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Synopsis

A series of experiments were carried out to investigate the operation and performance of zener diode voltage regulators. Measurements were taken and performance characteristics were calculated.

Experimental procedure

Part A

The circuit was constructed as fig.1 below.

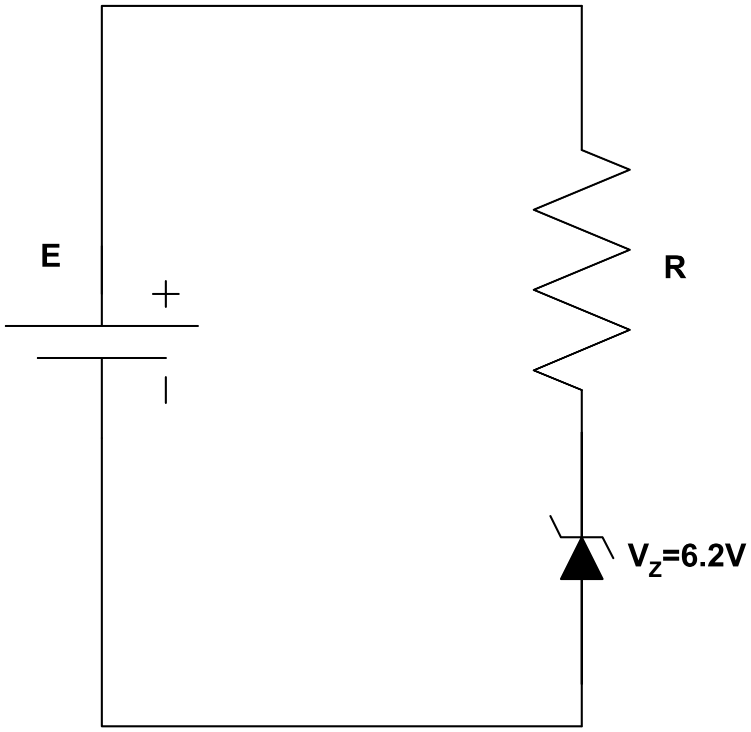


Fig.1 Circuit diagram part A

Zener and resistor voltage were measured for the following combinations of E and R:

E (V)	R (Ω)
10	180
10	220
10	270
15	220

Experimental procedure (cont.)

Part B

The circuit was constructed as fig.2 below:

