

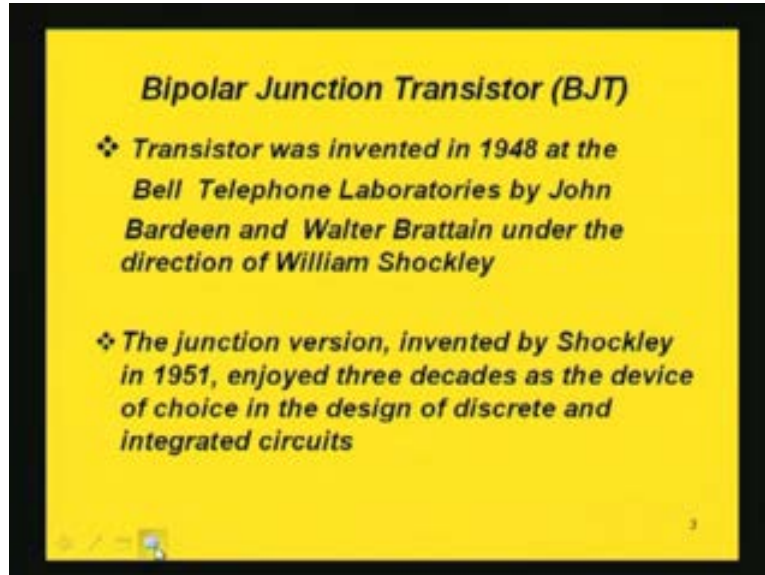
Basic Electronics
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Module: 2 Bipolar Junction Transistors
Lecture-1
Transistor Operation – Part 1

Today we will be discussing about a device named as bipolar junction transistor or BJT. The BJT is a three terminal doped semiconductor device which is used in amplification as well as switching operations. In last classes we have discussed about diode, which is a two terminal semiconductor device. But BJT is a three terminal device. This BJT is named as bipolar because there are two types of charged carriers which will be involved in the operation of a BJT, holes as well as electrons. As holes or electrons are having opposite polarities of positive and negative charges, this device which involves operation of both holes and electrons is known as bipolar junction transistor or BJT. This is bipolar because these two types of charge carriers are having opposite polarities. This junction transistor is having three terminals. It can be made of PNP that is the N type material will be sandwiched between two P type materials or it can be NPN where a P type material may be sandwiched between two N type materials. These two different configurations of PNP and NPN are there in transistor. We will discuss about both of these PNP and NPN transistors.

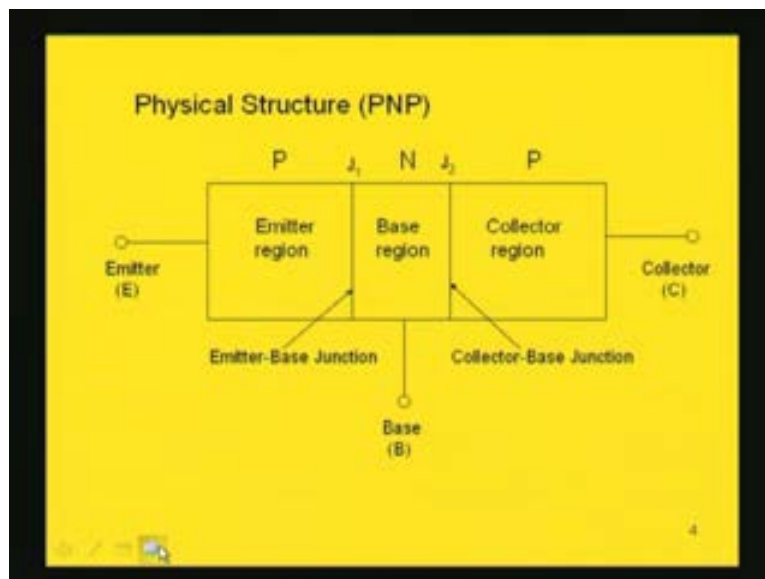
This transistor is a very important semiconductor device because we see enormous applications in electronics and mainly in amplification of a signal. When we want to amplify a small signal then we use this transistor as an amplifier and another application which finds immense use in digital circuits is in logic operations or also in switching and this transistor can be used as a discrete component or it can also be used in the ICs, that is integrated circuits. Both in analog and digital domain we find application of transistor. It was invented in 1948, in Bell telephone laboratories by John Bardeen and Walter Brattain under the direction of William Shockley.

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But its junction version was invented in 1951 by Shockley and it has been enjoying almost three decades of immense use in discrete and integrated circuits. Let us now consider the physical structure of a transistor. First let us take an example of the PNP transistor.

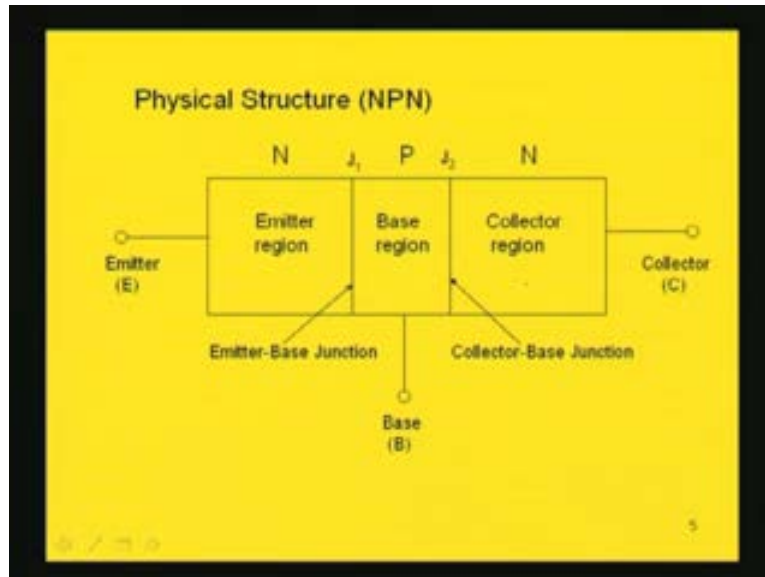
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The transistor has three regions; emitter, base and collector. The base region is sandwiched between emitter and collector regions. There will be two junctions J_1 and J_2 as I have named. This J_1 is the junction between emitter and base and J_2 is the junction between collector and base. These three terminals which are taken out from these three

regions are correspondingly emitter terminal, base terminal and collector terminal. This structure is PNP and if we consider an NPN transistor similarly we have these three regions emitter, base and collector regions.

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But here one P type material is sandwiched between two N type materials. As we can see here base region which is a P type is sandwiched between the two N type region of emitter and collector and there will be three terminals emitter, base and collector which are drawn out from these three regions. So it is a three terminal device having two junctions.

Depending upon the biasing condition of forward or reverse, for each of the two junctions the transistor has different modes of operation. Basically we will be getting three operation modes. One is active mode of operation which is generally the mode of operation where we use the transistor as an amplifier. Here in this mode of operation both junctions are differently biased. That is the emitter base junction will have to be forward biased and the collector base junction has to be reverse biased. This is for active mode of operation of the transistor which is generally the operating mode of a transistor. But there are other two modes of operation which are known as saturation mode and cutoff mode. These two modes are generally used in switching applications as for example in logic circuits and digital devices we find mostly the use of these two modes that is saturation and cutoff.

