Analog Circuits

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Module - 05
Lecture – 13

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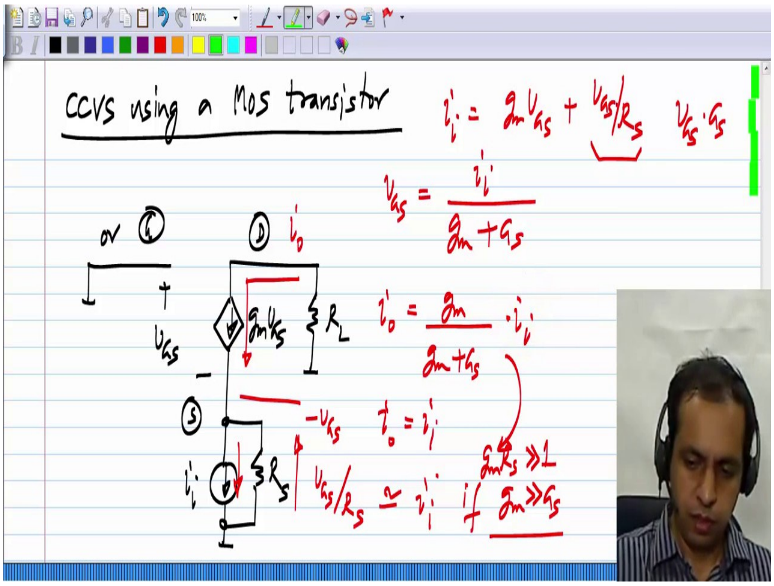

The gate is connected to ground and there is a load resistance here R_L. I will consider an input current i_i in parallel with a resistance R_s; and this is $g_m v_{gs}$, where v_{gs} is this voltage. This is the gate, this is the drain and this is the source. Now, we can do the analysis properly. If we take v_{gs} as this variable, this is at zero volt. So, the voltage at the source terminal is $-v_{gs}$, and the current flowing in R_s is upwards and it is equal to $\frac{v_{gs}}{R_s}$. And the sum of these two $g_m v_{gs}$ and $\frac{v_{gs}}{R_s}$ equals i_i. So, $i_i = g_m v_{gs} + \frac{v_{gs}}{R_s}$, or this can also be written as $v_{gs} G_s$, where G_S is the conductance of the input current source. So, $v_{gs} = \frac{i_i}{g_m + G_s}$

and the output current i_o, what is that that is $g_m v_{gs}$. So $i_o = \left(\frac{g_m}{g_m + G_s}\right) i_i$.

What did we want, we wanted $i_o = i_i$ and you can see that this reduces to that, it is approximately equal to i_i if $g_m >> G_S$; or put another way $g_m R_s >> 1$. In fact, we have been seeing similar expression everywhere, in case of the source follower, in case of the voltage controlled current source and here as well. This g_m times whatever resistance is connected between its source and ground; it happens to be the load resistance in case of a source follower; it happens to be the resistance defines the trans conductance in case of voltage controlled current source. And here, it is the internal resistance of the input source that must be much greater than one. In that case, this behaves like a current buffer of gain one. So, this is a pretty simple linear circuit, I am assuming you can analyze that. If you did not get this answer, please go back and analyze this, this is extremely simple, you will find that

$$i_o = \left(\frac{g_m}{g_m + G_s}\right) i_i$$

and it is very close to i_i, if $g_m >> G_S$.

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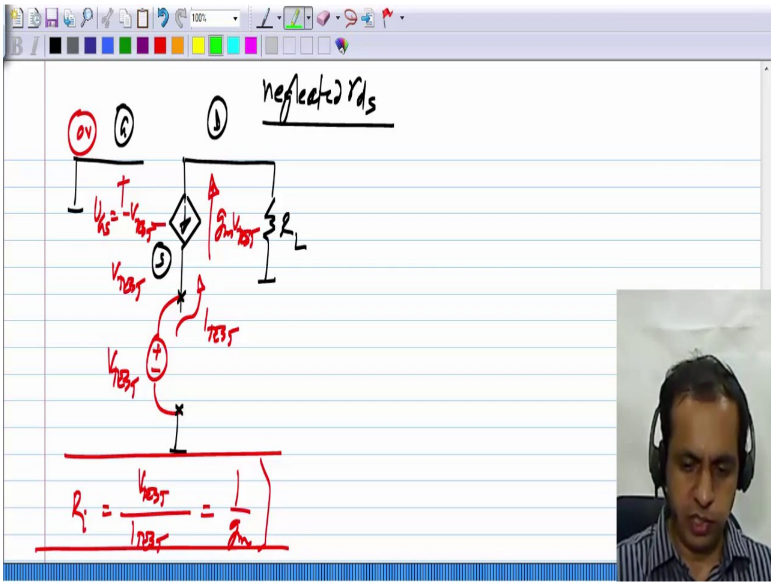

Now, what about the input and output resistances, the input source is connected between this point and ground so that is where we connect the input source. And I will evaluate the input resistance by applying a voltage V_{TEST}, and measuring the current I_{TEST}. This is very easy; the gate voltage is at zero; the source voltage is at V_{TEST}; so the gate source voltage v_{gs} is - V_{TEST}.

