Analog Electronic Circuits
Prof. Shouribrata Chatterjee
Department of Electrical Engineering
Indian Institute of Technology, Delhi

Lecture - 09
Source degenerated amplifier

Welcome back to Analog Electronic Circuits. This is the 9th lecture and today hopefully we will be working on source the source degenerated amplifier. Now, in the last several lectures over the last 8 lectures, we have understood the MOSFET how it behaves? And then we have looked at the three basic circuits' common source, common drain, and common gate. We have examined these three basic amplifier circuits the common source amplifier is you know the most the most generally the most popular one. And it has a reasonably high voltage gain it has infinite input impedance, but it has a large output impedance.

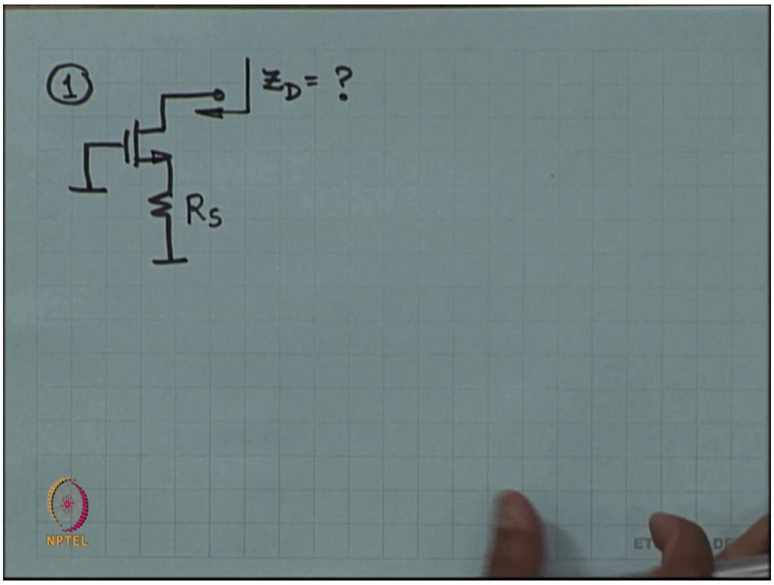
Then comes the common gate circuit the common gate circuit also has very high gain voltage gain right, but the common source amplifier had negative voltage gain this has the common gate amplifier has positive voltage gain, but then it has a low input impedance and a high output impedance ok. Low, because the input was at the source and looking into the source the input impedance is low.

Then the third structure we looked at was the common drain circuit and in the common drain circuit the gain the voltage gain is approximately equal to close to 1 that was the voltage gain actually it was less than one, we calculated somebody effect and so on and so forth right you recollect yes.

And the input impedance of the common drain circuit was infinite very large the output impedance was very low, because you were the output was at the source remember the source is the low impedance node, the drain is a high impedance node the gate is infinite impedance ok. So, if you take the output from the source the output impedance is low, if you apply the input into the source then the input impedance is low ok.

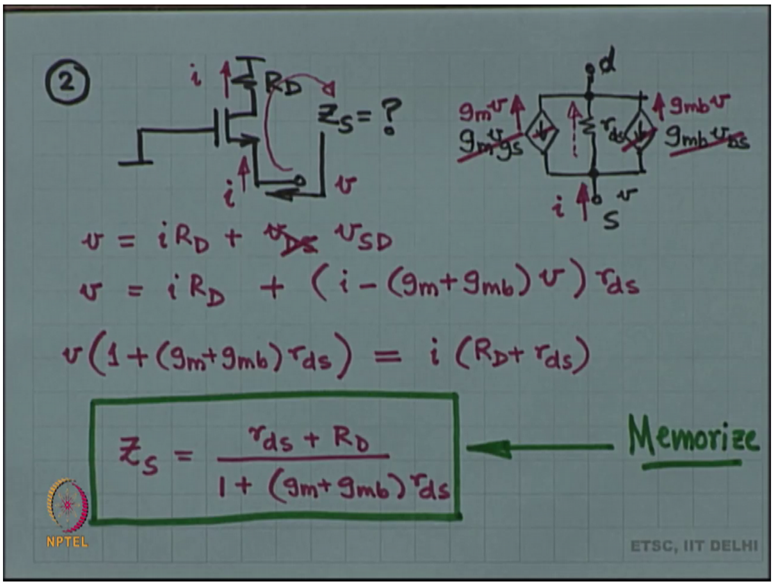
Now and then so, all of this we studied and then I said that there are 2 important structures that you have to analyze for impedance one important structure was this.

