

Power supplies

Regulation & Stabilisation

What you'll learn in Module 2

[Section 2.0 Regulation & Stabilisation.](#)

- Regulation & Stabilisation.
- Effects of Poor Regulation.
- The Shunt Regulator.
- The Series Regulator

[Section 2.1 Shunt Voltage Regulators.](#)

- The Zener Diode.
- The Basic Shunt Regulator Circuit.
- Calculate Component Values.
- Limitations of the Basic Shunt Regulator Circuit.
- Improving Current Rating and Line Regulation.

[Section 2.2 Series Voltage Regulators.](#)

- The Simple Series Regulator.
- Using Feedback & Error Amplification.
- Current Limiting.
- Over Voltage Protection.

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- Decoupling.
- Dropout.
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- Test Your Knowledge of Regulated Power Supplies.



Effects of Poor Regulation

The effect of poor regulation (or stabilisation) of the supply can be seen in Fig. 1.3.1 which shows graphs of output voltage (V_{DC}) for increasing load current (I) in various versions of a basic power supply.

Notice that the output voltage is substantially higher for full wave designs (red and yellow) than half wave (green and purple). Also note the slightly reduced voltage when a LC filter is added, due to the voltage drop across the inductor. In every case in the basic design the output voltage falls in an almost linear fashion as more current is drawn from the supply. In addition to this effect, the extra discharge of the reservoir capacitor also causes the ripple amplitude to increase.

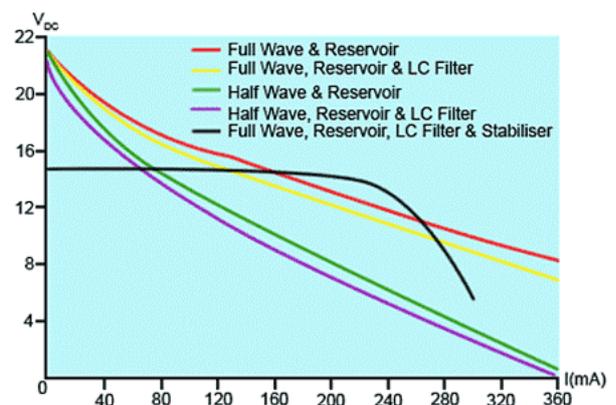


Fig. 1.3.1 Regulation Curves Compared

Regulator (Stabiliser)

These problems can be largely overcome by including a regulator stage at the power supply output. The effect of this circuit can be seen in Fig. 1.3.1. as the black line on the graph, where for any current up to about 200mA the output voltage (although lower than the absolute maximum provided by the basic supply) remains constant.

A regulator counteracts the effects of varying load current by automatically compensating for the reduction in output voltage as current increases.

It is also common in regulated supplies, that the output voltage is automatically and suddenly reduced to zero as a safety measure if the current demand exceeds a set limit. This is called Current Limiting.

Regulation requires extra circuitry at the output of a simple power supply. The circuits used vary greatly in both cost and complexity. Two basic forms of regulation are used:

1. The shunt regulator.
2. The series regulator.

These two approaches are compared in Fig. 1.3.2 & Fig 1.3.3

The Shunt Regulator

In the shunt regulator (Fig. 1.3.2) , a circuit is connected in parallel with the load. The purpose of the regulator is to ensure a stable voltage across the load at all times; this is achieved by arranging that a current will flow through the regulator circuit at all times. If the load current increases, then the regulator circuit reduces its current so that the total supply current I_T , (made up of the load current I_L plus the regulator current I_S), remains at the same value. Similarly if the load current decreases, then the regulator current increases to maintain a steady total current I_T . If the total supply current remains the same, then so will the supply voltage.

Regulator or Stabiliser?

Strictly speaking, compensating for variations in the mains (line) input voltage is called REGULATION, while compensating for variations in load current is called STABILISATION. In practice you will find these terms used rather loosely to describe compensation for both effects. In fact most stabilised or regulated power supplies compensate for both input and output variations and so are both (at least to some degree) stabilised and regulated power supplies.

In common with much modern usage, the term 'Regulator' will be used here to describe both regulation and stabilisation.

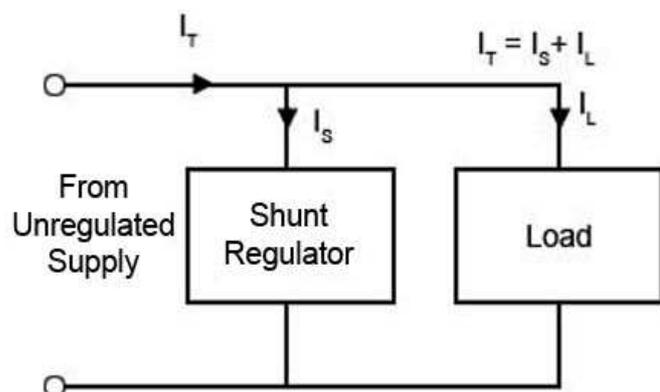


Fig. 1.3.2 The Shunt Regulator

The Series Regulator

In the series regulator (Fig. 1.3.3), the controlling device is in series with the load. At all times there will be a voltage drop across the regulator. This drop will be subtracted from the supply voltage to give a voltage V_L across the load, which is the supply voltage V_T minus the regulator voltage drop V_S . Therefore:

$$V_L = V_T - V_S$$

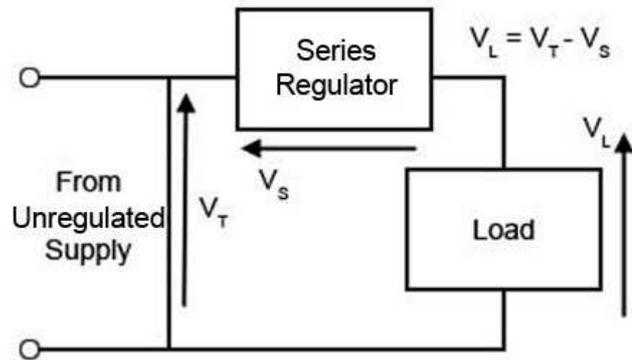


Fig. 1.3.2 The Series Regulator

Series regulators are usually controlled by a sample of the load voltage, using a negative feedback system. If the load voltage tends to fall, the smaller feedback causes the controlling device to lessen its resistance, allowing more current to flow into the load, so increasing the load voltage to its original value. An increase in load voltage will have the opposite effect. Like shunt regulation, the action of the series regulator will also compensate for variations in the supply voltage.

