Analog Electronic Circuits
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Lecture No 05
BJT Biasing and Bias Stability

This is a 5th lecture we start BJT biasing and bias stability. That biasing is a very important phenomenon. For using a device as an amplifier can hardly be over emphasized.

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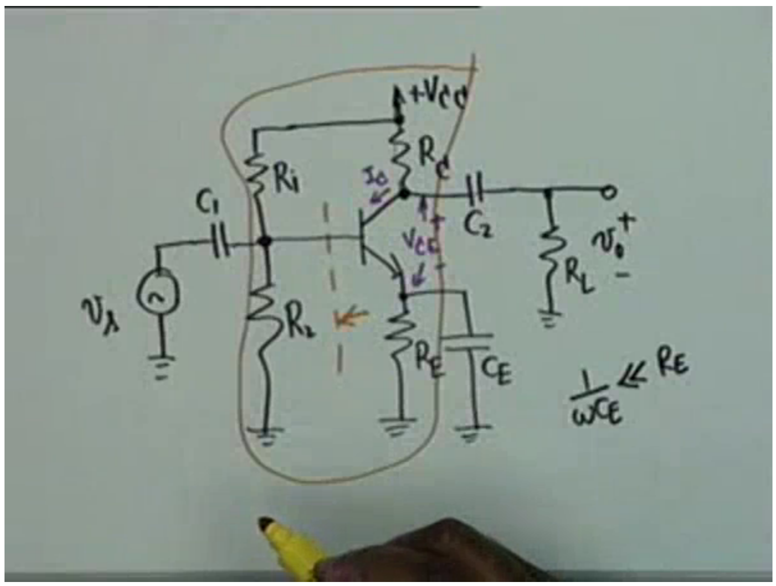

And the discussion we shall make with regards to a common emitter amplifiers. But the principles shall be applicable everywhere a common emitter. A common emitter BJT amplifier typical circuit is this you have an R E and R E is usually bypassed to ground by a capacity C E the collector is connected to a resistance R C collector resistance that to power supply plus V C C. And the base biasing the base current is provided from the same supply with 2 resistances with a potential divider. We call traditionally we call this resistance as R1 and this resistance as R 2. Obviously this is an npn transistor. And the signal is applied the signal to be amplified is applied through a capacity C 1 to the base circuit, this is the signal to be amplified V S and the out is take from the collector through a decoupling capacity C 2 to whatever the load is R L. So this is V S and this is the AC for the signal output.

You know the purpose of these 2 capacitors C 1 and C 2 are to decouple DC to AC. What we want is that the DC from here should not pass through the signal source. You see what is the internal resistance of this source? If you say voltage generator then the internal resistance is 0. Say it loud why are you so afraid, if you're wrong I will correct you. Okay so if this capacity is not there, then obviously R 2 will be short circuited isn't it right? If this capacitor is not there, the internal resistance of the source is 0 therefore R 2 will be short circuited. And therefore the base will be connected to ground. And the transistor would be off, it cannot be in the active region.

So the capacity C 1 decouples DC being short circuited. Sorry if the capacitor C 2 is not there then the current the current through R C will partly flow through to the collector and partly through R L we don't want that. For example this R L could be a loudspeaker. The load could be a loudspeaker. If it is an amplifier audio amplifier it could be a loud speaker. If it is a loudspeaker and a DC passes through a loudspeaker the magnet may get into saturation and therefore it may not respond to this signal okay. We don't want DC to pass through the load also if the load varies then the collector current shall also vary. If R L varies then the proportion by which I C and I L change that will change and therefore the biasing point shall also change. So this is a decoupling capacitor. This is another decoupling capacitor. These are facts of life you have to use them.

Student: Sir could you please (())(4:45)

Professor: Functions of C 1 and C 2.

C 1 prevents DC flowing through the signal source and C 2 prevents DC flowing through the actual load that's it. They decouple DC from AC. And the purpose of C E the third capacitor across the emitter resistance is to act as a short circuit to AC. As far as DC is concerned R E is effective. There is a drop in R E but as far as AC is concerned we don't want any drop in R E so we bypass R E by a large capacitor. If 1 by omega C E the reactance of the capacity is much less than R E. Then whatever AC tries, whatever AC comes from the emitter will flow through C E not through R E so C E is effectively an emitter short circuit. It is a short circuit to R E it is also it is also called a bypass capacity that is AC doesn't not flow through R E it flows through the bypass. It's called a bypass capacitor.

Student: What is the use of R L in this, we can directly take the input from the (())(6:04).

Professor: Then DC as well as AC will come.

Student: No No No if we connect a capacity and we don’t connected R L then we take..

Professor: R L is not a matter of choice it's fixed for example let say audio amplifier R L is the loudspeaker, we have to pass the AC through the loudspeaker in order to reproduce the sound. It's not a choice it's not your choice okay. It could be that the output is (())(6:30) that is the load is infinite. For example if you apply this to an oscilloscope, while the effective input impedance is infinity. And therefore it could be open circuit, R L is not your choice R L is dictated okay.

Now the point is in order that this may act as a good amplifier you must choose these 2 quantities carefully that is one is V C E and the other is the collector current I C. V C E and I C this define the operating point of the transistor and this operating point must be chosen carefully. Let's look at the DC model of this amplifier and then see where should the operating point be. If notice carefully as far as DC is concern, we can forget about C 1 and V S, V C is not affected by this. We can forget about C E we can forget about C 2 and R L. Therefore as far as D C is concerned all that we have to consider is this resistance, let me use some other color. All that we have to consider is this part of the circuit okay. The rest of the circuit can be ignored as far as DC is concerned. Also you notice that V C C the voltage source is applied across R 1 and R 2. It is a potential divider, so if I apply thevenin theorem to the left of this line I can replace V C C R 1 and R 2 by an equivalent voltage source which is V C C R 2 divided by R 1 plus R 2 open circuit voltage source. And the effected resistance looking back which is R 1 parallel R 2 alright.

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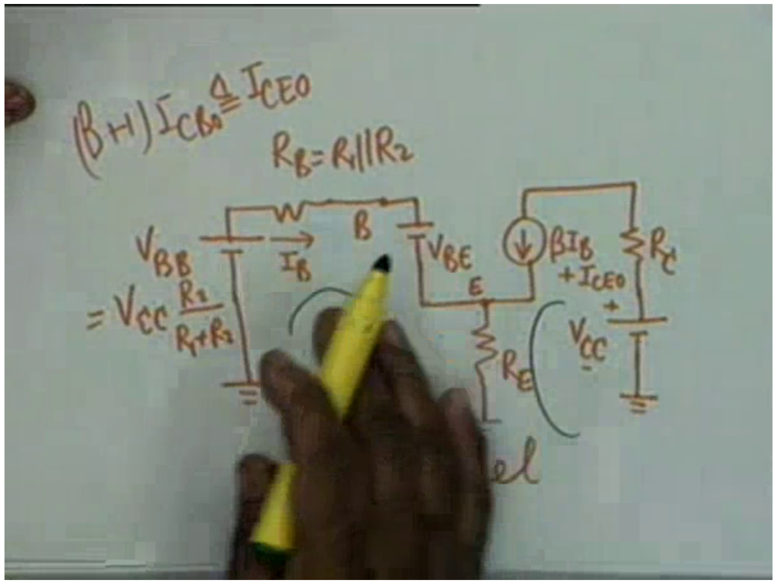

So if I do that if I do that then my equivalent circuit shall be V B B which is equal to V C C times R 2 divided by R 1 plus R 2 okay this is the thevenins source then a resistance R B which is R 1 parallel R 2 okay then we come to the base terminal. From the base to the emitter in the active region you know there is a drop of 0.7 volt. So let's call this as V B E 0.7 the numerical value we will come to later. This comes to the emitter. We are considering the active region so we're not using the diode. Ideal diode is the short circuit anyway okay. The transistor is in the active region and therefore all that happens is there is a drop V B E this is the emitter terminal.

