Analog Circuits
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Module - 03
Lecture – 11

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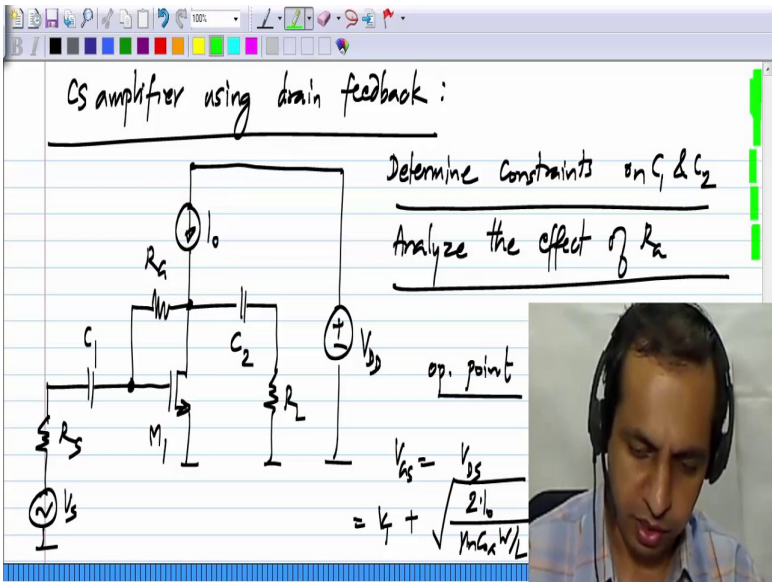

We now have the common source amplifier using drain feedback. And we have to analyze it properly to see the effect of extra components in the circuit such as R_G. And also we have to find the correct constraints on the capacitors values. So, this is the circuit you have, and you can think of it as let us say you were shown this circuit for the first time, you do not know how to analyze circuits including MOS transistor circuits. And you were shown this for the first time, what would you do, first you would check the operating point, the dc operating point, for that you have to open circuit all the capacitors and short circuits all the inductors. In fact, I would encourage you to do that for this afresh, although you know the answer. Then you can find the V_{GS}, V_{DS} and so on, see whether it is in saturation or triode region or whatever. Then calculate the small signal parameters of the transistor, then put down the small signal picture of the amplifier and see how it behaves.

Now, I am going to skip the operating point part, because if I open circuits C_1 and C_2, the source and load go away, and we just have the drain feedback circuit. And we know that both

V_{GS} and V_{DS} will be equal to each other and they will be equal to $V_t + \sqrt{\frac{2I_d/¿}{\mu_n C_{ox}(¿¿)\frac{W}{L}}}$. Now, let us

analyze the small signal incremental picture of this. As you know anything that is fixed such as a fixed voltage source that is shorted to ground, so this will get shorted to ground, and here we have a fixed current source I_0 and this becomes an open circuit, because there is no increment in that, it becomes zero in the small signal incremental picture, this is an open circuit.

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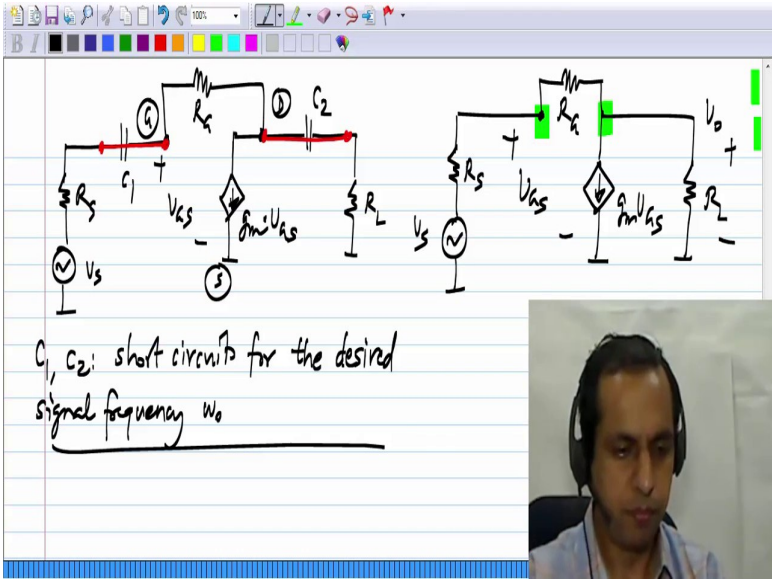

So, the circuit we will have in the small signal incremental sense is.. This is the small signal model of the MOS transistor. And we have the output coupling capacitor C_2, and R_L. This is V_{GS}, and this g_m multiplies this V_{GS}. I will mark the terminals. Initially especially when you do not have much experience in it, please be careful about drawing the small signal picture. In fact, the best thing is not to change anything, but start from the total circuit and replace only the MOS transistor with its small signal equivalent, and then redraw the circuit as you wish to do. Now, we have these two capacitors and we know that we want these capacitors to behave like short circuits. We will evaluate the constraints later, but for now, we will assume that they satisfy whatever constraint they have to, and they do behave like short circuits for the desired signal frequency.

