UEE30920 Certificate III in Electronics and Communications

UEEEC0075

Troubleshoot Single Phase Input

D.C Power Supplies

WorkBook

Contents

1. Semiconductors

In this unit you will learn about semiconductor materials, semiconductor doping and the PN junction. You will also learn about conductors and insulators.

This will enable you to understand how semiconductor diodes operate and how to test them with a multi-meter. It will also assist you in understanding how other semiconductor devices operate and the terminology used in electronics.

To pass this unit you must be able to:

- List and identify the names of common conductors, semiconductors and insulators.
- State the effect of doping a semiconductor.
- List the majority and minority carriers of P-type and N-type material.
- State the effect on a P-N junction depletion region when forward and reverse biased.

Conductors

Conductors are materials that allow current to pass through them very easily. Most metals such as gold, silver, copper, iron and steel are good conductors of electricity.

Zinc is also a conductor; it has applications as a non-corrosive plating on roofing iron, nuts, bolts and equipment frames and chassis. Lead and tin are also conductors which are mixed (alloyed) together to form solder. Salty water is also a conductor of electricity.

Metals are good conductors because of their atomic structure. The atoms of metals have one or more electrons in the outer orbit that are not attached to any particular atom and are said to be "free" or mobile.

When a voltage is applied to a metal the mobile or free electrons are easily swept along by the force of the applied voltage.

Insulators

Insulators are materials that do not allow the passage of electric current.

Some examples of insulators are: glass, most plastics such as PVC and polythene (as used in plastic bags), rubber, ceramic materials (like the power line insulators on electricity supply poles), wood, dry paper, mica (the flaky transparent material used to support toaster elements) and air.

Question 1.

Which of the following materials are conductors and which are insulators?

Indicate your answer by placing "C" for conductor or "I" for insulator in the space provided.

(a)	Zinc		(b)	Rubber		(c)	Polythene	
(d)	Dry paper		(e)	Tin		(f)	Aluminium	
(g)	PVC		(h)	Dry wood		(i)	Steel	

Semiconductors

A semiconductor is a material that is neither a conductor nor an insulator but something in between. The most commonly used semiconductor material is silicon although germanium is used in a few specialized applications. The word silicon is frequently abbreviated by the symbol "Si" and germanium has the common abbreviation "Ge".

Atomic Structure of Pure Silicon

Silicon is a crystalline material which means the atoms are arranged in a very regular pattern or structure. Some other examples of crystalline materials are sugar and salt. Each silicon atom has 4 electrons in the outer shell and each silicon atom is surrounded by 4 neighbouring atoms.

The bonding process that holds the atoms together involves the sharing of these outer or "valence" electrons.

The result of this type of bonding is that most of the electrons within pure silicon are occupied in forming bonds and very few electrons are available to participate in current flow.

Figure 1 shows the atomic structure of pure silicon. Each atom has a share of 8 electrons ie four of its own and 1 from each of its 4 neighbouring atoms.

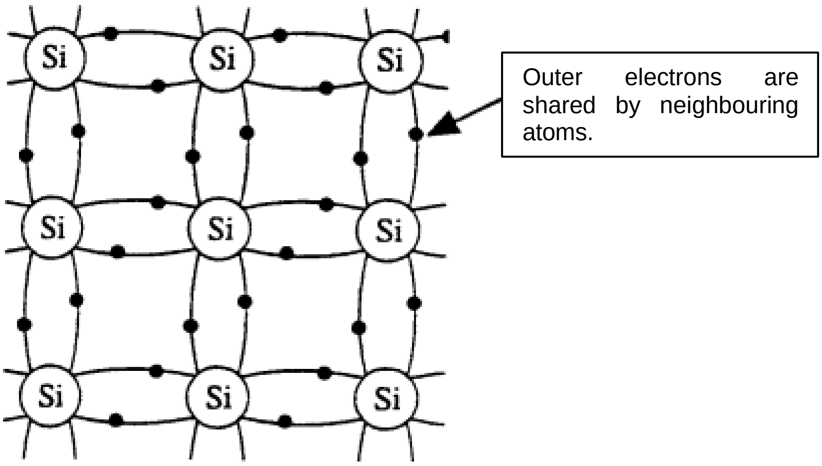

Figure I. Crystalline structure of silicon

Heat energy can free an electron from its bonds. This is shown in Figure 2. Even at room temperature a valence electron may gain sufficient energy to break away from the bonds and become a "free" or mobile electron. This process occurs at random.

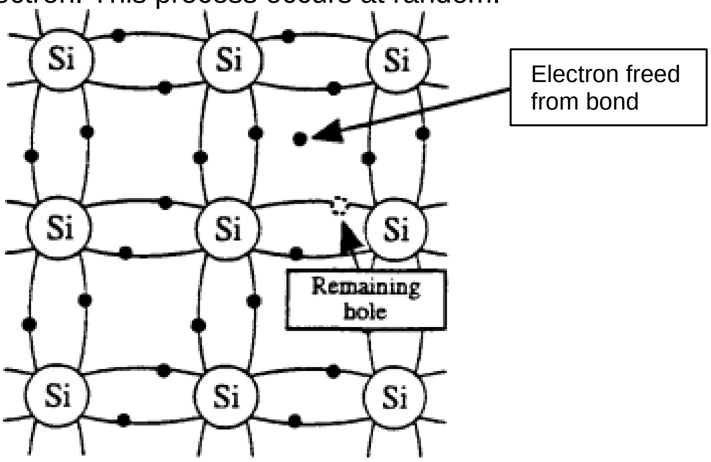

Figure 2. Thermally generated hole - electron

An atom which loses an electron in this manner will be left with a slightly positive charge, i.e the number of electrons will now be outnumbered by the protons. Such an atom is called a positive ion or the site of a "hole". Whenever an electron becomes free, a hole is also created. Such a pair is referred to as a thermally generated hole-electron pair.

Question 2.
Which of the following materials are conductors, semiconductors or insulators? Show your answer by placing C for conductor, S for semi-conductor or I for insulator, in the space provided.

(a)	Copper		(b)	Salt water		(c)	PVC	
(d)	Ceramics		(e)	Silicon		(f)	Gold	
(g)	Germanium		(h)	Si		(i)	Lead	

Semiconductor Doping

The introduction of small but precise quantities of other elements to a semiconductor has a very noticeable effect on the conduction properties. Elements that are added to alter the conduction characteristics of semiconductors are referred to as "impurities".

For example if the element "antimony" (symbol Sb) is added to silicon the conductivity of the silicon increases significantly. The process of adding small and controlled numbers of impurity atoms to a semiconductor is referred to as "doping". The concentrations of doping atoms are generally much less than one percent of the total semiconductor material.

Figure 3 shows the presence of an antimony impurity atom that has been added to otherwise pure silicon.

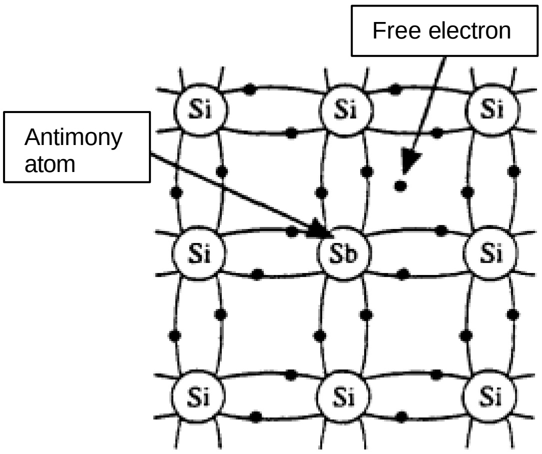

Figure 3. Silicon doped with antimony atoms

Antimony has a valence of 5, which means it has 5 electrons in its outer shell.

When the antimony atom joins or bonds with the neighbouring silicon atoms there is one electron in excess. The 4 neighbouring silicon atoms require a share of 1 electron each, but since the antimony atom has 5 electrons in its outer shell there is one electron left over.

The left over electron then becomes free or mobile and is thus able to drift about the semiconductor material.

The antimony atom now has a deficiency of one electron and is therefore a positive ion. This positive ion is locked into the silicon material by the bonding with neighbouring silicon atoms.

The addition of the antimony impurity atoms to silicon creates mobile electrons and fixed positive ions.

Although the doping material is added in small concentrations the effect is to create a large number of mobile charges that are available to participate in the conduction process.

Question

3. How many electrons are in the outer shell of silicon atoms?

Question 4.

(i) An atom that has gained an electron is called a negative _________________.

(ii) An atom that has lost an electron becomes a __________________ ion.

Question 5.

In pure silicon material, conduction occurs because there are mobile electrons and

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A piece of silicon that is doped with antimony atoms is still mainly pure silicon and thermally generated holes and electrons will exist in the bulk of the semiconductor material. The presence of antimony atoms produces only free electrons and so the number of free or mobile electrons will far exceed the number of holes.

N - Type Semi-Conductors

Elements such as antimony, phosphorous and arsenic have a valence of 5 and are called "donor" impurities because each of these atoms donates an electron to the bulk of the semiconductor material.

When a semiconductor is doped so that the number of mobile electrons exceeds the number of mobile holes the material is referred to as N-type semiconductor material because the majority of mobile charge carriers are electrons.

Note that N-type material also contains mobile holes but these are in the minority.

Question 6.
Silicon doped with a donor impurity has majority charge carriers that are (holes/electrons) and minority charge carriers that are (holes/electrons).

Conduction in N - Type Material

When a voltage is applied to a piece of N-type material current is able to flow mainly due to the presence of mobile electrons, these mobile electrons are the major carriers.

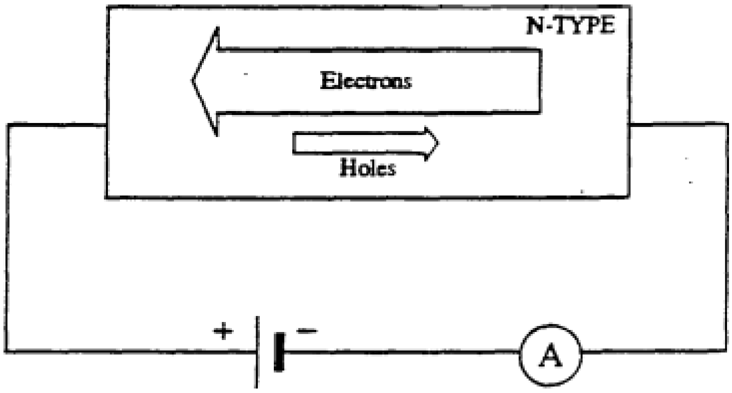


Figure 4. Charge carrier flow in N–Type material

Note the minority carrier holes are also affected by the applied voltage but they move in the opposite direction to the electrons.

The doping process has increased the number of free charges that are available to move and so the conductivity has increased. Resistance has therefore decreased.

P-Type Material

Elements such as boron, gallium and indium have a valence of 3. When these elements are used as impurities they become "acceptor" atoms.

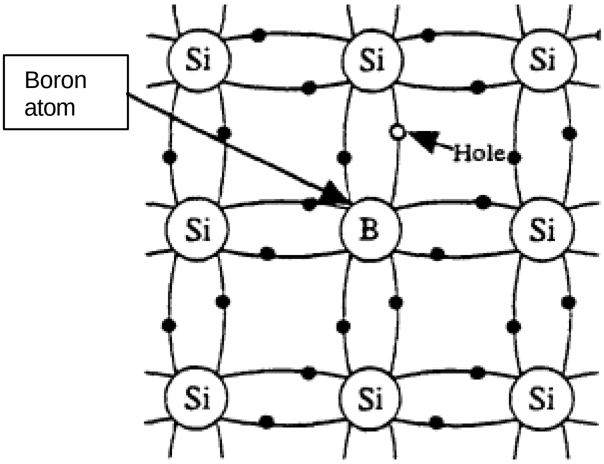


Figure 5. Silicon doped with boron atoms

Figure 5 shows the presence of a boron atom (symbol B) amongst neighbouring silicon atoms. Boron only has 3 electrons in the outer shell and to bond effectively with its neighbours it captures an electron from the bulk of the material. This makes the boron atom into a negative ion and the semiconductor material now has an extra mobile hole.

Impurities that have a valence of 3 are therefore called acceptor impurities because they accept an electron in the bonding process. In so doing they create mobile holes.

P-type material has thermally generated holes and electrons, but it also has many holes generated by the addition of the acceptor impurity atoms and these make up the majority of the charge carriers.

Question 7.

In P-type material the mobile (holes/electrons) outnumber the mobile (holes/electrons).

Question 8.
P-type material has majority carriers that are (holes/electrons) and minority carriers that are (holes/ electrons).

Conduction in P -Type Material

When a voltage is applied to a piece of P-type material current is able to flow mainly due to the presence of mobile holes. This is shown in Figure 6.

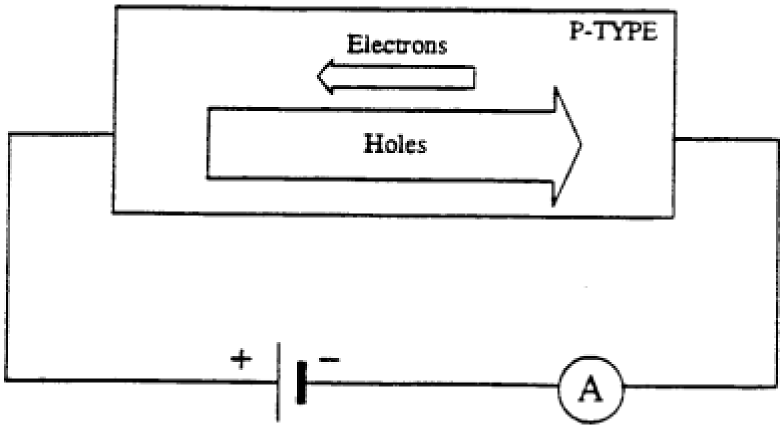


Figure 6. Charge carrier flow in P–Type material

Note that the minority carrier electrons are also affected by the applied voltage but they move in the opposite direction to the holes.

The doping process has increased the number of free charges that are available to take part in conduction and so the conductivity has increased and resistance has therefore decreased.

PN Junctions

When P-type and N-type semiconductor material are joined to form a junction, an electronic device is produced that has some very useful applications. The junction of P-type and N-type materials produces a diode. A diode is a device that conducts electric current easily in one direction but does not allow current to flow in the opposite direction. The diode gets its name from "di" meaning two, and "electr*ode*" which means connecting conductor, thus di-electr*ode* or simply diode.

PN junctions or diodes are made in different shapes and sizes, some examples of the different packaging styles are shown in Figure 7. The package is much larger than the actual piece of silicon containing the PN junction. The junction size is commonly about the size of a pin-head or smaller.

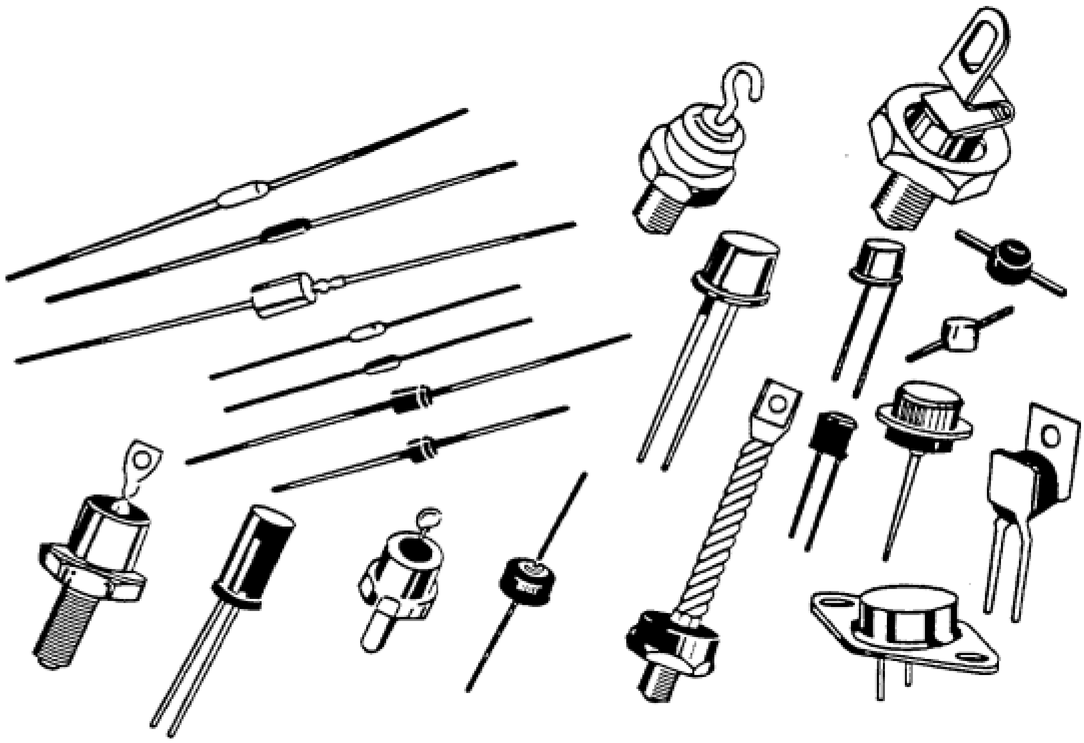


Figure 7. Diode packages

Question 9.
State the polarities of the electrical charges associated with holes and electrons and indicate the force (attraction/repulsion) that will exist between them.

The diagram in Figure 8 shows what happens when P-type and N-type material are brought together to form a P-N junction. Electrons on the N side are attracted to the positively charged holes on the other side of the junction. When an electron and hole meet, the electron "falls" into the hole. The process of holes and electrons combining at the junction produces a region that is depleted, or has a lack of, mobile charges. This region is therefore called the "depletion region".

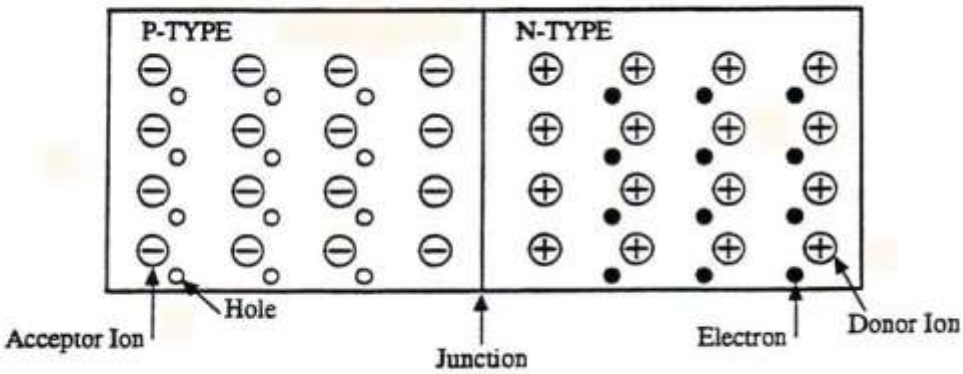


Figure 8. Depletion region at PN junction

Away from the depletion region electrical neutrality is maintained. This is because the number of impurity ions is equal to the number of mobile charges that were generated by the presence of the impurity atoms (donors or acceptors). In the depletion region however the impurity ions do not all have mobile charges because some of the mobile charges have combined at the junction. The impurity ions in the depletion region are therefore said to be "uncovered", because there is not an equal number of oppositely charged mobile carriers in this region.

Electrons from the N-type material that have combined at the junction leave an equal number of "uncovered" positive ions on the N side. The depletion region on the N side of the junction does not have electrical neutrality; it has a net positive charge. Similarly holes from the P side that have combined at the junction leave the P side of the depletion region with uncovered negative ions. The P side of the depletion region has also lost electrical neutrality. The P side of the depletion region has a net negative charge.

Remember that the ions are charged atoms and they are fixed in the atomic structure, ie unable to move. The uncovered charges are not able to move. The diagram in Figure 9 shows the uncovered charges in the vicinity of the junction of P and N type materials.

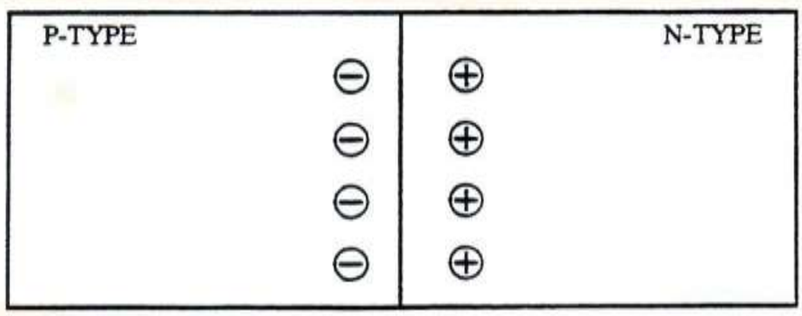


Figure 9. Charge barrier in depletion region

Question 10.

(i) What is the polarity of charge on the P side of the junction?

(ii) What is the polarity of charge on the N side of the junction?

The material as a whole is still electrically neutral, there has been a movement of charge from one side of the junction to the other but no change in the total number of positive and negative charges.

The existence of "uncovered" ions on each side of the junction sets up an electric force field, with the N side having positive charge with respect to the P side. This charge acts like a small cell or battery as shown in Figure 10.

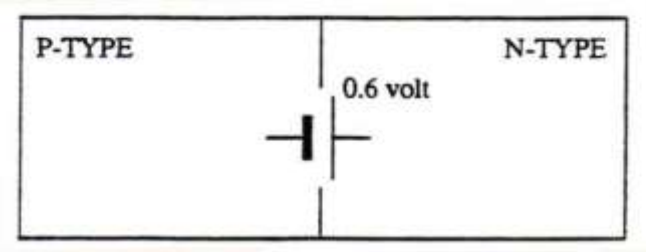


Figure 10. Potential barrier at PN junction

The positive charge on the N side prevents further electrons on the N side from moving toward the junction. The negative charge on the P side prevents holes on the P side moving toward the junction.

An equilibrium or balance is reached after the initial movement of charge. This equilibrium prevents further charge from moving to the junction to combine with its opposite charge carrier. The electric force field that prevents further charge carriers from moving to the junction is called the "junction barrier voltage" or "barrier potential". In silicon material the junction barrier voltage is approximately 0.6 V and in germanium it is about 0.2 V.

Question 11.
In the depletion region there are no free majority carriers. Will it have high or low resistance?

Biasing

When an external voltage is applied to a PN junction it is said to be "biased".

There are two ways in which bias may be applied.

One way is called forward bias and current flows easily through the device. The other way is called reverse bias and very little current flows.

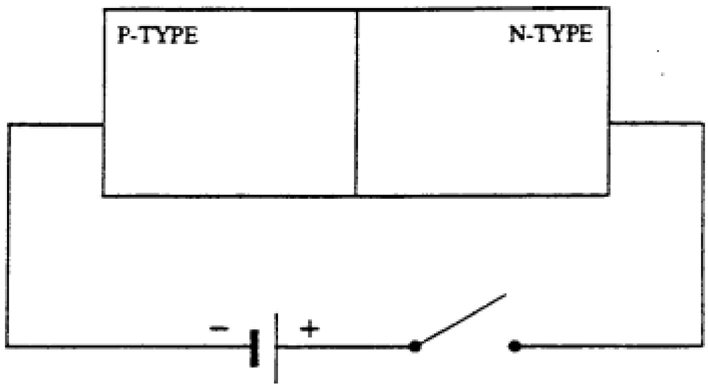


Figure 11. Reverse bias of PN junction

Question 12.
When the switch is closed in the circuit of Figure 11, what effect (attraction/repulsion) will the positive battery terminal have on the free electrons in the N material? What effect will the negative terminal have on the free holes in the P material?

At first there will be a movement of free carriers towards the oppositely charged external connections. This will result in more "uncovered" ions on each side of the junction and a widening of the depletion region.

Other than the initial movement of charge at the instant the external bias is applied, there is no continuous movement of majority carriers across the junction. The junction is said to be reverse biased.

The depletion region, which is a region of high resistance, becomes wider when reverse bias is applied.

There will however be a small amount of continuous current due to minority carriers, but this is extremely small and is typically less than 1uA in silicon. (It is somewhat larger in germanium devices). This current is called "reverse leakage current" and it is ignored in many applications, but we should be aware of its existence.

Question 13.
When reverse bias is applied to a PN junction or "diode" the width of the depletion region becomes (wider/narrower/unchanged).

Question 14.
When reverse bias is applied to a diode the current that flows is (large/ small/extremely small/zero).

In summary, a reverse biased diode can be regarded as an open switch or open circuit for most applications.

Forward Bias

To forward bias a diode the external voltage is connected the other way round. This time the Positive of the battery is connected to the P material and the Negative battery terminal is connected to N material. Refer to Figure 12.

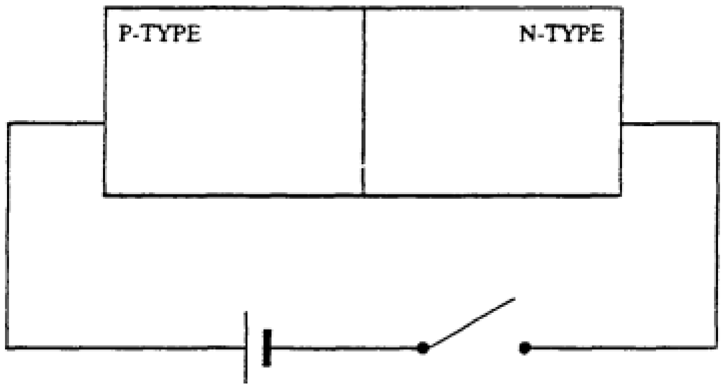


Figure 12. Forward bias of PN junction

Question 15.
In silicon material, what is the magnitude of the barrier voltage for an unbiased diode?

Question 16.
When the switch in Figure 12 is closed, what effect will the negative terminal of the battery have on the majority carriers in the N-type material?

If the externally applied voltage is greater than 0.6V then the electrons in the N material will be able to move to the junction region where they combine with holes that are moving to the junction from the opposite direction.

The electrode or connection point to the N material is called the "cathode". The electrode or connection point to the P material is called the "anode".
When a diode is forward biased electrons move in the external circuit wires, but holes and electrons move inside the diode. The movement of charge carriers in a circuit containing a forward biased diode is shown in Figure 13.

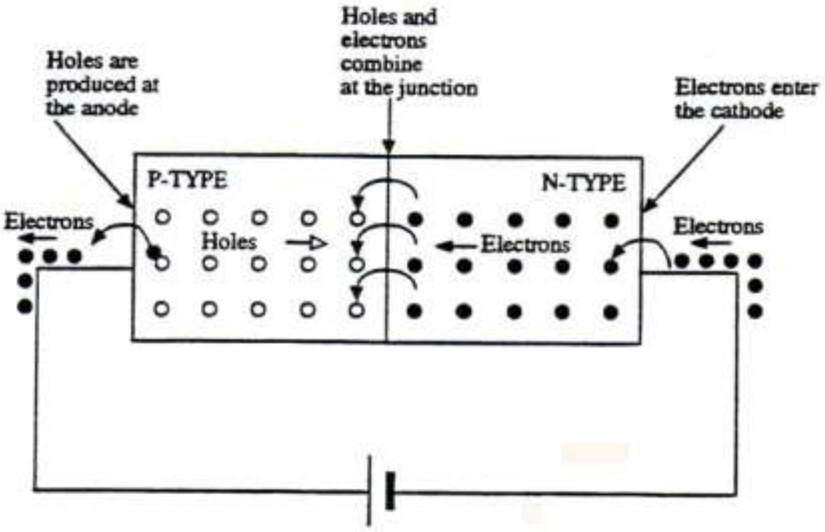


Figure I3. Charge flow in forward bias PN junction

Electrons from the negative terminal of the battery enter the cathode and travel through the N material to the junction where they combine with holes. Electrons leave the P material at the anode and in so doing create holes which move through the P material to the junction and combine with the electrons that entered from the cathode.

Question 17.
If 1000 electrons enter the cathode, how many electrons will exit at the anode?

Current enters one electrode of the diode and leaves the other electrode. A steady circuit current has been established and current will continue to flow provided the external bias voltage exceeds the barrier voltage of 0.6V.

The depletion region width is slightly reduced when a diode is forward biased, because forward bias reduces the barrier potential.

In summary, a diode is forward biased when the external voltage exceeds 0.6 V for a silicon diode (0.2V for a germanium diode) and has the following battery polarity:- positive to anode and negative to the cathode. The diode has low resistance and current flows easily. A forward biased diode is like a closed switch.

Question 18.
How does the resistance of a forward biased PN junction compare with that of a reverse biased device?

Question 19.
To forward bias a PN junction the external voltage must be at least equal to .... V for silicon and .... V for germanium.

Question 20.
A diode is reverse biased when the battery positive is connected to the (anode/ cathode) and the battery negative is connected to the (anode/cathode).

Diode Symbol and Body Markings

A common variety of diode has the shape and markings shown in Figure 14(a). One end of the diode body has a silver band which is closest to the cathode lead. The other end is of course the anode.

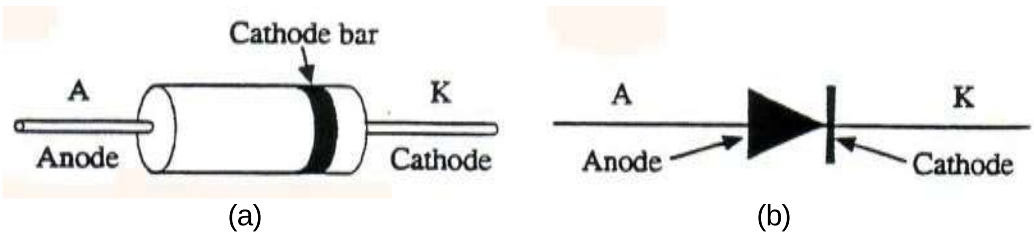


Figure 14. Diode electrode names

The standard circuit drawing symbol of a diode is shown in Figure 14(b). The bar of the symbol is the cathode. The diode symbol has the shape of an arrow, the arrow points to the direction of conventional current flow when the diode is forward biased.

Summary

1. Materials can be classified by their conduction properties as conductors, semiconductors or insulators.

2. Doping has the effect of increasing the conductivity of semiconductor material.

3. The majority carriers in P-type material are holes. The minority carriers in P-type material are electrons.

4. The majority carriers in N-type material are electrons. The minority carriers in N-type material are holes.

5. At the junction of P-type and N-type material a depletion region is created. The depletion region is a region of high resistance.

6. Forward bias occurs when the positive of the battery is connected to the anode and the negative of the battery is connected to the cathode. Forward bias reduces the width of the depletion region. Majority carriers flow when a PN junction is forward biased. A forward biased diode is like a closed switch.

7. Reverse bias occurs when the positive of the battery is connected to the cathode and the negative of the battery is connected to the anode. Reverse bias increases the width of the depletion region. An extremely small amount of minority carriers flow when a PN junction is reverse biased. A reverse biased diode is like an open switch.

2. Diode-Resistor Circuits

In this unit you will learn about the voltages and currents in series diode circuits.
This will enable you to find out if a series diode circuit is functioning correctly by using a multimeter.

To pass this unit you must be able to:

- Calculate voltages and currents in series diode circuits
- Measure voltages and currents in series diode circuits to find out if the circuit is performing correctly.

A Diode Switch

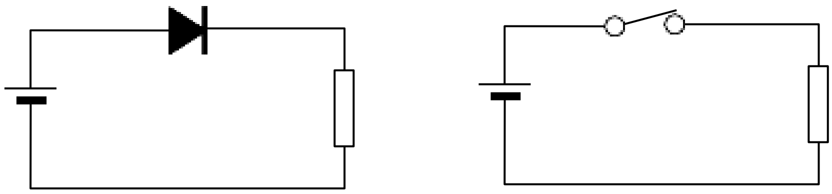
The semiconductor diode conducts much better in one direction than the other and can be thought of as acting in a similar way to a mechanical switch.

Question 1.
When a diode is forward biased its resistance is very (high/low).

Question 2.
A diode has a very high resistance when it is (forward/reverse) biased.

The diode in Figure 1(a) is forward biased and therefore current will flow through the circuit and there will be a voltage drop across the resistor.

In Figure 1(b) the contacts of the switch are closed and so the circuit is complete. Current will flow and there will be a voltage drop across the resistor.



(a) (b)

(b)

Figure 1. A closed circuit

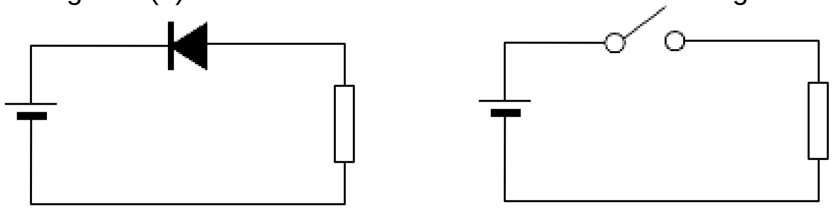
The forward biased diode circuit and the closed switch circuit are equivalent circuits. Their electrical behaviour is very similar.

Question 3.
When an ideal switch is closed, the resistance of the switch is approximately:

(a) infinite resistance
(b) Meg ohms
(c) 10 ohms
(d) zero ohms

The theoretical ideal diode will have a forward resistance of zero ohms, but a real diode will have some resistance. It will also have a small voltage drop across it of the order of 0.6 V for silicon and 0.2 V for germanium.

Question 4.
Refer to the circuit of figure 2(a) and circle the correct words in the following statement.



(a) (b)

Figure 2. An open circuit

The diode in this circuit is (forward/reverse) biased and will have extremely (high/low) resistance.

The extremely high resistance of the reverse biased diode prevents circuit current flowing and the diode behaves just like an open switch. The reverse biased diode shown in Figure 2a is equivalent to an open switch as shown in Figure 2b.

The behaviour of a semiconductor diode in a circuit is summarised by the following two statements.

A forward biased diode = A closed switch (low resistance)

A reversed biased diode = A open switch (high resistance)

Question 5.
The circuits below are series arrangements of a battery, diode and a lamp. Identify which lamps are "on". (Hint: Determine if the diode in each circuit is forward or reverse biased.)

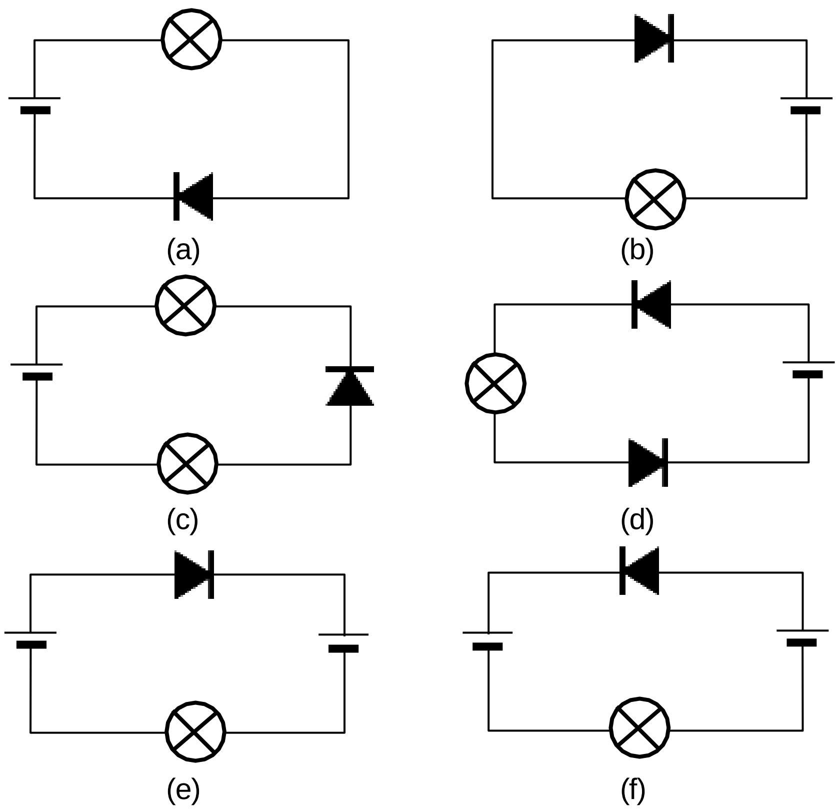


Figure 3. Series diode and lamp circuits

Series Circuit – Ideal Diode

A series circuit containing an ideal diode (or diodes) will either conduct or not conduct depending on the bias of the diode(s). For current to flow, all diodes in a series circuit must be forward biased. If one or more of the diodes in a series circuit are reverse biased, no current will flow.

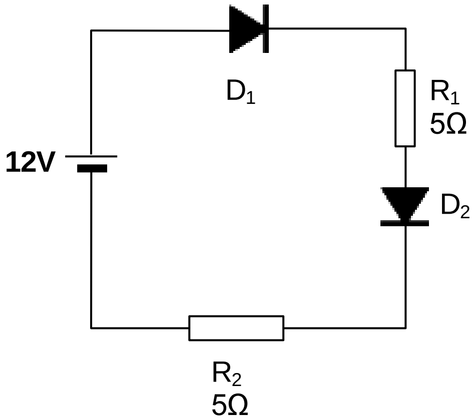


Figure 4. Diode series circuit

Question 6.
Refer to Figure 4 again and answer these questions:

(a) The voltage drop across each diode = ________ V

(b) The voltage shared by the two resistors = ________ V

Example To find the current in the circuit of Figure 4.

The circuit current can be determined by:

$$I = \frac{V}{R_{Tot}} = \frac{12}{10} = 1.2A$$

Question 7.
Find the current in the circuit of Figure 5:

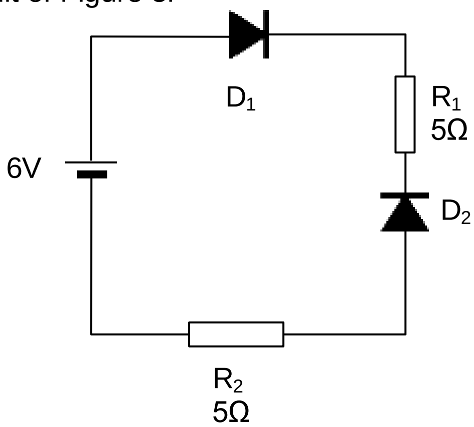


Figure 5. Series diode circuit

Series Circuit – Practical Diode

A practical diode (real diode) differs from the ideal diode because it has a small voltage drop across it when forward biased. If the applied circuit voltage is small then the diode forward voltage drop will have to be taken into account.
When a diode is reverse biased, there is a reverse leakage current, but in silicon this is generally less than a μA (1×10^{-6}A) and can be ignored. Therefore, the reverse current is taken as zero.

Question 8.
Are the diodes D_1 and D_2 of Figure 4 Forward or Reverse biased. ________________

Question 9.
The combined voltage drop across D_1 and D_2 = _________ V.

The remaining circuit voltage applied across the resistors in Figure 4 is equal to 12 – 1.2 = 10.8V.

The circuit current can now be calculated:

$$I = \frac{V_{R_{Tot}}}{R_{Tot}} = \frac{10.8}{R_{Tot}} = \frac{10.8}{10} = 1.08\text{mA}$$

In Figure 5, one of the diodes, (D_2) is reverse biased and even with practical diodes, the current is very close to zero.

Question 10.
Calculate the current in each circuit of Figure 6 assuming that the diodes are ideal.

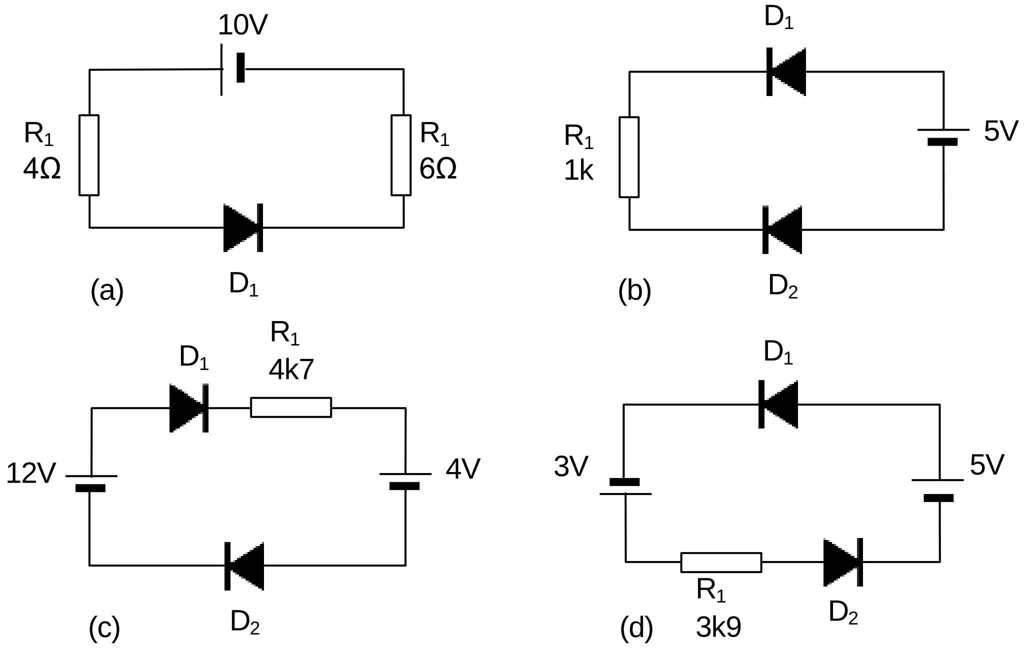


Figure 6. Circuits for problem

Question 11.
Referring again to Figure 6, calculate the circuit current for each circuit but this time allowing for a diode drop of 0.6V for each forward biased diode.