The emitter goes to ground through the resistance R E this is effective in DC and as far as the collector circuit is concerned what we have is I C which is equal to Beta I B if this current is I B then Beta I B plus beta plus one I C O. I C O sometimes we call I C B O alright I C B O. So Beta plus 1 I C B O and you also know that beta plus 1 I C B O we denote by I C E O. So let's denote it by I C E O. This is the current generator. This is the effective collector current. And we of course have the resistance R C which goes to not ground it's the DC model, I wanted you to make this mistake yes, it was intentional V C C so this is V C C plus minus that goes to ground the negative terminal okay. So this is my DC model of the common emitter PNP transistor amplifier. And now there are two loops in this circuit. I can write one loop equation here and the other look equation here okay. Let's look at this loop equation. The first loop the loop to the left.

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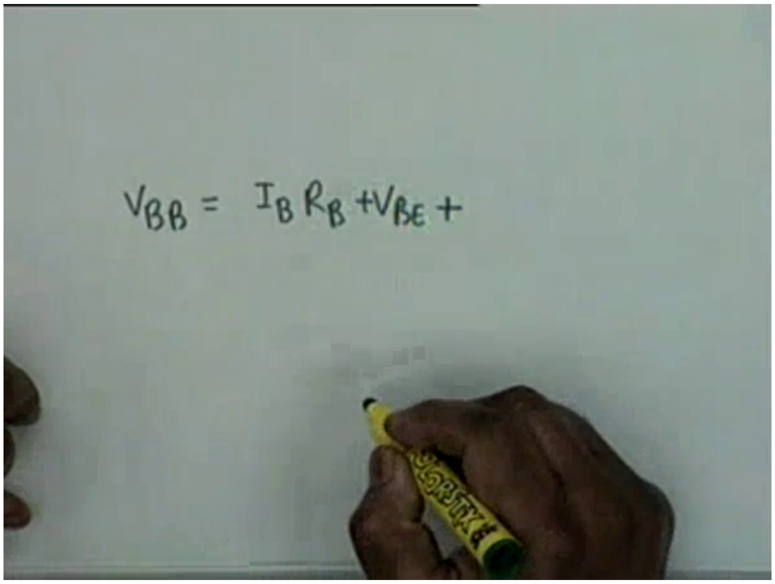

You notice that I can write V B B as equal to I C times R B this is the drop in the resistance R B which is the parallel combination of R 1 and R 2 plus V B E plus the current through R E. let's look at this current.

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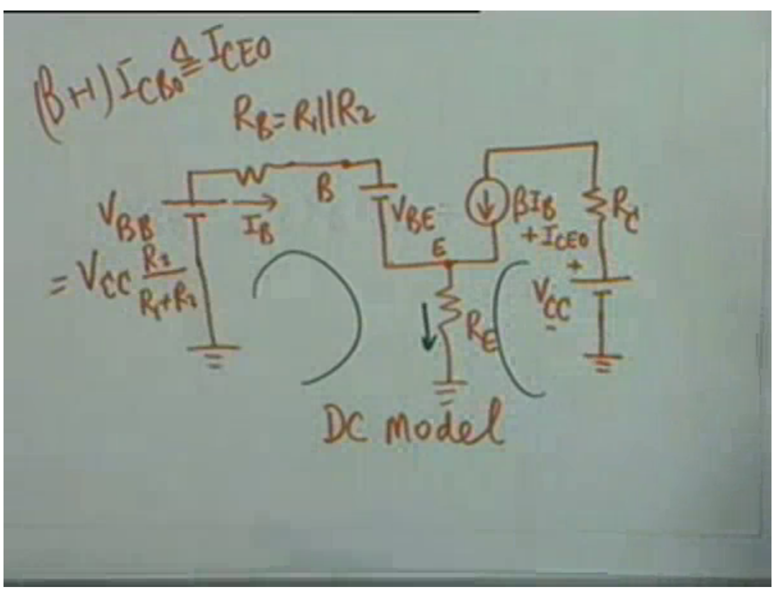

This current is the sum of I B and this current beta I B plus I C E O alright.

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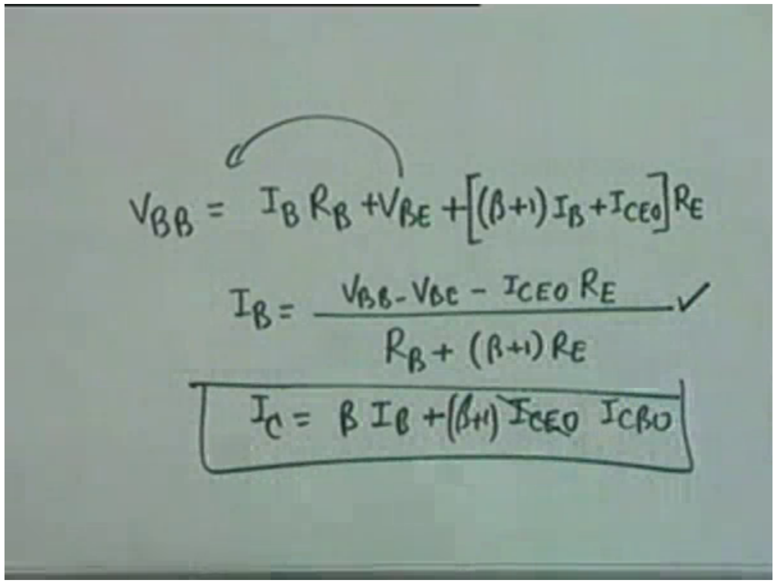

So the current is beta plus 1 I B okay. Beta I B and I B from I B from the left and the beta I B from the right, plus I C E O multiplied by R E. This is the base current. This is the left loop equation which gives you a base current as equal to, if you solve for base current it would be simply V B B minus V B E this term goes to the left. And what else minus I C E O R E divided by R B plus beta plus 1 R E. This is the base current alright. Here you will see uhh later on in order to find out I C. Can we find I C from here? I C is beta I B plus I C E O okay and therefore if I substitute beta I B from here, I can get an expression for I C. I will write this expression later because I shall need that. Alright and usually what I will do is when I write the expression for I C I will go back to I C B O that is instead of I C E O I would write beta plus 1 I C B O okay this is a side line we don't need this equation now but we will require this later on, we shall have to utilize this expression for I B.

