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Regulated D.C. Power Supply

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INTRODUCTION

In general, electronic circuits using tubes or transistors require a source of d.c. power. For example, in tube amplifiers, d.c. voltage is needed for plate, screen grid and control grid. Similarly, the emitter and collector bias in a transistor must also be direct current. Batteries are rarely used for this purpose as they are costly and require frequent replacement. In practice, d.c. power for electronic circuits is most conveniently obtained from commercial a.c. lines by using rectifier-filter system, called a *d.c. power supply*.

The rectifier-filter combination constitutes an ordinary d.c. power supply. The d.c. voltage from an ordinary power supply remains constant so long as a.c. mains voltage or load is unaltered. However, in many electronic applications, it is desired that d.c. voltage should remain constant irrespective of changes in a.c. mains or load. Under such situations, *voltage regulating devices* are used with ordinary power supply. This constitutes *regulated d.c. power supply* and keeps the d.c. voltage at a fairly constant value. In this chapter, we shall focus our attention on the various voltage regulating circuits used to obtain regulated power supply.

17.1 Ordinary D.C. Power Supply

An ordinary or unregulated d.c. power supply contains a rectifier and a filter circuit as shown in Fig. 17.1. The output from the rectifier is pulsating d.c. These pulsations are due to the presence of a.c. component in the rectifier output. The filter circuit removes the a.c. component so that steady d.c. voltage is obtained across the load.

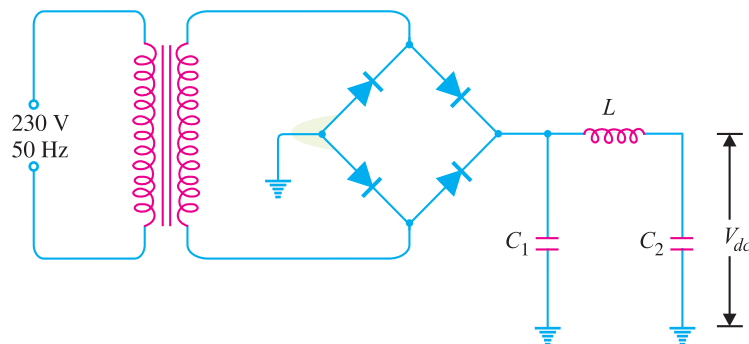


Fig. 17.1

Limitations. An ordinary d.c. power supply has the following drawbacks :

- (i) The d.c. output voltage changes directly with input a.c. voltage. For instance, a 5% increase in input a.c. voltage results in approximately 5% increase in d.c. output voltage.
- (ii) The d.c. output voltage decreases as the load current increases. This is due to voltage drop in (a) transformer windings (b) rectifier and (c) filter circuit.

These variations in d.c. output voltage may cause inaccurate or erratic operation or even malfunctioning of many electronic circuits. For example, in an oscillator, the frequency will shift and in transmitters, distorted output will result. Therefore, ordinary power supply is unsuited for many electronic applications and is being replaced by regulated power supply.

17.2 Important Terms

For comparison of different types of power supplies, the following terms are commonly used :

(i) **Voltage regulation.** The d.c. voltage available across the output terminals of a given power supply depends upon load current. If the load current I_{dc} is increased by decreasing R_L (See Fig. 17.2), there is greater voltage drop in the power supply and hence smaller d.c. output voltage will be available. Reverse will happen if the load current decreases. The variation of output voltage w.r.t. the amount of load current drawn from the power supply is known as *voltage regulation* and is expressed by the following relation :

$$\% \text{ Voltage regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

where

V_{NL} = d.c. output voltage at no-load

V_{FL} = d.c. output voltage at full-load

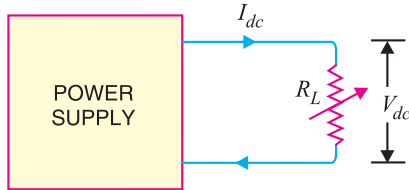


Fig. 17.2

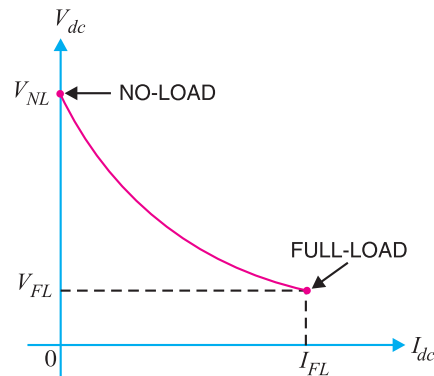


Fig. 17.3

In a well designed power supply, the full-load voltage is only slightly less than no-load voltage *i.e.* voltage regulation approaches zero. Therefore, lower the voltage regulation, the lesser the difference between full-load and no-load voltages and better is the power supply. Power supplies used in practice have a voltage regulation of 1% *i.e.* full-load voltage is within 1% of the no-load voltage. Fig. 17.3 shows the change of d.c. output voltage with load current. This is known as **voltage regulation curve**.

Note. The above voltage regulation is called **load regulation** because it indicates the change in output voltage due to the change in load current. There is another type of voltage regulation, called **line regulation** and indicates the change in output voltage due to the change in input voltage.

(ii) Minimum load resistance. The change of load connected to a power supply varies the load current and hence the d.c. output voltage. In order that a power supply gives the rated output voltage and current, there is minimum load resistance allowed. For instance, if a power supply is required to deliver a full-load current I_{FL} at full-load voltage V_{FL} , then,

$$R_{L(min)} = \frac{V_{FL}}{I_{FL}}$$

Thus, if a data sheet specifies that a power supply will give an output voltage of 100V at a maximum rated current of 0.4A, then minimum load resistance you can connect across supply is $R_{min} = 100/0.4 = 250 \Omega$. If any attempt is made to decrease the value of R_L below this value, the rated d.c. output voltage will not be available.

Example 17.1. If the d.c. output voltage is 400V with no-load attached to power supply but decreases to 300V at full-load, find the percentage voltage regulation.

Solution.

$$V_{NL} = 400 \text{ V}; \quad V_{FL} = 300 \text{ V}$$

$$\therefore \quad \% \text{ Voltage regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 = \frac{400 - 300}{300} \times 100 = 33.33 \%$$

Example 17.2. A power supply has a voltage regulation of 1%. If the no-load voltage is 30V, what is the full-load voltage ?

Solution. Let V_{FL} be the full-load voltage.

$$\% \text{ Voltage regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

or

$$1 = \frac{30 - V_{FL}}{V_{FL}} \times 100$$

\therefore

$$V_{FL} = 29.7 \text{ V}$$

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Example 17.3. Two power supplies A and B are available in the market. Power supply A has no-load and full-load voltages of 30V and 25V respectively whereas these values are 30V and 29V for power supply B. Which is better power supply ?

Solution. That power supply is better which has lower voltage regulation.

Power supply A

$$V_{NL} = 30 \text{ V}, \quad V_{FL} = 25 \text{ V}$$

$$\therefore \% \text{ Voltage regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 = \frac{30 - 25}{25} \times 100 = 20\%$$

Power supply B

$$V_{NL} = 30 \text{ V}, \quad V_{FL} = 29 \text{ V}$$

$$\therefore \% \text{ Voltage regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 = \frac{30 - 29}{29} \times 100 = 3.45\%$$

Therefore, power supply B is better than power supply A.

Example 17.4. Fig. 17.4 shows the regulation curve of a power supply. Find (i) voltage regulation and (ii) minimum load resistance.

Solution. Referring to the regulation curve shown in Fig. 17.4, it is clear that :

$$V_{NL} = 500 \text{ V}; \quad V_{FL} = 300 \text{ V}$$

$$I_{FL} = 120 \text{ mA}; \quad R_{L(\min)} = ?$$

$$(i) \text{ Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

$$= \frac{500 - 300}{300} \times 100$$

$$= 66.7\%$$

$$(ii) \quad R_{L(\min)} = \frac{V_{FL}}{I_{FL}} = \frac{300 \text{ V}}{120 \text{ mA}}$$

$$= 2.5 \text{ k}\Omega$$

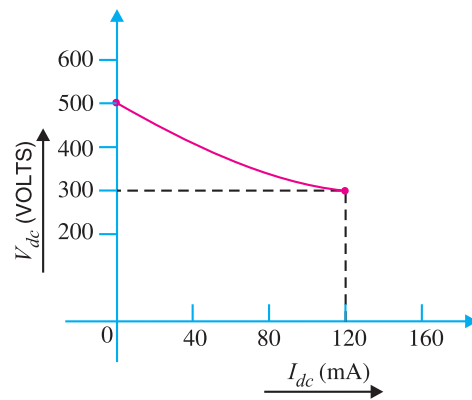


Fig. 17.4

Example 17.5. In adding 1A load to an existing 1A load, the output voltage of a power supply drops from 10.5V to 10V. Calculate (i) output impedance of power supply and (ii) no-load voltage of power supply.

Solution. All practical power supplies always have some internal impedance (often called output impedance) which is denoted by Z_o as shown in Fig. 17.5. It is given by the ratio of change in load voltage to the corresponding change in load current *i.e.*

$$Z_o = \frac{\Delta V_L}{\Delta I_L}$$

(i) Output impedance of power supply is

$$Z_o = \frac{\Delta V_L}{\Delta I_L} = \frac{10.5\text{V} - 10\text{V}}{1\text{A}} = 0.5\Omega$$

(ii) Now $Z_o = \frac{\Delta V_L}{\Delta I_L}$

$$\text{or} \quad 0.5 = \frac{V_{NL} - 10.5}{1\text{A}}$$

$$\therefore V_{NL} = 0.5 \times 1 + 10.5 = 11\text{V}$$

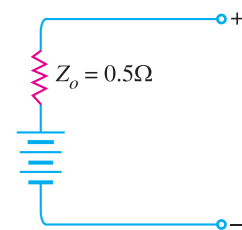


Fig. 17.5

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Example 17.6. A d.c. power supply is delivering 10V (normally) to a load that is varying sinusoidally between 0.5A and 1 A at a rate of 10 kHz. If the output impedance of the power supply is 0.01Ω at 10 kHz, determine the fluctuations in the output voltage caused by this periodic load change.

Solution. For rapidly changing load levels—the normal situation in electronic systems—the output impedance of power supply varies with the frequency of the load change. This change with frequency occurs because of the impedance of the power supply.

