Analog Electronic Circuits
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Lecture – 45
Common Collector and Common Drain Amplifiers (Contd): Analysis (Part A)

Dear students, welcome back to our online NPTEL certification course. The topic of this course is Analog Electronic Circuit. Myself Pradeep Mandal from E and ECE department of IIT, Kharagpur. Today's topic of discussion it is Common Collector and Common Drain Amplifiers, rather I should say it is continuation of this topic. Previous day we have discussed about relatively idealistic bias situation and today we are going to a little detail considering some practical circuit components also.

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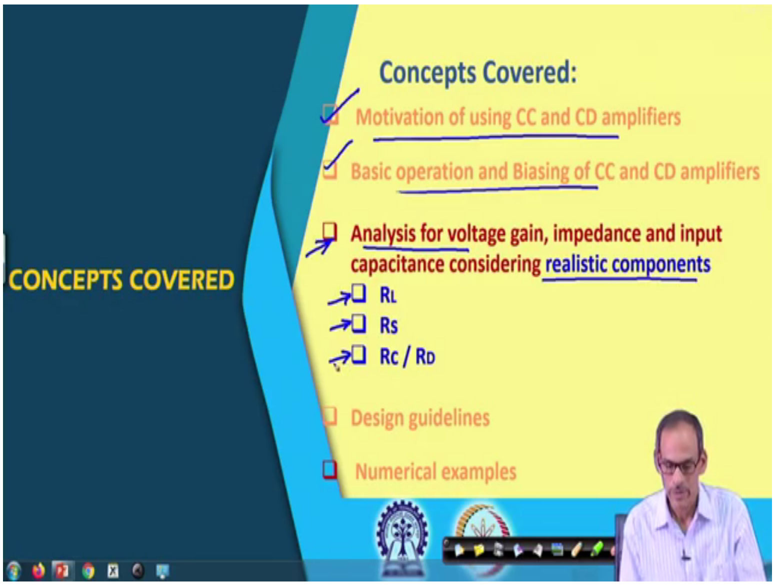

So, what we have to cover today, as I said we have discussed the motivation part of the common source and sorry common collector and common drain amplifier, basic operation and biasing also it is done. And we are going to go a little detail of analysis of voltage gain and impedance, input capacitance, considering realistic biasing and their associated components.

In fact, in the previous class we have discussed about the analysis of the circuit for voltage gain, impedance and input capacitance ignoring these components, and today we are going to see that what will be there you know consequences if we consider on a practical components. So, let us start with the common collector amplifier, considering the R L, and then we will be moving to the next one is considering the source resistance R S, and then we will go for the collector terminal resistance.

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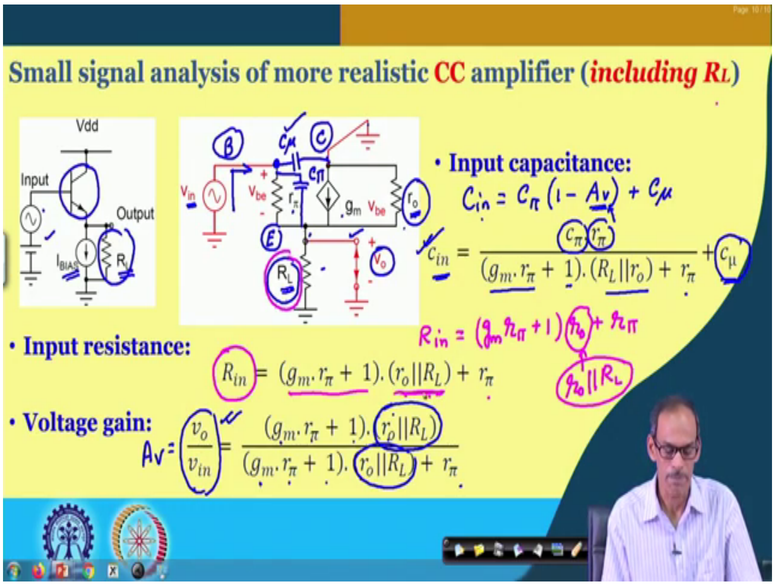

So, to start with let we let you consider the common collector amplifier and also in the common collector amplifier we are including this R L. So, this R L may be coming from the bias circuit, representing the finite conductance of the bias circuit or maybe and or maybe additional load resistance we are connecting at the output node with respect to ground.