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Depending upon the bias condition (forward or reverse) of each of the two junctions (emitter-base and collector-base), different modes of operation of the BJT are obtained

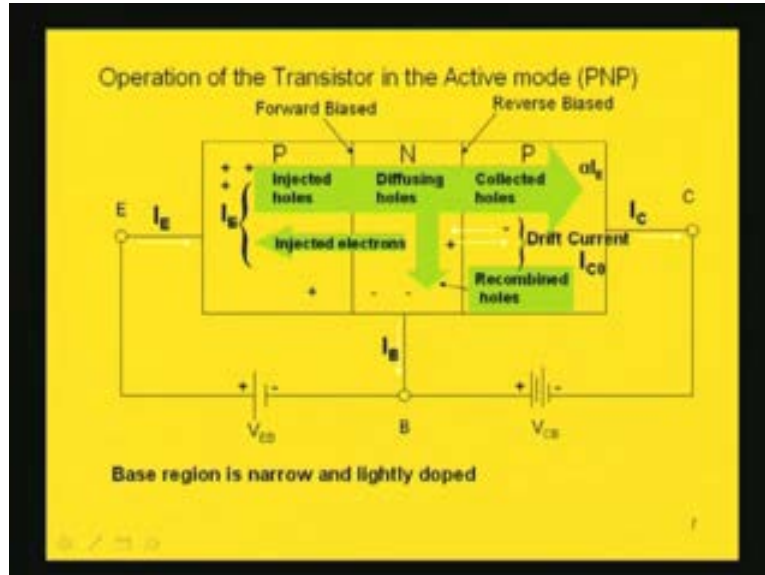
Mode	emitter-base junction	collector-base junction
Active	Forward	Reverse
Saturation	Forward	Forward
Cutoff	Reverse	Reverse

Active mode – transistor operating as an amplifier
Cutoff and Saturation mode – switching applications, e.g. in logic circuits

In saturation mode of operation the emitter base junction is forward biased and the collector base junction is also forward biased. Both the emitter base junction and collector base junction are forward biased and the last one that is in cutoff operation both the emitter base junction and the collector base junction are reverse biased. We have these three modes of operation according to the biasing condition of the two junctions.

Let us now see the operation of the transistor in the active mode and let us take for example a PNP transistor first. As a PNP transistor is having N sandwiched between two P's that is the base region which is N is sandwiched between emitter and collector regions which are the P type material. We will now study how the carriers will be moving to constitute the overall current flow through the device? In the PNP transistor as you can see here emitter, base and collector.

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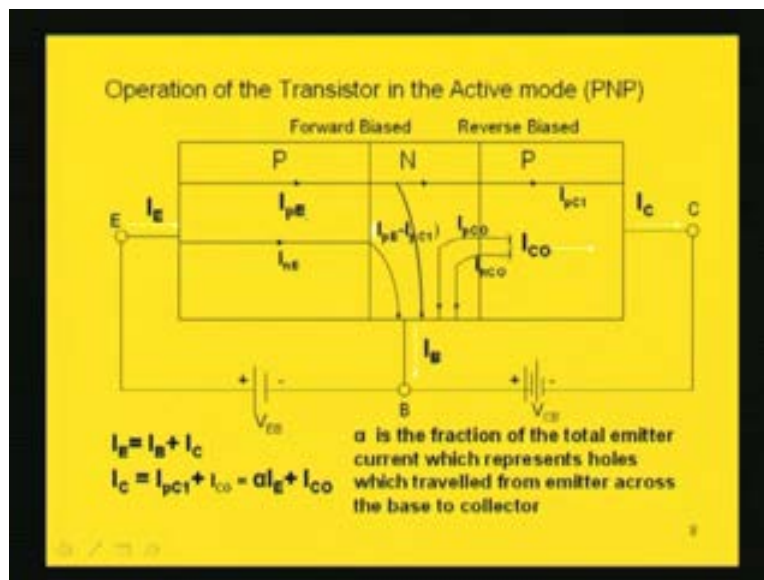
This P region is having holes as majority carriers. These are electrons which are majority carriers and here again holes are majority carriers. The junction between emitter and base should be forward biased that is P is at a higher potential than this N and this collector base junction is reverse biased. So this collector is at a lower potential than this base. These are done by the two potentials. V_{EB} is forward biasing the emitter base region and this V_{CB} is reverse biasing collector base region. Because of this forward biasing the holes which are majority carriers in this emitter will start traveling from left to right and it will be entering the base region and the electrons which are majority carriers in the base region they will be traveling from right to left because of this forward biasing of this base emitter region. If we consider the total current which will be flowing the conventional direction of current is in the direction from left to right. Emitter current will be constituted by this movement of holes from emitter to base as well as movement of electrons from base to emitter. Overall, the direction of current is giving the emitter current.

Out of these holes which are now entering the base region some will be recombining with the electrons. Because of this narrow width of the base region and as the base is very lightly doped only very less number of holes will be recombining with the electrons; maximum 5% of the holes are generally recombined. The rest of the holes will be continuing their travel from base to the collector region and the collector is reverse biased. The negative terminal of this battery V_{CB} will be attracting these holes. So they have easy travel. The rest of the portion of the holes after recombination or the electrons in the base region they will be reaching the collector and if we consider this junction, collector base junction which is reverse biased there will be a drift current because of the minority carriers. The minority carriers are holes in the N or base region here and electrons in this collector. These electrons will be moving because of this reverse biasing potential from right to left and the holes which are minority carriers in base will be

traveling from left to right. The total drift current due to this movement of minority carriers is I_{CO} that is the reverse saturation current or it is also called as leakage current.

The total collector current will be due to two components. One is due to the holes which are reaching from emitter crossing the base junction and reaching the collector and the other is due to the reverse saturation current. If we consider alpha as the fraction of the emitter current due to the holes which are reaching the collector from emitter then alpha times I_E is the portion of that current which will be constituting the collector current and another part is the reverse saturation current I_{CO} . This I_C will be equal to alpha times $I_E + I_{CO}$. If we consider again only the current flow after this knowledge of the movement of the majority and minority carriers then we get this picture that emitter current I_E is due to these two components I_{pE} and I_{nE} . The subscript p is for holes, subscript n is for electrons and e is for emitter.

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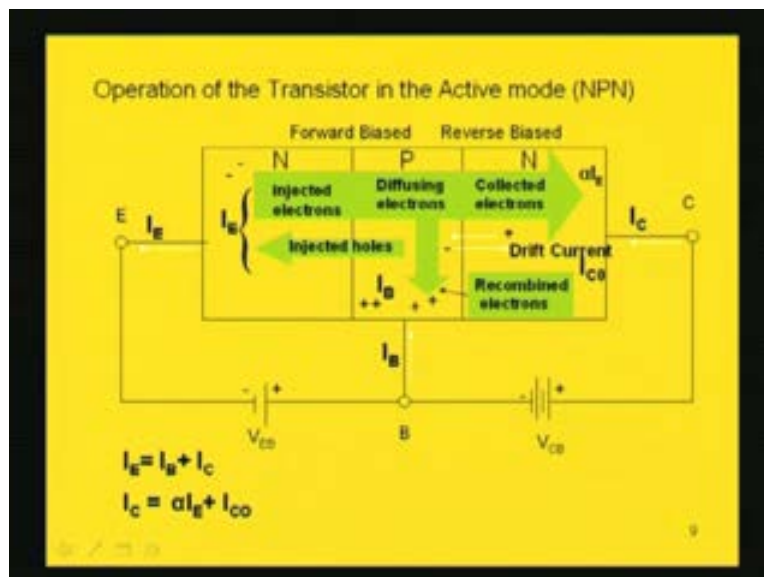
The holes are moving from the emitter towards right to the base giving rise to I_{pE} . The conventional direction of current is in this direction and the other is due to the electrons in the base to emitter giving rise to this I_{nE} current which is the conventional direction against the movement of the electrons. Total current is I_E from left to right that is it is entering the transistor; I_E current is the entering the transistor. Out of this I_{pE} the holes which will be reaching the collector after passing through this base is I_{pC1} . This is the portion of the current which is due to the holes which can travel to the collector but that portion which is recombined in the base region is $I_{pE} - I_{pC1}$. This portion is recombined. To replenish this portion of the recombined electrons in the base region this negative terminal of the potential V_B will be now providing electrons. These electrons will be flowing into the base region giving rise to the base current which has a direction from top to bottom. Basically this base current is due to the replenishment of the lost electrons in the recombination in the base region that is provided by this battery. This I_B is flowing out of this device and the collector current I_C is due to I_{pC1} and I_{CO} is a drift current or

saturation current or leakage current due to minority carriers, this minority carrier current being I_{pCO} and I_{nCO} . I_{pCO} means the holes which travel from the base to the collector region because these holes are the minority carriers in base and the other is the minority carriers which are electrons in this collector which are traveling from right to left giving rise to I_{nCO} . These two components I_{pCO} and I_{nCO} are summed up to give I_{CO} .

