HISTORY OF SEMICONDUCTORS:

Modern electronics may be considered to have begun in 1883 when Thomas Edison, experimenting with light bulbs, discovered what is now called the Edison Effect. Edison added a small metal plate to the light bulb in an attempt to improve its performance. He observed that a current would flow from the filament to the plate under certain conditions. However, since the addition of the plate did not help the performance of the light bulb it was merely noted and filed.

In 1898, J.A. Fleming studied the Edison Effect and made use of it as a vacuum tube diode for rectifying and detecting. He found it to be more sensitive than other devices in use at that time. In 1907 Lee Deforest added a third element, the control grid, to the diode in an attempt to increase its sensitivity. In doing so, he accidentally discovered the amplifying properties of the new tube called a triode.

Modern electronics advanced rapidly as the vacuum tube was studied and greatly improved. Its development led to such inventions as radio, television, radar, sonar, computers, and many special weapons control systems used by the armed forces in World War II.

In 1948, Dr. William Shockley and his associates discovered the ability of a germanium crystal to amplify as well as rectify. This had a revolutionary effect on the already well-established electronics industry.

The first transistors were very poor; they did not amplify much, produced no real power, developed great amounts of noise, worked only in the low frequency ranges and were extremely heat sensitive. However, because their potential advantages were so great, they were the subject of intense research. They offered the advantages of extreme simplicity, small power requirements, and small physical size.

At first transistors simply replaced vacuum tubes and provided the great advantages of saving space and power. Because of their special nature, transistors have been put to uses that can take advantage of these characteristics. There is no need to emphasize what a boon these characteristics have been to computers and space exploration.

STRUCTURE OF MATTER:

In order to clearly understand the internal operation of a transistor, we must briefly touch on the theory of the structure of matter. Matter is defined as any substance that has weight and occupies space. It can be a liquid, gas, or solid, i.e., water, air, or wood.

ELEMENTS AND COMPOUNDS:

Matter is made of one or more basic substances called ELEMENTS. An element is defined as a substance that can neither be broken up into other substances nor created by ordinary chemical means. To date scientists have discovered 105 elements, 13 of which are manmade. Examples of elements found in nature are gold, copper, aluminum, oxygen, hydrogen, and mercury.

MOLECULES:

If we divide water as far as we can, we have a single drop containing two hydrogen particles and one oxygen particle. If this MOLECULE of water were reduced any further, it would no longer be water but bits of hydrogen and oxygen. Thus a molecule is the smallest unit to which a compound can be reduced and still retain all its original properties and characteristics.

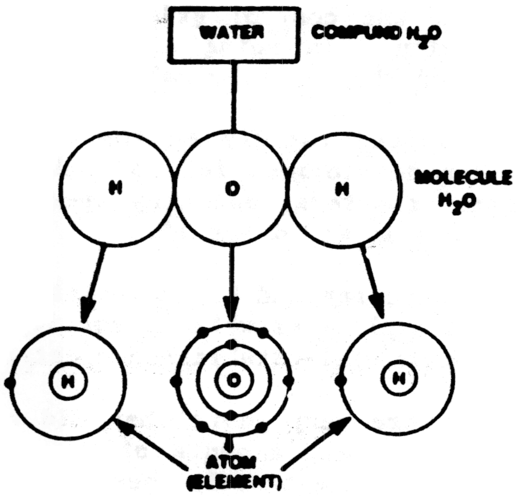

Fig 1.

ATOMS:

A single molecule of water contains two ATOMS of hydrogen and one atom of oxygen. An atom is the smallest particle into which an element can be divided and still keep its identity as an element.

SUBATOMIC PARTICLES:

At one time, it was thought that the atom was the smallest particle in existence. Today, we know it is composed of smaller subatomic particles.

The atom can be divided into two major parts. The NUCLEUS and orbiting ELECTRONS. Figure 2 shows the simplest known atom, hydrogen. The inner circle represents the nucleus and consists of a proton which has a positive (+) charge. The outer circle represents an electron circling the nucleus. The electron has a negative charge. Under normal conditions there will be the same number of protons and electrons in any given atom. Elements differ from one another in the number of protons and electrons their atoms contain.

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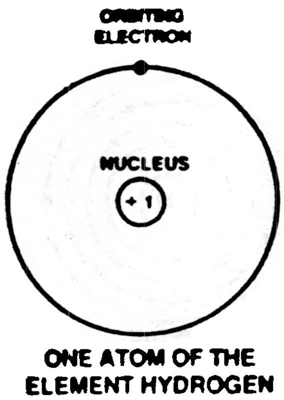


Fig 2

Figure 3 represents 4 different elements. Notice that each element has a different number of electrons and protons. All atoms of a particular element will contain the same number of electrons and protons. Silicon (Si) contains 14 protons in the nucleus and 14 orbiting electrons. The electrons are distributed in 3 rings.

Copper has 29 protons in the nucleus and 29 electrons. The electrons are distributed in 4 rings.

Each orbit is called a RING or SHELL and can contain only a certain number of electrons. The maximum number of rings any element can have is seven.

The last or outermost ring of any element is known as the VALENCE RING. Valence is defined as the ability of an element to combine with another element to form a molecule. The maximum number of electrons that can ever be present in the Valence ring is 8.

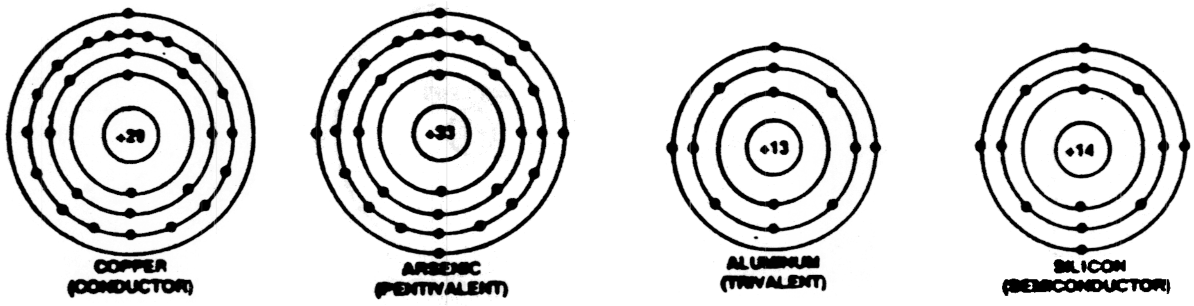


Fig 3.

The Valence ring is the only ring we will be interested in during the study of Semiconductors. It is the valence ring that determines how an atom may join with other atoms to form molecules. From this point on, the only electrons discussed will be valence electrons.

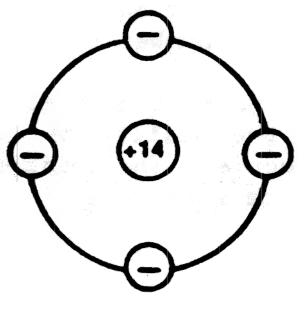


Fig 4.

Figure 4 indicates how atoms will be represented in drawings. Only the valence electrons will be indicated. It should be understood that the inner electrons are present but not shown.

CHARGES AND IONS:

Because the protons and electrons in an atom are equal in number, the atom is electrically balanced. In other words when the number of electrons equals the number of protons the charges cancel each other and the atom has no electrical charge. It is possible to transfer valence electrons from one atom to another under specific conditions. If an electron is removed from an atom the electrical balance no longer exists. The atom now has more protons (+) than electrons (-) and is now positively charged. If an atom accepts an extra electron it will have more electrons (-) than protons (+) and be negatively charged. When atoms are electrically unbalanced they are called IONS. They will be either negative ions or positive ions. Figure 5 shows a normal and an ionized silicon atom.

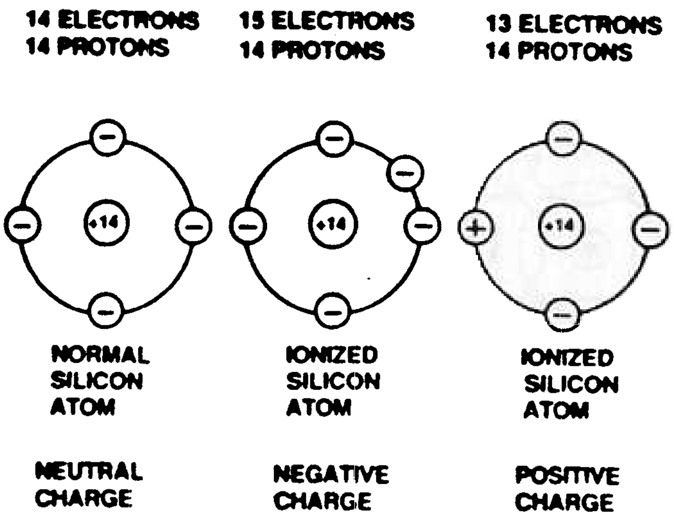


Fig 5.

INSULATORS, SEMICONDUCTORS AND CONDUCTORS

All matter may be classified as a conductor, semiconductor, or insulator depending on the characteristic of its valence ring.

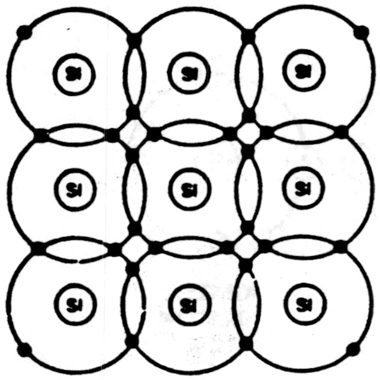
A material that permits electric current to flow through it is called a CONDUCTOR. The best conductors have 1 electron in the valence ring.

A good INSULATOR will not allow an electron current to flow. Insulators usually have 8 valence electrons.

A SEMICONDUCTOR is neither a good insulator or conductor. Typical semiconductor materials are GERMANIUM and SILICON. Both have valence shells containing 4 electrons.

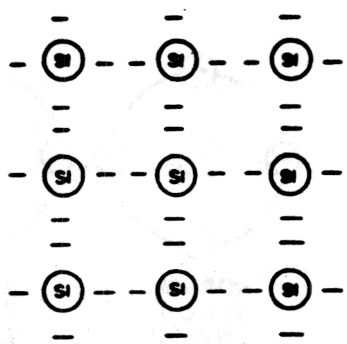
SEMICONDUCTOR COVALENT BONDING:

In its natural state a silicon atom has 4 electrons in its valence shell. As shown earlier, its valence shell is the third shell. Remember, the maximum number of electrons any atom can have in its valence shell is 8. If the third shell contains 8 electrons it is said to be stable and will not readily combine with another atom. Since there is a shortage of electrons in the valence shell of silicon it is unstable and will readily combine with another atom and share valence electrons. If many silicon atoms are brought together under favorable conditions, a sharing of valence electrons takes place among the atoms as shown in figure 6. Note the center atom shares its 4 valence atoms with 4 adjacent atoms. In turn these 4 atoms share their valence electrons with other atoms. The result is that all the silicon atoms form what is known as COVALENT BONDS.



