Analog Electronic Circuits
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Lecture - 12
Large-Signal Behaviour of the Common-Source Amplifier

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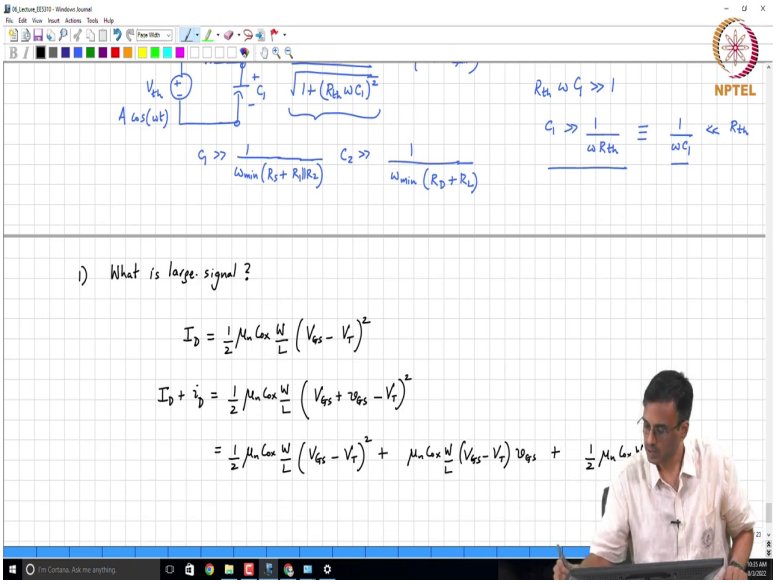

Remember, the MOSFET drain current in operating in saturation is,

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_T)^2$$

Right? And in the common source amplifier what are we doing? The incremental voltage is appearing across the between the gate and the?

Student: Source.

Source. So, basically what we are seeing is that capital $I_D + i_D$. It is,

$$I_D + i_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} + v_{GS} - V_T)^2$$

Does it make sense? Now, this is nothing but,

$$I_D + i_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_T)^2 + \mu_n C_{ox}\frac{W}{L}(V_{GS} - V_T)\,v_{GS} + \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\,v_{GS}^2$$

Okay alright and higher order derivatives of fortunately are 0, Okay.

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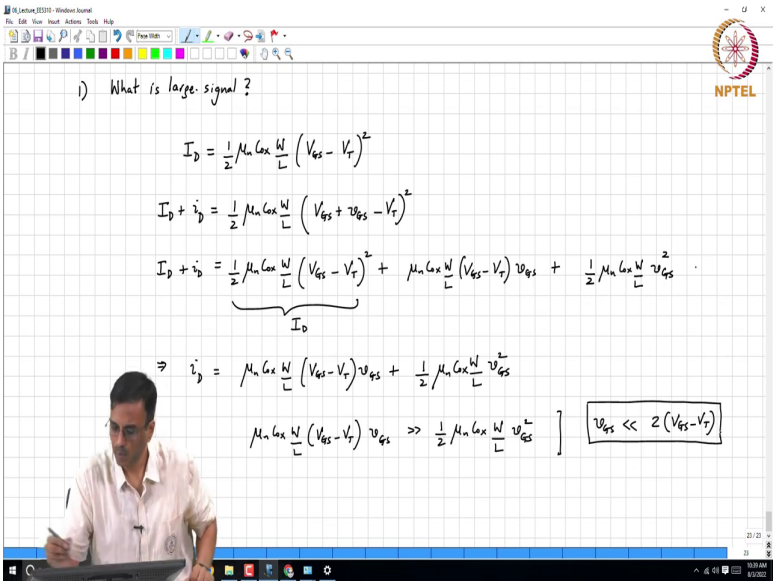

So, this is $I_D + i_D$ and this as you can see is I_D. So, which basically means that,

$$i_D = \mu_n C_{ox}\frac{W}{L}(V_{GS} - V_T)\,v_{GS} + \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\,v_{GS}^2$$

So, based on our discussions last week what comment can we make about? What constitutes a small signal?

