Course name- Analog VLSI Design (108104193)
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Welcome back. So, I hope you have already figured it out whether this configuration will work in its own or not and clearly this will not work. Why? Simply because this is not biased properly. I mean for example, let us say your Vi is small signal, we have not yet quantified what is small signal in case of a MOSFET, but let us say I think Vi is very infinitesimally small input right close to 0 right. So, Vi is here is equal to some Vp sin omega t where Vp let us say is 1 micro volt, I am just taking a number right ok. So, what do you think is the status of the MOSFET? By status of the MOSFET I mean is the MOSFET on or is the MOSFET off? You might turn around and say I have not given you adequate information right.

So, I can give you the information that you need. So, let us assume the threshold voltage of the MOSFET, of the MOSFET is 1 volt ok. let us assume threshold voltage So, then what do you think is going to happen? So, clearly the voltage between the gate and the source of the MOSFET is never crossing 1 volt right, it is 1 micro volt sin omega t, it is never crossing 1 volt which means your MOSFET is off right. So, clearly I will have to apply a voltage between the gate and the source which is larger than the threshold voltage, at least larger than the threshold voltage in order to ensure that the I get the requisite operation out of the MOSFET right, at least I can get the MOSFET to turn on.

Note that I have not yet turned my attention, we have not yet turned our attention towards the output terminal, this is only what at the input terminal right. But then I mean if our signal is of only 1 micro volt, so clearly this arrangement will not work right. So, what should we do right? Another way of looking at this problem is it as follows. So, what is the ID, VG characteristics of a MOSFET or rather what are the what is the current characteristics of the MOSFET, current voltage? So, there are two characteristics of the MOSFET that we are familiar with, one is that between Vgs and Ids and other is between Vds and Ids. So, what does the Ids versus Vgs curve look like? So, clearly till we have reached threshold voltage, the current is absolutely 0, then what happens after that? The current starts to pick right, but this is under what condition? When will this parabolic looking structure, what parabolic looking profile be realized? This is only when under the condition that your Vds is greater than equal to Vgs minus threshold voltage right, correct ok.

So, which means that in order to realize this, I will have to ensure that there is a non-zero Vds that has been that has been applied right. Now let us turn our attention to the Ids versus Vds characteristics, what does it look For a fixed Vgs again for a fixed Vds, so it should look like something like this right, which means that and what does this flat line, what does this flat line symbolize, what does this flat line symbolize? This symbolizes saturation region of operation, which means we need to be on that flat line, right. I have not drawn it perfectly flat, let me redraw it. And what is this? What is this turning point? What is this point where the curve goes from looking like a linear parabolic to a flat line? This is the, this is that location of Vgs minus threshold voltage. So, you will have to operate, you will have to operate on this side of the plot, this is looking at the output terminal right ok.

So, what does this mean then? Given that our threshold voltage is 1 volt, which means this is 1 volt, I have to ensure that the voltage between gate to source is at least 1 volt right. And note that these are DC characteristics, this Ids versus Vgs plot and Ids versus Vds plot these are all DC characteristics right. What do I mean by DC? All I mean is that how did you get this plot? You got this plot by incrementally varying one parameter very slowly while keeping all the other voltages constant right. The first plot you have got by varying the voltage between gate to source while keeping drain to source voltage constant. The right hand side plot we have got by varying the voltage between drain to source while keeping the voltage between gate to source constant right ok great.

So, now what am I looking for? I am looking for an operation of Vgs not only just greater than Vth right. If Vgs is just greater than Vth we are probably here right, but we would like to have a non-zero Ids because ultimately we also want some gm right. We also want some y21 what is the gm or what is the y21 ? y21 is nothing, but the slope of the Ids versus Vgs characteristics and clearly the slope is increasing as we as we go at higher and higher Vgs right. So, ultimately maybe we would want to operate somewhere over here right. We would like to operate somewhere over here where I have certain Vgs Q where Q denotes quiesent point and I will have a certain Ids Q where again Ids Q denotes the drain to source current right.

