Analog Electronic Circuits
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Lecture – 27
Common gate, common drain with capacitances

Welcome back to Analog Electronics. Today is lecture 27. And we are going to talk about the Common gate, common drain circuits. Once again, we are this recap of what we had done long time back. But this time, we are going to talk about it with the effect of capacitances in the MOSFET. And in the last class, we discussed primarily the common source circuit in the presence of capacitances right. We also discussed briefly about the how to draw bode plot and also about what the format of our transfer function is going to be and so on and so forth.

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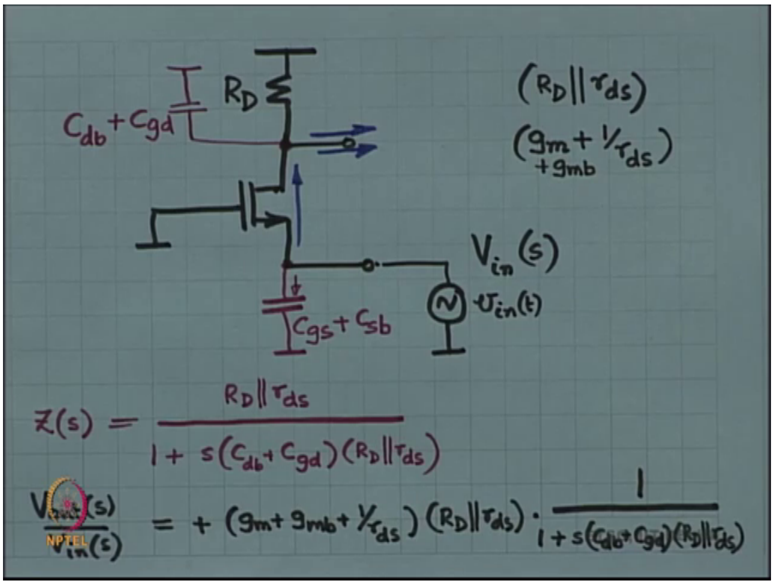

So, now first we will do the common gate structure. And in the common gate structure, the circuit is essentially, so this is your v in of t. But, if you write it in the Laplace domain, it will be written as capital V in of s. The common gate structure gate is at ground right that is why it is common. And you always you never apply signal at the drain, there is no point applying an input at the drain, it does not do much right, you are going to therefore, apply input at the source and you are going to take the output from the drain. So, this is the structure of the common gate circuit ok.

And ordinarily how do you do the analysis? The analysis is always with the help of the Norton equivalent method. And in the Norton equivalent method, you are going to first look at the output impedance. When you look at the output impedance, you will have to null the input signal source.

When you null the input signal source, the source is now at ground. And therefore, the output impedance looking in at the output is R D looking upwards and looking downwards it is just r ds. So, the ordinarily at DC, the output impedance is R D in parallel with r ds, this is the DC quantity. And at DC, if you think about the short circuit transconductance, you are going to put you are going to place a short circuit over here, so there is going to be no current through R D ok.

Now, you have applied signal at the source, so V gs is minus v in. If V gs is minus v in, then that is going to conduct a current, which is the opposite way of g m times V gs g m times v in is going to be conducted. But, it is going to go the opposite way, because V gs is minus v in. And in addition to this current, there is going to be a current through r ds, which is inside the MOSFET and that is nothing but v in by r ds. And the sum of these two currents is going to go out through the short circuit. And therefore, the total short circuit current is going to be g m times v in plus v in by r ds, the sum of these two currents right.

So, if you think of the short circuit transconductance, it is just g m, I am not going to write the v in, when it is transconductance plus 1 by r ds. So, this is the short circuit transconductance, this is the output resistance fine. Now, this is what happens at DC. However, we are now going to take into effect, all the different capacitors in the MOSFET.

What are the different capacitors? First we have got C gs, C gs is between the gate and the source. The gate is at ground, so effectively it is a capacitor from the source to ground. Then you have got C gd, gate to drain C gate to drain. And once again, gate is at ground, so C gd is essentially going to be a capacitor to ground from the drain.

Then there are two more capacitors. One is between source and body and that is C sb body is at ground, there is C gs already over here, so that comes in addition. And lastly, there is C drain to body. So, drain to body is at ground just like the gate body is at ground, so therefore this is going to be C gd plus C drain to body.