(Refer Slide Time: 03:05)



So, looking into the drain when the gate is terminated to ground when the source is terminated through R s to ground right looking into the drain, what is the impedance this was one question.

(Refer Slide Time: 03:57)



And a second question which looked exactly similar was this ok. Looking into the source what is the impedance when the gate is terminated to ground and the drain has R d to ground right these are all in the small signal ok.

And, then we did some calculations we had actually solve the second one not the first one right and this calculation was a little lengthy, because it involved some sort of k c l k v l you know let us just quickly do it. So, for example, if I assume that the current going this way is i when I have applied a voltage v ok, I have applied a voltage v let us assume that the current going in his i and now let us compute the overall voltage. So, let us do a k v l loop like this ok. So, v is equal to this current is also i right. So, the drop across the resistor is i times R D and then there is the drop across the source drain of the MOSFET.

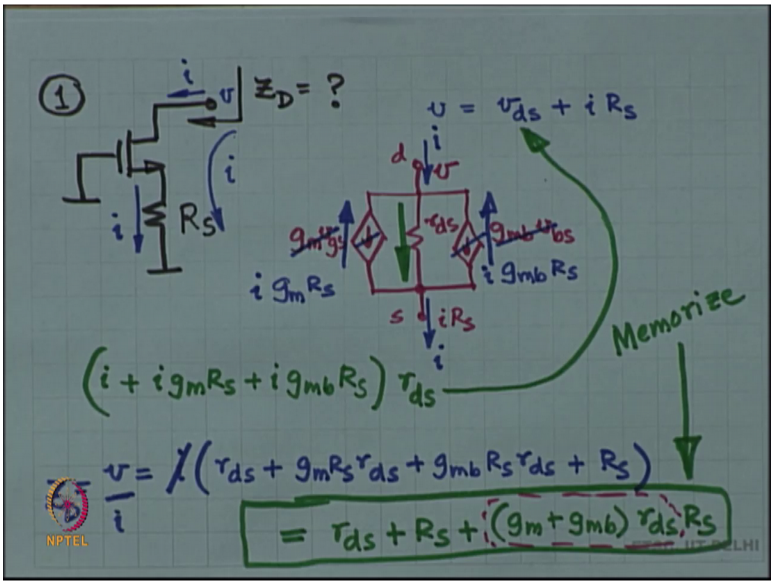
So I do not know what is the source drop across the source drain of the MOSFET I need to figure out fine sorry it is not v D S this is v S to D all right. Now what is inside the MOSFET you have got there is the structure ok. There is R d s there is g m times v g s and g m b times v b s and now inside this the sources at voltage v the gate is at ground. So, g m v g s is really minus v. So, let us correct this and likewise v b s the body is at ground the source is at v. So, g m b v b s is nothing but minus g m b times v. So, I am going to correct it to point upwards with g m b times v ok.

So, those are the 2 currents in those 2 elements total current over here was I which means that the remaining current through this R d s is i minus g m times g m v minus g m b v. So, the current through R D s is nothing but I minus all right this is the current through rds and the voltage drop across rds is therefore, this times rds and that is going to be v s d. So, this is the k v l ok.

Now, put all the vs together. So, I have put all the vs together and put all the is together and that will give me v by i that is the input impedance is equal to all right. Now this result happens to be important enough that you need to memorize it for this course all right. This result is important enough that you need to memorize it you also have to memorize the context, that is what was the experiment that was done that give this answer that also you have to memorize do not just memorize the answer, because if there is no context you cannot do it.

So, this result is important enough that for this course you need this result ok. And likewise the second one this I asked you to try in your free time, but never the less we are going to do it right now. So, this is looking into the drain what is the impedance. So, let us try that once again we can do a k v l.

(Refer Slide Time: 11:06)



We can assume that this current is i, so, this current is i, this current is i, which means that the drop across R s is i times R s right. I have applied a voltage v current is i. So, v is equal to drain to source voltage plus i times R s ok. And now all I need to figure out is what is that drain to source voltage for that think of what is inside the MOSFET, this is what is there, that is what is there inside the MOSFET. So, the drain is at a voltage v source is at i times R s gate is at ground.

