BASIC TRANSISTORS

PURPOSE AND USE OF TRANSISTORS

The first radio consisted of an antenna, a crystal, and a headphone set. This allowed only one person to listen to the broadcast at a time. With the advent of the vacuum tube, the received broadcast signal could be amplified and used to drive a speaker so that more than one person could listen at a time. In 1945, in the Bell Laboratories, a signal was amplified in the first transistor.

The transistor offers several advantages over the vacuum tube. It required only a fraction of the current that a tube does, generates very little heat, is very reliable and rugged, and operates off of low voltages.

A transistor is a device that will be used to control a large amount of current with a small amount of current. It is this property of a transistor that will allow it to be used as an amplifying device or a switch.

TRANSISTOR CONSTRUCTION

Transistors, like semiconductor diodes, are made from semiconduct materials (silicon and germanium) that have been doped to produce either N or P type materials. Once these materials have been produced they will pass current through them. Current flow in the N material will be the result of electron movement while current flow in P material is the result of hole movement. The doping materials will also be the same types used in diode construction. The transistor often is called a bipolar junction transistor (BJT). The word bipolar describes the fact that within the transistor, there are two majority current carriers: holes and electrons.

The diode consisted of two sections, cathode and anode. The transistor consists of three sections. They are called the EMITTER, BASE, and COLLECTOR. The emitter section is heavily doped (many impurities); its function is to emit or inject MAJORITY CURRENT CARRIERS into the base. The BASE is lightly doped (few impurities) and extremely thin (only a few thousandths of a millimeter thick). The base will control the amount of current that flows through the transistor. The logic on which the base is named comes not from the junction transistor but from the very earliest transistor, the point contact transistor. In this device the emitter and collector were formed on a base which acted as the center section. See figure 1. The doping of the COLLECTOR is between the heavy doping of the emitter and the light doping of the base. The collector is so named because it collects or gathers current carriers that have been emitted by the emitter. The collector is the largest of the three sections. It dissipates more heat than the emitter or base. The emitter and collector will always be made of the same type of material while the base is con-

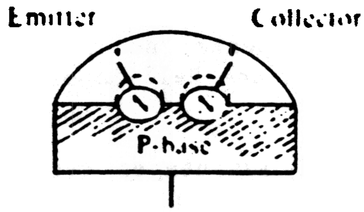


Fig. 1

structured of the opposite type material. The emitter and collector can be either type material. Fig. 2 shows the two types of transistors we will deal with.

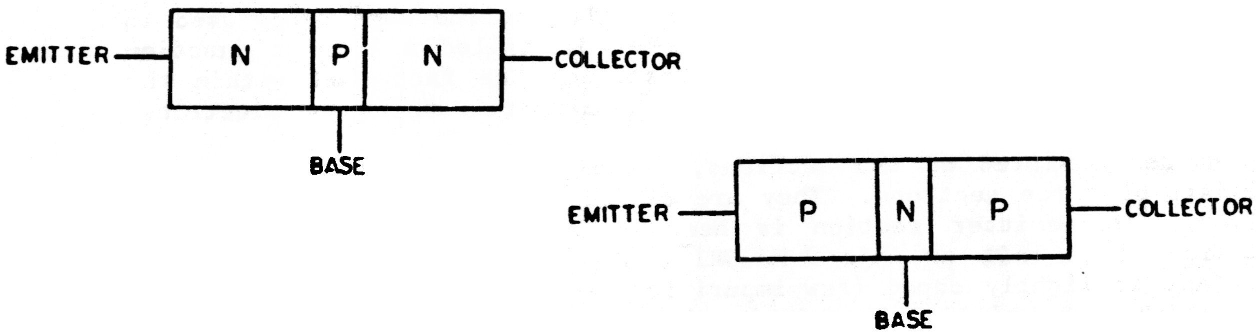


Fig. 2

They are NPN and PNP. These are block diagrams and indicate that the base is sandwiched between the emitter and collector. Notice that a junction is present between the emitter and base, and the base and collector, of both types of transistors. This junction will react the same as the junctions discussed in semiconductor diodes. When the emitter and base are brought together a depletion region is formed between the two sections. A junction is also present between the base and collector. A depletion region is also formed at this junction. See fig. 3.

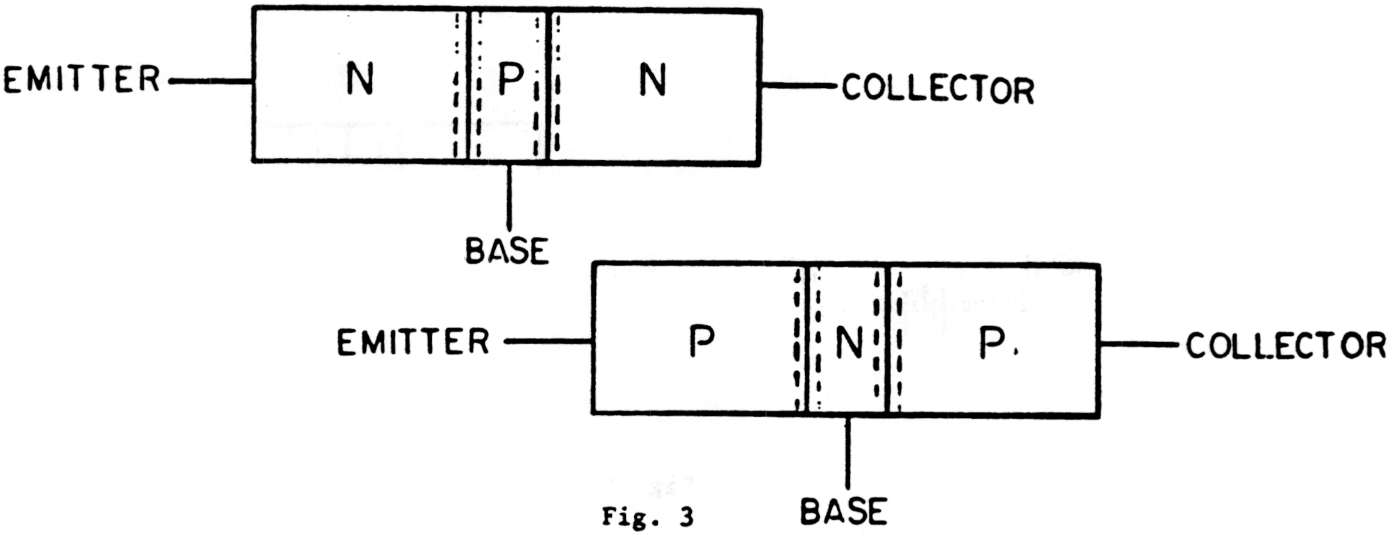


Fig. 3

JUNCTION BIASING

For a transistor to function normally both junctions must be properly biased. Under normal conditions the EMITTER/BASE junction will always be FORWARD BIASED. See fig. 4.

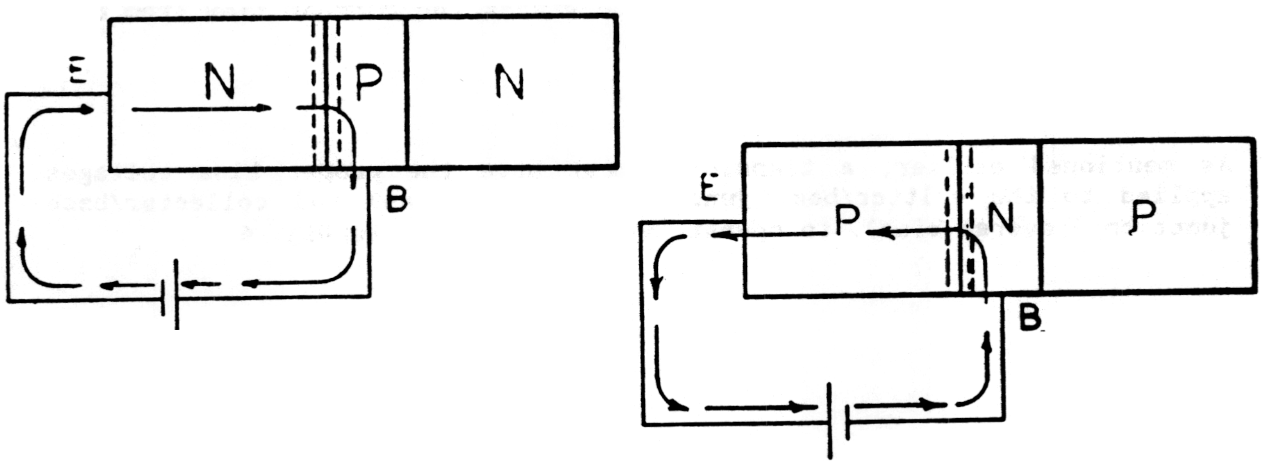


Fig. 4

With the emitter/base junction forward biased, the depletion region will be reduced and current will flow from the negative terminal of the battery, through the emitter/base junction and back to the positive battery terminal.

The COLLECTOR/BASE junction will always be REVERSED BIASED. See fig. 5.

