Microelectronics: Devices to Circuits
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Lecture No 05
BJT: Operation in Active Mode Circuit Symbol and Conventions - I

Hello everybody and welcome to the NPTEL online certification on Microelectronics: Devices to Circuits. We continue with the lecture which we had done in the previous turn and that is Operation in active mode. We will look at circuit symbols and certain conventions. In our previous discussion or interactions we had seen that we were able to understand the basic fundamental principles for functioning of a BJT.

We have also seen how a BJT works in a forward active mode. What we will be looking today is basically the common emitter configuration. What we will be looking today is basically common emitter configuration of a BJT and also known as emitter grounded configuration or common emitter configuration, right and what we do in this case is that if you and that is what you can see on this diagram here on this diagram here.

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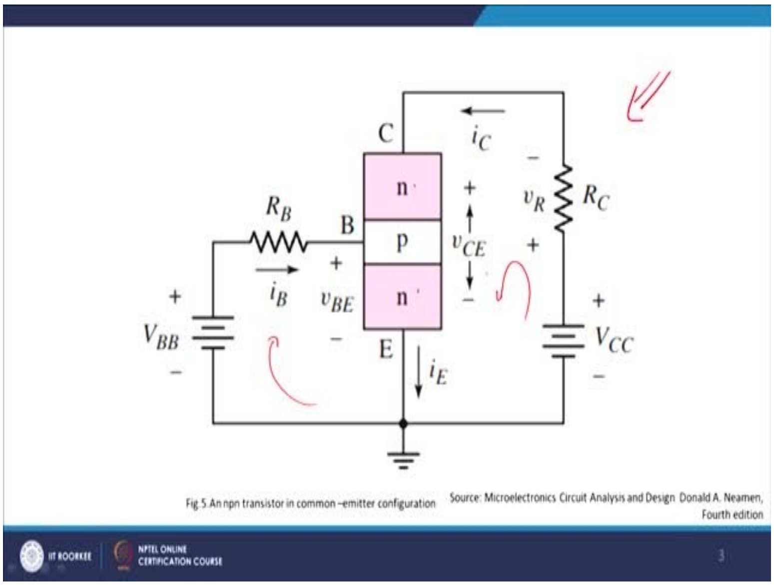

I will make it a much better diagram from the point of view of understanding which is this one, right. So I have an NPN transistor, I have a BJT and I have my base emitter junction forward biased, right and my collector base junction to be as reverse biased this one right.

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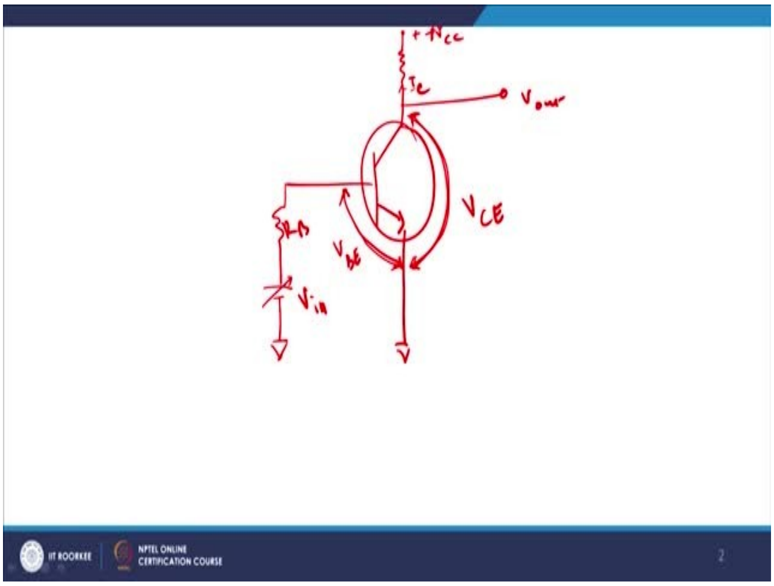

So let me just draw for you from the circuit point of view, right and let us see a common emitter configuration works in a sense in this case. So I have an RC here I have a base resistance R_B here and since this is NPN so I can just do like this, right and we can vary this one to a larger extent and maybe I can reverse maybe I can fix the value of voltage $+V_{CC}$ here. And we will try to take the value of V_{out} from this place particular place, right.

And this is R_B and this is my V_{in} and it is varying and I want to take out the output from this end and this is the collector current which is flowing here I_C. Now if you be so this is my V_{BE} base to emitter equals to input voltage and this is also referred to as V_{CE} collector to emitter voltage, right. So I have got V_{CE} here I have got V_{BE} here and I have got $+ V_{CC}$ which is ruling here.

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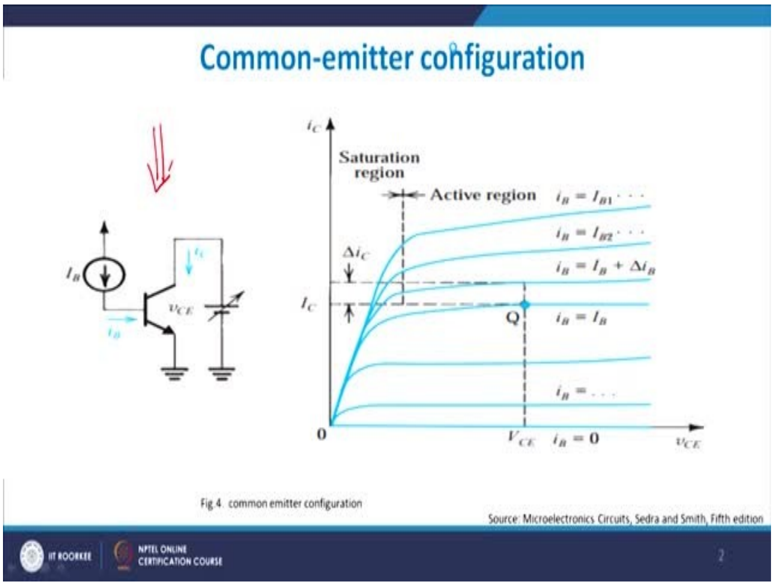

If you go back to the previous slide therefore you see that if you plot I_C versus V_{CE}.

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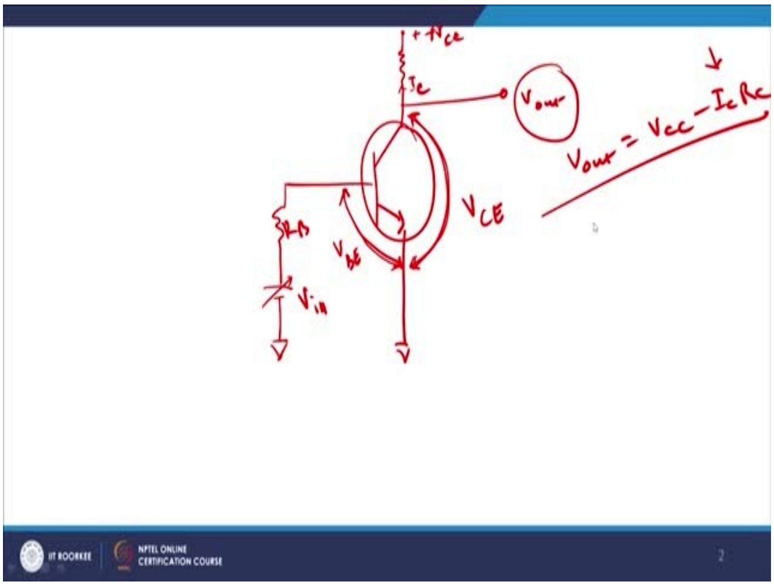

So let me plot IC which is the collector current versus V_{CE} which is this potential here right. This potential here is nothing but the value of V_{out} if you look very carefully this is nothing but the V_{out} which you see from here. So V_{out} if you find out will be equals to V_{CC} - $I_C R_C$. So if you can find out how I_C varies with V_{CE}, I can predict how my V_{out} will vary with V_{CC}. And this is straightforward linear relationship is there which is available with us.