So, whatever it is let you consider this R L in our analysis and here we do have small signal equivalent circuit of the common collector amplifier having this R L included. So, we do have r pi here and then g m into V be r naught coming from the mos at the BJT transistor, and then we do have this R L bias circuit it is then the I bias part it is 0 in this small signal equivalent circuit. So, likewise the DC part also it is 0, we do have only the signal coming to the base terminal. So, we do have base terminal here, and then we do have the emitter terminal here and then we do have the collector terminal. And this is the output port, so the output voltage it is V o and the emitter with respect to ground.

Now, in our previous analysis where we have excluded this R L there we have seen the expression of the input capacitance. Basically, the input capacitance at the base with respect to the AC ground. And there what we have seen if you consider the two parasitic components capacitive components one is c mu and then we do have the c pi here.

So, what are the contributions c mu the right side of c mu it is connected to ground. So, it is directly contributing to the input capacitance as is, as you have discussed before. On the other hand, this c pi it is making a connection from input to output of this amplifier. And the gain of this circuit we have discussed if you see here in fact, if we recall c in it is having two parts, one is c pi into 1 minus voltage gain of this amplifier plus c mu, and this voltage gain to get the expression of this one we need to get the voltage gain.

So, in our previous analysis we obtain the voltage gain v o divided by v in where R L it was very high. Now, if we consider this R L what you are getting this R L coming in parallel with r naught. So, whatever the previous expression we are having namely g m r pi plus 1 into r naught, and in the denominator it was g m into r pi plus 1 into r naught plus r pi.

Now, if we have this R L which is essentially coming in parallel with r naught then whatever the derivation we have done before that can be as well utilized just by replacing this r naught by R, r naught an R L in parallel. So, wherever we do have r naught in our previous derivation if you replace that by r naught in parallel with R L, then we do get the corresponding voltage gain.

So, if you put this expression of this voltage gain here, so this is A v. So, if you put that voltage gain expression here, what we will be getting here it is c in it is having c mu and then c pi part it is having a factor which is a having in the numerator we do have r pi and in the denominator we do have g m into r pi plus 1, then r naught and R L in parallel plus this r pi. So, that is the expression of c in.

Likewise, when you consider the input capacitance if you see the expression or if you recall the previous expression of the input resistance without considering this R L, what we had it is R in it was g m into r pi plus 1 into r naught plus r pi.

Now, in presence of this R L what you have to do? Again, instead of r naught here we need to replace this by r naught in parallel with R L. So, the expression of the input resistance we do have it is g m into r pi plus 1 into r o in parallel with R L plus r pi. So, that is how when you consider this R L in our circuit. What we are getting it is this additional you know modification and that is that is good enough to get its effect.

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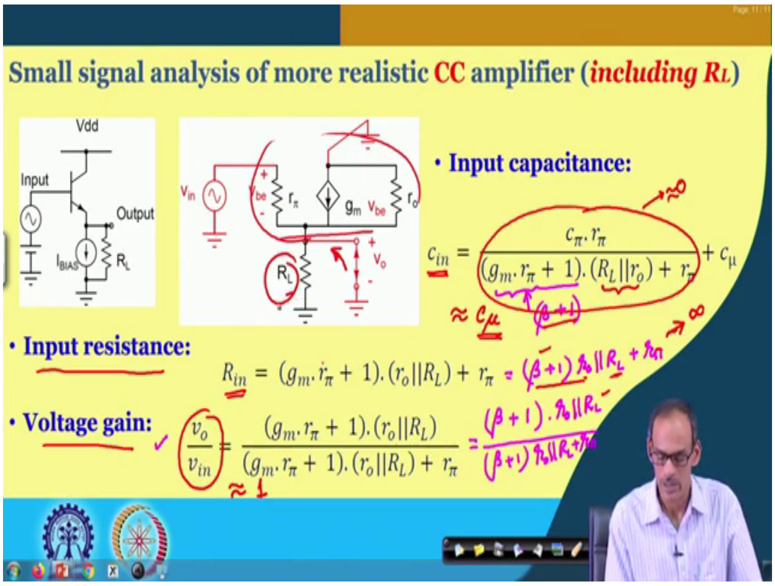