2.1 Shunt Voltage Regulators

What you'll learn in Module 2.1

After studying this section, you should be able to:

Understand the principles of shunt regulators.

- Regulating action of a zener diode.
- Operation of the basic shunt regulator circuit.
- Calculate component values for a basic shunt regulator circuit.

Recognise the limitations of the basic shunt regulator.

Understand methods for increasing current rating.

Recognise cascading techniques for improving line regulation.

Basic Shunt Regulator Circuits

Shunt regulators are widely used because they are cheap, effective and simple. It is unusual however, to find a shunt regulator used as the main regulating circuit in a large power supply. Shunt regulation is only really suitable, at reasonable cost, for relatively small currents and a range of fixed, usually fairly low voltages. As mentioned in power supplies module 2.0, a regulation current must always be flowing in addition to the load current. This is wasteful of power if large currents are involved.

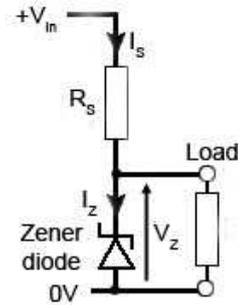


Fig. 2.1.1 Basic Shunt Regulator

The basic shunt regulator circuit is shown in Fig. 2.1.1 and consists of only two components; a series resistor R_S feeding current to a zener diode, which is connected in reverse polarity) across the load.

The Zener Diode.

The main property of a zener diode is that the voltage across the diode (V_Z) will remain practically steady for a wide range of current (I_Z) when the diode is operated in reverse bias mode, as shown in Fig. 2.0.1.

Fig. 2.1.2 illustrates the characteristic curve of a zener diode where the operating region (shown in green) of the zener diode is a range of current on the nearly vertical breakdown region of the curve.

Provided that the reverse current is kept at a value above about 1 to 2mA (avoiding the "knee" of the reverse characteristic) and does not exceed the safe working current for that particular diode type, very little change in reverse voltage takes place. It is this effect that is used to give the required regulating effect.

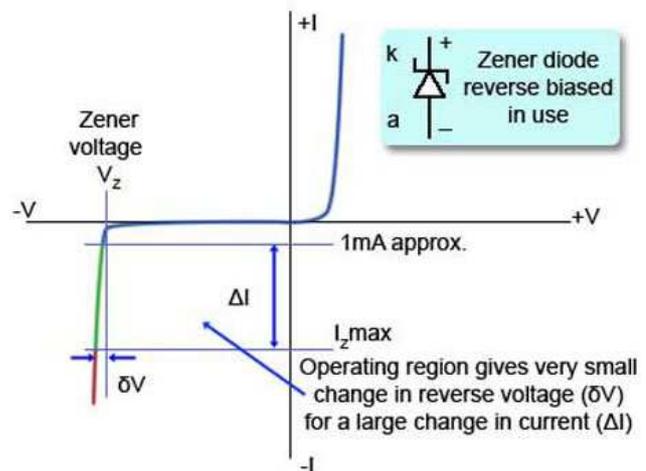


Fig. 2.1.2 Zener Diode Characteristic Curve

As the power supply operates, two conditions may occur to change the output voltage;

- The load current may vary.
- The supply voltage may vary.

The circuit is arranged so that the total supply current I_S is made up of the output load current I_{OUT} plus the current in the zener diode I_Z :

$$I_S = I_Z + I_{OUT}$$

Provided that the zener diode is working within its allowable range of current, the voltage V_Z will remain practically constant, deviating by only a very small amount (δV).

Point of Load Regulators

The most common method of using these basic zener diode shunt regulators is the 'point of load' regulation system. This method uses a number of fixed voltage, relatively low current regulators at various points around the circuit being supplied.

A relatively ineffective main regulator can then be used in the power supply unit because each section of the circuit has its own regulator. For example many complex circuits need different voltage levels for different electrical and electromechanical parts. Each may have its own regulated supply, e.g. 9V, 5V or 3.3V, using "point of load" shunt regulators fed from a single common supply, as shown in Fig. 2.1.3. Each of the voltage regulators will normally be placed as close to the circuit supplied as physically possible, and have additional decoupling capacitors to reduce any noise or cross talk between the individual supply lines.

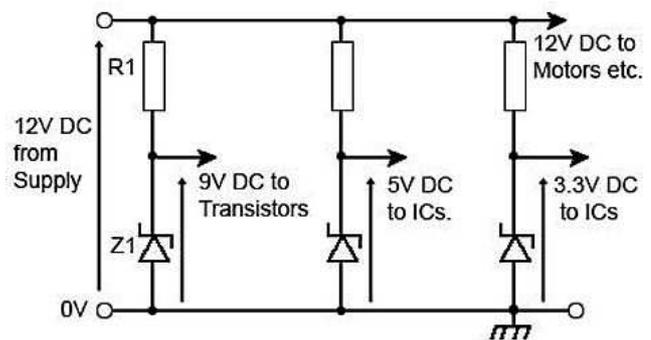


Fig. 2.1.3 Point of Load Regulators

Variations in Load Current

If the current in the load I_{out} tends to fall, the voltage across the load would tend to rise, but because it is connected in parallel with the diode the voltage will remain constant. What will change is the current (I_Z) through the diode. This will rise by an amount equal to the fall of current in the load. The total supply current I_S being always equal to $I_Z + I_{OUT}$. An increase in load current I_{OUT} will likewise cause a fall in zener current I_Z , again keeping V_Z and the output voltage steady.

Variations in Input Voltage

If the input voltage rises this will cause more supply current I_S to flow into the circuit. Without the zener shunt regulator, this would have the effect of making the output voltage V_{out} rise, but any tendency for V_{OUT} to rise will simply cause the diode to conduct more heavily, absorbing the extra supply current without any increase in V_Z thus keeping the output voltage constant. A fall in the input voltage would likewise cause a reduction in zener current, again keeping V_{OUT} steady.

Limitations

This simple shunt regulator is only suitable for relatively small currents and a fixed range of voltages. There are a number of limitations to the use of this circuit:

Output voltage:

The output voltage is equal to the zener voltage of the diode and so is fixed at one of the available voltage levels.

Output current:

If the output current falls to zero for any reason (the load may become open circuit due to a fault, or be disconnected from the power supply), all of the load current must be passed by the zener diode. Therefore the maximum current available for the load must be no greater than the maximum safe current for the zener diode alone.

