Analog Electronic Circuits
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Lecture – 07
Common gate, common drain

Hello welcome to Analogue Electronic Circuits, this is lecture 7 and today I planned to talk about Common gate and common drain circuits. So, this is the plan but let us see how far it goes. So, in the last class we had studied the common source amplifier; the common source amplifier had the source common to the input port as well as the output port or in other words if I draw sketch.

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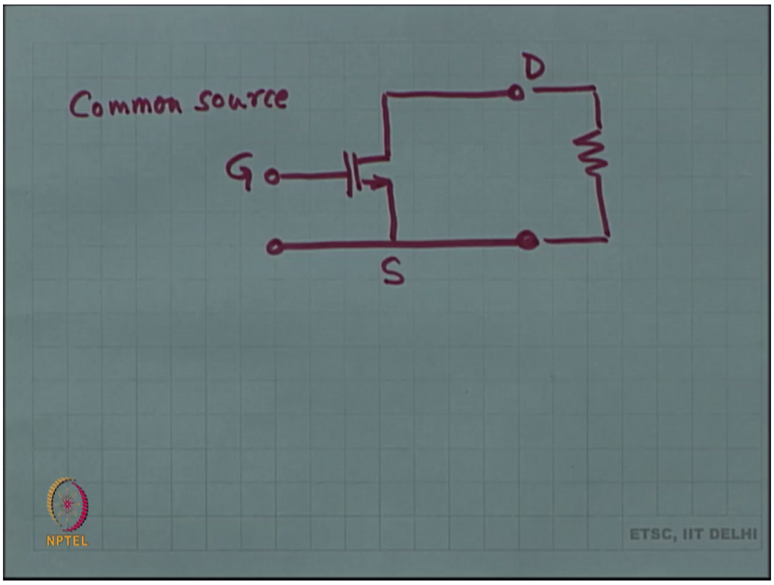

This is how it looks like; remember this is how the small signal picture look like for the common source. The source is common to the input port as well as the output port, this is the input port; this is a 2 port network the input port is between gate and source, the output port is between drain and source. And now of course, the other possibilities are to have the gate common and next the drain common.

So, which one you want to do first? Let us do the drain common first ok.

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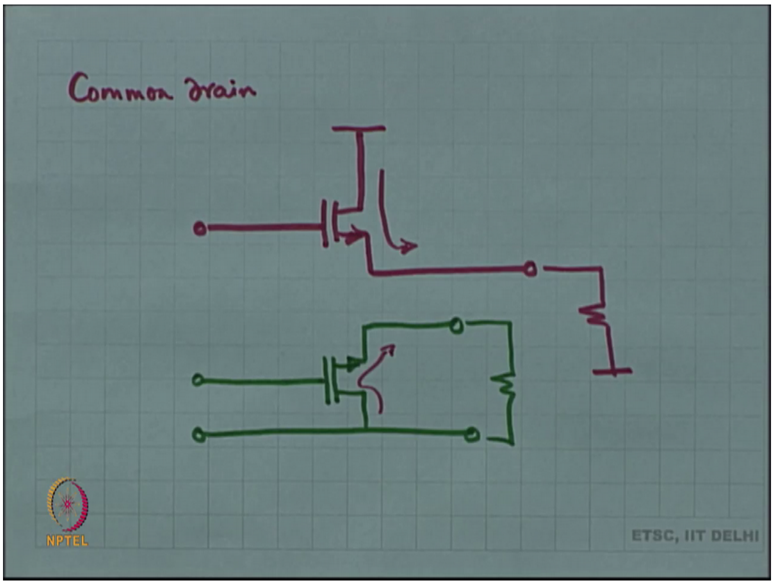

So, the common drain circuit this is the expectation that this is going to be an input port. And then the drain of the MOSFET is going to be the common node alright, this is the bare bone structure of course, you can flip it and draw it, but I like drawing like this. I mean if you flip it and draw it will look like this. Same thing that is how it will look; like it will look exactly like before, but with source and drain inter changed, but then I prefer the I prefer drawing it in the way that I have drawn in at first with red.

Ah The reason being that I like to keep the drain above the source, I do not like the source going above the drain and I do not like current going from bottom to top. Because that is what it looks like in the green circuit, it looks like the current is going from down to up this is the flow of current right; do not like this. So, that is why I like drawing in this fashion; so this is the overall topology, but remember this is not the final circuit right.

