Power Supply

DSE Paper: Physics of Devices and Instruments, Sixth Semester

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Author's words: This is a very simple class note to understand the basics regarding power supply. This is mainly made on the basis of the syllabus defined by Kazi Nazrul University, Asansol and also proposed by UGC. Students are allowed to ask any questions in this regard at my email-saumenbcc@gmail.com.

Syllabus:
Power supply: Block Diagram of a Power Supply, Qualitative idea of C and L Filters. IC Regulators, Line and load regulation, Short circuit protection **(3 Lectures)**

Power supply circuit is one of the main parts of any electronic device. It provides the required amount of power (may be AC or DC) to various sections of the device.

Need : Generally**,** the electronic devices like computer, television etc. consist of many small sections (each has their particular job). In performing their jobs they need power, but all of them don't need 230V AC which we get from main line supply. Instead one or more sections may need a 5V to 30 V DC. In order to provide such required DC voltages, the incoming 230v AC supply has to be converted into pure DC. The Power supply circuits serve this purpose.

<u>Block Diagram of a Power supply</u>

The block diagram of a Regulated Power supply unit is as shown below.

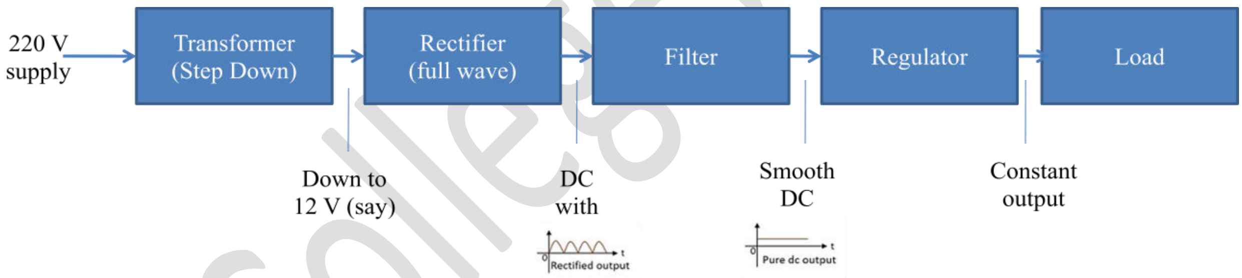


Fig. PS1

Function of different parts of a typical Power supply in brief:

- **Transformer** − The transformer is used to step down the 230 V AC to required value as per need.
- **Rectifier** − A rectifier circuit convert the AC signal to DC.
- **Filter** − A filtering circuit is followed just after the rectifier to smoothen the ripple present in the rectified output.
- **Regulator** − The regulator circuit is used to maintain the voltage at a desired output level.
- **Load** – Finally the regulated output is applied to a load.

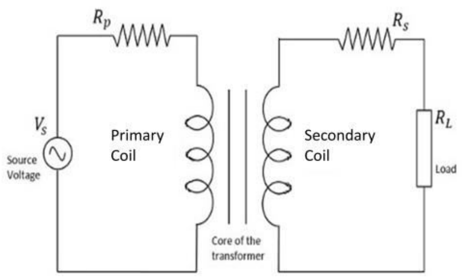


Fig. PS2

<u>Transformer</u>: The basic parts of a transformer are shown in Fig. PS2. It consists of primary coil, the secondary coil and the core. When a transformer is connected to the supply, it means the supply is given to the primary coil. As it is a varying supply so it produces varying magnetic flux and that flux is induced into the secondary coil of the transformer. This produces the varying EMF in the secondary. Depending upon the number of turns in the secondary winding, a transformer can be classified either as a **Step-up** (higher number of turns) or a **Step-down** (less number of turns) transformer. **(It is**

already studied in details in SEM-II in Electricity Magnatism)

Rectifier: During the process of rectification, the alternating current (AC) as obtained from the output of the transformer is changed into direct current (DC). With the use of diode based full wave rectifier circuit the current is allowed to flow only in positive direction and resisted in negative direction, just as in the Fig.PS3. **(It is already studied in details in SEM-III in analog electronics)**

Filters: The rectified version contains ripple in the signal, denotes the presence of some AC component. This ac component has to be completely removed in order to get pure dc output. So, we need a filter circuit that smoothens the rectified output into a pure dc signal. A **filter circuit** is one which removes the ac component present in the rectified output and allows the dc component to reach the load (Fig. PS3). The filter circuits are constructed using different combination of inductor and capacitor.

