Regulated Power Supply

Introduction :

Almost all-electronic equipment (communication, instrumentation, control, and data processor) and its subsystems require stabilized dc power supplies of different voltage levels. To cite few examples, all PCs require ±5V, +12V dc supplies. Similarly, analog circuits using operational amplifiers, instrumentation amplifier, analog to digital converter, digital to analog converters etc. require ±12V or ±15V. The industrial control loops work on 24V dc. The RADAR units require 10KV-15KV dc power supplies. The power ratings of these dc supplies may vary from a few watts to a few kilowatts. Hence we must know the requirements of dc power supplies. A dc power supply must meet the following requirement :

- Better Line Regulation,
- Better Load Regulation,
- Higher Conversion Efficiency,
- Higher power density for reduction in size and weight,
- Less Harmonics in Input and Output Waveform for reduction in Filter size,
- Higher reliability.

The regulated (stabilized) dc power supply family can be categorized as ;

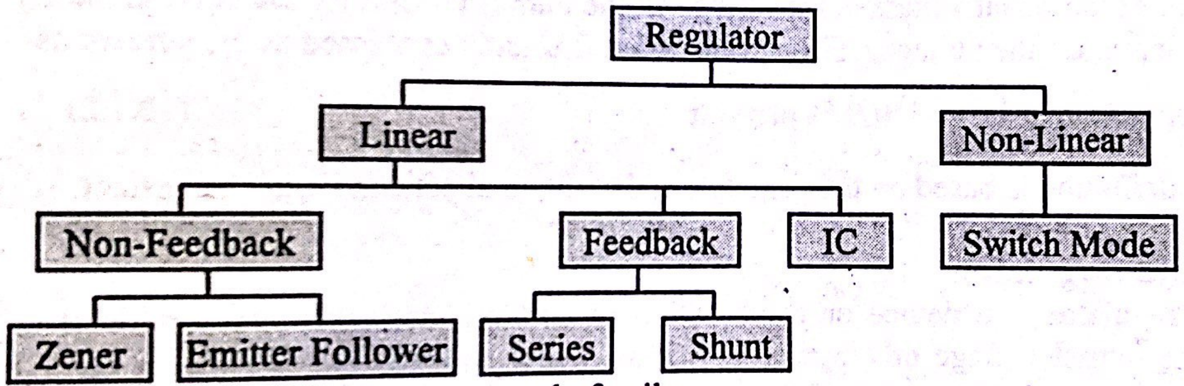


Fig.18.1 DC power supply family

The common terminology used for these dc power supplies is :

Regulated Output :

The output dc voltage of the supply must remain constant within a specified limit, usually 1% or better.

Isolation :

The output terminals of dc supplies must electrically be isolated from the input power source which is generally ac supply i.e. mains. This isolation permits different ground voltage levels in different sections of any electronic equipment or system/subsystems.

Multiple Outputs :

These different sections of any electronic equipment may require different output voltage levels of positive as well as negative polarities. The positive and negative voltage levels must also be isolated from each other, as well as from the ac mains.

Supervisory Circuits :
Different levels of dc voltages may be required in different sections of electronic equipment/systems at different time in a desired sequence which must be controlled with the help of logical supervisory circuit.

Load Regulation :
An ideal dc power supply must be able to supply a constant voltage between its output terminals, no matter what current is drawn from it. However, the output voltage of practical power supply does not remain constant, rather it changes with variation in the load current (I_L). Generally, the output voltage drops with increasing load current. The power-supply specifications include a full load current (I_{FL}) rating, which is the maximum current that can be drawn from it within the tolerance limit of its output voltage. The terminal voltage at full-load current(I_{FL}) is called the full-load voltage (V_{FL}). Similarly, the no-load voltage (V_{nL}) is the terminal voltage when zero current is drawn from the supply. In other words, it is called the open circuit voltage. One of the measures of power-supply performance is in terms of how well it is able to maintain a constant voltage between its no-load to full-load conditions. It is referred as load regulation and is expressed as ;

$$\% \text{ Load Regulation} = \frac{V_{nl} - V_{fl}}{V_{fl}} * 100 \qquad (18.1.1)$$

Line Regulation :
The line regulation is an another measure of the ability of a power supply to maintain a constant output voltage with the corresponding change in the mains voltage. In this case, it is a measure of the sensitiveness in the change of the output voltage for the corresponding changes in input, or line voltage. This specification is usually expressed as the percent as:

$$\% \text{ Line Regulation} = \frac{\Delta V_o / V_o}{\Delta V_i} \, 100 \,\% \text{ per volt} \qquad (18.1.2)$$

The above definition is based on the assumption that the load current remains constant.

18.2 Voltage Regulator :
A voltage regulator is a device or combination of devices, designed and combined to maintain the output voltage of a power supply as nearly constant as possible. It can be considered as a closed-loop system because it monitors output voltage and generates appropriate feedback that automatically increases or decreases the output supply voltage as per the necessity to compensate for any tendency in change of the output voltage. Thus the purpose of a regulator is to eliminate any variation in output voltage that might otherwise occur because of changes in load, line(input) voltage or changes in temperature. Thus the output voltage of a dc power supply might depend on the following :

- load current variation,
- input voltage variation, and
- temperature changes.

