Analog Electronic Circuits
Prof. Pradip Mandal
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture – 46
Common Collector and Common Drain Amplifiers (Contd.): Analysis (Part B)

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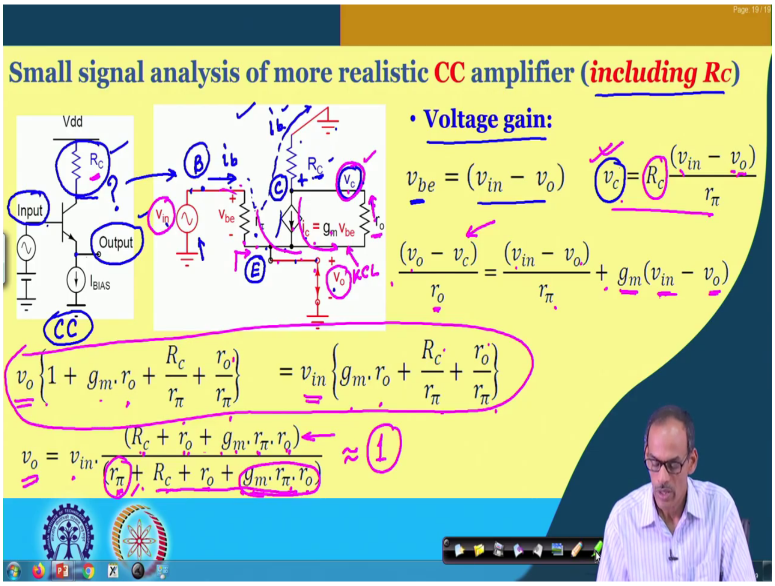

Yeah, welcome back after the short break and we are discussing about the Common Collector Amplifier, considering the; considering the resistance R c connected in the collector terminal in between collector and supply voltage V dd. So, let us see the circuit, which is the small signal equivalent circuit given here. The input voltage V in, we are applying at the base and then, we do have the collector terminal which is not a C ground rather it may be having a signal called say V c. So, this is very important change compared to our previous analysis. So, we do have non-zero value of V c and then, a rest of the things are same namely at the emitter we are observing the collector sorry, the output current output voltage V o.

So, the V be; V be it is V in minus V o as you have discussed before and but then V c if you see once we have this output terminal is open, whatever the current it is flowing here, base current that is flowing through this circuit and finally, it is going to the ground here. Because this current need to come back to the source through the ground.

So, we can say that the current flow after reaching to the emitter whether it is branching to the active device or through this r naught; finally, they are converging to the ground and we can say that this is also same as the base current ib. So, if I call this is ib, this is also base current. So, if ib is flowing through this Rc, the voltage getting developed here it is we call V c. So, we can say that V c at this point with respect to ground is R c multiplied by ib. On the other hand, ib is V in minus V naught divided by r pi. So, what we can say that this V c equals to R c multiplied by ib and ib, it is V in minus V naught divided by r pi.

So, this is what the important thing and that directly affects the current flow through this r naught. So, now, if I apply KCL at the emitter node, what we are getting? Here, it is current flowing through this this r o which is v o minus v c divided by r naught. So, that is equal to the summation of the two currents; one is the base current and other is the through the active device. So, the base current is v in minus v naught divided by r pi and the current flowing through this voltage dependent current source, it is gm into the V be rather minus V be going from going from yeah, the it is basically coming here yeah V be. So, we do have v in minus v naught.

So, summation of this current and this current, it is equal to this current so that is what we have written here. Now, this expression of this v c, it is in terms of v in and v o. So, this equation, it can be utilized to replace this V c as a result we can get an expression which involves only v o and v in. Now, if we rearrange that equation, what we will be getting is v o multiplied by 1 plus gm into r naught plus R c divided by r pi plus r naught divided by r pi equals to v in multiplied by gm into r naught plus R c divided by r pi plus r naught divided by r pi.

