Analog Electronic Circuits
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Lecture – 15
Analysis of Simple Non - Linear Circuits Containing a BJT (Contd.)

Start sir.

Welcome back after the break.

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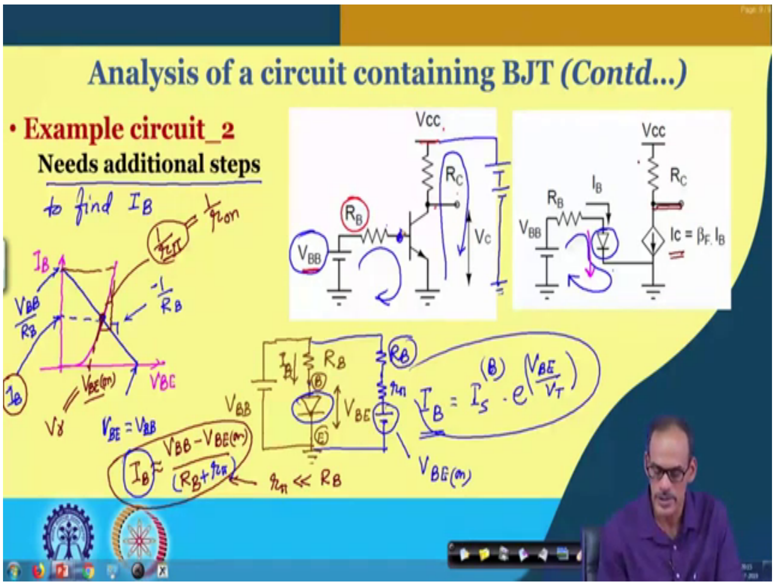

So, we do have this slide which is as I said very busy slide. So, what we have seen is that by considering the base loop we can find the base current and then we can proceed for finding the collector current and then we consider the collector loop. So, this is the base loop and then we do have the collector loop. So, this loop it is getting completed by whatever the DC voltage we are connecting here with respect to ground.

So, now let us see instead of giving this the voltage here by this mean. Let me see what are the different ways the signal can be given to the base of the transistor and let us see what is it is different implication for different cases of applying the in the voltage at the base.

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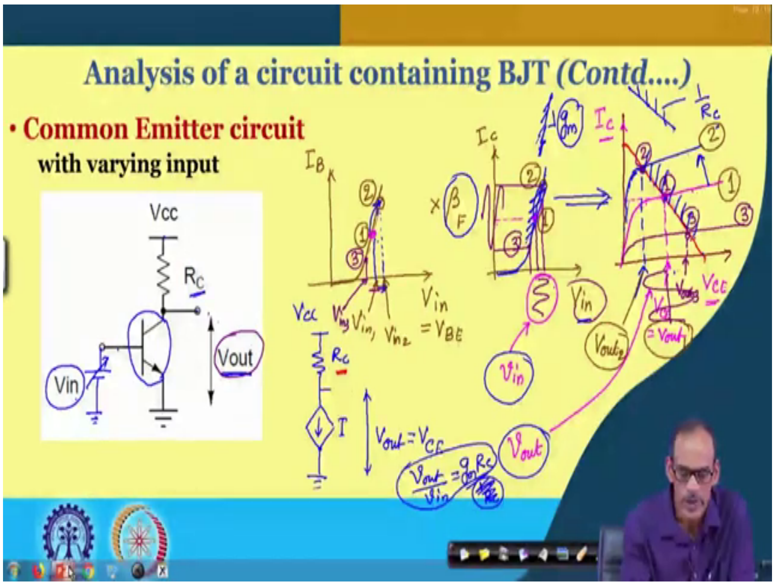

So, here we are throwing this new you know words called common emitter circuit configuration So, let us see what it is. So far we are discussing about this transistor, it is at the base we are connecting something and then the collector we are observing it is corresponding effect. While keeping the voltage at this node some DC voltage with respect to ground

Now, here if I give a voltage directly at the base and let you call that we are applying a voltage here and let you call this is input voltage. And if we vary this voltage the corresponding effect we like to observer the collector. So, we may say that we are observing the effect at the collector and hence let you call this is the output port and so and then this is input port.