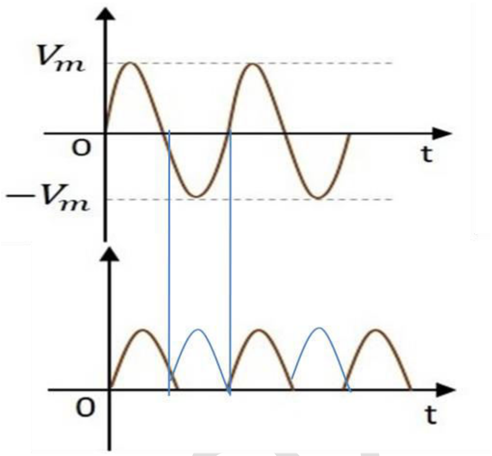


Fig. PS3

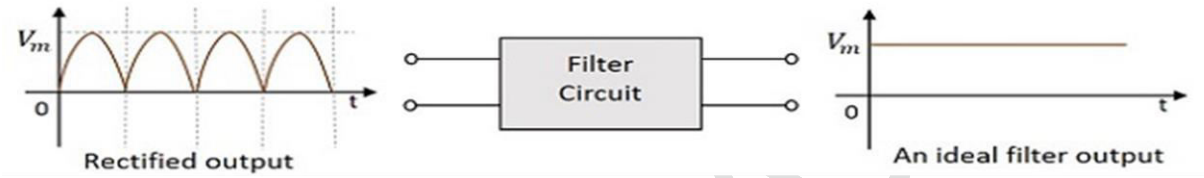


Fig. PS4

1. <u>**Series Inductor Filter**</u>

A **Series Inductor Filter** can be constructed by connecting an inductor in series, between the rectifier and the load. The figure below shows the circuit of a series inductor filter. The rectified output when passed through this filter, the inductor or the choke blocks the ac components that are present in the signal due to the fundamental property that inductance resist the fact for which it generated. Thus a less rippled output is obtained (Fig. PS5).

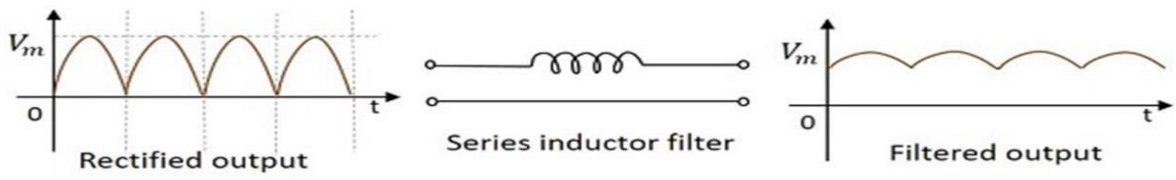


Fig. PS5

2. <u>**Shunt Capacitor Filter**</u>

A **Shunt Capacitor Filter** can be constructed using a capacitor, connected in shunt, as shown in Fig.PS6. The rectified output when passed through this filter, the ac components present in the signal are grounded through the capacitor (as the reactance is low enough for ac). The remaining dc components present in the signal are collected at the output. In other words, the system stores energy during conduction and release this energy at a lesser rate than the change occur in ac signal (depending upon the time constant of the capacitor circuit) at the non-conducting period. Thus it decrease the ripple considerably.

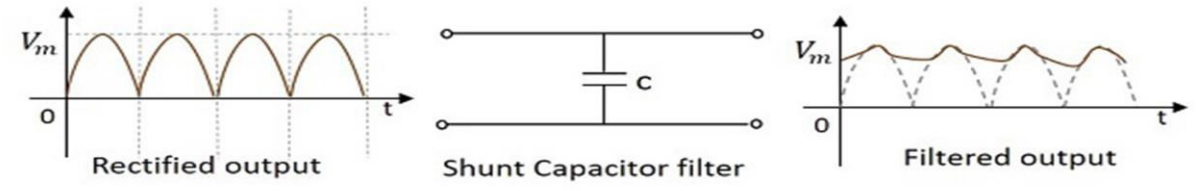


Fig. PS6

The above filter types discussed are constructed using an inductor or a capacitor and these are known as primary filters. Now, we use both of them to make a better filter. These are combinational filters.