So, from this relationship, between v naught and v in that gives us the voltage gain. In fact, we can say that v o equals to v in multiplied by R c plus r o plus gm into r pi r o divided by R c plus R c plus r pi plus ro plus gm into r pi into ro. In fact, if you see here this part it is common here and here. So, effectively you may say that the relationship between v in and v o if I say, it is the impedance here which is r pi and the impedance of rest of the circuit there.

Before we connect anything here whatever the impedance, we are having it is R c plus ro plus gm into r pi into ro. So, this part is essentially the impedance at this point, before we connect anything of course, here. So, whatever it is in this case again this part, it is typically dominates and so, we can see compared to r pi, definitely this is higher because we do have gm into r naught multiplied by this r pi. So, we can say that this part you can ignore and this can be well approximated by 1.

So, the voltage gain even if we have say R c getting connected here and if we have say the V c voltage, it is allowed to develop then also the voltage gain it is close to 1. Now, let us see what will happen for the other parameters namely the output resistance and then, input capacitance and so and so and input resistance right. So, we do have let us move to the next slide to do that.

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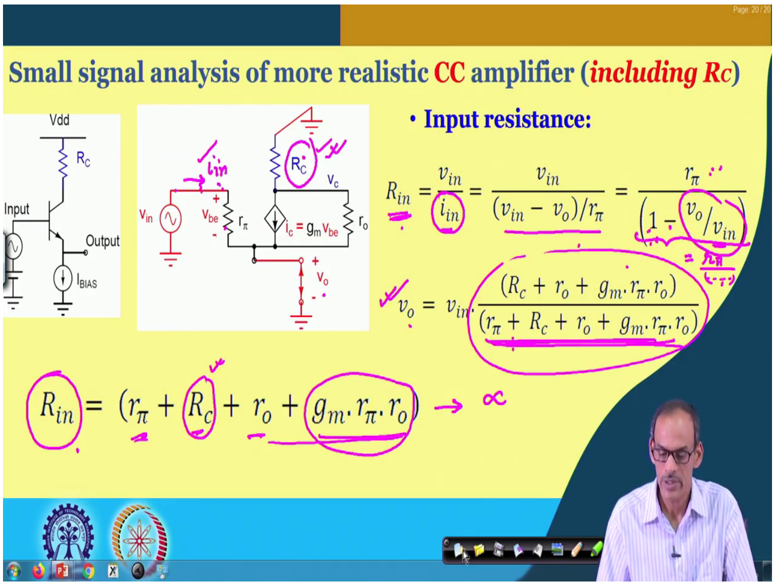

So, let us concentrate on the input resistance and here, we do have the same small signal equivalent circuit and for input resistance, what we have it is if we are applying V in here whatever the i in it is flowing. If I get the expression of i in in terms of V in that gives us the corresponding input resistance. So, r in it is v in divided by i in; whereas, i in, it is the base terminal current and base terminal current is v in minus v o divided by r pi. So, the expression of i in it is v in minus v o divided r pi. Now, probably you can rearrange this equation namely, we can write in this form r pi divided by 1 minus v naught divided by v in.

So, expression of this v naught by v in which is the voltage gain, we already have seen and that v o divided by v in is essentially this part. So, if I make 1 minus this part, what will be getting here in the denominator it is r pi. It will be getting here r pi and then, below of that will be having this whole thing. So, I should say this whole factor 1 minus vo divided v in, it is becoming r pi divided by the whole thing here and this r pi and this r pi is getting cancel, we can take this is in the numerator.

So, as a result input resistance what we can get it is this only. So, here we are just summarizing that. Input resistance is r pi in series with R c in series with r naught and then, the active device contribution. Again, because we do have this term coming in series, even though we do have this R c this is also going to be very high. So, we can consider this is very high. It is quite obvious that since we are considering this resistance in series, it is increasing the overall resistance, only by this part and this part earlier, we obtained that whatever the input impedance we are having.

So, the effect of non-zero value of this R c, it is increasing this resistance even higher. So, anyway that is in our favour considering the required input port characteristic. So, we have seen the voltage gain, we have seen the input resistance. Now, let us see the other parameter in the next slide.