This is just the bare bones picture the small signal incremental picture; this is what it is bare bones right absolutely barebones, small signal incremental picture is this drawing ok. And of course, you need to develop this drawing into whatever else is required, but all that you have to remember is that the drain terminal is common between the input port and the output port. And that automatically means that the input is going to be at the gate right, the drain is going to be at ground small signal ground.

And the output is going to be taken from the source and that is about it that is all that you need to know right and then we can arrange the circuit the way we want alright.

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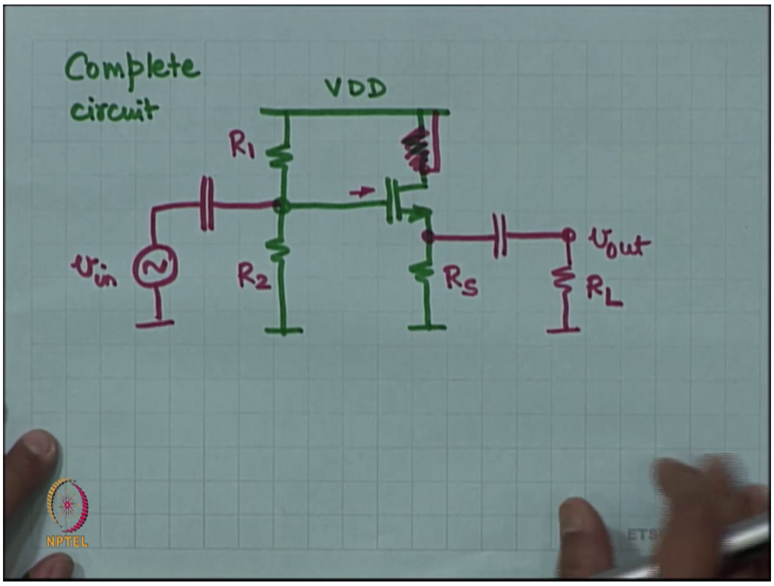

So, once again I am going to go back to the DC operating point circuit. So, this is the circuit that is going to be used to set the DC operating point fine and then we want to connect the drain to ground. So, connecting the drain to ground one way to do it would be to remove this resistor all together and short it and that would be fine. Because it does not really change DC operating point all that it does is it increases VDS which is very nice it does not change anything about I D alright.

So, we can modify it automatically drain becomes small signal ground, VDD is eventually small signal ground ok. And then we have to apply input at the gate how do we apply the input at the gate? By using a big fat capacitor and we have to take the output from the source, I have a question ok. So, the question is that why do not you take; why do not you apply input at the source and take the output from the gate; is that reasonable taking an output from a gate; can the gate the gate current is always 0 can you take an output from the gate? This gate does not provide any current right this current is 0 can you take an output from the gate is it ok.

I mean you can do it of course, and then you will see that there this circuit is useless ok. So, we do not apply input at the source and take output from the gate that is no good that is just not done ok. So, you apply input at the gate you can take output from the source alright. In the earlier structure also we never applied input at the drain and take output from the source from the gate because it is meaningless you cannot use the gate to drive an output ok. So, this is going to be my circuit, this top register can be removed and this is overall you know the final picture you know you have got your DC operating point circuit shown in green and on top you put the coupling capacitors.

So, that you can couple the signal in and then cup couple the signal decouple the signal out fine. And if you want you can have a load resistor at the output right; the output is going to drive something in that can be modeled as a load resistors ok. So, this is my circuit this is the common drain this is the complete common drain circuit fine and now what we are going to do is; we are going to analyze this. So, the DC operating point is exactly the same as before, there is nothing to analyze right.

You have a R 1 R 2 you find out the ratio of R 1 R 2 establish the gate voltage then you can do a KVL and figure out what is I D or you could just assume that vgs minus v t is approximately 0.2 volt, then you figure out the source voltage and that automatically gives you the drain current. And then you can go back compute for this drain current what is vgs what is vgs minus v t check is it 0.2 volts.

Oh no it was not 0.2 volts it is 0.14 volts and then re adjust right make this 0.14 volts plus v t then compute the drain current right. Then you find the drain current check what is vgs minus v t for this drain current, you are going to work out that oh it was not 0.14; it is 0.142 and you are all set ok. So, 1 or 2 iterations at max and you can figure out what is the exact drain current you can establish the drain current couple of iterations is good enough ok.

And then you say that you have got all the different parameters, you have got the source voltage, you have got the gate voltage, drain voltage is at VDD in this case because you do not really need the this register at the drain right in the common source circuit you needed this register at the drain because it the drain was driving something. So, at best it would drive in R L right at worst; so, in this case you do not need that register at all, you can just shot it to VDD and you are done ok.

