**Electronics for Analog Signal Processing - I**

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**Lecture – 24**
**Common Emitter Amplifiers**

In the last class, we discussed about this common emitter amplifier. Today, let us look at the complete picture of the amplifier.

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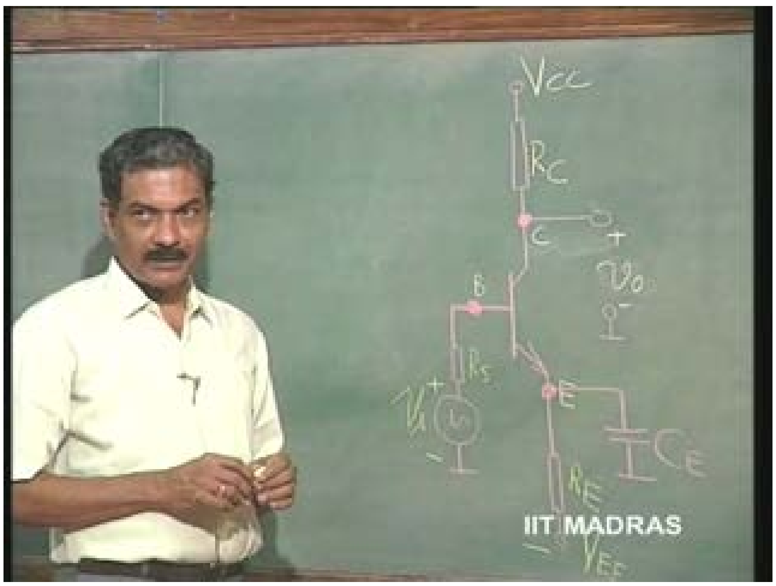


This R E and R C resistors have been introduced in order to do the biasing for the transistor. R E is going to fix up the current I E Q so that, irrespective of the transistor that is used, the operating current remains as fixed by you. Then, R C is fixed for a given V C C, for the required V C B, ((...Refer Slide Time: 2:10)) So, that is the operating point; a certain I E flowing with certain V C B will fix the transistor in the active region of interest to you, so that, you can use it as an amplifier.

Now, when this happens, let us see what exactly happens at any instant of time. So, we are now going to consider the effect at any given instant of time of applying a signal. So, we have here current that has been fixed for the transistor as I E Q; the quiescent D C current. I have told you that capital I with suffix capital indicates D C. So, corresponding to which, we have Alpha times I E Q flowing here which is I C Q. Strictly speaking, Alpha times I E Q plus I C naught; we have ignored I C naught. So, I C Q which is very nearly equal to I E Q, Alpha being close to 1; corresponding to which, we have the base current getting fixed as I B Q.

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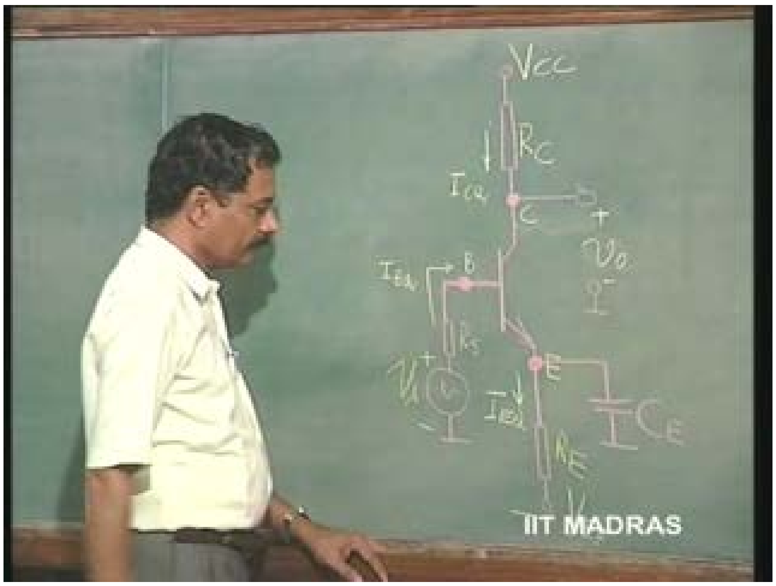


So, we have here this relationship: I E Q into Alpha is equal to I C Q; I B Q is equal to I E Q by Beta plus 1; this relationship getting satisfied. And, I E Q is going to be very nearly equal to V E E minus V Gamma divided by R E; V Gamma being equal to, typically, point 6.

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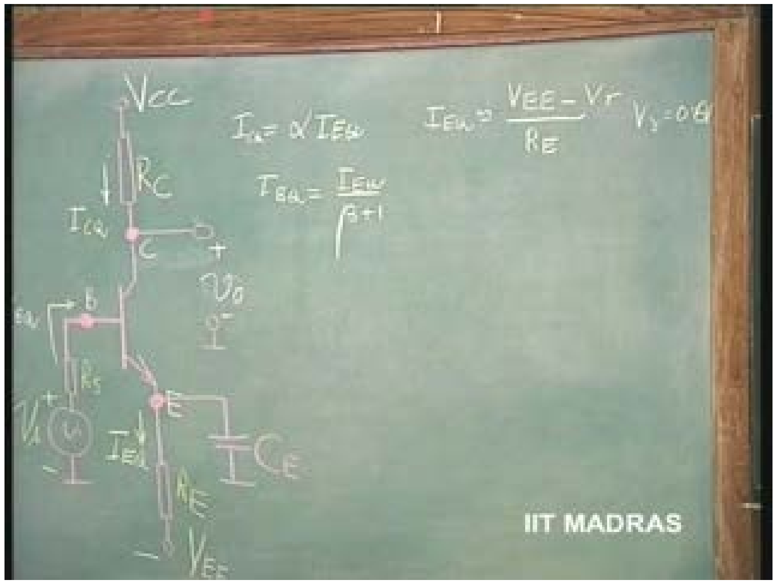


So, this is what we had biased the transistor at. The voltages V C C minus I C Q R C is equal to V C, with respect to ground; and V B, V C Q we will put it, V B Q is very nearly zero. This is what we said. Because, it is equal to I B Q into R S with a negative sign, minus I B Q into R S.

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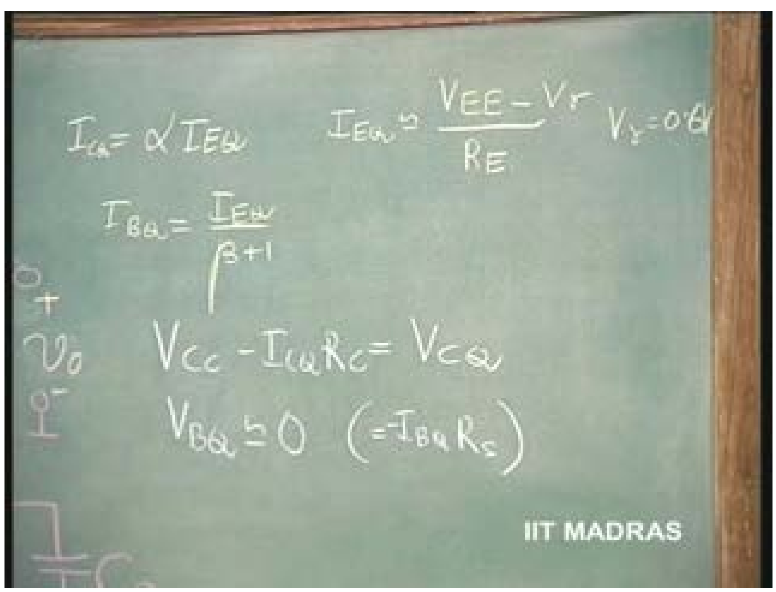

And, for most of the reasonable values of source resistance, this minus I B Q into R S can be ignored. So, it is very small. Or, it is actually I E Q R S by Beta plus 1; Beta being very high and most of the drop occurring across R E, we can ignore this. So, that is, under the assumption that R S divided by Beta plus 1 is much less than R E.

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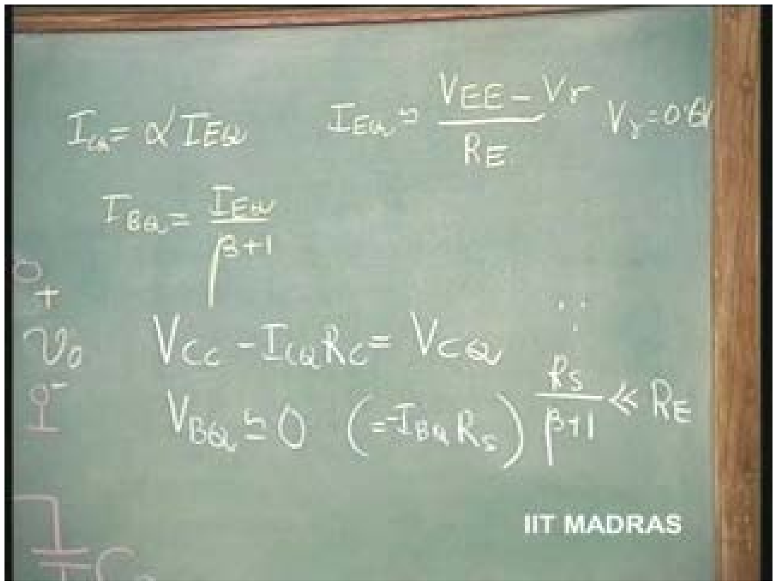


So, this is a proper way of biasing a common emitter amplifier circuit. This is what we had discussed so far. Now, let us superimpose over this. Because of v s, there will be a change in current. Let us say, it is plus here, minus here, indicating that the voltage is increasing. Delta v s is positive here. So please remember: small letters with suffix also small, indicates the time variation in signal. The small letters with capital suffix indicates the instantaneous value of the signal, ((attenuated Refer Slide Time: 7:00)), including D C as well as A C.