So, what is g m times v g s source is i times R s gate is at ground. So, I am going to correct g m times v g s to point upwards and the value will be g m times R s times i, that is the current pointing upwards. And likewise this is g m b times v b s body is at ground source is at i times R s, which means I am going to correct this to point upwards at and the value is now going to be g m b times R s times i fine I was the total current through the MOSFET ok.

So, what is the current through the resistor then what is this current this current is nothing but i plus i times g m R s plus I times g m b R s, that is this green the green current coming through r ds. And therefore, the voltage drop across r d s is this current times r d s and that is v d s this you plug in over here.

Now, let us take a look let us rewrite that top equation. So, v is equal to v d s which happens to be this complicated expression, which is nothing but I times r d s plus g m R s r d s plus g m b R s r d s, that is v d s and then i times R s ok. And then simplify to find out Z D, which is nothing but v by i and that is r d s plus R s ok. So, this is the result and once again this result is so, important that you need to memorize this result to ace this course to understand this course also, you know because I am going to invoke this right from time to time I am going to invoke this.

So, if you want to understand this course all right even for understanding sake, because every time you are not going to compute right we need to pull things out of our memory from time to time. So, therefore, I am recommending not recommending I am letting you know that, if you want to understand the remaining part of this course then it is vital that you memorize this expression and memorize this expression, expression 1 and expression 2 ok. Impedance looking into the source is so, much impedance looking into the drain is so, much right these 2 need to be absolutely memorized, because they are vital for you to understand the course am I clear memorize these 2 results right away.

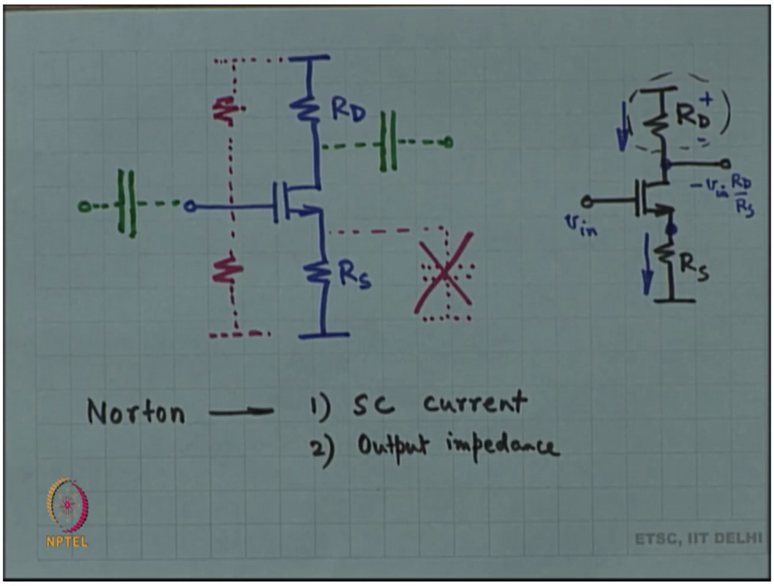
Looking into the drain the impedance is going to be high it is going to be r d s plus R s plus the gain of the MOSFET g m plus g m b times r d s that is the intrinsic gain of the MOSFET times R s what is on the bottom? Ok. So, once again let us look at it I am trying to help you memorize this. Let us look at it you are looking in to the drain of the MOSFET you see that on the source of the MOSFET there is R s. So, the net impedance is this source impedance plus the intrinsic gain of the MOSFET times the source impedance, plus r d s source impedance plus the intrinsic gain of the MOSFET times the source impedance plus r d s ok.

Looking into the drain of the MOSFET you see a high impedance the impedance multiplies up how much does it multiply? It multiplies up by a factor of the intrinsic gain of the MOSFET right this is the large number need you to understand this while understanding memorize.