If we consider the whole transistor as a device it is nothing but a junction where you can apply Kirchoff's current law. This Kirchoff's current law is applicable because it is a device which has a junction. The incoming current summed up will be equal to the outgoing current summed up. That is giving rise to the I_E equal to $I_B + I_C$ because if you look into the direction of movement or the direction of current then I_E is into the transistor, I_B is out of the transistor and because this direction of I_{CO} and I_{pC1} are same, the summed up I_C will be out of these transistors. It will be entering into this negative terminal. I_C is outgoing I_B is also outgoing. I_E is in coming so I_E is equal to $I_B + I_C$. This is the key equation which is satisfied in the transistor. Another equation which we have got from the collector current and emitter current relation that is equal to I_C equal to $I_{pC1} + I_{CO}$. I_{pC1} we can represent as αI_E , α being the fraction of the total emitter current which represents the holes which travel from emitter and reach the collector by passing through the base. So I_C equal to $\alpha I_E + I_{CO}$. These two equations are the key equations which you should remember for analyzing the transistor circuit.

If we consider the NPN transistor, the difference from PNP and NPN is that you will have emitter, base, collector as negative; N P and N materials.

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P is the base region sandwiched between two N type materials. The condition for active operation of the transistor is that the emitter base junction should be forward biased and the collector base junction should be reverse biased. That is satisfied by this battery with the polarities as indicated which shows that N is connected to negative, P is connected to

the positive. This junction between emitter and base is forward biased. P is at higher potential than N and similarly in the other junction which is the reverse bias or collector base junction, this reverse biasing is done by this potential V_{CB} the polarities being such that this collector is at lower potential than base. The major difference is in the carrier movement. Here the majority carriers which are in the emitter are electrons. These will be repelled by this negative terminal of the battery. This is a forward biased PN junction. That makes the emitter current analysis easier. It is nothing but a forward biased diode. The emitter current is due to electrons which are moving from the emitter to base and holes which are moving from base to emitter.

The direction of current is important here. Direction of current will be now the conventional direction of the emitter current which is outwards from the transistor. That is it is coming out of the device and entering this negative terminal because it is opposite to the direction of the electrons. Electrons are moving from left to right, so direction of this emitter current will be from right to left. As well, the hole movement is in synchronism with the direction of this emitter current, same direction. Electrons which are coming from emitter to base will be recombined with the holes in the base region. Due to this recombination of electrons and holes in the base region the current which will be provided by this battery V_{EB} is I_B but its direction is towards the transistor. That is it is going into the transistor because the recombination which is taking place in the base has to be replenished and that is done by the holes which are being provided by this battery. That is why hole movement is in this direction, so base current movement is also in this direction.

The diffusing electrons now after recombination, losing a portion of its total amount, will be reaching the collector. That part is alpha times I_E due to those electrons which are reaching the collector starting their travel from emitter after recombining in the base region to a certain extent. That is a maximum of 5% recombination may take place. Actually 0.95 to 0.99 can be practical value of alpha. If we consider that 5% recombination is occurring in the base region then 95% of the electrons will be reaching the collector. This is alpha times I_E current and this is I_{CO} drift current due to the minority carriers which are holes in the collector and electrons in the base. Due to movement of these minority carriers, the reverse saturation current I_{CO} flows; I_C equal to alpha times $I_E + I_{CO}$. These equations are valid for the transistor. Be it PNP or be it NPN, these are the key equations which must be satisfied.

If you look into the direction of currents still it is being satisfied because I_E is the outgoing current, I_B is incoming into the transistor and I_C is also into the transistor. This alpha times I_E is the electrons which reached that collector. From left to right these electrons are moving. Conventional direction of current is from right to left. Similarly I_{CO} is from right to left. The alpha I_E direction and I_{CO} direction are in the same direction. The total current I_C is due to these two components alpha $I_E + I_{CO}$ which will be in the same direction from right to left. This is into the transistor. I_C is into transistor, I_B is into transistor and I_E is out of the transistor. The Kirchoff's current law, here also is valid which we have just now seen and the other equation is I_C equal to alpha times $I_E + I_{CO}$.

One point to remember here is that this base region is lightly doped and this width is the narrowest among all the three. There are certain important consequences and this is evident which we have discussed right now because a very small percentage of holes and electrons recombine in the base region. This is due to the fact that this is lightly doped. The two reasons if we consider emitter and base although theoretically we have told and it is theoretically correct that the emitter current is due to the movement of electrons in this NPN transistor, electrons from left to right and holes from base to emitter but practically what happens because this base region is lightly doped majority of this emitter current is due to the injected electrons from emitter to base. The other portion, holes from base to emitter is very small. Mostly the current I_E is due to this movement of the charged carriers from emitter to base. The other portion is very small.

If we consider these two equations we can still further simplify it to get an important expression. That is first equation that we got is I_E equal the $I_C + I_B$ and we also got I_C equal to alpha times $I_E + I_{CO}$. From these two equations we can proceed a little further and we can write that I_C equal to alpha times $I_E + I_{CO}$. Here this I_E can be replaced by the first equation I_C plus I_B plus I_{CO} . Doing this little manipulation, transferring this alpha times I_C to the left side I get 1 minus alpha times I_C equal to alpha times $I_B + I_{CO}$. Again doing a little simplification we get I_C equal to alpha by 1 minus alpha into I_B plus 1 by 1 minus alpha into I_{CO} . Let us define this alpha by 1 minus alpha by a term beta. If we define this alpha by 1 minus alpha by beta then this expression becomes I_C equal to beta times of I_B plus from this expression I can find out what is 1 by 1 minus alpha. It is nothing but beta plus 1 because beta plus 1 if we check, right hand side is equal to what? alpha by 1 minus alpha plus 1; so that is equal to 1 minus alpha in the denominator and alpha plus 1 minus alpha in the numerator. That means 1 by 1 minus alpha. This expression 1 by 1 minus alpha can be expressed by beta plus 1. The whole expression will now become I_C equal to, this one if write again, beta times I_B plus beta plus 1 into I_{CO} . This is another important equation which we should remember.

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$$I_C = \alpha I_E + I_{CO}$$

or, $I_C = \alpha(I_B + I_C) + I_{CO}$

or, $(1 - \alpha)I_C = \alpha I_B + I_{CO}$

or, $I_C = \frac{\alpha}{1 - \alpha} I_B + \frac{1}{1 - \alpha} I_{CO}$

Defining $\frac{\alpha}{1 - \alpha} = \beta \rightarrow \frac{1}{1 - \alpha} = \frac{\beta + 1}{1 - \alpha}$

we get,

$$I_C = \beta I_B + (\beta + 1) I_{CO}$$

Handwritten notes on the right side of the slide:

$$I_E = I_C + I_B$$

$$I_C = \alpha I_E + I_{CO}$$

$$I_C = \alpha(I_C + I_B) + I_{CO}$$

$$I_C - \alpha I_C = \alpha I_B + I_{CO}$$

$$I_C(1 - \alpha) = \alpha I_B + I_{CO}$$

$$I_C = \frac{\alpha I_B + I_{CO}}{1 - \alpha}$$

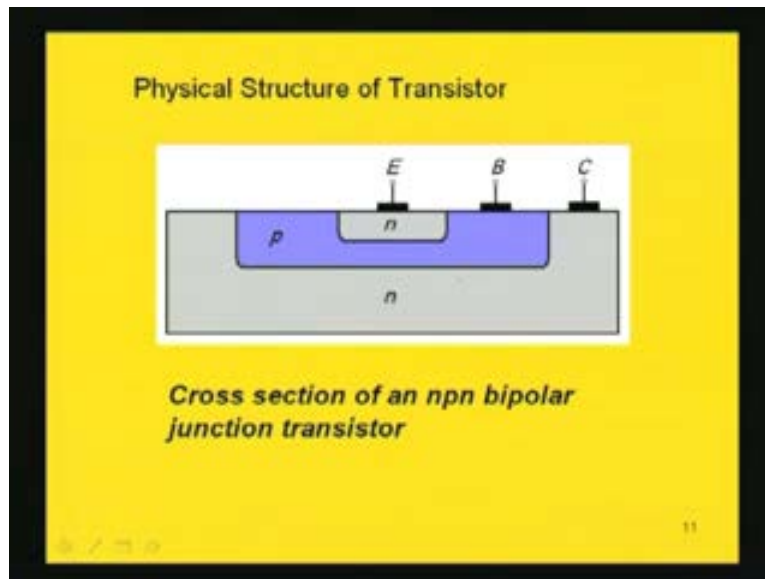
$$I_C = \frac{\alpha}{1 - \alpha} I_B + \frac{1}{1 - \alpha} I_{CO}$$

$$I_C = \beta I_B + (\beta + 1) I_{CO}$$

Beta is a term which we will be explaining later. It will be more important when we discuss common emitter transistor. Its significance will be mostly understood then better but still here we are getting βI_B plus β plus 1 into I_{CO} is equal to collector current I_C or I can also express it by this way of that I_C equal to α times I_E plus I_{CO} . We have to note these two expressions.