So, this is the variation v s. For this variation, there is going to be, this is going to increment the base emitter voltage. So, current is, base current is, going to increase; because emitter current increases, base current also increases. This polarity, the base current is also increasing in this direction. That means I B Q plus, we will put it as Delta I S; that is what we have been using. Or, we can indicate it as only signal i s.

So, this is equal to i B, instantaneous value of i B, because of this increase. And in this case, the incremental value of signal current is also the same as the incremental value of base current, because, this change in signal current is same as I B. So, this is i s equal to i b here. So, this is actually equal to I B Q plus i b because i b is equal to i s. Is this understood? These symbols and things like that?

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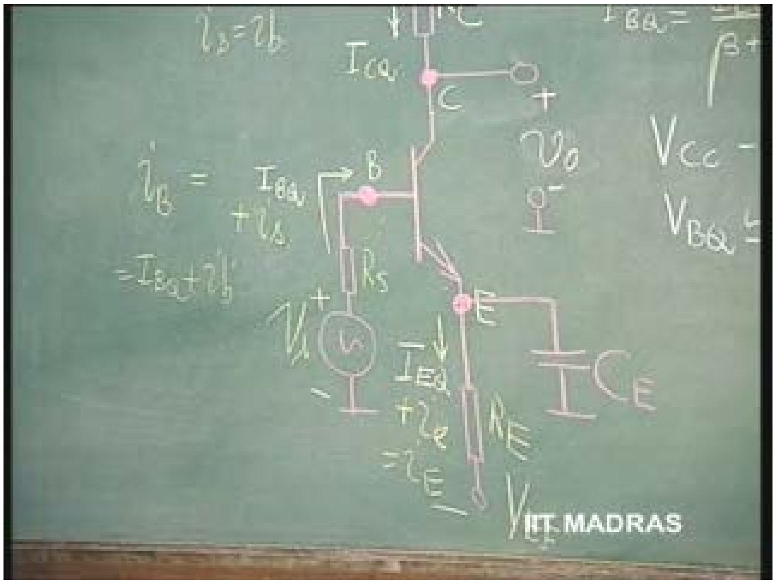


Now, when this happens, what will happen here? I E Q will be I E Q plus, the change that has been brought about, that is i small e, which is really the i instantaneous. So, for a change in signal voltage here, because base to emitter current, voltage, increases, correspondingly, emitter current increases, the base current increases; you can think of it that way. Then, corresponding to this, we will have a change in collector current, which will result in the instantaneous value.

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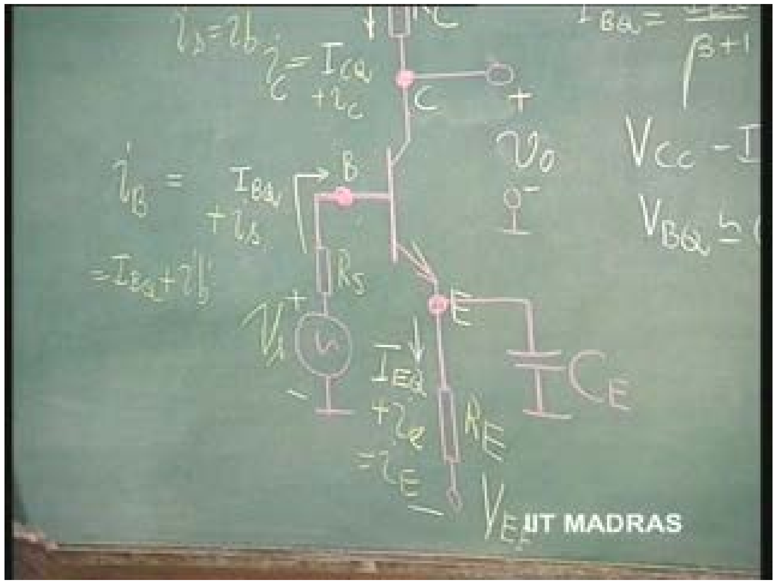


All these can be assumed to be linear relationship. That is, that I C Q equal to Alpha times I E Q is valid; and Delta I C Q is equal to Alpha times Delta I E Q is valid, assuming that Alpha A C is very nearly the same as Alpha D C. Then, the change, for change in signal also, this same relationship is valid.

So, we have all these relationships related by the same factor Alpha as far as the emitter current is concerned. Collector current is related to emitter current whether it is D C or incremental, by the relationship Alpha, assuming Alpha for D C is the same as Alpha for the changes.

Then, we know that when the signal, let us say, is a nice sinusoidal, let us say. This is the signal. So, we will call this, say, V p sine omega t. v s is a time varying signal, periodic. This is normally the test signal for testing any amplifier because any periodic signal can be broken up into summation of fundamental and its harmonics. So, we can therefore test any of your amplifier by using a sinusoidal as the test signal.

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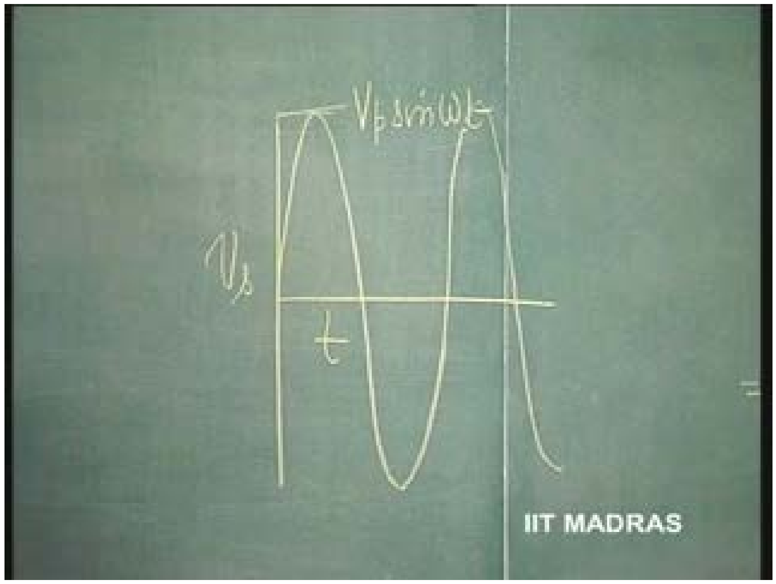


So, if v s is V p sine omega t, then, if the base to emitter change is very small, the change in voltage is very small, corresponding to which there is going to be a change in emitter current. That is, Delta V B E and Delta I E which are now being replaced by Delta i e; is replaced by i e, small suffix e.

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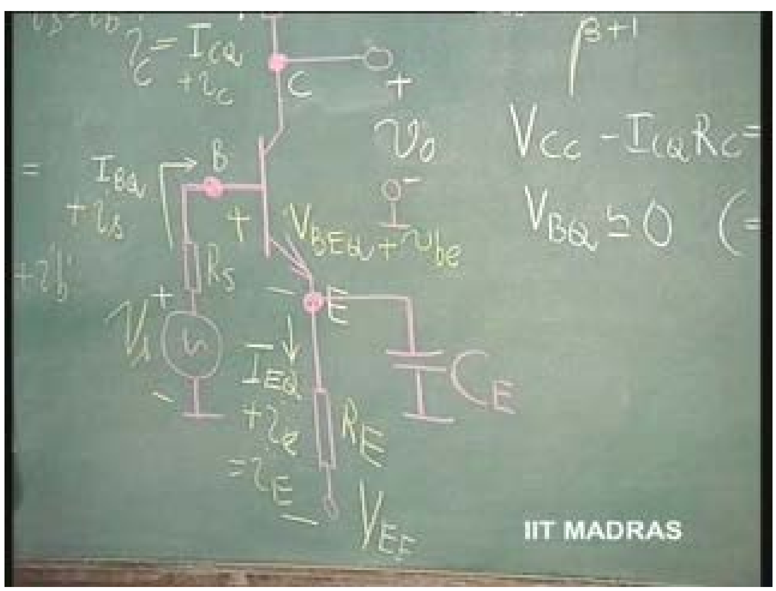

So, that is also going to be sinusoidal. Even though this V B E and I E are related exponentially, we can say that, as long as this Delta V B E is small over and above the V B E Q, this is going to be at v... D C, V B E Q which is point 6 let us say. And, this is going to change to V B E Q plus Delta V B E or v b e; whereas, if this change which is occurring over and above the quiescent, which is point 6, is very small, kept small, then, I can say that these two relationships, that is I E and V B E are linearly related and that linear relationship we have already established. What is it?

v b e by i e is equal to V T divided by I E Q, which is nothing but, actually, Delta V B E by Delta I E, which we have earlier established. This is a direct relationship. V T divided by I E Q where V T is equal to 26 millivolts at room temperature.