3. **L-C Filter**

A filter circuit can be constructed using both inductor and capacitor in order to obtain a better output where the efficiencies of both inductor and capacitor can be used. The Fig.PS7 shows the circuit diagram of a LC filter. The rectified output when given to this circuit, the inductor allows dc components to pass through it, blocking the ac components in the signal. Now, from that signal, few more ac components if any present are grounded so that we get a pure dc output. This filter is also called as a **Choke Input Filter** as the input signal first enters the inductor. The output of this filter is a better one than the previous ones.

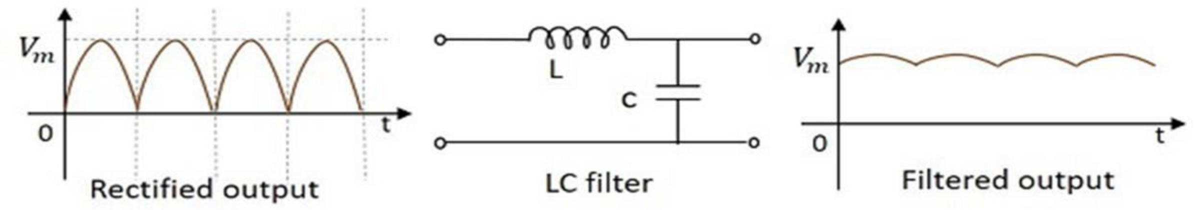


Fig. PS7

4. **Π- Filter (Pi filter)**

This is another type of filter circuit which is very commonly used. It has capacitor at its input and hence it is also called as a **Capacitor Input Filter**. Here, two capacitors and one inductor are connected in the form of π shaped network (Fig.PS-8). A capacitor in parallel, then an inductor in series, followed by another capacitor in parallel makes this circuit. If needed, several identical sections can also be added to this, according to the requirement. The figure below shows a circuit for π-filter (**Pi-filter**).

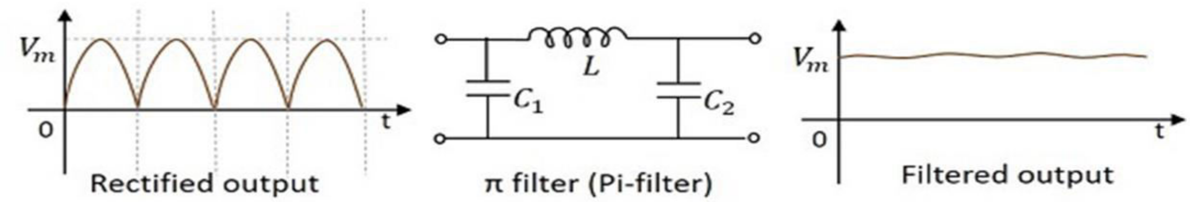


Fig. PS8

Here,

- **Capacitor C_1** offers high reactance to dc and low reactance to ac signal (present as ripple in rectified output). So a great part of the ac components present in the signal get grounded through this, the rest signal passes to the inductor for further filtration.
- **Inductor L** offers low reactance to dc components, while blocking the ac components if any got managed to pass, through the capacitor C_1.
- **Capacitor C_2** makes further smoothness by allowing any ac component present till in the signal, which the inductor has failed to block. Thus we, get the desired pure dc output at the load.

Regulator: It is very important to produce a constant voltage at the output of a power supply, irrespective of the input voltage variations or the load current variations. A **voltage regulator** is such a device that maintains constant output voltage, instead of any kind of fluctuations in the applied input voltage or any variations in current, drawn by the load.

Thus, from above definition of regulator it is clear that the regulators are mainly divided into two types namely, line and load regulators.

- **Line Regulator** − The regulator which regulates the output voltage to be constant, in spite of input voltage (line) variations, it is called as **Line regulator**.

  % Line regulation= $\frac{(V_{HL}-V_{LL})/V_{LL}}{\Delta V_{IN}} \times 100\%$ ×per volt, where $V_{HL}$is the voltage when line voltage is high, $V_{LL}$is the voltage when line voltage is low, $\Delta V_{IN}$is the change in line voltage.

- **Load Regulator** − The regulator which regulates the output voltage to be constant, in spite of the variations in load at the output, it is called as **Load regulator**.

  % Load regulation= $\frac{(V_{NL}-V_{FL})}{V_{FL}} \times 100\%$ where V_{NL} is the voltage when load current is zero (i.e. no load), V_{FL} is the voltage when load current is maximum (i.e. full load).