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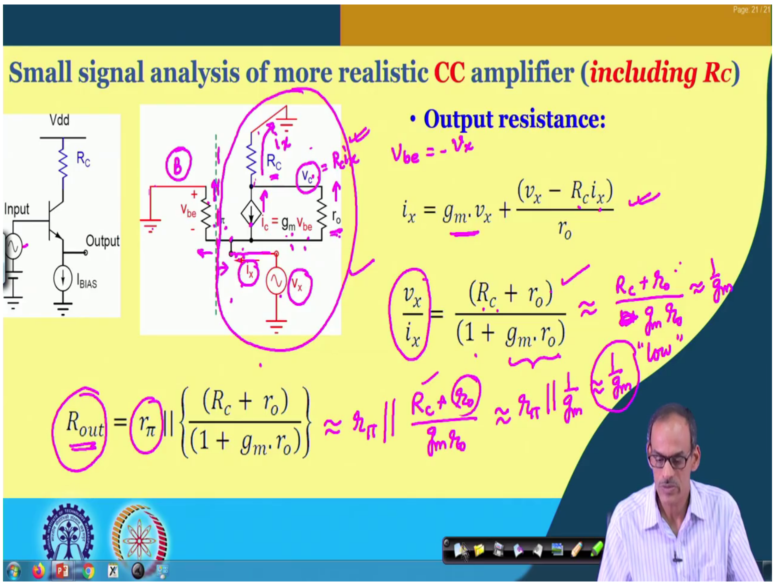

So, if you see the output resistance. So, we do have the same small signal model and to know the output resistance, we have to make the signal is equal to 0 namely base terminal we are making it AC ground. We are stimulating the circuit with V x and we are observing the corresponding current flowing through the circuit. So, what we have here it is this ix, it is summation of all these currents. So, the current flowing through the device here the whatever voltage dependent current source, it is gm into V be and incidentally V be equals to minus vx. So, we can say that this current is gm into v x and then, we also have the current flowing through this device and that device, it is we do have say V x minus whatever the current flow we do have.

Now, for simplicity what we have done is that since we are stimulating this terminal by V x directly, instead of considering this entire circuit and try to find what will be the impedance. We may split this part; one is this r pi part and then, rest of the things. Now, if I get the impedance of this rest of these things, then the total output impedance it will be simply this output resistance coming from the insertive one in parallel with r pi.

So, let us do this exercise considering only the insertive part. So, if we say that the current flowing through this this V x without considering this one it is ix, then this current flow actually it is same through this Rc. So, the current flow through this R c it is ix. So, the voltage here V c, it is R c multiplied by ix. So, the current flow through this r naught it is V x here minus V c divided by r naught and V c it is R c into ix.

So, that it is a small you know small trick by which we can we can simplify the analysis. If you want you can consider the entire circuit and you can find the output resistance. But if you do this one, it will be the analysis it will be simpler. Now, what we obtain here, it is the relationship between ix and V x and from that we can get the ratio of V x divided ix that gives us V c plus sorry R c plus r naught divided by 1 plus gm into r naught.

So, interestingly, the resistance coming from this circuit, it is again it will be quite small. This part it may be dominating. So, we may approximate this by R c plus r naught divided by 1 plus gm into r naught. In later of our discussion, in other circuits, we may come across the similar kind of circuit and try to remember this sorry this party you may ignore; try to remember this outcome of this analysis.

So, there based on the value of this R c and then, r naught it may be in the order of 1 by gm that may be the conclusion. Now, since we do have the r pi here, the total resistance, output resistance; it is the resistance coming from this encircle part and then, r pi part. So, this is again you may consider this is r pi in parallel with R c plus r naught divided by gm into r naught and if I say that this is this may be dominating over this R c. Then, you may approximate this by r pi in parallel with 1 by gm which is again it can be said that 1 by g m it is dominating over r pi.

So, the conclusion is that this output resistance in the order of 1 by gm which is quote and unquote load ok. So, let us see the effect of this R c on the input capacitance that is very tricky. So, in the next slide, we will be analysing the circuit to get the input capacitance.