Input voltage:

The input voltage must be higher (usually about 30% higher) than the output voltage to allow regulation to take place. It should not be too high however, as this will result in more power being dissipated by the diode.

Power dissipation:

The power dissipated in the diode must be kept within the safe working limits for the device chosen. Maximum power will be dissipated if the load is allowed to go open circuit while the input voltage is at its maximum value. This 'worst case' should not exceed the diode's maximum power rating.

The above limitations are controlled by the suitable choice of zener diode and series resistor R_S . The design of simple regulator circuits is fairly straightforward if a few simple steps are followed:

1. Decide on a zener diode of the required voltage.
2. Select a diode whose maximum current at least matches, and preferably exceeds the maximum current requirement of the load.

Note: Zener diode ratings usually quote maximum power dissipation rather than current, so you will need to work out the current rating from the power and voltage given for the device.

3. Find out the highest voltage likely to occur at the supply input. ($V_{IN\ max}$)
4. Calculate the value of a suitable series resistor R_S by using the formula:

$$R_S = \frac{V_{IN\ max} - V_Z}{I_{OUT\ max} + I_{Z\ min}}$$

Where:

$V_{IN\ max}$ = the highest likely input voltage.

V_Z = the zener diode voltage

$I_{OUT\ max}$ = the maximum output current.

$I_{Z\ min}$ = the minimum current at which the zener will operate (say about 1 to 2mA).

5. Calculate the power dissipated in the series resistor (R_S) by the formula:

$$\text{Power dissipated by } R_S = V_R \times I_{IN}$$

Note: When calculating power ratings and resistances, your answers will probably not exactly match the commercially available preferred values. Therefore choose the closest preferred value, and then put this value into your calculations to make sure the circuit will operate correctly with the preferred value. You should then be able to quote:

A suitable resistor value and its power rating and a suitable zener diode type number.

Example:

Design a simple zener diode (see Fig. 2.1.4) shunt regulator circuit with the following specifications:

Maximum load current required. 100mA

Output voltage. 12V

Input voltage. 15V nominal, 16V max.

Assuming a minimum zener current of 1mA

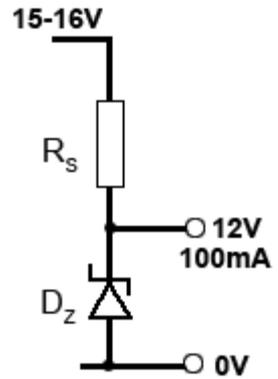


Fig. 2.1.4 Example

The problem can be solved in 4 steps.

1. Find a value for R_S

R_S must supply sufficient current to keep I_Z at or slightly above 1mA when the zener diode is passing its minimum current.

As the total circuit current $I_{IN} = I_{OUT} + I_Z$

The minimum zener diode current will occur when the input voltage (V_{IN}) is at its minimum value and the load current (I_{OUT}) is at its maximum value.

Under these conditions the current (I_{IN}) flowing through R_S will be $I_{OUT\ max} + I_{Z\ min}$

Which is $100\text{mA} + 1\text{mA} = \mathbf{101\text{mA}}$

As $R = V/I$ and the voltage across $R_S = V_{IN\ min} - V_Z$

Then $R_S = (V_{IN\ min} - V_Z)/I_{IN} = (15 - 12) / 101\text{exp}^{-3} = \mathbf{29.7\Omega}$

Therefore a practical value for R_S will be the next lowest preferred value $\mathbf{27\Omega}$

2. Calculate the maximum current ($I_{IN\ max}$) that will pass through R_S .

The maximum current ($I_{IN\ max}$) will occur when V_{IN} is at nits maximum value, i.e. 16V

$I_{IN\ max} = (V_{IN\ max} - V_Z) / R_S = (16 - 12) / 27 = 4 / 27 = \mathbf{148\text{mA}}$

3. Calculate the maximum power requirement for R_S

This will occur when V_{IN} is at its maximum value).

$(V_{IN\ max} - V_Z) \times I_{IN\ max} = (16 - 12) \times 148\text{exp}^{-3} = \mathbf{0.592\text{W}}$

A practical power rating for R_S will therefore be the next highest available power rating = $\mathbf{1\text{W}}$

4. Calculate the maximum power ($P_{Z\ max}$) that must be dissipated by the zener diode.

This will be the power that the zener diode would need to dissipate if the load was disconnected while the input voltage was at maximum, causing the maximum current ($I_{IN\ max}$) of 148mA to flow through the zener diode.

As Power $P = I \times V$, then $P_{Z\ max} = I_{IN\ max} \times V_Z = 148\text{exp}^{-3} \times 12 = \mathbf{1.776} = \mathbf{\text{approx. } 1.8\text{W}}$

A suitable shunt regulator would therefore consist of a 27Ω 1W resistor and a 12V zener diode with a power rating of at least 2Watts.

However, it is interesting to compare the power delivered to the load, $(12V \times 100mA) = 1.2W$ with the power dissipated in shunt regulator, $(0.592W \text{ in the resistor} + 1.776W \text{ in the diode} = 2.368W$.

Only about 33% of the total power is in the load with about 66% being dissipated by the shunt regulator!

The simple zener diode shunt regulator is therefore not very efficient when handling even these amounts of current. A better option can be to add a transistor to the circuit to handle larger currents.

Large Current Shunt Regulators

The current that can be handled by the simple zener diode/resistor shunt regulator is limited by the maximum current rating of the zener diode, but there are ways of increasing the maximum current capability of shunt regulators. One typical method is given in Fig. 2.1.5 where a power transistor, capable of passing an emitter current much larger than the zener diode is used.

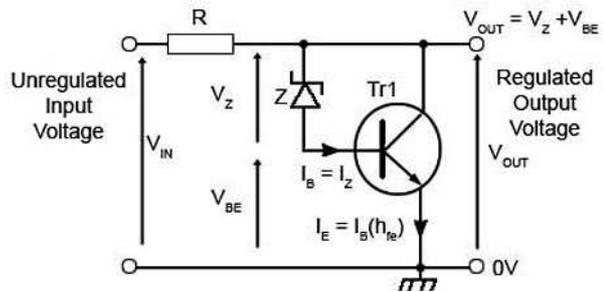


Fig. 2.1.5 Transistor Shunt Regulator

The zener diode now only handles the transistor base current and the main stabilising current I_E is approximately equal to the base current of the transistor, multiplied by the h_{fe} of the transistor:

$$I_E = I_B(1+h_{fe})$$

Therefore the regulator can handle $I_Z(1+h_{fe})$ amperes, allowing much larger load currents to be supplied by the regulator.

