BASIC ELECTRONICS
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LECTURE-10
TRANSISTORS

Hello everybody! We have been seeing over the past nine lectures on basic electronics learning by doing. In the previous lecture we saw about zener voltage regulator; how zener diode can be used as a voltage regulating device. We also saw some practical applications of a regulating circuit. Then we saw the different types by which we can construct regulated power supply and we also saw how easily we can make use of three terminal integrated circuit regulator IC regulator like 7805 or 7815 as the case may be where the last two digits correspond to the voltage that you want to obtain as the output after regulation. For example 7806 means 6V positive regulator. 7912 means negative voltage regulator with the 12V output. We also saw how these three terminal IC regulators can be used very quickly for constructing regulated power supply with fixed output voltage. Let us continue with our discussion and move on to next topic which is basically about transistors.

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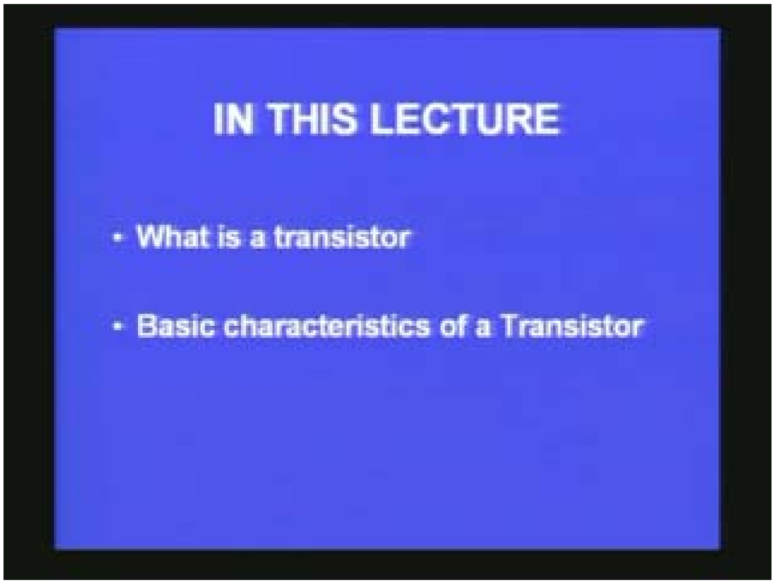

So far we have seen the passive devices like resistors, capacitors, inductances, diodes and then different types of diodes like light emitting diode, photo diode, zener diode, etc. Now we move on to the next very important device in electronics which is basically a transistor. The transistor is very important device as I said because it is one of the active devices. I already explained to you in earlier lectures what an active device is. An active device is something which can amplify or magnify an input signal as against the normal passive devices are like the diode and the resistors. The resistors and capacitors can only attenuate a signal; can only diminish a signal applied with reference to the output where as transistors can also amplify. So transistor is one of the very important active devices that we will be learning about. We will briefly see some of the features of transistors, about its construction and about its characteristics during this time. The diode is basically a two terminal device. It has got two terminals across. One is corresponding to the p-type semiconductor and the other is n-type. You form a junction with the p- and n-type semiconductor. That p-n junction diode is actually having two terminals.

The next question is what will happen if you go on to one more layer one more level. Instead of p-n, I go for p, n and p or n, p and n. I can have a three terminal device as it is shown on the screen. You can have the n, p and n three regions of semiconductor or it can also be p n p.

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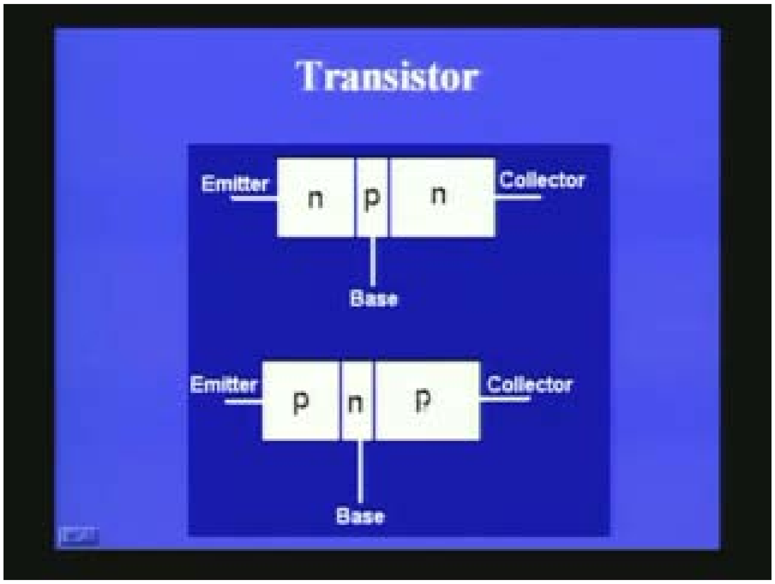

These are the two different types of transistors that you come across and there are three terminals. They are designated there. One is called the emitter, the middle one is called base and the last one is called the collector. You can have the two different types of transistors. One is called npn transistor the other is called pnp transistor where the n means it is a semi conducting area which is having majority of electrons; n type charge carriers namely electrons.

We also know that in this n region there will always be minority carriers which are basically holes which exist because of the normal temperature at which we operate. Only at absolute zero there will not be any holes. At normal temperatures due to intrinsic conductivity there will be small quantity of holes present in the n doped semiconductor in the first region and n is called the majority carrier and the holes here are called the minority carriers because the holes will be very, very small in number compared to the n. Similarly in the p-type region the majority carrier are holes and in the last n region the majority carriers are electrons. You have npn transistors and you can also have as I already mentioned to you pnp transistors where p here means majority holes and the n region majority electrons and here majority holes. So you can have two different types of transistors. They have very similar behavior for most of the applications but there are slight variations which we will discuss at some appropriate time when we come across those differences.

For the present we can assume that in principle in terms of the operational details both npn and pnp transistors are almost of the same type, identical nature. We should also remember that the names given to them have got some specific meaning. For example emitter means it is capable of emitting. You can have emitter means this n region will emit electrons into the base region. Therefore it is called emitter and the base region is the region over which this emission will take place and the transport of charge carriers will take place and this is called the base. The last region which is called the collector is the one which will collect all or accumulate all the electrons of the charge carriers that are flowing through the transistor. Therefore it is called a collector.

You can immediately recall a very similar situation with reference to vacuum tube triodes. These transistors are solid state devices which are replacing the well known olden day vacuum tube triodes. In the vacuum tube triodes, as the name itself suggests, it has got three electrodes triode and the three electrodes are called filament or cathode, a control grid and the plate. The filament or the cathode is the one which is used for emitting electrons, thermionic electrons. I briefly mentioned to you the historical background and then the control grid is one which is controlling the flow of electrons and the plate is one which is normally held positive which collects all the electrons. There is a correspondence between a vacuum tube triode which has got three terminals and the transistor which is equivalent in performance in terms of amplification action and it also has got three terminals and they are called emitter, base and collector. Just as the filament heats up and then emit electrons here the emitter emits electrons or holes into the base region and the base region is the region where the flow of electron are controlled and therefore it is like the control grid of a vacuum tube triode. The plate is the one which is normally held positive to attract all the electrons or collect all the electrons and the equivalent here is the collector which collects all the electrons when they flow.

In terms of the names or the functions there are lot of similarities between a vacuum tube triode and a three terminal transistor that we discussed. I have shown you the details of three layer npn and pnp and I have also shown you on the screen the circuit symbol of the npn and the pnp transistors. You can see the base, collector, emitter and then there is an arrow which actually distinguishes the two the npn transistor and the pnp transistor.

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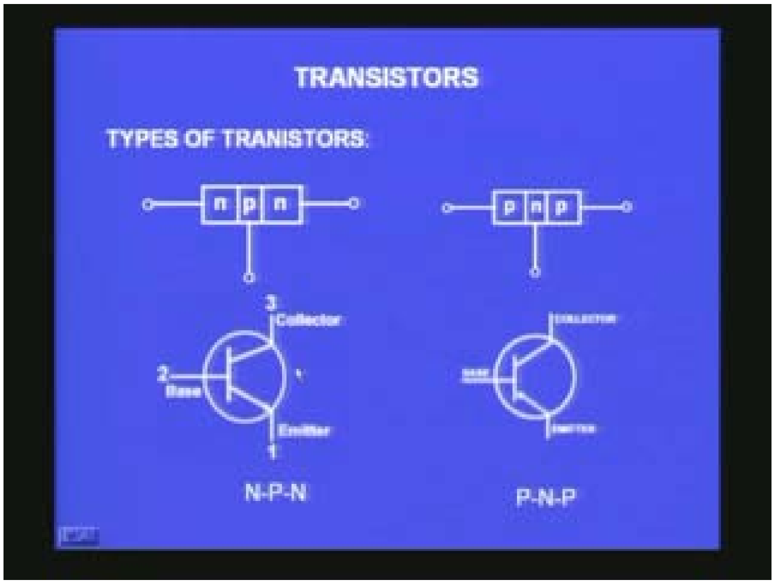

When I discussed about the various components I showed you some of the transistors and they come in different sizes and in different encapsulations. I have shown you some of the pictures here for recapitulation again.