Now, we forgot to take into effect the g mb, am I right? We forgot to take into effect g mb in the DC part right, in the DC part, the current over here is g m times V gs plus g mb times V bs and V bs happens to be equal to V gs because body and source are both at ground, so there is a correction. Now, these are the different capacitors ok.

What is going to happen? First what is going to happen to the output impedance? As far as the output impedance is concerned, when I look in from the output, the input is nulled ok, I null the input, which means I make this input of 0 volts voltage source right, so this. There is no current that can go through the capacitor, because both sides of the capacitor are at ground. So, therefore, you forget about it, it is just a ground.

And when you look in from the output, all you see therefore is R D, r ds as usual and you also see C db plus C gd. And therefore, your output impedance is going to look like the DC quantity divided by 1 plus s C r. You could have done, you could have placed all of them in parallel and done the algebra, you will get the same answer ok. I saved a few steps; is this ok, fine. So, output impedance is done.

Next step is to find the short circuit current. Now, when you are going to do the short circuit current, you apply v in over here, you apply a short over there right, there is a short at the output. What is the current in C db plus C gd, it is got to be 0, because both sides of C db plus C gd are at 0 volts, so no current can possibly go through them. So, it is irrelevant, you can strike it off from the circuit. When you are doing the short circuit current experiment, it is not needed just like R D. So, C db plus C gd is not relevant.

What about this particular capacitor, this particular capacitor is going to take a current a very nice clean current write v in times s C gs plus C sb, but that current is not going to proceed through the short circuit, it has no correlation with the other current, it has nothing to do with it ok. This is just a private loop private current loop. We are not interested in this loop of current; we are interested in this loop of current ok. So, this capacitor is also not relevant.

What does that mean? That means that my short circuit current remains exactly the same as what it was in DC ok. And therefore, what is the final transfer function, it is the DC quantity times no 0's over here, only 1 pole that is all. DC quantity times 1 by 1 plus s C R that is it, all right. So, unlike in the common source amplifier, the common source amplifier had 1 right half plane 0 and 1 pole. In this particular circuit, you have got only 1 pole right no 0's, just 1 pole plain and simple ok. So, this is actually nicer all right.

The common source amplifier had a right half plane 0, it made it some special circuit right. Right half plane 0 is actually something very annoying; you will soon realize that it is a nuisance ok. Soon means maybe around lecture 35 or so, you will realize that a right half plane 0 is a complete nuisance; it is very irritating ok. In this particular case, there is no such thing, no problem over here in the common gate circuit, no problem; it is very clean, fine. Shall we do the next one? Great. So, this is as far as the common gate circuit goes.

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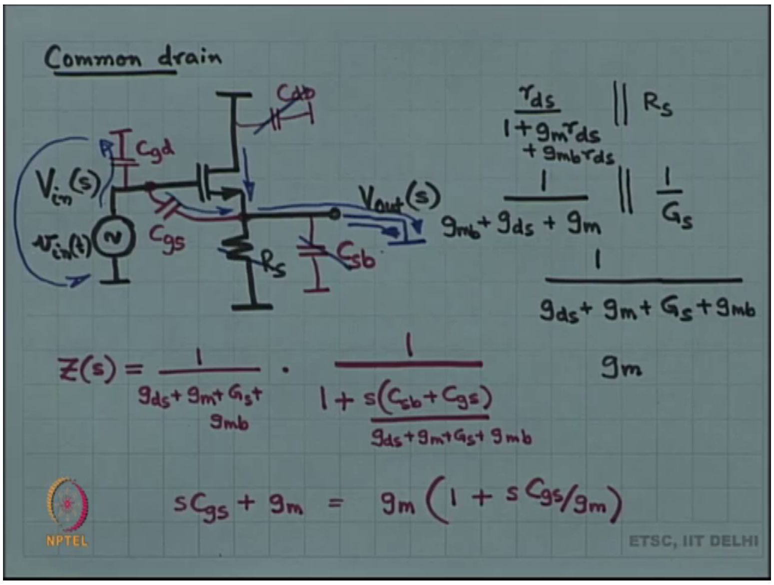

Then we have to do the common drain. So, what does the common drain circuit look like? The drain is at ground, the input is applied at the gate and the output is taken at the source ok. So, instead of calling it v in of t small v in of t, let us call it capital V in of s and correspondingly this one is capital V sub small out of s all right. And you can do the DC analysis first and keep your answers ready.