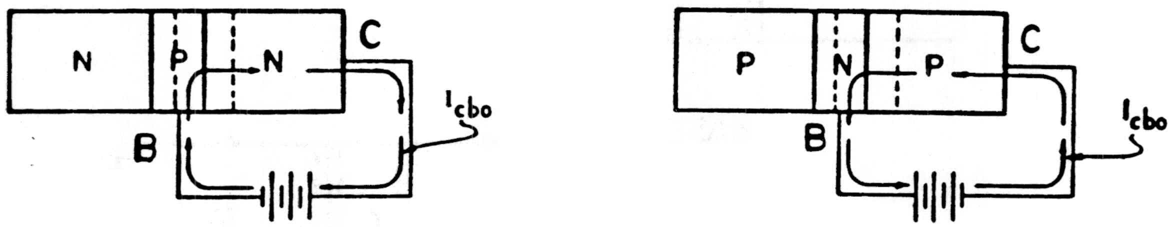


Fig. 5

With the collector/base junction reverse biased there will be no majority current flow across the collector/base junction. Due to the reverse biased condition, a small minority current will be present. Transistors, as well as diodes, are affected by minority current carriers. The collector/base junction is reverse biased. No current would flow in this circuit except for the presence of minority current carriers, electrons in the P material and holes in the N material. This current flow is extremely small and is called Icbo. Icbo stands for current flow from base to collector with the emitter open.

TRANSISTOR OPERATION

As mentioned earlier, a transistor must have the proper bias voltages applied to the emitter/base junction (forward bias) and collector/base junction (reverse bias), to operate properly. Refer to fig. 6.

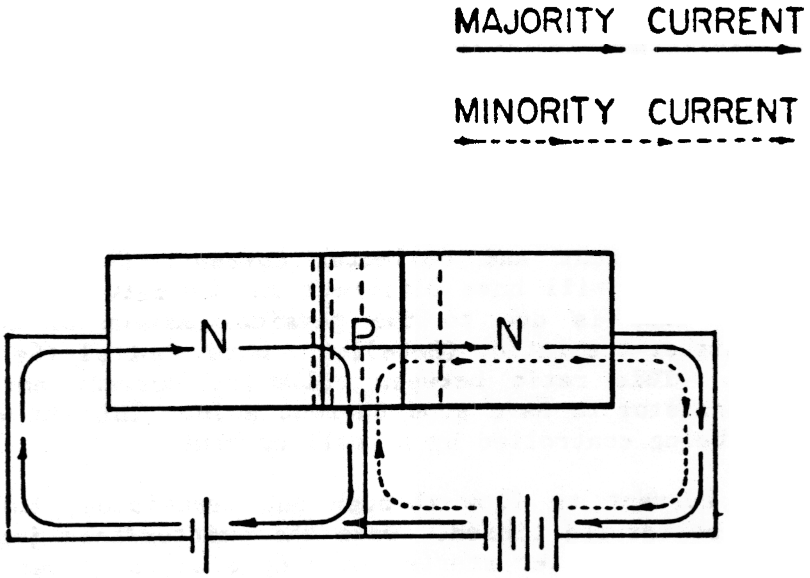


Fig. 6

The operation of an NPN transistor will now be discussed. Keep these points in mind. The emitter is heavily doped and has many majority current carriers present (free electrons). The base is extremely thin and very lightly doped. For explanation purposes only, assume the emitter has 100 free electrons that are free to move across the emitter/base junction. The base, being lightly doped, has only 5 holes (P material). When proper bias voltage are applied, the emitter/base junction becomes forward biased and the emitter starts to emit electrons into the base. If the emitter emitted 100 electrons into the base and the base has only 5 holes available, then only 5 electrons will be able to recombine with the holes. Each time one recombination takes place, one electron near the base lead will leave the orbit of an atom, leaving behind a hole, and be ejected from the base material into the base lead and returns to the emitter/base biasing battery. At the same time one electron enters the emitter from the battery. Since only 5 electrons could recombine, 95 are left as free electrons in the base. The collector/base junction which is reverse biased to majority carriers, now appears as forward bias to the electrons that are present in the base. The collector, being connected to the high positive potential of the collector/base bias battery, will now attract the electrons into the collector. Once inside the collector, the electrons are again majority carriers and will move through the collector and return to the bias battery.

It has been shown that all the current that flows through the emitter divides. In the case described above, 5% of the emitter current recombined and flowed out the base lead while 95% of the emitter current was left to flow through the base to the collector. The doping and thickness of the base controls the amount of recombination that occurs. If the base were doped lighter, less recombination would take place resulting in a lower base current and higher collector current. The relationship between base current and collector current is one of the most important transistor characteristics. This relationship is expressed as a ratio and can be stated mathematically as Ic/Ib. The ratio of collector current divided by base current is known as BETA and is symbolized by the Greek letter β . It should be noted that all the current that flows through the transistor flows through the emitter (100%). Emitter current, (Ie), equals base current, (Ib), plus collector current, (Ic), (Ie=Ib+Ic). Collector current is the difference between emitter current and base current, (Ic=Ie-Ib). Base current is equal to the difference between emitter current and collector current, (Ib=Ie-Ic). Different types of transistors will have different ratios between base and collector currents. This is due to the physical makeup of the transistor. Ideally, the higher the ratio, (Beta), the more control the base has over the collector. This ratio between collector current and base current allows the transistor to have good current gain. This is where we see a large current being controlled by a small current.

In order for current to flow through the transistor, the emitter/base junction must be forward biased. Once the emitter/base junction becomes forward biased, the emitter starts emitting electrons, part of which recombine in the base and determine base current. If the emitter/base forward bias is increased, the emitter/base depletion region will decrease. The emitter will now emit more electrons. More electrons are now available for recombination in the base and the base current increases. With more electrons being injected into the base, more electrons will pass through the base and enter the collector. Collector current will also increase. It should be noted that an increase in emitter/base forward bias results in an increase in base current (Ib). An increase in base current will result in an increase in collector current, (Ic). Thus, it can be seen that collector current is controlled by base current, and base current is controlled by emitter/base bias.

If the emitter/base forward bias is reduced to a point that the emitter/base junction is no longer forward biased, or if the path for base current is opened, base current will cease and collector current will stop. However, if the path for collector current is interrupted or collector/base bias is removed and the emitter/base junction remains forward biased, base current will continue to flow and will actually increase slightly because all the holes in the base that are available for recombination will now recombine resulting in a slight increase in base current.

Although the previous discussion of transistor operation dealt with an NPN transistor and the current carriers were electrons, the same explanation holds true for a PNP transistor. Now the current carriers will be holes. The emitter will emit holes which will cross the emitter/base junction. Some of the holes will recombine with electrons in the base creating base current. The majority of the holes will continue on into the collector where they are again majority current carriers. At the collector lead electrons entering the collector from the bias battery will recombine with the holes. Every time an electron enters the collector one leaves the emitter. Electron flow through a PNP transistor will be opposite that of an NPN.

SCHEMATIC SYMBOL IDENTIFICATION

Block diagrams of a transistor are not used in schematics. Figure 7 shows the schematic symbols for the transistor. In each symbol the EMITTER LEAD is identified by the ARROWHEAD. The arrowhead will ALWAYS be located on the emitter. The direction the arrowhead is pointing will indicate the type of transistor. The arrowhead ALWAYS points toward the N material. For example, on the NPN transistor, the arrowhead points away from the base. Since the arrowhead is pointing toward the emitter, the emitter is N material. Because the emitter and collector are made of the same type material the collector is also N material. This leaves the base. The base is always of the opposite type material as the emitter and collector. Thus, the base is P type material. The PNP transistor has the arrowhead pointing toward the base. Therefore, the base must be N material. This means the emitter and collector are P type material. The polarities on the transistor and the lead identification are important items and should be remembered. When looking at a schematic drawing, as with a diode, current will always flow against the arrowhead.

Fig. 7

TRANSISTOR CHARACTERISTICS CURVES

One method of demonstrating transistor operation is the use of graphs. Graphs can be constructed to illustrate many different transistor functions. The graph shown in figure 8 is a set of characteristic curves. Different transistors will have different shaped curves.

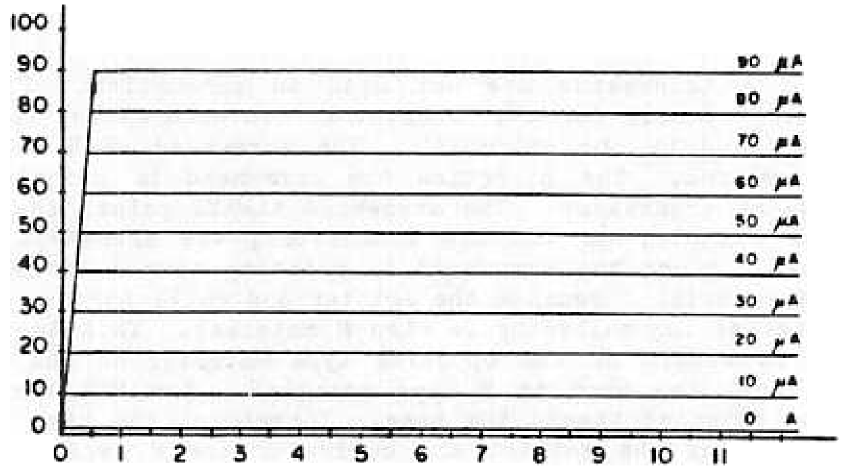


Fig. 8

The process used to construct a set of characteristic curves will now be covered. The graph below is laid out to indicate collector current, in milli amps, on the verticle axis. Collector voltage will be indicated along the horizontal axis, in 1 volt increments. The graph will be of a hypothetical transistor. See figure 9.