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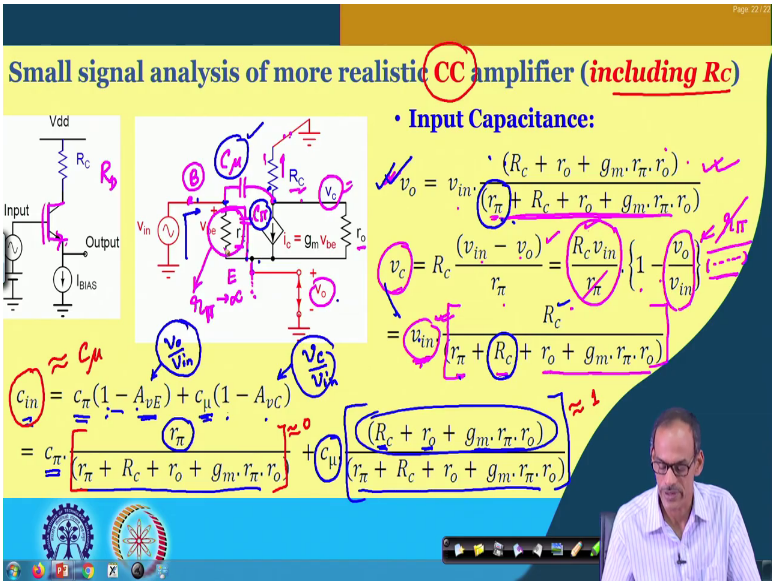

Yes. So, things are getting really getting complicated, let us see what are the complications are getting here. So, we do have the small signal equivalent circuit, we do have the C mu and then, C pi and note that compared to our previous discussion, the voltage here it is not AC ground rather voltage it is V c and V c, it is of course, it is function of input voltage.

Now, we may recall that the voltage at the output node Vo, we already have this expression of this Vo in terms of V in having this factor. So, numerator it is smaller than the denominator by this r pi and then, the expression of the of the V c, it is the R c multiplied by whatever the current is flowing and that is V in minus Vo divided r pi that we have discussed before.

This can be rearranged in this form. We can take v in outside. We are getting a factor 1 minus v o divided by v in. So, if I use the expression of v o in terms of v in and if I plug in that expression here for v o divided by v in, what I will be getting here? It is this factor in the numerator, I will be having this part minus this part and will be having r pi in the numerator and in the denominator whatever the things we do have here, it will be coming there. And the numerator this r pi it is getting cancelled here. So, what we have it is in the numerator, we do have R c and then V in and then, rest of the things in the denominator.

So, the expression of the v c, it is v in in terms of v in it is v in multiplied by R c divided by r pi R c plus r naught plus gm into r pi into r naught. So, anyway this is as expected; this is smaller than the input voltage. Note that we are not connecting any resistance here, the moment we connect the resistance here, the voltage here at the collector terminal it is expected to be having much higher value. But right now, we are not considering. If I consider RL is infinite here, earlier we consider RL.

So, if I consider that this gives an indication that V vc, it is a fraction of the v in. In fact, intuitively we can see that if this side is open and if I start from the base terminal and then, if you go to the emitter terminal, then if you go to the collector and then if you go to the ground, what we can see here it is we are seeing one resistance r pi; here, we do have one resistance R c and also we do have this resistance r naught multiplied by 1 plus gm into r pi, that can be expanded in this form.

So, from here to here that is the impedance and then the drop across this R c is the V c. So, you may say that v in it is getting potentially divided by this factor. So, that makes sense this expression of this one makes sense. So, whatever it is over the both r pi sorry C pi and C mu are getting miller affected. So, both C mu other terminal of the C mu, it is a non AC ground. And of course, C pi, it is also the other end, it is connected to Vo that is also non ac ground right they are having signals.