So, when you look at the DC analysis, you have to do two experiments; short circuit current and output impedance. If you look at the short circuit current over here, you want to do the output impedance first, fine. Let us do the output impedance first. Looking up into the source, so first of all you null the input, so the input is at ground right. When the input is at ground, the MOSFET is like a diode ok, it is called a diode connected circuit right.

The input impedance looking into the source of the MOSFET, you can recollect your formula number 2 right, it is going to be whatever is on the drain are on the drain, which happens to be 0 in this case plus r ds divided by 1 plus g m times r ds that is the impedance looking up into the source. And therefore, that is just r ds divided by 1 plus g m r ds all right. And this whole thing is going to be in shunt with R s.

Now, it just so happens that you can rewrite this in the form of conductances as opposed to resistances. So, for example, you can multiply numerator and denominator by g ds, so the numerator will become 1 and the denominator will become g ds plus g m ok. So, it is a conductance of value 1 by g ds plus g m. In shunt, with another conductance of value capital G s. And when you place two conductances in shunt, it is pretty much equal to so much, fine. So, this is the output impedance at DC. Then we have to do the short circuit current, the short circuit current, we made a mistake here. We forgot g mb, so this should have had g mb also ok, sorry ok.

Next, you have to find out the short circuit correct. When you find out the short circuit current, you place a short circuit at v out. So, no current goes through R s, because both sides of R s are at ground. No current goes through r ds, because both sides of r ds are at ground. No current goes through g mb, because both sides of g mb, V bs body is at ground, source is also at ground, so g mb, V bs also does not take any current.

The only thing that has any current in it is g m times V gs, V gs happens to be equal to v in. So, all of that g m times V gs current goes into the short circuit. So, the short circuit transconductance is nothing but g m ok and that gives you. So, the product of these two will give you the overall voltage gain ok and you recollect that the overall voltage gain is something less than 1 right g m divided by g m plus some other stuff ok, it is going to be something less than 1 all right.

Now, we are going to throw in the capacitors. This is all that happens at DC. Now, let us throw in the capacitors. What is going to what are the different capacitors that we have, first we have C gate to source, then we have C gate to drain ok, then we have C source to body and finally we have C drain to body in which both sides of C db are at ground. And therefore, it is not really doing anything.

Now, we are going to do the two tests, the short circuit current and the output impedance. So, first let us do the output impedance. So, when I do the output impedance, I am going to null the input voltage source, which means that the gate is now at ground, both sides of C gd are at ground. So, this is now become irrelevant. C gs is now a capacitance between source and ground, because gate is at ground. So, C gs is a capacitance between source and ground and adds onto C sb ok.

And then you look at the output, you have R s on this side, you have this DC stuff. And then in addition, you have C sb plus C gs. So, whatever you had earlier in shunt with it, it is C sb plus C gs, which means that the net output impedance is the DC quantity times 1 by 1 plus s C r ok. And you always will have the temptation to simplify this, do not simplify ok, we want it in this format all right. So, you do not simplify beyond this format. If you have the format, the format is 1 plus s times tau right, as soon as you have that, do not simplify further, done. This is z of s.

Next, we are going to do the short circuit current. Now, when I want to do the short circuit current, I am going to short the output and measure the current that goes through it. Now, as soon as I have shorted the output, C sb is no longer relevant, because no current can go through it. R s is no longer relevant, because no current can go through it. C gs is relevant right, current can go through C gs, it is just a capacitance between gate and ground, but that current gets added on right. So, you now have current that can come this way all right. And then you have current that can come through g m, g mb is not there right, g mb times V bs body is at ground source is at ground, so g mb is relevant; r ds is irrelevant, because drain is at ground, source is at ground.

Now, the C gd, yes sure current will go this way, but that forms a private loop of its own and this current does not interact with the current going into the short circuit. So, therefore, we do not worry about it, fine. So, I have the current that was coming earlier, which was g m times V gs g m times v in. In addition to that current, I have got a current that is coming through C gs.