So, the voltage you are applying here we are calling it is V in and the corresponding effect will be observing at the collector with respect to emitter let you call this is V out Now, we have discussed that what are the things it will happen for a given voltage at the base. So, in case if the voltage it is directly coming to the base, we have said that at the base side we do have Iv characteristic.

So, that gives us basically the base current. So, if I say that this is the V in which is incidentally same as V BE of the transistor and we know that this is having either you may say exponential in nature or we may say that we can approximate by linear line or whatever it is.

So, then from that we multiply with beta f to get the corresponding collector current. So, what we are getting here directly if I write that this is the Ic versus the same V in. So, we are getting the Ic versus V in like this. So, based on this scaling factor the corresponding scale here it will be different, but the nature here and this one it will be essentially same.

So, we may say that the based on this condition we are getting the corresponding collector current. Now, if you see the output port which is having the equivalent circuit like this. If I ignore the early voltage effect, so we do have Rc and then we do have the V CC and then we are observing the corresponding output voltage here. So, you may call this is V out that is what we are calling and incidentally that is same as V CE. So, if we draw the Iv characteristic of the output port on the other hand namely the I c versus VCE characteristic.

So, which means that for a given value of current say or let me start from here for a given value of V in say at this point we multiply with beta F then we are getting the corresponding collector current and this collector current is giving us at the output terminal and that current is flowing through this Rc.

So, if I ignore as I said if I ignore the early voltage, then you may say that the collector current it is almost independent of this V CE and so the you may say that pull down element characteristic it is you can say it is horizontal. On the other hand the load line namely the characteristic of the Rc it is giving us the corresponding load line ok.

So, now this is what earlier also we have discussed. Now see what are the things it will happen in case if we are changing this voltage. So far for a given value of V in we are getting the corresponding solution here namely the same collector current is coming here and then we are finding the solution here do which is VCE incidentally that is equal to V out.

Now, if I increase the say input voltage by some amount, which means that V BE of the device it is getting changed to some other value. So, from this point we are moving to this point. So, likewise the corresponding collector current is also changing up. Which means that it is corresponding characteristic or what you say that pull down element characteristic got shifted up ok, assuming that the device it is still in active region particularly while it is crossing this load line.

And while we are increasing the input voltage the characteristic of this Rc did not change only pull down element characteristic it got changed from the violet color to the blue color. So, due to this change of the V in what you can say that this intersection point got changed to this point, in other words the corresponding output voltage now will got change to this point.

So, let me put a number here. So, let me call this is the first case, for first case we do have this current. So, let me write this characteristic is for the first case and the corresponding V out here it is we call it is V out 1. So, this is also first case. Now, the second one the let me use a different color here. So, now we do we are at this point so; that means, at the input we are applying V in 2 earlier it was V in 1.

So, now we are at this point and then the corresponding characteristic also got shifted up and the intersection point going from this point to this point. So, we call this corresponding output it is say V out 2. So, likewise if on the other hand if we decrease the input voltage to a lower value say here let me call this is V in 3. So, that gives us say collector current somewhere here and that gives us the pull down characteristic here.

So, now the intersection point it got shifted here. So, initially it was here it got shifted to this point now it got shifted down on the other direction to this point. So, the corresponding voltage here will be calling say V out 3. So, if I vary this voltage and if we monitor or if you observe this voltage we can see that this variation it is creating an effect here.

And this effect if you see here incidentally while we are increasing this voltage the voltage here it is decreasing and vice versa, but most important thing is that, if we change a small amount here the corresponding variation here it is more. In fact, it is actually it is related to the slope of this line or slope of this line and slope of say the load line. In other words if I vary this V in and if I create the corresponding change in Ic.