Next one looking into the source what do you see. So, I am looking into the source of the MOSFET the drain is terminated with R d. Now naturally looking into the source I am going to see a low impedance right, but there is an impedance which is R d and there is also r d s and it looks like r d s is in series with R d. So, it is R d plus r d s and because it is low this whole thing is divided by the intrinsic gain of the MOSFET 1 plus the intrinsic gain of the MOSFET ok. I am trying to help you memorize these 2 results because they are so, important we need them right away we need them every in every lecture we are going to invoke these 2 formulae ok. They are important is it understood you are going to memorize these yes you need to memorize these to come to the next lecture all right.

Now, with this background what we have seen so, far is looking into the drain impedance is very high it multiplies by the by the intrinsic gain of the MOSFET. Looking into the source in the impedance is very low it divides by the intrinsic gain of the MOSFET ok.

(Refer Slide Time: 20:50)



This is what we have seen so, far our next circuit is going to be something that more or less looks like the common source amplifier, but remember when we studied the common source amplifier. First when we did the biasing, there was an R 1 over here. There is an R 2 over here right.

And then there was R S and there was R D this is what we had done during the biasing of the MOSFET. And then what did we do we had the capacitors to couple the signals right. So, we had an input capacitor to couple the signal in we had an output capacitor to take the signal out ok. In the small signal equivalent picture incremental picture these capacitors are short circuits. Then we said that R S does not appear in the small signal picture at all right it was not there because we wanted to make a common source circuit. So, we wanted to have the source connected to ground. So, therefore, we had placed a capacitor over here across R s over here right. And then we analyze the circuit this was our common source amplifier. Now, the question is what if this last 1 this capacitor was not there at all what would have happened how will you solve this question? Ok.

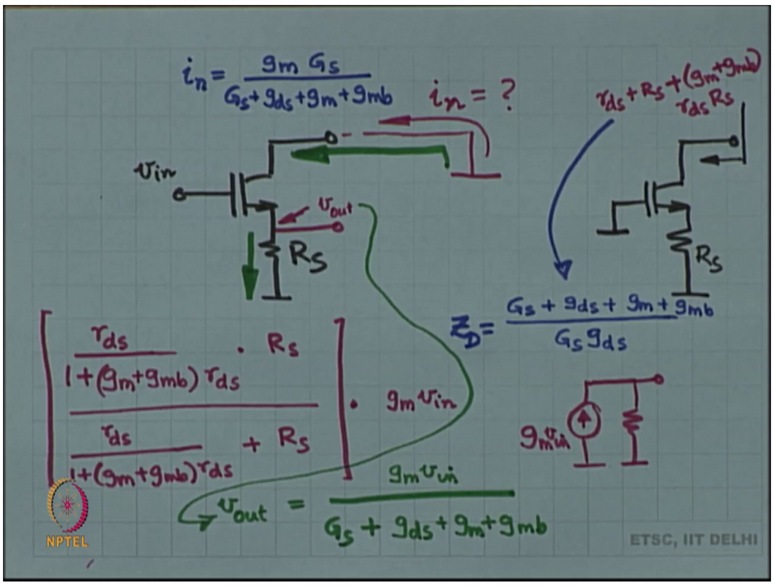
So, the way we solve our questions is by using a Norton equivalent model. So, first of all let us redraw that is all in the redrawing right. The green input and output capacitors are short circuits the red biasing resistors come in parallel with the input voltage source and they make no difference to the circuit. All that remains are the MOSFET R D and R S and instead of VDD instead of the power supply voltage you will have 0 volts over there in the small signal incremental picture ok, this is the story so, far.

Now, the question is what is the voltage gain? How are we going to find this we are going to evaluate the voltage gain of the circuit using the Norton equivalent method? How do we use the Norton equivalent method? We are first going to do the short circuit test we are going to measure the short circuit current and then we are going to measure the output impedance of the circuit ok.

So, for now let us assume that R D is the load R D is the load it is going to be in parallel with the load anyway, if there is some other load R l then R D and R l are in shunt with each other. So, you will write it as R D parallel R l.

So, nothing will change over there let us assume R D is outside as part of the load.

(Refer Slide Time: 25:42)



And let us just look at the bare minimum that is this portion alright. Now first experiment I am going to apply v in over here I am going to connect the output through a short circuit to ground and the question is going to be what is this short circuit current? Alright, this is going to be one experiment that I am going to do. The second experiment that I am going to do is I am going to measure the output impedance. And to measure the output impedance you are going to null all the input which means you are going to connect the gate to ground.