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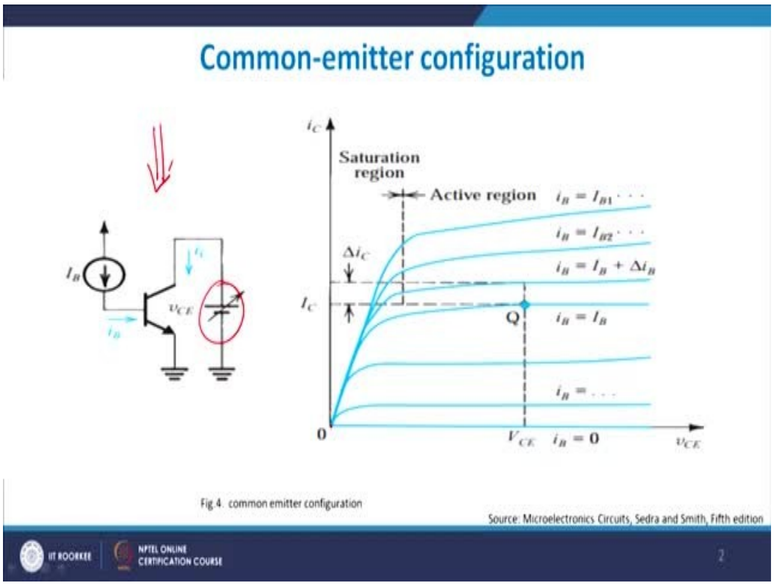

Now if you look very carefully here, when V_{CE} was equals to 0, right I had 0 current which is expected also the collector current was 0. And if V_{CE} is equals to 0 the collector to emitter voltage is 0 then I would expect to see 0 current available to me.

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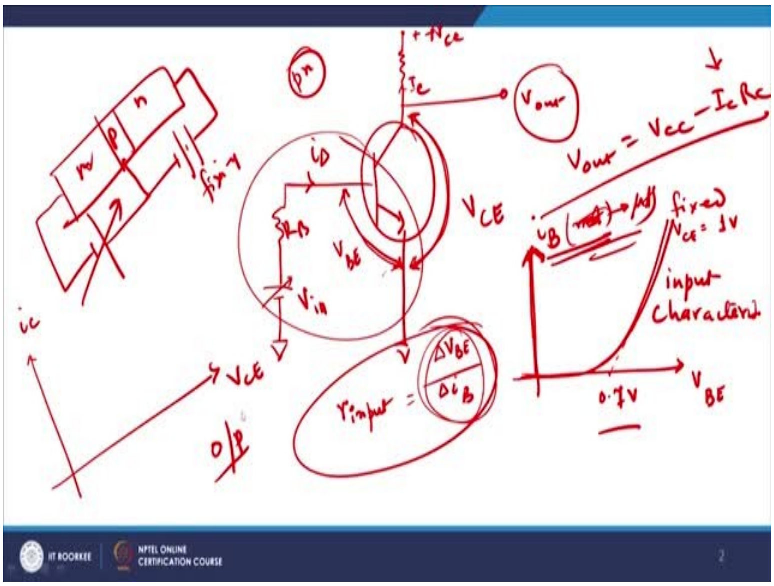

Quite interestingly let me also show to you if I want to plot I_B versus V_{BE} versus I_B, this is also known as input characteristics. So base current I_B versus V_{BE}, right for a fixed value of V_{CE}, right. So my V_{CE} is fixed V_{CE} I vary V_{BE} and try to take the value of I_B, right. So if you look very carefully for a fixed value of V_{CE} this starts so this starts to behave like a PN junction diode so in a forward bias condition.

So forward bias condition you very well know that it looks something like this for a fixed value of V_C so V_{CE} is equal to say 1 volt or 5 volts or whatever. And if you revert it backward it will be approximately equal to 0.7 volts which you see, right. And this will be your current which will be flowing because that is how the current in a PN junction diode forward biased characteristics looks like, right. If you go on varying the value of V_{CE} make the V_{CE} larger I would expect to see a larger current to flow in this case, right.

V_{CE} larger means large current will start to flow with the same value of so it will not be like this it will be something like this, right. It will be something like this which you will be seeing, fine. So this results in an understanding of input characteristics. Now if you want to find out the forward resistance of the PN junction diode then resistance will be ∂V_{BE} upon ∂I_B will be defined as input resistance of the R_{input} of the NPN transistor.

So it means that the V_{CE} is fixed so if you look very carefully my NPN this I am forward biasing it and this I am reverse biasing it, right. And I am fixing this one but now I am varying this one varying this one and I will get a profile something like this I will get a profile. As a result what will happen is that this profile will lead to a fact that this this implies that that if I want to find out the resistance offered $\partial V_{BE}/\partial I_B$ and it will be order of few ohms because is an on state resistance of the diode and it will be of the order of few ohms which is there this current will be of the order of few milliamperes to microamperes range of current will be there.

Very small current will be there microamperes range current will be there and that is what is what you get from this. So this is known as the input characteristics of the bipolar transistor right input characteristics of a transistor. Now if you want to plot therefore I_C versus V_{CE} also known as the output characteristic which is already plotted here in this region.

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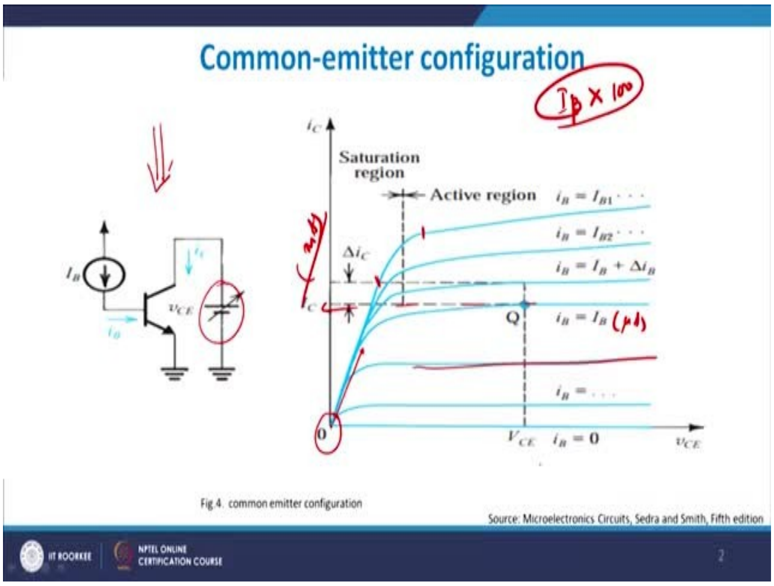

And I can explain to you what it happens. So for a fixed value of I_B your I_B is fix how I_B is fixed because your V_{BE} is fixed. So what we have done now is that rather than changing V_{CE} or V_{CB} we are changing we are fixing V_{BE} and therefore my I_B is fixed when my I_B is fixed I vary V_{CE} and try to get the value of I_C. So I try to get the value of try to get the variation of collector current with respect to collector to base voltage or voltage which is available with me.