So, the net transconductance is going to be s times C gs plus g m right, it was g m times v in that is the current through the transconductance g m times v in plus s C gs times v in. And I have taken v in away, because I want a transconductance, not a current. So, all that remains is s C gs plus g m, I do not of course like this format. So, the format has to be DC quantity times 1 plus s tau, fine. So, this is the format.

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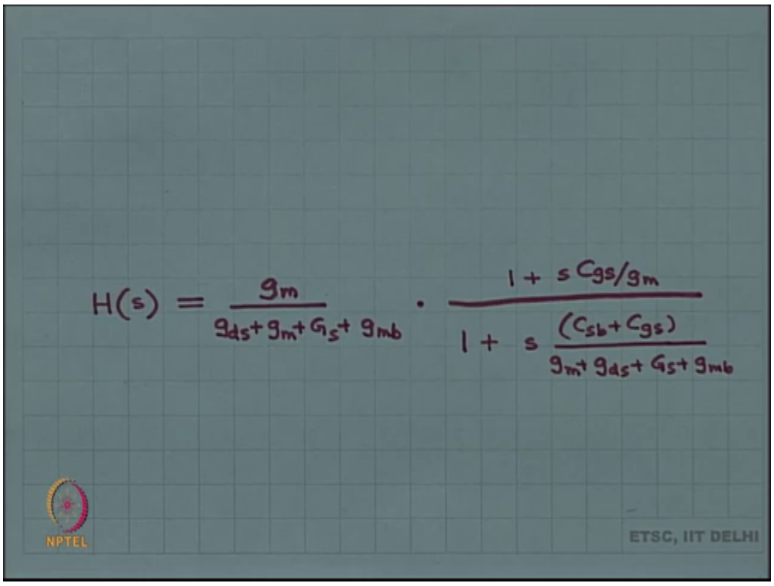

So, my net transfer function is the DC transfer function times 1 plus s C gs by g m that is the 0 part of it and 1 plus s that is the pole. So, you have got the DC transfer function times 1 plus s times the 0 divided by 1 plus at naught times the 0, it is by the 0 and 1 plus s by the pole frequency. So far, so good ok. This is great right; all of this is very good. You have got a 0, you have got a pole. By the way, which is larger, which is smaller?

Student: 0 is larger.

The 0 frequency has C gs by g m right. So, the frequency is g m by C gs that is the 0 frequency. On the other hand, the pole frequency is g m plus a lot of other things divided by C gs plus something more, it is not very clear ok. So, you cannot really you need some numbers to make a judgment, which is larger, which is smaller. Upfront it is looking as if you cannot make up your mind, whether the pole is at a larger frequency or whether the 0 it is at a larger frequency ok, upfront it is not possible to make that judgment.

Now, there is a Gotcha in this circuit. So, this common drain circuit, the analysis that we have done so far is correct, however there is a Gotcha ok, there is a problem with this analysis. You have to also remind yourself, what is the application. So, the application when are you going to use this common drain circuit, so this common drain circuit is going to be used as a buffer as something where in a in a situation, where the source is highly resistive. The source has a large impedance and is not able to drive a load ok.

Ordinarily if a sensor let us say you have got a sensor, the sensor has only so much available power, so it is a voltage source in series with the resistance ok; it is not an ideal voltage source. And if you try to drive a load with the from the sensor straight away, then the large series resistance is going to drop all the voltage and nothing will come on to the load right. So, the sensor would not be able to drive the load that is when you say that all right let us place a common drains of it over there in between, so that the common drain circuit will give a gain of one and it is going to be able to now drive the load ok. So, this is the application, this is the scenario.

Now, in this scenario, the source should also come with a large source resistance. At DC, it does not matter. Because, at DC, there is no current going into the gate anyway, so resistance or no resistance it makes no difference. But, now that we have all these capacitors, things are going to be different alright, things are in fact going to be very different, now that we have all the capacitors. So, we need to analyze the circuit in the presence of source resistance.