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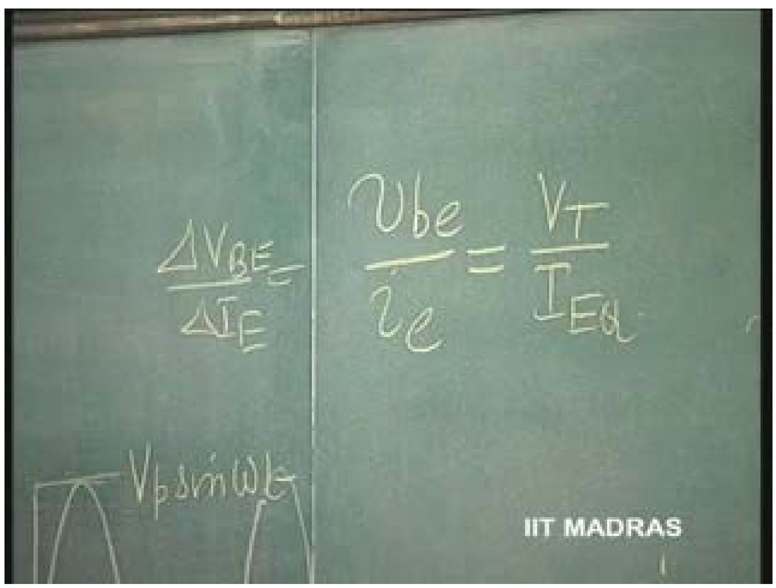


So, that means actually, for a change in voltage here, there will be some change in voltage here, and there will be a change in current in this structure, and the change in voltage and then change in current are linear if these changes are small; linearly related by this relationship. Now, if that is not the case, then what we should do is that I E Q i E therefore is equal to I E Q plus this i e.

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And how do we determine this? We can assume that this change v s, because we have put a capacitor here, it is a short circuit for the signal - that is this; and therefore, this terminal is almost at the same potential as this, as far as the signal is concerned. And therefore, this potential is going to be very nearly at this because we are neglecting the drop.

Or, we can just say that if this is v s, there will be some drop here which is I s into r s, I small s into r s; and the rest of it is going to be dropped across, across the transistor, which is Delta V i or Delta V B E, which you have been calling it.

So, we can therefore say that this potential is going to be Delta v i, considering that this is the input to the amplifier, this is grounded, this is Delta v i, is going to be same as Delta V B E is now v b e, according to our new terminology. Instead of putting all Delta, we know that we are going to discuss this as the time varying voltages.

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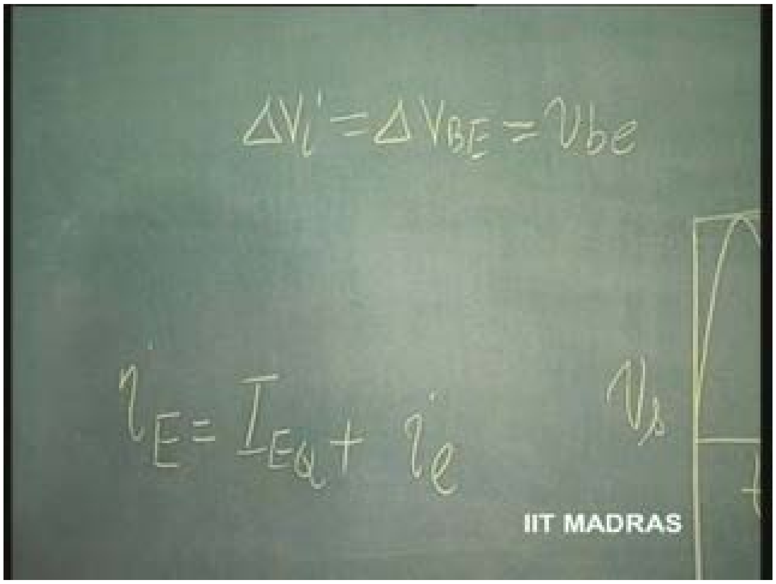


So, if I have the relationship i E, this instantaneous value of emitter current is related to this I E naught, reverse saturation current, exponent, into V B E divided by V T, approximately; minus 1 is ignored. This is the direct relationship. i E, instantaneous value of current, is non-linearly related to this. So, if this is this, then I E naught exponent V B E by V T can be written as exponent V B E Q by V T plus v b e by V T, the time varying component.

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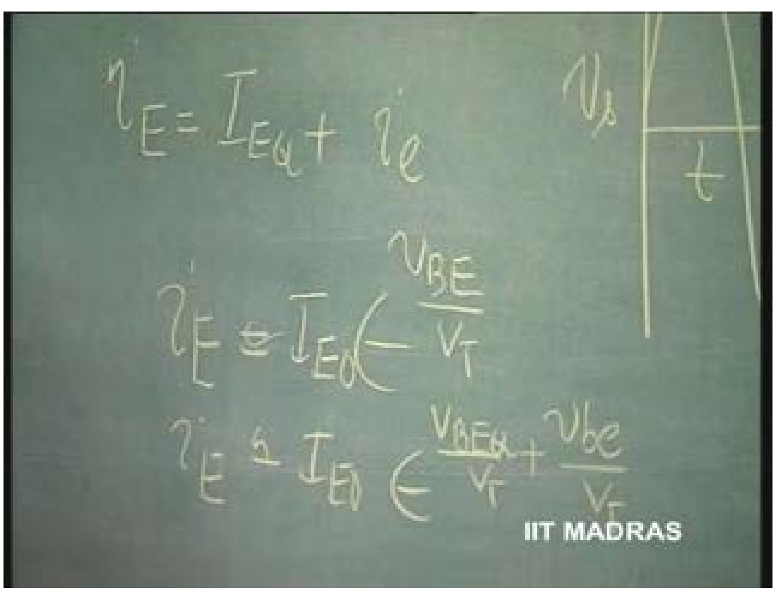

And this is, I E naught exponent V B E Q by V T into exponent V B E by V T. This part is nothing but... I E naught exponent V B E Q by V T, by definition, is I E Q, by definition. This I E Q is already fixed by us, operating current; into exponent v b e by V T. v b e is the input voltage, v i. So, in the common emitter configuration, v i is the voltage that is applied between this and this; or, this and ground.

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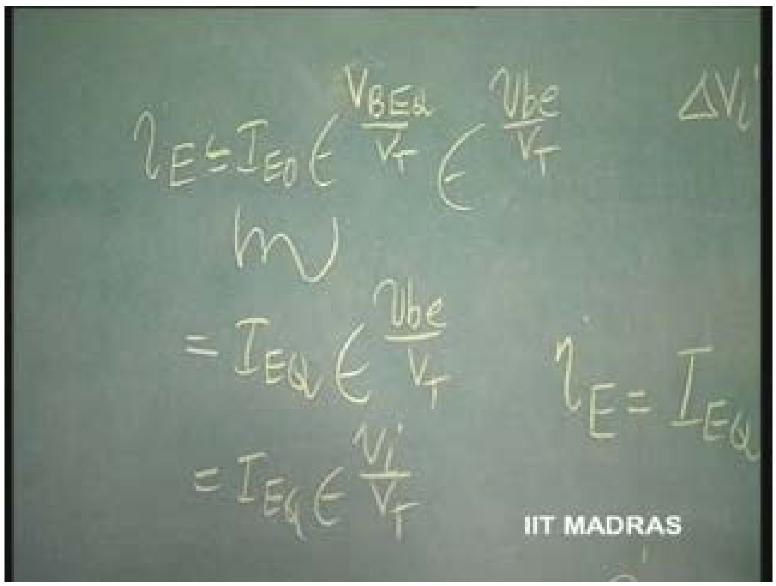


So, if this is the amplifier, that is the voltage appearing at the input of the amplifier. With that voltage, this current, instantaneous value of emitter current is related in an exponential manner. So, this is the non-linearity. So, if I make R S equal to zero let us say, very nearly, then, make v s equal to this, V p sine omega t, this way, then, this is going to be not really sinusoidal; this I E Q exponent v i by V T sine omega t, totally non-linear.

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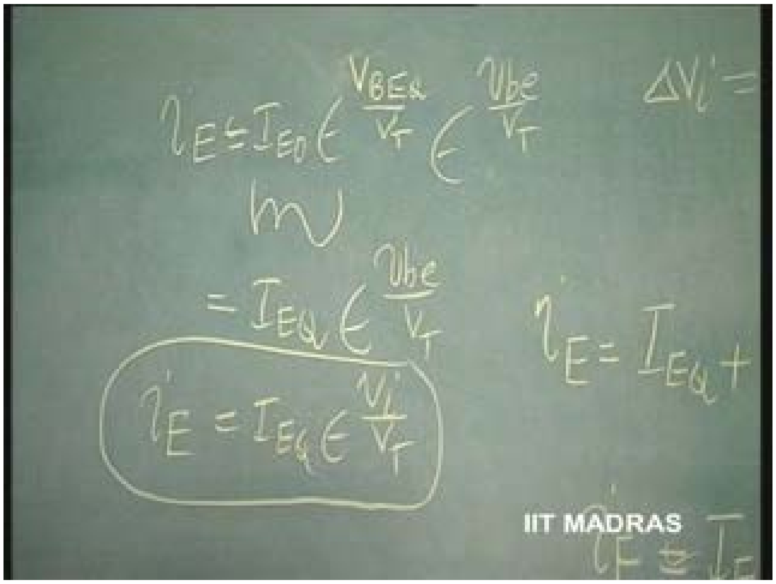


So, let us say, this R S equal to zero; assume R S equal to zero; then, v i is equal to v s.

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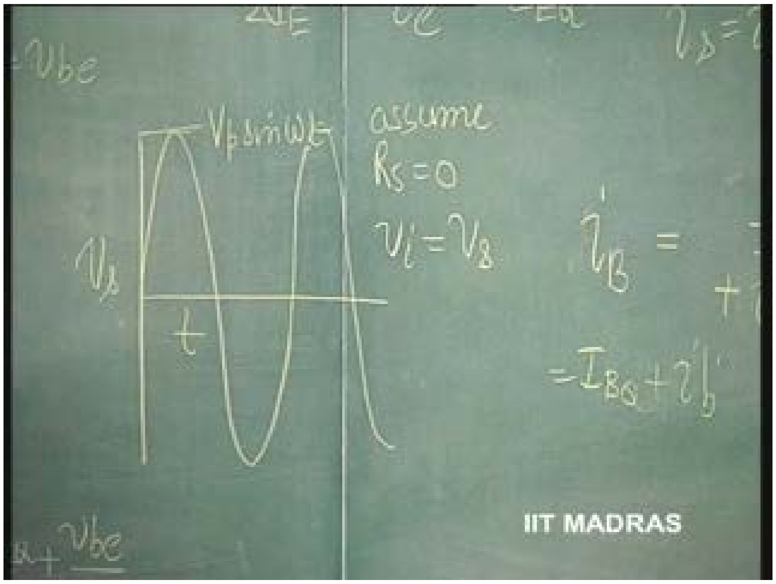


And at that situation, you can say that this is equal to I E Q exponent V p by V T sine omega t. Now, this is equal to I E Q into exponent x. When this quantity x is small, e to power x is, 1 plus, x plus, x square by factorial 2 plus, x cube by factorial 3. So, we expand that. So, 1 plus x, x square, so on...