In other words the output voltage is expressed as the function of three variables i.e. V_i, I_L, and T. Mathematically it is expressed as :

$$V_o = f(V_i, I_L, T) \qquad (18.2.1)$$

The output dc voltage is partially dependent on the change in the load current I_L, partially dependent on the change in the input voltage V_i, and partially dependent on the temperature change. The total change ΔV_o in the output voltage V_o can be expressed mathematically as the sum of the partial contributions of all parameters. Thus, ΔV_o can be written as :

$$\Delta V_O = \frac{\partial V_O}{\partial V_i}\Delta_i + \frac{\partial V_O}{\partial I_O}\Delta I_O + \frac{\partial V_O}{\partial T}\Delta T \tag{18.2.2}$$

or, $\Delta V_o = S_V \Delta V_i + S_{Ro} \Delta I_L + S_T \Delta T$

or, $\Delta V_o = S_V \Delta V_i + R_o \Delta I_L + S_T \Delta T$ (18.2.3)

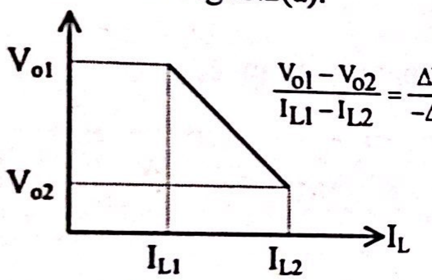
Each of the derivatives in Eqn.(18.2.3) is a measure of regulation or stabilization of the voltage regulator with reference to a particular variable. Thus, the input regulation or stabilization factor (S_V) is expressed as ;

$$S_V = \left.\frac{\partial V_o}{\partial V_i}\right|_{I_o \,\&\, T = \text{constant}} = \text{Constant} \tag{18.2.4}$$

As the load regulation is the ratio of change in the output voltage to the change in the load current, its dimension is of resistance and hence it is termed as output resistance (R_o) or internal resistance of the voltage regulator. It is given by :

$$R_o = -\left.\frac{\partial V_o}{\partial I_o}\right|_{V_i \,\&\, T = \text{Constant}} \tag{18.2.5}$$

The negative sign is associated as because with increasing load current output voltage decreases as indicated in Fig18.2(a).



$$\frac{V_{o1} - V_{o2}}{I_{L1} - I_{L2}} = \frac{\Delta V_o}{-\Delta I_L} = -\frac{\Delta V_o}{\Delta I_L} = -R_o$$

Fig.18.2(a) Output dc Voltage versus Load current Variation

The negative sign in the above expression indicates that R_o must be taken positive when V_o decreases for increasing $I_o = I_L$ or vice versa.

The temperature coefficient (S_T) of the voltage regulator is given by ;

$$S_T = \left.\frac{\partial V_o}{\partial T}\right|_{V_i \,\&\, I_L = \text{Constant}} \tag{18.2.6}$$

A dc power supply is normally rated in terms of output dc voltage and the output dc current or the output voltage & current product. In some power supply units, the output voltage can be varied within a certain voltage range with the condition that the units can be loaded up to a certain maximum permissible current limit.

18.3 Classification of Voltage Regulator :

Electronic power supplies (or power supplies used in electronic systems) are more or less charged with the task of controlling or regulating electrical power. The word control is quite inclusive here in this context because whether we rectify, invert, regulate, or change the voltage or current levels, some control technique is involved. Such control of power delivered to a load can be achieved only by absorbing surplus power in any control device. In order to be energy conscious, the very concept of surplus or throwaway power deserves close scrutiny. The voltage regulator employs different approaches to control the power and accordingly classified as :

- Linear (Dissipative) Voltage Regulator, and
- Switch-Mode (Nondissipative) Voltage Regulator.

18.4 Linear (Dissipative)Voltage Regulator :

In linear voltage regulator circuit, the control elements are generally an active device, e.g. power transistor, which is always operated in the active conduction mode. The active device senses the output of the circuit continuously, and adjusts its conduction to maintain output voltage at a desired value. Here the power dissipation is function of input voltage and load fluctuations. The linear voltage regulator can be of feedback or non-feedback type. The following voltage regulators are important in this category.

Non-feedback types:

- Zener diode regulator; and
- Emitter-follower regulator.

Zener diode and emitter-follower regulators are the simplest regulator, one can conceive. These are normally employed only for

- coarse regulation with low cost,
- low output current requirements, and
- Where efficiency is not an important consideration.

Feedback types:

- Series Regulator; and
- Shunt Regulator.

In series type regulator, the control element is in series between input and output circuit, so it can work with much lower voltage than the output voltage but the total load current passes through it. Hence, it is suitable for low current and high voltage regulation needs. In shunt type regulator, the control element is paralleled to the load, so it passes only a fraction of the total load current but works at full load voltage. Hence, it is suitable for high current and low voltage applications.

The Zener diode regulator circuits have been discussed in article-3.11.3. The advantages of Zener Regulators are ;

- simple,
- light in weight,
- reliable, and
- regulates over a range of current.

Its disadvantages are :

- poor efficiency due to loss in series resistance and diode itself,
- stabilized voltage is equal to breakdown voltage and can not be varied,
- breakdown voltage is dependent on temperature.

Stabistor :

Stabistor is the name given to the regulation achieved by a diode in forward biased region. It is well known that the diode current beyond cut-in voltage rises very sharply for fractional change of voltage across its base-emitter voltage. The typical change in voltage of 0.2V brings a change in few tens of mA. The single diode regulator in forward bias case is shown in Fig.18.4(a). A number of diodes as shown in Fig.18.4(a) may be connected in series to increase the regulated voltage.

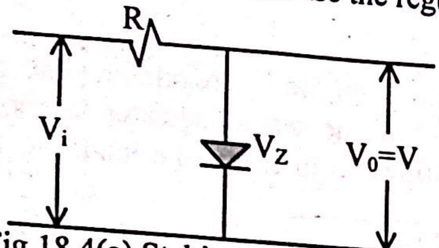


Fig.18.4(a) Stabistor type Regulator

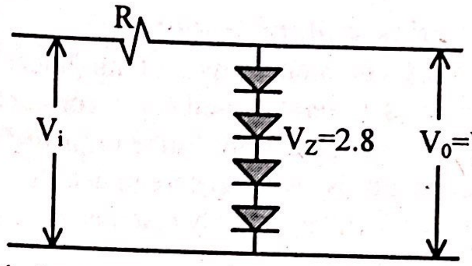


Fig.18.4(b) String of Diodes connected as Stabistor Regulator

18.5 Emitter Follower Regulator :

The Zener diode regulator has inherent limitation of current. In other words the current rating of the diode must be higher than the load current. This condition can not be met by one Zener diode. Hence, other type of regulator is required. The Emitter follower circuit shown in the Fig.18.5(a) is a simplest non-feedback type of transistor voltage regulator. The transistor, which is connected in series with the unregulated input and regulated, output voltages and hence called the series type of voltage regulator.

