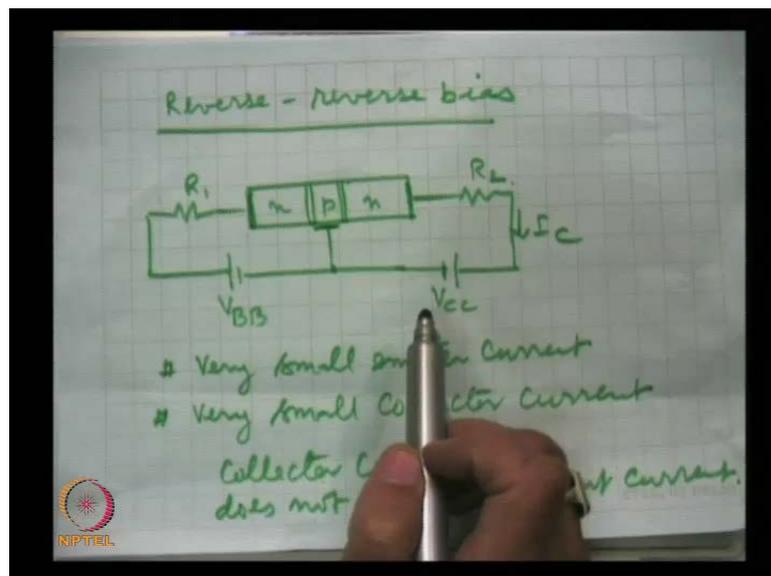


**Electronics**  
**Prof. D. C. Dube**  
**Department of physics**  
**Indian Institute of Technology, Delhi**

**Module No # 02**  
**Transistors**  
**Lecture No # 06**  
**Reverse-bias (Contd.)**

We were discussing the reverse bias that is when the emitter junction is a reversed bias and the collector junction is also reversed bias

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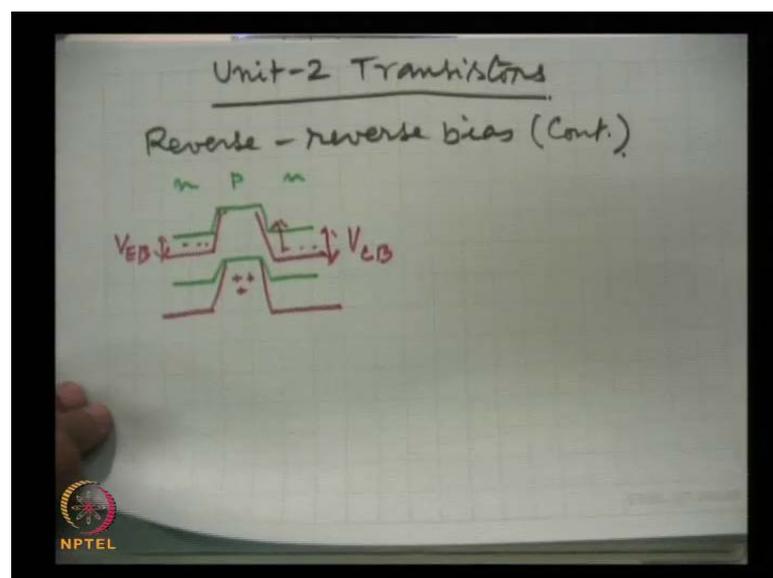


This was the circuit and as we have discussed earlier that because this emitter junction is reversed bias. So there will be very small emitter current, which will be mainly comprising of the minority carriers near and in the junction, which will drift because of the applied field. So there will be a very small emitter current in the same way because the collector junction is also reverse bias, so there will be a very small collector current. So this current will be because of the thermally generated charge carriers in an around the collector junction very important thing was said about these currents that they are small both currents the input current, which is emitter current the output current which is

collector current, but the important thing is both are independent. If we switch off this current making the emitter current zero this will almost have no effect on the output current this reverse bias junction will continue to have that a small current and if we increase this reverse current by say by change in the temperature of the emitter junction which is normally not  $d 1$  but for the sake of argument if this is increased but, this will not increase because this has nothing to do with that with the emitter current.

So this is simply trying to say that the two currents are independent to each other and such a circuit violates the major main requirement of the amplifying circuit in which the output current and voltage should be totally dependent to a very large extent they should depend on the input current and voltage. This thing can be shown reverse bias can be shown through a potential energy diagram , this is n p n.

