<div align="center">

Basic Electronics
Prof. Dr. Chitralekha Mahanta
Department of Electronics and Communication Engineering
Indian Institute of Technology, Guwahati

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

</div>

We will be discussing about another important characteristic which is the output characteristic for a transistor. In the last classes we have seen the input characteristic of a common base transistor. We will first discuss the output characteristic of a common base transistor. The output characteristic is the graphical representation of the output current with respect to the output voltage for different levels of input current. If we consider the common base transistor again here let us consider an NPN transistor which is in the common base configuration.

The basic equations we already know that I_E is equal to I_B+I_C and I_C is equal to alpha times I_E plus I_{CBO}. That is the reverse situation current and alpha is called the common base transistor current amplification factor or current gain and it is the ratio between the collector current and the emitter current. Alpha is the current amplification factor for a common base transistor which gives the idea about how the collector current will vary with respect to emitter current but alpha value can be maximum 1. It is always less than 1. Typical value of alpha is 0.95 to 0.99. Basically in common base transistor we do not get the current gain.

(Refer Slide Time: 2:53)
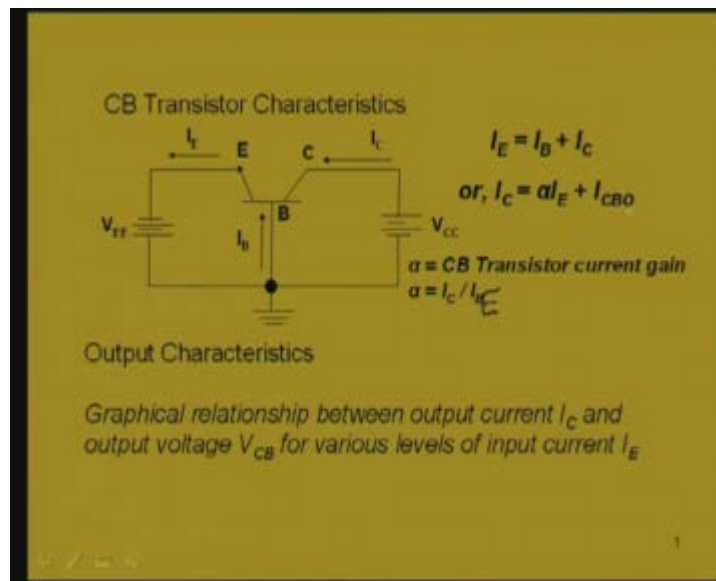
If we want to draw the output characteristic of a common base transistor we have to plot the characteristic of I_C versus V_{CB} for different levels of the input current I_E. This plot is

the output characteristic for a common base transistor. Here V_{CB} the collector to base voltage which reverse biases the collector base junction is in the x-axis and the collector current I_C for various levels of input current I_E is plotted.

(Refer Slide Time: 3:49)
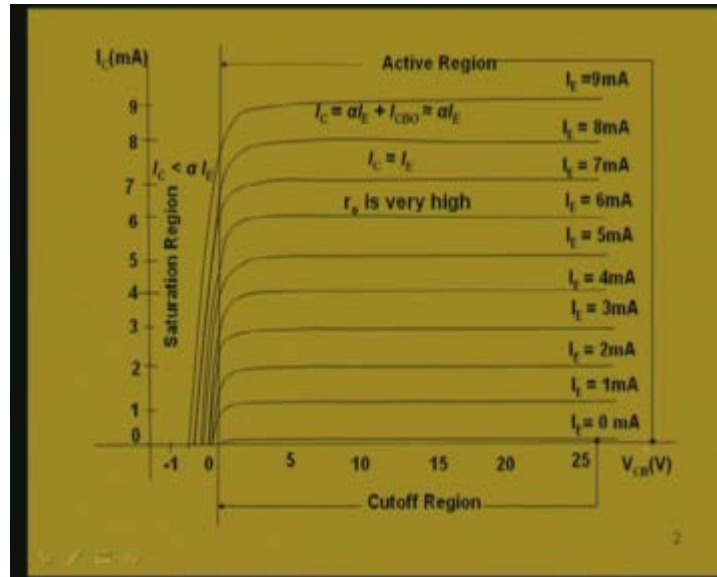
Different values of I_E if we take starting from zero then increase at steps of 1 milliampere say, for these different levels of I_E if we now want to plot I_C by changing V_{CB} we get almost horizontal characteristic. That is even though we may change V_{CB}, we go on increasing V_{CB} but practically the collector current does not vary. It is almost horizontal because the collector current is not dependent on the collector to base voltage but it is dependent on I_E only because I_C is equal to alpha times I_E and here if we note this equation actually I_C is equal alpha I_E plus I_{CBO}. I_{CBO} is the leakage current or reverse situation current which is very, very negligible. We can ignore this I_{CBO}. Then the equation will become I_C equal to I_E which is truly represented in these graphs.

As we can see that for a particular I_E if we consider say 2 milliampere then I_C will be almost equal to 2, a little less than 2 because there will be a very small base current. In fact this I_C will be I_E-I_B. But as this base current is of the micron order the I_C and I_E will be almost equal and this horizontal graph also represents a fact that the output resistance of this common base transistor will be very high since for a very wide range of V_{CB} also we are not getting any change in the I_C. I_C is almost equal to I_E in common base transistor but truly it is equal to alpha times I_E. This region, when the junction between emitter and base is forward biased but the junction between collector and base is reverse biased, this region is called active region. In the active region we see that the collector current is alpha times I_E which is almost equal to I_E.

There are two other regions also which are known as cutoff region and saturation region. The transistor is OFF in the cutoff region because here both the emitter base junction as well as the collector base junction are reversed biased. Below this line I_E is equal to zero.

We will get the input circuit, that is the junction between emitter and base is reverse biased and this region collector to base is also reverse biased. This region is cutoff where the transistor will be OFF; it will be simply switched off. Another region is known as saturation region which is to the left of this zero. If we see this region then we observe that the collector current is reducing and reducing. Then what is the value for a particular I_E? Say, for example if we consider this characteristic I_E is equal to 6 milliampere, if we go on decreasing this V_{CB} then if we go down below zero that is from this point to this left side it is negative.