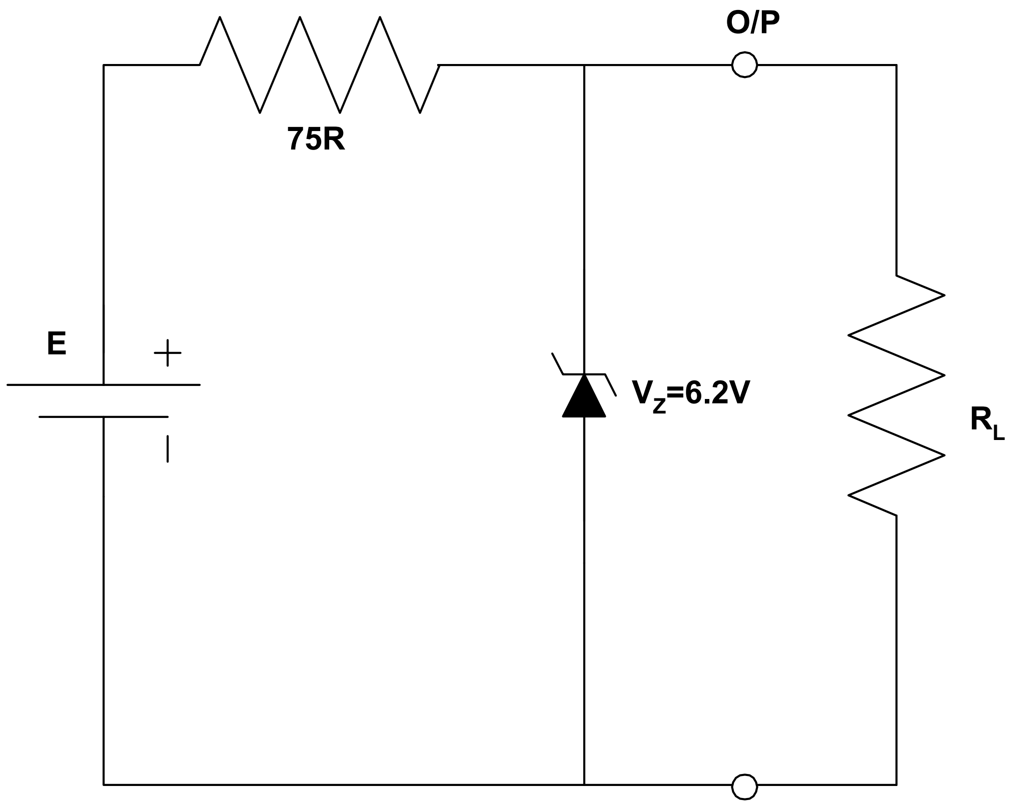


Fig.2 Circuit diagram part B

Output voltage was measured for the following combinations of E and R_L:

E (V)	R_L (Ω)
10	180
10	270
15	180

Experimental procedure (cont.)

Part C

The circuit was constructed as fig.3 below:

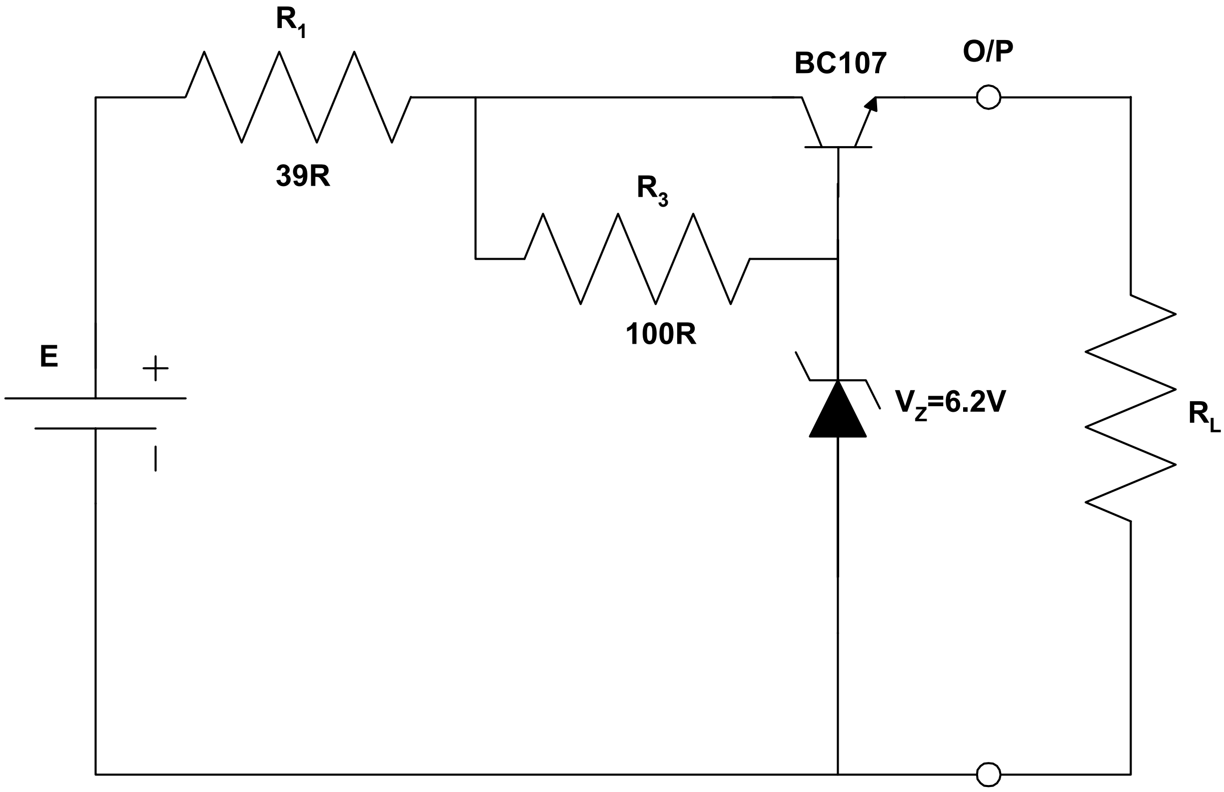


Fig.3 Circuit diagram part C

Output voltage was measured for the following combinations of E and R_L:

