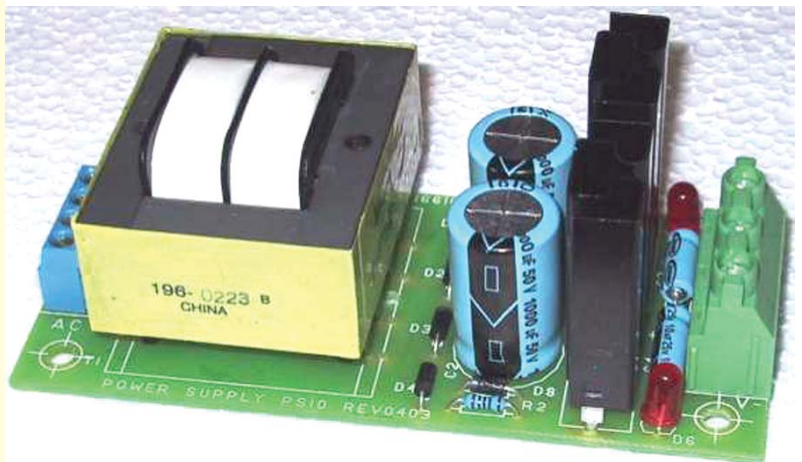


CHAPTER 56

Learning Objectives

- General
- Voltage Regulation
- Zener Diode Shunt Regulator
- Transistor Series Voltage Regulator
- Controlled Transistor Series Regulator
- Transistor Shunt Voltage Regulator
- Transistor Current Regulator
- Variable Feedback Regulator
- Basic OP-AMP Series Regulator
- Basic OP-AMP Shunt Regulator
- Switching Regulators
- Step-down Switching Regulator
- Step-up Switching Regulator
- Inverting Switching Regulator
- IC Voltage Regulators
- Fixed Positive Linear Voltage Regulators
- Fixed Negative Linear Voltage Regulators
- Adjustable Positive Output Linear Voltage Regulators
- Adjustable Negative Output Linear Voltage Regulators
- Use of External Pass Transistor with Linear Voltage Regulators
- Use of Linear Voltage Regulator as a Current Regulator
- Switching Voltage IC Regulators

REGULATED POWER SUPPLY



➤ Voltage regulator provides a constant dc output voltage that is essentially independent of the input voltage, output load current and temperature.

56.1. General

The various power-supply circuits considered in Chapter 5 suffer from the drawback that their dc output voltage changes with changes in load or input voltage. Such a dc power supply is called unregulated power supply. Regulated power supply can be obtained by using a voltage regulator circuit. A regulator is an electronic control circuit which is capable of providing a nearly constant dc output voltage even when there are variations in load or input voltage. A source of regulated dc power is essential for all communication, instrumentation, computers or any other electronic system.

We will consider both *linear* regulators and *switching* regulators which are also available in integrated circuit form. In linear regulators, the transistor operates somewhere between saturation and cut-off. It is always ON and dissipates power. Hence, its efficiency (output power/input power) is 50 per cent or less. In switching regulators, the transistor operates like a switch *i.e.* it is either saturated or cut-off. Hence, its power efficiency is 90 per cent or more.

The linear regulators are of two basic type *i.e.* series regulators and shunt regulators. Likewise switching regulators can be of three basic types *(i)* step-down type, *(ii)* step-up type and *(iii)* inverting type.

56.2. Voltage Regulation

As stated above, in an unregulated power supply, output voltage changes whenever input supply voltage or load resistance changes. It is never constant. The change in voltage from no-load to full-load condition is called *voltage regulation*. The aim of a voltage regulator circuit is to reduce these variations to zero or, at least, to the minimum possible value.

The percentage regulation or, simply, regulation of a power supply is given by

$$\% \text{ regulation} = \frac{V_{max} - V_{min}}{V_{max}} \times 100$$

where V_{max} = maximum dc output voltage and V_{min} = minimum dc output voltage.

When we say that 10 V regulated dc power supply has a regulation of 0.005 per cent, it means that dc output voltage will vary within an envelope 0.005 per cent of 10 V.

$$\begin{aligned} \text{Now, } 0.005\% \text{ of } 10 \text{ V} &= \frac{V_{max} - V_{min}}{V_{max}} \times 100 \\ &= 0.0005 \text{ V} = 0.5 \text{ mV} \end{aligned}$$

Hence, output voltage will vary by $\pm 0.25 \text{ mV}$. So, we see that instead of expressing voltage regulation by unwieldy expression 0.005 per cent, we can express it by a simple figure of $\pm 0.25 \text{ mV}$.

$$\text{In general, } \% \text{ regn.} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

where, V_{NL} = no-load or open-circuit terminal voltage of the supply (Fig. 56.1).
 V_{FL} = full-load terminal voltage of the supply

In an ideal or perfectly regulated dc power supply, the percentage voltage regulation is zero. This voltage regulation is also called *load regulation*.

56.3. Zener Diode Shunt Regulator

A simple shunt voltage regulating system using a zener diode is shown in Fig. 56.2. The

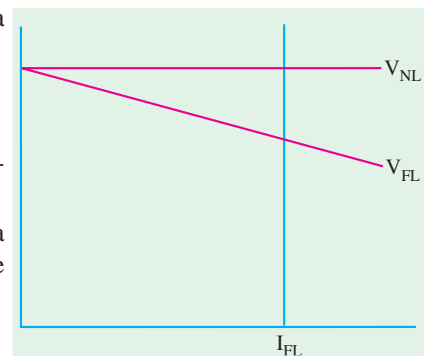


Fig. 56.1



input voltage V_{in} , in fact, is the unregulated output of a rectifier. This simple regulator restricts output voltage variations within reasonable limits around V_z in the face of changing load current or changing input voltage. Obviously, the Zener diode will regulate so long as it is kept in reverse conduction.

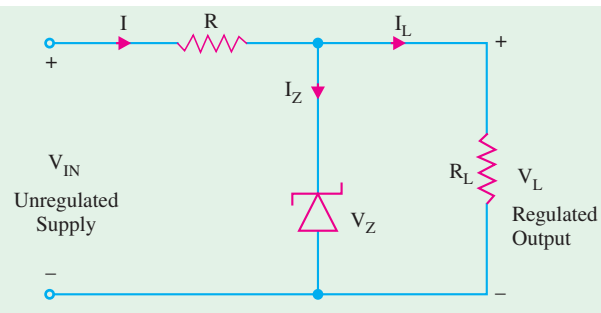


Fig. 56.2

Example 56.1. The Zener diode of Fig. 56.2 has the following ratings :

$$\begin{array}{ll} V_z = 6.8 \text{ V} & \text{at } I_z = 50 \text{ mA} \\ r_z = 2 \Omega & \text{at } I_z = 50 \text{ mA} \\ I_{z(\min)} = 5 \text{ mA} & I_{z(\max)} = 150 \text{ mA} \end{array}$$

What would be the load voltage when load current I_L varies from 10 mA to 120 mA ? Also, calculate voltage regulation of the regulator. (Power Electronics-I, Punjab Univ. 1992)

Solution. We will call $V_z = 6.8 \text{ V}$ and $I_z = 50 \text{ mA}$ as reference values and calculate changes in voltage with respect to these values.

(i) $I_L = 120 \text{ mA}$

$$\begin{aligned} \text{Obviously, } I_z &= 150 - 120 = 30 \text{ mA} \\ \text{Deviation from 50 mA} &= 30 - 50 = -20 \text{ mA} \\ \text{Drops across diode} &= I_z \cdot r_z = -20 \times 2 = -40 \text{ mV} \\ V_L &= V_z + I_z \cdot r_z = 6.8 + (-40 \times 10^{-3}) = \mathbf{6.76 \text{ V}} \end{aligned}$$

(ii) $I_L = 10 \text{ mA}$

$$\begin{aligned} \text{Now, } I_z &= 150 - 10 = 140 \text{ mA} \\ \text{Deviation from reference value} &= 140 - 50 = 90 \text{ mA} \\ \text{Diode drop} &= I_z \cdot r_z = 90 \times 10^{-3} \times 2 = 0.18 \text{ V} \\ \therefore V_L &= V_z + I_z \cdot r_z = 6.8 + 0.18 = \mathbf{6.98 \text{ V}} \end{aligned}$$

$$\% \text{ regn.} = \frac{6.98 - 6.76}{6.98} \times 100 = 3.15 \%$$

For many applications, a change in load voltage of 3.15% is acceptable but, in some, it may be intolerable. This regulation can be reduced to 1% or less with the help of circuits discussed below.

56.4. Transistor Series Voltage Regulator

The circuit is shown in Fig. 56.3. It is also called *emitter-follower* regulator because the voltage at the emitter follows the base voltage. In this set-up, the transistor behaves like a variable resistor whose resistance is determined by the base current. It is called *pass* transistor because total current to be regulated passes through it.