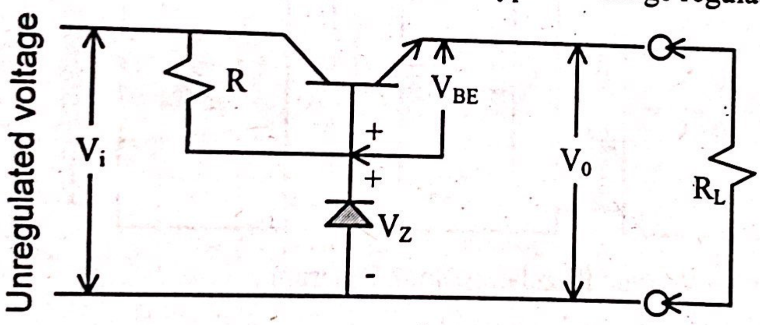


Fig.18.5(a) Emitter Follower Voltage Regulator

Here, the control element is the NPN transistor, often called the PASS transistor because it conducts or passes total load current of the regulator. It is usually a power transistor and mounted on a heat sink in a heavy-duty power supply, that delivers substantial current. The Zener diode provides the reference voltage, and the base to emitter voltage of the transistor is the control voltage.

The Zener diode is reverse biased and that reverse current is furnished to it through resistor R. Although V_i is unregulated, it must remain sufficiently large and R must be sufficiently small to keep the Zener in its break down region. Though the unregulated input voltage (V_i) varies V_R remains essentially constant.

Hence, $V_R = V_{BE} + V_o$ (18.5.1)

or, $V_{BE} = V_R - V_o$ (18.5.2)

As V_R is constant, any change in V_o must cause a corresponding change in V_{BE}, in order to maintain the equality valid. When V_o decrease, V_{BE} increases, which causes the NPN transistor to conduct more heavily and to produce more load current.

Notice that the transistor is used essentially is an emitter follower. The load is connected to the emitter and the emitter follows the base that is connected to a constant voltage V_R. Hence, it is known as emitter follower regulator. For successful regulator operation, the pass transistor must remain in its active region, V_i must not drop to a level so small that the Zener is no longer in its breakdown region and the Zener voltage V_R should be highly independent of both current and temperature.

$$V_i = V_{CE} + V_o \quad (18.5.3)$$

18.6 Series Voltage Regulator :

The most commonly used of all linear regulators is the series regulator. The shunt regulator is generally used for a constant load whereas the series regulator is normally used for a variable load. Since most of the applications require variable load, the series type regulator is taken up here in details.

A stabilized voltage supply essentially consists of following blocks :

- Transformer,
- Rectifier,
- Filter,
- Regulator, and
- Load.

The above blocks are connected in series as shown in Fig.18.6(a).

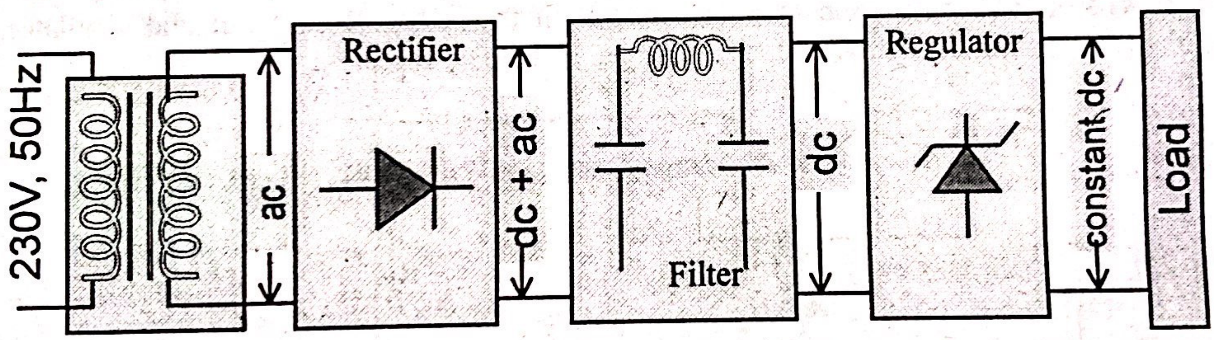


Fig.18.6(a) Voltage Regulator Block Diagram

As we have already discussed rectifiers and filters in Chapter-5, we start our discussions on regulators. A series regulator is divided into five blocks as arranged in Fig.18.6(b).

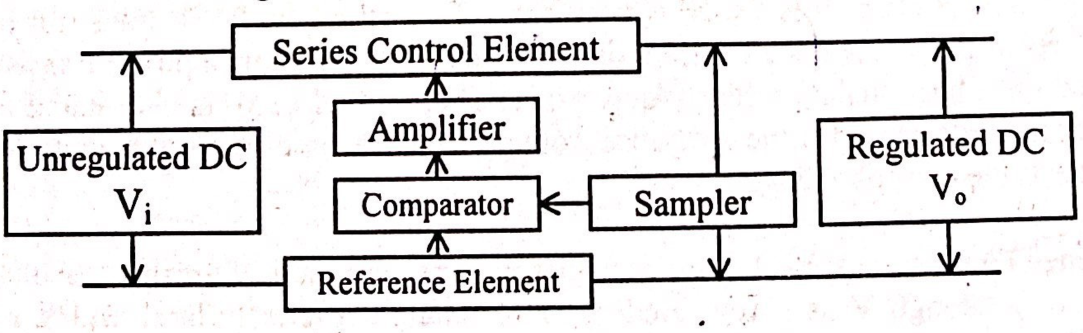


Fig.18.6(b) Block Diagram of Series Regulator

The voltage regulation is taken up here for load current (I_L) variation. The regulation against the load current variation is performed by comparing a sample of the output voltage w.r.t. a fixed reference voltage. The difference of the two is amplified and is used to control the series control element T1.