So, that is the DC operating point; so, VDS is larger in this case DC operating point having been done now what do you do? You short all the big fat capacitors short circuit all the big fat capacitors; null the static voltage sources. So, VDD is a static voltage source constant voltage source. So, nullified make it 0 volts which means that this becomes 0 volts and then redraw and then if you want you can re draw once again with the small signal model of the MOSFET. So, I recommend re drawing in 2 steps ok.

In the first step, you short the capacitors null the DC voltage sources and in the second step show the small signal model of the MOSFET. So, I strongly recommend that you do this redrawing part in 2 steps and not in one single step, this is a reason why. The reason is that a lot of times once you get a little practice a lot of times you will not even need to draw it the second time. And draw it drawing it this I mean the second actually replacing the small signal model of the MOSFET over here is not necessarily needed you can do a lot of calculations mentally right.

As an undergraduate students in engineering you are trying to become an engineer right and frankly speaking engineers one hallmark of an engineer is to skip a lot of steps ok. So, you should try to skip steps; I am not saying that you skip steps in the exam right. If you skip steps in the exam that is probably as long as you get the right answer not probably it is absolutely as long as you get the right answer.

But if you do not know how to get the right answer then do not skip the steps elaborate all the steps clearly and then do it. But if you are confident and that is what I want you to be you need some confidents right. If you want to be confident then it is a good idea to skip a few steps to practice skipping a little bit because that will that is a engineering for you right; engineering you skip a few steps you do not do everything accurately right you are really interested in reaching the as close to possible as close as possible to the final answer in a very short amount of time ok.

So, my recommendation is do not plant the small signal model of the MOSFET in the first go itself right. Re draw once and then redraw second time if needed; so, right now we will do it because we do not know the steps, but later on you will find that you do not need to re draw it the second time ok. So, I am going to re draw this with what? What am I going to do? I am going to short circuit these capacitors and I am going to null the voltage source that is the job that I am going to do.

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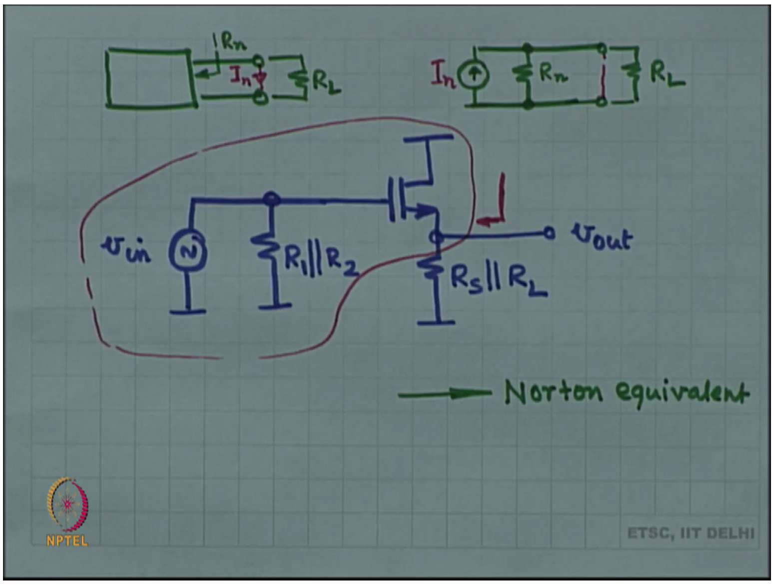

Ok now the technique that we are going to use to analyze this circuit is something that you have learnt in circuit theory ah. You have learnt about the Thevenin and Norton equivalent equivalence right Thevenin equivalent and Norton equivalent.

So, in an analogue electronic circuits we are going to have a bias these both of these techniques the Thevenin equivalent technique and the Norton equivalent technique; they are as good as each other right. And most of most of the time they are equally difficult or equally easy to work with; however, in analogue electronic circuits, we will strongly prefer using the Norton equivalent strongly preferred this preference is so, strong that almost always ok.

As long as you are using a MOSFET you are going to use the Norton equivalent method ok; this is the method that we are going to use to analyze the circuit ok. So, what do I mean by the Norton equivalent method? So, re collect the Norton equivalent method; you have a box with 2 wires coming out ok, connected to a load resistance right. So, you are going to model the box as a current source which happens to be the short circuit current right. If I make a connection between these 2 there will be a current through this red wire right.

