Analog Electronic Circuits
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Lecture No 02
Review of DC Models of BJT's (Contd.) and FET

This is second lecture in 204 on review of DC models of Bipolar Junction Transistors as we started last time. And we will also discuss little bit about Field Effect Transistors. I wish all of you a happy new year. And the rhyme if you wonder is as per my desire.

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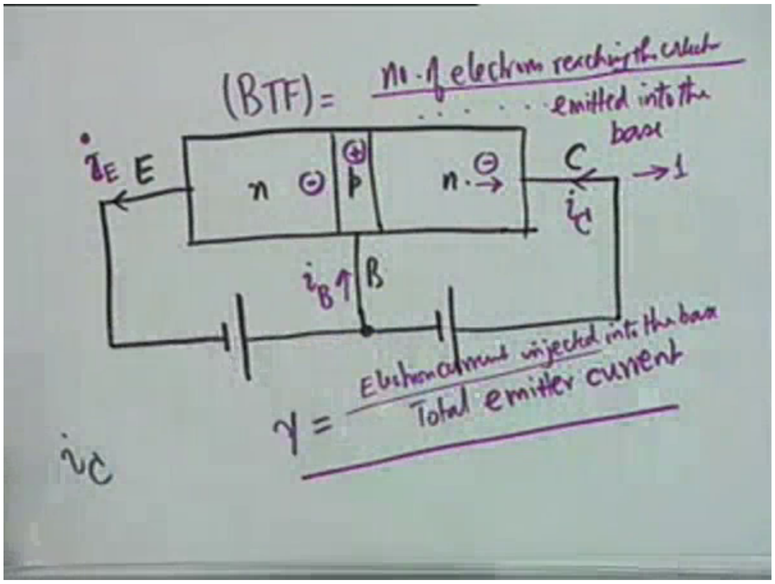

While we were talking about the npn transistors BJT this is emitter, this is the collector and this is the base. The base as you know is a very thin region and normally in the active region the emitter base junction is forward biased which means that the emitter is connected to a negative terminal and base with positive terminal. This is a forward biasing. And the collector base junction is reverse biased which means that this is negative and this is positive. The conduction mechanism is that the emitter injects electrons into the n region most of which most of which pass into the p region and because the p region is thin the electrons cross over to the n region and these electrons are then collected by the positive potential of the battery. This is the basic operation of an npn transistor. Where the electrons are majority carriers here, electrons minority carriers here and here also electrons are majority carriers.

As I told you the emitter current which flows in this direction, the emitter current which flows in this direction let's call it I E let's call it small i subs script capital E. I will explain the notations in a minute. The emitter current consists of electron current as well as hole current because there are holes which are minority carriers here. Now therefore the electrons the electrons that are injected into the p region will only form a part of the total emitter current. So if you define this ratio as electrons electron current injected into the base electron current injected into the base divided by total emitter current, this ratio is called the Emitter Efficiency. And it's denoted by Gamma.

This ratio usually it is close to unity 0.999 is a typical figure. For a good transistors 0.999 is a typical figure. The reason is that the holes are in minority and therefore the hole current is negligible compared to the electron current and most of the current that enters into the p region is the electron current. This is emitter efficiency and then the electrons which are injected into the base not all of them can cross. Some of them will combine with the majority carriers which are the holes in the p region okay. Some of the electrons injected will combine with the holes in the p region. And this combination, this recombination appears as the base current i B the base current normally if there are no recombination then the base current should be zero. But since there is recombination uhh excuseme there is a base current okay.

So some of the electrons which are injected into the base region they recombine with holes and therefore the number of electrons reaching the collector. Number of electrons reaching the collector will be less than the number of electrons emitted from the emitter region. If this ratio uhh called the BTF – Base Transport Factor is defined as number of electrons reaching the collector divided by the number of electrons emitted into the base, emitted into the base. This ratio electrons reaching the collector divided by the number of electrons emitted into the base this ratio is called the Base Transport Factor and this also is very close to unity, very close to unity may be 0.99 is a typical figure. Because the base current normally is very small. The reason being that the time that these electrons get to the combine with holes is very little, very little time is available because they have to they have to respond to the call of the positive potential of the collector.

So they are forced it's like a flood which crosses this barrier. Some of them are left behind to be eaten by the holes into a base current okay. So this Base Transport Factor is also approximately equal to 1. And then the collector collector current which is the direction of flow of positive charges shall be in this direction and you can see that normally if i B is equal to 0 then the collector current should be equal to the emitter current. But because of i B and because of this ratio, because of holes also contributing to conduction i C the collector current is slightly less than the emitter current. And the exact relationship is i C the collector current.

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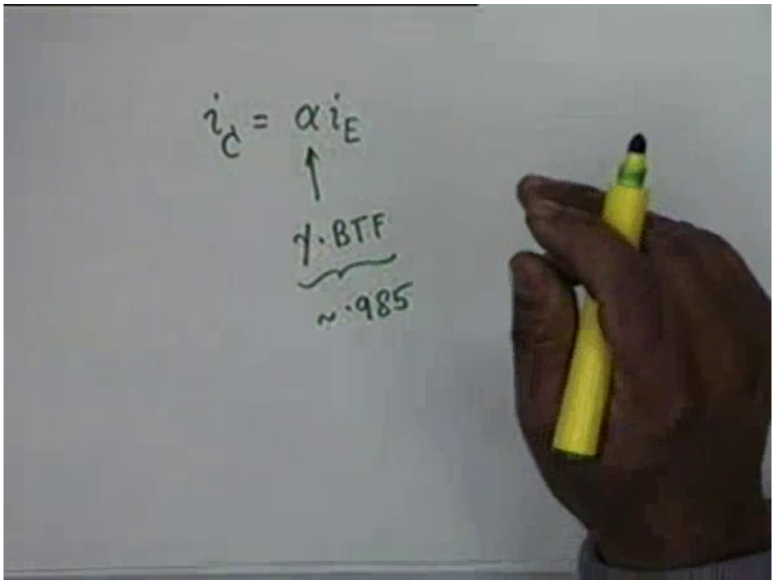

Let me change this slide, the collector current i C is a fraction of the emitter current Alpha i E where alpha is the product of, there are two reasons contributing to this constant alpha is a product of emitter efficiency and the base transport factor. And alpha in practice also is very close to unity because both these factors are close to unity and typical figure is 0.98 let say. 0.98 is not a very good transistors. It's more than 0.98 okay, may be 0.985 alright.

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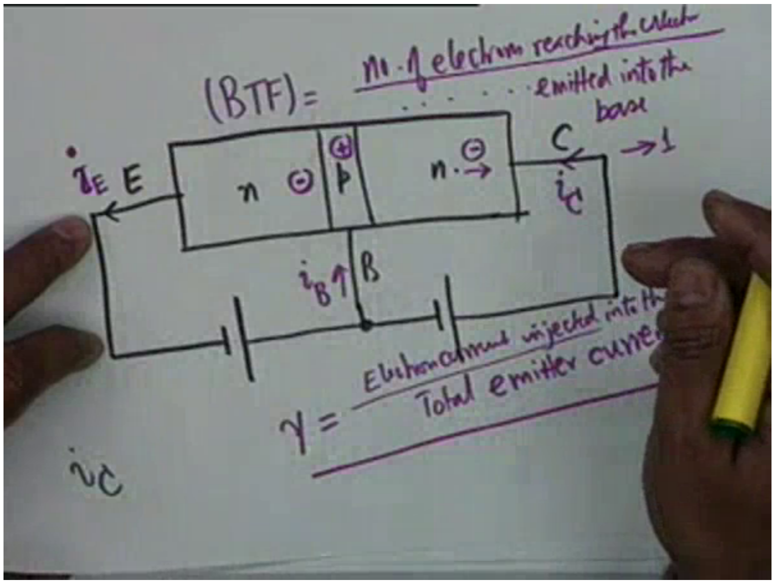

Now the question is this the only current that flows into the collector. Now you must realise that a collector base junction is a reverse biased junction and in reverse biased junction there is a current called the reverse saturation current and therefore the total collector current shall consist of not only the current due to the electrons emitted from the emitter but also the reverse saturation current.