So, the input capacitance at the base terminal, what will be getting it is C pi multiplied by 1 minus gain from base to emitter and let you call this is gain it is A vE and this A vE, it is Vo divided by V in. On the other hand, contribution of the C mu, it is C mu multiplied by 1 minus A vC and what is A vC? We are defining this A vC by AC divided by V in and we already have the expression of these two ratios; one it is from here; another it is from here. So, if you plug in those expressions and if we subtract from one, the first part if you see, what will be getting in here? It is the denominator and if I compare denominator and numerator, we do have only r pi is the difference. So, in the first part, what we will be getting is that C pi getting multiplied by r pi divided by the entire thing.

So, likewise when you consider the contribution of the C mu and if I take this ratio getting subtracted from 1, what will be getting? Here, it is except R c which is here rest of the things it will be there. So, that is why this C mu, it is getting multiplied by this part which is having Rc, then r naught gm into r pi into r naught and then, denominator it is same as this one. So, you may say that this part this factor, this factor it is approximately 1; whereas, this part it is very small. So, approximately 0. So, we can say that the C in, it is approximately equals to C mu for all practical purposes.

So, again, we are converging to the similar kind of conclusion, namely the input capacitance is low, input resistance of this circuit it is high; output resistance, it is remaining low, voltage gain it is approximately remaining 1. So, we have done this analysis for a common collector circuit considering this collector resistance.

Similar kind of things we can do for the MOS counterpart and there instead of Rc, we may say that we may be connecting RD at the drain terminal and this may be the corresponding MOS transistor and we can do the similar analysis and in the small signal equivalent circuit, it will be very similar except this corresponding r pi will not be there or whatever the analysis so far we have done, that can be utilized judiciously by considering this r phi approaching to very high value ok.

So, this is what you can share the analysis across different types of the circuit configuration rather different types of circuit namely analysis from common collector, you can propagate to common drain. Note that it is not possible the other way because in common drain circuit. We do not consider this gate to source resistance. So, as a result deriving the expression, it will be for the common collector from the common drain, it is not possible.

I should say rather analysis for common collector, it is relatively generic that can be extended for the common drain circuit. So, as I said that let us look into the common drain amplifier considering the resistance connected to the drain terminal.

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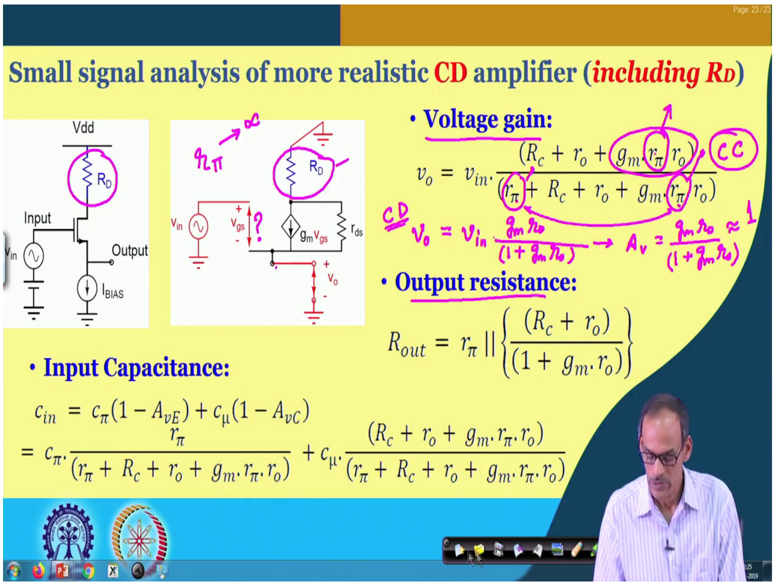

So, we do have this resistance connected to the drain terminal and then, we do have the RD coming in the small signal equivalent circuit and then, we do not have any r pi here. So, rather if I say that whatever the previous analysis we have done, if I consider the r pi in those equation approximately going to be very high. Then, we can get the equation for the common drain. So, let us start with the voltage gain and let us follow that approach for common. So, this is the equation, we obtain for common collector circuit and let us try to do for the common drain circuit, namely this circuit.

