Analog Circuits
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Module - 03
Lecture – 02

We now know that the I D, V D S characteristics of a MOS transistor or the port two characteristics of the MOS transistor are not exactly flat in the saturation region. So, they have a slight upward slope, a current does increase slightly with increasing V D S.

In terms of the expression for the current, we have its additional factor one plus lambda V D S. What we need to do now is to find out the effect of this on the small signal model. So, this small signal model so far as we know consists of just the g m. So, this is the gate, this is the drain, and this is the source; this is V G S, and this is g m V G S, and this is the incremental V D S. This by the way is the small signal incremental model. And the symbol for the MOS transistor itself is like that. Now, this g m is nothing, but the partial derivative of I D with respect to V G S. And if I calculate that I get mu n C ox W by L V G S minus V T times one plus lambda V D S, so this one plus lambda V D S appears in this expression as well.

More importantly earlier, the conductance that we call y 2 2 that is the conductance that appears across the terminals of port two, in case of a MOS transistor, we know that it is called g d s the drain to source conductance. The partial derivative of I D with respect to V D S, this we have thought was zero that is basically that is the slope of this curve, the slope of the red curve here is zero, but we now know that it is really the purple curve, so the slope is not zero. So, this is not really the case. And if we calculate that from this expression, you will easily see that it is equal to lambda times mu n C ox by 2 W by L V G S minus V T square. In fact, the biggest qualitative change appears in this g d s; g d s was originally zero. There was no conductance here, now we have a conductance g d s given by this expression.

The value of g m is also modified by some number. Earlier, we were calculating this; now we have this additional modifier. Now, this is not a big change, as I said this lambda

V D S is expected to be small compared to one. So, the value of g m changes a little bit, but we do not usually worry about that. Whereas, this one it was zero, and now have a non-zero conductance. So, this is the most important effect. So, we have a non-zero, drain to source conductance, and of course, this applies to the incremental picture. We have a non-zero drain to source incremental conductance.

So, what do we do in practice, the expression for the current in saturation is mu n C ox W by L V G S minus V T square times one plus lambda V D S. The expression for g m is mu n C ox W by L V G S minus V T times one plus lambda V D S, and the expression for g d s is lambda times mu n C ox by 2 W by L V G S minus V T square. So, everything changes and these things are now little more cumbersome, because you have a non-linear function, and you also have this additional variable. So, usually what is done is for operating point calculations, this is ignored. So, we just do not even worry about it, when we want to find the drain current, we base it only on the gate to source voltage. This is inaccurate, but again like I said earlier, the goal is to understand the phenomena, not to make the calculation to the last decimal point, because even if you include this, this itself is not accurate. The actual model of the MOSFET is really, really complicated.

So, to get some insight into the operation, this is good enough. So, for operating point calculation most often we just use this. And if we do have to use that one, we actually use incremental calculations to find the effect of this one. We calculate the approximate operating point only using this part of the expression and any effect of this we add in later so that is what we normally do. And similarly, for g m also, this is ignored, because again we will operate under the assumptions that this lambda V D S is much smaller than one, so we will ignore this. And calculate g m based on only this one. And of course, for g d s, we cannot ignore this lambda; if we do, we will get zero, and we will be ignoring a qualitatively significant phenomenon. So, for g d s, we use this. Now, you notice that this part of the expression is nothing, but I D. So, we say that g d s is approximately lambda times I D. So, this g d s itself it is proportional to the drain current. And this is the expression that is most often used. We calculate g d s using this expression lambda times I D. So, I hope this part is clear.

Again this is the expression, but for simplifying the calculations, we ignore this one plus lambda V D S term, while calculating the operating point current or while calculating the g m of the transistor. But we do take into account lambda, while calculating g d s, because that is what gives you a non-zero value of lambda.

And just to get a feel for numbers, let me assume that lambda is point zero five inverse volts. Now, let me first assume that lambda equal to zero and calculate everything. And I will use the same transistor as I always been using with a threshold voltage of 1 volt, and a current factor of 100 microamperes per volt square. And I will use an operating point, V G S to be 3 volts. If I do this, I know that if I assume lambda equal to 0, I get a drain current of 200 microamperes. You can verify this very easily. And I also get a g m of 200 micro Siemens. And the drain source conductance will be zero. By the way, let me also assume V D S equal to 3 volt, so that it remains in saturation region. So, this implies saturation, because V D S is more than V G S minus V T.

Now, if I take this lambda value 0.05 volt inverse, what do I get, I get I D to be whatever I got from the original expression times 1 plus lambda V D S. And lambda V D S in this case, is 0.05 volt inverse times 3, so this is 0.15. So, the actual value of I D turns out to be 230 microamperes. So, there is an error, if we assume 200 microamperes, but that is ok, because if we include this in every expression, we would not be able to calculate anything at all. Similarly, g m will be the g m calculated from the original expression, which is 200 micro Siemens times one plus lambda V D S. These calculations are quite simple, so that is why I am not going through them step by step. So, I assume that you can work out these things quite easily by yourself.

Again, this will turn out to be 200 micro Siemens times this number is 0.15, so this will be 230 micro Siemens. There is an increase in g m, if you use the complete expression, but usually we ignore that. And finally, g d s itself would be lambda times I D that we originally calculated, which is 200 microamperes. So, lambda is point zero five; now 0.05 times 200 microamperes is 10 micro Siemens. So, our model will consist of g m V G S, and we will continue to use g m of 200 micro Siemens, ignoring the 1 plus lambda V D S term, but significantly we have a resistor here between these two a conductance, the conductance is 10 micro Siemens or whose resistance is 100 kilo ohms. This is the gate, this is the source, and this is the drain. So, the most important effect of this lambda is to introduce an incremental conductance between the drain and source of the MOS transistor, and this will directly affect the characteristics of the common source amplifier. What that effect is, we will analyze in the following lessons.