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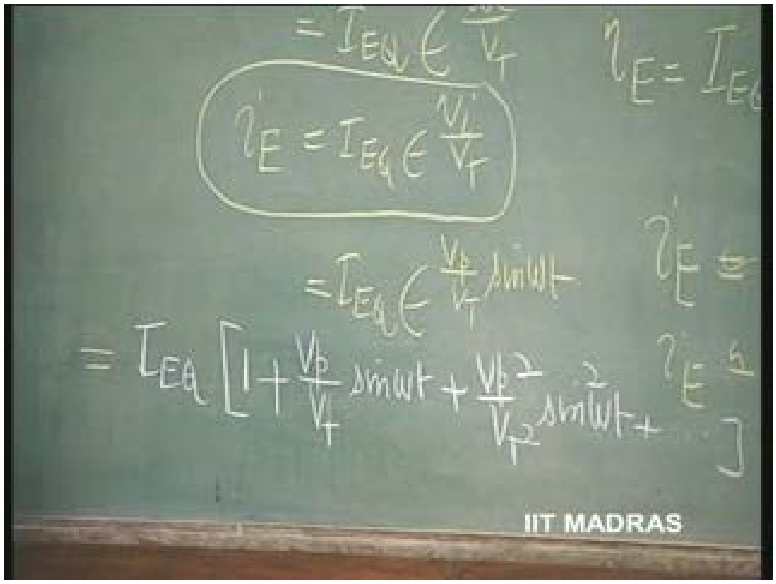


This, we had derived in the earlier situation also. This is what is wanted. Actually, if I want the instantaneous value of the emitter current to be linear with the input voltage which is V p sine omega t, linearly related; I want these factors to be very small compared to this factor.

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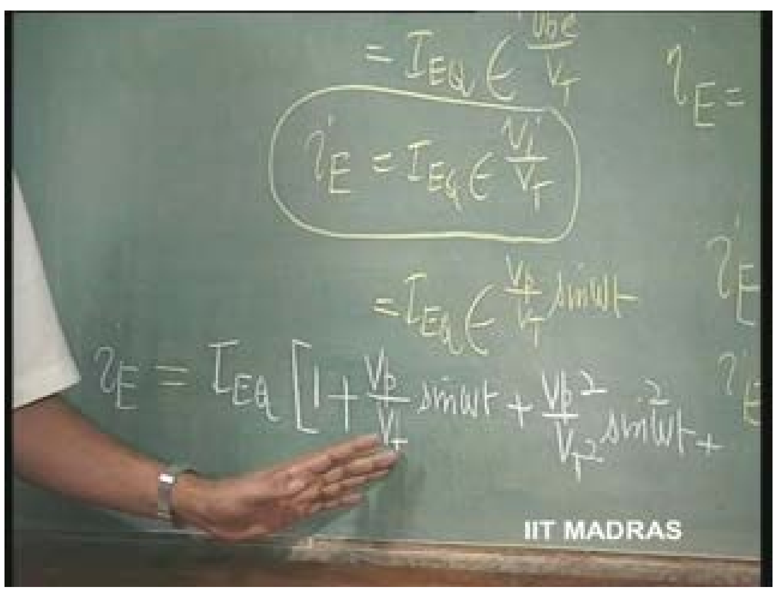

So, there is i E superimposed over I E Q plus I E Q by V T into V p sine omega t; this is the input voltage. So, this I E Q by V T into V p sine omega t is the factor of importance in an amplifier, linear. The other part is, let us see, V p square by V T square into... sine square omega t can be expanded as 1 minus cos 2 omega t by 2. So , ignoring the other higher harmonic factors, because there will be factorial x square by factorial 2 t and x cube by factorial 3, which is 6, so on...

So, that will be reducing. So, this 2 and this 2... will result in the harmonics getting reduced as we... So, we have here an important piece of information. If we want this to be very small, this factor, V p square by 2 V T square, dimensional ((ex...Refer Slide Time: 23:08)) should be very small compared to this here; this into what? – I E Q, because I E Q has been coming everywhere.

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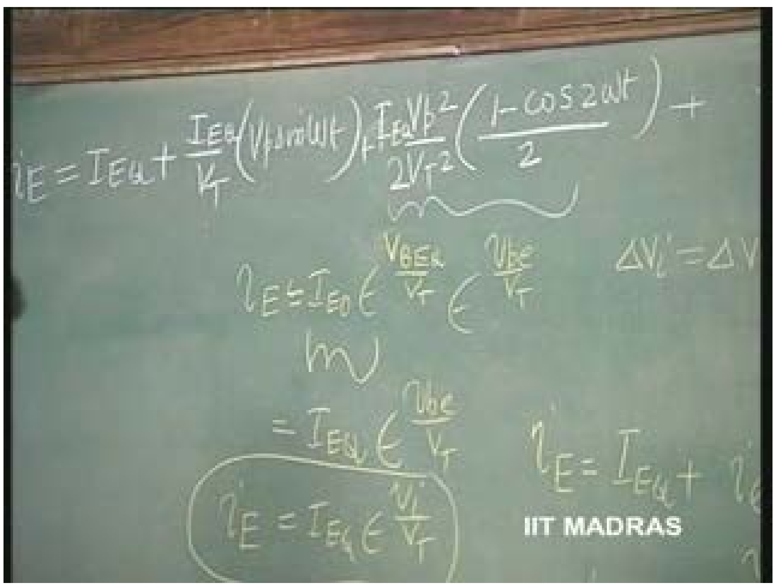


So, this is one way of testing the linearity. If an amplifier is biased at I E Q, when you apply a sine wave signal, pure sine wave signal, the bias point, D C point itself shifts. And the amount by which it shifts gives you an idea about the distortion. This is what is unwanted. The second harmonic component was not there in the input; this has been created by the amplifier non-linearity; and this is called distortion.

So, a quick quantitative assessment of the distortion can be done by merely finding out the shift in the D C operating point of your amplifier. Is this understood? Because, the shift in the D C operating point which is corresponding to this by an extent which is earlier I E Q gets shifted to I E Q into V p square by 4 V T square.

So, that will straight away give you an idea about V p square by 4 V T square; a measurement technique, simple measurement technique of what? – distortion; the extent of second harmonic distortion it is giving. So, that is the prominent harmonic distortion in a common emitter amplifier, please remember. Therefore, the common emitter amplifier has predominant distortion, which is the second harmonic distortion. So, the D C is I E Q into 1 plus V p square by 4 V T square, plus I E Q by V T into V p into sine omega t.

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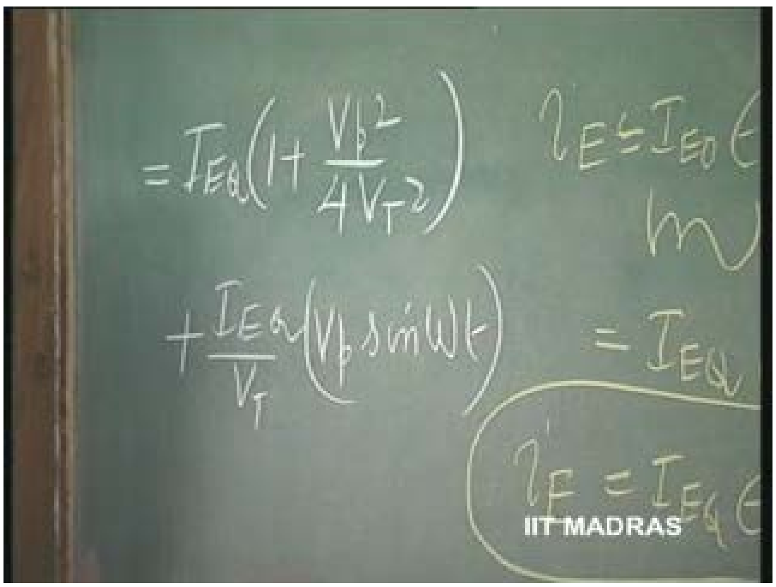


So, this is getting transformed; this V p sine omega t is going to be transformed by a transconductance factor, which is, I E Q by V T here. A change in input voltage, which is V p sine omega t, becomes a change in emitter current by a factor which is I E Q by V T, V p sine omega t being the input voltage.

So, I E Q by V T is the transfer parameter factor. So basically, it is called transconductance. Now, apart from this, we have minus I E Q V p square by 4 V T square cos 2 omega t. So, measuring this I E Q V p square by 4 V T square is going to give you the peak value of the second harmonic.