Note that the output voltage is no longer equal to V_Z but to V_Z+V_{BE} . The transistor will have a V_{BE} of typically 0.7V, so to produce a 5V regulator, a zener diode of 4.3v would be chosen.

Operation

If the current in a load attached to the regulator output decreases, the voltage at the right hand end of the series resistor (R) will tend to increase. When this happens, the base-emitter voltage of the transistor will increase by a similar amount, as the voltage across the zener diode is constant.

This increase in base-emitter voltage will cause the transistor (Tr1) to conduct more heavily until the extra current taken by the transistor balances the reduction in current taken by the load, the output voltage of the regulator is therefore returned to its previous 'normal' value.

If the load current increases, a similar action takes place, but this time there will be a reduction in Tr1 base voltage. This will reduce current through the transistor, thereby balancing the increase in load current. Again, the output voltage of the regulator remains relatively constant.

Improving Line Regulation

An effective regulator circuit should compensate for variations in input voltage as well as variations in output voltage (Output stabilisation). These input variations may be due to changes in the AC mains (line) supply, hence the name line regulation, or changes in the rectified DC input to the regulator circuit caused by variations in current drawn by other parts of the electronic system sharing the same supply.

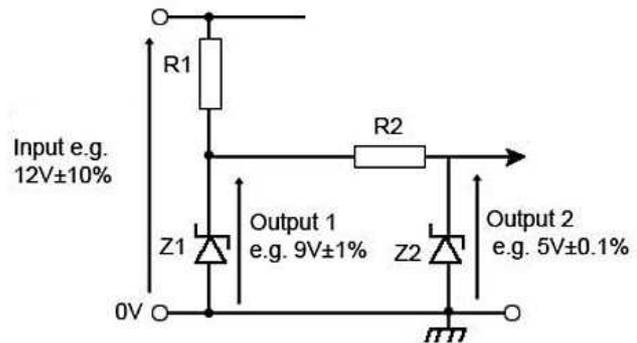


Fig. 2.1.6 Cascaded Shunt Regulators

How well line regulation works can be determined by comparing any change in the regulator output voltage with the change in regulator input voltage (assuming a constant load current). This can be expressed as the line regulation factor, and quoted as a percentage. For example if the input voltage to the regulator changes by $\pm 2V$ but the output voltage only changes by $\pm 0.2V$ the line regulation factor is $\pm 10\%$.

Fig. 2.1.6 shows how line regulation can be improved by using a series of zener diode regulators connected in cascade, each one will have a lower voltage that the previous one, but by connecting regulators in cascade, the overall regulation factor is the product of the factors of the individual circuits. Therefore two regulators each having a regulation factor of 10% or 0.1 would give an overall factor of $0.1 \times 0.1 = 0.01$ or 1%.

2.2 Series Voltage Regulators

What you'll learn in Module 2.2

After studying this section, you should be able to:

Understand the operation of series voltage regulators.

- The simple series regulator.
- Feedback and error amplification.
- Over current protection (current limiting).
- Over voltage protection.

Simple Series Voltage Regulators

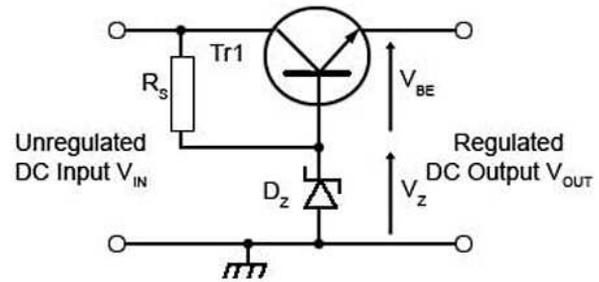


Fig. 2.2.1 Simple Series Regulator

In Fig. 2.2.1 R_S and D_Z form a simple SHUNT regulator as described in power supplies module 2.1. In this circuit however, they are used to provide a stable voltage reference V_Z at the base of $Tr1$. The emitter voltage of $Tr1$ will be typically about 0.7V less than the base voltage and V_{OUT} will therefore be at a lower voltage than the base.

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

If the output voltage V_{OUT} falls due to increased current demand by the load, this will cause V_{BE} to increase and as a result, current through the transistor (from collector to emitter) will increase. This will provide the extra current required by the load and thus regulate the output voltage V_{OUT} .

If V_{OUT} tends to rise due to reduced current demand by the load, then this will reduce V_{BE} as the emitter voltage rises and the base voltage remains stable due to D_Z . This reduction in V_{BE} will tend to turn the transistor off, reducing current flow, and again regulating the output voltage V_{OUT} .

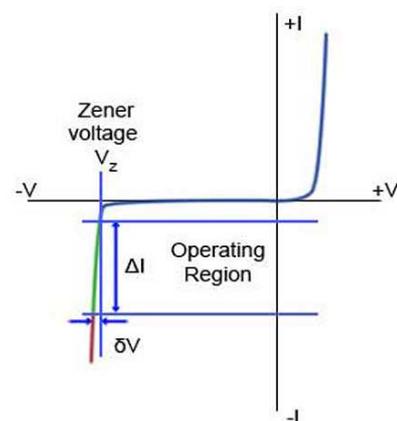
This regulating effect is due to the base potential of $Tr1$ being held steady by D_Z so that any variation in emitter voltage caused by varying current flow causes a change in V_{BE} , varying the conduction of the transistor $Tr1$, which will usually be a power transistor. This action counteracts the variation in load current. With this simple circuit however, regulation is not perfect, and variations in output do occur for the following reasons.

Fig. 2.2.2 Zener Diode Operating Region

1. Any increase in load current (I_L) causes a small increase in base current by the ratio I_L/h_{fe} . This in turn causes an increase in V_{BE} and because the output voltage $V_{OUT} = V_Z - V_{BE}$ any increase in V_{BE} tends to reduce the output voltage. The amount of this fall is about 0.25V for a change in output current from 10mA to 1A.

2. Since base current increases with load, the current through the zener diode D_Z will decrease as more current is taken by the base of $Tr1$. Because the diode characteristic has a slope over its operating region as shown in Fig. 2.2.2, a large change in zener current (ΔI) will cause a very small change in zener voltage (δV). This in turn will slightly affect V_{BE} and the output voltage.