A

SILICON ATOMS IN COVALENT BONDS SHARING VALENCE ELECTRONS



B

SIMPLIFIED VIEW OF SILICON COVALENT BONDS

Fig 6.

CRYSTALS

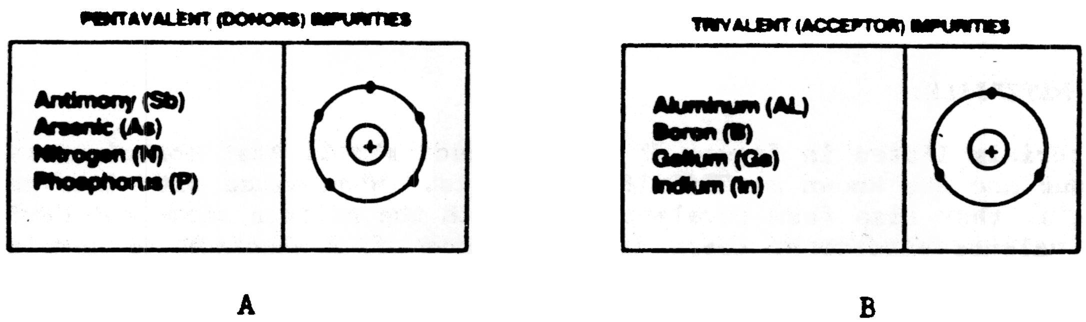
The joining of the silicon atoms by covalent bonding forms a crystal of pure silicon. A crystal is a material in which the atoms are arranged in a definite pattern that is repeated regularly in three dimensions. We have discussed the covalent bonding of silicon atoms to form a silicon crystal. Germanium atoms will also form covalent bonds to produce a germanium crystal in the same manner. A crystal in its pure form is known as an INTRINSIC material.

Ideally the crystal is 100% pure and displays no electrical charge. A crystal in its pure state has very limited use in electronics. The crystal must be modified to function properly as a useful semiconductor.

8

DOPED CRYSTALS

As mentioned, a pure silicon or germanium crystal is useless for semiconductor application. To make the crystalline material useful for semiconductor application we will add VERY SMALL amounts, (1 part in 10 million) of other elements to the intrinsic crystalline material. When these elements are added, the intrinsic material is no longer pure. Because the addition of these elements reduces the purity of the material to which they are added they are known as IMPURITIES. The addition of impurities to the intrinsic material is known as DOPING. The number of impurities that are added determines the DOPING LEVEL. The more impurities that are added to the instrinsic matter the heavier it is doped. A material that is heavily doped will have more impurities than a material that is lightly doped. Figure 7 indicates some of the elements that may be used as impurities.



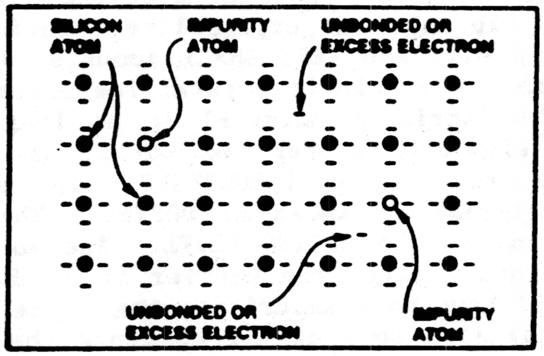
TYPICAL IMPURITIES USED FOR DOPING INTRINSIC MATERIALS AND THEIR SIMPLIFIED ATOMIC STRUCTURES.

Fig 7.

N-TYPE MATERIALS

The first category of impurities, Figure 7A, has 5 electrons in the valence shell. Since they have 5 valence electrons they are known as PENTIVALENT materials. When an impurity atom of this type is added to an intrensic material (Silicon) only 4 of its valence electrons are used to form a covalent bond locking the impurity atom into the crystalline structure. The fifth electron will not enter into the covalent bond because the silicon atoms now each have eight valence electrons and are now stable. The fifth electron will detach itself from its original atom and be free to wander throughout the crystal material. The impurity atom is not free but is locked into the crystal material. Since Pentavalent atoms provide or donate a free electron to the material they are called DONOR impurities. Intrinsic material that has been doped with a donor impurity has an excess of electrons in the crystal and is known as negative or "N" type material. Figure 8 is a simplified diagram of N type semiconductor material.

N MATERIAL



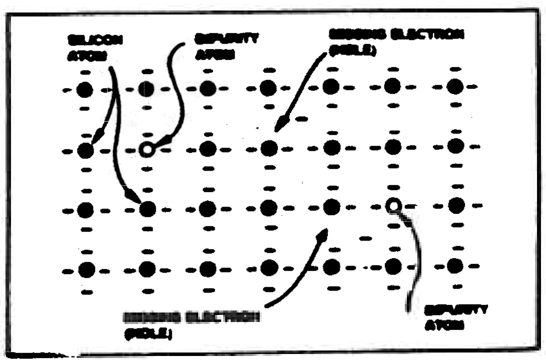
SILICON CRYSTAL, DOPED WITH ARSENIC (DONOR)

Fig 8.

P-TYPE MATERIALS:

The materials listed in figure 7B have valence shells that contain only 3 electrons and are known as TRIVALENT elements. When mixed with intrinsic materials, they also form covalent bonds with the silicon atoms but having only 3 valence electrons, there is an absence of 1 electron to complete the covalent bond. This space is the absence of the eighth electron needed to complete the covalent bond. This space caused by a missing electron is called a HOLE. Holes, being the absence of negatively charged electrons will display a positive (+) charge. Holes will readily accept electrons if they are made available. An intrinsic material that has had a TRIVALENT IMPURITY added to it will be known as an ACCEPTOR material. A material that has been doped with acceptor impurities has an excess of Holes (+) and is known as positive or "P" material. As in N material, the total number of electrons and protons are still equal so the P material still has a neutral charge. Current flow in P material will be the result of Hole movement. Figure 9 is a simplified diagram of P type semiconductor material.

P MATERIAL



SILICON CRYSTAL, DOPED WITH ALUMINUM (ACCEPTOR)

Fig 9.

CURRENT FLOW IN SEMICONDUCTOR MATERIAL

Figure 10 illustrates how current will flow in an N type semiconductor material. Electrons will leave the left side of the battery and eventually reach the left side of the block of the N material and, being free electrons, drift to the right, attracted by the positive polarity of the battery. Every time one electron enters on the left one leaves on the right, returning to the positive side of the battery. Conduction in N material is similar to conduction in a piece of wire.

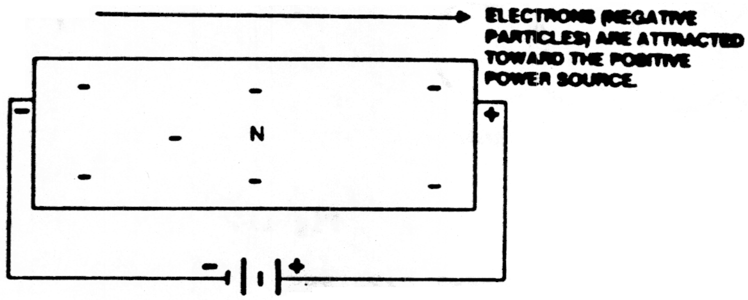


Fig 10.

Figure 11 illustrates how current will flow in P type semiconductor material.

An electron will again leave the negative terminal of the battery and eventually reach the left side of the block of P material. Remember, holes support current flow in P material. Upon entering the P material the negative (-) electron will be attracted to a positive hole. At this time the electron will fill the hole (opposite polarities attract). This process is called RECOMBINATION. At the instant recombination occurs on the left side of the block an electron is forced out of the valence shell of an atom on the right side of the block creating a hole. This electron then leaves the semiconductor material and enters the wire where it returns to the battery. Since holes are majority current carriers in P material the hole just created will be attracted to the negative terminal of the battery and move through the P material to the left side of the block. Hole movement in the P material takes place as electrons move from atom to atom recombining with holes and again breaking this bond to move to another hole. Electron flow and hole flow is in the opposite direction. It is important to understand that for a hole to move an electron must also move in the opposite direction. Again it must be emphasized that every time an electron enters the material, one leaves the other side.

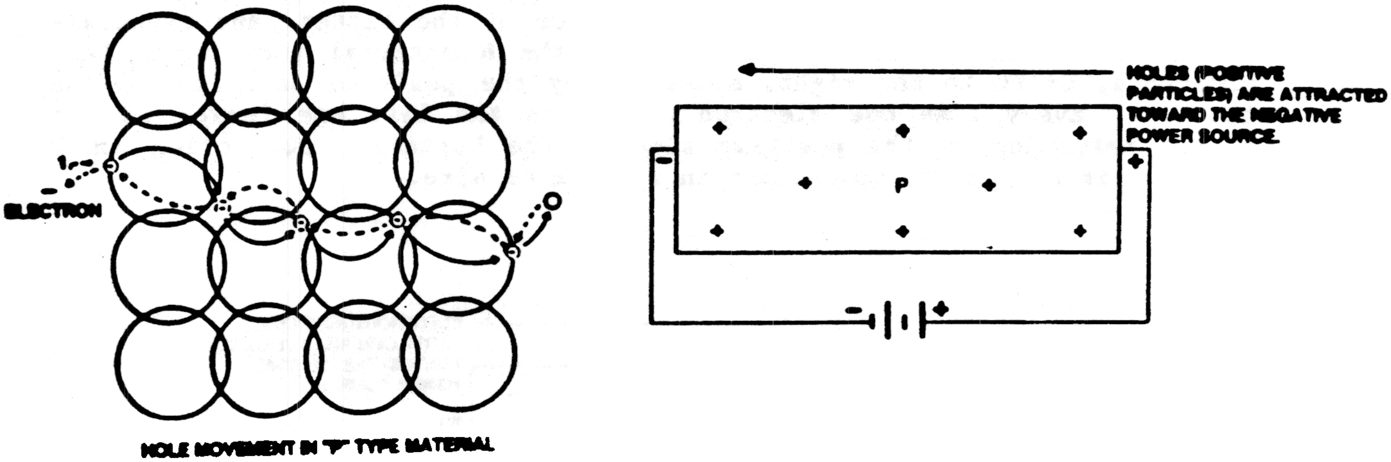


Fig 11.

MAJORITY AND MINORITY CURRENT CARRIERS.