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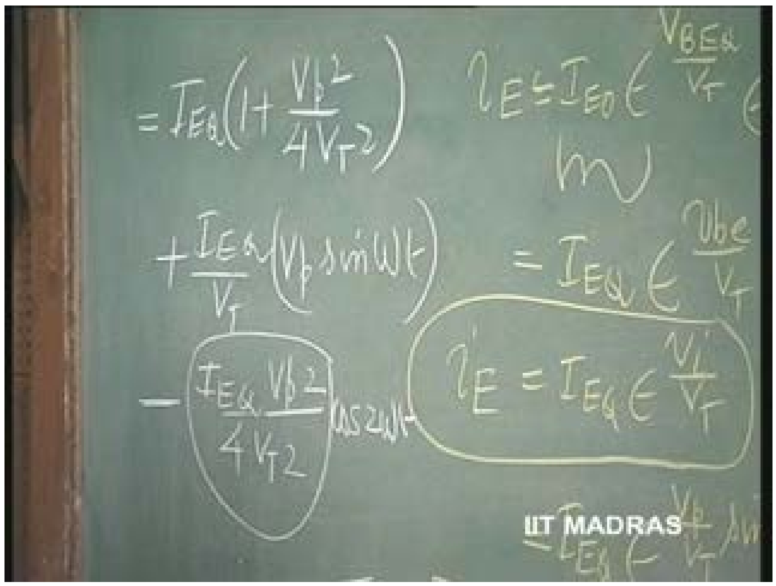


A quick way of distortion factor assessment is, this divided by what? – this is the peak factor V p I E Q into V T of the fundamental. So, I E Q V p by V T – so, percentage distortion or distortion factor is fundamental. That is, second harmonic. This is the peak; r m s is also going to be proportional to the peak; and over, peak over root 2. So, ratio of the r m s value of the second harmonic divided by the fundamental will give you the distortion factor, approximately, because we have ignored third harmonic onwards.

So, how much is this? I E Q, I E Q gets cancelled. So, it looks that the distortion factor is fairly independent of what? – the operating point. So, we see here, I E Q getting cancelled; and it is equal to V p divided by 4 V T.

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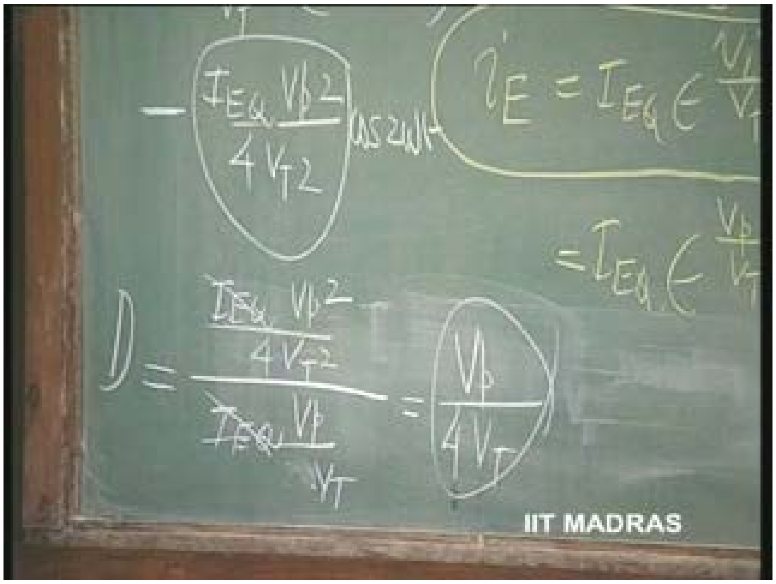


It is an important thing; quickly you can assess now, the amount of distortion in a common emitter amplifier if your input voltage is given as, let us say, 1 millivolt, let us say peak; V p is given as 1 millivolt, peak, 1 millivolt sine omega t, let us say. Then, this will be 1 by 4 into 26 millivolts. If you want for assessment, you can take V T as 25. So, 1 percent distortion is what is going to be caused for a signal of 1 millivolt.

So, we had just seen that when I apply a signal v s equal to V p sine omega t, and if r s is zero, then i E is equal to this; and i c is equal to Alpha times i e; and V naught, output voltage, is going to be equal to V C C minus Alpha times i c; that is, Alpha times i e; or, V C C minus i c times R c, which is, Alpha times i E times R c, which is going to be V C C minus Alpha I E Q R c into 1 plus this.

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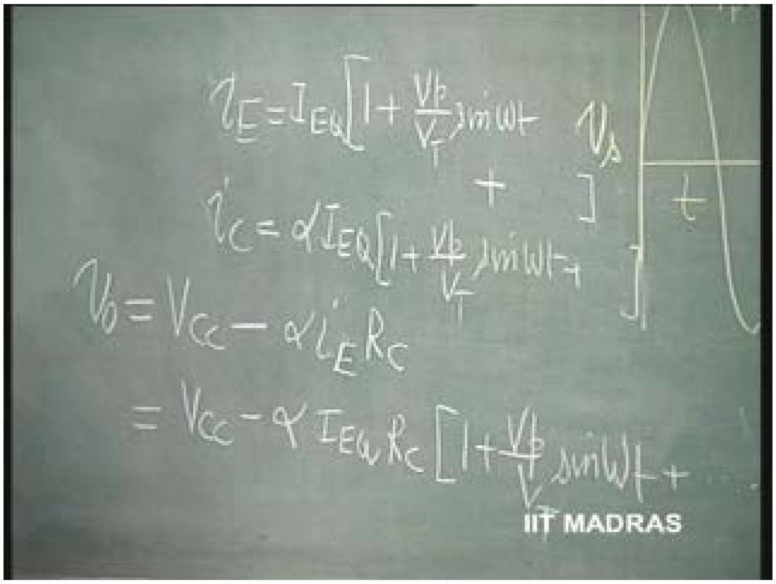


So, this is the output voltage for a sine wave input which is V p sine omega t. So, output voltage is exactly replica in shape of the input voltage, but by an amplification factor. Amplify only if these are negligible; otherwise, it has other harmonic contents in it; therefore, distortion occurs, so that we have to make sure by making V p much less than 4 V T – an important design criteria, so that all these factors do not disturb our operating point, as well as do not cause any distortion.

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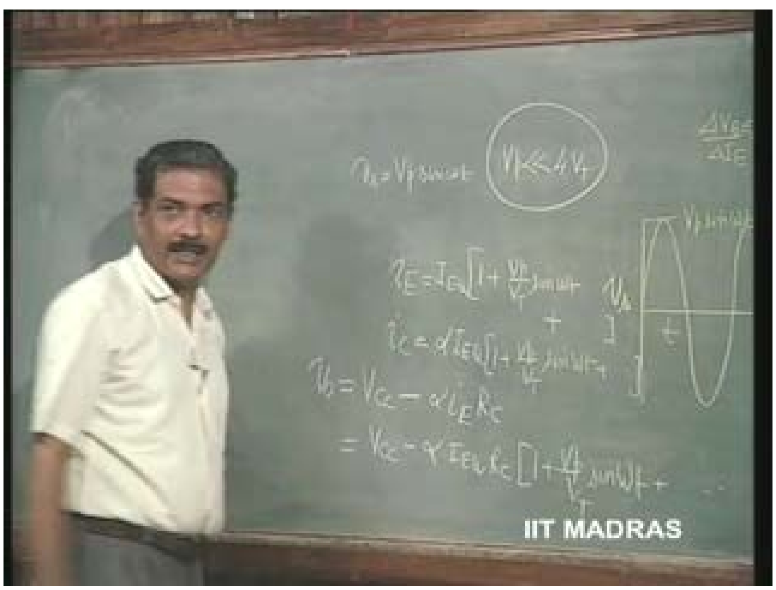

In which case, we can neglect the effect of all these things and say that output is essentially this plus this. What is this? V C C minus Alpha I E Q, which is I C Q; Alpha I E Q is equal to I C Q, into R c is nothing but V C Q. V C C minus Alpha I E Q is V C Q, quiescent, minus Alpha I E Q by V T into R c into V p sine omega t.

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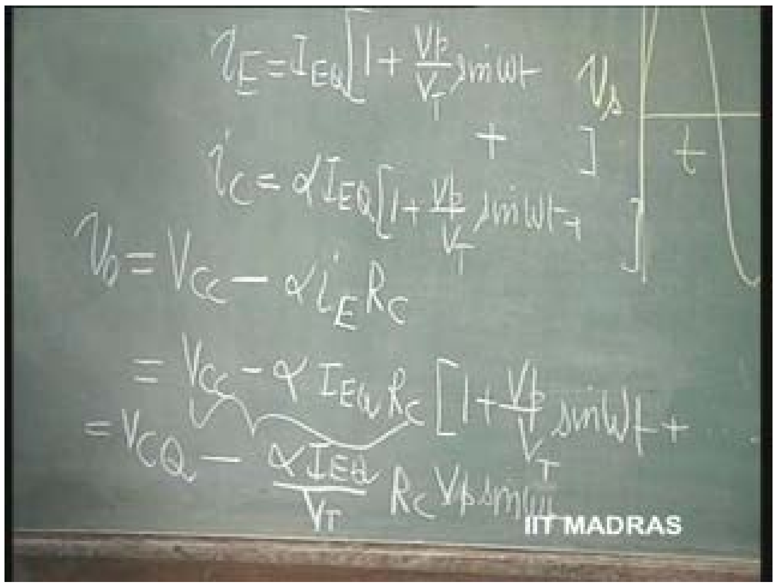


So notice this. It is V C Q. That means, this is V C Q. Let us say, this is V C Q. Let us pictorially indicate. And, if input is such that it is increasing like this, V p sine omega t, output will decrease; so, they are minus. That means, this voltage is decreasing and it will increase like this. V C Q minus – that is the significance of minus. Around V C Q, this is the quiescent voltage of the output around V C Q; and it is because of input, this is what is going to happen. And, extent of, extent to which it is going to amplified is going to be... V p is its peak. Now it is V p into Alpha I E Q by V T into R c. This is called transconductance of the transistor, defined as g m.