So, if I vary this V in like this the corresponding effect here it is in the current also it is coming here and that makes this characteristic is also going up and down and making this voltage it is remaining on this load line; however, it is going from this point to this point. As a result the corresponding output corresponding effect it is coming like to the output in the amplified form.

So, if I say that this is the; this is the cause if I say this is the cause or input may be signal input called say small V in and the corresponding variation here whatever we are getting here it is the V out. So, based on as I said that based on this slope and based on this slope we can say that signal it is getting amplified. So, you may say that it looks like there are two mirrors say this mirror it takes this signal converts the voltage signal in the form of current. So, depending on the slope of this line you can see that for a given variation here it is having good amplification.

And then this variation it is coming to this y axis and then load line it is working as another mirror working in opposite direction namely converting current into voltage. So, if the slope of this mirror it is very stiff compared to the this mirror then we will be getting the amplification. So, intuitively you can see that this I v characteristic which is of course, it is exponential which is having very sharp you know slope and on the other hand this line slope of course it is decided by 1 by R c.

So, relative slope of these two so called mirrors they are providing a gain. So, if I say that slope of this line it is gm called transconductance of the circuit why is it called transconductance. Of course, it is current to voltage to current relationship. So, that is why it is conductance and also it is relating input voltage to output current or collector terminal current that is why it is called trans conductance and then if I consider the slope here it is one by r c.

So, if I combine this slope here 1 by Rc and this g m together and of course, it is bringing back this the current to voltage so. In fact, if I take reciprocal of this one that gives us the overall gain, namely this divided by V in. So, V out by V in is this gm divided by slope of that line 1 by Rc or this Rc it is directly coming here. So, you can say that this is gm into Rc. So, instead of writing like this we can directly write gm into Rc.

So, that gives you some idea that how the this circuit can be utilized as an amplifier. So, we are getting a notion of amplifier. So, instead of changing this voltage slowly, if we vary rapidly probably we can find nice amplification.

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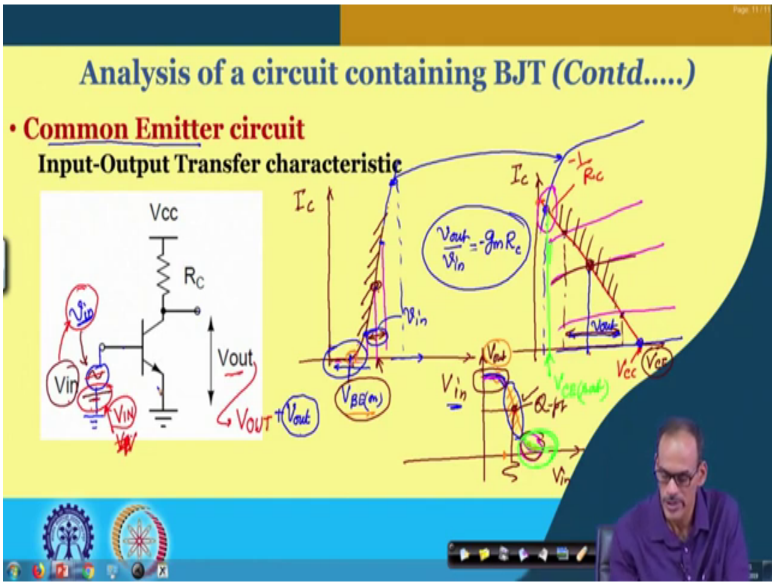

So, let us see so we do have; we do have the same circuit here. So, instead of giving the DC signal we may call this is V in and whatever the things we are observing here we call it is V out. And as we have discussed in the previous slide, so if I vary this input over a wide range.

So, if I vary this input over a wide range, what we have seen is that I c it is changing with respect to V in and this change it is coming to the output port. So, I c versus VCE which is of course incidentally that is V out. So, this characteristic this characteristic curve it is after multiplying with beta it is getting as output characteristic like this.