In fact, you can further simplify this one wherever we do have the g m into r pi you may replace this by beta of the transistor. So, here also we can write this is beta plus 1 into r naught in parallel with R L plus r pi. So, likewise here also you can write this part you can write beta plus 1 into this one. So, similarly for the voltage gain here you can write in terms of beta instead of g m and r pi, so we can say that this is beta plus 1 into r o in parallel with R L divided by beta plus 1 into r o in parallel with R L plus r pi.

So, whatever it is all practical purposes, for all practical purposes even if you consider the this R L you can well approximate that this part after multiplying with beta into 1, it will be very high and you may say that this part it is almost 0 compared to c mu. So, as a result you may say that c in it is practical it is c mu.

Likewise, when you consider the input resistance it is we do have r pi coming in series with beta into r naught plus R L. So, though r o or r naught coming in parallel with R l, but even though if I consider the effect of R L since we do have beta plus 1 it is coming in the multiplication again this may be you may consider this is very high. So, we may say that this is going to be a very high compared to other resistances in the circuit. So, likewise when you consider the voltage gain even if I consider the effect of R L this is this can be well approximated by close to 1.

So, the bottom line is at even if I consider R L the main property of the input resistance to be high, voltage gain it is close to 1, input capacitance is very small defined by c mu, those things are getting retained. Also the other parameter we have to think of is that the output resistance. So, if you see this circuit and at this point if you see what is the output resistance, it is basically the output resistance coming from the rest of the circuit coming in parallel with R L.

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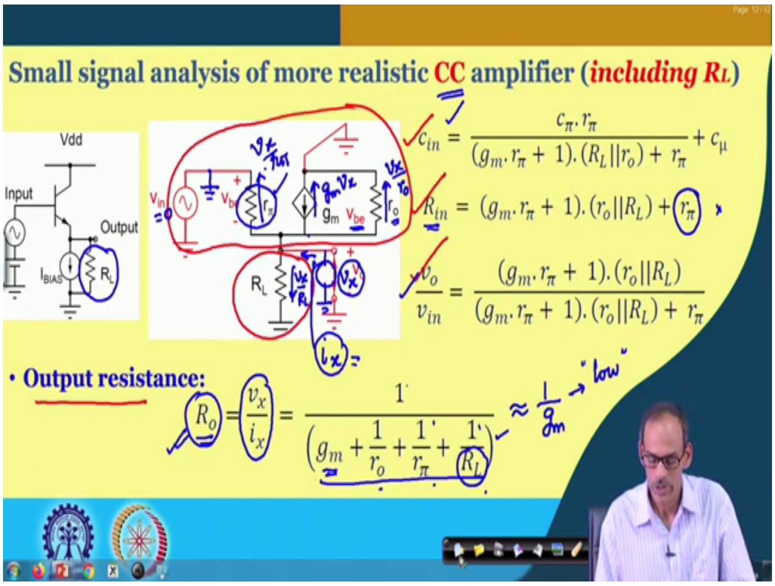

So, that is I guess it is very straight forward to converge. So, I do have, yes. We do have this is the expression of r naught. The derivation of the c in R in and voltage gain we already have done, so these things are already done. Now, in addition to that if you want to know what will be the output resistance is basically this resistance coming in parallel with whatever the resistance we do have in this circuit.

And again, if we refer back to our previous analysis without considering this R L, where to get the output resistance what you have done is that we made this is AC ground and then we stimulate this circuit by say v x, and then we observed the corresponding current say i x, and then if you say what is the; so, this is i x then if I take the ratio of v x by i x that is supposed to be giving us the output resistance.

And earlier whatever the discussion we had you may recall, that if I apply v x here the current flow here it is v x divided by r naught, current flow here it is g m into v x because the V be equals to minus v x, and then current flow here it is since this is a c ground, so this is 0, v in is 0. So, this current it is again v x divided by r pi. So, likewise the current flowing through this circuit it is v x divided by R L.