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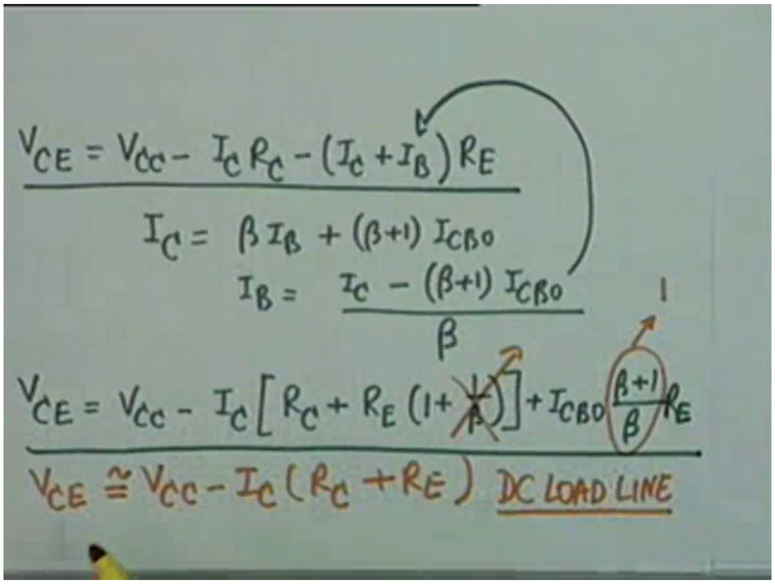

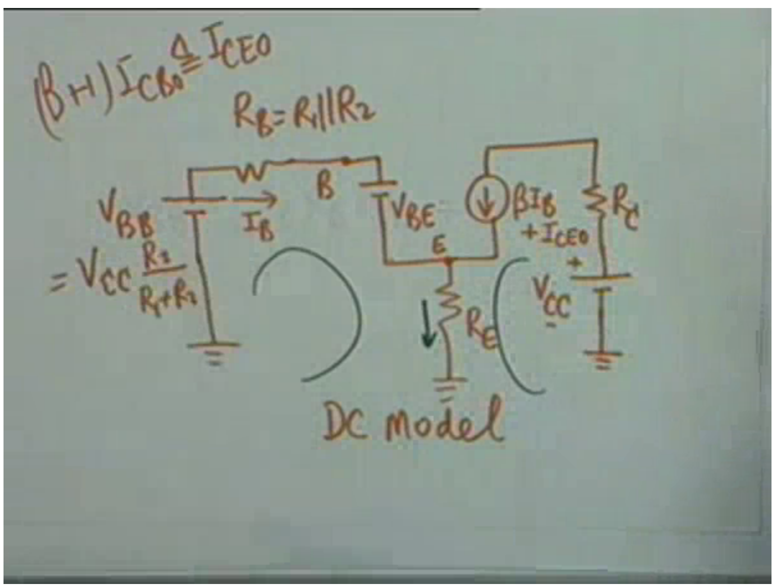

On the right loop if you notice I have V C E okay this voltage from here to here V C E. V C E would be V C C minus this drop drop in R C which is I C R C and then the drop across R E which is also we have found out. Therefore my V C E should be equal to V C C minus I C R C minus I C plus I B I want to write this expression in terms of I C alright. So I don't write beta plus 1 I B plus I C E O. Instead I write I C plus I B times R E and in this I substitute I want to write this expression in terms of I C only. I don't want I B, so what I do is I write I C equal to beta I B plus beta plus one I C B O which means that I B I substitute in this as I C minus Beta plus 1 I C B O divided by beta agreed and this expression I substitute here. This expression for I

B you see I B now contains of I C and some parameters of the transistor. If I do that then I can simplify V C E. I leave the algebra to you as V C C minus I C R C plus R E one plus 1 over beta plus I C B O times beta plus one divided by beta times what R E I think so. I B multiplied yes that is correct. So this is my equation. Is the whole equation visible on the monitor, whole equation including this part?

Student: Yes

Professor: Okay fine.

Now a couple of comments before I go to the next point for consideration. Couple of comments, you know that beta is normally much greater than 1. Beta is the order of 100 and therefore 1 plus 1 by beta approximately you can ignore this part. You can ignore this term 1 by beta. It will be 0.01 1 percent of this term. Similarly. Beta plus 1 by beta you can take approximately as 1. Not just that I C B O you know is of the order of nano ampere 10s of nano amperes. And R E is of the order of a K and therefore this whole term is very very small and therefore you can approximate this by V C C minus I C R C plus R E agreed and this equation describes what is known as the DC load line, DC load line. At DC the load of the transistor is equivalent load is R C plus R E. They don't exactly add to each other. They add with the factor 1 plus 1 by beta. Because beta is very large one can take the total load to be R C plus R E and this equation describes the collector emitter voltage V C E and the operating current I C in terms of constants in the circuit namely V C C and the total load resistance. So this is called as DC load line. We shall see what import of the DC load line is, but before that let's take a small example.

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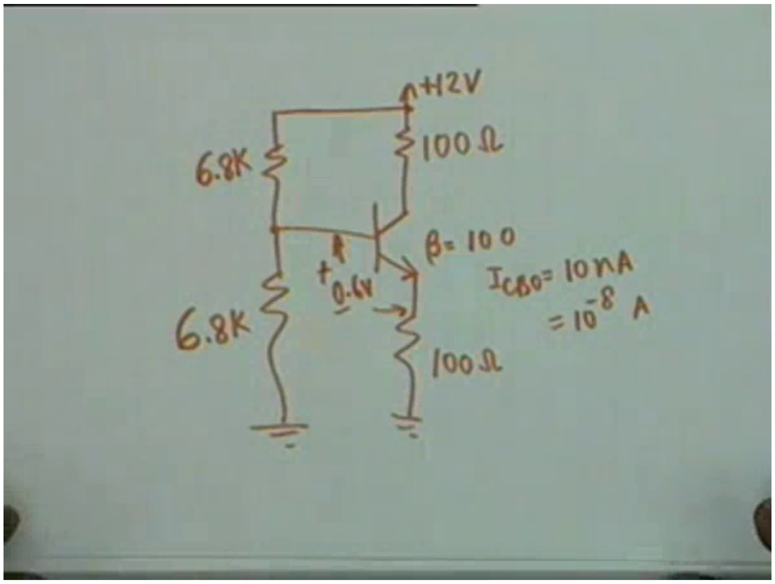

And this example we shall we shall continue to take the same example again and again to illustrate the points. It's a typical common emitter pnp transistor amplifier. The plus V C C is 12 volt beta is equal to 100 V B E is given as 0.6 volt for a change 0.6 volt I C B O is given as 10 nano-amperes which is equal to 10 to the power of minus 8 amperes this is given. R 1 and R 2 both are 6.8K. And R E and R C both are 100 ohms. Suppose this is the circuit alright. We r required to find out the operating point of the transistor.