That is the small signal approximation. The question I am asking you now is what constitutes? What is the limit for small signal operation? What do we compare it with, in other words when V_{GS} is small that small is in relation to something else, correct? The question is what is the meaning? What is that something else? Yes.

Student: It is the first term.

Yeah. So, basically all small V_{GS} where the first order term in the Taylor series expansion is much larger than the?

Student: Second order.

Second order term. The higher order terms are anyway 0 here. So, as long as,

$$\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_T)\,v_{GS} \gg \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\,v_{GS}^2$$

that basically is the definition of all small V_{GS} which satisfies this inequality is considered a small signal.

Now, question of you know what is this much much greater than again that is a matter of definition, right. Some people may say 10 is greater than 1, other people may say no 10 is not sufficiently larger than 1 maybe 100, Okay whatever right. As long as you make a definition and stick to it that is fine. So, therefore, when you say V_{GS} is a small signal V_{GS} must be compared to what quantity therefore?

Student: twice.

Twice the gate over drive voltage. Again, we see that this quantity the gate over drive V_{GS} - V_T which we call the gate over drive voltage keeps appearing in the expressions. Does it make sense? Alright, okay. But remember, that the transistor current is a function of both the gate source volt in general. The current in the transistor is a function of both the gate source voltage and the?

It is a 3 terminal device what is the drain current a function of?

It is a function of both the?

Student: Gate source voltage.

Gate source voltage and the?

Student: Drain source.

Drain source voltage. So, now, what constitutes a small signal v_{ds}?

In saturation what constitutes a linear a small signal change in v_{ds}? 0, why? I mean intuitively what is happening? Alright.

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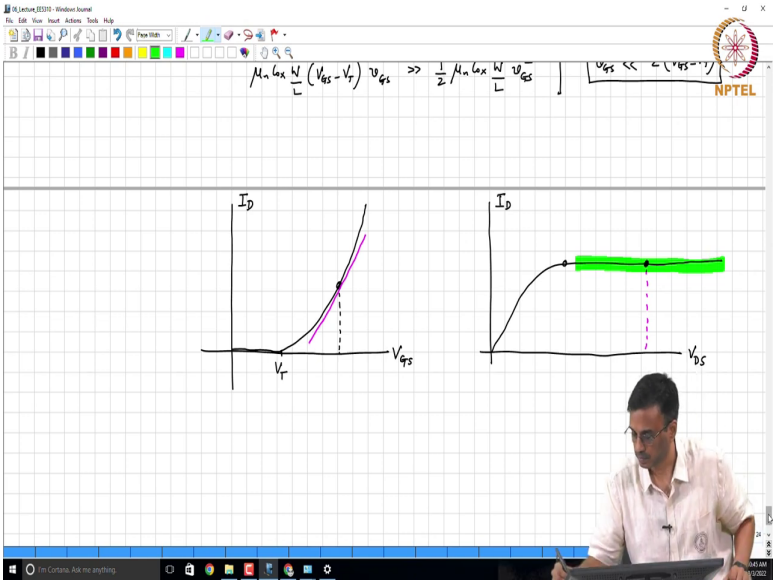

Let me go back to V_{GS}. If I plot the drain current as a function of gate source voltage in saturation, what curve will I get?

Student: quadratic.

Please understand the question carefully before you answer. The question is the transistor is operating in saturation, I am plotting I am varying the gate source voltage and plotting the?

Student: Current.

Drain current. What do we expect to see?

Student: Straight line, parabolic line, straight line.

Student: Quadratic equilibrium.

I am getting all answers except the correct one.

Student: V_{DS}.

Where is V_{DS}? Look at and what am I plotting on the x axis.

Student: V_{GS}.

V_{GS}. I am telling you the transistor is assumed to be operating in?

Student: Saturation.

Saturation. So, what comment can we make about the drain current as a function of the gate source voltage?

Student: current.