In the physical structure of transistor, if we see the cross sectional view physically it is like this. Here this sandwiched region which is base region is narrower.

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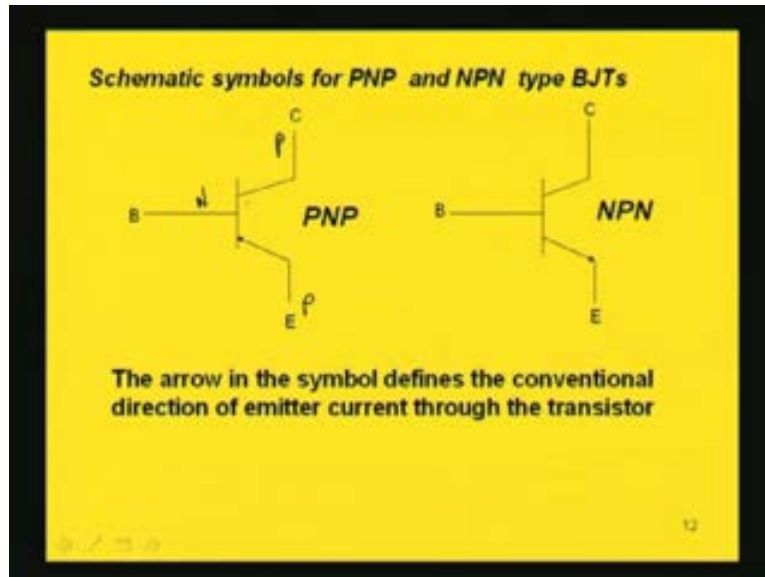


If we compare the cross section this is having the least value area wise and collector region is the region which is the largest and there is a certain reason for this also which we will get later because the collector has to handle large amount of power. Current will be increased in the transistors in the collector region. So I_C will be very large. The power dissipation capability of the collector should also be enhanced. That is why practically what is done is this area is made large so that it can dissipate the power in a better way because if the area is larger we can dissipate it more without increasing the temperature. That is the reason why actually the collector region is the largest practically in a transistor. This base region is least in cross section and its width is also actually lesser.

We have to know schematically the symbolic representation of a transistor for both PNP and NPN. While using in an electric circuit we will not be drawing the whole transistor. We will be only drawing the symbolic representation. Symbolically a PNP transistor is represented like this. We have three terminals; emitter, base and collector. There is an arrow marking in the emitter terminal that is the significant point. How to differentiate between a PNP and NPN transistor? The arrow in this symbol of transistor actually denotes the conventional direction of the emitter current through the transistor. If it is a PNP transistor, we have seen that because this emitter based junction will be forward biased and collector based junction will be reverse biased, the emitter current will be

flowing towards the device. It will be flowing towards the transistor. This is P, N and P. P is connected to positive terminal, so it will be repelling the holes to move to base. Current will be towards the device.

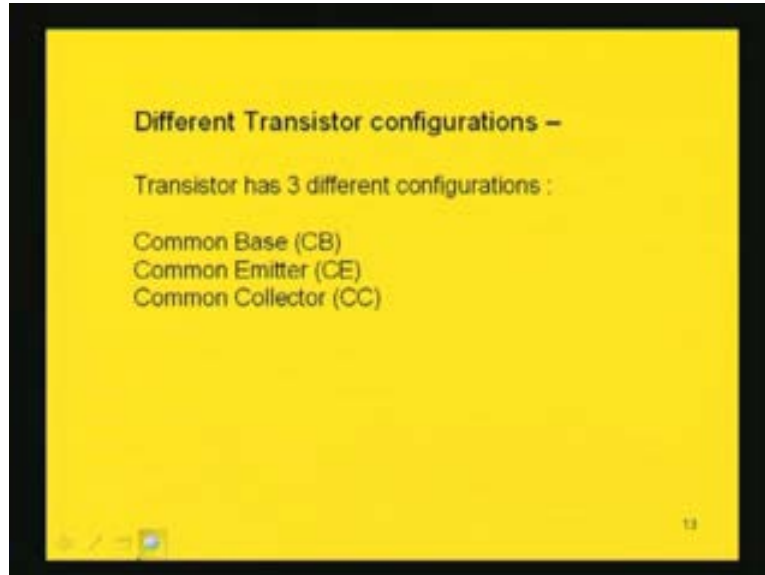
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But in NPN it's the other way round. That is in NPN, the emitter is having majority carriers, electrons and it is forward biased. Negative terminal will be repelling the electrons to move to the base region from emitter region. The conventional direction of the emitter current will be outwards away from the transistor. It is coming out of the transistor. The conventional direction will be opposite to the movement of electrons. The direction of current will be outwards. This direction is important to know whether you are operating with a PNP transistor or an NPN transistor. That is known by the arrow mark in the emitter terminal.

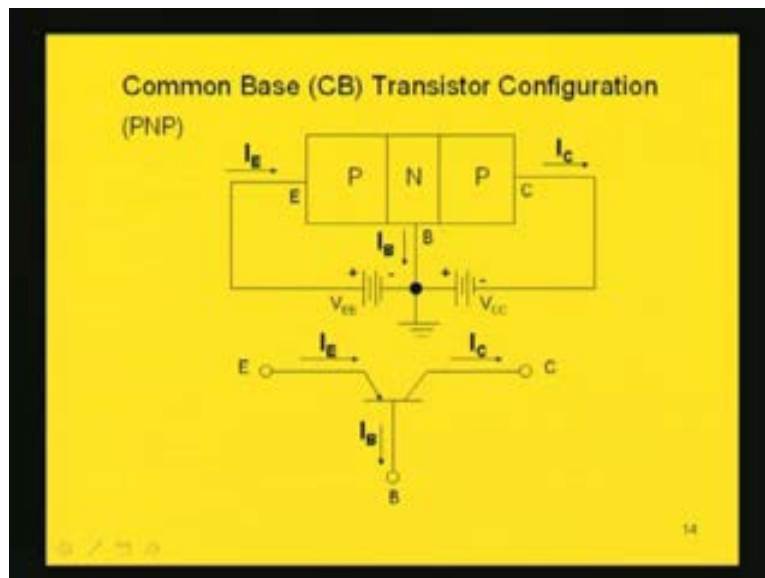
There are three different configurations in which we will use the transistor. The three different configurations are common base configuration, common emitter configuration and common collector configuration.

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As the name suggests common base means the base is common to the input and output circuits. Let us see a common base transistor. The configuration of common base transistor is like this.

