Analog Electronic Circuits
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Lecture – 48
Common Collector and Common Drain Amplifiers (Contd.): Numerical Examples (Part B)

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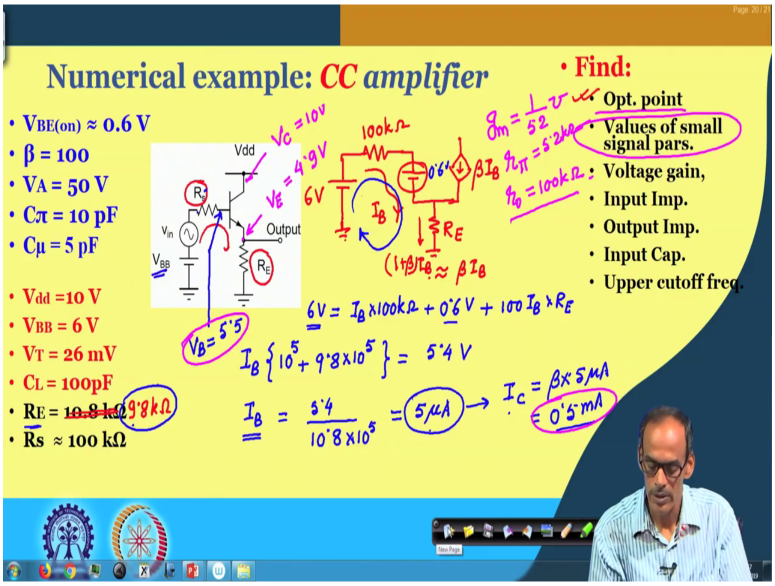

Welcome back after the short break. So, we do have here it is the third example. So, it is you can see that essentially, we are adding one resistance at the emitter instead of having ideal bias current and also we do have the R S at the base node. We can say the source resistance. Let you consider this R E 9.8 kilo ohms. So, let me change this one to 9.8 kilo ohms and let us try to analyze the circuit to find the operating point of the transistor.

So, to start with let me draw the DC loop here. So, we do have V dd which is 6 volt and then we do have the R S, which is 100 k and then we do have the V BE on this diode drop and then we do have the resistance here R E. So, that you consider the current flow here it is I B. And then of course, we do have the beta times of this I B current it is coming from the collector. So, we can say that this is beta into I B. So, that is the IC part.

So, the current flowing through this register on the other hand it is 1 plus beta into I B. So, if I consider that this current it is approximately equals to beta into I B and then if you analyze this circuit. Namely, if we consider the potential drop through this loop. So, what we can get it is in this loop. We do get 6 volt here and then we do have 0.6 volt here. So, 6 volt equals to we do have I B into 100 k plus 0.6 volt and then roughly you can say that 100 times I B into R E ok. And R E, we said 9.8. So, what we are getting here it is I B multiplied by 100 k. So, that is 10 to the power 5 and then R E we do have 9.8 k.

So, this is this plus. So, this is 9.8 into 10 to the power 5. So, this is equals to 5.4 volt. So, that is 5.4 volt is 6 minus 0.6. So, that gives us I B equals to 5.4 divided by 10.8, yes 10.8 into 10 to the power 5. So, that gives us 5 micro ampere. So, just a make a note that we have intentionally have tuned it this resistance. So, that we can get the same value of this I B, what we have obtained in our previous example of 5 micro ampere.

So, even if this resistance it is something else of course, the circuit it will be working fine, but it is just for making this circuit comparable with the previous circuit we are making this R E equals to 9.8. So, once we obtain this I B of say 5 micro ampere, so, that gives us the I C equals to 100 into 5 micro ampere. So, then beta into this 5 micro ampere so, that is equals to 0.5 milliampere right.

And then once we have the I C equals to this one, then you can calculate what will be the voltage here. Similar to the previous case; the voltage here it will be 6 volt here minus this drop, drop across this R S and this that drop it is 0.5. So, we can say the voltage here V B equals to 6 minus 0.5. So, that is 5.5 let me use a different color.

So, the voltage at the base it is 5.5, the voltage coming here it is 5.5 minus 0.6. So, the voltage here it is emitter voltage equals to 4.9 volt. So, that is 5.5 minus 0.6 and of course, the collector voltage here it is 10 volt.

So, that gives us the operating point of the circuit. Now using this values of the quotient currents and voltages we can find the small signal parameter. And since the currents particularly, the collector current and base current they are same. So, we can see that the g m value of the g m remains the same. Namely, 1 by 52 ampere per volt mu and likewise r pi equals to 5.2 k and then r naught equals to 100 k right. So, we obtain the small signal parameter. Now then we can find what will be the voltage gain input impedance output impedance so and so.

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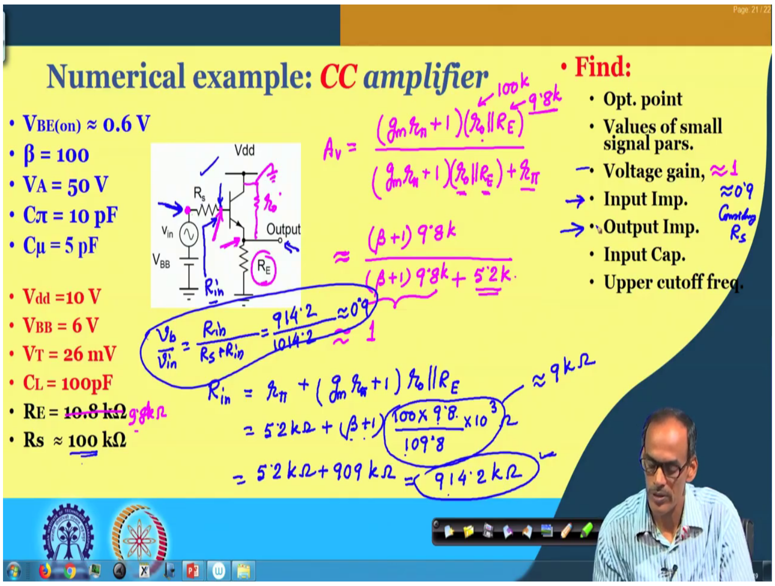

