Analog Circuits
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Module - 06
Lecture – 02

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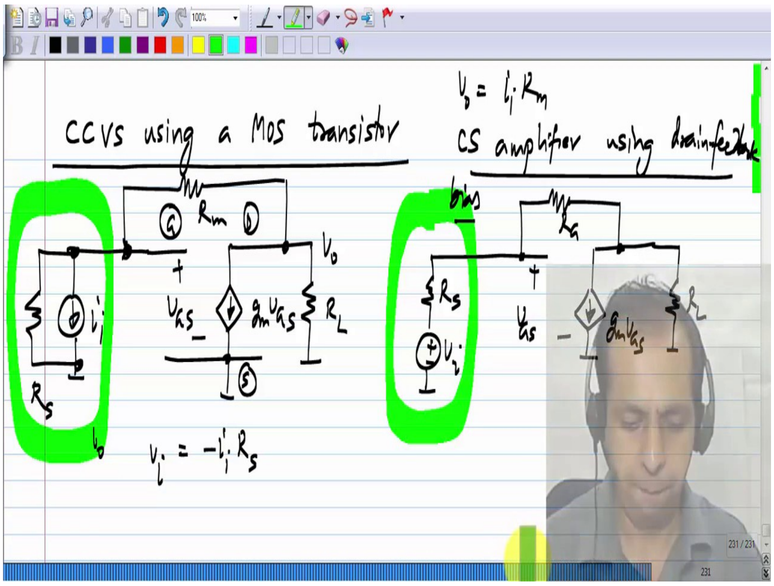

We have synthesized the topology of the current controlled voltage source using a MOS transistor. Now, we will analyze it to see exactly how it behaves. We have the input current source ii, we have the MOS transistor here, gate, drain and source. And we have to connect the resistance, which represents the trans resistance that is we want V_O to be equal to $i_i R_m$. So, the output V_O is over there. This is V_{GS}, and this is $g_m v_{gs}$. Now, in addition to this, our current source may not be perfect, so it has a resistance R_s across it, and of course, there will be a load, because we want to be driving something. This is the complete circuit.

And you can now analyze what really is $\frac{V_O}{i_i}$ in this circuit. As usual I would encourage you to carry out the linear circuit analysis and find the transfer function, and then you can compare it to what I get here. Now, this particular circuit, it turns out that we have analyzed this before in a somewhat different form, so if you remember long back, we realized a common source amplifier using drain feedback bias. If you recall the small signal equivalent circuit of that was like this. The MOS transistor was here, the input was voltage source V_i in series with the resistance R_s; and the feedback resistance, it was called R_G; this is V_{GS}, and g_m V_{GS}, and this is R_L.

Now, you can see that what I have here looks exactly the same as this. What is R_G here is denoted by R_m over there; and instead of a voltage source in series with the resistance R_s, I have a current source i_i in parallel with the resistance R_s. So, all the results that I obtained here can be used here. Now, we can go and analyze this from scratch; in fact, as I suggested please do that and make sure that the answer that you get are exactly the same as what I get. Now, one of the reasons I am connecting it to this is just be able to use results from a previous analysis, which sometimes you can do. And also to illustrate, how the same circuit can behave quite differently, when components values change, because this as I said it is a common source amplifier, and this one is a current controlled voltage source. Obviously, it behaves like a common source amplifier for some combination of values, and a current controlled voltage source for some other combination of components value. We will see all of those things.

Now, how do I relate these two; this part here – V_i and R_s is the same as that part. These two will be exactly identical to each other, if $V_i = -i_i R_s$, what I mean is this current source in parallel with R_s will be the norton equivalent of this voltage source in series with R_s, if $V_i = -i_i R_s$. We get minus i_i, because this current source is pointing downwards, whereas, this voltage source has positive terminal on top. Now, with this mapping, we can use whatever results we have for this circuit, for our current controlled voltage source. The only other thing we need to do is wherever we have R_G, we have to replace that with R_m, that is the trivial modification.

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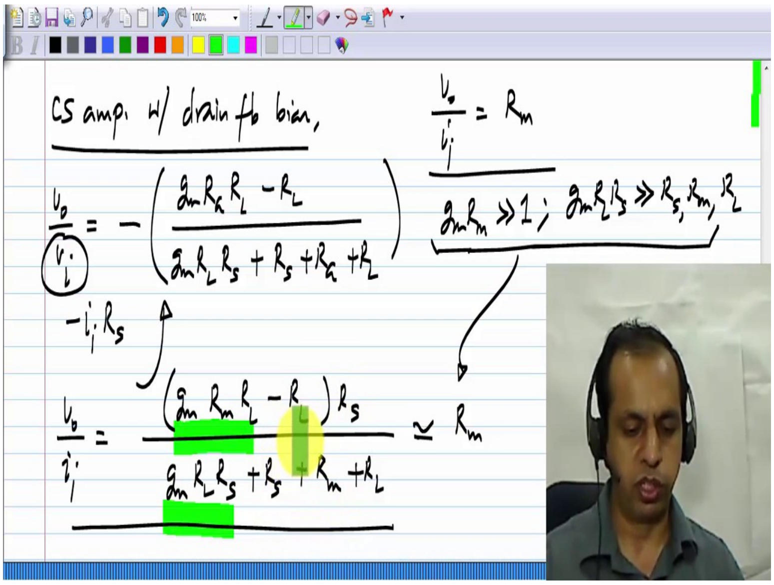