When intrinsic silicon or germanium is prepared, during the manufacturing process, the aim is to make it 100% pure. This goal, at present, is unachieveable so there will always be some impurities left in the intrinsic material. It has already been noted that electrons support current in N material and holes support current in P material. These electrons and holes are the MAJORITY current carriers in their respective materials. The impurities that can not be removed during the initial manufacture of the intrinsic material will also support current. Any holes that might be present in the N material and electrons that might be present in the P material will also support current in the opposite direction of majority current. These current carriers are referred to as MINORITY current carriers and the current is MINORITY CURRENT. Minority current is very small in respect to majority current. Minority current is so small that it is normally ignored.

Minority carriers are also generated when semiconductor material is subjected to heat. Current flow through the material as well as ambient temperature (room temperature) are two sources of heat that can be responsible for the generation of minority carriers. Heat is a form of energy and when applied to an atom it can add enough energy to force a valence electron to leave its orbit and drift through the semiconductor material as a free electron. When the electron leaves its orbit, it leaves behind a hole which is bound to the atom. This process is known as ELECTRON-HOLE PAIR GENERATION. It makes no difference whether the electrons in P material or holes in N material are the result of the manufacturing process or heat, they are still minority current carriers and their presence will be responsible for MINORITY CURRENT. See Figure 12.

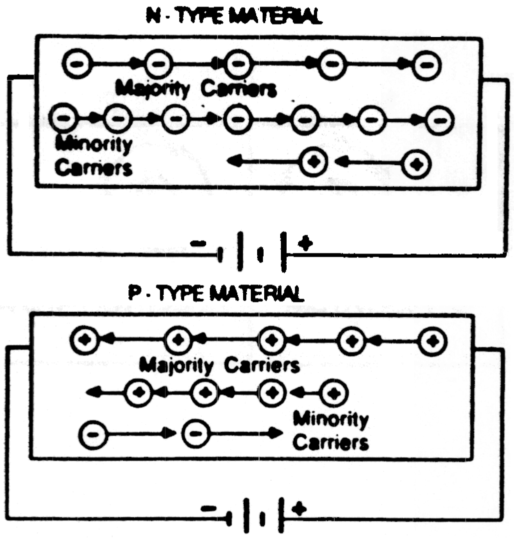


Fig 12.

PN JUNCTIONS

Up to this point all we have really done is discussed the formation of N and P materials and illustrated how current will flow through them. In order to utilize the semiconductor material to its fullest advantage we must create a junction between the two.

JUNCTION FORMATION:

We will now look at the action that takes place when P and N material are first brought together and form a junction. Refer to figure 13.

We will first look at what happens to two atoms, one in the P material and one in the N material, that are very close together when the junction is formed. Keep in mind we are observing only two atoms but the action described will occur along the entire length of the junction. Refer to figure 14.

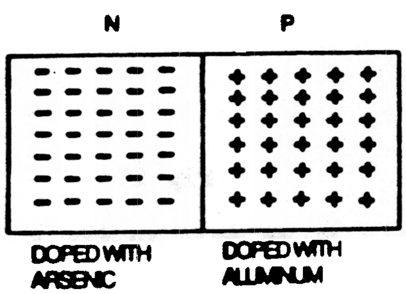


Fig 13.

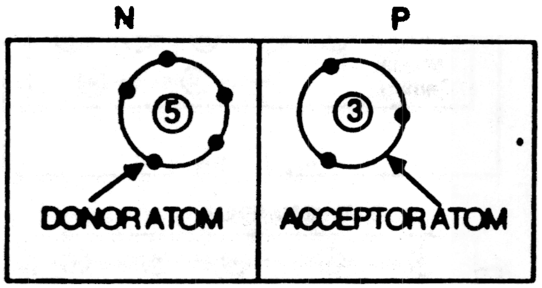


Fig 14.

A loosely bound electron (-) in the valence shell of the donor atom comes under the influence of the hole (+) in the valence shell of the acceptor atom in the P material. Since the electron is not tightly bound to the donor atom, it will leave the N material, and cross the junction, attracted by the hole and recombine with the hole. See figure 15.

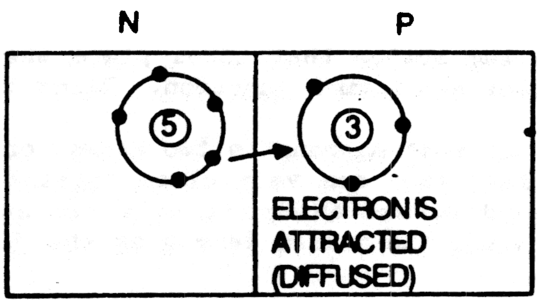


Fig 15.

The electron, leaving the donor atom in the N material will cause the atom to become a POSITIVE ION. The atom has now lost its current carrier. When this electron recombines with the hole in the P material, the added electron causes the acceptor atom to become a NEGATIVE ION. Since the hole no longer exists the acceptor atom no longer has a current carrier. See figure 16.

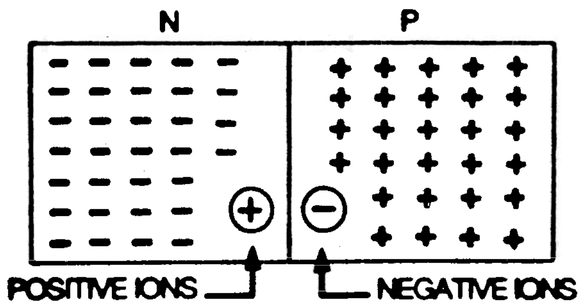


Fig 16

This process occurs for a short time along with the entire length of the junction, and an area of positive and negative ions is now present on each side of the junction. See figure 17.

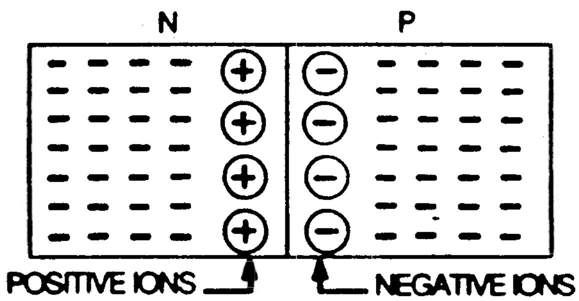


Fig 17.

This action will not continue indefinitely because as more electrons attempt to leave the N material they will be repelled by the negative ions in the P material. See figure 18.

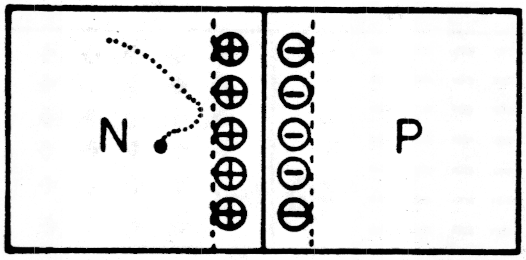


Fig 18.

As previously stated the recombination of holes and electrons at the junction has formed ions and eliminated current carriers at the junction. Since the area on either side of the junction has been depleted of current carriers it is called the DEPLETION REGION. See figure 19.

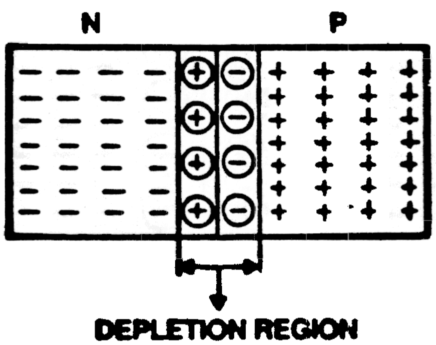


Fig 19.

Once the Depletion Region is formed, any additional electrons that try to move across the junction will be repelled by the negative ions now present in the P material.

Due to the charge on the ions on either side of the junction, a difference in potential exists across the depletion region. This difference in potential can be represented by a small battery as shown in figure 20. The difference in potential will be called the Junction Barrier Potential. In order to make current carriers cross the depletion region the Junction Barrier Potential must be overcome by an exterior voltage source.

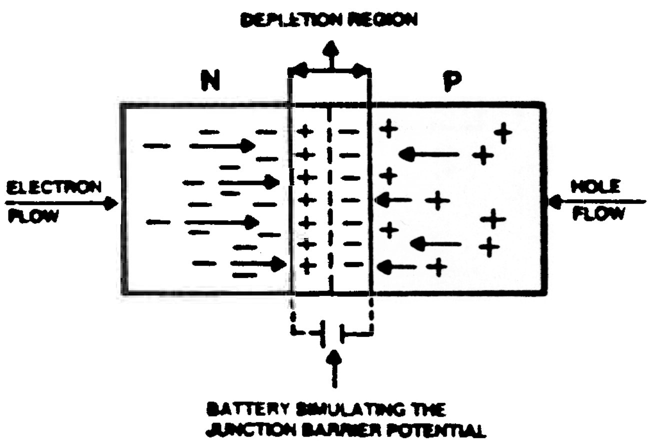


Fig 20.

Due to the fact that Silicon and Germanium have different numbers or orbital shells, their valance electrons will take different amounts of energy to break them free. The result of this is that if the basic (intrinsic) material was Germanium the difference in potential is approximately 100mV. If the intrinsic material is Silicon the junction barrier potential is 600mV. YOU SHOULD COMMIT THESE FIGURES TO MEMORY AS THEY WILL BE REFERRED TO MANY TIMES IN THE FUTURE.

BIASING

What happens to the depletion region when different potentials are applied to the P and N material will now be discussed. Figure 21 illustrates a PN Junction that now has two leads, (known as elements), and attached to the P and N material. The leads will allow the device, (PN JUNCTION) to be connected to the battery.

BIAS is defined as the difference in potential between two given points or elements. BIASING is the method used to provide the difference in potential. Biasing can be accomplished by using batteries or voltage dividers. We will explain biasing using batteries now and cover biasing using voltage dividers later.

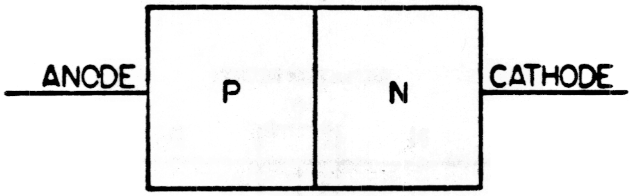


Fig 21.

Refer to figure 22. Observe that the P material is connected to the positive terminal of the battery. Also notice, the N material is connected to the negative terminal of the battery. When the PN JUNCTION is connected to an external source of this manner, it is said to be FORWARD BIASED.

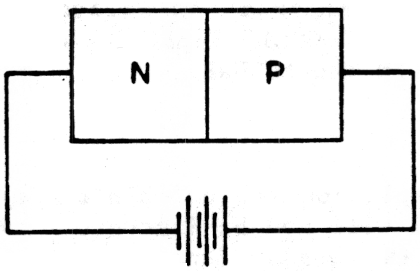


Fig 22.