E (V)	R_L (Ω)
10	180
10	270
15	180

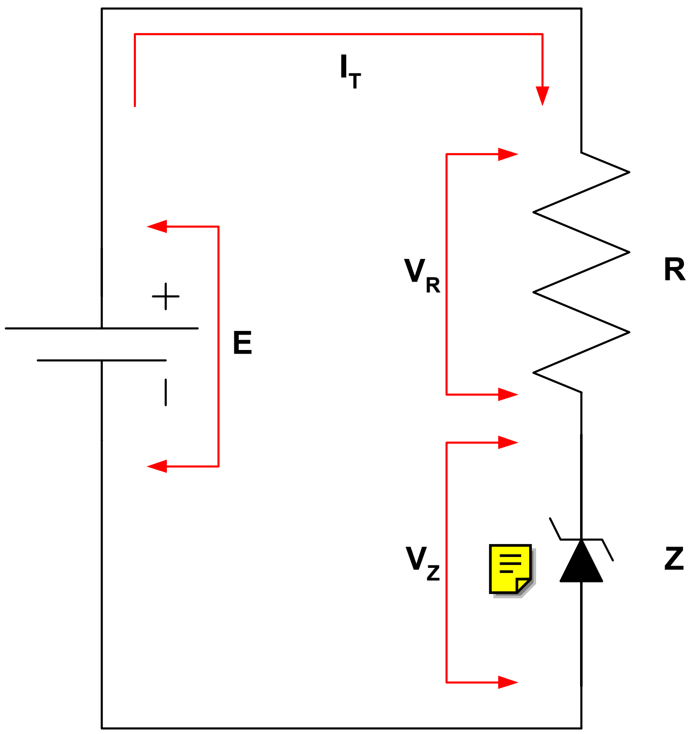
Equipment Used	
Equipment	Serial Number
Wavetek 2030 DVM	950124019
Power supply	EE1048

Results

Part A

R (Ω)	Measured				Calculated	
	E (V)	R (Ω)	V_Z (V)	V_R (V)	V_Z+V_R (V)	I_T ($V_R/R_{measured}$) (mA)
180	10.00	180.2	6.27	3.71	9.98	20.59
220	10.00	220.4	6.25	3.74	9.99	16.97
270	10.00	268.1	6.24	3.75	9.99	13.99
220	15.00	220.4	6.36	8.59	14.95	38.97

Fig.4 Table of results for part A



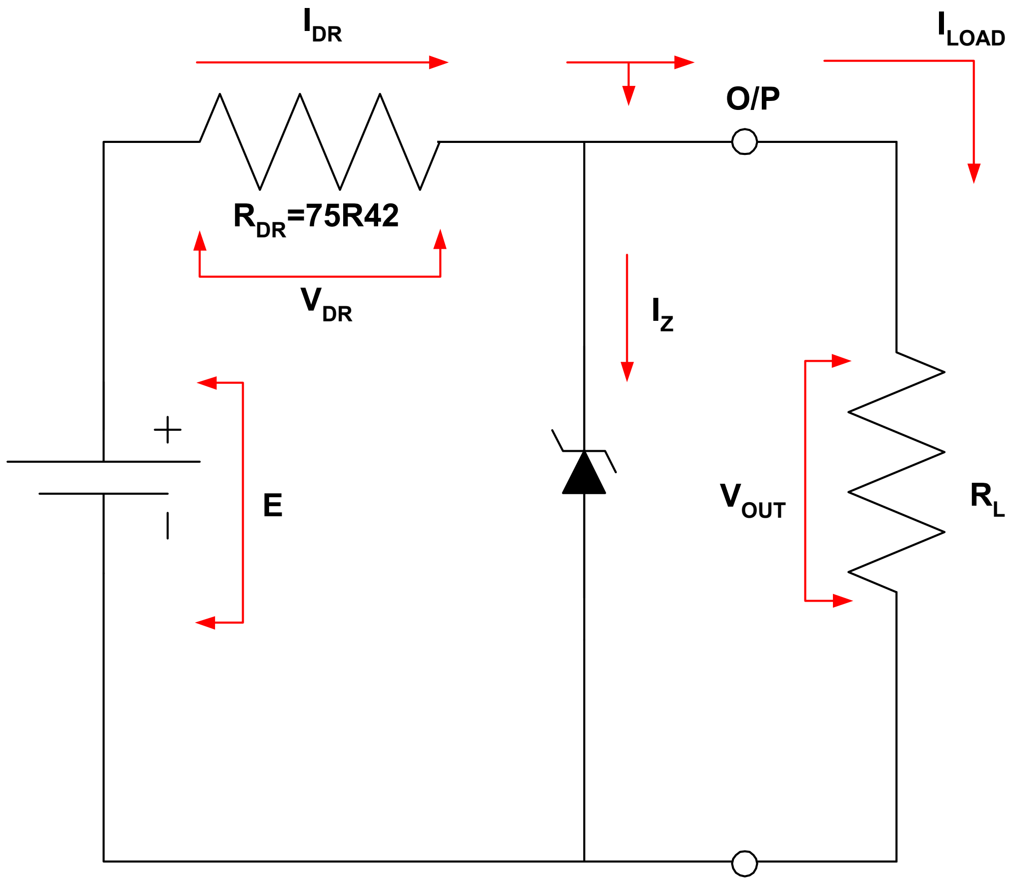
Results (cont.)