That is the short circuit current and in shunt with the short circuit current, you will have the equivalent resistance or impedance of this black box. How will you measure the equivalent impedance or resistance of this black box, you are going to null all the voltage sources inside look, in from outside to measure R n alright. So, this is the technique we are going to use and then you are going to apply R L and you are going to solve the circuit. So, this is the Norton equivalent method you this is just for your recap and this is what we are going to do right what we are going to do is to find out the short circuit current that will give me I n.

So, basically I am going to replace R S parallel RL with a wire and find I n that is going to be the short circuit current right. If you are confused think of it this way if I replace RL with a wire all of I n is going to flow through RL that will give you the sorry all of I n will flow through that wire that is going to tell you the direction of the flow of current right; so, it is important to know the direction. Once I have done that I know I n and then the next step is going to be to find out the output impedance. So, I am going to nullify all the input voltage sources that is v in and then measure the resistance looking in from the output. So, how do you measure the resistance? We will apply current voltage and see how much current goes in.

So, this is the standard technique that we are going to use; this is the Norton equivalent method alright. So, what is the first step in the Norton equivalent method? The first step notice that I have not yet redrawn the MOSFET ok; I need to replace the MOSFET with its small signal model, I will do it. I just want to elaborate a little bit as to what exactly I want to do before doing it. So, the analysis that I am going to do is; I am going to model this box as I n, R n where I n is some function some function of v in right R n. And then I am going to apply R S parallel R L over here and compute the voltage v out that is my plan this is the plan ok.

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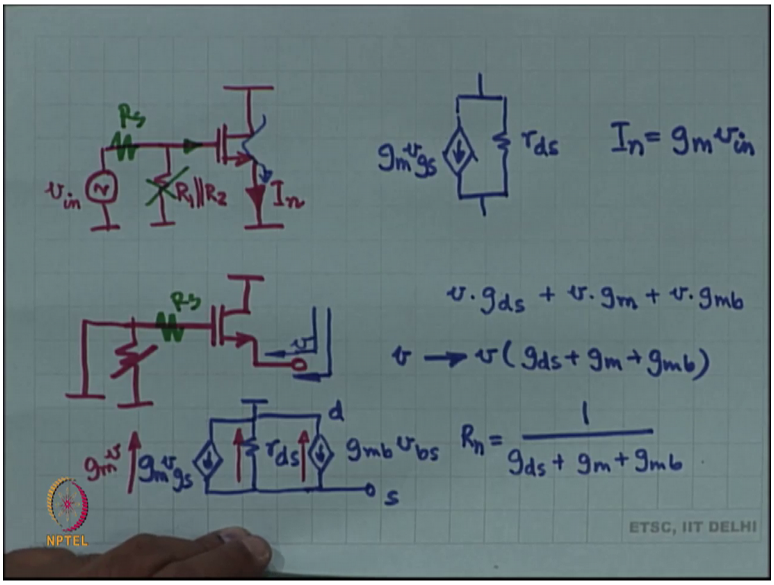

So, let us do it step by step; first we are going to measure the short circuit current. So, this is my circuit and you will see how easy this is this was the original circuit.

So, when I short circuit I am going to short circuit over here and measure the current going through the short circuit wire. So, that is exactly what I have done right, I have connected the source back to ground and now I want to measure the current in the source what is it? So, I apply v in over here right now imagine the model imagine the model; inside this MOSFET right I am not going to redraw it, but this is just for your imagination; inside the MOSFET this is what is there you want a gmb also gmb does not matter sources to ground source is connected to ground ok.

So, that body voltage is not going to play a role, but inside the MOSFET this is what is there this is gm vgs and then there is an rds and what is vgs? Vgs is v in right. So, it is appearing across gate and source; so, gm times v in is the current that is flowing over here and rds is not really going to carry any current at all because both sides of rds R at 0 volts.

So, I n is nothing, but gm times v in and you are done right. So, this is something that you imagine you do not really have to draw it every time I have drawn it right now just so, that this is the first time we are doing it, but the next time you just think what is inside the MOSFET? This is the gm, this is a vgs gm times vgs there is an rds and then there is gmb times vbs right; vbs is 0. So, gmb vbs does not matter rds has both sides connected to 0 volts.

So, rds does not matter all that matters is gm vgs and vgs happens to be equal to v in. So, I n is nothing, but gm times v in and we have found out the Norton equivalent current already. So, one job is already done now the next job the next job what do we have to do? We have to null the voltage source, look in from outside and see how much resistance do we have?