Output impedance of power supply is

$$Z_o = \frac{\Delta V_L}{\Delta I_L}$$

or
$$\Delta V_L = Z_o \times \Delta I_L = 0.01 \times (1 - 0.5) = 0.005\text{V} = 5\text{mV}$$

Therefore, the *output voltage will have 5mV p-p fluctuations at a rate of 10 kHz.*

Note. The power supply not only acts as a voltage source but also includes an output impedance. When specifying a power supply, output impedance is an important consideration. The smaller the output impedance of a power supply, the better it is.

Example 17.7. A voltage regulator experiences a $10\ \mu\text{V}$ change in its output voltage when its input voltage changes by 5V. Determine the value of line regulation for the circuit.

Solution. In practice, a change in input voltage to a voltage regulator will cause a change in its output voltage. The *line regulation* of a voltage regulator indicates the change in output voltage that will occur per unit change in the input voltage *i.e.*

$$\begin{aligned} \text{Line regulation} &= \frac{\Delta V_{out}}{\Delta V_{in}} \\ &= \frac{10\ \mu\text{V}}{5\text{V}} = 2\ \mu\text{V/V} \end{aligned}$$

The $2\ \mu\text{V/V}$ rating of the voltage regulator means that the output voltage will change by $2\ \mu\text{V}$ for every 1V change in the regulator's input voltage.

17.3 Regulated Power Supply

A d.c. power supply which maintains the output voltage constant irrespective of a.c. mains fluctuations or load variations is known as **regulated d.c. power supply.**

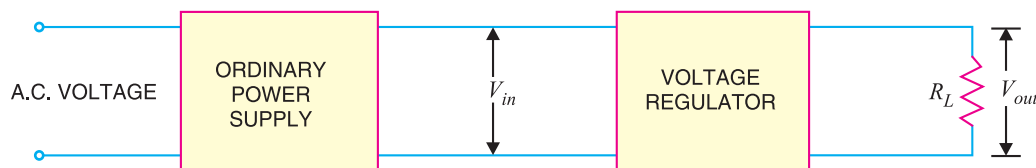


Fig. 17.6

A regulated power supply consists of an ordinary power supply and voltage regulating device. Fig. 17.6 shows the block diagram of a regulated power supply. The output of ordinary power supply is fed to the voltage regulator which produces the final output. The output voltage remains constant whether the load current changes or there are fluctuations in the input a.c. voltage.

Fig. 17.7 shows the complete circuit of a regulated power supply using zener diode as a voltage regulating device. As you can see, the regulated power supply is a combination of three circuits *viz.*, (i) bridge rectifier (ii) a capacitor filter C and (iii) zener voltage regulator. The bridge rectifier converts the transformer secondary a.c. voltage (point P) into pulsating voltage (point Q). The pulsating d.c. voltage is applied to the capacitor filter. This filter reduces the pulsations in the rectifier

d.c. output voltage (point R). Finally, the zener voltage regulator performs two functions. Firstly, it reduces the variations in the filtered output voltage. Secondly, it keeps the output voltage (V_{out}) nearly constant whether the load current changes or there is change in input a.c. voltage. Fig. 17.8 shows the waveforms at various stages of regulated power supply. Note that bridge rectifier and

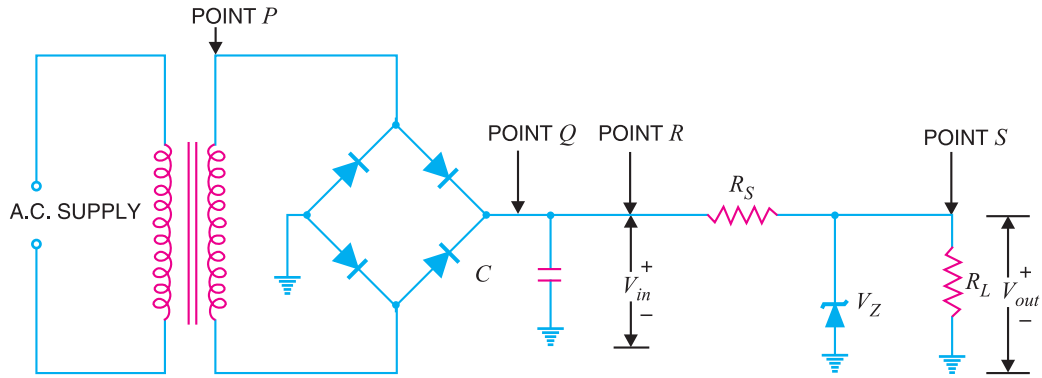


Fig. 17.7

capacitor filter constitute an ordinary power supply. However, when voltage regulating device is added to this ordinary power supply, it turns into a regulated power supply.

Note. In practice, this type of regulator is rarely used. The primary problem with the simple zener regulator is the fact that the zener wastes a tremendous amount of power. Practical voltage regulators contain a number of discrete and/or integrated active devices. Nevertheless, this circuit gives an idea about the regulated power supply.

Need of Regulated Power Supply

In an ordinary power supply, the voltage regulation is poor *i.e.* d.c. output voltage changes appreciably with load current. Moreover, output voltage also changes due to variations in the input a.c. voltage. This is due to the following reasons :

(i) In practice, there are considerable variations in a.c. line voltage caused by outside factors beyond our control. This changes the d.c. output voltage. Most of the electronic circuits will refuse to work satisfactorily on such output voltage fluctuations. This necessitates to use regulated d.c. power supply.

(ii) The internal resistance of ordinary power supply is relatively large ($> 30 \Omega$). Therefore, output voltage is markedly affected by the amount of load current drawn from the supply. These variations in d.c. voltage may cause erratic operation of electronic circuits. Therefore, regulated d.c. power supply is the only solution in such situations.

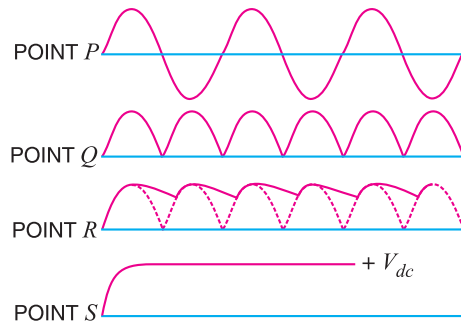
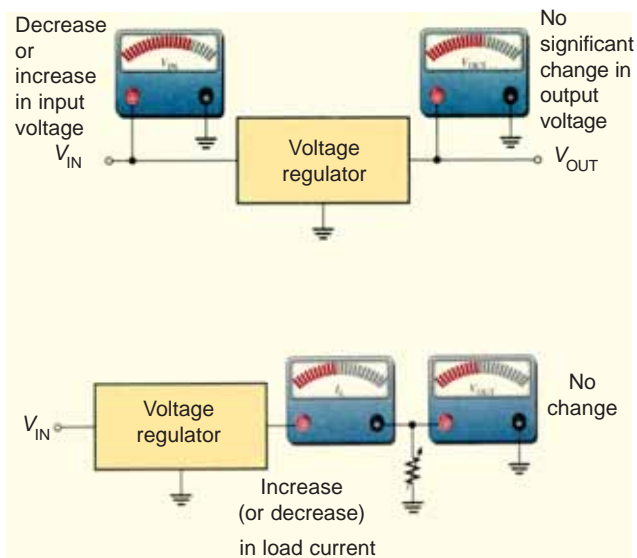


Fig. 17.8



17.4 Types of Voltage Regulators

A device which maintains the output voltage of an ordinary power supply constant irrespective of load variations or changes in input a.c. voltage is known as a *voltage regulator*. A voltage regulator generally employs electronic devices to achieve this objective. There are basic two types of voltage regulators viz., (i) series voltage regulator (ii) shunt voltage regulator.

The series regulator is placed in series with the load as shown in Fig. 17.9 (i). On the other hand, the shunt regulator is placed in parallel with the load as shown in Fig. 17.9 (ii). Each type of regulator provides an output voltage that remains constant even if the input voltage varies or the load current changes.

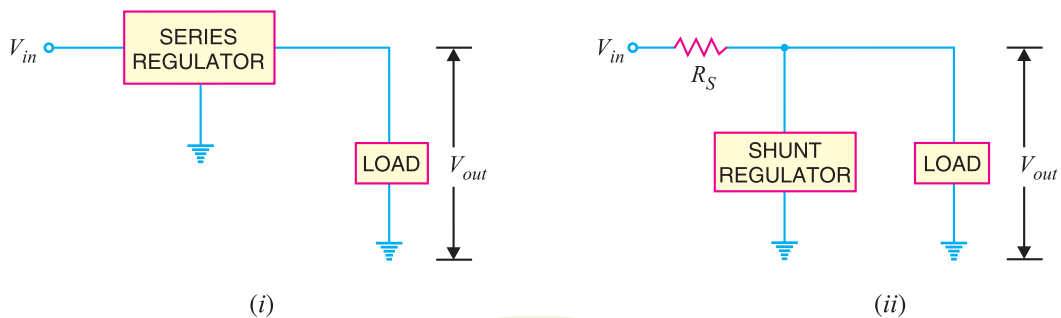


Fig. 17.9

1. For low voltages. For low d.c. output voltages (upto 50V), either zener diode alone or zener in conjunction with transistor is used. Such supplies are called transistorised power supplies. A transistor power supply can give only low stabilised voltages because the safe value of V_{CE} is about 50 V and if it is increased above this value, the breakdown of the junction may occur.

2. For high voltages. For voltages greater than 50 V, glow tubes are used in conjunction with vacuum tube amplifiers. Such supplies are generally called tube power supplies and are extensively used for the proper operation of vacuum valves.



Voltage Regulator

17.5 Zener Diode Voltage Regulator

As discussed in chapter 6, when the zener diode is operated in the breakdown or zener region, the voltage across it is substantially constant for a large change of current through it. This characteristic permits it to be used as a voltage regulator. Fig. 17.10 shows the circuit of a zener diode regulator. As long as input voltage V_{in} is greater than zener voltage V_Z , the zener operates in the breakdown region and maintains constant voltage across the load. The series limiting resistance R_S limits the input current.