Part B

Dropper resistor	$R_{DR}(\Omega)$	$R_{DR}(\Omega)$ Measured
	75	75.42

R_L (Ω)	Measured			Calculated			
	R_L (Ω)	E (V)	V_{OUT} (V)	V_{DR} (V)	I_{LOAD} (mA) (V_{OUT}/R_L)	I_{DR} (mA) (V_{DR}/R_{DR})	I_Z (mA) (I_{DR}-I_{LOAD})
180	179.8	10.00	6.250	3.74	34.67	49.59	14.92
270	268.2	10.01	6.295	3.70	23.50	49.06	25.56
180	179.8	15.04	6.574	8.42	36.43	111.64	75.21

Fig.5 Table of results for part B

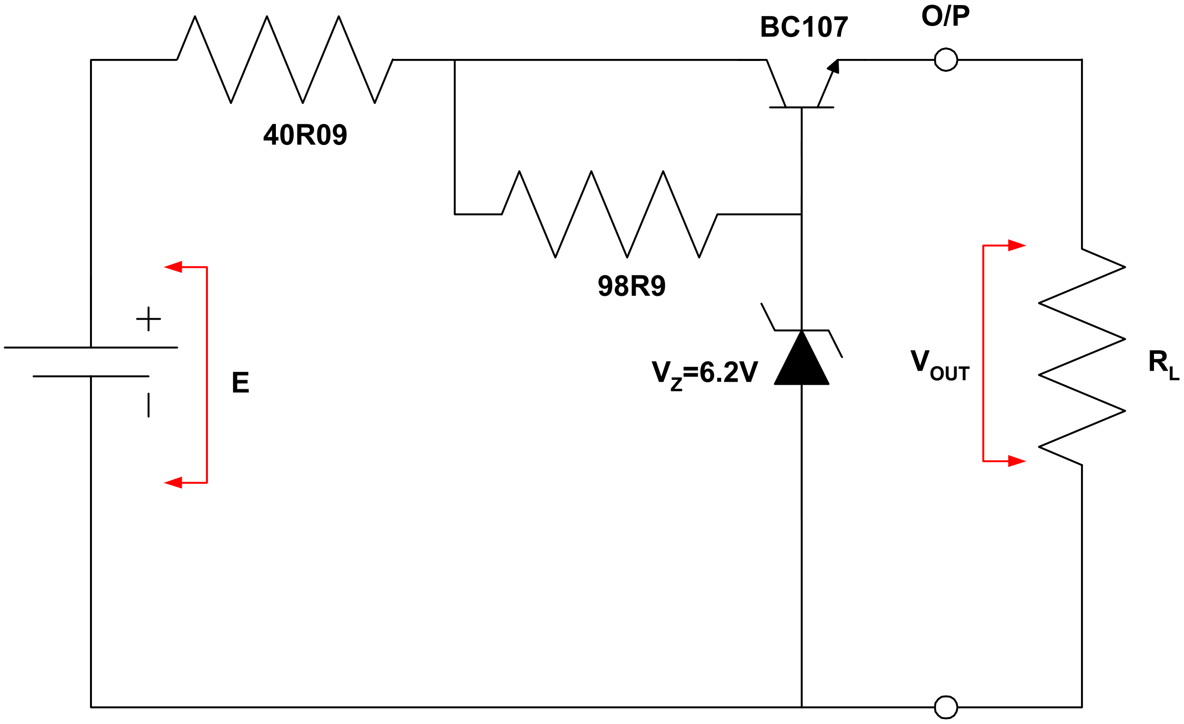


Results (cont.)

Part C

R_L (Ω)	Measured		
	R_L (Ω)	E (V)	V_{OUT} (V)
180	181.0	10.03	5.599
270	282.5	10.03	5.613
180	181.0	15.06	5.850

Fig.6 Table of results for part C



Questions

Part A

1. With R constant at 220Ω, the value of E, the applied input voltage, was increased from 10V to 15V, giving a 50% increase. The percentage increase for the zener voltage was:

$$\frac{V_{Z_{15V}} - V_{Z_{10V}}}{V_{Z_{10V}}} \times 100\% = \frac{6.36 - 6.25}{6.25} \times 100\% = 1.76\%$$

2. With E constant at 10V, R was changed form 180Ω to 270Ω, giving a 50% increase. The percentage decrease in the circuit current was:

$$\frac{I_{T_{R180\Omega}} - I_{T_{R270\Omega}}}{I_{T_{R180\Omega}}} \times 100\% = \frac{20.59 - 13.99}{20.59} \times 100\% = 32.05\%$$

3. With E constant at 10V, R was changed form 180Ω to 270Ω, giving a 50% increase. The percentage decrease in the zener voltage was:

$$\frac{V_{Z_{R180\Omega}} - V_{Z_{R270\Omega}}}{V_{Z_{R180\Omega}}} \times 100\% = \frac{6.27 - 6.24}{6.27} \times 100\% = 0.48\%$$

Part B

Mode of operation

1. The circuit shown in figure 1 is configured as a zener shunt regulator. The voltage across the zener remains almost constant for a given input voltage (within the device ratings). With R_1 acting as the series current limiting resistor, as the input voltage is increased or decreased, I_Z increases or decreases proportionally. The minimum and maximum input voltages are dependant upon I_{ZK} and I_{ZM}, which can be obtained from