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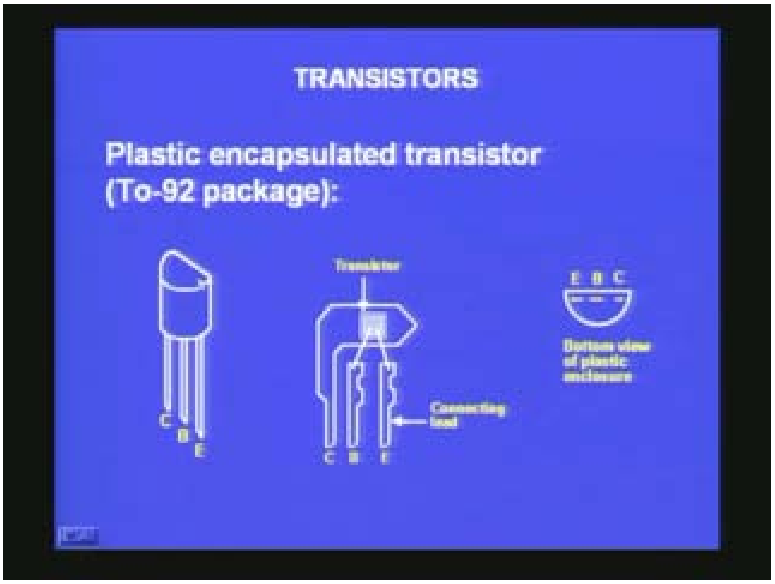

There is a small semi cylindrical package which is called the plastic encapsulated transistor. This is one type. It is called TO-92 package in the electronics parlance. TO means transistor outline; 92 is the part number. The transistor outline 92 package corresponds to the this type of a package where you can see the collector, the base and the emitter are shown by the symbols C, B and E and the actual construction inside will be like this. This is a metal electrode these are other two electrodes and this is the region where you have actually the semiconductor pnp or npn as the case may be and the leads are taken and connected to the external electrodes so that we can use this in a given circuit in whatever manner we want by soldering or connecting to a breadboard. These are the connecting leads. Otherwise this transistor region itself is a very, very small region as you can see. Within the very small region you have all the three layers; the n layer, p layer and the n layer and this brings down the size of the transistors.

I mentioned to you that in comparison to vacuum tube triodes, the transistor will perform almost the same function of amplification. But the greatest advantage that you get here is that it is going to be very, very small and therefore there is miniaturisation which comes along with this. Transistor receiver or whatever electronic circuit that you build can become very, very small and there are other benefits like very low voltage operation which I already mentioned to you earlier. If you look at bottom view that means you are looking from the bottom side you can see the EBC terminals which are actually pins coming out of this surface and these are the emitter, base, collector terminals which will have to be used in any given circuit.

There are other circuit packages that I have shown here.

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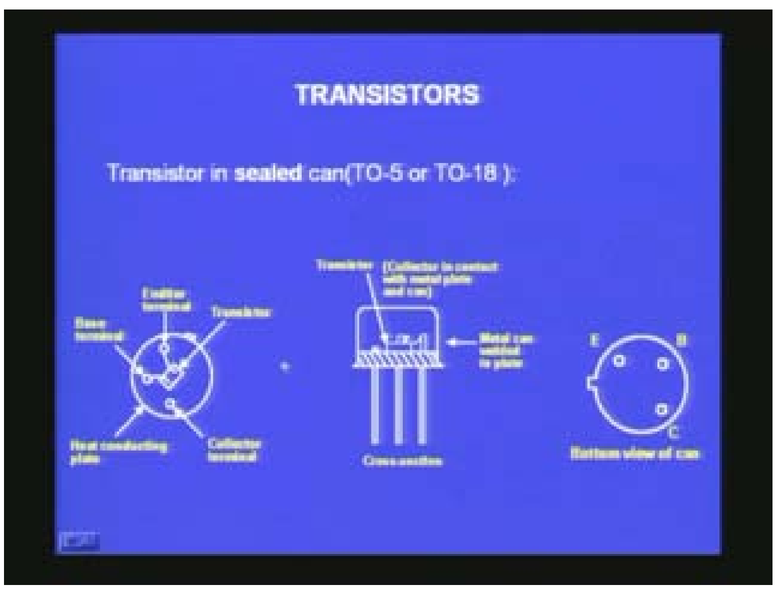

One is the very popular TO-5. TO-5 means transistor outline number 5 or transistor outline number 18. They differ in the size. They look similar. There is a metal can and you have a small region where the npn or pnp semiconductor region is held and the leads are taken from them and connected to three external leads which are on the header as they are called. This part is called a header and over the header you put a metal can and seal it thermatically so that the environmental conditions like moisture will not affect the transistor operation inside. The bottom view is shown at the last picture on the right and you can see the emitter, the base and the collector. This is an identifying tab and from the tab you go along the clockwise direction to identify the various pins. The first pins after the tab is the emitter and the next one in clockwise direction is base and the next one is the collector. This tab is the one which is used in identifying the different pins in this type of metal can and you should always remember it is the bottom view of the can that we should consider when we want to identify the pins whereas in the case of IC's later on you would find you should always look from the top view. Here we have to look at the bottom view and then identify the pins.

This is again one more transistor package which is called a TO-3 package; transistor outline 3 package and there is also a plastic package TO-221 package. Two different packages are shown here and this is usually a very big transistor which was also shown to you in one of the earlier lectures and this has got big metal part and the big metal part forms a part of the collector.

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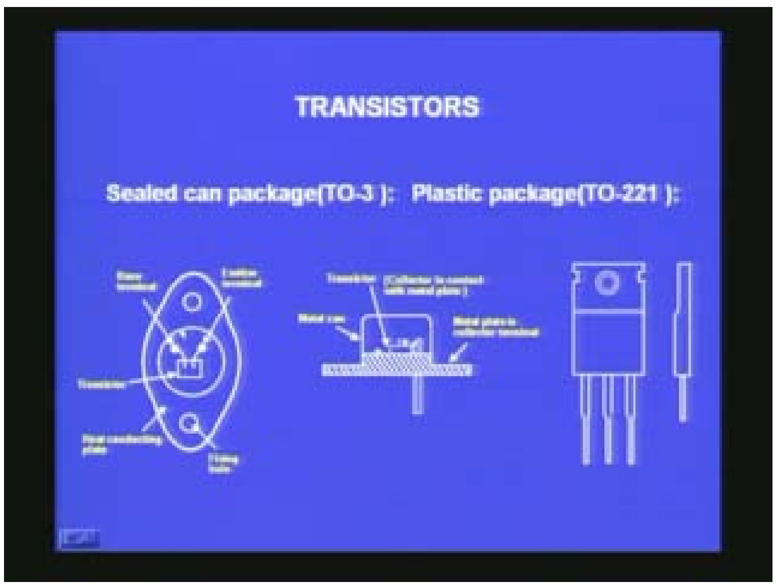

Then you have two other pins which will come over here like it is shown in this other diagram and they are the emitter and the base. The emitter and base are only shown as two independent pins and the collector is formed by the metal can itself, the total metal can. That obviously shows that it has got a different purpose to serve apart from a being a transistor which is capable of amplifying, this will handle must large power. This is used for power applications. This is called a power transistor 3055. There are several such transistors which you may perhaps come across and this is a power transistor and this is of a bigger package and that is shown on the side view on the right.

This plastic package which is called transistor outline 221 package is also similar to the three terminal regulator that we saw in the previous lecture. You have three terminals and these are also meant for large power than the normal small can or plastic package or TO-5 or TO-18. Here again you have three terminals. They correspond to the emitter, base, collector and they can be used for high power applications.

So what is a transistor? A transistor is an active device. I already mentioned to you and it is a very important device used in several applications in integrated circuits, microprocessors and in all different types of electronic circuits. There are two types of transistors that we know of basically in terms of the behavior. Both will do may be the similar function like amplification but they are different in their working principles. For example one is called the BJT which is bipolar junction transistor.