Keeping in mind the polarities of different voltages, they are related by the equation derived from *KVL*

$$V_L + V_{BE} - V_z = 0$$

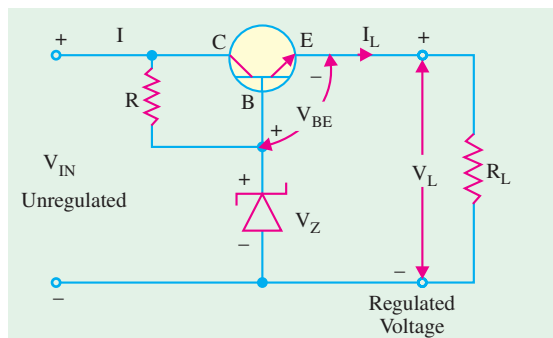


Fig. 56.3



$$\therefore V_{BE} = V_z - V_L$$

(fixed)

When current demand is increased by decreasing R_L , V_L tends to decrease. As seen from the above equation, it will increase V_{BE} because V_z is fixed. This will increase forward bias of the transistor thereby increasing its level of conduction. This, in turn, will lead to decrease in the collector-emitter resistance of the transistor which will slightly increase the input current in order to compensate for decrease in R_L so that $V_L = (I_L R_R)$ will remain at a constant value. Incidentally, R is used for limiting current passing through the Zener diode.

56.5. Controlled Transistor Series Regulator

The circuit employing a second transistor T_2 as a sensing element is shown in Fig. 56.4. It has the additional feature of control with the help of potentiometer $R_1 - R_2$. In the discussion to follow, it will be assumed that I is much greater than I_{B2} . Now, there is a drop of V_L on $(R_1 + R_2)$ and a drop of $(V_z + V_{BE2})$ across R_2 .

$$\frac{V_L}{V_z + V_{BE2}} = \frac{R_1 + R_2}{R_2} \quad \text{or} \quad V_L = \frac{R_1 + R_2}{R_2} (V_z + V_{BE2})$$

Now, $(R_1 + R_2)$ and $(V_z + V_{BE2})$ both have constant values so that $V_L \propto 1/R_2$. If the potentiometer is adjusted so that R_2 decreases, then V_L increases and *vice versa*.

Suppose R_L is decreased. Then, I_L increases but V_L decreases. Decreases in V_L decreases I_{B2} and I_{C2} . Assuming I_3 to be relatively constant (or decreasing only slightly), I_{B1} is increased thereby decreasing the terminal (collector-emitter) resistance of T_1 . This leads to decrease in V_{CE1} thereby offsetting the decrease in V_L which is, therefore, returned to its original value.

In sequential logic, we have

$$V_L \downarrow \quad I_{B2} \downarrow \quad I_{C2} \downarrow \quad I_{B1} \uparrow \quad V_{CE1} \downarrow \quad V_2 \uparrow$$

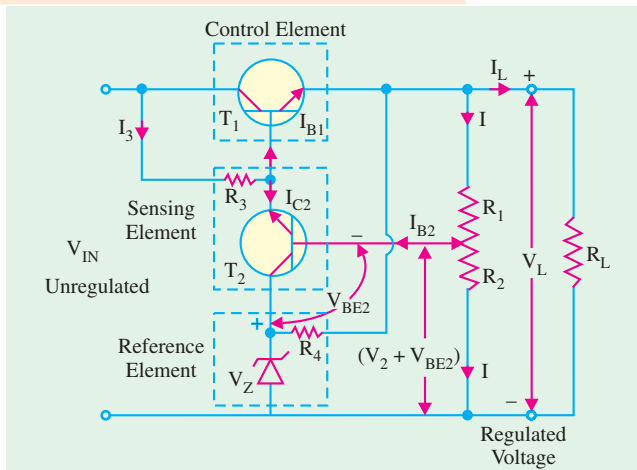


Fig. 56.4

56.6. Transistor Shunt Voltage Regulator

It employs the transistor in shunt configuration as shown in Fig. 56.5.

Since path AB is in parallel across V_L , we have from Kirchhoff's Voltage Law

$$V_L - V_z - V_{BE} = 0$$

or $V_{BE} = V_L - V_z$ (fixed)

Since V_z is fixed, any decrease or increase in V_L will have a corresponding effect on V_{BE} . Suppose, V_L decreases, then as seen from the above relation, V_{BE} also decreases. As a result, I_B decreases, hence,

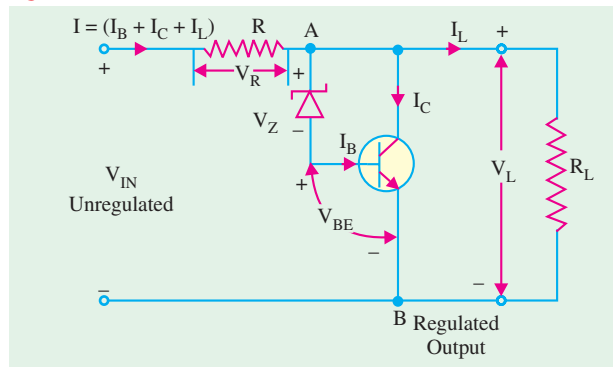


Fig. 56.5



$I_C (= \beta I_B)$ decreases, thereby decreasing I and hence $V_R (= IR)$. Consequently, V_L increases because at all times

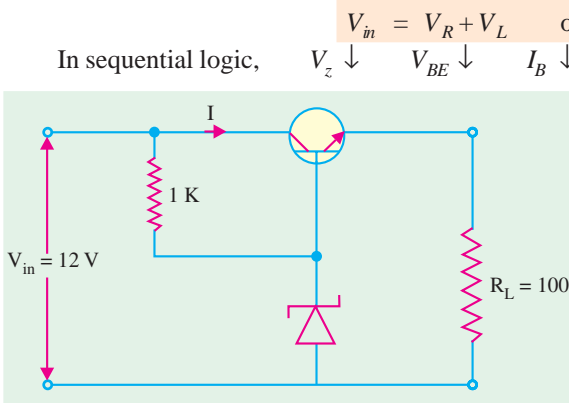


Fig. 56.6

Same line of logic applies in case V_L tries to increase.

Example 56.2. In the NPN emitter-follower regulator circuit of Fig. 56.6, calculate (i) V_L , (ii) V_{CE} , (iii) I_E and (iv) power dissipated. Take $V_{BE} = 0.7$ V.

Solution.

(i) $V_L = V_{out} = V_Z - V_{BE}$
 $= 9 - 0.7 = 8.3$ V

(ii) $V_{CE} = V_{in} - V_{out} = 12 - 8.3 = 3.7$ V

(iii) $I_E = I_L = V_L / R_L$

$= 8.3 / 100 = 83$ mA

(iv) Power dissipated $= V_{CE} I_E$
 $= 3.7$ V \times 83 mA = 310 mW

Example 56.3. Compute the output voltage V_{out} for the op-amp series regulator shown in Fig. 56.7. (Industrial Electronics, Bombay Univ. 1992)

Solution. We are given that $V_{REF} = 6$ V and $R_2 = R_3 = 1$ K
 $V_{out} = V_{REF} (1 + R_z / R_3)$
 $= 6(1 + 10/10)$
 $= 6 \times 2 = 12$ V

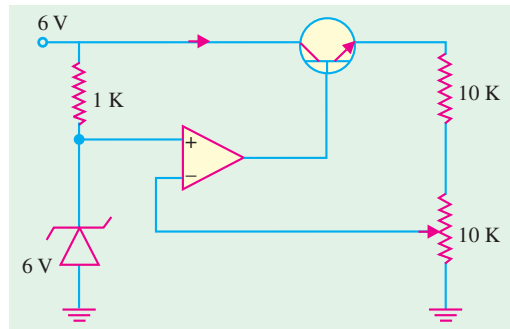


Fig. 56.7

56.7. Transistor Current Regulator

The main function of a current regulator is to maintain a fixed current through the load despite variations in the terminal voltage. Such a circuit employing a Zener diode and a PNP transistor is shown in Fig. 56.8. Suppose, due to drop in V_L , current $I_L (= I_C)$ is decreased. This will decrease $I_E (\cong I_C)$. Hence, drop across R_E i.e. V_{RE} will decrease. As per Kirchoff's Voltage Law

$-V_{RE} - V_{BE} + V_z = 0$, or $V_{BE} = V_z - V_{RE}$
 (fixed)



Transistor current regulator

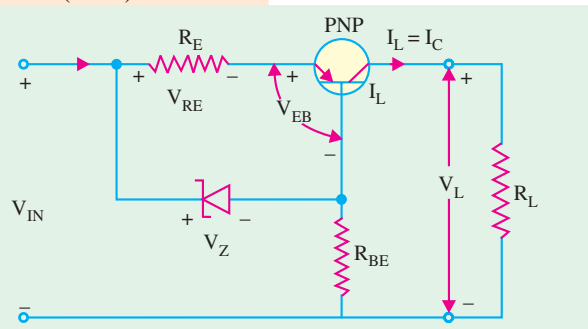


Fig. 56.8



Hence, a decrease in V_{RE} will increase V_{BE} and, hence, the conductivity of the transistor thereby keeping I_L at a fixed level.