So, we have to null this voltage source first. So, when I say null the voltage source; it means connect make the voltage source equal to 0 volts. So, if I null this voltage source; the voltage source has 0 volts a short circuit. This R 1 parallel R 2 is irrelevant and this is all you have and now once again you do not really have to draw it, but let us draw it let us in. So, you want to measure with a multi meter, you want to measure the impedance looking in from that terminal ok.

Or in other words you apply a voltage of v v over here and see how much current goes back inside. So, I I am going to apply v and see how much current is going inside the circuit fine this is the plan. Now there are 2 things 2 or 3 things inside this MOSFET the first thing that is there is rds, if I apply v over here and I have got rds connected between v and ground what is the current in rds? Is v by rds or in other words it is v times gds; that is one current going. Then there is a parallel path once again imagine the MOSFET; the MOSFET has rds fine these are the elements inside the MOSFET.

So, I have applied voltage v at the source I have already found out that the current in rds is v times gds. So, this current is already accounted for; done next continue with the same exercise. I have applied v voltage over here what is vgs? Gate is at ground; if I apply v voltage over here, vgs is minus v which means gm times v current is going to go upwards corresponding to this current source right vgs is now minus v.

So, all that you can think is that the current source direction flips which means the gm times v current is now going upwards as opposed to gm vgs going downwards what about. So, we add that on and then what about here? The body is also at ground body is always at ground which means exactly the same thing happens I have applied v at the source. So, vbs is really minus v which means gmb times v current is going upwards.

So, I have applied a voltage v and I have got a current v times gds plus gm plus gmb, I have applied a voltage v; I have got a current v time gds plus gm plus gmb which means that the impedance looking into this node over here is equal to 1 by; so, this is your Norton equivalent resistance fine. Now what this means is that this entire circuit this entire box, this entire dashed area; this red area can be modelled as; so, let me re draw.

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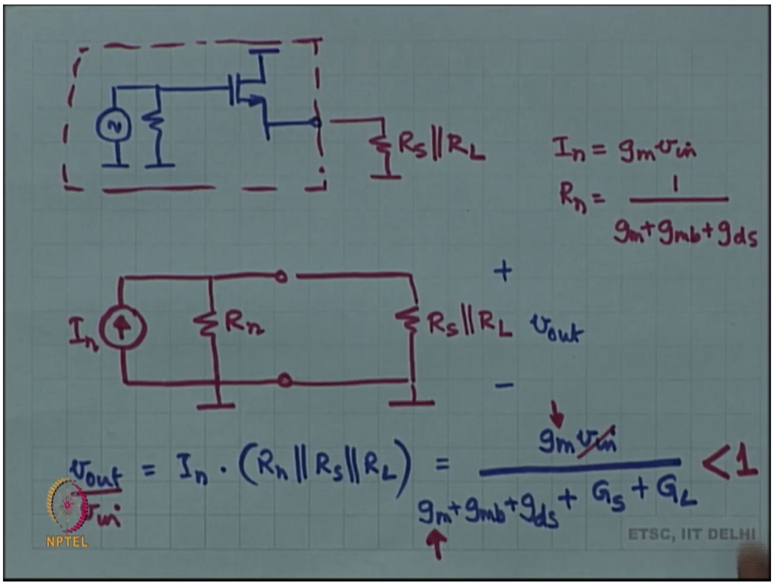

Right this is what we are trying to model, this entire region can be modelled as where I n is nothing, but gm v in R n is nothing, but 1 by gm plus gmb plus gds ok. So, that is the model this is the Norton equivalent model and therefore, what is the voltage over here?

So, I have got a current I n in shunt with R n, trying to push current into R S parallel R L ok, this is going to be some current sharing or you could think of you could try thinking of combining these 2 resistors; now you get R n parallel R S parallel R L and then I n is pushing current into this. So, the net voltage is going to be I n times; so, this voltage, this is v out is going to be I n times R n in parallel with R S in parallel with R L and R n in parallel with R S in parallel with R L means 1 by ok. So, I n is a gm v in and R n parallel R S parallel R L is 1 by R L becomes G L, R S becomes G S and R n becomes g m; g m is nothing, but so, much. So, this happens to be your voltage gain v out by v out by v in fine.

So, the voltage gain is equal to g m by gm plus gmb plus gds plus G S plus G L and naturally if you look at this fraction, then naturally this is always strictly less than 1.

Why? Because you have got gm in the numerator and gm plus other things in the denominator; any questions? You have a question yeah what is the utility of the circuit yeah. So, what use is a circuit that has a gain less than 1 right you want voltage gain you think do you think that voltage gain is everything? What about current? What about current? Current also can have some gain, loss etcetera right.