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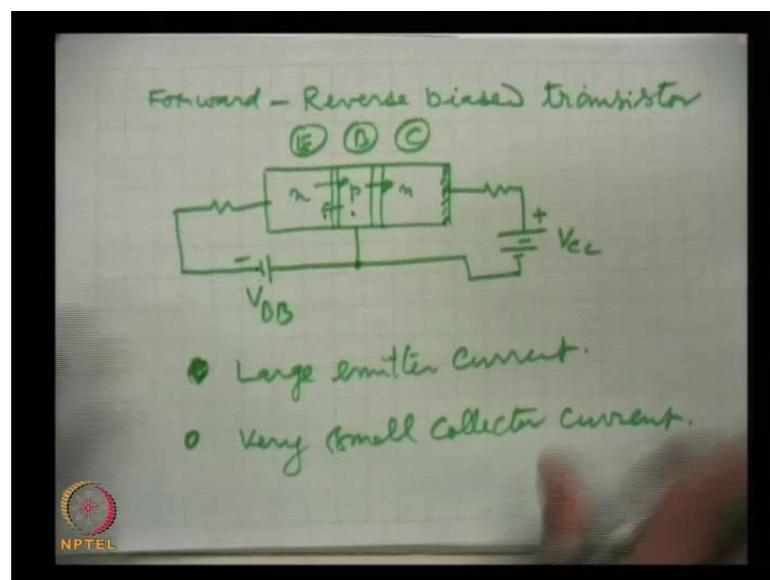


This was the potential energy diagram in equilibrium when there was no field. Now we have reversed bias and you will recall that in the reverse bias. The potential hill this

increases, so this red one is the this is now the potential hill and here there are electrons, here there are holes the majority carriers the height of the barrier has gone up they will not be able to cross over to the p side or to the n side. And similarly the electrons from this side they will not be able to go around over the potential barrier because it is now much higher it was even in equilibrium they were not able to move that is why the equilibrium was achieved. Similarly these holes from the p region of base they will be unable to diffuse or diffuse either to the collector or to the emitter side

So this way of course,, this difference in the two this is equal to the voltage which will be present between emitter and base junction which we properly write as  $v_{e b}$  and this difference from here to here this will be  $v_{c b}$  and so no currents will flow except very small currents in the two circuits the emitter circuit and collector circuit and that 2 currents will be the two currents will be independent of each other. And hence are not suitable the circuit is not suitable to function as a amplifier. Let us see let us look at the third possibility of biasing which is forward reverse biasing forward reverse.

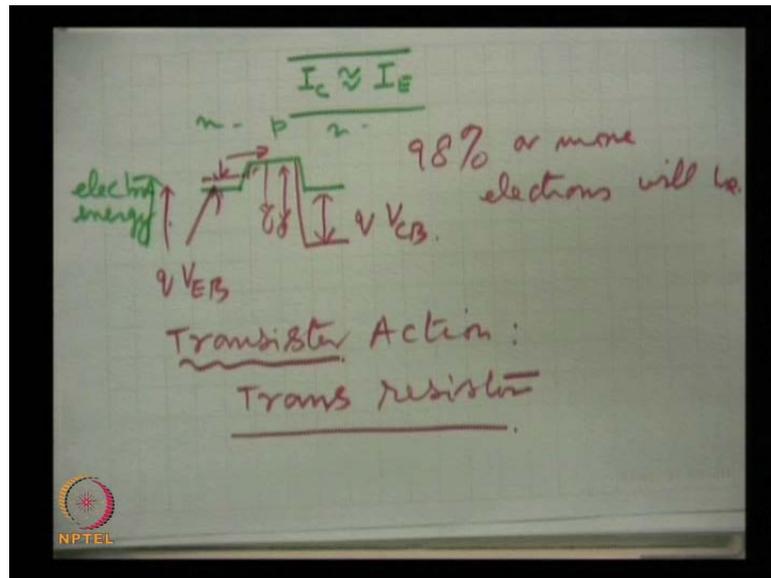
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Biased transistor here emitter junction is forward bias the collector junction is reverse bias and we can depict this situation like this is the emitter base junction is forward biased we have connected the negative side the n side semi conductor to the negative terminal of the battery. And on the other side the this is reverse bias junction collector junction is reverse bias and the n type semi conductor is connected to the positive