So, the total current i x it is actually summation of all these four currents. And so if you if you simplify that what will be getting is that output resistance is reciprocal of the total conductance; total conductance coming from all these four elements, one is g m part, another one is 1 by r naught, then another one is 1 by r pi here and then 1 by R L. So, the total resistance again it is its expression is given here, but all practical purposes, even if I consider practical value of R L this g m it dominates over rest of the things, so you may approximate this is equals to 1 by g m. So, this is as I said that basic property we are looking out of this common collector which is buffer voltage buffer it should be low, so that is what here also we are obtaining the same thing.

Now, that is about the common collector amplifier if you consider its counterpart mass counterpart namely the common drain stage and then if you consider this R L for that, what you will be getting it is similar kind of things we can get only difference is that this r pi, it will be it will not be there. So, you may say that because this r pi is theoretical, it is in finite for common drain amplifier. So, this input resistance for common drain stage any way it is high. So, we may ignore this part. Rest of the parameters namely c in voltage gain and then output resistance we can think of. And everywhere again we can converge to the same conclusion.

So, let us see what I do have for you, yeah.

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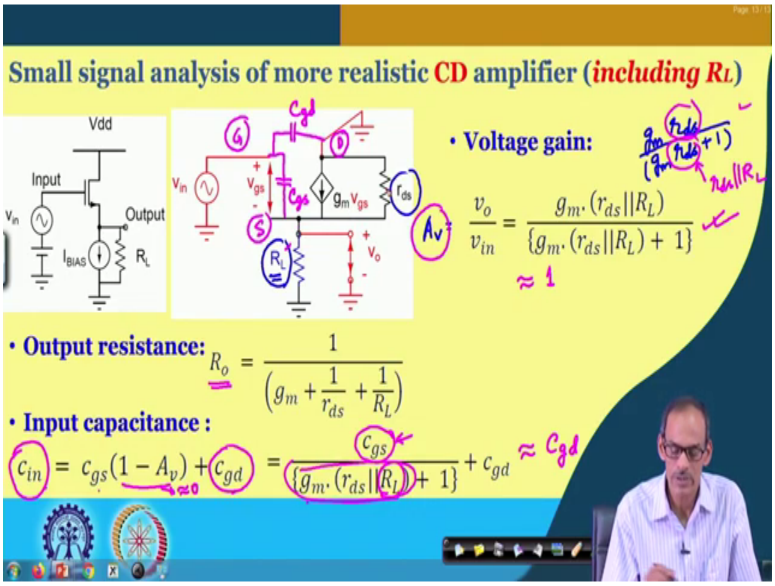

So, the common drain stage considering R L and its voltage gain, voltage gain it is given here. So, again you may recall the previous analysis where we have not considered R L, for that the voltage gain it was g m into r ds divided by g m into r ds plus 1.

Now, in presence of this R L this R L it is coming in parallel with r ds. So, you may say that wherever we do have the r ds, we can we can replace this r ds, this r ds, and this r ds by r ds in parallel with R L and that gives us the corresponding voltage gain. So, likewise if I use this expression to find the input capacitance and its expression it is c gs multiplied by 1 minus voltage gain plus c gd, where c gs it is the capacitance from gate to source.

So, we do have c gs here, and then likewise we do have the c gd gate to drain and so this is c gd. So, the expression of the input capacitance is c gs multiplied by 1 minus 1 minus A v and then plus c gd, so that gives us if I use the expression of the A v here, what we are getting is that c gs it is getting divided by a big factor here and as a result you may approximate again this by c gd.

So, note that even if I consider the effect of R L since this part it is much higher than 1, its effect it is very negligible and as a result the effect of c gs it is very small. So, in fact, it is also very clear that if the voltage gain it is approximately one then this part it becomes approximately 0 or very small. So, we do have only c gd left behind for the c in. And again for the output resistance if I consider this R L in addition to the other components what we have it is; so, let me use different color, yeah.