Question 12.
Referring to Figure 7, calculate the current in each of the circuits and the voltage drop across each resistor. Assume the diodes are ideal.

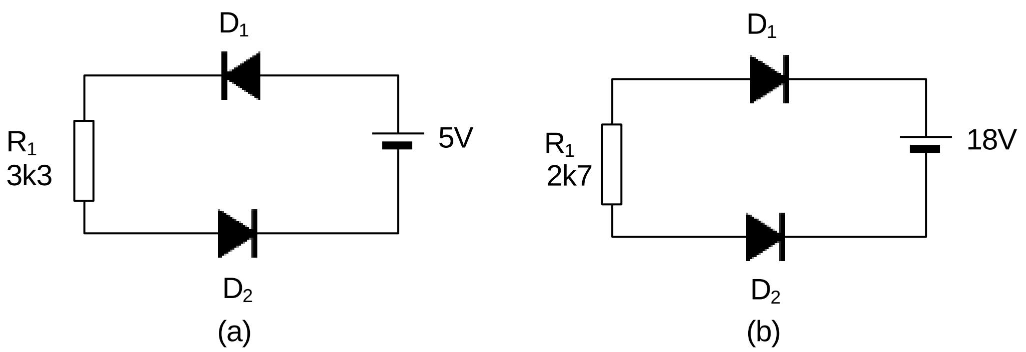


Figure 7. Circuits for problems

Question 13.

Refer to Figure 8. Assume a diode drop of 0.6V for each forward biased diode.

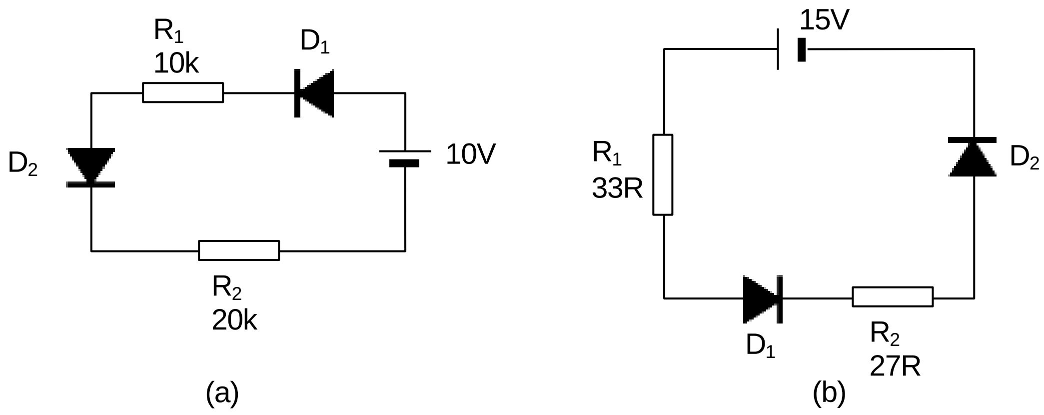


Figure 8. Circuit for problem

a). State the voltage drop across each diode in Figure 8(a).

V_{D1} =

V_{D2} =

b) Calculate the circuit current in Figure 8(a).

I =

c) Calculate the voltage drops across R_1 and R_2 in Figure 8(a).

d). State the voltage drop across each diode in Figure 8(b).

V_{D1} =

V_{D2} =

e) Calculate the circuit current in Figure 8(b).

I =

f) Calculate the voltage drops across R_1 and R_2 in Figure 8(b).

Question 14.
Refer to Figure 9. Assume a diode drop of 0.6V for each forward biased diode.

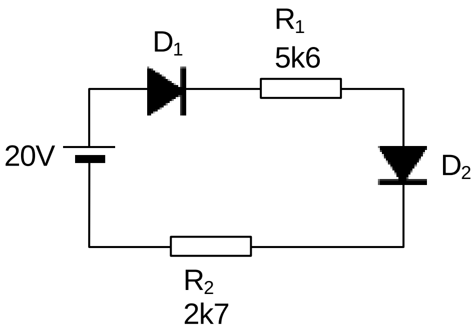


Figure 9. Circuit for problem

a) Determine the circuit current.

I =

b) Calculate the voltage across R_1, R_2, D_1 and D_2.

Question 15.
Refer to Figure 10. Assume a diode drop of 0.6V for each forward biased diode.

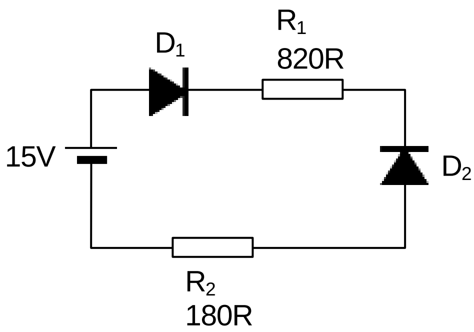


Figure 10. Circuit for problem

a) Calculate the circuit current.

b) Calculate the voltage drop across R_1, R_2, D_1 and D_2.

Summary

A diode behaves like a switch. When a diode is forward biased it is like a closed switch; when it is reverse biased it is like an open switch.

The diode drop across and ideal diode is assumed to be zero volts. However, the diode drop across a practical diode is approximately 0.6V.

The current in a forward biased diode circuit is limited by the circuit resistance.

The current in a reverse biased diode circuit is very small and is considered to be zero.

Self Evaluation Test

1. In Figure 15 the condition of the lamps is:

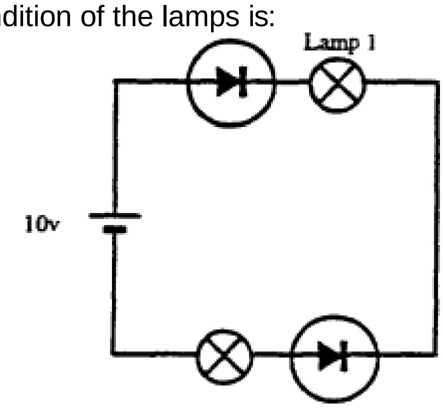


Figure 15.

(a) lamp 1 is ON and lamp 2 is ON

(b) lamp 1 is ON and lamp 2 is OFF

(c) lamp 1 is OFF and lamp 2 is ON

(d) lamp 1 is OFF and lamp 2 is OFF

2. The voltmeter in figure 16 readings V1 and V2 are most likely to be:

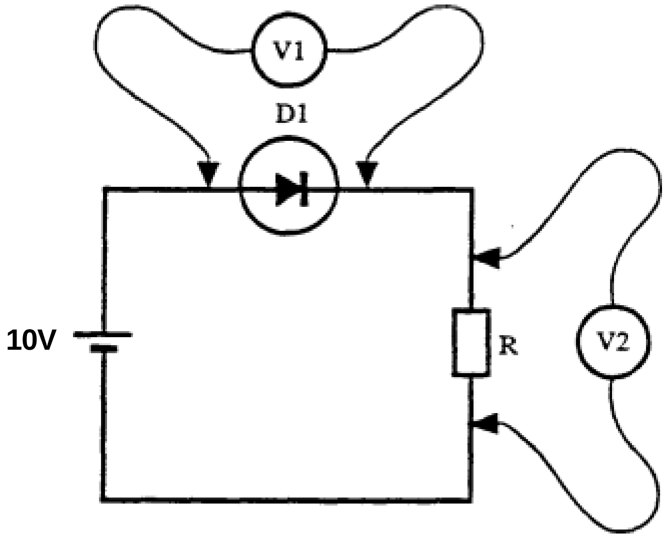


Figure 16.

(a)	$V_1 = 0V$	and	$V_2 = 0V$
(b)	$V_1 = 0.6V$	and	$V_2 = 9.4V$
(c)	$V_1 = 9.4$	and	$V_2 = 0.6V$
(d)	$V_1 = 10V$	and	$V_2 = 0V$

3. The voltmeter readings V1 and V2 are most likely to be:

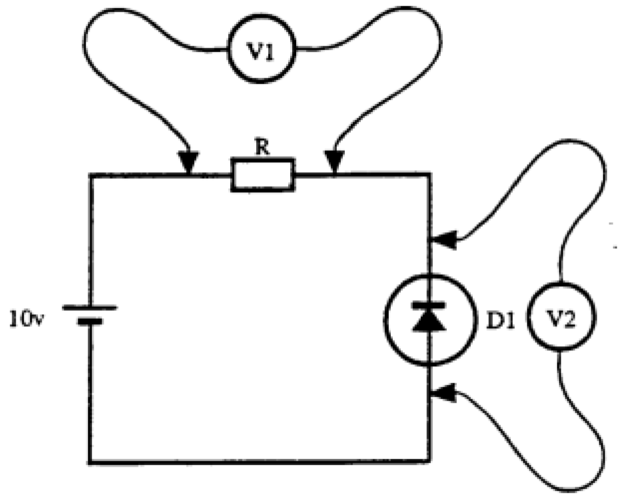


Figure 17.

(a)	$V_1 = 0V$	and	$V_2 = 0V$
(b)	$V_1 = 0.6V$	and	$V_2 = 9.4V$
(c)	$V_1 = 9.4$	and	$V_2 = 0.6V$
(d)	$V_1 = 0V$	and	$V_2 = 10V$

4. Calculate the voltmeter and ammeter readings for each of the circuits below. (assume a drop of 0.6 V for forward biased diodes)

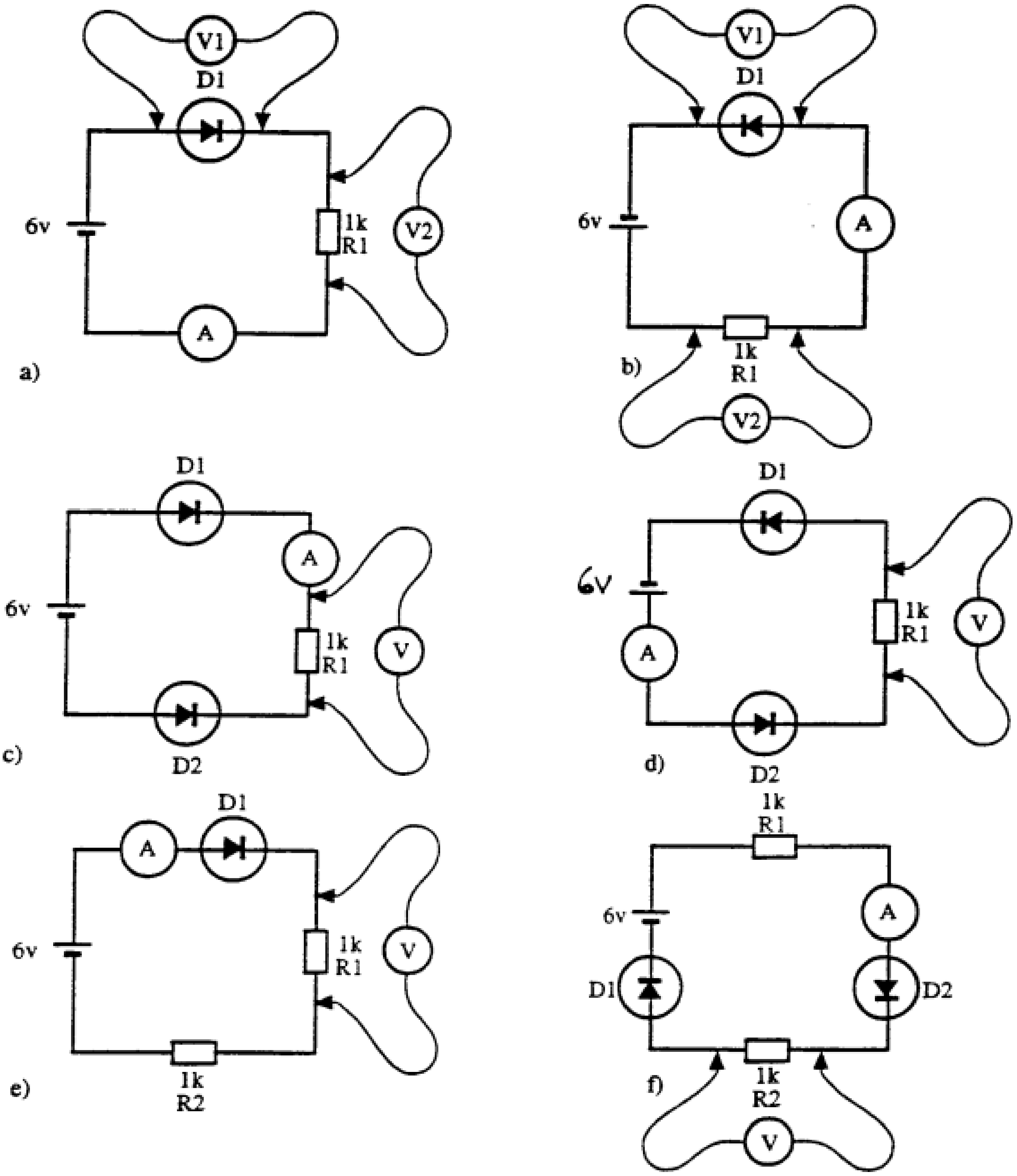


Figure 18.

Answers to Questions

1. A diode has low resistance when it is forward biased.

2. A diode has very high resistance when reverse biased.

3. Zero ohms.

4. The diode in this circuit is reverse biased and will have extremely high resistance.

5. (a) lamp in ON
   (b) lamp is OFF
   (c) both lamp 1 and lamp 2 are OFF
   (d) lamp is ON
   (e) lamp is ON
   (f) lamp is OFF

6. (a) The voltage across each diode is 0 V (assuming ideal diodes).
   (b) The voltage shared by the two resistors is 12V Each has 6 volts.

7. In Figure 5, diode DI is forward biased but diode D2 is reverse biased and so the circuit current is zero.

8. D 1 and D2 are forward biased.

9. The combined voltage drop across D_1 and $D_2 = 0.6V + 0.6V = 1.2V$.

10. (a) I = 1A,
    (b) I = 0A,
    (c) I = 1.7mA,
    (d) 2.05mA

11. (a) I = 0.94A,
    (b) I = 0A,
    (c) I = 1.45mA,
    (d) I = 1.74mA

12. (a) $I = 1.52mA$, $V_{R1} = 5V$,
    (b) $I = 0A$, $V_{R1} = 0V$

13. (a) $V_{D1} = 0.6V$, $V_{D2} = 0.6V$,
    (b) 293μA,
    (c) $V_{R1} = 2.93V$, $V_{R2} = 5.87V$,
    (d) $V_{D1} = 0.6V$, $V_{D2} = 0.6V$,
    (e) 230mA,
    (f) $V_{R1} = 7.59V$, $V_{R2} = 6.21V$

14. $I = 2.27mA$, $V_{RI} = 12.7V$, $V_{R2} = 6.14V$, $V_{D1} = 0.6V$, $V_{D2} = 0.6V$

15. $I = 0A$, $V_{R1} = 0V$, $V_{R2} = 0V$, $V_{D1} = 0V$, $V_{D2} = 14.4V$

Answers to Self Evaluation Test

1. (d) lamp 1 is OFF, lamp 2 is OFF

2. (b) $V_1 = 0.6V$, $V_2 = 9.4V$

3. (d) $V_1 = 0V$, $V_2 = 10V$

4. (a) $V_1 = 0.6V$ $V_2 = 5.4V$ $I = 5.4mA$
   (b) $V_1 = 0.6V$ $V_2 = 5.4V$ $I = 5.4mA$
   (c) $V = 0V$ $I = 0mA$
   (d) $V = 4.8V$ $I = 4.8mA$
   (e) $V_1 = 2.7V$ $I = 2.7mA$
   (f) $V = 2.4V$ $I = 2.4mA$

3. The ½ WaveRectifier, Filtering and Ripple

Introduction

In this unit you will learn about rectification and rectifier circuits. You will also learn about the voltages and currents in a rectifier circuit.

This will enable you to find out if a rectifier circuit is functioning correctly. To pass this unit you must be able to:

- Calculate load voltages and currents.
- Calculate diode currents and voltages.
- Determine the reverse voltage rating for diodes in half- wave and full-wave rectifier circuits.
- Sketch half-wave and full-wave rectifier circuit connections
- Sketch rectifier circuit voltage and current waveforms.

Rectification

A very common use of a diode is to convert AC into DC. This process is called "rectification".

Many household appliances such as the TV, cassette player and clock radio are powered from the 240 volt mains power point. The 240 volt AC that enters these appliances is first stepped down to a much lower voltage by a transformer. This lower AC voltage is then rectified by diodes to produce a DC voltage to operate the electronic circuits within the appliance.

AC Wave-forms

The AC power delivered to us from the electric supply company produces voltages and currents that are alternating in polarity at a rate of 50 cycles per second or 50 Hz The characteristics of AC quantities can be represented by a sine-wave graph:

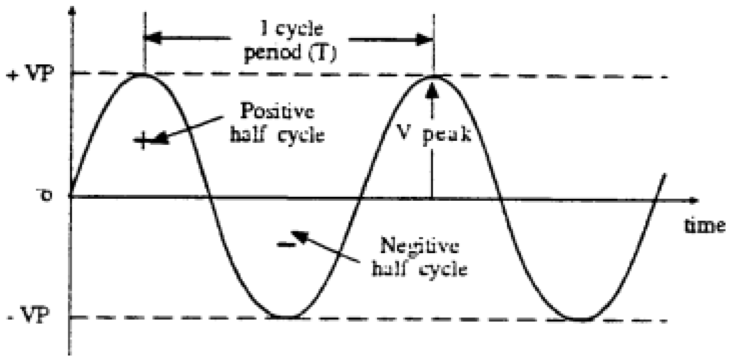


Figure 1. AC Waveform

During the positive half cycle, current in an AC circuit flows in one direction. Current flows in the opposite direction during the second half cycle.

The amplitude of an AC waveform is constantly changing with to time. The size of AC voltages and currents are often expressed in volts "RMS" or amps "RMS". The peak value is related to the RMS voltage by the equation:

peak voltage = $\sqrt{2} \times V_{rms} = 1.414 \times V_{rms}$.

Question 1.
Find the peak value of a $25V_{rms}$ voltage source.

Question 2.
In Figure 2, on the positive half cycle of V_s, is the diode forward or reverse biased?

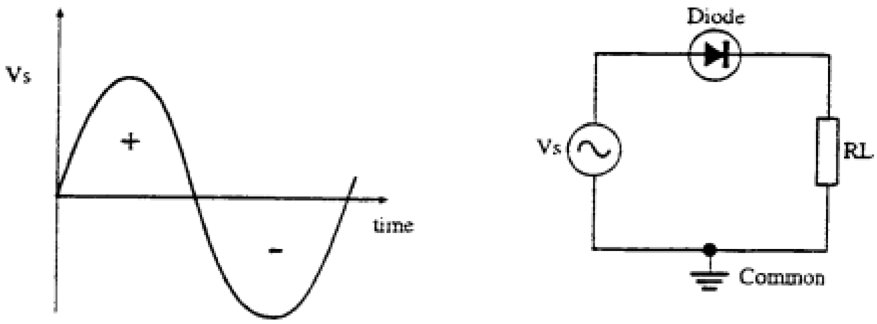


Figure 2. Half-wave rectifier

Question 3.
In Figure 2 on the negative half cycle of V_s is the diode forward or reverse biased?

Half-Wave Rectifier

The diode conducts on the positive half cycle. This is because it is forward biased during that time interval. It does not conduct on the negative half cycle because it is then reverse biased.

For the moment let us consider the diode to be an ideal diode, in which case the diode resistance is zero when forward biased and infinite when reverse biased.

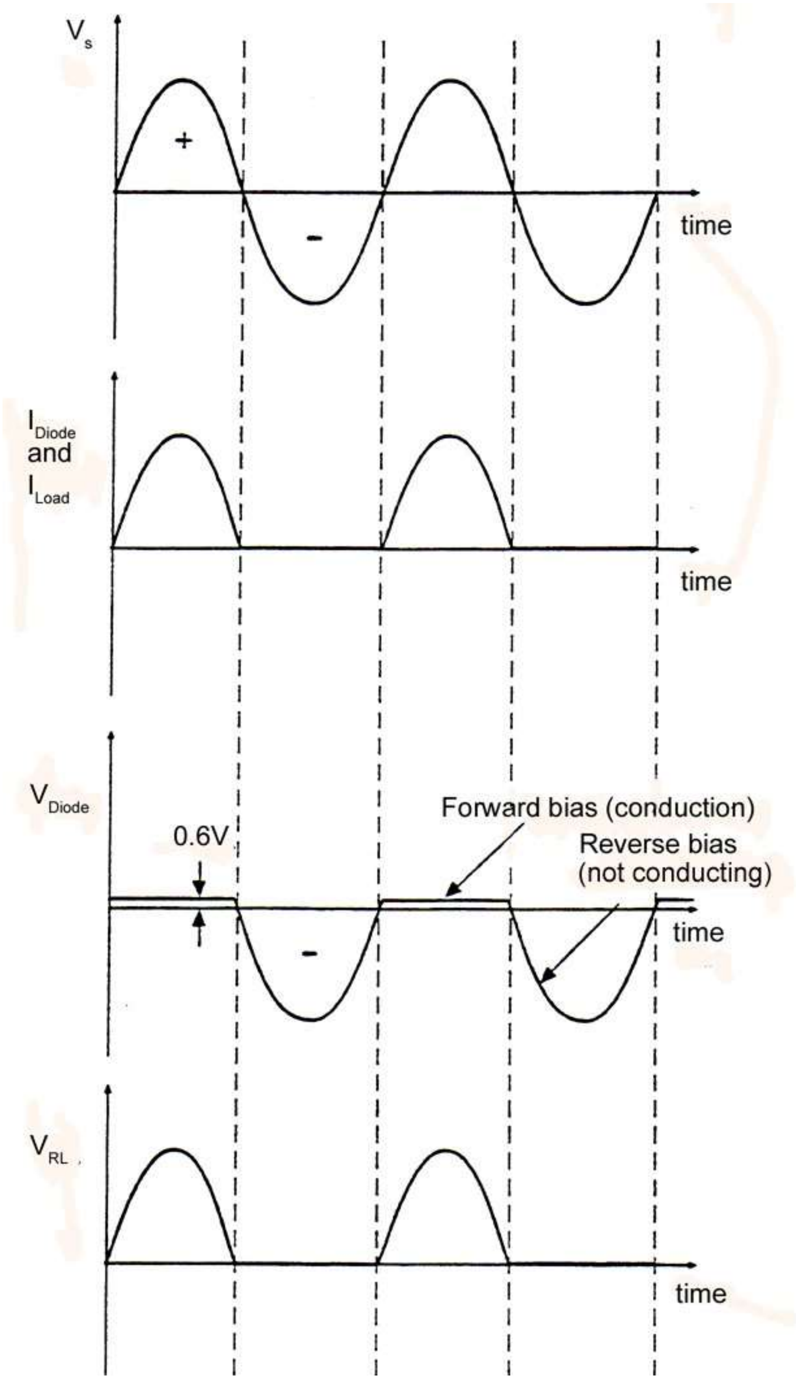


Figure 3. Half-wave rectifier waveforms

The load voltage waveform (V_{RL})shown in Figure 3 is called a "half wave rectified waveform". This is because half of the input waveform is conducted to the load when the diode is forward biased. The other half of the input cycle is prevented from reaching the load because the diode is then reverse biased. Notice also in Figure 3 that diode and load current only flow on the positive half cycles of the input The diode waveform shows that the diode has a small forward bias (0.6 V approx for Si) across it while it is conducting. The diode has a large reverse bias while it is not conducting. The circuit is a series circuit and the diode current is the same as the load current. Current only flows on the positive half cycles which corresponds with forward bias on the diode.

While current flows, the diode voltage is small (0.6V). During the parts of the input cycle when current does not flow, the diode is reverse biased and has a negative voltage across it Voltage across the load appears during the periods of diode conduction.

Question 4.
In Figure 4 the diode has been reversed.

(a) On what part of the input cycle will current flow.

(b) Draw the voltage waveform you would expect across the load resistor.

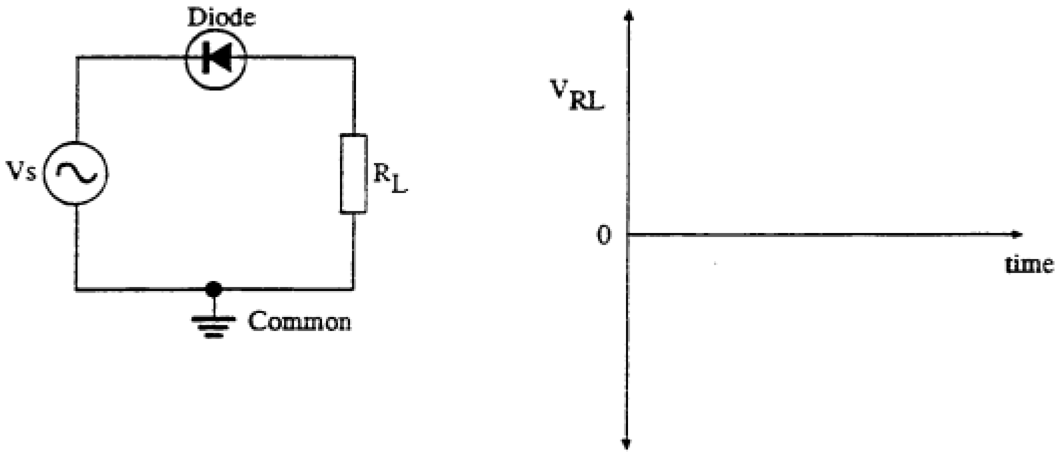
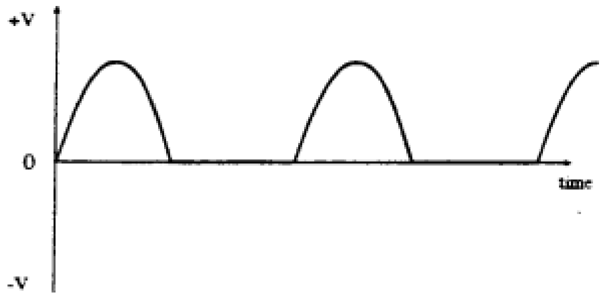


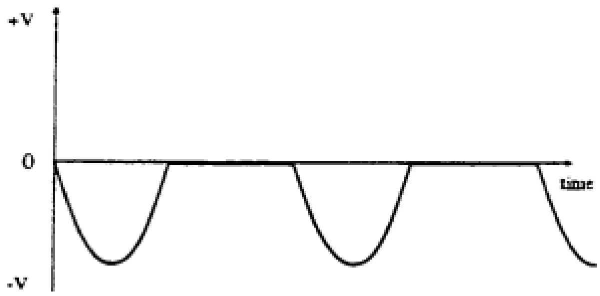
Figure 4. Half-wave rectifier

If the diode is reversed, the output waveform is inverted and the output polarity is reversed.

Pulsating DC



(a)



(b)

Figure 5. Positive and negative polarity wave forms

Question 5.
Refer to Figure 5. Are these waveforms AC or DC?

The rectification process has converted the AC waveform into a single direction or "direct current" waveform. This waveform is pulsating. It requires considerably more processing before it can be used to supply a piece of electronic equipment.

To predict the average DC voltage across the load resistor the voltage drop across the diode will need to be taken into account.

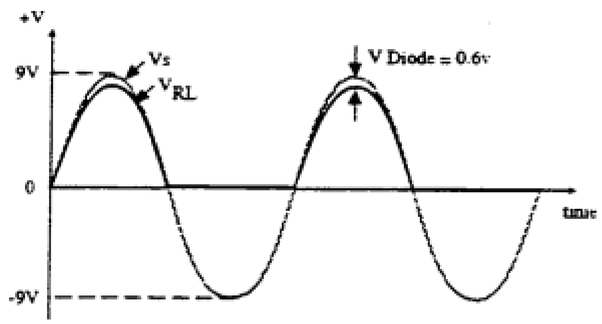


Figure 6. Effect of diode drop on wave form

When the diode voltage drop is taken into account the peak voltage across the load is slightly lower than the peak voltage of the input waveform.

Question 6.
What is the typical voltage drop across a forward biased silicon diode?

Question 7.
What is the peak voltage across R_L in figure 6?

In rectifier circuits the size of the currents flowing may be many amps and the voltage drop across the forward biased diode may be as much as 1 volt or even more.
When a DC voltmeter is used to measure a rectified waveform, the meter gives a reading of the average value of the waveform. Inspect the load waveform in Figure 7. You can see that the average voltage across the load will be somewhere between 0 volts and the peak of 40 volts. By eye you can estimate that the average voltage is less than half the peak voltage.

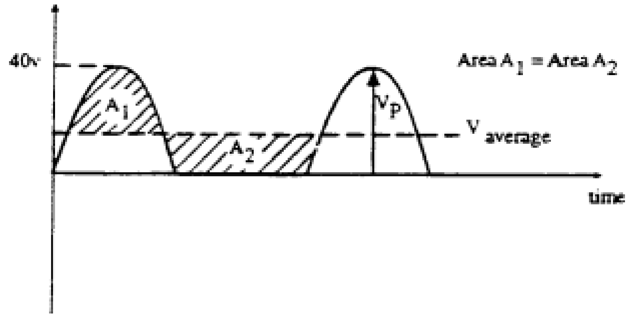


Figure 7. Average voltage

The precise value of the average voltage is given by the formula:

$$V_{av} = \frac{1}{\pi} V_p$$
$$= 0.318V_p$$

To determine the DC or average voltage across the load several steps are required. Example: Determine the average voltage across the load in Figure 8.

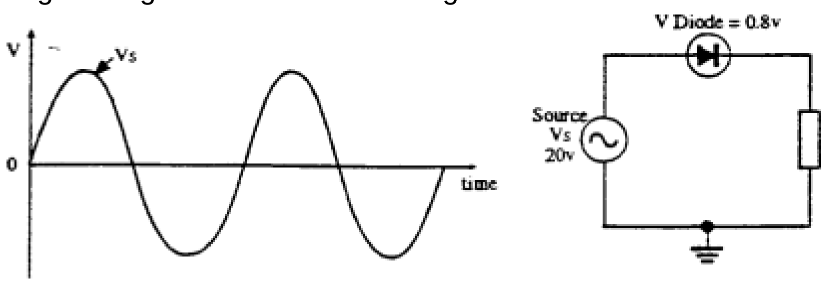


Figure 8. Half wave-rectifier

AC voltages are always assumed to be RMS unless otherwise indicated, therefore the 20V shown in Figure 8 means 20 volts RMS which must be converted to the peak value.

The peak source voltage, V_p (source) $= 1.414 \times V_{rms}$
$= 1.414 \times 20$
$= 28.28$ V

If the diode voltage drop is 0.8 V, then the peak voltage across the load will be 0.8 V less than the peak source voltage.

The peak load voltage, V_p (load) $= V_p$ (source) - 0.8 .
$= 28.28 - 0.8$
$= 27.48$ V

The average load voltage is determined by the peak load voltage using the formula given before.

V_{av} (load) $= 0.318 \times V_p$ (load)
$= 0.318 \times 27.48$
$= 8.74$ V

This average voltage is what will be measured using a DC voltmeter.

Question 8.
For the circuit shown in Figure 9, calculate the average voltage across the load.

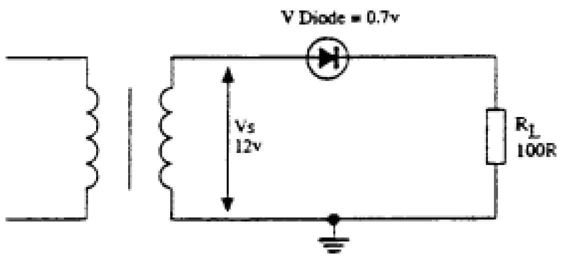


Figure 9. Half Wave-rectifier

Question 9.
For the circuit shown in Figure 10
(a) Indicate the polarity of the load voltage.
(b) Calculate the voltmeter reading.

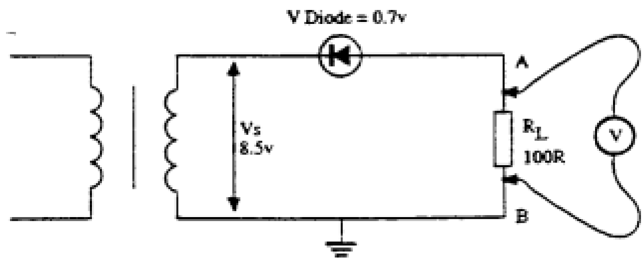


Figure 10. Half wave-rectifier

The peak and average current can be easily determined from the peak and average voltage.

$I_P = V_P/R_L$
and $I_{av} = V_{av}/R_L$

The current is the same throughout a series circuit.
The peak diode current is equal to the peak load current.
The average diode current is equal to the average load current

Question 10.
Calculate the peak and average diode current in the circuit of Figure 11

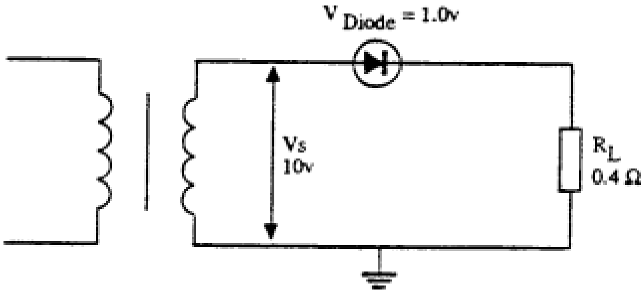


Figure 11. Half wave-rectifier

Question 11.
Again referring to Figure 11 sketch the diode voltage waveform on the axis provided in Figure 12

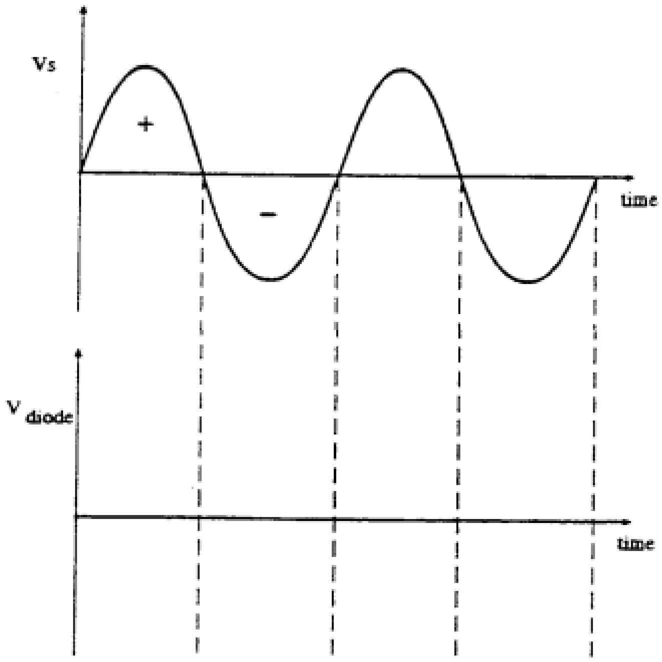


Figure 12.

Maximum Reverse voltage (V_{rrm})

Half-wave rectifier

Notice that on the negative half of the input cycle the diode is reverse-biased. It is subjected to a peak reverse voltage equal to the peak value of the input voltage. The diode must be able to withstand this reverse voltage.

The allowable peak reverse voltage that a diode can withstand is specified as "V_{rrm}" (repetitive reverse maximum).

When selecting a diode for an application or as a replacement, the diode must be chosen so that it has a V_{rrm} rating that exceeds the peak reverse of the input voltage. The peak reverse voltage experienced by the reverse biased diodes in a rectifier is also called the PIV or peak inverse voltage.

Diode Selection

There are two main factors to consider when selecting a diode for an application or replacement One is the PIV experienced by the diode when reverse biased. The other is the average current when it is forward biased. The average forward current may be abbreviated as I_{av} or I_{fav} (forward average current).

Question 12.
Refer to the diode data sheet at the back of this book and select a diode that would be suitable to operate in the circuit of Figure 13.

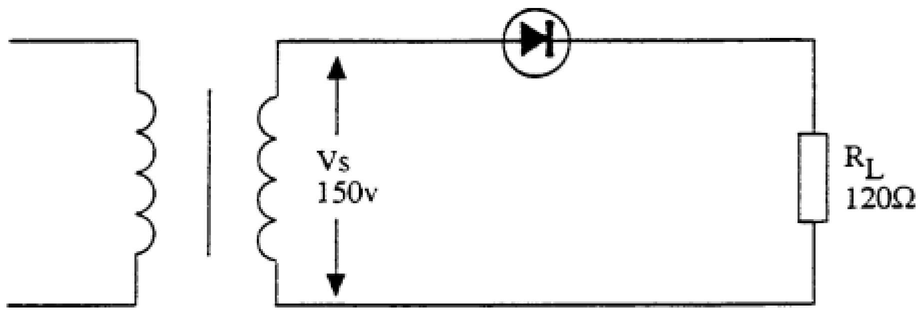


Figure 13.

Filtering

Introduction

In this you will learn about power supply filtering. This will enable you to determine if a filter circuit is operating correctly, and to locate a faulty component.

To pass this unit you must be able to:

- State the effect on ripple and average voltage that changes in capacitor value will cause.
- State the effect on ripple and average voltage that changes in load current will cause.

Rectified Waveforms

AC voltage that is rectified may have a waveform like one of those shown below:

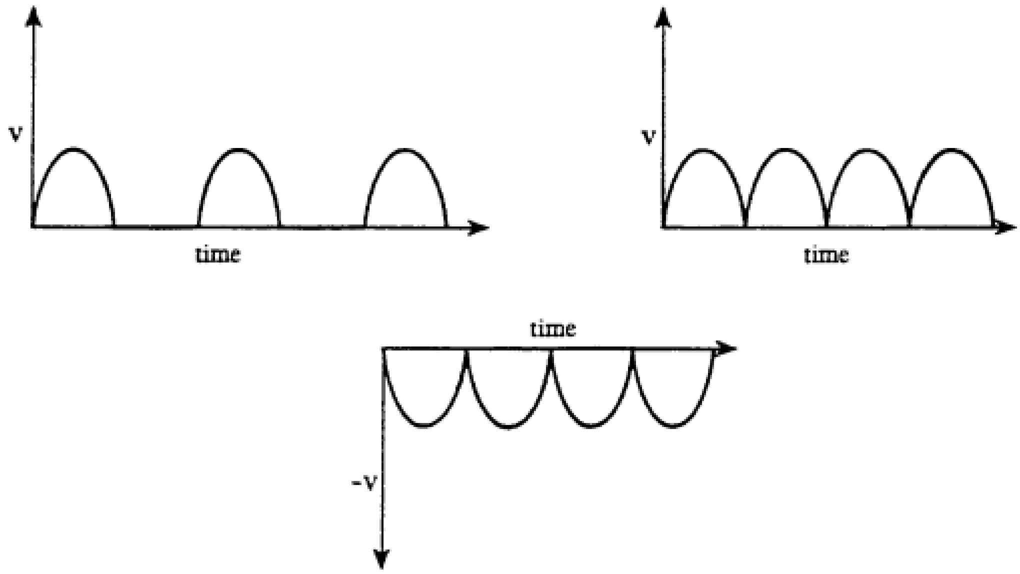


Figure 1. Rectified waveforms

These waveforms are unsuitable for powering most electronic circuits because of their pulsating character.

An ideal DC voltage is very steady in amplitude. The “raw” or “pulsating” DC from the rectifier can be smoothed considerably by the addition of a capacitor.

Capacitive Filter

The addition of a large value capacitor in parallel with the load has the effect of filtering or "smoothing" the pulsating DC rectifier voltage.