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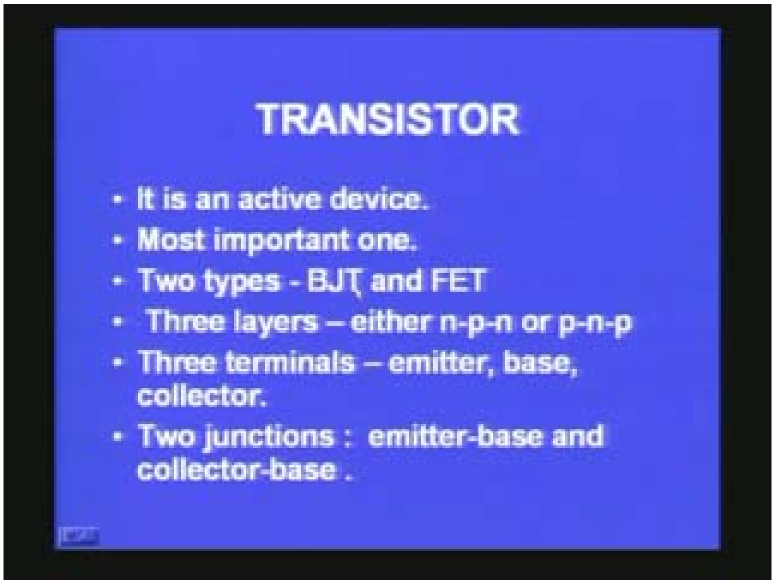

It is a bipolar junction transistor. That is what we are going to discuss today. But there is another type which is called field effect transistor, FET. BJT means bipolar junction transistor. The bipolar means that the transistor operation will depend on two different types of charge carriers. I already mentioned to you. One is the hole the other is called the electron. In a BJT there will be contributions to current due to both bipolar. That means both electrons and holes whereas in a FET, a field effect transistor, which is a unipolar device there are only one type of charge carriers. Either a n channel or a p channel you will use and conduction will be due to n type electrons or p type holes. That is the first major difference between these two but we will discuss little more details of the field effect transistors later on but the BJT is what we are now discussing about.

This is basically a current controlled device and the field effect transistor is a voltage controlled device. There are several relative characteristics which will come into the game when you really want to construct very specify types of circuits. Both of them have three layer device pnp or npn. Even in the field effect transistor you will have the source, ……. and drain, three terminals. They have three terminals. That I already mentioned to you in BJT; emitter, base and collector. Here after we will only discuss more about the bipolar junction transistor and is has got two junctions. Let me go back and show you the earlier figure. There is one junction here between n and p that is called junction between emitter and the base. It is called a emitter base junction and the other one is between the collector and the base and this junction is called the collector base junction and this one is called the emitter base junction. In the two transistors you have two different types of junctions; one is the emitter base junction the other is called the collector base junction.

I already mentioned to you that it is very similar to the triode. That is what I have mentioned here in this slide. Let me show you a typical transistor with the three layers. There is a n layer here and there is a p layer which is shown in a different shade here at the center and you have a collector region. If you want to operate the transistor you have to have two different voltage sources.

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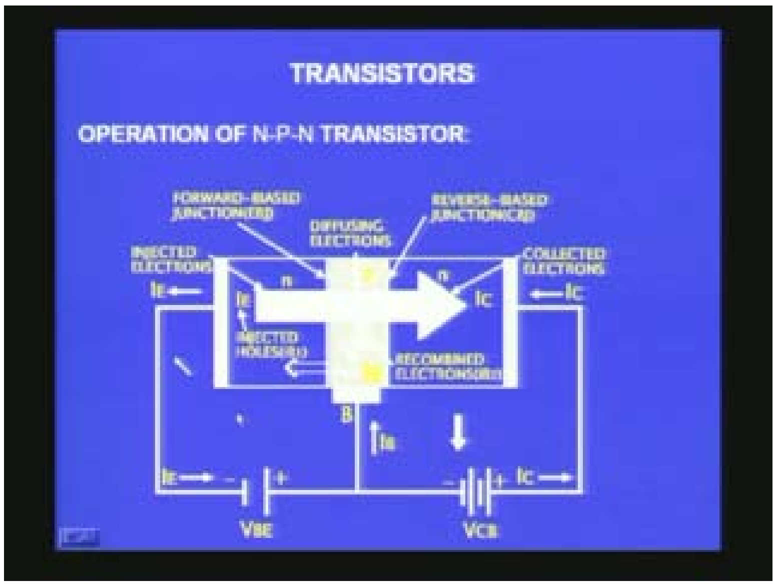

You have to apply a voltage source between the emitter and the base and you have to apply another voltage source between the base and the collector. So you require two bias circuits. One is called a emitter base bias the other is called a collector base bias or collector. It depends on how you use in what configuration. In a basic configuration we can say there is a power supply between the emitter and base and it is called VBE here in this picture and it is a very small voltage source just about 1 or 2V whereas if you go to the collector base junction or the collector base side you have a much bigger power supply and this is very important. You require larger voltage source on the collector base side and you require a smaller voltage source on the base emitter junction and they can be connected in different ways as you can see. This is the npn transistor I have taken as example and n is connected to the negative here and the p region, base region is connected to positive with reference to the power supply.

You know what it means? In the diode we know when the p is connected to positive and n is connected to negative the diode is said to be forward biased. What happens to a forward biased diode? This also we have discussed in the previous lectures. When you forward bias a diode you have a low resistance across the junction. So it becomes an easy current flow path. But when you reverse bias that means when I connect the n-type to the positive and the p-type to the negative then the resistance of the junction increases and it is not useful. In this case what we have done is we have connected the n-type to the negative and p-type to the positive. That means the emitter base junction will be forward biased. This is a very important point.

If you look at the collector base junction n-type of the collector is connected to the positive of the large power supply and the p-type of the base is connected to negative of the power supply and the collector base junction will be reverse biased. So this becomes a high resistance path. The emitter base junction is a low resistance path the collector base junction is a high resistance path. This is the configuration of all the various possibilities that you think of. For example I can forward bias this; I can reverse bias the base emitter junction and reveres bias collector. So several possibilities are there. The most important and useful way of connecting a transistor is to make use of emitter base junction as a forward biased junction and make use of the collector base junction as a reverse biased junction. You can see why it is very useful?

When I connect in this forward bias way then the width of the junction will become very small and the electrons will start crossing over to the base region or the p region. Similarly the holes from the p region will cross over to the n region. They will both exchange. When that happens electrons are emitted into the base region. We are not worried about the holes. We are more worried about the electrons. The electrons are emitted in the base region. That is what is happening when I apply a forward bias condition for the emitter base junction. Two things can happen when these electrons come to the base region. One of the very important thing that can happen is these are electrons and there are abundant of holes in the p region or the base region. Some of the electron can get trapped by the holes. Thereby we will loose both the electrons and the hole.

If that happens it is bad for the device because we have lost an electron and a hole. But you can also have another condition. That is the electron in the base region, as you all know, is a minority carrier because base in this case is a p type semiconductor. In that the electrons are pushed from the emitter and these electrons are minority carriers in the p region or base region and these electrons will be finding it very easy to cross over to the collector region because for them there is no potential well or barrier here between the collector base junction. The potential barrier in this junction is only for the holes on the left side and the electrons on the right side whereas what we have now in the base is abundant of electrons which have come from the emitter and they will find there is actually a valley for that. They will slide down and go into the collector region.

The other way to look at it is this large power supply will provide a very large field across the junction so that these electrons will be attracted towards or collected by the positive region of the collector and most of the electrons which are emitted by the emitter into the base will find themselves happily on the collector side. But there will be a finite number of electrons which will find corresponding holes and they will be lost. But this loss will correspond to a small current in the base region which is called the base current. The electrons moving in this direction will correspond to a current in the opposite direction. You know that conventional current is opposite to the direction of electron flow and this corresponds to a small base current.

If you look at this circuit on the base emitter side there will be a very small current flowing through the base. There will be a large current flowing through the emitter because large numbers of electron are emitted in the base. That means there will be a current in the opposite direction because conventional current is opposite to electron flow. So there will be a large current flow here; there is a finite small current into the base and there will be a large current flowing into the collector again because most of the electrons are collected by the collector and there will be electron flow into this. Almost 90% of all the electrons emitted into the base will come to the collector. There will be a large flow of electrons here which corresponds to a current in the opposite direction. IE will be equivalent to IC+IB. Some electrons are collected through the collector; some electrons find their way through the holes and back into the base region and that corresponds to a small IB. So IB+IC will be equal to IE. This is a very important relationship we should always remember.

What is basic action of the transistor? What is transistor action here? What do you mean by the word transistor? It is transfer resistor. You can see the electrons are pushed through two different regions having two different resistances. The first region is a low resistance region and the next region which is the collector base region is a high resistance region with the reverse bias junction. Therefore I am able to push almost the same amount of electrons through a low resistance region which again automatically passes on to a high resistance region. I am able to push a large current through a large resistance on the collector base junction and that corresponds to the product of large current into large resistance is large voltage. There is voltage amplification because of the transfer resistance. This is low resistance region; this is high resistance region. I am pushing a current through that. For pushing the current I require a very small voltage. Therefore there is amplification. There is a mechanical advantage. With small voltage you are able to push large number of electrons and these electrons are automatically collected by the collector through high resistance region. Therefore you get a voltage gain. There is voltage amplification. There is a no current gain. The current actually is falling. IE is slightly less than IC because some IB is lost. But still because almost the same IE is flowing through the base emitter junction and the collector emitter junction the voltage developed in the collector region will be larger and there is amplification associated. So this is the basic action of a transistor.