Now when my therefore V_{CE} equals to 0, right my collector current will also be equal to 0. And the reason is that when my V_{CE} is equal to 0 there is no electric field on the collector side to accept the electrons which are coming from the emitter side. So even if there is a base current or even if there is a emitter current available all the emitter current is either going to the base because you do not have any potential on the collector side to accept the charge carriers and therefore the current is 0 and that is the reason the current is 0 for V_{CE} equals to 0.

As you start to increase your V_{CE} the current starts to rise and therefore you see a linear increase in the value of current, right there is a linear increase in the current. As you make your V_{CE} larger and larger there is a linear region and then you enter into a non-linear region of operation of the V_{CE} current increases because more and more charge carriers from the emitter side passing through the base side is collected by the collector. And a time comes when you will approximately get a straight line here for a fixed value of I_B.

Currently meaning that it starts to behave like an ideal current source and therefore the collector current is almost independent of value of voltage across the collector to emitter voltage and it has got a fixed value with respect to the output current. So what we do is now if we go on increasing the current I_B current by changing the value of V_{BE} of course the collector current will also change, right. And the collector current will change by how much. So this will be in microamperes, right I_B whereas this will be in milliamperes the collector current will be in milliamperes because you multiply I_B with a factor known as which is approximately equals to the 100 multiply.

Why do you multiply because the simple reason that your emitter current is equal to your collector current, right? Your base current is just very small because of recombination. So whatever is left is basically collector current and therefore the collector current I_C is of the order of few milliamps where the base current is of the order of few microamps. Now if you look very carefully the region which you see in front of you.

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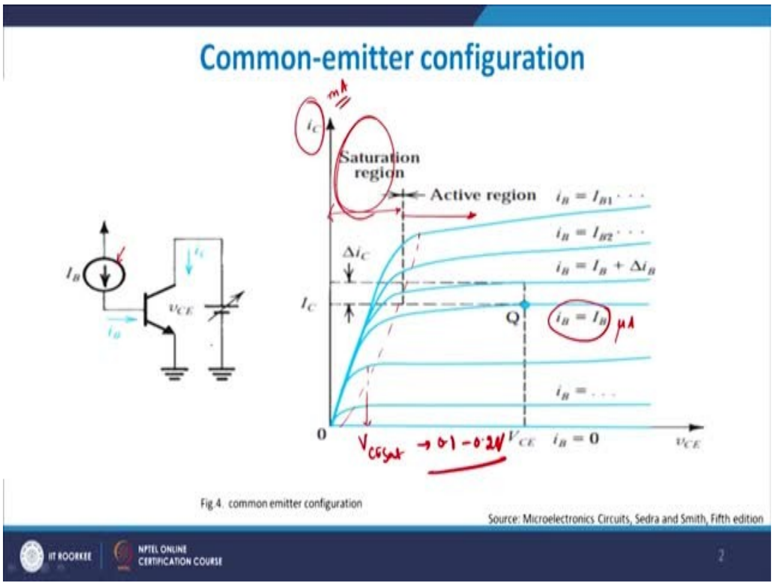

I will just show it to you by discussion here, this region from 0 to approximately this region $V_{CE\ sat}$ this is also referred to as line this is known as this point where the transistor actually saturates is known as $V_{CE\ sat}$. It is typically 0.1 to 0.2 volts is the maximum value of voltage at which the saturation tendency comes into picture. And this region is actually known as the saturation region. This region starting from here to here and beyond that is defined as my active region. Beyond that is defined as my active beyond the $V_{CE\ sat}$ part. This is my active region for the NPN transistor forward active mode so this is the active mode is basically the region.

Now you see in a common emitter configurations let us suppose write in a common emitter configurations this is my emitter now for a fixed base current I get a fixed for example so we have understood two things therefore I have a common emitter configuration I have a saturation region I have an active region, right. Saturation region is the region where the output current will be a linear or non-linear variation depending upon the value of V_{CE}.

$V_{CE\ sat}$ is the saturated collector to emitter voltage beyond which the current will be independent of V_{CE} behaving like a constant current source approximately 0.12 volts will be the approximate value of the current technology. Also if you look very carefully that you have this I_B value of the order of few microamperes whereas this collector current is of the order of few milliamperes. And that you need to find out or you need to know this basic fundamental principle.

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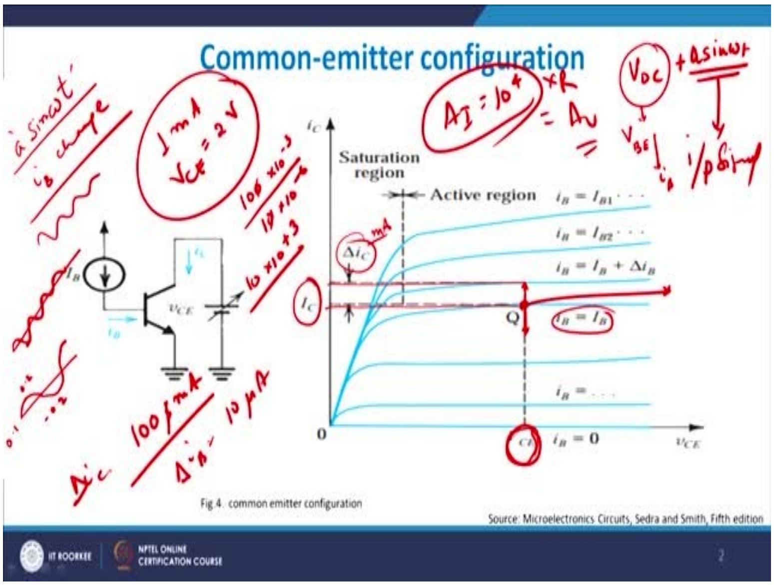

Now let us look at one small point before we move forward that in fact evenly, even without doing any drastic mathematical formulation I can show to you that we are actually indeed doing a small amount of amplification here. And how the amplification is done I can just show it to you roughly by this diagram only.

You see you generally apply the signal to the base side right. Now for achieving amplification in a common emitter configuration for any configuration. The device should be initially biased in the active region of the operation of the device. If it is not, your amplification will be a non-linear amplification, right. In the emitter in the active region only you will automatically get a very linear A_V. So A_V or the voltage gain will not be a function of the input voltage or the output voltage.

It will be fixed if you bias your device in active region therefore what you generally, what generally people do is they apply first of all a DC bias. A DC V_{BE} and a DC V_{CE} such that the device is biased in this Q point this Q so this is the value of V_{CE} and this is the value of I_C. So I know the value of I_C as 1 milliamp and V_{CE} as say 2 volts, right. I just take up a circuit. This value of V_{CE} and this value of 1 milliamp we get and then we bias it by an external DC source.

Now this DC source will not change across the experiment it will still remain the same it will just help you to bias the device in an region or place the device in a region where amplification is possible and not only possible but it will give you a linear amplification independent of the input voltage. Once you have fixed the DC bias super imposed on that you will have to give your AC bias, right. So what you do is you first insert a DC bias V_{DC} and then add to it *ASinwT*. This is your input signal fine.

So what will happen I will tell you what will happen? So I have a V_{DC} because of V_{DC} which is basically V_{BE}, right I will have a fixed value of I_B. So let us suppose this is the value of I_B which I am getting. This is the value of I_B which I am inserting and I am fixing the value of here. Corresponding to this my V_{CE} value is already fixed at say 1 volt or 2 volt. Now what I do now I give a signal which is input signal which is *ASinwT* let us suppose.