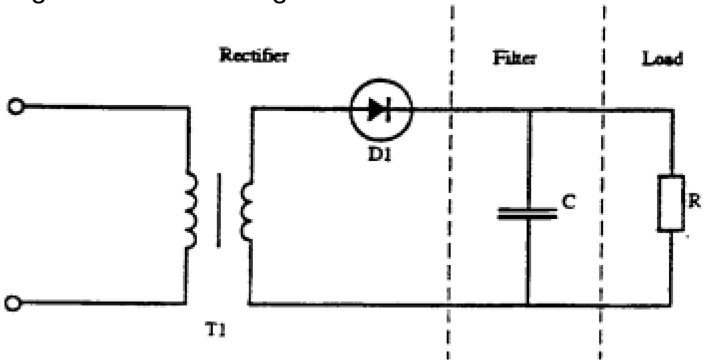


Figure 2. Half-wave rectifier with filter capacitor and load

Question 1.
What does a capacitor store?

A large value capacitor will store a large amount of charge. When the rectifier voltage starts to fall, the capacitor discharges energy to the load and prevents the voltage across the load from falling to zero.

The smoothing action relies on the capacitor retaining a portion of its charge between the pulses from the rectifier.

Figure 3 shows a typical load voltage waveform as a result of the inclusion of the filtering capacitor in the circuit. The unfiltered waveform is shown a dashed line.

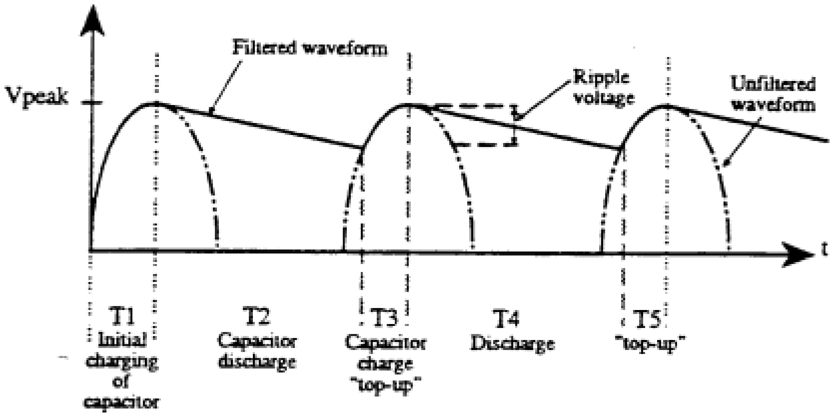


Figure 3. Filtered load voltage waveform

The first positive-going quarter cycle of voltage from the rectifier (time interval T1) charges the capacitor to a voltage equal to the peak output voltage from the rectifier.

The capacitor discharges slowly into the load during time T2. to ensure that the capacitor discharges slowly, the discharge Time Constant is made long by using a large value electrolytic capacitor. A capacitor value of thousands or tens of thousands of microfarads is common.

During time interval T3, the output voltage from the rectifier rises once again and, when it exceeds the voltage across the capacitor, the charge lost by the capacitor during time interval T2 is “topped up” with charge from the AC supply via the rectifier diode.
The cycle then repeats as shown in time intervals T4 and T5.

The capacitor can be thought of as a reservoir of energy that is continually being topped up and partially drained to produce a more or less steady voltage across its terminals.

The action of the capacitor is to “filter” or “smooth” the otherwise pulsating DC voltage from the rectifier circuit. The inclusion of the smoothing capacitor has created a circuit that is called a “DC Power Supply”.

The waveform has a steady DC value but with minor fluctuations called “ripple voltage”. This is shown in Figure 3.

Question 2.
During time interval T2, is the voltage from the rectifier rising, holding steady or falling?

Question 3.
If the capacitor discharges slowly during time interval T2, is the diode D1 forward biased or reverse biased?

Ripple Frequency

The frequency of the ripple voltage that accompanies the DC is determined by the frequency of the AC source and whether the rectifier is a half-wave or full-wave type.

Question 4.
What is the frequency of the mains voltage supplied by your local electricity supply authority?

In a half-wave rectifier, there is only one DC pulse during each cycle of the AC source and so, if the source frequency is 50Hz, then the ripple frequency is also 50Hz. This is shown in Figure 4.

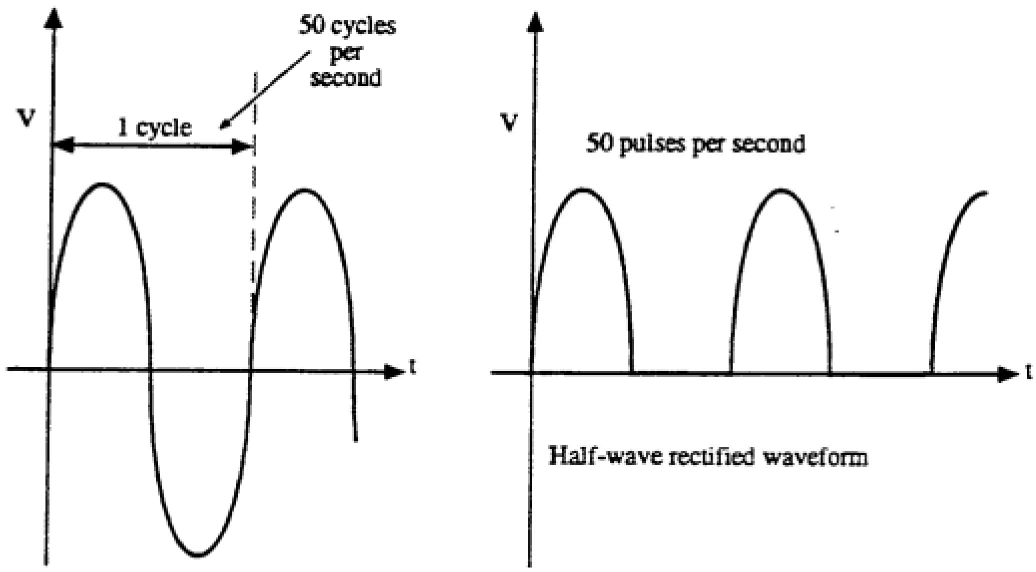


Figure 4. Half wave rectification

For a full-wave rectifier, there are two pulses of DC during each cycle of the AC source. Therefore the ripple frequency is two times the AC source frequency. If the AC source frequency is 50Hz, then the frequency of the ripple voltage is 100Hz. This is shown in Figure 5.

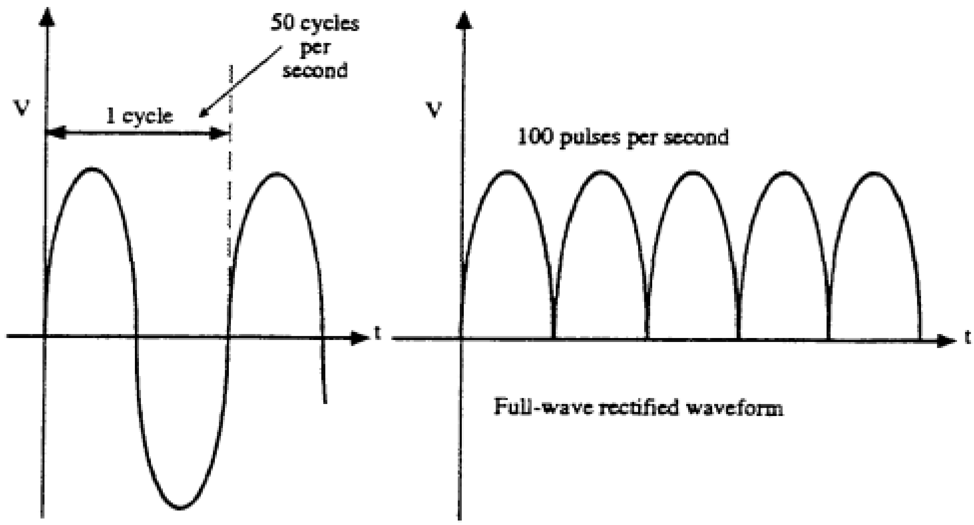


Figure 5. Full-wave rectification

Factors Affecting Ripple Voltage

The amplitude of the ripple voltage will depend on how much the capacitor discharges between top-ups.

The amount of capacitor discharge, and thus the amplitude of the ripple voltage, is determined by three factors:

1. The load current.
2. The size of the capacitor.
3. The time interval between top-ups; the time between top-ups is related to the AC input frequency.

Question 5.
If R_L were infinite resistance, how much ripple would there be on the output?

Explain why.

Load Variations

Ripple will appear when load current is drawn, and its amplitude will depend partly on the load current. Figure 6 shows a half-wave rectifier with a variable load.

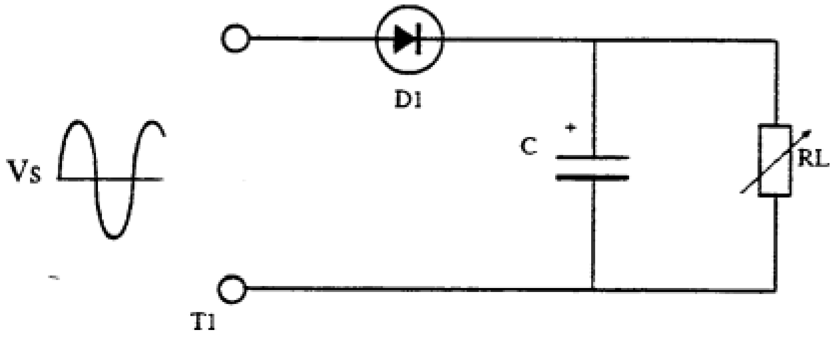


Figure 6. Varying the load current

Question 6.
When the load resistance is reduced, what effect will this have on the load current?

Question 7.
If the load current is increased (by reducing R_L), what effect will this have on the ripple voltage?

As R_L is reduced, the load current will increase. The ripple voltage will increase because the capacitor will lose more charge between top-ups. This effect is shown in Figure 7.

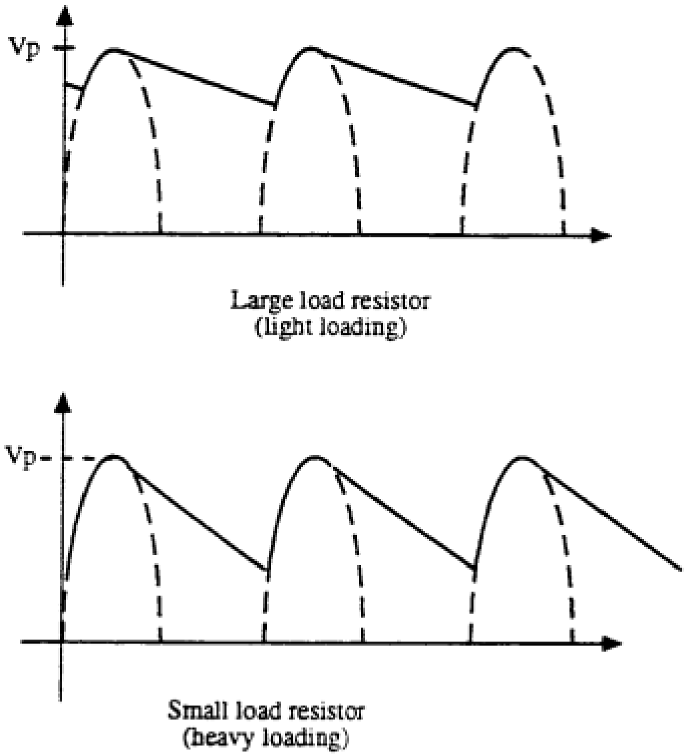


Figure 7. Effect of changing R_L

The ripple voltage is directly proportional to the load current. That is, doubling I_{RL} will double the amplitude of the ripple voltage (V_r).

$$V_r \propto I_{RL}$$

The Value of Capacitance

When the filter capacitor is very large, the amount of energy it discharges will be small compared to the total charge held by the capacitor. This means that the voltage will only decrease a small amount, and the resulting amplitude of the ripple voltage will be small.

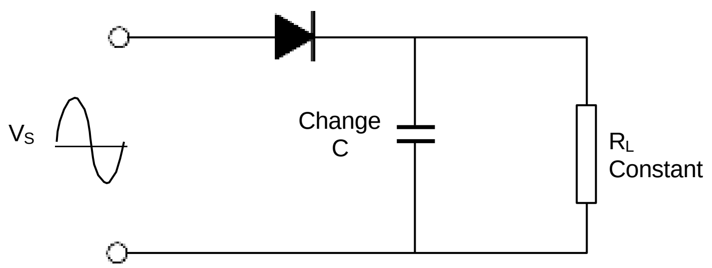
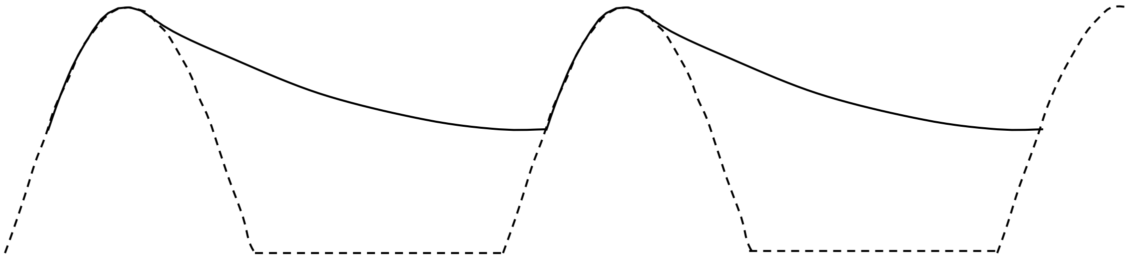
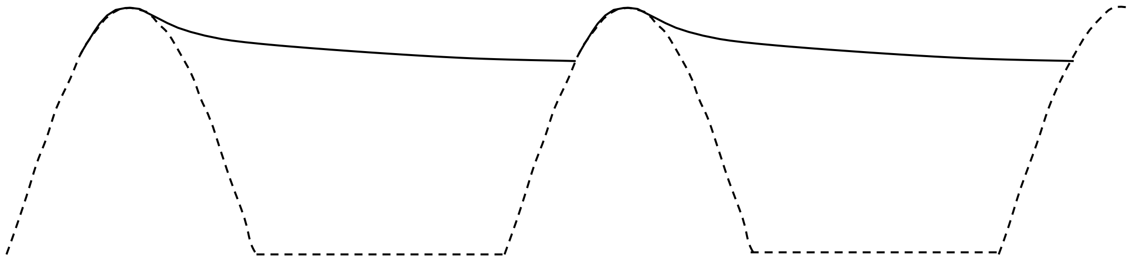


Figure 8. Changing the capacitor value

The ripple voltage is inversely proportional to the size of the capacitor. That is, doubling the value of capacitance will halve the amplitude of the ripple voltage. $V_r \alpha 1/C$



Small filter capacitor



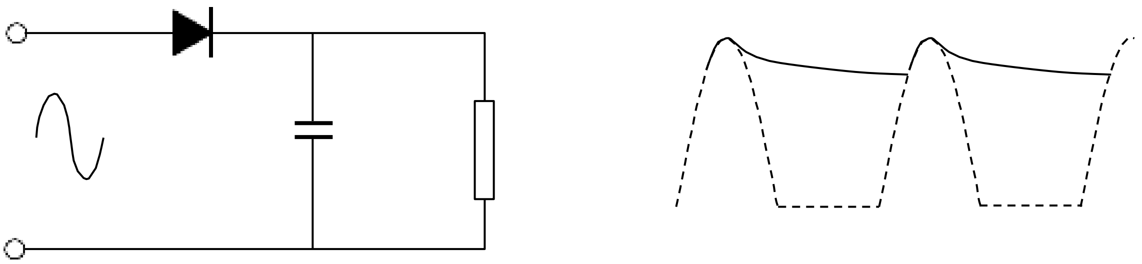
Large filter capacitor

Figure 9. Effect on changing C

Question 8.
What is the ripple frequency of a half-wave rectifier if the frequency of the supply voltage is 50Hz?

Half-wave:

Frequency



Half-wave

Figure 10. Ripple waveform

Figure 10 shows the unfiltered (dashed lines) and filtered (solid lines) waveforms for a half-wave rectifier.

The lower the ripple frequency, the greater the time between top-ups, and so the amplitude of the ripple voltage is higher.

The ripple voltage is therefore inversely proportional to ripple frequency:

$$V_r \propto 1/f$$

The relationship between these three quantities is summarised in the equation:

$$V_r = \frac{I_{DC}}{fC}$$

where :

V_r = pk – pk ripple voltage (Volts)

I_{DC} = DC load current (Amperes)

f = ripple frequency (Hertz)

C = capacitor value (Farads)

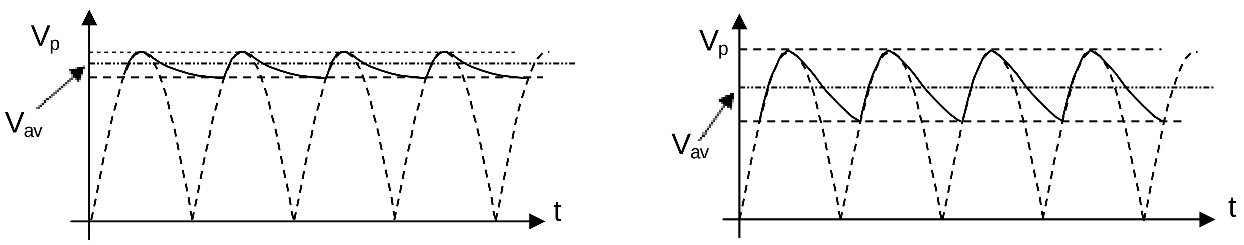
Question 9.
A half-wave rectifier has a filter capacitor of 4700μF and delivers 1.2A to the load. If the AC input to the rectifier has a frequency of 50Hz, calculate the peak-to-peak ripple voltage.

a) What will be the frequency of the ripple voltage?

Average Load Voltage

As the AC source voltage is constant, the peak load voltage will be the same regardless of the amount of ripple; that is, the peak of the ripple waveform will stay the same regardless of changes in the amplitude of the peak-to-peak ripple voltage.

It is the *minimum* value of the ripple voltage that changes. This can be seen in Figure 11.



(a) Light load (b) Heavy load

Figure 11. Riplle and average voltage

Question 11.
Explain what happens to the average load voltage as the amount of ripple increases (refer to Figure 11).

Summary

The addition of capacitive filtering produces a DC voltage that contains ripple.

The amount of ripple is determined by:

- The load current.
- The size of the capacitor.
- The ripple frequency.

The equation that summarises this relationship is:

$$V_r = \frac{I_{DC}}{fC}$$

As the ripple voltage increases, the average load voltage decreases.

The aim of the DC supply is to provide a steady voltage that does not have ripple and does not vary with changes in load current.

The simple capacitive filter is far from the ideal power supply, but it is used as the basis for most regulated power supplies that will be studied in the following units.

4. Transformers

In this unit you will learn about the electrical transformer.

You will learn how the transformer can increase or decrease an AC voltage, and increase or decrease an AC current. You also will learn about the applications of transformers in typical electrical and electronic circuits.

This Knowledge will enable you to calculate the voltages and currents in circuits that contain transformers. This will enable you to determine whether a transformer circuit is operating correctly, and to identify faults in transformer circuits.

To pass this unit you must be able to:

Describe the basic operation of an electrical transformer.
Calculate step-up and step-down voltages and currents.
List applications using electrical transformers.
Measure voltages and currents in a circuit using an electrical transformer.

The electrical transformer:

A transformer is a device that increases or decreases an AC voltage or current.
Figure 1 shows a typical transformer.

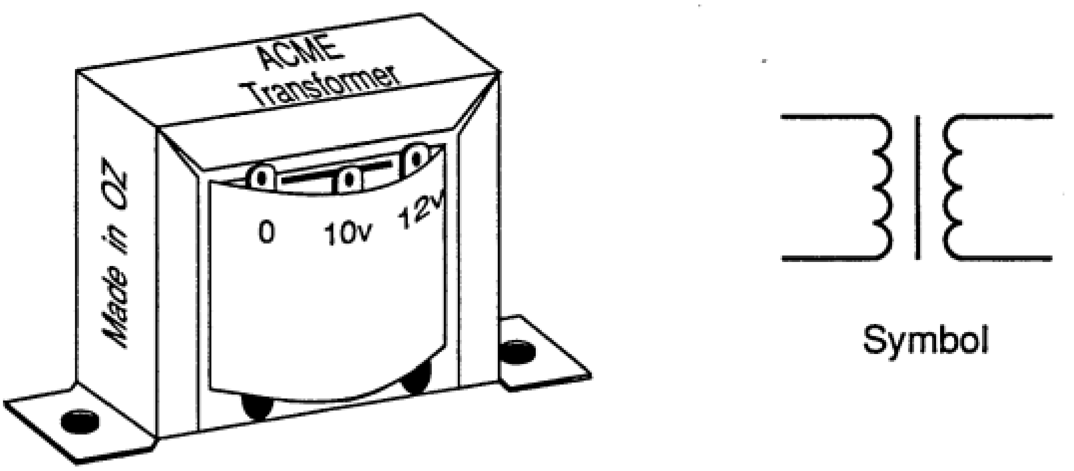


Figure 1. ***A typical transformer.***

Theory of Operation

If a direct current flows through a wire, it creates a magnetic field around the wire as shown in Figure 2a.
We can wind the wire into a coil to concentrate this magnetic field. If we also insert a core of magnetic material, such as iron into the coil, the field becomes even more concentrated, see Figure 2b for a typical example.

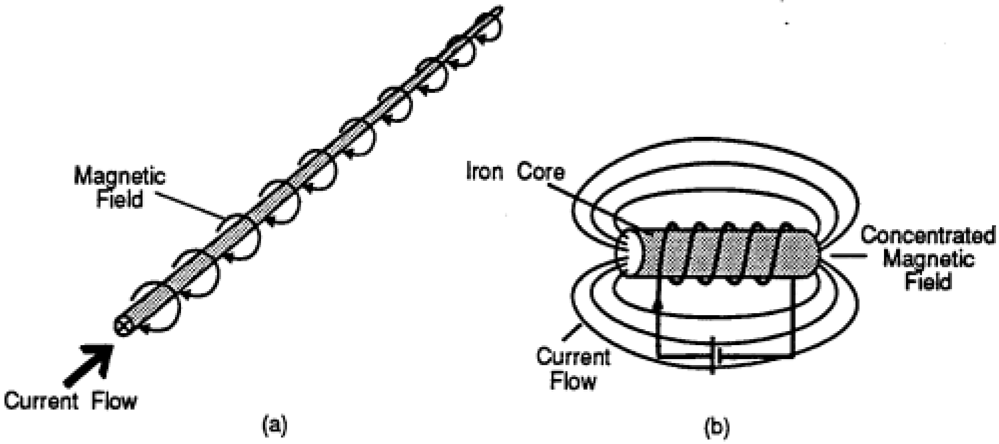


Figure 2. Electromagnetic field

If we pass a wire through this magnetic field, a voltage is induced into the wire. If we also form this wire into a coil, then move this second coil through the first coil's magnetic field, we will induce a voltage in the second coil. Also we find that any changing magnetic field in the first coil will induce a voltage in the second coil. This voltage is induced without any physical movement of the coils.

Let's place two coils of wire on the one magnetic core as shown in Figure 3 and apply an alternating current to one coil.

Now the alternating current of the primary (first) coil will induce an alternating magnetic field in the core; and

The alternating magnetic field in the core will induce an EMF in the secondary (second) coil. If we connect a load to the secondary winding, an alternating current will flow in the secondary circuit.

The primary and secondary coils are also called windings. Figure 3 shows a simplified transformer.

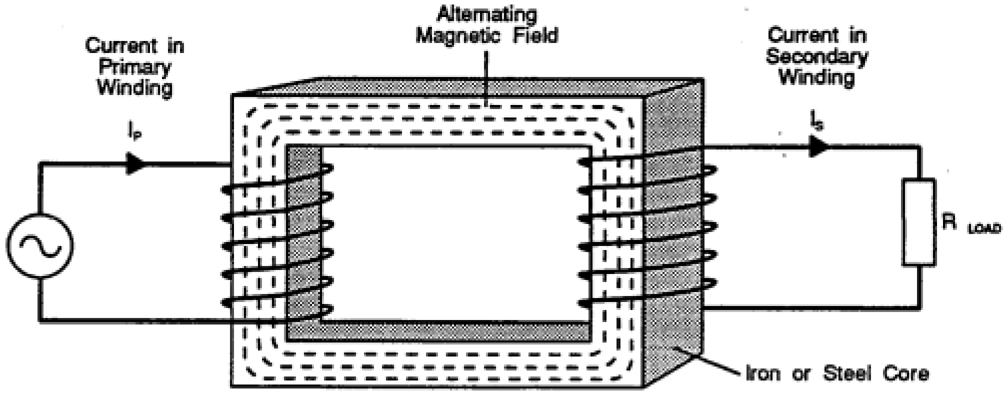


Figure 3. A basic transformer

Self-Help Question

1. Briefly explain the operation of an electrical transformer.

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Losses in a transformer

If the number of turns on the two windings are identical, then a perfect transformer will deliver an output voltage and current equal to the input voltage and current. The ideal transformer has an efficiency of 100 percent. A practical transformer can be made to give an efficiency more than 95 percent. The wasted energy appears as heat in the windings and in the core. An efficient transformer will have:

- Low resistance windings, so there is very little power wasted due to heating of the windings.
- A low-loss core, so there is very little power wasted due to heating of the core.

Figure 4 shows the major sources of power loss in a transformer.

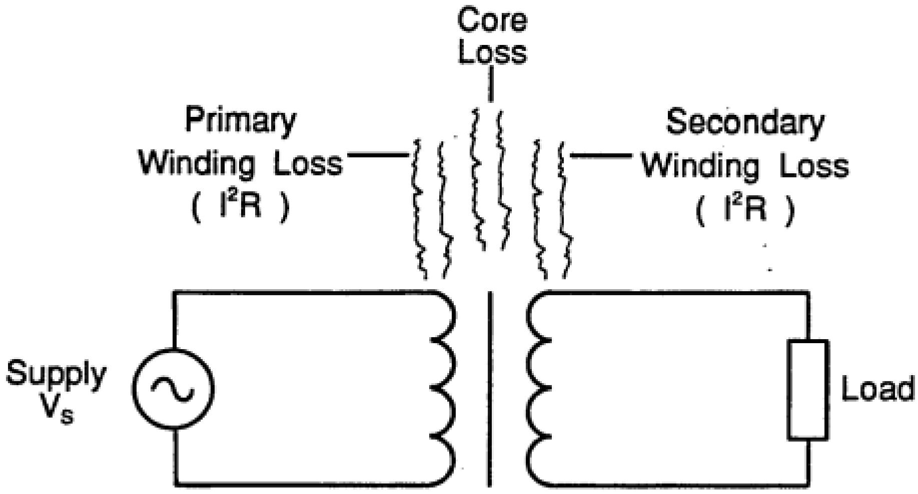

Figure 4. Energy lost in heat.

Self-Help Question

2. What are two important features in the design of an efficient transformer? Why are these important?

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Applications of transformers

The electrical transformer is widely used in electrical and electronic equipment. Remember that the transformer must have a changing magnetic field (flux) in the core before a current is induced in the secondary winding. This means that the transformer will only operate with AC applied to it.

The electrical transformer may be used in one (or more) of several applications:

- To increase or decrease alternating voltage or current
- To match impedance between two parts of a circuit.

- To transfer electrical power from a mains supply to electrical or electronic equipment without any direct electrical connection. This is called isolation. Isolation greatly improves safety when working on some types of equipment.

- To transfer an AC signal between two parts of a circuit while eliminating any DC component in the signal.

- To transfer an AC signal from a moving part of a machine to a stationary part without using brushes or other moving contacts. An example is the spinning heads in a VCR.

Figure 5 shows some typical applications of transformers.

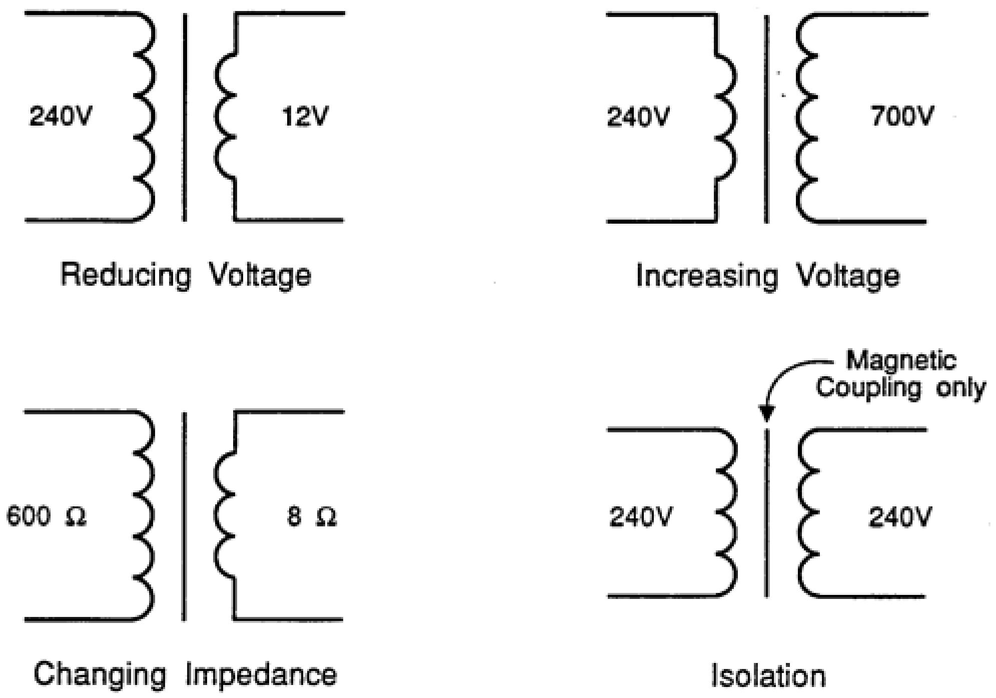

Figure 5. Uses of a transformer.

Self- Help Question

3. List five applications of transformers.

(a)______________________________________

(b)____

(c)__________________________________

(d)____________________________________

(e)__________________________________

Core materials

The core material has a major effect on a transformer's performance. Low-frequency transformers, that operate at 50 Hz, or at audio frequencies, usually use silicon steel. High-performance audio transformers use special alloys, since these allow a more efficient and compact core design than silicon steel does. Steel and alloy-cored transformers perform well at 50 Hz and low audio frequencies, but their core losses increase at higher frequencies. These losses mean that different core materials must be used for high-frequency transformers. High-frequency transformers, such as those used in switched mode power supplies, or television deflection circuits, use ferrite cores. Transformers in radio receivers and transmitters may use ferrite cores, or no core material at all. Remember that a magnetic field can be created in air, with no magnetic material at all.

The alternating magnetic field can induce small, unwanted electric currents in the core material. These are called eddy currents. If the eddy currents become large, a lot of power can be wasted, and the transformer's core will become hot. Many transformer designs use thin sheets for the core. These sheets are insulated from each other, so the eddy currents are kept to a minimum. Steel-cored and alloy-cored transformers use laminated (sheet) cores.

Figure 6 shows how eddy currents form, and how laminations reduce eddy current losses.

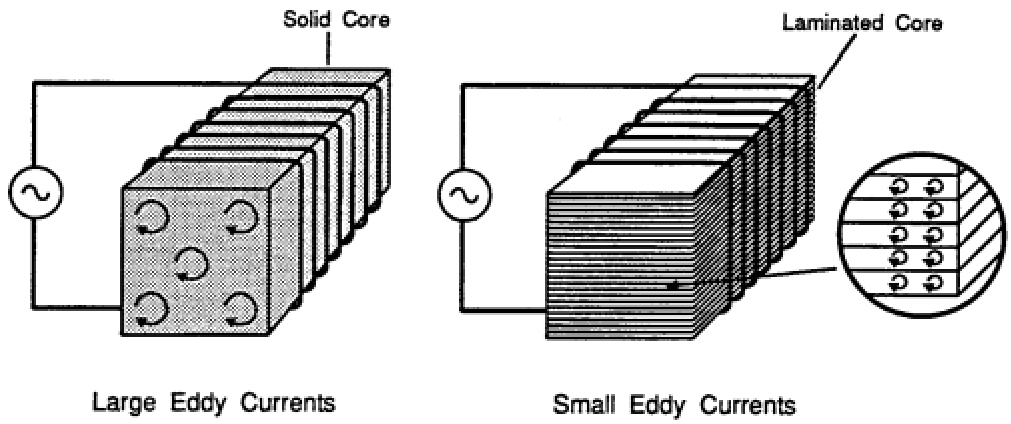

Figure 6. Laminations reduce Eddy current losses

Steel-cored and alloy-cored transformers commonly use "E-I" or "C" laminations. These are shown in Figure 7.

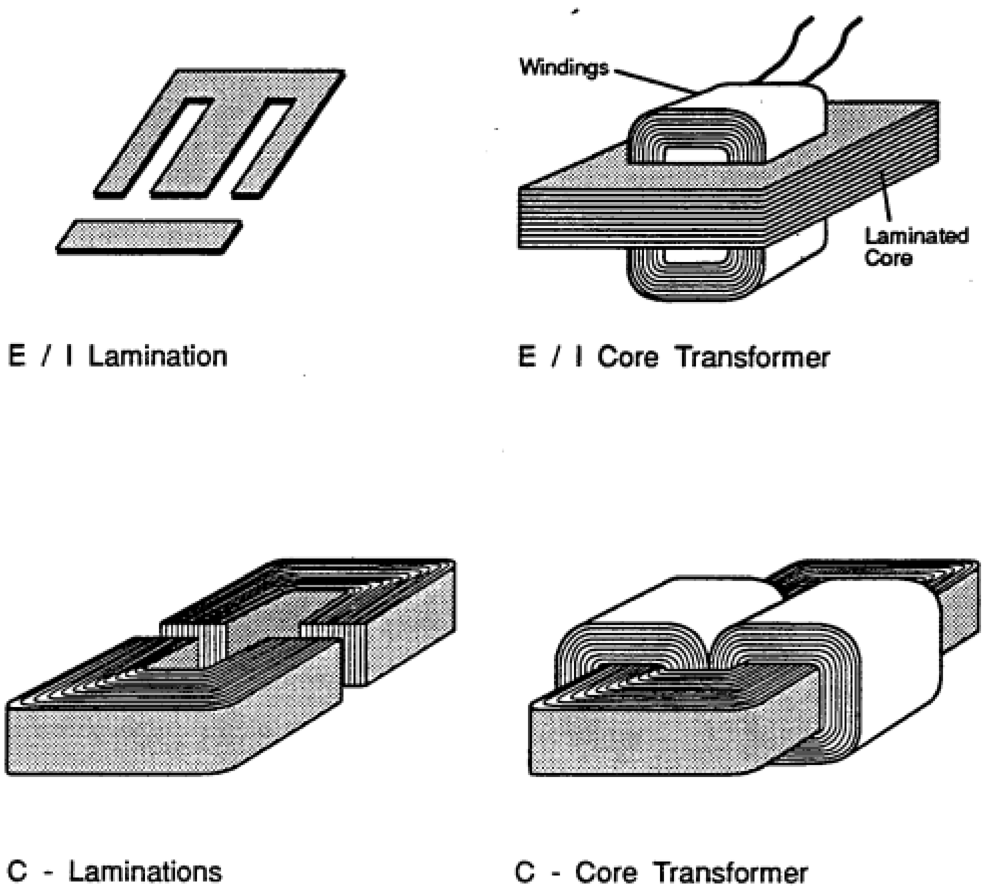

Figure 7. Laminated cores

You may also see “Toroidal” cored transformers, as shown in Figure 8.

The “E-I” construction is simple and low-cost; the toroidal form is more efficient but is more difficult to wind.

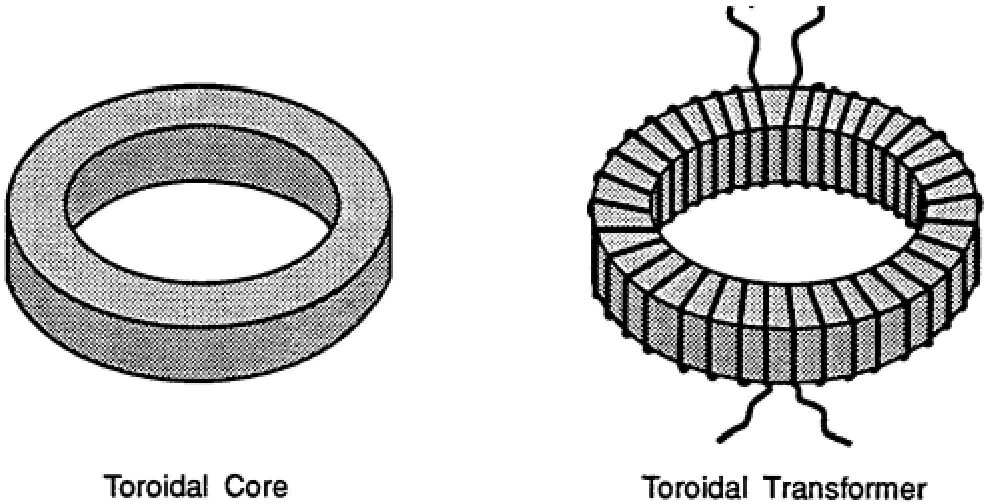

Figure 8. Toroidal ferrite core.

Ferrite is another material which is often used for a transformer core.

Ferrite cores use a powdered magnetic material in a non-conducting ceramic which is moulded into a solid block. The small granules of the powered material keep eddy currents to a minimum. This means that ferrite cores do not need to be laminated, so they can be moulded into a wide variety of shapes.

Air does not conduct electricity, so eddy currents do not exist in air-cored transformer.

Self-Help Questions

1. 4. List four typical core materials for transformers.

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5. (a) What are eddy currents ?

____

(b) Why do eddy currents cause problems in transformers?

____

(c) How are eddy currents minimised in each type of core, listed in question 4 ?

____

Step-up and step-down transformers

The basic transformer has two windings. The primary winding receives power from the AC mains. The secondary winding delivers power to the transformer's load.
If the secondary voltage is greater than the primary voltage, we have a step-up transformer. If the secondary voltage is less than the primary voltage, we have a step-down transformer.
Figure 9 illustrates step-up and step-down transformers.

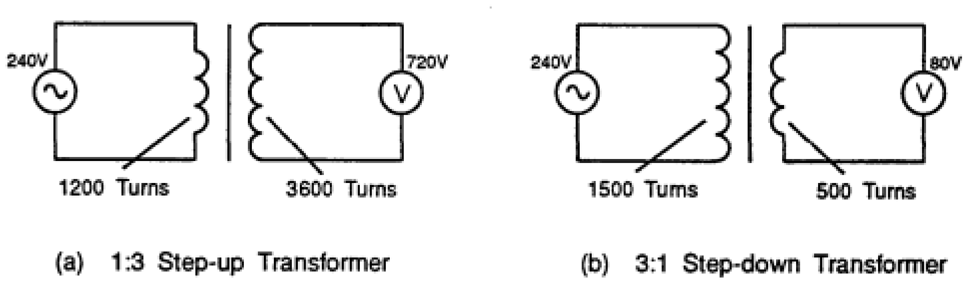


Figure 9. Step-up & step-down transformers

The ratio of the number of primary turns and the number if secondary turns is called the turns ratio (n).

$n = N_P / N_S$

The turns ratio can be used to calculate the voltages or currents in a transformer circuit.

When considering voltage transformation we use this equation:

$$\frac{N_P}{N_S} = \frac{V_P}{V_S}$$

and for current transformation we use this equation:

$$\frac{N_P}{N_S} = \frac{I_S}{I_P}$$

Where –

V_P is the primary voltage

V_S is the secondary voltage

I_P is the primary current

I_S is the secondary current

You will notice that the turns ratio is "upside-down" in the current formula. This is because a transformer that steps down voltage will step up current and vice versa. A transformer that steps up voltage with will step down current into the load.

Figure 10 shows a typical transformer.