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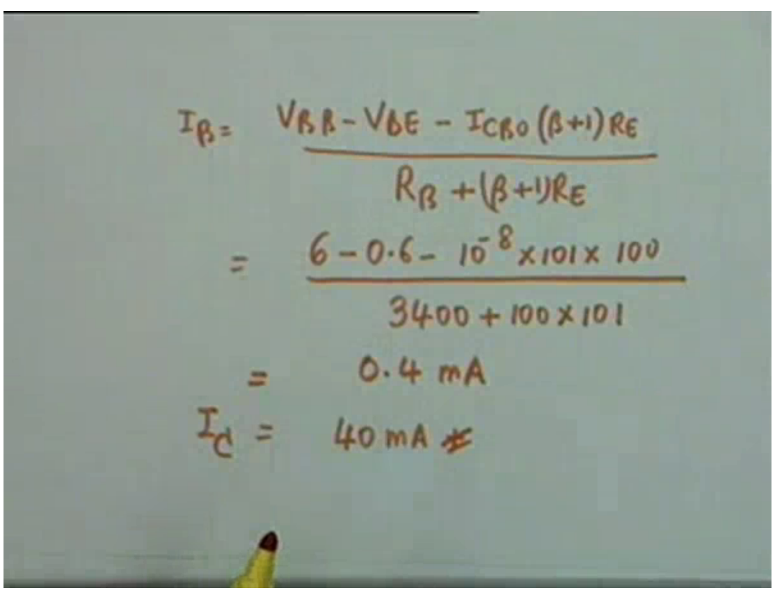

The first thing one does is one uses the relation for I B and you remember that I B is equal to V B B minus V B E what else minus I C B O times beta plus 1 times R E divided by R B plus Beta plus 1 R E. If you substitute this, 6 V B B would be 6 volts now V C C R 1 R 2 divided by R 1 plus R 2 minus 0.6 minus 10 to the minus 8. Beta plus 1 is 101 R E is 100. Even if this, this is of the order of 10 to the minus 4, isn't it right?

Student: Yes sir.

Therefore it can be ignored okay, divided by R B is 3400 ohms. R B is the parallel combination of 6.8K and 6.8K so it is 3.4K, 3400 ohms plus 100 multiplied by 101, agreed okay. So this comes out as 0.4 milli-ampere. Which means that I C if this is 0.4 milli-ampere then I C is beta times this that is 40 milli-amperes plus beta plus 1 I C B O which is negligible okay and therefore it is 40 milli-ampere. You see in this relationship I B equal to 0.4 milli-amps and I C equal to 40 milli-amps the effect of I C B O is negligible because I C B O itself is very very small okay, it's a good transistor. 10 nano-ampere I C B O is a good transistor.

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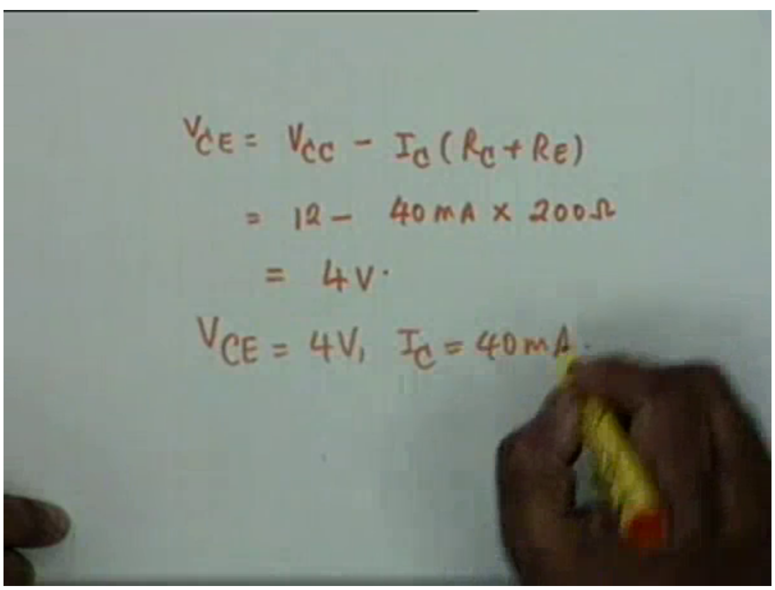

Now if you know I C naturally you can find out V C E. V C E is yes V C C minus I C times R C plus R E. We have ignored that beta 1 by beta term. And also beta plus 1 plus beta and then the whole I C B O term. It must be understood because in a lousy transistor where I C B O is not that small you have to consider the effect of that alright also if the temperature rises you know I C B O I told you that the reverse saturation current of a diode approximately doubles for every 10 degree centigrade rise in temperature. And therefore if there is rise in temperature you might have to consider I C B O.

For example if rise in temperature is let say by 100 degree C, room temperature is 25 suppose the temperature is raise to 125 then I C B O will multiply by 2 to the power 10, is that clear. We will consider such an example later, now in this particular this is 12 I C is 40 milli-amperes multiplied by 200 ohms. So this is equal to 4 volts okay. So this is my operating point, operating point is V C E equal to 4 volt and I C equal to 40 milli-amps. Now let's look at this operating point uhh I am tempted to alright this is the operating point now, I have slight temptation which I which I want to discuss, a little bit of detour.

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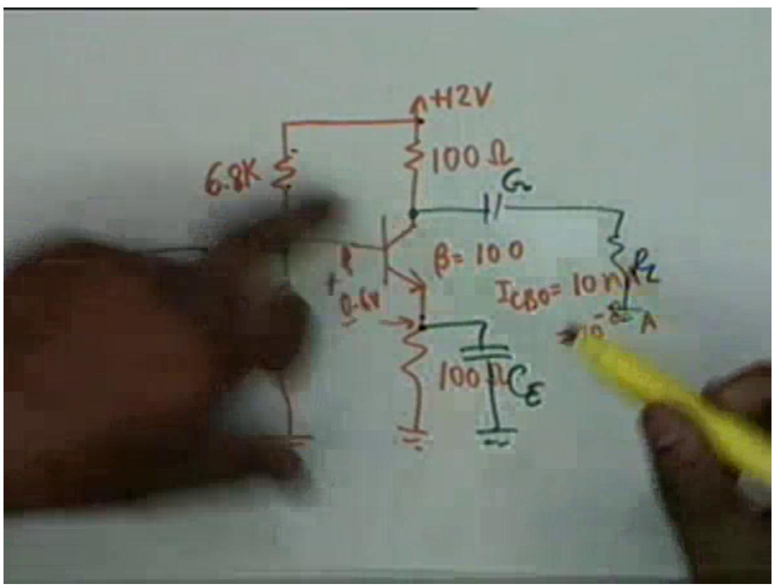

You see all that I need to make this into and amplifier all we shall need to make it into and amplifier is to connect a voltage source here and connect a load here okay. That’s all I need, now if I want to draw the AC equivalent circuit alright. What we shall have is the source V S the capacity C 1 and C 2 I also need to connect a bypass here C E. The capacity C 1 and C 2 are so large that at the signal frequency they will act as short circuits. Similarly C E will also act as short circuit. So in the AC equivalent circuit the emitter shall be virtually grounded yes.

Student: Why don’t you want any drop in the R E in case of.

Professor: If there is a drop in R E then it causes loss of gain, it acts as a negative feedback as you shall see later we don't want this. We want as much gain as possible unless it is intentional. Sometimes it is intentional, sometimes negative feedback is used intentionally to stabilize the amplifier, but normally we don't it we want to bypass.