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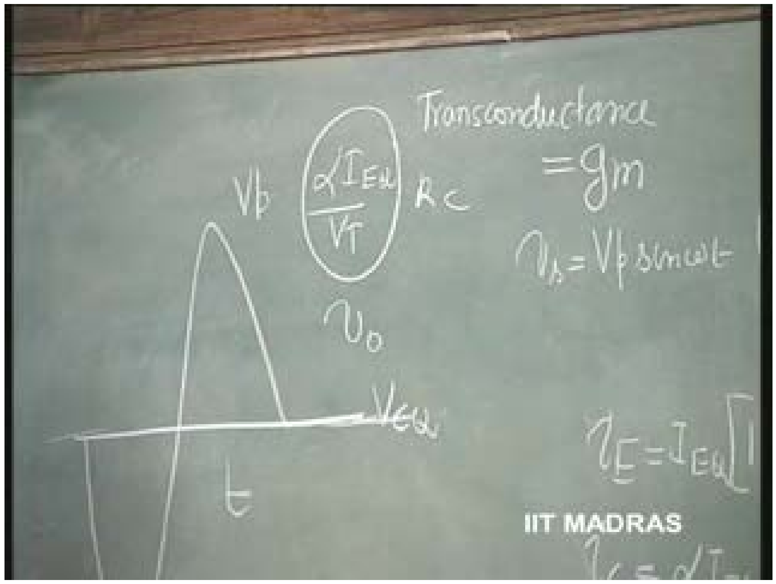


Alpha I E Q by V T is defined as g m, transconductance; and it is current divided by voltage. That is why it is called conductance. Transfer, because, for an input change in signal v i, there is going to be an output change in current; because of that, it is arising. Because of the output change in current, and that change in current passing through R c, this amplification factor is arising. So, g m into R c into V p is this. So, V p was the input and this factor is called the voltage amplification. So, please remember, in any amplifier therefore, the voltage amplification factor is always equal to minus g m into R c. g m is defined as the transconductance.

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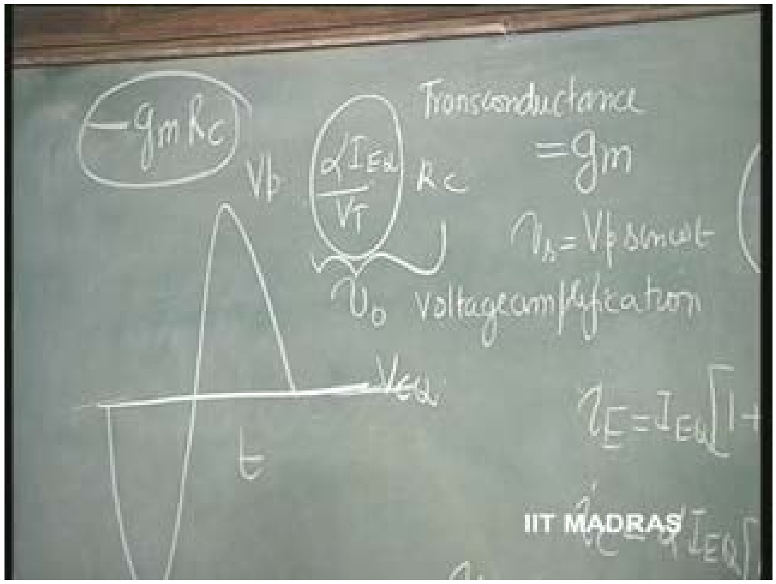


So, typically for example, for 1 milliampere of operating current, if V T is 26 millivolts, 1 by 26... or, we can take it as 1 by 25, for example, is going to be 40 millisiemens, is a typical transconductance of a bipolar junction transistor for 1 milliampere operating current. So, 1 milliampere divided by 26 millivolts. Alpha is very nearly equal to 1. So, which is about, what is it? 1 by 25, we will take. So, 40 millisiemens. Instead of calling millimhos, we will call it millisiemens.

So for higher current, for example, it is 2 milliamperes, it will be 80 millisiemens. So, if you just know what the operating current is, you know the transconductance of your bipolar junction transistor. That is not the case with other active devices. The greatest advantage of bipolar junction transistor is, you know most of your story, the moment you know the operating point.

So, this is an important factor that you should remember; that, the transconductance factor is immediately known, the moment we know the operating current. And, if you fix the collector resistance R c, then the amplification factor is also known. So, if R c is, let us say 1 Kilo ohm, and operating current of the transistor is 1 milliampere, for which we are assuming that the transconductance is 40 millisiemens, the gain of the amplifier is minus 40, voltage gain. Or suppose you are asked to design an amplifier with gain of 100, let us say, minus 100, and you have fixed the operating point at 1 milliampere, for which the transconductance is 40 millisiemens, then the r c that you should select is 2 point 5 Kilo ohms. Is this clear?

So, designing a common emitter amplifier for a specific gain, given the operating point or otherwise, becomes now very simple affair. How to fix R c, how to fix the operating point, given R c; these are going to be simple affairs. We can do it without any effort on your part, just by using this information – that g m of a trans... What is it? – a bipolar junction transistor is I E Q divided by V T, Alpha I E Q by V T.

Now, this inversion is an important aspect of the amplifier. So, that is why it is an inverting amplifier. That is why the gain is given as minus g m into R c, indicating a phase inversion of 180 degree. A sine wave of this type is going to appear as the sine wave of the other. Now, as we go on increasing, let us now understand its behavior in the limiting range. This is going to be perfectly linear and this factor can be used, as long as we do not violate this too much.

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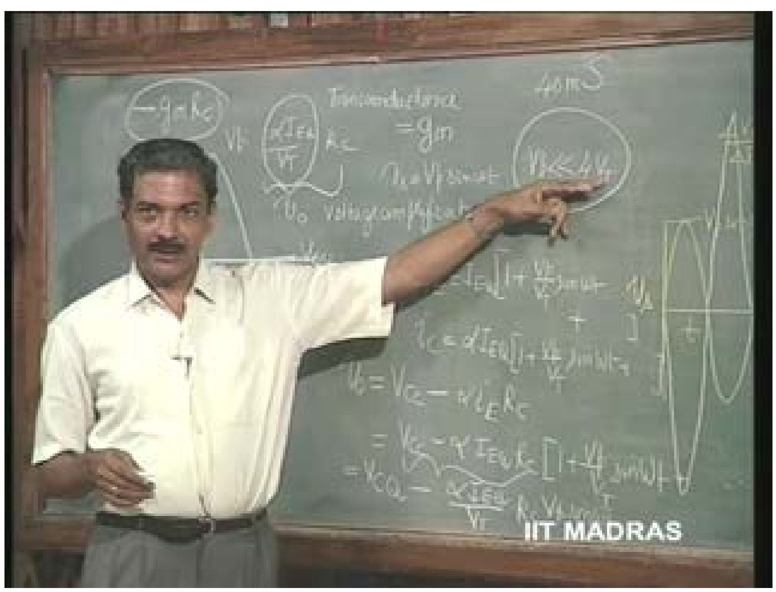

But the moment we start violating it, moment the input signal becomes of the order of, let us say, hundreds of millivolts, then we can no longer use this information. It is not true that this is exact replica of this input here. It is not a sinusoidal. What happens? We would like to know. What happens?

Now, we know that the diode characteristic is something like this. This is i E versus V B E, like this. What does it tell? As V B E is increased by a small amount, the current increases by a huge amount. As V B E is increased by a small amount, the current increases by a huge amount on this side; whereas if V B E is decreased from this point, let us say this is V B E Q, this point is V B E Q; so, if I now increase V B E by some amount, this is the increase in current, i e. Whereas, the decrease by the same amount is going to cause much less change in current.

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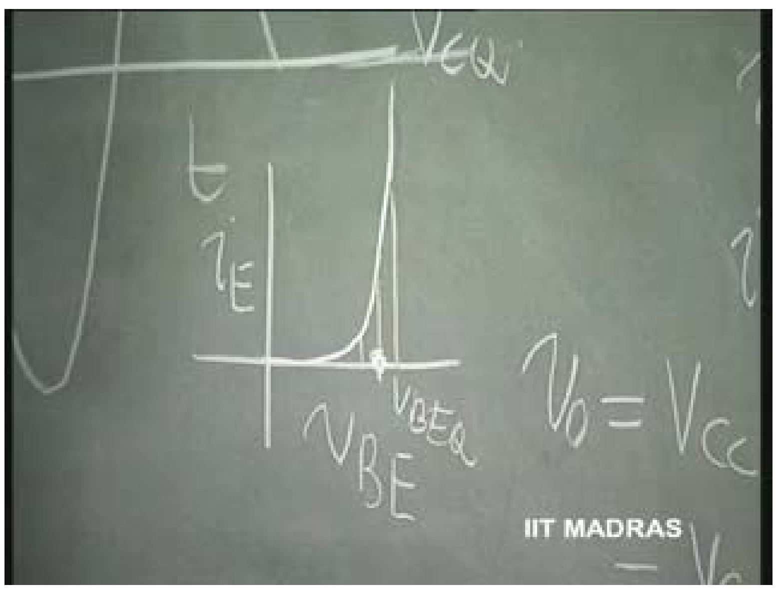


So, the increase in current is higher than the decrease in decrement in current. Increment in current is higher than the decrement in current, because of the exponential relationship; which means that, as this signal is applied, the emitter current is increasing here because V B E is increasing; but the increment in current is going to be much more than the decrement.