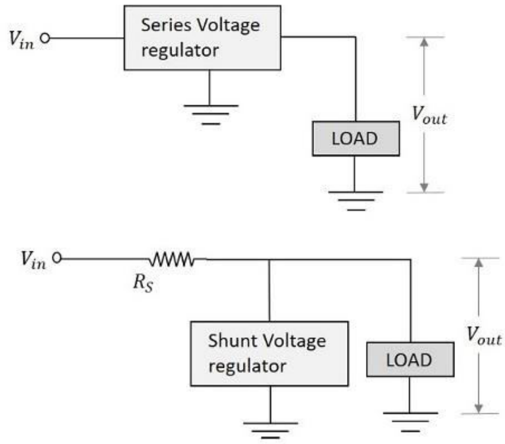


Fig.PS9

We already studied the application of zener diode as a voltage regulator in semester-III, but it has some limitations. They are,

- It is less efficient for heavy load currents.
- The Zener impedance slightly affects the output voltage.

Hence a Zener voltage regulator is considered effective for low voltage applications. Now, let us go through the other types of voltage regulators, which are made using transistors with zener diode. Depending upon the type of connection, there are two types of voltage regulators (Fig.PS9). They are

- Series voltage regulator
- Shunt voltage regulator

Transistor Series Voltage Regulator

This regulator has a transistor in series to the load. The transistor works as a variable resistor regulating its collector emitter voltage in order to maintain the output voltage constant. The Fig.PS10 shows the transistor series voltage regulator.

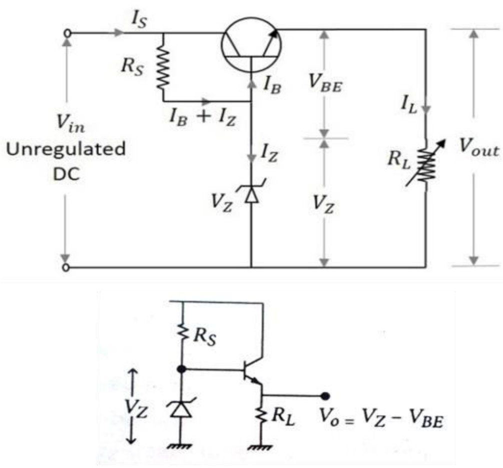


Fig. PS10

The current through the base of the transistor changes with the input operating conditions. This affects the voltage across the base emitter junction of the transistor (V_{BE}). The output voltage is maintained by the Zener voltage V_z which is constant. Thus any change in the input supply is compensated by the change in emitter base voltage V_{BE}. According to the second figure, the output voltage V_{out} can be understood as, $V_{out} = V_z - V_{BE}$.

Line Regulation: If the input voltage is increased, the output voltage also increases. But as the zener voltage is constant so this makes the voltage across the base emitter junction (V_{BE}) to decrease. Decrement in V_{BE} decreases the conduction through transistor (as if the resistance across emitter collector region increases). Reduce current reduce the drop across the load, thus reducing the output voltage V_{out}. This will be similar when the input voltage decreases.

Load Regulation: If the resistance of the load decreases, the output voltage V_{out} decreases. That means the emitter base voltage V_{BE} increases as V_z is constant. With the increase in the emitter base voltage V_{BE} the conduction increases (reducing the emitter collector resistance). This in turn increases the current through the transistor which compensates the decrease in the load resistance and makes the output voltage constant. This will be similar when the load increases.

Limitations of Transistor Series Voltage Regulator

The main advantage of series regulator is better efficiency, but it has the following limitations −

- The voltages V_{BE} and V_z are affected by the rise in temperature.
- No good regulation for high currents is possible.

Power dissipation is high.To minimize these limitations, transistor shunt regulator is used.

Transistor Shunt Voltage Regulator

A transistor shunt regulator circuit is formed by connecting a resistor in series with the input and a transistor whose base and collector are connected by a Zener diode. The Fig.PS11 shows the circuit diagram.

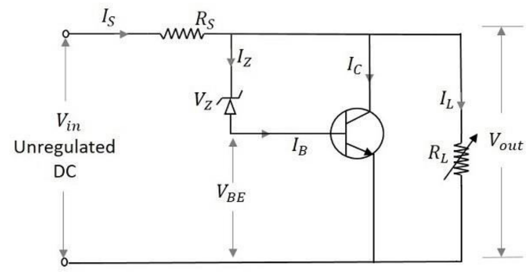


Fig.PS11

Line Regulation: As from figure, $V_{out} = V_Z + V_{BE} = V_{in} - I_s R_s$

If the input voltage increases, the V_{BE} and V_{out} also gets increased (V_z remains constant).