So, let me use the same space and let me clear it and again this we are considering it is 9.8. Sorry for the correction here again and again. But, anyway we do have the voltage gain you may recall the voltage gain A V, since we do have the R E here earlier in our analysis we have considered this resistant resistance as R L with that. So, the voltage gain we obtain it is g m into r pi plus 1 into r naught in parallel with this R E right.

So, that is because we are having this r naught coming here and this R E and r naught they are coming in parallel because this terminal for signal it is AC ground. So, r naught and R E they are coming in parallel. In the denominator on the other hand; we do have gm into r pi plus one into r o in parallel with R E plus r pi.

So, what are the changes we do have here it is; this is of course, beta plus 1. Now r o it is 100 k and R E it is 9.8 k right. So, close to this one, 9.8 k or to be more precise it will be close to 9.5 or something like that. But whatever it is say we approximate by this R E, it is a 9.8 k. So, likewise in the denominator we do have beta plus 1 into whatever 9.8 k and then we do have the r pi. So, this r pi it is this is 5.2 k. Note that this voltage gain it is from this point to this point.

We do have R S also to be considered, but attenuation for this circuit from this point to this point, it is expected to be very small even though R S it is 100 k. Mainly because, you do have the resistance here, input resistance here it is very high. But anyway, we will see that, but for the time being let you consider voltage gain from precisely at the base terminal to the emitter terminal and even though this R E it is coming in parallel with r naught because, this we do have 1 plus beta getting multiplied.

So, still this part it is dominating over this part. So, still and hence we can say that this is approximately 1. So, the voltage gain it is approximately 1. Now let us look into the input resistance. So, let you consider the input resistance. So, the input resistance on the other hand it is as we have discussed before. So, this will be r pi plus g m into r pi plus 1 into r naught coming in parallel with R E. And again this is the input resistance looking into the base of this one, base of the transistor without considering this RS.

So, we do have r pi equals to 5.2 kilo ohms and then a we do have beta plus 1 and then this resistance it is whatever 100 multiplied by 9.8 divided by 109.8 into 10 to the power 3 kilo right. And so, this part again either we can approximate by 9.8 or so, we can say that this is close to 9. But, it will be very close to 9 this if you say that this is 10 11. So, that will be close to this one, but whatever it is. It, we do have so if I approximate this part or this is equal to very close to 9 kilo ohm.

So, even then we do have 5.2 kilo ohm and then we do have 100, one getting multiplied with and this 9. So, that is giving us 909 kilo ohm. So, that is equals to 914.2 kilo ohm that is definitely it is higher than this resistance. So, the attenuation coming at this point, because the input resistance here it is given here. Attenuation due to this finite value of R S which is I should say the voltage here with respect to this one or rather base voltage Vb with respect to V in it is given by R in divided by R S plus R in. And R S is 100 k R in it is close to 900 k. So, accordingly you can say that this is 914.2 divided by this is 1014.2.

So, it is very close to 0.9. So, even if I consider this finite value of R S then the voltage gain starting from the primary terminal to this point even though I do have R S is quite high, still it is around 0.9, considering this R S high value of R S right. So, that is about the voltage gain remaining close to 1. Output resistance we have discussed before. So, again we can probably we can go through that the let me clear this and this is 9.8 k as we have taken.

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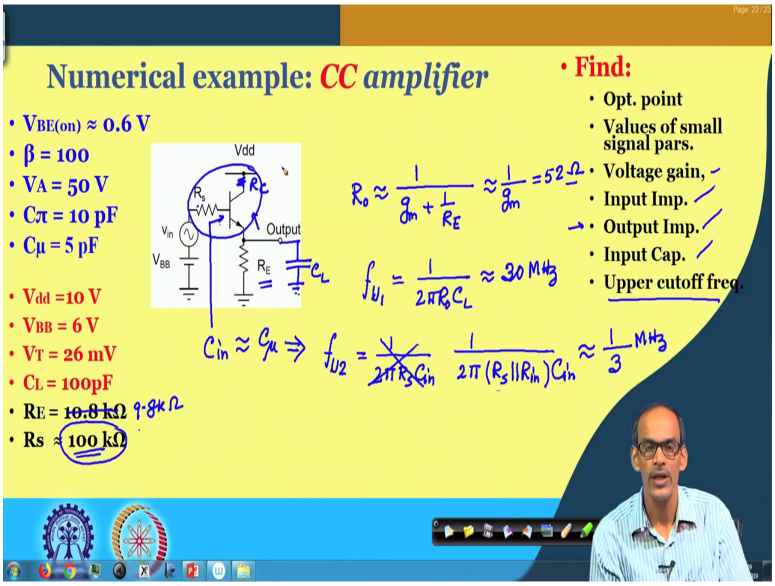

So, the output impedance it is if I consider this part this is giving us the output impedance very close to 1 by gm. So, R O it is very close to 1 by g m and then we also have this 1 by R E and R E since it is quite high compared to 1 by g m. So, this is remaining close to 1 by gm which is 52 ohms.