Okay so R E will be short circuited in other words the emitter itself shall go to ground between the base and emitter I shall have the parallel combination of 6.8K and 6.8K is that right, between this point and the emitter or ground. At AC this point will be virtually grounded virtually grounded. So between this point and ground we shall have 6.8K and 6.8K in parallel because the battery is virtually grounded AC grounded so that would be equivalent to 3.4K. Then from here to here I shall have R X plus R Pie and the current that flows with the small I B okay when I come to the collector side. In the collector side only the current generator beta times I B shall remain alright and in parallel with in parallel with R C and R L. R C and R L shall be parallel.

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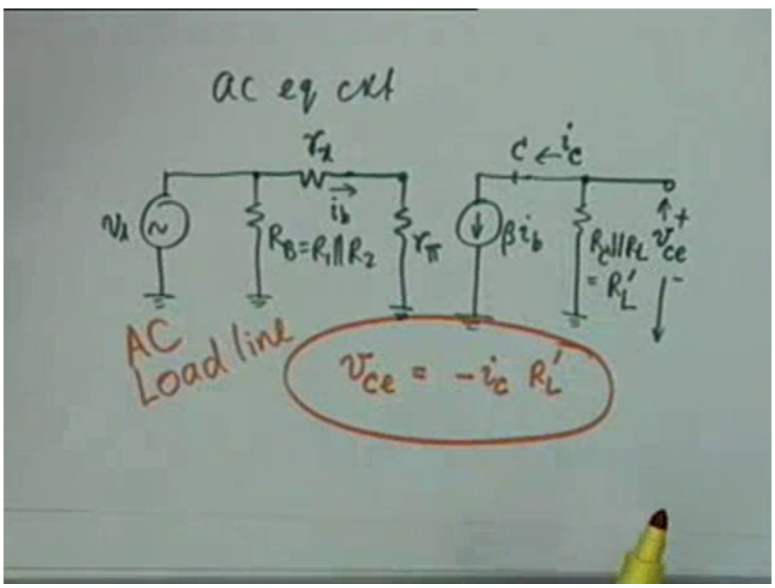

So this this small discussion should convince you that my AC equivalent circuit would be like his V S then I shall have R B which is a parallel combination of R 1 and R 2 let me indicate this R 1 parallel R 2 then I shall have R X which is the base spread IN resistance and R pie. This current is I B this current is I B and then on the other side I shall have the current generator from the collector. This is the collector. From the collector I shall have Beta times I B okay beta times I B then in parallel with R C parallel R L. Let's call this resistance as R L prime and this value this voltage therefore is the output voltage and as you see this is the voltage between small v voltage between the collector and the emitter. And since this is AC we write this as V C E plus minus agreed?

Student: Sir please repeat.

This point is the collector and the emitter has been grounded so the output voltage is the incremental part of collector emitter voltage. And since this is AC voltage we used a symbol small v small c small e agreed. And this is the collector current AC collector current which is i c okay. What is the relationship between this voltage, this current and this voltage. Isn't this simply V C E as equal to minus i c times R L prime agreed. We will require this relationship a little later. We will require this relationship, there is a negative sign because there is a phase change alright, there is a negative sign minus i c R L prime is parallel combination of R C and R L. This in fact we brought this in because this equation describes the A C load line. The D C loadline had R C plus R E as the load D C load. The AC load is R C parallel R L so it is R L prime. And this is the relationship. V C E equal to minus I C times R L prime. We will require this in few moments.

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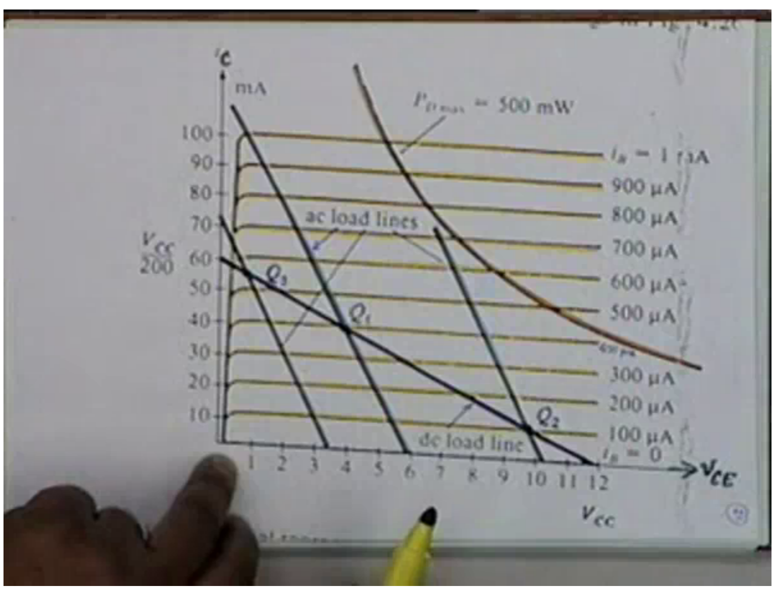

Now let's look at this figure the limits on operation of the common emitter transistor amplifier. I want a different color, green one shall do okay. These are the transistor characteristics this yellow, light yellow shaded curves, these are the transistor characteristics. Typical BJT characteristics as you can see they are approximately parallel to each other and they are approximately equi-distant. That is from 500 to 600 the increase is about 10 milli-amperes. From 500 to 400 500 is the base current. From 500-400 the difference is approximately again 10 milli-amperes okay. I C is a plot of I C versus V C E. It is a plot I C versus V C E. This line is the saturation line. So our amplifier operation should never go below this line alright. Now there is another line which restricts the operation of a transistor, and this is what I want to introduce at this moment. You see V C E and I C they denote the Q the operating point of the transistor.

Now if you maintain a voltage V C E in a device across 2 terminal through which a current I C flows obviously the product V C E times I C this much power is absorbed by the device alright. And this power is dissipated in the device. How is dissipated, the transistor gets heated. It gets dissipated in the form of heat. Now if the heat is excessive if the heat is excessive then the junction temperature rise and if the temperatures rise 3 things happen. Beta changes, beta changes approximately 50 percent for a 100 degree centigrade rise in temperature. Beta changes if beta changes, it changes it increase, if temperature rise beta increases. Now if beta increases then naturally the collector current again increases isn’t that right? If I B remains the same then the collector current is beta times I B so it changes it increases. If it increases it causes more dissipation and therefore the transistor temperature goes higher up and this is a regenerated process that means it's a vicious circle ultimately, unless you put off the power supply the transistor may burn.