For the common source amplifier, with drain feedback bias, we had $\frac{v_o}{v_i} = \frac{-g_m R_G R_L - R_L}{g_m R_L R_s + R_s + R_G + R_L}$. Now, exactly the same thing works for us except I have to replace this v_i with $-i_i R_s$. If I do that I get $\frac{v_o}{-i_i R_s}$ to be equal to that; and I want only v_o by i_i, so I multiply this with - R_s. So, $\frac{v_o}{i_i} = \frac{(g_m R_m R_L - R_L) R_s}{g_m R_L R_s + R_s + R_m + R_L}$. Now, what is that we wanted, we wanted $\left(\frac{v_o}{i_i}\right) = R_m$. Now, will this expression ever equal that one, and it looks like that. Let say if this term happens to be dominant in the denominator, let say this is the only term that is dominant in the denominator and of course, this dominates over that, that is not difficult, because this $g_m R_m$ can be quite a bit larger than one. So, this will dominate over that.

If $g_m R_m \gg 1$, and $g_m R_L R_s \gg R_s, R_m, R_L$. In this case, clearly you can see that this approximately equals R_m under these conditions. So, what we synthesized as a current controlled voltage source using our intuitive idea of negative feedback, thus behave like that. The exact ratio of output voltage to input current is not R_m, but some value like this, but it will be very close to R_m. In fact, if these conditions are satisfied it will be close to R_m. So, when you choose the component values you have to make sure that these conditions are satisfied. So, this is the expression for $\frac{v_o}{i_i}$, we will simplify it in different ways and see what comes out of it. .

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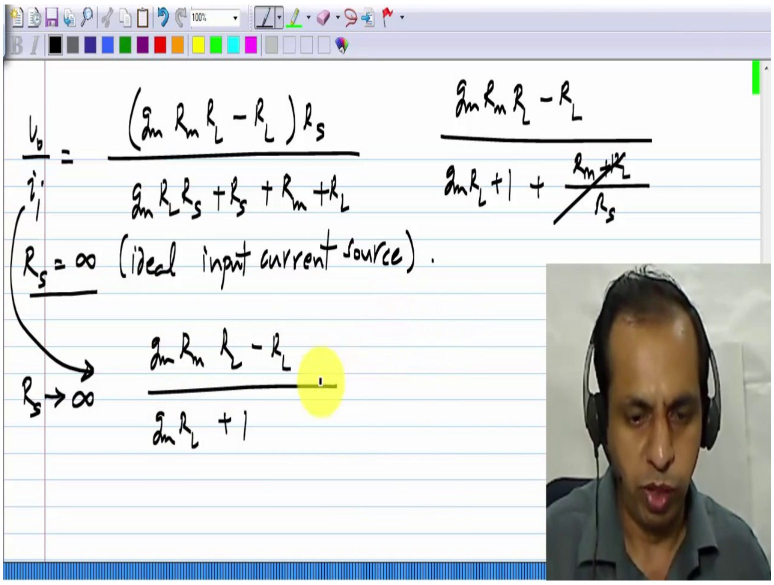

So, first of all if it is driven with an ideal current source that is R_s equals infinity, then what happens, I have to evaluate this expression in the limit R_s tending to infinity. It is very easy to do, I divide both numerator and denominator by R_s. I will get $\frac{g_m R_m R_L - R_L}{g_m R_L + 1 + \left(\frac{R_m + R_L}{R_s}\right)}$; obviously, as R_s tends to infinity, this goes away. And I will have $\frac{g_m R_m R_L - R_L}{g_m R_L + 1}$.