the zener data sheet. As load current is taken, some of the current that was flowing through the zener diode is supplied to the load, reducing the zener current available and making the zener conduct less – this will have the effect of reducing the output voltage slightly. If the load is reduced the zener will take more of the current and conduct more and the output voltage will rise slightly. The output voltage will remain constant provided $I_Z > I_{ZK}$ and $I_Z < I_{ZM}$.

Load and Line regulation

2. Disadvantages of this circuit are that if the load current is too high (or the supply voltage too low) and the zener current falls below I_{ZK}, the zener will not conduct and the voltage regulation will fail. Conversely, if the load becomes open circuited (or the supply voltage rises too high), the zener diode will have to take increased current supplied via R_1, and will be damaged unless R_1 is selected so that I_Z remains within the device parameters ($I_Z < I_M$) when there is no load attached.

3. With E constant at 10V, R was changed form 180Ω to 270Ω, giving a 50% increase. The percentage increase in the output voltage was:

$$\frac{V_{O_{R270\Omega}} - V_{O_{R180\Omega}}}{V_{O_{R180\Omega}}} \times 100\% = \frac{6.295 - 6.250}{6.250} \times 100\% = 0.72\%$$

4. With R constant at 180Ω, the value of E, the applied input voltage, was increased from 10V to 15V, giving a 50% increase. The percentage increase for the output voltage was:

$$\frac{V_{O_{15V}} - V_{O_{10V}}}{V_{O_{10V}}} \times 100\% = \frac{6.574 - 6.250}{6.250} \times 100\% = 5.18\%$$

5. The current through the dropper resistor is given by:

$$I_R = \frac{V_R}{R} = \frac{3.74}{75.42} = 49.59\text{mA}$$

The current through the load is given by:

$$I_L = \frac{V_Z}{R_L} = \frac{6.25}{179.8} = 34.76\text{mA}$$

$\therefore$ The zener diode current is given by:

$$I_Z = I_R - I_L = 49.59 - 34.76 = 14.83\text{mA}$$

Questions (cont.)