So, the upper cutoff frequency considering the C L and the output resistance if I consider. So, this upper cutoff frequency coming from the output node, if I say that f U 1. So, that is equal to 1 by 2 pi R o into C L. So, this is remaining very close to thirty mega Hertz. And then if I consider the input capacitance; again C in it is still we will approximated by C mu and hence f U 2, the second option for the upper cutoff frequency which is 1 by 2 pi R S and C in.

So, that part it is I should say I do have the R in also, but yeah R in is much higher than RS. In fact, to be more precise I should rather consider the R in also. So, we should consider R S in parallel with R in and then C in. And of course, here this resistance it is coming close to and this close to 100 kilo Hertz as kilo ohm. So, again this frequency it is very close to 1 by 3 mega Hertz.

So, the conclusion here it is what we can say that even if you consider R E and R S still we do have the overall performance of the circuit even with R S is very high overall performance of the circuit or the qualitative performance of the circuit. Namely, the voltage gain approximately one and then input resistance is very high, output resistance is very small, input capacitance is low and then the upper cutoff frequency it remaining high only right.

Now, if I consider the other resistance also R C then of course, there will be a change. So, we will see that, but before that let you consider the most counterpart also, namely common drain amplifier. So, in the next slide we will be going for common drain amplifier yeah. So, here we do have the common drain amplifier.

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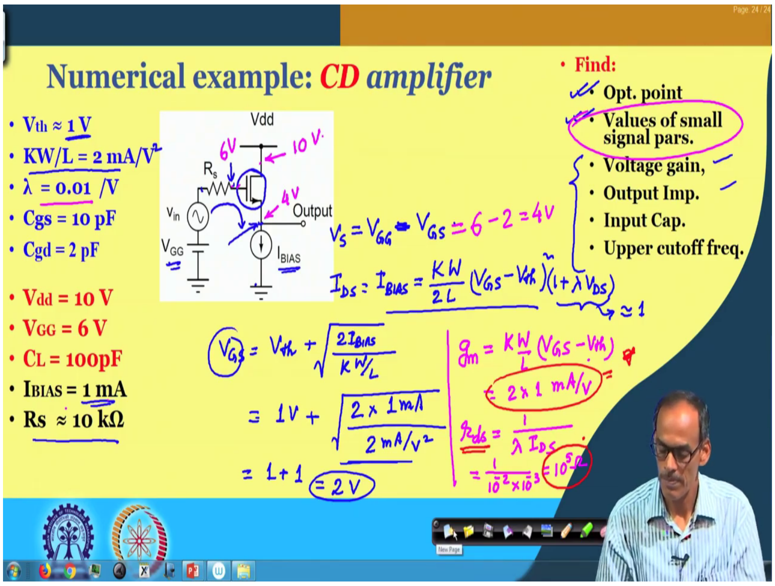

Again for this circuit also to find the to find the performance parameters, we need to follow the same procedure. Namely, we need to find the operating point then we need to find the small signal performance then as parameters values and then we can find the corresponding voltage gain output resistance in then input capacitance in so and so.

So, here of course, the circuit it is different slightly different. So, let us try to see with this example, how do we find the operating point of the transistor. Remaining things it will be similar to the common collector circuit. So, let us try to see that. So, to get the DC operating point, let we consider this circuit. So, what we have here it is in DC condition; VG if I say that R S it is even though it is say 10 k or 100 k since the current flow here it is 0, DC wise. So, the drop across this R S is 0. So, we can say that V GG it is directly coming to the gate node.

So, if I say that V GG equals to, I do have the V GS of the transistor and then we do have the current flowing here right. And this current flow of course, it is we do have say 1 milli ampere of current. So, we are expecting that to find the voltage here which is basically the V GG minus this 1 sorry, I should say that the V S voltage or V out voltage it is V GG minus V GS.

Now, to find the V GS what you have to do this is now IDS. So, we can say that I DS equals to I BIAS equals to the expression of the current which is K W by L by 2 into V GS minus V th square. And we may drop this 1 plus lambda VDS factor. We can approximate this is may be equals to 1. So, if I equate this part; what we can get here it is V GS equals to V th plus 2 times I BIAS and then divided by K W by L and then square root.

So, here we do have V th of the transistor it is given here which is 1 volt plus 2 times I bias it is 1 milliampere and then the device parameter it is given here it is K W by L equals to 2 milli ampere per volt. So, 2 milli ampere per, I should say this is volt square. So, what we have here it is this 2 and this 2 it is getting cancelled. We do have milliampere it is also getting canceled. So, this part, this part as a result it is we do you have 1. So, the V GS it is 1 plus 1 equals to 2 volt right. So, that is the V GS.

So, from that we can say that the voltage at the source it is 6 minus 2, that is 4 volt. So, the voltage here it is 4 volt and of course, the drain voltage here it is 10 volt and gate voltage here it is 6 volt. So, that gives us the operating point of the transistor of course, it ensures the transistor it is in saturation region of operation which is of course, required. And then we can calculate the small signal parameter. So, let us try to see what will be the small signal parameter values. Let me use this space here.

So, the gm particularly the gm it is K W by L into V GS minus V th. So, what we have it is 2 milli ampere per volt square and this is 1 volt. So, 2 into 1 milli ampere per volt, on the other hand the r ds which is 1 divided by lambda into I DS. Now lambda it is given here it is 0.5 0.01 0.01. So, that is 1 divided by 0.01 which is 10 power minus 2 and then I DS it is 1 milliampere which is 10 power minus 3.

So, that gives us 10 power 5 ohms. So, that is the; that is the impedance we are getting for this r ds and this is the gm part. So, using that we can find now we can find the voltage gain. So, you can probably for the to calculate the voltage gain, let you try to remember the value of this V GS and sorry, the gm and the corresponding value of the r ds.