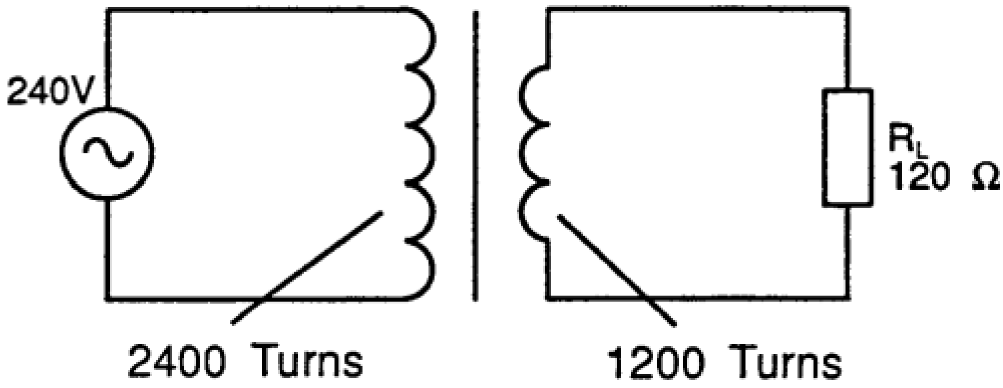


Figure 10. A 2:1 step-down transformer.

The transformer in Figure 10 has 2400 turns on the primary and 1200 turns on the secondary. The primary is connected to a 240 volt AC supply.

To calculate turns ratio:

$$n = N_P / N_S$$
$$= 2400 / 1200$$
$$= 2 / 1 \text{ or } 2:1$$

To calculate the secondary voltage:

$$V_P / V_S = N_P / N_S$$

$$240 / V_S = 2400 / 1200$$
$$V_S / 240 = 1200 / 2400$$
$$V_S / 240 = 1/2$$
$$V_S = 120 \text{ V}$$

To calculate the secondary current:

$$I_S = V_S / R_L$$
$$= 120 / 120$$
$$= 1 \text{ amp}$$

To calculate primary current:

$I_P / I_S = N_S / N_P$
$I_P / 1A = 1200 / 2400$
$I_P = 1 / 2\ A$
$I_P = 500mA$

Self-Help Questions

6. A step-down transformer has a turns ratio of 15:1. It delivers 30 amps to a load on the secondary.

   (a) What current does it draw from a 240 volt supply?
   (b) What is the secondary voltage?

7. A transformer has 500 turns on the primary and 750 turns on the secondary. It draws 600 Watts from a 240 volt supply.

   (a) What is the power in the load?
   (b) What is the primary current?
   (c) What is the secondary voltage?

8. A transformer draws 8 watts from a 240 volt supply, and delivers 10 volts to the load. What is the transformer's turns ratio? What current does the transformer draw from the supply? What is the secondary current?

Reflected impedance

A transformer can be used to match the impedance between two circuits. Impedance matching is necessary to give the maximum transfer of power Figure 11 shows two examples of transformers used to match impedances.

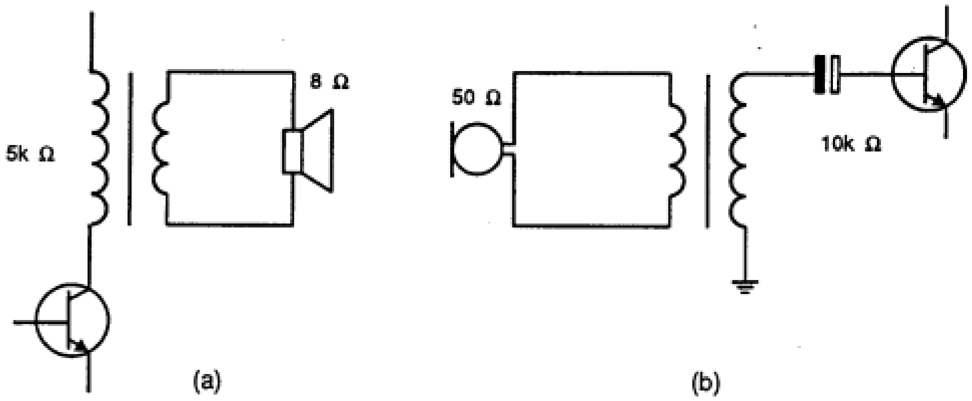


Figure 11. Impedance matching

Figure 11(a) shows a loudspeaker with an impedance of 8 ohms. This must be matched to the 5 k ohm impedance of the transistor to give maximum power transfer. The transformer must “step down” the transistor’s 5 k impedance to the speaker’s 8 ohms impedance.

The transformer in Figure 11 (b) is a step-up transformer. It must increase the microphone’s 50 ohm impedance to the transistor amplifier’s input impedance of 10 k ohm.

Impedance ratio

The turns ratio and impedance ratio of a transformer are related by this formula:

$$\frac{Z_P}{Z_S} = \frac{N_P^2}{N_S^2}$$

Where Z_P is the primary impedance and Z_S is the secondary impedance.

To find the primary impedance (Z_P) we need to transpose the equation.

$$Z_P = \frac{N_P^2}{N_S^2} \times Z_S$$

Lets calculate the input impedance of the transformer in Figure 12.

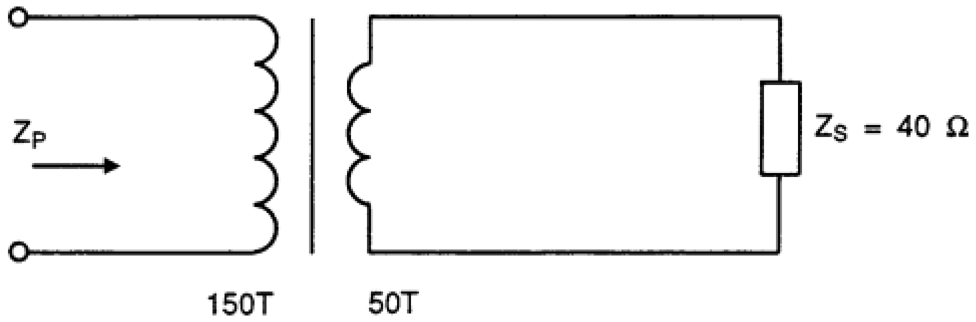


Figure 12

$$Z_P = \frac{N_P^2}{N_S^2} \times Z_S$$

$$Z_P = \frac{150^2}{50^2} \times 40$$

$$ZP = 3^2 \times 40$$

$$ZP = 360\ \Omega$$

Self-Help Questions

9. Now it is your turn. Calculate the primary impedance of the transformer in Figure 12 if the load is changed to 65 Ω.

10. A transformer has a load of 4 ohms, and a turns ratio of 20:1. What load does it present at its primary?

11. A transformer is required to transform a 200 ohm load into a 600 ohm primary impedance. What turns ratio is needed ?

12. A step-down transformer has a turns ratio of 22.4:1. If the primary impedance is 800 ohms, what is the load on the secondary ?

SUMMARY

- A transformer operates on the principle of electrical to magnetic energy and magnetic to electrical energy conversion.

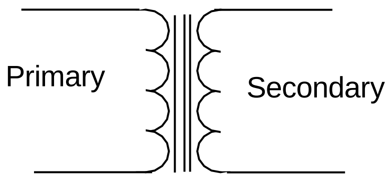
- A transformer requires alternating current to operate. Any direct current flowing through the primary will not contribute to the output.

- A transformer may have the AC output voltage greater than the AC input voltage, in which case it is referred to as a step-up transformer.

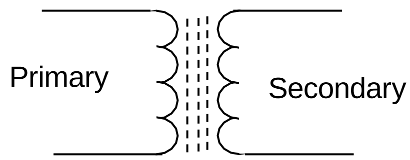
- Or the AC output voltage maybe smaller than the AC input voltage, in which case it is referred to as a step-down transformer.

- Or the AC output voltage maybe the same as the AC input voltage, in which case it is referred to as an isolation transformer.

- A transformer consist of two or more coils of wire (usually enamelled covered copper wire) wound on a magnetic core and is represented by the various circuit symbols such as:-



Power or Low Frequency Steel or Alloy core



High Frequency Iron powder or Ferrite core

- Trans separate secondary windings to produce various output voltages.

- The relationship for voltage step-up or voltage step-down is determined by the turns ratio between the primary coil and the secondary coil.

- The turns ratio is expressed as a ratio and is determined by the formula n = Np/Ns. The ratio maybe given as 10:1, eg. for every 10 turns on the primary winding there is 1 turn on the secondary winding (in relation to a step down transformer) or as 1:12, eg. for every 1 turn on the primary winding there are 12 turns on the secondary winding (in relation to a step up transformer).

- The turns ratio can be determined by the relationship between the primary and secondary voltages or the primary and secondary circuit currents, using the following formula :-
- Vp/Vs = Np/Ns or Is/Ip = Np/Ns

- The above formula maybe used to determine the missing value if the other three quantities are known.

- Different types of core material are used in different types of transformer applications including AIR, IRON POWDER and FERRITE for Radio Frequency applications and STEEL, Various steel alloys and Ferrite for Audio Frequency and

Power Transformers.

- To minimise energy losses during the conversion process, a transformer needs :

Low resistance windings (windings where high current exist)

Low loss core (low magnetic energy loss)

- Eddy Currents are the main cause of transformer magnetic loss and can be reduced by laminating the core into insulated thin plates or granulating the core into small particles and are glued together, this is called iron powder or ferrite.

- The impedance presented by the primary winding to the circuit it is connected to is determined by the formula :

$$Zp/Zs = Np^2/Ns^2$$

- Maximum power transfer will occur when the secondary load resistance equals the secondary impedance as calculated by this formula, for a given primary impedance value.

- When a load resistance is connected to the secondary winding, the Zp as determined by this formula is referred to as the reflected impedance.

- Transformers have many applications in electronics, some of which are :

- Voltage conversion, high or low current.
- Impedance matching.
- Electrical isolation.
- DC signal elimination
- Power transformers in appliances, welders, etc.
- Radio Frequency in radios, televisions, transmitters, etc.
- Audio systems in stereos, microphone connections, etc.

Self Evaluation Test

1. Explain the operation of an electrical transformer.

2. List the two most important features in the design of an efficient transformer.

3. Explain the answers to Question 2.

4. List four applications of transformers.

5. List four typical core materials for transformers.

Describe the term “eddy currents”.

____

____

6. Match the type of core material listed below with the means used to reduce eddy currents.

Material	***Method used to reduce eddy currents***
ϒ *Silicon steel*	(a) Eddy currents do not exist
ϒ *Alloy steel*	(b) Small insulated granules
ϒ *Ferrite*	(c) Laminated core
ϒ *Air*	

7. Write the formula to calculate the reflected impedance in the primary.

8. What is the efficiency of an ideal transformer?

____

9. The power drawn by a transformer.

   a. is constant for all loads
   b. is maximum for maximum load
   c. is greatest with no load
   d. depends on the turns ratio

10. A transformer can only be used in AC circuits because:

   a. transformer loads are all AC components
   b. the transformer must have a changing magnetic flux.
   c. DC voltages do not need to be increased or decreased.
   d. eddy currents would be excessive in a DC circuit.

11. The impedance that a transformer presents depends on the:

   a. turns ratio
   b. type of core
   c. load impedance and type of core
   d. turns ratio and load impedance

12. A transformer draws 8 amps from a 240 volt supply. It delivers 70 amps at 24 volts. Calculate -

(a) the input power,
(b) output power,
(c) the turns ratio.

13. A transformer's primary is connected to 240 volts. It delivers 1.2 amps at 8 volts to the load and there is no power wasted in the transformer. Calculate:

(a) the output power,
(b) input power,
(c) input current.

14. A transformer has a turns ratio of 25 to 1. Assume its efficiency is 100% and it delivers 30 amps to a load on the secondary.

(a) what current doe it draw from a 240 volt supply?
(b) what is the secondary voltage?

15. A transformer has a turns ratio of 1:1. It draws 350 watts from a 240 volt supply.

(a) what is the power in the load ?,
(b) what is the primary current ?,
(c) what is the secondary voltage ?

16. A transformer is supplied with 240 volts and delivers 10 volts at 0.5 amps. What current does the transformer draw from the supply?

17. A transformer has a load of 4 ohms, and a turns ratio of 15:1. What load does it present at its primary?

18. A transformer is needed to match 200 ohms to 50 ohms. What turns ratio is needed?

20. A transformer has a turns ratio of 3.46:1. If the reflected primary impedance is 600 ohms, what is the value of the load resistor on the secondary?

Answers to Self-Help Question

1. The alternating current in the primary winding induces an alternating magnetic field in the transformer's core. The alternating magnetic field in the transformer's core induces a current in the secondary winding.

2. Low resistance windings, so there is little loss due to heating, and low-loss core, so there is little power wasted in the core.

3. Increasing or decreasing alternating current or voltage, matching impedances, providing isolation, transferring an AC signal while eliminating a DC component and transferring an AC signal between moving and stationary parts.

4. Silicon steel, steel alloy, ferrite and air.

5. (a) Eddy currents are small currents in the core material.
   (b) Eddy current cause heating of the core, and power wastage.
   (d) Iron and alloy cores use laminations, ferrite cores have small granules that reduce eddy currents, and air does not suffer from eddy currents.

6. (a) Primary current = 2 A
   (c) Secondary voltage = 16V

7. (a) Secondary power = 600 W
   (b) Primary current = 2.5 A
   (d) Secondary voltage = 360 V

8. n = 24:1, I_P = 33.3mA, I_S = 800mA

9. 585 Ω

10. 1600 Ω

11. N_P / N_S = 1.73:1

12. 1.6 Ω

Answers to Self Evaluation Test

1. The alternating current in the primary winding induces an alternating Magnetic field in the transformer's core. The alternating magnetic field in the transformer's core induces a voltage in the secondary winding.

2. Low loss core, low resistance windings.

3. A low loss core reduces power losses in the core, low resistance windings will reduce the I^2R (Power) loss in the windings.

4. Increasing or decreasing alternating current or voltage, matching impedances, providing isolation, transferring an AC signal while eliminating a DC component, coupling an AC signal to a moving part.

5. Silicon steel, steel alloy, ferrite and air.

6. Small currents that flow in a transformer's core.

7. c. Silicon steel
   e. Alloy steel
   b. Ferrite
   a. Air

8. $$Z_P = \frac{N_P^2}{N_S^2} \times Z_S$$

9. 100 percent

10. b

11. b

12. d

13. (a) 1920 watts, (b) 1680 watts, (c) 10:1

14. (a) 9.6 watts (b) 9.6 watts (c) 40mA

15. (a) 1.2 amps (b) 9.6 volts

16. (a) 350 watts (b) 1.46 amps (c) 240 volts

17. Primary current = 20.8mA

18. 900 ohms

19. 2:1

20. 50 Ω

5. Full-Wave Rectifiers, Dual Rail Rectifiers

Full-wave Centre Tapped Rectifier

A full wave rectified voltage can be achieved with only 2 diodes if a suitable transformer is used. The transformer shown in figure 22 has two identical secondary windings which are connected with the phasing shown. The linking point forms a centre tapping and this is usually the common reference point of the circuit. All voltages are measured with respect to this point.

(a)

(b)

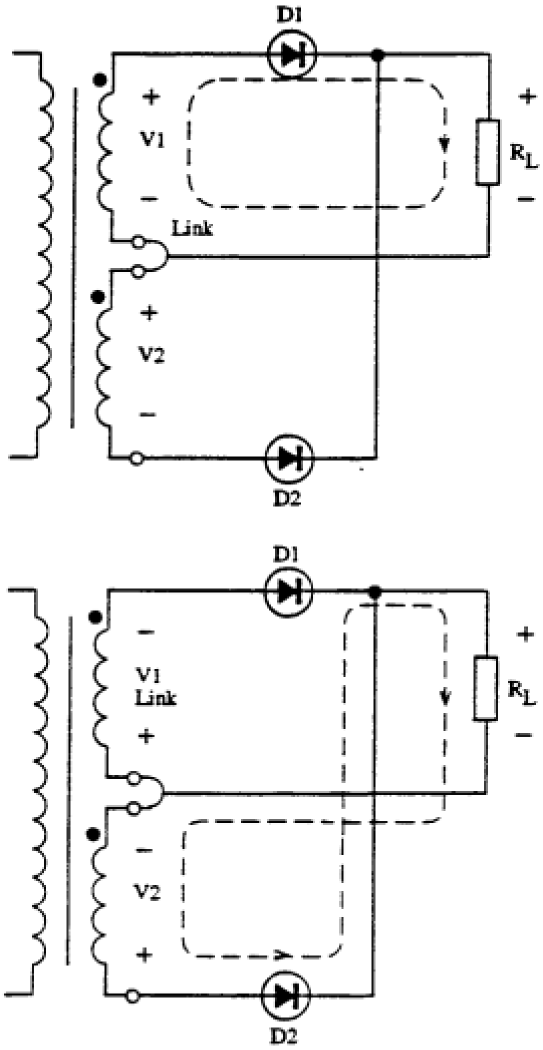


Figure 22. Full- wave centre tapped rectifier

The black dots on the diagram indicate the ends of the windings that are "in phase".

When V1 and V2 have the polarities as shown in Figure 22 (a), D1 conducts while D2 is reverse biased. When the input polarity reverses, so do V1 and V2 resulting in D2 conducting and D1 becoming reverse biased as shown in Figure 22 (b).

The load polarity is the same for both halves of the input cycle and so full-wave rectification takes place.
The currents and voltages to the load are calculated in a similar way to the half-wave and full-wave bridge circuits. The supply and load voltage waveforms are shown in Figure 23.

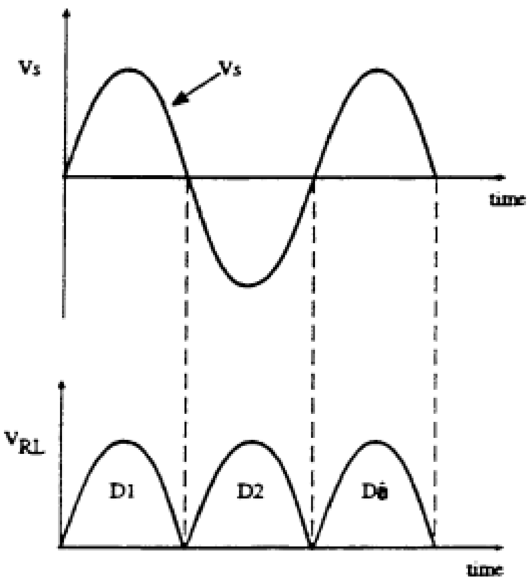


Figure 23. Full-wave tapped rectifier wave forms

Question 17.
In the full-wave centre tapped rectifier how many diodes conduct on each half cycle?

Question 18.
If the peak voltage of V1 and V2 in the circuit of figure 22 is 40V, what is the peak load voltage? (Vdiode = 0.6V)

Example
Refer to figure 24. Determine the peak and average load voltage and the peak and average load currents.

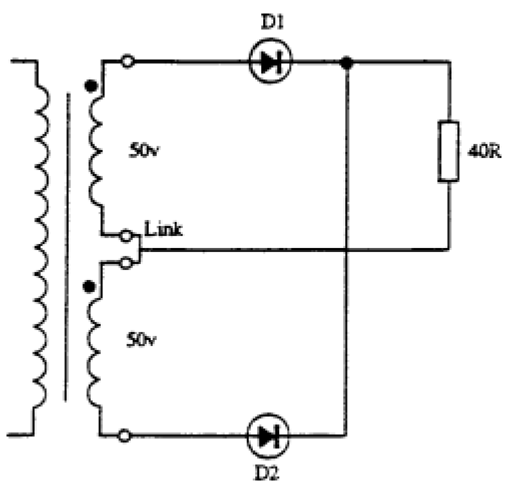


Figure 24. Loaded full-wave centre tapped rectifier

The peak secondary voltage: $V_p(sec) = 1.414 \times 50 = 70.70$ V

The peak load voltage, V_p (load) = 70.70 – 0.6 (one diode drop) = 70.10V

Notice that only half of the total secondary is used to determine the load voltage. This is because only half the secondary conducts at any one time.

The peak current
$$I_p = V_p / R_L = 70.10 / 40 = 1.75A$$

$$V_{av}(load) = 0.637 \times V_p(load) = 0.637 \times 70.10 = 44.65V$$

$$Iav = V_{av} / R_L = 44.65 / 40 = 1.12A$$

Question 19.
When diode D1 is conducting in Figure 24

(a) What is the peak voltage on the cathode of D2?
(Hint: calculate the peak voltage with respect to the centre tap of the secondary winding)

(b) What is the peak voltage on the anode of D2?

(c) What is the voltage between anode and cathode of D2?

Note The peak inverse voltage for the diodes in a full-wave centre tapped rectifier is equal to the peak of the full secondary voltage. (50 + 50) x 1.414 in this example

Centre Tapped Full-wave

Transformer Secondary Connections

A transformer that has two separate secondary windings can be used to produce a full-wave rectifier by connecting the windings as discussed in the previous section. Such a transformer can also be used in conjunction with a full-wave bridge rectifier.

Series Connection

When the windings are connected in series, the peak voltage applied to the bridge rectifier is twice the peak voltage of the individual windings. This is because voltage sources in series add together to produce a total secondary voltage equal to twice the individual voltages. This is shown in figure 25.

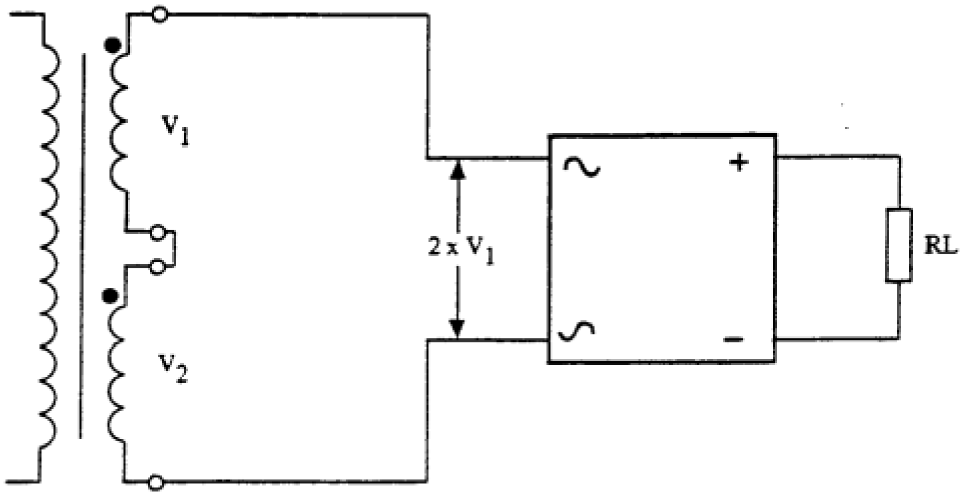


Figure 25.

Parallel Connection

When the windings are connected in parallel with the polarity shown in figure 26 the peak voltage into the rectifier is equal to the peak voltage of the individual windings. However the current capacity is doubled provided the polarity is correct.

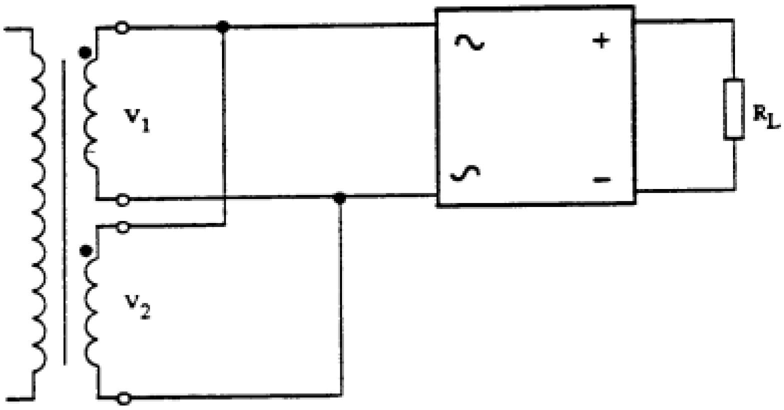


Figure 26.

Question 20.
State the two different ways of connecting the two secondary windings.

Question 21.
For the circuit of fig 25. calculate the peak load voltage if the secondary voltage V1 = V2 = 20 V and the individual diode drop = 1.0V

Question 22.
If the individual secondary windings are capable of delivering 1.5 A, what is the current capability if the windings are connected in parallel?

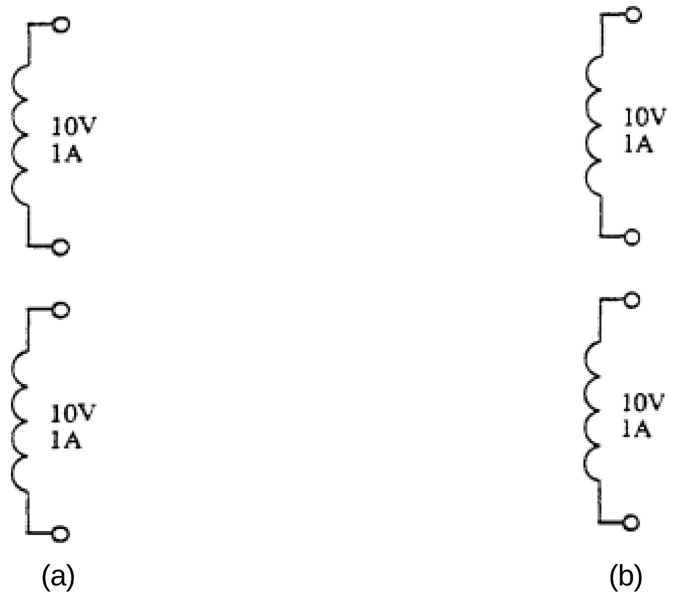


Figure 27.

Question 23.
Refer to the diagram in Figure 27 and answer the following questions:
The transformer secondary windings shown in Figure 27 each have an RMS voltage of 10V. Each winding also has a maximum current rating of 1 amp.

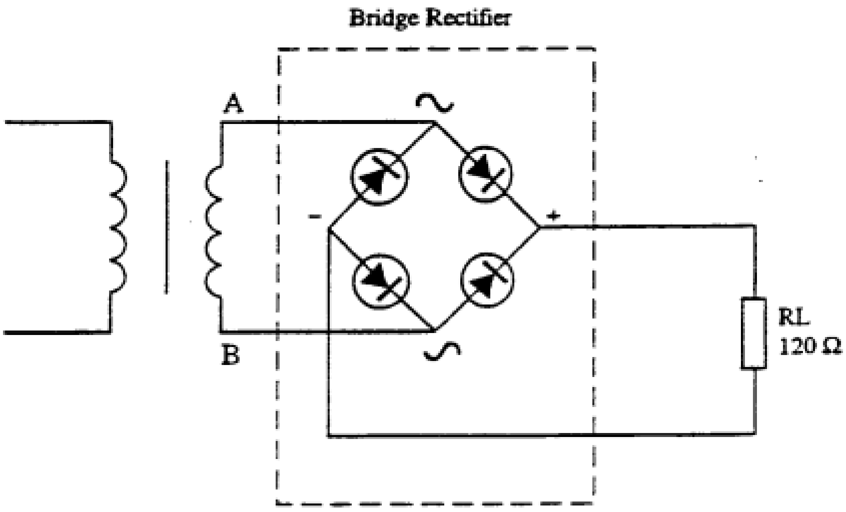
(a) Draw on the diagram of Figure 27(a) the wire connections to produce 10V at 2A

(b) Draw on the diagram of Figure 27(b) the wire connections to produce 20V.

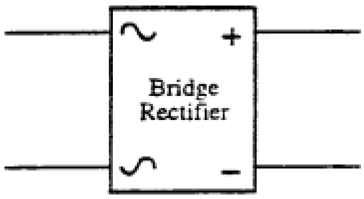
(c) What is the current rating for the connection to produce 20V?

The Bridge Full Wave Rectifier

An AC source can be rectified so that both halves of the input waveform are put to use. Such a rectifier is called a full-wave rectifier. The circuit in figure 14a achieves this by having 4 diodes arranged in a diamond or "bridge" configuration.



(a)



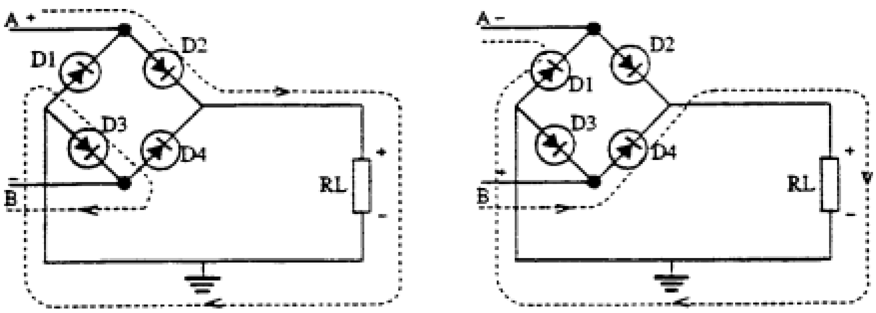
(b)

Figure 14.

The 4 diodes can be "discrete" components (on their own) or "encapsulated" into a single package. Encapsulation makes wiring assembly simpler.

Figure 14b shows the symbol of a bridge rectifier package.

Let's examine the current paths through the circuit on the positive and negative halves of the input cycle.



(a) (b)

Figure 15. Full-wave rectifier

When the terminals A-B have the polarity shown in Figure 15(a), current flows as indicated and the load voltage has positive polarity.

Figure 16(a) shows that diodes D2 and D3 conduct on the positive half cycle.

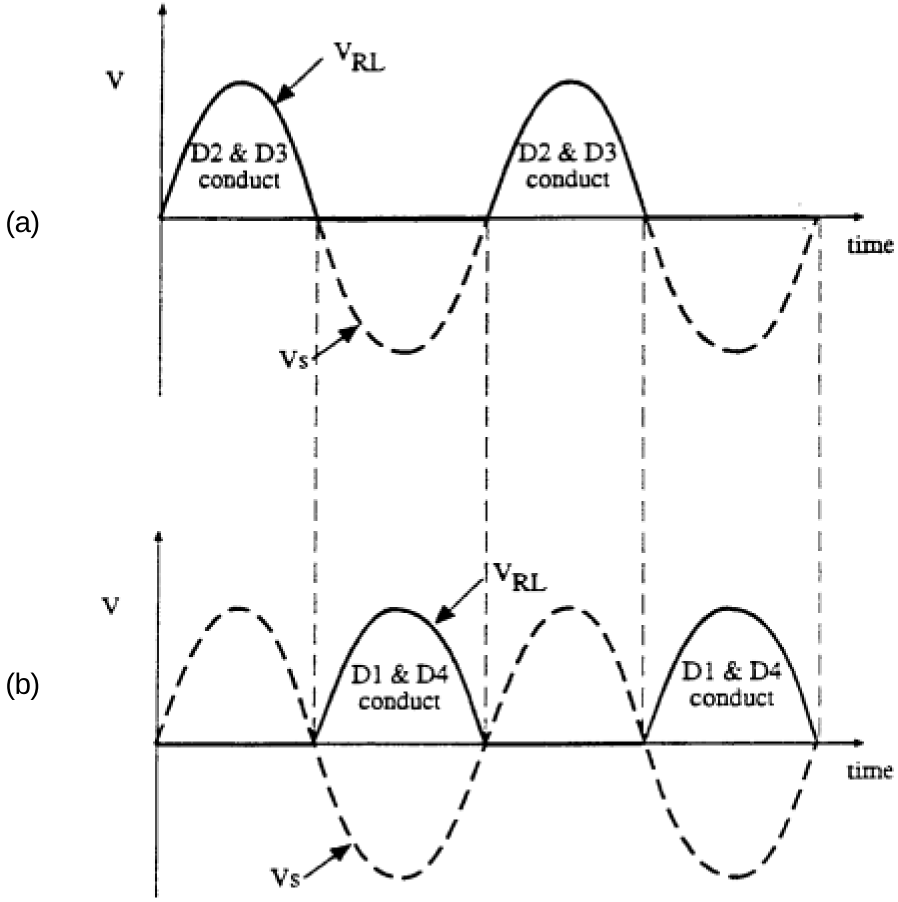


Figure 16. Full-wave rectifier

When the terminals A-B have the polarity shown in Figure 15(b), current flows as indicated. The load voltage has positive polarity once again, even though the input voltage at A-B has been reversed. Figure 16(b) shows diodes Dl and D4 conduct on the negative half cycle.

A positive polarity pulse is delivered to the load on both positive and negative half cycles of the input wave; thus the term "full-wave" rectification. The resulting output waveform is shown in Figure 17.

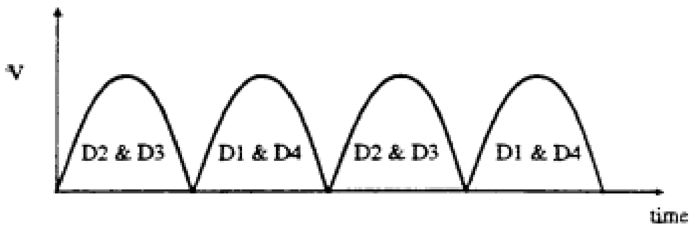


Figure 17. Full-wave rectifier output voltage waveform

Compared with a half-wave rectifier, current flows to the load for the full input cycle, not just half of it And so the average voltage and current delivered to the load with a full-wave rectifier is twice that of a half-wave rectifier.

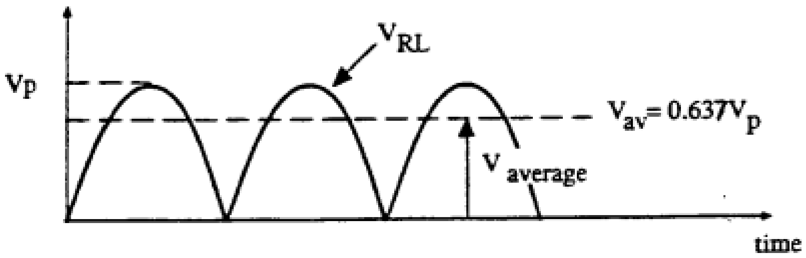


Figure 18. Average of full-wave rectifier waveform

V_{av} $=2\pi \times V_p$
$=0.637 \times V_p$

and I_{av} $= V_{av} / R_L$

Question 13.
Refer to the circuits of Figure 15.
(a) Trace the current path using a red pen.
(b) How many diodes does the current pass through on each half cycle?

Question 14.
If each diode drop is 0.6 V, how does the peak load voltage compare to the peak input voltage?

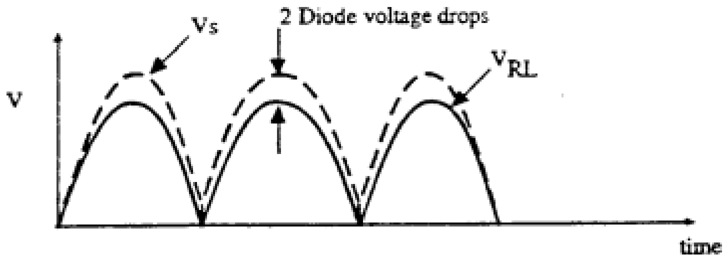


Figure 19. Effect of diode voltage drop

In a full-wave bridge rectifier the peak load voltage is 2 diode drops less than the peak input voltage.

To find the load voltages and currents, similar calculations are required to those that we used for the half-wave rectifier.

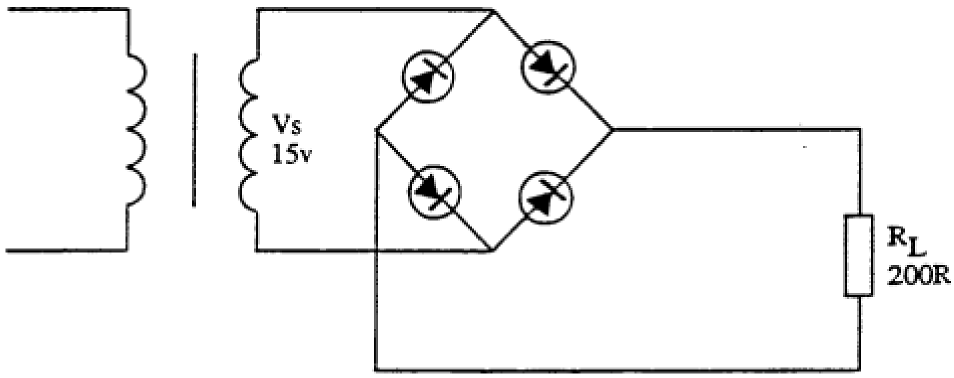


Figure 20. Load connected to a full-wave rectifier

Example:
Determine the peak and average load voltages and currents. Assume a diode drop of 0.7 V for each diode.

The peak secondary voltage: V_p (sec.) = 1.414 x V_S = 1.414 x 15 = 21.21 V

The peak load voltage: V_p (load) = 21.21 – (2 x 0.7) = 21.21 – 1.4 = 19.81 V

The average load voltage: V_{av} (load) = 0.637 x V_p(load) = 0.637 x 19.81 = 12.62V

The peak and average currents can now be determined by using Ohm's law:

$I_p = V_p / R_L$
= 19.81/200
=99.1mA

$I_{av} = V_{av} / R_L$
= 12.64 / 200
= 63.2mA

Question 15.
For the circuit of figure 21 determine the peak voltage across the load, average load voltage and average load current Assume 0.7 V for each forward biased diode.

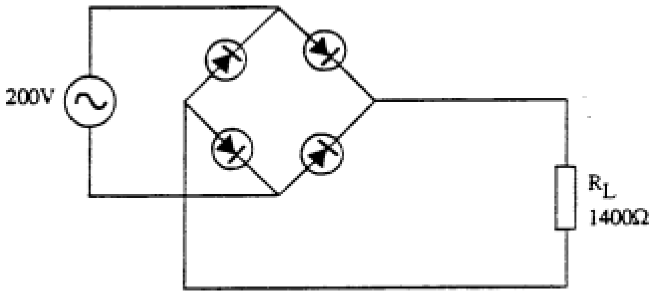


Figure 21. Load connected to full-wave rectifier

In Figure 15(a) when diodes D2 and D3 are conducting, diodes D1 and D4 are reverse biased. The peak inverse voltage across either D1 or D4 is equal to the peak of the input voltage. The peak reverse voltage on each diode is actually equal to the input peak voltage minus one diode drop. However for the purpose of determining a suitable diode from a data sheet a V_{rrm} much greater than V_p should be selected. The diode voltage drop can then be ignored.

Question 16.
For the circuit of Figure 21 determine a suitable diode from the diode data at the back of this book.

Summary

The process of converting AC into DC is called rectification. Three common diode rectifier circuits are the

- half-wave rectifier
- full-wave bridge rectifier
- full-wave centre tapped rectifier

The peak secondary voltage is given by $V_p = 1.414 \times V_{rms}$

The peak load voltage is less than the peak secondary voltage. It is reduced by the number of diode volt drops in the conduction path.

The average load voltage is given by $V_{av} = 0.318 \times V_{pk}$ for a half wave rectifier and $0.637 \times V_{pk}$ for a full-wave rectifier. Where V_{pk} in both cases is the peak load voltage.

The average load current $I_{av} = V_{av} / R_L$ and the peak load current $I_{pk} = V_{pk} / R_L$

The average diode current is equal to the average load current in half-wave rectifiers only. The average diode current is equal to half the average load current in full-wave rectifiers.

The peak reverse voltage experienced by a diode is equal to the peak secondary voltage for a half-wave rectifier and full-wave bridge rectifier.

The peak reverse voltage experienced by a diode is equal to the peak secondary voltage for a half-wave rectifier and full-wave bridge rectifier. The peak reverse voltage experienced by a diode in a full-wave centre tapped rectifier is equal to the peak of the full secondary voltage. (double the secondary voltage x 1.414).

Self Evaluation Test

2. Refer to Figure 34.

   a) Determine the average load voltage and the peal load current.
   b) Sketch the load voltage and diode current waveforms

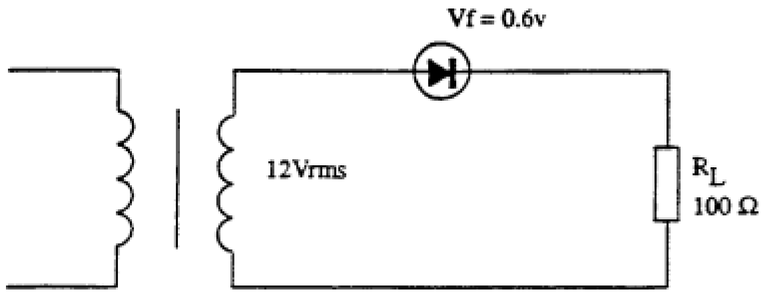


Figure 34.

3. Refer to Figure 35

   a) Determine the average load voltage and the peak current through each diode.
   b) State the PIV for the diodes.