This takes into account this takes this while fixing these currents and voltages we are making a critical assumption and the assumption that we are making is that the saturation condition is valid right that is Vds is greater than Vgs minus threshold voltage right. And let us assume that again now this is the input side this is the transfer characteristics between the Vgs and Ids, but if we turn our attention to the curve on the right what should we what should we look for? We should look for that particular value of Vds for which we get this Ids Q right. So, it might as well be let us say this Ids Q is I mean our let us assume that in this transfer characteristics we got Ids Q to be equal to 1 milliamps right. Let us assume we got Ids Q equal to 1 milliamps for Vgs Q equal to 2 volt. Let us assume that we have got that value right.

So, how should I how should I figure out what is the appropriate appropriate Ids Vds curve where we get this which means that I mean which essentially means that I will have to I will have to plot multiple of this Ids Vds guide plots right and find out that particular plot for which for which Ids is equal to 1 milliamps. Let us assume that this plot refers to Ids of equal to 0.5 milliamps maximum Ids is 0.5 milliamps which means I will have to find another plot and what will be that plot be that that plot will be corresponding to the maximum Ids of 1 milliamps right. So, which means that I will have to find another plot where the maximum Ids will be 1 milliamps and clearly where will that break point be where will this turning point be will it be at the same same point or where at which the Ids of 0.

5 milliamps plot break obviously not because this will be a higher Vds value right ok. So, I will I will say that the mean that the minimum Vds right the minimum Vds for which I can satisfy both the input and output condition is when I hit this value Vds Q mean if I can bias my circuit if I can bias or rather if we can bias our circuit on this side of the if this region of this I d Vds characteristics right if we can bias our circuit in such a way that Vds is above Vds Q mean right for Vgs Q which is equal to this Vgs Q at which I have bias the bias the transistor at the input side then then we would be we would be able to bias our transistor in the in the right manner. Now when I explained to you when if you are following this explanation it seems very convoluted right it seems like I have to look at the input characteristics I have to look at the output characteristics and I have to figure out where exactly the Vgs Q is where exactly Vds Q mean is where exactly the Ids plot I have to find out the Ids bias point at the input side then I have to move to the next plot find out the Ids characteristics at the output side it looks too cumbersome a process right our little human at least my brain cannot take into account so many information at once. So, what we will do we will simplify this process we will try and simplify this process and see given that we can only handle one or two variables at a time efficiently if we can distill down this information if we can distill this information down to one or two things that we should keep in mind right. So, what is the most critical thing we should keep in mind the most critical thing we should keep in mind is the following that your Vgs Q that is the quiescent bias point this is the quiescent point quiescent Vgs should be such that the transistor is on not only this and also Vgs Q should be such that the transistor is on and meets the requirement of gm or y21 we can do this assuming.

So, do this exercise do this assuming saturation right why did I say do this assuming saturation because we will try to figure out whether the transistor is in saturation or not when we look at the output side let us not bother about whether the transistor actually is in saturation right now that is only concentrate on the input side right when we will go to the output side we will try to figure out if the transistor is actually in saturation or not if it is not then we will take a call of what needs to be done right. So, fine if that is the scenario, if that is the scenario then what should we do. So, we need to ensure that we get the value of gm now from where will I get the value of gm I have not told you anything clearly I have not told you anything, but generally a top level specification when you are building an amplifier is what is the amplification factor. So, that will be given to you right if that is not given to you for what reasons are you building an amplifier. So, let us assume that you need an amplification a gain of 10 right assume let us assume we need Av of, mod Av of 10 let us assume we are not bothered about the fact that Av is negative right let us assume that we need a more gain of 10 which implies gm times RL is equal to 10.

Now, this is a multiplication of two variables which is leading to 10 which means that I can have infinite solutions of gm and R L right that is correct, but when you are building an amplifier the other critical thing that will be given to you is the load resistance right generally the load resistance will be will be provided right. So, essentially load resistance and output spec you are driving an R L since you are driving an R L the value will be given I mean let us assume that this R L is let us say 1 kilo ohm right. So, let us assume let us assume R L is equal to 1 kilo ohm ok. So, what does it mean then this implies this implies my g m has to be equal to 10 by 1 kilo ohm which is 10 millisiemens ok. So, now in this particular configuration of amplifier if g m is 10 millisiemens what does it mean what is the expression of g m what is the basic expression of gm it is mu n Cox W/L VgsQ- Vth which is 10 millisiemens right.