terminal of the battery. Now here this is the most important combination trans[istor]- the biasing combination when emitter junction is forward biased, collector junction is reverse bias here what we expect and what actually happens these are entirely two different things and that is behind what we call the transistor revolution, what we expect in the emitter circuit emitter junction is forward bias. We expect a large a large emitter current this is the we expect and collector junction being reverse bias so we expect that very small collector current this is the expected one, but this actually does not happen what happens is this now this is very important that in the when the emitter junction is forward bias and remember that emitter this is emitter base collector emitter is heavily doped. So the electron density is very high this forward bias implies that electrons will be injected into the base, that means they will diffuse towards the base in a very large number. And a holes being very because this base region is very lightly doped, so there is a small density of holes here they will also diffuse to the emitter. So the high density of electrons a very large number of electrons which have been injected into the base from the emitter. Actually most of the electrons will be able to cross over to the collector. Now remember that base was kept very thin and we will quantify how thin this base has to be but, at the moment this is sufficient that base is very thin. So that that most of the electrons why I am saying most of the electrons, because some of the electrons will recombine here what will happen to those electrons recombine electrons we will talk little later. Here the important thing is that most of the electrons say ninety nine percent or more which have been injected from the emitter to the base are able to cross over towards the collector and here because this is the positive terminal so they will be able to be taken away at and they will move towards the electrode what we call collector.

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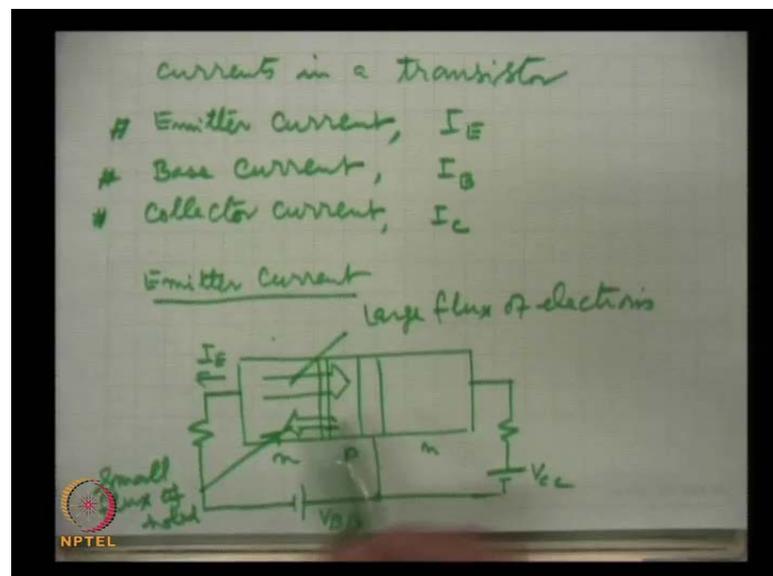
So actually speaking in this case, the collector current is very close to the emitter current. This is a very important step we were expecting very high current in the emitter circuit but, very low current in the collector circuit but what is happening is this that collector current is almost equal to the emitter current. This is I will repeat and I will put emphasis I had this point and I will try to explain that this is called transistor action. And this is also responsible for the name transistor we can discuss with the help of the potential energy diagram also, let us first finish that part that, now this is electron energy this is n region emitter p region and n region this is electron energy is moving this direction and for simplicity I just draw the half side of the energy band diagram that now this is reduced because this is forward bias junction while this barrier at the collector junction has gone up because it is reverse bias and the potential barrier at the emitter junction has been reduced because of the forward bias and these this is correspondingly equal to the because it is energy. So  $q$  this is equal to  $q$  into  $v_{eb}$  and this much change this much change this is  $q v_{cb}$ .

This is reduced so a large number of electrons will move towards the base and base is p type so a small number less than a percent will recombine here, they will fall in the holes and they will recombine and ninety eight percent or more. Electrons will be able to first they will drift into the collector region and finally, they will be taken away they will diffuse and will be taken away towards the collector and a large collector current will flow that is why it was said that collector current is very close to the emitter current.

Now this is what is called the transistor action we have achieved something significant in this case by transferring the current from a low impedance circuit emitter junction being forward biased has a low resistance. And this was said that this resistance is few tens of ohms while collector junction is reverse bias and it is having this will have very high resistance of the order of a hundred kilo ohms or few mega ohms. So we have transferred the almost the same amount of current from a low impedance circuit to a low resistance circuit to a high resistance circuit from there this is known as transistor action.

And this is responsible for all the voltage gain and we will see that how we get current gain also from here now this is trans resistor transistor if we break then it is trans resistor transferring current from low resistance circuit to a high resistance circuit that is the transistor action and from here the name came trans resistor very important. And this has revolutionize the electronics and as we know that there is it is very difficult to assume today the life without electronics all the later developments of integrated circuit development and all that they followed the discovery of transistor. we will further discuss the various currents and I will elaborate few points .