3. Because of reasons 1 and 2 above, any change in load will result in less than perfect regulation; therefore any change at the output will slightly change the loading on the input circuit. As the input



is normally taken from an un-regulated supply, the input voltage will be easily affected by slight changes in load current, As the input voltage is also the supply for the reference voltage V_Z any change in output current, by affecting the input voltage, can produce a noticeable effect on the output voltage, slightly reducing the effectiveness of the regulation.

Each of the above effects is small, but added together they will provide an overall effect that is noticeable when the supply is operating under demanding conditions. Nevertheless this inexpensive circuit is effective enough for many applications, and is more efficient than the shunt regulator. Also, by using a suitable power transistor, the series regulator can be used for heavier load currents than the shunt design.

Feedback and Error Amplification.

To improve on the simple series regulator a feedback circuit and error amplifier can be added to the basic series circuit.

Fig. 2.2.3 shows a block diagram of a series regulator circuit with error amplification. In this system the reference voltage V_Z is compared with a feedback voltage V_F , which is a portion of the actual output voltage. The difference between the two inputs produces an error voltage that is used to vary the conduction of the control element, correcting any error in the output voltage.

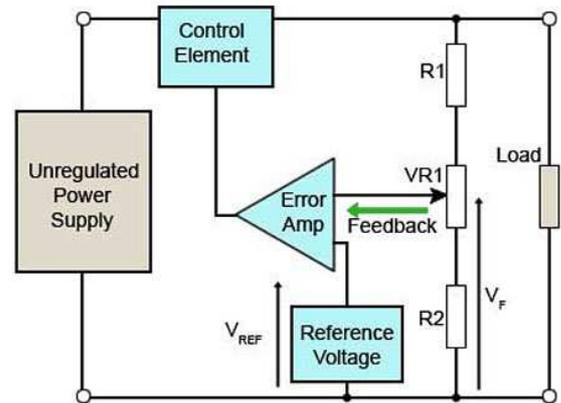


Fig. 2.2.3 Series Regulator with Feedback & Error Amplifier

Circuit Diagram.

A circuit diagram for this system is shown in Fig. 2.2.4. Tr1 is the series control element. It will usually be a power transistor, mounted on a substantial heat sink to cope with the necessary power dissipation.

A stable reference voltage is provided by R4 & D1 from the un-regulated input voltage. Tr2 is the error amplifier and its gain is set by the value of its load resistor R3. Tr2 compares the fraction of the output voltage V_F fed back from the output potential divider R1/R2 with the stable reference voltage V_Z across the zener diode D_Z .

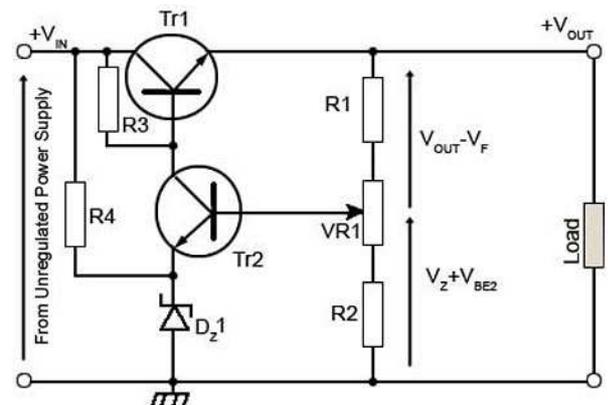


Fig. 2.2.4 Circuit Diagram for Fig. 2.2.3

The output voltage V_{OUT} in Fig. 2.2.4 can be expressed as:

$$V_{OUT} = (V_Z + V_{BE2}) + (V_{OUT} - V_F)$$

Where:

V_Z is the voltage across D_Z

V_{BE2} is the base/emitter voltage of Tr2

V_F is the feedback voltage derived from the slider of VR1

Therefore:

$(V_Z + V_{BE2})$ is the voltage across R2 and the lower portion of VR1

and $(V_{OUT} - V_F)$ is the voltage across R1 and the upper portion of VR1

If the feedback voltage V_F is altered by adjusting VR1 potentiometer, the difference between V_F and V_Z will change. This will cause a change in the error voltage controlling Tr1 and a change in the output voltage V_{OUT} . VR1 therefore provides a variable output voltage, which, once set remains stable at that setting.

The regulating action of the circuit is governed by the voltage across the base/emitter junction of Tr2, i.e. the difference between V_F and V_Z .

If V_{OUT} tends to increase, then $V_F - V_Z$ also increases. This increases the collector current of Tr2 and so increases the p.d. across R3 reducing the base voltage, and therefore the base/emitter voltage of Tr1, reducing the conduction of Tr1, so reducing current flow to the load.

The output voltage V_{OUT} is reduced in this way until a balance is reached, as the feedback portion (V_F) of V_{OUT} is also reducing. The overall effect is that the output is maintained at a level, which depends on the proportion of feedback set by the variable resistor (part of R1/R2).

If the output voltage tends to decrease, then so does V_F . The base/emitter voltage of Tr2 is reduced due to the stable V_Z on the emitter. Tr2 conducts less and the current through R3 falls, reducing the p.d. across it. Tr1 base voltage rises, and increases the conduction of the control transistor. This increases output current and V_{OUT} until V_F is once more at the correct level.

Protection Circuits Over Current Protection (Current Limiting)

Fig. 2.2.5 shows how the series stabiliser can be protected against excessive current being drawn by the load. This will prevent damage to the supply in the event of too much current being drawn from the output, or even a complete short circuit across the output terminals.

Two components have been added, Tr3 and R5. The resistor R5 is a very low value (typically less than 1Ω).

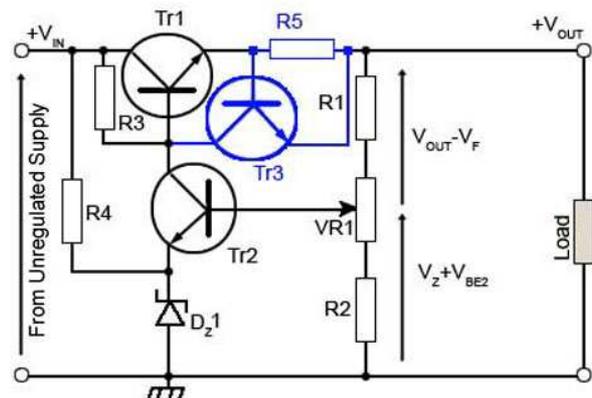


Fig. 2.2.5 Series Regulator with Over Current Protection

When the load current rises above a predetermined value, the small voltage developed across R5 will become sufficient (at about 0.7v) to turn Tr3 on. As Tr3 is connected across the base/emitter junction of the main control transistor Tr1, the action of turning Tr3 on will reduce the base/emitter voltage of Tr1 by an amount depending on the amount of excess current. The output current will not be allowed to increase above a predetermined amount, even if a complete short circuit occurs across the output terminals. In this case Tr1 base/emitter voltage will be reduced to practically zero volts, preventing Tr1 from conducting. Under these conditions the output voltage will fall to zero for as long as the excess current condition persists, but the supply will be undamaged.