So, for different input, so for different input if I consider the corresponding output of course let me draw the load line. So this load line of course, this is slope it is 1 by Rc with a minus sign this point is V cc. And what we said it is so for we are talking about input if we change over a small range, then we have say we have say that the corresponding the pulldown characteristic also getting shifted up or may be shifted down and so and so.

But then if I vary it if the if I vary this input over a wider range, say for example if I take this variation even a smaller value. So, the corresponding output characteristic it will be like this. So, the corresponding voltage here output voltage may get stuck at V cc particularly. If the V in is less than this point you may call this is whatever cutting voltage or V BE on and if the input voltage is less than that of course, the output is a remaining there.

On the other hand if the output is going beyond certain level. So, it may be going very high here and the corresponding pull up characteristic it may be like this, corresponding to say this point and that may be making the transistor entering into the saturation region and the corresponding output it will be almost to remaining close to 0.

So, if I vary this input over a wider range and then if I observe the corresponding output here. So, this is corresponding to the middle one this is corresponding to this point and this is corresponding to say this point and so and so. Then what whatever the behavior we observe namely let me use this space, V in to V out characteristic that we get something like this.

So, till V in is V BE on the corresponding output it is stuck at V cc and then it goes down fairly in linear way or rather whatever the characteristic we do have here. And then again once the device it is entering into the saturation region, output remain close to ground like this. So, this point is corresponding to this point, on the other hand once you exceed say beyond some point here we are going to this point.

So, you may say that in the middle range; middle range is the behavior input to output transfer characteristic behavior it is quote and unquote linear. On the other hand if you are going here due to this part the input output transfer characteristic it is getting saturated on the other hand due to the other side due to this part is getting saturated. So, this non-linear behavior it is coming from the trans characteristic non-linear part and this non-linear part it is coming due to the output port characteristic and on the other hand in the middle we are getting fairly good linear part.

So, whenever we are considering say this circuit as an amplifier. What we like to do here it is we like to keep the device in this middle portion preferably with respect to a middle point here. And then input will be varying with respect to that and we should rather avoid this part and this part where the signal it is getting clipped.

There may be different application specific application where we may push this device into this two non-linear part. But unless otherwise it is stated for analog circuit we prefer to keep the circuit here and how do you do that we make sure that V in it is beyond V BE and also the VCE it is such that the device it is not entering into the saturation region.

Where you may be you may recall that one important thing is that, in this portion the device in if the device is entering into a region where the input to output transfer characteristic it is getting saturated. So, in other words you may say that if I want to use this circuit as an amplifier, it is corresponding output is getting saturated that is why this portion this portion. If the VCE is less than some value called VCE sat, if it is less than that we call it is the device it is in saturation region.

So, now at least we are moving to a direction that we will be keeping the device at some stable point called Q point or operating point. In other words we like to keep the device somewhere here called whatever it is Q point. So, you may say that the corresponding pull down characteristic it is basically this one and then with respect to that we like to vary the input plus or minus with respect to the Q point. And as a result we will be seeing the corresponding intersection point of the pulldown characteristic and the load line it is going up and down, which is making the corresponding output here.

So, in other words you may say that instead of a considering this signal as DC, we may say that it is having some sinusoidal part and then also it is having a DC part. And this V in we may say that small signal part or the signal part we denote by small V in. And on the other hand the large signal part or the DC part which is defining the operating point by say capital V BE or whatever capital V in. Let me write here capital Vin.

So, you may say that this capital V small in it consists of this part small signal part as well as the DC part and the DC part should be such that this operating point should be in the middle preferably in the middle of the suitable range of the input to output transfer characteristic and then we apply the signal with respect to that.

And likewise at the output whatever the voltage we will be observing, corresponding to this DC it may be having a DC part called capital V small out and then it is also having influence of the small signal and the corresponding influence or effect we call small v out. So, we will say that this is the small signal part.