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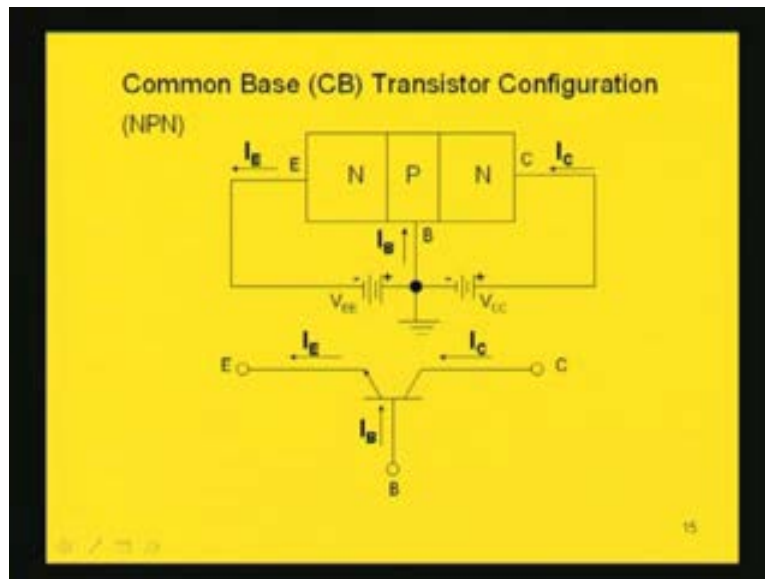


Here this is emitter, this is base and this is collector. Base is common between the input and output circuits. Input circuit is between emitter and base and output circuit is between collector and base. Emitter base junction is forward biased. By this battery V_{EE} , we are forward biasing emitter base junction. Collector base junction is reverse biased. We are reverse biasing the collector base junction by this V_{CC} battery and symbolic representation

of a common base transistor is like this. This is the base, emitter and collector terminal. You note the direction of current flow. It is a PNP transistor that we have taken. So the direction of emitter current will be into the transistor. This is showing the emitter current direction. Base current will be out of the transistor, so this is out. Collector current is out of the transistor, so this is out. I_E incoming is equal to $I_B + I_C$ outgoing.

If we consider NPN common base transistor configuration this is NPN; emitter, base and collector.

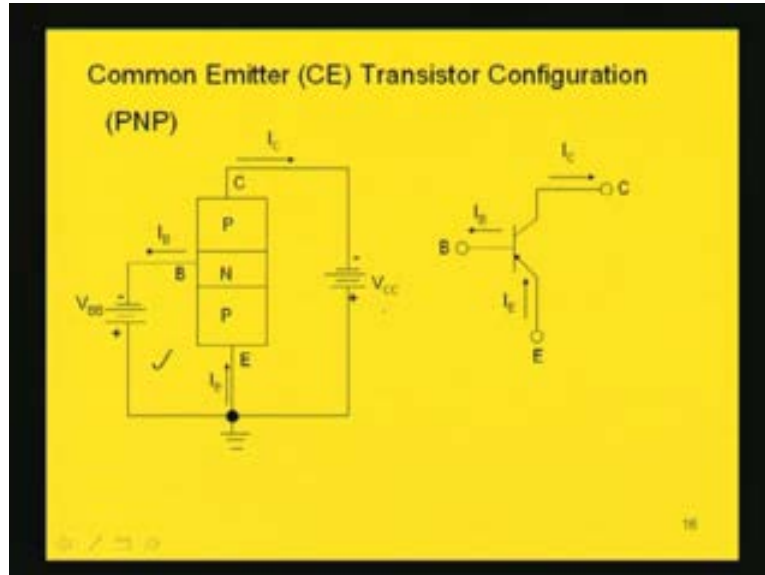
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Forward biasing of this emitter base region is done by this V_{EE} . The polarity you have to note. N is connected to negative, P is connected to positive. Other junction, collector base junction is reverse biased. V_{CC} is reverse biasing, collector being connected to positive this base is connected to negative and base is common which is grounded. Base terminal is grounded in common base transistor. This is the symbolic representation of the common base transistor. Emitter, base, collector and emitter current is going out. Collector current is coming into the transistor and base current is coming into the transistor.

Similarly the common emitter transistor configuration if we see, here the emitter is common to both input and output circuit and it is grounded. Input circuit between emitter and base is this one. This is the input circuit. This is emitter, this is base and this is collector. The forward biasing of this emitter base junction is done by this potential V_{BB} . This N is connected to negative, P is connected to positive, emitter terminal is also grounded and this junction, collector base it is reverse biased by V_{CC} potential.

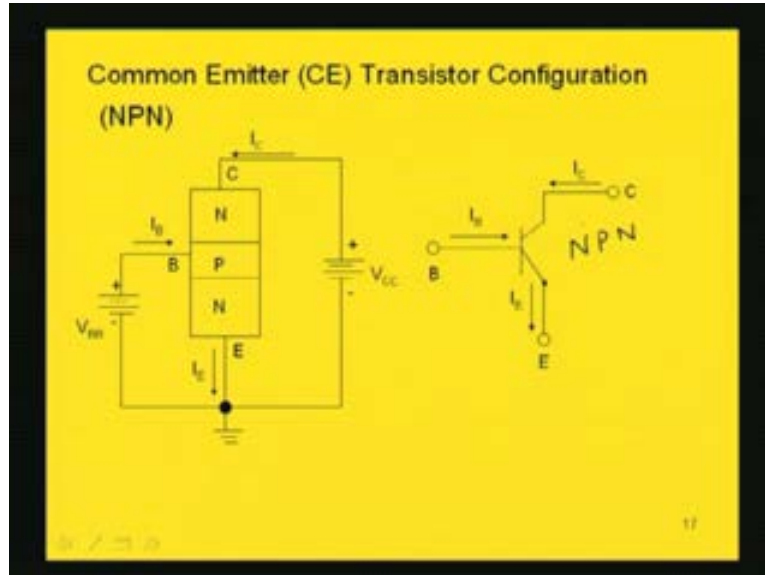
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This P is connected to negative and positive is to E, which is grounded and direction of currents if we see in this common emitter transistor configuration using PNP transistor, emitter current will be into the transistor because it is flowing in this direction. Base current will be out of the transistor. It is entering the negative terminal. Collector current will be entering this negative terminal V_{CC} means out of the transistor. Symbolic representation is like this. Emitter terminal is here, base, collector and it is a PNP transistor. Emitter current direction is into the transistor and the current directions of these three terminals if you see I_E is into the transistor, I_B is out, I_C is out and this is the representation for common emitter PNP transistor.

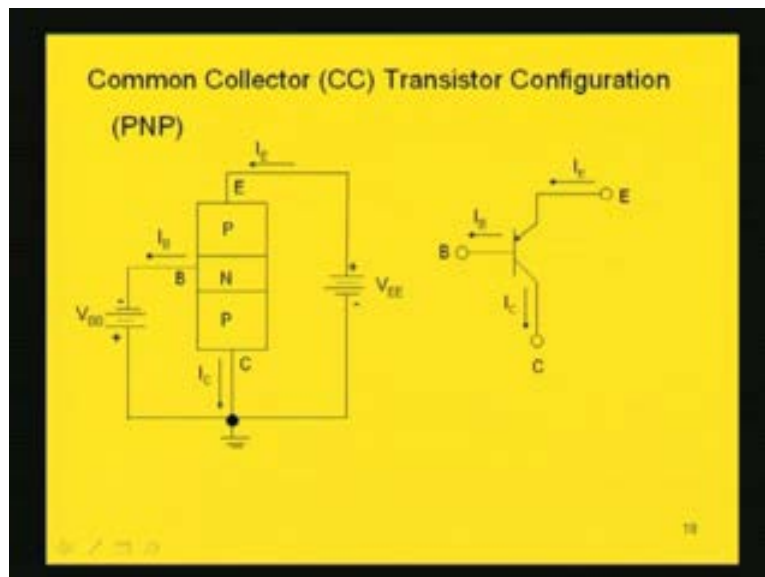
Similarly in the common emitter NPN transistor, the base emitter junction should be forward biased. It is NPN. So this N is connected to negative, P is connected to positive so that this region, emitter base is forward biased and collector base is reverse biased. It is done by V_{CC} . Positive is connected to N, negative is grounded and connected to emitter. The symbolic representation of common emitter transistor using NPN configuration is this. Here the direction of the arrow in the emitter will be outwards. It is NPN. We have this emitter current coming out. This is N, this is P, this is N and base current and collector current are with these directions. Base and collector current will be flowing into the transistor. This is your NPN transistor.

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Another configuration is there which is only used for certain applications not very commonly like for impedance matching it is used that is common collector configuration. In common collector configuration collector is common to both the input and output circuits. If we see the common collector transistor configuration utilizing PNP transistor it is like this.