Over Voltage Protection.

Where regulated supplies are used, the DC input voltage to the regulator is often considerably higher than the required output voltage. Therefore if a PSU fault occurs, it is possible that the regulated output voltage may suddenly rise to a level that can damage other components. For this reason it is common to find over voltage protection included in stabilised supplies. The circuit shown in Fig. 2.2.6 is sometimes called a "crowbar" circuit because when it operates, it places a complete short circuit across the across the output, a similar effect to dropping a metal crowbar across the positive and ground output terminals!

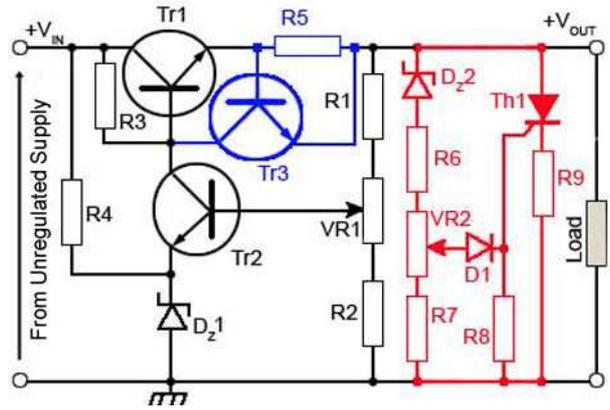


Fig. 2.2.6 Series Regulator with Over Current & Over Voltage Protection

Crowbar Circuit Operation.

In Fig. 2.2.6 the zener diode D_{Z2} has a breakdown voltage slightly less than the maximum allowed value for V_{OUT}. The remainder of V_{OUT} is developed across R6, VR2 and R7.

VR2 is a potentiometer, so that a voltage may be taken from the resistor network to correctly bias the diode D1. This diode has its cathode held at 0V by R8, and VR2 is adjusted so that D3 is just out of conduction, i.e. with about 0.5V on its anode.

Now, if V_{OUT} increases, the voltage across R6, VR2 and R7 will rise by the same amount, as the voltage across D_{Z2} will remain the same. Therefore there will be a substantial rise in the voltage at R7 slider, and at D1 anode. This will cause D1 to conduct, supplying a pulse of current to the gate of thyristor Th1, causing it to "fire" and conduct heavily until V_{OUT} falls to practically 0v. R9 is included to limit the resulting current flow through the thyristor to a safe level.

The large current that flows as Th1 fires will cause the current limiter circuit to come into operation as previously described. This will safely shut down the supply until the over current caused by Th1 has disappeared, which will of course happen as soon as V_{OUT} reaches 0V, but should the over voltage still be present when Th1 switches off and V_{OUT} rises again, the circuit will re-trigger.

2.3 I.C. Voltage Regulators

What you'll learn in Module 2.3

After studying this section, you should be able to:

Recognise commonly used I.C. Voltage Regulators.

In Relation to the 78xx series of Voltage Regulators:

- Select appropriate decoupling components.
- Understand the term 'Dropout'.
- Understand possible causes of IC failure & their prevention.
- Understand methods of producing positive, negative & dual supplies.

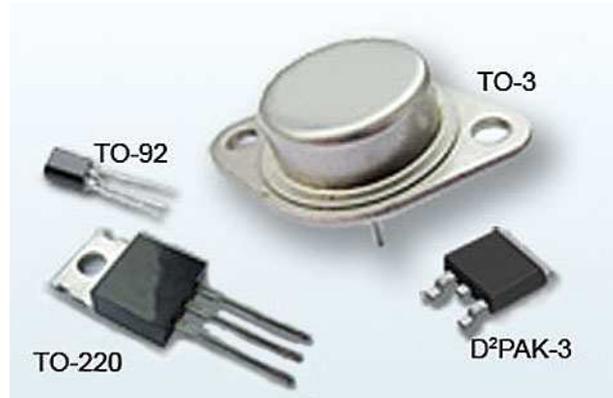


Fig. 2.3.1 Typical LM78xx Series Packages

The LM78Xxx Integrated Circuit (I.C.) Range

The availability of regulator circuits in I.C. form has greatly simplified power supply design, and since their introduction, the variety of designs, their power handling capacity and their reliability has steadily improved. Integrated circuit regulators are readily available in a variety of current and voltage ratings for shunt or series applications as well as complete switched mode types. It is now quite rare to find regulators in the truly discrete forms described in PSU Modules 2.1 to 2.3 but the popular 78Xxx types of regulator (where X indicates the sub type and xx represents the output voltage) use much the same principles, with enhanced circuitry, in an integrated form.

There are various ranges, in several package types available from many component manufacturers, some of which are shown in Fig. 2.4.1. The package choice is dependent space and performance requirements. Typical ranges are summarised in Table 1.

Table 1				
Range	Output Voltages (V_{OUT})	Maximum Current	Maximum Input Voltage	Typical Dropout Voltage
LM78Lxx	5.0V, 6.2V, 8.2V, 9.0V, 12V, 15V	100mA	35V	$V_{OUT} + 1.7V$
LM78Mxx	5V, 12V, 15V	500mA	35V	$V_{OUT} + 2V$
LM78xx	5.0V, 5.2V, 6.0V, 8.0V, 8.5V, 9.0V, 12.0V, 15.0V, 18.0V, 24.0V	1A	35 or 40V dependent on type	$V_{OUT} + 2.5V$

Dropout Voltage

One of the important pieces of data published in data sheets on linear I.C. regulators is the devices dropout voltage. With any linear regulator, built with discrete components or integrated such as the 78 series, the output voltage is held steady for differing current flows by varying the resistance of the regulator, (actually by varying the conduction of a transistor as explained in Power Supplies Module 2.2).

For this reason two things must be true:

1. The output voltage must always be lower than the input voltage.
2. The greater the difference between the input and output voltages (given the same current) the more power must be dissipated in the regulator circuit, so the hotter it will get.