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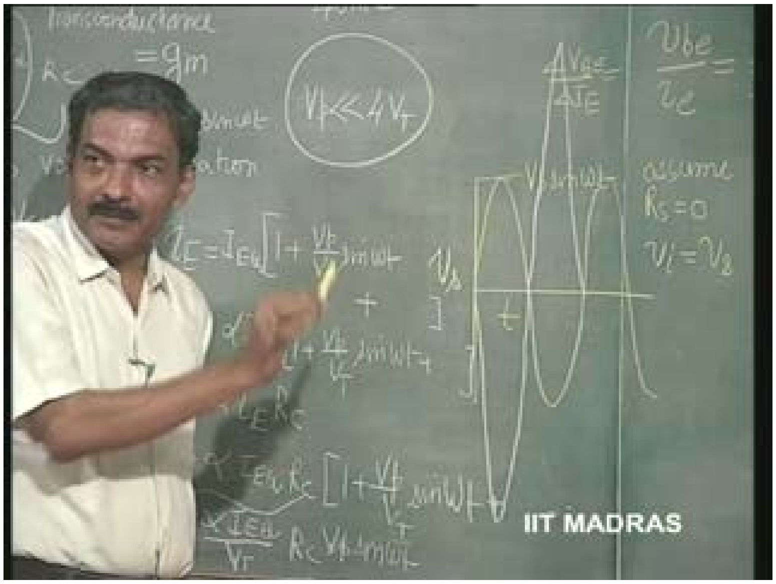


If the increment in current occurs, that causes decrease in voltage. So, for the same increase in voltage at the input, there will be higher swing here than here. Is this point understood?

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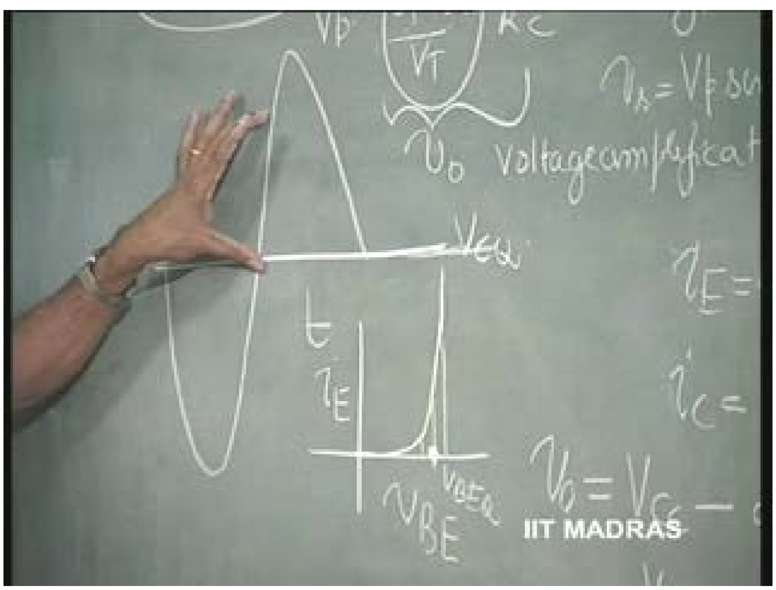


This side, the voltage is going towards V C C; may be V C C, may be somewhere here, because the current, instantaneous value of current, is decreasing. The voltage is therefore increasing. It is V C C minus something, i c times. So, as i c increases, or i E increases and i c increases, the output voltage decreases, output voltage decreases. As i c decreases, output voltage increases. So, this is going to be becoming flatter and this is going to become longer.

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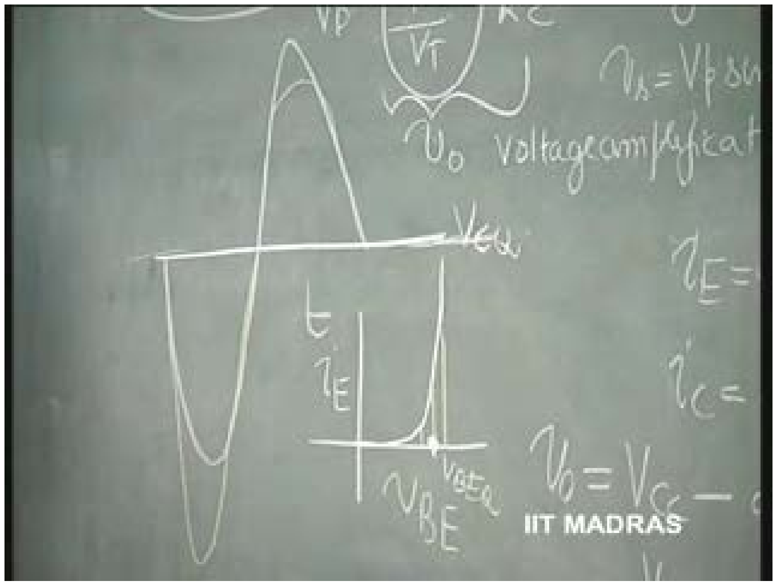


So, this is what you expect under linear behavior. Because of the non-linear behavior, this is going to become flatter and this is going to become longer. This is because of the exponent non-linearity. This is what exactly you will see on your oscilloscope if you apply a signal at the input of a common emitter amplifier. This is going to become shorter and this is going to become longer. Is this distortion understood?

This is one type of distortion which we have measured. At low levels, we have measured this with the help of this equation. Other type of distortion which comes about... let it happen, we are not bothered. What we will say is, I will still increase this input voltage. V p – I will keep on increasing. What will happen? This increase is going to occur; but it is disproportionate compared to this increase.

So, for the next level, may be this is the increase and here it may be only this. Is this clear?

So, this kind of distortion will keep on happening until at a point this voltage, V naught, ultimately will reach at under the limiting situation of... this is nothing but... Why is it decreasing or increasing? Because, this current is changing from I C Q to I C Q plus i c, which is a Delta i c. That Delta i c can be positive or negative. That means instantaneous value of this current can be increasing above I E Q, I C Q, or decreasing.

When it is going on decreasing, ultimately, it can go to only zero, where I C Q, minus I C Q, this will become; after which, you cannot have further change in current because the transistor is off. Instantaneous value of emitter current is zero. Therefore, instantaneous value of collector current is zero and therefore the voltage here will reach V C C.

So, this is what is going to happen ultimately. This here, it will be just a flat portion, because beyond that, it cannot further increase. So, this point, the transistor is said to go to cut off. This is important that you remember what it is. The transistor is said to go to cut off. This point, if you keep on increasing, what will happen, let us see. As I keep on increasing this voltage, this current will keep on increasing, this voltage will keep on decreasing; because, effective instantaneous value of current is increasing; this drop is going to decrease.

So, this voltage will keep on decreasing and it will reach a point when V C B is equal to zero. Thereafter, the transistor is said to go to saturation. So, instantaneous value of current, i c equal to zero, cut off; or actually speaking, i E equal to zero, i c is equal to zero, all are same. Instantaneous value of V B C equal to zero saturation. So, after saturation, the transistor is not in the active region. So, this kind of sat... what happens under saturation? This potential becomes same as this potential. Thereafter, this junction starts getting forward biased. No longer will you have i c equal to Alpha times i E. Transistor equation is not any longer valid.

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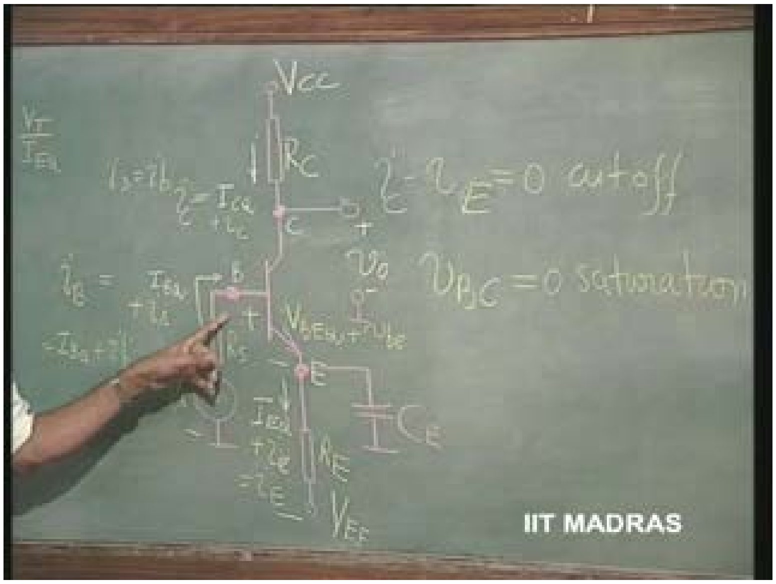


So, this entire transistor is now trying to become a short circuit. So actually, the inversion is lost. This point is going to be very nearly at the same point as this. If this voltage increases, this will also now increase. So actually speaking, if it is not a large amplification, you will see that the input voltage will appear here increasing, because it is increasing at the input here; so, it will increase at the input. Until that saturation is reached, when this is increasing, this will be decreasing. So, how do you see saturation?

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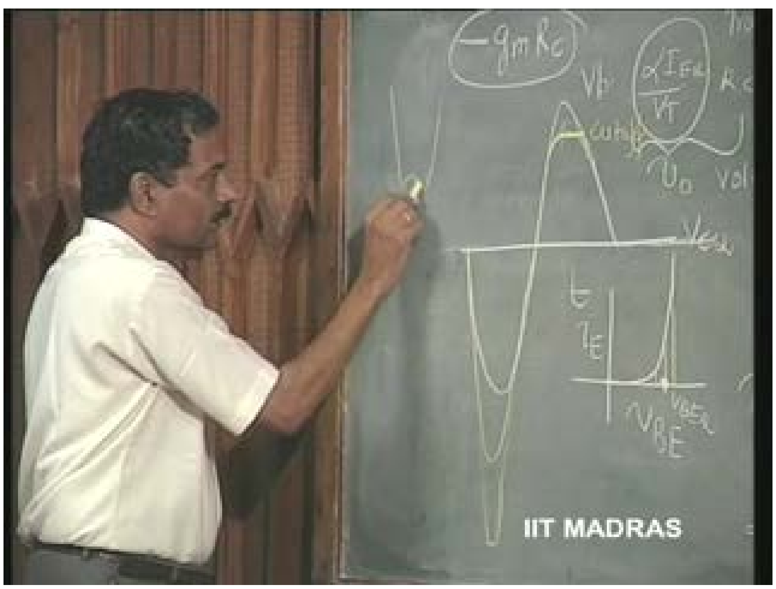

Actually if you magnify this point at this thing, it will look as though... so, it will... this portion of the sine wave now will come here as such, because there is no phase inversion. Otherwise, it would have come as this. So, this will simply appear.