A similar logic applies when there is increase in V_L .

56.8. Variable Feedback Regulator

The regulators considered so far provide a non-adjustable output voltage. This would be fine if only single value of regulated voltage is required. Fig. 56.9 shows a feedback regulator which provides different values of regulated dc voltage.

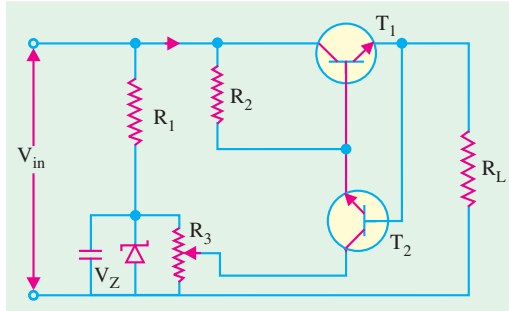


Fig. 56.9

In Fig. 56.9, T_1 is the pass transistor and T_2 is the feedback transistor whose job is to provide and sample output (*i.e.* load) voltage. It offsets any change in the output voltage. Since potentiometer R_3 is connected in parallel with Zener diode D , it has Zener voltage V_z applied across it. Voltage across the wiper varies from 0 to V_z . Capacitor C ensures that voltage across D and R_3 does not change suddenly.

Voltage at the base of T_2 is 0.7 V more positive than the voltage at its emitter. Its emitter voltage and hence the base voltage can be changed with the help of R_3 . Since base of T_2 is tied to the output, it is responsible for providing output or load voltage. The voltage V_{CE1} across the pass transistor is given by the difference of input voltage and output voltage. The current through T_1 is equal to the load current. R_2 prevents saturation of transistors whereas R_1 limits the current flowing through D .

The working of feedback transistor can be explained as follows :

Since base voltage of T_2 is directly related to V_{out} it will change if V_{out} changes. The base and collector of T_2 are 180° out of phase with each other. If base voltage increases due to increase in V_{out} collector voltage would decrease. Now, collector of T_2 controls base of T_1 . As the base voltage of T_1 decreases, its collector-emitter resistance increases which lowers the load current. This, in turn, lowers the output voltage thereby offsetting the attempted increases in V_{out} . The opposite of these steps provides the action of an attempted decrease in output voltage.

Example 56.4. In the variable feedback regulator circuit of Fig. 56.8, $V_{in} = 25\text{ V}$, $V_z = 15\text{ V}$ and $R_L = 1\text{ K}$. If the wiper of R_3 is adjusted half-way and assuming silicon transistor, compute (i) V_{out} (ii) I_L (iii) I_{E1} (iv) P_1 .

Solution. (i) $V_{out} =$ voltage at wiper + $V_{BE2} = (15/2) + 0.7 = 8.2\text{ V}$
 (ii) $I_L = V_{out}/R_L = 8.2\text{ V}/1\text{ K} = 8.2\text{ mA}$
 (iii) $I_{E1} = I_L = 8.2\text{ mA}$
 (iv) $V_{CE1} = V_{in} - V_{out} = 25 - 8.2 = 16.8\text{ V}$
 $\therefore P_1 = 16.8\text{ V} \times 8.2\text{ mA} = 140\text{ mW}$

56.9. Basic Op-amp Series Regulator

Its circuit is shown in Fig. 56.10 and its operation is as follows :

The potentiometer R_2 - R_3 senses any change in out-

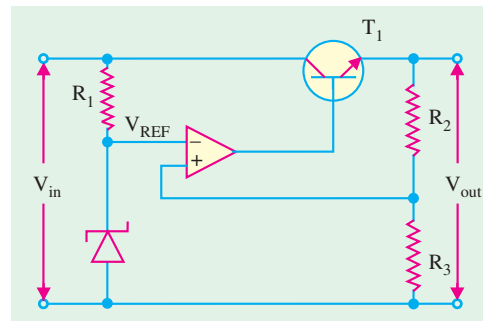


Fig. 56.10



put voltage V_{out} . When V_{out} attempts to decrease because of decrease in V_{in} or because of the increase in I_L , a proportional voltage decrease is applied to the inverting output of the op-amp by the potentiometer. Since, the other op-amp input is held by the Zener voltage at a fixed reference voltage V_{REF} , a small difference voltage (called error voltage) is developed across the two inputs of the op-amp. This difference voltage is amplified and op-amp's output voltage increases. This increase in voltage is applied to the base of T_1 causing the emitter voltage ($= V_{out}$) to increase till the voltage to the inverting input again equals the reference (Zener) voltage. This action offsets attempted decrease in the output voltage thus keeping it almost constant. The opposite action occurs if the output voltage tries to increase.

Calculations

It will be seen that the op-amp of Fig. 56.10 is actually connected as a non-inverting amplifier where V_{REF} is the input at the noninverting terminal and the R_2/R_3 voltage divider forms the negative feed-back network. The closed-loop voltage gain is given by $A = 1 + (R_2/R_3)$. Neglecting base-emitter voltage of T_1 , we get

$$V_{out} = V_{REF}(1 + R_2/R_3)$$

It is seen that V_{out} depends on Zener voltage and potential divider resistors R_2 and R_3 but is independent of input voltage V_{in} .

56.10. Basic Op-amp Shunt Regulator

Such a shunt type linear regulator is shown in Fig. 56.11. Here, the control element is a series resistor R_1 and a transistor T_1 in parallel with the load. In such a regulator, regulation is achieved by controlling the current through T_1 .

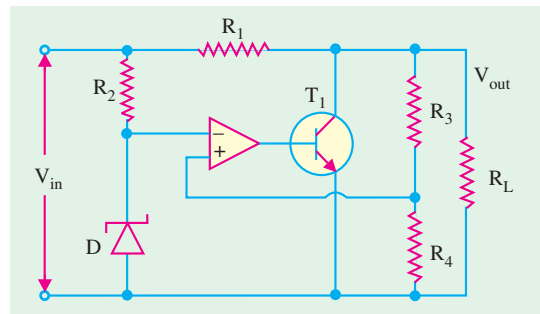


Fig. 56.11

Working

When output voltage tries to decrease due to change in either the input voltage or load current or temperature, the attempted decrease is sensed by R_3 and R_4 and applied to the non-inverting input of the op-amp. The resulting difference in voltage reduces the op-amp's output, driving T_1 less thus reducing its collector current (shunt current), and increasing its collector-to-emitter resistance. Since collector-to-emitter resistance acts as a voltage divider with R_1 , this action offsets the attempted decrease in output voltage and hence, maintains it at a constant value. The opposite action occurs when output voltage tries to increase. The shunt regulator is less efficient than the series type but offers inherent short-circuit protection.

56.11. Switching Regulators

In the linear regulators considered so far, the control element *i.e.* the transistor conducts all the time, the amount of conduction varying with changes in output voltage or current. Due to continuous power loss, the efficiency of such a regulator is reduced to 50 per cent or less.

A switching regulator is different because its control element operates like a switch *i.e.* either it is saturated (closed) or cut-off (open). Hence, there is no unnecessary wastage of power which results in higher efficiency of 90% or more.

Switching regulators are of three basic types : (i) step-down regulator, (ii) step-up regulator and (iii) inverting regulator.



56.12. Step-down Switching Regulator

In this regulator (Fig. 56.12), V_{out} is always less than V_{in} . An unregulated positive dc voltage is applied to the collector of the NPN transistor. A series of pulses from an oscillator is sent to the base of transistor T which gets saturated (closed) on each of the positive pulses. It is so because an NPN transistor needs a positive voltage pulse on its base in order to turn ON. A saturated transistor acts as a closed switch, hence it allows V_{in} to send current through L and charge C to the value of output voltage during the on-time (T_{ON}) of the pulse. The diode D_1 is reverse-biased at this point and hence, does not conduct.

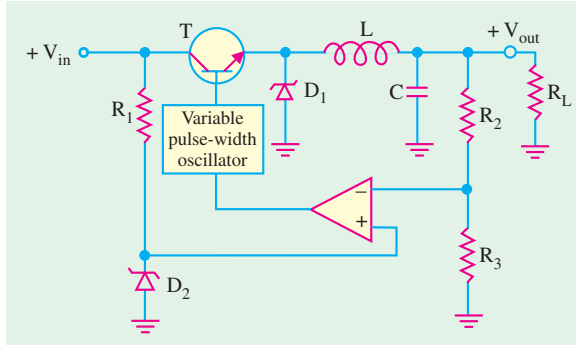


Fig. 56.12

Eventually when positive pulse turns to zero, T is cut-off and acts like an open switch during the off period (T_{OFF}) of the pulse. The collapsing magnetic field of the coil produces self-induced voltage and keeps the current flowing by returning energy to the circuit.