So, again let me use the space and clean it. So, what we are looking for it is the voltage gain A V.

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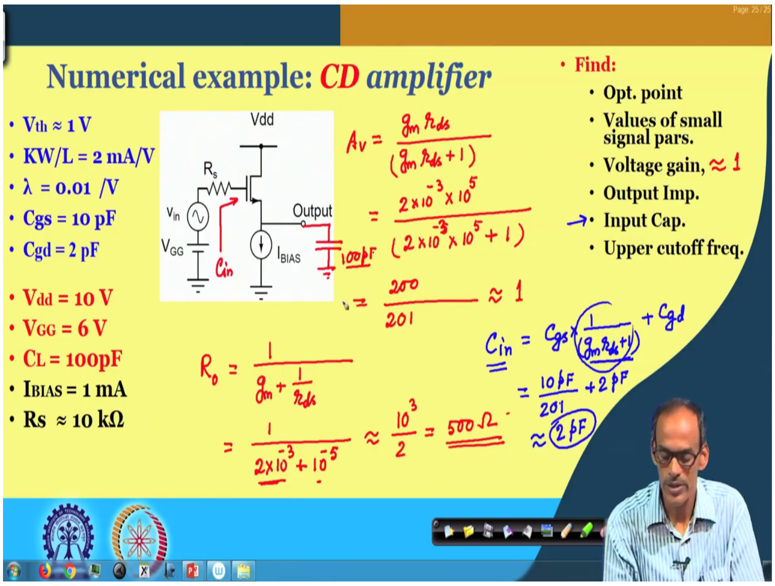

So, what is the voltage gain of this circuit? The g m into r ds divided by g m into r ds plus 1 and gm it is 2 milli, 2 into 10 to the power minus 3 and r ds it is 10 to the power 5 ohms. So, likewise here also 2 into 10 to the power minus 5 into 10 to the power sorry, minus 3 and 10 to the power 5 plus 1.

So, here in the numerator we do have 200 and in the denominator we do have 201. So, we can approximate this by 1. So, the voltage gain it is 1. And then the output impedance if you see the output impedance R out equals to 1 divided by g m plus 1 by r ds. So, what we have here it is 1 divided by g m it is 2 milli, 2 into 10 to the power minus 3 and then 1 by r ds. So, that is 10 to the power minus 5 right.

So, again this is this part it is dominating over this. So, we can approximate this by so, 10 to the power 3 by 2 which is 500 ohms. Of course, it is not as small as the previous case; namely as small as R out of common collector stage, but still it is low and then if you consider we do have the capacitance coming here of say 100 pico Farad.

So, from that we can calculate the upper cutoff frequency. But before that we can find what will be the C in. So, let me use different color for C in. So, now, we are going to calculate C in which is C gs. So, we do have the C gs part multiplied by 1 by g m r ds plus 1, you may recall this expression plus C gd.

So, this part of course, we do have here it is 201. So, we may drop this part or rather I should say C gs we do have the 10 pico Farad divided by 2 0 1and C gd it is 2 pico Farad. So, this part we can say it is closed to we can approximate this 2 by 2 pico Farad only. Because, how much is it, this is 10, 5, 5 and it is just right. It is it is very small we can ignore this part definitely we can ignore. So, this is what the input capacitance.

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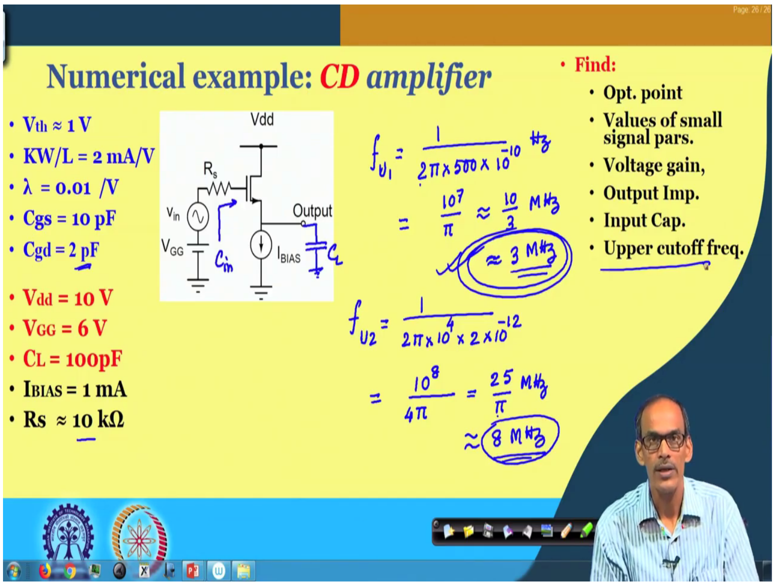

Now, if I say the upper cutoff frequency let me again clear it and use the space here. So, upper cutoff frequency coming from C L. f u 1 equals to 1 by 2 pi output resistance it is 500 and C L it is 10 to the power minus 10 Hertz.

So, we can multiply this 2 with 500 to get 1000 here. So, what you are getting it is 10 to the power 7 divided by pi. So, approximately equals to 10 divided by 3 mega Hertz or we can say that this is close to 3 mega Hertz of course. And then the other candidate to define the upper cutoff frequency which is coming from this R S and C in. So, f u 2 equals to 1 by 2 pi into R S, we are taking 100 k 10 to the power 4 and then C in it is 2 pico Farad so, 2 into 10 to the power minus 12.

So, this 4 and this minus 12, if you see we do have minus 8 here. So, we can see it is 10 to the power 8 divided by 4 pi or we can say this is 25, 25 by pi mega Hertz. Or we can further simplify if I consider this is 3. So, roughly it is 8 mega Hertz.