We are considering a transistor which is NPN. If this collector to base voltage instead of reverse biasing if this polarity is such that N is not connected to P or if we see that this collector to base junction is forward biased. What will happen if we have the collector to base junction forward biased? This transistor is NPN. That means this N which is the collector will be having a negative with respect to the base. That is happening here. We are having a negative voltage V_{CB} or it is forward biasing the collector base junction of the common base transistor. The collector base junction is forward biased as well the emitter base junction is also forward biased. That means both emitter base junction and the collector base junction are forward biased. Under that situation what will happen? This is N, this is P and in the forward biased condition by this V_{CB} voltage the holes from this base will be traveling to the character region. The I_C current will be opposed by this hole current. The I_C current will be reducing. It will be reducing and reducing. In fact if I go on increasing the V_{CB} in the forward direction too much then ultimately the direction of I_C will be reversed. That is evident from this figure here.

The collector base junction being reverse biased, the I_C current was flowing in this direction from right to left. But if we forward bias it then after compensating for the hole current it will be now in the opposite direction. It will be flowing in the opposite direction to what it is. We can say that it will be in the reverse direction if we go on increasing the V_{CB} in the forward bias condition. These three regions are actually applied for different applications and the saturation and cutoff are basically for switching ON or switching OFF of a transistor. Basically transistor is operated under normal condition always in the active region. This characteristic curves show that we have no change in the collector current even though if we go on changing V_{CB}. We should not go on increasing the V_{CB} in the reverse bias condition to a too high value because then the breakdown will be occurring. Within the safe limit of operation we do not see any change in the collector current. Collector current is almost constant which is equal to I_E. If we consider saturation region as I_C is reducing, the value of I_C is not actually alpha times I_E here. Here I_C will be less than alpha times I_E. This alpha and this alpha in the active region they are not same. The value of alpha will be less in the saturation region.

Another type of transistor which is very much useful in amplification is common emitter transistor configuration. As we discussed common emitter means the emitter is common to both the input and output circuits. Here the emitter is grounded and the emitter will be common to the input circuit which is between the base and the emitter and the output circuit which is between collector and emitter. If we consider an NPN transistor then this input circuit between base and emitter, this junction, should be forward biased; emitter

base junction should be forward biased. If we consider an NPN transistor the emitter and base is N and P respectively. This base which is P will be having a higher potential than the emitter.

(Refer Slide Time: 13:55)
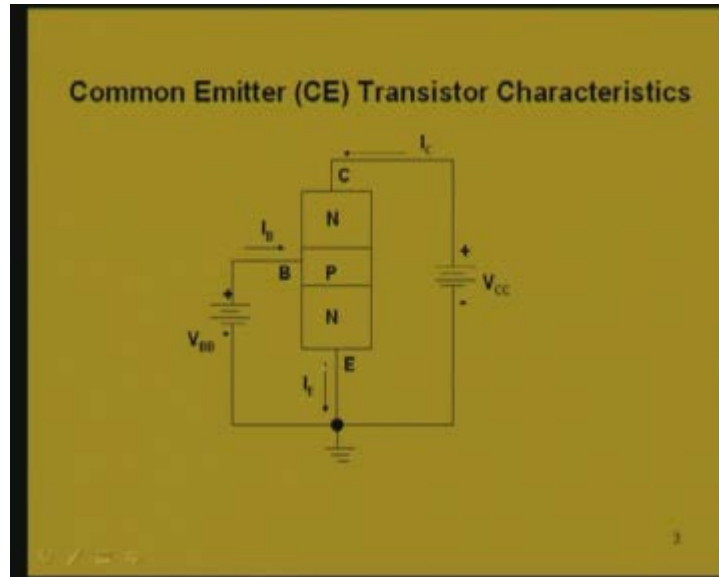
This is the biasing. V_{BB} is biasing it in the forward direction and the collector base junction should be reversed bias and that is taken care of by this potential V_{CC} and with these polarities when we are connecting then collector is N and base is P. The collector will be at a lower potential with respect to the base and that is ensured by this biasing voltage V_{CC}. In this configuration let us now explore into the two characteristic curves. In order to plot the characteristic curve we must now vary the input voltage to see the effect on the input current. That means here we will be varying the base emitter voltage and we will be plotting the input current which is here I_B and for different V_{CE} we will now see what will be happening in the input characteristic.

Similarly in the output characteristic we will be plotting this collector current I_C versus the collector to emitter voltage for different levels of input current. Here the input current is the base current. Experimentally also we can determine this characteristic curves. If we consider the common emitter transistor circuit, NPN transistor we are taking for an example and here the governing equations for the current that we discussed is I_C equal to beta times of I_B plus beta plus 1 into I_{CO}. Here this beta is alpha by 1 minus alpha and this beta is called the current amplification factor for common emitter transistor. This beta is an important parameter as far as common emitter transistor is concerned because it determines the current amplification. How much the output current is amplified with respect to the input current that is determined by this beta value and alpha value is very less. We know it is less than 1. But for a small alpha corresponding beta will be very large. For example if we consider say alpha is equal to 0.9 it is a typical value for a transistor we are considering and by substituting this alpha value in this expression for beta the corresponding beta becomes 49.