So, this current downwards is $-g_mV_{TEST}$ or upwards it is g_mV_{TEST}. So, the input resistance R_i which is $\frac{V_{TEST}}{I_{TEST}}$, this equals $\frac{1}{g_m}$. So, the input resistance of this is $\frac{1}{g_m}$.

Notice that in both the calculation of the gain i_o by i_i, and in the calculation of the input resistance, I have neglected r_{ds}, because including r_{ds} it will change the expression, but assuming that r_{ds} is quite large, it does not make any qualitative changes, so I ignored that. The last thing we have to evaluate is the output resistance.

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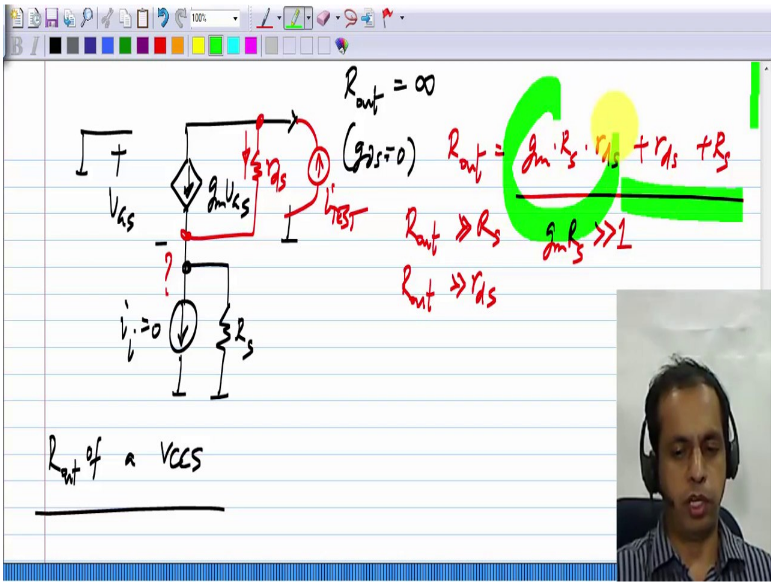

The output resistance, of course we have to include the input source i_i which is set to zero in parallel with the source resistance R_s. And this is g_mv_{gs} this is v_{gs}, and the load is connected between this point and ground that is where we have to evaluate the output resistance. Now, in this case, when you set i_i equal to zero, and if this is all the circuit, you see that the consistent solution is for this voltage to be zero, and this current source to be zero, and consequently an open circuit. Remember, this is exactly the same thing that we evaluated for the output resistance of a voltage controlled current source. It is exactly the same thing. We had call this R_l there, now we call it R_s.

So, if you evaluate R_{out} with g_{ds} equal to zero, or r_{ds} equal to infinity, it will come to be infinity. It will appear like an ideal current source. So, in this case also the presence of r_{ds} makes a qualitative difference, it will make the output resistance to be different from infinity, it will be finite. And I would not evaluate this again. As I mentioned earlier, in case of the voltage controlled current source, it easiest to evaluate with a current input I_{TEST}, then you can first calculate this voltage and then calculate v_{gs} from there, calculate the current flowing through r d s and find the answer. The answer turns out to be $R_{out}=g_mR_sr_{ds}+r_{ds}+R_s$. So, although it is not infinite, it is much greater than R_s.

What is R_s, it is the resistance of the input current source. The resistance of the current controlled current source is much higher than that. The output resistance is much higher than that. So, what it means is, it gives you the same current value, because the current gain is one, but with a much higher output resistance meaning it becomes a much better current source. And of course, R_{out} is also much greater than r_{ds}, which is just the output resistance of a transistor, because for this current buffer to work properly, we have to choose g_mR_s>>1. Now, there are these other terms also in the output resistance, and they will be much smaller than this term which will be the dominate one.