The value of output voltage depends on input voltage and pulse width *i.e.* on-time

of the transistor. When on-time is increased relative to off-time, C charges more thus increasing V_{out} . When T_{ON} is decreased, C discharges more thus decreasing V_{out} . By adjusting the duty cycle (T_{ON}/T) of the transistor, V_{out} can be varied.

$$\therefore V_{out} = V_{in} (T_{ON}/T)$$

where T is the period of the ON-OFF cycle of the transistor and is related to frequency by $T = 1/f$. Also, $T = T_{ON} + T_{OFF}$ and the ratio (T_{ON}/T) is called the **duty cycle**.

The regulating action of the circuit is as follows :

When V_{out} tries to decrease, on-time of the transistor is increased causing an additional charge on the capacitor C to offset the attempted decrease. When V_{out} tries to increase, T_{ON} of the transistor is decreased causing C to discharge enough to offset the attempted increase.

56.13. Step-up Switching Regulator

The circuit is shown in Fig. 56.13. When transistor T turns ON on the arrival of the positive pulse at its base, voltage across L increases quickly to $V_{in} - V_{CE(sat)}$ and magnetic field of L expands quickly. During on-time of the transistor, V_L keeps decreasing from its initial maximum value. The longer transistor is ON, the smaller V_L becomes.

When transistor turns OFF, magnetic field of L collapses and its polarity reverses so that

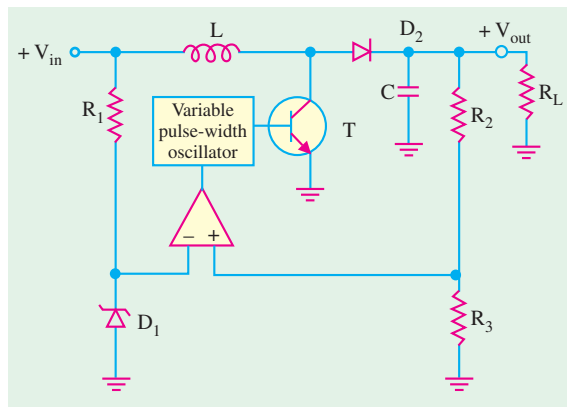


Fig. 56.13



its voltage adds to the input voltage thus producing an output voltage greater than the input voltage. During off-time of the transistor, D_2 is forward-biased and allows C to charge. The variations in V_{out} due to charging and discharging action are sufficiently smoothed by filtering action of L and C .

It may be noted that shorter the on-time of the transistor, greater the inductor voltage and hence greater the output voltage (because greater V_L adds to V_{in}). On the other hand, the longer the on-time, the smaller the inductor voltage and hence, lesser the output voltage (because smaller V_L adds to V_{in}).

The regulating action can be understood as follows :

When V_{out} tries to decrease (because of either increasing load or decreasing V_{in}), transistor on time decreases thereby offsetting attempted decrease in V_{out} . When V_{out} tries to increase, on-time increases and attempted increase in V_{out} is offset.

As seen, the output voltage is inversely related to the duty cycle.

$$\therefore V_{out} = V_{in} (T/T_{ON})$$

56.14. Inverting Switching Regulator

The basic diagram of such a regulator is shown in Fig. 56.14. This regulator provides an output voltage that is opposite in polarity to the input voltage.

When transistor T turns ON by the positive pulse, the inductor voltage V_L jumps to $V_{in} - V_{CE(sat)}$ and the magnetic field of the inductor expands rapidly. When

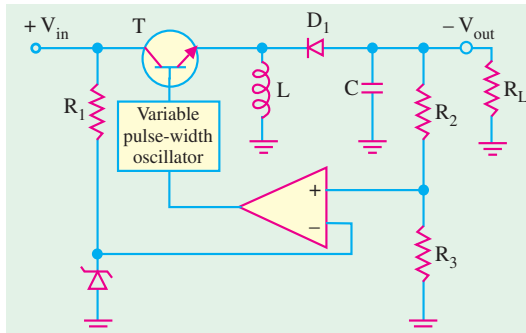


Fig. 56.14

transistor is ON, the diode D_2 is reverse-biased and V_L decreases from its initial maximum value. When transistor turns OFF, the magnetic field collapses and inductor's polarity reverses. This forward-biases D_2 , charges C and produces a negative output voltage. This repetitive ON-OFF action of the transistor produces a repetitive charging and discharging that is smoothed by LC filter action. As in the case of a step-up regulator, lesser the time for which transistor is ON, greater the output voltage and *vice versa*.

56.15. IC Voltage Regulators

Due to low-cost fabrication technique, many commercial integrated-circuit (IC) regulators are available since the past two decades. These include fairly simple, fixed-voltage types of high-quality precision regulators. These IC regulators have much improved performance as compared to those made from discrete components. They have a number of unique build-in features such as current limiting, self-protection against overtemperature, remote control operation over a wide range of input voltages and foldback current limiting.

Now we will study the following types of IC voltage regulators : (1) fixed positive linear voltage regulators, (2) fixed negative linear voltage regulators, (3) adjustable positive linear voltage regulators, and (4) adjustable negative linear voltage regulators.

56.16. Fixed Positive Linear Voltage Regulators

There are many IC regulators available in the market that produces a fixed positive output voltage. But 7800 series of IC regulators is representative of three terminal devices that are available



with several fixed positive output voltages making them useful in a wide range of applications. Fig. 56.15 (a) shows a standard configuration of a fixed positive voltage IC regulator of 7800 series. Notice that it has three terminals labelled as input, output and ground. The last two digits (marked xx) in the part number designate the output voltage. For example, IC 7805 is a +5 V regulator. Similarly IC 7812 is a +12 V regulator and IC 7815 is a +15 V regulator. The capacitor C_1 (typically $0.33 \mu\text{F}$) is required only if the power supply filter is located more than 3 inches from the IC regulator. The capacitor C_2 (typically $0.01 \mu\text{F}$) acts basically as a line filter to improve transient response.

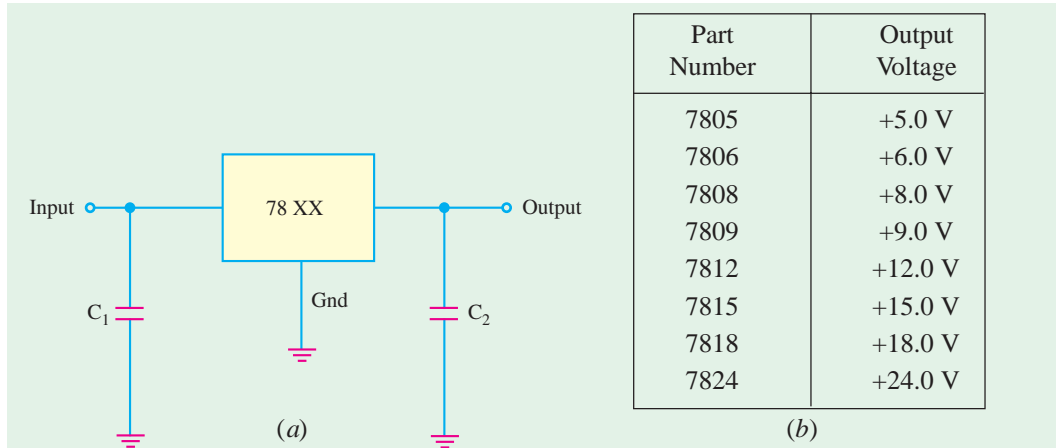


Fig. 56.15

Fig. 56.15 (b) shows the part number and the output voltage of 7800 series IC voltage regulators. As seen from this figure, the 7800 series has IC regulators that can produce output voltages ranging from +5.0 to +24.0 volt. It may be carefully noted that although these regulators are designed primarily to produce fixed output voltage but they can be used with external components to obtain adjustable output voltage and current.

Fig. 56.16 shows the circuit indicating the use of 78XX as an adjustable voltage regulator. The output voltage is given by the equation,

$$V_{out} = V_{fixed} + \left(\frac{V_{fixed}}{R_1} + I_Q \right) R_2$$

For example, for a 7805 IC regulator, $V_{fixed} = 5 \text{ V}$. Let $R_1 = R_2 = 1 \text{ k}\Omega$ and $I_Q = 5 \text{ mA}$, then its output voltage is,

$$V_{out} = 5 + \left(\frac{5}{1 \text{ k}\Omega} + 5 \text{ mA} \right) \times 1 \text{ k}\Omega = 15 \text{ V}$$

Thus output voltage of IC 7805 regulator can be adjusted anywhere between 5 V to 15 V.

This example indicates that the output of IC 7805 regulator is adjusted to 15 V using external resistances R_1 and R_2 .