But this happens initially. Actually when V_{in} increases, V_{out} and V_{BE} increases. The increment of base emitter voltage of transistor increases the collector current (I_c). Thus, I_s also increases (as $I_s = I_c + I_L$). This increased current when flows through R_S, causes an increased voltage drop across the series resistor. So, this makes V_{out} to decrease. Now this decrease in V_{out} compensates the initial increase maintaining it to be constant. If the output voltage decreases instead, the reverse happens.

Load Regulation: If the load resistance decreases, there should be decrease in the output voltage V_{out}. 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 output voltage V_{out} decreases, the base emitter voltage of transistor also decreases. As a result, lesser 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.

The following are the drawbacks of a transistor shunt voltage regulator :

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

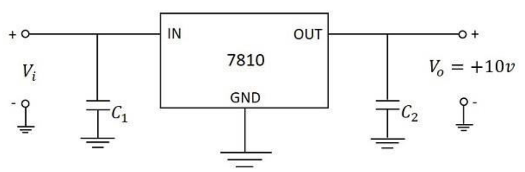
IC Regulators

Voltage Regulators are now-a-days available in the form of Integrated Circuits (ICs). These are in short called as IC Regulators. Along with the functionality like a **normal regulator**, an IC regulator has the properties like **thermal compensation, short circuit protection and surge protection** which are built into the device.

Types of IC regulators

IC regulators can be of the following types −

- Fixed Positive voltage regulators
- Fixed Negative voltage regulators
- Adjustable voltage regulators
- Dual-tracking voltage regulators



Fixed Positive Voltage Regulator

Fig.PS12

1. Fixed Positive Voltage Regulator

The output of these regulators is fixed to a specific value and the values are positive, which means the output voltage provided is positive voltage. The most used series is 78XX series and the ICs will be like IC 7806, IC 7812 and IC 7815 etc. which provide +6v, +12v and +15v respectively as output voltages (digits XX of IC indicates the value of regulated output). The Fig.PS12 shows the IC 7810 connected to provide a fixed 10v positive regulated output voltage.

In the Fig.PS12, the input capacitor C_1 is used to prevent unwanted fluctuations of the input line and the output capacitor C_2 acts as a line filter to improve transient response.

2. Fixed Negative Voltage Regulator

The output of these regulators is fixed to a specific value and the values are negative, which means the output voltage provided is negative voltage. The most used series is 79XX series and the ICs will be like IC 7906, IC 7912 and IC 7915 etc. which provide -6v, -12v and -15v respectively as output

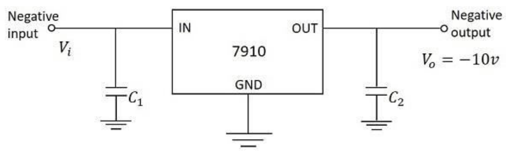


Fig.PS13

voltages (digits XX of IC indicates the value of regulated output). The Fig.PS13 shows the IC 7910 connected to provide a fixed 10v negative regulated output voltage. In the figure, the input capacitor C_1 is used to prevent unwanted fluctuations of the input line and the output capacitor C_2 acts as a line filter to improve transient response.

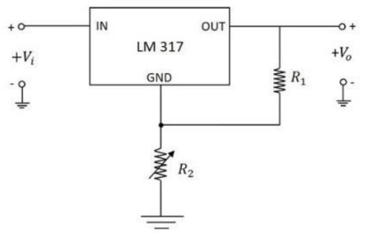


Fig.PS14

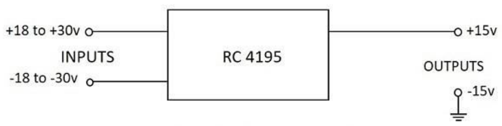


Fig.PS15

3. Adjustable Voltage Regulators

An adjustable voltage regulator has three terminals IN, OUT and ADJ. The input and output terminals are common whereas the adjustable terminal is provided with a variable resistor which lets the output to vary between a wide range.