(Refer Slide Time: 17:08)
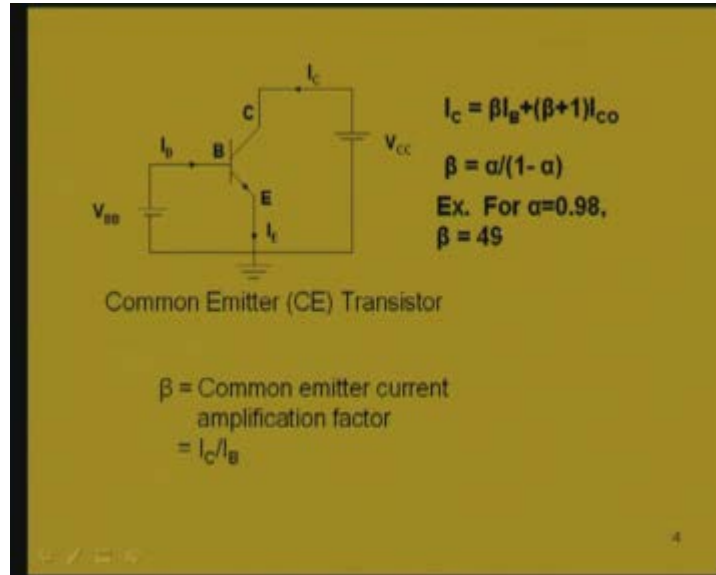
For even a small change of alpha the corresponding change in beta is drastic. That means we will get higher current amplification in common emitter than compared to common base and this fact is very much utilized in building common emitter amplifiers. The beta expression can be simplified by simply I_C by I_B because in this expression if we just observe then the leakage part or the reverse saturation current part which is beta plus 1 I_{CO}, this is not comparable with the other component. That is I_B is considerably large compared to I_{CO}. This beta times of I_B is quite higher in comparison with this latter term beta plus 1 I_{CO}. We can very well ignore this part, second part and we can write down I_C equal to beta times of I_B. From that the DC value of beta is obtained by I_C by I_B.

The typical value of beta which may be varying from 50 to 400 just roughly I am saying because for every transistor in the specification sheet or data sheet its corresponding parameters are specified and for a common emitter transistor the beta value for that particular transistor will be specified in the data sheet and different transistors may be having a change in the value of beta. But almost it will be varying between say 50 to 400. That means we get quite high value of beta and that is why we can get very high collector current I_C even though the I_B is less because I_B base current is in the order of say microampere. But I_C will be in the order of milliampere and in this particular configuration of common emitter transistor input current is I_B, base current. By varying this base current we can vary the collector current enormously. That is the main advantage of this common emitter transistor.

Now we will discuss about the input characteristic of a common emitter transistor. As the name is input characteristic we naturally will know that we will get a plot of the input current versus input voltage and in this particular transistor which is common emitter in the input circuit if we observe the input current is I_B and the input voltage which will be effecting I_B is V_{BE} that is base to emitter voltage. Here one point to note is that this V_{BB} is the biasing voltage. That is V_{BB} actually is biasing the transistor emitter base junction in

the forward bias condition. But basically we have to determine the voltage across this emitter base junction which is V_{BE} because emitter is grounded. So the voltage at the base terminal with respect to the emitter that is the input voltage and in this circuit this is a very simple circuit because there are no resistances anywhere and there is no resistive drop or any drop in the circuit. Whatever voltage is there V_{BB} biasing voltage that is available at this base point. If we now plot the current I_B versus V_{BE}, this V_{BE} voltage is the voltage across the emitter base junction in the input circuit.

(Refer Slide Time: 21:43)
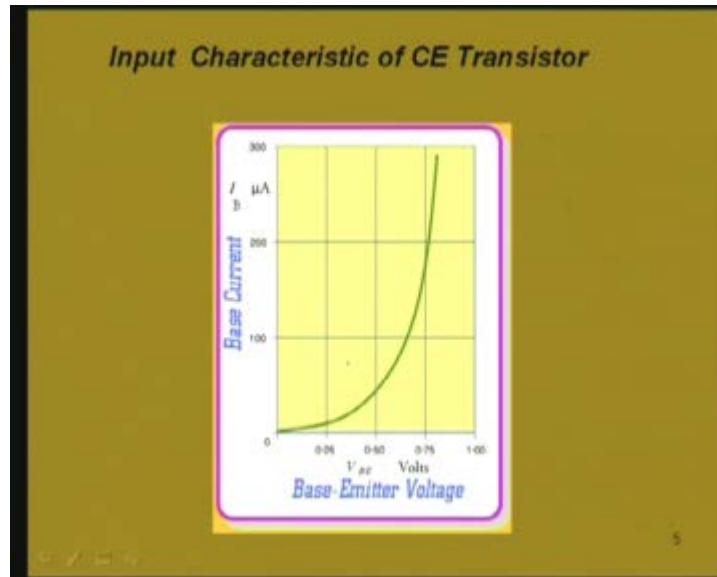
This is a very familiar characteristic. We know from our earlier PN diode that it is nothing but a forward biased diode characteristic. When you go on increasing the voltage across this diode there is an increase of current which sharply increases after the threshold voltage that is 0.7 volt for silicon. This typical characteristic of a forward biased diode is the input characteristic that we see in the transistor input circuit. Because here if we look into this circuit, this forward biased junction if we go on increasing the voltage across this then there will be increase of this base current following the typical characteristic of the diode because the emitter base junction of the transistor is nothing but the PN diode in the forward biased region. Here for increment of this base emitter voltage the current I_B will be rising but this order is small. It is in the microampere range. For up to say around 0.7 volt the current rise is very small and then it will be rising. It is a magnified scale. If we look into this scale, it is 0.25, 0.5, etc. This is 1 volt. This is a magnified scale so that we see the important point where it is rising. That is the current rises after the threshold voltage is over come. Then it is almost constant. This voltage will not be changing much although the current I_B will be changing or increasing very sharply. This characteristic is the input characteristic of common emitter transistor.

Here in this characteristic we have shown only one single curve which means that we are plotting the curve or we are plotting the input characteristic for a particular value of the collector to emitter voltage. But if we now change the collector to emitter voltage we will

be getting different plots. If collector to emitter voltage is now increased that is suppose this reverse biasing voltage is increased what will happen? Earlier also in common base input characteristic we have seen that the increment of the collector to emitter voltage which is reverse biasing will have an effect that is known as an early effect. Early effect means the modulation in the base width because if we increase this collector to emitter reverse biasing voltage, V_{CE} is increased. That means collector to base junction will have more reverse biasing voltage because if we consider this circuit V_{CE} is nothing but $V_{CB}+V_{BE}$. $V_{BE}+V_{CB}$ equal to V_{CE}. If we increase collector to emitter voltage then collector to base voltage will increase because V_{BE} is almost constant at 0.7 volt. If that happens that is V_{CE} increment will result in the increment of collector to base reverse biasing voltage then there will be a modulation in the base width. If we now focus on this base width, this base width is W_B that is the metallurgical base width.