So you can now distinguish between distortion occurring due to saturation, distortion occurring due to cut off. These things are very clear. When it is cut off, it is just, almost chopping off, because there is no voltage further increase that can occur; just chopping off. When it is in saturation, it is not. This signal still appears. But, the amplification factor is not at all there. It may appear just as such; whereas, this is the amplifier signal.

So, you might not really see that increase there. Or, it also might appear almost flat, if it is a good amplifier. If it is a bad amplifier, you will clearly see that it has gone over to saturation, because there is going to be this flip-over of this portion of the signal. Is it clear?

Now, this is the saturation non-linearity; this is the cut-off non linearity. Now, I want to make a very important thing clear here. The transistor amplifier is said to go to saturation in both these cases, because it is not now any longer acting as an amplifier. The transistor amplifier is said to go to saturation. It is reaching its limiting level of output on either side. The transistor by itself may go to cut off or saturation, when the transistor amplifier goes to saturation. Is this clear?

So, when you are considering amplifier, you will not bother about these two points as saturation points. Where the amplifier characteristics will be just this; this is the linear characteristics; non-linear... these are the two saturation levels. This, at this point, the transistor is going to saturation; at this point the transistor has gone to cut off. But, as far as the amplifier itself is concerned, this whole thing is called saturation non-linearity, limiting non-linearity it is called.

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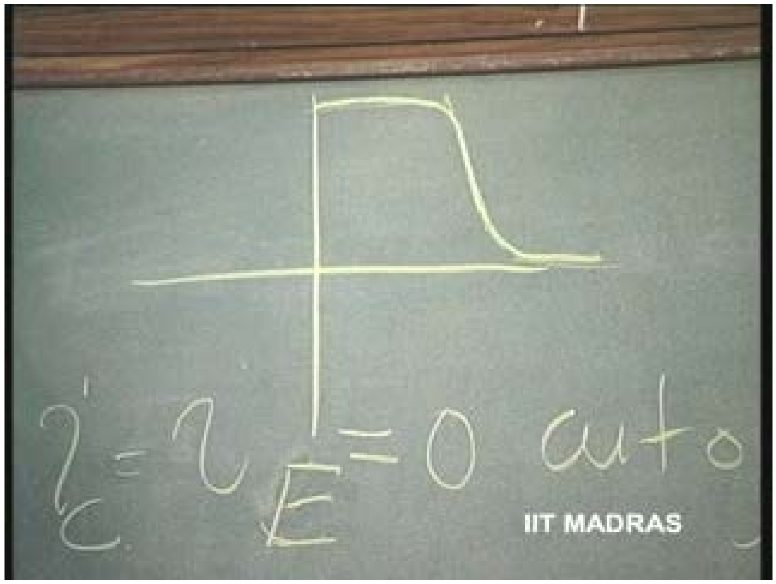


So, this comprehensive thing is important in that in the initial stages, when these non-linearities do not come into picture, when this system can be assumed to be linear, when this V p is much less than 4 times V T, then I can say that I will have one circuit for D C, another circuit separately for A C. This is V C C and there is no change here. At this point, there is a change which is V naught, possible, because current i c is changing here; and that is flowing through r c.

So, for all changes, increments in voltages, I am going to set up a separate equivalent circuit. For that purpose, wherever there is no change in voltage, that point is considered as ground point; no change in voltage with respect to common ground. That means it is the same as ground point. So, V C C is grounded, V E E, minus V E E is grounded; and therefore, the equivalent circuit for this now, for only changes, can be extracted from this. This R C is going to be grounded, grounded through capacitor C E.

And this is the... this is the equivalent for only changes, when the changes are small.

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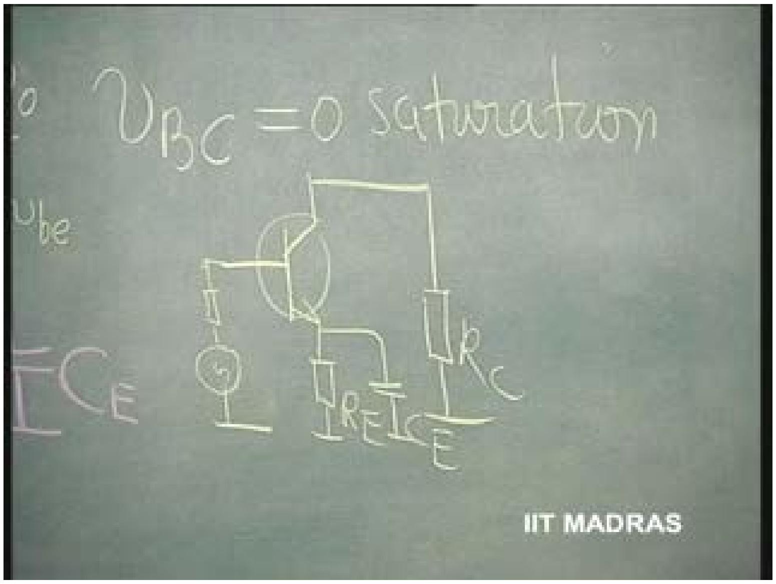


Now, the transistor can be replaced by its equivalent circuit, linear equivalent circuit, where you are going to replace this by small r e; and this by Alpha times i e, when this current is.... All these directions, you must definitely put. This is valid all for...only this signal, i s. So, v s is kept as such, r s is kept as such; and through this v s r s combination, instead of I B Q plus i s flowing now, only i s will flow. So, through this, only small i s will flow.

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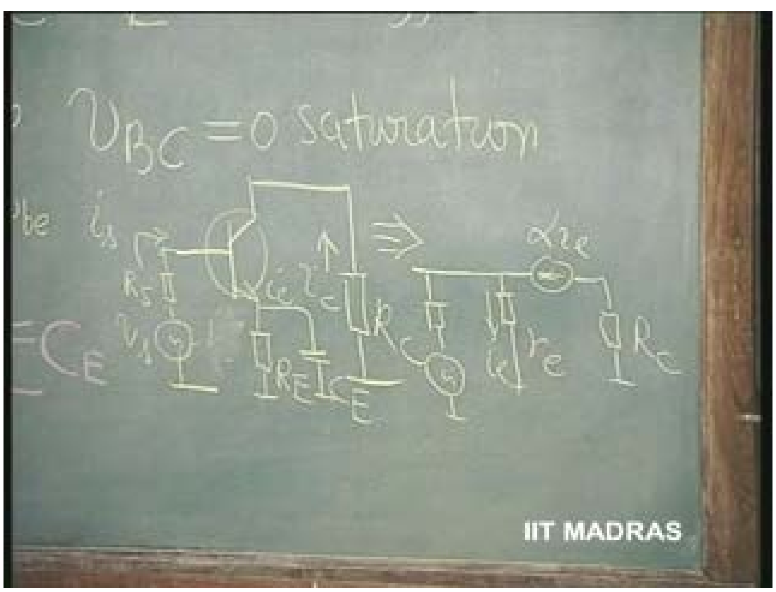

Now, V C C is grounded; and instead of through this now, I C Q plus i c flowing, only i c will flow. Instead of through this, actually speaking, we will put it here, i e will flow. And this i e will flow, not through this r e, but through this capacitor which is a short circuit.

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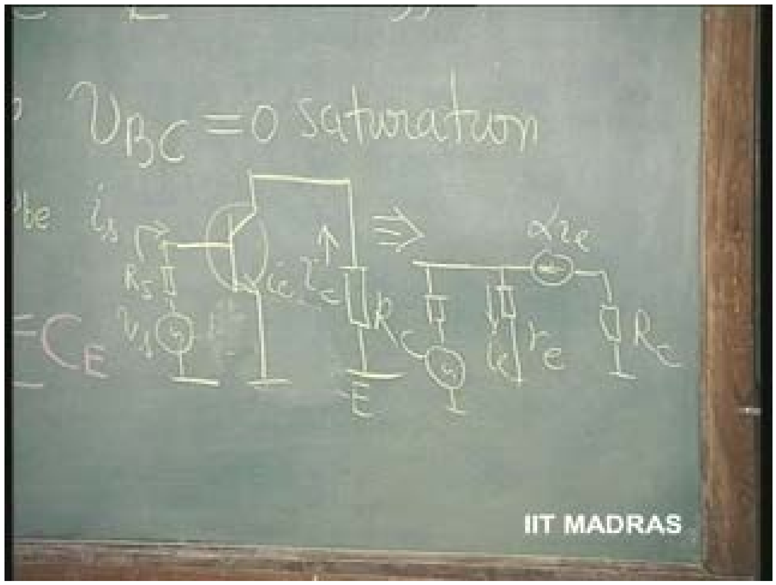


So basically speaking, therefore, this is going to be... because the potential here remains constant, which is nothing but minus V E E plus I E Q into R E, constant potential, if you have selected the capacitor properly. So, whenever there is a constant potential, we are grounding it.