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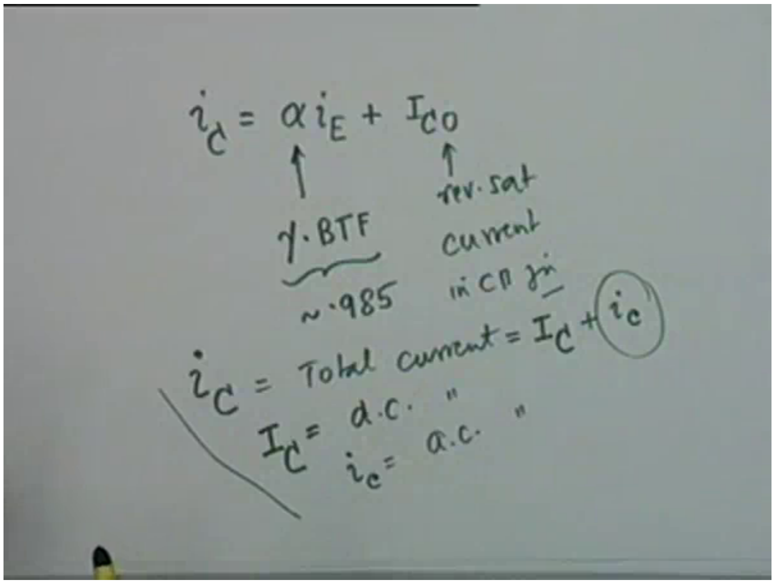

$i_C = \alpha i_E + I_{CO}$

α ↑ $\gamma \cdot$ BTF ~ .985

I_{CO} ↑ rev. sat current in CB jn

i_C = Total current = $I_C + i_c$

I_C = d.c. "

i_c = a.c. "

Which we indicate by I C O, this is the reverse saturation current in the reverse biased collector base junction okay. So this is the current relationship. i C the collector current is equal to alpha i E plus I C O. As a matter of notations let me clarify why I put these notations. What we will do is if I use a small symbol small case letter small i with a subscript of with a capital subscript like C then denotes the total current. On the other hand if I use a capital I subscript capital C then this is the DC part of the current. This is the DC current, this is the steady current and if I use small i subscript small c then then this is the AC part of the current the AC part of the current and therefore small subscript capital C shall be equal to capital I subscript capital C plus small i subscript small c. It is this part of the current which will be of interest to us throughout the duration of the course that is the incremental part.

It is necessary for a transistors to be biased at the appropriate q point or the operating point, to be able to to be able to function as a good amplifier or other device other application it must be biased appropriately and it is the incremental part of the voltages and current which shall be of interest. Nevertheless we shall use this terminology for for the rest of the course.

Student: Which thing are (())(11:23) as incremental (())(11:24)

Incremental is there is a DC current flowing into the collector if you introduce a small AC into a base region. For example a small base current in series with the base then there will be a corresponding change in the collector current. It is this incremental part. Increment means over and above the DC or quotient or q point of the transistors okay.

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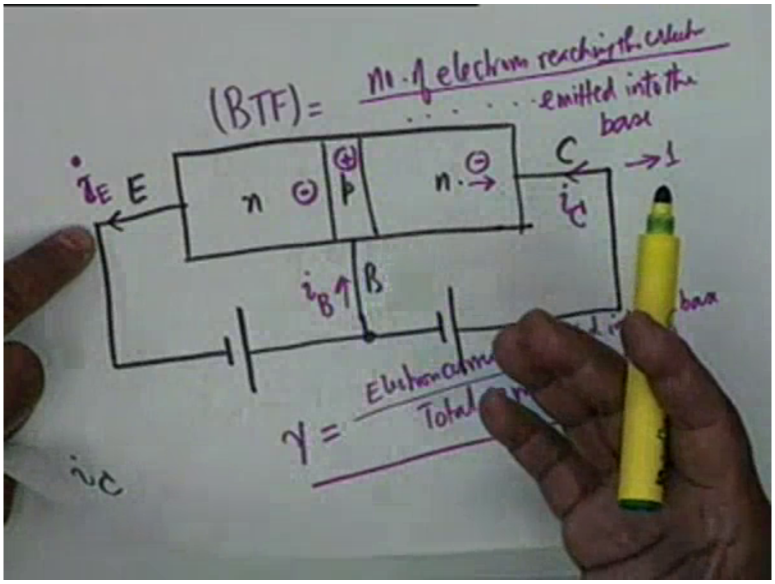

The other relationship that I get if you look at this carefully. i E it the sum of i C and i B okay. This is by KCL, the current that leaves must be equal to the total current that comes in.

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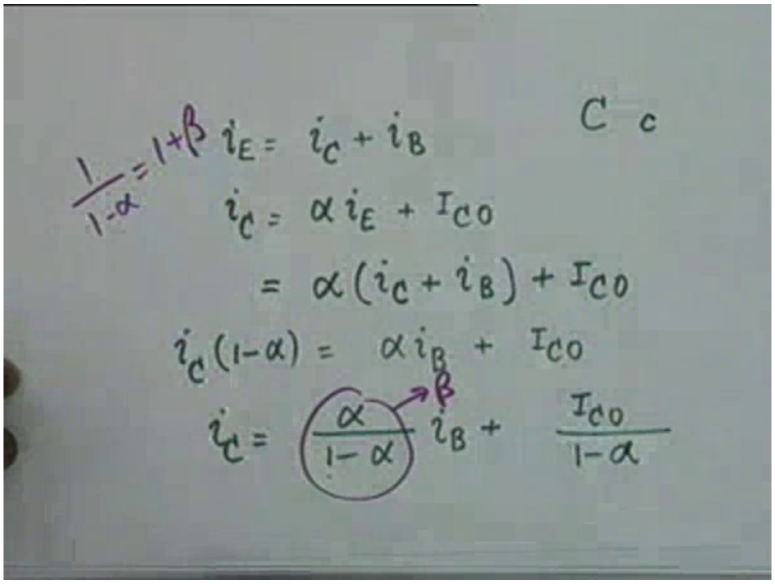

$$\frac{1}{1-\alpha} = 1+\beta \qquad i_E = i_C + i_B$$

C c

$$i_C = \alpha i_E + I_{CO}$$

$$= \alpha(i_C + i_B) + I_{CO}$$

$$i_C(1-\alpha) = \alpha i_B + I_{CO}$$

$$i_C = \overset{\beta}{\boxed{\frac{\alpha}{1-\alpha}}} i_B + \frac{I_{CO}}{1-\alpha}$$

And therefore I have two relations i E is equal to i C plus i B you must distinguish between cap and small. This I will write as capital C and this I will write as small c okay. The other relation is that i C is equal to alpha i E plus I C O this is reverse saturation current. If I substitute for i E here I get alpha i C plus i B plus I C O and it is very easy to see that what I get is i C 1 minus alpha this I have transferred this to the left hand side becomes equal to alpha i B plus I C O. In other words the collector current the relationship between collector current and the base current is that alpha by 1 minus alpha i B plus I C O divided by 1 minus alpha. And since alpha is very close to unity naturally this quantity will be very large.

For example if alpha is 0.98 when I get 0.02 here and therefore my this factor will be 49, is that correct? You can also see that 1 by 1 minus alpha can be written as 1 plus this quantity. So if I write this quantity as Beta then 1 by 1 minus alpha can be written as 1 plus Beta, agreed?