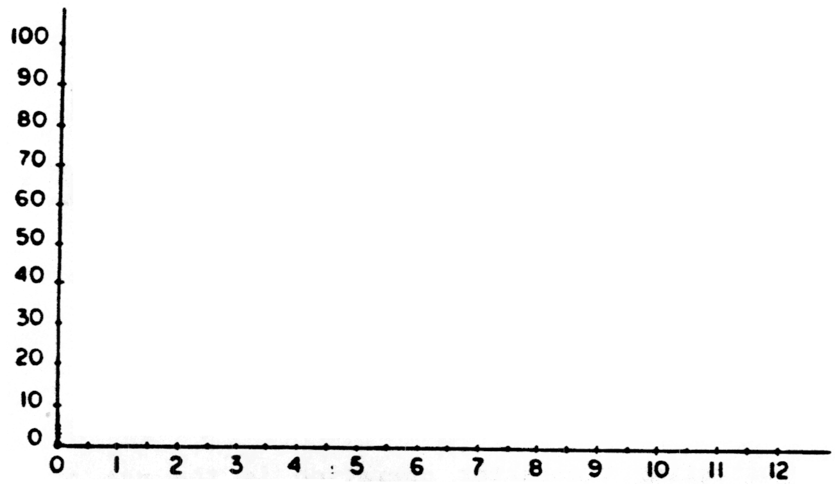


Fig. 9

Refer to figure 10. To construct the first curve assume that the base current of the transistor is 0 amps (no base current). This would mean that there isn't enough forward bias to make the emitter/base junction conduct. If collector voltage is reduced to 0v then no collector current will flow. This is indicated at point A. Holding base current at 0 amps we will start to increase collector voltage. Notice point B. With .5v of collector voltage applied, 1 milli amp of collector current is now flowing. Point C indicates collector voltage has been increased to 1v. Notice collector current has not changed. At point D collector voltage has been increase to 4v and collector current is still 1 milli amp. If all 1v increments were plotted and then the points connected the graph would look like figure 10.

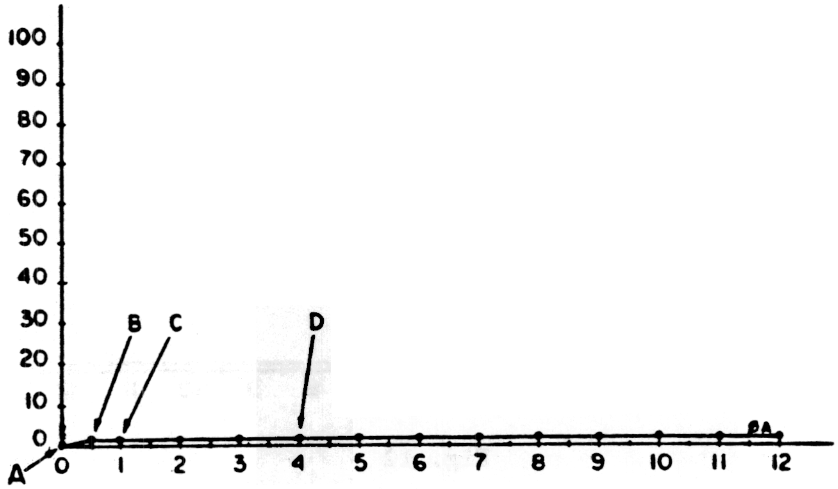


Fig. 10

Notice that the plotted curve for this set of points is labeled 0 amp. The slight amount of current flow that is displayed is due to the actual resistance (bulk resistance) of the transistor and not due to normal transistor conduction. See figure 11.

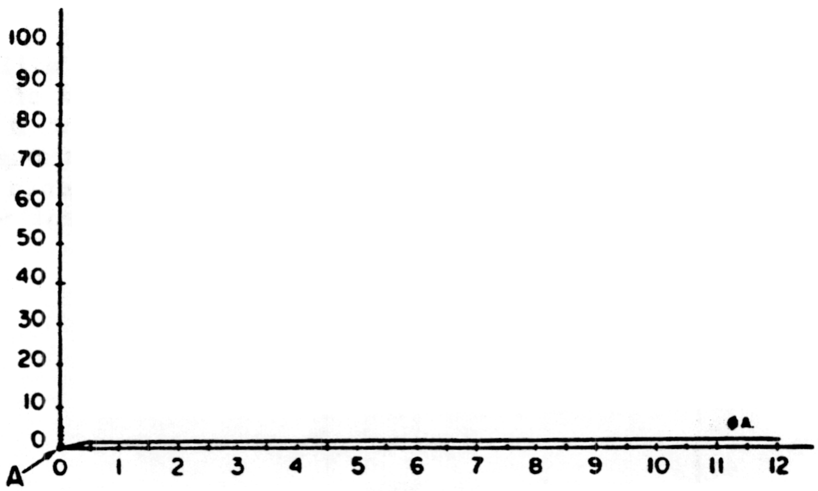
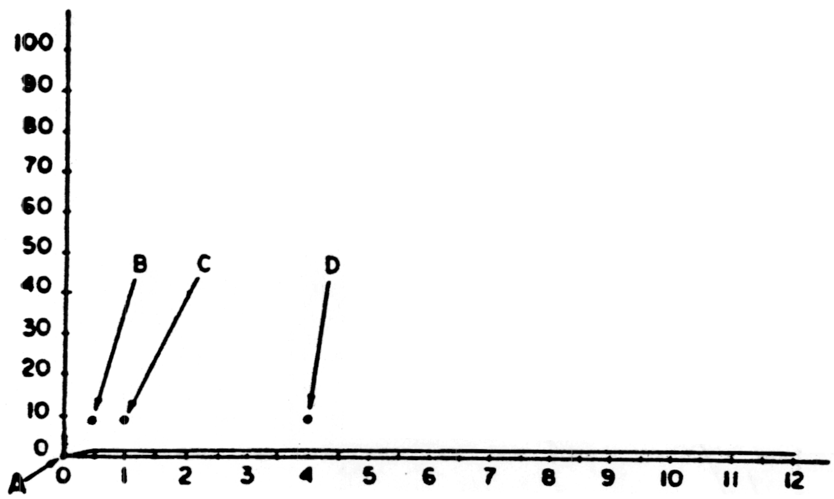


Fig. 11

The second line or curve will now be plotted. Assume that emitter/base bias has been increased so that 10 micro amps of base current now flows. Refer to figure 12.



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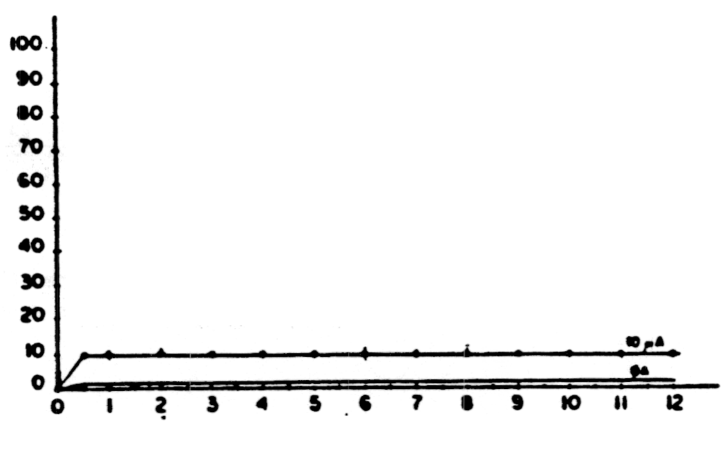
The first curve has been left on the graph. Again the collector voltage has been reduced to 0v. Even though 10 micro amps of base current is flowing, no collector current will flow. With 0v felt on the collector there is nothing to attract the current carriers now being injected into the base. Again we will call the first point, point A. Point A=0 collector current, and 0 collector volts. Collector voltage is now increased to .5v.

Point B indicates that with .5v of collector voltage, 10 milli amps of collector current will flow. Point C indicated that with 1v of collector voltage, collector current remains at 10 milli amps. Point D indicates that collector current has remained at 10 milli amps even though collector voltage has increase to 4v. Again if all 1 volt increments are plotted and connected, the curve for 10 micro amps of base current would look like figure 13.



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The curve for 20 micro amps of base current will now be plotted. Refer to figure 14. Curves for 0 base current and 10 micro amps of base current have been left on the graph.

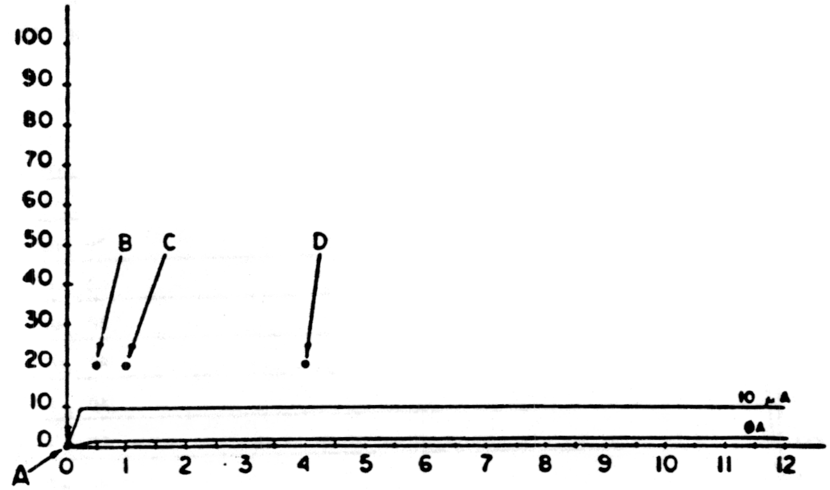

Fig. 14

Collector voltage is again reduced to 0v. Assume base current has increased to 20 micro amps. Point A indicates no collector current will flow even though base current has been increased. This indicates collector voltage must be present for collector current to flow. Point B indicates collector voltage has been increased to .5v. With 20 micro amps of base current, collector current is now 20 milli amps. Point C indicates collector voltage has been increased to 1v. Collector current remains at 20 milli amps. Figure 15 shows the completed curve for 20 micro amps.