Part C

Mode of operation.

1. This circuit is similar in operation to the circuit in figure 2, with the addition of a current amplifying transistor. The transistor is connected in series with the load and acts as an emitter follower – the load is connected to the emitter and the emitter follows the base, which is the constant zener voltage. The transistor is used as current amplification for the load and prevents the zener diode being excessively loaded. Resistors R_1 and R_3 supply current to the zener, which operates at its breakdown voltage and supplies a fixed voltage to the base of Q_1. The voltage on the base of the transistor forward biases the emitter/base junction and the transistor conducts, the resultant output at the collector being equal to the zener voltage minus the base/emitter voltage drop (approx 0.7V). In our circuit the zener voltage is 6.2 minus the $0.7V_{BE}$ drop which gives 5.5V, which compares well with the measured value of 5.599V. Resistor R_1 is used to protect the transistor from excess current being drawn (e.g. output short circuits) by limiting the current.

2. **When the input voltage rises**, the output will rise. Since the base voltage is held fixed by the zener diode, the potential difference across the base-emitter junction will fall and V_{BE} will reduce in value. The effect of this is to make the transistor conduct less heavily and the resistance between collector and emitter to increase – **the volt drop across the transistor increases and the output voltage drops** accordingly until V_{BE} reaches 0.7V again **and V_{OUT} is restored to its previous level**.

3. **When the load resistor increases in value**, i.e. the load is drawing less current, V_{OUT} increases (because $V_{OUT}=I_L \times R_L$), which causes V_{BE} to increase. This in turn causes the transistor to conduct less heavily and so **less current is supplied to the load**. This reduction in current causes a reduction in V_{OUT} (because $V_{OUT}=I_L \times R_L$) and **thus V_{OUT} is restored to its previous level**. This is demonstrated in the results obtained below.

$R_L(\Omega)$	Measured		Calculated
	V_{OUT} (V)	R_L (Ω)	I_L (mA)
180	5.599	181.0	30.93
270	5.613	282.5	19.87

4. With R constant at 180Ω, the value of E, the applied input voltage, was increased from 10V to 15V, giving a 50% increase. The percentage increase for the output voltage was:

$$\frac{V_{O_{15V}} - V_{O_{10V}}}{V_{O_{10V}}} \times 100\% = \frac{5.850 - 5.599}{5.599} \times 100\% = 4.48\%$$

5. With E constant at 10V, R was changed form 180Ω to 270Ω, giving a 50% increase. The percentage increase in the output voltage was:

$$\frac{V_{O_{R270\Omega}} - V_{O_{R180\Omega}}}{V_{O_{R180\Omega}}} \times 100\% = \frac{5.613 - 5.599}{5.599} \times 100\% = 0.25\%$$

Discussion

The equivalent circuit for a zener diode can be thought of as a battery of V_Z volts, in series with a resistor of R_Z ohms. It is because of this internal resistance that a voltage drop occurs across the zener diode, which is added or subtracted from the device rating to give an increased or decreased output. The value of R_Z can be obtained from the manufactures data sheet for the device and is specified at a given current (I_{ZT}). Increasing the current through the zener higher than I_{ZT}, increases the voltage dropped across the internal impedance ($\Delta V_Z = \Delta I_Z R_Z$) and the voltage across the zener diode increases. Likewise if the current through the zener drops lower than I_{ZT}, the voltage dropped across the internal impedance ($\Delta V_Z = \Delta I_Z R_Z$) decreases and the voltage across the zener diode decreases.

The major drawback of these types of regulators is their poor efficiency. This is due to the fact that current is drawn constantly regardless of the load. This constant usage of current means these designs are not really suitable for battery-powered equipment. The losses appear as heat in the series elements and the design must take into consideration these factors and therefore are only suitable for low power applications.

Reference material

- Lecture notes – Dr.J.Raczkowycz
- Electronic Devices 4^{th} Edition – Floyd – Prentice Hall