Refer to figure 23. The negative terminal will repel the free electrons in the N material, moving them toward the junction. Some of these electrons will enter orbits around the positive ions and they will no longer be positive ions. In addition to the negative terminal repelling the electrons in the N material, the positive terminal will, at the same time, be attracting them. In the P material, the majority current carriers are holes and, being positive, they are repelled by the positive battery terminal and attracted by the negative terminal.

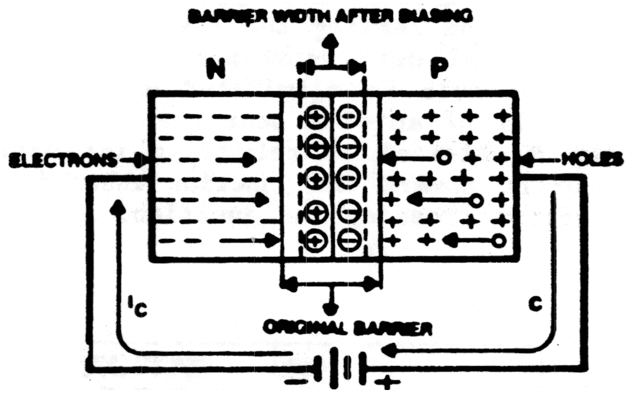


Fig 23.

The electrons in the N material, moving toward the junction, now neutralize many of the positive ions that appeared to form the positive terminal of the junction barrier potential battery (figure 20). Holes in the P material, being repelled by the positive potential of the biasing battery, move toward the junction where they neutralize many of the negative ions which appeared to form the negative terminal of the junction barrier potential battery on the P side of the junction. The result is that the depletion region is now made smaller (more narrow). If the potential of the biasing battery is increased the depletion region will continue to narrow. If the bias battery is increased to the point that it is the same size as the junction barrier potential, current will then start to flow through the junction. Without the biasing battery no current could flow through the junction. When the biasing battery was connected to the device, the depletion region became more narrow. Increasing the size of the battery resulted in the depletion region narrowing further until the point at which current began to flow. It can be said that the increasing the forward bias caused the RESISTANCE of the junction to decrease.

ELECTRON FLOW IN THE CIRCUIT.

Refer to figure 24. An electron leaves the negative terminal of the battery, travels down the conductor and eventually enters the N material. Here it becomes a majority current carrier, (free electron), and drifts toward the junction. With the PN junction forward biased. the depletion region becomes very narrow. When the electron reaches the narrowed depletion region, very little resistance is offered to it at the junction and it passes through. Once in the P material, it immediately recombines with a hole. In the P material, the electron continues to move toward the positive battery potential by moving from valence shell to valence shell or from hole to hole. Once the electron reaches the positive lead, it leaves the P material and enters the conductor where it returns to the battery. When the PN Junction is forward biased, there is a continuous stream of electrons leaving the battery, entering the N material, recombining at the junction, and leaving the P material. Every time an electron enters the N material one recombines at the junction eliminating a hole. The instant that hole is eliminated at the junction, an electron leaves the valence shell of an atom near the positive lead creating a new hole and leaves the P material to return to the battery. The new hole just created will drift toward the junction where it will eventually recombine with an electron crossing the junction. Thus you see this is an ongoing process.

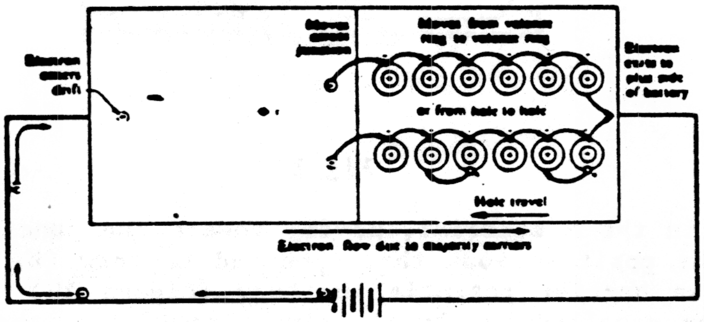


Fig 24.

It can be seen that if an electron leaves the P material at the same time that one enters the N material current must be flowing through the device.

FOR CURRENT TO FLOW THROUGH A PN JUNCTION IT MUST BE FORWARD BIASED.

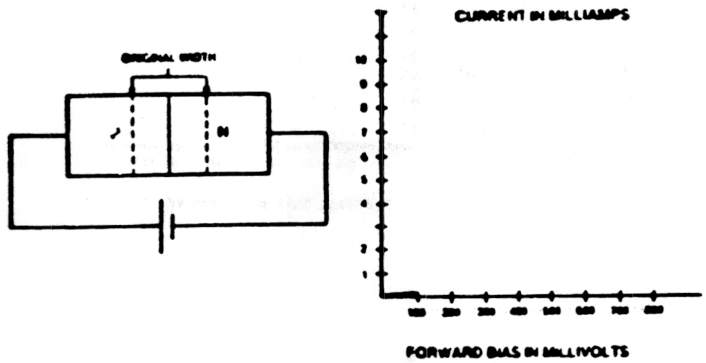
When a PN junction is forward biased several conditions exist:

1. DEPLETION REGION NARROWS

2. RESISTANCE OF THE DEPLETION REGION DECREASES

3. CURRENT FLOWS THROUGH THE DEVICE.

Refer to figure 25. The PN Junction consists of doped Silicon semiconductor material. As mentioned earlier, the junction barrier potential of Silicon is 600mV. Notice that the battery is a 100mV battery. Also notice that the positive terminal is attached to the P material and the negative terminal is attached to the N material. Observe, the junction is forward biased, but it does not have enough forward bias to overcome the junction barrier potential. At this time the depletion region is wide, and the resistance of the junction is very high. Very little current will flow across the junction due to the high resistance. The graph at the right of the junction shows the relationship between the forward bias in mV, and current flow through the junction, measured in mA.



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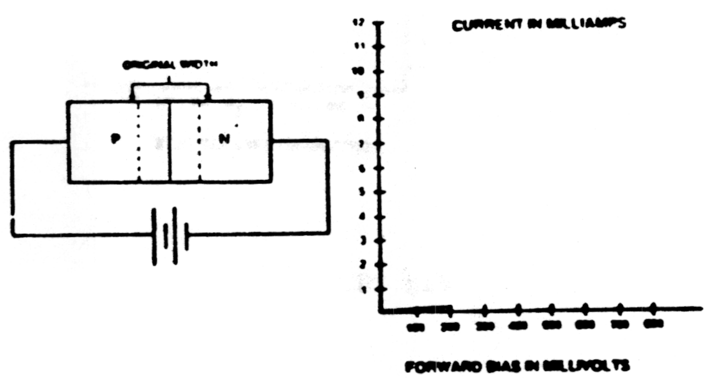
Figures 26 thru 30 indicates what happens as forward bias is increased.



26.

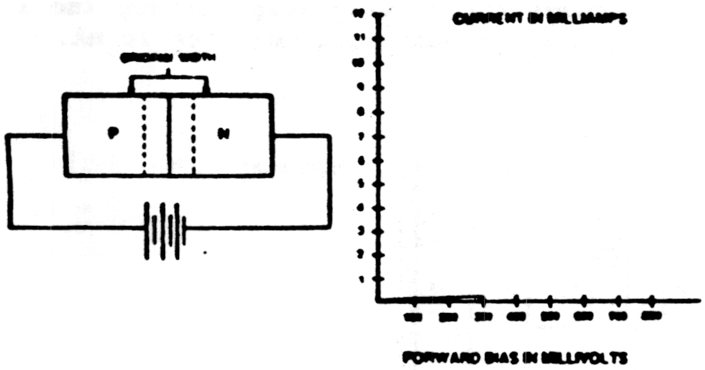

CURRENT IN MILLIAMPS
P
N
FORWARD BIAS IN MILLIVOLTS

Fig 27.

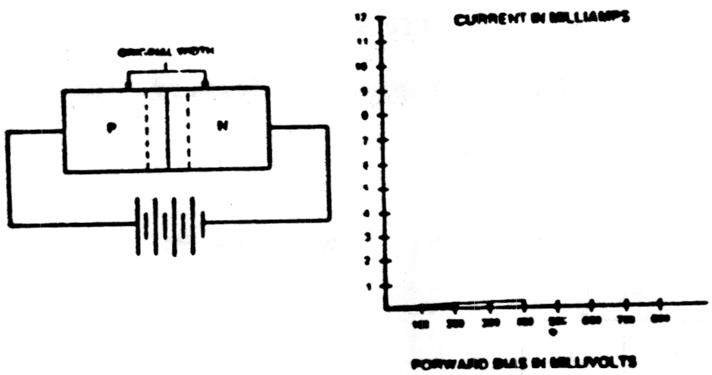

CURRENT IN MILLIAMPS
P
N
FORWARD BIAS IN MILLIVOLTS

Fig 28.

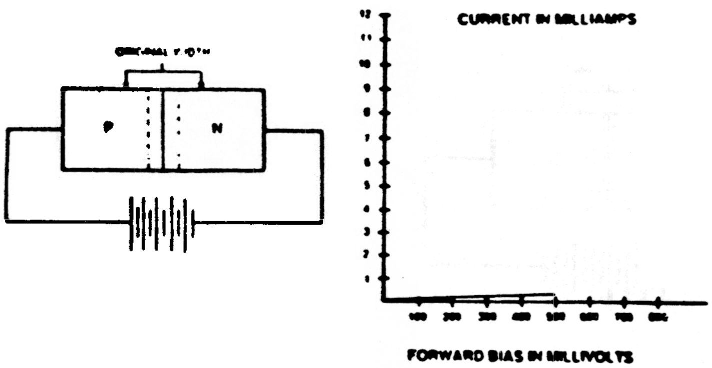


Fig 29

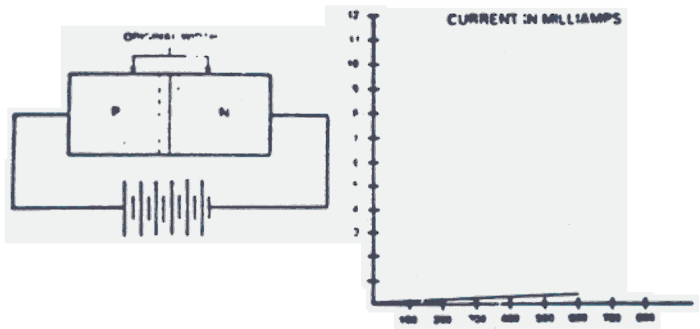


Fig 30

Observe that as forward bias is increased, between 0V and 500mV, the depletion region starts to narrow. As the depletion region narrows, the resistance of the junction starts to decrease and current increases. When the forward bias increases to approximately 600mV the junction barrier potential is overcome. The depletion region is very narrow at this point. Resistance of the junction is now very low and current easily flows through the junction.