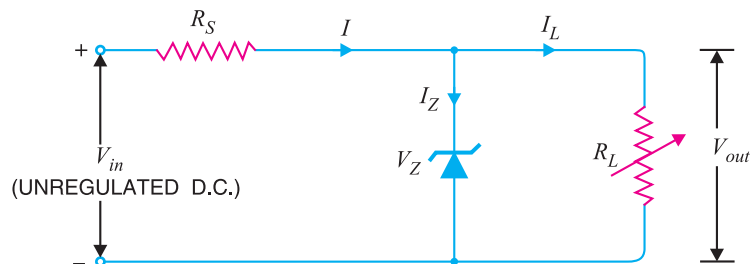


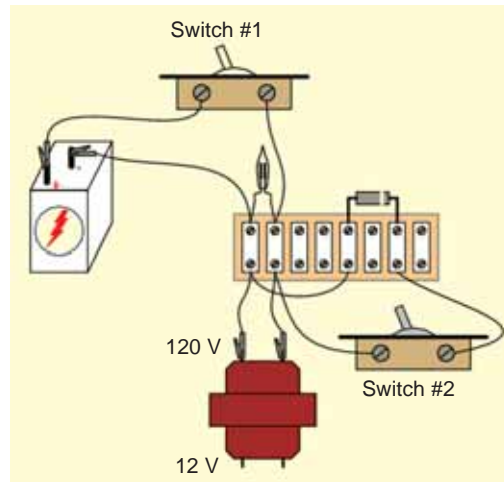
Fig. 17.10

Operation. The zener will maintain constant voltage across the load inspite of changes in load current or input voltage. As the load current increases, the zener current decreases so that current through resistance R_S is constant. As output voltage = $V_{in} - IR_S$, and I is constant, therefore, output voltage remains unchanged. The reverse would be true should the load current decrease. The circuit will also correct for the changes in input voltages. Should the input voltage V_{in} increase, more current will flow through the zener, the voltage drop across R_S will increase but load voltage would remain constant. The reverse would be true should the input voltage decrease.

Limitations. A zener diode regulator has the following drawbacks :

(i) It has low efficiency for heavy load currents. It is because if the load current is large, there will be considerable power loss in the series limiting resistance.

(ii) The output voltage slightly changes due to zener impedance as $V_{out} = V_Z + I_Z Z_Z$. Changes in load current produce changes in zener current. Consequently, the output voltage also changes. Therefore, the use of this circuit is limited to only such applications where variations in load current and input voltage are small.



17.6 Conditions for Proper Operation of Zener Regulator

When a zener diode is connected in a circuit for voltage regulation, the following conditions must be satisfied :

(i) The zener must operate in the breakdown region or regulating region *i.e.* between $I_{Z(max)}$ and $I_{Z(min)}$. The current $I_{Z(min)}$ (generally 10 mA) is the minimum zener current to put the zener diode in the *ON state i.e.* regulating region. The current $I_{Z(max)}$ is the maximum zener current that zener diode can conduct without getting destroyed due to excessive heat.

(ii) The zener should not be allowed to exceed maximum dissipation power otherwise it will be destroyed due to excessive heat. If maximum power dissipation of a zener is $P_{Z(max)}$ and zener voltage is V_Z , then,

$$P_{Z(max)} = V_Z I_{Z(max)}$$

$$\therefore I_{Z(max)} = \frac{P_{Z(max)}}{V_Z}$$

(iii) There is a minimum value of R_L to ensure that zener diode will remain in the regulating region *i.e.* breakdown region. If the value of R_L falls below this minimum value, the proper voltage will not be available across the zener to drive it into the breakdown region.

Example 17.8. Fig. 17.11 shows the zener regulator. Calculate (i) current through the series resistance (ii) minimum and maximum load currents and (iii) minimum and maximum zener currents. Comment on the results.

Solution.

(i)
$$I_S = \frac{V_{in} - V_{out}}{R_S} = \frac{24 - 12}{160} = \frac{12 \text{ V}}{160 \Omega} = 75 \text{ mA}$$

(ii) The minimum load current occurs when $R_L \rightarrow \infty$.

$$\therefore I_{L(min)} = 0 \text{ A}$$

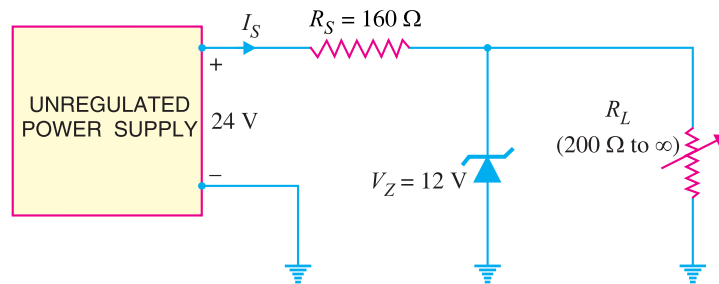


Fig. 17.11

The maximum load current occurs when $R_L = 200 \Omega$.

$$\therefore I_{L(max)} = \frac{V_{out}}{R_{L(min)}} = \frac{12 \text{ V}}{200 \Omega} = 60 \text{ mA}$$

$$(iii) \quad \begin{aligned} I_{Z(min)} &= I_S - I_{L(max)} = 75 - 60 = 15 \text{ mA} \\ I_{Z(max)} &= I_S - I_{L(min)} = 75 - 0 = 75 \text{ mA} \end{aligned}$$

Comments. The current I_S through the series resistance R_S is constant. When load current increases from 0 to 60 mA, the zener current decreases from 75 mA to 15 mA, maintaining I_S constant in value. This is the normal operation of zener regulator i.e. I_S and V_{out} remain constant inspite of changes in load current or source voltage.

Example 17.9. A zener regulator has $V_Z = 15\text{V}$. The input voltage may vary from 22 V to 40 V and load current from 20 mA to 100 mA. To hold load voltage constant under all conditions, what should be the value of series resistance ?

Solution. In order that zener regulator may hold output voltage constant under all operating conditions, it must operate in the breakdown region. In other words, there must be zener current for all input voltages and load currents. The worst case occurs when the input voltage is minimum and load current is maximum because then zener current drops to a minimum.

$$\therefore R_{S(max)} = \frac{V_{in(min)} - V_{out}}{I_{L(max)}} = \frac{22 - 15}{0.1} = \frac{7 \text{ V}}{0.1 \text{ A}} = 70 \Omega$$

Example 17.10. Determine the minimum acceptable value of R_S for the zener voltage regulator circuit shown in Fig. 17.12. The zener specifications are :

$$V_Z = 3.3\text{V} ; I_{Z(min)} = 3 \text{ mA} ; I_{Z(max)} = 100 \text{ mA}$$

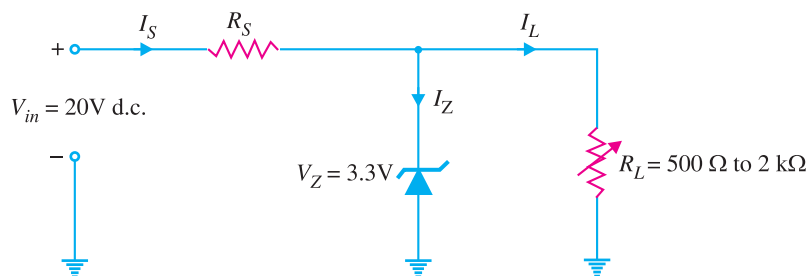


Fig. 17.12

Solution. When load R_L goes open (*i.e.* $R_L \rightarrow \infty$), the entire line current I_S will flow through the zener and the value of R_S should be such to prevent line current I_S from exceeding $I_{Z(max)}$ if the load opens.

$$\begin{aligned} \therefore R_{S(min)} &= \frac{V_{in} - V_Z}{I_{Z(max)}} \\ &= \frac{20\text{V} - 3.3\text{V}}{100\text{ mA}} = \mathbf{167\Omega} \end{aligned}$$

Example 17.11. Determine the maximum allowable value of R_S for the zener voltage regulator circuit shown in Fig. 17.12.

Solution. The maximum value of R_S is limited by the total current requirements in the circuit. The value of R_S must be such so as to allow $I_{Z(min)}$ to flow through the zener diode when the load is drawing *maximum* current.

$$\begin{aligned} R_{S(max)} &= \frac{V_{in} - V_Z}{I_{L(max)} + I_{Z(min)}} \\ \text{Now } I_{L(max)} &= \frac{V_Z}{R_{L(min)}} = \frac{3.3\text{V}}{500\Omega} = 6.6\text{ mA} \\ \therefore R_{S(max)} &= \frac{20\text{V} - 3.3\text{V}}{6.6\text{ mA} + 3\text{ mA}} = \frac{16.7\text{V}}{9.6\text{ mA}} = \mathbf{1739\Omega} \end{aligned}$$

17.7. Transistor Series Voltage Regulator

Figure 17.13 shows a simple series voltage regulator using a transistor and zener diode. The circuit is called a series voltage regulator because the load current passes through the series transistor Q_1 as shown in Fig. 17.13. The unregulated d.c. supply is fed to the input terminals and the regulated output is obtained across the load. The zener diode provides the reference voltage.

Operation. The base voltage of transistor Q_1 is held to a relatively constant voltage across the zener diode. For example, if 8V zener (*i.e.*, $V_Z = 8\text{V}$) is used, the base voltage of Q_1 will remain approximately 8V. Referring to Fig. 17.13,

$$V_{out} = V_Z - V_{BE}$$

(i) If the output voltage decreases, the increased base-emitter voltage causes transistor Q_1 to conduct more, thereby raising the output voltage. As a result, the output voltage is maintained at a constant level.

(ii) If the output voltage increases, the decreased base-emitter voltage causes transistor Q_1 to conduct less, thereby reducing the output voltage. Consequently, the output voltage is maintained at a constant level.

The advantage of this circuit is that the changes in zener current are reduced by a factor β . Therefore, the effect of zener impedance is greatly reduced and much more stabilised output is obtained

Limitations

(i) Although the changes in zener current are much reduced, yet the output is not absolutely constant. It is because both V_{BE} and V_Z decrease with the increase in room temperature.

(ii) The output voltage cannot be changed easily as no such means is provided.

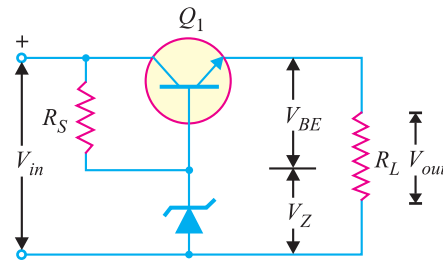


Fig. 17.13

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Example 17.12. For the circuit shown in Fig. 17.13, if $V_Z = 10\text{V}$, $\beta = 100$ and $R_L = 1000\ \Omega$, find the load voltage and load current. Assume $V_{BE} = 0.5\text{V}$ and the zener operates in the breakdown region.