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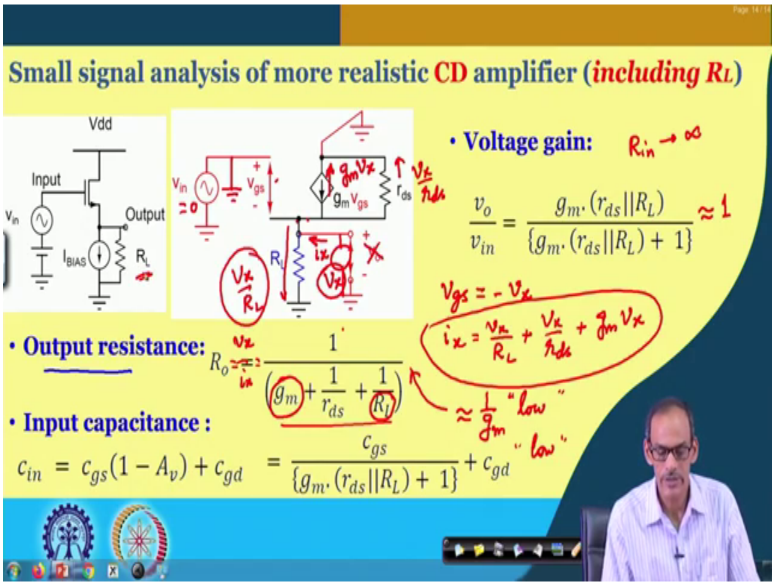

So, if I want to know what will be the output resistance, let me use red color, yeah. So, we have to make it this is ground and then we need to stimulate this circuit by say v x and then current flowing through this is i x and the moment we are applying say v x here the current flowing through this r ds it is v x divided by r ds and then v x incidentally it is same as minus v gs.

So, as a result the current flow through this active device it is g m into v x because v gs is equal to minus v x. So, this minus sign it is suggesting that the direction of the current it will be from source to drain and g m multiplied by that v x. So, here of course, we do not have any conducting path and then the current flowing through this R L it is v x divided by R L.

So, we do have these 3 components. And what gives us this i x is equal to v x divided by R L plus v x divided by r ds plus g m into v x. Now, from this one we can directly say that the v x divided by i x equals to reciprocal of these total conductance. Again, even if I consider the effect of R L for all practical purposes we can say that g m it dominates, as a result here also we can say that the output resistance is approximately 1 by g m, which is you may say that low cut and uncut low, input capacitance is low and the voltage gain it is approximately 1, right. And of course, the R in it remains infinite. So, this summary is that even if I consider R L the basic property of the buffer it is getting maintained.

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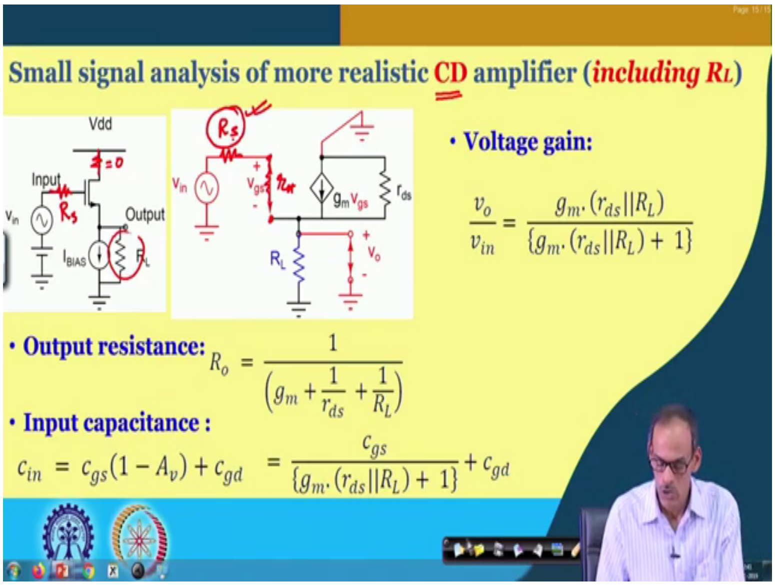

Now, so far we have discussed about the effect of R L and so likewise we may think of the resistance at this terminal resistance at this terminal considering some practical purposes.

