Design and Analysis of VLSI Subsystems

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Lecture - 09

Channel Length modulation index

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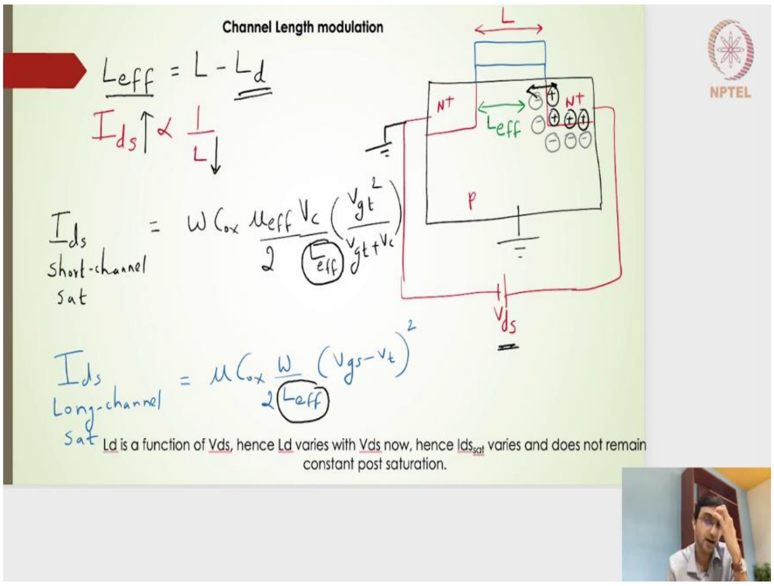

The Channel Length modulation, this is the third effect. What we have seen is the short channel current expression which is attributed only towards the mobility degradation as well as the velocity saturation effect. This one talk more about the channel length modulation that was the third non ideal effect which we had seen in the last lecture. What it really means is, if I increase this V_{ds} value, that means the drain is becoming more and more positive. This particular side is becoming more and more positive with respect to the source and assuming that the source and then the body are at the same potential. This source also I will make it like a ground here. What it really means is that drain is becoming more and more positive thereby it is going to attract more of the majority carriers.

In this case it will be the electrons which will be attracted towards the positive potential side, thereby leaving the lot of a lot amount of immobile positive ions. On the other side of the junction a similar effect will be seen and then we will have lot of many immobile negative ions. This particular region is closer to the drain side that is going to increase if we make this V_d value to be larger and larger.

If the drain is becoming more positive and positive, we will get this particular as the depletion region to be larger and larger and that is kind of represented by this L_d variable. The effective length decreases, as I increase the drain potential. That is how if we increase this effect or rather decrease this effective channel length and then we know that the drain, the I_{ds} current is a function of $\frac{1}{L}$.

If I take the long channel current or the short channel current,

$$I_{ds,short-channel} = WC_{ox}\frac{\mu_{eff}}{2}\frac{V_c}{L_{eff}}\left(\frac{V_{gt}^2}{V_{gt}-V_c}\right)$$

$$I_{ds,long-channel} = WC_{ox}\frac{W}{2L_{eff}}(V_{gs} - V_t)^2$$

You will see that on the denominator side we have this channel length which I can now call it as effective channel length and this effective channel length as it decreases because of the higher drain potential, this depletion region is going to increase and thereby L_d is going to increase and L_{eff} channel length is going to decrease. With the decrease, this current is going to increase. L_d is a function of V_{ds} that is what I have written and hence I_d varies with the V_{ds} now. Hence I_d saturation varies and does not remain constant post the saturation and that is why the post saturation even if I keep on increasing the V_{ds} value. That means the drain potential keeps on increasing, this depletion region length increases and thereby the effective channel length decreases.

As effective channel length decreases thereby the current increases. That is why we see a slight slope instead of a constant line after the V_{ds} saturation. The current which we had expected that it should be a straighter line a saturation current point, but it is actually varying with a slight slope.