Solution.

$$\begin{aligned} \text{Output voltage, } V_{out} &= V_Z - V_{BE} \\ &= 10 - 0.5 = \mathbf{9.5\text{ V}} \end{aligned}$$

$$\text{Load current, } I_L = \frac{V_{out}}{R_L} = \frac{9.5\text{ V}}{1000\ \Omega} = \mathbf{9.5\text{ mA}}$$

Example 17.13. A series voltage regulator is required to supply a current of 1A at a constant voltage of 6V . If the supply voltage is 10V and the zener operates in the breakdown region, design the circuit. Assume $\beta = 50$, $V_{BE} = 0.5\text{V}$ and minimum zener current = 10 mA .

Solution. The design steps require the determination of zener breakdown voltage and current limiting resistance R_S . Fig. 17.14 shows the desired circuit of series voltage regulator.

(i) **Zener breakdown voltage.** The collector-emitter terminals are in series with the load. Therefore, the load current must pass through the transistor *i.e.*,

$$\text{Collector current, } I_C = 1\text{ A}$$

$$\text{Base current, } I_B = I_C / \beta = 1\text{A} / 50 = 20\text{ mA}$$

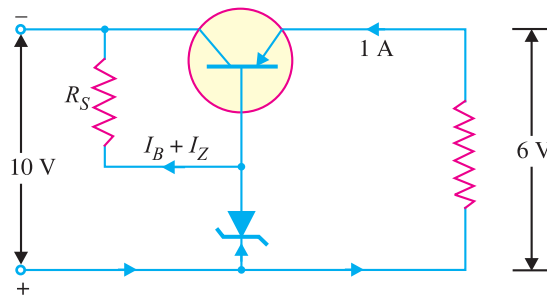


Fig. 17.14

$$\text{Output voltage, } V_{out} = V_Z - V_{BE}$$

$$\text{or } 6 = V_Z - 0.5$$

$$\therefore V_Z = 6 + 0.5 = \mathbf{6.5\text{ V}}$$

Hence zener diode of breakdown voltage 6.5V is required.

(ii) **Value of R_S**

$$\text{Voltage across } R_S = V_{in} - V_Z = 10 - 6.5 = 3.5\text{ V}$$

$$\therefore R_S = \frac{\text{Voltage across } R_S}{I_B + I_Z} = \frac{3.5\text{ V}}{(20 + 10)\text{ mA}} = \mathbf{117\ \Omega}$$

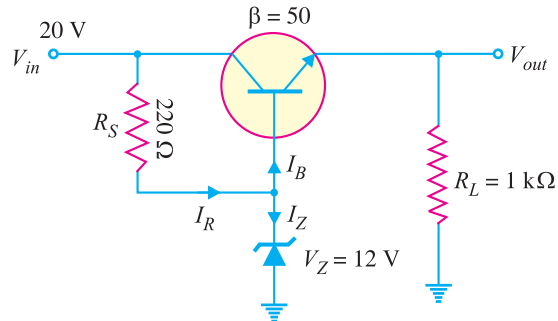
Example 17.14. For the series voltage regulator shown in Fig. 17.15, calculate (i) output voltage and (ii) zener current.

Solution.

$$(i) \quad V_{out} = V_Z - V_{BE} = 12 - 0.7 = \mathbf{11.3\text{ V}}$$

$$(ii) \quad \text{Voltage across } R_S = V_{in} - V_Z = 20 - 12 = 8\text{ V}$$

$$\text{Current through } R_S, I_R = \frac{8\text{ V}}{220\ \Omega} = 36.4\text{ mA}$$


Fig. 17.15

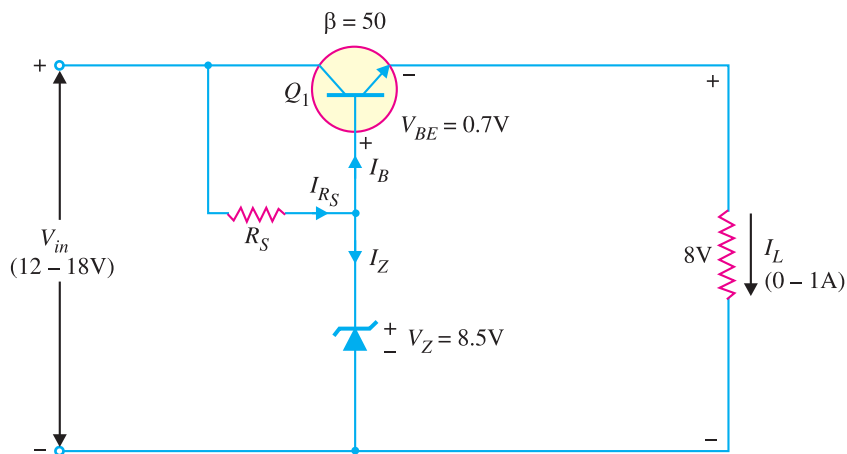
$$\text{Load current, } I_L = \frac{V_{out}}{R_L} = \frac{11.3 \text{ V}}{1 \text{ k}\Omega} = 11.3 \text{ mA}$$

$$\text{Base current, } I_B = \frac{I_C}{\beta} = \frac{11.3}{50} = 0.226 \text{ mA}$$

$$\therefore \text{ Zener current, } I_Z = I_R - I_B = 36.4 - 0.226 \approx \mathbf{36 \text{ mA}}$$

Example 17.15. In a series transistor voltage regulator (See Fig. 17.16), the load current varies from 0 – 1A and the unregulated d.c. input varies from 12 – 18V. The 8.5V zener diode requires atleast 1 mA of current to stay in its regulating region (i.e. $I_{Z(\min)} = 1 \text{ mA}$).

- (i) Determine the value of R_S to ensure proper circuit operation.
- (ii) Determine maximum power dissipation in R_S .
- (iii) Determine maximum power dissipation in zener diode.


Fig. 17.16

Solution.

(i) The value of R_S should be such that it supplies current for the base of transistor Q_1 and for the zener diode to keep it in the regulating region. The worst condition occurs at the minimum input voltage and maximum load current. This means that under worst condition, the current through R_S must be atleast $I_{Z(\min)} = 1 \text{ mA}$ plus maximum base current.

$$I_{B(\max)} = \frac{I_{L(\max)}}{\beta} = \frac{1 \text{ A}}{50} = 20 \text{ mA}$$

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$$\begin{aligned} I_{R_S} &= I_{Z(\min)} + I_{B(\max)} \\ &= 1 + 20 = 21 \text{ mA} \end{aligned}$$

Now 21 mA must be drawn by R_S under all conditions of input voltage variations—even when the input voltage falls to 12V which causes the minimum voltage across R_S and hence the lowest value of current it will be able to supply.

$$\begin{aligned} \therefore R_S &= \frac{V_{in(\min)} - V_Z}{I_{R_S}} \\ &= \frac{(12 - 8.5) \text{ V}}{21 \text{ mA}} = \frac{3.5 \text{ V}}{21 \text{ mA}} = \mathbf{166 \Omega} \end{aligned}$$

(ii) The maximum power dissipation in R_S occurs when the voltage across it is maximum.

$$\text{Max. voltage across } R_S, V_{R_S(\max)} = V_{in(\max)} - V_Z = 18 - 8.5 = 9.5 \text{ V}$$

$$\therefore \text{Max. power dissipated in } R_S = \frac{(V_{R_S(\max)})^2}{R_S} = \frac{(9.5)^2}{166} = \mathbf{0.542 \text{ W}}$$

(iii) Maximum power dissipation in zener occurs when current through it is maximum. The zener current will be maximum when V_{in} is maximum and load current is minimum (*i.e.* $I_L = 0$). Now $I_L = 0$ means $I_E = 0$ and hence $I_B = 0$. This, in turn, means that all the current passing through R_S will pass through the zener diode.

$$\begin{aligned} \therefore I_{Z(\max)} &= I_{R_S(\max)} = \frac{V_{in(\max)} - V_Z}{R_S} \\ &= \frac{18 \text{ V} - 8.5 \text{ V}}{166 \Omega} = \mathbf{57.2 \text{ mA}} \end{aligned}$$

\therefore Max. power dissipated in zener diode is

$$\begin{aligned} P_{Z(\max)} &= V_Z I_{Z(\max)} \\ &= 8.5 \text{ V} \times 57.2 \text{ mA} = \mathbf{0.486 \text{ W}} \end{aligned}$$

17.8 Series Feedback Voltage Regulator

Fig. 17.17 shows the circuit of series feedback voltage regulator. It employs principles of negative feedback to hold the output voltage almost constant despite changes in line voltage and load current. The transistor Q_2 is called a *pass transistor* because all the load current passes through it. The sample and adjust circuit is the voltage divider that consists of R_1 and R_2 . The voltage divider samples the output voltage and delivers a negative feedback voltage to the base of Q_1 . The feedback voltage V_F controls the collector current of Q_1 .

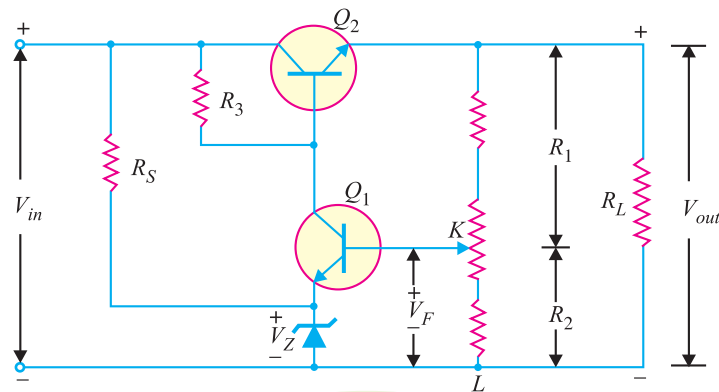


Fig. 17.17

Operation. The unregulated d.c. supply is fed to the voltage regulator. The circuit maintains constant output voltage irrespective of the variations in load or input voltage. Here is how the circuit operates.

(i) Suppose the output voltage increases due to any reason. This causes an increase in voltage across R_L (*i.e.*, R_2) as it is a part of the output circuit. This in turn means that more V_F is fed back to the base of transistor Q_1 ; producing a large collector current of Q_1 . Most of this collector current flows through R_3 and causes the base voltage of Q_2 to decrease. This results in less output voltage *i.e.*, increase in voltage is offset. Thus output voltage remains constant.