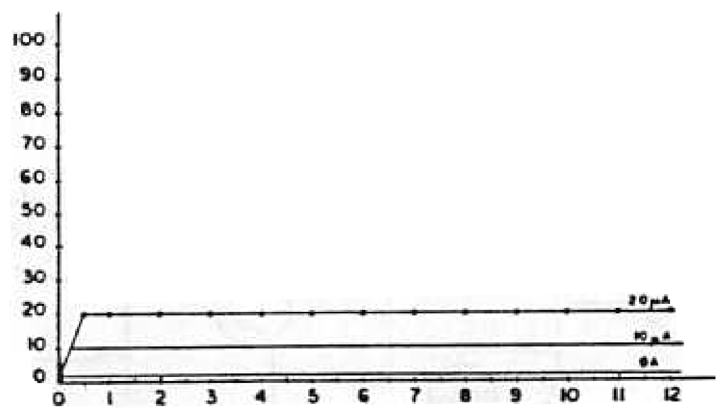

Fig. 15

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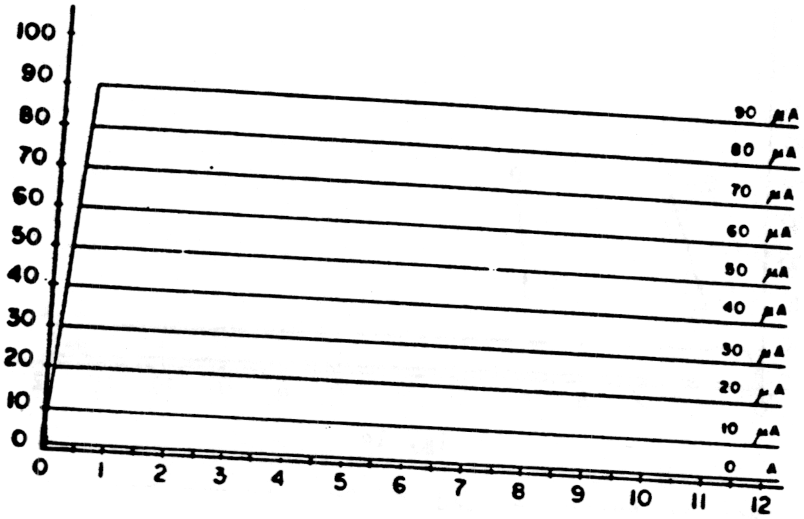
Observe that once the collector voltage is increased to the point that it is attracting all the current carriers that have not recombined in the base, further increasing the collector voltage will not increase collector current. Figure 16 is a complete set of curves for a hypothetical transistor. All the curves have been plotted in the same manner as previously indicated.



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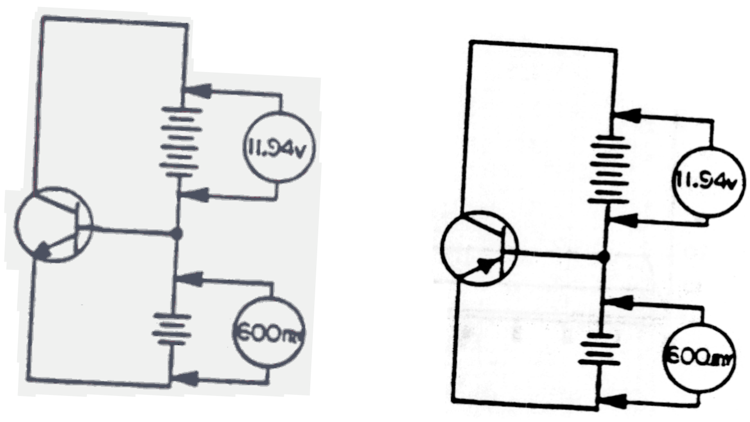
As stated earlier, the emitter emits or injects current carriers into the transistor. This means that the transistor is a current operated device. Although it is current operated the voltages felt around the transistor are very important. It is much easier to measure voltages rather than to open the circuit and measure current. An understanding of the voltages around a transistor becomes extremely important. By analyzing the voltages an indication of transistor operation can be determined. Refer to figure 17, below.



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Notice the emitter/base junction of both transistors is forward biased. A voltmeter placed between the emitter and base leads would indicate 600mv of forward bias. The collector/base junctions are reverse biased. A voltmeter placed between the collector and base would indicate 11.94v of reverse bias. It can be seen that a voltmeter can be used to determine what the bias on either junction is.

Up to this point batteries have been used to supply the bias. This has been done for ease of explanation but is highly impractical for actual circuit operation. Biasing transistor circuits is normally done using voltage dividers.

The use of voltage dividers allows the use of one power supply to provide the biasing voltages. Space and weight is also saved by the use of voltage dividers. Before proceeding to an actual circuit a quick review of voltage dividers is in order. Kirchoffs Law states that the sum of all voltage drops in a circuit will be equal to the applied voltage. See figure 18. If the resistors are of equal value they will drop equal voltages. If R1 is twice the size of R2 it will drop twice the voltage as R2. Regardless of each individual drop the sum of the drops must equal the total applied voltage.

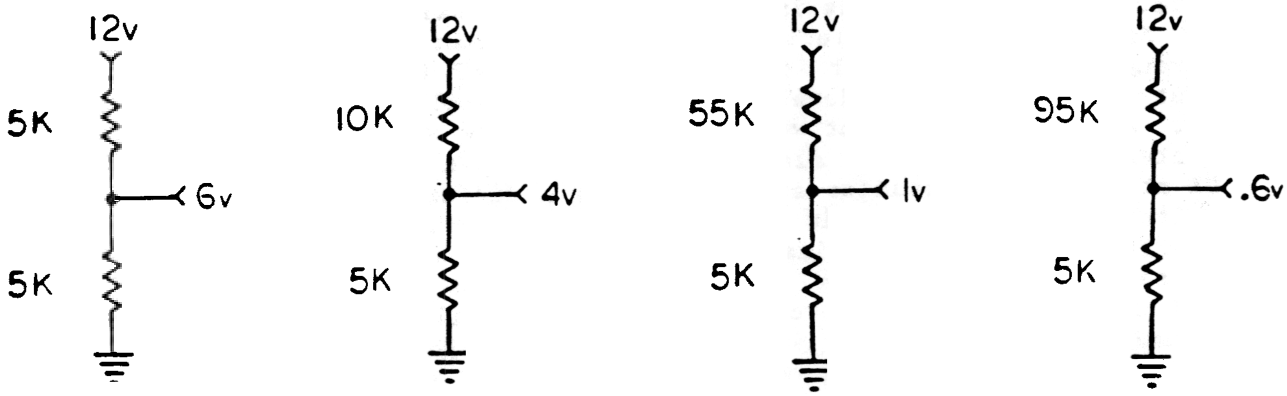


Fig. 18

It should be noted that the selection of the size of resistors will determine the voltage present at TP 1 in figure 18. With the proper selection of the resistors in the voltage divider any voltage between 12v and 0v can be felt at TP 1.

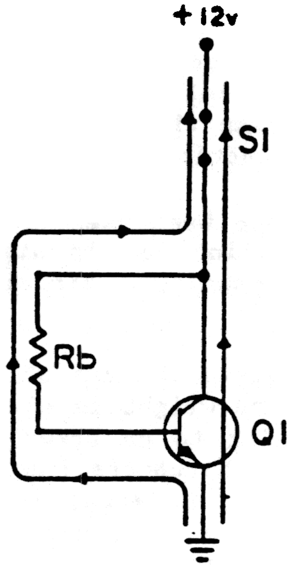


Fig. 19

Refer to figure 19. This is the most basic transistor circuit that could be designed. The collector of the transistor is connected to +12v through S1. The emitter is connected to ground (0v). Rb is a resistor that will be used to develop the bias that will be felt by the base of Q1. At the first instant when S1 is closed 12v will be felt at the collector of Q1. 12v will also be felt at the base of Q1. With the base of Q1 at 12v and the emitter at 0v there is a difference of 12v between the emitter and base. Q1 is a silicon transistor. For the emitter/base junction to be forward biased the base must be at least 600 mv positive in respect to the emitter. With 12v on the base these conditions are met and current will start to flow. Current will flow up from ground, through the emitter/base junction, through Rb to the power supply. Recall that any PN junction will develop a small voltage drop due to its low resistance. The resistance of the junction is in series with Rb and forms a voltage divider with Rb. If the emitter/base junction drops 600mv due to its forward biased condition, then the remaining 11.4v must be dropped by Rb. The 12v that was felt at the base originally, was of such short duration that it is impossible to measure. The emitter/base junction is now forward biased and the emitter will start emitting electrons into the base. The high positive voltage connected to the collector attracts the electrons on through the collector and a second path for current is now created. An ammeter placed in series with the base and collector would indicate a low base current (1ma.) and high collector current (40ma.). See figure 20.