As a result my current IB, right will also change sinusoidally it will change sinusoidally, right. So I have a DC bias and there will be an AC bias overriding over it which is basically my sinusoidal signal input signal so I will have a sinusoidal input signal. Which means that the current will once it will go from nominal value to a high value and then come down go to the bare minimum low value then again it goes up and again it comes down, goes up, comes down so on and so forth.

Which means that I_B so if your nominal value was say suppose 0.1 and your peak to peak variation is say 0.4 then say 0.1 it goes to 0.2 it again goes to 0.1 and again comes to minus 0.2 let us suppose and then goes up. Let us suppose this is how the variation is. So the peak to peak variation is plus 0.4 and so on and so forth. Which means that this Q point by virtue of the signal being inserted into the base to emitter junction of the NPN common emitter configurations this Q point will shift by 0.2 volts at the top and then go minus 0.2 volt at the bottom in current sorry.

So the base current will go so the Q point will go top and then it will again go at the bottom again it will go at top again it will go at the bottom by application of a principle. But please understand this will give rise to a change in the current which is so much∂ I_C and this is in milliamperes because we just now learnt it. Which means that a microampere change in the current results in a millampere change in the output current.

So the input current changes by let us say 10 micro amp and the output current changes by say 100 millamp. So ∂ I_B is this much and ∂ I_C is this much so if I want to find out the current gain I will get 100 into 10^{-3} divided by 10 into 10^{-6}. So this cancels out 10 into 10^{+3}, right.

So automatically I get a current gain A_I current to be equals to approximated to the power four time increase in current which means that for a small change of approximately 10 microampere peak to peak change if I get a 100 millampere peak to peak change I get 10 to the power four times A_I. This if you multiply with an external resistance R is basically my voltage gain or voltage change which you see fine. So this is what you get as a common emitter mode configuration basic amplification which you see as far as this basic understanding is concerned right. So this is the common emitter configuration as far as the previous discussion which we had as far as concern.

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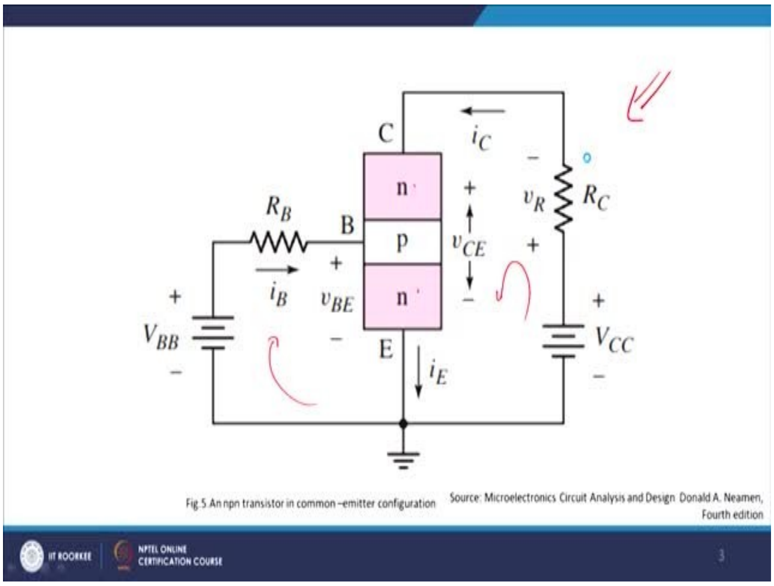

This is the active common emitter mode configuration active source forward active mode configuration with the schematic shown in this figure.

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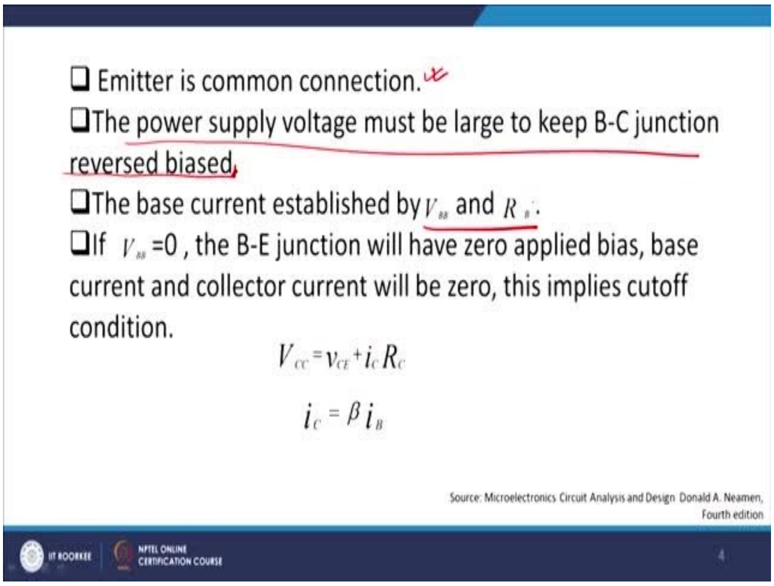

So as I was discussing with you therefore the emitter is common connection between the ground, right. Now I think this is clear to you that the power supply has to be must be large to keep the base collector junction reverse biased, right is it okay? Now the base current is established by V_{BB} and R_B why?

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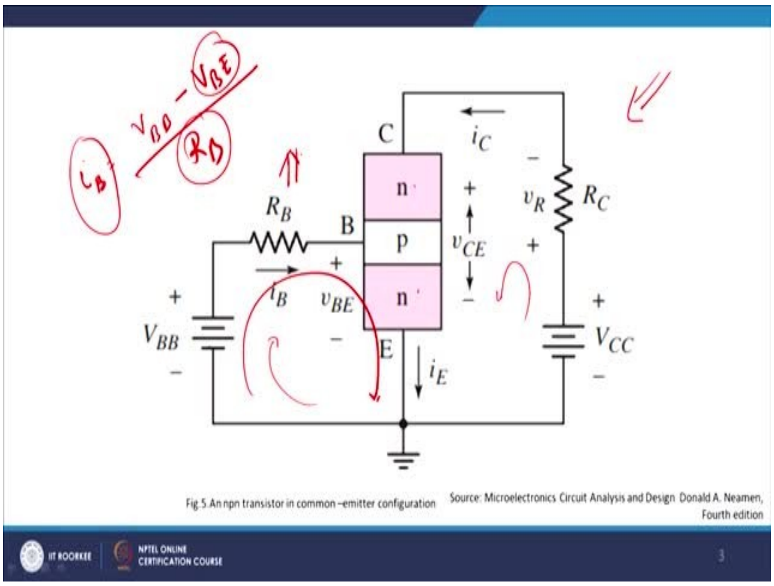

If you look at V_{BB} this is my V_{BB} and this is my R_B right. So I get I_B to be equals to V_{BB}, right, if you go from this side to this side V_{BB} - V_{BE} right base to emitter junction divided by R_B. This is 0.7 this has to be of the order of few kilo-ohms for this to be in the order to few microamp. So this has to be of the order of few large value of voltage has to be R_B has to be typically very large otherwise the base will short out.