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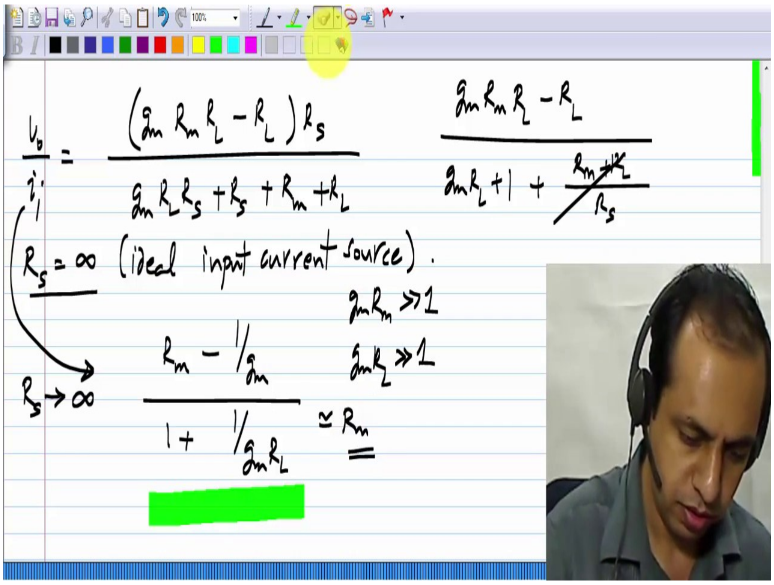

What I will do is I will divide all the terms by $g_m R_L$, so in that case I will get $\frac{R_m - \left(\frac{1}{g_m}\right)}{1 + \left(\frac{1}{g_m R_L}\right)}$.

So, this is the expression if R_s is infinity, that is if the current controlled voltage source is driven by an ideal current source. Now, what is this saying if g_m is very large that is basically if $g_m R_m >> 1$, then this term in the numerator will be much smaller than this and can be neglected. And similarly if $g_m R_L >> 1$, then this entire thing approximates to R_m. So, essentially just like in all the other cases in the negative feedback amplifier, just like in all the other controlled sources, the g_m of the transistor the trans conductance of the transistor has to be very large; if it is very large, in fact, if it tends to infinity, we will get exactly the relationship that we want. For instance, here, you can see that if g_m tends to infinity, you will get R_m exactly, so that is what is happens in every case.

So, if g_m tends to infinity here also, you can see that you will get only R_m right. Now, if g_m is finite, it will slightly deviate from R_m, this was the case for all the controlled sources as well, there was some small difference we wanted a voltage controlled voltage source with the unity gain for the source follower, but you know that the source follower gain is close to one, but not exactly one. It will be equal to one, if g_m is infinite. So, as R_s tends to infinity you get this.

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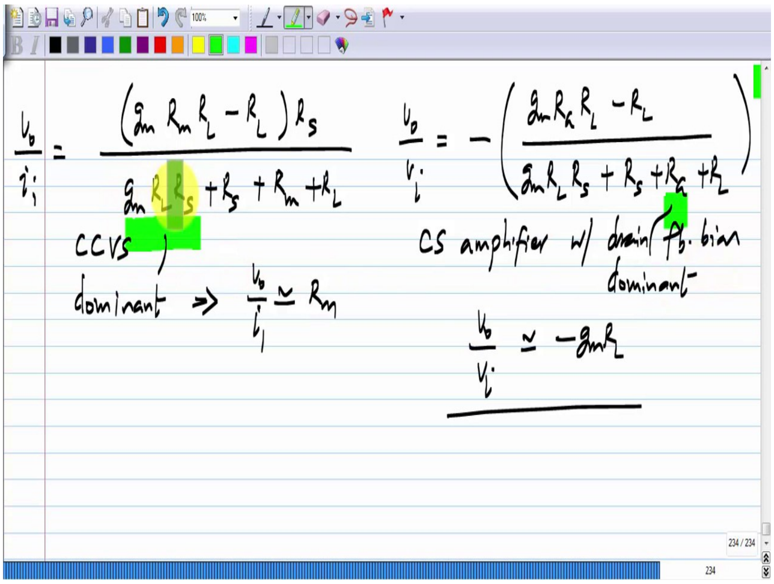

So, let us look at these two expressions, this is the gain or ratio of output voltage to input current for the current controlled voltage source, and this was the gain of the common source amplifier with drain feedback bias. So, in this case, we want this particular term to be dominant one, if that is dominant then we get approximately what we want, $\frac{v_o}{i_i}$ approximately equals R_m. Whereas, in the common source amplifier with drain feedback, if you recall we wanted this to be dominant, R_G to be dominant in the denominator. So, if this is dominant then we have $\frac{v_o}{i_i}$ approximately $-g_mR_L$. So, there are quite different, the quite different from each other.

Now, you can see that the only difference is in the values of the components. If you choose the values such that this R_G is dominant over all these terms, it behaves like a common source amplifier with drain feedback. And if you choose value so that this is dominant, the term containing g_m is dominant then it behaves like a current controlled voltage source. So, this also emphasizes that you have to understand what is going on in the circuit, exactly the same circuit, they will look exactly the same, the topology is exactly the same, but the behavior is very different depending on the values of components.