So, that gives us the upper cutoff frequency it is defined by this only. So, that is the upper cutoff frequency. So, that is how you can analyze this circuit.

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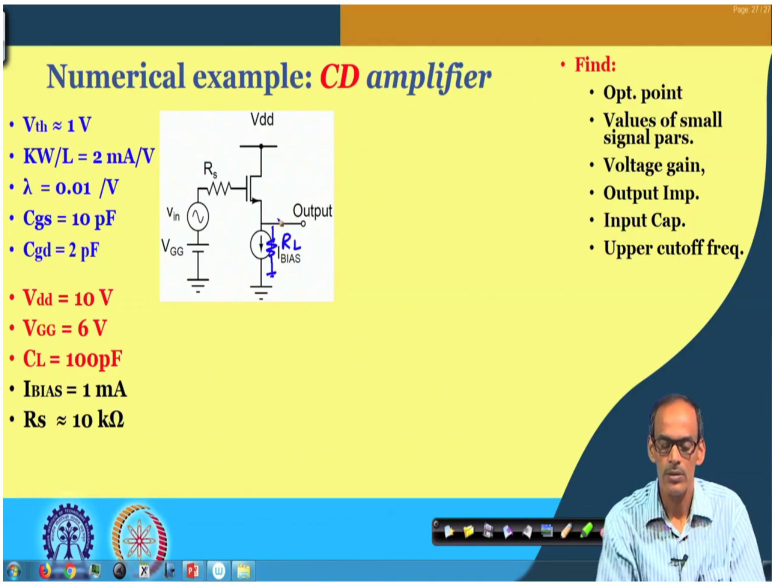

So, similarly, if I consider the common drain circuit with say resistance here R L instead of BIAS, then we can get the similar kind of performance probably you can work it out.

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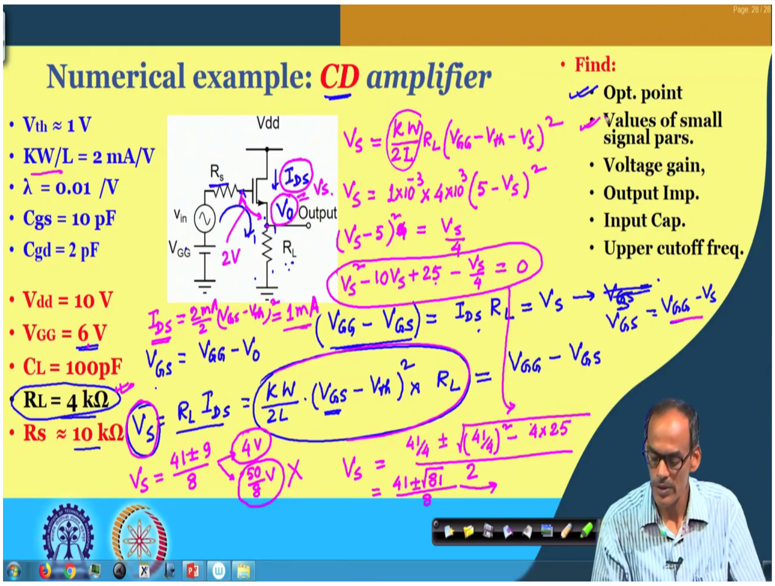

So, let us see what is the circuit I do have for you yes. So, here we do have same common drain amplifier, but we do have R L having a value of 4 k. R S, we do have same 10 k. So, instead of having ideal BIAS circuit if we put say R L of say 4 k and then V GS of say 6 volt with whatever the parameter it is given here, then how do you find the operating point.

So, this part since it is tricky. So, let me explain to you, rest of the things probably you can do it yourself. So, again if I consider this loop; what we can get here it is the drop across this R S is 0. So, we can say that gate voltage it is directly coming here DC wise and then we do have the V GS here and then we do have the ir drop. So, if I call this is V O output voltage, then V GG, V GG minus V O it is essentially V GS of the transistor right.

So, we can say that the voltage here on the other hand, if the current flow here it is say I DS, the voltage here it is R L multiplied by I DS. So, in other words we can say that the V GG minus this V GS. So, that is equal to. So, this voltage that is equal to I DS multiplied by RL. Now this V GG if you on the other hand if I say that V GS and the yeah. So, this is so I can say the other way also say I D S equals to K W by 2 L multiplied by V GS minus V th square.

And then if I multiply this by RL. So, what we are getting it is RL into I DS, but that is equal to this one. So, we can say that, this is equal to V GG minus V GS right. So, probably, we can try to see what will be its expression of this I DS from this or from how do we proceed the, maybe you can try to write. So, this in terms of V S and so, this is V S then, so this is V S. So, from that we can say that V GS equals to no V GS sorry, so V GS equals to V GG minus V S.

Yes. So, now, we can say that V S equals to this one. On the other hand V GS, we can replace by this V GG minus V S. So, we can let me use different color. So, using this part and this part along with this one, what we can say that V S equals to K W by 2 L into RL multiplied by V GS which is V GG minus V th minus V S square.

Now, let me put the value of different parameters here. So, we do have R L equals to 4 k and this part it is 1 milliampere per volt. So, we can say that V S equals to 1 milliampere; 1 into 10 to the power minus 3. R L equals to 4 k, 4 into 10 to the power 3 and then we do have V GG minus V th, that is 6 minus 1, so, that is 5 minus V S square. Or we can probably you can make it V S minus 5 square. So, V S minus 5 square into 4 equals to V S right. Or we can say that we can take this 4 here.