(Refer Slide Time: 26:29)
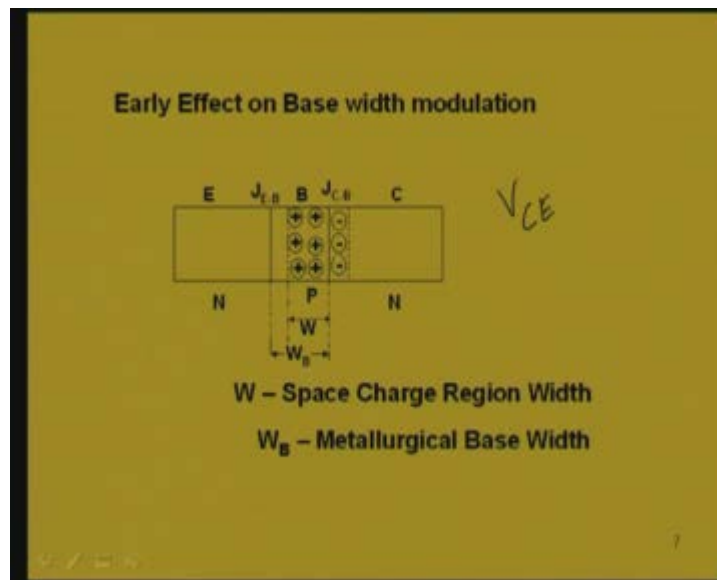
This collector base junction is reverse biased. The space charge region which will be formed around the junction will be penetrating more into the base region because the base is lightly doped. Mostly the space charge region will be available or penetrating into the base region because of this fact that the base is lightly doped in comparison with the collector.

If W is space charge region width then the width which is W_B-W is the effective electrical base width in the base region where recombination can take place. The recombination gives rise to the base current. If we now increase this V_{CB} collector to base reverse biasing voltage we know that the width of space charge region will be increasing because it is affected by the magnitude of the collector base reverse voltage. The width increases and it will be now more penetrating into the base region. That means now W will be more. If we increase V_{CB}, W will be more. The overall effective electrical base width which is now available for combination is W_B-W. W is increasing means effective electrical base width will be decreasing.

(Refer Slide Time: 28:11)
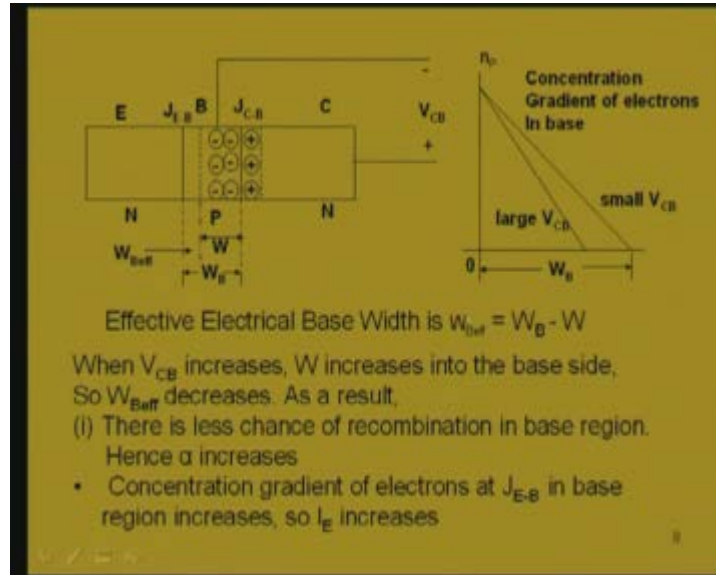
That means less recombination will take place now in this base region. Less recombination takes place means it is less base current. As a result of increment in the collector to base reverse biasing voltage we have lesser base current I_B. That is now reflected in this input characteristic. As we can see now V_{CE} is increasing to the right. If we go on increasing V_{CE} then this curve or the plot will be shifting to right as I_B is decreased. For a particular V_{BE}, greater the V_{CE} is lesser the base current. V_{BE} is constant at say around 0.7. If we now project it vertically we can see this was the base current at 1 volt. At 10 volt it becomes lesser and at 20 volt it is even lesser.

(Refer Slide Time: 29:30)
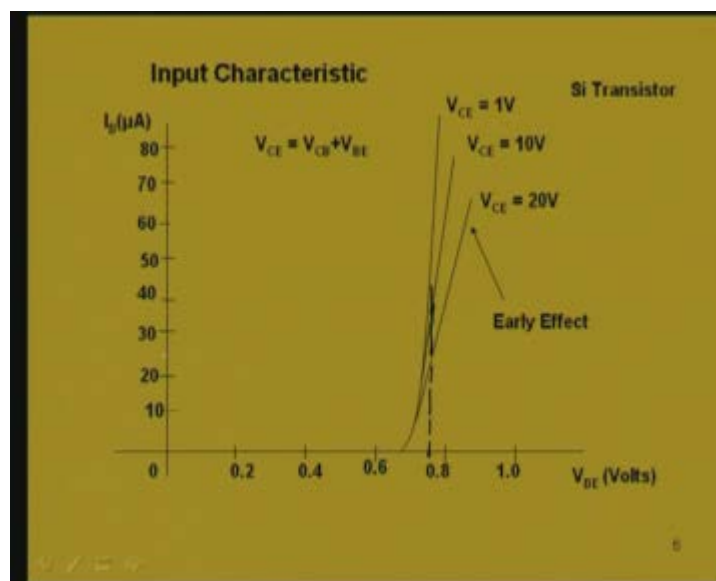
The curves of the input characteristic will be shifting to the right and right if we go on increasing the V_{CE} which means increasing the collector to base reverse bias voltage. This is the input characteristic and this effect of shifting of the curves to the right is because of that early effect which is the modulation of the base width.

If we now see the output characteristic of a common emitter transistor, output characteristic of a common emitter transistor is plotted between the output current and output voltage for different levels of input current. If we plot this V_{CE} that is the output voltage collector to emitter voltage which is reverse biasing and I_C collector current for different levels of input current means different levels of the base current because input current is now base current.