Let us assume for the time being mu n C ox is given let us assume mu n C ox is 200 micro amp per whole squared or in terms of milliamps let us say this is 0.2 milliamp per whole square right. Let us assume this is given right this technology that you are using ensures that this is the case right and for the time being let us also assume that we for some reason we have chosen W over L is equal to 10 right. So, we can choose any W over L right we can choose any W over L I can choose W over L equal to 1, 100, 1000 whatever I want. But let us assume we have chosen W over L we will come back later in the course and see what will happen if we change W over L that is a critical design variable.

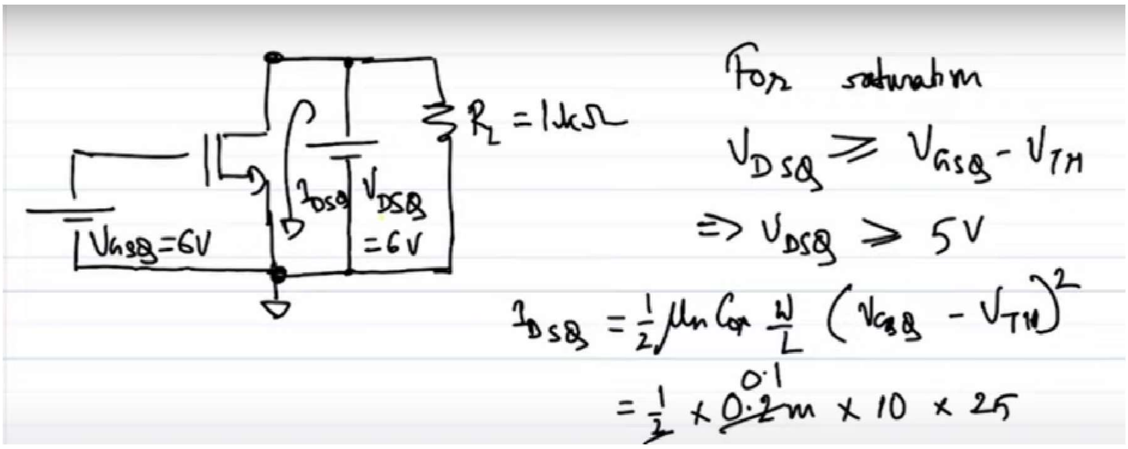
But let us assume that we have chosen W over L for the time being right. So, we have to choose something right start let us start with W over L equal to 10. So, what does this imply? This essentially implies that 0.2 milliamp times 10 times Vgs cube minus 1 volt by threshold voltage is 1 volt is 10 milli which means that Vgs cube is equal to 5 this becomes 2 5 plus 1 that is 6 volts ok. So, this essentially implies that I will have to apply a Vgs cube of 1 volt correct ok that is great which essentially means that I have a MOSFET I will have to apply a Vgs cube of 6 volts what is Vgs how do I apply a fixed voltage of 6 volts I will have to use a battery right.

So, let us say I have a battery say I have a battery between the drain and the gate and the source and I say this Vgs cube is equal to 6 volts right. Now, let us turn our attention to the for the load side for the output side right. So, if Vgs cube is equal to 6 volts and RL is how much RL is 1 kilo ohm. So, let us say this RL equal to 1 kilo ohm ok. So, what do you think is the status of the transistor is the transistor on clearly the transistor on is on because the Vgs cube is greater than threshold voltage.

So, I have a channel the inversion I mean I have I mean since Vgs cube is greater than the threshold voltage I will be having that the MOSFET will have 3 electrons in the channel to be all between the drain and the source junctions. But in order to do so I will have to apply a Vds right is the transistor in saturation in the way I have drawn what is the what is the voltage difference between the drain and the source. The voltage difference between the drain and the source is clearly 0 because I do not have any battery between the drain and the source or any potential between the any battery at the output side in this loop in this loop we do not have any in this loop we do not have any battery. Since we do not have any battery there cannot be any electric potential between the drain and so or electric field between the drain and the source which means there only any current which means I need to put a battery right. So, where do you think I can put a battery and not only that we need to put a battery we will have to ensure that the battery should be such that should be such that the transistor is in saturation right.