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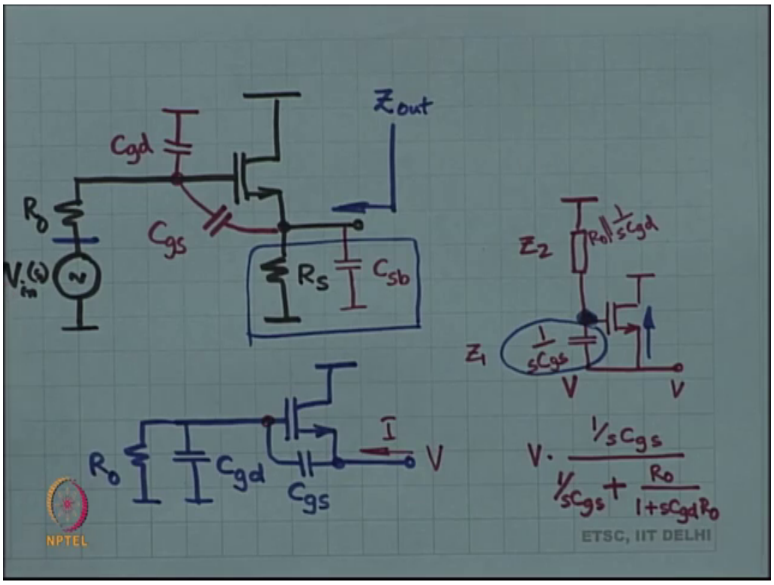

Ok. So, the DC answer remains exactly the same, nothing changes in the DC picture all right, but things are going to change, when you look at the AC part of it, the capacitive part of it ok, the poles and zeros. So, let us you understand, why the DC is not going to change, the DC is not going to change, because v in is not pushing any current into the circuit and therefore the drop across R naught is always going to be equal to 0. So, at DC, whether you are planning to do the short circuit current experiment or the output impedance experiment nothing changes ok.

So, let us draw the capacitors once again. So, I have C gate to drain, I have C gate to source, I have C source to body and the drain to body capacitance is not relevant. And in this, let us think once about the transconductance and once about the output impedance. So, let us do the which one; output impedance.

Now, when you are going to do the output impedance, the plan is always to null the input voltage source ok. So, you are going to null it, so ground is going to appear over there, this input voltage source does not really matter all right, but now the gate is not at ground anymore. You see you see what happened, the gate is no longer at ground ok. So, you have got C gs current can come in through C gs and it can you know flow into R naught and C gd and so on. And therefore, the gate need not be at ground, earlier the gate was at ground ok, earlier the gate was straightaway at ground and therefore, you could do all your easy calculations. Now, the gate is not at ground any more ok. So, we need to be careful.

On one side, we have R s and C sb ok. We have R s and C sb, let us keep this keep these two aside right, let us not worry about R s and C sb. Let us only look at this particular structure that is it. So, I have decreased the problem simplified ok, R s and C sb will place in parallel later on as an when needed, after we have the answer to this. Now, suddenly things are not going to be very obvious how to proceed. So, in such a scenario, you are going to apply a test voltage and see how much current goes in.

So, you are going to apply a test voltage V of s and I of s current is going in ok and this MOSFET has g m, it has g mb and it has r ds, these are the three parameters that it has. Now, if this voltage is v, what is the voltage at the gate? No, it is a voltage division. Let us redraw. So, if the voltage on this side is v, what is the voltage at the gate, it is a voltage division right between this capacitor and this impedance, this impedance is R naught in shunt with C gd ok. So, you actually have a voltage division.

So, with the help of a voltage division, you are going to find out what is the gate voltage ok, or in fact the voltage across this capacitor 1 by s C gs is V gs. So, V gs is nothing but the voltage across the capacitor all right. So, I need to find out the voltage across the capacitor that gives me V gs and that immediately tells me what is going to be the current going up through the MOSFET, is that ok, this is understood so far.

So, earlier we were considering the gate voltage to be at ground at DC. At DC, the gate voltage was ground, because you know the capacitor is not going to take any current, this capacitor is an open circuit. So, the gate voltage was effectively at ground, so no problem. Then this current would be g m times V gs. V gs happens to be V V sg happens to be V in this case, but now there is going to be a voltage division. And therefore, this current is no longer g m times v, it is g m times that divided voltage ok.