(Refer Slide Time: 30:41)
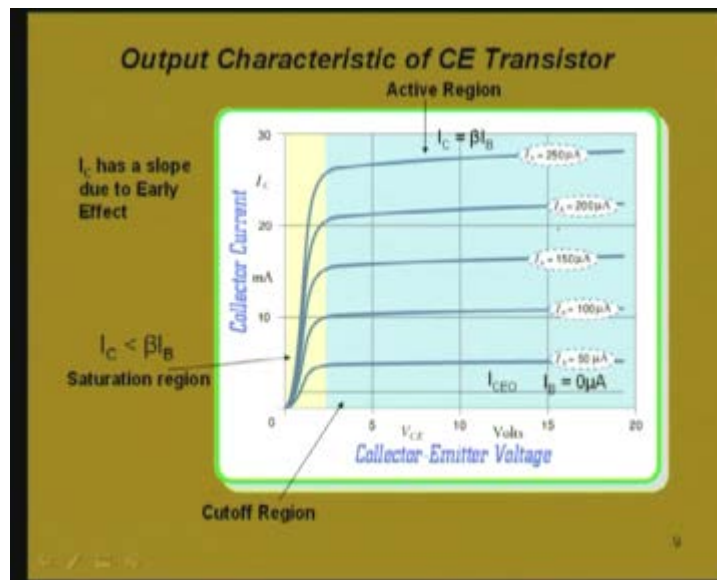
Here at the plots now I_B is varied from say zero onwards. I_B is zero means we do not have any base current and the equation of the collector current is I_C equal to beta times of I_B plus beta plus 1 into I_{CO}. I_B zero means we are left with only the leakage current at a reverse saturation current that is represented by I_{CEO} that is collector to emitter current when base is open and this represents the reverse saturation or leakage current only because you can see here if this base circuit is open means I_B is zero. Then still there will be a current. The collector current will not be zero because if you look into this equation I_B is zero still there will be beta plus 1 I_{CO} and here we have to note one fact that it is simply not I_{CO} it is beta plus 1 into I_{CO}.

An important observation we should make here that this I_{CEO} is not merely I_{CO}. It is actually beta plus 1 I_{CBO}. I_{CBO} was the leakage current in common base transistor. But then in a common emitter transistor the leakage current is much more than the common base transistor and this is beta plus 1 times the I_{CBO} or I_{CO}. Even when you make I_B is equal to zero you are not able to make I_C is equal to zero truly because this part of the current will be there which is known as I_{CEO}. The name is given because CEO means

collector to emitter current when the base is open. That current will flow between collector and emitter. If we look into the output circuit again then this current will be between collector and emitter. Even this base circuit is open. That is why it is called I_{CEO}. That I_{CEO} is the current when I_B is equal to zero. This is the current. It is not exactly zero it has a considerable amount.

If we go on increasing the I_B current now, we will get the I_C current and this I_C and I_B has a relation which is beta times of I_B if we ignore the leakage part. This region is collective region when the base emitter region is forward biased and collector emitter region is reverse biased. In this region beta times of I_B is very much valid because the leakage current or the reverse saturation current beta plus 1 into I_{CBO} or I_{CEO} that is very little as compared to beta times I_B part. That is why we can make these assumptions without any violation of these practical conditions I_C equal to beta times I_B. I_C is equal beta times I_B is the plot. This is almost a linear plot. Beta is the factor which relates I_C and I_B and for a particular transistor if we consider then this beta is constant. Beta cannot be kept exactly constant because of some other factors. But for the moment we are considering active region. So it is assumed that beta is constant. Beta times of I_B will be I_C, so we can actually calculate what will be the I_C if we know the value of beta. Here we see that it is 50 microampere I_B. Then it is increased to 100 microampere, 150 microampere, etc. In steps of 50 microampere we are increasing.

If we observe this plot at I_B is equal to 100 microampere, I_C is almost constant at 10 milliampere. What will be the beta factor? What will be beta value that can be calculated by simply I_C by I_B. Substituting the values of beta and I_B we can find out I_C. In these plots we know I_B. We know what is I_C? We can find out value of beta. It is equal to 10 by 100 microampere. This 10 to power -3 we will have to multiply. We get this equal to 0.1 into 10 to the power 3. That means it is equal to 100. Beta is 100. For every I_B value we can see that same beta.

(Refer Slide Time: 36:35)

10
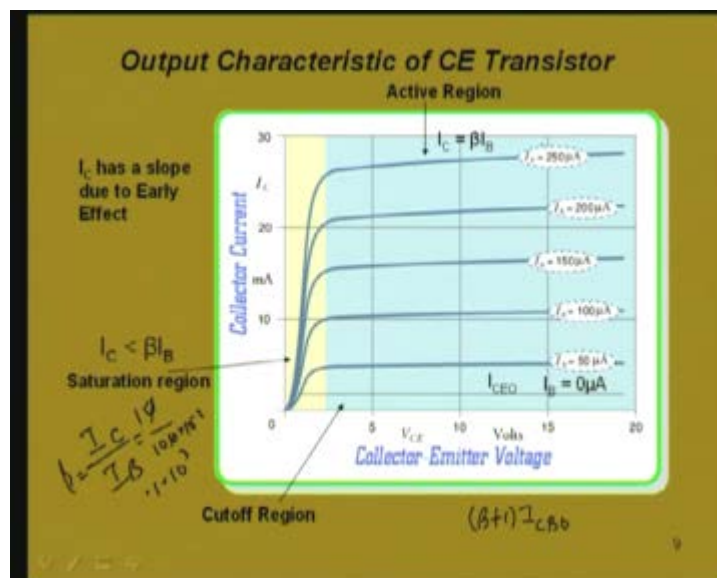
That is even if you look into this 150 it is at 15 milliampere. But that I_C is not constant but has a slope to the right. That is we can see here that I_C is increasing a little to the right. When you increase V_{CE}, there is a slight increase in I_C and this slope is much larger than the slope that we observed in common base. In fact common base transistor was not having any slope almost zero or horizontal line we were getting but here there is a slope. Again that effect which we have just now discussed that is early effect is responsible for this slope. We know that when V_{CE} is increased, collector base reverse bias will be increased. So there will be increment in collector base reverse bias means there will be a modulation in the base width which will reduce the base current because of lesser recombination. Lesser base current means collector current will be higher. That is why collector current is little higher in the right side when we go on increasing V_{CE}. That is observed in these plots. This region is active region as the emitter base junction is forward biased and collector emitter junction is reverse biased.