(ii) Similarly, if output voltage tries to decrease, the feedback voltage V_F also decreases. This reduces the current through Q_1 and R_3 . This means more base voltage at Q_2 and more output voltage. Consequently, the output voltage remains at the original level.

Output Voltage. The voltage divider $R_1 - R_2$ provides the feedback voltage.

$$\text{Feedback fraction, } m = \frac{V_F}{V_{out}} = \frac{R_2}{R_1 + R_2}$$

$$\text{Closed loop voltage gain, } A_{CL} = \frac{1}{m} = \frac{R_1 + R_2}{R_2} = 1 + \frac{R_1}{R_2}$$

Now $V_F = V_Z + V_{BE}$
 or $m V_{out} = V_Z + V_{BE}$ ($\because V_F = m V_{out}$)

or $V_{out} = \frac{V_Z + V_{BE}}{m}$

or $V_{out} = A_{CL} (V_Z + V_{BE})$ ($\because 1/m = A_{CL}$)

Therefore, the regulated output voltage is equal to closed-loop voltage gain times the sum of zener voltage and base-emitter voltage.

17.9 Short-Circuit Protection

The main drawback of any series regulator is that the pass transistor can be destroyed by excessive load current if the load is accidentally shorted. To avoid such an eventuality, a current limiting circuit is added to a series regulator as shown in Fig. 17.18. A current limiting circuit consists of a transistor (Q_3) and a series resistor (R_4) that is connected between base and emitter terminals.

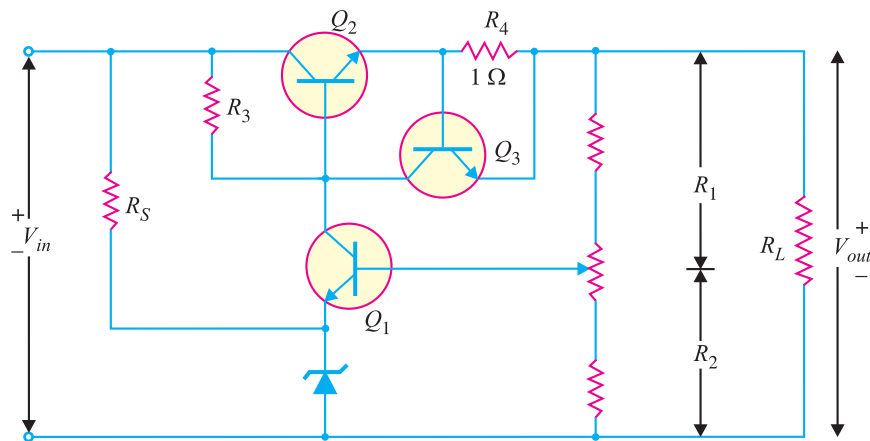


Fig. 17.18

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(i) When the load current is normal, the voltage across R_4 (= voltage across base-emitter of Q_3) is small and Q_3 is *off. Under this condition, the circuit works as described earlier.

(ii) If load current becomes excessive, the voltage across R_4 becomes large enough to turn on Q_3 . The collector current of Q_3 flows through R_3 , thereby decreasing the base voltage of Q_2 . The decrease in base voltage of Q_2 reduces the conduction of pass transistor (*i.e.*, Q_2), preventing any further increase in load current. Thus, the load current for the circuit is limited to about 700 mA.

Example 17.16. In the series feedback voltage regulator shown in Fig. 17.18, $R_1 = 2 \text{ k}\Omega$, $R_2 = 1 \text{ k}\Omega$, $V_Z = 6 \text{ V}$ and $V_{BE} = 0.7 \text{ V}$. What is the regulated output voltage?

Solution.

$$\text{Feedback fraction, } m = \frac{R_2}{R_1 + R_2} = \frac{1}{2+1} = \frac{1}{3}$$

$$\therefore \text{ Closed-loop voltage gain, } A_{CL} = \frac{1}{m} = 3$$

$$\begin{aligned} \therefore \text{ Regulated output voltage, } V_{out} &= A_{CL} (V_Z + V_{BE}) \\ &= 3 (6 + 0.7) = \mathbf{20.1 \text{ V}} \end{aligned}$$

Example 17.17. In the series feedback regulator circuit shown in Fig. 17.18, $R_1 = 30 \text{ k}\Omega$ and $R_2 = 10 \text{ k}\Omega$. What is the closed loop voltage gain?

Solution. Feedback fraction, $m = \frac{R_2}{R_1 + R_2} = \frac{10}{30+10} = \frac{1}{4}$

$$\therefore \text{ Closed-loop voltage gain, } A_{CL} = \frac{1}{m} = \mathbf{4}$$

17.10 Transistor Shunt Voltage Regulator

A shunt voltage regulator provides regulation by shunting current away from the load to regulate the output voltage. Fig. 17.19 shows the circuit of shunt voltage regulator. The voltage drop across series resistance depends upon the current supplied to the load R_L . The output voltage is equal to the sum of zener voltage (V_Z) and transistor base-emitter voltage (V_{BE}) *i.e.*,

$$V_{out} = V_Z + V_{BE}$$

If the load resistance decreases, the current through base of transistor decreases. As a result, less collector current is shunted. Therefore, the load current becomes larger, thereby maintaining the regulated voltage across the load. Reverse happens should the load resistance increase.

Drawbacks. A shunt voltage regulator has the following drawbacks :

- * In order that Q_3 is ON, voltage across R_4 must be about 0.7 V. This means that load current then is $I_L = 0.7\text{V} / 1 \Omega = 700 \text{ mA}$. Therefore, if load current is less than 700 mA, Q_3 is off. If load current is more than 700 mA, Q_3 will be turned on.

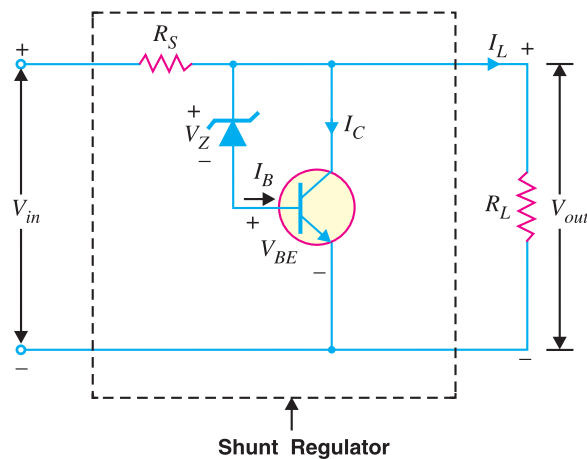


Fig. 17.19

- (i) A large portion of the total current through R_S flows through transistor rather than to the load.
 - (ii) There is considerable power loss in R_S .
 - (iii) There are problems of overvoltage protection in this circuit.
- For these reasons, a series voltage regulator is preferred over the shunt voltage regulator.

Example 17.18. Determine the (i) regulated voltage and (ii) various currents for the shunt regulator shown in Fig. 17.20.

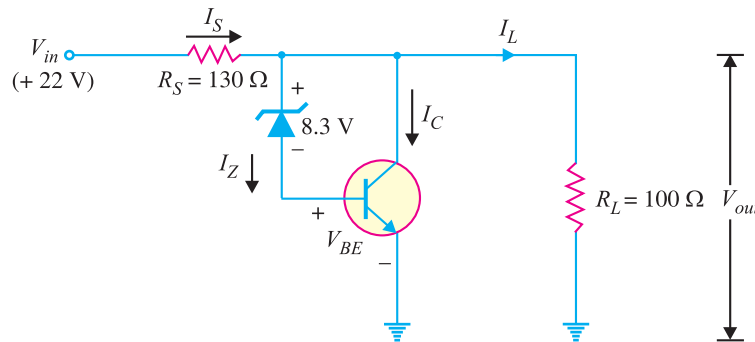


Fig. 17.20

Solution. (i) Output voltage, $V_{out} = V_Z + V_{BE} = 8.3 + 0.7 = 9\text{ V}$

(ii) Load current, $I_L = \frac{V_{out}}{R_L} = \frac{9\text{ V}}{100\ \Omega} = 90\text{ mA}$

Current through R_S , $I_S = \frac{V_{in} - V_{out}}{R_S} = \frac{22 - 9}{130} = \frac{13\text{ V}}{130\ \Omega} = 100\text{ mA}$

\therefore Collector current, $I_C = I_S - I_L = 100 - 90 = 10\text{ mA}$

17.11 Shunt Feedback Voltage Regulator

This circuit is an improved form of the simple series voltage regulator discussed in Art. 17.8. As we shall see, this regulator is nearly identical to the series feedback regulator.

Circuit details. Fig. 17.21 shows the various parts of a shunt feedback voltage regulator. This circuit uses an error detector (Q_2) to control the conduction of a *shunt transistor* (Q_1). The error detector (Q_2) receives two inputs : a *reference voltage* and a *sample voltage*. The sample circuit is a simple voltage divider circuit ($R_2 - R_3 - R_4$) and derives the sample voltage from the regulated output voltage. The reference circuit is made up of zener D_1 and R_1 and derives the reference voltage from the unregulated d.c. input voltage. The outputs from the sample and reference circuits are applied to the error detector (Q_2). The output from Q_2 is used to control the conduction of the shunt transistor Q_1 . Since Q_1 (shunt transistor) is in parallel with load R_L , the change in the current conduction through Q_1 can control the load voltage.

Circuit operation. In a shunt feedback voltage regulator, the outputs from the sample and reference circuits are applied to the *error detector/amplifier* Q_2 . The output from Q_2 controls the conduction current through the shunt transistor Q_1 to maintain the constant load voltage V_L .

* Note that transistor Q_1 is in parallel with the load, it is called shunt transistor and hence the name of the regulator.