So, this input to this output of course we are expecting gain and again what did we say that the slope of this mirror or this trans characteristic to the load line slope or whatever you say this mirror, they are defining the gain of this V in to V out. So, end of it what you are getting is so we are having this is V out small v out and this part it is small v in and v out divided by v in is essentially slope of this line which is gm divided by slope of this line which is 1 by R. And so it is coming Rc of course it is having a minus sign so that makes the minus sign here.

So, you may say that the circuit gain it is minus gm into Rc and as I said that we do have a notion something called amplification. So, this circuit it is providing a good gain and we call this circuit it is common emitter, that is because the signal we are applying here at the base and we are observing the output at the collector and the emitter it is connected to either DC voltage or in this case it is ground.

So, we may say that for the signal emitter it is also working as a reference terminal and that is why you call it is common emitter amplifier. Note that emitter need not be connected to ground, as long as it is this emitter it is connected to a constant DC voltage then also we call it is common emitter amplifier. So, there will be different other configurations, but before we go into that let me we summarize whatever we have discussed here.

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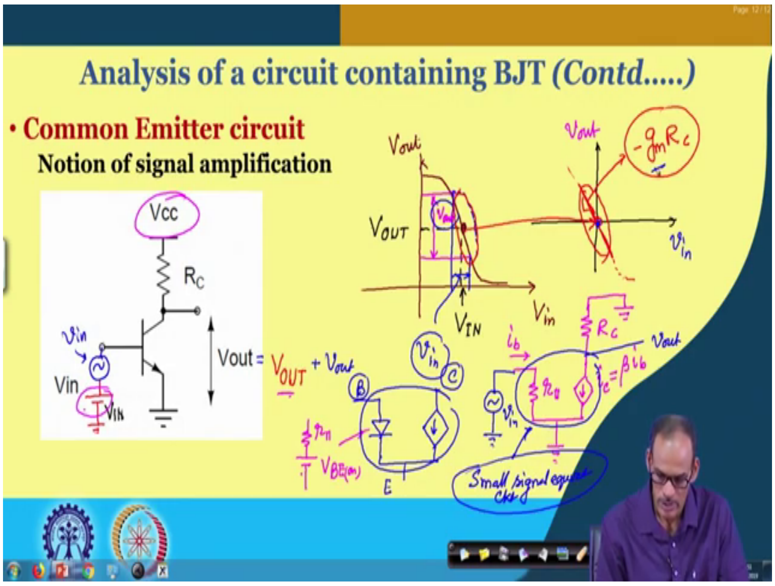

Ah so let me rather use different slide here. So, at the input; at the input as I said that we do have a DC part and then we do have a small signal part together. And it is creating an effect here which is having a again the corresponding DC part and then it is having a small signal part.

And from the input to output transfer characteristic what we said is. So, this is capital V small out and x axis is capital V small in and as I said that it is having fairly non-linear part initially and then it is having a linear part and then it is getting saturated like this. And at the input at the input whatever we are saying that V capital IN is basically capital V capital IN, that gives us capital V capital OUT.

And with respect to that we do have if we apply some input. So, with respect to that we are applying input here. So, that is small v small in and the corresponding effect we are getting here it is variation of the V out and we call this is small v out.

Now, so you may say that for every time this is our reference point. So, if I change this V in over this range and to find the corresponding solution, either we can use this non-linear characteristic curve every time. Or the better option is that since we are interested of the small signal to this small signal output. Probably it is better to consider only this segment this segment of the characteristic curve and we can confined our discussion with respect to that.

Namely let you consider now this is small v in to small v out and this whole characteristic now it is getting shifted to the origin. So, you may say that the characteristic it is only this part. So, this point it is coinciding with this origin and this segment of the transfer characteristic curve it is here.

So, every time if we ensure that this operating point is not changing, that means this point is not changing and then if you have any signal here ensuring that this Q point is not changing. Then this characteristic curve it is sufficient and slope of course slope of this characteristic curve as you said that this will be gm into Rc with of course, a minus sign.