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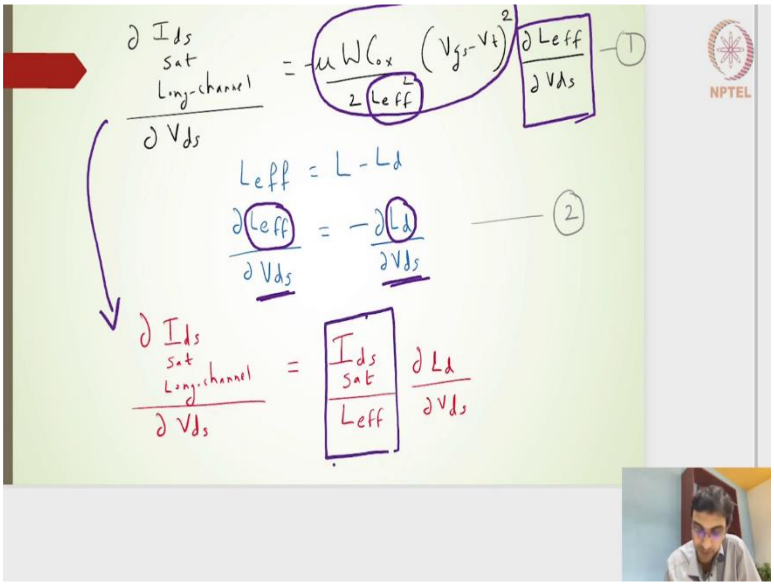

Now, we need to understand what is the accommodating the channel length modulation index or the channel length modulation effect, what is the actual expression of the current? So, there is a particular expression which is given in some of the references that is.

I have just taken a long channel example the similar example or expression you can arrive at in the short channel also. But I have just taken just for the easy referencing I have taken the long channel expression which is nothing but Ids saturation of the long channel. If I do a differentiation first order differentiation with respect to V_{ds} I will get the same equation.

The long channel current expression is

$$I_{ds,long-channel} = WC_{ox}\frac{W}{2L_{eff}}(V_{gs} - V_t)^2$$

If I do a first order differentiation with respect to V_{ds},

$$\frac{\partial I_{ds,long-channel}}{\partial V_{ds}} = \frac{-\mu WC_{ox}}{2L_{eff}^2}(V_{gs} - V_t)^2\frac{\partial L_{eff}}{\partial V_{ds}} \qquad (1)$$

Where, $L_{eff} = L - L_d$

If I do a differentiation with respect to V_{ds} it is nothing but the L_d with respect to the first order differentiation of L_d with respect to V_{ds}. What it implies is, if L_d keeps on increasing the L_{eff} decreases makes sense.

$$\frac{\partial L_{eff}}{\partial V_{ds}} = \frac{\partial L_d}{\partial V_{ds}} \tag{2}$$

If I put this particular second equation in the first equation.

$$\frac{\partial I_{ds,long-channel}}{\partial V_{ds}} = \frac{I_{ds,sat}}{L_{eff}} \frac{\partial L_d}{\partial V_{ds}}$$

I will get this for first particular equation as the first order I_{ds} saturation long channel current is nothing but this if you look into this particular expression, this is nothing but the Ids saturation current itself. That is what I have written here and then there is a negative sign here which becomes positive and then we finally get this one $\frac{\partial L_d}{\partial V_{ds}}$ and then there is an L_{eff} square here.

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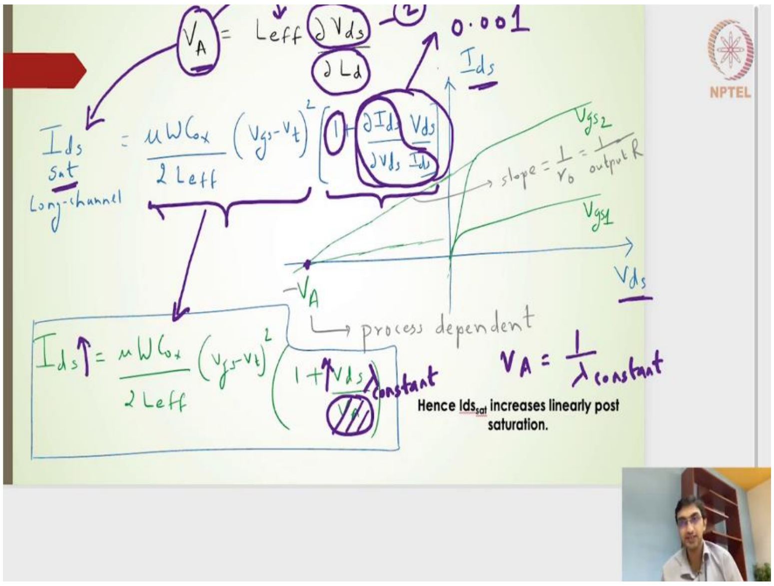