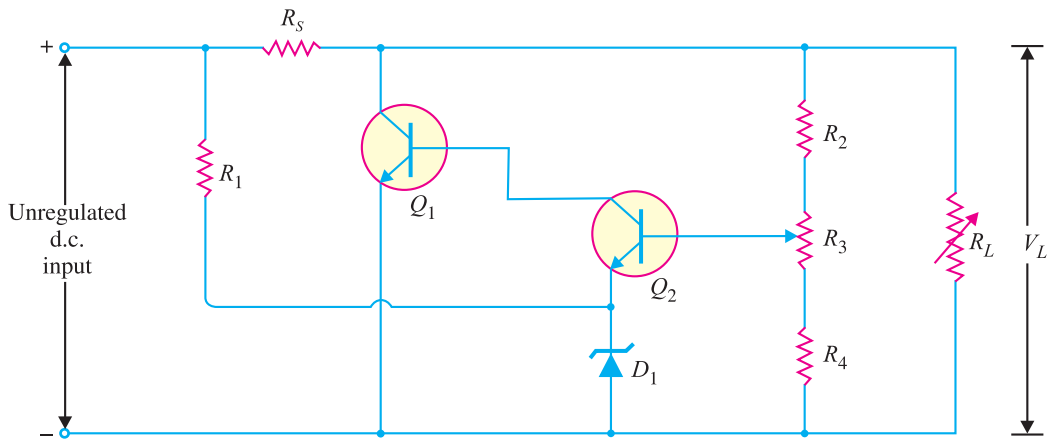


Fig. 17.21

(i) Suppose the load voltage V_L decreases due to any reason. This decrease causes the base voltage of Q_2 [$V_{B(Q2)}$] to decrease. Since emitter voltage of Q_2 [$V_{E(Q2)}$] is set to a fixed value (V_Z) by the zener diode, $V_{BE(Q2)}$ decreases when $V_{B(Q2)}$ decreases. This decreases base current $I_{B(Q1)}$ through the base of transistor Q_1 . This in turn causes I_{C1} to decrease; thus increasing $V_{C(Q1)}$. Since $V_L = V_{C(Q1)}$, the increase in $V_{C(Q1)}$ offsets the initial decrease in V_L .

(ii) Suppose the load voltage increases due to any reason. This increases the conduction through Q_2 , causing an increase in $I_{B(Q1)}$. The increase in $I_{B(Q1)}$ causes the shunt transistor's conduction to increase, decreasing $V_{C(Q1)}$. The decrease in $V_{C(Q1)}$ offsets the initial increase in V_L .

17.12 Glow-Tube Voltage Regulator

As discussed in chapter 3, when a glow tube (cold cathode gas diode) is operated in the *normal glow region*, the voltage across the tube remains constant over a wide range of tube current. This characteristic permits it to be used as a voltage regulator. Fig. 17.22 shows the circuit of a glow-tube voltage regulator. The unregulated d.c. input voltage must exceed the striking voltage of the tube. Once the gas in the tube ionises, the voltage across the tube and the load will drop to the ionising voltage. The tube will maintain constant voltage so long as the input d.c. voltage is greater than this value. The resistance R_S is used to limit the input current.

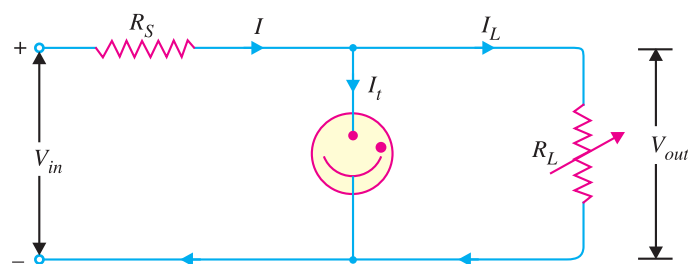


Fig. 17.22

Operation. The glow tube will maintain constant voltage across the load in spite of the changes in load current or input voltage. Now, should the load decrease, the output voltage would tend to

increase. The glow tube will draw more current *without any increase in the output voltage. Meanwhile, the drop in load current is offset by the increase in tube current and the current through R_S remains constant. As output voltage = $V_{in} - IR_S$, therefore, output voltage remains unchanged. Similarly, the circuit will maintain constant output voltage if the input voltage changes. Suppose the input voltage decreases due to any reason. This would result in less current flow through the glow tube. Consequently, the voltage drop across R_S decreases, resulting in constant voltage across the load.

17.13 Series Triode Voltage Regulator

Fig. 17.23 shows the circuit of a series triode voltage regulator. It is similar to series transistor regulator except that here triode and glow tube are used instead of transistor and zener diode. The resistance R and glow tube (V.R.) help to maintain constant potential across the load. A potentiometer R_p is connected across the glow tube and its variable point is connected to the grid of the triode.

Operation. The d.c. input V_{in} from the unregulated power supply is fed to the voltage regulator. The circuit will maintain constant output voltage (V_{out}) inspite of changes in load current or input voltage. The output voltage is given by :

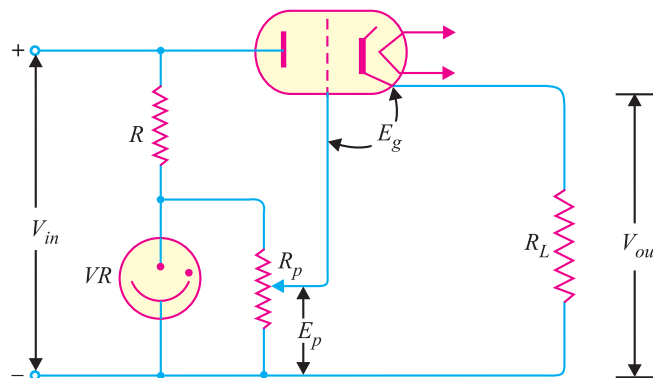


Fig. 17.23

$$V_{out} = E_p + E_g$$

Now, E_p is constant because the glow tube is operating in the normal glow region. Also grid voltage E_g is constant because it hardly depends upon plate current. Therefore, output will remain accurately fixed at one value. Any increase in the output voltage causes greater voltage drop across the limiting resistance R , tending to restore the output voltage to the original value.

17.14 Series Double Triode Voltage Regulator

Fig. 17.24 shows the circuit of a series double triode voltage regulator. Triodes T_1 and T_2 are used as direct coupled feedback amplifier in which output voltage variations are returned as feedback to oppose the input changes. The glow tube VR maintains the cathode of triode T_2 at constant potential w.r.t. ground. The triode T_2 functions as a control tube and obtains bias from the potentiometer R_3 . The resistances R_3 and R_4 are range limiting resistors. The capacitor across VR tube helps to minimise the tendency of the circuit to generate audio frequency oscillations.

* More current will cause further ionisation, decreasing the tube resistance. Therefore, voltage across the tube remains unchanged.

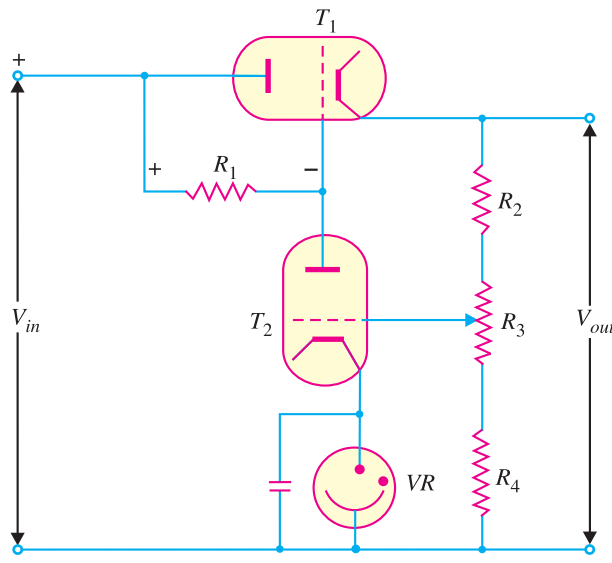


Fig. 17.24

Operation. The unregulated d.c. supply is fed to the voltage regulator. The circuit will produce an output voltage (V_{out}) which is independent of changes in input voltage and of changes in the load over a wide range. With a decrease in load or increase in the input voltage, there would be tendency for the voltage across the resistive network R_2 , R_3 and R_4 to rise. The result is that voltage on the grid of triode T_2 becomes less negative. The triode T_2 then conducts more current and a greater current flows through R_1 which causes a greater voltage drop across this resistor. The increase in voltage across R_1 will raise the negative potential on the grid of triode T_1 . This increases the resistance of T_1 and hence the voltage across it. The rise in voltage across T_1 tends to decrease the output voltage. The reverse would be true should the load increase or input voltage decrease.

17.15 IC Voltage Regulators

We can also use integrated circuits (IC) to produce voltage regulators. One advantage of IC voltage regulators is that properties like thermal compensation, short circuit protection and surge protection can be built into the device. Most of the commonly used IC voltage regulators are three-terminal devices. Fig. 17.25 shows the schematic symbol for a three-terminal IC voltage regulator.

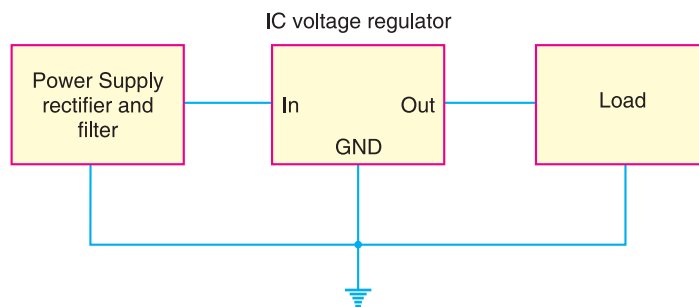


Fig. 17.25

There are basically four types of IC voltage regulators viz.

- (i) Fixed positive voltage regulators
- (ii) Fixed negative voltage regulators

- (iii) Adjustable voltage regulators
- (iv) Dual-tracking voltage regulators

The *fixed positive* and *fixed negative IC voltage regulators* are designed to provide specific output voltages. For example, *LM 309* (fixed positive) provides a + 5V d.c. output (as long as the regulator input voltages are within the specified ranges). The *adjustable voltage regulator* can be adjusted to provide any d.c. output voltage that is within its two specified limits. For example, the *LM 317* output can be adjusted to any value between its limits of 1.2V and 32V d.c. Both positive and negative adjustable regulators are available. The *dual-tracking regulator* provides equal positive and negative output voltages. For example, the *RC 4195* provides outputs of + 15V and – 15V d.c. Adjustable dual-tracking regulators are also available.

17.16 Fixed Positive Voltage Regulators

This *IC* regulator provides a fixed positive output voltage. Although many types of *IC* regulators are available, the 7800 series of *IC* regulators is the most popular. The last two digits in the part number indicate the d.c. output voltage. For example [See Table below], the 7812 is a + 12V regulator whereas the 7805 is a + 5V regulator. Note that this series (7800 series) provides fixed regulated voltages from + 5 V to + 24V.