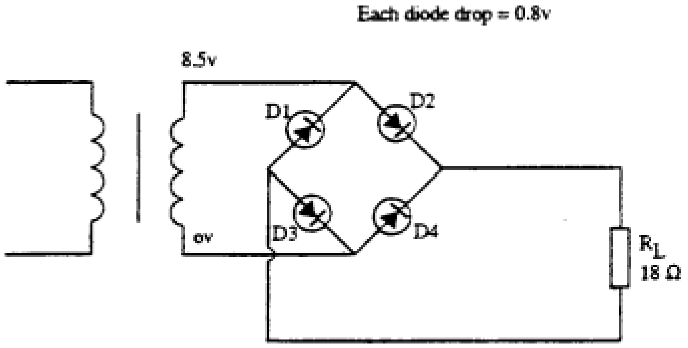


Figure 35.

4. Refer to Figure 36.

   (a) Determine the average load voltage.
   (b) Determine the peak load current.
   (c) Find the average load current.
   (d) Sketch the diode current waveform.
   (e) Determine the average current through each diode.
   (f) State the PN for the diodes.

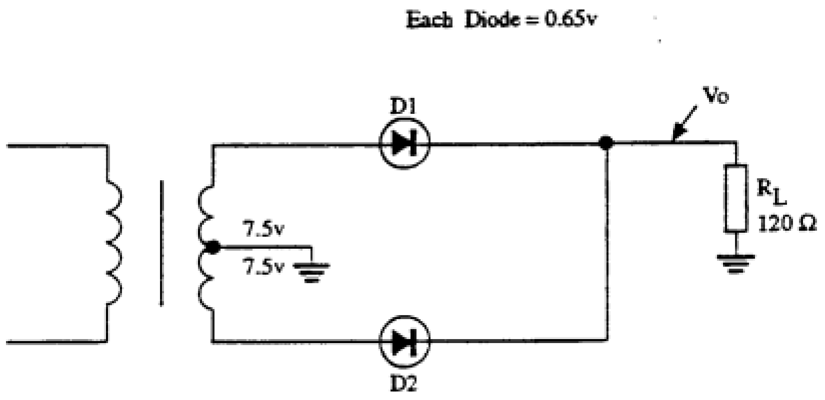


Figure 36.

5. Refer to Figure 37.

   Show how the transformer secondary wires are to be connected to give maximum V_o.

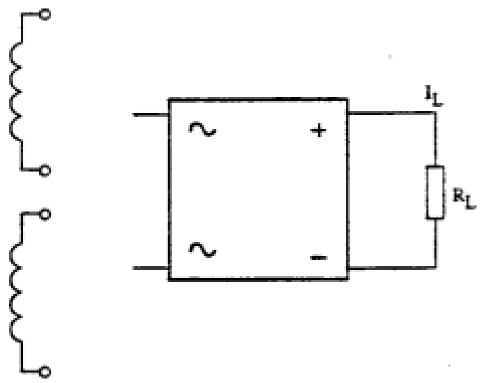


Figure 37.

6. Show how the transformer secondary wires in Figure 38 are to be connected to provide maximum load current

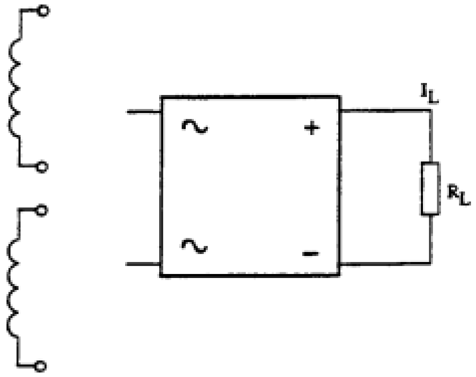


Figure 38.

7. Sketch a full-wave centre tapped rectifier and transformer showing how a negative supply can be produced.

Answers to Questions

1. 35.4V
2. Forward biased
3. Reverse biased
4. Negative $\frac{1}{2}$ cycle (see Figure 5(b)).
5. These are pulsating DC waveforms
6. 0.6V
7. 9 – 0.6 = 8.4V
8. 5.18V
9. (a) point A is negative (b) 3.61 V
10. Ip = 32.85A I_{av} = 10.46A
11. See Figure 3(c).
12. A diode with a PIN higher than 212V and 560mA avg.
    (a) 1N4004 would be OK
13. 2 diodes conduct on each half cycle.
14. The peak load voltage is 1.2V less than the peak input voltage
15. V_P(load) = 281.4V V_{av} = 180V I_{av} = 128mA
16. A diode with a PIV greater than 283V and an average current of more than 129mA. A 1N4004 will be OK.
17. One diode conducts on each half cycle
18. 39.4V
19. (a) 70V approx. (b) –70V (c) 140V approx
20. Series or parallel
21. 40 x 1.414 – 2 = 54.6V
22. 3A
23. Refer to Figures 25 and 26 for (a) and (b). (c) 1A

Answers to Self Evaluation Test

1. $V_{av} = 5.21V$ $I_p = 164mA$
   The voltage and current waveforms are similar to Figure 3.

2. (a) $V_{av} = 6.64V$ $I_p = 579mA$

   (b) PIV = 12V

3. (a) 6.34V
   (b) 83.0mA
   (c) 52.8mA
   (d) (same as figure 17)
   (e) 26.4mA
   (f) 21.2V

4. See figure 25

5. See figure 26

6. See figure 24 but with both diodes reversed

Question 9.
A full-wave bridge rectifier has a filter capacitor of 4700μF and delivers 1.2A to the load. If the AC input to the rectifier has a frequency of 50Hz, calculate the peak-to-peak ripple voltage.

Question 10.
If the full-wave bridge rectifier in the previous question is replaced with a half-wave rectifier:

a) What will be the frequency of the ripple voltage?

b) What effect will this have on the ripple voltage?

2. For the circuit in Figure 13:

a) Calculate the expected peak load voltage (allow 0.6V for each forward biased diode).

b) Calculate the ripple voltage for the circuit of Figure 13.

c) Recalculate the ripple voltage if a 2k2 resistor is connected across the 1k load.

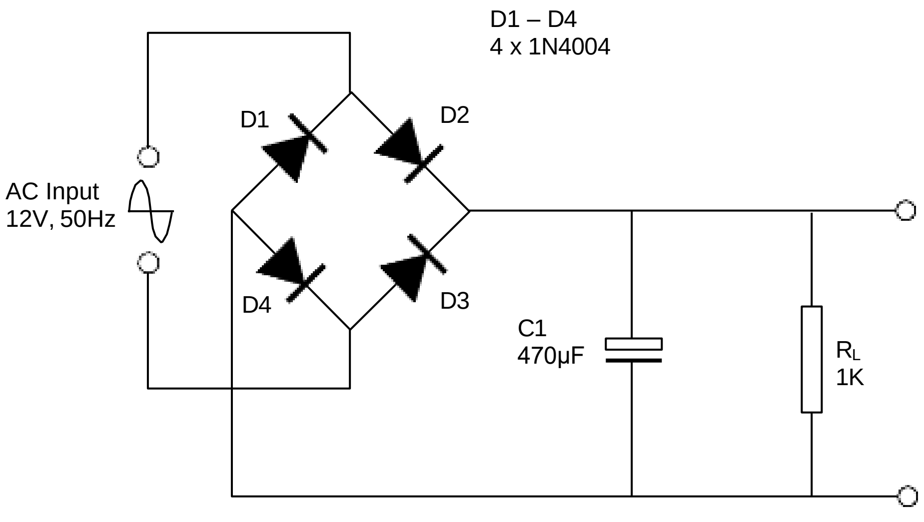


Figure 13.

3. For the circuit in Figure 14:

a) Calculate the expected peak load voltage (allow 0.6V for each forward biased diode).

b) Calculate the ripple voltage for the circuit of Figure 14.

c) Recalculate the ripple voltage if a 2k2 resistor is connected across the load.

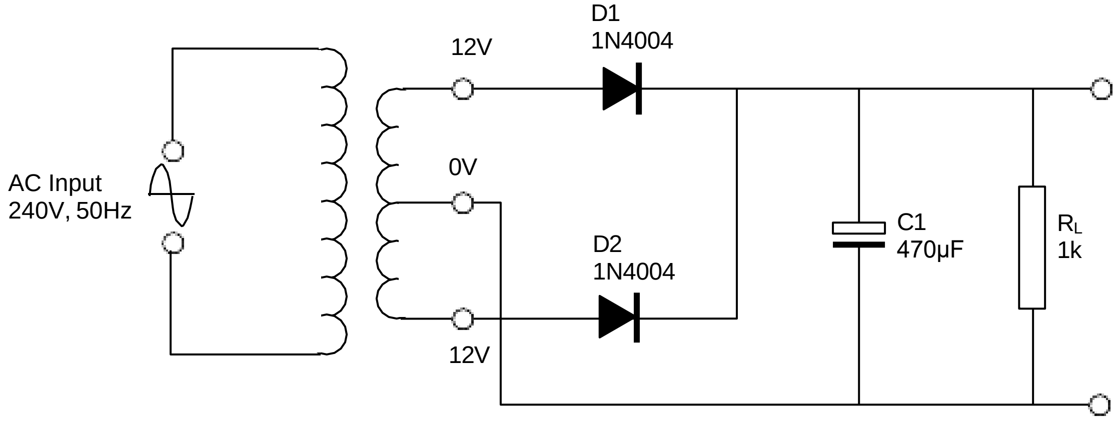


Figure 14.

4. Have your instructor check your work.

Checked:

Self Evaluation Test

1.

(a) The current through R_L in Figure 24 is 450mA. Calculate the peak-to-peak ripple voltage.

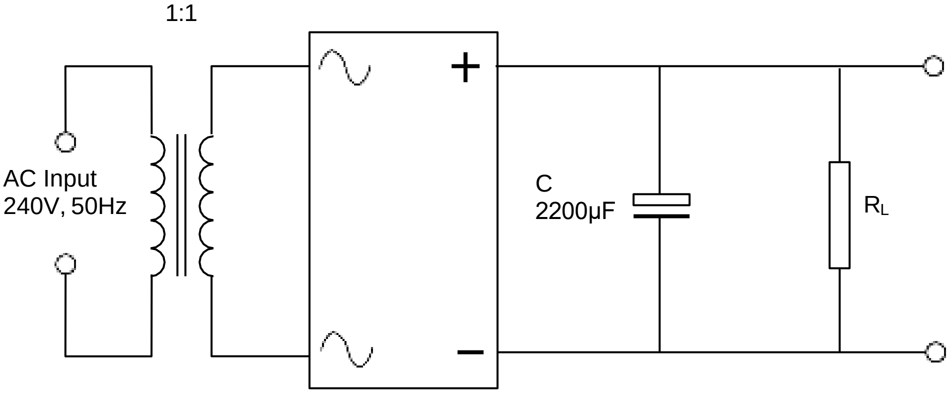


Figure 24.

(b) State the effect on the ripple voltage if the load increases to 900mA.

(c) If the ripple voltage across the load increases, what effect will this have on the average load voltage?

2.

(a) If the load current in Figure 25 is 2A, calculate a suitable value capacitor for this power supply so that the ripple voltage is less than 3.2V.

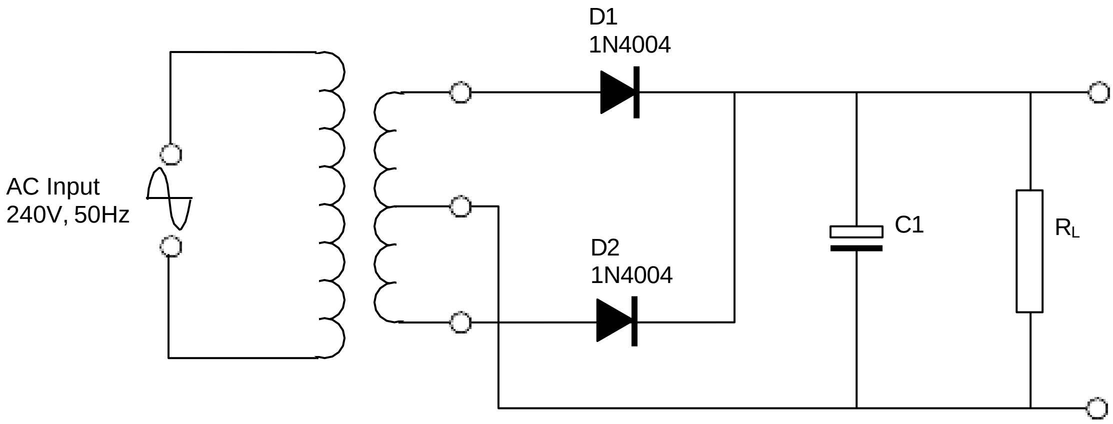


Figure 25.

(b) If a capacitor of twice the value you calculated is used in the power supply of Figure 25, state the expected value of ripple voltage.

---

3. If one of the diodes in Figure 25 becomes an open circuit:

(a) There will be no ripple.
(b) Ripple will be unchanged.
(c) Ripple voltage will double.
(d) Ripple frequency will double.

Answers to Questions

1. Charge

2. Falling

3. Reverse biased

4. Usually 50Hz. In the USA and some other countries it is 60Hz

5. The ripple voltage would be zero. The capacitor would charge to the peak load voltage and remain at that voltage because it will not be discharged (the load being an open circuit).

6. Load current will increase

7. Ripple voltage will increase

8. Full-wave: **100Hz**
   Half-wave: **50Hz**

9. Ripple frequency = 100Hz and V_r = 2.55V

10.
    (a) Ripple frequency will halve that is, will be 50Hz
    (b) Ripple voltage will double

11. The average voltage will fall

Answers to Self Evaluation Test

1.
   (a) $V_r = 2.05V$
   (b) V_r will increase to 4.1V
   (c) It will decrease

2.
   (a) C = 6300μF
   (b) It will halve. Vr = 1.6V

3. (c) ripple voltage will double if one of the diodes becomes an open circuit.

6. Zener Diodes

In this unit you will learn about Zener diodes and their characteristics. This will help you understand how Zener diodes can be used in regulating supply voltage.

To pass this unit you must be able to:

- State and recognise the forward and reverse bias characteristics of a zener diode.
- State and recognise that Zener voltage is dependent on temperature and this effect varies with the devices nominal Zener voltage.

Zener Diode Characteristic Curve

A Zener diode is a silicon diode that has a special property that makes it useful in DC power supplies.

In rectifier circuits, the low forward resistance and extremely high reverse resistance of a diode is used to convert AC into DC.

A Zener diode behaves like an ordinary diode when forward biased, but has a special characteristic when reverse biased.

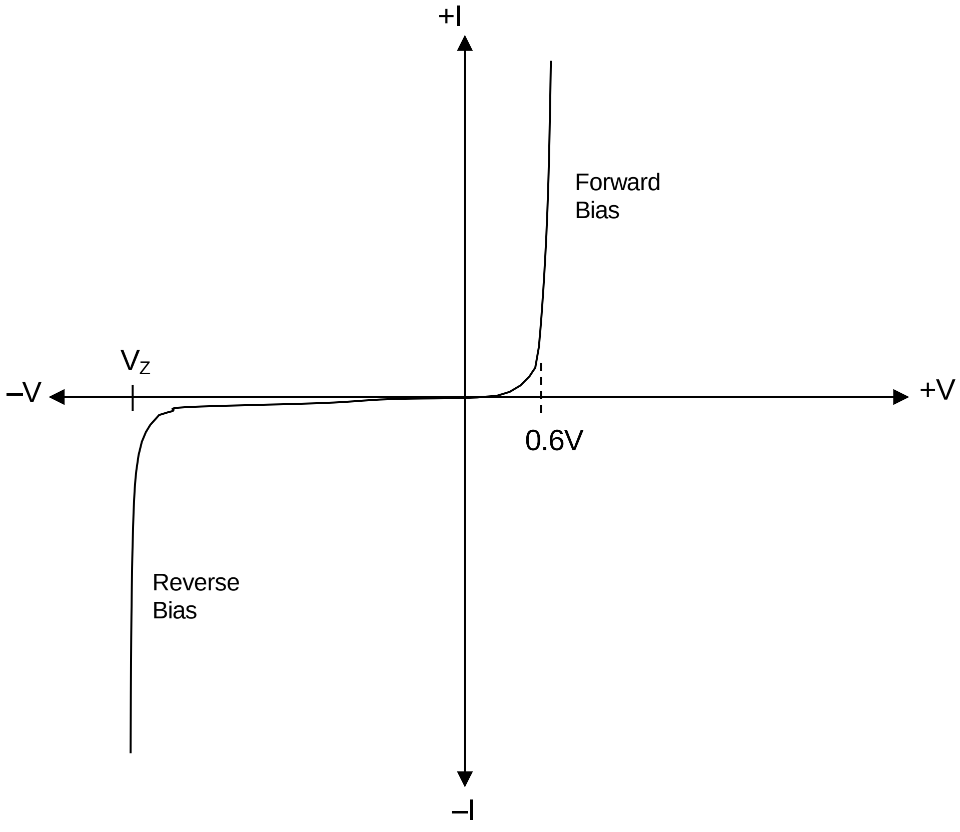


Figure 1. Zener diode characteristic curve

The voltage (V_Z) is a reverse voltage and it is commonly in the range from approximately 3V to 30V depending on the particular device.

When a reverse voltage equal to the Zener voltage is applied, the device will conduct. The steep part of the Zener characteristic curve indicates that the voltage across the Zener is almost constant over a wide range of reverse currents.

For Zener diodes below about 5V, the reverse conduction mechanism is due to electrons being torn from their outer shells to participate in conduction. This is called the “Zener effect”. High impurity doping is used to achieve this action. The Zener effect occurs suddenly and at a particular voltage called the “Zener voltage”.

For Zener diodes above 5V, the reverse current is produced by the reverse minority carriers being accelerated. They collide with atoms and dislodge other electrons as they are accelerated by the applied reverse voltage. This is an “avalanche” effect (such diodes are also referred to as Avalanche diodes).
For our purposes, the nature of the mechanism is not very important. The characteristics and circuit behaviour of the Zener diode is what we will concentrate on.

The circuit symbol for a Zener diode is similar to the standard diode symbol except the cathode bar is drawn differently (the right-angle represents the “knee” of the Zener curve).

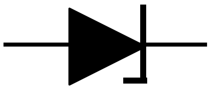


Figure 2. Zener diode symbol

A Zener diode type number 1N755 has a Zener voltage, V_Z, of 7.5v. The Zener diode is usually used with reverse bias applied.

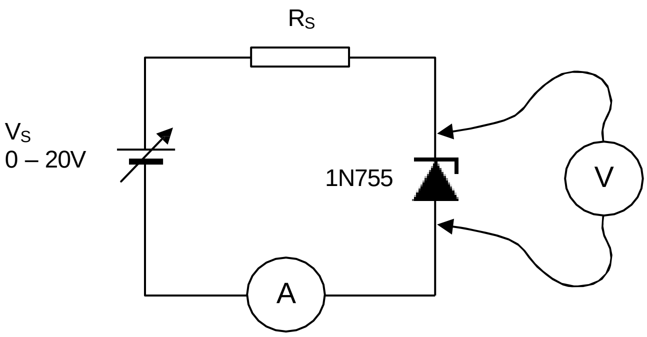


Figure 3. Basic Zener diode circuit

Question 1.
Is the diode in Figure 3 forward or reverse biased?

Question 2.
When V_S in Figure 3 is below 7.5V:

(a) The ammeter reading will be ____________________ .

(b) The voltmeter reading will be ____________________ .

Question 3.
When V_S in Figure 3 is greater than 7.5V, the voltmeter reading will be:

Question 4.
Knowing that the Zener diode conducts at 7.5V, what is the purpose of the resistor R_S?

As the supply voltage is increased beyond 7.5V the circuit current is limited by the series resistor to a safe value for the diode. The voltage difference between V_S and V_Z is taken up across the series resistor R_S.

Temperature Coefficient

Semiconductor device parameters are slightly temperature dependent. This is because thermally generated hole-electron pairs affect both forward and reverse bias junction conductivities.

The Zener voltage for a particular Zener diode will change with changes in device temperature. The device temperature may change due to changes in the surrounding or “ambient” temperature. The device temperature may also change because it is getting hot due to its own power dissipation.

Zener diodes above 5V have positive temperature coefficients. This means that as temperature goes up, the Zener voltage will increase slightly.

Question 5.
A negative temperature coefficient means that as temperature goes up, the Zener voltage will:

Zener diodes with voltages below about 5V have negative temperature coefficients. In other words, as temperature goes up, the Zener voltage goes down slightly.

Zener diodes of about 5V have very mall temperature coefficients. This tells us the Zener voltage stays almost constant even though the device temperature may change.

Question 6.
An item of equipment is subject to large temperature changes. When choosing a Zener diode for this application, what would be the most appropriate Zener voltage to use?

Summary

The characteristics of a Zener diode are the same as a rectifier diode in the forward bias direction.

When reverse biased, the Zener diode has a precise conduction voltage that remains constant as current changes.

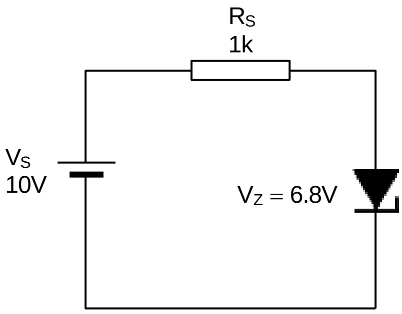
Zener diodes above 5V have a positive temperature coefficient.

Zener diodes below 5V have a negative temperature coefficient.

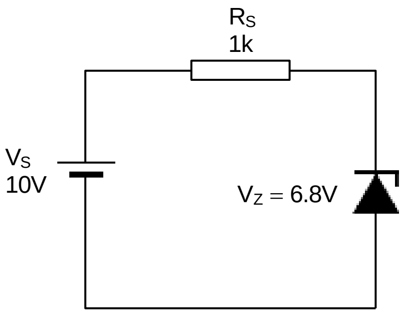
Zener diodes about 5V have a temperature coefficient of approximately zero.

Self Evaluation Test

1. State the approximate voltage across the Zener diode in each circuit.



(a)



(b)

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2. For the following Zener voltages, state whether the Zener voltage is likely to rise, fall, or remain constant as temperature increases.

(a) A 3.3 volt Zener ________________

(b) A 5.1 volt Zener ________________

(c) A 24 volt Zener ________________

Answers to Questions

1. Reverse biased

2. (a) the ammeter reading will be ZERO.
   (b) the voltmeter reading will be equal to V_S.

3. 7.5V

4. To limit the current through the Zener diode.

5. Go down.

6. 5V to 6V

Answers to Self Evaluation Test

1. (a) 0.6V due to forward bias.

2. (a) V_Z will decrease
   (b) V_Z will stay about the same
   (c) V_Z will rise

Diode Parameters

In this unit you will learn about diode data sheet information. This will enable you to select an appropriate replacement diode from manufacturer's data.
To pass this unit you must be able to:

- List the essential parameter values from data sheets.

Rectifier Diode Parameters

When selecting a diode for an application, the main requirements are that the forward current and reverse voltage capabilities of the diode are not exceeded.
Manufacturers publish data books that provide users with information regarding the safe current and voltage limits of the devices they manufacture.
When a diode is used as a rectifier, the peak voltages and currents are repeated each cycle and so the term "repetitive" is used to describe some diode parameters.

Question 1.
For the circuit of Figure 1, calculate:

(a) The average load current (allow 0.6V for the diode).

(b) The reverse voltage maximum (PIV).

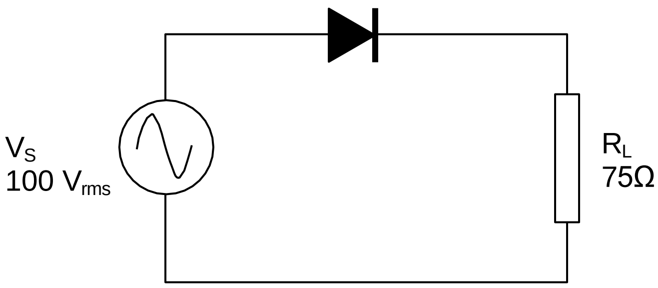


Figure 1. Half-wave rectifier

To select a diode for the circuit of Figure 1 we must find one whose parameters exceed both the average current and reverse voltage present in this circuit.

Diode Parameter Definitions

$I_{F(av)}$ is the maximum average current in the forward direction. Also called I_O on Motorola data sheets.

V_{RRM} is the Voltage Repetitive Reverse Maximum.

If these maximum ratings are exceeded, the device may be destroyed!

$V_{F(av)}$ is the average forward voltage drop across the diode.

Question 2.
Refer to the data sheet at the end of this book for the 1N400X series of diodes. For a 1N4001 diode, determine the following:

(a) V_{RRM}

(b) I_O

(c) $V_{F(av)}$

Question 3.
Refer to the circuit of Figure 1. Find a suitable for this application from the 1N400X series of diodes.

Did you notice that the 1N400X "family" of diodes are all have a Forward Average Current rating of 1A, but that they all have different Reverse Voltage ratings?

In the circuit of Figure 1, a 1N4004, 1N4005, 1N4006 or 1N4007 diode could also have been used.

Question 4.
Refer again to the data on the 1N400X series of diodes. Sketch the diode package and show how the anode and cathode are identified.

Question 5.
Refer to the data on the MDA3500 series of bridge rectifiers. Determine the part number of a rectifier suitable for an application that has an average forward current of 25A and a PIV of 150V.

Zener Diode Parameters

The Zener diode is most commonly employed for its reverse voltage characteristic. This is shown in Figure 2 and the reverse region is shown in more detail in Figure 3.

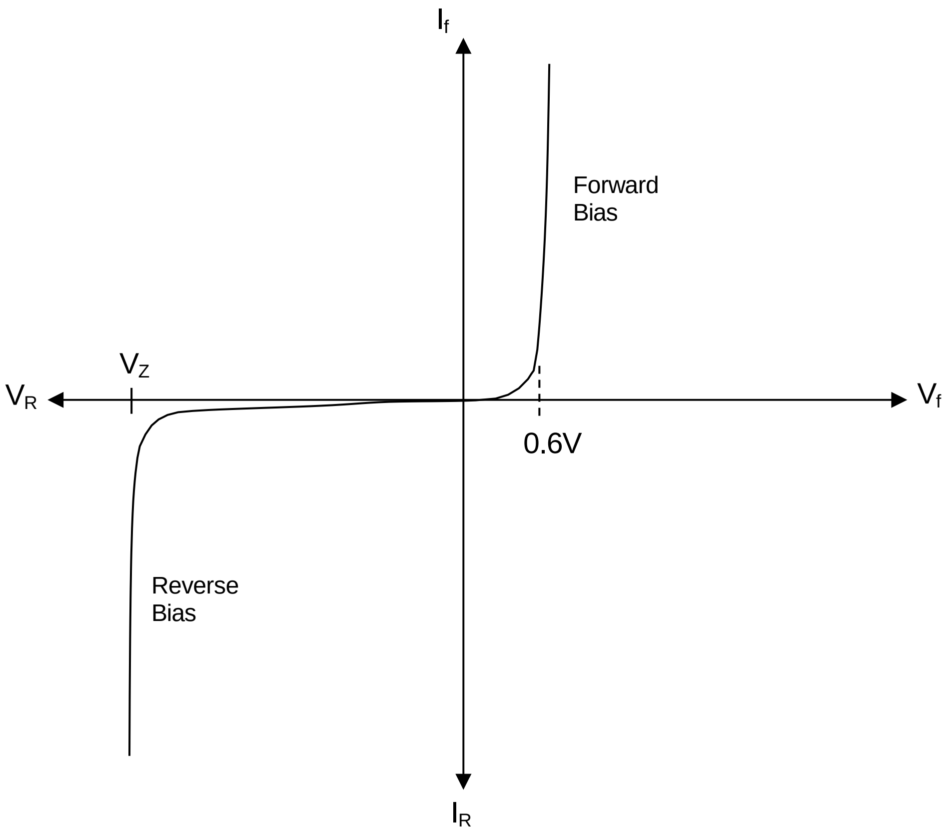


Figure 2. Zener diode characteristic curve

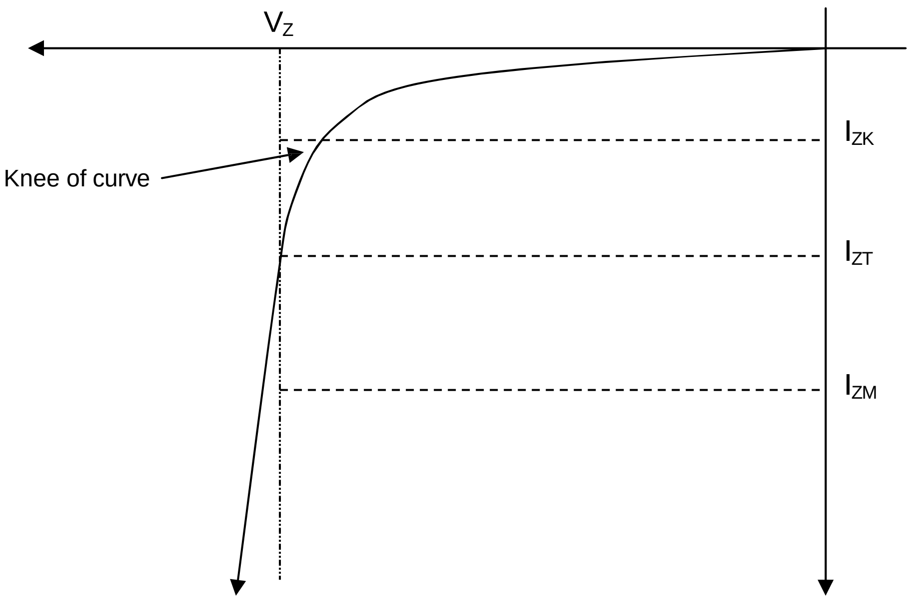


Figure 3. Zener diode reverse characteristic

Zener Diode Parameter Definitions

The Zener voltage varies slightly with the amount of current flowing through the device and with device temperature. The nominal Zener voltage (V_Z) is specified at a test current called I_{ZT}.

I_{ZK} is the current at the knee of the curve.

I_{ZM} is the maximum current rating of the Zener before the allowable power dissipation is exceeded. If I_{ZM} is not given on the data sheets, it can be determined by simply dividing the power rating by the nominal Zener voltage ($I = P_D / V_Z$).

P_D is the maximum package dissipation allowed. If exceeded, the semiconductor junction temperature may rise to the point of device destruction.

Question 6.
Refer to the data sheet on the 1N47XX series of Zener diodes.

(a) What is the nominal voltage of a 1N4737 Zener diode?

(b) At what current does a 1N4740 Zener diode have a voltage of 10V?

(c) If a 1N4740 diode is operated at a current of 50mA, the Zener voltage will slightly greater/less than the nominal 10V (cross out the incorrect word).

(d) What is the maximum power dissipation of this series of Zener diodes?

(e) Calculate the maximum current for a 1N4742 Zener diode.

Summary

Manufacturers of semiconductor devices publish data books. We must refer to these when selecting a device for a particular application.

The parameter ratings of the selected device must be higher than those found in the circuit application.

For rectifier diodes, the most important parameters are the current handling ability and the maximum allowable reverse voltage.

For Zener diodes, the most important parameters are the Zener voltage and power rating.

Self Evaluation Test

1. Refer to the data on the 1N5400 through 1N5406 series of rectifier diodes. Determine the part number of a diode suitable for an application that has an average current of 2A and a PIV of 85V.

2. Refer again to the data on the 1N5400 through 1N5406 series of rectifier diodes. State the maximum average current and V_{RRM} for a 1N5404 diode.

3. Refer to the data sheet for a 1N4745 Zener diode to determine the following:

(a) Power rating

(b) Package style (sketch your answer and identify the cathode identification marking).

(c) The knee current.

(d) Nominal Zener voltage and the test current for determining this voltage.

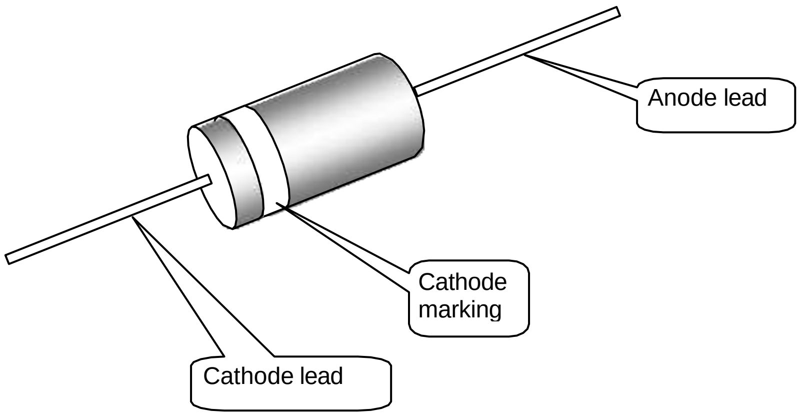
Answers to Questions

1. (a) $I_{av} = 597mA$
   (b) PIV = 141V

2. (a) $V_{RRM} = 50V$
   (b) $I_O = 1.0A$
   (c) $V_{f(av)} = 0.8V$ max.

3. 1N4003

4.



5. MDA3502

6. (a) 7.5V
   (b) 25mA
   (c) Greater than the nominal voltage. Refer to the characteristic curve of Figure 3 to see why.
   (d) 1.0W
   (e) 83.3mA

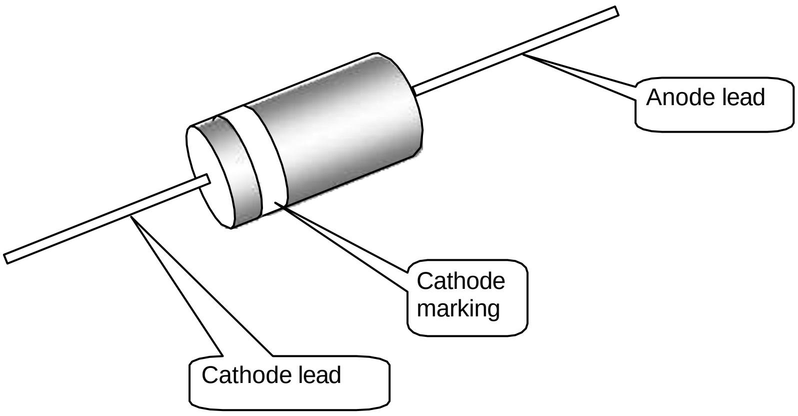
Answers to Self Evaluation Test

1. 1N5401

2. 3A and 400V

3. (a) 1W

   (b)



   (c) 0.25mA

   (d) V_Z nominal = 16V at a test current of 15.5mA

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The Zener Diode Regulator

In this unit you will learn about zener regulator circuits.
This will enable you to determine if a zener regulator circuit is operating correctly.

To pass this unit you must be able to:

- Calculate voltage, current and power dissipation in the components of a shunt zener regulator
- Measure currents and voltages to determine if the circuit is operating correctly

Introduction

Zener diodes maintain a constant voltage when reverse biased. This property can be put to use in making a simple voltage regulator circuit as shown below in Figure 1. The function of a regulator is to regulate or maintain some quantity at a constant level. In the case of a voltage regulator, this is a circuit that will maintain a constant output voltage under varying load current conditions.

Question 1.
Write the names of the components in the unregulated section of the power supply circuit shown in Figure 1.

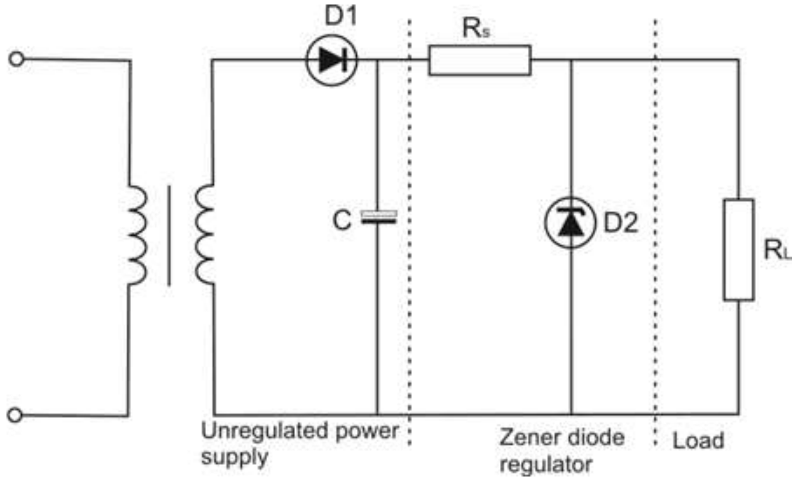


Figure 1. An electronic power supply

While the unregulated input voltage has variations due to fluctuations in the mains voltage and ripple, the voltage across the load in Figure 1 will be substantially constant. The load voltage is equal to the zener diode voltage. This voltage is not totally constant because the zener voltage varies a small amount as the zener diode current varies. However the fluctuation in zener diode voltage is very much smaller than the variations in the voltage of the unregulated diode-capacitor power supply.

Zener Regulator Calculations

To find out the zener diode regulator circuit is functioning properly it is necessary to calculate the expected circuit voltages and currents.
Calculation: Find V_{RS}, V_{RL}, I_{RS}, I_{RL}, and I_Z in the circuit of Figure 2.

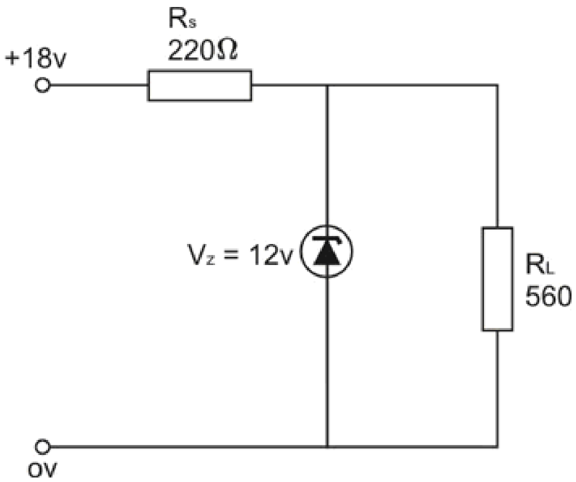


Figure 2. Zener diode shunt regulator

The voltage across Rs is given by the difference between the 18V input voltage and the zener voltage:

V_{RS}=18V–V_Z
= 18–12
= 6V

The voltage across the load is equal to the zener diode voltage because they are in parallel:

V_{RL}=V_Z=12V

The current through the series resistor is given by the voltage across it divided by its resistance:

I_{RS}=V_{RS}/$_{RS}$
=6V/220R
=27.3mA

The load current is given by the load voltage divided by the load resistance:

I_{RL}=V_{RL}/$_{RL}$
= 12/560
= 21.4mA

The current through the zener diode is determined by subtracting the load current from the total current:

$I_Z = I_{RS} - I_{RL}$
$= 27.3mA - 21.4mA$
$= 5.9mA$

Important relationships in the circuit are:

$V_{RL} = V_Z$
$V_{RS} = V_S - V_Z$
$I_Z = I_{RS} - I_{RL}$

Question 2.
For the circuit of Figure 3 calculate the following: V_{RS}, V_{RL}, I_{RS}, I_{RL} and I_Z.

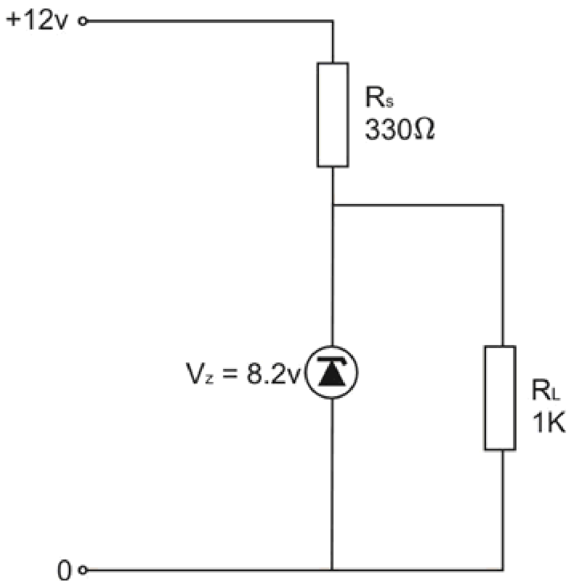


Figure 3. Zener diode shunt regulator

Each of the components in the circuit of Figure 3 will dissipate power. Sufficient voltages and currents have been calculated to find the power dissipated by each of the components (R_S, R_L and the zener diode). The power dissipated by each component is determined by multiplying the voltage across the components by the current trough it, P =VI.

Question 3.
Calculate the power dissipated by each of the components in the circuit of Figure 3.
The power dissipated by the series resistor, P_{RS}.