So, voltage gain is not necessarily everything ok; power gain is what matters at the end of the day are you amplifying power or not. Amplifying power means you know you are drawing power from the voltage source from the DC voltage source of course,, but the signal power is it getting amplified or not that is the bigger question then voltage gain ok.

So, let us see if we are amplifying power or not and the answer will be yes you are actually increasing the power; even though the voltage is less the current is going to be more and therefore, the power is going to actually get amplified hopefully; let us check right. So, power gain is what matters the most not voltage gain ok; so this circuit is very useful do not worry. Even though the gain is less than 1, it looks like it is completely useless because the voltage gain is smaller than 1, but very soon you are going to figure out that this circuit is very useful ok.

So, first of all let us try to understand power gain ok.

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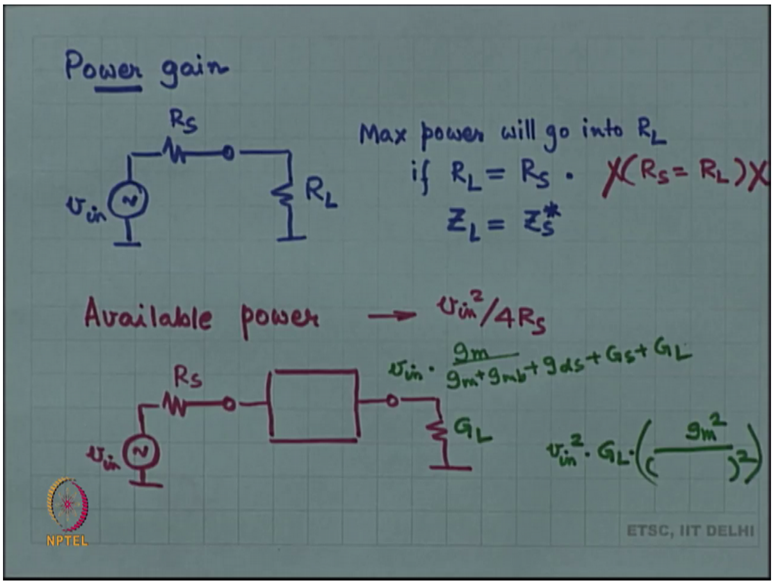

So, do you know the maximum power transfer theorem? What is the maximum power transfer theorem? If I have got a voltage source v in, in series with the resistance R S, then the maximum power will be transferred to a load R L, if R L is equal to R S. This is the maximum power transfer theorem; if you work it with impedances as opposed to resistances then Z L has to be equal to conjugate of Z S. So, Z L should be equal to Z S star alright.

This is the statement of the maximum power transfer theorem, now the converse is not true. So, you cannot state this maximum power transfer theorem in the other way for example, you cannot write R S equal to RL this is wrong RL is equal to R S not R S is equal to RL; you want it to clarify? If R L is equal to R S why is R S not equal to RL yeah? So, this is a technicality and yes this is something very important you cannot write R S is equal to R L and I will state why.

So, here the unknown is RL the unknown is not R S the statement of maximum power transfer theorem is as follows. If I have a voltage source v in, in series with the resistance R S or an impedance Z S; then maximum power is transferred to a load Z L, if Z L is equal to Z S star. It is not if I have a v in over here and R S over here maximum power is transferred to Z L; if Z S is equal to Z l star no.

Why not? Because maximum power will be transferred into Z L if Z S is equal to 0, if you have any flexibility in choosing the value of the source resistance then the source resistance should be equal to 0 ok. And that will give you maximum power right for example, in this case if R L is equal to R S, then what do you get ? So, let us say yeah these this is R S R S.

So, this voltage becomes v in by 2 right and v squared by v in by 2 whole squared by RL will give you the power delivered to R L. So, that is v in squared by 4 RL is the power delivered to R L, but if you could choose the value of sorry we inspired by 4 R S is the value of the power delivered to RL ok. If you can choose instead the value of R S then I would suggest make R S equal to 0 ok. If I make R S is equal to 0 then all v in appears across the RL the factor of 4 goes away, now I have v in squared by R L you see what I mean ?.

So, that is why R S is equal to R L is incorrect you should not write it this way you have to write it the opposite way RL is equal to R S; so, anyway. So, this is the maximum power transfer theorem this is a diversion ok, but what we say is that the available power from a voltage source is v in squared by 4 R S, this is the maximum power that you can deliver to a load RL right.