This we have just done right what is this output impedance just done it. You remember r d s plus R s plus g m plus g m b times r d s times R s g m plus g m b times r d s is the intrinsic gain of the MOSFET times R s plus R s plus R d s ok. That is the impedance one experiment done already, I look I am not even expanding the MOSFET I do not need to know what is inside anymore just using that expression earlier expression ok.

Now, the other experiment has to be done I need to find out what is i n. Now this is something that you have already done have not you is not this the common drain circuit is not it is not it the common drain circuit the drain is connected to power supply over here, drain is connected to power supply you have got some resistor on the source, this is indeed the common drain circuit and we have already studied this. So, what did we do in that case we found out the value of voltage over here this was some output voltage that we had figured out ok, in that case? And we had remember we had figured out that the gain the voltage gain was less than 1 you want to do it once again ok.

So, if you want to do that let us forget this experiment right let us assume this is connected to ground we eventually want to find out i n, but let us for now just find out v out ok. Now to find out v out you are again going to use the Norton equivalent method what does the Norton equivalent method. What is it has 2 parts find out the short circuit current and find out the output impedance. So, I look at this node what is the output impedance I can look down I see R s and when I look up I look into the source of the MOSFET R D is 0 ohms to ground right.

So, my formula this was formula number 2 I am referring to this formula looking into the source of the MOSFET R D is 0 ohms right. So, the impedance is R D plus r d s r d s plus R D is 0 divided by 1 plus 1 plus g m plus g m b times r d s this was the impedance looking up.

And looking down I have got R S, which means that the net impedance is the parallel combination of this and R S. So, this times R S divided by something like this. This was the impedance over there right that is done I am trying to find out this voltage ok. Now the next thing is what was the short circuit current? So, if I connect this 2 ground what would be the current through it, if I connect this node to ground drain is also ground source is ground. So, inside the MOSFET there is g m g m b r d s the current through r d s is nothing but 0 because both terminals are grounded the current through g m is v in times g m ok. And the current through g m b body is at ground source is ground is 0 ok. So, the current the short circuit current is nothing but g m times v in ok.

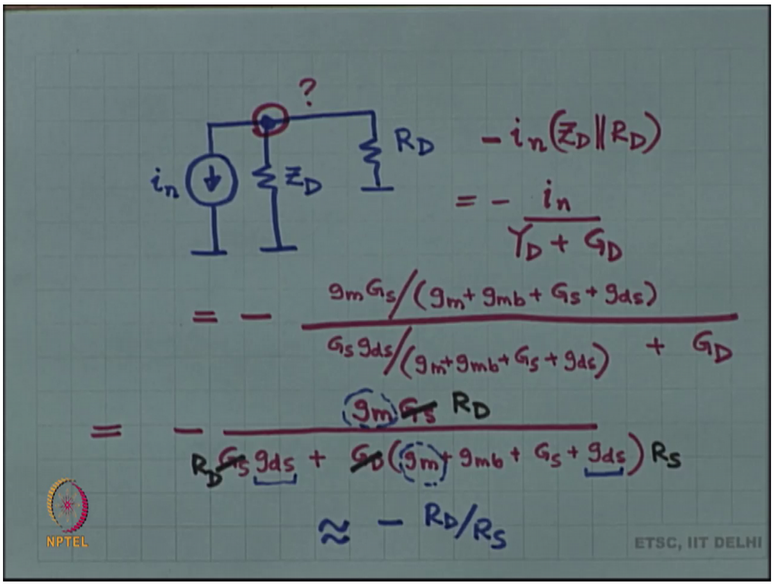
So, my short circuit current is g m times v in the impedance at that node is this complicated expression, which means that the voltage over here is nothing but g m times v in times this ok. So, this is the voltage, you do not remember a complicated expression is that it the question you do not remember the complicated expression. Correct you do not remember the complicated expression, because we had worked with conductances at that time not with resistances. You will see that if you work with conductances things become a lot easier right because you know these are in parallel ok.

So, for example, 2 resistors in parallel right you have to do R 1 R 2 divided by R 1 plus R 2 if you are done 2 conductors in parallel instead of resistors, then you would have just done g 1 plus g 2 and in that case the expression would be the same g m v in over here, but instead of a multiply it would be a divide by G s and that is in parallel with this conductance right. This conductance is 1 by of what I have written here. So, it is 1 by r d s plus g m plus g m b r d s by r d s, you see it is lot it is a lot simpler right if you work with conductances. So, that was the voltage over there.