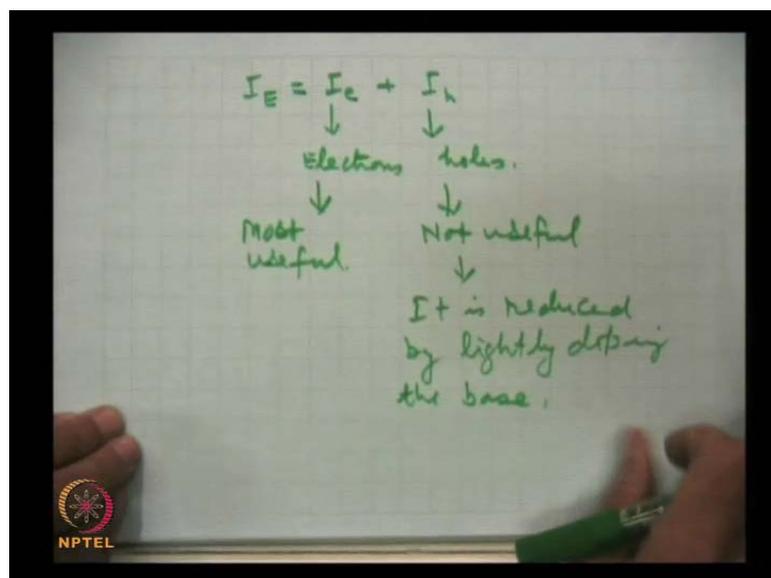
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In this so currents in a transistor now we will be discussing the this very case where emitter junction is forward bias collector junction is reverse bias that is under discussion that part is over when both junctions where forward bias there were very heavy currents in the input circuit that was emitter circuit and very high current in the collector circuit

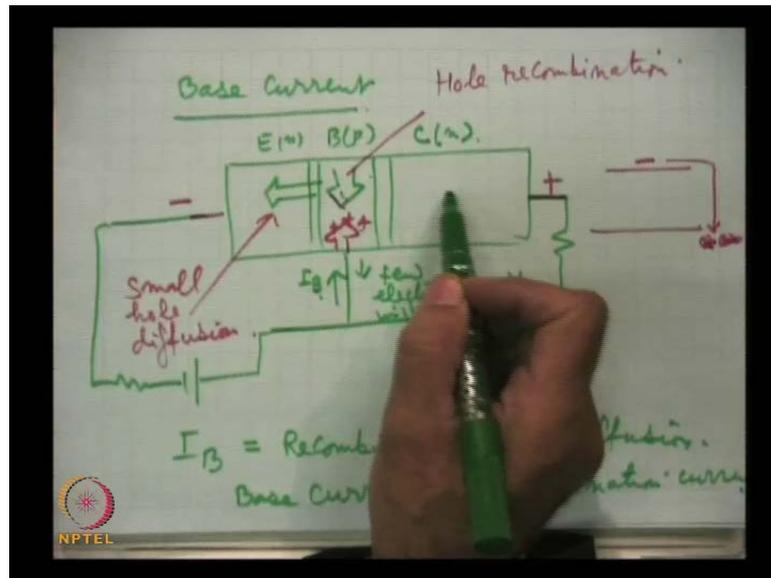
but, the two currents were independent of each other almost independent and not suitable for a amplifying device. Similarly when both junctions who are reverse bias then the currents were very feeble and they were also independent of each other if we switch off the emitter current completely this will have a negligible influence on the collector reverse current and so they the two were independent and hence again not suitable for a amplifying device. But, here in this case where emitter junction is forward bias collector junction is reverse bias here we are seen something very important fantastic very useful that is the collector current is almost equal to the emitter current and the collector current, almost depends it will vary as we vary the input emitter current. So all amplifying circuits this is the biasing which is used that emitter junction is always in a amplifier the emitter junction is always forward bias and the collector junction is also is always reverse bias. Now we will see the components of current and they will further illustrate that why we said that the dopings of emitter are heaviest and base is most light doped and collector is moderately doped about that we shall we shall come up in this section first we talk about the emitter current. There are three currents emitter current, base current and collector current. This is written as  $I_e$ , this is written as  $I_b$  and this is written as  $I_c$ . So first let us talk about the emitter current, emitter current will have two components and from where they will come I will illustrate through this diagram. This is emitter junction forward bias so very large flux of electrons will move will be injected into the base large flux of electrons.