The region below this I_B is equal to zero microampere is the cutoff region. In order to switch the transistor OFF, it is not simply enough to make the I_B zero because as we have seen just now there will be leakage current which will be flowing which is beta plus 1 into I_{CBO}. That is why we have to reverse bias the input circuit. That means we have to reverse bias the base emitter junction and then only the transistor will be switched OFF. That is why this region is below this. I_B equal to zero means input circuit is reverse biased; output circuit is also reverse biased. That is the region called cutoff region. That means in this region the transistor is switched OFF.

The other region which is saturation region will be obtained when you have this V_{CE} very, very small. That is if V_{CE} is made very small what will happen? We know that V_{CE} is actually equal to $V_{CB}+V_{BE}$. V_{BE} is almost constant 0.7 volt. The collector base voltage is equal to $V_{CE}-V_{BE}$. That means it will be $V_{CE}-0.7$. If V_{CE} is very small say less than 0.7 volt for silicon, then what will be the collector base voltage? Collector base voltage is equal to let us for example take V_{CE} is equal to 0.2 volt, very small lesser than 0.7 volt. Then collector to base voltage will become 0.2-0.7 that is -0.5. What will happen when we have a voltage -0.5? That is equivalent to forward biasing the output circuit because we are considering an NPN transistor; N, P and N.

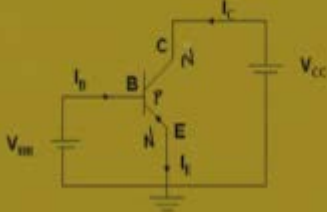(Refer Slide Time: 40:33)

Saturation Region

$V_{CE} = V_{CB} + V_{BE}$

or, $V_{CB} = V_{CE} - V_{BE}$

If V_{CE} is very small, less than V_{BE}, V_{CB} becomes -ve

e.g. $V_{CE} = 0.2V$, $V_{CB} = 0.2 - 0.7 = -0.5V$

CB junction is forward biased (NPN Transistor)

The collector to base voltage is negative means the collector to base region is forward biased. If this happens, the forward biasing of input as well output circuit happens. Then phenomenon similar to that occurred in common base transistor will be here also. This saturation region will be having lesser and lesser collector current because of this phenomena where the collector base region is forward biased when this V_{CE} is very small. Actually in this region a transistor is operated for switching ON or saturation occurs. How this saturation will be utilized in switching ON that we will discuss later in detail. But for the time being active region, cutoff region and saturation region, these three regions we should be familiar with and we will be mostly utilizing this transistor in the active region that is when the base emitter junction is forward biased and collector emitter junction is reverse biased. That is the normal or operating mode of a transistor as an amplifier. Earlier also we discussed that in the saturation region the collector current will be less than beta times I_B. In this region this beta value is not the same beta as we have in the active region because I_C is lesser and so beta will be also lesser. This is the plot giving the characteristic in the output circuit.

From these two transistor configurations that we discussed till now that is common base and common emitter the two key equations which are representing the two transistor configurations are one is I_C equal to alpha times I_E and the other is I_C is equal to beta times I_B. These two are the key equations if we ignore the leakage part. One important aspect that we can observe and then infer from these two equations is that the collector current which is the output current is affected by the input current. In the common base transistor, I_E is the input current and in common emitter transistor it is I_B. It is basically a current source which is controlled by another current source. It is called current controlled current source. The source is the input current which is controlling the output current. That means we are having a current source. I_{CE} is nothing but a current source which is controlled by another current source which is the input current. So it is called current controlled current source. Transistor is a current controlled current source.

(Refer Slide Time: 44:08)

If we want to change the output current that is the current source at the output circuit we have to do it by varying the input current source. That is why it is called CCCS, current controlled current source. The study of this input and output characteristic gives another relevant fact that the resistance in the input characteristic is very low. But in output characteristic the resistance of the transistor is quite high. That fact we can very well see in these characteristic curves. There is a very little slope of this collector current. That means the output resistance of the transistor is very high in the order of meg ohms and in common base it is even higher than common emitter. It is almost like infinity so that there is no change of current even if you go on changing the collector to base voltage in the common base. But here it is a little lesser; the output resistance r_o is little lesser than common base because of the presence of this slope.

(Refer Slide Time: 45:21)
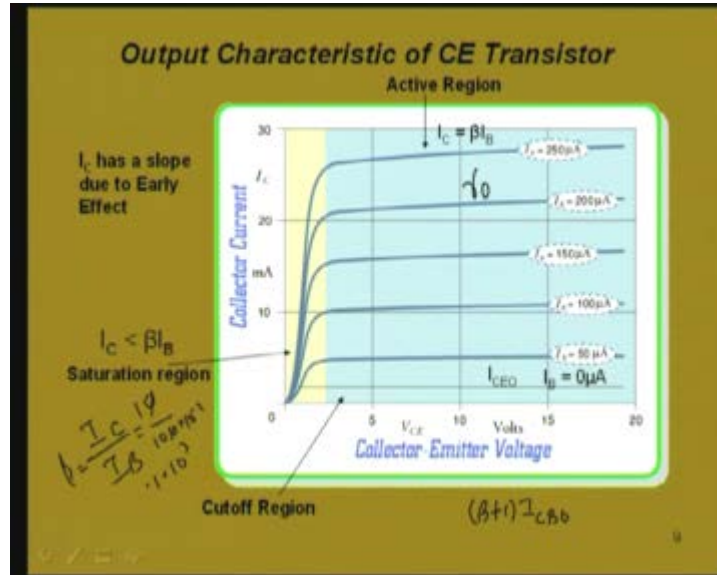
We have the common emitter transistor configuration having this relationship. Actually the current relationship is I_C is equal to beta times of $I_B + I_{CEO}$ and I_{CEO} is nothing but beta plus 1 I_{CBO}. That is the I_{CBO} is reverse saturation current in common base and it can be written as 1 by 1 minus alpha into I_{CBO} and to illustrate this fact that how drastically beta changes for even a small change in alpha or if we take a very small alpha say 0.996, a typical value, the corresponding beta value will be alpha by 1 minus alpha and if we substitute alpha here we get 249 and the corresponding I_{CEO} leakage current in common emitter transistor becomes 250 times I_{CBO}. That represents the fact that common emitter transistors have much higher leakage current than common base transistor.