Type number	Output voltage
7805	+5.0 V
7806	+6.0 V
7808	+8.0 V
7809	+9.0 V
7812	+12.0 V
7815	+15.0 V
7818	+18.0 V
7824	+24.0 V

The 7800 series

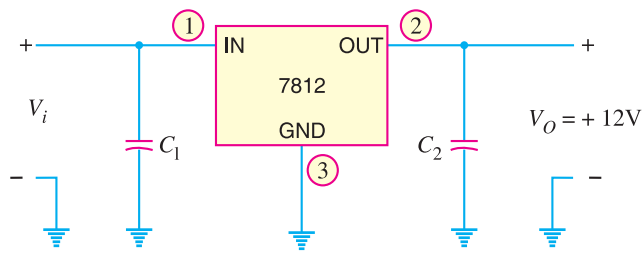


Fig. 17.26

Fig. 17.26 shows how the 7812 *IC* is connected to provide a fixed d.c. output of + 12V. The unregulated input voltage V_i is connected to the *IC*'s *IN* terminal and the *IC*'s *OUT* terminal provides + 12V. Capacitors, although not always necessary, are sometimes used on the input and output as shown in Fig. 17.26. The output capacitor (C_2) acts basically as a line filter to improve transient response. The input capacitor (C_1) is used to prevent unwanted oscillations.

Example 17.19. Draw a voltage supply using a full-wave bridge rectifier, capacitor filter and *IC* regulator to provide an output of + 5V.

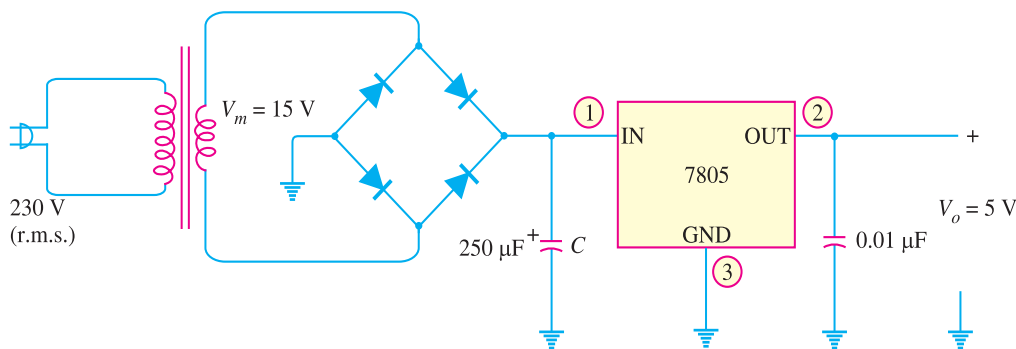


Fig. 17.27

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Solution. The resulting circuit is shown in Fig. 17.27. Here we use 7805 IC with unregulated power supply.

17.17 Fixed Negative Voltage Regulators

This IC regulator provides a fixed negative output voltage. The 7900 series of IC regulators is commonly used for this purpose. This series (7900) is the negative-voltage counterpart of the 7800 series [See Table below]. Note that 7900 series provides fixed regulated voltages from -5 V to -24 V .

Type number	Output voltage
7905	-5.0 V
7905.2	-5.2 V
7906	-6.0 V
7908	-8.0 V
7912	-12.0 V
7915	-15.0 V
7918	-18.0 V
7924	-24.0 V

The 7900 series

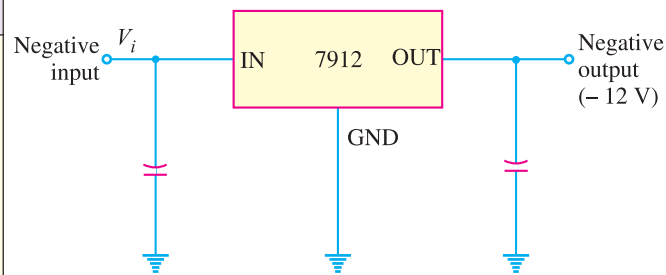


Fig. 17.28

Fig. 17.28 shows how 7912 IC is connected to provide a fixed d.c. output of -12 V . The unregulated negative input voltage V_i is connected to IC's IN terminal and the IC's OUT terminal provides -12 V . Capacitors used in the circuit perform the same function as in a fixed positive regulator.

17.18 Adjustable Voltage Regulators

The adjustable voltage regulator can be adjusted to provide any d.c. output voltage that is within its two specified limits. The most popular three-terminal IC adjustable voltage regulator is the LM 317. It has an input terminal, output terminal and an adjustment terminal. An external voltage divider is used to change the d.c. output voltage of the regulator. By changing R_2 , a wide range of output voltages can be obtained.

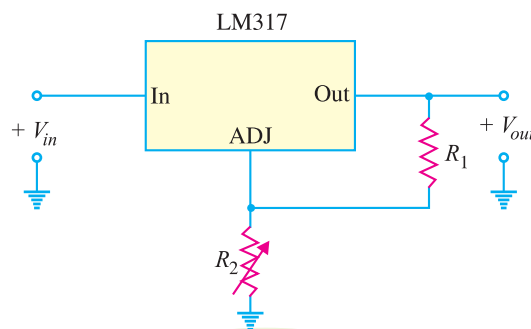


Fig. 17.29

The LM 317 is a three-terminal positive adjustable voltage regulator and can supply 1.5 A of load current over an adjustable output range of 1.25 V to 37 V . Fig. 17.29 shows an unregulated power supply driving an LM 317 circuit. The data sheet of an LM 317 gives the following formula for the output voltage :

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

This formula is valid from 1.25 V to 37 V .

Example 17.20. In Fig. 17.30, R_2 is adjusted to 2.4 k Ω . Determine the regulated d.c. output voltage for the circuit.

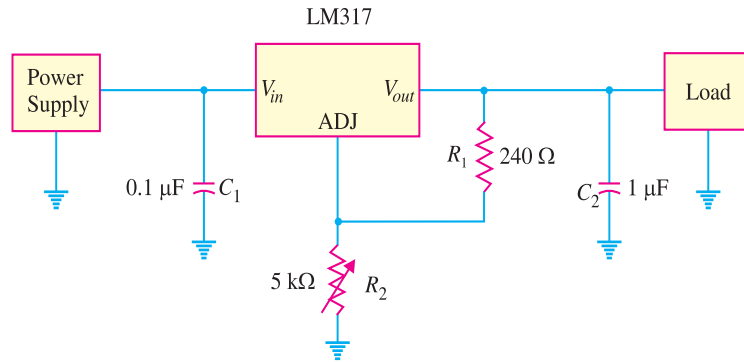


Fig. 17.30

Solution. The regulated d.c. output voltage for the circuit is given by ;

$$\begin{aligned}
 V_{out} &= 1.25 \left(\frac{R_2}{R_1} + 1 \right) \\
 &= 1.25 \left(\frac{2.4 \text{ k}\Omega}{240 \Omega} + 1 \right) = (1.25) (11) = \mathbf{13.75V}
 \end{aligned}$$

Example 17.21. The LM 317 is adjusted to provide a + 8 V_{dc} regulated output voltage. Determine the maximum allowable input voltage to the device.

Solution. The maximum allowable difference between V_{in} and V_{out} of an adjustable voltage regulator is called its input/output differential rating and is denoted by V_d . If this rating is exceeded, the device may be damaged. For the LM 317, $V_d = 40V$. Therefore, the maximum allowable value of input voltage is

$$\begin{aligned}
 V_{in(max)} &= V_{out(adj)} + V_d \\
 &= + 8 V_{dc} + 40 = \mathbf{+ 48V}
 \end{aligned}$$

17.19 Dual-Tracking Voltage Regulators

The dual-tracking regulator provides equal positive and negative output voltages. This regulator is used when split-supply voltages are needed. The RC 4195 IC provides d.c. outputs of + 15V and - 15V. The device needs two unregulated input voltages. The positive input may be from + 18V to + 30V and the negative input from - 18V to -30V. As shown, the two outputs

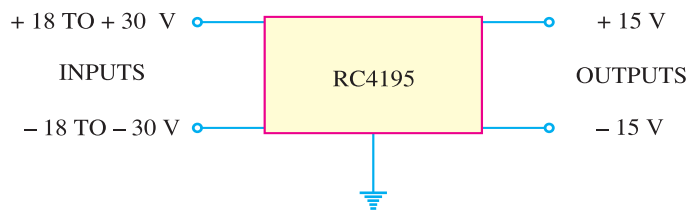


Fig. 17.31

are $\pm 15V$. The data sheet of an RC 4195 lists a maximum output current of 150 mA for each supply and a load regulation of 3mV. Adjustable dual-tracking regulators are also available. These regulators have outputs that can be varied between their two rated limits.

MULTIPLE-CHOICE QUESTIONS

1. In an unregulated power supply, if load current increases, the output voltage
 - (i) remains the same
 - (ii) decreases (iii) increases
 - (iv) none of the above
2. In an unregulated power supply, if input a.c. voltage increases, the output voltage
 - (i) increases (ii) decreases
 - (iii) remains the same
 - (iv) none of the above
3. A power supply which has a voltage regulation of is unregulated power supply.
 - (i) 0 % (ii) 0.5 %
 - (iii) 10 % (iv) 0.8 %
4. Commercial power supplies have voltage regulation
 - (i) of 10 % (ii) of 15 %
 - (iii) of 25 % (iv) within 1 %
5. An ideal regulated power supply is one which has voltage regulation of
 - (i) 0 % (ii) 5 %
 - (iii) 10 % (iv) 1 %
6. A zener diode utilises characteristic for voltage regulation.
 - (i) forward (ii) reverse
 - (iii) both forward and reverse
 - (iv) none of the above
7. Zener diode can be used as
 - (i) d.c. voltage regulator only
 - (ii) a.c. voltage regulator only
 - (iii) both d.c. and a.c. voltage regulator
 - (iv) none of the above
8. A zener diode is used as a voltage regulating device.
 - (i) shunt (ii) series
 - (iii) series-shunt (iv) none of the above
9. As the junction temperature increases, the voltage breakdown point for zener mechanism
 - (i) is increased (ii) is decreased
 - (iii) remains the same
 - (iv) none of the above
10. The rupture of co-valent bonds will occur when the electric field is
 - (i) 100 V/cm (ii) 0.6 V/cm
 - (iii) 1000 V/cm
 - (iv) more than 10^5 V/cm
11. In a 15 V zener diode, the breakdown mechanism will occur by
 - (i) avalanche mechanism
 - (ii) zener mechanism
 - (iii) both zener and avalanche mechanism
 - (iv) none of the above
12. A zener diode that has very narrow depletion layer will breakdown by mechanism.
 - (i) avalanche (ii) zener
 - (iii) both avalanche and zener
 - (iv) none of the above
13. As the junction temperature increases, the voltage breakdown point for avalanche mechanism
 - (i) remains the same
 - (ii) decreases (iii) increases
 - (iv) none of the above
14. Another name for zener diode is diode.
 - (i) breakdown (ii) voltage
 - (iii) power (iv) current
15. Zener diodes are generally made of
 - (i) germanium (ii) silicon
 - (iii) carbon (iv) none of the above
16. For increasing the voltage rating, zeners are connected in.....
 - (i) parallel (ii) series-parallel
 - (iii) series (iv) none of the above
17. In a zener voltage regulator, the changes in load current produce changes in
 - (i) zener current (ii) zener voltage
 - (iii) zener voltage as well as zener current
 - (iv) none of the above