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And this is after all it is the junction so here this is a small flux or a small number of holes and the direction of hole flow is the direction of current. So this will be the direction of emitter current and the two components are one arising because of the electrons high density of electrons injected into base and a very low density of holes which are injected from the base towards the emitter and hence the emitter current the two components are  $I_e$  because of electrons. This is because of electrons plus  $I$  this is due to holes in our discussion of this transfer of current from the emitter to the collector we saw that here this is the electrons which are being collected at the collector, because here is the appropriate polarity the positive potential which will collect the electrons there is no contribution in this current of useful current which is being collected at  $I_c$  the hole contribution. so this is not useful, this is most useful but, this cannot be made zero. Because base if this base is not there the junctions will not be formed the junctions will not be formed and the transistor action which we have been talking will not occur so it is the necessity that some hole component of current will be there. But this is reduced heavily by making the hole region it is reduced by lightly doping the base, because this is not useful in the n p n transistor and here the holes which are most useful and we make this contribution large by making emitter heavily doped so the factors which we discussed in the beginning they are now coming so this is about the emitter current.

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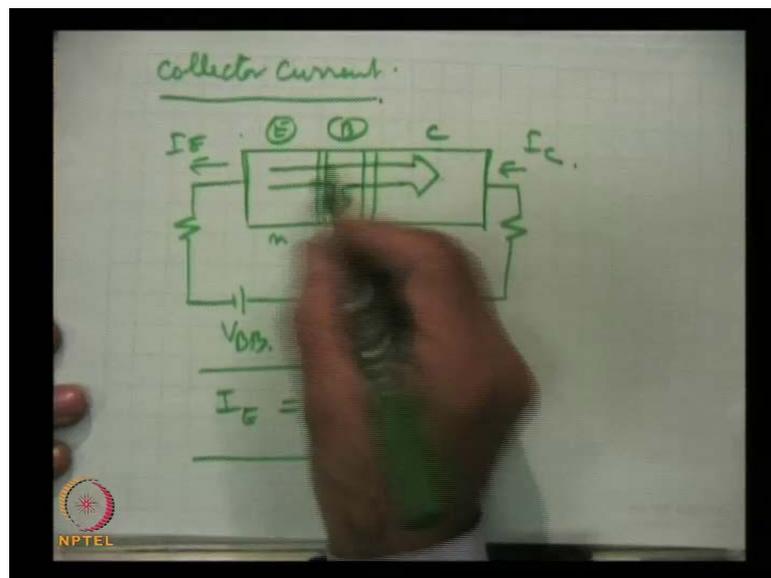
Now we talk about the base current, base current also has two components and these are this is n type emitter this is base p type and this is collector again n type. Now here some holes have diffused this is of course, the same polarities this is n type and this is having negative potential this is having positive potential this is reverse bias junction this is forward bias junction and so this is the small hole diffusion I said collector current is almost equal to the emitter current why almost when these electrons from the base region are moving through the base. A very small percentage of holes recombine and so there is a component of hole recombination, this is hole recombination. So from the p type base holes have been lost two ways one is the small percentage of holes have diffused towards the n region the emitter region and other is the loss because of the recombination you will recall that in recombination the electron and hole both disappear.

For example I remind that this is the free electron this electron which was coming from here and in the base region these are the holes when it moves some of them are trapped. So these holes are again fill the state and in are in a recombination the electron hole pair they disappear in the same. In the sense that electron is trapped here it is it has made hole in mobile because the holes existence was because of the absence of the electron from here and the electron which was mobile it was in the conduction band that has been trapped here so hole has vanished and electron has been trapped made in mobile so there are two ways that the holes are lost. And this is compensated by pumping either we can say that holes are injected and this injection of holes is by removal of electrons, so

electrons few electrons will flow and that will constitute current  $I_b$  what we call  $I_b$ . Let me state in another way that some holes are moving in this direction and diffusing and electrons are recombining so those recombine electrons they are in excess here.

The system overall has been neutral so those excess electrons required to maintain the neutrality of charge neutrality of this region they will be taken out and that will constitute part in this direction. So the two components of base current  $I_b$  the base current that one component is the recombination current and partly the hole diffusion. Recombination part is much higher as compared to this and that is the reason that the hole the base current is called recombination current. Base current is largely a recombination current now it becomes clear that, let us assume just for the time being if it is a figure that hundred electrons start moving from the emitter one percent they recombine, so that will form the base current finally they will come out from here and ninety nine percent are collected by the collector.