The power dissipated by the load resistor, P_{RL}.

The power dissipated by the zener diode, P_Z.

Summary

- The property of a zener diode in maintaining a constant voltage when reverse biased can be utilised in voltage regulator circuits.

- Calculations can be used to find the voltages, currents and power dissipations of the components in a zener diode voltage regulator.

Self Evaluation Test

1. For the circuit shown in Figure 8, calculate the following:

   a) The load voltage

   b) The voltage across the series resistor R_S

   c) The current through the series resistor

   d) The zener diode current

   e) Power dissipated by the zener diode, series resistor and load.

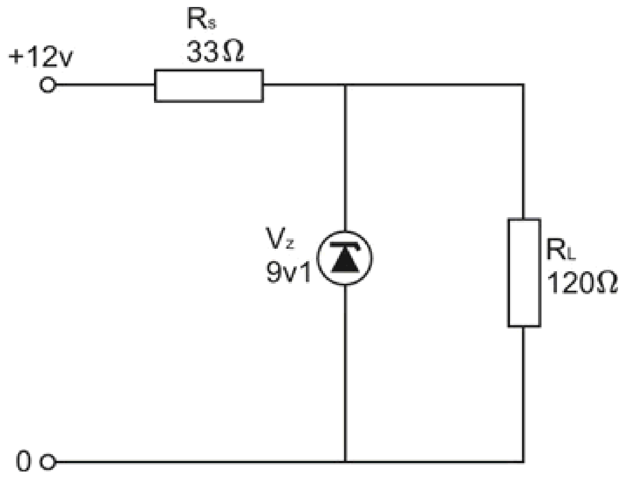


Figure 8

2. Which of the following statements are true and which are false if the load resistor is removed from the circuit of Figure 8?

   a) More current will flow though the zener diode. True/False

   b) Less current will flow though the R_S. True/False

   c) Less current will flow through the zener diode. True/False

   d) The voltage across the zener diode will increase. True/False

Answers to Questions

1. Transformer
   Diode
   Capacitor

2. V_{RS} = 3.8V
   V_{RL} = 8.2V
   I_{RS} = 11.5mA
   I_{RL} = 8.2mA
   I_Z = 3.3mA

3. P_{RS} = 43.8mA
   P_{RL} = 67.2mW
   P_Z = 27.1mW

Answers to Self Evaluation Test

1. a) V_{RL} = 9.1V
   b) V_{RS} = 2.9V
   c) I_{RS} = 87.9mA
   d) I_Z = 12.1mA
   e) P_Z = 110mW P_{RS} = 255mW P_{RL} = 690mW

2. a) T
   b) F
   c) F
   d) F

7. The Series Regulator

In this unit you will learn about simple series regulator circuits. You will also lean about current limiting.

This will enable you to determine if a simple regulator circuit is operating correctly.

To pass this unit you must be able to:

- State the reason for using a series pass transistor
- Calculate voltages and currents in series regulator circuits
- Measure voltages and currents and determine if a regulator is operating correctly.

Introduction

Figure 1 shows the circuit of a simple series voltage regulator. It is called a series regulator because the transistor (Q_1) is in "series" with the load. The main circuit current passes through the transistor and the load

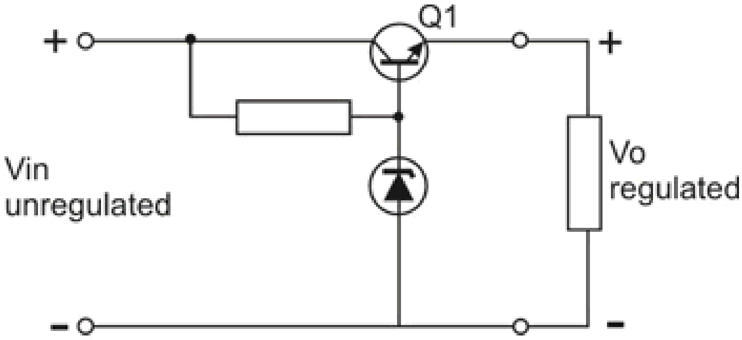


Figure 1. Series transistor regulator

Before going on to examine the series regulator, we will have a brief look at transistor operation.

Transistor Operation

A transistor is a three layer semiconductor device and it has three terminals. The terminals are named Collector, Emitter and Base. The structure and circuit symbol of a NPN transistor are shown in Figure 2. This type of transistor is also called a Bipolar Junction Transistor or BJT. It contains two PN junctions and there are two polarities of charge carriers, i.e. holes and electrons; thus the terms bipolar and junction.

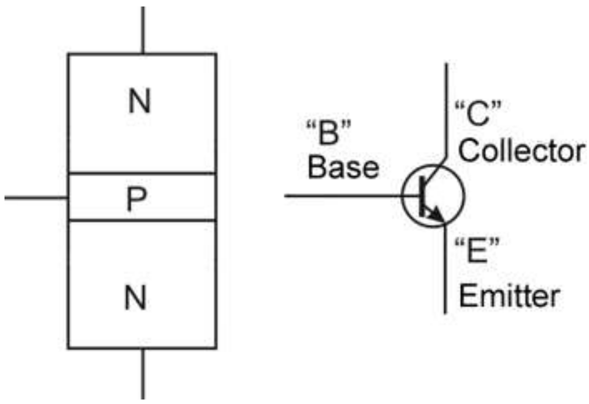


Figure 2. BJT structure and symbol

In order to function, the transistor is biased with DC voltages as shown in Figure 3. The voltage from the collector to the emitter (V_{CE}) is usually much larger than the voltage from base to the emitter (V_{BE}). Typical values may be V_{CE}=6Vand V_{BE}=0.6V. The main circuit current is I_C and this is controlled by the much smaller base current I_B.

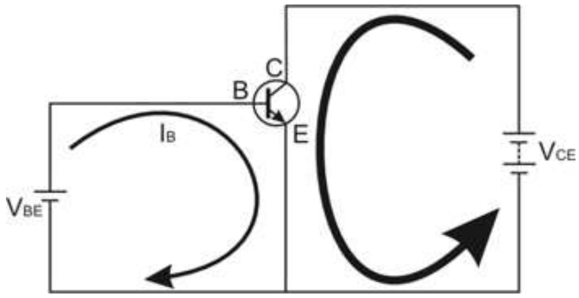


Figure 3. Current paths in bipolar transistor

Question 1.
Notice in Figure 3 that the base-emitter junction has a battery polarity of positive to the P-type and negative to the N-type.

Is this forward or reverse bias? Yes / No

A forward based diode has a voltage of approximately 0.6V and this is the usual voltage that can be found between the base and emitter terminals of a correctly biased transistor.

The size of the collector current is directly proportional to the size of the base current.

$I_C \propto I_B$

A slight increase in V_{BE} will produce an increase in I_B, This will cause a proportional increase in I_C.

In the circuit of Figure 4 the main circuit current passes through the transistor and load resistor. The base current controls the collector current, which in turn determines the load voltage.

In this circuit if V_{BE} is increased, I_B will increase and so will I_C. The load voltage will therefore also increase.

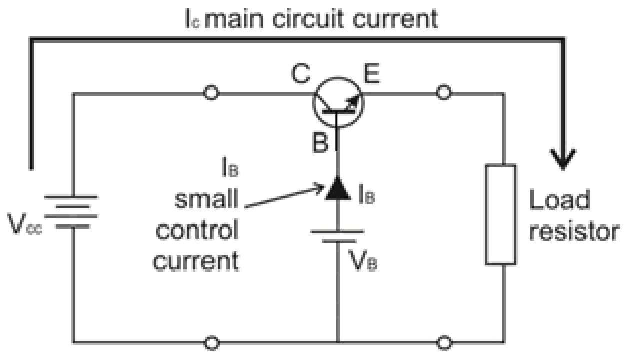


Figure 4. Current control of bipolar transistor

If however V_{BE} is reduced to zero, base current will cease to flow, the collector current will become zero and the load voltage will also become zero.

Practical Exercise (Optional) – Bipolar Transistor Operation

In this Practical Task you will:

1. Connect a transistor circuit
2. Measure the relationship between base and emitter currents
3. Measure the relationship between base and voltage emitter voltage.

Equipment required:

- 1 x dual variable power supply
- 2 x digital multimeters (DMM)

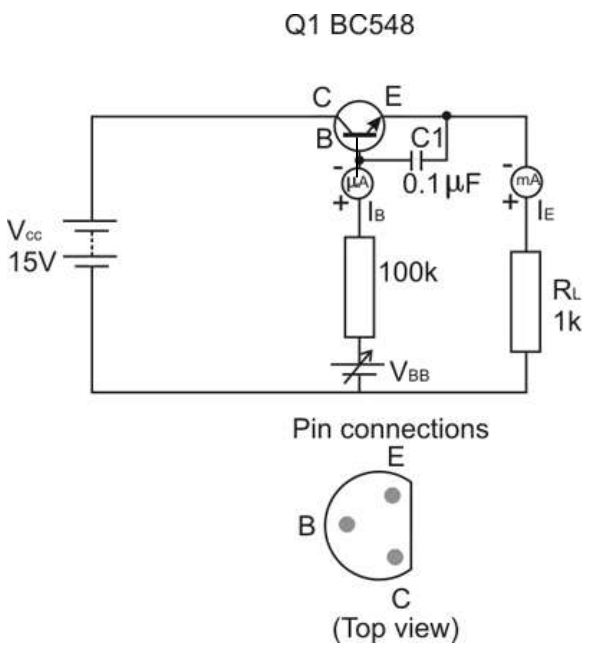
Components:

- 1 x BC548 transistor
- 1 x 100K resistor
- 1 x 1K resistor

Procedure:

Part A

Set up the circuit shown. Make sure you set the DMM's to the current range. Start with V_{BB} on zero volts and increase V_{BB} until I_E = 1mA. Record I_B in Table 1 below. Increase V_{BB} until I_E = 2mA. Record I_B. Continue for all values of I_B.



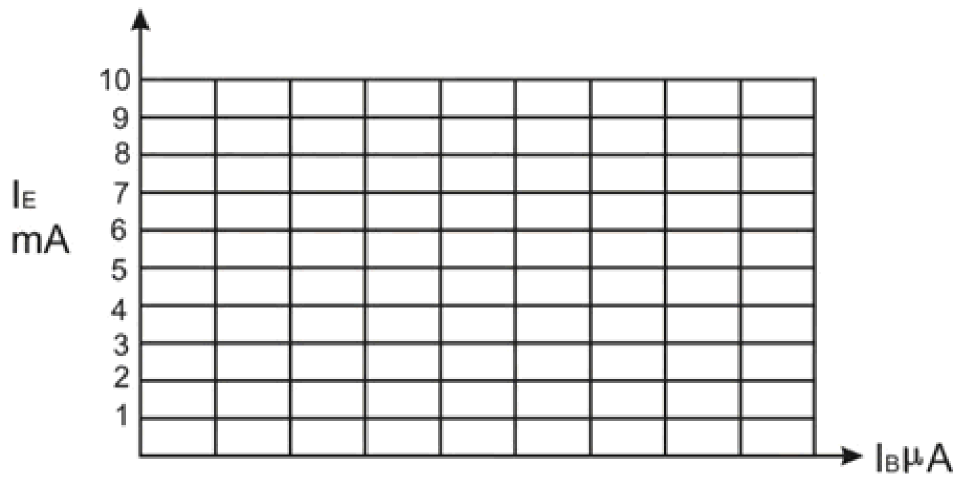
*C1 is added to prevent oscillations

Figure 5.

I_E	1mA	2mA	3mA	4mA	5mA	6mA	7mA	8mA	9mA	10mA
I_B										

Table 1

Sketch a graph of I_E against I_B from the results recorded in Table 1.



Graph 1.

The points on the graph form an approximate straight line. This indicated that the emitter current is directly proportional to the base current.

Part B

Connect the circuit shown in Figure 6. Increase V_{BB} until V_B = 1_V. Measure and record the value of V_E in Table 2. Continue for the other values of V_B.

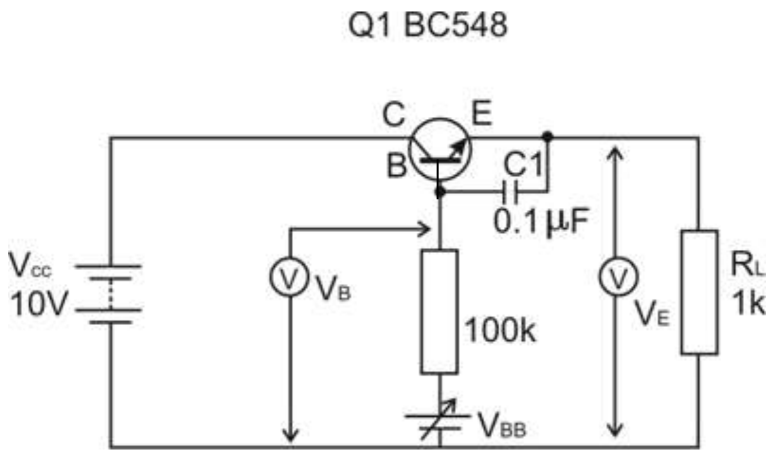


Figure 6.

V_B	1v	2v	3v	4v	5v	6v	7v	8v
V_E								

Table 2.

Have your instructor check your results.

Checked:

Clean up your work area, put away all parts and equipment. Have your instructor check this has been done.

Checked:

Practical Exercise – Bipolar Transistor Operation

Review

1. When I_B was increased what happened to I_E? Did it increase or decrease?

2. How much larger is I_E (at 5mA) than I_B?

   Hint: do this by dividing I_E by I_B.

3. How much less is V_E than V_B (at 5V)?

4. When V_B was increased what happened to V_E?

   Did it increase or decrease?

Have your instructor check your results.

Checked:

Series Regulator

The circuit shown below is a series regulator. It uses a bipolar transistor as the series pass element. The load current passes through the transistor, from collector to emitter.

This circuit is capable of more efficient operation, and is capable of supplying larger load currents than the simple zener shunt regulator.

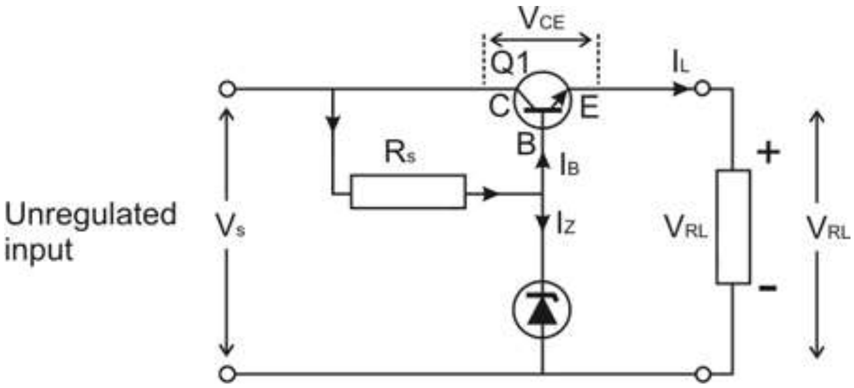


Figure 7.

R_S and the zener in this circuit form a simple zener regulator that holds the base of Q_1 at constant voltage.

The resistor R_S provides base current (I_B) to Q_1 and current to the zener diode (I_Z). The major circuit current is the load current (I_L) and this flows trough the transistor Q_1. The load current is the emitter current of Q_1.

How is the size of the output voltage determined? Figure 8 below has the voltage polarities marked on it and this will help determine the size of the output voltage.

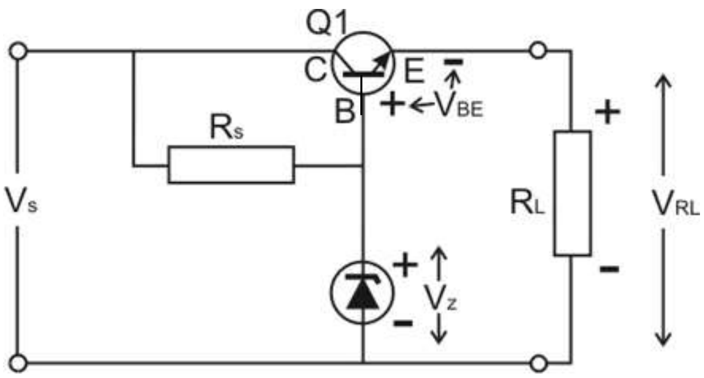


Figure 8.

The output or load voltage is determined by subtracting V_{BE} from the zener voltage.

Question 2.
If V_Z = 10V and V_{BE} = 0.6V calculate V_{RL}.

Question 3.
If, in the above example, V_S is 15V, where will the excess voltage ($V_S - V_{RL}$) be dropped?

The load voltage V_{RL} will remain constant if V_{BE} and V_Z do not change.

In practice as the load changes or the supply changes there will be minor changes in V_{BE} and V_Z. However the regulation properties of this circuit are far superior to the unregulated power supply and it is similar in regulation performance to the shunt zener diode regulator.

Current Limiting

The series regulator describes above has a major draw-back. It has no protection against the load becoming a short circuit. If the load is accidentally short circuited the rectifier diodes or power transformer may have their current rating exceeded. Or the power rating of the pass transistor Q_1 may be exceeded because it now has the full input voltage across it and high current flowing through it. Permanent damage of the rectifier diodes, power transformer or pass transistor is a likely outcome if the load becomes a short circuit.

In the circuit below the diodes D_1 and D_2, together with the low value resistor R_1 from a current limiting circuit.

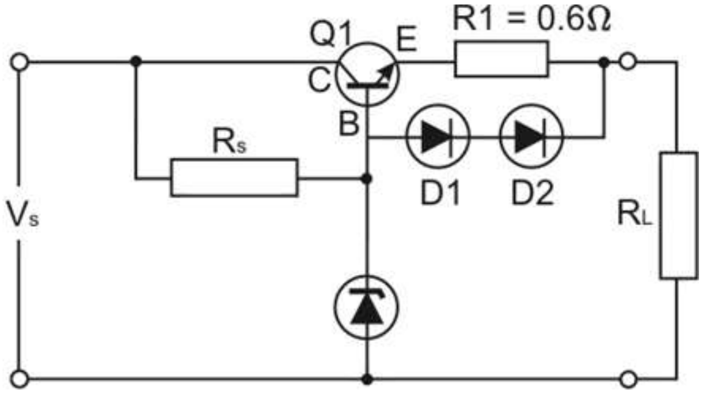


Figure 9.

Circuit Operation

Under normal circuit operation voltage across R_1 plus the V_{BE} of Q_1 is not enough to make D_1 and D_2 conduct. The regulator functions just like the circuit of Figure 1 except the output voltage is reduced slightly by the voltage across R_1. As R_1 is a small value resistor, the resultant drop in V_{RL} is not very big and may be ignored.

Question 4.
Refer to Figure 9. What voltage across R_1, plus V_{BE} of Q_1, will make D_1 and D_2 conduct?

If the load becomes a sort circuit or very low resistance the current through R_1 will increase and cause a corresponding increase in the voltage across R_1. When the voltage across R_1 plus V_{BE} of Q_1 is equal to approximately 1.2V, D_1 and D_2 will start to conduct.

When D_1 and D_2 conduct the current through R_S hat went to the base of Q_1 is diverted through the diodes because they are now conducting. The diversion of base current has a limiting effect on the emitter current. This is because the emitter current is directly proportional to base current. Limiting the emitter current also limits the load current because these are in fact the same current.

Let's now work out the maximum load current that can be drawn before the current limiting circuit starts to work.

Question 5.
What is the combined voltage across D_1 and D_2 when they are conducting?

Question 6.

What is the value of V_{BE} of Q_1?

Question 7.
What is the size of the voltage drop across R_1 when D_1 and D_2 are conducting?

V_{R1}

In this circuit current limiting occurs when the voltage across R_1 is equal to 0.6V. By Ohm's law this is happens when the load current has reached 1A (1A x 0.6ohm = 0.6V). I.e. the current is limited to approximately 1A under short circuit load conditions.

Question 8.
For the circuit of Figure 9, if R_1 is replaced with a 0.42ohm resistor, determine the new value of current limit. The circuit shown in Figure 10 is another form of current limiting circuit.

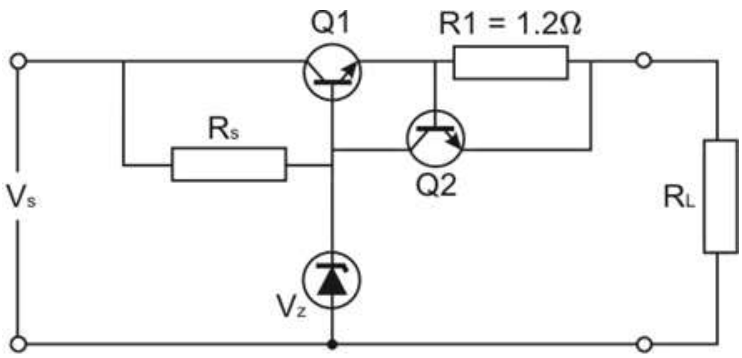


Figure 10.

Question 9.
What voltage drop is required across R_1 before Q_2 will begin to conduct?

Question 10.
What load current will produce a 0.6 volt drop across R_1?

The circuit in Figure 10 operates so that when the load current rises to 0.5A, Q_2 will begin to conduct, which will divert base current from Q_1 and limit the load current to approximately 0.5A.

Summary

- The base emitter voltage for a correctly biased transistor is approximately 0.6V.
- The collector and emitter current are controlled by the much smaller base current.
- The bipolar series regulator is used in high current applications in preference to the zener shunt regulator.
- The output of the simple series regulator is equal t V_Z-V_{BE}.
- The available current from a series regulator can be limited by adding suitable current limiting circuitry.

Self Evaluation Test

State the approximate voltage across the load resistor in Figure 15.

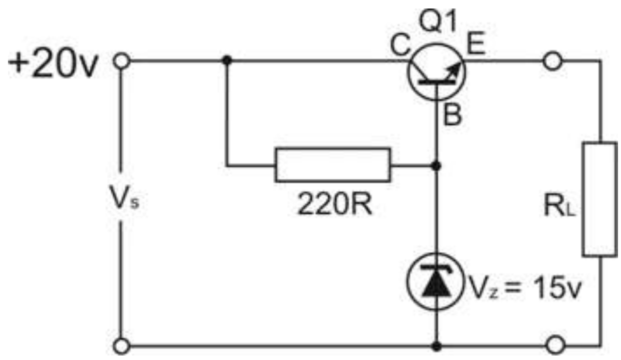


Figure 15.

1. For the circuit of Figure 16:
   a) Calculate the output voltage at zero load current

   b) Calculate the output voltage as the limiting current value

   c) Calculate the limiting current value.

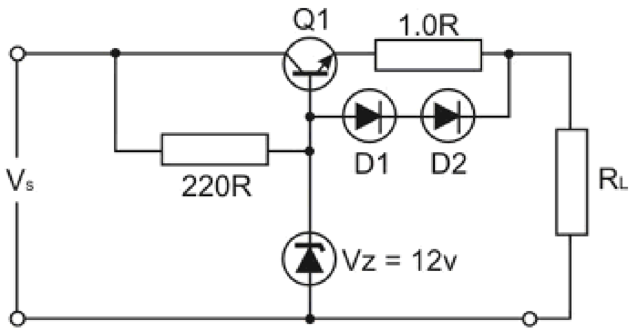


Figure 16.

2. For the circuit of Figure 17:
   a) Calculate the output voltage at zero load current

   b) Calculate the output voltage at the limiting current value

   c) Calculate the limiting current value

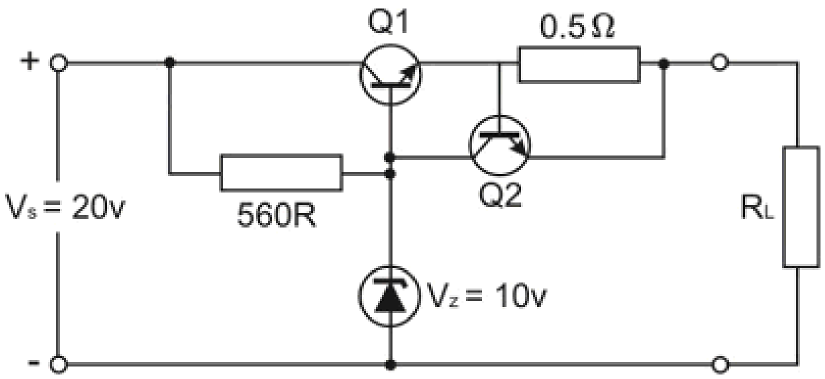


Figure 17

3. State an advantage of the series regulator compared to the zener diode regulator.

Answers to Questions

1. Forward bias
2. 9.4V
3. Across the series transistor (V_{CE})
4. 1.2V (approx)
5. 1.2V
6. 0.6V
7. 0.6V
8. 0.6/0.42 = 1.43A
9. 0.6V
10. 0.6/1.2 = 0.5A

Answers to Self Evaluation Test

1. 14.4V

2. a) 11.4V b) 10.8V c) 600mA

3. a) 9.4V b) 8.8V c) 1.2A

4. The series regulator is able to handle larger currents than the simple zener regulator. This is because bipolar transistors are available with high current ratings.

   When the load current is small the series regulator is more efficient than the zener regulator. This is because the zener regulator has a higher zener current when the load current reduces. This results in wasted power in the zener diode and thus poor efficiency.

8. The Error Amplifier and 3-Terminal Regulators

In this unit you will learn about the use of an amplifier to improve the performance of a voltage regulator. You will learn how to estimate the output voltage of a regulator circuit.

This will enable you to determine if a regulator with an error amplifier is operating correctly.

To pass this unit you must be able to:
- Identify the error amplifier in a regulator circuit.
- Calculate the output voltage of a regulator containing an error amplifier.

Error Amplifier Regulator

This is an example of a feedback circuit. A sample of the output voltage is taken by the voltage divider, R_2 and R_3. This sample of the output voltage is compared to the zener reference voltage, V_Z.

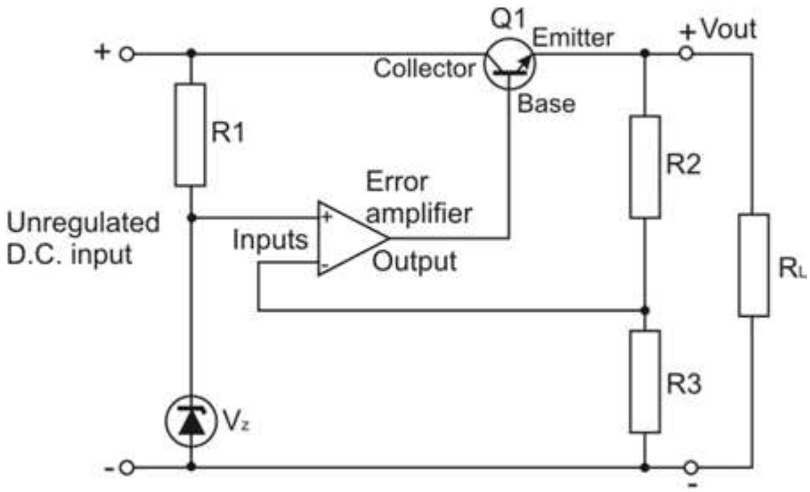


Figure 1. Adjustable voltage regulator

The error amplifier acts in such a way as to maintain its two inputs at the same voltage. To achieve this, it adjusts the base current and therefore the emitter current of Q_1 to produce the required output voltage to achieve this situation.

The Error Amplifier

The error amplifier has two inputs, one called the non-inverting input (+ input) and the other is called the inverting input (- input). There is one output which drives the series pass transistor.

If the non-inverting input voltage exceeds the inverting input voltage, the error amplifier output will increase and cause the pass transistor to conduct more. If the inverting input voltage exceeds the non-inverting input voltage, the error amplifier output will decrease and cause the pass transistor to conduct less.

When the circuit settles after the initial switch on, the error amplifier maintains the inverting and non-inverting inputs at the same voltage and the output voltage is constant.

Changes in the Load Current

If the load changes, for example the load current increases because the load resistance has fallen, the circuit will respond in the following manner:

The output voltage will tend to fall, this is due to the drop in the unregulated input voltage as the load current increases.

If the output tends to fall the sampled voltage across R_3 will also tend to fall.

Thus the inverting input will be less than the non-inverting input and the output of the amplifier will increase. The pass transistor will be driven harder to restore the output voltage to the previous level.

Changes in Input Voltage

If the unregulated input voltage should rise there would be a tendency for the load voltage to rise. A rise in output voltage would be accomplished by a rise in the sampled output voltage across R_3. This will make the inverting input to the error amplifier higher than the non-inverting input and the pass transistor will be driven less to restore the output voltage to its former level.

Most regulated power supplies use an error amplifier and feedback control as just described. Very high performance power supplies can be designed on the basis of this principle. The output voltage on these power supplies is held rock steady even when the input voltage changes or the load changes, the output ripple is also very low, typically only $50mV_{P-P}$.

Calculating the Output Voltage

The output voltage ht calculated by determining the voltage across each of the resistors in the sample network, i.e. V_{R2} and V_{R3} and the adding them up.

Question 1.
Refer to Figure 2. Given that the error amplifier maintains its inputs at the same voltage, what is the voltage across R_3?

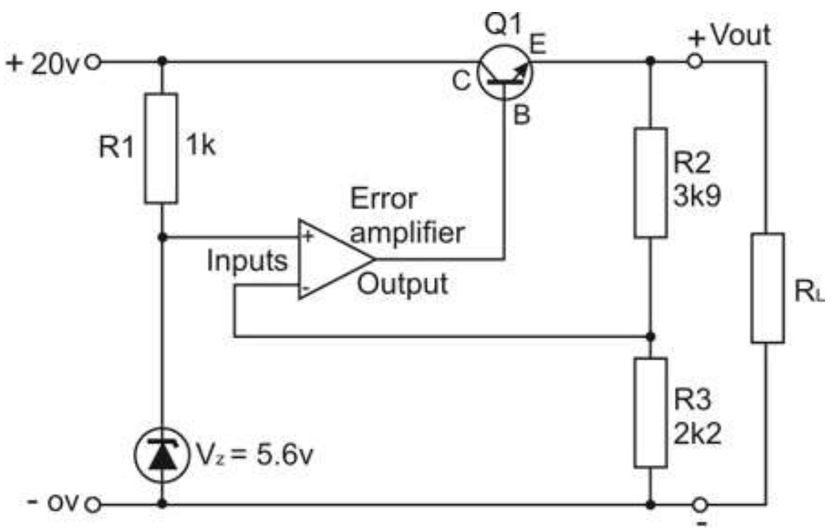


Figure 2. Series regulator with error amplifier

Using Ohm's law we can now calculate the current through R_3.

I_{R3} = 5.6/2k2 (For the op amp comparator, V+ = V– = 5.6V)
= 2.55mA

The input resistance of the error amplifier is extremely high and so the current through R_2 is the same as the current through R_3.

Question 2.

Calculate the voltage across R_2.

Now that we know the voltage across R_2 = 9.9V and the voltage across R_3 = 5.6V, the output voltage can be determined.

V_O = $V_{R2} + V_{R3}$
= 9.9V + 5.6V
= 15.5V

Note that the unregulated input Voltage (V_S) must be higher than the regulated output Voltage (V_{RL}). A minimum of approximately 1V is required between the collector and emitter of the pass transistor. In this circuit the 20V unregulated input is an average voltage. This may have several volts of peak to peak to ripple. The minimum of this input voltage must be at least 1V higher than the output voltage.

A Variable Power Supply

Many applications require the output voltage to be adjustable. An example of this is the laboratory power supply you have used in previous lab exercises.

The output of this power supply depends on the setting of the potentiometer RV1. To determine the output voltage range two calculations are necessary, one at the upper and one at the lower extreme positions of R_{V1}.

When R_{V1} is at the position "B" a voltage equal to the zener voltage appears across R_3. This is because the error amplifier maintains the two inputs at the same voltage.

(Questions 3 to 12 refer to Figure 3.)

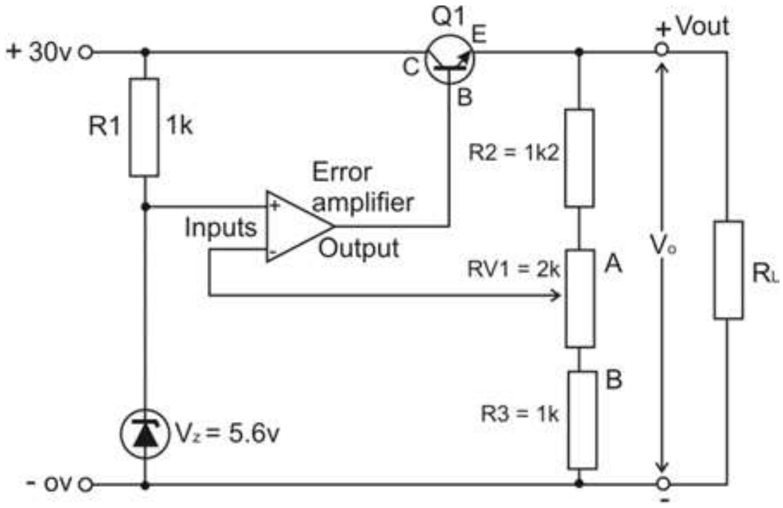


Figure 3. Adjustable voltage regulator

Question 3.
State the value of V_{R3} when R_{V1} is set to position "B".

Question 4.
Calculate the current through R_3.

Question 5.
What is the size of the current through R_2 and R_{V1}?

Question 6.
Calculate the voltage across R_2 and the voltage across R_{V1}.

Question 7.
Determine the output by the sum:
$V_O = V_{R3} + V_{RV1} + V_{R2}$

$V_O =$

This is the maximum value of V_O. If the wiper of the potentiometer is moved to position “A”, the minimum output voltage can be calculated.

Question 8.
What is the total voltage across R_{V1} and R_3 when the wiper is in position “A”?
(Hint: remember that the error amplifier inputs are the same voltage.)

$V_{R3} + V_{RV1} =$

Question 9.
Calculate the current through R_{V1} and R_3.

$I =$

Question 10.
Calculate the voltage drop across R_2.
(Hint: The current through R_2 is equal to the current through R_{V1} and R_3 because they form a series circuit)

$V_{R2} =$

Question 11.
Calculate V_O:

$V_O = V_{R2} + (V_{RV1} + V_{R3})$
=
=

Question 12.
State the possible range of output voltages for the circuit of Figure 3.

………V to............V

Summary

- Regulated power supplies may use an error amplifier to maintain a constant output voltage.
- The output voltage is determined by calculating the voltage across the sampling circuit.
- Regulation of an error amplifier power supply is far superior to simpler supplies.

Self Evaluation Test

1. Calculate the output voltage of the regulator circuit shown in Figure 4.

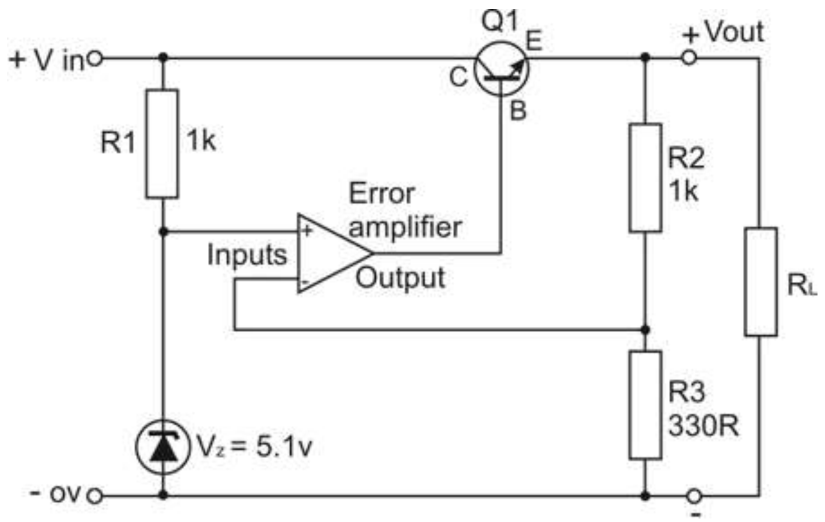


Figure 4.

2. Refer again to Figure 4. Q1 requires a minimum voltage of 1V between the collector and emitter. Calculate the minimum value of the unregulated input voltage (V_{in}).

3. Refer to Figure 5. Calculate the minimum and maximum output voltage for this circuit.

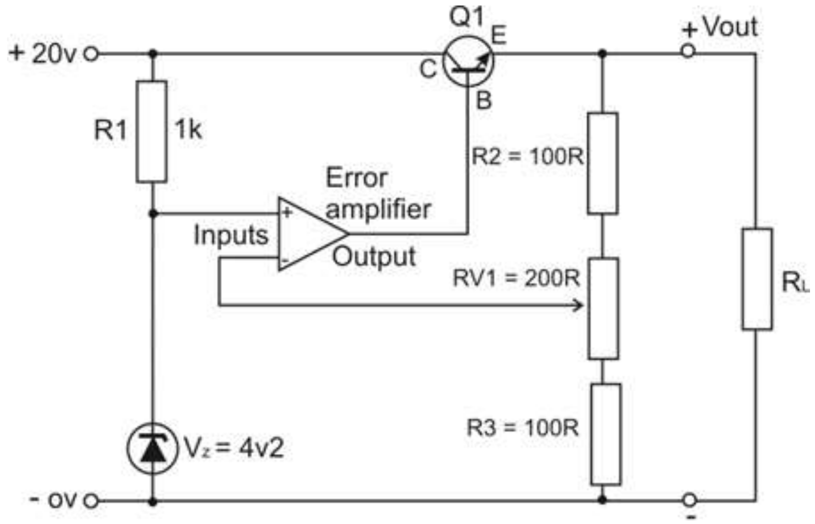


Figure 5

Answers to Questions

1. 5.6V
2. 9.9V
3. 5.6V
4. 5.6mA
5. 5.6mA
6. V_{RV1} = 11.2V V_{R2} = 6.72V
7. V_O = 23.5V
8. 5.6V
9. 1.9mA
10. 2.24V
11. 7.84V
12. 7.84V to 23.5V

Answers to Self Evaluation Test

1. 20.6V
2. 21.6V
3. 5.6V to 16.8V

Three Terminal Regulators

In this unit you will learn about three terminal regulators. You will also learn how to use data sheets and how to determine the output of a three terminal regulator.

This will enable you to determine if a three terminal regulator circuit is performing correctly and how to look up a suitable replacement device.

To pass this unit you must be able to:
- List the essential parameters of a three terminal regulator from data sheets
- Calculate the output voltage for a circuit containing a three terminal regulator
- Measure voltages and currents and determine if a three terminal regulator circuit is operating correctly

Integrated Circuit Regulators

Three terminal regulators are integrated circuits (IC) which have been designed to provide a fixed output voltage. They also have many built in features which make them easy to use and very versatile.
- They require very few additional external components
- They have protection against sort circuits currents
- They have automatic thermal shutdown (they reduce the output when they reach a predetermined temperature)
- They have a very constant output voltage
- They have a very small ripple output

Three terminal regulators come in a range of fixed voltages or can be adjusted to almost any desired voltage by the addition of a simple zener diode or resistor network.

The plastic TO-220 style package is the most common but they also come in other packages as shown in the data sheets at the end of this unit

Question 1.
Refer to the data at the end of this book. Name and sketch two package styles other then the TO-220 style.

Fixed Voltage 3-Terminal Regulators

Figure 1 shows the TO-220 style package of a three terminal regulator with the pin functions labelled. The circuit symbol if also shown.

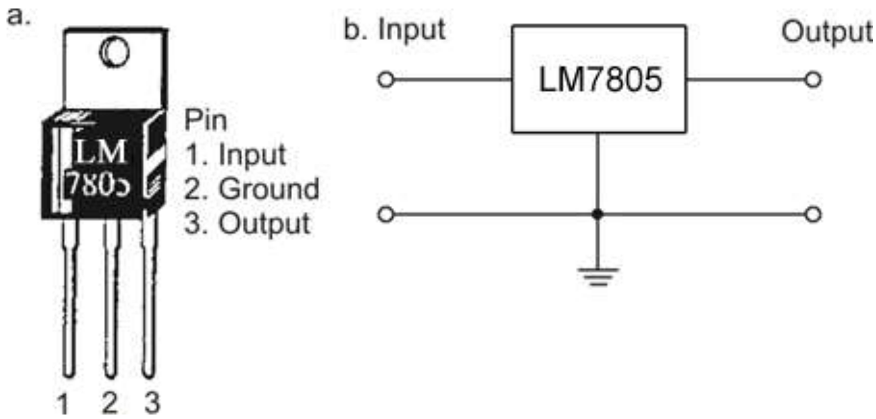


Figure 1. (a) 3-Terminal Regulator (b) Circuit symbol for 3-terminal regulator

The input to the regulator is filtered by the capacitor, but will have some ripple. It is this unregulated voltage from the rectifier that is the input to the regulator. The output from the regulator is constant DC with virtually no ripple.

