Analog Circuits
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Module - 02
Lecture – 08

We are now familiar with the large signal model of the MOS transistor. In this lesson, we will look at the small signal model. Now, the large signal model is given here, the small signal model of course, depends on the operating point; and in each region, we will have a different expression for the small signal parameters. Now, the region of most interest was is this, the saturation region. In cut off of course, there is nothing the current is zero, so there is nothing in the small signal model, the small signal current, the incremental current is also zero. Now, in this case, in the triode region, there will be some incremental model and in the saturation region there will be another incremental model. So, we will consider these now.

First, we will look at the small signal incremental model in the saturation region. This is the complete expression for the drain current and of course, we know what the small signal model consists of, in general it consists of these four elements, y 2 2, y 1 1, y 1 2 v two, where this is v two and y 2 1 v one, where this is v one. And we know that in a MOS transistor, y 1 1 and y 1 2 are zero, because the gate current is zero. So, this resistance is an open circuit, and this current source is zero also an open circuit. And y 2 1 is the partial derivative of I two with respect to V one or I d the drain current with respect to V G S the gate source voltage. And that we can easily get by differentiating this and it is equal to mu n C ox W by L times V G S minus V T.

And when we refer to a MOS transistor, we do not use the generic terminology y 2 1, we refer to this as g m. In general, g m is the symbol for trans conductance that is the transfer conductance from port one to port two; and this y 2 1 will be refer to as g m in the context of the MOS transistor, and its expression is given here. You can clearly see that it depends on the operating point. Now, for the values we had taken where mu n C ox W by L is 100 microamperes per volt square, and the threshold voltage V T is one volt. You can very easily see that for V G S equals two volt, g m will be one hundred micro Siemens. This term in parenthesis here V G S minus V T will be one volt, this constant is hundred microamperes per volt square, so the trans conductance is hundred microampere per volt or hundred micro Siemens.

And y 2 2, which is the partial derivative of the I d with respect to V D S or V two is of course, zero, because you can see no dependence on V D S in this expression. We will later see that this is only approximate, this will not be exactly zero, but we will consider that aspect later. And again in the context of the MOSFET, we do not use generic terminology like y 2 2; this is called g d s, the drain to source conductance. So, now we can see in saturation region, the model of the MOS transistor is very simple. These two are anyway zero, and y 2 2 or g d s also zero. So, this is also an open circuit. So, the MOS transistor simply consists of a voltage controlled current source whose value is given by this.

So, the small signal incremental model of the MOS transistor in saturation region. We will have the incremental voltage V one, which of course, refer to as V G S. Keeping in consistency with the terminology of the MOSFET. The voltage V two will be V D S, and this current is g m times V G S, and the conductance is zero. There would be a conductance here, but because the drain current has not dependence on the drain source voltage, this conductance is zero. And the expression for g m is given by mu C ox W by L times V G S minus V T. So, if you have a certain load resistance and if you want to obtain certain gain, you know how to calculate the value of g m; and then from that you can figure out what operating point the transistor must be set.

We will come to the amplifier example later, now let us look at the small signal incremental model in the triode region or the linear region. The expression for the current is mu n C ox W by L times V G S minus V T times V D S minus V D S square by 2. Now, again we will have the same model with y 1 1 and y 1 2 being zero. We will have y 2 1 V 1, which in the terminology of the MOSFET is g m times V G S; and y 2 2, which in MOSFET terminology is g d s and this voltage is V D S. This trans conductance g m is given by the partial derivative of I D with respect to V G S which you can easily work out to be mu n C ox W by L times V D S. Now, the conductance g d s which is the partial derivatives of I D with respect to V D S is given by mu n C ox W by L times V G S minus V T minus V D S.

So, let us examine these two in a little more detail, but the point is that g d s is not zero. We evaluated the constraints required for a good amplifier that provides a high gain. And we saw that y 2 2 or g d s should be 0, but in this case, it is not 0, so that is the reason why triode region is not the desired region for operating an amplifier. You can do it, you can always set the operating point in triode region and try to make it work like an amplifier, but it would not be as good an amplifier in triode region as it good be in saturation region.

So, to do that, we will compare these quantities between these two regions, saturation region and triode or linear region. So, g m value in saturation region is given by mu n C ox W by L V G S minus V T; and in triode region, it is given by mu n C ox W by L times V D S. And we know that the triode region is defined by V D S being smaller than V G S minus V T. So, it is very obvious that any g m that you get in triode region is going to be smaller than in saturation region. So, g m in triode will be less than the g m in saturation region. And the g d s value in saturation region is zero, according to our model; later we will see that it is a small non-zero value. And in triode region, it is mu n C ox W by L V G S minus V T minus V D S. The value of V D S itself will be between… So, this g d s will be some positive quantity; so g d s in triode region is more than in saturation region; g m in triode region is less than in saturation region. So, any amplifier that you make with the transistor biased in triode region will have a smaller gain than if it, if it were operating in saturation region.

And you can also see that in this case, as V D S goes from zero to V G S minus V T, g d s changes from mu n C ox W by L times V G S minus V T to zero. And g m changes from you can see, in this V D S will be zero initially; zero to mu n C ox W by L V G S minus V T. So, these two changes in complementary ways; g d s is maximum when V d s is zero that is the transistor has no voltage across it. And in fact, the value of g d s equals the value of g m in saturation region, and it reduces to zero, whereas, g m increases from zero to mu n C ox W by L V G S minus V T.

Pictorially, we will assume V G S to be fixed, and this value is mu n C ox W by L V G S minus V T. So, g d s starts from here, and then falls linearly to zero, and then it remains thereafter according to our current model. And g m starts from zero, and it increases linearly and reaches a maximum of this value at V D S equals V G S minus V T and remains constant. So, this is the saturation region, and this is the triode or linear region.

So, you can clearly see that to have highest trans conductance and lowest output conductance, you have to operate in saturation region.