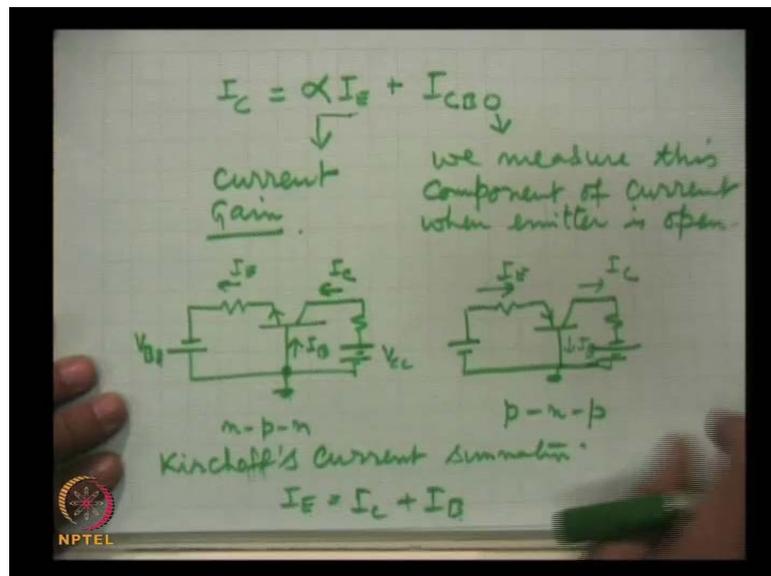
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Now the collector current, Collector current again it has two components the collector current the first component let us look at this figure that from the emitter a very large flux of electron was induced into the collector region and very small fraction got recombined. So two things become clear from here one is that actually because the emitter, the electrons which were emitted from the which were injected from the emitter

they have been shared by the two a much larger portion goes to collector. So  $I_e$  is equal to actually  $I_c$  plus  $I_b$  because base current also basically is because of the electrons which have been injected from the emitter so this is the relation which we will always remember. And I will show you that this comes by collecting by summing up the currents that this is  $I_e$  this is  $I_c$  and this is  $I_b$  the currents which are entering in the device they are taking as positive and this is  $I_c$  and  $I_b$  both are entering to the device and the current which is coming out of the device is  $I_e$ . So  $I_e$  is equal to  $I_c$  plus  $I_b$ .

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Now this is anyway we were talking about current component so the first component of current  $I_C$  is fraction and that let us call that alpha and we will define what is alpha is  $I_c/I_e$ . Now this is the contribution because of the electrons which are which have been injected from the emitter, but we should not forget that this collector junction is a reverse biased junction. So even if this current emitter current is made zero. But this current will be there reverse saturation current and that we write as  $I_{cbo}$ . This current actually indicates we measure this component of current, when emitter is open that means no current when  $I_e$  is zero then whatever is the reverse current that is this  $I_{cbo}$  this will also be in the same direction which I can explain here that this is the reverse bias junction. Thermally generated holes will move in this direction and thermally generated holes electrons in the p region. They will move in this direction, so the electrons will move in this direction holes will move in this direction that will constitute the reverse saturation current and hole direction is the the conventional direction of current, so this is

in the same direction. So these are the two components of current this is very small component at least two orders of magnitude is smaller than this first part. So basically the collector current is alpha times  $I_e$  and alpha as we will see that this is one of the gains current gain actually and we soon talking about this in more detail current gain this is close to one but less than one. Because you know that  $I_c$  is actually speaking in little less than  $I_e$  and how much less the portion which has recombined in that base region so this is the current gain by definition we will talk about little later and this.

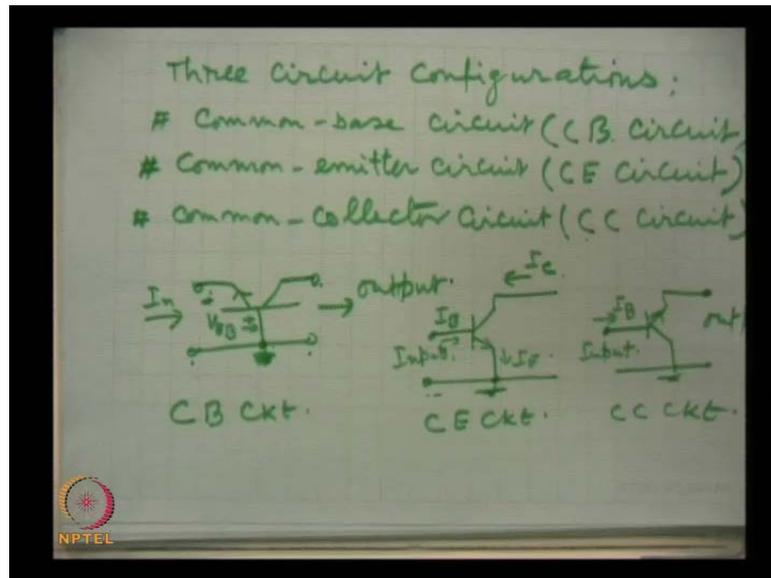
The part of the collector current and we have talked about the small number of electrons coming out from here and these holes will be flowing and they will be taking out from here large number of electrons. And they will constitute this part of the current, so this was about the three currents the emitter current this should be large and to make it large because there are two components the electronic component and hole component. The electronic component is useful component hole component does not play any role in transistor action and so that is the part hole part is reduced by taking the doping of the base region lightly and another current is made to the largest possible extent of made of electrons in n p n transistor and that is made by heavily doping the emitter collector current is basically the current which is flowing because of the input current, which is this part alpha times  $I_e$ .