The standard 7800 series can produce output current in excess of 1 A when used with adequate

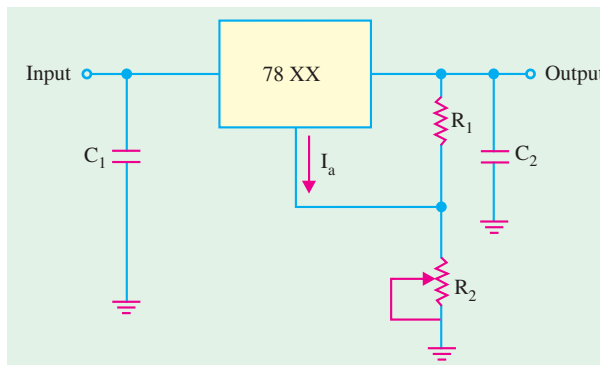
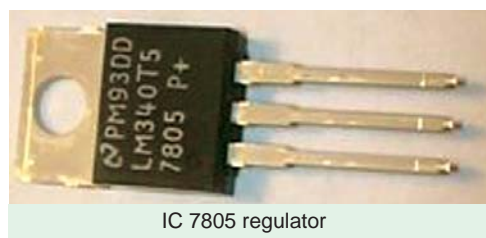


Fig. 56.16



heat sink. It is available in aluminium can package TO-3 (indicated by *K* in the part number) and plastic package TO-220 (indicated by *T* in the part number), The 78L00 series can provide up to 100 mA and is available in TO-92 and metal TO-39 low profile packages. The 78M00 series can provide upto 0.5 A and is available in plastic TO-202 package. Fig. 6.17 shows the typical metal and plastic packages for the *IC* voltage regulators.

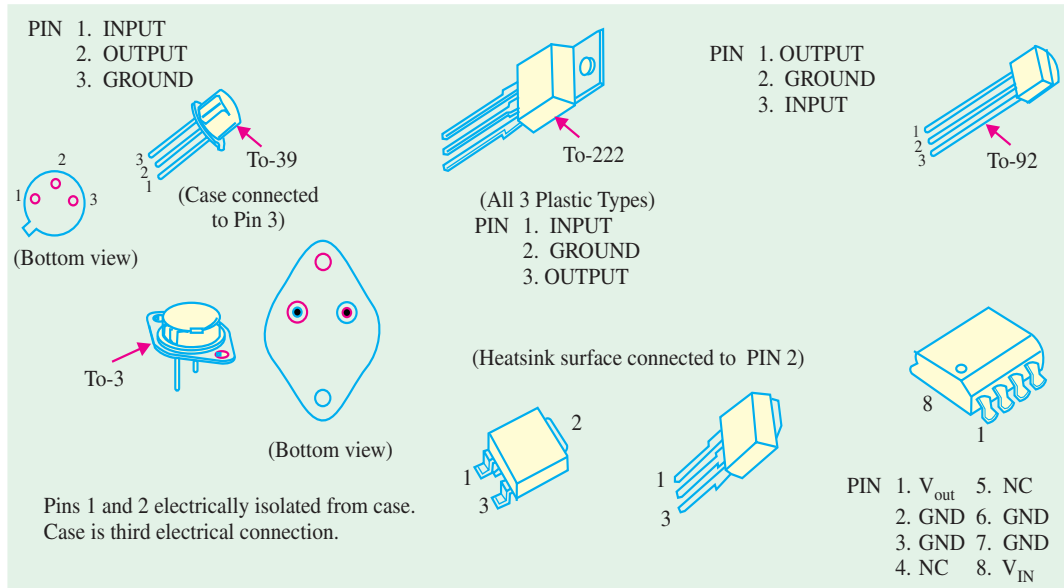


Fig. 56.17

It may be noted that the input voltage for the *IC* regulator must be at least 2 V above the output voltage. This is required in order to maintain regulation. The input voltage should not be more than 35 or 40 volts depending upon the part number. The circuit inside all the *IC* regulators have internal thermal overload protection and short-circuit current-limiting features. Thermal overload in a *IC* regulator occurs whenever the internal power dissipation becomes excessive and the temperature of the device exceeds a certain value.

In India, Bharat Electronic Limited, Bangalore manufactures the *IC* voltage regulators with output voltages of 5 and 12 V. These are available in the market with part numbers BEL 7805 and BEL 7812 respectively.

Fig 56.18 shows a picture of a transformer bridge rectifier and voltage regulator in a dc power supply.

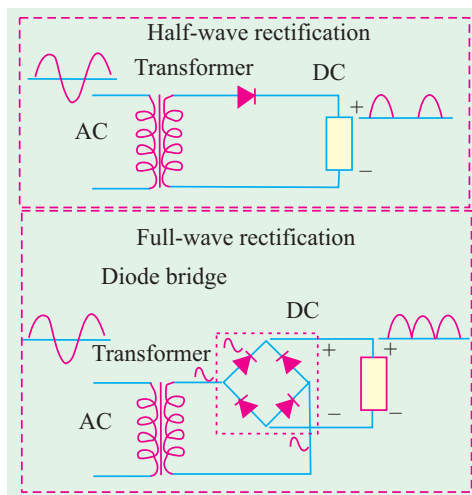


Fig. 56.18

56.17. Fixed Negative Linear Voltage Regulators

The 7900 series is typical of three-terminal *IC* regulators that provide a fixed negative output voltage. This series is a negative-voltage counterpart of the 7800 series and shares most of the same features, characteristics and package types. Fig. 56.19 (a) indicates the standard configuration and Fig. 56.19 (b), the part numbers with corresponding output voltages that are available in 7900 series.



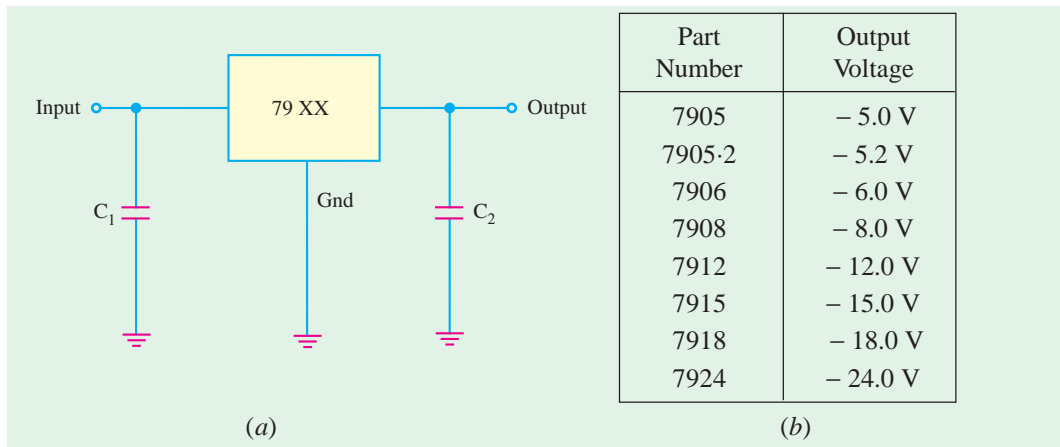


Fig. 56.19

The capacitor C_1 (typically $0.22 \mu\text{F}$) is required only if the power supply filter is located more than 3 inches away from the IC regulator. The capacitor C_2 (typically $1 \mu\text{F}$) is required for stability of the output voltage. Both capacitors C_1 and C_2 must be solid tantalum capacitors.

Fig. 56.20 shows the use of 79XX to produce an adjustable output voltage. The capacitor C_3 (typically $25 \mu\text{F}$) improves the transient response of the output voltage. The output voltage is given by the equation,

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

The recommended value of R_2 , for 7905 is 300Ω , for 7915, its value is 750Ω and for 7915 is $1 \text{ k}\Omega$.

In India, BEL manufactures IC regulators with output voltage of -5 V and -12 V . These are available in the market with part numbers BEL 7905 and BEL 7915 respectively.

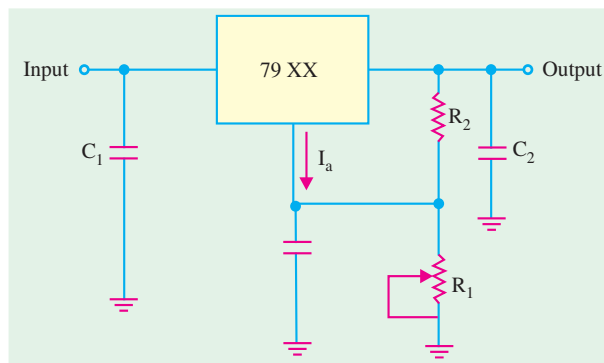


Fig. 56.20

56.18. Adjustable Positive Output Linear Voltage Regulators

We have already seen in Art. 56.16 that by adding external resistors, we can adjust the output voltage of 7800 series IC regulators higher than their fixed (or set) voltages. For example, the output voltage of 7805 can be adjusted higher than 5 V. But the performance and reliability of 7800 series to produce voltage higher than its fixed value is not considered to be good.

The LM 317 and LM 723 are IC regulators whose output voltage can be adjusted over a wide range. The output voltage of LM 317 can be adjusted from 1.2 V to 37 V, it can supply output current of 100 mA and is available in TO-92 package *i.e.*, it is also a 3 terminal IC regulator. On the other hand, the output voltage of LM 723 can be adjusted from 2 V to 37 V, it can supply output current of 150 mA without external transistor. But with the addition of external transistor, the output current capability can be increased in excess of 10 A. The LM 723 is available in dual-in-line package and in a metal can package.