So, if I say that expression of the Vo can be obtained by considering this equation which you already have derived and that can be done by making this is going to be very high and this is going to be very high and this is also going to be very high. Namely, in the numerator if I keep this term and in the denominator if I keep this term and this term and then, if I pull out this r pi and if I cancel it what will be getting here it is V in multiplied gm into r naught in the numerator and in the denominator, we will be having 1 plus gm into r naught.

So, from here directly we can say that the voltage gain, it is gm into r naught divided by 1 plus gm into r naught ok; yeah. So, here this RD, I should say on the in the voltage gain, it is hardly having any effect and again finally, we approximate this by 1. Now, similar kind of things we can do for the output resistance. This part let me clear; yeah.

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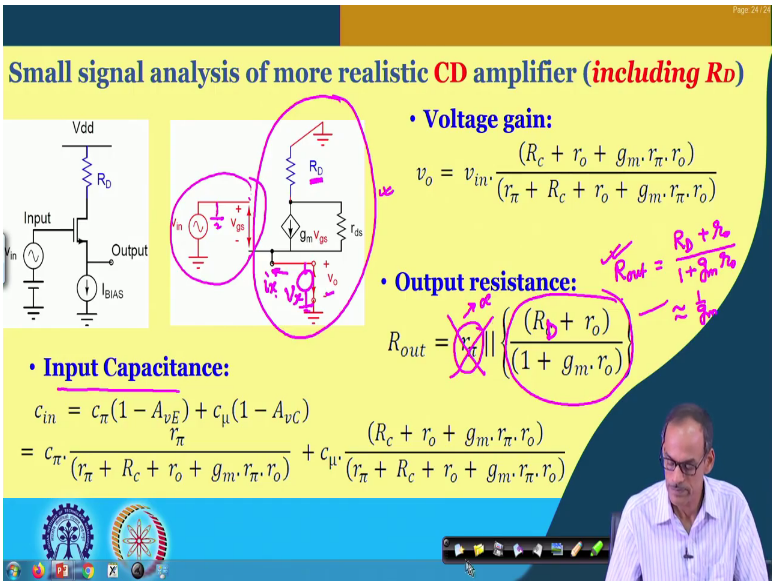

So, if I consider say this part, earlier we have seen that if I want to know the resistance or impedance at the output terminal and if I stimulate this circuit by a voltage source called V x and then, if I consider the corresponding ix and then, if I take the ratio of this two that is supposed to be given as the resistance coming from this circuit. And the previous analysis shows that the corresponding resistance is R c plus r naught divided by 1 plus gm into r naught.

Now, this R c instead of Rc, we can write RD for this case and rest of the things it is same. Now, if I consider this part also while you are considering this output resistance of course, you have to make it ground and since, this r pi it is very high. So, this is very high. So, we can say that you can neglect this part and you can consider only this one.

So, what we have it is r naught or r out, it is RD. This is D; RD plus r naught divided by 1 plus gm into r naught right. So, that is how we do get the expression of output resistance. Again, this is in the order of 1 by gm. Now similarly, we can find what will be the input capacitance. Again, for this circuit let me clear it up; yeah.

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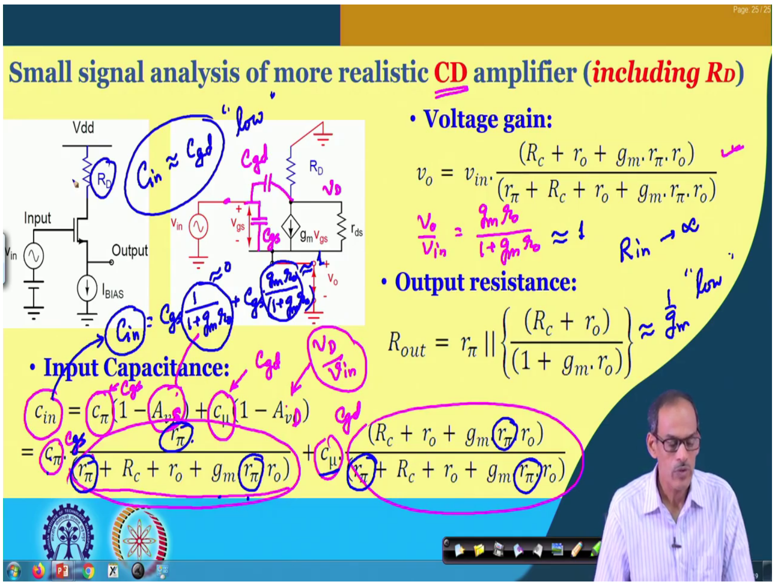