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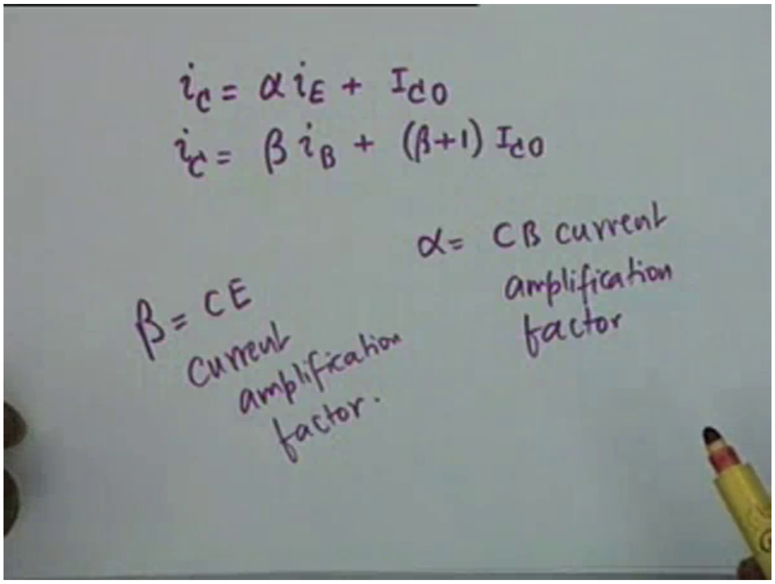

$$i_C = \alpha i_E + I_{CO}$$
$$i_C = \beta i_B + (\beta+1) I_{CO}$$

α = CB current amplification factor

β = CE current amplification factor.

Therefore my final relationship becomes i C is equal to Beta, i B plus Beta plus 1 I C O, okay. And as you can see you see that the previous relation was i C equal to alpha i E plus I C O. This is the relationship between the collector current and the emitter current. This is the relationship between the collector current and the base current. And as you can see either of them the emitter current or the base current controls the collector current and this the main feature of the solid state device called the transistor. You can also see that the slope of i C versus i E that is d i C d i E is simply equal to alpha. And therefore alpha is called the current amplification factor under common base connection. Alpha is the CB Common Base i E is the input and i C is the output the base is common. So it the CB current amplification factor. Amplification the term amplification is unfortunate here because alpha is less than 1. Nevertheless it is called amplification or gain whatever it is CB.

On the other hand d i C d i B is equal to Beta which is much greater than 1. And therefore Beta is called the CE Common Emitter. Emitter is common now. Base is feeding the output is the collector current. And therefore this is called the CE Current Amplification factor of the transistor. Beta is much greater than unity. As you can see the common base connection cannot give you a current amplification, common emitter can give you a current amplification. And Beta and Alpha are so related.

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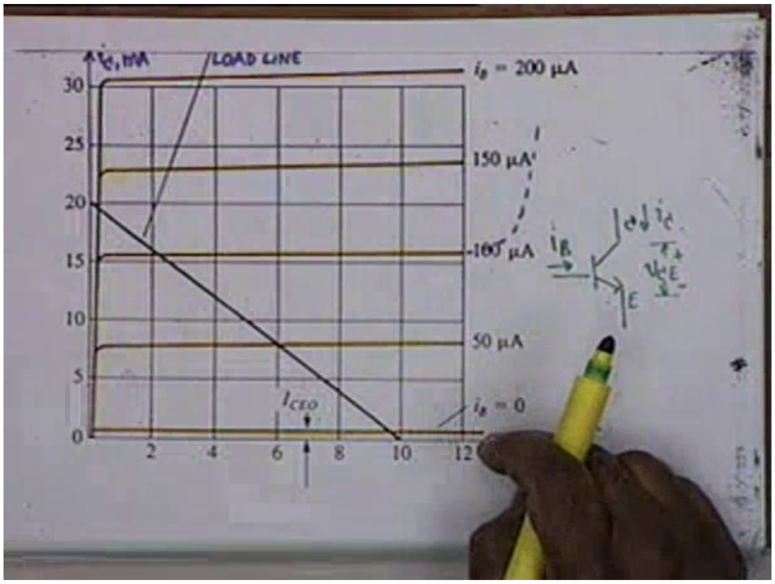

Now a typical transistors characteristics will look like this. Is the picture clear on the monitor. This is a typical transistor characteristics where what I plot i C the collector current is in milli-amperes versus V C E that is the let me put this here, this is E this is C and this the current i C this is the current i B okay and this is the voltage V C E plus minus okay. What we are plotting is the collector current versus collector to emitter voltage. And as you can see this characteristics i C versus V C E depends on what you inject at the base depends on what i B is. It is controlled by the base current. And as you can see as I increase i B the collector current increases.

For example take one typical example let say this curve for 50 micro-ampere 50 micro-ampere is the base current and with this current a constant if I vary V C E then the current gradually rises like this and then becomes becomes almost flat, alright, it becomes almost flat. And this happens at every values of i B as you go on increasing i B the collector current increases and can if you look at this characteristics, these are actual characteristics of 2 and 222 transistor. And as you can see the intervals that is at equal increments of the base current. 50 to 100, 100 to 150, the increment of the collector current is almost the same. Which means that these curves are parallel to each other and it is this parallelism an equal increments for equal base current increment that gives you a linear amplification. The transistor is a highly non-linear device. It a diode at the input it is a diode at the output. The diode characteristics are non-linear. But overall characteristics of the collector current collector to emitter voltage is such that it can be used a linear amplifier.

For example if I if my operating point is somewhere here let say and I increase i B by 50 micro-ampere and decrease i B by 50 micro-ampere it is the same change in the collector current which means that there is a linear amplification. Now let's have a things to be noticed namely, that for if i B if there is no injection if there is no injection at the base, if the base current is 0 then the collector current is approximately equal to 0, because it is a base current which controls the collector current.

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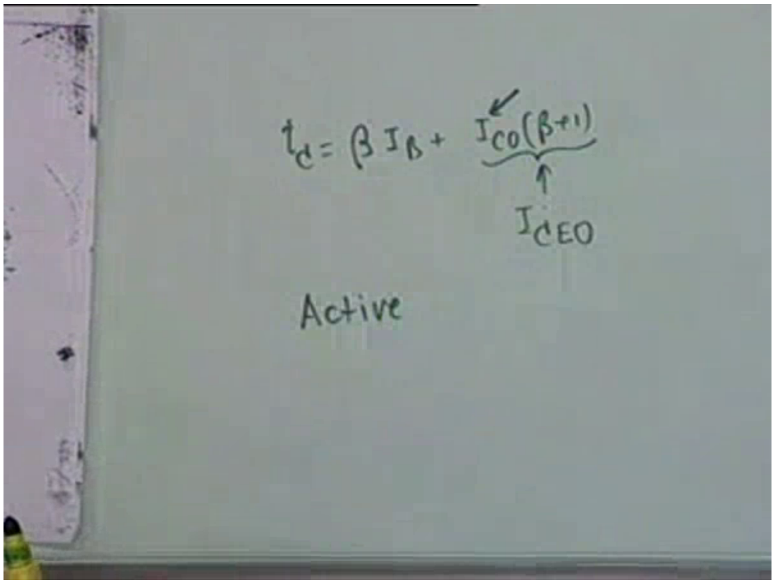

$$i_C = \beta I_B + \underbrace{I_{CO}(\beta+1)}_{\uparrow\ I_{CEO}}$$

Active

And you have also seen the relationship that is i C is equal to Beta i B plus did I introduce this term I C O Beta plus 1, this is usually called I C E O, this is the name given to it. Normally I C E

O is a very small quantity. I C O is of the order of micro-amps a few micro-amps. Beta plus 1 may be typically 50, so this is of the order of 50 to 100 micro-amps, that's about it. On the hand i C is he order of a milli-ampere or more. And therefore this term is usually negligible. So the relationship that is valid is i C equal to Beta i B. And when this relationship is valid we call we call transistor to be working under active region. The transistor is said to be in the active region.