So, what is the condition for saturation? The condition for saturation is for saturation Vds has to be greater than equal to Vgsq minus actual voltage and since we have fixed Vgsq which means Vdsq let me say here Vdsq because we are trying to fix the quiescent point here should be greater than equal to 5 volt right. So, this has to be this voltage difference has to be greater than 5 volt greater than equal to 5 volt. So, how can I how can I ensure that this is greater than equal to 5 volt? So, I can say that I put a battery where should I put a battery to ensure that this is greater than equal to 5 volt I can as well let us say put a battery between the drain and the source and say this is Vdsq and let me choose a value of more than 5 volt let me choose 6 volts right. Let us say this is equal to Vdsq equal to 6 volt is greater than 5 volt right. So, do you think the transistor is in saturation? Clearly it is clearly it is because we are satisfying this condition of Vds to be greater than Vgs minus Vth and I mean you do not even have to take bother about the source all you all you need to ensure is the check the voltage at the gate check the voltage at the drain and see if the difference is if the gate is at least or rather if the difference is less than or more than a threshold voltage right.

So, the drain can go at least one threshold voltage below if it is not going below one threshold voltage then gate you are good. So, clearly this is in saturation and what is the current what is this current I dsq? So, I dsq that will flow through the transistor is mu n 1 by 2 mu n Cox W over L Vgsq minus threshold voltage whole squared which is half times 0.2 milli times 10 times this is 6 minus 1 5 25 right 25. So, this becomes 0.1 milli this is 125 milliamps right.



So, I dsq is 25 milliamps from where is this 25 milliamps coming from this clearly this 25 milliamps is coming from the battery right. This will be the loop of the current that is flowing into the into the MOSFET from the battery and clearly there will also be a current flowing through RL that is equivalent to 6 volt divided by 1 kilo ohms that is 6 milliamps through the RL that comes from the battery ok. So far so good right. Now, we will have to now we will have to apply I have to apply an input right. So, where should we apply an input? Note that again let me take you back couple of slides or couple of pages note that incrementally we wanted incrementally wanted the voltage between the voltage of the input VI to appear between the gate and the source terminals correct ok.

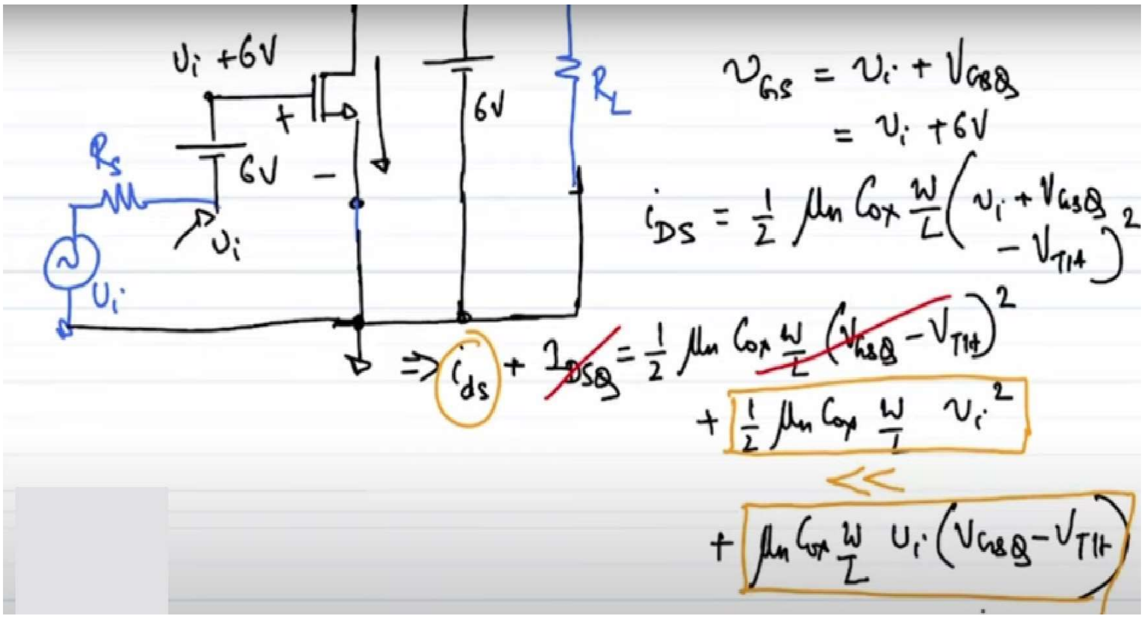
So, then we said that if I directly apply VI like this it will not work why because transistor is not biased. Now, my transistor is biased where should I how should I incrementally apply my input right. So, clearly I mean if I have an input if I have an input source and RS where should I connect this and how should I connect this. So, let me ask you to connect RL should be drawn in a different color right because this is an external thing that we were applying that we or rather that we were interested to get the amplification across. So, if I connect my input let us say like this VI RS this is 6 volt this is 6 volt will this work? Clearly this will not work why because the voltage across voltage across VGS is always 6 volt.