Pardon.

Student: up to V_T.

Yeah. So, basically up to V_T.

Student: 0.

The current is 0 beyond that what happens?

Student: Parabolic.

It is a parabola. Okay. At some operating point when we make a small signal approximation what are we saying? We are approximating this curve by?

Student: Straight line.

A straight line around the operating point. Does it make sense? Ok, alright. Now as long as this straight line approximates the curve reasonably well we are with calling it?

Student: Small signal.

Small signal alright, okay.

So, now if I plot now what we the question we are trying to answer is what constitutes a small signal?

Student: For V_{DS}.

For V_{DS}. So, for that what do we do? What should we plot and I mean of course, you can write the equations, but you know intuitively graphically how would we do it? Plot I_D versus?

Student: I_D versus.

Student: V_{DS}.

V_{DS} and you will get a curve like that. Okay. And that curve in the saturation this is the saturation region that is the boundary of saturation. In the saturation region what comment can we make about the drain current?

Student: Constant.

Its constant, alright. So, around this operating point in the saturation region therefore, what constitutes a small signal?

Student: Any swing.

Any swing as long as you do not get into the?

Student: Linear region.

Linear region constitutes a?

Student: Small signal.

Small signal, because at least under the assumptions that we have made the curve is a straight line that is parallel to the>

Student: V_{DS}.

x axis, correct? The fact that it is parallel to the x axis is irrelevant, right? As long as we assume that it is a straight line right you will find that if you draw tangent at that point it will coincide with the?

Student: Straight line.

straight line as long as you do not enter the?

Student: Linear region.

Linear region, Okay. So, you know as per our simplified model that we have been using so far the drain current is independent of the?

Student: Drain source.

Drain source voltage. And therefore, any swing between the drain and the source constitutes a?

Student: Small signal.

Small signal as long as the transistor does not enter?

Student: Linear.

The linear. Is that clear?

Student: Yes.

And again, it is based on the simple thing that what constitutes small signal is where the first order term in the Taylor series does a good job of approximating the true characteristic, right? In the case of the gate source swing we can see that definitely the straight-line deviates from the curve, right? So, therefore, you can only have small excursions around the operating point.

Whereas, in the case of the drain source voltage we can see that large swings, still the characteristic is since we assume that the characteristic is a straight line in saturation parallel to the x axis. It follows that any swing constitutes a small swing. Is that clear people? Very good.

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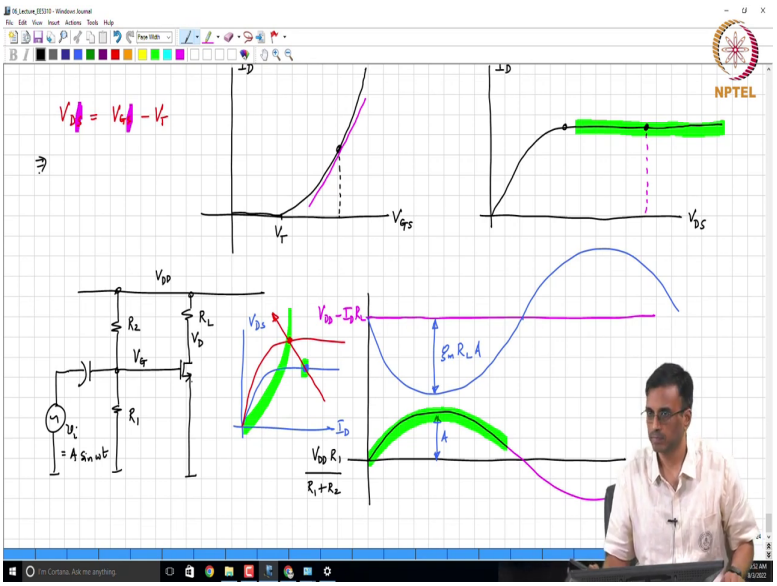

So, coming back to our common source amplifier. Now, this is R_1, this is R_2. Let me take the simplest possible one. So, I will put R_L here, this is V_{DD}. These are infinite capacitor we do not worry about it at this point simply because we already know what constitutes an infinite capacitor.