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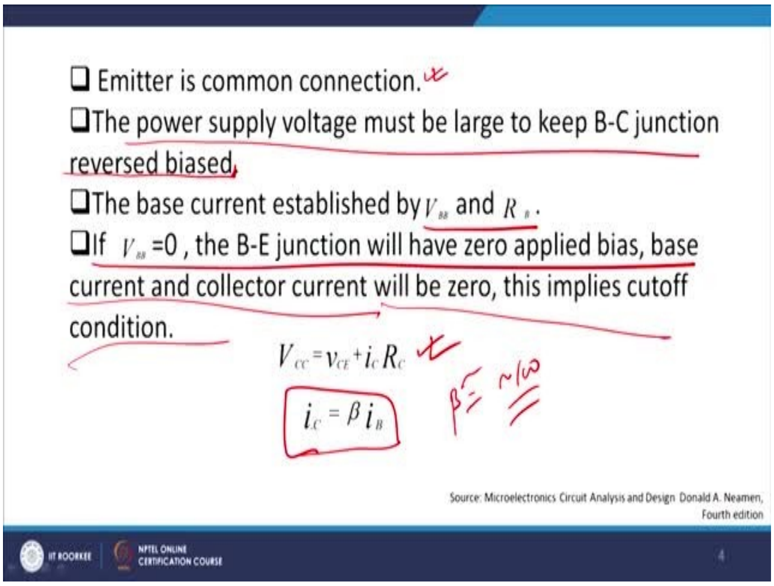

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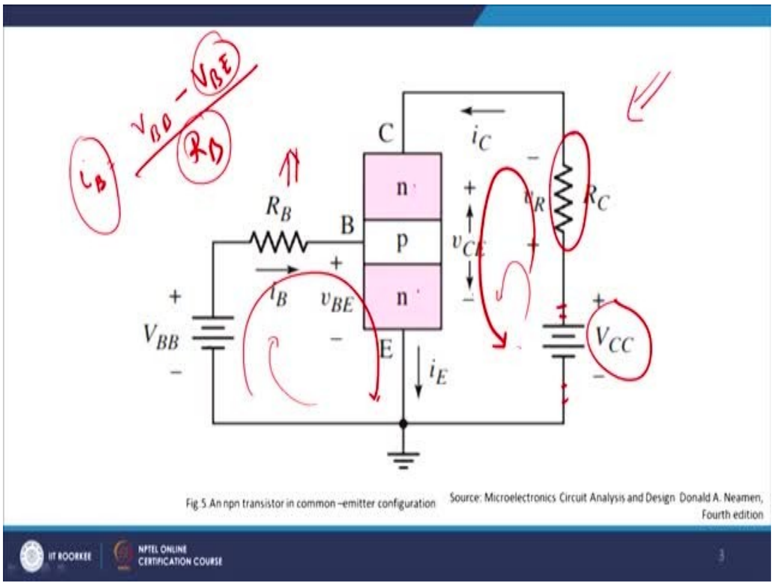

So what we get from here is that yes if V_{BB} is equals to 0 the base emitter junction will have 0 applied bias right. Why it will have 0 applied bias because with V_{BB} equals to 0 effectively your base emitter current if I am assuming it to be ideal one is 0. So 0 minus 0 is 0 and I get no current available to us and therefore your base current and the collector current will all be 0.

And this implies in cut-off condition so which means that if your V_{BE} or V_{BB} is 0 you are not able switch on the transistor and therefore you reached to cut-off condition. In that case we write down V_{CC}, V_{CC} is what may be I use the previous slide. V_{CC} is this one V_{CC} is equals to V_{CE} + I_C R_C we have discussed this point. V_{CE} so if you go by this loop V_{CC} is this is equals to I_C R_C + V_{CE}. I_C R_C is the voltage drop here + V_{CE} and that is what is given by this value.

And we know that I_C is equals to β times I_B right β is of the order of few hundreds of the order of few hundred only and therefore I get I_C equals to β times I_B. And therefore I_B is of the order of few microamperes I would expect to see I_C of the order of few millamperes in this case.

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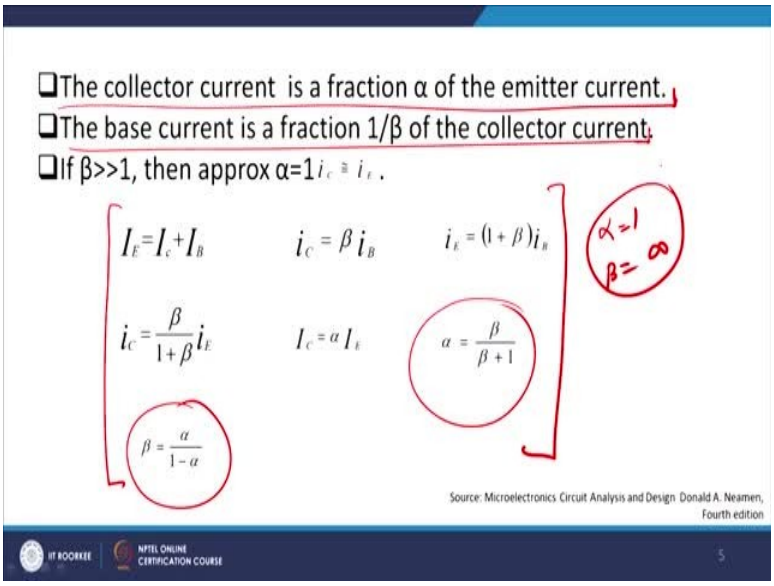

Right and then I was discussing the collector current is therefore is a fraction α of the emitter current. And for α is very close to 1 so if emitter current is 1 millamp you will expect to see collector current very close to 1 millamp because α is very close to 1, right. And the base current is 1 by β of the collector current. This we have already seen just now in this case and these are the few important parameters found in the book also.

Out of which these two are quite important parameters. I will not do a formal derivation here. I will leave an exercise to you that α is equals to β upon β + 1 and β equals to α upon 1 - α. And therefore for α equals to 1 I get β equals to infinity and β equals to infinity. So infinity it will be infinitely high value of β you will get.

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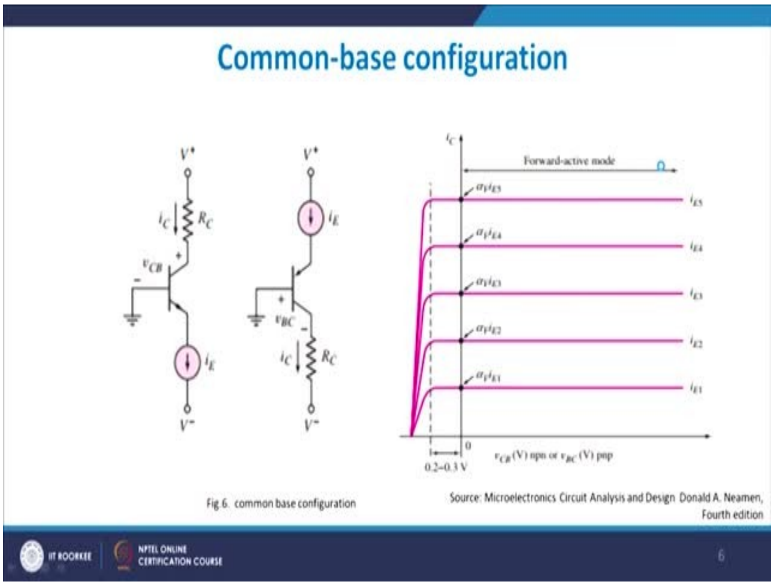

And this is what a typical configuration.