The figure shows an unregulated power supply driving a LM 317 adjustable IC regulator which is commonly used. The LM 317 is a three terminal positive adjustable voltage regulator and can supply 1.5A of load current over an adjustable output range of 1.25v to 37v.

4. Dual-Tracking Voltage Regulators

A dual-tracking regulator is used when split-supply voltages are needed. These provide equal positive and negative output voltages. For example, the RC4195 IC provides D.C. outputs of +15v and -15v. This needs two unregulated input voltages such as the positive input may vary from +18v to +30v and negative input may vary from -18v to -30v.

The image shows a dual-tracking RC4195 IC regulator. The adjustable dual-tacking regulators are also available whose outputs vary between two rated limits.

The topics discussed till now represent different sections of power supply unit. All these sections together make the **Linear Power Supply**. This is the conventional method of obtaining DC out of the input AC supply.

Linear Power Supply

The Linear Power Supply (LPS) is the regulated power supply which dissipates much heat in the series resistor to regulate the output voltage which has low ripple and low noise. This LPS has many applications.

A linear power supplies are used in many semiconductor devices to regulate the output voltage. Linear power supplies have transient response times up to 100 times faster than the others, which is very important in certain specialized areas.

Advantages of LPS

- The power supply is continuous.
- The circuitry is simple.
- These are reliable systems.
- This system dynamically responds to load changes.
- The circuit resistances are changed to regulate the output voltage.
- As the components operate in linear region, the noise is low.
- The ripple is very low in the output voltage.

Disadvantages of LPS

- The transformers used are heavier and large.
- The heat dissipation is more.
- The efficiency of linear power supply is 40 to 50%
- Power is wasted in the form of heat in LPS circuits.
- Single output voltage is obtained.

In spite of the above disadvantages, Linear Power Supplies are widely used in low-noise amplifiers, test equipment, control circuits. In addition, they are also used in data acquisition and signal processing.

All the power supply systems that needs simple regulation and where efficiency is not a concern, the LPS circuits are used. As the electrical noise is lower, the LPS is used in powering sensitive analog circuitry.

Overload Protection Circuit (Short Circuit Protection) in Regulated Power Supply:

In any power supply there is always the risk that the output will experience a short circuit. Accordingly it is necessary to protect the power supply from damage under these circumstances. There are a number of circuits that can be used for power supply protection; here we discuss the basics of few of them.

1. **Diode based current limited circuit**

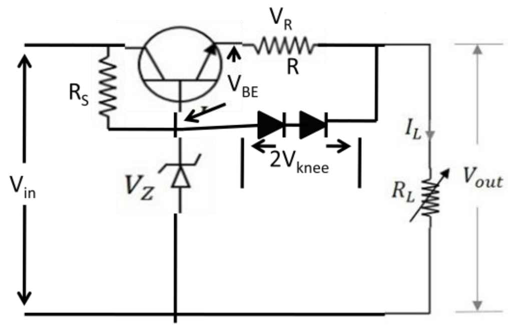


Fig.PS16

The most simple protection circuit is designed with help of diodes. The circuit uses a sense resistor placed in series with the emitter of the output pass transistor and two diodes placed between the output of the circuit and the base of the pass transistor (Fig.PS16). When the circuit is operating within its normal operating range a small voltage drops across the series sense resistor (V_R) and the voltage V_R plus the base emitter voltage (V_{BE}) of the transistor is less than the voltage drop across two diode junctions. So, the two diodes remain non-conducting. However, as the current increases the voltage across the resistor also increases. When the sum of V_R and V_{BE} equals with the turn on voltage of two diodes, they start to conduct. This lowers down the voltage of the base emitter junction of the transistor, thereby limiting the current that can be drawn. Here the maximum possible value of load current is $I_{Lmax} = \frac{(2V_{knee} - V_{BE})}{R}$. However it is always best to ensure that there is some margin in hand by limiting the current from the simple power supply regulator before the absolute maximum level is reached.

2. **Transistor current limited circuit**

In above circuit minimum of two diodes must be used. We can also used transistor instead of diode which gives far better regulation. The operation of such circuit is very straightforward. When the power supply is supplying current below the maximum level, the potential difference develops across the sense resistor is small and less than the base emitter voltage (V_{BE}). The value of the resistor is chosen so that at when the maximum allowable current flows from the power supply, a voltage equal to the turn on voltage (i.e V_{BE}) of the current sense transistor is developed across it. This is typically 0.6 volts, assuming that a silicon transistor is used.