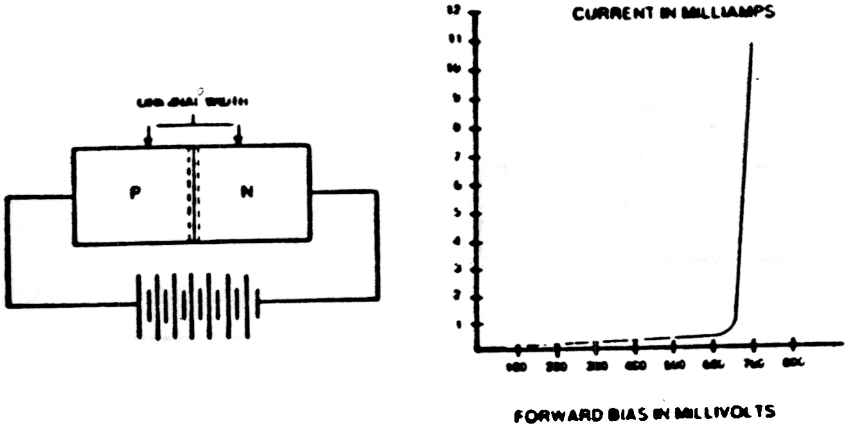


Fig 31.

Once the junction barrier potential has been overcome very, small changes in forward bias will result in very large changes in current through the junction. See figure 31. Notice that a change of only 100mV of bias results in a change in current of 10mA.

Review the conditions required to allow current to flow through a PN junction.

1. Positive polarity applied to the P material
2. Negative polarity applied to the N material
3. Enough potential applied to overcome the junction barrier potential.

It should be understood by now that FORWARD BIAS relates to both POLARITY AND POTENTIAL.

Normally, when discussing a PN junction, if it is said that the PN Junction is FORWARD BIASED it is thought of as CONDUCTING.

REVERSE BIAS.

Refer to figure 32. Observe that the negative terminal is connected to the P material. The positive terminal of the battery is connected to the N material.

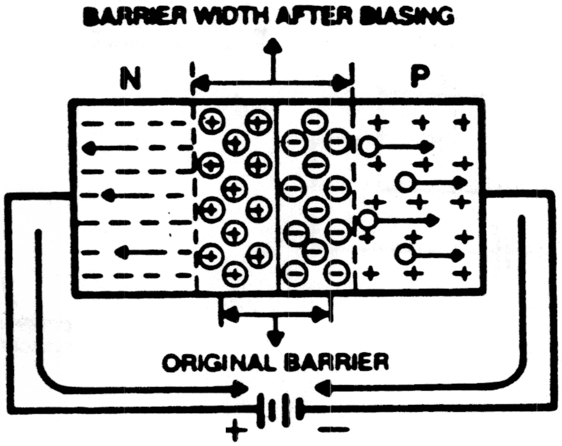


Fig 32

The positive terminal of the battery, connected to the N material attracts the free electrons and draws them away from the junction. The negative terminal of the battery connected to the P material attracts the holes and draws them away from the junction. The result is that there are no current carriers left in the vicinity of the junction. This has the effect of widening the depletion region. THE GREATER THE REVERSE BIAS THE WIDER THE DEPLETION REGION BECOMES. This action effectively reinforces the junction barrier potential and prevents any majority carriers from flowing across the junction. The Resistance of a REVERSE BIASED junction is very high.

The effects of reverse bias will now be examined. Refer to figures 33 thru 37. It should be noted that increasing the reverse bias increases the width of the Depletion Region. Note that reverse bias potential is indicated in volts and reverse bias current in micro Amps. Any current that is indicated is due to minority carriers and will be extremely low. It will be called reverse current since it is the result of reverse bias. Because there are so few minority current carriers, the reverse current will remain fairly constant over the majority of the graph.

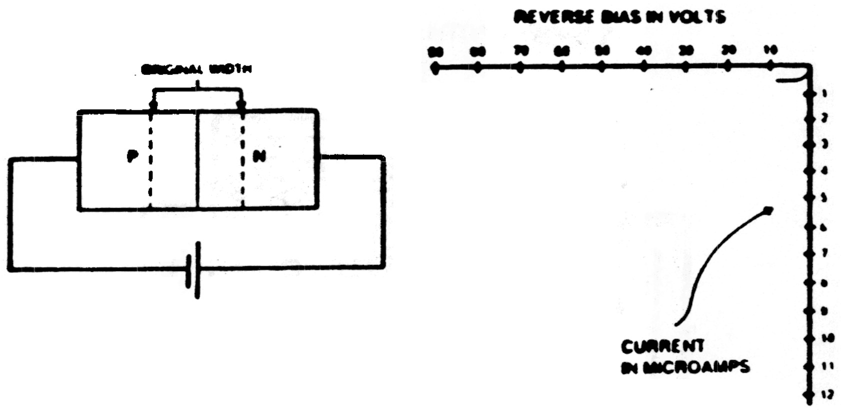

REVERSE BIAS IN VOLTS
ORIGINAL WIDTH
P
N
CURRENT
IN MICROAMPS

Fig 33.

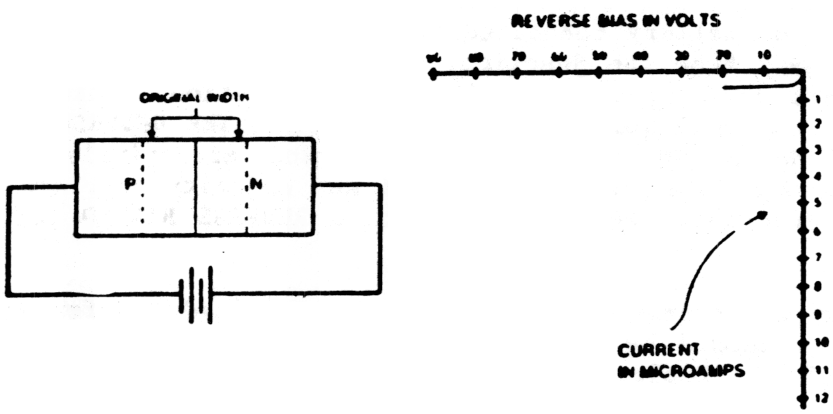

REVERSE BIAS IN VOLTS
ORIGINAL WIDTH
P
N
CURRENT
IN MICROAMPS

Fig 34.

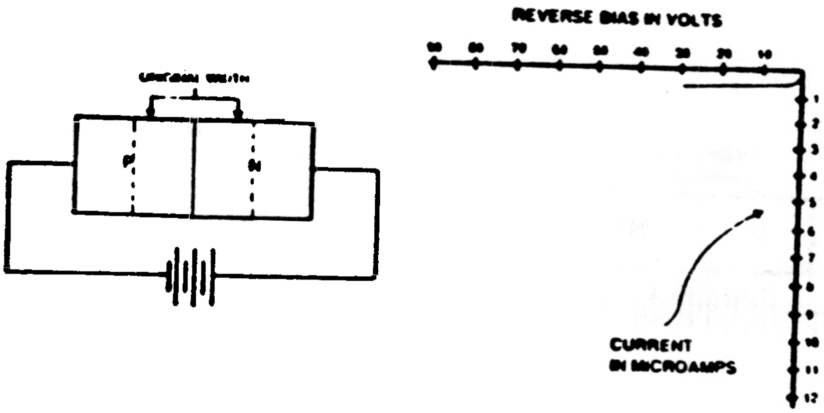

REVERSE BIAS IN VOLTS
P
N
CURRENT
IN MICROAMPS

Fig 35.

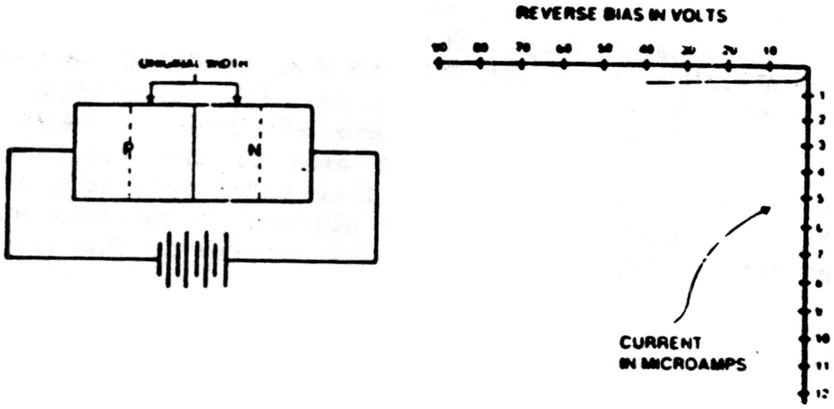

REVERSE BIAS IN VOLTS
P
N
CURRENT
IN MICROAMPS

Fig 36.

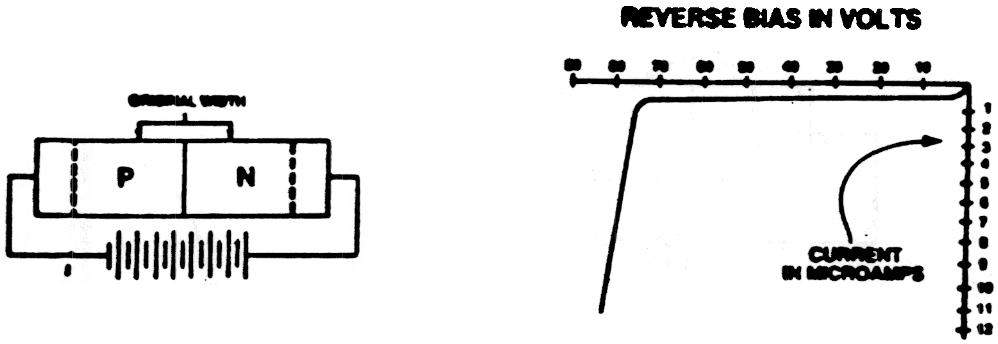


Fig 37

Notice that the reverse current remained almost constant until the reverse bias increased to around 75V. At this point, it can be observed that reverse current increases greatly. This increase in current is due to a condition called AVALANCHE. As the Reverse Bias is increased the minority carriers are forced through the junction at high velocities. Remember that minority carriers in P material are electrons. These electrons strike valence electrons of atoms in the area of the junction breaking their bonds and driving these electrons into other valence electrons, in turn driving them from orbit. If this is allowed to continue an enormous increase in current is experienced and will eventually destroy the junction.

Avalanche or Reverse Current occurs only when the MAXIMUM REVERSE VOLTAGE is exceeded.

JUNCTION DIODES

The device that we have been discussing up to this point is called a JUNCTION DIODE. The word DIODE is a contraction of two words; Two and Electrode, where di stands for two. From this point on a PN Junction will be referred to as a JUNCTION DIODE or just plain DIODE.