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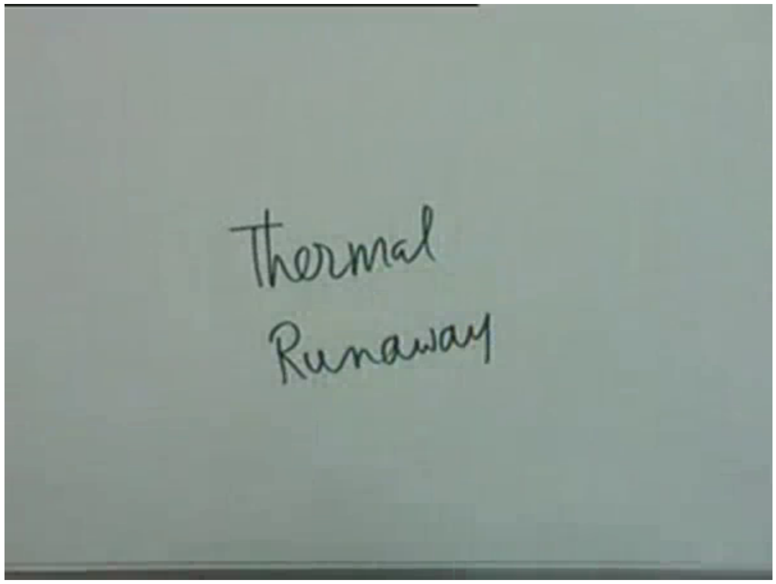

This phenomenon is called thermal runaway, Thermal Runaway. The transistor ultimately gets destroyed.

Student: Sir explain this heating effect once more.

Professor: This heating effect okay.

If the transistor is heated, if the transistor is heated because of an excessive current going through the transistor. Then the junction temperature rises and if the junction temperature rises 3 things happen beta changes beta increases V B E decreases I C no I am sorry I C B O what happens to I C B O? Increases okay beta this rates our beta approximately changes 50 percent for every 100 degree centigrade rise in temperature. That is if beta was 100 and the temperature is raised by 100 C then beta will become 150. If beta increases, well the other 2 are V B E decreases at the rate of, I told you. V D D V D D P in the first lecture itself 2.5 millivolt per degree C. V B E decreases by 2.5 volt per degree C. This is the rule of thumb okay. And I C B O doubles for every 10 degree centigrade rise of temperature. But the most harmful effect is that of increase in beta if beta increase I C which is beta times I B increases causes further dissipation further heat generation and therefore, and this is a regenerative process. The transistor cannot come out of it, ultimately more heat more I C more heat and ultimately the transistor gets burnt off. And this phenomenon is called Thermal Runaway.

Therefore there must be all manufactures say your V C and I C must be such that the maximum power dissipation allowed is not exceeded.

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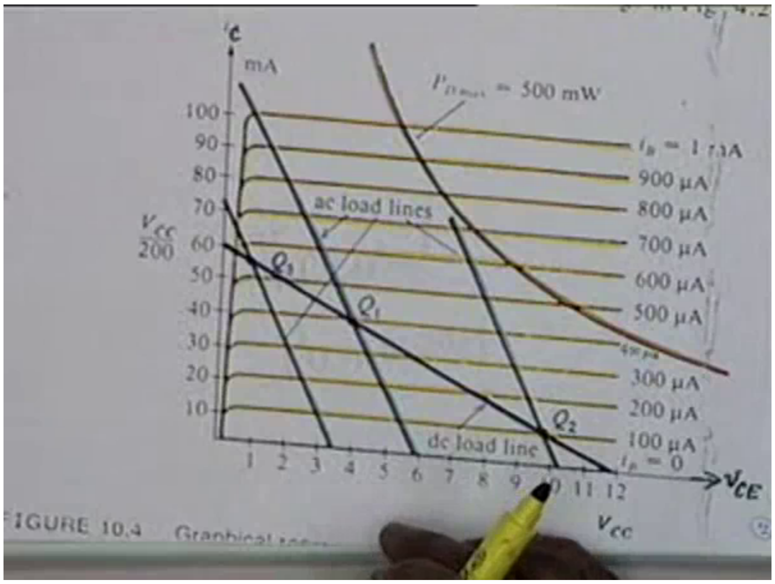

And for this transistor which is a 2N 222 transistor the PD max is 500 millivolt. This is specified by the manufacturer. Therefore you draw a curve on I C V C E such that the product. I C V C E is 500 milli-volts obviously this would be a hyperbola.

Student: Sir how do they calculate the power dissipation of transistor is it simpl V C E into I C.

Professor: It is V C E into I C plus V B E times I B but normally I B is 100 times beta times less. And therefore that dissipation is negligible compared to the collector junction dissipation. We normally take V C E times I C now on this characteristics if you plot V C E time I C equal to PD max, there is a max allowed power dissipation. You will get a hyperbola. So your operating point must be on the left side of this hyperbola. Is the point clear. This light brown shaded hyperbola. This is the Pd max curve. And do you understand how this is plotted? It is simply V C E times I C is equal to P D max alright. So you're operation must be to the left of this line. Left of this hyperbola. You're operation must be to the right of this saturation line. So it gradually constraint.

In addition there are other constraints, for example you cannot increase V C E beyond a certain limit what happens? There occurs a breakdown and this breakdown for this particular transistor occurs at about 30 volts. So 12 volt is a safe limit okay, you can't apply a V C C of let say 100 volts, then in all probably the transistor will breakdown. So there is a vertical here, there is a vertical line which restricts no only PD max curve but there is a vertical line occurring at V C E max. This will also be specified by the manufacturers. Sometimes it is specified as breakdown collector voltage, there are various terms, but you should understand.

Similarly the current that can be drawn from a transistor there is an absolute limit. There is a limit you cannot drop more than that, so there would be a vertical line somewhere here for this transistor this is 800 milli-amps and our operation normally will be restricted to about 1 10^{th} or 1 8^{th} of this. About 100 milli-amps we will not draw more than that.

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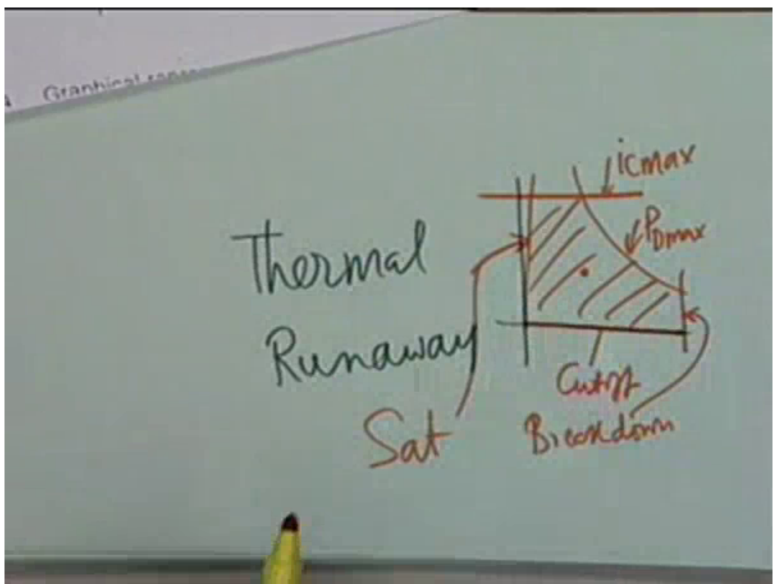

So you see the operation the Q point of a transistor must lie between several is bounded by several limits one is Pd then you have the saturation line, you have the vertical line collector breakdown limited by collector breakdown. You have a horizontal line limited by the maximum allowable collector current. This is the I C max, this is Pd max, this line is saturation, this line is decided by breakdown. And whatever the other dimension, cut-off, cut-off is obviously this line right so cut-off. You're key point must lie in this shaded region. You're Q point cannot should not should not lie outside this. Also to be able to operate this as a good amplifier with a reasonably good dynamic range that is if you want a large signal operation then you're Q point must be somewhere, somewhere well inside the region isn't it? Is should not be too close to the cut-off. It should not be too close to saturation, it should not be too close to Pd max curve, it should not be too close to breakdown or the I C max. It must be well inside this, is the point clear? The general principle, that Q point must be well inside this region. What is the best, what is the best? That depends on the situation.