Fig. 56.21 (a) shows the LM 317 connected to the external resistors R_1 and R_2 to produce an adjustable output voltage.



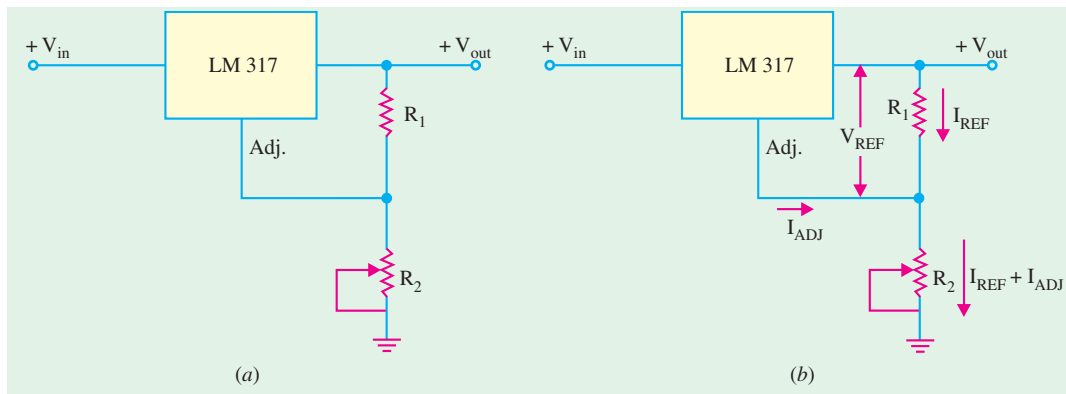


Fig. 56.21

In operation, the LM 317 develops a constant 1.25 V reference voltage (V_{REF}) between the output and adjustment terminal. This constant reference voltage produces a constant current, (I_{REF}) through R_1 , regardless of the value of R_2 Fig. 56.20 (b). Notice that the value of current through R_2 is the sum of I_{REF} and I_{ADJ} , where I_{ADJ} is a very small current at the adjustment terminal. The value of I_{ADJ} is typically around 100 μ A. It can be shown that the output voltage.

$$V_{out} = V_{REF} \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ} \cdot R_2$$

It is evident from the above equation that the output voltage is a function of R_1 and R_2 . Usually the value of R_1 is recommended to be around 220 Ω . Once the value of R_1 is set, the output voltage is adjusted by varying R_2 .

Example 56.5. Calculate the minimum and maximum output voltages for the IC voltage regulator shown in Fig. 56.22. Assume $I_{ADJ} = 100 \mu$ A, $V_{in} = +35$ V.

Solution. The equation for output voltage of the IC voltage regulator is given by,

$$V_{out} = V_{REF} \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ} \cdot R_2$$

When R_2 is set at its minimum value (i.e. 0 Ω), the output voltage,

$$\begin{aligned} V_{out(min)} &= 1.25 \left(1 + \frac{0}{220} \right) + (100 \times 10^{-6}) \times 0 \\ &= \mathbf{1.25 \text{ V}} \end{aligned}$$

When R_2 is set at its maximum values (i.e. 5 k Ω), the output voltage,

$$\begin{aligned} V_{out(max)} &= 1.25 \left(1 + \frac{5000}{220} \right) + (100 \times 10^{-6}) \times 5000 \\ &= 29.66 + 0.5 = \mathbf{30.16 \text{ V}}. \end{aligned}$$

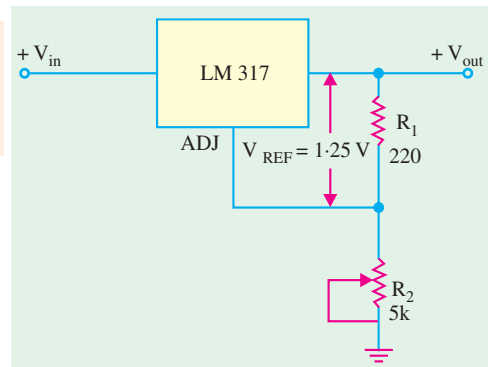


Fig. 56.22

56.19. Adjustable Negative Output Linear Voltage Regulators

A good example of this type of regulators is LM 337. The regulator is a negative output counterpart of LM 317. The LM 337 (like LM 317) requires two external resistors for adjustment of output



voltage as shown in Fig. 56.23. The output voltage can be adjusted anywhere from -1.2 V to -37 V depending upon the external resistor values.

The LM 723 can also be used as an adjustable negative output voltage regulator. The output voltage of this IC regulator can be adjusted anywhere from -2.0 V to -37 V depending upon the external resistor values.

56.20. Use of External Pass Transistor with Linear Voltage Regulators

We have already mentioned in the last two articles that a linear voltage regulator (7800 and 7900 series) is capable of delivering only a certain amount of output current to a load. For example, the 7800 series regulators can handle a maximum output current of at least 1.3 A and typical 2.5 A. If the load current exceeds the maximum allowable value, there will be a **thermal overload** and the regulator will **shut down**. *A thermal overload condition means that there is excessive power dissipation inside the regulator.*

If an application requires a larger value of load current than the maximum current that the regulator can deliver, we will have to use an external pass transistor as shown in Fig. 56.24. The value of R_{ext} (current-sensing resistor) determines the value of current at which the external pass transistor (T_{ext}) begins to conduct because it sets the base-to-emitter voltage of the transistor.

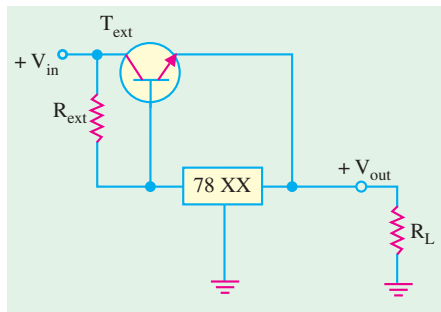


Fig. 56.24

As long as the current is less than the value set by R_{ext} , the transistor T_{ext} is off and the regulator operates normally. This is because the voltage drop across R_{ext} is less than 0.7 V (i.e. the base to emitter voltage required to turn T_{ext} on). The value of R_{ext} is determined by the equation $R_{ext} = 0.7\text{ V}/I_{max}$ where I_{max} is the maximum value of current that the voltage regulator is to handle internally.

When the current is sufficient to produce at least a 0.7 V drop across R_{ext} , the transistor T_{ext} turns on and conducts any current in excess of I_{max} . The transistor T_{ext} will conduct current depending on the load requirement. For example, if the total load current is 5 A and I_{max} was selected to be 1 A, then the external pass Transistor (T_{ext}) will conduct 4 A of current through it.

It may be noted that the external pass transistor is a power transistor with heat sink that must be capable of handling a maximum power given by the equation,

$$P_{ext} = I_{ext} (V_{in} - V_{out})$$

One major drawback of the circuit shown in Fig. 56.24 is that the external pass transistor is not protected from excessive current, such as would result from a shorted output. This drawback can be overcome by using an additional current limiting circuit as shown in Fig. 56.25.

The operation of this circuit may be explained as follows. The current sensing resistor, R_{lim} sets the base-to-emitter voltage of T_{lim} . The base-to-emitter voltage of T_{ext} is now determined by $(V_{R_{ext}} - V_{R_{lim}})$ because they have opposite polarities. So for normal operation, the drop across R_{ext} must be sufficient to overcome the opposing drop across R_{lim} .

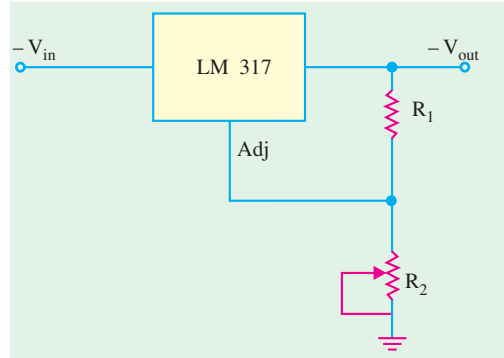


Fig. 56.23



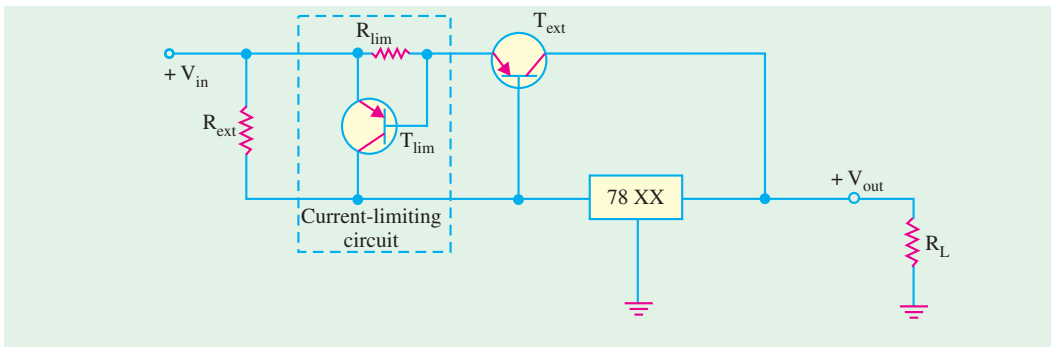


Fig. 56.25

If the current through T_{ext} exceeds a certain maximum value, ($I_{ext(max)}$) because of a shorted output or a faulty load, the voltage across R_{lim} reaches 0.7 V and turns T_{lim} on. As a result, T_{lim} now conducts current away from T_{ext} and through the regulator. This forces a thermal overload to occur and shut down the regulator. Remember, the IC voltage regulator circuitry is internally protected from thermal overload as part of its design. This way the external pass transistor is protected from excessive current.