So, to get the input capacitance C in, we do have the contribution coming from Cgs earlier it was for common collector it was C pi. So, we need to replace this by Cgs. So, likewise here also we are having now it is Cgd; earlier in common collector circuit, it was C mu. So, that need to be replaced by C g d and then, we do have the voltage gain from here to here. So, it is it should not be emitter this rather from gate to source and gate to drain and this, this gate two source gain we already obtained here which is given here.

And we say that the corresponding voltage gain vo divided by v in it was gm r naught divided by 1 plus gm into r naught and so, that that gives us the corresponding ratio likewise you can find what will be the this the AvD. So, that is v D; v Dis the voltage here divided by V in. And if you plug in that expression, what you will be getting is that C in, it is C gs multiplied by a factor like this and then, C g d multiplied by this factor. Now, whatever the factor we are writing here, here and here of course, therefore, common collector. To convert the equivalent factor for common drain, what you have to do you have to you know make this term, this term and this term dominating.

So, likewise here also we can see that these terms are dominating. So, in this case what we will be getting is that C in it will be C gs multiplied by 1 divided by 1 plus gm into r naught. So, let me write here C in equals to C gs multiplied by 1 divided by 1 plus gm into r naught and then, C gd. Here C g d multiplied by we do have here gm into r naught divided by 1 plus gm into r naught. So, this part it is approaching to 0; this part it is approaching to 1 ok.

So, then we can say that C in; C in it is approximately equal to C g d right again this is quote and unquote low. This is approximately 1; output resistance is in the order of 1 by g m which is quote and unquote low. Input resistance of course, remains high. So, then you can say that for common drain even if I consider RD, then the basic required property of the buffer, it remains the same.

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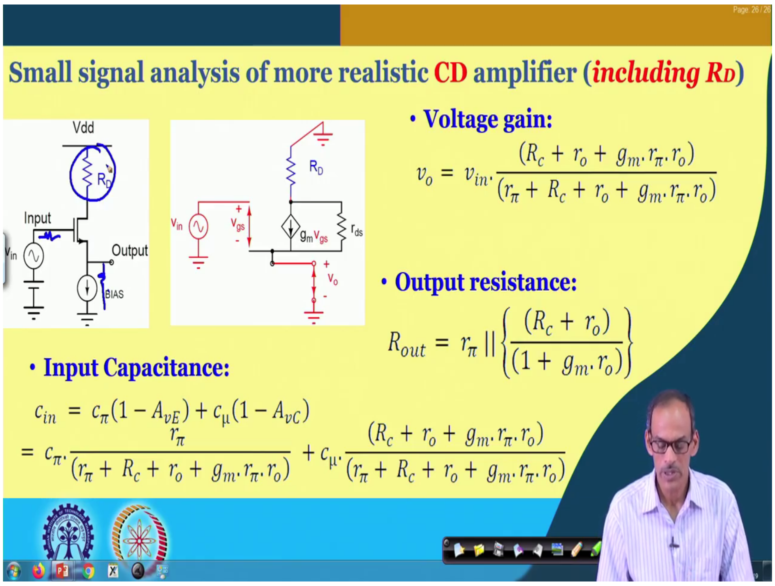

Now, so far, we have considered either R D or R L here or maybe R s here. Now, if I consider maybe multiple elements together, things of course, it will be getting more and more complicated.