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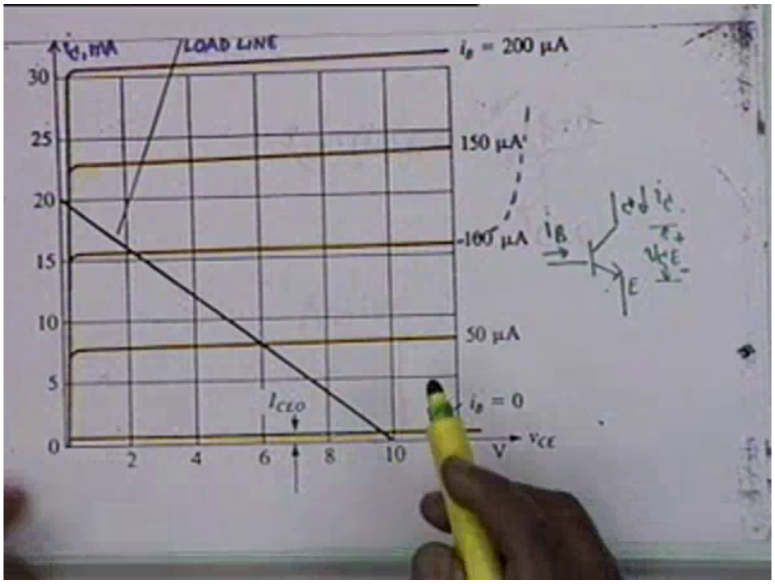

If you look at this characteristics the active region is contributed to by the region of the characteristic in which equal increments of i B lead to equal increments of i C that is this parallel lines. Naturally the rising portion of the characteristic is excluded from the active region. In other words the active region is excluded active region is bounded by this line. It is also bounded by this line, because if i B is 0 on negative then the transistor doesn’t come back. This current that flow you have only I C E O which is 10s of micro-amperes alright. This is not the current that we want. We want a much larger current. So if I if I if i B is negative then of course the collector current will 0. If i B is 0 a small current flows which is of no concern. So this line is called the cut-off line. When the transistor is operating under such conditions it is said to be cut-off.

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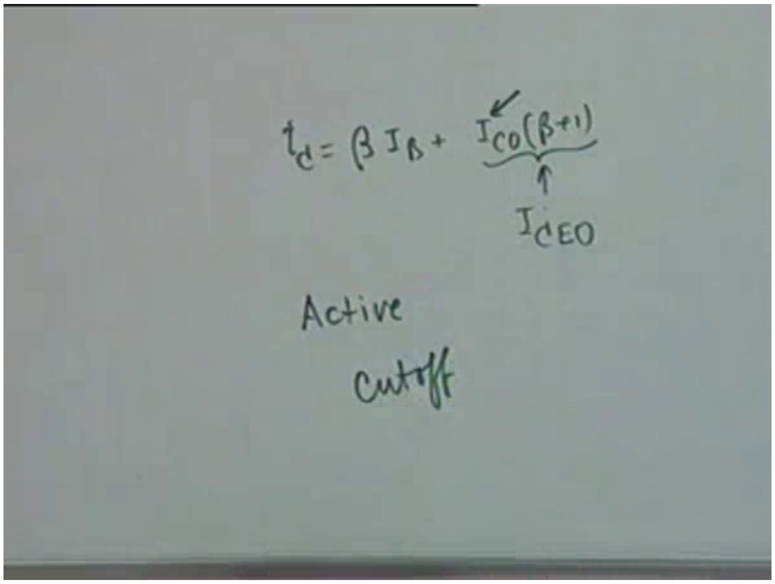

$$i_C = \beta I_B + \underbrace{I_{CO}(\beta+1)}_{I_{CEO}}$$

Active

Cutoff

So I have defined an Active region and the cut-off region.

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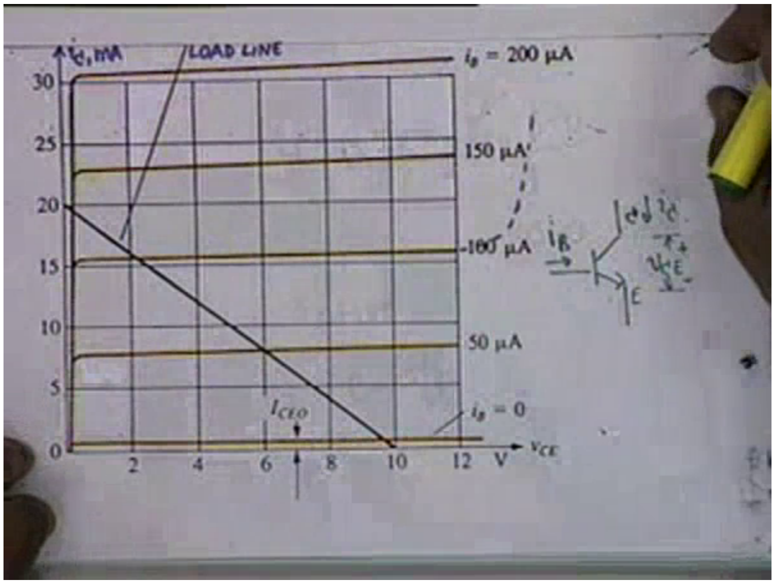

Obviously the active region is bounded by this line and this line okay. Is there a third bound. The question is, is there a third bound? Third bound comes because if you remember i C versus V C E while collector base junction is also a diode. A junction diode which is reverse biased. And V C E is reverse biased. And therefore I cannot continue to increase V C E without destroying the device. There will be some point of V C E at which the current will try to rise. Current will start rising very fast in other words the collector junction will breakdown. And when it breaks down obviously this parallelism and this nice relationship between i C and i B will not be valid. And therefore the active region is bounded by the cut-off line. This line which I shall come to in a minute. This line is called the Saturation Line Saturation Line. And the breakdown region on the third side, on the fourth side it is bounded by what load you apply. For example if a load is such that the load line is this, then the upper limit is this upper limit is this.

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Now what the load line is load line, if you remember the collector will ofcourse be connected to a positive supply through a resistance. Let's say R L or R C call it a collector resistance. When it goes to a positive supply V C C. And therefore if this grounded and this is V C E small v then V C E is equal to V C C minus this is the collector current i C small i C minus i C R C. This is very simple, the collector emitter drop is the supply minus the drop in the collector resistance alright.

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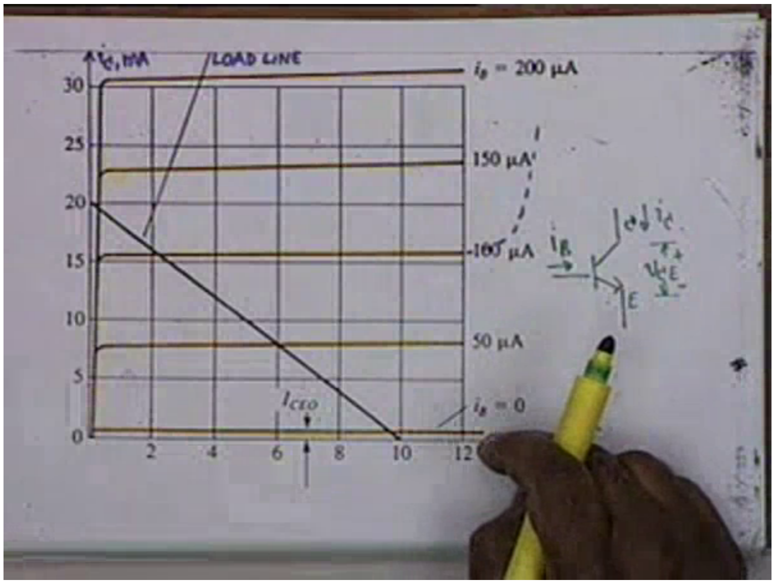

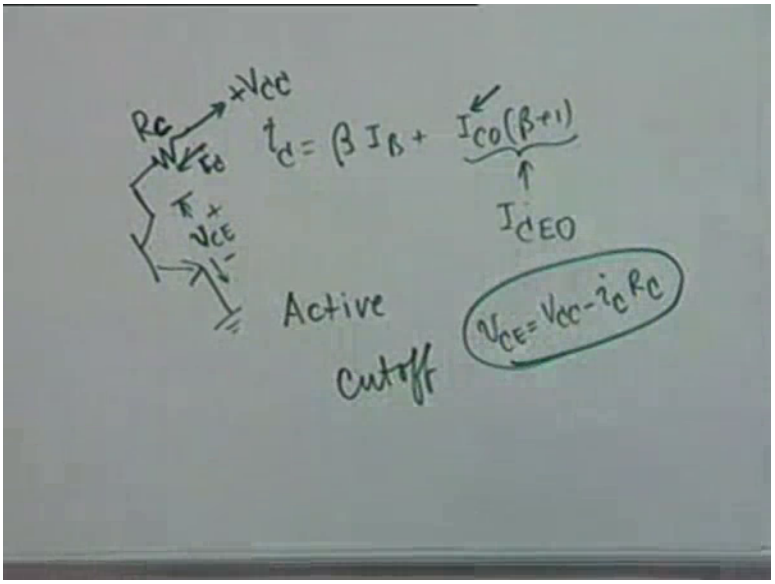

This equation when plotted on this graph gives what is called a load line.