There are lots of important voltages and currents which come into the game. This is called common base circuit because the base is common to the input side or the output side. In any amplifier you have two inputs and two outputs side. But in the transistors we have only three leads.

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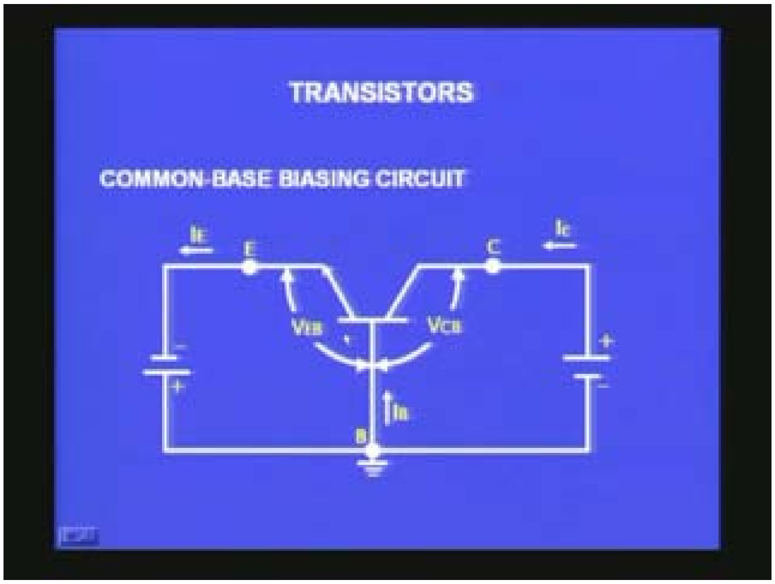

One lead will have to be used common to both the input and output. If I use the base region as common as it is in this diagram this becomes a common base amplifier. So this is a common base. You have the emitter here; you have the collector here. In this case IE is equal to IC+IB. From the direction also you can see; from ……. also you can see and then if you look at the voltages there is a voltage between the base and the emitter which is called VEB, voltage between the emitter base and there is also a voltage CB which is the voltage between the collector and the base. The applied voltage will almost be equal to C.

Let us see how we can use it in some simple application.

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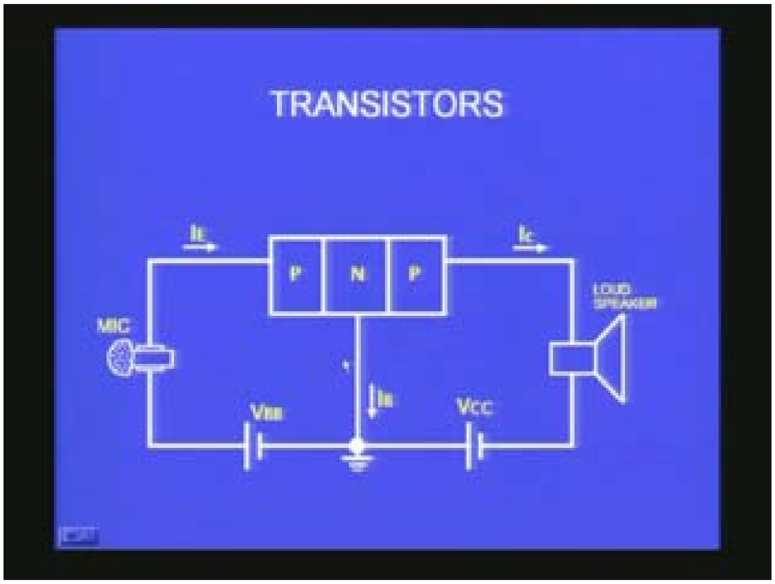

What I have done is I have used the battery which is VBB on the left side between emitter and this which is the pnp transistor and on the right side I have used a large voltage source VCC between the collector and the base region. What is going to happen? I connect a mic here, microphone and on this side I connect a loud speaker. When I speak into the mic it is going to generate some electrical pulses; voltages, fluctuations, AC voltage due to the vibration of the dias. There is a small AC voltage which will be generated and what will be the effect of this AC voltage? The effect of this AC voltage is to modify a constant base VBB voltage that I have connected to base and the emitter by a small variation. This will correspond to a small variation of a similar type in the emitter current. So the amount of electrons emitted into the base will also fluctuate in the similar fashion as a current generated here. But because this is forward biased large number of electrons will be fluctuating in this direction. All these electrons will also flow through this and they will flow through this loudspeaker and the current through the loudspeaker can be much larger than the current generated by microphone. So you will get a much larger amplification here. This is a very simple scheme to understand the basic voltage amplification of a transistor.

I have shown the two structures of a pnp and npn where I have shown the forward biasing and the reverse biasing corresponding to the pnp transistors and the npn transistors. This we have already seen.

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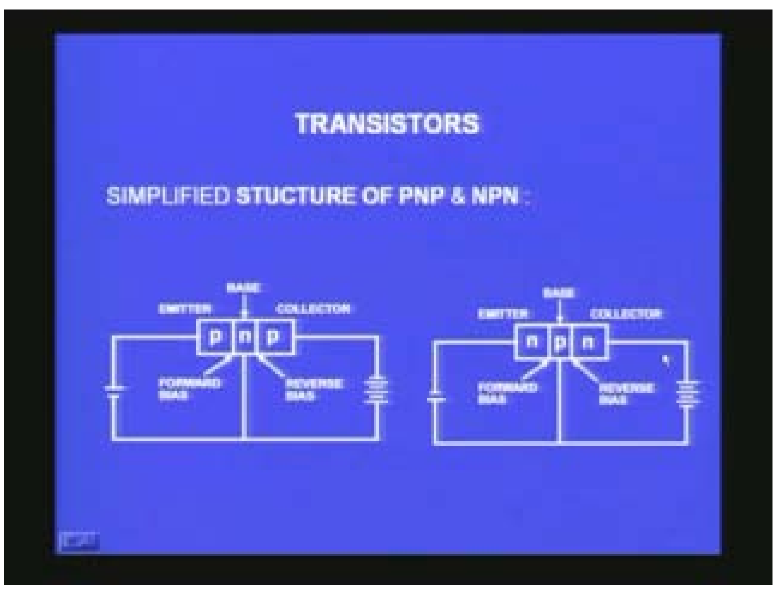

I want to use this transistor in a slightly different way for understanding the current gain also. You just saw how you get the voltage gain in the case of the transistors. By changing the configuration you can also get current gain. When we discussed transistor action we said there is going to be a very small base current. If I use the base as the input terminal and the emitter as the common terminal and use the collector as the output terminal then you can see for making very small currents here you require very small voltages only at the input. But this current when it comes to the collector it will be very large component and there is a current gain which is called in this case beta.

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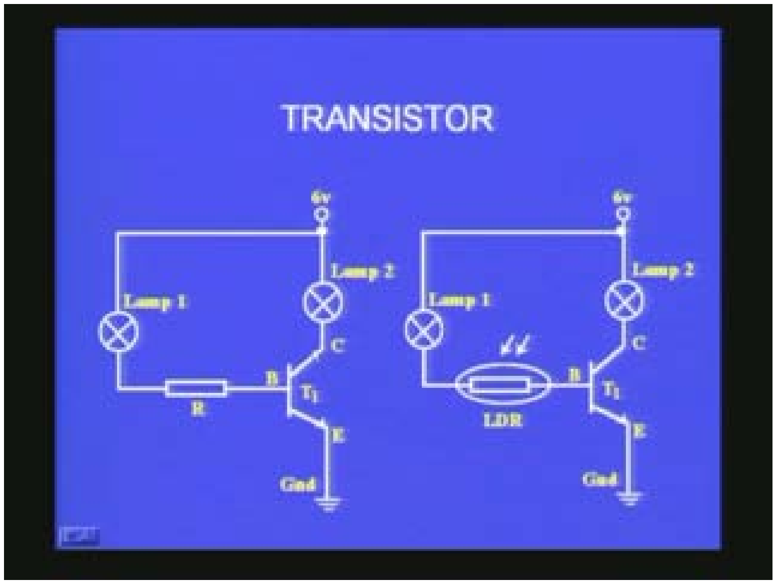

The IC/ IB is called beta or the current gain of the transistor. The current gain IC/IE is called the alpha in the case of a common base amplifier. Here we are using a common emitter configuration. Here there is a very small base current and you get a very large collector current .This can be very easily shown. For example if I have a lamp here and connect the same 6V to the transistor; this is the transistor, npn transistor. You have a lamp here; you have another lamp here in the base and you have a resistor in series and that is connected to the base and the emitter is grounded.