A complete power supply circuit using a fixed voltage three terminal regulator is shown in Figure 2.

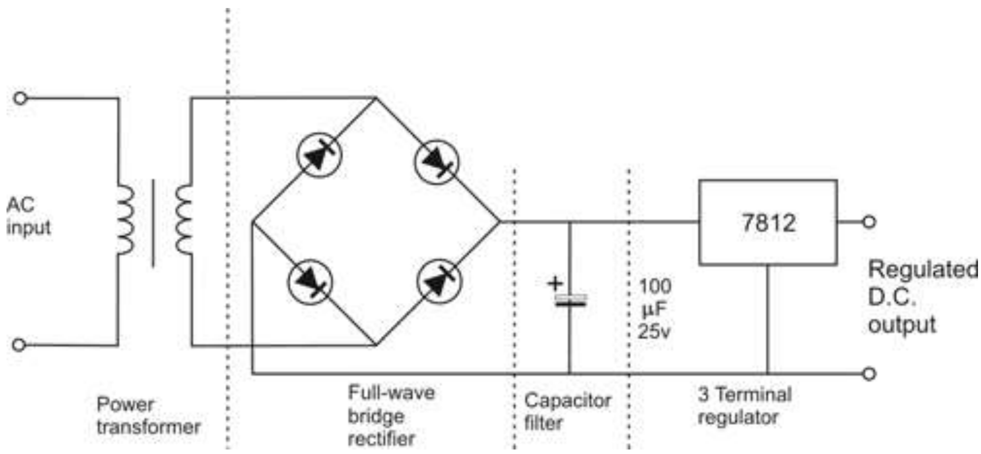


Figure 2. A complete regulated power supply circuit

Some common three terminal regulator and their voltage and current capabilities are listed below.

Part No	Output voltage	Output current
LM 78L05	5.0V	> 100mA
LM 7805	5.0V	>1A
MC 7809T	9.0V	>1A
LM 317T	1.25V	>1.5A
LM 309K	5.0V	>1A

Table 1. Common regulator ICs

Parameters of Three Terminal Regulators

Output Voltage

The part number includes reference to a nominal output voltage. For example the LM7805 has a nominal output of five volts. Refer to the data on the LM7805 sets at the end of this book. The first line in the table of Electrical Characteristics for the LM7805 states that at a junction temperature of 25 degrees Celsius (T_j = +25°C) the output voltage for a particular 7805 could be as low as 4.8V or as high as 5.2V.

Question 2.
Refer to the data on the LM309.
Determine the minimum, typical and maximum output voltages with T_j = +25°C.

V_{min} = V_{typ} = V_{max} =

Output Current

The maximum current that an IC regulator will deliver to the load depends on three factors:

- The device temperature
- The difference between the input and output voltage (also called the input-output voltage differential)
- The load current

The data sheet description usually specifies the guaranteed current that can be supplied by the regulator. Sometimes the manufacturer specifies the current handling ability of the IC when it is operating under worst case conditions.

Question 3.
Refer to the data sheets at the end of this book.
What is the guaranteed current output from the following?

LM78xx series LM109K series

I = I =

Maximum Input Voltage

The unregulated input voltage must not exceed the maximum rated voltage, $V_{in(max)}$.

If the input exceeds $V_{in(max)}$, the device maybe destroyed. Damage to the device is almost certain to occur if $V_{in(max)}$ is exceeded and the output is short circuited.

Question 4.
Refer to the Maximum Ratings Tables on the data sets at the end of this book. What is the maximum input voltage, Vin (max), for the following IC regulators?:

LM7812	LM109
$V_{in(max)}$ =	$V_{in(max)}$ =

Input-Output Voltage Differential (Drop out Voltage)

The regulated input must always be higher than the required output voltage. For many regulators the input must exceed the output by at least two volts. If this condition is not met the regulator will "drop out" of regulation, the output voltage will fall and severe ripple will become evident.

The minimum input-output differential voltage is also called the "drop out" voltage.

$$V_{in(min)} = V_O + V_{DROP\ OUT}$$

OR

$$V_{DROP\ OUT} = V_{in(min)} - V_O$$

Question 5.
What is the minimum input voltage for a LM7812 IC regulator?
(Hint: Look up the Input-Output Voltage Differential first.)

$V_{in(min)}$ =

Quiescent Current (I_Q)

Not only must the rectifier provide the output current to the load, it must also provide a small current to power the circuitry in the regulator IC itself. This current is called the quiescent current (I_Q) and it flows out of the common or ground terminal of the IC package.

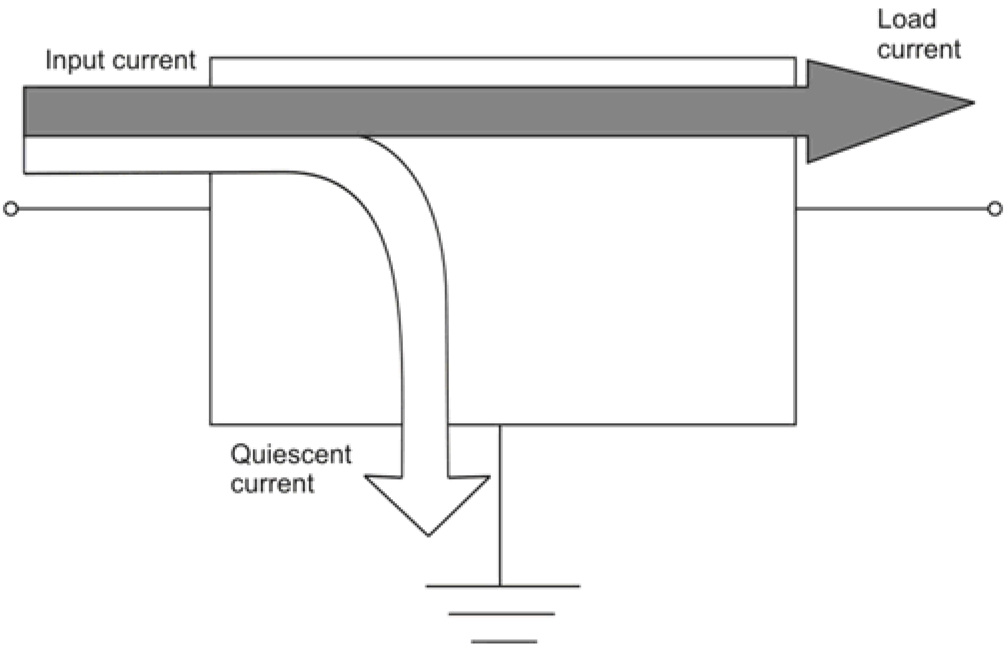


Figure 3 Current path in regulatory circuit

The LM7805 has a quiescent current(I_Q) that is typically 4.3mA. If we look at the data sheets we will find it has a maximum quiescent current of 8.0mA.

Question 6.
Refer to the data on the LM309.
Look up the typical and maximum quiescent current

$I_{Q\ typ}$ = $I_{Q\ max}$ =

Input Regulation

Input regulation refers to the IC's ability to regulate the output voltage or hold it constant against changes in input voltage.

Look at the first row (line regulation) of the Electrical Characteristics for the LM7805 in the data sheets at the end of this book. For a change in input voltage from 7.0Vdc to 25Vdc the output changes by only 3.0mV typically and the worst case figure is 50mV. This is a very small change in output voltage for a very large change in input voltage.

Ripple Rejection

The unregulated input voltage will contain some ripple voltage. The ripple rejection parameter gives us a measure of the output ripple compared to the input ripple. The ripple rejection is usually expressed in dB and a figure of 60 dB or more is common.

60 dB is equal to a voltage ratio of 1000:1. A three terminal regulator that has a ripple rejection ratio of 60 dB will have an output ripple that is one-thousandth of the input ripple.

E.g. If the input ripple contains $4V_{pk-pk}$ ripple rejection is 60 dB, the output ripple will be only $4mV_{pk-pk}$. This is a very small amount of output ripple and for many applications we regard this as negligible ripple.

Load Regulation

Load Regulation is a measure of the IC's ability to maintain a constant output voltage as the load current changes.

Data for the LM7805 shows that as the load is changed from 5mA to 1.5A, the output voltage only drops by 10mV typically and 50mV maximum. This is a very minor change in output voltage for an enormous change in load current.

External Components

Although a three terminal regulator will operate without external components, there are some practical reasons for adding some.

Manufacturers recommend that a small value capacitor be placed as close to the input terminals as possible, this is to prevent the IC from oscillating (producing its own unwanted AC). It is common practice to se a 100nF disc ceramic or 1uF tantalum capacitor for this application. C_1 is included in Figure 4 for this purpose.

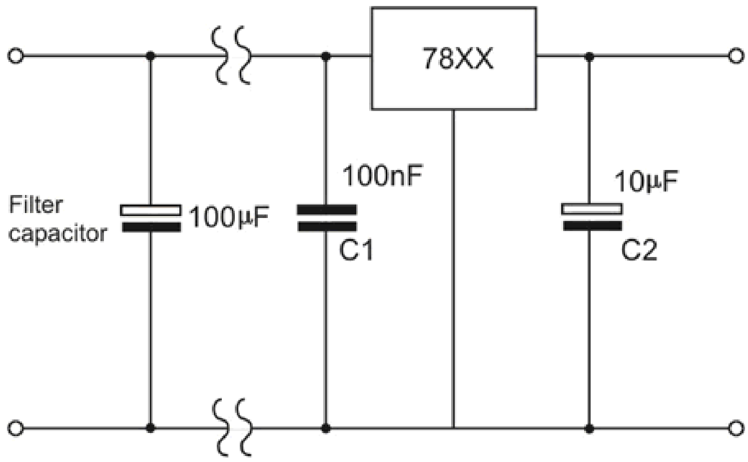


Figure 4.

Rapidly changing load conditions such as those that occur in digital circuits can produce voltage transients on the power supply rail. C_2 suppresses these transients by acting as a small reservoir to absorb voltage spikes or provide short duration bursts of load current. A tantalum capacitor in the range of 1uF to 10uF is frequently used in this application.

Setting the Output Voltage

A three terminal regulator holds the voltage between the output and the common terminal at a constant level. This Is shown in Figure 5. This feature can be utilised to produce a voltage that is different to the “nominal” regulator voltage.

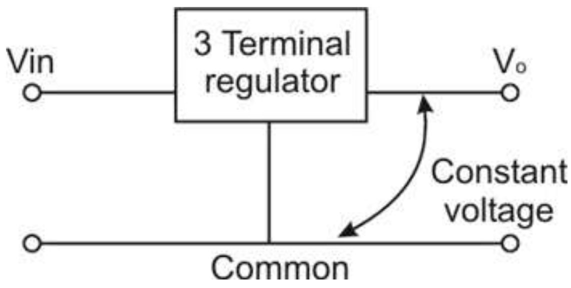


Figure 5. Constant output voltage

Consider the circuit shown in Figure 6. The quiescent current of the IC regulator plus the current through R_S ensure the zener is operating well clear of the zener “knee”.

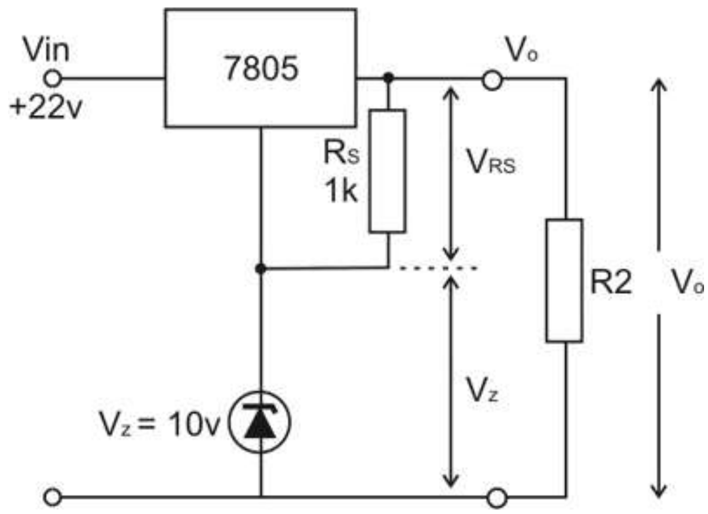


Figure 6. Increasing the output voltage

Question 7.
What is the voltage across R_S?

V_{RS} =

The output voltage is equal to the sum of V_{RS} plus V_Z, which in this circuit is equal to 5V + 10V = 15V. The addition of a resistor and a 10 volt zener diode has increased the output voltage to 15V.

As regulators are manufactured for a very limited range of fixed values, this technique may be used to produce any desired output voltage.

Question 8.
Refer to Figure 7. Determine the output voltage for this circuit.

V_O =

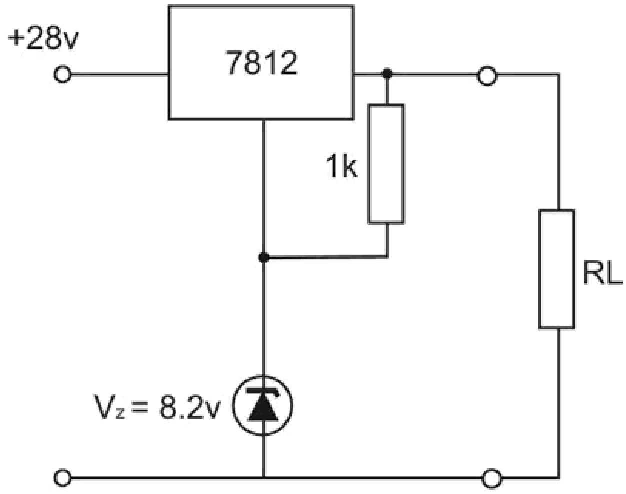


Figure 7. Increasing the output voltage

As a better alternative to using a zener diode, two resistors can be used as shown in Figure 8. The output voltage is given by the sum of V_{R1} plus V_{R2}.

Question 9.
What is the voltage across R_1 in Figure 8?

V_{R1} =

The voltage across R_1 is calculated by R_2 multiplied by the current through it.

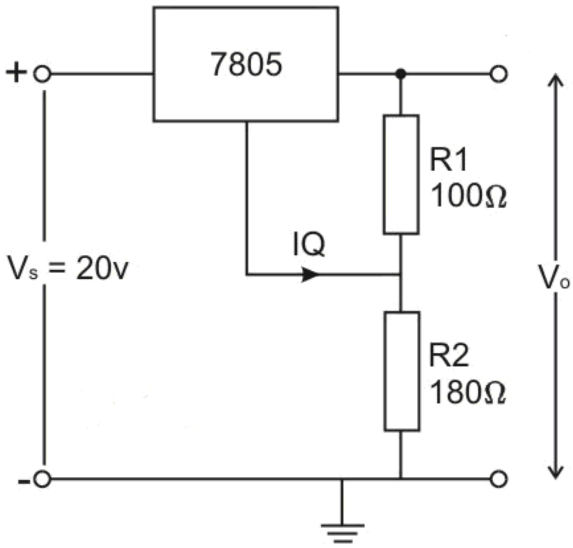


Figure 8. Fixed output voltage regulator

Question 10.
Calculate the current through R_1 in Figure 8.
(Note: this current also passes through R_2)

I_{R1} =

Question 11.
Refer to the data sheets and look up the quiescent current for the LM7805.
(Use the typical figure.)

I_Q =

Question 12.
Now calculate the total current through R_2.
Hint: $I_{R2} = I_{R1} + I_Q$

Question 13.
Calculate the voltage across R_2

V_{R2} =

Question 14.
Now determine the output voltage by adding V_{R1} plus V_{R2}

V_O =

A limitation on the above techniques is that the output voltage has to be higher than 5V (the fixed voltage of the IC regulator). Also the quiescent current has to be allowed for in the calculations and its precise value will vary sightly from device to device.

LM317 is a low output voltage regulator IC. It is made especially for adjustable voltage regulator applications.

LM317 maintains a constant voltage of 1.25 volts between the output and the adjustment (ADJ) terminal.

The LM317 has a very low quiescent current from the adjustment terminal. I_{adj} is 100uA maximum and can usually be ignored.

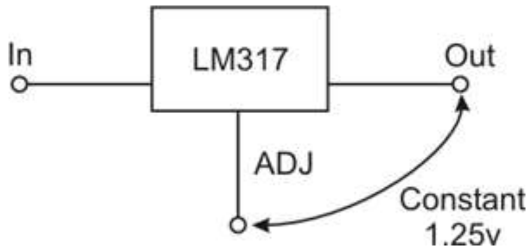


Figure 9. LM317 – Low output voltage regulator

In the circuit of Figure 10 the ADJ current or an LM317 is negligible. The output voltage is therefore the sum of V_{R1} plus V_{R2}.

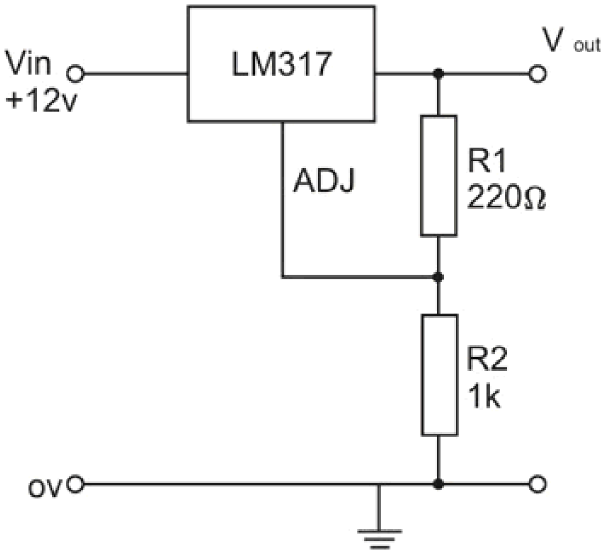


Figure 10. Fixed output voltage regulator

Question 15.
State the value of V_{R1} in Figure 10.
(Hint: Look for the typical device reference voltage in the data sheet at the end of this book.)

V_{R1} =

Question 16.
Determiner the current through R_2.
(Hint: This is the same as I_{R1}, as we ignore I_{adj} as it is so small.)

I_{R2} =

Question 17.
Calculate the voltage across R_2.

V_{R2}=

The output voltage can now be determines by adding V_{R1} plus V_{R2}.

V_O = 1.25V + 5.68V = 6.93V

Given that the LM317 has a nominal voltage of approximately 1.25V we can expect an output of approximately 6.9V from the circuit of Figure 10.

Adjustable Output Regulator

If R_2 is now replaced with a variable resistor (potentiometer) R_{V1}, as shown in Figure 11, the output is continuously variable depending on the setting of R_{V1}.

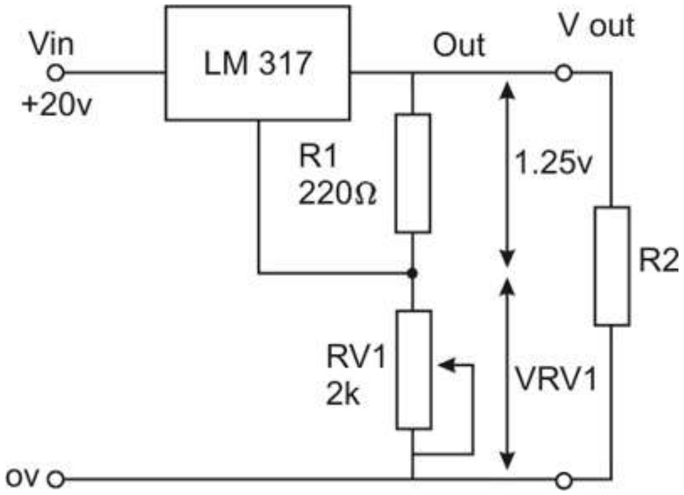


Figure 11. Adjustable voltage regulator

Question 18.
What is the voltage across R_{V1} when it is set to zero ohms?

V_{R1} now equals V_{out} =

Question 19.
What is the output voltage when R_{V1} is set to zero ohms?

V_{R1} =

Question 20.
When R_{V1} is set to its maximum resistance i.e. of 2K ohms, calculate the output voltage. Use the same method as before:

(a) I_{R1} = 1.25 / R_1

=

=

(b) V_{RV1} = I_{R1} x R_{V1}

=

=

(c) V_{out} =V_{R1} + V_{RV1}

=

=

For the circuit of Figure 11 the output can be continuously adjusted over the range of 1.2V up to 12.6V. By selecting suitable values for R_1 and R_{V1} the output of this regulator circuit can be made adjustable from a minimum of 1.2V up to a maximum of approximately 37V.

Summary

Manufacturers' data sheets provide information about the parameters of three terminal regulators. These include:

- V_O the nominal output voltage
- I_O max the maximum output current
- I_Q the quiescent current
- V_{DO} the drop out voltage
- Ripple rejection ratio.

As well as fixed voltage applications, three terminal regulator circuits can be preset to a desired value or made continuously adjustable over a range of voltages.

Self Evaluation Test

1. Refer to the data on the LM7812 Series Voltage Regulators

   Determine the following:
   a) Output voltage
   b) Maximum input voltage
   c) Output current maximum (not peak current)
   d) Quiescent current
   e) Drop out voltage
   f) Ripple voltage

2. Determine the output voltage for the IC regulator circuit shown in Figure 15.

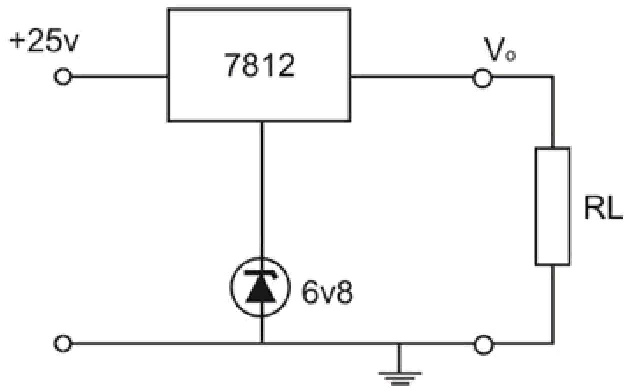


Figure 15.

3. Calculate the output voltage for the circuit on Figure 16.
   (Use the typical quiescent current.)

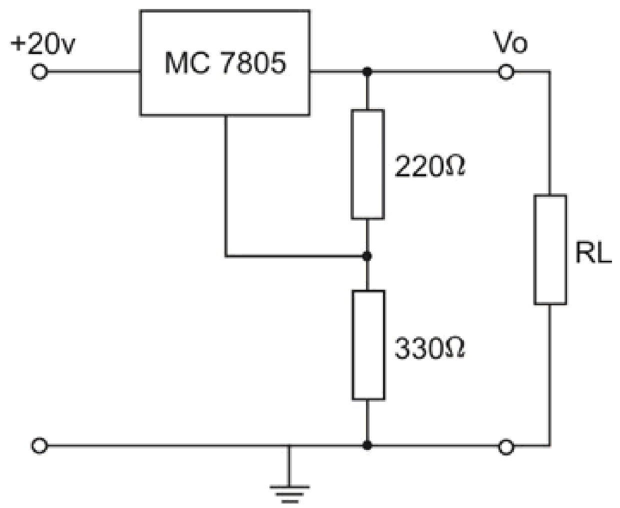


Figure 16.

4. Calculate the maximum and minimum output voltages for the circuit in Figure 17 (Use typical values).

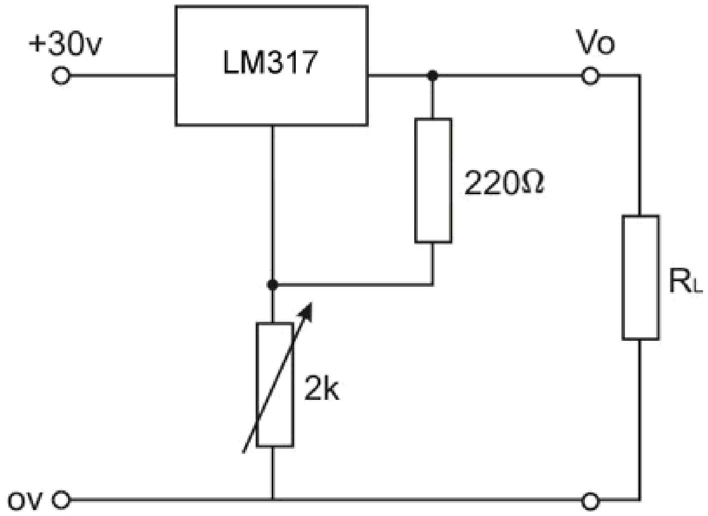


Figure 17.

Answers to Questions

1. Case 1-3 TO-3 TO-39 TO-92 Case 79-05 (TO-5)
2. V_{min} = 4.8V V_{typ} = 5.05V V_{max} = 5.2V
3. LM7800 series – Imax > 1A

   LM109 series – Imax > 1A
4. LM7812 $-V_{in\ max}$ = 35V

   LM109 $-V_{in\ max}$ = 35V
5. 14V (12 + 2.0)
6. $I_{Q\ typ}$ = 5.2mA $I_{Q\ max}$ = 10mA
7. V_{RS} = 5V
8. V_O = 20.2V (12 + 8.2)
9. 5V
10. 50mA
11. 4.3mA
12. 54.3mA
13. 9.77V
14. 14.77V
15. 1.25V
16. 5.68mA
17. 6.68V
18. 0V
19. 1.25V
20. a) I_{R1} = 5.68mA b) V_{RV1} = 11.36V c)12.61V

Answers to Self Evaluation Test

1. a) 12 V
   b) 35V
   c) 1A
   d) d) 4.4mA (typ)   8mA (max)
   e) 2.0V
   f) 60dB (typ)
2. 18.8V
3. 13.6V
4. V_{Omin} = 1.25V
   V_{Omax} = 12.6V

9. Fault Finding

In this unit you will learn about the effects of fault conditions in regulator circuits.
This will enable you to identify the faulty component in a regulator circuit that is not functioning properly.

To pass this unit must be able to:

- Identify a faulty component in a malfunctioning regulator circuit by making measurements on the circuit.

Faults in a Zener Regulator

The circuit below should provide a regulated output voltage of 6.8V across the load. The regulator circuit consist of two components, the series resistor R_S and the zener diode.

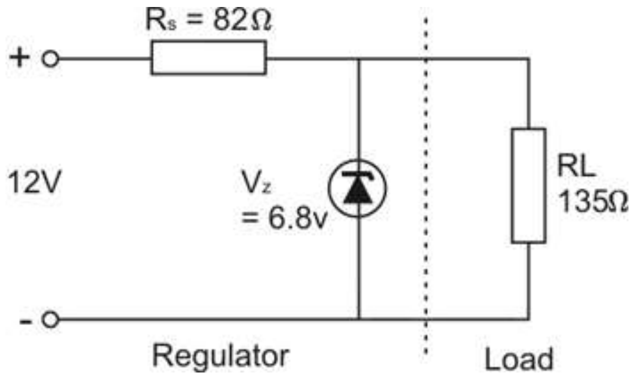


Figure 1. Shunt zener regulator

A fault condition will produce a load voltage of something other than 6.8V. Let's now investigate some of the possible faults.

The most likely fault with a resistor is for it to become an open circuit, or go very high in value. This is because the wire or carbon track of the resistor may break or possibly the end cap or lead termination may break.

The zener diode on the other hand may become an open or short circuit. This may be caused by the lead termination breaking or, if it gets too hot, it may become low in resistance.

Before looking at the effects of these possible faults we should know what voltages to expect in a circuit that is functioning correctly.

Question 1.
In Figure 1 if a voltmeter is placed across the load, what voltage reading is expected?

V_{RL} =

Question 2.
If a voltmeter is placed across the series resistor R_S, what voltage reading is expected?

V_{RS} =

Now we will look at the effects of various faults on this type of zener regulator.

R_S = Open Circuit

The current to the zener diode is zero if R_S is an open circuit. Therefore the load voltage will be zero. A voltmeter placed across the load as shown in Figure 2 will read zero.

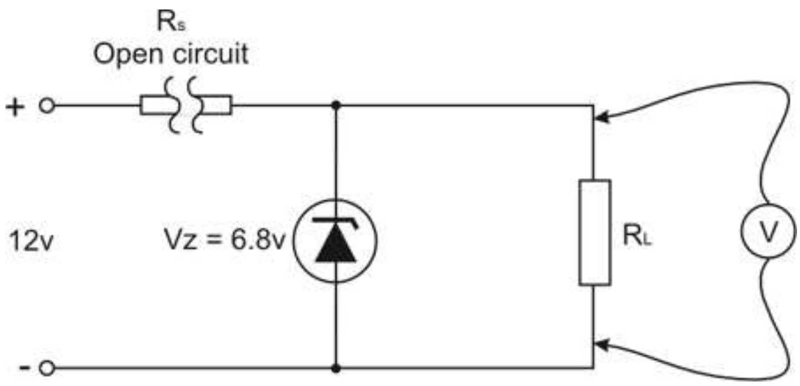


Figure 2. R_S open circuit

Question 3.
If a voltmeter is now re-positioned to be across R_S as shown in Figure 3, what meter reading is expected of R_S in an open circuit?

V_{RS} =

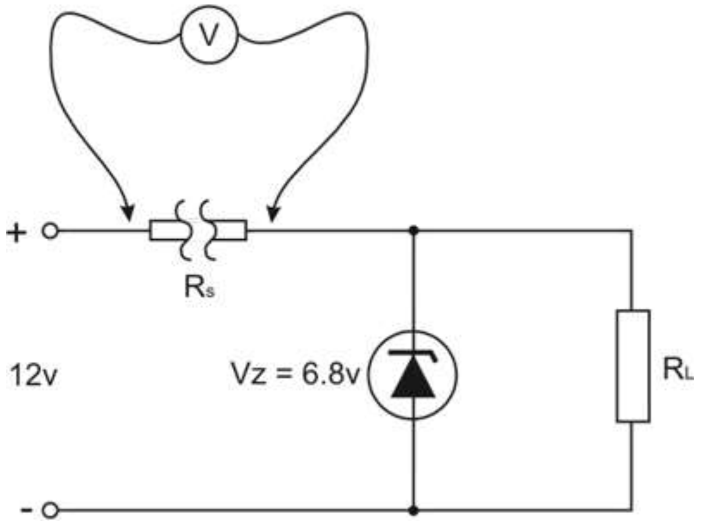


Figure 3. R_S open circuit

Zener Diode Open Circuit

If the zener diode becomes an open circuit, current will continue to flow to the load via the series resistor R_S. However the series resistor R_S and the load resistance act as a voltage divider.

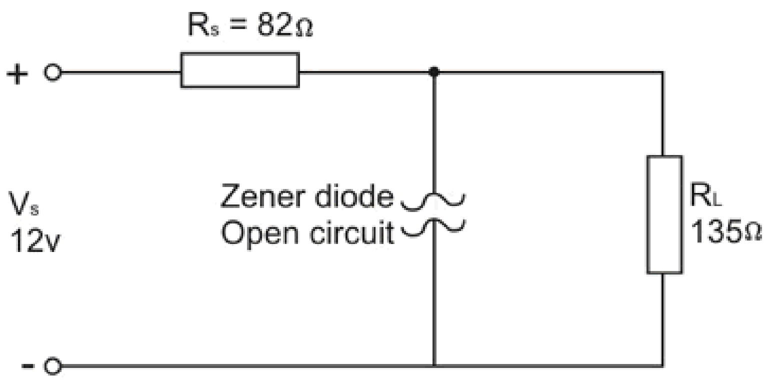


Figure 4. Zener diode open circuit

Question 4.
Now calculate the load voltage for the circuit of Figure 4.

V_{RL} =

Inspection of the circuit shows that a rise in load voltage can be expected if the zener diode becomes an open circuit. This is because $_{RS}$ will no longer provide zener diode current and it will therefore have a lower voltage drop. The load must consequently have a higher voltage dropped across it.

Zener Diode Short Circuit

In the event of the zener diode becoming a short circuit, current will bypass the load in preference for the easier path through the short circuited zener diode.

The voltage across the load will therefore be zero because the voltage across zero ohms is zero volts.

Question 5.
If the voltage across the load is zero volts, what is the voltage across the series resistor?

V_{RS} =

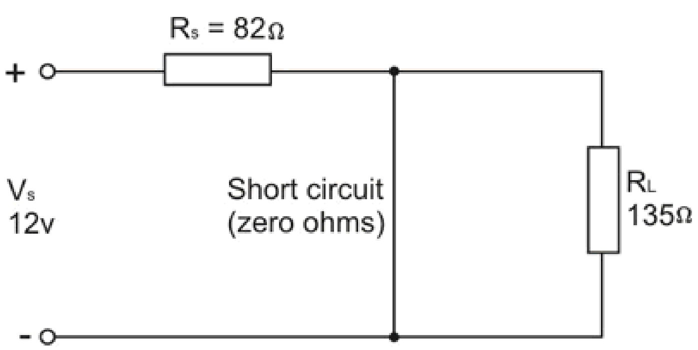


Figure 5. Zener diode short circuit

Faults in Simple Series Regulator

As the complexity of a circuit increases the number of possible faults increases also. A few of the possible faults in a simple series regulator are considered below.

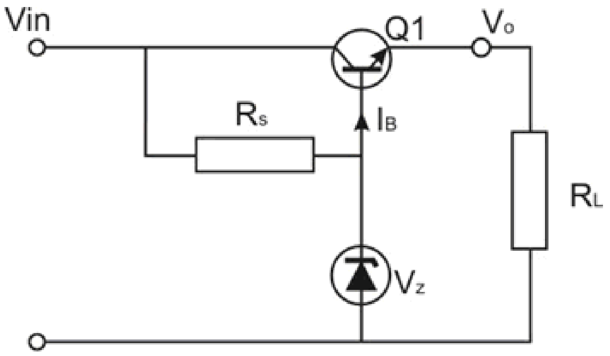


Figure 6. Simple series regulator

Question 6.
If the fault in the circuit on Figure 6 is an open circuit R_S, how much base current will flow into Q_1?

R_S – Open Circuit

If there is no base current to Q_1 there will be no emitter current (remember that emitter current is directly proportional to base current). Therefore the load voltage is zero.

Zener Diode – Open Circuit

If the zener diode becomes an open circuit, more current will go to the base of Q_1. Therefore Q_1 will conduct more and the output voltage will rise.

Zener Diode – Short Circuit

If the d becomes a short circuit then all the current trough R_S will pass through the shorted diode and none will go to the base of Q_1.

Question 7.
If the base current to Q_1 is zero, escribe the effect this will have on emitter current and load voltage.

Q_1 Short Circuit

If the pass transistor gets too hot, for example by a brief accidental short across the load, the pass transistor may become a short circuit between collector and emitter.

Question 8.
If Q_1 becomes a short circuit between collector and emitter, what is the likely effect on the output voltage?

Faults in IC Regulator Circuits

Consider the fixed voltage IC regulator circuit on in Figure 7.

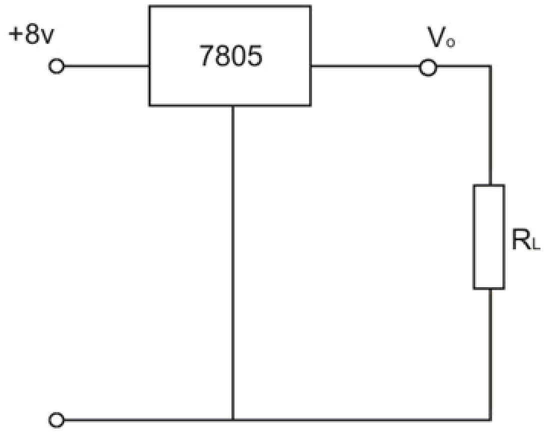


Figure 7. Three terminal regulator

Question 9.
State the value of the expected output voltage of the circuit in Figure 7 is functioning normally.

Question 10.
Consider the case when a fault develops in the IC that make is behave like a short circuit between input and output. What will be the expected output voltage?

Question 11.
State the expected output voltage if the IC develops a fault that makes it an open circuit.

When a three terminal regulator is used with external components a fault may develop in either the IC or one of the external components.

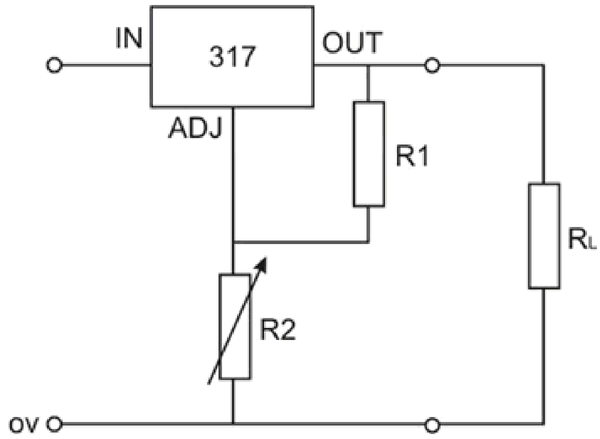


Figure 8. Adjustable regulator

If a short circuit or open circuit develops in the IC in Figure 8 then the fault symptoms will be the same as those discussed previously for the fixed voltage regulator. Let's now look at possible faults in the external components

R_1 Open Circuit

If R_1 becomes an open circuit the voltage between the output and the adjustment pin will remain at the nominal 1.25V of the 317 regulator. However the voltage across R_2 will be solely due to the adjustment pin quiescent current. The voltage across R_2 will therefore be very small because the quiescent current for a 317 is typically less than 100uA.

The output voltage will be approximately equal to 1.25V for a 317 regulator.

R_2 Short Circuit

If R_2 becomes a short circuit the voltage across it will be zero. The output voltage will therefore be equal to the nominal value of 1.25V of the 317 regulator.

R_2 Open Circuit

The other possible fault condition is for R_2 to become an open circuit. This would cause the output voltage to become almost as high as the unregulated input voltage.

Self Evaluation Test

1. The zener regulator shown in Figure 9 has a fault. From the following measurements determine the likely fault. Explain your answer.

   V_{RS} = 12V V_{RL} = 0V

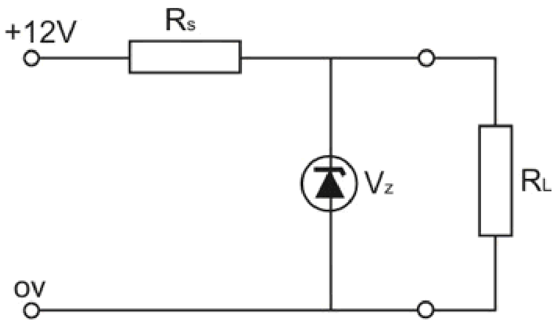


Figure 9. Shunt zener regulator

2. The zener regulator shown in Figure 10 has a fault. From the following measurements determine the likely fault. Explain your answer.
   V_{RS} = 2.4 V_{RL} = 9.6

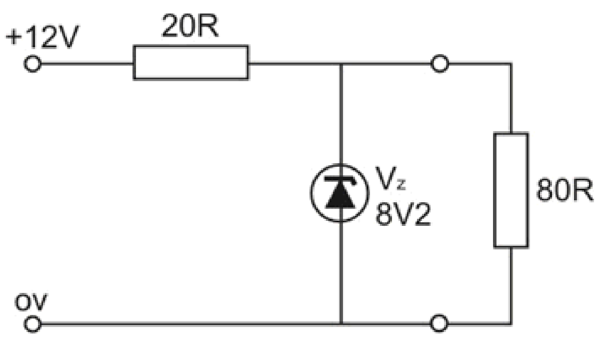


Figure 10. Shunt zener regulator

3. In the circuit of Figure 11 below, the output voltage is measured to be approximately 16V. The transistor Q_1 Is tested and found to be in working order.
State the likely fault.

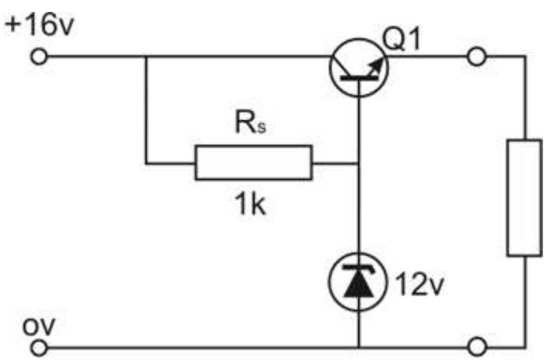


Figure 11. Series transistor regulator

4. In the circuit below the output voltage is measured to be 0V. The transistor Q_1 is tested and found to be in working order.
State the likely fault.