This equation is plotted here for example when V C E is equal to 0 V C E is equal to 0 i C is V C C by R C.

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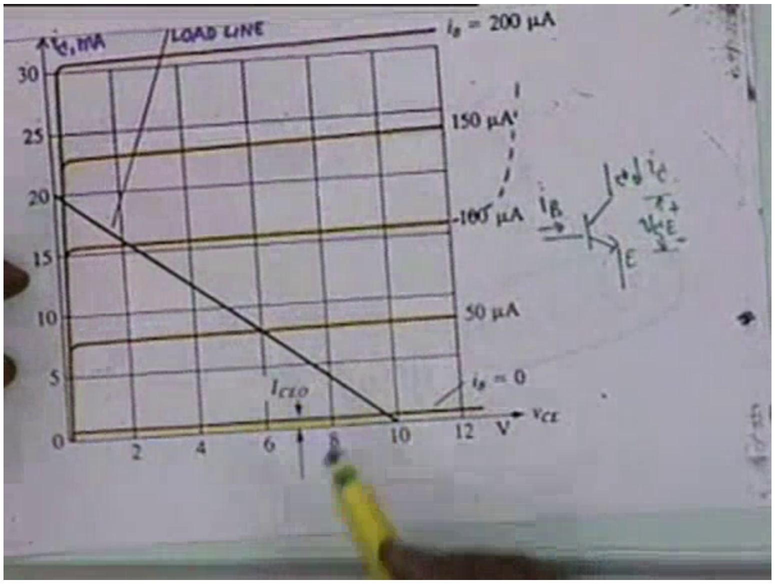

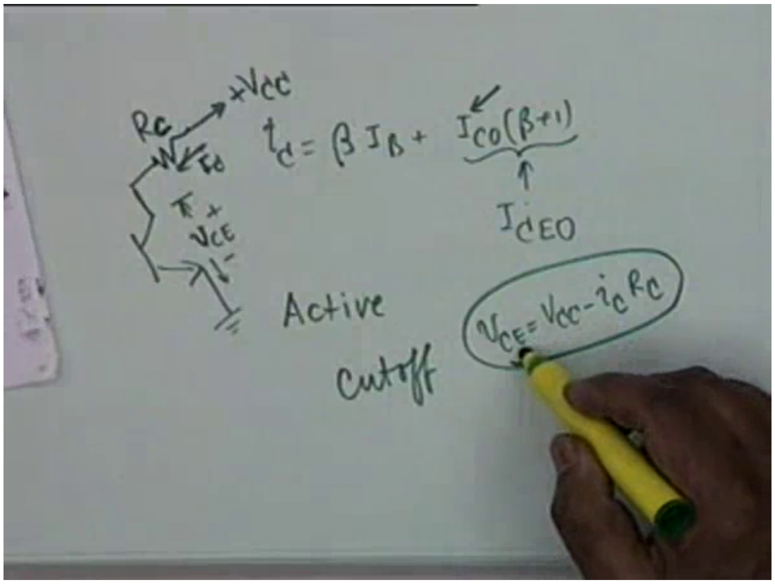

This is the point, when V C E is equal to 0. On the other hand when i C is equal to 0 V C E equal to V C C.

So here the supply can immediately be read. What is the supply here? 10 volts okay. So this is the load line. So the upper limit, upper limit is settled by the load line nothing else alright. The lower limit is set by cut-off, the left hand vertical limit is set by the saturation line. And the right hand line, right hand limit is set by breakdown. Bounded by this this 4 lines we get the active region and this is the region of interest as far as this course is concern. Nevertheless we shall threw example which will illustrate what happens under cut-off what happens in saturation and so on and so forth. But you must remember that it is this large region of the characteristics which we are concerned with in which the lines, the lines of i C versus V C E for a fixed i B is a parameter now. For a fixed i B, when these are parallel this is the region that defines our region of interest. We are not interested in other regions. Other regions will be taken care of in the Digital Electronics Class or non-linear transistor circuits.

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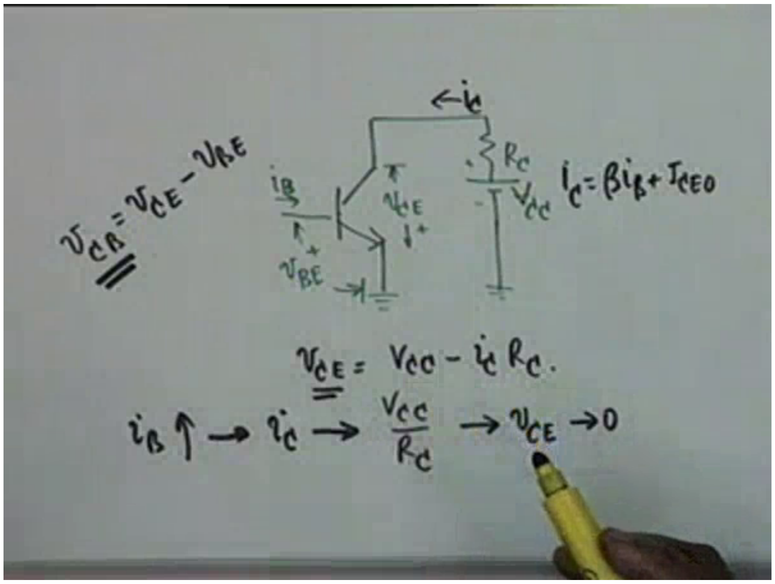

Let's now explain what this line corresponds to and why do we call it a saturation line. Let's look at a typical transistor circuit. This is an npn transistor npn because here it points out. And I said there is an R C and there is a plus V C C. V C C is the positive supply. And this goes to ground this goes to ground. V C E and this is i B this voltage is V B E okay. V B E as you see in the active region shall be taken as how much 0.7 if the transistor is silicon not otherwise. And it is silicon transistor which is mostly which is mostly used these days we don't use any other transistor okay. Now if you look at this obviously V C E is equal to V C C minus if this current is i C minus i C R C okay.

And we also know that as we increase i B the collector current i C increases, because i C is equal to Beta i B plus I C E O alright. Now question is how long can we increase i B how long can we increase, how much can we increase i B now as i B increases i C increases so V C E decreases isn't it right? And the maximum i C that we can get from the circuit is V C C by R C. That is when i C, when i B increases i B increases i C turns to V C C by R C and if that happens then that leads to V C E turns to 0 right? Okay if that happens, if V C E turns to 0 this voltage turns to 0. Then what will happen is V C B that is the voltage between the collector and the base which I can write as V C E minus V B E agreed? V C E turns to 0, then V B E is left with 0.7 and therefore V C B becomes negative, what does it mean? If the collector base junction is negative, then the collector base junction becomes forward biased alright.

So it is this external circuit which under certain conditions can dictate the biasing of the 2 junctions. The emitter base junction is forward biased if the collector based junction is also forward biased then you see V C E turns to 0 and saturation of current occurs. The current cannot exceed beyond this alright? Current cannot exceed V C C by R C and therefore this is called the saturation region. And under saturation conditions, V C E it is found cannot exactly reach 0. It saturates at the value 0.2 normally.