So, we are getting V S square minus 10 V S plus 25. Then minus V S by 4 equals to 0. Now if you solve this second order equation; what will be getting is that one solution you will be getting for V S is V S equals to. So, the coefficient of V S here it is 41 by 4 with a minus sign. So, 41 by 4 plus or minus square root of 41 by 4 square minus 4 into whatever it is.

So, we do have A into C. So, we do have 4 into 25, so, that is 100 divided by 2. So, if you take 4 outside what we will be having here it is 41 divided plus minus. So, here we do have 41 square and here you do have 16 yes so, 4 square. So, basically you will be getting 81 square root divided by 4 into 2 8.

So, this gives you this is 9. So, we can say that V S, I am using this space sorry for clumsy here, clumsy arrangement 41 plus minus 9 divided by 8. So, one solution if I consider minus, one solution it is 4 volt and the other solution if I consider this is plus that is 50 divided by 8.

Now, this is not possible that because, the transistor enters into cutoff. So, we are not considering this one, we need to consider this one. So, if I consider V S the voltage here actually. So, this is same as the source voltage V S if the V S it is 4 volt; we do have 6 volt. So, the voltage drop here it is 2 volt.

So, that gives us V GS is equal to 2 volt. If the V GS is equal to 2 volt, then we can say that the corresponding I DS equals to K into W by L, that is 2 milli and then divided by 2 into V GS is 2 volt minus V th square so, that gives us 1 milliampere. So, again we are making this R L is equal to 4 k. So, that the current flow I DS it is consistent with the previous example right.

So, let you consider that that much of current and it is consistent to the previous case and once you obtain the value of this I D S. So, then we can find the corresponding value of the small signal parameters. So, let me calculate the small signal parameter.

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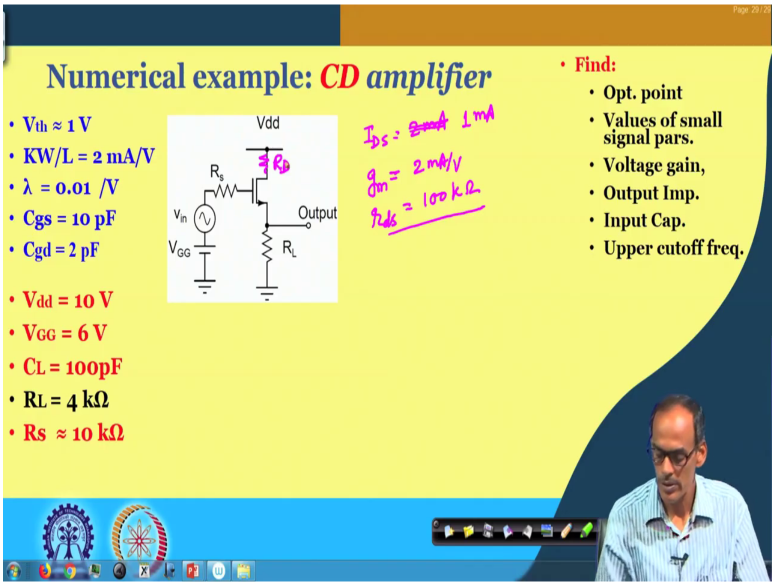

So, I think we already have done that since I DS equals to 2 milli ampere sorry, 1 milli ampere. The corresponding g m, it was coming 2 milli ampere per volt and of course, the r ds it is same as the previous case; 100 k. And rest of the parameters you can calculate yourself. So, I am not going to repeat that part now if you have say r ds connected here then what will happen?

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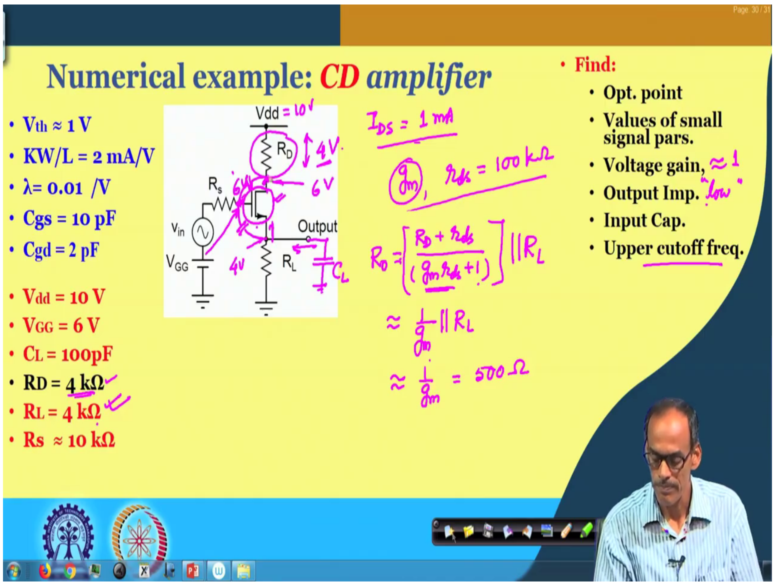

So, let me see that part. So, we do have this R D also connected we do have the R D connected here. So, what we say that we do have RD which is 4 k and then R L also 4 k. Assuming this transistor it is in saturation earlier we already have analyze that for R L of 4 k, I DS equals to so, that is equal to 1 milliampere and if this is R D is equal to 4 k. So, the drop across this R D is 4 volt.

So, we do have 6 volt coming here. So, this is 6 volt and the source we do have 4 volt. So, the voltage coming here after subtracting 4 volt from 10 volt, it is 6 volt. So, we do have 6 volt here, we do have 6 volt here. So, that this transistor it is still in saturation region of operation. So, that makes the circuit it is still working as a good amplifier. And then you can use the this I DS current and the V GS to calculate the g m and this r d s it still remains high namely 100 k.

