 5.00 V for input voltages greater than 6.61 V. Hence, the minimum input voltage required for regulation is $V_{\min} \approx$ 6.61 V. The graph indicates that the output voltage of the IC 7805 increases with input voltage up to a certain minimum input value, beyond which it stabilizes at approximately 5.00 V. This minimum input voltage corresponds to the dropout voltage of the IC. The graph confirms excellent line regulation of the IC 7805, as the output voltage remains constant over a wide range of input voltages.

6 Load Regulation Using IC 7805

6.1 Observation Table

Sr. No.	Input Voltage V_i (V)	Load Resistance R_L (Ω)	Load Current i_L (mA)	Output Voltage V_o (V)
1	15.00	0.00	2.29	4.99
2	15.00	62.78	2.23	4.99
3	15.00	86.36	2.20	4.99
4	15.00	119.27	2.18	5.00
5	15.00	148.84	2.15	5.00
6	15.00	184.83	2.11	4.99
7	15.00	221.15	2.08	5.00
8	15.00	264.71	2.04	5.00

Sr. No.	Input Voltage V_i (V)	Load Resistance R_L (Ω)	Load Current i_L (mA)	Output Voltage V_o (V)
9	15.00	325.00	2.00	5.00
10	15.00	391.75	1.94	4.99
11	15.00	447.37	1.90	5.00
12	15.00	505.38	1.86	4.99
13	15.00	583.33	1.80	4.99
14	15.00	655.37	1.77	5.01
15	15.00	758.82	1.70	5.01
16	15.00	796.41	1.68	4.99
17	15.00	853.66	1.64	4.99
18	15.00	913.04	1.61	4.99
19	15.00	968.35	1.58	5.01
20	15.00	1019.23	1.56	4.99

Table 5: Load Regulation Using IC 7805

6.2 V_o vs R_L Plot

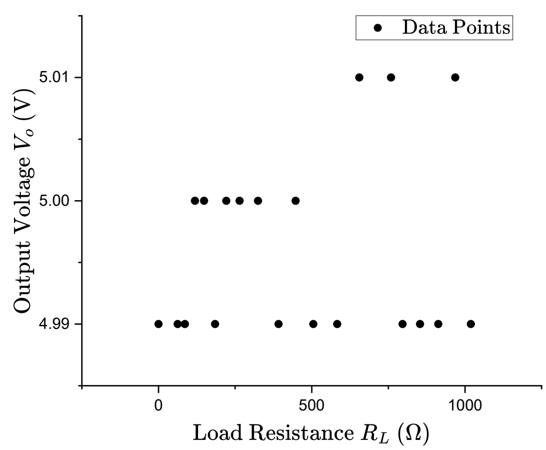

Figure 10: Output Voltage V_o (V) vs Load Resistance R_L (Ω)

6.2.1 Discussion

The graph shows that the output voltage remains nearly constant at 5.00 V for a wide range of load resistance values. This demonstrates the excellent load regulation capability of the IC 7805. Unlike the Zener diode regulator, the IC maintains stable output voltage even under varying load conditions, highlighting its superiority as a voltage regulator.

7 Sources of Error

The possible sources of errors in the experiment are classified into systematic and random errors as follows:

7.1 Systematic Errors

1. **Instrument calibration error:** The voltmeters and ammeters used in the experiment may not be perfectly calibrated, leading to consistent deviation in the measured values of voltage and current.

2. **Internal resistance of measuring instruments:** The finite internal resistance of voltmeters and ammeters alters the actual circuit conditions, thereby affecting the true values of voltage and current.

3. **Tolerance of resistors:** The actual resistance values of R_S, R_C, and R_L may differ from their nominal values due to manufacturing tolerances, causing systematic deviation in current measurements.

4. **Non-ideal behavior of Zener diode:** The Zener diode does not exhibit an ideal sharp breakdown; its dynamic resistance causes slight variation in output voltage even in the breakdown region.

5. **Voltage drop across connecting wires and breadboard:** Small but finite resistance of connecting wires and breadboard contacts leads to voltage drops that affect the measured output voltage.

6. **IC 7805 internal losses:** Internal power dissipation and dropout voltage of the IC 7805 cause slight deviation of the output voltage from the ideal 5.0 V.

7.2 Random Errors

1. **Fluctuations in input voltage:** Minor fluctuations in the power supply output lead to random variations in measured voltages and currents.

2. **Contact resistance variations:** Imperfect and unstable contacts in the breadboard and connecting wires introduce random changes in resistance during measurements.

3. **Thermal fluctuations:** Heating of the Zener diode, resistors, and IC during operation causes random changes in their electrical characteristics.

4. **Reading errors:** Errors in reading the analog or digital meters, including least count uncertainty and parallax error (if analog meters are used), contribute to random variations.

5. **Noise in electronic components:** Electrical noise inherent in semiconductor devices introduces small random fluctuations in current and voltage measurements.

8 Results

The Zener diode was successfully used as a voltage regulator and its breakdown voltage was determined from the V_o vs V_i characteristics. Line regulation and load regulation of the Zener diode were verified, and it was observed that the presence of a current limiting resistor significantly improves load regulation. The breakdown voltage V_Z of zener diode was found to be about 5.46 V. The IC 7805 voltage regulator was found to maintain a constant output voltage of approximately 5.00 V for input voltages above its minimum operating voltage, found to be about 6.61 V, independent of load resistance. Overall, the IC 7805 exhibited better voltage stability and regulation compared to the Zener diode regulator.

9 Conclusion

This experiment demonstrates the principles of voltage regulation using both discrete and integrated components. While the Zener diode provides a simple and cost-effective method for voltage regulation, its performance is limited by power dissipation and poor regulation accuracy. The IC 7805 offers superior line and load regulation, higher current capability, and built-in protection features, making it more suitable for practical electronic systems.

In this experiment, the working of a Zener diode as a voltage regulator and the performance of the IC 7805 voltage stabilizer were successfully studied. The Zener diode was found to maintain a nearly constant output voltage equal to its breakdown voltage over a wide range of input voltages and load conditions, provided it operated in the breakdown region. The line regulation and load regulation characteristics of the Zener diode were verified through appropriate graphical analysis. The IC 7805 voltage regulator was observed to provide a stable output voltage of approximately 5.0 V for input voltages above its minimum required value, independent of variations in load resistance. Thus, the IC 7805 was found to offer better voltage regulation and stability compared to the Zener diode regulator.

Future Scope of Improvement

The accuracy and performance of the experiment can be further improved by incorporating the following measures:

- Using precision resistors with lower tolerance to reduce systematic errors.
- Employing regulated and low-noise power supplies to minimize input voltage fluctuations.
- Using digital multimeters with higher accuracy and lower internal resistance.
- Studying voltage regulation characteristics under higher load currents and comparing with other voltage regulator ICs for enhanced understanding.

References

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