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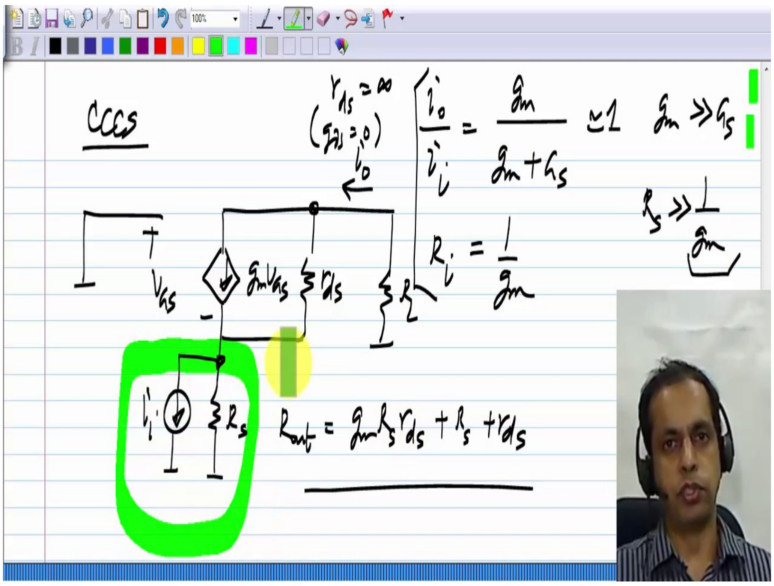

So, in summary, our current controlled current source this small signal picture looks like this. The gate is connected to ground, and the input source is connected to source terminal, this is i_i and R_s. This is v_{gs} and this is g_mv_{gs}. This is r_{ds}, and we have R_L; this is the output current.

What we have calculated so far is that $\frac{i_o}{i_i}=\frac{g_m}{g_m+G_s}\ 1$, if g_m>>G_S. And the input resistance

$R_i = \frac{1}{g_m}$. Now, both of these expressions have been evaluated with r_{ds} equal to infinity or g_{ds} equal to zero. I would encourage you to try it out with r_{ds} not being infinity, you will get a more complicated expression of course, but essentially the result will be these two. Now, as far as, R_{out} is concerned, it does not make sense to neglect r_{ds}, because in that case we simply get infinity as the answer, R_{out} will be $g_m R_s r_{ds} + R_s + r_{ds}$. So, it does behave like a current buffer; it has a small input resistance.

What does the small mean? It is small compared to the resistance of any current source that you connect. It should be small compared to R_s, and it will be the case, because $g_m >> G_S$; and if you rewrite it, $R_s >> \frac{1}{g_m}$. The input resistance of the current controlled current source will be much smaller than R_s that has to be the case. And then R_{out} will be much more than R_s, so it takes a bad current source and gives you a much better current source, that is the role of a current buffer.

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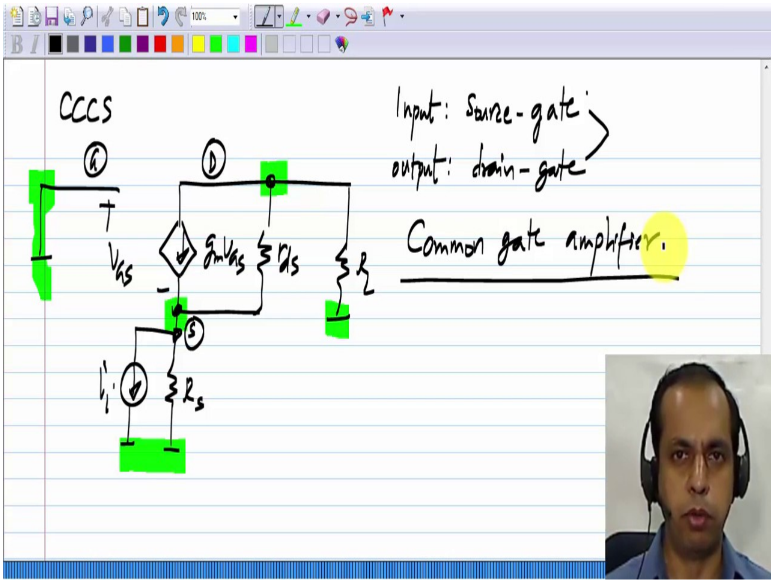

This is the current controlled current source with a gain of one, and you can see in this case that this is the gate, drain and source terminal of the mos transistor. The input is applied between source and ground. The output is taken between drain and ground, and the gate is grounded. So, we can say that, the input is applied between source and gate and the output is taken between drain and gate. And because gate is common to the input and output, this is also known as common gate amplifier. So, it is a current buffer or a current controlled current source of gain one, and it is also known as the common gate amplifier. It is one of the basic building blocks using a single transistor.