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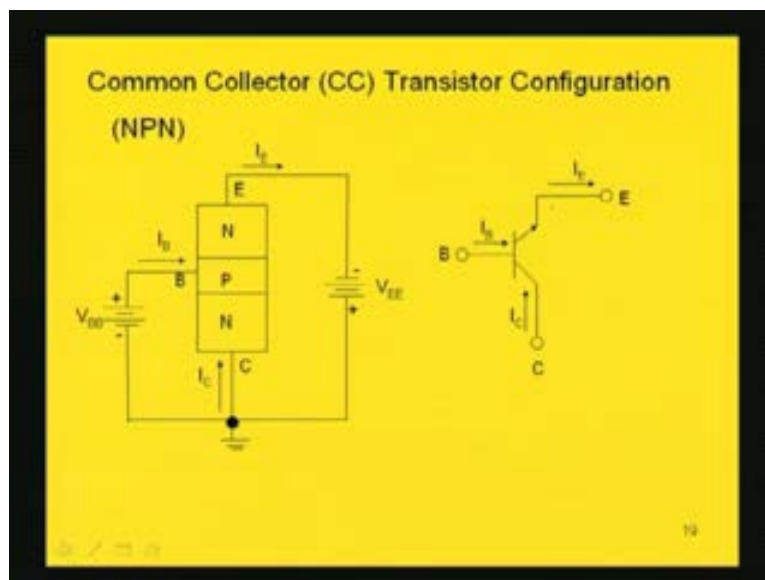


Your emitter base collector is this one. Emitter base junction is to be forward biased and collector base junction is to be reverse biased. That is done by this V_{BB} and V_{EE} batteries. This is your P, this is N. This is connected to positive terminal. Here this base is

connected to negative terminal. P is at higher potential than N. Similarly this collector base junction will be reverse biased, collector is grounded. This is the junction between collector and base. It will be reverse biased. The symbolic representation is this one. Here this is emitter, base and collector. This is the direction of the emitter current. Since it is PNP, it will be into the transistor and these are the collector and base terminals and base current and collector current will be outwards and emitter current will be into the transistor.

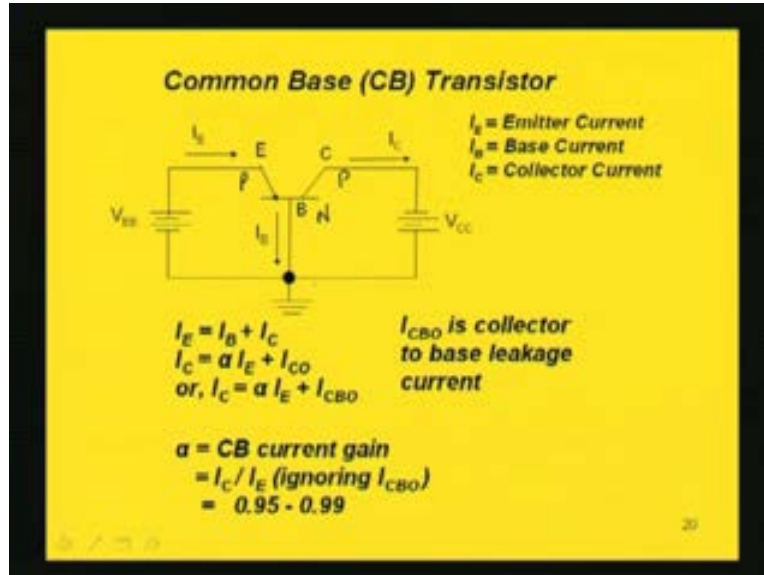
Similarly if we consider NPN configuration of common collector transistor you have the symbolic representation showing the emitter current out of the transistor. That is this one, out of the transistor and base and collector currents are into the transistor.

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This is the NPN representation of the common collector transistor configuration. Here forward biasing has to be done between emitter and base junction and it is N and P respectively. So N will be connected to negative, P is connected positive and collector base junction is reverse biased. This junction between this N and P will be reverse biased by this configuration. Here collector is grounded. Common base transistor has this configuration. If we look into the three currents emitter current, base current and collector current in a PNP transistor configuration, this is P, this is N, this is P; into the transistor is shown the emitter current direction. V_{EE} is forward biasing emitter base junction and collector base junction is reverse biased by this V_{CC} with this polarities. This V is connected to negative of the V_{CC} and base is grounded.

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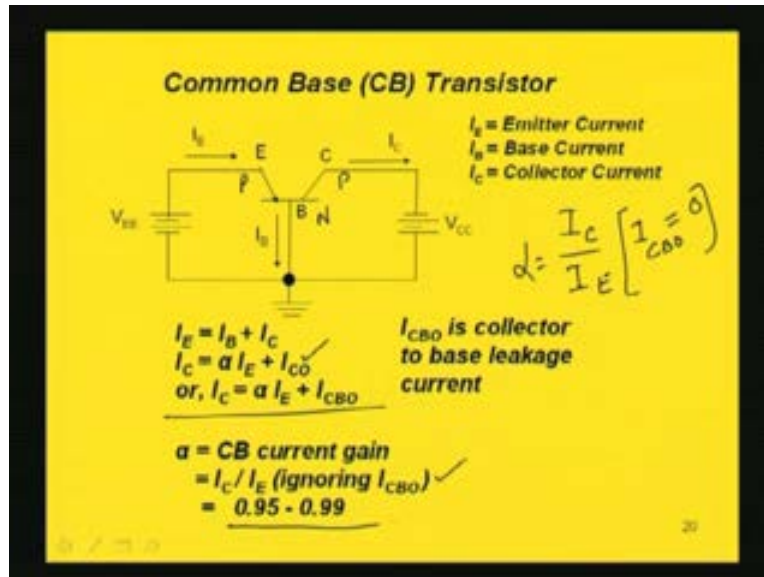


We will be discussing common base transistor in details. First we again have to recall the key equations to go any further. First equation is the Kirchoff's current law equation that we already have seen and it's valid for transistors also. I_E equal to $I_B + I_C$ is the Kirchoff's current law. Another equation we have got I_C equal to alpha times I_E plus I_{CO} . If we discuss common base transistor let us name a particular representation for I_{CO} which is given by I_{CBO} . I_{CBO} is the collector to base leakage current. Instead of writing CO, which is also reverse saturation current, same reverse saturation current that we are discussing we will be considering common base transistor going into its characteristic. So we will name that reverse saturation current by CBO. Basically it means collector to base current when emitter is open.

If we open circuit this emitter base junction that is if we open circuit input junction between emitter and base what will happen? There is no emitter current since it is open circuit. That means it is not forward biased. There will be no emitter current but still there will be a current flowing in the collector which is only due to the minority carriers, the reverse saturation current. See this equation. Alpha times I_E plus I_{CO} is I_C . Alpha times I_E will be zero when you open circuit the input but still there will be a current in the collector. Though it may be small in magnitude but still there is a current. Which current is it? It is reverse saturation current I_{CO} . That current let us name it by I_{CBO} , collector to base current when emitter is open. To name the reverse saturation current we have coined another representation name I_{CBO} . This is the equation for this collector current in a common base transistor I_C equal to alpha times $I_E + I_{CBO}$. If we know alpha, that is the current amplification factor for common base transistor it is called and alpha is I_C by I_E , if we ignore this I_{CBO} totally. I_{CBO} is very small and in active mode of operation it is so small that we can neglect it or ignore it and write down the collector current representation as alpha times I_E only. Then alpha will be equal to I_C by I_E neglecting I_{CBO} . That is make I_{CBO} zero. This is almost practically valid. We are ignoring it since it is very small and alpha is equal to I_C by I_E . This is a very important factor. For common base

transistor configuration alpha is the factor which gives you the relation between the collector current and the emitter current and that value of this alpha is typically 0.95 to 0.99. That is maximum 95% of the emitter current can be the current which will be flowing in the collector.