So, we have to find out this portion of the voltage V, g m times that voltage is the current going through the transconductance that is going to come in shunt with g mb times V, because V is the voltage at the source, voltage at the body is still ground and r ds ok. So, there are three portions g ds right, it is going to be g mb plus g ds plus this fraction of g m ok. These three conductances are going to be added and 1 by of that is going to give you the output impedance, fine just for this part. And then later on you have to add shunt G s and s C sb, is this clear ok.

So, what is that portion, what is the voltage across this capacitor? So, if you think of this as z 1, this as z 2, then it is very clear right. You apply V the voltage across the capacitor is V times z 1 by z 1 plus z 2. And z 1 over here is 1 by s C gs, z 2 is something a little more complicated. So, parallel combination of R naught and s C gd 1 by s C gd ok and then you are going to simplify.

So, this is the voltage over here, g m times this voltage is going to be this blue current plus g mb times V plus g ds times V is going to be the net blue current. So, the net current that I have is therefore, going to be V times; so, we can delete the V right, because we want a transconductance; no, this is not a transconductance, this is going to be the output conductance there. If I delete the V, it is just an output conductance, not impedance, 1 by of that will be the impedance. Let us delete the V.

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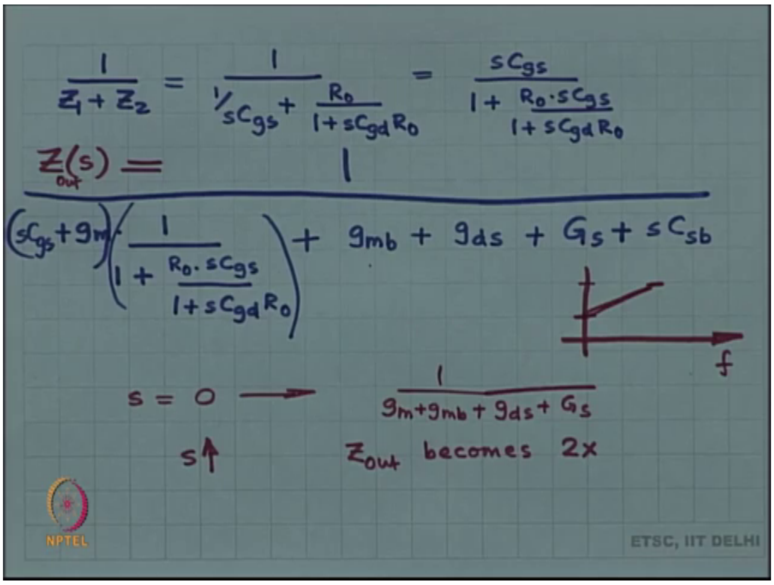

Output conductance is g m times this fraction and that fraction is 1 by s C gs. Let us multiply numerator and denominator by s C gs. These are the three conductances. And there are two more, which we were to place later on ok, so many all of these together are the output conductance. Earlier, we did not have this fraction, at DC we just had g m. Remember right, we just had g m over there at DC. Now, we have g m times of fraction.

And earlier, we did not have C sb at all. Why did not we have C sb, we did have C sb, we did have this complicated thing as part of the output impedance. But, earlier C gs was coming in parallel with C sb, C gs was coming in parallel with C sb, because this was at ground right, now that is no longer the case right. C sb is on its own, C gs is part of this fraction, fine. This discussion is fine.

So, if you place R naught equal to 0, then this expression and the earlier expression are going to become equal right. You should cross check, you place R naught equal to 0, this term goes away, this term goes away, does not work out right, R naught equal to 0. Did we make a mistake? I multiplied numerator and denominator. Yes, I have I have made a mistake. There is one more current. So, it is not just the blue current, we have forgotten one more current. What have you forgotten? So, the current going into the source of the MOSFET is the blue current that is right, there is one more current. If you apply V over here, there is also going to be current through this path, we had forgotten that ok.

So, you see we did a sanity check, we plugged in R naught equal to 0 and tried to get our earlier answer and we found our mistake ok. It did not quite work out, because R naught equal to 0 is giving me just these five things ok. Whereas, earlier we had a much more complicated expression, we had four things and then you had we had more complicated stuff. So, this is fine, these five things are fine right, but there is one more piece in parallel and what is that, that is the serial combination the series combination of z 1 and z 2 ok.