We later see what constraints are. So, the circuit we have is really simple; we have V_s, R_s, g_m V_{GS}, where this is V_{GS}; R_G and the load resistance R_L. By the way, in all of this analysis, we have omitted the small signal output conductance of the MOS transistor, but if you do want to include it, it is very easy. Here it appears in parallel with R_L; in some other circuits, it may be different, but in all the circuits we have discussed so far in the common source amplifier it appears in parallel with R_L. So, if you want to know the results including the small signal output conductance, all you have to do is to consider the parallel combination of r_{ds} and R_L instead of the load resistance R_L alone.

Now, this is just regular linear circuit analysis, and we have only two nodes in this circuit, and let me call this voltage V_o that is the voltage across R_L. I will write down the node equation, usually I prefer to do things systematically, and I would recommend the same especially in the early stages when you are still getting practice with circuits.

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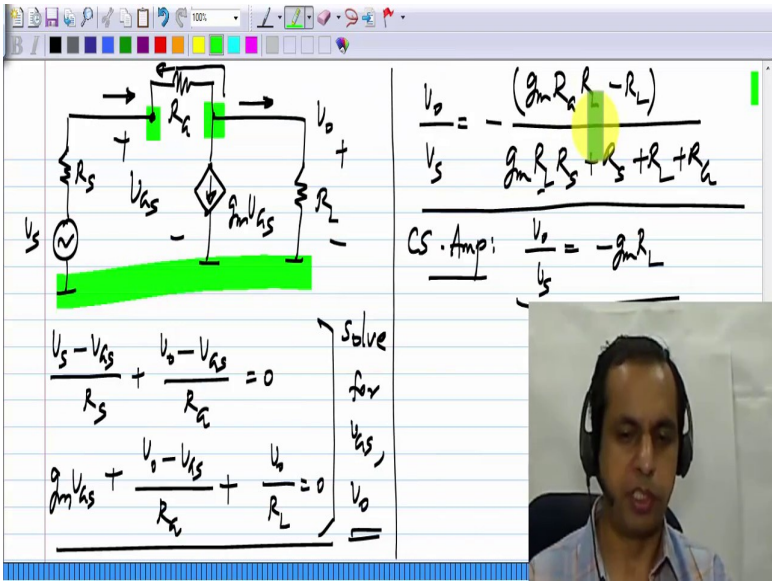

Let me copy over this. Now, I will write the equation at this node, and the equation at that node, that is the total current flowing into that node, current flowing in R_s is $(V_s - V_{GS})/R_s$; by the way, this V_{GS} is also measured with respect to ground, because this source is grounded, so, be careful about that, that may not be true in all circuits; plus

$(¿¿o - V_{GS})/R_G$, which is the current flowing through R_G, this is equal to zero. And at this

node, at the output node, we can consider either currents flowing into the node or away from the node. Since g_m is already flowing away, I will take all the currents going away this way, that way, and $g_m V_{GS}$. The current flowing out here, that is $g_m V_{GS}$ plus the current flowing out

in R_G is $(¿¿o - V_{GS})/R_G$ plus a current flowing out in R_L is V_o/R_L . And all these things

sum to zero.

And we have to solve these two a system of linear equations, for V_{GS} and V_o; the output voltage is V_o. Now, please solve this for yourself, I am going to just write down the answer, I am not going to go through the steps of eliminating the variables and all the stuff. So, if you

do solve for it, you will find $\frac{V_0}{V_s} = \frac{-g_m R_G R_L - R_L}{g_m R_L R_s + R_s + R_L + R_G}$. Appears to be a somewhat

complicated expression. Remember for a common source amplifier, the very basic version of a common source amplifier without any extra components, what should be the V_0 by V_s, it should be - $g_m R_L$.

Now, we have a somewhat different expression, but let us see what that means. First of all, why did we have this R_G? We have this R_G to provide dc feedback to the gate of the transistor, it is needed only for the dc picture; it is actually not there in the small signal incremental picture of the common source amplifier. So, when a resistance is not there meaning it is open circuited, its value is infinity. So, even without doing anything else, you can guess that this R_G has to be very large because in the small signal picture it should be as good as not being there.