What is going to happen? If I wire this circuit this lamp with this resistance for example 100 ohms or 200 ohms there is going to be a very small current flowing through this. There will be a very small current flowing through this. This voltage is nothing but the forward biased junction of the base emitter and for silicon the forward bias junction voltage is around 0.65 or 0.7V. We know that this voltage VBE for a silicon transistor is going to about 0.7V. If this is about 6V then 6V-0.7 is the voltage available for passing the current through the lamp and the resistor. If you neglect the resistance of the lamp this will be a considerable current only decided by the R. The lamp will normally glow very dimly because of the presence of this resistance. But this is only the base current. This base current will introduce a large collector current in this circuit and the lamp in the collector will be very, very bright. There will be a very large current flowing through the collector and the emitter and the lamp will be glowing brightly. But this current will flow only as long as there is this current provided by the base circuit. If I remove this resistor by disconnecting this circuit this lamp also will go off. Because for making this transistor work you have to have a forward biasing of the base emitter junction and you have to connect a lamp or a resistor with the power supply to make a finite voltage appear across base emitter junction which is corresponding to about 0.65 or so. Only then this lamp will glow.

If I increase the value of resistor, this lamp will not show very significant change in intensity. But when I increase the resistance enormously for example 10,000 ohms from 100 ohms if I put 10,000 ohms this lamp will not glow because the current through the circuit will become very, very small. But this current you will still see some glow here even though it will be some what less there will be a glow here. That means there is amplification which comes in the game and this amplification is called the beta of the common emitter configuration.

This can be very nicely demonstrated. I will show you also later on that by removing this R I introduce another resistor which is called LDR. What do you mean by LDR? LDR is light dependent resistor. It is a cadmium sulphate semiconductor device. When you shine light its resistance is very, very small. If you cut off light its resistance becomes very high. The small and the high can be of the order of some kilo ohms and Meg ohms. The variation in this resistance can be brought about light falling on. Here I removed the 100 ohms and introduced 10 K, 100 K, etc., manually whereas here that can be done by the amount of light falling on it. If I put a LDR here if I close the LDR completely the resistance of the LDR will become very large and there is very little current and so the lamp will not even glow. But when I remove my hand more light falls on it. The resistance of the LDR will become very small and so there will be large current flowing into the base and a large current flowing into the lamp and the lamp will be glowing brightly. It can be used as a photo device, optical detector, and light detector. Several application circuits can be constructed with this basic principle of current amplification in the case of a transistor. This is what I would demonstrate to you little later.

There is another aspect which I wanted to talk to you. That is if I have a gain of beta for one transistor then if I use combination of transistors, two transistors for example then you might perhaps be able to enhance the amplification factor still further. Here what we do is we have one well known configuration which is called Darlington configuration after the name of the person who designed this.

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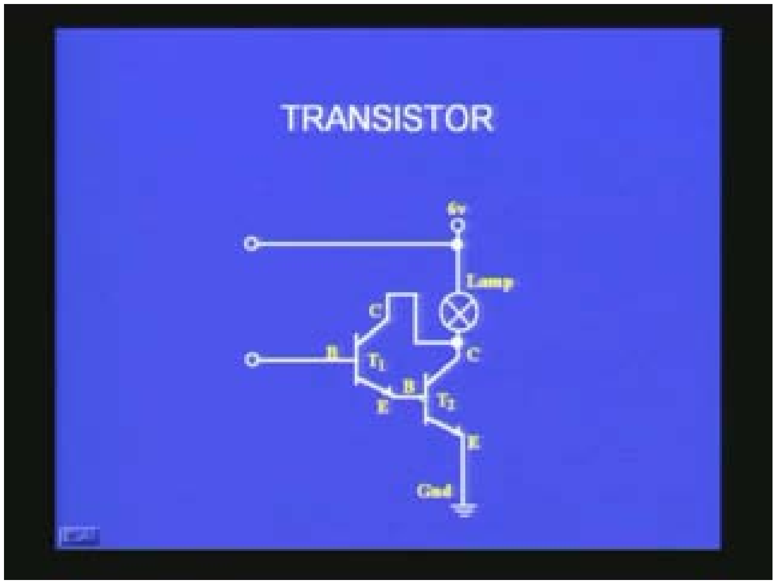

Here what we do is take one transistor; connect the emitter of the transistor into the base of the next transistor and use the emitter of the next transistor as the regular emitter of a overall transistor and the base of the first transistor is the base of the combination and the two collectors are connected together as you can see and this becomes a collector. So you have now formed a new transistor with one base, one collector and one emitter. But internally you have got two transistors combined as shown in the figure. When this happens this is called the Darlington configuration. What is the advantage of this Darlington configuration? A very small base current will provide a large emitter current in the common emitter configuration. This large emitter current now becomes the base current of the next transistor. Because there is a large amplification already this will again be amplified by the current gain of the next transistor and the emitter current of the over all transistor will be very, very large. If beta one is the current gain of the first transistor T_1 and beta two is the current gain of the next transistor T_2 then the overall current gain of the transistors will be beta one into beta two. If this is about 100 they are almost of the same value of 100 each then 10,000 will be the current gain of this transistor. You have enormously improved the current gain of the transistor by using two transistors in combination which is called Darlington pair. This is called the Darlington pair transistor and this can be used in several applications.

The current gain of this transistor is so large that if I now connect between these two terminals at the base for providing a forward bias I have to connect some resistor here. Previously I used lamp and LDR. Instead if I now put my hand, connect my two hands one hand here and one hand here I will be including by body resistance. Every body has got a body resistance. It depends on the skin temperature and dampness of the skin. It will normally be very, very high of the order of several Meg ohms. But even if it is very high of the order of Meg ohms 6V by Meg ohms will be very small current of the order of microamperes or less. Even that current because we have a very large current gain it is 10,000 or beta one product beta two that will be able to provide enough current here and make the lamp glow. This is another demonstration which I would like to show you. Let me just quickly show you these two demonstrations and I will come back to the transistor characteristics and then we will discuss about that.

I have shown here a circuit which is wired here and it is a very familiar circuit which I have already shown just few minutes ago.

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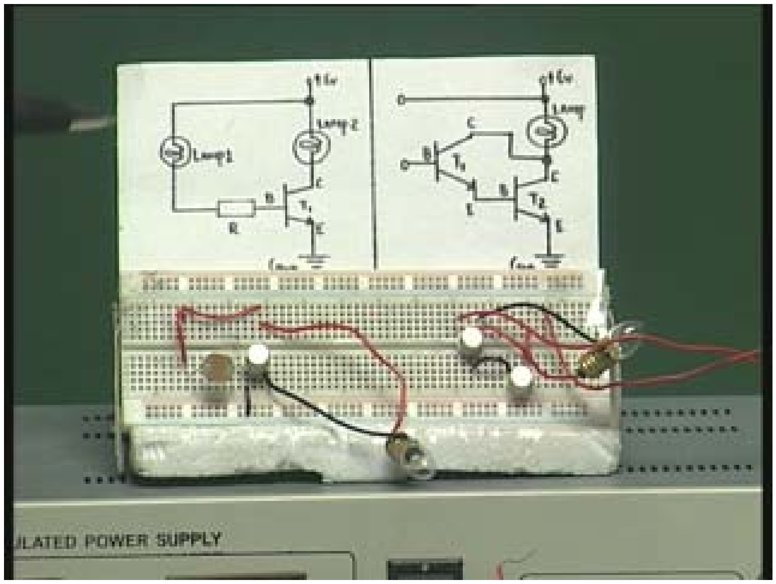

You have the transistor T_1, the emitter is grounded and the collector I have connected to the lamp and in the base I have put a resistor and a lamp. This lamp is not connected. Here I have LDR right now. I will remove it and put some value of resistor for example 100 ohms. I have 100 ohms resistor here in the base circuit and I have connected a lamp in the collector; this is 6V lamp and the emitter is grounded by using the black wire exactly similar to this circuit. I hope you are able to see this. If I connect the power supply lines to the collector end and the other end negative to the negative end, the bulb is glowing because there is a base current that is amplified and so you get a very bright glow.