So, the current over here is V divided by z 1 plus z 2, which means that its conductance is 1 by z 1 plus z 2. So, z 1 was so, we have to add to it, 1 by z 1 plus z 2, z 1 was 1 by s C gs, z 2 was R naught by 1 plus so much. So, this is another portion that we have to add to this ok, is it ok. I have added this entire quantity has been added to the earlier part, earlier it was g m times this, now it is g m plus this numerator s C gs times the 1 by 1 plus etcetera, fine.

And now, if you plug in R naught equal to 0, then this whole denominator will become a 1 ok, so this entire fraction is going to become a 1. And therefore, you are going to have g m plus s C gs plus g mb plus g ds plus G s plus s C sb, which is exactly the same as the earlier expression. The earlier expression was the product of this and this, this denominator times this denominator. So, g ds plus g m plus G s plus g mb plus s times, this and this cancel out, s times C sb plus s times C gs, so you have got six terms; 1, 2, 3, 4, 5, 6 ok. So, this is the complete expression for the output impedance sorry output conductance. And if I make this a 1 by, now it is the output impedance all right great.

Now, you can put it into your template for the template, you have to divide the entire denominator by g m plus g mb plus g ds plus G s that is your job, you can do it in that template all right. You can do all the algebra. You can try looking at a lot of you know you can find try finding out the precise transfer function after that, but I am going to stop you. And I am going to try to take some get some insight from this expression. This is my output impedance ok; this is your z of s. Can you get any insight? First of all what happens at s equal to 0, DC ok, s equal to 0 is DC. And at DC, we know the answer, the answer is 1 by g m plus g mb plus g ds plus G s ok and you know all of this works out to a big 0. This entire fraction is 0, because s is equal to 0 and 1 by 1 plus 0 is 1, fine.

And then let us increase s, let us increase the value of s all right. As you increase the value of s along the j omega axis, but of course, what are you going to observe? Is this value, is this denominator going to increase or decrease? So, if I increase the value of s, this fraction is no longer going to be 1, it is going to become smaller than 1 ok. For example, let us make a s very large. If I make s very large, what happens, this entire fraction drops to a 1 ok. So, now this is 1 by 2 all right.

So, now you have got g m by 2, you are not really you do not really have g m anymore, now you are with g m by 2 at very high frequencies right. And then you have the addition of s C sb and s C gs, which are anyway they are like a pole right, so they are going to degrade the output impedance right; they are going to make the output impedance smaller. But, let us try to understand the effect of g m, the effect of g m is reduced to g m by 2.

Instead of making s very large, let us make R naught very large ok, s is a medium value. Let us make R naught very large. What is going to happen, if I make R naught very large, once again this becomes a 1, which means now instead of looking at g m, you are only using g m by 2. And what does that mean is the impedance output impedance going to go up or going to go down. The output impedance the impedance value is going to go up is going to increase, because instead of g m in the denominator, now you have g m by 2 in the denominator, which means anyway g m is the dominant term right, all of these other terms are useless ok, g m is supposed to be much larger than g ds right. Hopefully, if you have made a good circuit, then G s all of these other terms are not relevant, only g m is relevant.

Now, you are saying that g m instead of remaining with g m, it has become g m by 2 that automatically means that your entire denominator has become half, so the output impedance has become double effectively ok, it should not z out of s all right. So, if you draw a little plot over here as a function of frequency ok, let us say it is a linear axis and I am not going to draw a bode plot here.

At DC, it is some value. And at high frequencies, it is double the value. Sorry, at DC, it is some value; at high frequencies, it is double the value, fine. What kind of response is this, what is this output impedance? Is this output impedance it is very complicated agreed, but such an output impedance is the characteristics of an inductor ok, the impedance of an inductor increases with frequency all right.

So, an important thing over here is that the output impedance of this common drain circuit is actually going to increase with frequency. And the reason, why it is going to increase with frequency is not C sb or C gd or C gs, it is because the value of g m, the effective value of g m is decreasing with frequency ok. So, the output impedance is going to increase with frequency all right. And therefore, the output impedance, if you look in at the output, it looks like an inductor, the circuit behaves as if it is got many components, but it also has some series inductance all right. So, let us stop here. And we will proceed forward in the next class.

Thank you.