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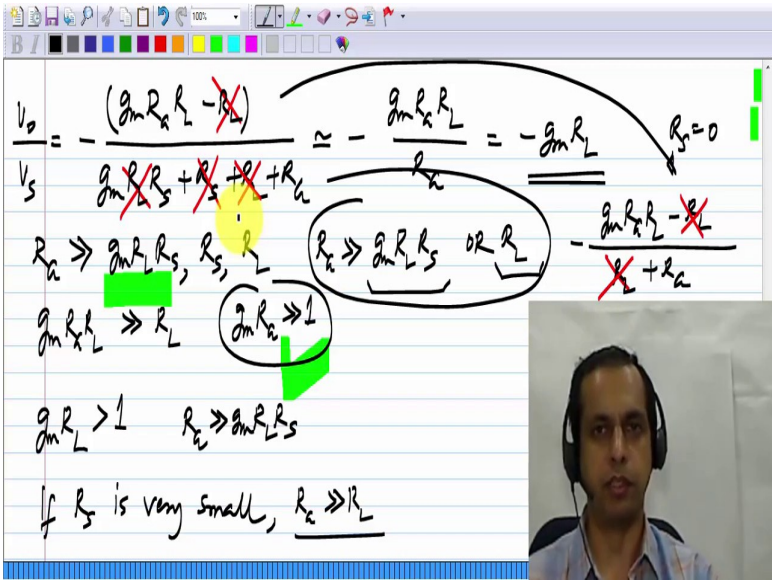

Now, let us go back to this expression here. Let us see what happens. Now, let us say R_G is very, very, very large, so; that means, that you have R_G in the denominator, and we have number of terms one of them is R_G itself and we have three other terms, and let say that R_G is much more than each of those other terms $g_m R_L R_s$, R_s and R_L. And similarly, in the numerator, let say that the term containing R_G is much more than the others, that is, $g_m R_G R_L$ is much more than R_L. In this case, I can neglect all the other terms and retain only the terms containing R_G. Remember even intuitively, we know that R_G has to be large, and now we are kind of taking an extreme case, it is very large, we have not quantified it yet, but it is very large, and solve the other terms.

So, this can be neglected, this can be neglected, that can be neglected, and in the numerator that can be neglected. If we do that this approximates to minus $g_m R_G R_L$ divided by R_G, which is equal to minus $g_m R_L$. And it is exactly the same as the expression for the gain of a common source amplifier. So, it does behave like a common source amplifier, if R_G is very, very large. How large should it be? It should satisfy these two constraints, but actually, we see that if you satisfy one of them, other will be automatically satisfied. So, first of all, we are looking at an amplifier, so the quantity $g_m R_L$, itself can be expected to be much more than one. It is definitely more than one; it could be substantially more than one. So, it is very obvious that if R_G is much more than this first term, it will be automatically more than that one and that one, because you have this $g_m R_L$ multiplying that. So, essentially the condition we need is for R_G to be much greater than $g_m R_L R_s$.

Now, the second condition says that $g_m R_G R_L$ must be much greater than R_L, and R_L is common to both sides. So, it is really saying that $g_m R_G$ must be much greater than one. And you can see that this is also automatically satisfied if R_G is very large because we expect the gain $g_m R_L$ to be much more than one, and R_G is much more than R_L from the first condition, so this will also be automatically satisfied. So, essentially what you need is for R_G to be much greater than $g_m R_L R_s$. Now, of course, you can ask what happens if the source is ideal, the signal source is ideal and R_s is zero then this says that R_G is much more than zero, which is true for any number R_G. So in that, case if R_s is very small then satisfying the first one here, for instance, if R_s is zero, satisfying the first one does not mean others are satisfied.

In that case, basically R_G has to be much more than R_L, so R_G has to be much more than $g_m R_L R_s$ or R_L. So, I just explain it with R_s being zero, what you can do is solve for the gain V_0 by V_s with R_s specifically being zero. If we do that for instance we get, let me substitute that in here, if R_s is zero, we will have $g_m R_G R_L - R_L$, and in the denominator we will only have $R_L + R_G$. So, if R_G is much more than R_L, this goes away, and this also goes away. So, once this condition is satisfied, you will have the behavior of common source amplifier, although there is a resistance between drain and gate. So that is the constraint on R_G. This is the very common situation in circuits. So, you want the element to be significant for some picture let say dc or ac picture, and insignificant for the other one. And what you have are constraints, remember you do not get from this analysis R_G should be equal to something, so R_G has to be much more than something, and you have to choose something much larger than that. And just like I mentioned for the capacitor, you could choose let say ten times or hundred times more and be done with it.