Now, if I consider say source resistance and still if I consider this is 0 then even if I connect the source resistance R s, since from this terminal to this terminal, there is no DC path. So, you may say that even if I consider R s the behavior of the circuit remains unchanged. So, for common drain stage we need not to consider this case because we know that whether we consider R s or naught or it is impact it is not there.

However, if I consider say common collector stage; obviously, there will be the corresponding element here called r pi. So, it is better to in case if we consider R s, then we need to; need to analyze its effect particularly for common collector stage.

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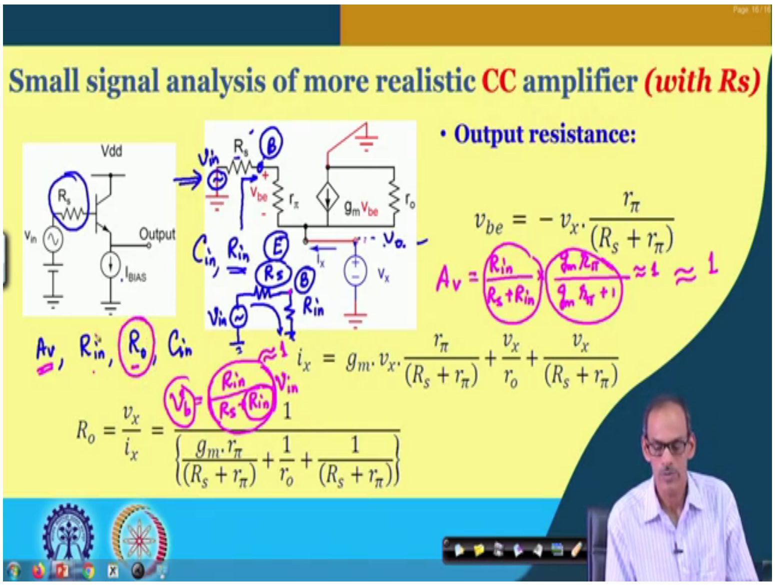

So, let us see the common collector amplifier considering this source resistance, signal source resistance. So, we do have the circuit given here. So, we are considering this source resistance R s. Again, R L we are ignoring, so we are considering one effect at a time. And then the small signal model of this circuit is given here and of course, we should have considered the signal here. Now, this supposed to be the output v o. Now, what are the parameter we need to consider, the voltage gain? Input resistance, then output resistance, and then c in.

Now, if you see that if I consider this R s the behavior of the circuit from here to the output from the base terminal to the emitter terminal, the behavior remains the same. In fact, if you see the input resistance of this part and if I call this is the input resistance that remains the same as what we have discussed before. So, we are not going to consider the analysis for again repeating this R in. Same thing for c in also.

So, whatever the c in we do have, so c in also remains unchanged from base terminal to the emitter terminal. Even if I consider R s and the voltage gain if you see of course, if I consider this is the primary input and this is a corresponding primary output, and if I say the voltage gain from again from base to collector, the emitter terminal gain remains the same namely close to 1, only difference is that if I consider R s I do have v in here and then we are applying the signal through this source resistance R s to the effective input resistance, whatever the effective input resistance we do have.

Now, to consider the effect of this R s in the in the voltage gain we need to consider what is the potential division it is happening before it before the signal arrives to it is a base terminal. So, what is the additional factor we will be getting in the voltage gain? It is R in divided by R s plus R in. So, this is the additional factor. So, if I multiply this with v in that gives us the base voltage, and then from the base point to the corresponding collector point the gain it is approximately 1.

Now, if you see here most of the time this R in as I said R in is very high. So, this factor whole factor it is approximately 1. So, I should say that the voltage gain A v which is in this case R in divided by R s plus R in multiplied by whatever the previous voltage gain we are having. Namely, if you recall it was g m into yeah r pi divided by g m into r pi plus 1. So, it was it was I should say rather this portion it was approximately 1, and this is also getting approximately 1, as a result overall it is also becoming approximately 1.

So, again we are not going to discuss about the output similar to output input resistance, we are not going to discuss about the voltage gain. Only thing we are going to discuss here it is the output resistance.