This transistor in two configurations that we studied can be utilized with a DC source and other resistances and also later we will observe that it can be applied to increase the level of a signal. But before giving an AC signal to a transistor let us first discuss what will be the analysis of a transistor with DC only. So far we were not exactly discussing an electrical circuit with resistances etc and incorporating transistor. We were only utilizing the sources to bias the transistor in forward bias, reverse bias. But then if we use a transistor along with other resistances etc, build a circuit with a DC source, 1 or 2 DC sources then how to find the node voltages, how to find a branch currents that can be discussed by analyzing the transistor circuit under DC.

Let us take one example of a circuit having a transistor in a common emitter configuration and more over it is an NPN transistor indicated by this arrow head in the emitter and these other resistances R_C in the collector, emitter has also resistance connected to it which is R_E and base is having a resistance which is R_B. These biases V_{BB} and V_{CC} are there for taking care of the forward biasing and reverse biasing of the junctions. We can find out the currents I_C, I_E and I_B and for that you have to assume V_{BE} is equal to 0.7 volt.

(Refer Slide Time: 49:04)
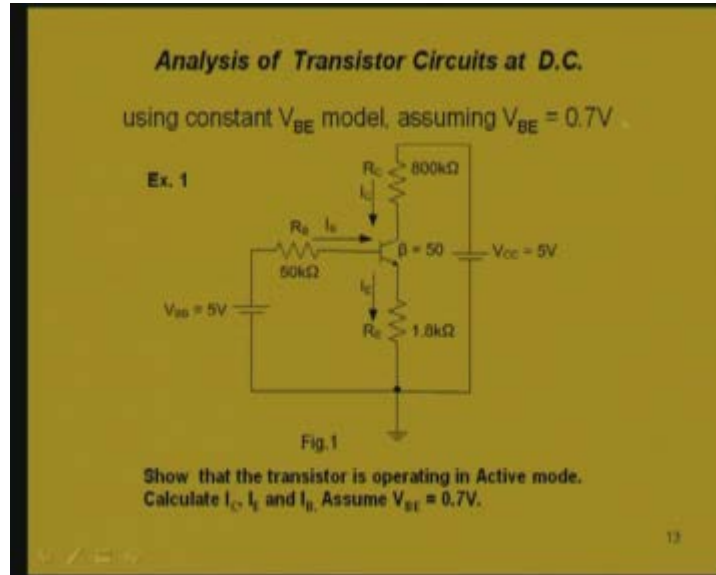
In the analysis that we will be doing we will be using mostly constant voltage drop model that is constant V_{BE} model. When the transistor is ON, then the drop V_{BE} will be 0.7 volt and that is the drop in silicon transistor and generally we will be assuming silicon transistor and this will be followed throughout and this constant V_{BE} model will be used for the transistor. When it is ON it will have a drop of 0.7 volt in the base to emitter region. You are asked to show that the transistor is operating in active mode. In this transistor we can find out these currents I_C, I_B and I_E provided the transistor is in active mode. It has to be ascertained first whether the transistor is in active mode of operation or not. To solve that and to know whether it is in the active mode we must see whether the transistor is forward biasing the base emitter junction and it is reverse biasing the collector emitter junction or collector base junction; that is reverse biasing between collector and base junction and forward biasing between emitter and base junction.

Let us do that and this circuit we will now solve. To find out the currents, we will use those laws which are relevant; Kirchoff's voltage law, current law, etc. In this transistor circuit, if we look into this base emitter loop, this loop, we can apply KVL. Applying KVL, one important factor beta you must know for solving this circuit and that is given as 50. In the example beta value is given as 50. Applying KVL in the base emitter loop we can write the equation. In the base emitter loop the algebraic sum of the voltage drop is zero that is the KVL. Start from this negative to positive; rising voltage, so it will be positive +5 volt. If we write down this equation what will it be? V_{BB} minus the current in the base terminal is I_B, so V_{BB} minus I_B into R_B minus base to emitter drop. This is the base point, this is the emitter and this is the collector.

Assuming the transistor is ON, first we will assume that the transistor is in the active region. Then we will verify that fact by finding out the collector to base voltage whether it is reverse biasing or not. Let us first assume that the transistor is in active mode and we will find out the V_{CB}. If I write this equation V_{BB} minus $I_B R_B$ minus V_{BE} minus V_E, the

voltage drop at this emitter that can be represented also by $I_E R_E$. That is equal to zero. This is the first equation Kirchoff's voltage law we get in the loop of the input circuit. 5259What type of values we can represent? We can substitute here V_{BB} is known it is 5 volt. I_B we do not know. We have to find out I_B. R_B we know. V_{BE} constant voltage drop model we have to use if it is specified. Even if it is not specified we will assume that it is 0.7 volt drop for transistor base emitter junction. 0.7 volt is this one. I_E we do not know but we can represent it in terms of I_B using the fact that I_E is equal to $I_C + I_B$. Again what is I_C beta times of I_B? Ultimately I_E is nothing but beta plus 1 into I_B.