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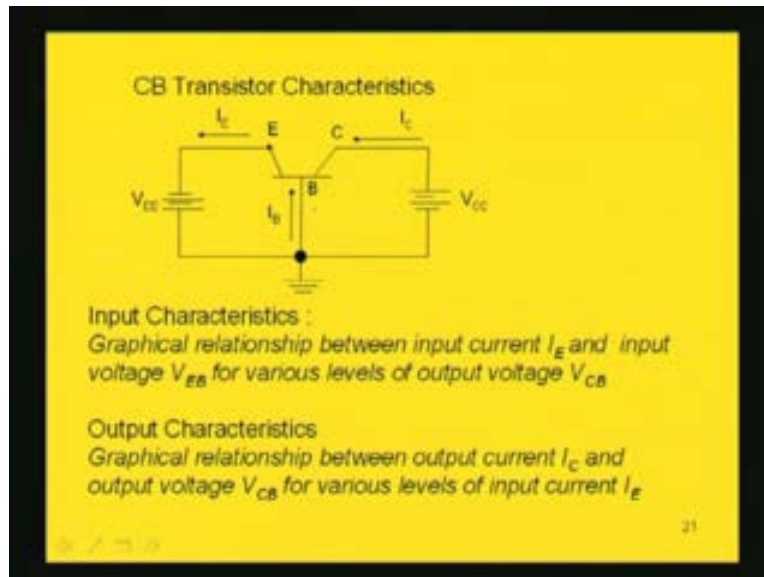


That is 5% recombination has taken place in the base region. If 5% recombination takes place in the base region then the rest 95% or 0.95 times I_E will be I_C . That means 0.05 times I_E will be I_B . Base current will be point 0.05, only 5% of the emitter current. That is the maximum recombination and minimum recombination is the value of 0.99. That is 99% of the injected carriers from emitter reach the collector. Only 1% is recombined. That is the limiting value. Maximum and minimum values are like this and theoretically we can say if no base current flows that means almost zero recombination takes place then I_C will be ideally equal to I_E ; if there is theoretically no recombination in the base region. But that is not true practically. We will be having some recombination. Although the magnitude may be very small still we will be having recombination current in the base region. That is why base current flows. This is the common base transistor configuration.

In order to know about the common base transistor configuration, we must first know what are the characteristics of the transistor? By characteristic I mean the graphical representation of the input and output. That is input is nothing but the forward biased diode. That is the diode between emitter and base. Input characteristic if we consider that is typically the characteristic of forward biased diode and output characteristic if we consider the output characteristic is nothing but the characteristic between the output current and output voltage. That is output can be I_C , this collector current and the output voltage is collector to base voltage. There is family of curves that can be drawn representing the input characteristic as well as output characteristic. Input characteristic will be the graphical relationship between input current I_E and input voltage be V_{EB} for

various levels of output voltage V_{CB} . If we change V_{CB} that is collector to base voltage there will be an effect on the input characteristic; that we will have to see.

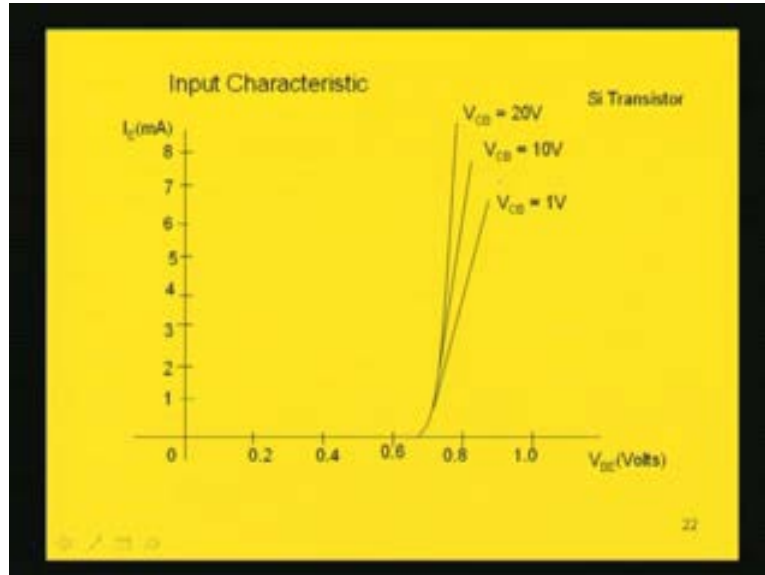
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That is we can draw the input characteristic easily because it is nothing but the forward bias characteristic. That is the relationship between I_E and V_{EB} . If we go on increasing the forward bias voltage after overcoming the threshold voltage the current will increase. That we have seen in diode and after that point it will be almost linear. That characteristic is for a particular V_{CB} . But if we now change V_{CB} what is the effect on that input characteristic that also we have to see because there is an effect for change of the V_{CB} on the input characteristic. Similarly the output characteristic is the graphical relationship between the output current I_C and the output voltage V_{CB} for various levels of input current I_E . Output characteristic can be drawn for various levels of I_E , input current and between V_{CB} and I_C . These two characteristics we have to know in detail.

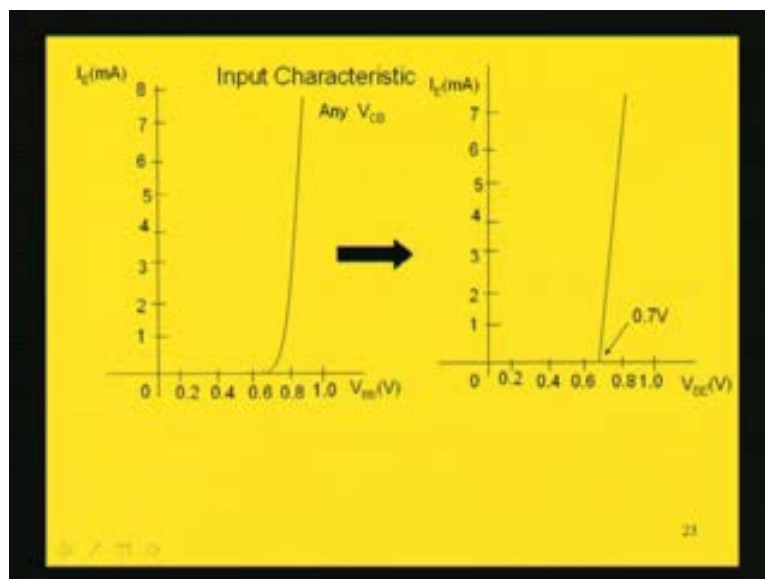
Let us first consider the input characteristic. Input characteristic means we have to plot the graphical representation between I_E and V_{EB} . V_{EB} is the emitter to base voltage or the forward bias voltage and I_E is the emitter current. For this particular transistor configuration, we are taking an NPN transistor; mind it, this is an NPN transistor. In the common base characteristic we are having an NPN transistor. This is N, this is P and this is N. This is denoted by this arrow mark in the emitter current. It is going out of the transistor. This forward biasing of this base emitter region that is E is at lower potential than B. This is N, this is P, this N. We will be plotting I versus V_{BE} that is base emitter voltage because base is at higher potential than emitter, so that will be reflected here. We plot I_E versus V_{BE} . Now go on varying V_{BE} . You recall that in a diode we have seen explicitly that up to around 0.7 volt for silicon the current flowing in the diode will be practically zero and after 0.7 that is after overcoming the threshold voltage only current will rise sharply. Here that is followed. These are for various V_{CB} curves.

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Why this is happening? If we vary V_{CB} , the curves are shifting towards left. That we will be explaining. But before that suppose for a particular V_{CB} 20 volt if we consider then we see this particular graph up to around 0.7 volt current is zero and then it is almost linearly increasing. This is the diode characteristic. What we can infer from this is that up to 0.7 volt current is zero means we can represent the forward bias diode by its equivalent model which is nothing but the linear approximation that is by this curve.

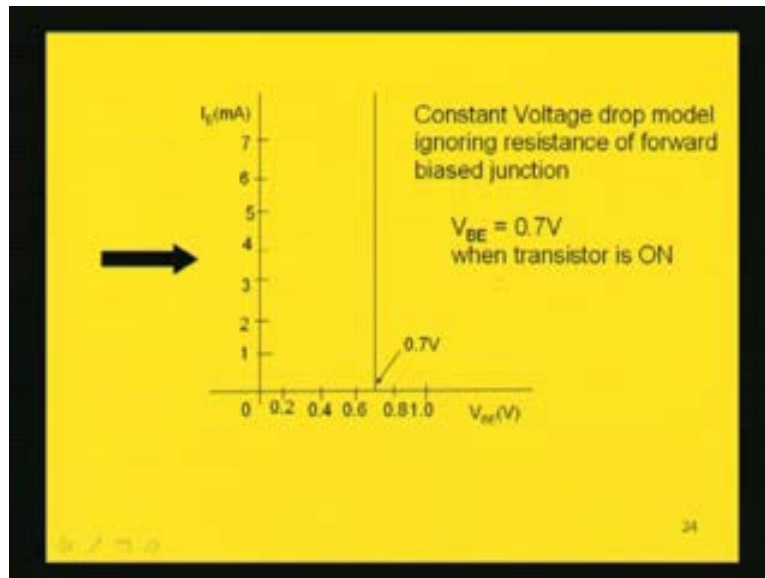
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That is input characteristic can be approximated by this linear characteristic having the current value zero up to 0.7 volt which is the threshold voltage and then it is linearly

increasing. This is piecewise linear characteristic or piecewise linear equivalent model for this forward bias junction of the transistor. For a particular V_{CB} we are having say this model which can further be approximated by the constant voltage drop model without violation because the constant voltage drop model means 0.7 volt drop in the diode that is in the forward bias junction of the transistor. As soon as the transistor is forward biased and the input current is rising we can approximately model it by 0.7 volt.