DIODE SYMBOLS

The schematic symbol for a Diode is shown in figure 38. The direction of current flow through the PN junction is indicated by the arrow. It will always be from the negative to the positive material or from N to P. Majority current will always flow AGAINST THE ARROW.

CR - 1

Fig 38.

Diodes are designated CR followed by a number. The arrowhead represents the lead or element called the ANODE. The bar represents the element called the CATHODE. Current will always flow from the cathode to the anode. It has been stated that current will only flow through a forward biased diode, so, for current to flow, the cathode must be negative and the anode positive. When these conditions are reversed, cathode positive (+) and anode negative (-), the diode is reverse biased and current will not flow. Because a diode displays these characteristics, a diode is said to be a Unidirectional Device. This means that current will flow in only one direction through the diode.

DIODE IDENTIFICATION

Diodes come in many different physical shapes and sizes from the size of a pinhead to very large. Because there are so many different types of diodes, a means of identification is needed to distinguish one from another. This is accomplished with the Semiconductor Identification System shown in figure 39. This system is used not only for diodes but also for transistors. As illustrated in figure 39, the system uses numbers and letters to identify different types of semiconductor devices. The first number in the system indicates the number of junctions in the semiconductor device. Thus 1 designates a diode; 2 designates a transistor. The letter "N" following the first number indicates it is a semiconductor. The 2 or 3 digit number following the letter "N" is a serialized identification number.

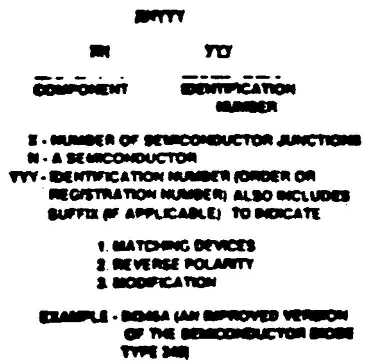


Fig 39

When working with different types of diodes, it is necessary to distinguish one end of the diode from the other, (anode from cathode). For this reason, manufacturers generally code the cathode end of the diode with a "K", "cath", "color dot or band", "schematic symbol of a diode", or by an unusual shape (raised edge or taper) as shown in figure 40. In some cases, standard color code bands are placed on the cathode end of the diode. This serves two purposes: it identifies the cathode end of the diode, and it serves to identify the diode by number.

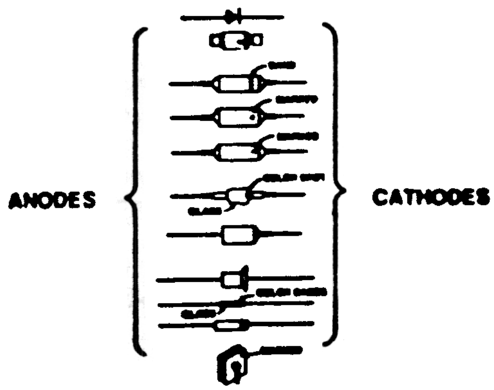
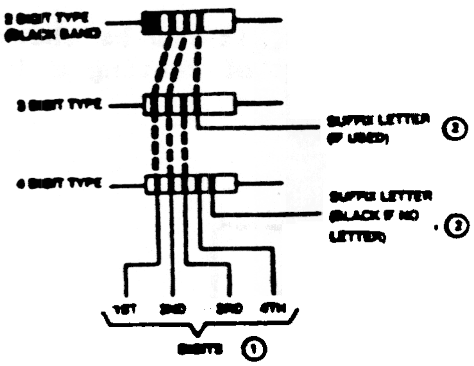


Fig 40.

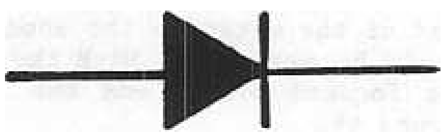
The standard diode color code system is shown in figure 41. Take for example, a diode with brown, orange, and white bands at one terminal and figure out its identification number. With brown being a 1, orange a 3, and white a 9, then the device would be identified as a type 139 semiconductor diode, or specifically, a 1N139.



COLOR	① DIGIT	② DIODE SUFFIX LETTER
BLACK	0	-
BROWN	1	A
RED	2	B
ORANGE	3	C
YELLOW	4	D
GREEN	5	E
BLUE	6	F
VIOLET	7	G
GRAY	8	H
WHITE	9	J
SILVER	-	-
GOLD	-	-
NONE	-	-

Fig 41

Keep in mind, whether the diode is a small crystal type or large power type, both are still represented schematically by the schematic symbol shown in figure 42.



CR1

Fig 42.

DIODE TESTING

Diodes are rugged and efficient and are expected to be relatively trouble free. In theory, a diode should last indefinitely. However, if diodes are subjected to excessive current, their junctions may be destroyed. Excessively high operating voltages can also damage junctions. Heat can increase the number of current carriers in a semiconductor which leads to increased current resulting in junction failure.

If a diode is suspected of being defective, it can be checked in various ways. The most convenient and quickest way of testing a diode is with an ohmmeter. See figure 43.

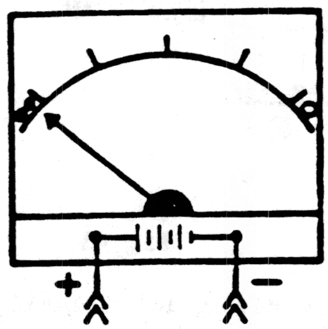


Fig 43.

Connect the negative lead of the ohmmeter to the cathode lead of the diode and the positive lead of the meter to the anode. The resistance indicated on the ohmmeter should be very low. With the leads connected in this manner the junction is forward biased and the junction offers very little resistance. See figure 44.

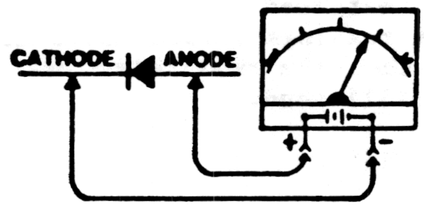


Fig 44.

Reverse the leads; negative lead to the anode and positive lead to the cathode. The battery in the ohmmeter now has the junction reverse biased and it has a high resistance. See figure 45.

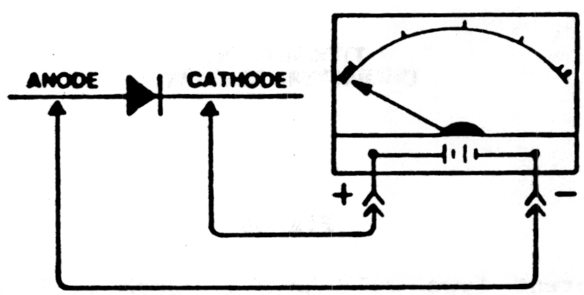


Fig. 45

A normal set of readings will show a high resistance when the junction is reverse biased and a low resistance when the diode is forward biased.

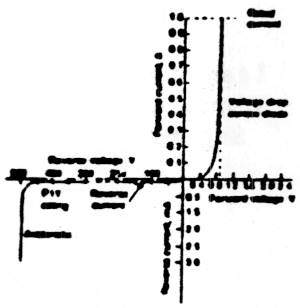
It is desirable to have as great a ratio (often known as the front to back ratio) as possible between the reverse and forward biased measurements. A small signal diode will have a ratio of several hundred to one, while a power diode may be as low as 10:1.

If both measurements indicate HIGH RESISTANCE the diode is OPEN. If both measurements indicate LOW values of resistance the diode is SHORTED.

Due to the internal wiring of some multimeters, the voltage supplied by the meter in the ohms function will be placed on the common lead. It should be known which test lead has the voltage applied to it, but it is not essential. If the readings listed above are 180 degrees out of phase from what is stated, then the multimeter has the voltage on the common lead and the diode is still good.

DIODE CHARACTERISTIC CURVE

Refer back to figures 31 and 37. If the two graphs are joined together they will form a graph as shown in figure 46. This is called a DIODE CHARACTERISTIC CURVE. All diodes of the same type will have curves that are nearly identical.



TYPICAL DIODE
CHARACTERISTIC CURVE

Fig 46.

A diode of a different type will have a curve similar in shape but displaying different values. See figure 47.

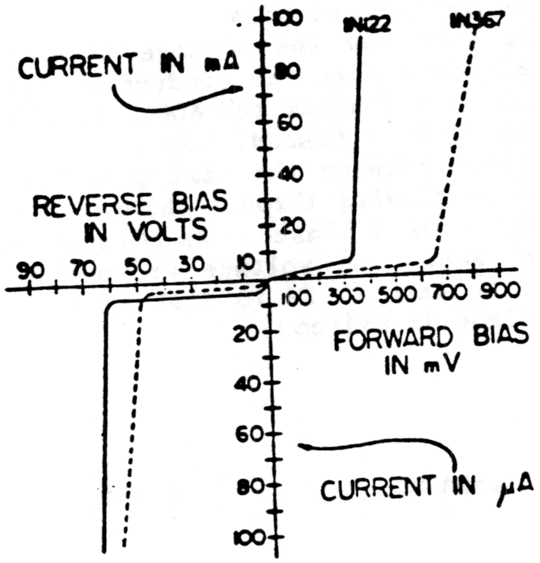


Fig 47.

DIODE RATINGS

Different types of diodes display different characteristics. This is due to a number of differences during the manufacturing process, such as different basic materials, different types of doping materials, different doping levels, etc. Each different type of diode has certain conditions or ratings that should be met. A few of these conditions are:

1. MAXIMUM AVERAGE FORWARD CURRENT: This rating indicates the maximum average (steady) current that can be permitted to flow when the diode is forward biased.

2. PEAK RECURRING FORWARD CURRENT: This is the maximum peak current which can be permitted to flow in the form of recurring pulses when the diode is forward biased.

3. MAXIMUM SURGE CURRENT: The maximum current permitted to flow in the forward direction in the form of non-recurring pulses.

4. PEAK INVERSE VOLTAGE: PIV indicates the maximum reverse bias condition that may be applied to a diode without destroying it.

DIODE VOLTAGE DROPS

Refer to figure 48. In circuit (a), a meter placed between TP1 and ground will indicate approximately the applied voltage. Notice the diode is reverse biased so no current will flow. Once the meter is placed in the circuit an alternate path for current is provided. The high internal resistance of the meter holds current to a very low level. The resistor will drop a very low voltage, (100mV to 200mV). The remainder of the applied voltage is then dropped across the meter, (9.8V to 9.9V). In circuit (b) the diode is forward biased. Since the resistance of a forward biased diode is very low the voltage dropped by the diode will be very low. A meter placed across the conducting diode will indicate 100mV to 300mV if the diode is germanium and 600mV to 900mV if the diode is silicon. Circuit (c) is reverse biased. No current will flow in the circuit, and a meter placed between the test point and ground would indicate 0V because no current is flowing through the resistor to develop a voltage drop. Circuit (d) is forward biased. As already stated, a forward biased diode drops a low voltage. The voltage dropped by the resistor will be close to the applied voltage (9.7V to 9.9V if the diode is Germanium and 9.4V to 9.2V if the diode is Silicon).