(Refer Slide Time: 53:49)
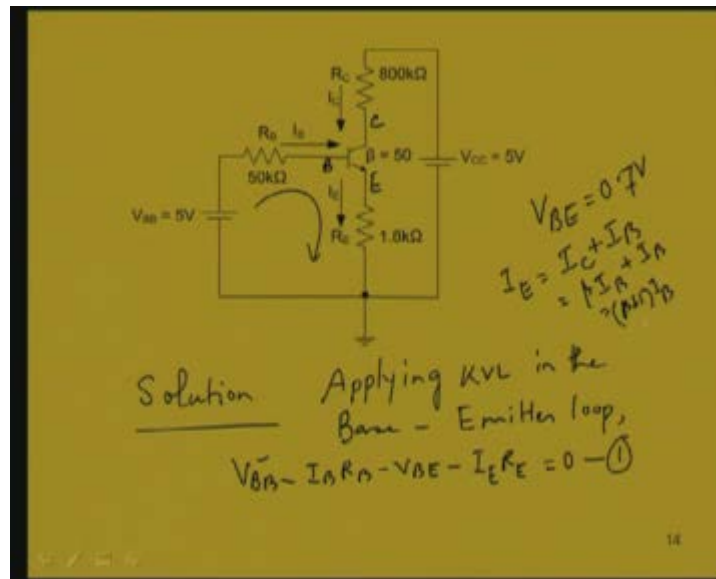
Representing that I_E by this beta plus 1 I_B and putting down the value of R_E the equation will be now V_{BB} minus $I_B R_B$ minus V_{BE}; this drop you should not forget. You always have to remember this drop in the transistor when it is ON minus $I_E R_E$ equal to zero. Here I am replacing that I_E by beta plus 1 into I_B R_E equal to zero. It will be V_{BB} minus I can take this common, R_B plus beta plus 1 into R_E, whole thing multiplied by I_B minus V_{BE} is equal to zero. We can very well find out the value of I_B by simplification which is equal to V_{BB} minus V_{BE} divided by R_B plus beta plus 1 into R_E. This is the value of I_B. Replacing all the values, given value of V_{BB} is 5. It is 5 volt. V_{BE} is 0.7 divided by R_B value is 50 k ohm and R_E is 1.8 k. So 50 plus, beta is given as 50; 50 plus 1 into R_E value which is 1.8. If we do this calculation we will get that is equal to I_B is equal to 0.03 milliampere or it is 30 microampere.

$$V_{BB} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{BB} - I_B R_B - V_{BE} - (\beta+1) I_B R_E = 0$$

$$\sim V_{BB} - \left[R_B + (\beta+1) R_E\right] I_B - V_{BE} = 0$$

$$\sim I_B = \frac{V_{BB} - V_{BE}}{R_B + (\beta+1) R_E}$$

$$= \frac{5 - 0.7}{50 + (50+1) \times 1.8}$$

$$= 0.03 \, mA$$

If I_B is this, the value of I_C we can immediately find out beta times of I_B. Beta is 50 into 0.03. This calculation will give me that is equal to 1.5 milliampere. I_C we have found out. I_B we have found out. We can also know I_E which is equal to $I_B + I_C$. Substituting the value of I_B and I_C, 0.03+1.5 that is equal to 1.53 milliampere. We know all the currents I_B, I_C and I_E. Now what is needed is to find out whether the transistor is in active mode of operation or not. That means we have to know the collector to base voltage. If we focus in the output circuit, again apply the KVL. What will it be? V_{CC} minus I_C minus V_{CE} minus $I_E R_E$ that is equal to zero. We can find out basically what is V_{CE}.

Let us find out V_{CE}. Applying KVL in output circuit that will give, V_{CE} equal to V_{CC} minus $I_C R_C$ minus $I_E R_E$. Everything is known, so we can just substitute. V_{CC} is equal to 5 minus I_C we have found out 1.5 and this R_C is given as 800 kilo and minus $I_E R_E$. This unit should be in conformity. I am writing I_C in milliampere so that we may not write this 10 to the power 3 because this will volt only and the $I_E R_E$ part 1.53 milliampere into 1.8. That gives the value of V_{CE} equal to 1.022 volt.

$$I_C = \beta I_B$$
$$= 50 \times 0.03$$
$$= 1.5 \, mA$$

$$I_E = I_B + I_C = 0.03 + 1.5 = 1.53 \, mA$$

KVL in output cht,
$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$
$$= 5 - 1.5 \times 800 \, - 1.53 \times 1.8$$
$$= 1.022 \, V$$

Checking this answer we should get 1.022 volt here. We now have V_{CE} is equal to 1.022 volt. If I know V_{CE} now then what will be this V_{CB}? That can be found out simply using that equation that V_{CE} equal to. What will be V_{CE}? From this point to this point the voltage drop is V_{CE} that is equal to collector to base drop plus base to emitter drop. Writing in that way that is V_{CB} plus V_{BE} that means we can find out what is V_{CB}? That is equal to V_{CE} minus V_{BE}. V_{BE} we know 0.7 volt. V_{CE} we have found out 1.022 minus 0.7 that gives 0.322 volt. This is a positive voltage. If collector to base voltage is positive since V_{CB} is positive and knowing the fact that the transistor which is used here is an NPN transistor if we look back into the circuit this is an NPN transistor. Collector to base junction is reverse biased because the voltage which is biasing that collector to base region is 0.322, positive. This point N is positive. With respect to P it is reverse biased. That means the transistor is in active mode. The assumption that we initially assume that the transistor is ON is correct because input is already forward biased. V_{BE} is positive we assume initially, so again we verify reverse biasing. The V_{CB} is reverse biasing.

(Refer Slide Time: 1:00:08)

$$V_{CE} = V_{CB} + V_{BE}$$

$$\therefore \quad V_{CB} = V_{CE} - V_{BE}$$

$$= 1.022 - 0.7$$

$$= +0.322V$$

V_{CB} is +ve /
So reverse biasing
C-B

Therefore the transistor is in active mode. In this way we can check whether we are going in the right directions. From the beginning assuming that the transistor is ON we have solved this problem and finally we are again getting or verifying that the transistor is in active mode really by finding out the collector to base region as it is reverse biased.

In this way we can analyze the transistor circuit by simple application of this relevant laws like beta times of I_B is equal to I_C, alpha times of I_E is equal to I_C for common base and we can solve for that different node voltages as well as the currents in the branches of the transistor circuit and that will be required for knowing in what mode the transistor is operating.