So, for our analysis we will assume that the capacitor is indeed infinite, okay. Now, the question I would like to ask is well we know that if v_i is a small signal then the incremental drain swing is you know whatever minus $-g_m\ v_i\ R_l$, Okay. Now, the question is of course, I know that v_i must be a small signal, right. For this analysis to be valid. But the question I would like to ask is what happens if I go on making v_i larger and larger, okay, alright.

So, let us take an example where v_i is some A sin ωt, okay, and what comment can we make about the absolute potential at the gate? Let us plot as a function of time. What is the quiescent value of the gate potential?

Student: $V_{DD}\, R_1/(R_1+ R_2)$.

$V_{DD}\, R_1/(R_1+ R_2)$, Okay. So, what comment can we make about the waveform at the gate?

Student: Only if there sin term.

Yeah basically, the total voltage at the gate is the sum of the quiescent value plus the?

Student: Increment.

Increment, what is the increment?

Student: A sin ωt.

A sin ωt. So, what comment can you make about the total waveform at the gate?

Student: A plus.

Yeah. It will be basically a sinusoid of amplitude A riding over a quiescent or DC value of $V_{DD}\, R_1/(R_1+ R_2)$. So, it basically is something like that, alright. What comment can we make about the quiescent value of the drain the drain potential?

Student: V_{DD} - $I_D R_L$

V_{DD} - $I_D R_L$ where capital I_D is?

Student: Quiescent value.

Quiescent value which can be found from knowledge of the threshold voltage I mean basically the properties of the transistor as well as the gate source voltage. So, under quiescent circumstances the output voltage would have been like that. Now, what happens? When you apply the signal what comment can we make about the total waveform at the drain?

Student: Its inversing minus.

Its inverting. So, basically.

Student: Minus.

It does something like that, right. As you can see, I am not a great artist. So, you should assume that the blue wave form is indeed a sin wave. So, this amplitude is A what comment can you make about that distance? The amplitude is,

Student: $g_m R_L A$.

$g_m R_L A$, alright, Okay. So, as we keep going you know as time keeps marching and in the positive half of the input cycle namely that part what comment can we make about the region of operation of the transistor? So, originally the transistor was operating, let us say with a constant V_{GS} under quiescent circumstances this is a V_{DS} and this is I_D. Under quiescent circumstances we were there.

So, when we apply an input voltage what comment can we make about the region of operation of the transistor? Is it going deeper into saturation or is it going closer towards the triode region?

Student: Closer to Triode region.

Closer to the triode region, why?

Because, the voltage across the drain and the source is?

Student: Decreasing.

Decreasing. So, in which direction are we going? I mean this is the triode region. That is the boundary of the triode region. We can go this way, we can go this way, which way are we going?

Student: Towards the left.

Towards the left of course. And upwards or downwards?

Student: Upwards, increasing upward.

So, what is happening?

The gate source voltage is increasing. In the positive half of the input cycle, you can see that the gate source voltage is increasing. So, we are as time goes by we are operating on a different V_{GS} curve right and that V_{DS} is reducing. So, basically, we are going into the triode region in that general direction, alright.

So, if you make A too large what will eventually happen? The drain potential will go lower than the gate potential and the moment it goes lower than the gate potential by? So what is the limit for triode region operation?

Student: V_{DS}

$V_{DS} = V_{GS} - V_{T}$.

So, in English what does this mean? That the source potential is common to both sides. So, we can scratch that off. So, basically this is equivalent to saying that the NMOS transistor goes into triode if the absolute potential of the drain goes one threshold below the absolute potential of the gate. Does it make sense? So, with this you do not have to worry about the source voltage. As soon as the absolute potential of the drain goes one threshold below the absolute potential of the gate, the transistor enters?

Student: Triode.

The triode region, alright. So, we will continue.