A simple circuit of a series regulator is shown in Fig.18.6(c)

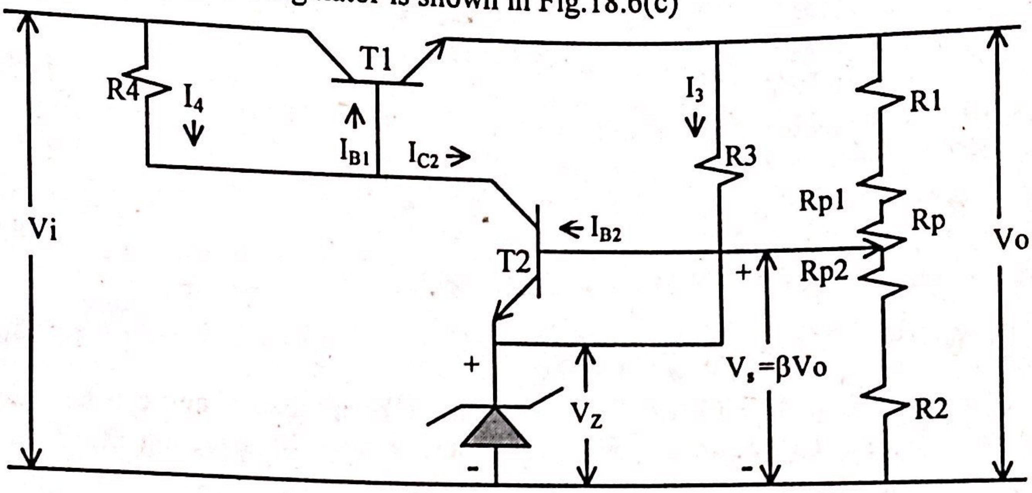


Fig.18.6(c) Series Regulator

18.7 Sampler :

Usually it is a simple resistive voltage divider across the regulated output V_o as indicated in Fig.18.7(a).

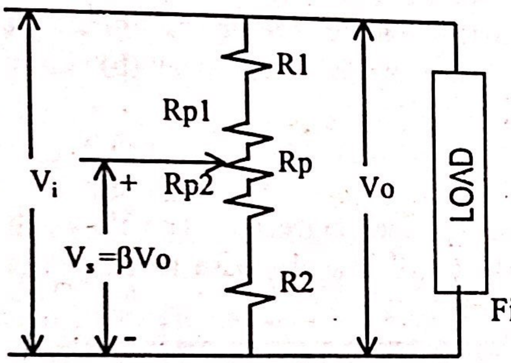


Fig.18.7(a) Sampler Circuit

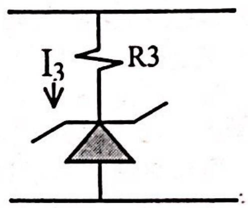


Fig.18.8(a) Zener Reference

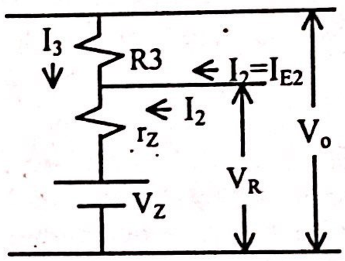


Fig.18.8(b)Equivalent circuit

The sample voltage (V_s) derived from the sampler is :

$$V_s = \frac{R_2 + R_{p2}}{R_1 + R_2 + R_{p1} + R_{p2}} V_o = \frac{R_2 + R_{p2}}{R_1 + R_2 + R_p} V_o \quad (18.7.1)$$

The resistances R_1, R_2, and $R_{p1}+R_{p2}=R_p$ should be made of the same material and are kept at the same temperature.

18.8 Reference Element :

Generally Zener diodes are used as constant voltage reference element as because its breakdown voltage remains relatively constant over a wide range of reverse current. The effect of temperature, reverse current, and diode resistance on the breakdown voltage are the characteristics that are taken into considerations for the selection of the Zener diodes as the reference element.

The complete equivalent circuit of the Zener diode in the Zener region includes a small dynamic resistance r_z in series with a battery voltage equal to the Zener breakdown potential V_z as indicated, in Fig.18.8(b). However, for all practical applications it is assumed that the external resistances are much larger than the dynamic resistance of the

Zener diode and hence r_z=0. Thus the Zener diode is equated by a constant voltage V_z only. From Fig.18.8(b).

$$I_3R_3+r_z(I_3+I_2)+V_z=V_o \qquad (18.8.1)$$

As $I_3 >> I_2$ Eqn.(18.8.1) reduces to :

$$I_3R_3+r_zI_3+V_z=V_o \qquad (18.8.2)$$

$$(R_3+r_z)\Delta I_3=\Delta V_o \qquad (18.8.3)$$

As, $\Delta V_z=0$, $r_z\Delta I_3=\Delta V_R \qquad (18.8.4)$

Hence, combining Eqns.(18.8.3) and (18.8.4) yields :

$$(R_3+r_z)\frac{\Delta V_R}{r_z}=\Delta V_O\text{, or, }\frac{\Delta V_R}{\Delta V_O}=\frac{r_z}{R_3+\cancel{r_z}} \qquad (18.8.6)$$

It is clear from Eqn.(18.8.6) that the change in the reference voltage can be made very small w.r.t. to the change in the output regulated voltage by selecting the Zener diode having very low dynamic resistance.