So, if that is the voltage then what is this current that voltage divided by R S right and that is the same as this current i n. So, i n is nothing but this v out this voltage over here divided by R S or multiplied by G s, whichever way you want to look at it. So, my final expression for i n is g m times G s divided by G s plus g d s plus g m plus g m b that is my expression for i n. And my expression for the output impedance is so much would you like to convert this to G s to conductances, it would be a bad idea generally to convert this to conductances, because these are all in series right, but you can do it r d s is 1 by g g d s R S is 1 by G s alright.

So, this output impedance is nothing but so, much ok. So, this is the output impedance is the reason why I did that actually note this numerator and this denominator are the same they are the same very good. So, I have the output impedance I have the output impedance over here and I have the short circuit current over there. So, what is the model, the model for the circuit remembers I have taken out R D R D is not there the drain resistance is gone right.

(Refer Slide Time: 37:00)



So, the model for the circuit is this. So, these are the 2 quantities that you have computed why is the current pointing that way because the current is pointing this way when you measured it right. So, when you replace this by a short circuit the current is going to be consistent with your measurement that is why this is important what I just said. This you have to maintain consistency in direction right, this current when you did this short circuit experiment the current point out in this fashion. Over here if you had a short circuit instead of R D the current would go in the same direction.

So, what is the voltage over here i n times minus i n times Z D parallel with R D or minus i n divided by this output conductance plus G D. And then what is i n we had it from here that is i n and what is Y D this is Z D ok. So, y d is 1 by this and the drain conductance alright. And then of course, these 2 are the same which means that this entire thing is going to simplify is it is it fine so far, alright. Now what we are going to do now is we are going to first multiply numerator and denominator by R S, and then we are going to multiply numerator and denominator by R D just because I want to.

So, numerator and denominator let us multiply both by R S times R D. So, what happens over here when I multiply numerator by R S R D the G s goes away and R D stays denominator I am going to multiply by R S R D. So, this becomes R D and this becomes R S, alright. And this is where I stop doing work and start interpreting things what is the interpretation? So, first of all g m is supposed to be if you have done a good job with the transistor then g m is hopefully large. So, if g m is large all right especially compared to g d s, especially compared to g d s g m is large. So, let us you know throughout the terms with g d s let us just focus on the g m term this again there is a g d s.

Although, it is g d s times R D I do not know the relationship between you know R D and R S, but let us assume that R D and R S are relatively similar resistors ok. They might not be 1 k and 1 k maybe they are 1 k and 5 k relatively similar, but g d s is much much smaller than g m this is my first assumption.

In a very good transistor you know the ideal transistor g d s is 0. So, if g d s is 0 for example, then this entire term goes away this goes away right and the denominator is dominated by g m, which means let us let us forget g m b and let us say that g m is much larger than G s, after all G s is in your own hands ok. So, let us make g m the dominating factor over here. In which case the entire denominator is going to become g m times R S, the numerator is only g m times R D thrown out. So, what do you get this is approximately equal to g m times R D divided by g m times R S, that is a very nice result ok.

The gain of the amplifier is just minus R D by R S actually it is lower than that, but that is kind of an approximation to what the gain of the amplifier is going to be, let us look at it in a different way this was the circuit ok. So, if you say that you have got a source follower common drain circuit. The drain resistance did not really matter right at that time. In which case the voltage over here is more or less equal to v in; that means, this current is v in by R S, this current is v in by R S. So, the drop across R D is v in by R S times R D and therefore, the output voltage is minus v in times R D by R S ok.