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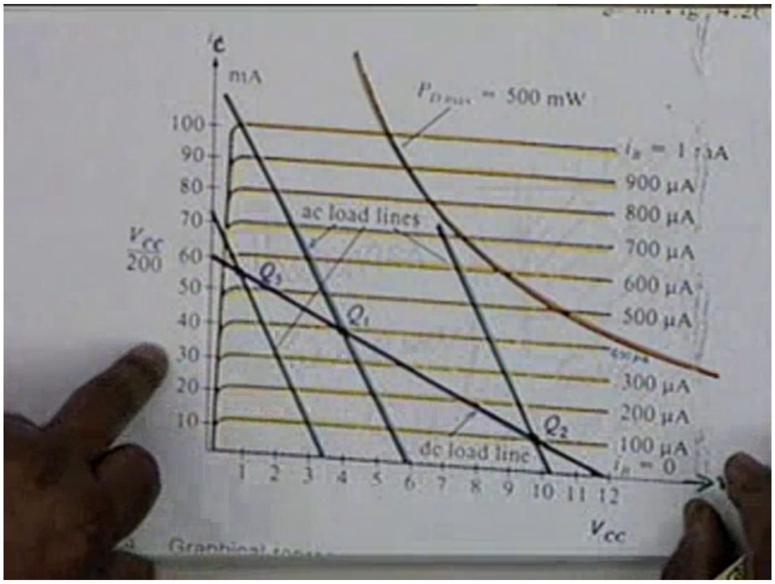

Let's look at the present example. In the present example this light violet colored line joining Q1 Q2 Q3 is the DC load line. You see DC load line as I have told you the equation to the DC load line what is the equation.

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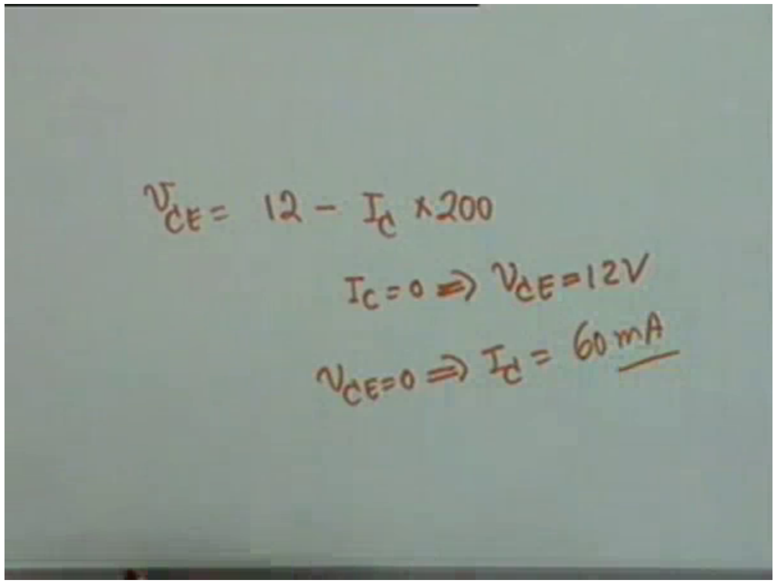

V C E is equal to 12 minus I C multiplied by which is 200 ohms. So if I C is 0 V C E is 12 volt alright. And if V C E is 0 then I C is 60 milli-amperes agreed. So to draw 1 straight line 2 point are enough.

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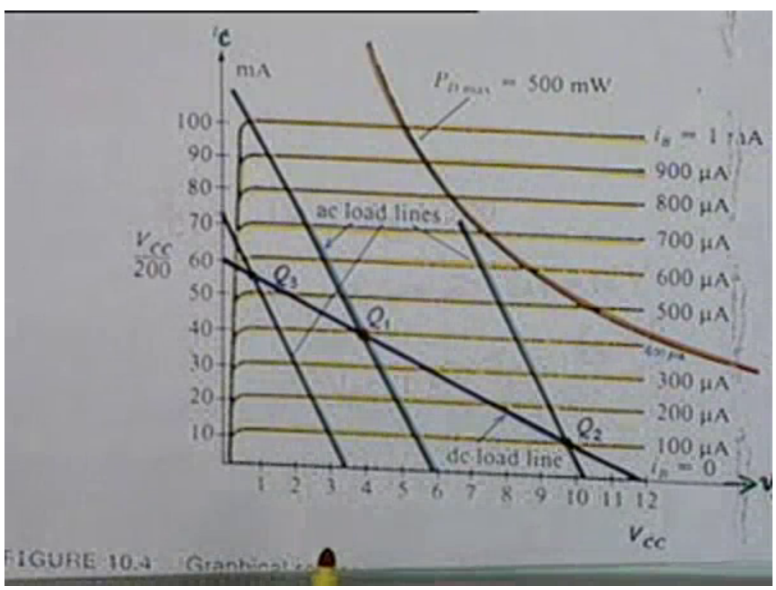

These are the 2 points. You see 12 volt and 0 current 60 milli-amperes and 0 volt. So join these two, then this is the DC load line okay. We have also found out the Q point or the operating point. The operating point was 4 volt and 40 milli-amps. So Q1 is the operating point, is the point clear? The operating point clear, point about the operating point?

Student: No Sir.

Professor: Is the load line clear?

Student: Yes

Okay we had already found out that I C with the kind of biasing that we had found out for the example the collector current was 40 milli-amp and the collector emitter voltage was 4 volts. So draw a vertical line at 4 volt and draw a horizontal line at 40 milli-amps where they meet is the operating point. So Q1 is our operating point alright. Now if Q1 is the operating point and this is the DC load line okay and we're working as, no is Q1 reasonably good operating point?

Student: Yes sir.

It's well inside it's well inside but let's see how it behaves in the in the phase of AC. In the phase of a signal okay. If there is a signal then you know the DC load line is not enough.

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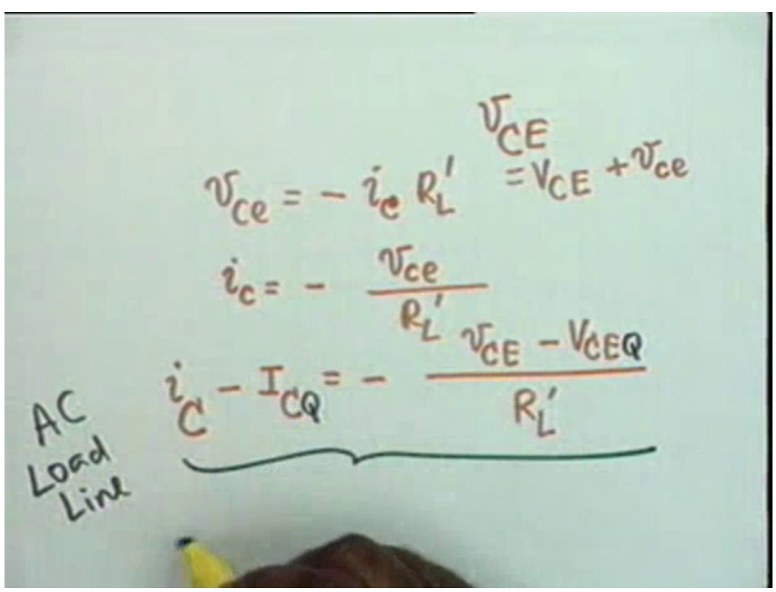

We have to draw an AC load line and AC load line from the AC equivalent circuit we have already seen, that the AC load line is V C E is equation minus I C small c small c R L prime. I can write this as I C as minus V C E divided by R L prime.