18.9 **Comparator** :

The comparator compares the sample of the output voltage w.r.t. the constant reference voltage V_s and produces output proportional to the difference of the two signals. A CE amplifier or emitter coupled differential amplifier is normally used as a comparator. The choice depends upon the degree of regulation and temperature stability required. The simple comparator with its equivalent circuits is drawn in Fig.18.9(a) and (b). From Fig.18.9(b)

$$V_{BE2}+V_z=V_s \qquad (18.9.1)$$

Since $I_{B2}=f(V_{BE2})=f(V_s-V_z) \qquad (18.9.2)$

Suppose output voltage V_o decreases with increase in the load current I_L. The V_{BE2} will also decrease accordingly and hence the base current will also decrease as shown in Fig.18.9(c).

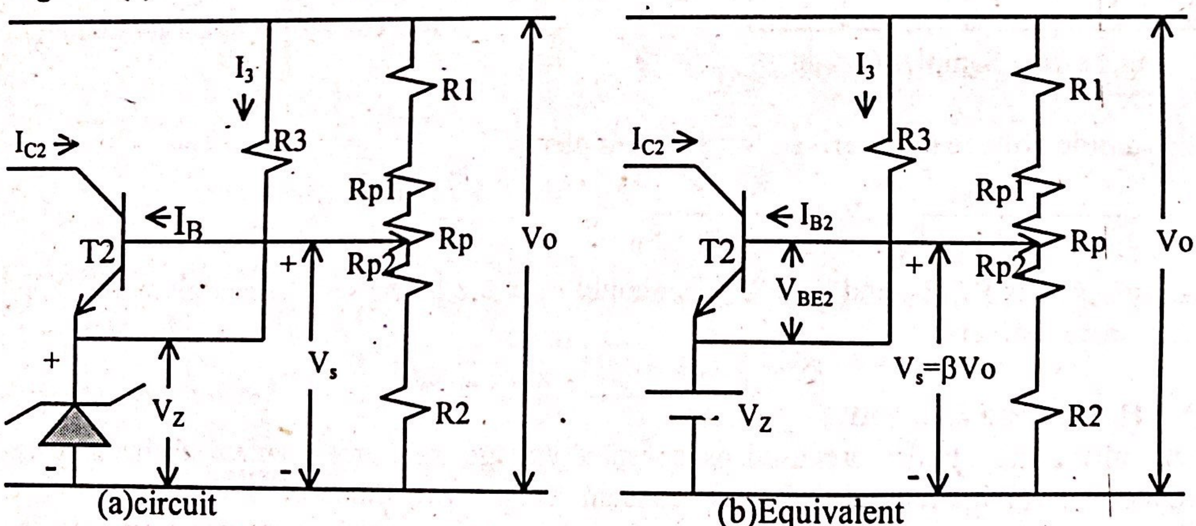
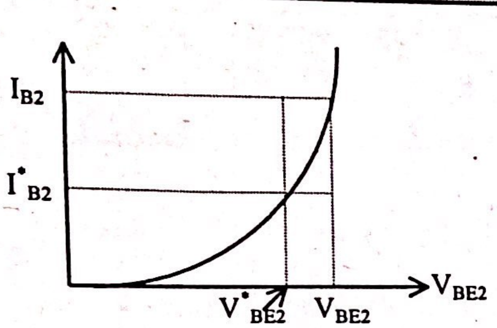


Fig.18.9 Comparator

Since I_C is proportional to I_B, the decrease in I_{B2} will force I_{C2} also to decrease proportionately.

18.10 Amplifier :

The amplifier raises the level of the difference signal to such a value that is sufficient to drive the series control element. In most of the cases the single transistor T2 as shown in Fig.18.9(a) performs the comparison and amplification.



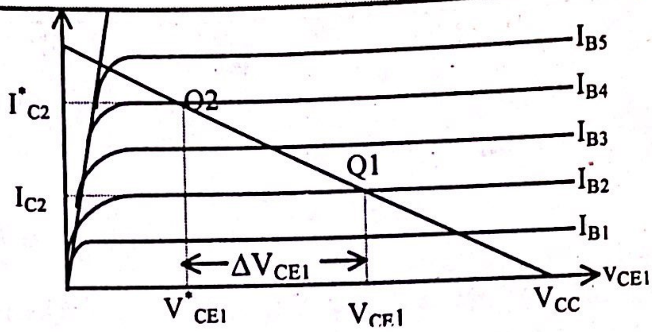


Fig.18.9(c) Variation of I_{B2} with Forward bias V_{BE2} . Fig.18.11(b) I_{C2} with V_{CE2}

18.11 Series Control Element :

The series control element interprets the amplified difference signal and makes appropriate adjustment to maintain the output voltage constant. The circuit of a series control element is shown in Fig.18.6(c) is redrawn as Fig.18.11(a). In order to understand the process of adjustment; let us assume that the base and collector currents of transistor T2 are I_{B2} and I_{C2}. Similarly, the base and collector currents of transistor T1 are I_{B1} and I_{C1}. If the output (load) voltage V_o decreases due to increase in the load current I_L, then the forward bias between base-emitter of T2 = $V_{BE2} = V_s - V_z$ also decreases. Since the base current of T2 = $I_{B2} = f(V_{BE2}) = f(V_s - V_z)$, it decreases consequently from I_{B2} to I^*_{B2} as indicated in Fig.18.9(c) and I_{C2} will also proportionally decrease. The base current of T1 = $I_{B1} = I_4 - I_{C2} = I_4 - \beta I_{B2}$. As I_4 remains constant because input voltage for the time being assumed to be constant, decreasing IC2 forces I_{B1} to increase. The collector current of T1, thus, increases proportionately from I_{C1} to I^*_{C1} as shown in Fig.18.11(b). It is evident from Fig.18.11(b) that the quiescent point shifts from Q_1 to Q_2 resulting in decrease of V_{CE1} to V^*_{CE1}. Thus, the part of the voltage released by V_{CE1} ($\Delta V_{CE} = V_{CE1} - V^*_{CE1}$) is gained by the output voltage V_o. Hence, any attempt to decrease in the output voltage is compensated by the equal amount of voltage released by V_{CE1}. This process is explained by a flow chart in Fig.18.11(c).