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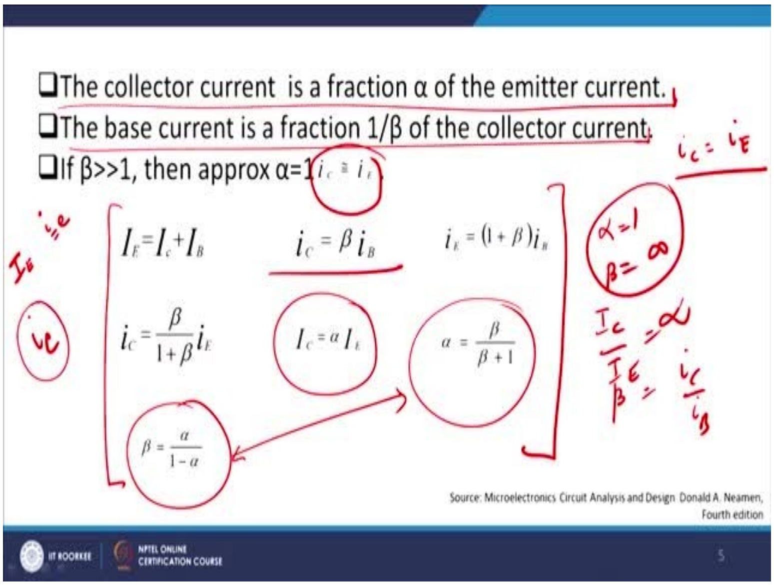

So let me therefore at this stage let me finish off with common emitter configuration understanding. When we meet next time we will start with common base and common collector and that will take care of the effective values here. So what we have learned this lecture is common emitter configuration module and how we can calculate the value of current and basic amplification in a common emitter configuration and we have also learned how I can act as a switch also.

So when β is much larger than 1 then I get approximately α equals to 1 and I get I_C equals to I_E which you can see from here. I get I_C equals to I_E and therefore the collector current is approximately equals to the emitter current. Now the very important certain very important formulae's which is shown in front of in this slide is one is α is how related to β and how β and α are related to each other is like this.

And standard books which you will find you will get the methodology for how you got this α and β from basic Kirchoff's law. And we have also understood that I_C is equals to α times I_E and therefore I_C by I_E is basically equals to α which we have already seen we have seen β to be equals to I_C by I_B for all practical purposes.

So this is what we get from it. Just wanted to make one small important this thing observation before we move forward. That when we refer as capital I there is a difference between capital I and small I, right. Now capital I primarily refers to as DC current so whenever you have DC currents or DC biases we refer this to be as capital I, and small i is generally referred to the case when you have got AC currents.

Similarly if you have got subscripts as capital and subscript as small then when subscript is capital you are going to get DC bias and small means you are doing a transient analysis, right. So you should be very careful when you use these, so if I have got I and C which is this case it primarily means that I am using an AC analysis small signal AC analysis but I am trying to find out the total current flowing through the circuitry. So I have got therefore this notation is quite important in terms of understanding this basic principle.

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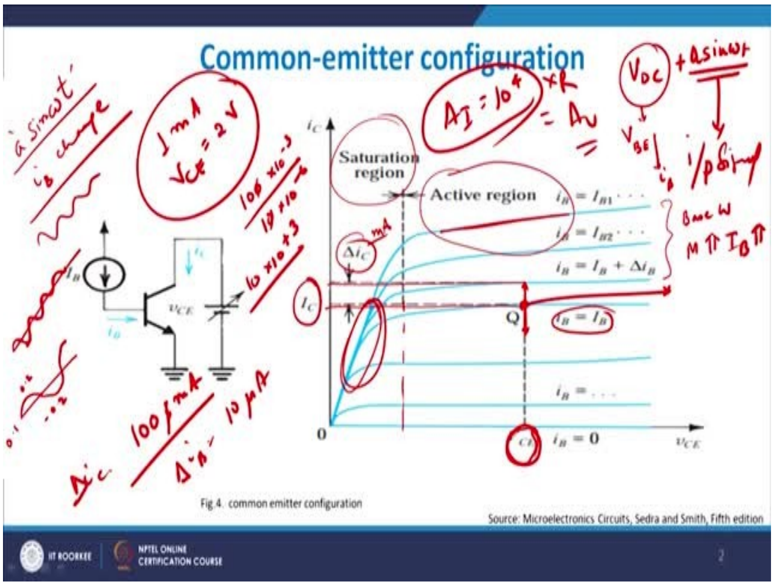

What we also learned in the previous slides or previous discussion is two important points that if you look at this graph once again if you see then at least for the higher values of I_B your base width modulation is very-very large, right. So your base width modulation is quite large for large values of I_B. So when I_B is low you generally do not see or even your V_{BE} is low you do not see large amount of base width modulation. But you see a large amount of base width modulation when you have larger value of I_B effectively with you.

The second thing which you can see is that in the saturation region, right, the resistance offered is typically relatively low whereas in the active region the resistance offered is relatively very high, right. Resistance offered by the device is very-very high. And that has to do of course with understanding that during the saturation region which is the just before the $V_{CE\ sat}$ we end up having the device is just going to the ON state.

Please understand various books and various sources give you different regions some of the books also give you this region to be as the saturation region and this region to be as the active region. But we will follow the same trend for all our subsequent lectures. And we will assume that the active region is the region where you should bias the device in order to use it as an amplifier, right. And this is the active biasing which you should do in this case.

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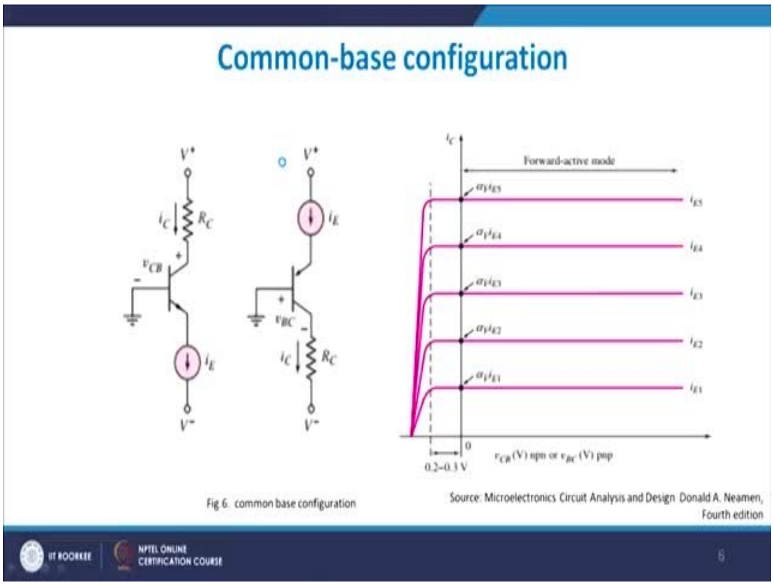

We come to the next important configuration and that is known as common base configurations. And in common base configurations maybe I will just show you here, maybe I can just show you here. Okay I do not have it in that sense but I can show you here in a common base configuration how it works out.