And so, what will happen is that the impedances; particularly, the output impedance it will be having little modification gm the voltage gain since the gm it is remaining same voltage gain again approximately it will be 1, output impedance it will be having slight change. In fact, if we see the R out, if you look into this circuit; the R out it will be R D plus r ds divided by gm into r ds plus 1. So, that you can calculate.

So, that is the resistance here and the total resistance looking into the circuit; it will be this part coming in parallel with R L. Now here if you see the numerical value; this part it may be dominating over 1 and then r ds it is also dominating. So, as a result this part it is becoming 1 by g m only all practical purposes. And then, R L even though R L it is coming in parallel. So, it is since 1 by gm it is 500 ohms. So, again this can be well approximated by 1 by gm and it is 500 ohms.

So, even though we do have R D it is there, but the if you see the output impedance it is remaining low quote and unquote low. And it is expected that upper cutoff frequency defined by output resistance and the C L, it is almost remaining the same. Only another important thing you must be careful that voltage coming from this point to this point it is also prominent. So, as a result and that not only the C gd, it will be contributing through Miller effect, but sorry, C gs. But C gd, it is also having Miller affected part. So, what is the voltage gain coming from the gate to drain that we need to see.

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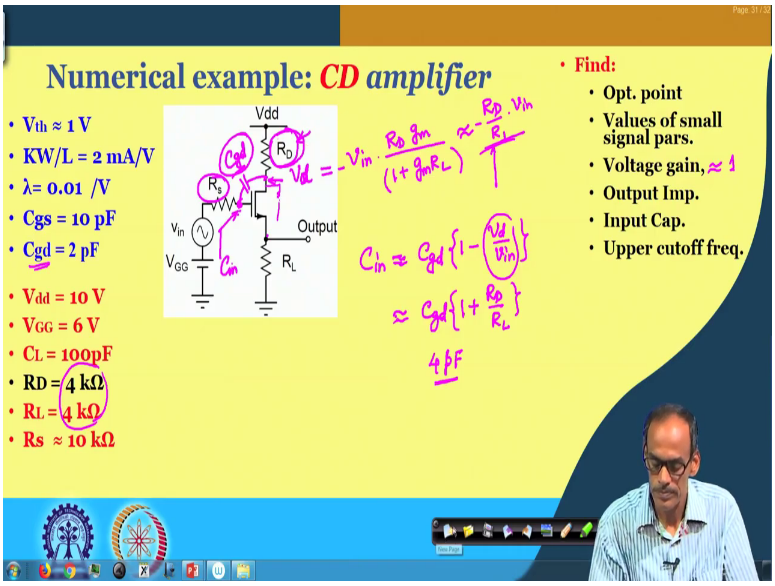

So, if you see the voltage gain coming from gate to source that is approximately 1, that is what we said. But in addition to that, if you see the C gd and the voltage coming here we call say V d so V small d. So, that is definitely it is nonzero and the voltage coming here it is V in multiplied by approximately multiplied by R D divided by the so, that is multiplied by g m R D divided by 1 plus g m into R L.

So, if I consider this resistance is very high compared to R D. So, that is what I will be getting and this can be well approximated by R D by R L with a of course, a minus sign. So, now, in this example since we are taking both of them are equal. So, we can say that the voltage gain from here to here, it will be close to 1 with a minus sign. So, we can see that C in; it is having primary contributor is C gd, but it is getting affected by this voltage gain, 1 minus V d divided by V in and this part it is given here.

So, from this equation if you see this part it is C gd multiplied by 1 and then minus 1 is also there. So, it becomes plus 1 R D by R L. So, I should say that this becomes practically 4 pico Farad. So, what is the conclusion here it is even though we do have R D here and we do have the signal coming here since, C gd it is small and then the input capacitance still it is remaining low.

But, we need to be careful that R d may be allowed to some extent, but if the R D it is coming more and more then, the contribution of the C gd to the input capacitance it will be large. And as a result the upper cutoff frequency defined by R S and the C in that may be a problem.

So, unnecessarily, we should not be putting this R D. So, that is what the conclusion. So, let us see what is the design guidelines we can follow based on this knowledge? So, let me I think I do have a slide for that.

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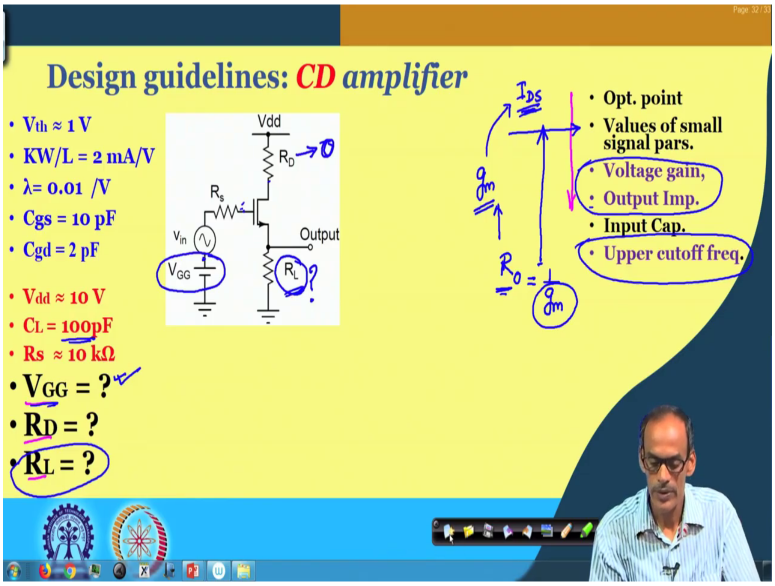

So, with here it is the analysis the knowledge of the circuit analysis can be utilized where in the analysis part; we have started the calculation from top to bottom of this list. While these parameters it was given to us. So, that was the numerical analysis we have done for the common collector or common drain circuit.