So, that is the slope of this characteristic curve and so from that we can find what will be the input output relationship. Of course, if you go beyond this one then there will be non-linear part which we are not interested in.

Since we are suppose if we ensure this Q point always aligned with this origin of this small v into small v out transfer characteristic, then we may say that the analysis of the circuit it will be much simpler. Which means that if we draw the corresponding equivalent circuit, so instead of.

So, if you see the device large signal wise we do have this model of the BJT. So, this is the base terminal and then this is the emitter terminal and this is the collector terminal. So, this circuit of course, we do have Rc connected here and this model it may be simplified or linearized

So, when you may recall that this consists of one on resistance and then the cut in voltage in this case we call this is V BE on and this is base to emitter resistance called r pi. So, whenever we are shifting this Q point to this origin, equivalently saying that we are dropping the DC part.

That means, we are making this is ground this is also ground and we are also probably we will be getting this also ground and not only this external DC voltage need to be dropped. But whatever the internal DC voltage is existing within the model itself that also need to be drawn.

So, the whole circuit now it becomes simpler like we do have r pi here. So, this part it is getting dropped and then here we do have I may say this is remaining current control current source. So, here now it is only the signal part we will consider. So, we use small ic which is beta times, i b where i b it is the small signal current flowing here.

So, then of course we do have the Rc connected here, but then Rc it is connected to DC voltage which is AC ground. Emitter node anyway it is connected to ground and at the input the signal, whatever the signal we are applying here that is the input signal and the DC part it is getting dropped out. So, we may call this is the V in and the corresponding voltage you will be getting here it is called the small signal V out.

So, instead of using this model now we are going to use this model. So, similar to diode here also we do have a notion called small signal equivalent circuit, which is also giving small signal model of the whole circuit. And once we translate this into a small signal equivalent circuit the, as I said that we are simplifying the circuit not only by just dropping the DC part, but also making all of the DC component internal to the device or also getting removed.

And most important thing is that since this characteristic curve it is going through the origin ah, that means input to output relationship it is linear and hence superposition theorem can also be deployed once we consider this configure this simplification. Only thing is that we have to ensure that this Q point is not getting shifted.

So, along with the signal amplification we are also getting a notion something called small signal equivalent circuit. So, this is referred as small signal equivalent circuit ok. So, we will be later on we will be frequently using this model, only thing is that you need to be of course, we have to consider this model to get the value of the DC current and to get the gm.

Of course, these gm it is a strong function of the DC collector current So, we will be discussing that later, but just to highlight that in our later examples those are the things we will be discussed more.

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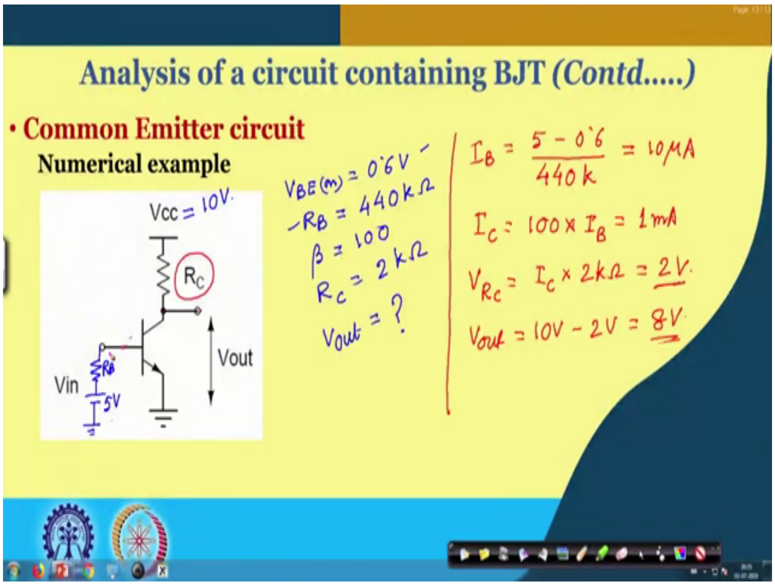

Now, probably we can try out one numerical solution numerical examples. So, suppose we do have a circuit like this, let you consider this is 10 volt and let you consider V BE on equals to 0.6 volt and at this point we are connecting a DC source through RB. And let you say this is 5 volt and let you say that this RB equals to maybe 40 440 kilo ohms and beta is equal to say 100.