18. A zener voltage regulator is used for load currents.
 (i) high (ii) very high
 (iii) moderate (iv) small
19. A zener voltage regulator will cease to act as a voltage regulator if zener current becomes
 (i) less than load current (ii) zero
 (iii) more than load current
 (iv) none of the above
20. If the doping level is increased, the breakdown voltage of the zener
 (i) remains the same
 (ii) is increased (iii) is decreased
 (iv) none of the above
21. A 30 V zener will have depletion layer width that of 10 V zener.
 (i) more than (ii) less than
 (iii) equal to (iv) none of the above
22. The current in a zener diode is limited by
 (i) external resistance
 (ii) power dissipation
 (iii) both (i) and (ii)
 (iv) none of the above
23. A 5 mA change in zener current produces a 50 mV change in zener voltage. What is the zener impedance ?
 (i) 1 Ω (ii) 0.1 Ω
 (iii) 100 Ω (iv) 10 Ω
24. A certain regulator has a no-load voltage of 6 V and a full-load output of 5.82 V. What is the load regulation ?
 (i) 3.09 % (ii) 2.87 %
 (iii) 5.72 % (iv) none of the above
25. What is true about the breakdown voltage in a zener diode ?
 (i) It decreases when load current increases.
 (ii) It destroys the diode.
 (iii) It equals current times the resistance.
 (iv) It is approximately constant.
26. Which of these is the best description for a zener diode ?
 (i) It is a diode.
 (ii) It is a constant-current device.
 (iii) It is a constant-voltage device.
 (iv) It works in the forward region.
27. A zener diode
 (i) is a battery
 (ii) acts like a battery in the breakdown region
 (iii) has a barrier potential of 1 V
 (iv) is forward biased
28. The load voltage is approximately constant when a zener diode is
 (i) forward biased
 (ii) unbiased
 (iii) reverse biased
 (iv) operating in the breakdown region
29. In a loaded zener regulator, which is the largest zener current ?
 (i) series current (ii) zener current
 (iii) load current (iv) none of the above
30. If the load resistance decreases in a zener regulator, then zener current
 (i) decreases (ii) stays the same
 (iii) increases (iv) none of the above
31. If the input a.c. voltage to unregulated or ordinary power supply increases by 5 %, what will be the approximate change in d.c. output voltage ?
 (i) 10 % (ii) 20 %
 (iii) 15 % (iv) 5 %
32. If the load current drawn by unregulated power supply increases, the d.c. output voltage
 (i) increases (ii) decreases
 (iii) stays the same (iv) none of the above
33. If a power supply has no-load and full-load voltages of 30 V and 25 V respectively, then percentage voltage regulation is
 (i) 10 % (ii) 20 %
 (iii) 15 % (iv) none of the above
34. A power supply has a voltage regulation of 1 %. If the no-load voltage is 20 V, what is the full-load voltage ?
 (i) 20.8 V (ii) 15.7 V
 (iii) 18.6 V (iv) 17.2 V
35. Two similar 15 V zeners are connected in series. What is the regulated output voltage?
 (i) 15 V (ii) 7.5 V
 (iii) 30 V (iv) 45 V

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36. A power supply can deliver a maximum rated current of 0.5 A at full-load output voltage of 20 V. What is the minimum load resistance that you can connect across the supply?
 (i) 10 Ω (ii) 20 Ω
 (iii) 15 Ω (iv) 40 Ω
37. In a regulated power supply, two similar 15 V zeners are connected in series. The input voltage is 45 V d.c. If each zener has a maximum current rating of 300 mA, what should be the value of series resistance ?
 (i) 10 Ω (ii) 50 Ω
 (iii) 25 Ω (iv) 40 Ω
38. A zener regulator in the power supply.
 (i) increases the ripple
 (ii) decreases the ripple
 (iii) neither increases nor decreases ripple
 (iv) data insufficient
39. When load current is zero, the zener current will be
 (i) zero (ii) minimum
 (iii) maximum (iv) none of the above
40. The zener current will be minimum when
 (i) load current is maximum
 (ii) load current is minimum
 (iii) load current is zero
 (iv) none of the above

Answers to Multiple-Choice Questions

- | | | | | |
|-----------|-----------|-----------|-----------|-----------|
| 1. (ii) | 2. (i) | 3. (iii) | 4. (iv) | 5. (i) |
| 6. (ii) | 7. (iii) | 8. (i) | 9. (ii) | 10. (iv) |
| 11. (i) | 12. (ii) | 13. (iii) | 14. (i) | 15. (ii) |
| 16. (iii) | 17. (i) | 18. (iv) | 19. (ii) | 20. (iii) |
| 21. (i) | 22. (iii) | 23. (iv) | 24. (i) | 25. (iv) |
| 26. (iii) | 27. (ii) | 28. (iv) | 29. (i) | 30. (i) |
| 31. (iv) | 32. (ii) | 33. (ii) | 34. (i) | 35. (iii) |
| 36. (iv) | 37. (ii) | 38. (ii) | 39. (iii) | 40. (i) |

Chapter Review Topics

- What do you understand by unregulated power supply ? Draw the circuit of such a supply.
- What are the limitations of unregulated power supply ?
- What do you understand by regulated power supply ? Draw the block diagram of such a supply.
- Write a short note on the need for regulated power supply.
- Explain the action of a zener voltage regulator with a neat diagram.
- Write short notes on the following :
 (i) Transistor series voltage regulator
 (ii) Negative feedback voltage regulator
 (iii) Glow tube voltage regulator
- What are the limitations of transistorised power supplies ?
- Draw the circuit of the most practical valve operated power supply and explain its working.

Problems

- A voltage regulator is rated at an output current of $I_L = 0$ to 40 mA. Under no-load conditions, the output voltage from the circuit is 8V. Under full-load conditions, the output voltage from the circuit is 7.996 V. Determine the value of load-regulation for the circuit. **[100 μ V/mA]**
- The zener diode in Fig. 17.32 has values of $I_{Z(min)} = 3$ mA and $I_{Z(max)} = 100$ mA. What is the minimum allowable value of R_L ? **[241 Ω]**

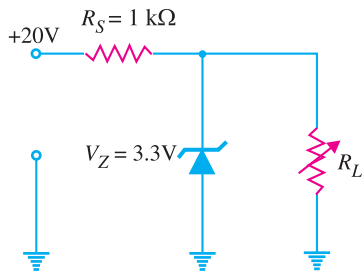


Fig. 17.32

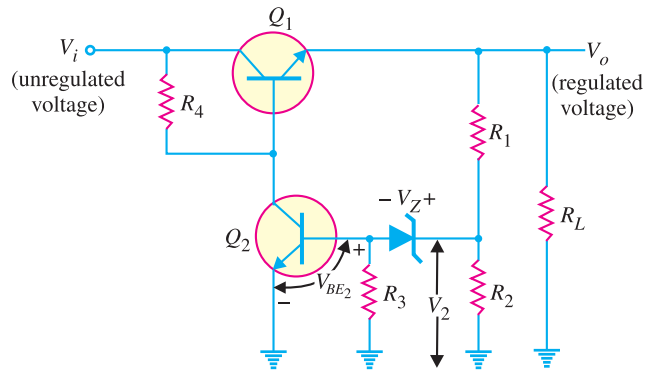


Fig. 17.33

3. What regulated output voltage is provided by the circuit of Fig. 17.33 for circuit elements : $R_1 = 20 \text{ k}\Omega$, $R_2 = 30 \text{ k}\Omega$ and $V_Z = 8.3\text{V}$? [15 V]
4. Calculate the output voltage and zener diode current in the regulator circuit of Fig. 17.34 [7.6 V, 3.66 mA]

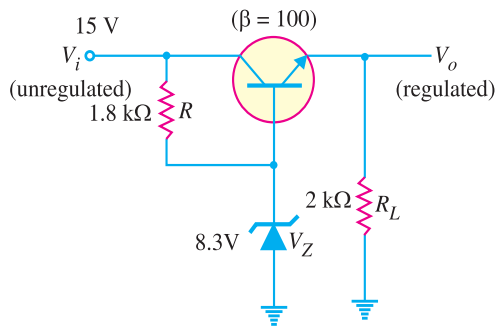


Fig. 17.34

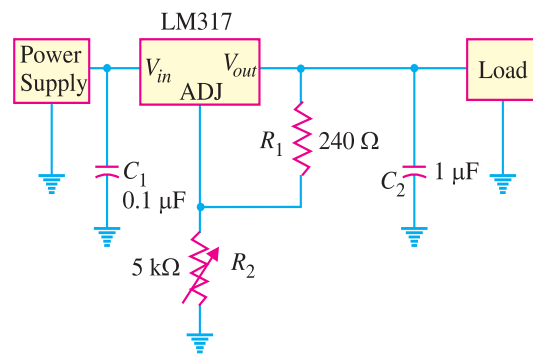


Fig. 17.35

5. If R_2 in Fig. 17.35 is adjusted to $1.68 \text{ k}\Omega$, determine the regulated d.c.output voltage for the LM 317. [10 V]

Discussion Questions

1. Why do you prefer d.c. power supply to batteries ?
2. How can you improve the regulation of an ordinary power supply ?
3. How does zener maintain constant voltage across load in the breakdown region?
4. Why is ionising potential of glow tube less than striking potential ?
5. What is the practical importance of voltage regulation in power supplies ?