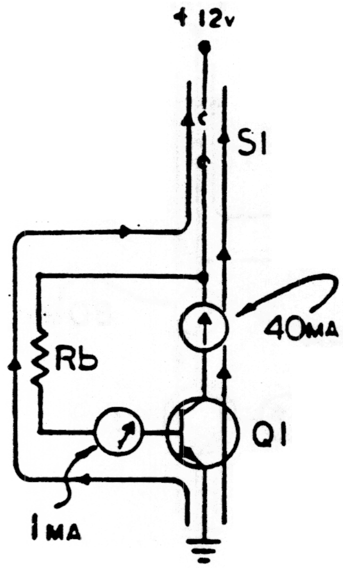


Fig. 20

If the size of Rb were decreased base current would then increase. Decreasing the size of Rb means that it must drop less voltage in respect to the emitter base junction. The voltage present at the base will increase. Recall that an increase in base voltage will be more forward bias which will result in the resistance of the emitter/base junction decreasing. The resistance of the emitter/base junction is very small in respect to Rb. Although the resistance of the emitter/base junction decreased, due to an increase in forward bias, it did not decrease at the same ratio as Rb. The resultant increase in current, due to the reduction of Rb, results in an increase in the voltage dropped across the emitter base junction.

Simply stated

a. As Rb is decreased the emitter/base bias increases.

b. There-by reducing the emitter/base junction resistance.

c. Allowing an increase in base current which

d. Causes an increase in collector current. See figure 21.

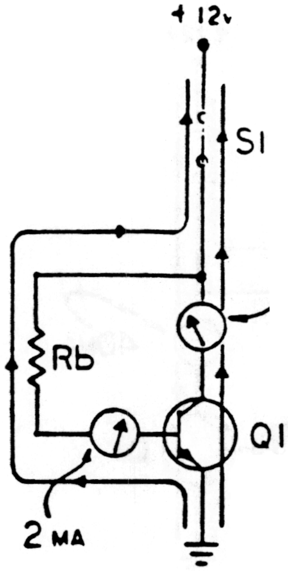


Fig. 21

The transistor can be viewed as a variable resistor. If increasing the emitter/base bias results in an increase in base current, and base current flows through the emitter/base junction, it should be understood that the resistance of the emitter/base junction will decrease if the bias is increased. An increase in bias will also result in a decrease of the resistance between the collector and emitter. A decrease in bias results in an increase in resistance.

Since the resistance of the emitter/base junction depends on the amount of forward bias applied to it, it cannot be measured but can be calculated.

To calculate the resistance of the emitter/base junction/the current flow through the junction and the voltage drop across it must be known. R=E/I. Refer to figure 22.

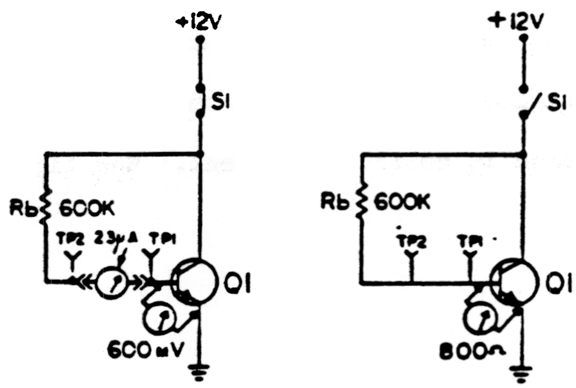


Fig. 22

An ammeter placed between TP1 and TP2 will indicate base current (Ib). Since the emitter/base junction is in series with the biasing resistor (Rb) base current will be used in the calculation. Assume base current is 23 A. Placing a meter across the emitter/base junction provides the voltage drop for the calculations. Using these figures, the resistance of the junction is 26K . This figure may seem high for a forward biased PN junction but there are other factors involved besides the junction itself. The large size of the biasing resistor (600K) will reduce the amount of current available to flow through the junction. If the biasing resistor was reduced by one-half then twice the current would be available. Forward biasing the emitter/base junction would then result in more current flow through the junction and a reduction of emitter/base resistance.

Opening S1 will remove the bias from the transistor. An ohmmeter placed across the emitter/base junction will forward bias it and the resistance of the junction, itself, can be read. A normal reading of the junction resistance will usually be less than 1K

If Rb was opened, no voltage could be applied to the base. Also, there would be no current path for base current. With no base current there will be no collector current because collector current is directly related to base current. See fig 23.

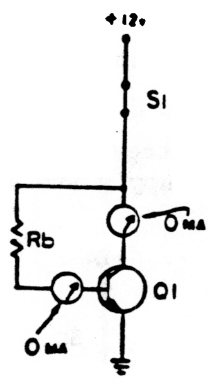


Fig. 23

The circuit just discussed illustrates proper transistor biasing but is of little practical use. More circuit components will be added to enhance its operation.

It is possible to determine the conduction level of the transistor by adding a test point to the collector and taking voltage readings between the collector and ground. See figure 24.

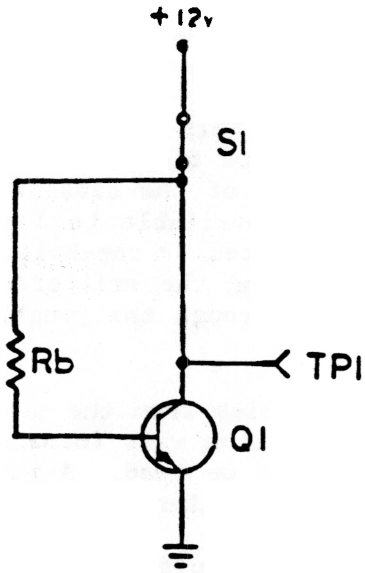


Fig. 24

Notice that if the circuit in figure 24 is left as shown the voltage drop across the transistor would always be 12v regardless of the conduction level of the transistor. If Rb were increased in size less base current would flow resulting in a decrease in collector current but the collector voltage would always be 12v.

For TP1 to provide any useful voltage readings a resistor must be added to the circuit between the power supply and TP1. See figure 25.

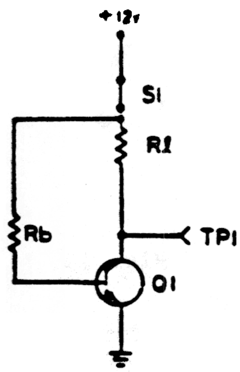


Fig. 25

The resistor placed between the collector and the power supply is called the LOAD RESISTOR. It will be referred to as RL. The addition of RL establishes a voltage divider consisting of RL and the resistance of the transistor. The transistor can be looked at as a variable resistor. With RL placed in the circuit, the collector and TP 1 are now separated or isolated from the power supply. A voltmeter placed between the collector and ground will now indicate the voltage drop of the transistor which is directly related to its resistance. The greater the resistance of the transistor the greater the voltage drop across it. According to Kirchoff's Law, if 12v is applied to the circuit, RL and Q1 must drop the total voltage (ER1+EQ1=Eapp). For instance, if the transistor drops 2v, RL must drop 10 volts. If the transistor drops 7v, R1 must drop 5v.

The voltage that is read at TP1 will be called the OPERATING POINT or Q POINT. Once the bias and conduction level of the circuit have been established it is extremely important that the Q POINT is not allowed to vary.

At the beginning of this lesson Icbo was discussed. Recall that Icbo is the result of minority current carriers. One drawback of transistors is that they are temperature sensitive. Any increase in temperature will result in the generation and increase in minority current carriers which will result in an increase in Icbo. If Icbo increases it adds to collector current resulting in an increase in collector current. Under normal conditions the only thing that should be changing the Q Point is the emitter base bias. Allowing the conduction level to increase means more current flows through the transistor generating more heat which in turn results in more minority current carriers which increases Icbo adding to the collector current. If this condition is allowed to continue the Q POINT will change. If the problem is allowed to become excessive the collector current may become so large that the transistor is destroyed. This condition is called THERMAL RUNAWAY.

TRANSISTOR BIAS STABILIZATION

Once the transistor has been biased to operate at a certain Q point it is the function of the surrounding circuits to maintain this Q Point. Three different circuits can be used to aid in BIAS STABILIZATION: the EMITTER RESISTOR, the EMITTER SHUNT RESISTOR, and the COLLECTOR FEEDBACK.

Figure 26 shows an example of the first type of bias stabilization method.

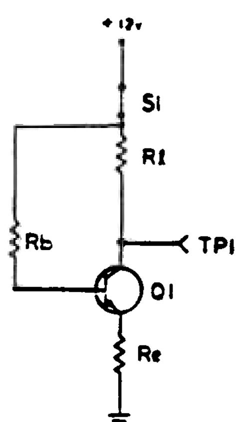


Fig. 26

An emitter resistor (Re) has been added to the circuit. This resistor is used to help maintain a constant current flow through the emitter therefore holding the Q Point steady. With Re in the circuit when the transistor starts to conduct a voltage drop is developed across Re and the emitter is no longer at ground potential (0v). The emitter voltage will now be at some low potential that is negative in respect to the base. This will set a certain level of forward bias. Remember, bias is the difference in potential between the emitter and the base.