While this current is thermally generated current this is temperature dependent  $I_c$  fortunately this is also it is not important because this current will not vary with the input current any fraction of the current which is invariant as far as the input current is concerned that is not playing any useful role in amplification. This part will because this is this part of the collector current is totally dependent on the emitter current, so this plays the major role main role and this is insignificant actually this is what causes the thermal noise to the transistor it is a parasite. But we cannot get rid of it completely this was about the three currents, I was drawing block diagrams taking these n p n transistor I can draw a circuit for it and this will be like this. Actually base is many times grounded when it is this configuration this is  $I_e$  this is  $I_c$  and this is  $I_b$  this is for n p n transistor and summation the kirchoff's summation. Kirchoff's current summation gives  $I_e$  equal to  $I_c$  plus  $I_b$  we can draw and we should draw to know about the p n p transistor am taking n p n transistor as an example because it is more popular but I said that p n p transistor will work perfectly all right only difference is that when we go on

increasing the frequency then n p n transistor will function better and that also that will give its maintain its performance up to higher frequency and you can see here that in n p n transistor.

This is all the role of electrons and electrons are having higher mobility and therefore they can respond up to higher frequency. Now a similar circuit can be drawn with p n p transistor there will be the arrow direction will have to reverse the direction of currents will be opposite to this and the battery polarities because now it is p n p transistor p n p. So this polarity of the batteries will also be changed they are just opposite to what are in this case and the current direction this is  $I_e$ , this is hole current holes if we talk of p n p transistor this will be very rich in hole very small density of electrons and very high density of holes, so the holes from here will be injected a percent or so will recombine with the electrons and the remaining one will be here and then they will diffuse. And they will be taking care by as soon as they reach near the electrode then this favorable potential will take them will collect them this is how it will work and the current directions will be  $I_c$  and this will be  $I_b$ . So here also  $I_e$  is equal to  $I_c$  plus  $I_b$ .

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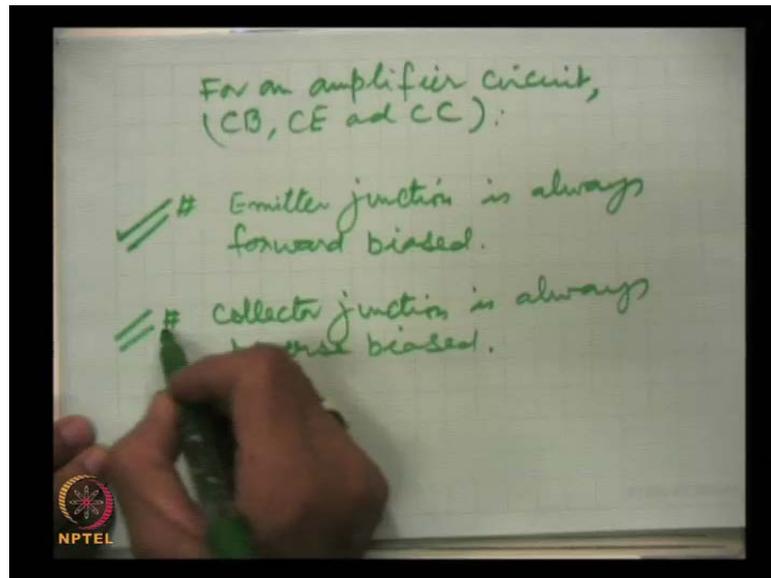


Now we talk about the 3 configurations in which a transistor can be used. Three circuit configurations a transistor one same transistor it can be sued in three ways in three different circuit profiles one is the common base, common base circuit popularly name known as c b configuration c b c tends for common b for base so common base configuration or circuit. The second one is common emitter, common emitter circuit this is called c e circuit c e circuit c for common e for emitter common emitter circuit c e circuit. And the third one is common collector circuit that is c circuit common collector circuit, so transistor is same only how we connect in the circuit that will tell whether it is common base circuit common emitter circuit or common collector circuit the three configurations are these. So for what we were discussing actually this was c c b configuration this is ground and this is the input is given here and output is taken from collector between collector and ground. This is output this is c b circuit and this voltage between emitter and base this is called  $v_{be}$  emitter between emitter and base here this is positive, this is negative this is for n p n, p n p thing we have just compared that all the directions of currents will be reverse to in the p n p case the batteries I have to be put in the reverse direction so that is it now again we have come back to n p n transistor so this is the the the base is common to input and output and hence this is called common base circuit. This is the other circuit this is the input and here this will be the input current, input current will be base current and output is taken from collector and ground between collector and ground. So this is  $I_c$  and this is  $I_e$  this is common emitter circuit. And common collector circuit output and here this is input this is common collector circuit.