You have flexibility in choosing the value of R L, but R S exists right R S is fixed and the maximum power that you can deliver to a load is inspired by 4 R S this is called the available power from any voltage source alright; so this is the definition. Now think of the following you have got a sensor; this sensor could be some you know microphone pick up this microphone pick up ok.

This microphone pickup has a fixed source resistors; suppose in that case the available power from this microphone pickup is v in squared by 4 R S, this is the available power. Power more than this cannot be taken out of the microphone; v in squared by 4 R S is the available power, a power more than this value cannot be drawn from this microphone at all done.

Now, I am placing the amplifier in between and I am delivering power to a load to an arbitrary load alright. So, then; so, suppose this is your common drain circuit, now imagine the following. Suppose in your common drain circuit; this voltage source comes with the source resistance. Now what is going to happen? Forget about R 1 parallel R 2 just annoying ok; let us forget about it for the time being. Suppose imagine R 1 and R 2 are so, high that they are you know mega ohms R 1 and R 2 can be in mega ohms right 10s of mega ohms whatever you want R 1 parallel R 2 do not matter ok.

They are so, high that they are not in the circuit the away this is your R S; what changes over here? Does the Norton equivalent current change? Does I n calculation change? Forget R 1 parallel R 2 right imagine it is not there. And now I am saying add in throw in R S over here does the Norton equivalent current calculation change? There is no current going into the gate this current is 0; so, v in is still. So, vgs is still equal to v in which means I n still going to become gm times v in; so, it is still the same.

Impedance calculation Norton equivalent impedance calculation; I am now going to have a resistance over here called R S. Anything significant going to happen? The current in R S is anyway 0 right because there is no current in the gate which means that the gate is still at ground potential which means all the earlier computation this particular remains exactly the same as before. So, R m continues to be exactly the same as before.

So, the Norton equivalent calculation has no change whatsoever. So, I still have exactly the same Norton equivalent over here right I n remains the same, R n remains the same; v out by v in remains the same ok. No matter what the value of this source impedance is; what the source impedance is does not matter, it could be 1 mega ohm for example, right? It could be fairly large; the Norton equivalent remains exactly the same. So, the voltage gain remains exactly the same correct; you see what I am driving at? I am driving at the following that the available power from this voltage source was very very low.

So, the available power from here is be inspired by 4 R s, but what you got over here the voltage over here is v in times that voltage gain which is gm by gm plus gmb plus gds plus G S plus G L correct. That is the voltage v out and this is G L; so, the power delivered to G L is this voltage squared times G L correct; v voltage squared by resistance voltage squared times conductors. So, the power delivered is v in squared times G Ll times some fraction which is less than 1 ok.

How much less than 1 is it? gds is very small compared to gm compared to gm gds is very small; gmb is also a fraction of gm typically the fraction is of the order of one third or one fourth something like that. So, for example, if gm is 1 unit or let us say gm is 4 units; this is 4 this would be 1, 5 gds is nothing right or 0.1 or something like that. So, 5.1 and G S and G L can be some quantities which means that the overall voltage gain is something less than about 0.8 or so.

So, with G this fraction is 0.8 or so,. So, 0.8 the whole squared is what I have over here 0.8 squared times G L times v in squared is the power delivered. The available power from the source is v in squared by 4 R S; so, what is the gain in terms of power? Remember this R S is the source resistance not 1 by G S, this is something else. So, the available the voltage gain is therefore, v in squared v in squared cancel the power gain. This quantity times 4 R S and R S the source resistance can be anything, can be very large which means that potentially this circuit has very high power gain ok.

So, this is an amplifier in its own right just not a voltage amplifier, the voltage gets attenuated right the voltage gain is something less than 0.8 or so, right, but the powers still gets amplified and that is fantastic because it is an amplifier ok. So, this particular circuit has many names ah, it is the common drain circuit, but a lot of people call it differently. So, some people call it a voltage follower because the voltage at the source follows the voltage at the gate to some extent 0.8 times the voltage at the gate.

So, it is also called a voltage follower it is also called a buffer because now it can drive this circuit can drive from a very weak drive, you can you have power gain right. So, the input source v in might not have had any available power; it would not have been able to drive a load, but this circuit can drive a load ok; so, it is called a buffer ah.