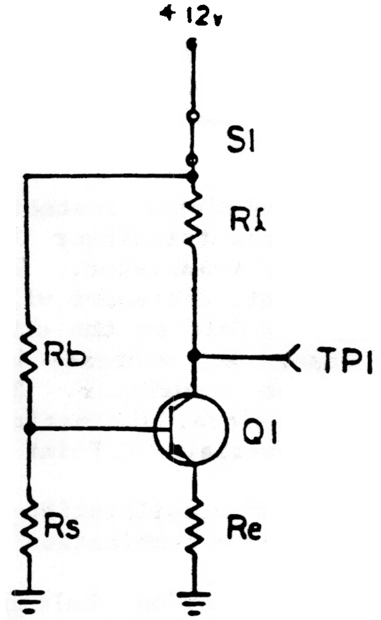
If the transistor starts to heat up, due either to current flow or as a result of an increase in room temperature the transistor will start to increase its conduction. This increase in conduction is due to the addition of extra current carriers (minority carriers) that are generated by the rise in temperature. As the conduction increases more heat is generated creating more minority current carriers, which further increases the transistors conduction. If allowed to continue, the transistor may be destroyed. This condition is called Thermal Runaway.

This increase in current would result in a decrease of the Q Point. The EMITTER RESISTOR has been added to help compensate for this change in current. As the transistor current increases, the current through the emitter resistor will increase causing the voltage drop across the emitter resistor to increase. This results in a less negative (more positive) being felt on the emitter. Emitter/base forward bias is then reduced which results in the transistor conduction level decreasing to its original level. If the circuit is functioning properly the correction will be felt instantly and the Q Point will never get a chance to change.

The insertion of an emitter resistor is sometimes not sufficient to provide total bias stabilization. The circuit is not totally effective because the rise in voltage across Re is sometimes not great enough to reduce base current sufficiently to cancel the rise in collector current. This is because Rb is generally so large in respect to Re, that it is the major factor in controlling base current. Rb must be large in respect to Re in order to develop the low biasing voltages for the base of the transistor.

Re cannot be made too large because it is in series with RL and the transistor. The output power of the transistor is determined by the voltage drop of the transistor (Vce), times the collector current (Ic), (Pout=Vce X Ic)). Any voltage dropped by Re lowers the voltage dropped by the transistor. The greater the value of Re the lower the power output of the circuit.

The stabilizing effect of Re can be increased by reducing the size of Rb. Decreasing the size of Rb has the same effect as increasing the size of Re. Reducing the size of Rb will result in an increase in base current. An increase in base current will result in an increase in collector current and a corresponding shift of the Q Point.



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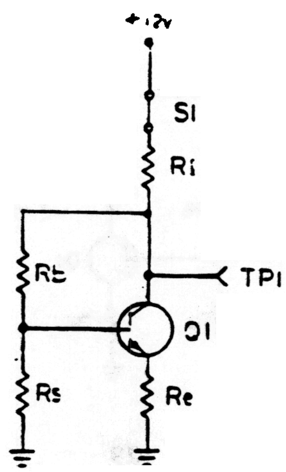
To decrease Rb without increasing base current and additional path for current must be provided. This can be accomplished by inserting an additional resistor in parallel (shunt) with Re. This shunt resistor will be labeled Rs. See figure 27.

Rb can now be reduced giving Re greater control. The reduction of Rb means more current will now flow through Rb. The addition of Rs provides an additional current path. Current flow through Rs joins with base current allowing an increase in the current through Rb without increasing the base current. Base current then remains unchanged, collector current remains unchanged and the Q Point remains steady. Re now has a greater effect in controlling the stability of the circuit.



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A third type of stabilizing circuit is called, COLLECTOR FEEDBACK. The action in this circuit is to couple a part of the collector voltage feedback to the base. An example of collector feedback is shown in figure 28. Notice that Rb is no longer tied to the power supply but is connected directly to the collector.

One of the main reasons for transistor instability is varying temperatures. If the temperature in the transistor increases there will be an increase in current through the transistor. If current increases, the voltage at the collector, Q point, decreases will change (Q Point). This decrease in collector voltage is felt on the other side of Rb (feedback) which is connected to the base. Any decrease in voltage at the base decreases the forward bias on the transistor. Reducing forward bias decreases collector current, therefore, increasing the collector voltage. This action tends to keep the transistor Q Point very stable.

Under most conditions some type of stabilization will be used. It may be any one of those just discussed or a combination of all three.

In the discussion of bias stabilization, holding the Q Point at a constant point has been stressed. Any changes of the Q Point were due primarily to changes in temperature. In the discussion of conduction levels that follows, the Q Point will be shifted intentionally. The intentional shifting of the Q Point will be the result of varying the emitter/base bias.

THREE BASIC CONDUCTION LEVELS

As explained earlier, by measuring the voltages around a transistor it is possible to determine if the transistor is conducting.

There are three basic levels of conduction of a transistor. The first that will be discussed is CUTOFF.

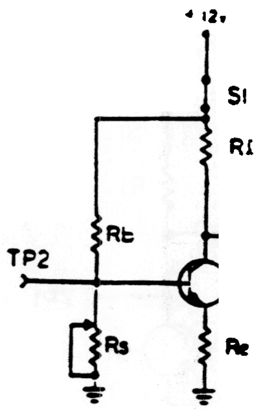

Fig. 29

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In figure 29, Rs is a variable resistor. In addition to providing bias stabilization Rs also is part of a VOLTAGE DIVIDER network that will help develop the bias that will be applied to the base of Q1. By making Rs variable the bias that will be applied to Q1 can be varied.

Notice that the wiper arm of Rs has been moved to the top of Rs. By moving the wiper to the top of Rs, the resistor has been bypassed and ground (0v) is felt at TP2. TP2 is connected to the base of Q1. With 0v felt on the base and 0v felt on the emitter, there is no difference in potential between the base and emitter (no forward bias). With no forward bias the emitter will not emit current carriers, so no current will flow through the transistor.

If the transistor was a silicon transistor the resistor (Rs) would have to be adjusted so that TP2 would read 600mV before the emitter/base junction barrier potential was overcome. At this point the transistor would start to conduct very lightly. Anytime the base voltage (bias) is at a level that is to low to allow conduction the transistor is said to be CUTOFF. This term refers to emitter-collector current and indicates no emitter-collector current is flowing.

In figure 30 a voltmeter has been placed between the collector and ground.

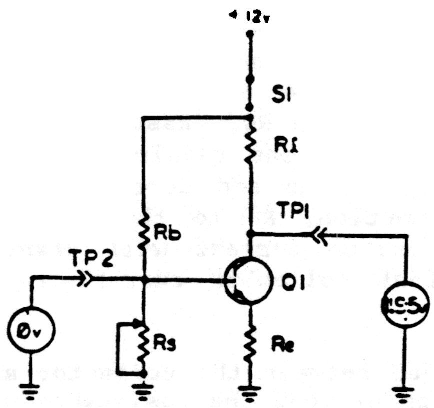

Fig. 30

If the bias is too low to allow the transistor to conduct the resistance of the transistor must be very high. A meter placed across this high resistance will indicate a large voltage drop across the transistor. When the meter is connected it provides an alternate current path. The internal resistance of the meter is lower than the resistance of the transistor but is still very high. A very small current will flow through RL to ground, through the meter. The voltage dropped by RL will be extremely low due to the low current (ERL=IRL X RL). If RL drops .05V then the voltage present at TP1 will be 11.95V (12v-.05V=11.95V). When the collector voltage is the same as or very close to the applied voltage the transistor is CUTOFF.

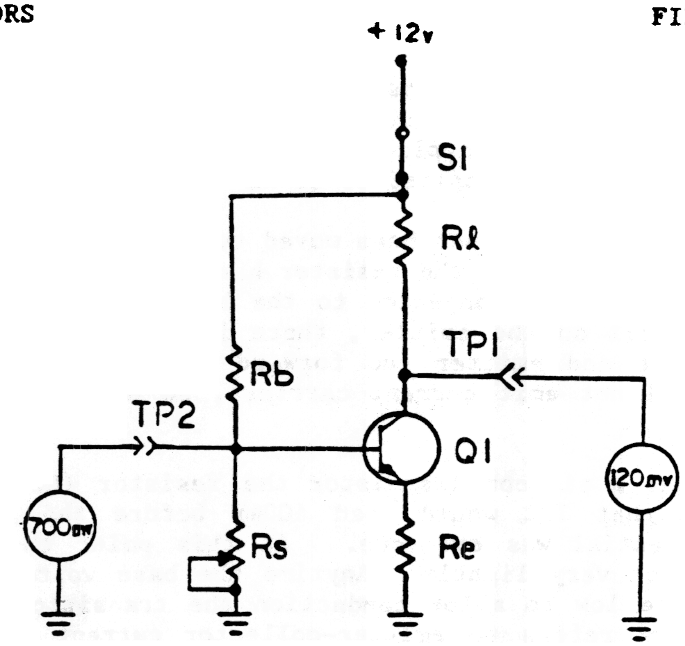

Fig. 31

The second conduction level that will be discussed is called SATURATION Refer to figure 31.

Notice that the wiper arm of the variable resistor (Rs) has been moved very close to the bottom. Depending on the size of Rb and Rs the voltage at TP2 will be near the maximum that can be dropped by Rs. Keep in mind that Rb is considerably larger than Rs. Assume that the voltage felt at TP2 is 700mV. This is more than the required 600mV. The emitter/base junction will become forward biased and current will flow from ground, through Re, emitter/base junction, Rb to the power supply. Once base current is established collector current will start to flow. It has already been established that collector current is controlled by base current.

Again a meter has been placed between the collector and ground. The meter reads 120mV. This indicates that the resistance of the transistor is now very low. With a high current flowing through RL it will now drop a large amount of the applied voltage. If RL drops 11.88v only 120mV is left to be dropped between TP1 and ground.

For these indications to be true, the emitter resistor (Re) must be a very low value. The voltage at the top of Re would have to be slightly less than the collector voltage due to the voltage divider formed by the collector and emitter circuits. If the emitter resistor was a large value and dropped 6V, for example, the collector voltage would never go below 6V under normal conditions.