Student: Sir you said V C E is the increment, can you please repeat that?

Professor: V C E is the AC signal that means it is the power transition well as I have said the total collector emitter voltage is equal to V C E the DC voltage plus small v small c small e. So this is an increment on the DC collector voltage, okay. In order to, well in order to bring this into the picture I write this as i C total collector current minus I C alright, this is the value of I C that is equal to minus 1 over R L prime. V C E can be written as total collector emitter voltage minus V C E. And in order to emphasize that this is an increment over the Q point or the operating point. Operating point is also called the Q point. I will introduce the additional symbol Q here. That is I C minus I C Q equal to V C E minus V C E Q divided by R L prime. One thing is obvious that this is the AC load line. AC Load line. Significance of Q.

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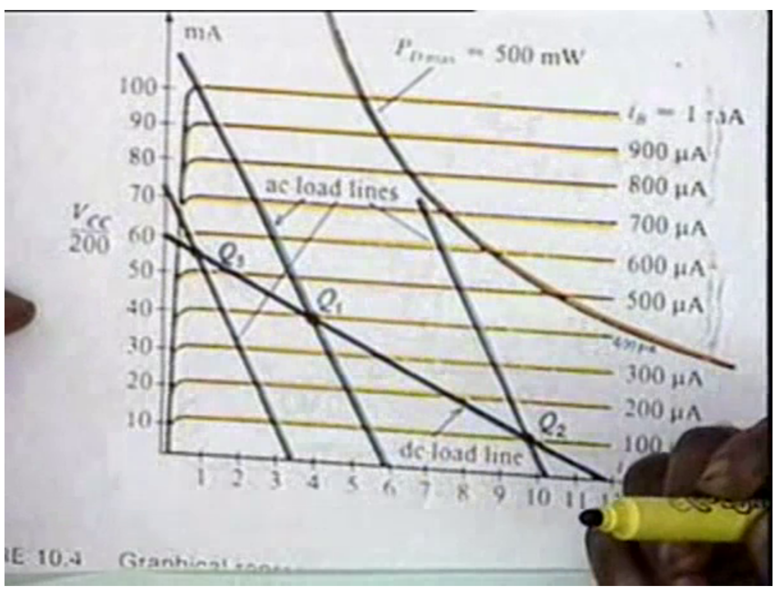

Operating point is sometimes called the Q point and therefore our amplifier operates around this point that is a signal excursion on the either side of this point. If the signal goes up the collector current goes up, if the signal goes down the collector current goes down okay.

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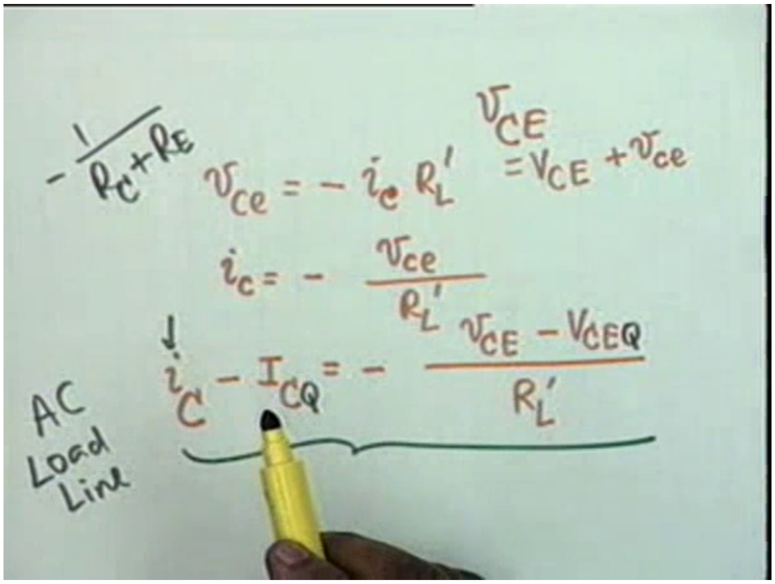

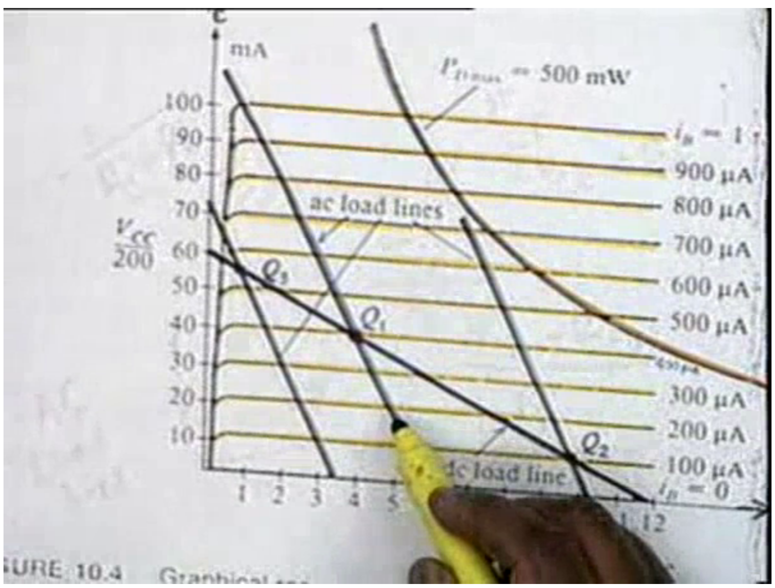

So I have used the additional symbol Q here to emphasize that amplifier operation is around that particular operating point. This is the equation to the AC load line. And one of the things that is obviously is that it is a straight line, isn't it right? Y equal to MX plus C Y is your total collector current. And the slope is minus 1 by R L prime. This slope obviously is greater than the slope of the DC load line. What is the slope of the DC load line? Minus 1 by R C plus R E and R L prime is less than R C. Therefore the slope of AC load line is greater than the slope of the DC load line. Is that point clear?

And the second thing is that the AC load line must pass through the Q point, why? Because when V CE is equal to V C E Q I C must be equal to I C Q, isn’t it right? So the A C load line must be passed through the Q point. And this blue line is the AC load line. As you can see it's slope is minus 1 by, what is the value here? 100 ohms and, did I mention what the load is? Load I didn’t mention. Take the load as 100 ohms. R C was 100 ohms, take this also equal to R L. Then the slope of this line, the slope of this line is minus 1 by the DC load line minus 1 by 200. The slope of this line is minus 1 by 50. So if you know the slope and one point on the line you can draw the line?