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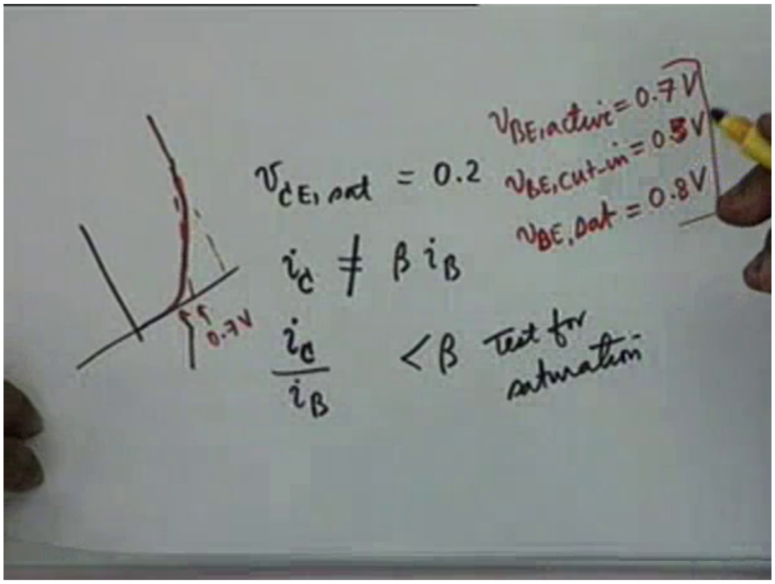

$v_{CE,sat} = 0.2$

$v_{BE,active} = 0.7V$

$v_{BE,cut\text{-}in} = 0.5V$

$v_{BE,sat} = 0.8V$

$i_C \neq \beta i_B$

$\frac{i_C}{i_B} < \beta$ Test for saturation

So our V C E Sat is equal to 0.2 of the order of 0.2 okay. V C E under saturated conditions. And you must remember the collective current cannot go beyond V C C by R C. Now what will happen if I continue to increase i B. I continue to increase i B i C is saturated at V C C by R C so this relation i C equal to Beta i B shall no longer be valid okay, shall no longer be valid. Because i C has reached a saturation. In fact one of the tests for saturation is i C by i B shall be less than Beta. This is test for saturation. When the base current is very large that the collector is not able to cope with it in a linear manner this is the onset of saturation. And when saturation occurs the base emitter voltage V B E. V B E (())(31:14) has a limit because after all you remember that the diode characteristics is like this okay, it cannot go beyond a certain voltage. And what we do is, now you must be careful. What we do is as I said for making a model we take this as 0.7 volt. That is the linear approximation to the characteristic cuts the voltage axis at 0.7.

So we take V B E note this carefully, V B E active as equal to 0.7 volt. V B E active is 0.7. Then in describing transistor action we must also we must also take care of the voltage at which the diode just starts to conduct because there are circuits in which the regeneration is automatic, digital circuits, logic circuits for example. And the voltage at which the emitter base junction just starts to conduct is called the V B E cut-in. That is it was cut-off earlier now it is cut-in. This is taken as 0.5 volt. These are gross figures used for silicon transistor, there may be small variations. For example instead of 0.7 the actual value could be 0.65, instead of 0.5 the actual value could be 0.6. And you see when the transistor is saturated V B E Sat when the transistor is saturated this voltage after all cannot exceed a certain value. And this value is taken as 0.8 volt V B E Saturated. So under saturated condition of a transistor hmm V C E Sat is 0.2 V B E Sat is 0.8 V B E Active is 0.7 and V B E Cut-in is 0.5. These figures you must remember. In actual transistor case, there may be small variation, this will be specified by the manufacturers but if nothing is specified these are very good figures to take and designs based on this, after all no design made on paper is going to work in the laboratory, you have to make adjustments. And therefore this are good figure to start with you design the circuit (())(33:52) up and then you make small adjustments here and there to get what you want okay. That's a fact of life.

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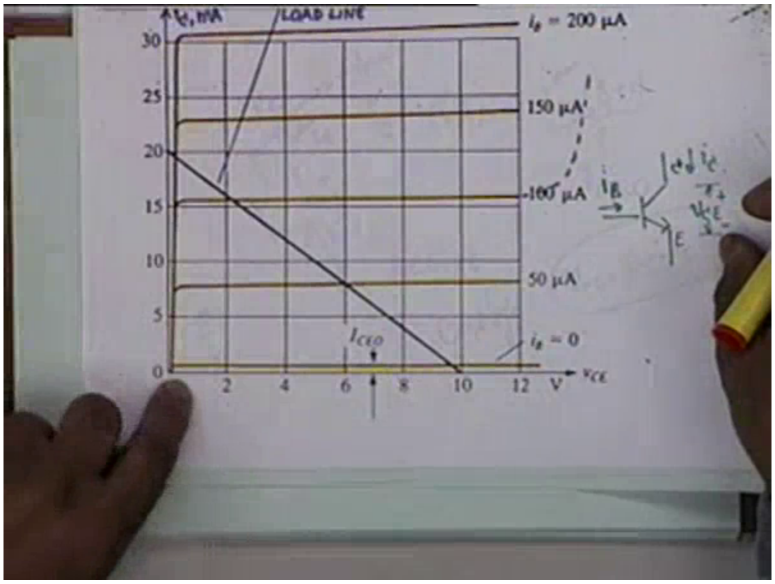

To understand what I mean by saturation, it's very important to understand. This is the saturation line, and saturation occurs from V C E is very small tends to 0 and this value is taken as 0.2. In the ideal case we will not take this line as incline. In the ideal case we will take it to be vertical. We will take it to be as vertical, parallel to the i C axis starting at 0.2 volt okay. Now therefore one more thing that I want to point out in connection with this. If you notice carefully, these lines are not absolutely parallel to the V C E axis they are slightly inclined. It's not quite saturated, there is a small increase in collector current as you increase V C E. All of these lines in fact, you see that the difference here is not the same as the difference here. So there is a slight inclination and this happens because with increase of V C E the base region the base region becomes thinner and thinner. The depletion region extends right into the base and it becomes thinner and thinner.

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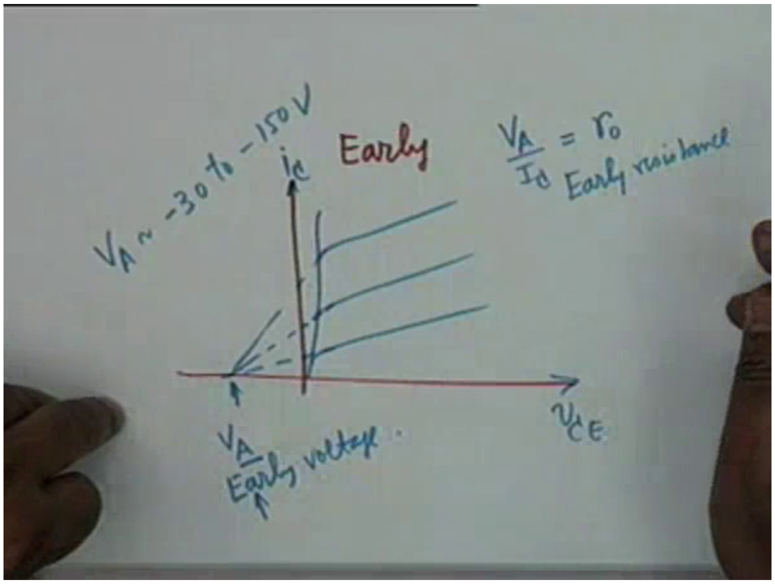

And this was first discovered by a gentleman called Early and this is why this is called Early Effect, it was discovered very early in fact. It is not been taken care of so far. How to take care of this is the following. Suppose you have a characteristic like this. I am showing and exaggerated picture, I am showing this inclination in an exaggerated manner. Now if I extent, it is also shown by Early. It is very interesting and very elegant geometrical figure. It was shown by early that if I increase if I extend this on the left hand side this is i C versus V C E characteristic okay. And if I increase, if I extent all of these lines to the back it turns out that they meet approximately at the same point. It's a very interesting discovery, so this point the value of the voltage, this is V C E axis it's a negative voltage. The value of the voltage was called V A and it is called the Early Voltage.