This is what we get moving forward. If you have looked into especially in the V_{jt} amplifier, if I draw the output current with respect to the V_c voltage the collector emitter voltage and then in the output current we will get the slope of that particular collector current. If I actually take it back alright to an imaginary point in the negative V_c value we will get an early voltage.

Similarly, we have for the same NMOS transistor, we can actually draw the output current with respect to the output voltage. I_{ds} and if I draw it against V_{ds} especially for the short channel model where the channel is actually for the transistor, where the channel length is very small then we will have a slope here a defined slope here, which will actually meet into the x-axis called as V_A which is nothing but the early voltage.

Now, V_A by definition it is given by the change the incremental change in the V_{ds} with respect to the incremental change in the L_d.

$$V_A = L_{eff} \frac{\partial V_{ds}}{\partial L_d}$$

A change of whatever 0.1 volts and the change of the L_d value, however it changes with respect to the effective channel length.

That is given by, that is also defined by the V_A the early voltage. If I put this particular expression somehow bring this V_A parameter into the current expression. Now, the current expression actually if I consider the long channel or whatever the short channel, I can write that particular expression which is nothing but in this case I have taken the long channel $\frac{\mu W C_{ox}}{2L_{eff}}\left(V_{gs} - V_t\right)^2$, because it is a saturation current.

And then of course, we are interested in the saturation region the slope of the saturation region, what happens to the slope of the current in the saturation region. Up till now here it is nothing but this particular value is nothing but the saturation current equation. After this, we have just introduced to accommodate the change in the depletion region length, which is having an effect on the effective channel length and thereby having an effect on the current. We have introduced this particular expression as,

$$I_{ds,sat,long-channel} = \frac{\mu W C_{ox}}{2L_{eff}}\left(V_{gs} - V_t\right)^2 [1 + \frac{\partial I_{ds}}{\partial V_{ds}} \frac{V_{ds}}{I_{ds}}]$$

This 1 is nothing but whatever current expression we have plus the delta changes here. What we are assuming is this particular expression $\frac{\partial I_{ds}}{\partial V_{ds}} \frac{V_{ds}}{I_{ds}}$, It will be a scalar factor it will not have any units and it will have a very minimal change. What we are saying is now, if we change the V_{ds} minutely what is the effect that we are going to have in the I_{ds} value.

That is what if the change in the I_{ds} value it turns out to be very very small, but overall the current expression will be nothing but the same expression multiplied by 1 plus some value

0.001 or whatever 0.0001 or something like that. So, this expression is likely to give me a very small value.

But with the help of this particular expression, I can bring in the early effect factor which will indirectly give me the L_{eff} which is nothing but $L - L_d$. If I use this particular expression, that is what I have done. The same expression goes here

$$I_{ds} = \frac{\mu W C_{ox}}{2L_{eff}}\left(V_{gs} - V_t\right)^2 [1 + \frac{V_{ds}}{V_A}]$$

This whole expression V_{ds}, this particular term right is considered as V_A and if I look into this particular previous slide expression ∂V_{ds}. This is one equation I have and this is the second equation I have and if I put one of both the equations in here I should get the V_A value. What it says is, hence the I_{ds} saturation increases linearly post the saturation.

Then this particular V_A value can be written as,

$$V_A = 1/\lambda$$

Or

$$V_A = 1/\lambda \text{constant}$$

Again, this instead of lambda I will write it as λ constant. This lambda is not that lambda of the design rule, where we had 2 λ is equal to 50 nanometer. That is not the one this is another constant value just as a constant. V_A is basically nothing but a fabrication constant. It really does not, that is a constant value. An increase in the I_d, V_{ds} value is likely to give me an increase in the I_{ds}. That is where the saturation profile is we have a positive slope there.