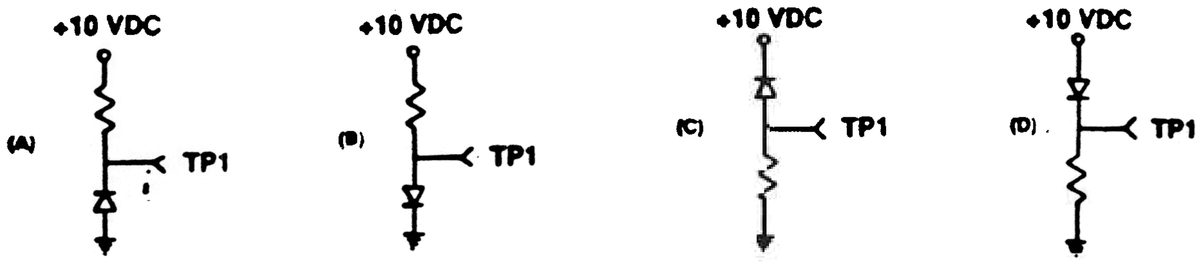


Fig 48.

USES OF SEMICONDUCTOR DIODE

RECTIFIERS

One function of a diode is to rectify. Rectification is the act of removing one alternation of an AC sinewave. AC is alternating current which means it flows in one direction, stops, then flows in the opposite direction. Since a diode is a device that will allow current to flow in only one direction it can readily be used for rectification. In the following circuits we will discuss how the diode functions as a rectifier.

Before discussing the operation of the rectifier, notice the sinewave in figure 49.

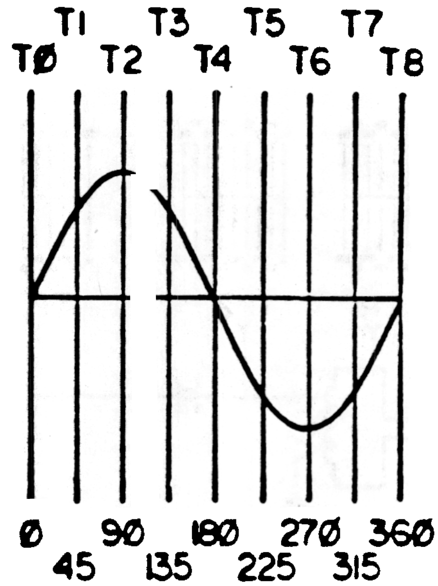


Fig 49.

It has been divided into 45 degree sections with each section being labeled with a time reference. 0 degree = T0; 45 degree = T1 and so on. During the discussion the different time references will be referred to in order to emphasize voltages at that particular time.

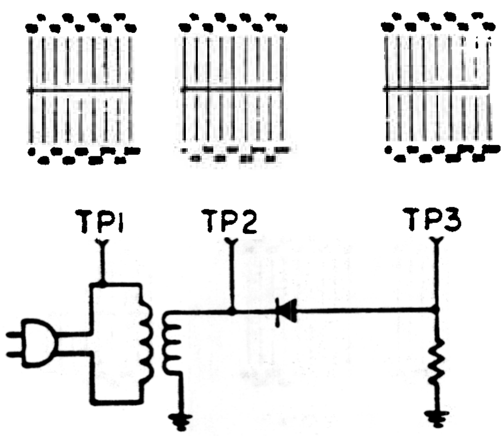


Fig 50.

At T0 the voltage present at TP1 is 0V. At this time no current flows in the primary, no magnetic field is built up so no voltage is induced into the secondary. As a result, TP2 reads 0V at this time. With 0v felt on the anode of CR1 and 0V felt on the cathode, CR1 has no bias applied. CR1's depletion region is wide and its resistance is high. With no difference in potential between the cathode and anode, no current flows. There is no voltage felt at TP3.

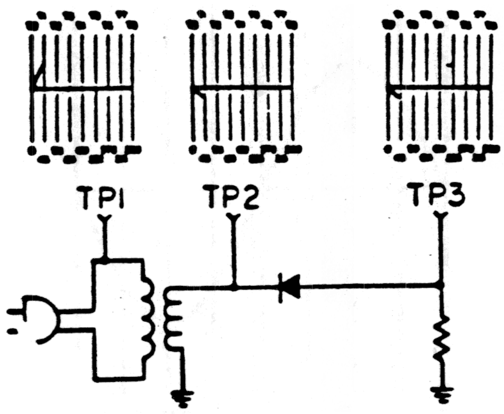


Fig 51.

At T1, figure 51, the line voltage at TP1 has increased from 0V to 115v. Current is now flowing in the primary inducing a voltage into the secondary. The transformer is wound so that it is a step-down transformer and also develops a 180 degree phase shift at TP2. At T1 the voltage present at TP2 is -28v. This negative voltage on the cathode forward biases the diode and causes the depletion region to decrease. The resistance of the diode decreases, and current is flowing as shown in figure 51. With current flowing through RL, (load resistor), a voltage is developed across it. The signal at TP 3 displays this voltage drop. The negative voltage present at TP3 will be slightly less than that at TP2 due to the voltage dropped by the low resistance of CR1 (600mV if silicon).

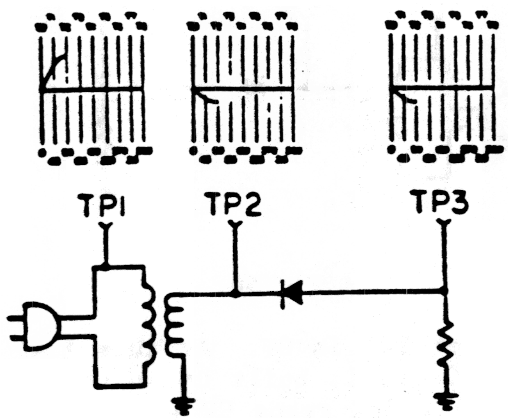


Fig 52.

At T2, figure 52, line voltage is maximum (162v). The voltage induced at TP2 is now -40v. This further increases the forward bias applied to CR1 which narrows the depletion region further and allows current to increase. The increase in current flow through RL results in it dropping more voltage and developing the signal at TP3. With -40v present at TP2 and CR1 dropping 600mV the rest of the voltage must be dropped across RL.

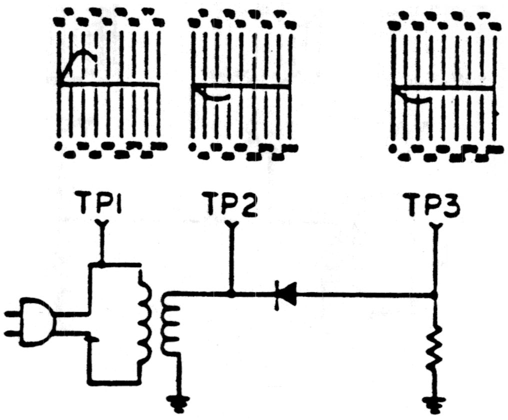


Fig 53.

At T3, figure 53, line voltage has decreased to 115v at TP1. The voltage at TP2 is now reduced to -28v. This is felt as a decrease in forward bias by CR1. The depletion region widens and current decreases. The decrease in current through RL reduces the voltage drop across it. The voltage felt at TP3 is now 27.4V. Don't forget the 600mV drop of CR1.

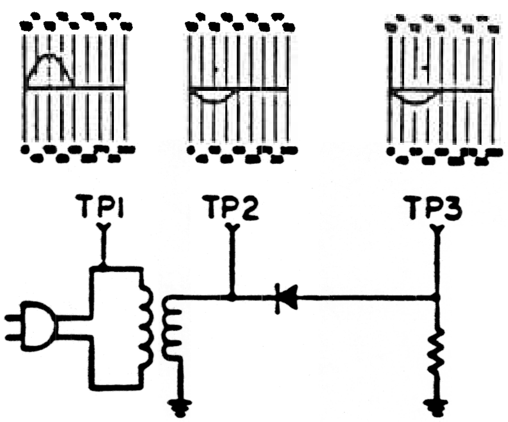


Fig 54

At T4, figure 54, the line voltage has returned to OV. TP2 is now Ov. The depletion region has returned to its normal width. Resistance of the diode has gone back up, and current flow in the circuit has ceased. With no current flow through RL, no voltage is dropped and OV is felt at TP3.

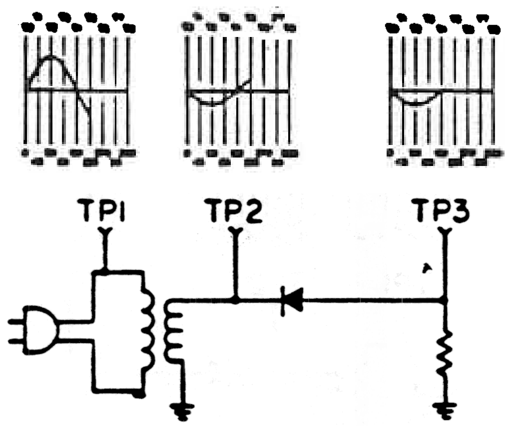


Fig 55.

By comparing TP2 and TP3, it can be said that because CR1 was forward biased the negative alternation felt at TP3 was passed through the forward biased diode.

At T5, figure 55, line voltage is now -115v. TP2 will now be +28V. The anode is now positive with respect to the cathode. This is felt as reverse bias by CR1 and the depletion region widens further. Current will attempt to flow in the opposite direction but cannot due to the high resistance of the reverse biased diode. Refer to figure 45 and recall that a very small current will flow from cathode to anode, when the diode is reverse biased, due to minority current carriers. This is an extremely low current and is usually ignored but does actually exist. This leakage current will develop a very small voltage drop across RL, and it too is usually ignored.

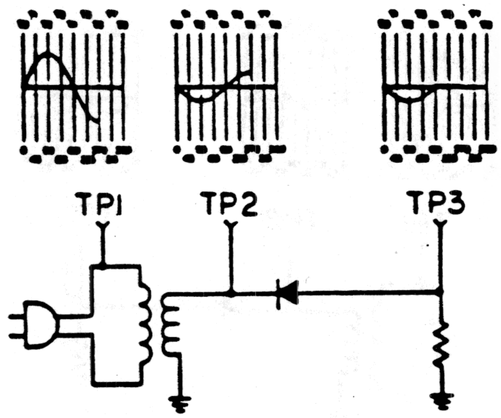


Fig 56.