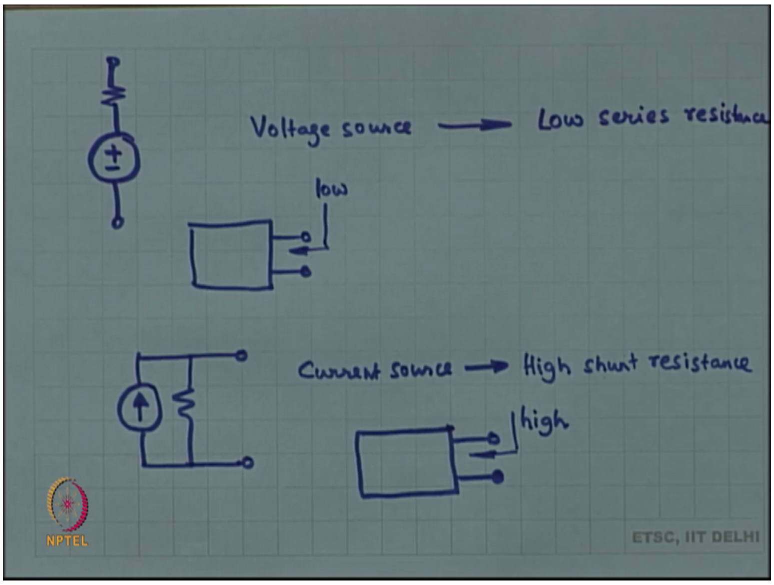
And, where was the approximation over here the approximation was to make an estimate initial guess or rather an estimate not a guess an educated estimate, that the voltage at the source is more or less equal to v in right. It is actually less it is less substantially, it is less by actually a factor of so, much which kind of reflects in this picture ok.

So, if you ignore this term totally if you say that g d s is nothing even then you will be left over with this portion is this ok. So, this is a neat little circuit right you throughout that capacitor and then what do you see you see that you have got a gain, which is related to the resistor values only not no longer to the device parameters. So, your gain is now minus R D by R S right if I choose some resistor ratio even when temperature changes the resistor ratio is going to be maintained. And therefore, the gain is going to be maintained more or less a constant and this is something very nice alright.

However, you are not going to get large gains why not why would not can R D b equal to hundred times R S no R D cannot be equal to 100 time R S, because then you have to do the full work right. If R D is 100 times R S, then remember we are thrown out this term over here right, there was an R D in the denominator this going to come back into play and then your gain is no longer going to be minus R D by R S it is going to be some much number much smaller. So, R D cannot be you know arbitrarily large fine. So, this is called the source degenerated amplifier what we had upfront this is the source degenerated amplifier there is resistance at the source. So, the source is degenerated.

Now, I want to have a few words some important, but rather abstract words and these are going to be some abstract comments, try when I have this following discussion try not to be overly rigid ok. Be a little flexible give me some leave right and then maybe you will have a better time following this course ok. So, what do I want to say? Suppose I want to make a battery.

(Refer Slide Time: 48:20)



If you want to make a battery right you invariably end up with some source resistance and that source resistance appears in series with the battery with the voltage source. So, if you try to make a voltage source you will never end up making an ideal voltage source, you will always have some series resistance. To make a very good voltage source this series resistance has to be made, lower, and lower fine. How low this series resistance is gives you a quality of how good this voltage source is.

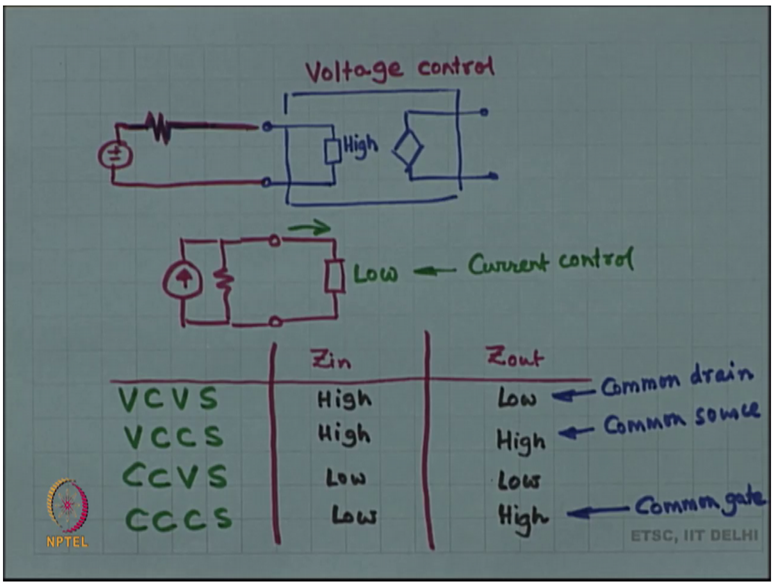
So, a very good voltage source will have a very low series resistance fine is this comment understood the reason why I said do not be too rigid is because this low this value low what is low this is all you know subjective I mean what I call low you might call it to high ok. In electronics we call 0.1 ohms as low, but you go to power engineering and you say I have got a wire with 0.1 ohms they are going to laugh at you that is not a wire yet all ok.