Then and also Rc equal to say 2 kilo ohm, then can you find V out. So, how do you proceed, first thing is that we need to find IB by considering this RB and V BE on and then 5 volt. So, you may say that I B solution wise, so IB equals to 5 volt minus 0.6 volt divided by 440 k. So, that gives us 10 micro ampere and then Ic equals to beta times IB. So, that gives us 1 milliampere and then drop across Rc equals to I c into 2 kilo ohm. So, that gives us a 2 volt. So, the V out which is 10 volt V cc minus 2 volt that is 8 volt.

Now here of course, here we have assumed the device it is in active region and since this is 8 volts and the voltage coming here it is close to 0.6. So, definitely base to collector junction it is reverse bias and hence the device it is in active region and hence everything is consistent. But of course, if I increase this Rc then and if this drop it is approaching towards 10 volt the device it may be entering into the saturation region.

Now, on top of this one if I say that if I feed a signal here at the base, then what may what it may happen. So, probably today we are running short of time. So, let me consider that example maybe next day.

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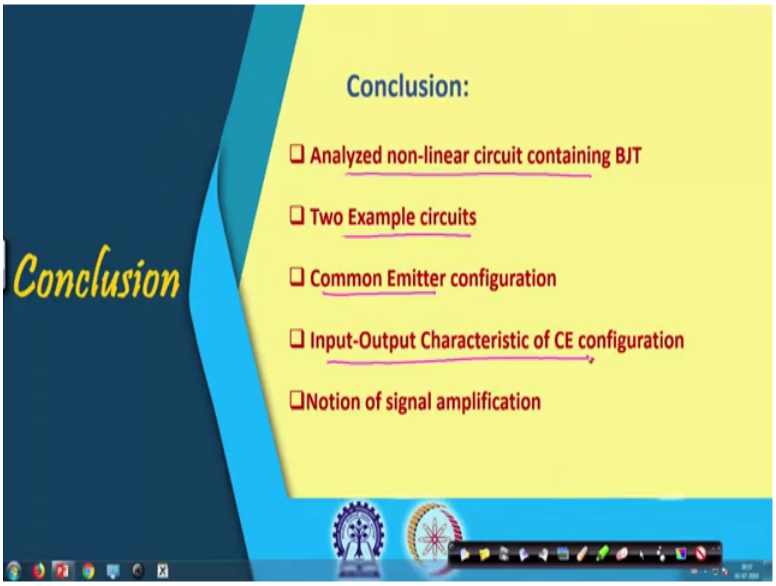

So what we have covered? So, far we have analyzed non-linear circuit containing BJT and we started with two examples where we have applied voltage at the base and then we have observed the corresponding currents at the collector and then the corresponding output voltage.

Then we have entered into some circuit called amplifier, where we say that the circuit is having specific name called common emitter configuration. We also have observed that input to output large signal characteristic of the common emitter amplifier and then portion of the large signal characteristic can be considered as small signal input to output transfer characteristic.

And slope of the transfer characteristic which is we have seen that it comes from the gm and the load Rc together to define the slope of that and that is making if it is higher than 1 that is making the circuit as an amplifier. So, we have seen that notion of a signal amplification by this common emitter amplifier and we have given a slight hint of moving to small signal equivalent circuit and a small signal model of the BJT. So, later on we will be discussing that part for the detail, we just gave a small example numerical example we will be having more examples later on.

I think that is all I do have today.

Thank you for listening.