The discovery is that not only this curves are not parallel to V C E axis but if you extent them backwards then they meet at a certain point on the V C E axis and this the value of the voltage here in order to honor Early is called the Early Voltage. We should have used V sub capital E because E is the first letter in Early but V E is unfortunately used for emitter voltage, therefore we end up with the next letter A, is that clear. V A is the Early voltage and typically V A is of the order of minus 30 to minus 150 volts okay. And you see this current, this ratio V A by I C at a particular operating point is is the dimension of resistance. And this is denoted by r 0 and this is called as Early Resistance Early Resistance. This resistance is useful in the transistor modelling. It is not only the ratio of V A to I C but it is also the slope of this line. The slope of this line is R 0, is that clear. The reciprocal of the slope. Don’t agree with me on all (())(38:12) It's d V C E over d I C. So this resistance will be useful in the AC modelling of the transistor. Now I have to do something else. This is as far as the collector base junction is concern. Let's look at the emitter base junction, that is the input junction.

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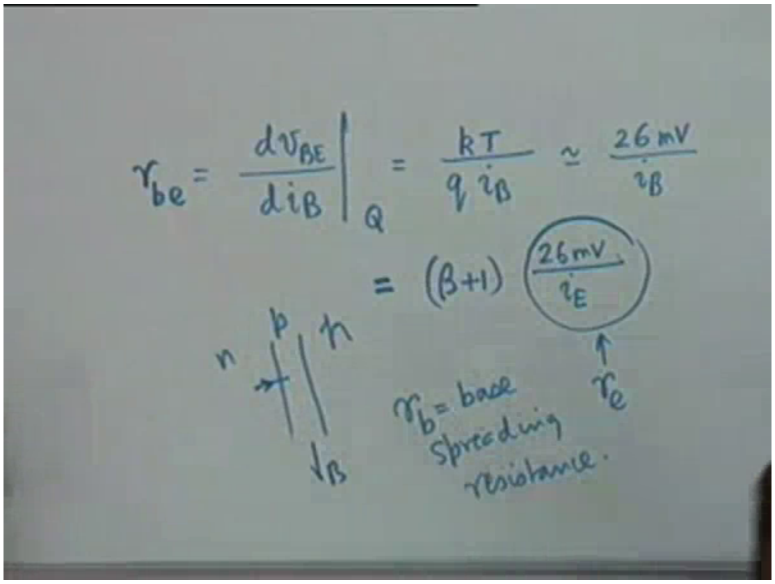

$$r_{be} = \left.\frac{dv_{BE}}{di_B}\right|_Q = \frac{kT}{q\,i_B} \simeq \frac{26\,mV}{i_B}$$

$$= (\beta+1)\,\underbrace{\left(\frac{26\,mV}{i_E}\right)}_{r_e}$$

r_b = base spreading resistance.

In the input junction if I take the ratio d V B E d i B at the Q point the emitter base junction is a diode, and therefore this slope would be given by if you remember kT by q i B this resistance is the resistance appearing between base and emitter and therefore it is denoted by R B E base and emitter, not these symbols. This is small b small e which means that it is the incremental resistance okay, incremental resistance. Now this is kT by q and you know kT by q is approximately 26 milli-volt. So this is of the order of 26 milli-volt divided by i B and i B as you know is given by i E divide Beta plus 1 times 26 milli-volt divided by i E or i C if you so desire, because they are approximately equal they differ only by I C O.

Now this resistance obviously is the resistance which is faced at the emitter terminal and therefore this is denoted by r E at the emitter terminal. As if i E is the input current to the diode, then this is the resistance that you face. You see the difference of resistance r B E and r E occurs because they reference current in once case is i B and the reference current in the other case is i B they differ by a factor of Beta. Actually Beta plus 1 but Beta is very large so Beta plus 1 is okay. Therefore in AC modelling of a transistor between the base and the emitter you need a resistance r b e. In addition however thin the base may be any electron current any current that is to come to the base region, that is to come to the base, let say this is npn.

Any current that is to come to the base has to traverse this width of the base, the physical fabrication physical parameter is such that the width of the base has to be traverse by any current that comes here. And the resist the resistance of this this thin base region comes into effect and this resistance is called r b and is called the base spreading resistance. Now conceptually this is the matter. This is that any current coming to the terminal base terminal must go through the width of the base and that resistance will have to come into effect whereas r b e is not a physical resistance of a material, it is noted as L by A. It is the resistance occurring because of the junction, because of the semiconductor junction because of the semiconductor junction diode.

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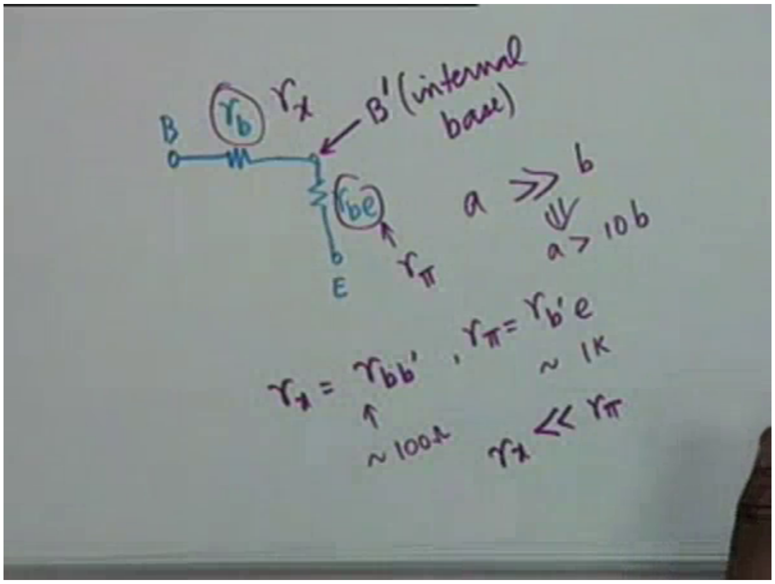

And therefore if base is this terminal and emitter is this terminal and emitter is this terminal. From base to emitter it's not simply r b e I am talking of AC it first comes with r b that is the physical resistance of the base it's called base spreading resistance and then from this point to emitter is r b e and therefore between base and emitter there are two resistance in series one is due to the physical resistance of the base region and the other is the diode resistance diode dynamic resistance r b e. And for the reasons to be made clear later and for simplicity and for uniformity we shall denote this resistance by r x. In our circuit modelling in the analysis of transistor and all that and this resistance we will call as r pie to simplify notations. This is r x, this is r pie and this hypothetical node is called the internal base and it's denoted by B prime, this is called internal base and is denoted by B prime.

So some textbooks instead of r x they use r b b prime that is between the actual base terminal external base terminal and the internal hypothetical base r b b prime and sometimes textbooks use instead of r pie they use r b prime e. Now r b prime e is of the order of a K 1 K. Whereas the base spreading resistance is usually a very small quantity of the order of 100 ohms. There must be there is at least a 1 order magnitude difference between r x and r pie and you know in electrical engineering if any quantity is greater than another quantity by a factor of 10 we say the former is much greater okay. Much greater sign a much greater than means, much greater than b means that a is greater than 10 times b. So r x is usually taken as much less than r pie. And in circuit modelling to keep life simply we usually ignore r x not always. There are situations when r x cannot be ignored and we have to take account of r x.

Student: Excuse me sir

Professor: Yes

Student: How about the emitter resistance, is it much more smaller than the other resistance?

Professor: This is the resistance.

Student: Sir r e

Professor: r e is the relation between r e is r pie is obvious.

If it is a common base circuit if the emitter is the input and base is common then the resistance that will come between emitter and base would be r e and this will be beta plus 1 times r pie okay. So r e and r pie are very simply related.

Student: Sir what about the physical resistance of ohmic resistance.

Professor: Physical Resistance…

Student: Physical resistance of the emitter, like you called the physical resistance of the base, what about the physical resistance of the emitter.

Professor: Well that doesn’t come into consideration, because this is already taken care of by the current voltage relationship of the diode. You see in the base it matters b it's a very thin region and much less heavily doped than the emitter region. Emitter region is very heavily doped because it is to emit.

Now if you area heavily doped if you make the doping as n plus and you know that the number of carriers available is very large. If the number of carriers are very large then the resistance goes to 0. It can conduct very well and therefore the emitter bulk does not offer a substantial resistance. On the other hand the collector bulk does offer a resistance. This was already explained r 0 small r 0. Which happens because of the Early effect because it's a it's less heavily doped than the emitter. So the emitter region does not contribute to a bulk resistance, is the point clear.