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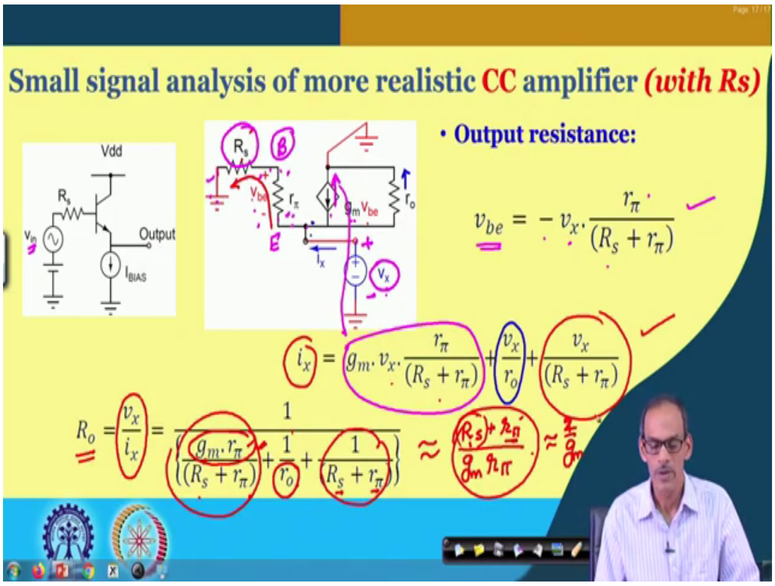

So, let us see what is the output resistance of the common collector amplifier will be getting in presence of this source resistance R s. Now, to get the source resistance sorry the output resistance of this circuit, what you have to do? We need to stimulate the circuit by say v x and we need to observe the corresponding current here i x. So, before we go into the i x expression, we need to make the voltage, the signal here it is 0, so that is why you are making this is a c ground and if we apply v x here, the voltage coming at the base to emitter terminal, so between base to emitter terminal what we have it is V be that is it is essentially the potential division of this v x appearing across this r pi.

So, we can say that the voltage appearing across r pi it is v x multiplied by r pi divided by R s plus r pi, but then this side we for V be we call this is positive and this is negative and v x we are applying here it is positive and this is negative So, as a result the expression of the V be in this case it is minus v x multiplied by r pi divided by R s plus r pi. So, this is one relationship we obtained between V be and v x. Now, the current flow through this active device is g m into V be, so that becomes g m into V be instead of V be we can write minus v x into so and so on.

So, we may say that the current actually it is; so, this starts flowing in this direction and its expression is this one. So, this current expression is given here. On the other hand, the current flowing through this i naught r naught, it is v x whatever the voltage you are applying here divided by r naught and the current flowing through the base terminal towards the base, namely this current it is v x divided by R s plus r pi. So, this is what we are getting. So, the total i x current we can write in terms of v x. So, from this one we can get the ratio of v x divided by i x and that gives us the output resistance. So, which is reciprocal of the conductance of the 3 parts and the first part conductance it is g m into r pi divided by R s plus r pi, second one is 1 by r naught, third one it is 1 by R s plus r pi.

So, in this case again depending on the value of this R s we may consider say this R s with respect to r pi, but most important thing is that we do have g m into r pi getting multiplied. So, now, we can directly see that compared to this term this term it is dominating, and same the similar kind of conclusion we can make because this r naught it is reasonably high, as a result you can say that this term it is dominating. So, the resistance you may say that R s plus r pi divided by g m into r pi.

Now, if I say that R s is varying, R s is maybe comparable with r pi then it remains low, but if say R s is very high if it is very high then of course, we may not be able to approximate this by 1 by g m. So, depending on the relative value of this R s and r pi, we can get the corresponding output resistance. But again even if the R s it is in the order of same as r pi then also you can say that this is in the order of 1 by g m. So, in case say R s equals to r pi, then this may be 2 divided by g m that that gives you some idea that what may be the effect of this R s on the output resistance.