At T6, figure 56, line voltage is at its maximum negative voltage (-165V). TP2 is now 40V and CR1 has the maximum reverse bias applied at this time. The resistance of CR1 is maximum and there is still no current flow through the current.

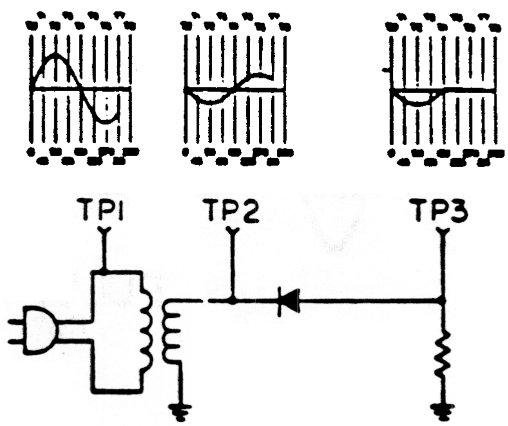


Fig 57.

At T7, figure 57, the line voltage has decreased to -115v. TP2 has decreased to 28V and TP3 is still almost 0V.

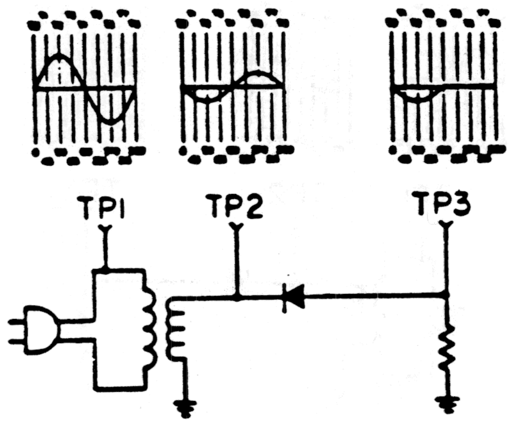


Fig 58.

At T8, figure 58, one complete cycle has been completed and all voltages and currents are back to 0.

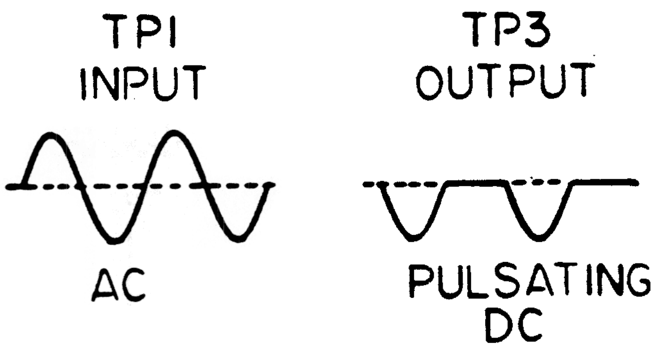


Fig 59.

By comparing the input (TP1) to the output (TP3) we can see that the positive alternation has been eliminated. If the diode was turned around and the same input applied, the diode would conduct during the positive half cycle and produce a positive output. The output signals shown above are called PULSATING DC. When looking at Pulsating DC, voltage and current never change polarity or direction, they just increase and decrease in intensity.

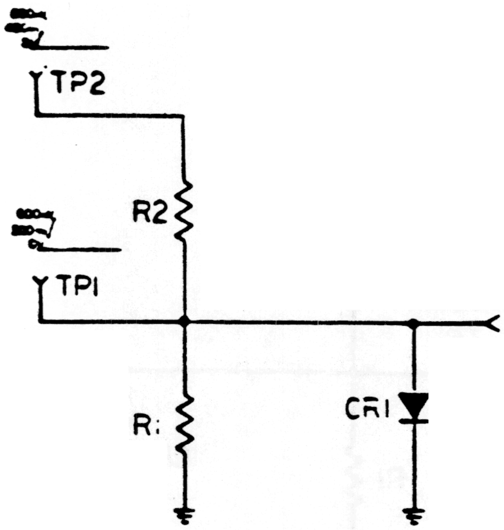


Fig 60

DIODE LIMITERS

POSITIVE LIMITER

Limiters are devices that limit the amplitude of an AC waveform. Figure 60 is a POSITIVE LIMITER. As the name implies, it will limit the positive alternation of the applied waveform. R1 and R2 form a voltage divider network that will reduce the amplitude of a sinewave present at the input of the circuit. Current will flow from ground, which is negative in respect to the positive input voltage, up through R1 and R2. This develops a positive going signal at TP1. The diode is silicon which means 600mV is required to overcome the junction barrier potential. As the input starts to go positive, a positive potential is now applied to the anode of CR1. Assume the positive going signal at TP1 reaches 300mV. This positive potential is forward bias but is not enough to overcome the junction barrier potential of the diode. As the input signal continues to increase the signal at TP1 reaches 600mV. At this time the junction barrier potential of the diode is overcome and the diode now begins the conduct. Once the junction barrier is overcome, resistance of the diode is extremely low and current now flows through the diode.

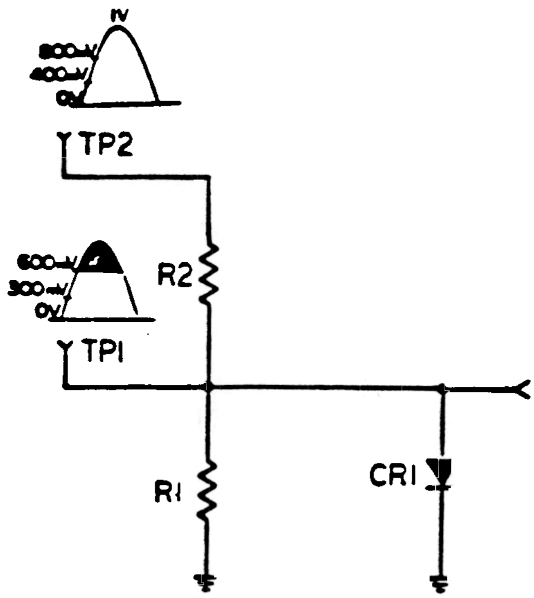


Fig 61.

As the input reaches its maximum positive (1V) it continues to apply forward bias to CR1. Due to its low resistance, CR1 continues to drop 600mV. For the entire time CR1 is forward biased it will drop 600mV. As the input starts to decrease it will eventually return to 600mV. Once TP1 drops below 600mV, CR1 ceases to conduct and current again flows through R1. As the input continues to decrease, TP1 will now decrease, returning to 0V.

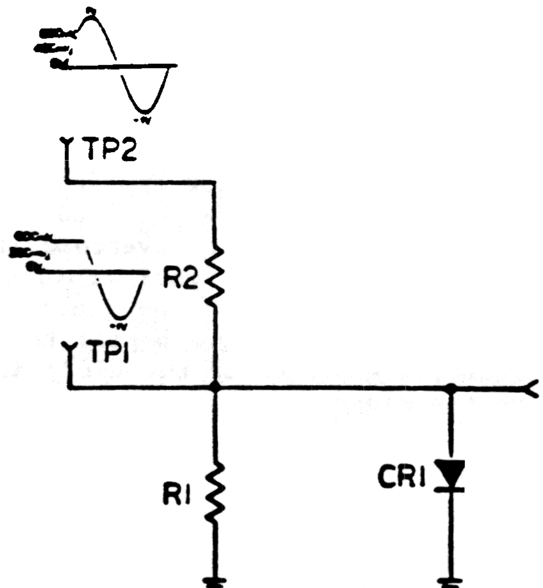


Fig 62.

As the negative alternation is applied to the circuit, current flows through R2 and R1 as shown in figure 62. The negative potential keeps CR1 reverse biased for the entire negative alternation. This develops the entire negative alternation at the output.

By comparing the input to the output we see that the 1V peak signal at the input has been limited to 600mV at the output. See figure 62.

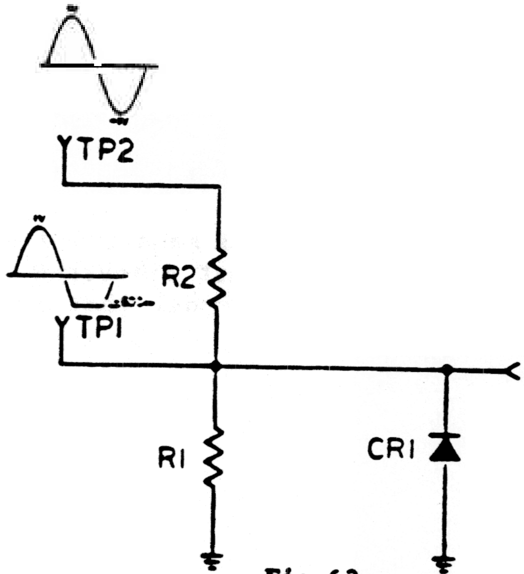


Fig 63

NEGATIVE LIMITER

A negative limiter is shown in figure 63. The only difference between the positive and negative limiter is the way CR1 is connected in the circuit. Notice it is connected with the anode to ground. During the time that a positive potential is applied to the cathode CR1 will be reverse biased and current will flow through R1 and R2. As the positive input alternation varies, current flow through R1 varies, resulting in R1 developing the signal at TP1.

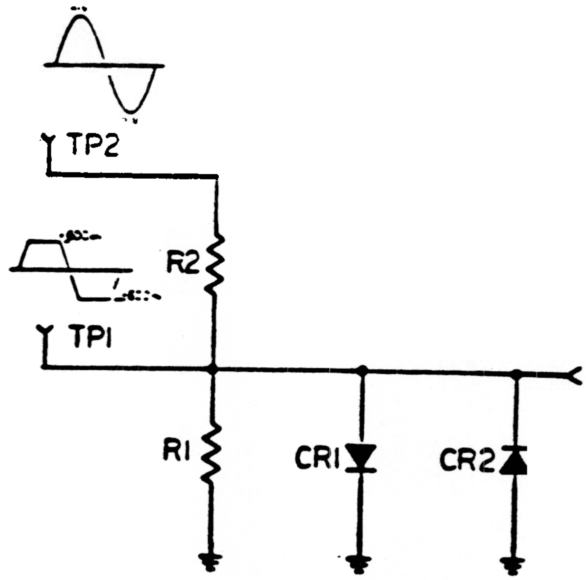


Fig 64.

As the input continues negative, the signal at TP1 will now reach -600mV. At this time, CR1 becomes forward biased enough to overcome the junction barrier potential and current will flow through the diode. During the time CR1 is conducting, it drops 600mV and will continue to do so until TP1 again becomes less than -600mV. At this time, CR1 ceases to conduct and current again flows through R1.

POSITIVE AND NEGATIVE LIMITERS.

Figure 64 is a schematic of a positive and negative limiter. It operates in the same manner as the two limiters just discussed. The output of the positive and negative limiter will be a signal that is limited to +600mV and -600mV for a total of 1200mV.