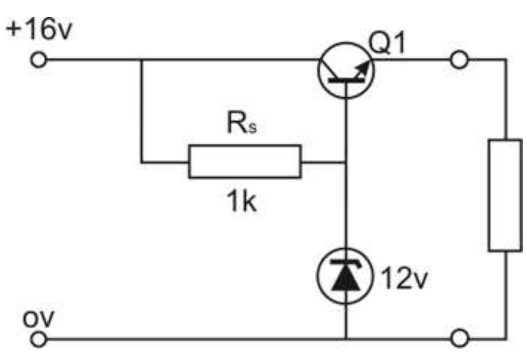


Figure 12. Series transistor fault

5. State the expected voltage across the 100R resistor in Figure 13 under the following conditions:
   a) normal circuit operation

   ---

   b) $Ic_{1=1}$ is a short circuit between the input and output

   ---

   c) Ic_1 is an open circuit between the input and output

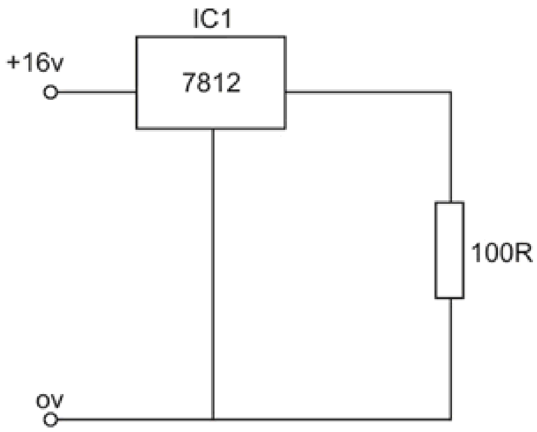


Figure 13. Fixed voltage three terminal regulator

6. For the circuit of Figure 14, state the expected voltage across the 150R resistor under the following conditions:
   a) R_1 is an open circuit

   ---

   b) R_2 is a short circuit

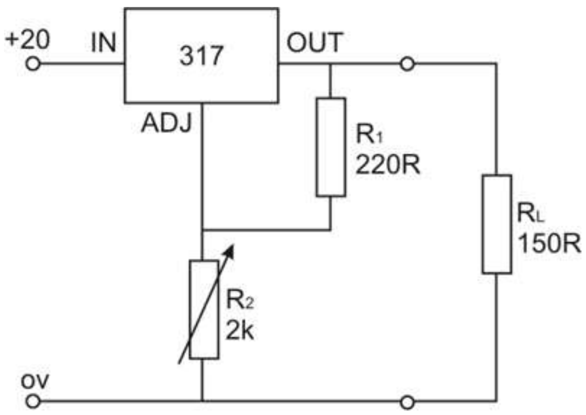


Figure 14. Adjustable voltage three terminal regulator

Answers to Questions

1. 6.8V
2. 5.2V (12-6.8)
3. 12V
4. 7.47V
5. 12V
6. Zero base current
7. The emitter will be zero and the load voltage will be zero
8. The output voltage will become high, approximately equal to the unregulated input voltage
9. 5V (This can be found in the data sheets)
10. The output voltage will become high, approximately equal to the unregulated input voltage.
11. 0V

Answers to Self Evaluation Test

1. The fault could be one of two things:
   a. an open circuit R_S, the load current will be zero and thus the load voltage will be zero.
   b) a short circuit zener diode, the voltage across a sort circuit is zero and so the load voltage will be zero.
2. The circuit is functioning as a voltage divider and so the zener diode is an open circuit
3. The zener diode is likely to be an open circuit. The base current will be larger than normal and the emitter current will also be proportionally larger. This will cause the output voltage to rise.
4. The 1k resistor is likely to be an open circuit. This will reduce the base current to zero. This results in zero emitter current and zero output voltage.
5. a) 12V
   b) 16V
   c) 0V
6. a) 1.25V
   b) 1.25V

10. Data Sheets

Device	Description
LM109/LM309	5 Volt Regulator
LM117/LM317	Three Terminal Adjustable Regulator
LM78XX	Series Voltage Regulators
1N4001	Standard Recovery Rectifiers
1N4728/1N4764	1W Zener Regulator Diodes
1N5400/1N5406	Standard Recovery Diodes

National Semiconductor

April 1998

LM109/LM309
5-Volt Regulator

General Description

The LM109 series are complete 5V regulators fabricated on a single silicon chip. They are designed for local regulation on digital logic cards, eliminating the distribution problems association with single-point regulation. The devices are available in two standard transistor packages. In the solid-kovar TO-5 header, it can deliver output currents in excess of 200 mA, if adequate heat sinking is provided. With the TO-3 power package, the available output current is greater than 1A.

The regulators are essentially blowout proof. Current limiting is included to limit the peak output current to a safe value. In addition, thermal shutdown is provided to keep the IC from overheating. If internal dissipation becomes too great, the regulator will shut down to prevent excessive heating.

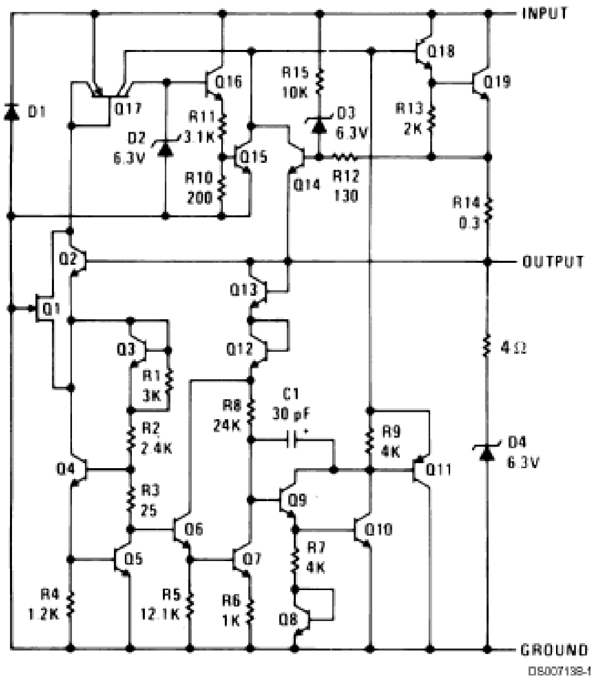
Considerable effort was expended to make these devices easy to use and to minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response somewhat. Input bypassing is needed, however, if the regulator is located very far from the filter capacitor of the power supply. Stability is also achieved by methods that provide very good rejection of load or line transients as are usually seen with TTL logic.

Although designed primarily as a fixed-voltage regulator, the output of the LM109 series can be set to voltages above 5V, as shown. It is also possible to use the circuits as the control element in precision regulators, taking advantage of the good current-handling capability and the thermal overload protection.

Features

- Specified to be compatible, worst case, with TTL and DTL
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required

Schematic Diagram



 DS007138 www.national.com

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Input Voltage	35V
Power Dissipation	Internally Limited
Operating Junction Temperature Range	
LM109	−55˚C to +150˚C
LM309	0˚C to +125˚C
Storage Temperature Range	−65˚C to +150˚C
Lead Temperature (Soldering, 10 sec.)	300˚C

Electrical Characteristics (Note 2)

Parameter	Conditions	LM109			LM309			Units
		Min	Typ	Max	Min	Typ	Max	
Output Voltage	T_j = 25˚C	4.7	5.05	5.3	4.8	5.05	5.2	V
Line Regulation	T_j = 25˚C 7.10V ≤ V_{IN} ≤ 25V		4.0	50		4.0	50	mV
Load Regulation	T_j = 25˚C							
TO-39 Package	5 mA ≤ I_{OUT} ≤ 0.5A		15	50		15	50	mV
TO-3 Package	5 mA ≤ I_{OUT} ≤ 1.5A		15	100		15	100	mV
Output Voltage	7.40V ≤ V_{IN} ≤ 25V, 5 mA ≤ I_{OUT} ≤ I_{MAX}, P < P_{MAX}	4.6		5.4	4.75		5.25	V
Quiescent Current	7.40V ≤ V_{IN} ≤ 25V		5.2	10		5.2	10	mA
Quiescent Current Change	7.40V ≤ V_{IN} ≤ 25V			0.5			0.5	mA
	5 mA ≤ I_{OUT} ≤ I_{MAX}			0.8			0.8	mA
Output Noise Voltage	T_A = 25˚C 10 Hz ≤ f ≤ 100 kHz		40			40		μV
Long Term Stability			10			20		mV
Ripple Rejection	T_j = 25˚C	50			50			dB
Thermal Resistance, Junction to Case	(Note 3)							
TO-39 Package			15			15		˚C/W
TO-3 Package			2.5			2.5		˚C/W

Note 1: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

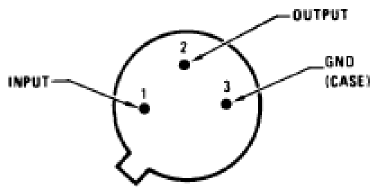
Note 2: Unless otherwise specified, these specifications apply −55˚C ≤ T_j ≤ +150˚C for the LM109 and 0˚C ≤ T_j ≤ +125˚C for the LM309; V_{IN} = 10V; and I_{OUT} = 0.1A for the TO-39 package or I_{OUT} = 0.5A for the TO-3 package. For the TO-39 package, I_{MAX} = 0.2A and P_{MAX} = 2.0W. For the TO-3 package, I_{MAX} = 1.0A and P_{MAX} = 20W.

Note 3: Without a heat sink, the thermal resistance of the TO-39 package is about 150˚C/W, while that of the TO-3 package is approximately 35˚C/W. With a heat sink, the effective thermal resistance can only approach the values specified, depending on the efficiency of the sink.

Note 4: Refer to RETS109H drawing for LM109H or RETS109K drawing for LM109K military specifications.

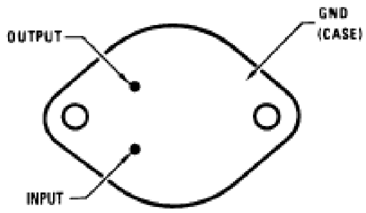
Connection Diagrams

Metal Can Packages



DS007138-33

Order Number LM109H, LM109H/883 or LM309H
See NS Package Number H03A



DS007138-34

Order Number LM109K STEEL or LM309K STEEL
See NS Package Number K02A
Order Number LM109K/883
See NS Package Number K02C

National Semiconductor

August 1999

LM117/LM317A/LM317 3-Terminal Adjustable Regulator

General Description

The LM117 series of adjustable 3-terminal positive voltage regulators is capable of supplying in excess of 1.5A over a 1.2V to 37V output range. They are exceptionally easy to use and require only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, the LM117 is packaged in standard transistor packages which are easily mounted and handled.

In addition to higher performance than fixed regulators, the LM117 series offers full overload protection available only in IC's. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An optional output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejection ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM117 is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded, i.e., avoid short-circuiting the output.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment pin and output, the LM117 can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

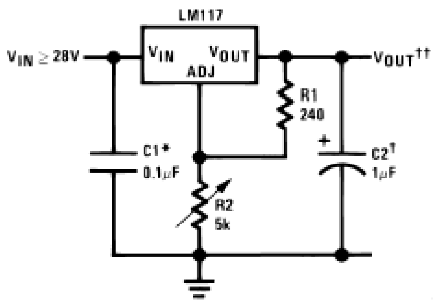
For applications requiring greater output current, see LM150 series (3A) and LM138 series (5A) data sheets. For the negative complement, see LM137 series data sheet.

Features

- Guaranteed 1% output voltage tolerance (LM317A)
- Guaranteed max. 0.01%/V line regulation (LM317A)
- Guaranteed max. 0.3% load regulation (LM117)
- Guaranteed 1.5A output current
- Adjustable output down to 1.2V
- Current limit constant with temperature
- P+ Product Enhancement tested
- 80 dB ripple rejection
- Output is short-circuit protected

Typical Applications

1.2V–25V Adjustable Regulator



Full output current not available at high input-output voltages

*Needed if device is more than 6 inches from filter capacitors.

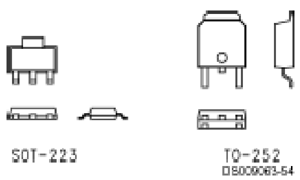
†Optional — improves transient response. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

$$††V_{OUT} = 1.25V\left(1+\frac{R2}{R1}\right) + I_{ADJ}(R_2)$$

LM117 Series Packages

Part Number Suffix	Package	Design Load Current
K	TO-3	1.5A
H	TO-39	0.5A
T	TO-220	1.5A
E	LCC	0.5A
S	TO-263	1.5A
EMP	SOT-223	1A
MDT	TO-252	0.5A

SOT-223 vs D-Pak (TO-252) Packages



Scale 1:1

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Power Dissipation	Internally Limited
Input-Output Voltage Differential	+40V, −0.3V
Storage Temperature	−65˚C to +150˚C
Lead Temperature	
Metal Package (Soldering, 10 seconds)	300˚C
Plastic Package (Soldering, 4 seconds)	260˚C
ESD Tolerance (Note 5)	3 kV

Operating Temperature Range

LM117	$-55^\circ C \le T_J \le +150^\circ C$
LM317A	$-40^\circ C \le T_J \le +125^\circ C$
LM317	$0^\circ C \le T_J \le +125^\circ C$

Preconditioning

Thermal Limit Burn-In	All Devices 100%

Electrical Characteristics (Note 3)

Specifications with standard type face are for T_J = 25˚C, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} - V_{OUT}$ = 5V, and I_{OUT} = 10 mA.

Parameter	Conditions	LM117 (Note 2)			Units
		Min	Typ	Max	
Reference Voltage					V
	$3V \le (V_{IN} - V_{OUT}) \le 40V$, $10\ mA \le I_{OUT} \le I_{MAX}$, $P \le P_{MAX}$	**1.20**	**1.25**	**1.30**	V
Line Regulation	$3V \le (V_{IN} - V_{OUT}) \le 40V$ (Note 4)		0.01	0.02	%/V
			0.02	**0.05**	%/V
Load Regulation	$10\ mA \le I_{OUT} \le I_{MAX}$ (Note 4)		0.1	0.3	%
			0.3	**1**	%
Thermal Regulation	20 ms Pulse		0.03	0.07	%/W
Adjustment Pin Current			**50**	**100**	µA
Adjustment Pin Current Change	$10\ mA \le I_{OUT} \le I_{MAX}$ $3V \le (V_{IN} - V_{OUT}) \le 40V$		**0.2**	**5**	µA
Temperature Stability	$T_{MIN} \le T_J \le T_{MAX}$		**1**		%
Minimum Load Current	$(V_{IN} - V_{OUT})$ = 40V		**3.5**	**5**	mA
Current Limit	$(V_{IN} - V_{OUT}) \le 15V$				
	K Package	**1.5**	**2.2**	**3.4**	A
	H Packages	**0.5**	**0.8**	**1.8**	A
	$(V_{IN} - V_{OUT})$ = 40V				
	K Package	0.3	0.4		A
	H Package	0.15	0.2		A
RMS Output Noise, % of V_{OUT}	$10\ Hz \le f \le 10\ kHz$		0.003		%
Ripple Rejection Ratio	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 0 µF		65		dB
	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 10 µF	**66**	80		dB
Long-Term Stability	T_J = 125˚C, 1000 hrs		0.3	1	%
Thermal Resistance, Junction-to-Case	K Package		2.3	3	˚C/W
	H Package		12	15	˚C/W
	E Package				˚C/W
Thermal Resistance, Junction-to-Ambient (No Heat Sink)	K Package		35		˚C/W
	H Package		140		˚C/W
	E Package				˚C/W

National Semiconductor

May 2000

LM78XX
Series Voltage Regulators

General Description

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expanded to make the LM78XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

Features

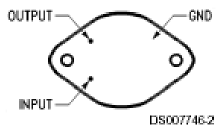
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

Voltage Range

LM7805C	5V
LM7812C	12V
LM7815C	15V

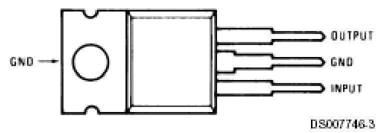
Connection Diagrams

Metal Can Package
TO-3 (K)
Aluminum



Bottom View
Order Number LM7805CK,
LM7812CK or LM7815CK
See NS Package Number KC02A

Plastic Package
TO-220 (T)



Top View
Order Number LM7805CT,
LM7812CT or LM7815CT
See NS Package Number T03B

Absolute Maximum Ratings (Note 3)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Input Voltage	
(V_O = 5V, 12V and 15V)	35V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range (T_A)	0°C to +70°C
Maximum Junction Temperature	
(K Package)	150°C
(T Package)	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package K	300°C
TO-220 Package T	230°C

Electrical Characteristics LM78XXC (Note 2)

0°C ≤ T_J ≤ 125°C unless otherwise noted.

		Output Voltage		5V			12V			15V			Units
		Input Voltage (unless otherwise noted)		10V			19V			23V			
Symbol	**Parameter**	**Conditions**		**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	Tj = 25°C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)			V
ΔV_O	Line Regulation	I_O = 500 mA	Tj = 25°C		3	50		4	120		4	150	mV
			ΔV_{IN}	(7 ≤ V_{IN} ≤ 25)			14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)			V
			0°C ≤ Tj ≤ +125°C			50			120			150	mV
			ΔV_{IN}	(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)			V
		I_O ≤ 1A	Tj = 25°C			50			120			150	mV
			ΔV_{IN}	(7.5 ≤ V_{IN} ≤ 20)			(14.6 ≤ V_{IN} ≤ 27)			(17.7 ≤ V_{IN} ≤ 30)			V
			0°C ≤ Tj ≤ +125°C			25			60			75	mV
			ΔV_{IN}	(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)			V
ΔV_O	Load Regulation	Tj = 25°C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			25			60			75	mV
		5 mA ≤ I_O ≤ 1A, 0°C ≤ Tj ≤ +125°C				50			120			150	mV
I_Q	Quiescent Current	I_O ≤ 1A	Tj = 25°C			8			8			8	mA
			0°C ≤ Tj ≤ +125°C			8.5			8.5			8.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A				0.5			0.5			0.5	mA
		Tj = 25°C, I_O ≤ 1A				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN}≤ 27)			(17.9 ≤ V_{IN} ≤ 30)			V
		I_O ≤ 500 mA, 0°C ≤ Tj ≤ +125°C				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(7 ≤ V_{IN} ≤ 25)			(14.5 ≤ V_{IN}≤ 30)			(17.5 ≤ V_{IN} ≤ 30)			V
V_N	Output Noise Voltage	T_A =25°C, 10 Hz ≤ f ≤ 100 kHz			40			75			90		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection		I_O ≤ 1A, Tj = 25°C or	62	80		55	72		54	70		dB
		f = 120 Hz	I_O ≤ 500 mA 0°C ≤ Tj ≤ +125°C	62			55			54			dB
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)			V
R_O	Dropout Voltage	Tj = 25°C, I_{OUT} = 1A			2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz			8			18			19		mΩ

Electrical Characteristics LM78XXC (Note 2) (Continued)

0°C ≤ T_J ≤ 125°C unless otherwise noted.

Output Voltage			5V			12V			15V			Units
Input Voltage (unless otherwise noted)			10V			19V			23V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
	Short-Circuit Current	Tj = 25°C		2.1			1.5			1.2		A
	Peak Output Current	Tj = 25°C		2.4			2.4			2.4		A
	Average TC of V_{OUT}	0°C ≤ Tj ≤ +125°C, I_O = 5 mA		0.6			1.5			1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	Tj = 25°C, I_O ≤ 1A		7.5		14.6			17.7			V

Note 1: Thermal resistance of the TO-3 package (K, KC) is typically 4°C/W junction to case and 35°C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4°C/W junction to case and 50°C/W case to ambient.

Note 2: All characteristics are measured with capacitor across the input of 0.22 µF, and a capacitor across the output of 0.1µF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_W ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

Note 3: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. For guaranteed specifications and the test conditions, see Electrical Characteristics.

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

Order this document
by 1N4001/D

Axial Lead Standard Recovery Rectifiers

This data sheet provides information on subminiature size, axial lead mounted rectifiers for general–purpose low–power applications.

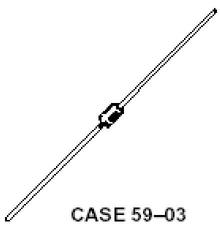
1N4001 thru 1N4007

1N4004 and 1N4007 are Motorola Preferred Devices

LEAD MOUNTED RECTIFIERS 50–1000 VOLTS DIFFUSED JUNCTION

Mechanical Characteristics

- Case: Epoxy, Molded
- Weight: 0.4 gram (approximately)
- Finish: All External Surfaces Corrosion Resistant and Terminal Leads are Readily Solderable
- Lead and Mounting Surface Temperature for Soldering Purposes: 220°C Max. for 10 Seconds, 1/16″ from case
- Shipped in plastic bags, 1000 per bag.
- Available Tape and Reeled, 5000 per reel, by adding a "RL" suffix to the part number
- Polarity: Cathode Indicated by Polarity Band
- Marking: 1N4001, 1N4002, 1N4003, 1N4004, 1N4005, 1N4006, 1N4007



CASE 59–03
DO–41

MAXIMUM RATINGS

Rating	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
*Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
*Non–Repetitive Peak Reverse Voltage (halfwave, single phase, 60 Hz)	V_{RSM}	60	120	240	480	720	1000	1200	Volts
*RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
*Average Rectified Forward Current (single phase, resistive load, 60 Hz, see Figure 8, T_A = 75°C)	I_O	1.0							Amp
*Non–Repetitive Peak Surge Current (surge applied at rated load conditions, see Figure 2)	I_{FSM}	30 (for 1 cycle)							Amp
Operating and Storage Junction Temperature Range	T_J T_{stg}	– 65 to +175							°C

ELECTRICAL CHARACTERISTICS*

Rating	Symbol	Typ	Max	Unit
Maximum Instantaneous Forward Voltage Drop (i_F = 1.0 Amp, T_J = 25°C) Figure 1	v_F	0.93	1.1	Volts
Maximum Full–Cycle Average Forward Voltage Drop (I_O = 1.0 Amp, T_L = 75°C, 1 inch leads)	$V_{F(AV)}$	—	0.8	Volts
Maximum Reverse Current (rated dc voltage) (T_J = 25°C) (T_J = 100°C)	I_R	 0.05 1.0	 10 50	µA
Maximum Full–Cycle Average Reverse Current (I_O = 1.0 Amp, T_L = 75°C, 1 inch leads)	$I_{R(AV)}$	—	30	µA

*Indicates JEDEC Registered Data

***ELECTRICAL CHARACTERISTICS** (T_A = 25°C unless otherwise noted) V_F = 1.2 V Max, I_F = 200 mA for all types.

JEDEC Type No. (Note 1)	Nominal Zener Voltage V_Z @ I_{ZT} Volts (Notes 2 and 3)	Test Current I_{ZT} mA	Maximum Zener Impedance (Note 4)			Leakage Current		Surge Current @ T_A = 25°C i_r – mA (Note 5)
			Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} @ I_{ZK} Ohms	I_{ZK} mA	I_R µA Max	V_R Volts	
1N4728A	3.3	76	10	400	1	100	1	1380
1N4729A	3.6	69	10	400	1	100	1	1260
1N4730A	3.9	64	9	400	1	50	1	1190
1N4731A	4.3	58	9	400	1	10	1	1070
1N4732A	4.7	53	8	500	1	10	1	970
1N4733A	5.1	49	7	550	1	10	1	890
1N4734A	5.6	45	5	600	1	10	2	810
1N4735A	6.2	41	2	700	1	10	3	730
1N4736A	6.8	37	3.5	700	1	10	4	660
1N4737A	7.5	34	4	700	0.5	10	5	605
1N4738A	8.2	31	4.5	700	0.5	10	6	550
1N4739A	9.1	28	5	700	0.5	10	7	500
1N4740A	10	25	7	700	0.25	10	7.6	454
1N4741A	11	23	8	700	0.25	5	8.4	414
1N4742A	12	21	9	700	0.25	5	9.1	380
1N4743A	13	19	10	700	0.25	5	9.9	344
1N4744A	15	17	14	700	0.25	5	11.4	304
1N4745A	16	15.5	16	700	0.25	5	12.2	285
1N4746A	18	14	20	750	0.25	5	13.7	250
1N4747A	20	12.5	22	750	0.25	5	15.2	225
1N4748A	22	11.5	23	750	0.25	5	16.7	205
1N4749A	24	10.5	25	750	0.25	5	18.2	190
1N4750A	27	9.5	35	750	0.25	5	20.6	170
1N4751A	30	8.5	40	1000	0.25	5	22.8	150
1N4752A	33	7.5	45	1000	0.25	5	25.1	135
1N4753A	36	7	50	1000	0.25	5	27.4	125
1N4754A	39	6.5	60	1000	0.25	5	29.7	115
1N4755A	43	6	70	1500	0.25	5	32.7	110
1N4756A	47	5.5	80	1500	0.25	5	35.8	95
1N4757A	51	5	95	1500	0.25	5	38.8	90
1N4758A	56	4.5	110	2000	0.25	5	42.6	80
1N4759A	62	4	125	2000	0.25	5	47.1	70
1N4760A	68	3.7	150	2000	0.25	5	51.7	65
1N4761A	75	3.3	175	2000	0.25	5	56	60
1N4762A	82	3	200	3000	0.25	5	62.2	55
1N4763A	91	2.8	250	3000	0.25	5	69.2	50
1N4764A	100	2.5	350	3000	0.25	5	76	45

*Indicates JEDEC Registered Data.

NOTE 1. TOLERANCE AND TYPE NUMBER DESIGNATION

The JEDEC type numbers listed have a standard tolerance on the nominal zener voltage of ±5%. C for ±2%, D for ±1%.

NOTE 2. SPECIALS AVAILABLE INCLUDE:

Nominal zener voltages between the voltages shown and tighter voltage tolerances.

For detailed information on price, availability, and delivery, contact your nearest Motorola representative.

NOTE 3. ZENER VOLTAGE (V_Z) MEASUREMENT

Motorola guarantees the zener voltage when measured at 90 seconds while maintaining the lead temperature (T_L) at 30°C ± 1°C, 3/8″ from the diode body.

NOTE 4. ZENER IMPEDANCE (Z_Z) DERIVATION

The zener impedance is derived from the 60 cycle ac voltage, which results when an ac current having an rms value equal to 10% of the dc zener current (I_{ZT} or I_{ZK}) is superimposed on I_{ZT} or I_{ZK}.

NOTE 5. SURGE CURRENT (i_r) NON-REPETITIVE

The rating listed in the electrical characteristics table is maximum peak, non-repetitive, reverse surge current of 1/2 square wave or equivalent sine wave pulse of 1/120 second duration superimposed on the test current, I_{ZT}, per JEDEC registration; however, actual device capability is as described in Figure 5 of the General Data — DO-41 Glass.

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

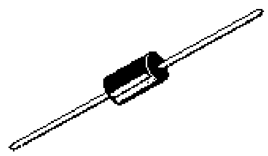
Order this document
by 1N5400/D

Axial-Lead Standard Recovery Rectifiers

1N5400 thru 1N5408

1N5404 and 1N5406 are Motorola Preferred Devices

STANDARD RECOVERY RECTIFIERS 50–1000 VOLTS 3.0 AMPERE



CASE 267–03

Lead mounted standard recovery rectifiers are designed for use in power supplies and other applications having need of a device with the following features:

- High Current to Small Size
- High Surge Current Capability
- Low Forward Voltage Drop
- Void–Free Economical Plastic Package
- Available in Volume Quantities

Mechanical Characteristics

- Case: Epoxy, Molded
- Weight: 1.1 gram (approximately)
- Finish: All External Surfaces Corrosion Resistant and Terminal Leads are Readily Solderable
- Lead and Mounting Surface Temperature for Soldering Purposes: 220°C Max. for 10 Seconds, 1/16″ from case
- Shipped in plastic bags, 5,000 per bag.
- Available Tape and Reeled, 1500 per reel, by adding a “RL” suffix to the part number
- Polarity: Cathode Indicated by Polarity Band
- Marking: 1N5400, 1N5401, 1N5402, 1N5404, 1N5406, 1N5407, 1N5408

MAXIMUM RATINGS

Rating	Symbol	1N5400	1N5401	1N5402	1N5404	1N5406	1N5407	1N5408	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Non–repetitive Peak Reverse Voltage	V_{RSM}	100	200	300	525	800	1000	1200	Volts
Average Rectified Forward Current (Single Phase Resistive Load, 1/2″ Leads, T_L = 105°C)	I_O	3.0							Amp
Non–repetitive Peak Surge Current (Surge Applied at Rated Load Conditions)	I_{FSM}	200 (one cycle)							Amp
Operating and Storage Junction Temperature Range	T_J T_{stg}	– 65 to +170 – 65 to +175							°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Typ	Unit
Thermal Resistance, Junction to Ambient (PC Board Mount, 1/2″ Leads)	$R_{\theta JA}$	53	°C/W

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
*Instantaneous Forward Voltage (1) (i_F = 9.4 Amp)	v_F	—	—	1.2	Volts
Average Reverse Current (1) DC Reverse Current (Rated dc Voltage, T_L = 80°C)	$I_{R(AV)}$ I_R	— —	— —	500 500	µA

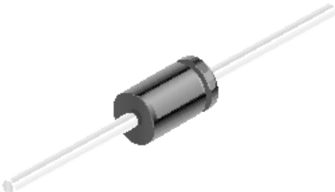
* JEDEC Registered Data.
(1) Measured in a single phase halfwave circuit such as shown in Figure 6.25 of EIA RS–282, November 1963. Operated at rated load conditions T_L = 80°C, I_O = 3.0 A, V_r = V_{RWM}.
Preferred devices are Motorola recommended choices for future use and best overall value.
Ratings at 25°C ambient temperature unless otherwise specified.
60 Hz resistive or inductive loads.
For capacitive load, derate current by 20%.

FAIRCHILD
SEMICONDUCTOR®

1N4001 - 1N4007

Features

- Low forward voltage drop.
- High surge current capability.



DO-41
COLOR BAND DENOTES CATHODE

General Purpose Rectifiers (Glass Passivated)

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value							Units
		4001	4002	4003	4004	4005	4006	4007	
V_{RRM}	Peak Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
$I_{F(AV)}$	Average Rectified Forward Current, .375 " lead length @ T_A = 75°C	1.0							A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	30							A
T_{stg}	Storage Temperature Range	-55 to +175							°C
T_J	Operating Junction Temperature	-55 to +175							°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	3.0	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	50	°C/W

Electrical Characteristics T_A = 25°C unless otherwise noted

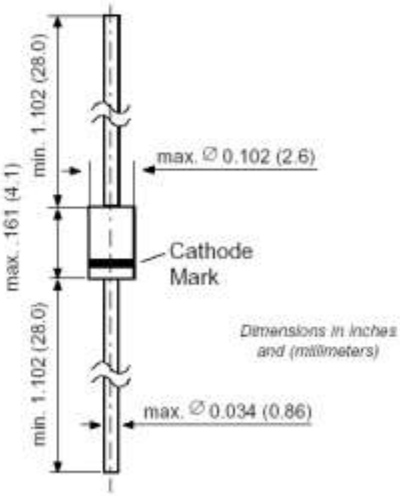
Symbol	Parameter	Device							Units
		4001	4002	4003	4004	4005	4006	4007	
V_F	Forward Voltage @ 1.0 A	1.1							V
I_{rr}	Maximum Full Load Reverse Current, Full Cycle T_A = 75°C	30							µA
I_R	Reverse Current @ rated V_R T_A = 25°C T_A = 100°C	5.0 500							µA µA
C_T	Total Capacitance V_R = 4.0 V, f = 1.0 MHz	15							pF

GENERAL SEMICONDUCTOR®

1N4728 thru 1N4764

Zener Diodes

DO-204AL (DO-41 Glass)



Features

- Silicon Planar Power Zener Diodes
- For use in stabilizing and clipping circuits with high power rating.
- Standard Zener voltage tolerance is ±10%. Add suffix "A" for ±5% tolerance. Other Zener voltages and tolerances are available upon request.
- These diodes are also available in the MELF case with type designation ZM4728 thru ZM4764
- For bidirectional product, contact local Technical Sales office.

Mechanical Data

Case: DO-41 Glass Case
Weight: approx. 0.35g
Packaging Codes/Options:
D9/5K per 13" reel (52mm tape), 10K/box
E1/5K per Ammo mag. (52mm tape), 10K/box

Maximum Ratings & Thermal Characteristics

Ratings at 25°C ambient temperature unless otherwise specified.

Parameter	Symbol	Value	Unit
Zener Current		See Next Page	
Power Dissipation at T_{amb} = 50°C	P_{tot}	1.0(1)	W
Thermal Resistance Junction to Ambient Air	$R_{\theta JA}$	170(1)	°C/W
Junction Temperature	T_j	200	°C
Storage Temperature Range	T_S	–65 to +200	°C

Note: (1) Valid provided that electrodes at a distance of 10mm from case are kept at ambient temperature.

GENERAL SEMICONDUCTOR®

1N4728 thru 1N4764

Zener Diodes

Electrical Characteristics (T_A = 25°C unless otherwise noted). Maximum V_F = 1.2V at I_F = 200mA

Type	Nominal Zener voltage[3] at I_{ZT} V_Z (V)	Test current I_{ZT} (mA)	Maximum Zener impedance[1] Z_{ZT} at I_{ZT} (Ω)	Maximum Zener impedance[1] Z_{ZK} (Ω)	Maximum Zener impedance[1] at I_{ZK} (mA)	Maximum reverse leakage current I_R (μA)	Maximum reverse leakage current at V_R (V)	Surge current at T_A = 25°C I_R (mA)	Maximum regulator current[2] at T_A = 50°C I_{ZM} (mA)
1N4728	3.3	76	10	400	1.0	100	1	1380	276
1N4729	3.6	69	10	400	1.0	100	1	1260	252
1N4730	3.9	64	9	400	1.0	50	1	1190	234
1N4731	4.3	58	9	400	1.0	10	1	1070	217
1N4732	4.7	53	8	500	1.0	10	1	970	193
1N4733	5.1	49	7	550	1.0	10	1	890	178
1N4734	5.6	45	5	600	1.0	10	2	810	162
1N4735	6.2	41	2	700	1.0	10	3	730	146
1N4736	6.8	37	3.5	700	1.0	10	4	660	133
1N4737	7.5	34	4.0	700	0.5	10	5	605	121
1N4738	8.2	31	4.5	700	0.5	10	6	550	110
1N4739	9.1	28	5.0	700	0.5	10	7	500	100
1N4740	10	25	7	700	0.25	10	7.6	454	91
1N4741	11	23	8	700	0.25	5	8.4	414	83
1N4742	12	21	9	700	0.25	5	9.1	380	76
1N4743	13	19	10	700	0.25	5	9.9	344	69
1N4744	15	17	14	700	0.25	5	11.4	304	61
1N4745	16	15.5	16	700	0.25	5	12.2	285	57
1N4746	18	14	20	750	0.25	5	13.7	250	50
1N4747	20	12.5	22	750	0.25	5	15.2	225	45
1N4748	22	11.5	23	750	0.25	5	16.7	205	41
1N4749	24	10.5	25	750	0.25	5	18.2	190	38
1N4750	27	9.5	35	750	0.25	5	20.6	170	34
1N4751	30	8.5	40	1000	0.25	5	22.8	150	30
1N4752	33	7.5	45	1000	0.25	5	25.1	135	27
1N4753	36	7.0	50	1000	0.25	5	27.4	125	25
1N4754	39	6.5	60	1000	0.25	5	29.7	115	23
1N4755	43	6.0	70	1500	0.25	5	32.7	110	22
1N4756	47	5.5	80	1500	0.25	5	35.8	95	19
1N4757	51	5.0	95	1500	0.25	5	38.8	90	18
1N4758	56	4.5	110	2000	0.25	5	42.6	80	16
1N4759	62	4.0	125	2000	0.25	5	47.1	70	14
1N4760	68	3.7	150	2000	0.25	5	51.7	65	13
1N4761	75	3.3	175	2000	0.25	5	56.0	60	12
1N4762	82	3.0	200	3000	0.25	5	62.2	55	11
1N4763	91	2.8	250	3000	0.25	5	69.2	50	10
1N4764	100	2.5	350	3000	0.25	5	76.0	45	9

Notes:

(1) The Zener impedance is derived from the 1KHz AC voltage which results when an AC current having an RMS value equal to 10% of the Zener current (I_{ZT} or I_{ZK}) is superimposed on I_{ZT} or I_{ZK}. Zener impedance is measured at two points to insure a sharp knee on the breakdown curve and to eliminate unstable units

(2) Valid provided that electrodes at a distance of 10mm from case are kept at ambient temperature

(3) Measured under thermal equilibrium and DC test conditions

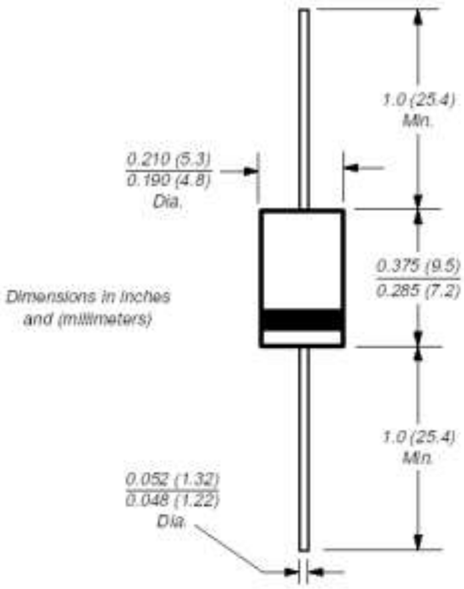
1N5400 thru 1N5408

Vishay Semiconductors
formerly General Semiconductor

General Purpose Plastic Rectifiers

Reverse Voltage 50 to 1000V
Forward Current 3.0A

DO-201AD



Features

- Plastic package has Underwriters Laboratories Flammability Classification 94V-0
- High surge current capability
- Construction utilizes void-free molded plastic technique
- 3.0 Ampere operation at T_L=105°C with no thermal runaway
- Typical I_R less than 0.1µA
- High temperature soldering guaranteed: 250°C/10 seconds, 0.375" (9.5mm) lead length, 5 lbs. (2.3kg) tension

Mechanical Data

Case: JEDEC DO-201AD, molded plastic body
Terminals: Plated axial leads, solderable per MIL-STD-750, Method 2026
Polarity: Color band denotes cathode end
Mounting Position: Any
Weight: 0.04 oz., 1.1 g

Maximum Ratings & Thermal Characteristics

Ratings at 25°C ambient temperature unless otherwise specified.

Parameter	Symb.	1N 5400	1N 5401	1N 5402	1N 5403	1N 5404	1N 5405	1N 5406	1N 5407	1N 5408	Unit
* Maximum repetitive peak reverse voltage	V_{RRM}	50	100	200	300	400	500	600	800	1000	V
* Maximum RMS voltage	V_{RMS}	35	70	140	210	280	350	420	560	700	V
* Maximum DC blocking voltage to T_A = 150°C	V_{DC}	50	100	200	300	400	500	600	800	1000	V
* Maximum average forward rectified current 0.5" (12.5mm) lead length at T_L = 105°C	$I_{F(AV)}$	3.0									A
* Peak forward surge current 8.3ms single half sine-wave superimposed on rated load (JEDEC Method) at T_L=105°C	I_{FSM}	200									A
* Maximum full load reverse current, full cycle average 0.5" (12.5mm) lead length at T_L = 105°C	$I_{R(AV)}$	500									µA
* Typical thermal resistance[(1)]	$R_{\theta JA}$	20									°C/W
Maximum DC blocking voltage temperature	T_A	+150									°C
* Operating junction and storage temperature range	T_J, T_{STG}	–50 to +170									°C

Electrical Characteristics

Ratings at 25°C ambient temperature unless otherwise specified.

Parameter	Condition	Symb.	Value	Unit
* Maximum instantaneous forward voltage at 3.0A		V_F	1.2	V
* Maximum DC reverse current at rated DC blocking voltage	T_A = 25°C T_A = 150°C	I_R	5 500	µA
Typical junction capacitance at 4.0V, 1MHz		C_J	30	pF

Note: (1) Thermal resistance from junction to ambient at 0.375" (9.5mm) lead length, P.C.B. mounted with 0.8 x 0.8" (20 x 20mm) copper heatsinks
*JEDEC registered values