Now the same transistor can be used in 3 different configurations as I said, if the input we are giving is between the emitter and base and output we are taking from collector and base then it is common base circuit. The other circuit where instead of emitter the input is connected between base and emitter and output is collected from the collector with respect to ground this emitter terminal here is grounded so this will be the common emitter circuit. Common base circuit in which input is given at emitter collector from collector this is common emitter circuit input is connected to the base and input is the base current and output is the collector. The third circuit the common collector circuit in which the input of course is the base current but output is taken from the emitter. Whenever you see that output is being taken from the emitter we are talking of common collector circuit. Whenever the input is at base and the output is at the collector this is common emitter circuit. And if the emitter the input is at the emitter and output is collected from the collector this is c b circuit.

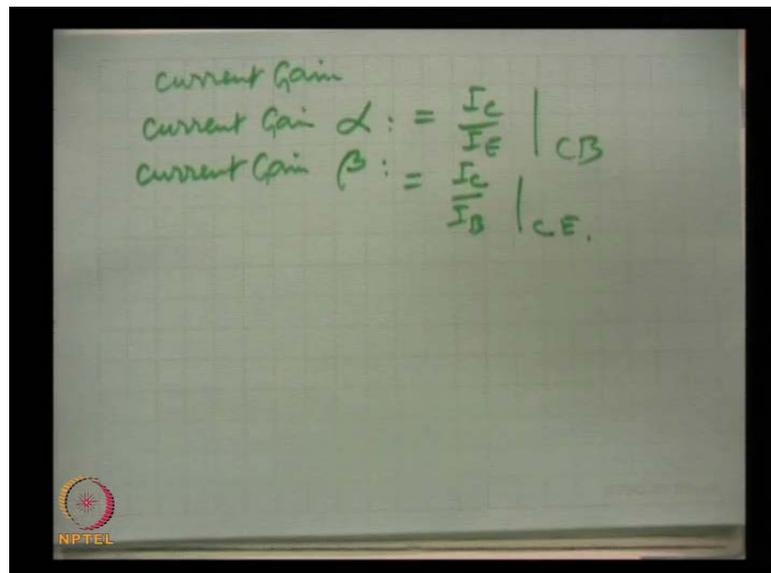
All these three configurations are important and widely used for amplifying purposes few things we should remember that, whether we are talking of common base circuit or common emitter circuit or for that reason common collector circuit emitter junction when it is a the amplifier the emitter junction has to be forward bias always remember and the collector junction has to be reverse bias. We will come how the biasings are achieved in practice what are the different ways of achieving these biasing we will be talking that also but we should always remember that whatever is the configuration whenever we are connecting the transistor for amplification purposes it has to be the emitter junction has to be the forward bias and the collector junction has to be reverse bias to put more emphasis.

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I write this point that for an amplifier circuit in any of the configuration common base common emitter or common collector whatever is the circuit emitter junction is always forward biased and collector base junction which is collector junction is always reverse biased this is very important.

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Now we talk about the current gains, current gain alpha current gain beta alpha and beta these are the two current gains which we encounter when we talk of transistor. Now this we will talk about these current gains current gain alpha and beta, actually alpha is for c

b circuit where it will define the ratio of output by gain. The fundamental definition is output to the input if we talk of current gain then output current to the input current in this case it is  $I_c$  over  $I_e$  which happens in the c b circuit where input is the emitter current output is collector current this happens  $I_c$  over  $I_b$  this happens in c e circuit. And we will talk about these current gains now I am sure we have followed what is the basic physics of transistor why we as took in the beginning specified dopings that emitter is most heavily doped and base is lightly doped and collector doped and about the sizes because the collector has to collect the electrons so the size has to be larger and the other two are slightly a smaller from one each other. And then we discussed the biasing because there are two junctions there is forward bias no use for amplifier heavy currents in both circuits emitter circuit and collector circuit but the two currents are largely independent hence not useful for amplifier and in the other case that both are reverse bias there also it is not useful that two currents are small independent of each other. The third case is most important emitter junction forward bias collector junction reverse bias and we will see that this will give a high voltage gain current gain and so on that we will continue.