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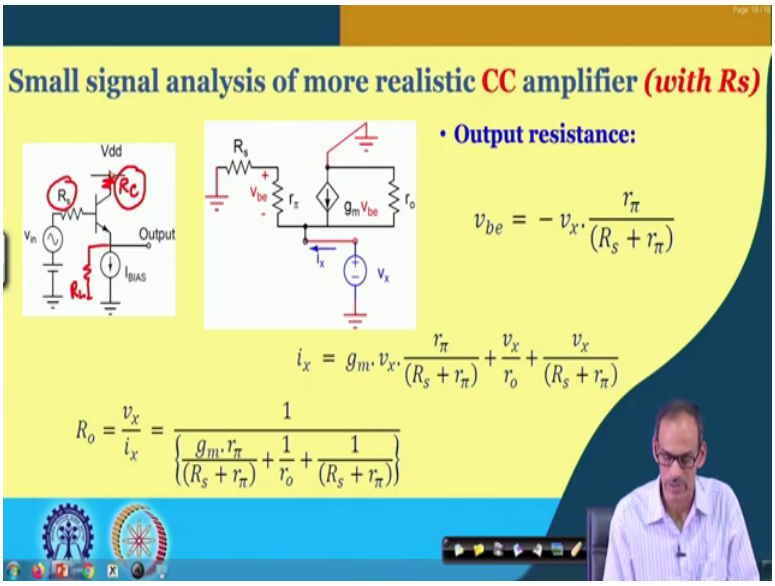

So, this is the effect coming from the R s. So, likewise if I consider, yeah. So, so far we have considered the R s, earlier we have considered the effect of R L and then other part is also possible depending on the circuit connection. It may not be intentional, but there may be some practical situation due to which there may be resistance coming in the collector terminal, in between the collector terminal and the V dd.

So, let us consider the effect of this resistance call R c on different parameters of the common collector amplifier.

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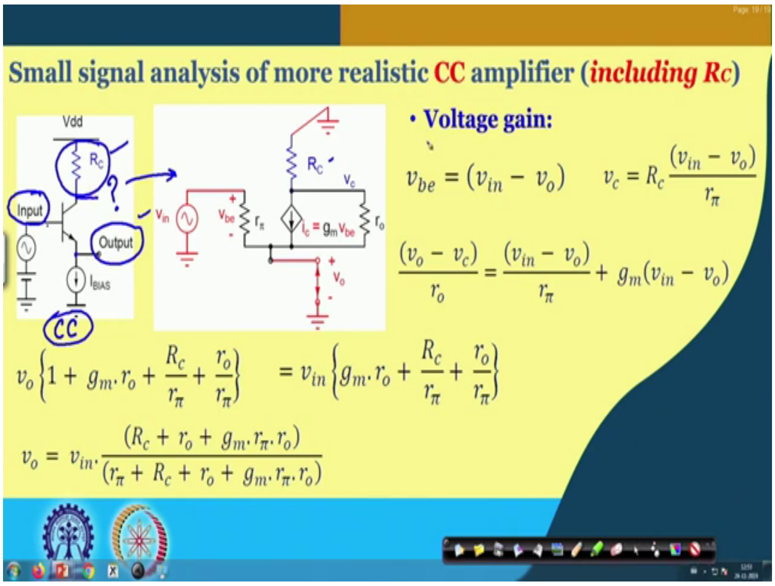

So, what we have it is, yeah. So, here we do have the circuit the corresponding circuit, we do have the common collector circuit having this R c connected to V dd. Note that, please do not get confused that output still remains, the output terminal is basically the emitter of the transistor even though we do have a meaning maybe some signal coming to the collector terminal, but we may not be really concerned about this signal unless otherwise it is stated.

So, our input and output terminal remains base and emitter respectively. And even though we do have R c connected here still we call this is common collector amplifier. We may say that collector is having some resistance, but still we call it is common collector without any you know confusion.

And here we do have the small signal equivalent circuit and if you see the small signal equivalent circuit we are adding this R s. And then, if you see this circuit we can go step by step and we can you can find what will be the impact of this R c on different parameters namely voltage gain, then output resistance, and then input capacitance and so and so.

So, let me take a small break and then we will come back to discuss all those things, namely we will start with voltage gain.

Thank you.