It should be noted that by increasing the bias (adjusting Rs) that the transistor was changed from a non-conducting state to a conducting state. Refer to figure 32.

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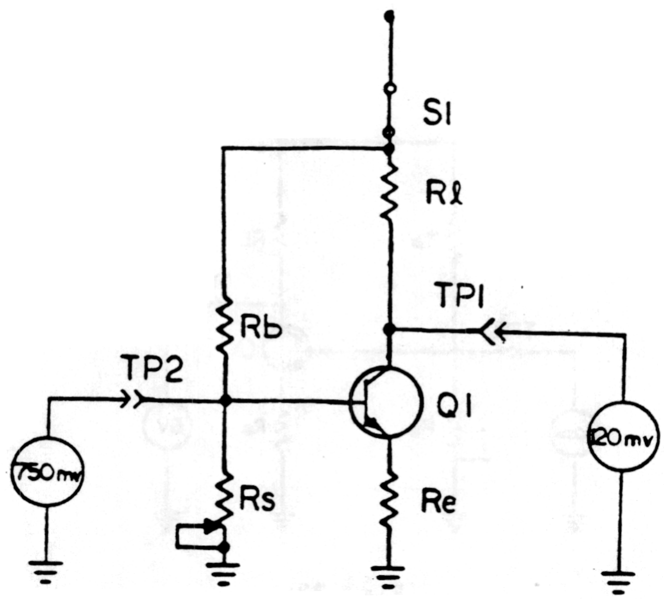


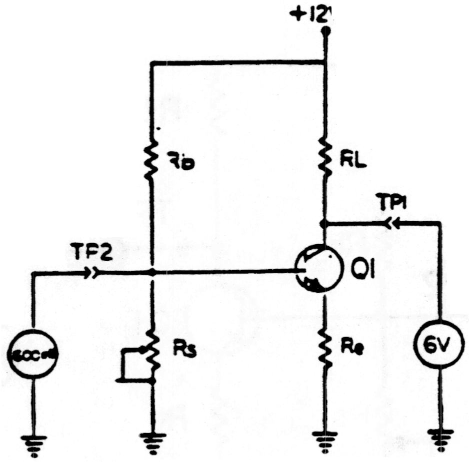
Fig. 32

The wiper arm has now been moved to the bottom of Rs. The voltage (bias) will now be the maximum that can be developed by the voltage divider (Rb and Rs). The voltage at TP2 has now increased to 750mV. This is an increase in emitter/base bias of 50mV. Normally, this increase in bias would result in an increase in the transistors conduction level, however, the voltage at TP1 has not changed. With an increase in bias the resistance of the transistor should have decreased and the conduction level increased.

However, in actual transistor operation, base bias can only increase so much, until no increase in the conduction level is seen. Once the transistor has reached a point that an increase in forward bias no longer increases the conduction level the transistor is at a conduction level called SATURATION.

The two extremes of transistor conduction have been discussed. When the transistor is not conducting due to insufficient forward bias at the emitter/base junction, current flow through the transistor if Cutoff. Cutoff is identified when the collector voltage equals the applied voltage. The other extreme is Saturation. Saturation is when the transistor is conducting as hard as it is possible to conduct. When a transistor is Saturated, increasing forward bias will not make it conduct any harder. Saturation is indicated when the collector voltage reads very close to the emitter voltage. Keep in mind that for the collector voltage to vary a Load Resistor must be connected between the power supply and the collector.

A third conduction level exists. When the emitter/base bias has been adjusted so that the collector voltage falls between Saturation (0V) and Cutoff (applied voltage) the transistor is operating in its ACTIVE REGION. See figure 33.



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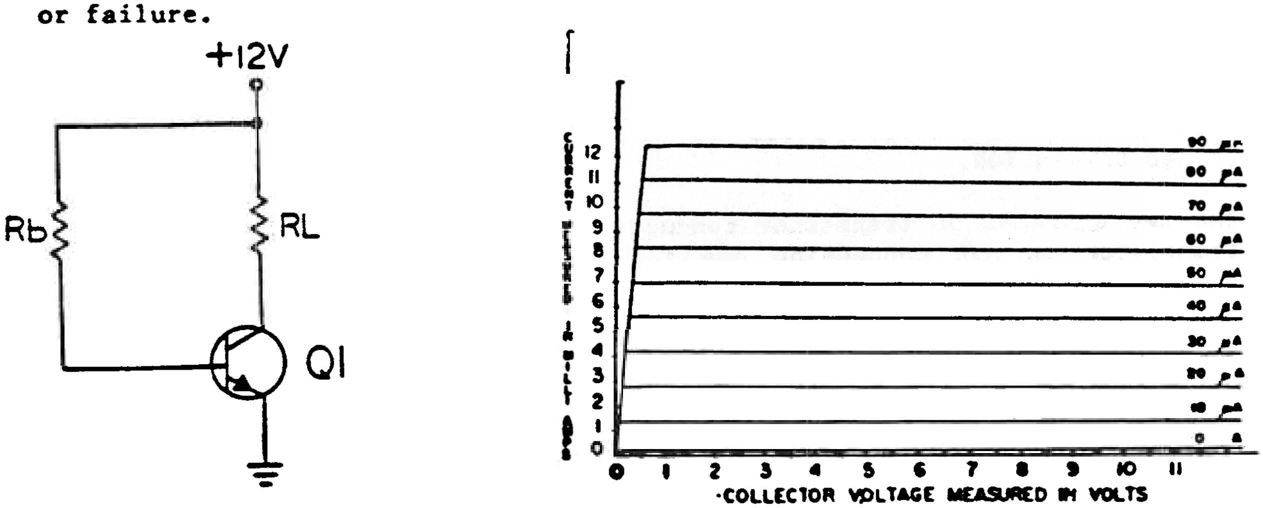
LOAD LINES

To insure proper operation, a transistor circuit must be designed so the transistor will operate within its set of Characteristic Curves. Figure 34(b) is a set of Characteristic Curves for the transistor circuit in 34(a). For the circuit shown in figure 34(a) the choice of the operating point is determined by RL and Vce (voltage drop Collector to Emitter). An improper choice of these values can result in the transistor operating point being placed in an area that will result in inefficient operation or failure.



(a) (b)

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A method of indicating the area of operation (Q Point) on the Characteristic Curves is to plot a LOAD LINE. All points on the LOAD LINE between Cutoff and Saturation are the Active Region of the transistor.

The development of the load line is based on two conditions, Cutoff and Saturation. When the transistor is Saturated its resistance is very low and maximum current will flow. The second condition is the transistor is Cutoff. When the transistor is Cutoff its resistance is maximum and no current will flow.

Refer to Figure 34. If the transistor was Saturated maximum current would flow from emitter to collector. With the applied voltage being 12V and the load resistor 1K the maximum current that could flow would be 12mA. (12V/1K=12mA). Since the transistor is Saturated, we will consider it a short and the voltage dropped across it would be 0V. The collector voltage is then 0V. When the transistor is Saturated 12mA of current flows through it and 0V is felt on the collector. An indication of these conditions will now be plotted on the Characteristic Curve graph, figure 35. This point will be labeled Point Y. The second condition, Cutoff, means no current is flowing through the transistor. Its resistance is very high and an indication of Cutoff is that the applied voltage is felt at the collector. This condition can also be plotted on the graph. See figure 36.

This point will be labeled Point X

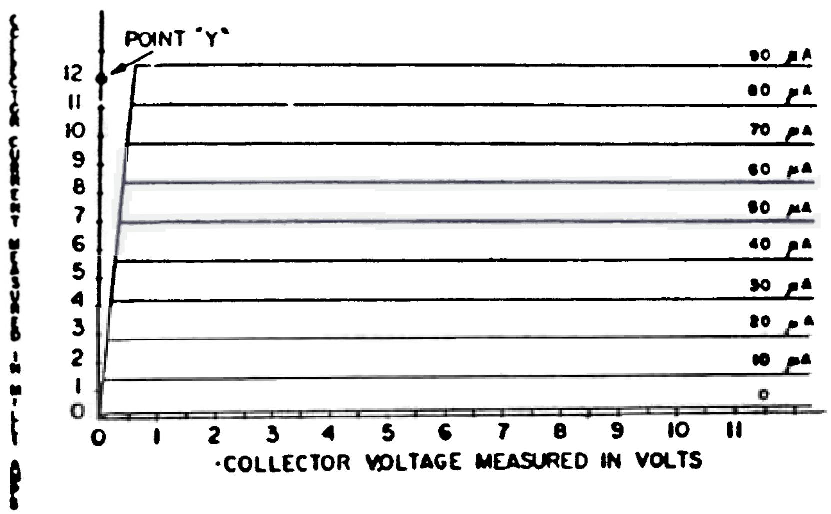
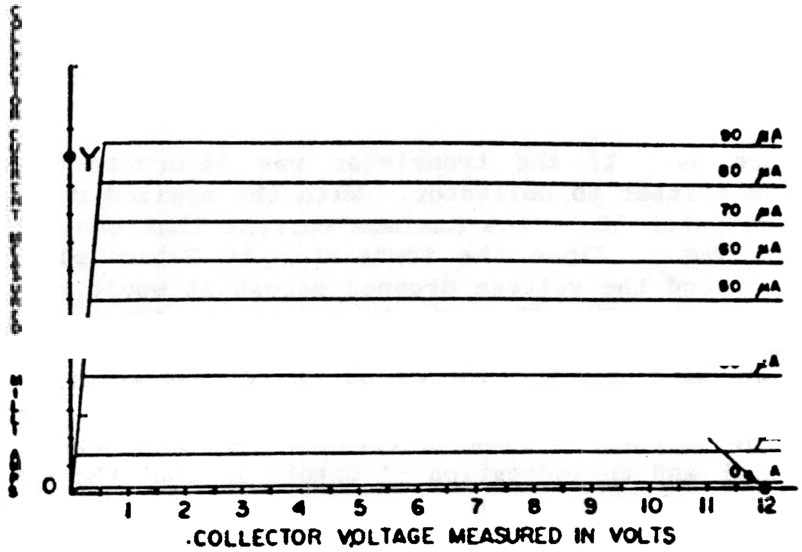