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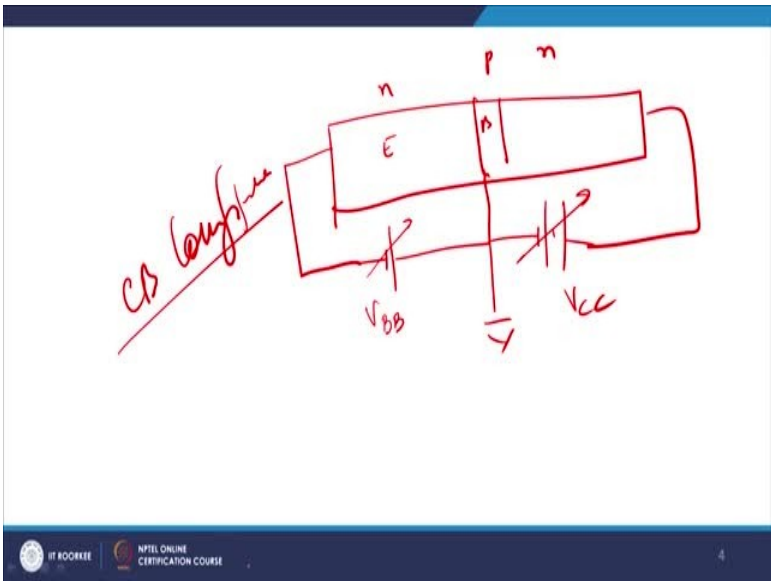

So common base means the base is common between the emitter and collector. So if I have an NPN and this I have been doing for quite often now that this emitter base will therefore be forward biased right and therefore this will be also this will be reverse biased in the sense. And therefore this will be this will be like this, right.

So this is the common base common base CB configuration common base configuration which you see. And as you can see we have already discussed this time and often. This is V_{BB} let us suppose and this is V_{CC} and you can vary both of them and so on and so forth. And you can get you can get large amount of characteristics out of it from this characteristics.

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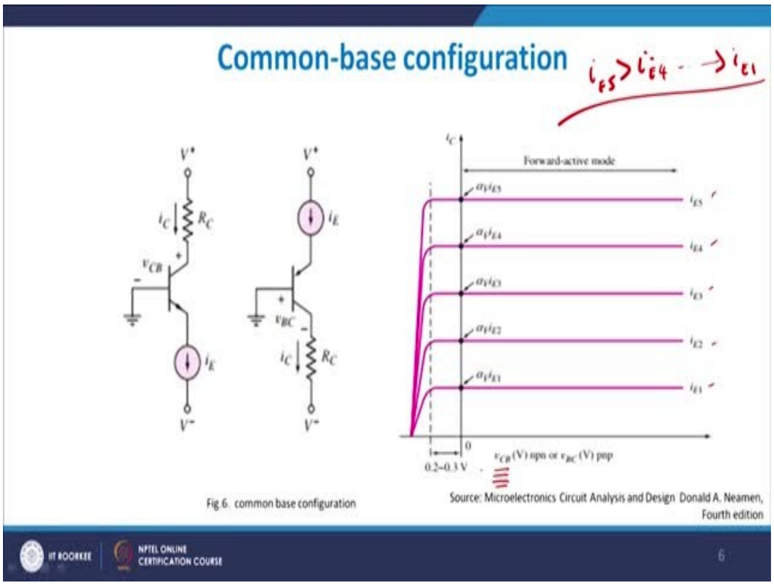

Common base configuration as the name suggests when we plot therefore for NPN V_{CB} CB V_{CB} collector to base versus I_C, right. Now you see quite interestingly even when I think all of you can understand this graph this is for a fixed emitter current so for varying emitter current, right I_{E1} greater I_{E1}, I_{E2}, I_{E3}, I_{E4}, I_{E5}. Such that I_{E5} is greater than I_{E4} and so on and so forth and the last one is I_{E1}. With this condition or with this idea what we see is that as VCB is positive it primarily means, it is positive means what? It positive means what positive means I will show you it positive means this is positive.

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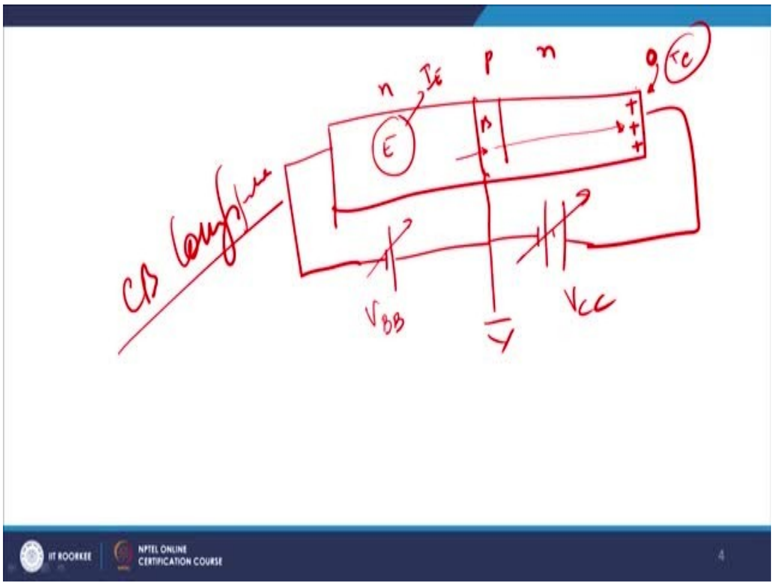

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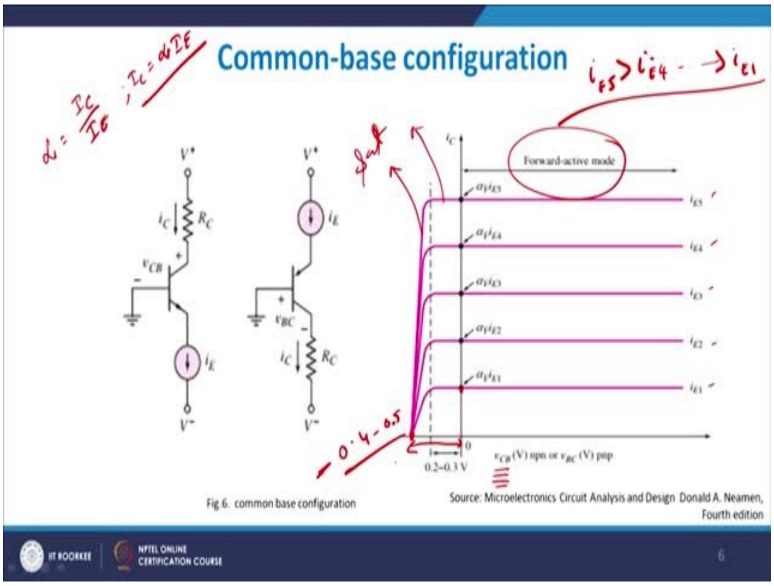

So I have a biased positive so when it is 0 bias even when it is 0 biased. You will see that you still have large amount of current flowing through the device. And the reason being very simple that even at 0 bias you have applied such a large electric filed because of the V_{BB} that electrons which were predominantly my emitter current I_E, right passed through the base region very fast and they cross through this region very fast and reach the collector side.

Though we did not applied any potential positive potential on the collector side on the I_C side collector side but still current from the emitter side is reaching towards the collector side in a very fast pace manner. And the reason is that though a bias was not applied but the velocity is so strong that it can easily cross the base region and reach the collector side.

And therefore if you see very carefully that you will always have a current which is equal to α into I_E because you remember α was equal to was defined as I_C by I_E. So I_C will be nothing but α times I_E. So I get α times I_E. Similarly I_{E1}, I_{E2}, I_{E3}, I_{E4}, I_{E5}. Now if you increase V_{CB} it is almost constant independent that we have already discussed why is it like that.

But then it means that you have to make your V_{CB} go in forward bias in order to stop the current flow and I think you can understand why. So you have to give a negative potential here in order to repel the electrons to move in this direction and not reach here. Is this concept clear? Which means that you minimum have to give this to be approximately equal to 0.4 to 0.5 with a negative sign so that it is in the cut-off mode.