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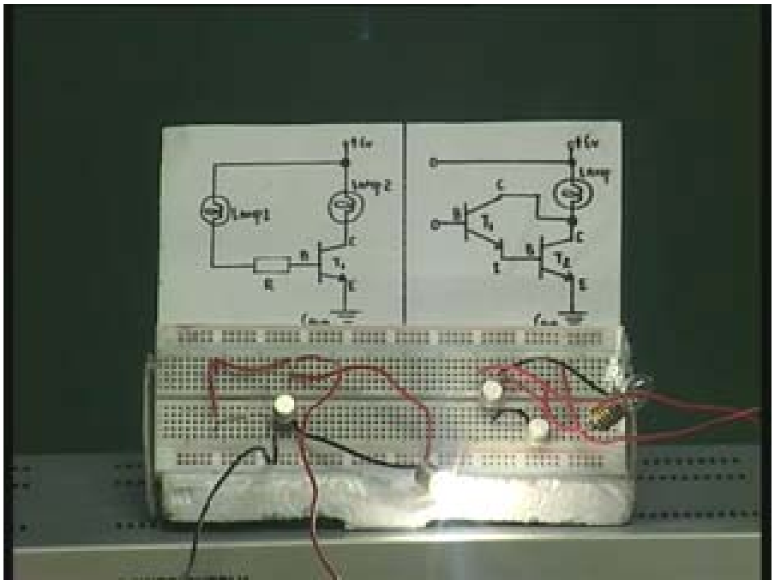

I will remove this resistor here and I connect a much large resistor may be about 1 Kohms and let us see what happens. When I connect a 1 Kohms resistor I am sure you can see the brightness of this lamp has come down compared to the previous case.

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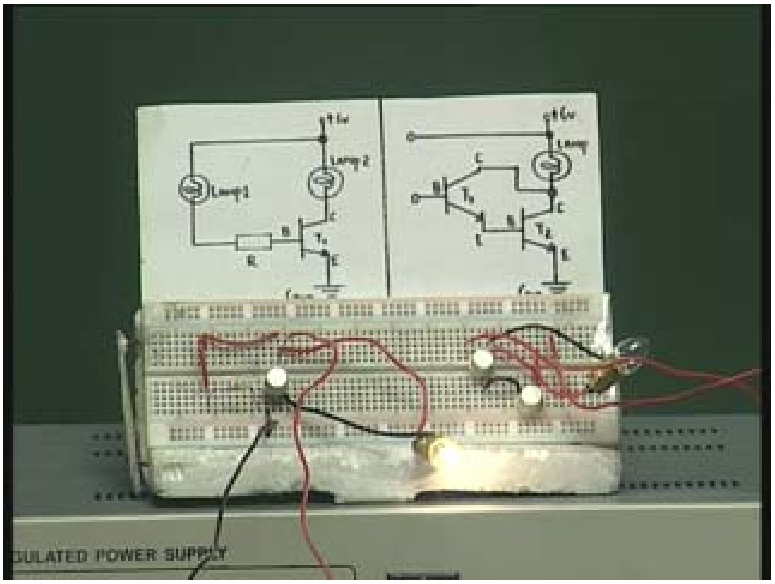

Because I put 1 Kohms here this current now is much less than what it was before; this resistor is ten times larger. I want to put still large resistor. That means 10 Kohms. Let us see what happens. I put a 10 Kohms resistor here and you can see the lamp is barley glowing.

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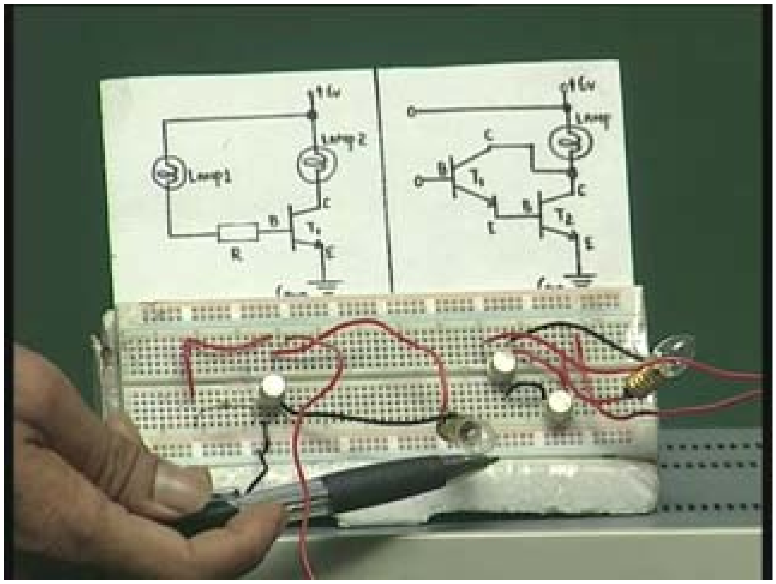

There is not much current at all even though there is a very faint glow here which perhaps you cannot see and as I keep on increasing the resistance here the current decreases and hence the corresponding current on the collector side also is decreasing.

This manual variation of different resistors is brought about by using the light dependent resistors. By changing the amount of light, there is enough light here which makes the resistance of LDR which is shown here very, very small and you get a glow here.

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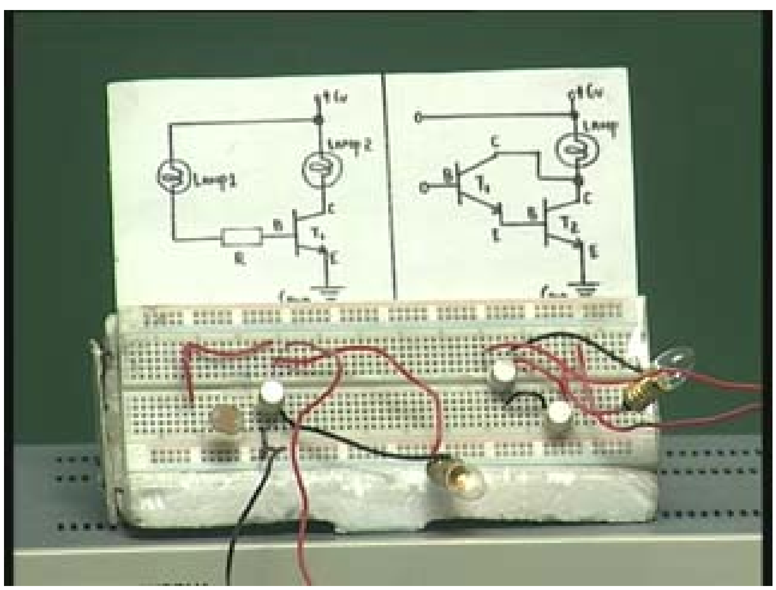

If I close it with some cardboard you can see immediately the resistance increases and the lamp is no more glowing.

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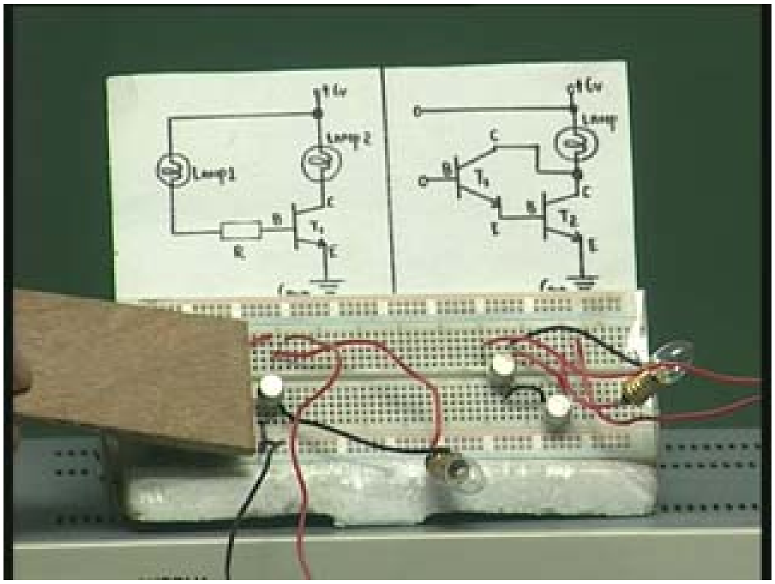

When I take it out the lamp is glowing. Now the lamp is not glowing. I have another 6V lamp connected which I can bring it closer we find the intensity of the bulb is much higher now.

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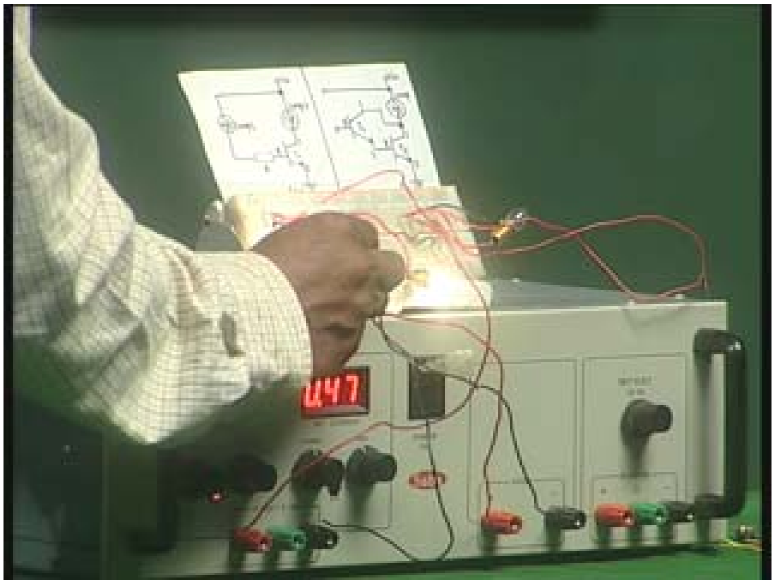

This bulb is glowing with much higher intensity. If I close it, it is gone. If I take it out it is glowing. This is what I mentioned that you can make use of very simple circuit with the transistor as a current amplifier and a LDR to make the optically operated lamp.