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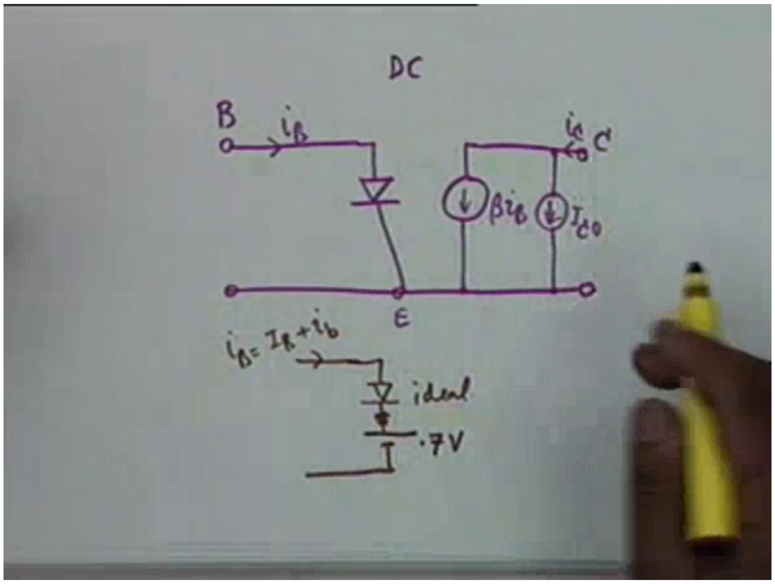

Okay now the DC model therefore that we shall be using for a common emitter transistor would look like this, we have a base, we have a collector and we have an emitter. Between the base and the emitter, DC model what we have is a diode okay and between, alright let me extend this. Between the collector and the emitter we have a current, if this current is i B then the collector current consist of 2 component, 1 is beta i B and the other is I C O and this is my i C, this is the DC model that we shall be using for a common emitter Bipolar Junction Transistor. If you so desire this diode can be replaced by and ideal diode. You must write ideal and what else a 0.7 volts battery. This is as far as DC is concerned. When it is AC we shall replace this, we shall include we can replace the ideal diode by a short circuit the 0.7 volt with a short circuit and we shall include a resistance which is equal to r pie agreed?

Now as far as the…

Student: Excuse me sir, if this is a DC model then why are we taking and incremental value of i B we should take only the DC value.

Professor: We have taken the DC value.

Student: Symbol used is like…

Professor: That is only for AC, that is why there is an increment here as far as the increment is concern, suppose okay I get your point. Suppose i B equal to I B plus small i b when as far as if small i b is 0 then this is the model if small i b is there then in addition because both of these will be short circuits in addition we will have to consider a small resistance which is the incremental resistance okay.

As far as the output circuit is concern where for DC for DC this is the circuit but for AC which will disappear, will both of them disappear?

Student: IC

This will disappear but Beta i B shall remain because beta is the slope d i C d i B agreed?

Student: Yes Sir.

Professor: Okay

And in addition for AC there shall occur a resistance from collector to emitter and this resistance is the Early resistance, is it okay?

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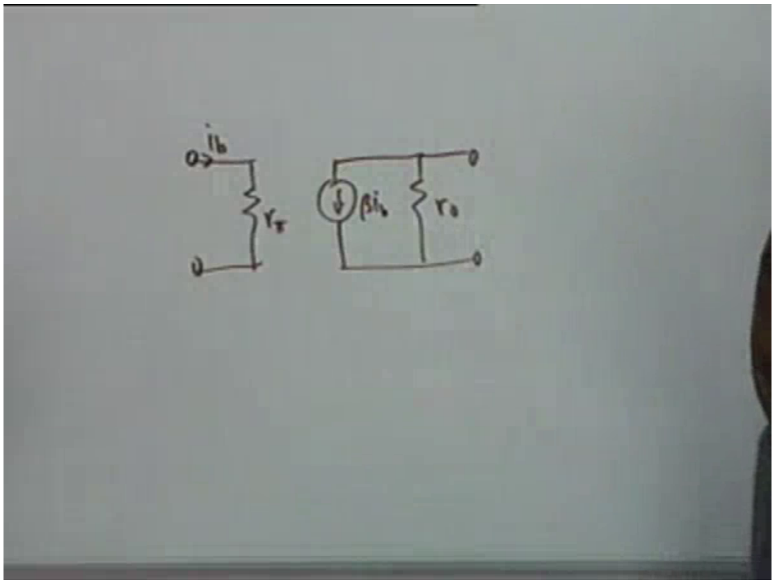

So AC model would be r pie if ignore r x or if you don't want to ignore r x then you put r x in series and you have beta i B in parallel with r (())(50:43) this is AC model, provided a transistor is at the appropriate operating point okay.

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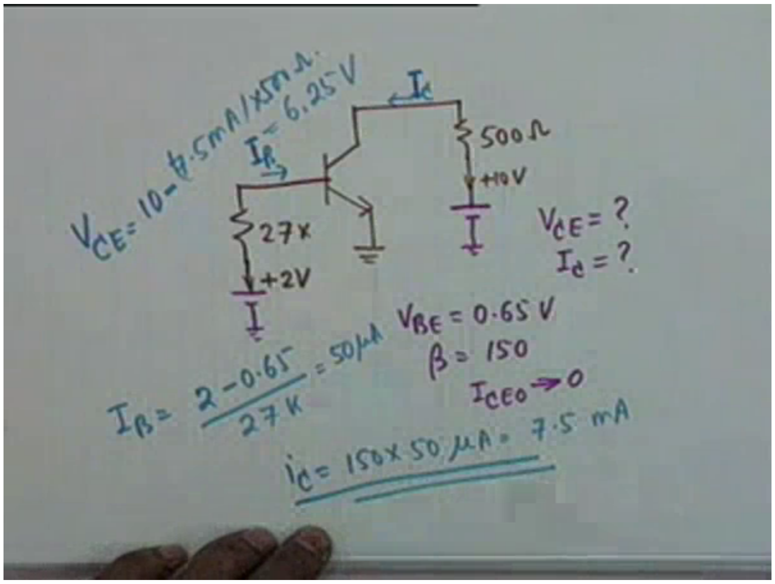

We can take a quick example to illustrate this. And this example is a common emitter transistor and a resistance 27k in series of the base then a battery of plus 2 volt. This supplies the base current. And we have a resistance of 500 ohm in series of a plus 10 volt and this is grounded. What this means is that there is a battery 10 volt here, the negative terminal of which is grounded. Similarly here there is a battery of plus 2, the negative terminal is grounded. The question is to find out the V C E now I have use capital V sub C E which means that the DC operating point V C E and I C. It is given that V B E is equal to 0.65 volts, not exactly 0.7 slightly less than 0.7. 0.65 volt, it is given that beta is equal to 150 a large value and that I C E O can be ignored. I C E O tends to zero the question is to find V C E and I C alright.

To solve this problem what we do is we first find out I B capital I sub B DC conditions okay. I B obviously would be equal to 2 volt minus this voltage minus 0.65 divided by 27k and this comes out as 50 micro-amps. If you know this then you can find out I c. I c is beta times so 150 multiplied by 50 micro-ampere, this is equal to 7.5 milli-amps. And we know I must use I c and therefore you can find out V C E that would be equal to V C C 10 minus 7.5 milli-amps multiplied by 500 ohms. And this comes as 6.25 volts. We have solved the problem. Suppose a question, suppose this voltage came out as 0.2 what would have been your conclusion?

Student: Parallel saturation condition.

Professor: That the transistor is in saturation. If it is anywhere close to 0.2 even 0.3 or 0.4 you must look up on all these calculation with suspicion because V C E Sat is not exactly 0.2 it might go on the other side. But if it is 0.1 then you definitely know that it is in saturation. If it is in saturation then obviously this utilizing this relationships is suspect. You cannot use this I C E equal to beta times i B. We will continue second part of this problem tomorrow.