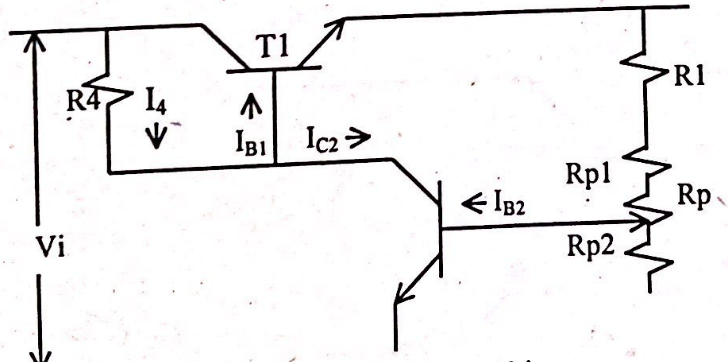


Fig.18.11(a) Series element working

As V_i is constant, $V_i = V_{CE1} + V_o$, With decreasing value of V_o, V_{CE1} has to increase. Following characteristics are essential for the selection of the series control element:

$V_{CE(min)} \geq V_{i(max)} - V_{o(max)}$

$I_{C(max)} \geq I_{o(max)}$

$P_{C(max)} \geq V_{o(max)} I_{C(max)}$

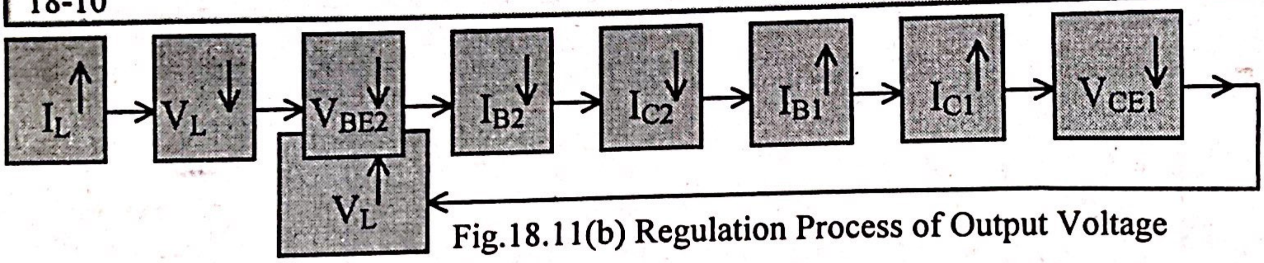


Fig.18.11(b) Regulation Process of Output Voltage

18.12 **Preregulator** :

The preregulator is included as one of the blocks in the voltage regulator to take care of the input voltage variations. The preregulator is to provide the constants current to the junction of the base of T1 and the collector of the T3. A simple preregulator circuit is shown in Fig.18.12(a)

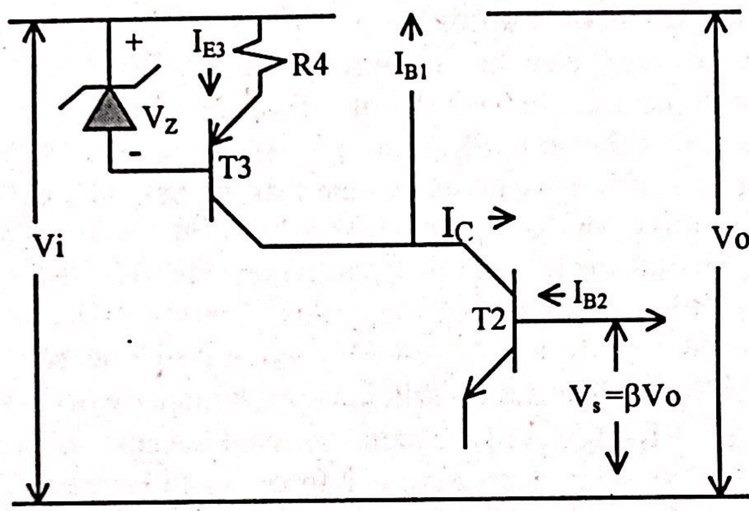


Fig.18.12(a) Preregulator

As V_z is connected across R_3 and V_{BE3},, the collector current of T3 is independent of the change in V_{BE3} caused by even the input voltage variation. In other words, transistor T3 is working as a constant current source.