The dropout voltage for any regulator states the minimum allowable difference between output and input voltages if the output is to be maintained at the correct level. For example if a LM7805 regulator is to provide 5V at its output, the input voltage must be no lower than $5\text{V} + 2.5\text{V} = 7.5\text{V}$.

However dropout voltage is not an absolute value, it may vary by about 1V depending on the current drawn from the output and the temperature at which the regulator is operating. It seems sensible therefore to allow a comfortable margin between the lowest possible input voltage and the minimum voltage allowable (the output voltage + the dropout voltage).

The maximum input voltage listed in table 1 shows that there is plenty of allowable difference between maximum and minimum input voltage, however it should be remembered that the higher the input voltage for a given output, the more power will need to be dissipated by the regulator. Too high an input voltage and power is wasted, this is bad for battery life in portable equipment and bad for reliability in high power equipment as more heat means a greater possibility of faults.

For example a LM7805 delivering 1A at 5V to a load means that the load is consuming 5Watts. If the input voltage is 8V the current through the regulator is still 1A, which is 8W; so the regulator is dissipating $8\text{W} - 5\text{W} = 3\text{W}$. However if the input voltage is 20V for example, then the excess power that must be dissipated by the regulator is now $20\text{V} \times 1\text{A} = 20\text{W}$ minus the 5W consumed by the load = 15W.

In modern linear I.C. regulators however, as well as protection against over current and over voltage protection, as described in PSU Module 2.3 there are additional thermal shut down circuits to prevent failure due to overheating, so that if power is excessive, rather than destroying the IC the output will fall to 0V until the IC has cooled.

Even at more sensible input voltages, regulator I.Cs. do develop considerable amounts of heat, therefore it is essential that excess heat is dissipated efficiently by the use of appropriate heat sinks. The criteria for using heat sinks is the same as that for power transistors, discussed in Amplifiers Module 5.1.

Complementing the 78xx series is the 79 series, which offers I.Cs. for commonly used negative supply voltages in a similar range of characteristics to the 78 series but with a negative voltage output.

Reducing AC Ripple

Fig. 2.3.2 shows a series regulator I.C. and its connections. Notice that C1 and C2 are much smaller than would be found in discrete component power supply. A large reservoir capacitor is not necessary, as the regulating action of the I.C. will reduce the amplitude of any AC ripple (within its maximum input voltage range) to just a few millivolts at the output.

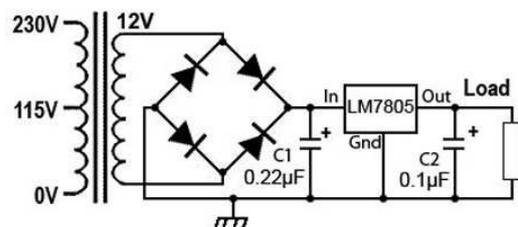


Fig. 2.3.2 Basic PSU Circuit Using a 7805 Linear Regulator I.C.

Ensuring Stability

C2 is no longer a traditional filter capacitor but is there to improve the transient response, protecting against sudden changes in mains or load conditions e.g. surges. The use of these capacitors, which with the values shown will be polarised tantalum types and although not strictly essential in all circuits, are recommended to ensure maximum stability, preventing any tendency of the I.C. to oscillate. They should be mounted as close as possible to the regulator, and the I.C. ground connection should be connected to 0V as physically close as possible to the ground connection of the load. These issues can be best accommodated when the regulator I.C. is used as a ‘point of load’ regulator, rather than (or as well as) a main regulator for the whole system power supply.

Reliability

The use of linear regulator I.C.s. has greatly improved the reliability of power supplies, but because these I.C.s are often located on plug in sub-panels with a system, there is a danger that damage may occur to the regulator I.C. (as well as to other components) if panels are inserted or removed whilst the main power supply is still live. This may be either because the system is still connected to the mains supply or because capacitors in the main supply are not fully discharged.

The reason is that when unplugging or connecting multi-way connectors there is no guarantee in which order individual pins are connected or disconnected, and this can lead to unexpected short circuit or open circuit faults occurring momentarily during the connection or disconnection process.

To guard against this possibility several additional safeguards can be designed around the regulator circuitry to safeguard the I.C.

In some circuits electrolytic capacitors may be used for C1 and C2 as an alternative to using tantalum or polyester capacitors, but in this case the capacitance use will be considerably greater, 25µF or more.

However, in circuits where C2 is 100µF or more, there is a possibility that if the input is shorted to ground, either temporarily (or permanently because of a fault) that the charge on C2 will cause a large current to flow back into the I.C. output terminal, damaging the I.C. To prevent this, a diode such as a 1N4002 can be connected across the I.C. as shown in Fig. 2.3.3 so that if, at any time the input terminal is at a lower potential than the output, the diode will conduct any charge at the output terminal to ground, rather than allowing the current to flow through the I.C.

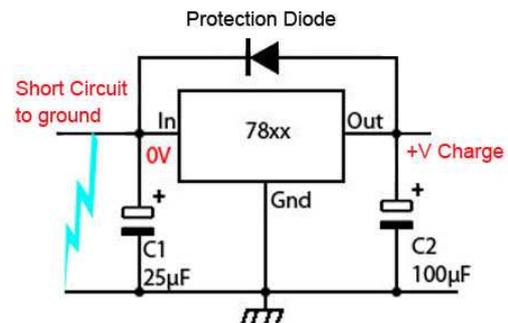


Fig. 2.3.3 Protection Diode Used With 7805 & Large Capacitors

If a circuit panel is unplugged whilst the supply is live it is possible that the ground connection to the I.C. may be disconnected momentarily before the input as indicated by Fig. 2.3.4. In such event the output terminal can rise to the voltage level of the unregulated input, which could cause damage to components being supplied by the regulator. Also if the panel is plugged in with power already present, the same situation, with the ground connection momentarily open circuit, then damage to the I.C. is likely.

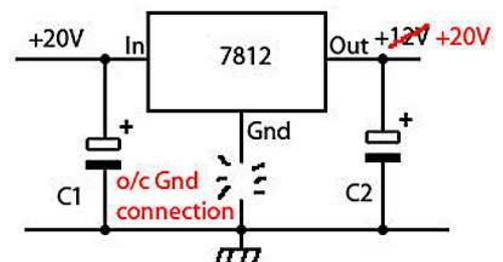


Fig. 2.3.4 Effect of Open Circuit Gnd Connection on a 7812 IC

As voltage regulators are generally fed from the main power supply, they can be susceptible to any mains borne voltage spikes as well as back e.m.f. voltage spikes from other parts of the circuit. Any positive voltage spikes greater than the maximum permitted input voltage (around 35V or 40V) or any negative spikes greater than -0.8V that have sufficient energy to cause substantial currents to flow are likely to damage the I.C. Some protection can be given by using a large value capacitor at the input terminal and/or making sure that likely causes of transients are minimised by using transient suppressors at the mains input and preventing back e.m.fs. as described in A.C. Theory Module 3.2.