So therefore this is known as forward active mode as I have written here. This is the forward active mode and this is the cut-off mode which you see. This is the cut-off mode, right. We define this to be as the saturation mode and this to be as the cut-off so you can do cut-off here. So this much amount of minimum amount of V_{CB} has to be provided in order for the device to be in cut-off.

So if you want to switch ON the device you have to bias your device to go from VCB of - 0.5 volts to approximately 0 volts for our practical purposes. And this this though it has been shown in a much greater sense but the drop is very-very drastic it is a very fast drop which you see here. And it is almost a straight line curve for a common base configuration.

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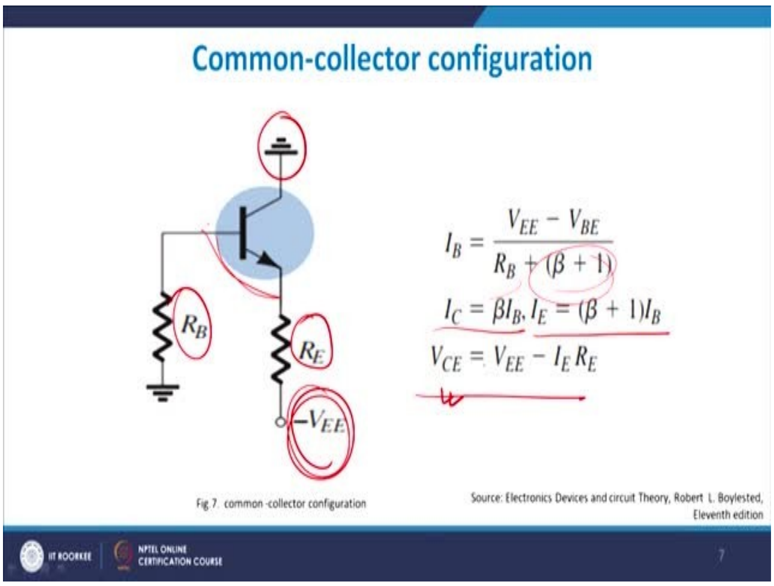

But what you will see here α is very close to 1 so you do not get any amplification out of common base configuration because the amount of emitter current that you are getting is approximately same as the collector base configuration, right. And that is the basic idea of a common base collector common base configurations.

We do have a common collector configurations which is there with us. In which the collector is common or collector grounded configuration. In which the collector is grounded or it is common between the base and the emitter. R_B is the base resistance and R_E is the emitter resistance and we apply minus V_{EE} here in order to bias the device into the active region of operation.

If you look very carefully here I_B the base current will be equals to V_{EE}. V_{EE} is this much minus V_{BE} which is the voltage drop across this part divided by R_B which is the resistance here plus β plus 1 which is β plus 1 is the effective value of which you see. I_C equals to β times I_B I_E is equals to β plus 1 I_B and V_{CE} equals to V_{EE} minus $I_E R_E$. So this will give you but common collector is not very seldom used. It is generally used for impedance matching but generally not used for any other purposes. Most commonly used is common emitter configuration device and that is the most commonly used configuration here.

We end today's topic by doing two things. By seeing the circuit symbols we have already seen this. But arrow pointed outwards which is this one.

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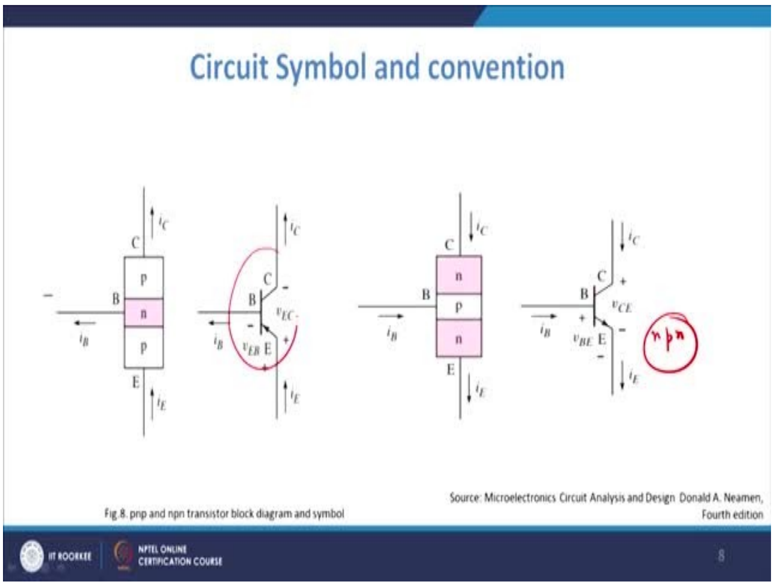

Primarily means it is the direction of the holes so holes move from base to emitter, which primarily means that the electrons are moving inwards and therefore this is basically an NPN transistor, right. And since it is a PNP transistor since holes are moving from emitter towards base side the region is shown in this manner, right. So you will have to convention in the sign convention you just have to worry about the direction of the arrow, right.

The arrow head direction gives you the direction of the holes and that is what is shown in this diagram. Let me recapitulate for both the transistors and that will take care of approximately all the understanding of common emitter common base common collector.

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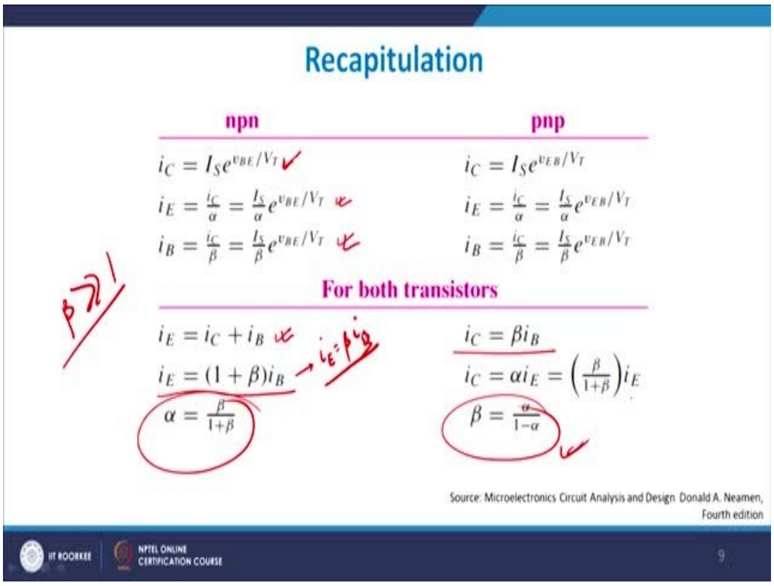

If you look at the collector current it is given by this and for one you can see other we can always learn. I_E is equals to I_C by α I get this I_B equals to I_C by β I get this for both the transistors I will get automatically I_E equals to I_C + I_B because Kirchhoff's current law cannot be violated. I_C equals to β times I_B right. I_E equals to actually equal to 1 + β but β is since it is very-very large as compared to 1. I can approximate this as I_E equals to β times I_B, right.

α equals to β upon β + 1 and β equals to α upon 1 - α and this is how you show the values of it. So which this let me thank you and give you an idea about what we did in the previous lecture series. That we have understood therefore the various configurations of working of a PNP and NPN transistors and which one is the best.

So the best option available to us is the common emitter for voltage amplification purposes. You can use common emitter as a switch as well, we can also common base as a switch for practical purposes. When we meet next time we will do certain other applications of BJT and we will do Ebers-Moll model for BJT. Thank you very much!