56.21. Use of Linear Voltage Regulators as a Current Regulator

The 3-terminal linear voltage regulator can be used as a current source when an application requires that a constant current be supplied to a variable load. The basic circuit is shown in Fig. 56.26. Here R_1 is the current-setting resistor. The regulator provides a fixed output voltage, V_{out} between the ground terminal and the output terminal. However, it may be noted that the ground pin of the regulator is not connected to the circuit ground. The constant current supplied to the load, is given by the equation,

$$I_L = \frac{V_{out}}{R_L} + I_Q$$

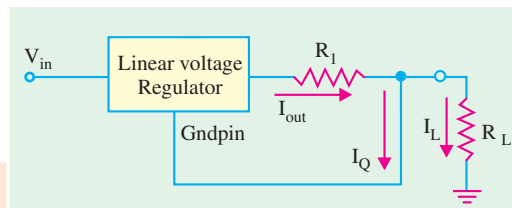


Fig. 56.26

Usually the current, I_Q is very small as compared to the output current and hence can be neglected, therefore

$$I_L \approx \frac{V_{Out}}{R_L}$$

For example, if we use 7805 regulator to provide a constant current of 1 A to a variable load, then

$$R_1 = \frac{5}{1} = 5 \Omega$$

Please note that input voltage must be at least 2 V greater than the output voltage. Thus for 5 V regulator, V_{in} must be greater than 7 V.

56.22. Switching Voltage IC Regulators

There are several switching voltage IC regulators available in the market. The choice depends upon the desired application and the cost. However, we will illustrate it with the IC 78S40. This device is a universal device that can be used with external components to provide step-up, step down and inverting operation.

Fig. 56.27 shows the internal circuitry of the IC 78C40. The circuitry can be compared to the basic switching regulators discussed in Art. 56.12, 56.13, and 56.14. As seen from this diagram, the



oscillator and comparator functions are directly comparable. The logic gate and flip-flop in the 78S40 were not included in the basic circuit of Fig. 56.12, but they provide additional regulation. Transistor T_1 and T_2 perform the same function as T in the basic circuit. The 1.25 V reference block in the 78S40 has the same purpose as that of the zener diode in the basic circuit and diode D_1 in the 78S40 corresponds to D_1 in the basic circuit.

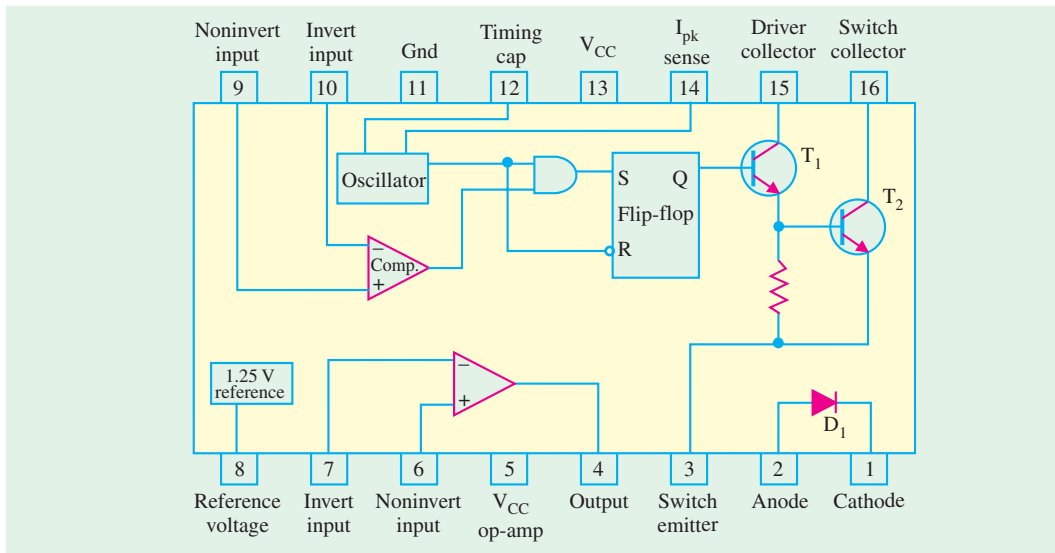


Fig. 56.27

The circuitry of 78S40 has also an uncommitted or unused OP-AMP. We require external circuitry to operate this device as a regulator.

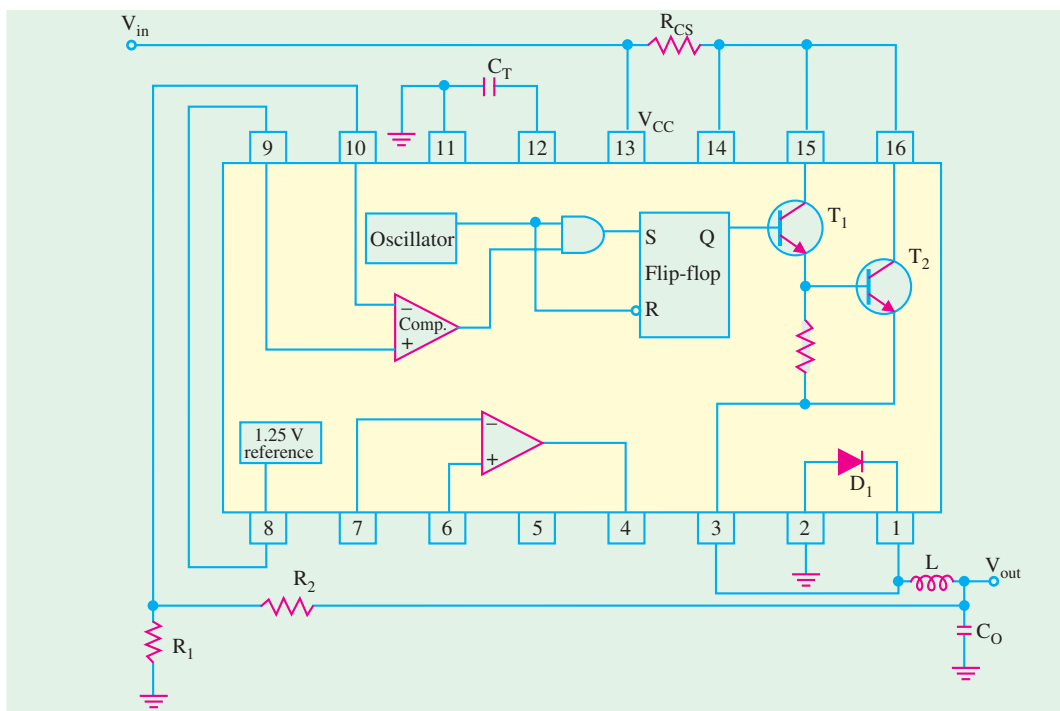


Fig. 56.28



Fig. 56.28 shows the external connections of the IC 78S40 for a step-down switching regulator configuration. Note that in this configuration the circuit produces an output voltage which is less than input voltage.

Fig. 56.28 shows the IC 78S40 connected to the external components for a step-up switching regulator configuration. In this case the output voltage is greater than the input voltage. An inverting configuration is also possible but is not shown here.

In both the circuits of Fig. 56.27 and Fig. 56.28, the capacitor C_T (called timing capacitor) controls the pulse width and frequency of the oscillator and thus establishes the on-time of transistor T_1 . The voltage across the resistor R_{CS} (called current-sensing resistor) is used internally by the oscillator to vary the duty cycle based on the desired peak current. The voltage divider made up of R_1 and R_2 reduces the output voltage to a value equal to the reference voltage. If the output voltage (V_{out}) exceeds its set value, the output of the comparator switches to the low state, disabling the gate to turn T_2 off until the output decreases. This regulating action is in addition to that produced by the duty cycle variation of the oscillator.