So, this high and low this is all very subjective let it be let it remain subjective for now just go along with the flow right just listen to what I have to say. So, what I have to say is as follows if I want to make a voltage source I need a low series resistance or in other words if I make a circuit that has a low output impedance then it behaves like a voltage source. So, the backwards think is also applicable. So, if I have let say a box and I measure the Thevenin equivalent or Norton equivalent impedance of this box right and if this output impedance is low then; that means, this box behaves like a voltage source is this all right.

Next a current source suppose you try to make a current source. You will never really make an ideal current source; you will always end up with some resistance in parallel with it ok. Now this is not in series this is in parallel if this is current source in series with a resistance is a current source voltage source in parallel with a resistance is a voltage source. Current source in series with the resistance is a current source the non-idealities when the resistance appears in parallel ok; if, this resistance where to be infinite then the current source would have been an ideal current source. So, therefore, if you are trying to make a current source, then you need a high a very high shunt resistance ok.

In other words if you are made a box and you find the Thevenin or Norton they are the same right the Thevenin equivalent impedance is the same as the Norton equivalent impedance. If you find out this output impedance of this box and find out the rate is high, again low and high these are all relative terms and subjective ok. So, keep it keep it that way let us keep it subjective let us keep it relative, when the output impedance is high I am going to call this box a current source is this is this understood very good. So, low output impedance it is a voltage source high output impedance it is going to be a current source.

(Refer Slide Time: 53:33)



Then suppose I have a circuit which has an input impedance this is my circuit and then you know it has some control mechanism maybe it is a control voltage, control current, whatever it is ok. So, it could be a controlled voltage, source or a controlled current source.

Now suppose this impedance is very high if this impedance is very high, then whatever is driving this node this, this from outside let us change the color, maybe it is a voltage source is driving this node or maybe it is a current source that is driving the node, it does not matter whatever is driving the node this if it is a voltage source driving the node and this is a high impedance then this voltage is the same as this voltage. So, you know the voltage over here the voltage over here does not change because of the impedance over here right

So, we call this voltage control ok. So, a voltage controlled source will have a high input impedance ok, likewise if there were a current source over here and you wanted current control, then that current source would have some shunt resistance and this is the input of your box ok. The current source has some shunt resistance. Now if you want the current over here to be equal to the current source value, then this impedance should be high or low it should be low, because if it is low then this entire current is going to go this way ok. So, a current controlled source has a low input impedance and now you combine. So, you have got a voltage controlled voltage, source voltage, controlled current source, current controlled voltage source and current controlled current source these are the 4 controlled sources that you have learned right.

Voltage controlled voltage source, voltage controlled means that the input impedance has to be high; voltage controlled means the input impedance has to be high. Current control means the input impedance is low and then if it is a voltage source then the output impedance has to be low if it is a current source then the output impedance has to be high all right.

So, for example, if you have a common gate circuit a common gate amplifier ok, it has an input impedance that is low because it is at the source and the output impedance is high because it is at the drain what is it then, all right input impedance is low output impedance is high. So, we should not look at the voltage gain at all because it is a current controlled current source ok. Then if it is a common drain circuit the input impedance is very high the output impedance is very low all right. If it is a common source circuit then the input impedance is high the output impedance is high and so, on and so forth ok.

I do not have an example right now of current controlled voltage source right now I do not have it, maybe if you want to make a current controlled voltage source you place a current controlled current source, which has a high output impedance. And then you are kind of stuck then you can put a voltage controlled voltage source at the backend which has low output impedance ok.

Voltage V C V S has infinite input impedance. So, this high output impedance will not matter ok. So, you could do something like that, but anyway I just want to give you a; this was a relative picture of how what is the current source? What is the voltage source? It is a relative matter it is totally subjective whether a source is going to behave like a voltage source or a current source it is relative right it all depends on the impedance of the source, ok.

Thank you very much. See you in the next class.