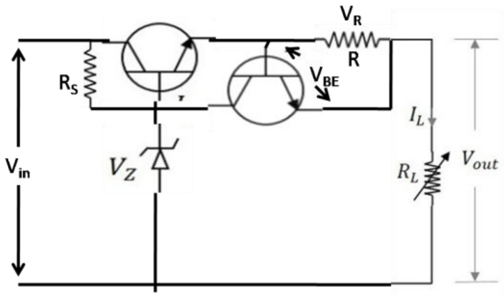


Fig.PS17

As the voltage across the current sense resistor reaches V_{BE} (i.e. $V_R = V_{BE}$), so the current sense transistor starts to conduct. When it does this, the base voltage of the main power supply pass transistor is pulled down, thereby preventing any increase in the output current of the power supply. Here the maximum possible value of load current is $I_{Lmax} = \frac{V_{BE}}{R}$.

For regulator circuits using regulator integrated circuits, these are virtually certain to include current limiter circuitry based around this principle.

3. **Foldback Current Limiting**

A problem with the simple current limiting circuit just discussed is that there is a large amount of power dissipation in series pass transistor Q_1 while the regulator remains short-circuited. The foldback current limiting circuit is the solution of above problem.

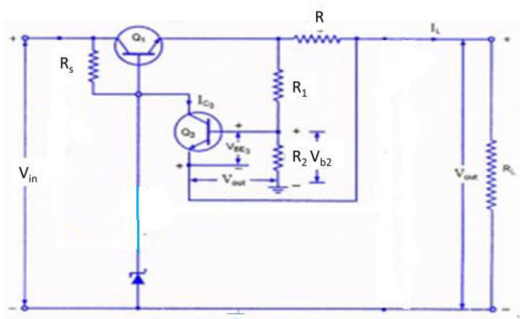


Fig.PS18

The circuit of a transistor series voltage regulator with foldback current limiting facility is illustrated in the Fig.PS18. Here, the base of transistor Q_2 is biased by a voltage divider circuit with resistors R_1 and R_2. The load current I_L flows through the sense resistor R (when Q_2 non conducting), causing a voltage drop of $I_L R$ (approximately) across it. Thus a voltage of ($I_L R + V_{out}$) acts across the voltage divider circuit.

The voltage applied to the base of transistor Q_2 is equal to the voltage drop across resistor R_2 and is given as

$$V_{b2} = (R_2 / R_1 + R_2)\ (I_L R + V_{out})$$

Emitter of transistor Q_2 is connected to the positive terminal of V_{out}. Applying Kirchhoff's voltage law to closed mesh of Q_2 shown in the figure we have

$$V_{out} + V_{BE2} = V_{b2}$$

$$\text{or } V_{BE2} = V_{b2} - V_{out} = K\ (I_L R + V_{out}) - V_{out} = KI_L R + (K - 1)\ V_{out}$$

where $K = R_2 / R_1 + R_2$. Now if load resistance decreases, may be due to any reason, load current I_L will increase causing voltage drop $I_L R$ to increase. This causes V_{b2} to increase and therefore V_{BE2} to increase. This makes transistor Q_2 on. The increased collector current I_{C2} of transistor Q_2 flows through the resistor R_S thereby decreasing the base voltage of transistor Q_1. This results in reduction of the conduction level of transistor Q_1. Thus further increase in load current is prevented.

From the equations above it is obvious that V_{BE2} in this circuit is much more than that was mentioned in previous section (only $I_L R$). It means that the increment in load current is limited by larger amount in circuit shown in figure.

Due to reduction in load resistance R_L, V_{BE2} increases to a level so that transistor Q_2 gets saturated. Now collector current I_{C2} becomes constant. Any further decrease in R_L will have no effect on I_{C2}. The corresponding load current is I_{Lmax} and is given as

$$I_{Lmax} = (V_{BE2} + (1\text{-}K) * V_{out}) / KR$$

When load resistance R_L is zero that is, when output terminals get shorted the output voltage V_{out} becomes equal to zero. Substituting $V_{out} = 0$ in the above equation we have

$$I_{SL} = V_{BE2}/KR$$

That is, shorted-load current I_{SL} is very much smaller than maximum load current I_{Lmax} proving the foldback current limiting. The smaller I_{SL} limits power dissipation in pass transistor Q_1 preventing it from being damaged. This is the main advantage of this circuit.

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