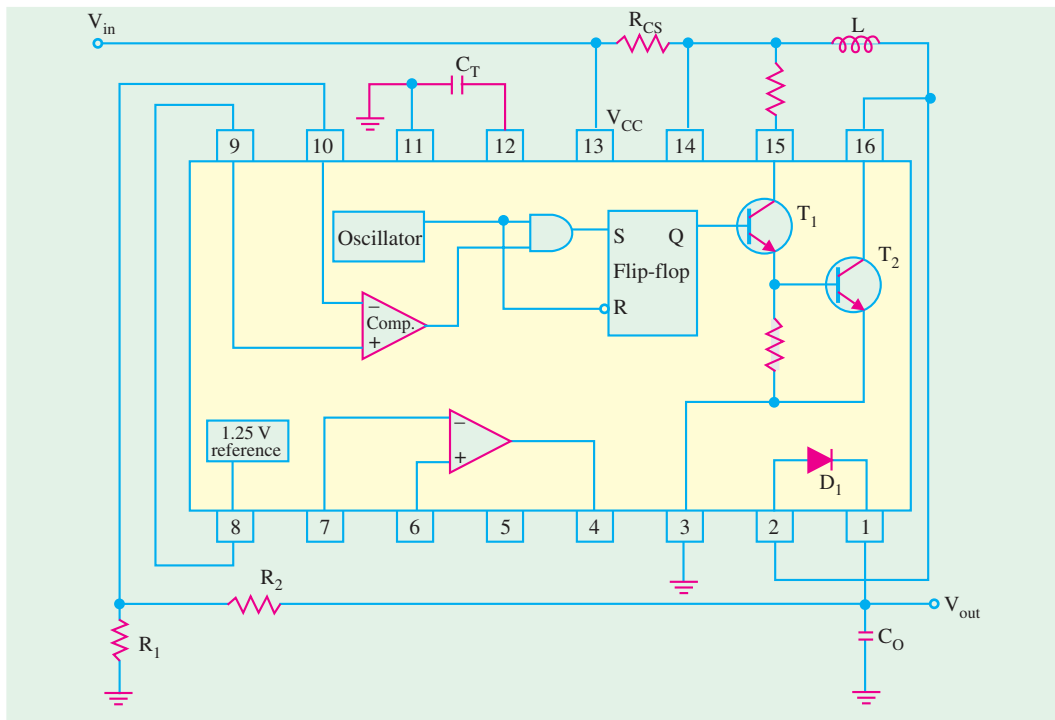


Fig. 56.29

Tutorial Problems No. 56.1

- The Zener diode of Fig. 56.30 has the following ratings :

$$\begin{array}{lll} V_z = 15 \text{ V} & \text{at} & I_z = 17 \text{ mA} \\ r_z = 14 \Omega & \text{at} & I_z = 17 \text{ mA} \\ I_{z(\min)} = 0.25 \text{ mA} & & I_{z(\max)} = 66 \text{ mA} \end{array}$$

What would be the load voltage when load current I_L varies from 1 mA to 60 mA. Also calculate the voltage regulation of the regulator.

(14.846 V, 15.672 V, 5.27%)



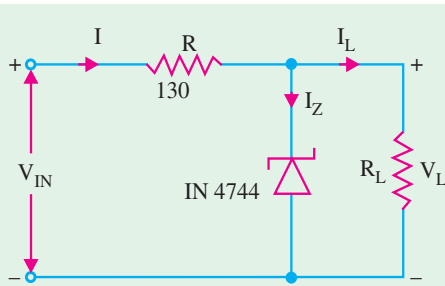


Fig. 56.30

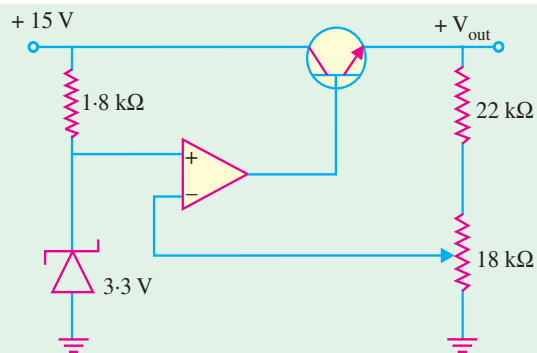


Fig. 56.31

2. Determine the output voltage, V_{out} for the op-amp series regulator shown in Fig. 56.31. (7.3 V)
3. Calculate the minimum and maximum output voltages for the IC voltage regulator shown in Fig. 53.32. Assume $I_{ADJ} = 50 \mu\text{A}$, $V_{in} = +35 \text{ V}$, $V_{REF} = 1.2 \text{ V}$ (1.25 V, 12.71 V)

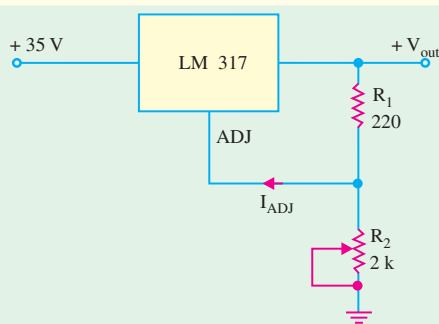


Fig. 56.32

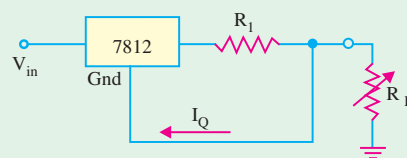


Fig. 56.33

4. Fig. 56.33 shows the circuit of a current regulator. What value of R_1 is necessary to provide a constant current of 1 A. (12 Ω)

OBJECTIVE TESTS – 56

1. The main job of a voltage regulator is to provide a nearly—output voltage.
 - (a) sinusoidal
 - (b) constant
 - (c) smooth
 - (d) fluctuating.
2. A 10-V dc regulator power supply has a regulation of 0.005 per cent. Its output voltage will vary within an envelope of millivolt.
 - (a) ± 2.5
 - (b) ± 0.5
 - (c) ± 5
 - (d) ± 0.05
3. An ideal voltage regulator has a voltage regulation of
 - (a) 1
 - (b) 100
 - (c) 50
 - (d) 0.
4. In a Zener diode shunt voltage regulator, the diode regulates so long as it is kept in condition.
 - (a) forward
 - (b) reverse
 - (c) loaded
 - (d) unloaded
5. The power efficiency of a switching voltage regulator is much higher than that of a linear regulator because it operates.
 - (a) in saturation
 - (b) in cut-off
 - (c) like a switch
 - (d) on high duty cycle.
6. A transistor series voltage regulator is called emitter-follower regulator because the emitter of the pass transistor follows the voltage.
 - (a) output
 - (b) input
 - (c) base
 - (d) collector



7. In an op-amp series voltage regulator, output voltage depends on
 (a) Zener voltage
 (b) voltage divider resistors
 (c) output voltage
 (d) both (a) and (b)
8. In a feedback series regulator circuit, the output voltage is regulated by controlling the
 (a) magnitude of input voltage
 (b) gain of the feedback transistor
 (c) reference voltage
 (d) voltage drop across the series pass transistor
9. An op-amp shunt regulator differs from the series regulator in the sense that its control element is connected in
 (a) series with line resistor
 (b) parallel with line resistor
 (c) parallel with load resistor
 (d) parallel with input voltage.
10. A switching voltage regulator can be of the following type :
 (a) step-down (b) step-up
 (c) inverting (d) all of the above
11. In an inverting type switching regulator, output voltage is input voltage.
 (a) lesser than (b) greater than
 (c) equal to (d) opposite to.
12. The output voltage of a step-down type switching voltage regulator depends on
 (a) input voltage (b) duty cycle
 (c) transistor on-time (d) all of the above.
13. As compared to voltage regulators made up of discrete components, IC regulators have the inherent advantage/s of
 (a) self protection against over-temperature
 (b) remote control
 (c) current limiting
 (d) all of the above
14. A 12 V monolithic regulator is adjusted to obtain a higher output voltage as shown in Fig. 56.34. The V_0 will be

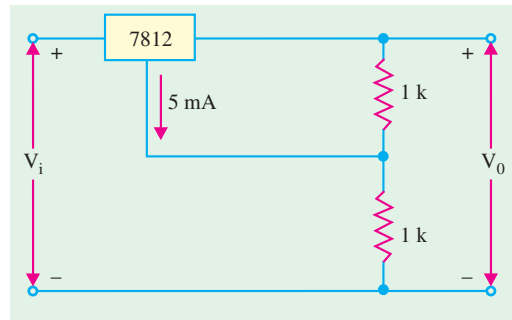


Fig. 56.34

- (a) 12 V (b) 17 V
 (c) 24 V (d) 29 V

15. A three terminal monolithic IC regulator can be used as
 (a) an adjustable output voltage regulator alone
 (b) an adjustable output voltage regulator and a current regulator
 (c) a current regulator and a power switch
 (d) a current regulator alone

ANSWERS

1. (b) 2. (a) 3. (d) 4. (b) 5. (c) 6. (c) 7. (d) 8. (d) 9. (a) 10. (d) 11. (d) 12. (d)
 13. (d) 14. (d) 15. (d).



ROUGH WORK