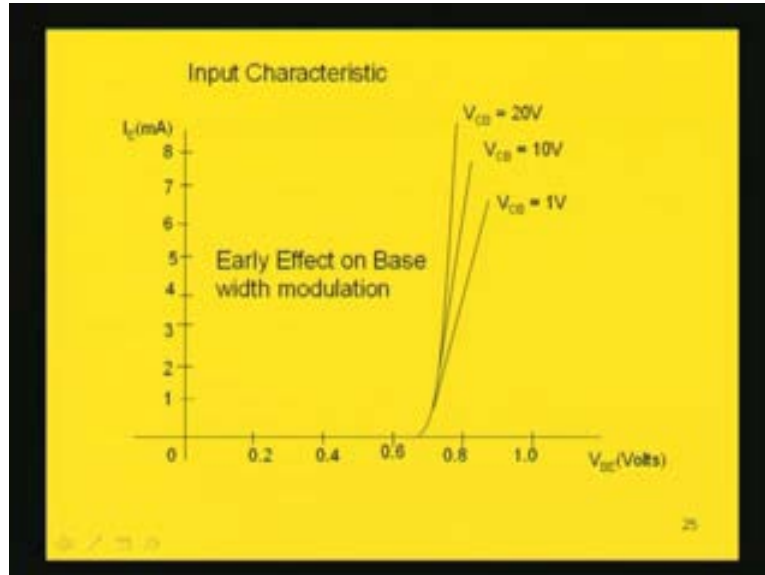
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The transistor is ON means it is forward biased sufficiently to overcome the threshold voltage and once it is ON the transistor will have a forward drop of 0.7 volt. For all practical purposes and in our analysis also mostly we will be adhering to this type of a characteristic that is the forward biased region will be approximated by 0.7 volt constant drop model. In this constant drop model we will be ignoring the forward resistance which is very small in the forward bias junction. That is why we can neglect it effectively. This input characteristic we will be approximating. When the transistor is ON always we will be considering the drop in the forward bias region V_{BE} to be 0.7 volt. This is the constant voltage drop we will be considering.

The input characteristic will be different if we go on increasing the V_{CB} . It will be shifting left means for the same V_{BE} we will be getting higher input current I_E . That is because of an effect known as early effect.

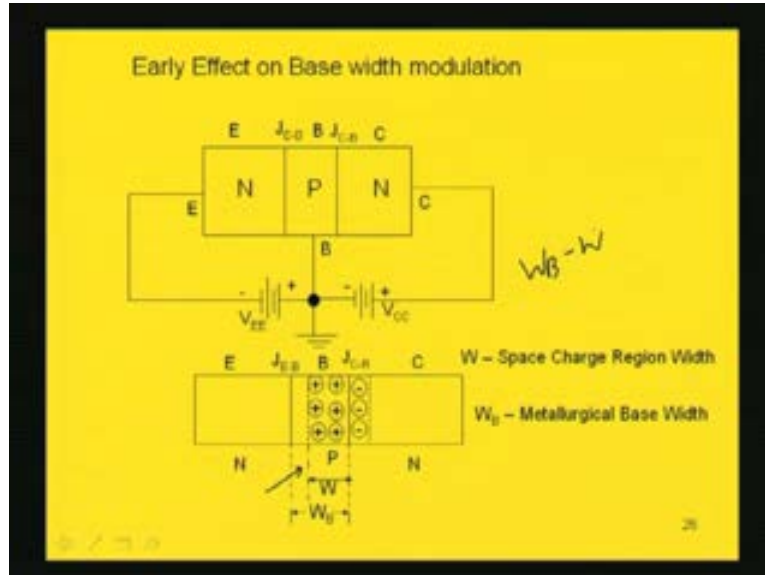
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Early effect is basically the modulation of the base width when you increase the reverse bias potential. If we go on increasing the reverse bias potential what will happen is that considering base width of this transistor basically there are two junctions. One is the forward bias, one is the reverse bias. But then this base is lightly doped. Reverse bias junction mainly or practically penetrates into the base region more than the collector region because the base region is lightly doped and so it will penetrate more. This space charge region will be penetrating more into the base region than the collector region. Mostly the space charge region will be in the base region. If we increase the V_{CB} what will happen is that the space charge region will be increasing.

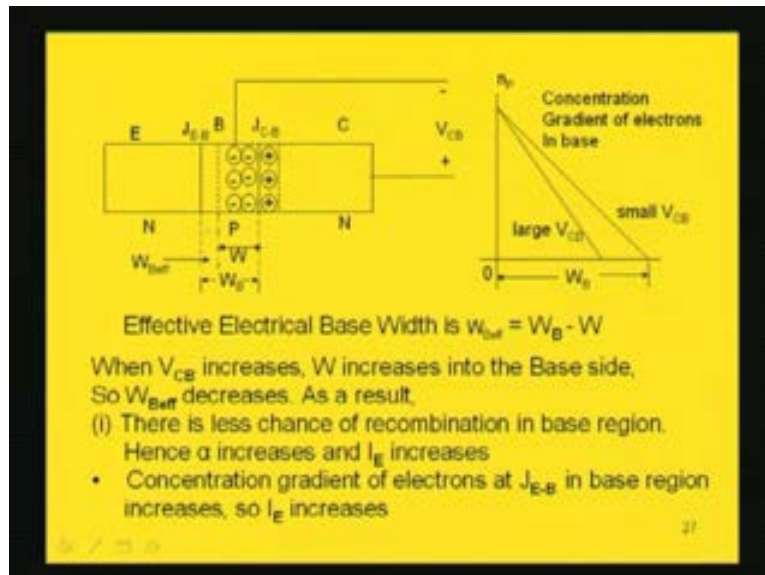
If we represent the metallurgical base width by W_B and the space charge region by W then this region is basically the region where recombination can take place and that is $W_B - W$.

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The effective electrical base width, W_B effective is $W_B - W$. Here the recombination can take place.

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When the collector base voltage increases this W will be more and more, so this W_B effective will be lesser and lesser. There will lesser and lesser region available as a result of which there will be lesser recombination in the base region. Since there is less space available for recombination the alpha value will be increasing. Alpha value will increase because of less recombination. Alpha value increases means this I_E also increases. This alpha will be increasing and when alpha increases what will be the effect? That we will

get again in the output characteristic but another consequence of this early effect is that this W_B that is base width is reducing. The concentration gradient of the minority carriers in the base region will be increasing. For a small V_{CB} this is the concentration gradient of the minority carriers which are holes in the base region. We are considering NPN transistor. If this region is smaller then concentration gradient is more. That means more steeper will be the concentration gradient.

As the concentration gradient is more there will be injection of more majority carriers from the emitter to the base because the diffusion takes place depending on the concentration gradient at the base region. If this concentration gradient is more we will be getting more diffusion of majority carriers from the emitter which means more emitter current. The emitter current will be more and that is why we will be getting more emitter current when you have increased reverse bias voltage. That means for increased reverse bias voltage for the same V_{EB} we will be getting a higher emitter current. That is why the curves are shifting to the left means for the same V_{EB} we are getting higher I_E . That is due to the early effect.

We have seen that the common base transistor configuration input characteristic will be like a diode characteristic in the forward biased condition but there is an effect of the reverse bias voltage also. If we gone on increasing the reverse bias voltage, we will be getting higher and higher emitter current for the same V_{EB} .