You can also extend this concept. Instead of a light dependent resistor here I can use the thermistor. What is a thermistor; a temperature dependent resistor. If I remove this and introduce a temperature dependent resistor when I heat it with a matchstick or a candle the resistance will come down the lamp will glow brightly and when I cool it the lamp will go off. I can make use of this simple circuit for different applications to detect temperature, to detect light or to detect magnetic field we have a magneto resistance and different types of censer resistor can be used here in a very simple circuit and you can learn about the application of the circuit.

Let me quickly go on to the next demonstration which I want to show you which is by using the two transistors. These are what are known as XL 100 power transistors of the TO-5 package that I already mentioned to you and I have two transistors connected in the Darlington pair configuration and in the collector I have a lamp connected of this Darlington pair. The emitter is at bottom so that is connected to the negative of the battery power supply. The positive of the battery is connected to the collector circuit and I have two leads coming from them which are the ones where normally I will connect a resistor. Instead of connecting a resistor I am going to touch with my hands. When I touch them with my hands my body resistance comes into the game into the circuit and a very small currant flows through the base. But because there is a Darlington pair there is enormous amplification which is correspond to beta one into beta two and the lamp is glowing.

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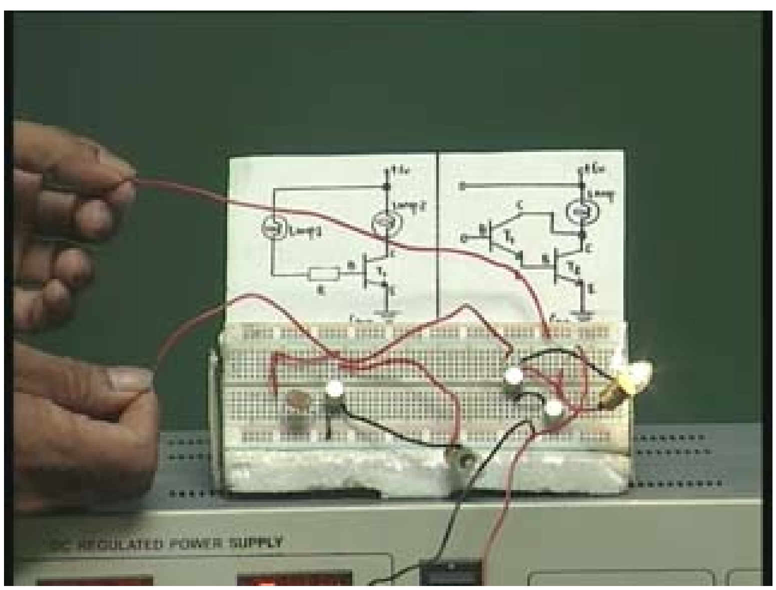

When I remove my hand it goes off. When I touch again it comes on, when I remove it goes. It is only because of my touching that you get the current there and the Darlington combination can help in current amplification by a large extent. That is what is shown here in the circuit. The Darlington connection is shown with the lamp. This is exactly the circuit that is put here. In a very simple scheme a basic transistor can be used for amplification purposes and very simple application circuits can be built using this transistor circuit. Let me also show a very simple demonstration of the same thing over on a breadboard. You can do it yourself by simulation here. You have the two Darlington transistors connected in Darlington configuration. I switch on the power supply and I apply the voltage and if I touch you can see there is a hand coming and touching here. Immediately the lamp is glowing.

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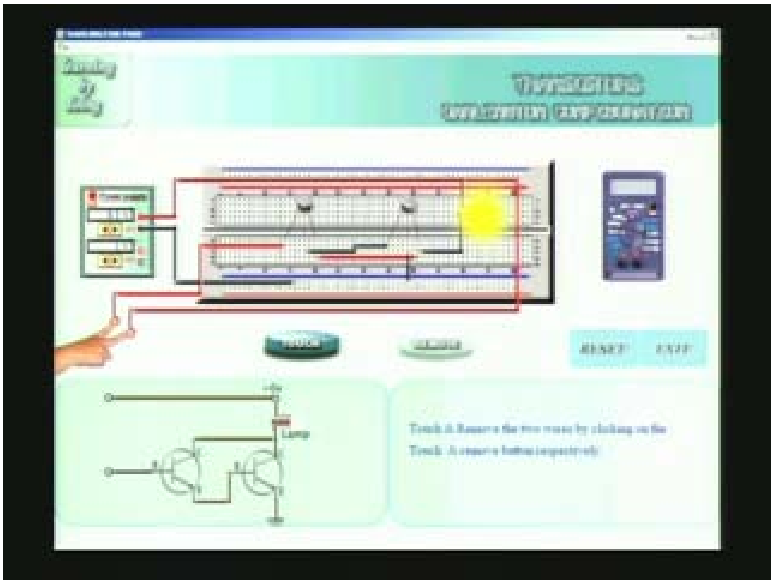

These two Darlington provide a very large current gain. Therefore the lamp is glowing and when I remove my hand the lamp goes off.

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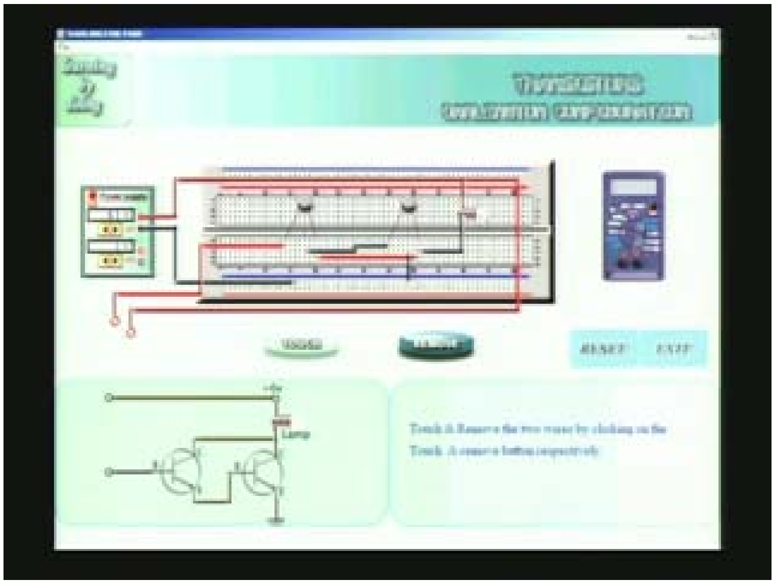

When I again touch the lamp comes on very brightly and when I remove it goes off. This is exactly what we saw in the circuit just now demonstrated. You do have here a very similar circuit which is also shown to you earlier.

What about the characteristics of the transistor? The transistor as I already mentioned to you has got three terminals. That means there is an input side and an output side. In the input side what you have is a base emitter junction and if I want to study the input characteristics then you know what it is going to be? It is just a diode; base emitter junction is just a diode. When I have input characteristics which shown on the screen you have a VBE here which is the base emitter voltage and you have an IB a base current and it is nothing but a normal diode characteristics.

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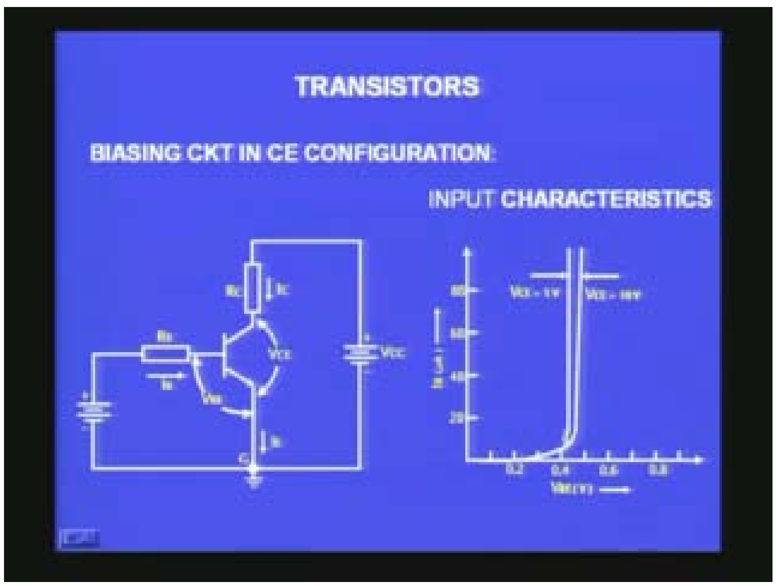

Beyond 0.4 or 0.5 the current starts increasing enormously and there is very little change in the voltage. This is a normal diode behavior that you know of. If it is a normal silicon transistor this cut in voltage will be around 0.65 and if it is a germanium transistor it will be 0.1 or 0.2. While I am doing this variation at the base emitter junction what is called VBE I can have some fixed value of resistors between the collector and the emitter. If I have a 5V power supply between the VCE then this will be the graph I will get and if I replace it with a much large voltage then you will get a slightly different curve. But over all it is just similar to a forward biased diode. There is not much of an interest on the input characteristics except that it behaves more like a diode.