Hence, $I_{C3} = I_{E3} - I_{B3} = I_{B1} + I_{C2}$ (18.12.1)

$V_z = V_{BE3} + R_4 I_{E3}$ (18.12.2)

or, $R_4 = \dfrac{V_Z - V_{BE3}}{I_{E3}}$ (18.12.3)

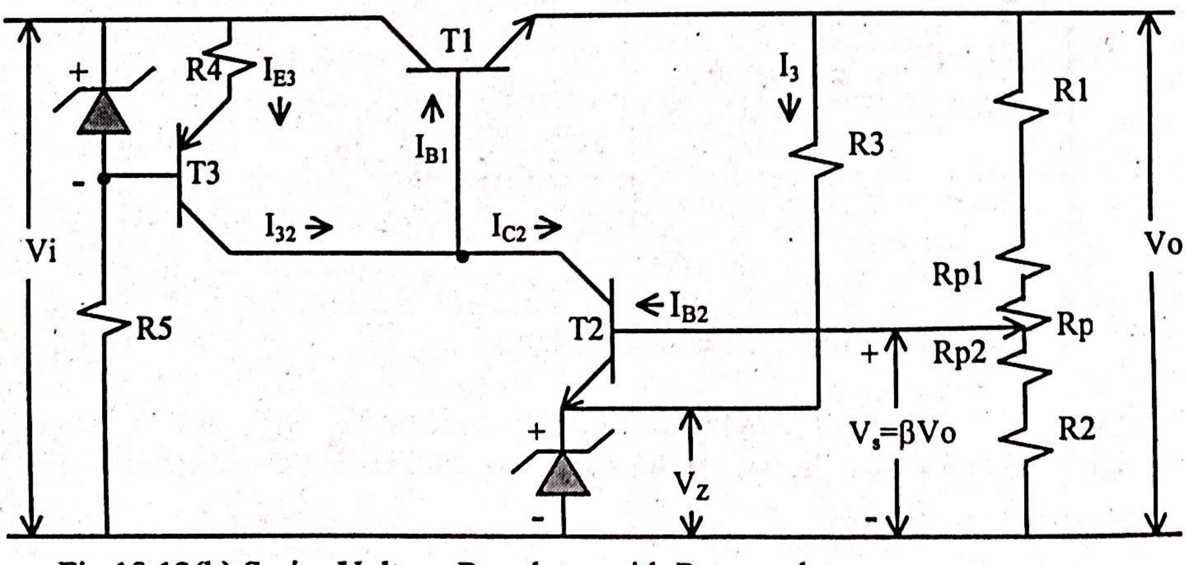


Fig.18.12(b) Series Voltage Regulator with Pre-regulator

As V_z is constant, forward bias to the base of T3 is also constant. Hence, I_{B3}, I_{C3}, and I_{E3} will be constant even if the input voltage varies. The value of R_5 may be obtained as :

$$R_5 = \frac{V_{i(min)} - V_Z - I_Z r_Z}{I_Z + I_{B3}} \qquad (18.12.4)$$

A simple circuit of series voltage regulator is shown in Fig.18.12(b).

The prominent disadvantages of linear type dc voltage regulators are ;

- Less efficient,
- Large size due to large transformer,
- Heat sink for series transistor to dissipate heat due large power loss.

18.13 Shunt Regulator :

The shunt regulator is an another from of the feedback regulator as described by blocks in Fig.18.13(a). In sharp contrast to the series regulator, the control device in this case is in the shunt path. Although the shunt regulator is not as efficient as the series regulator, it has advantage of :

- greater economy and
- simplicity.

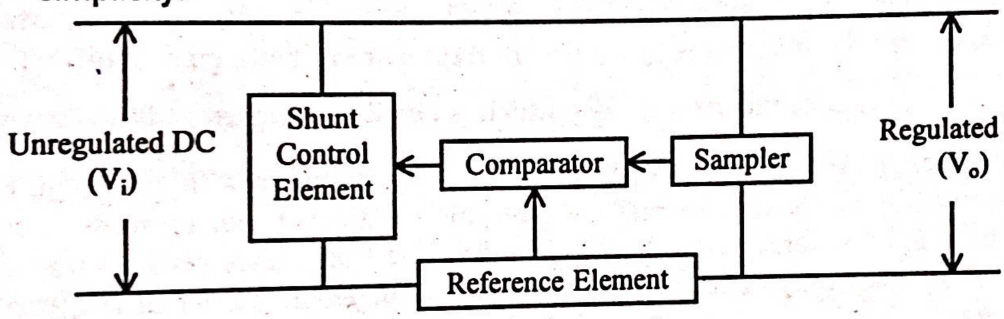


Fig.18.13(a) Block Diagram of Shunt Regulator

This type of regulator is usually recommended for relatively constant load. Each of the blocks in the shunt regulator performs the same function as its counterpart in the series regulator. The control element that is in parallel to the load maintains a constant load voltage by shunting more or less current from the load. The simplest shunt voltage regulator circuit is shown in Fig.18.13(b).

It is convenient to think that the control element in shunt regulator works as a variable resistor. When the load voltage decreases, the resistance of the control element is made to increase, thus diverting less current from the load, and hence the load voltage rises. Conversely, when the load voltage increases, the resistance of the control element decreases, and more current is shunted away from load. From another view point, the source resistance on the unregulated side forms a voltage divider with the parallel combination of the control element and R_L. Thus, when the resistance of the control element increases, the resistance of the parallel combination increases and by voltage divider action the load voltage increases.

Applying KVL results in $V_{BE} = V_L - V_Z$, As V_Z =constant

$V_{BE} \propto V_L$, & $I_B \propto V_{BE}$, $I_C = \beta I_B$, $I_C \propto I_B$

Thus, with decreasing V_L, I_C decreases and hence I_L increases. As I_C decreases, the drop across $V_{CE} = V_L$ increases to the original value. Other way $V_L = V_Z + V_{BE}$, as V_z =constant, decreasing V_L decreases V_{BE} and hence I_B and I_C. Decreasing I_C increases the drop across V_{CE} to reach the original value and hence remains constant.