Fig. 35



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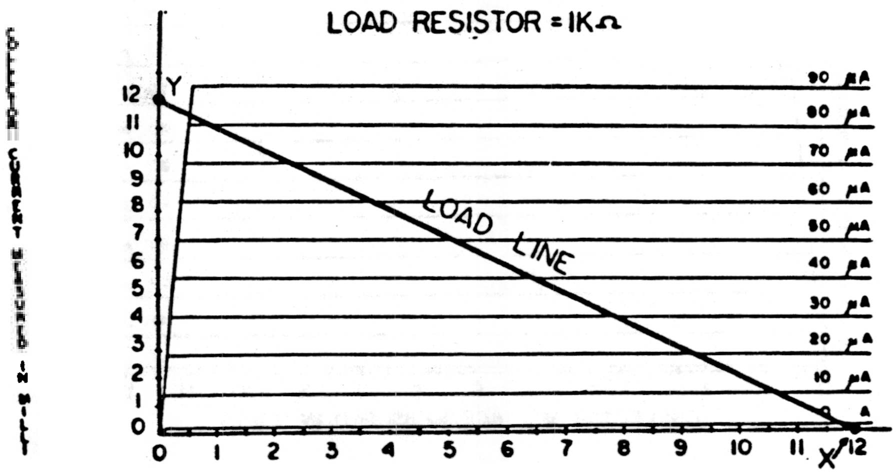
Points X and Y are then connected. See figure 37. The line formed is called the LOAD LINE.



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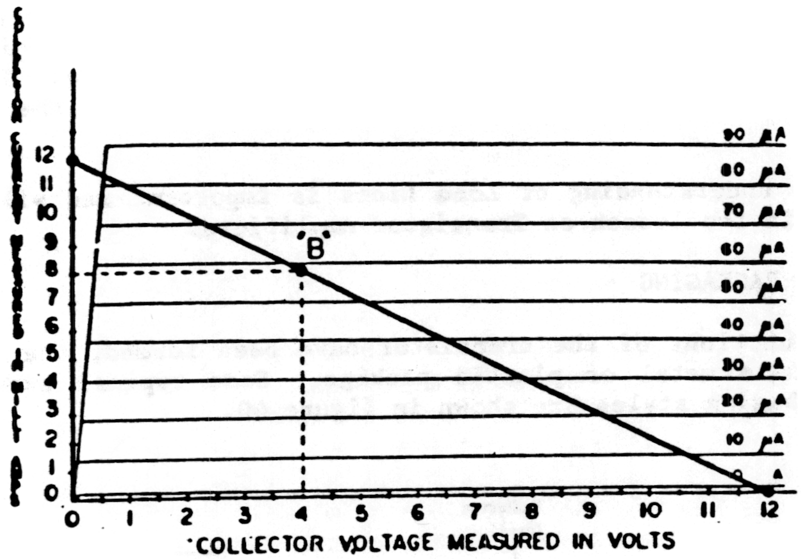
Much information can be gained by analyzing a load line. See figure 38.



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For instance, point B designates a particular operating point (Q Point). This Q Point was set by adjusting the bias so that 58 micro amps of base current was flowing. By dropping a line down from point B we see that for 58 micro amps of base current the collector voltage is 4v. Also for 58 micro amps of base current 8ma of collector current flows.

It should be noted that the load line was established for a 1K ohm load resistor. The angle of the load line is dependent upon the size of the load resistor. If the size of the load resistor is changed the angle of the load line will also change. Consider that the load resistor is now 2K ohms. Maximum circuit current will now be 6ma (12V/2K=6mA). Point Y will now be plotted at 6ma. While point X remains constant. Point X will remain the same because cutoff will always be 12V for the circuit. See figure 39.

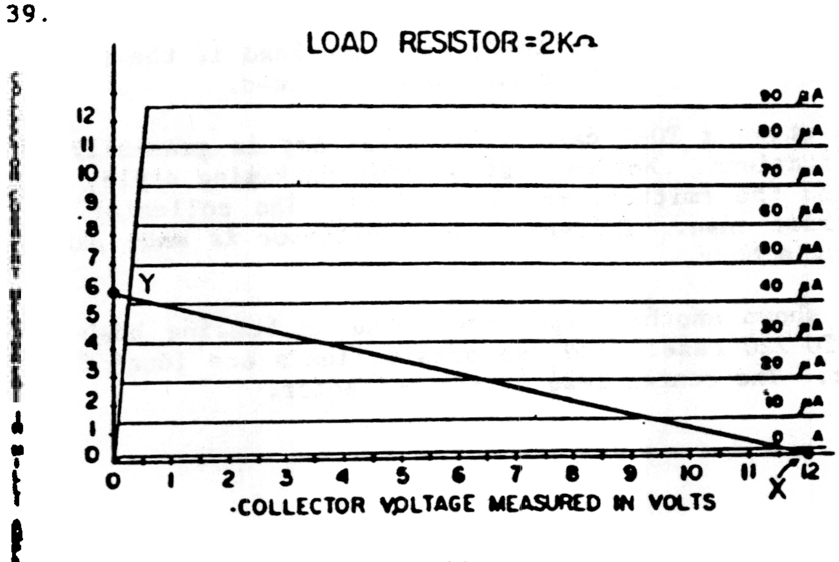

Fig 39

Notice that the angle of the load line has decreased. The circuits characteristics will also change. The cutoff and saturation points are areas that should be avoided during normal circuit operation. The best location for the Q Point during normal operation is around the middle of the load line.

A thorough understanding of Load Lines is important and will be used extensively in the lesson on Transistor Amplifiers.

TRANSISTOR PACKAGING

Once the junctions of the transistor have been formed, the transistor is placed into a metal or plastic package. Some typical examples of four common packaging styles are shown in figure 40.

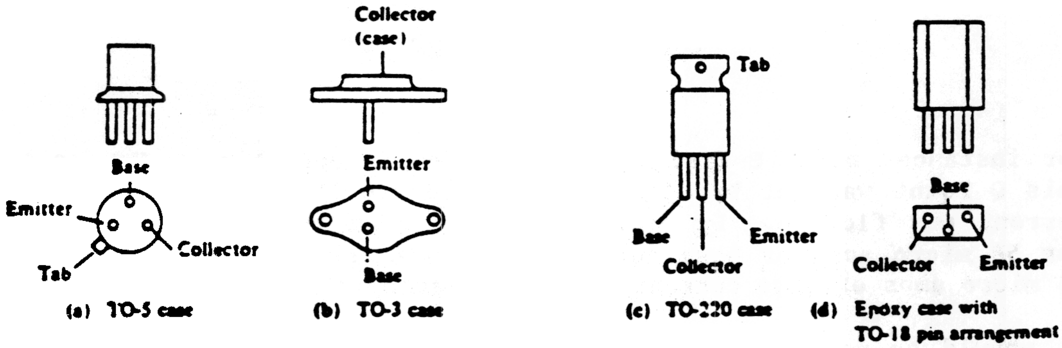

Fig. 40

A TO-5 package is illustrated in figure 40a. The drawing contains side and bottom views of the transistor. Of importance is the identification of the three leads. Note the tab on the bottom view. The closest lead to this tab is the emitter lead, the next lead is the base lead, and the lead farthest from the tab is the collector lead.

Figure 40b shows a TO-3 case. The TO-3 case is generally used in high-power applications. Notice that on this packaging style, only two leads, the base and the emitter, are identified. The collector is always tied to the outside case. Therefore, the collector is made part of the transistors case's body.

Figure 40c shown another type case found in housing high-power transistors, the TO-220 case. The two outside leads are identified as the base and emitter. The center lead is the collector.

Figure 40d illustrates an epoxy case style with TO-18 pin arrangement. This is a very popular style case. As a general rule, the base lead is the center lead, and the emitter and collector leads are on either side of the base lead. Looking at the transistor with the curved edges toward you and the leads pointing down, the emitter will be on the right.

Because the TO-220 and TO-3 cases are usually used for high-power applications the should be HEAT SINKED properly to dissipate the heat. Figure 41 shows an example of a typical heat sink used for the TO-3 style of transistor. This type of heat sink is found in the audio output section of AM-FM stereo receivers.

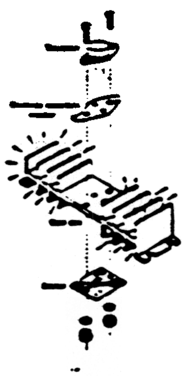

Fig. 41

The four housing types just described are the most common transistor housings within consumer products. Additional package styles are too numerous to list. If a question arises about the case style or lead identification, a transistor data book should be consulted. This book should contain all the important information about transistor characteristics.