Dual and Negative Supplies

Linear regulator I.C.s can also be used to provide regulated negative supplies using the LM79xx range of regulators are available in a similar range of voltages as the 78xx series but with negative outputs. They can be used for regulating negative supply or dual supply rails.

2.4 Regulated Power Supplies Quiz

Try our quiz, based on the information you can find in Power Supplies Module 2. Check your answers at <http://www.learnabout-electronics.org/PSU/psu24.php> and see how many you get right. If you get any answers wrong. Just follow the hints to find the right answer, and learn about Regulated Power Supplies as you go.

1.

Refer to Fig. 2.4.1. What would be the likely output voltage V_{OUT} ?

- a) 4.3V
- b) 4.7V
- c) 5.0V
- d) 3.6V

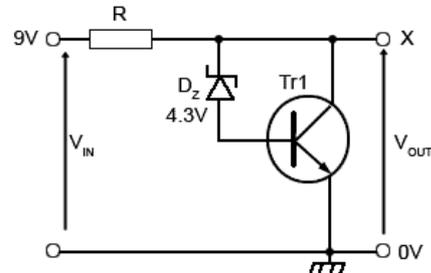


Fig. 2.4.1

2.

Refer to Fig 2.4.1. Which of the following actions would occur if a load resistance connected across the output terminals decreased in value?

- a) The output current would increase and Tr1 would conduct less heavily to maintain a constant output voltage.
- b) The output current would decrease and Tr1 would conduct more heavily to maintain a constant output voltage.
- c) The output voltage would decrease, reducing the voltage across D_z causing Tr1 conduction to decrease and the output voltage to rise to norm
- d) D_z would ensure that the base voltage of Tr1 remains at a constant voltage so that the output voltage also remains stable.

3.

Refer to Fig 2.4.2. What preferred value of resistance would be required for R in order to maintain a minimum zener current (I_z) of 1mA?

- a) 330Ω
- b) 270Ω
- c) 220Ω
- d) 180Ω

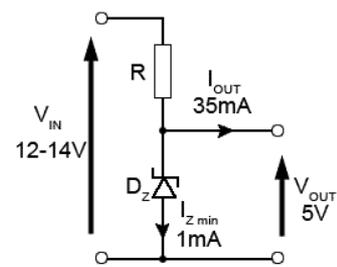


Fig 2.4.2

4.

Which of the following methods would be used to improve the regulation factor of a shunt regulator circuit?

- a) Connect a second shunt regulator in cascade.
- b) Use a point of load regulator.
- c) Use a transistor shunt regulator.
- d) Use a decoupling capacitor across the regulator output.

5.

Refer to Fig 2.4.3. Which of the following statements correctly describes the output voltage V_{OUT} ?

- a) $V_{OUT} = V_{CB} Tr1 + V_{CE} Tr2$
- b) $V_{OUT} = V_{R1} + V_{DZ}$
- c) $V_{OUT} = V_S - V_{CE} Tr1$
- d) $V_{OUT} = V_{R2} + V_{CE} Tr2 - V_{DZ}$

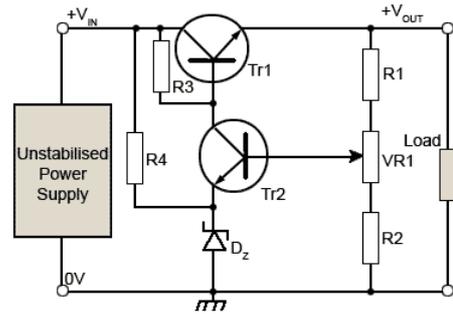


Fig. 2.4.3

6.

Refer to Fig 2.4.3. What will be the effect of moving the slider of VR1 downwards?

- a) The current through Tr2 will increase.
- b) The output voltage will decrease.
- c) The voltage across Tr1 collector/emitter will decrease.
- d) The current through Dz will be unchanged.

7.

Refer to Fig 2.4.3. What is the purpose of Tr2?

- a) Shunt regulator current amplifier transistor.
- b) Over voltage protection transistor.
- c) Over current shut down transistor.
- d) Error amplifier transistor.

8.

Refer to Fig 2.4.4. Which of the following components is responsible for sensing the current value?

- a) R4
- b) R5
- c) R8
- d) R9

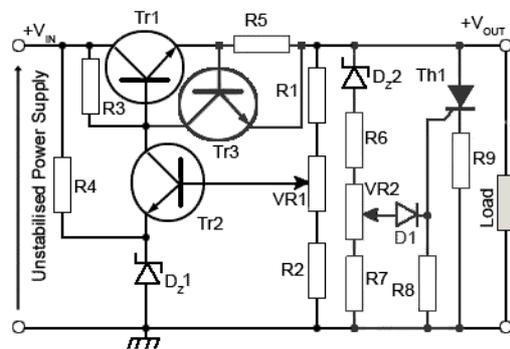


Fig. 2.4.4

9.

Refer to Fig 2.4.4. What is the purpose of Dz2?

- a) To regulate the output voltage.
- b) To act as a fast switch for the crowbar circuit.
- c) To activate the over current circuit.
- d) To increase the sensitivity of the crowbar circuit.

10.

Refer to Fig. 2.4.5. What is the purpose of D1?

- a) To prevent damage to the I.C. in case of a short circuit input.
- b) To prevent damage to the circuit being supplied, in case of a faulty I.C.
- c) To remove positive voltage spikes at the I.C. output.
- d) To provide negative feedback for the I.C.

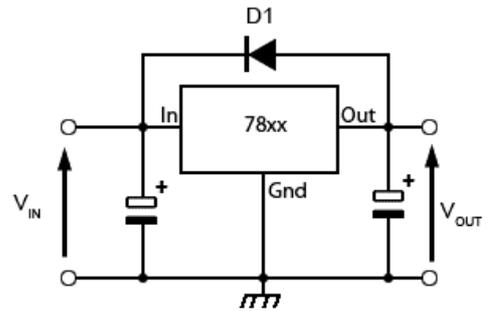


Fig. 2.4.5