But if you come to the output characteristics then you have the VCE, the collector emitter voltage on the X-axis and the IC or the collector current in the Y-axis.

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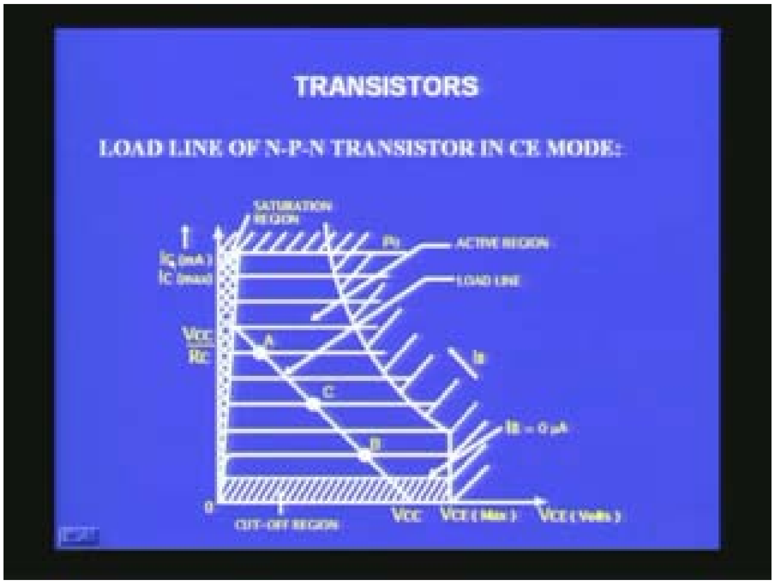

This is called the common emitter configuration which is the most useful configuration in transistor applications. This is for a NPN transistor in common emitter mode or the CE mode. I will go to a smaller, simpler picture. You have the VCE and you have the IC. What you do is you maintain a constant base current of about 10 microamperes by adjusting emitter base voltage VBB.

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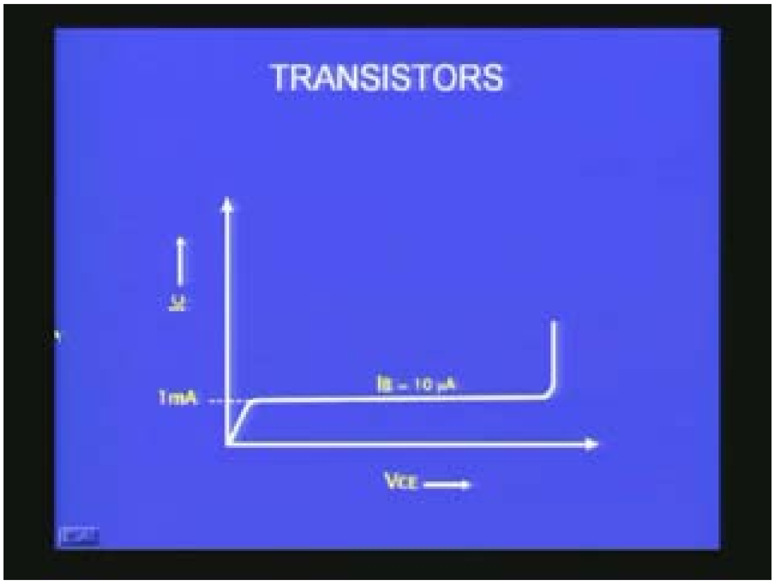

You adjust the emitter base voltage; maintain a base current of about 10 microamperes and now you increase the VCC voltage between the collector and emitter by changing the VCC power supply. Initially the collector current will slowly increase linearly and beyond some point will remain constant irrespective of the voltage that you increase on the collector side. The graph will look almost flat beyond 2V or 1.5V and beyond 30 or

40V depending on given transistor it may even breakdown and then you get very large current flowing through the device. Then it will become perhaps spoiled because large current flowing will produce large heat and that may damage the transistor. We should not go into this region. The graph has a small linear region and then almost flat constant collector current. That is what you get for a given 10 microamperes. If you go for different base current, higher base current for example 20 microamperes if I take this saturation comes at a later stage. That is what is shown in the graph that is shown here on the screen.

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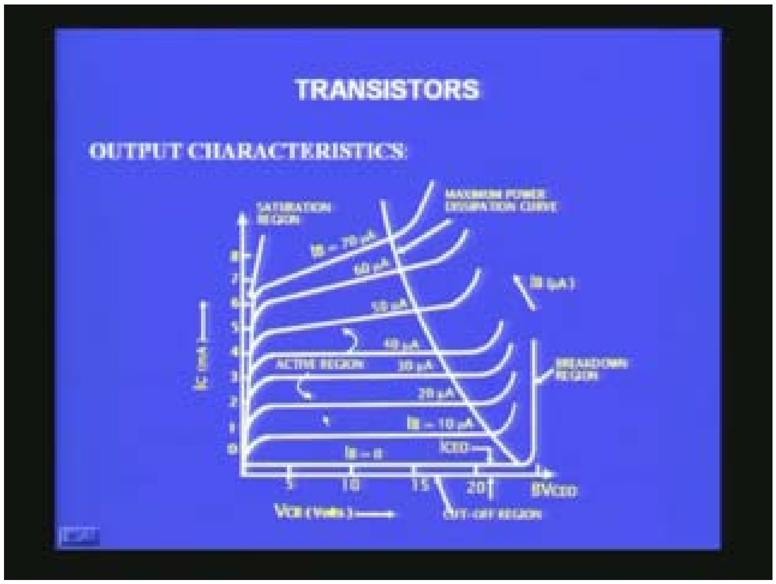

This is for one current IB is equal to 10 microamperes; this is for the second current IB is equal to 20 microamperes and this for 30 microamperes. As you keep on increasing the current the graph will go according to what is shown here. Initially you find this a linear region that you have here. Then you have a flat region and then you have a breakdown region. But you should never go into these regions and that is dictated by the maximum power rating of the transistor. Every transistor can be operated with a maximum power to deliver the maximum power, to dissipate the maximum power. You should never exceed that power rate. That is given by V into I. Maximum V_{CC} or V_{CE} and maximum I_C. I_C max and V_{CE} max product gives you the power rating and that is basically a rectangular hyperbola and it will be like as shown in the picture. That is the limit beyond which you should never operate your transistor; you should never go beyond this limit. This is the region in which you should make your transistor work for you for different applications and this is the output characteristics of a transistor. In this case it is npn transistor with common emitter configuration.

This is actually the basis under which you will design your circuit. It is like a map for a given device. The characteristics is such an essential part of the design that you have to have a clear understanding of the transistor characteristics to really make use of them. I mentioned to you that it is like a map and if you want the transistor to operate in a particular way you have to fix the operating point of the transistor circuit somewhere in this region. It is like saying in a map you are here. Only when you say in a given map you are here then the whole map becomes meaning full to us. Otherwise we cannot understand what the map says. There will be mountains; there will be trees; there will be everything else. But you can never understand in which direction they are unless somebody tells you, you are here. The moment the map tells you with an arrow you are here you are able to understand the whole map. If I go along the east there will be a tree, if I go along the west I will get a mountain. It is very important that you provide a bias to a transistor before you can operate it. That means what? You must make sure that the transistor is operating in forward bias condition with reference to the base emitter junction and reverse bias condition with reference to the collector base junction to make it into an amplifier. Such ideas are very important in the design. We will see how the output characteristics can be used to fix an operating point and we will discuss about how the transistor can be biased. That is a technical term. How the transistor can be biased to make it to operate at a very specific point along it characteristics and how the amplifier can be used for different applications. We will see all these in the next lecture most probably and then we will not discuss all the different configurations possible. We will try to identify very important concepts with reference to the applications of transistor in different circuits and we will focus only on essential configurations and discuss their future in some detail and we will also perhaps see how the characteristic can be obtained and where ever possible I will also try to show you a exact circuit working and then readings can be seen and verified. I think I will stop here. In the next lecture we will talk about transistor biasing and how transistor amplifiers can be made use of using a simple common emitter configuration. Than k you!