So, I have a battery of 6 volt connected directly between the gate and the source. So, clearly this arrangement will not work right. So, whatever incremental voltage that VI will that VI will generate all the current will flow into or flow into or flow out of this loop without causing any change of voltage between the gate and the source right. So, clearly this is not going to work. So, what are the what are the other options if connecting this entire thing in parallel to the 6 volt battery does not work what is the other option we can try? We can try putting it in putting it in series right.

So, let us do that. So, let us say we have this and we put this in the VGS this entire put the our VI RS in series and let us say this is 6 volt battery. Now, ground is we would like to ensure the ground is common to everybody. So, let us connect the grounds properly ok. So, what do you think will this work? So, what is the gate voltage now? So, what is the current in the input loop? What is the current in this loop? This current in this loop is 0 because no current can flow in right IG is equal to 0. So, no current can be flown in you are not drawing any current from the battery.

If you are not drawing any current from the battery what is this voltage? This voltage becomes VI right had you drawn current it voltage would have been VI minus that current times RS, but we have current is 0. So, this voltage becomes VI if that voltage is VI what is the voltage at the gate? The voltage at the gate is VI plus 6 volt right. So, what is VGS now? What is the total VGS? Total VGS right note mind the notation small v capital subscript which means total VGS is VI plus 6 volt right. So, let me write in terms of VGSQ which is VI plus 6 volts right. So, it looks like I have been able to apply an input right.

So, what is the current? What is the total current that is flowing through the MOSFET right? What is the total current? Again note the notation small i capital DS right which is half mu n Cox W over L VI plus VGSQ minus threshold voltage whole squared right. So, which is equal to half mu n Cox W over L let me club VGSQ minus VTH together. So, this becomes VGSQ minus threshold voltage whole squared plus other squared term that is half mu n Cox W over L VI squared plus another term that is twice into half into mu n Cox W over L half and 2 goes off. So, this becomes mu n Cox W over L VI times VGSQ minus threshold voltage right. Note that the total IDS is equal to total IDS is equal to what is total? Total is incremental plus quiescent correct.



So, that is small IDS plus quiescent correct and same old same old what we will do? We will see that this quiescent, this quiescent cancels off we get what remains? Remains the remainder the incremental IDS and two terms on the right hand side right and just like in case of Taylor series if we assume that this term here is much much less than, so let me make some space. If we assume that this term is much much less than this term that is I am I can ignore the higher order terms in a in a Taylor series expansion right. This is nothing but a Taylor series expansion. If we can ignore the higher order terms what do we what do we end up with? We end up with IDS that is the small signal incremental current is equal to mu n Cox W over L let me write this Vgs Q minus threshold voltage here times V i and what is this notation? This is nothing but gm which means IDS is equal to gm times V i right which essentially means that this current that I have drawn here will be equal to approximately be equal to IDS Q and what is IDS Q? IDS Q is 25 milliamps that is 25 milliamps plus gm times V i correct ok. So, as far as getting incremental current out of my device is concerned this job seems to be fine, but will we get what is the voltage that we will get across RL? Note that the voltage that we will get across RL is still 6 volt because the battery has been connected in parallel with RL right.

So, so whatever do we do with the incremental current all the incremental current will flow into the into the battery why because battery is an incremental short right. What is the short circuit equivalent of a battery? Short circuit equivalent of a constant voltage source is a short circuit right. So, which means that the incremental current of gm times V i will flow into the battery and not into RL you would want all the incremental current to flow into RL which is not happening in this model right. So, what is the what is the solution? I would encourage you to come up with a solution of your own till then till we meet in the next class right.

We will see you in the next class. Thank you.