So, these are all the different names one is the voltage follower, one is the buffer and of course, this is actually the common drain circuit. A lot of times what people try to do is to improve the voltage gain of the circuit. So, right now the voltage gain of the circuit is about 0.8 or so, and one of the reasons why it is 0.8 or so, is because of the presence of gmb ok. So, this gmb over here brings it down; so, if for example, gm is 4 units, gmb is going to be 1 unit; so, this ratio is going to be 4 by 5 alright.

So, to improve this what they try to do is to make sure that v b S is equal to 0, but how can you do that? How can you make vbs equal to 0 when the source is moving right the source has got to be moving. So, one way to do that is to make b also move along with the source. So, they connect b to S and this is very very risky business right connecting b 2 S in a an n MOS device is very risky because the body of the n MOS is shared is a shared body; it is a platform on which all the other n MOS devices resides right it is a common body.

So, a lot of times what is done is a p MOS is used and every p MOS device has its own body, it comes in its own well a p MOS device comes inside an n well.

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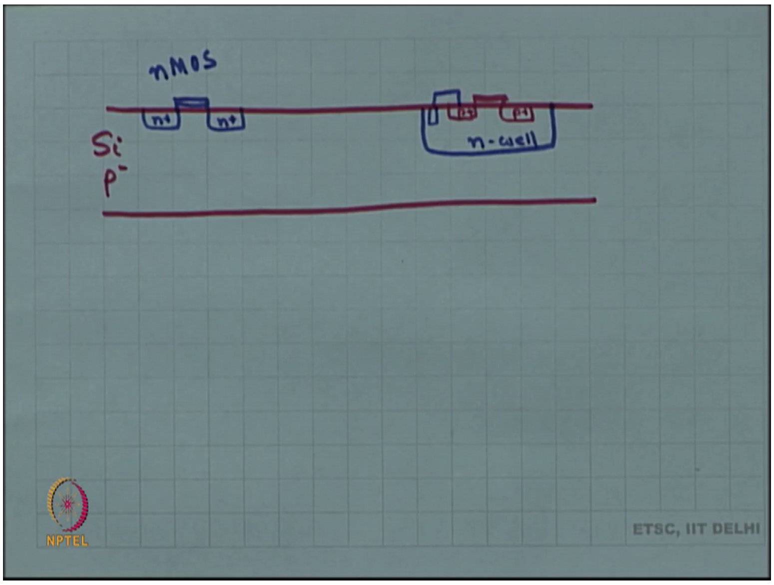

So, normally what happens is that you have silicon right and the silicon is doped; lightly doped with P this is the silicon wafer and then all the devices have to be made on this way.

So, the starting material is p type doped silicon lightly p type doped silicon this is the starting material. Now when you make n MOS devices this is fantastic because you just implant n plus and make the gate. So, this is an n MOS device right, but for a p MOS device, you need an n type body. So, what they do is they make a little well over here which is called the n well and inside the n well they make the p MOS device ok.

So, every p MOS device can be made in a different n well whereas, all the n MOS devices have to reside on the same silicon substrate ok. So, if I say that no I will connect the body of the n MOS device to the source, then you are taking a big risk right you are actually connecting the body of all the other n MOS devices to some source and that is not a good idea right.

If you are going to take risk; take a risk with one device not with all the devices on the same substrate ok. So, in that sense you are never really going to connect the body of the n MOS to the source; however, if you are dealing with one p MOS device one solo p MOS device inside an n well then you can take that risk, you can say that I will take this body of this particular n well and connect it to the source and that way you will be able to avoid the effect of gmb right.

Because now body and source will be at the same potential which means this gmb factor is not going to come in which means; now R n will only be gds plus gm and therefore, that will mean that you will have 4 units on top, 4 units in the bottom right this will be let us say 0.1 unit. So, 4.1; so it is now 4 by 4.1 plus G S plus G L we do not know what those are ok.

So, the gain can be substantially improved if you use a p MOS device with body and source connector ah. Let us stop here we started with the plan that we will do both common source common drain and common gate amplifiers, but we managed to do only the common drain circuit the common drain amplifier. It is not a voltage amplifier, it is more like a power amplifier right and it is also called the buffer circuit. We saw the interaction of the body right, this is the first time the body actually shows up and it plays an active role in your circuit analysis ah.

We also saw how to sometimes you might be able to mitigate the body effect by connecting the body to the source external right. And that you can do only in case of a p MOS, not in an n MOS ah. Let us close with this the common drain circuit is has a gain slightly less than 1 voltage gain, but power is power gain is a different matter all together; it can have very large power gain even though the voltage gain is low alright um. So, in the next class we will continue with the common gate amplifier.

Thank you.