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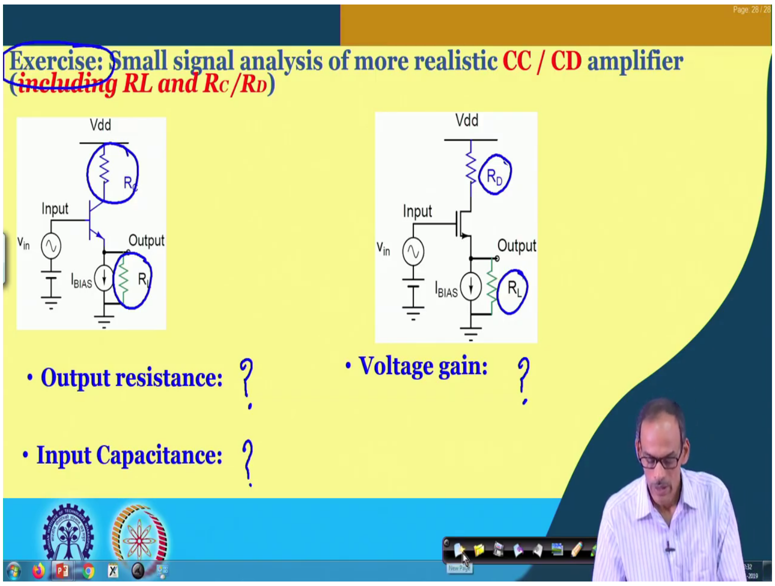

You may try out; you may try out to solve say this kind of circuits, where we do consider we do consider say the R c part and then, R L part. So, likewise we can consider R D and R L together and then, you can try to see what is the corresponding input resistance voltage gain and then, input capacitance ok. So, I rather suggest you, you can work it out in our numerical examples. So, we will be covering. So, we may not be repeating the analysis again here ah. But in our numerical examples, we will be discussing that. I think what we have, it is I think today let we let we conclude whatever the things we have covered.

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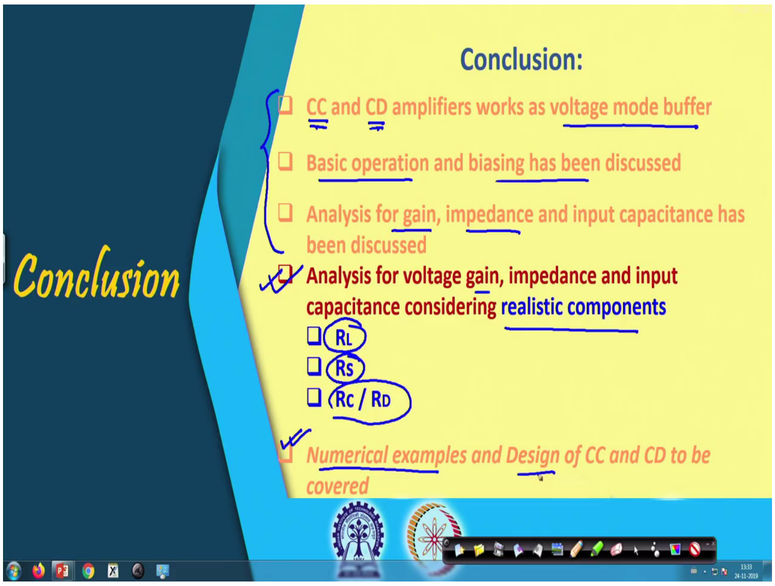

So, far as I say that we are talking about common collector and common drain amplifier. Previous lecture, we have discussed about this part namely the c in common collector and common drain as voltage mode buffer. Basic operation and biasing, we just touched upon and then, we did the analysis for voltage gain and then, impedance and then, input capacitance for idealistic bias. And today, what you have done it is, we have done the analysis considering realistic components to get the voltage gain, impedance and input capacitances.

Realistic components are the load resistance may be connected at the emitter or common or the source of the transistor respectively for BJT and MOS transistor and then, source resistance, then also we have discussed about the effect of resistance at the collector terminal or drain terminal. What we are planning to go for the next class, it is numerical examples and some design guidelines. I think that is all I do have to cover.

Thank you for listening.