Now, if we have to make a design, where in fact, these parameters it will be given to us. Voltage gain should be close to 1, then output impedance it will be given to us, then maybe for a given value of the load capacitance; the cutoff frequency may be given to us from that we need to calculate R O.

So, this output impedance we can find. So, the way we will be proceeding while we have to design the circuit it is basically from bottom to up. And so, from the requirement of the output impedance which we know that this output impedance is 1 by, roughly 1 by gm and that gives us the requirement here. So, then once you have the value of the gm, from that we can calculate what will be the corresponding I DS.

So, what is the sequence? From R O we calculate gm and then from that we calculate I D or I DS. And to achieve this I DS, we can find what supposed to be the meaningful DC voltage and what will be the corresponding meaningful resistance of the source. And better, we should avoid this resistance and ideally we want this resistance should be 0. So, that unnecessarily we do not want to complicate the circuit and contribution of the C gd, we do not want to take it to the input capacitance otherwise that will affect the upper cutoff frequency.

So, the summary of the design guidelines is that we start from output resistance particularly for common drain circuit then we calculate gm, we calculate the required I DS to achieve the required I DS, then we can find what will be the value of this one and also the corresponding DC voltage here. In fact, this DC voltage it may be coming from the previous stage. So, in case if this is given to us; accordingly, then we can calculate the corresponding R L. So, it boils down to the point that we need to calculate the corresponding R L of the circuit.

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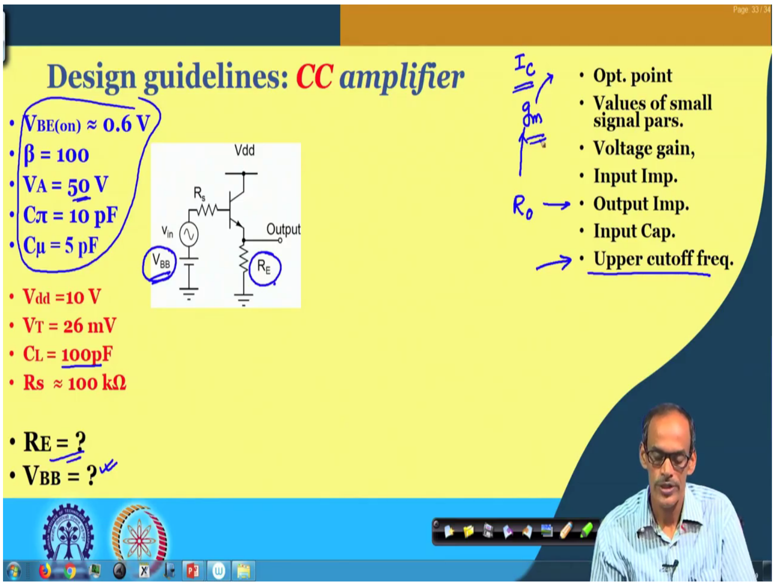

So, similar kind of guidelines it can be followed for the common collector circuit also. Where, again the information may be given or rather requirement it will be given for the upper cutoff frequency for a given load capacitance. So, from that we need to calculate what is the R O. And this R O, since it is predominantly defined by gm from that we can find what is the corresponding trans conductance and from that we can find what will be the corresponding collector current. And if the collector current is known to us, then for a given value of V BB, we can find what will be the corresponding R E.

So, if V BB, it is given to us then, the last thing it is we need to find the corresponding R E. But whatever the calculation we will be doing. We are assuming that the remaining parameters are given to us. Namely, the device parameters particularly the early voltage and C pi C mu even though we do have so many parameters, but primarily we do have the main thing is the collector current and gm it is defining the circuit performance of this voltage buffer.

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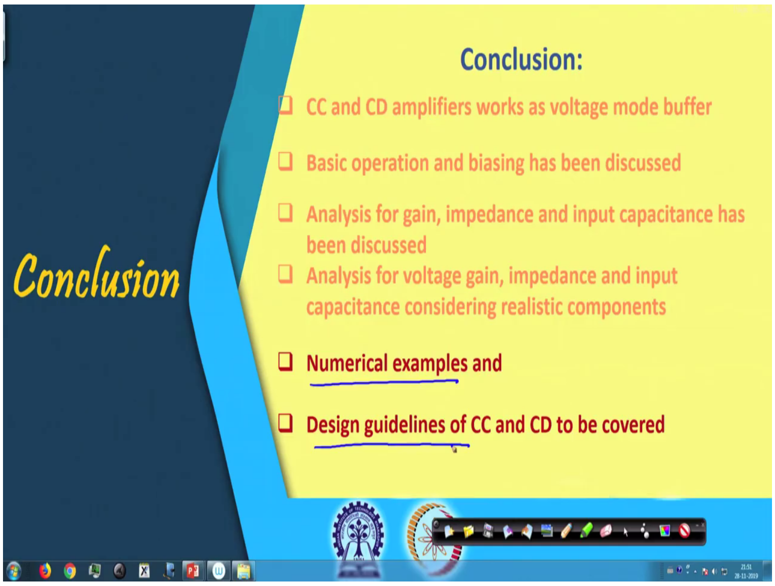

I think we need to conclude now. So, what we have done today? It is we are we have concluded with numerical examples and exhaustive numerical examples it is giving us to understand how we proceed for designing a circuit. So, the design guidelines of the common collector and common drain, it is also covered and so, that is all about this second configuration. Now in the next class; we will be going for the other configuration namely the common base and common gate configuration.

Thank you for listening.