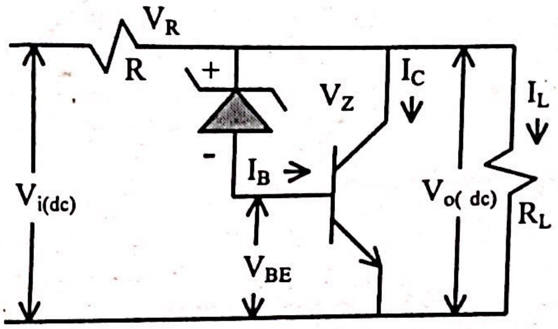


Fig.18.13(b) Shunt Voltage Regulator

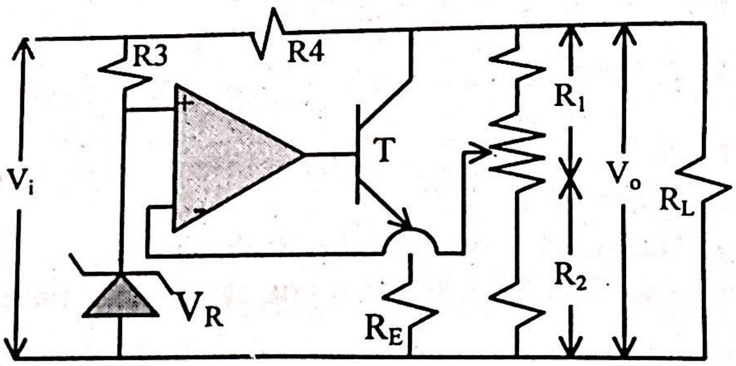


Fig.18.13(c) Shunt Voltage Regulator Circuit Diagram

Resistance R_1 and R_2 form a voltage divider as depicted in Fig.18.13(c) that feeds a voltage proportional to V_o back to the non-inverting input. This voltage is greater than the reference voltage V_R applied to inverting input, so the output of the amplifier is a positive voltage proportional to $\beta V_o - V_R$. If V_o decreases, the amplifier output decreases and transistor (T) conducts less heavily and hence $V_{CE}=V_o$ becomes more. One important advantage of shunt regulator circuit is that it has inherent current limiting capability. It is clear that the load current cannot exceed $\frac{V_i}{R_4}$ which is equal to the current flow through R_4 under short-circuited condition of output. Since the load current must flow through R_4, the power dissipation in the resistor may be quite high, especially under short circuit conditions. This condition forces us to think to include some circuit arrangements that can take care of it automatically. These types of circuit arrangements are called current limiting circuits.

18.14 Current Limiting Techniques :

Almost all-general purpose dc power supplies have short-circuited or overload protection facility. One form of protection circuitry is called current limiting where by specially designed circuitry limits the current that can be drawn from the supply to a certain specific maximum, even if the output terminals are short-circuited. In other words, the protection circuit provides a shunting path to it.

It is well known that the voltage regulator circuits offer very low output resistance. Therefore, it is necessary to introduce protective measures for the over load current in the circuit. This is particularly important in the emitter follower regulator and the series regulator circuits wherein the load current can vary over a wide range. In the series regulator circuit, overloading can result in even a permanent damage to the series-pass transistor (T1), if it is not properly protected. For example, when the output terminals are shorted, full input voltage (V_i) appears across transistor T1 and the resulting current out of it $=V_i/R_o$ passes through it. In such a case, the power dissipated in T1 can become several times the transistor ratings. Hence, it is essential that the protective means introduced to it become effective almost instantaneously.

A series fuse is sometimes used in an attempt to protect the series-pass transistor from excessive power dissipati...

The 723 is a general-purpose integrated circuit voltage regulator. It is an example of a popular and very versatile adjustable (variable) regulator. It can be connected to produce:

- positive or negative outputs from 2V to 37V,
- can provide either current limiting, or fold back limiting,
- with an external pass transistor it can handles load currents up to 10A, and
- can be used as switching regulator.

Table-18.18(a) shows electrical characteristics of the 723. Note the terminal labeled V_{REF} at the output of the voltage reference amplifier. This is an internally generated voltage of approximately 7V that is available with at an external pin.

Table-18.18(a) Electrical characteristic of the 723

Parameter	Min	Typical	Max
Input Voltage	9.5V	------	40V
Output Voltage	2.0V	------	37V
Input output Voltage Difference	3.0V	------	38V
Short Circuit Current Limit ($R_{sc}=10\Omega$, $V_{out}=0$)	----	6.5mA	----
Standby Current Drain($I_L=0$, $V_{in}=30V$)	----	2.3mA	4.0mA
Long Term Stability	----	0.1%/ 1000Hrs	----
Ripple Rejection (50Hz, to 10KHz, $C_{Ref}=0pF$)	----	74db	----
(50Hz, to 10KHz, $C_{Ref}=5pF$)	----	86db	----
Average Temp. ($-55°C \le T_A \le +125°C$)	----	0.002% /°C	0.015% /°C
Coeff. of Output voltage($0°C \le T_A \le 70°C$)		0.003%/°C	0.014%/°C
Output Noise Voltage (BW=100Hz to10KHz, $C_{REF}=0pF$)	---	$20\mu V_{rms}$	----
(BW=100Hz to10KHz, $C_{REF}=5pF$)	$2.5\mu V_{rms}$		
Current from V_Z	---	----	2.5mA
Current from V_{REF}	----	----	15mA
Internal Power Dissipation	----	----	800mW
Reference Voltage	6.8V	7.15V	7.5V
Line Regulation ($V_i=12V$ to 15V, $0°C \le T_A 70°C$)	----	$0.01\%V_o$	$0.1\%V_o$
($V_i=12$ to 40V, $0°C \le T_A 70°C$)	----	$0.1\%V_o$	$0.2\%V_o$
Load Regulation($I_L=1mA$, to 50mA)	----	$0.03\%V_o$	$0.15\%V_o$
($-55°C \le T_A \le +125°C$)		$0.6\%V_o$	-----

In order to set a desired regulated output voltage, the user connects this 7V output, or an externally divided-down portion of it, to one of the line input of the error amplifier. The error amplifier is a comparator that compares the externally connected reference to a voltage proportional to V_o. Depending on whether the reference is connected to the non-