Analog Circuits
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Module - 05
Lecture – 11

In this lesson, we will take further look at the voltage controlled current source that we have designed, and also understand some terminology that is commonly encountered and so on.

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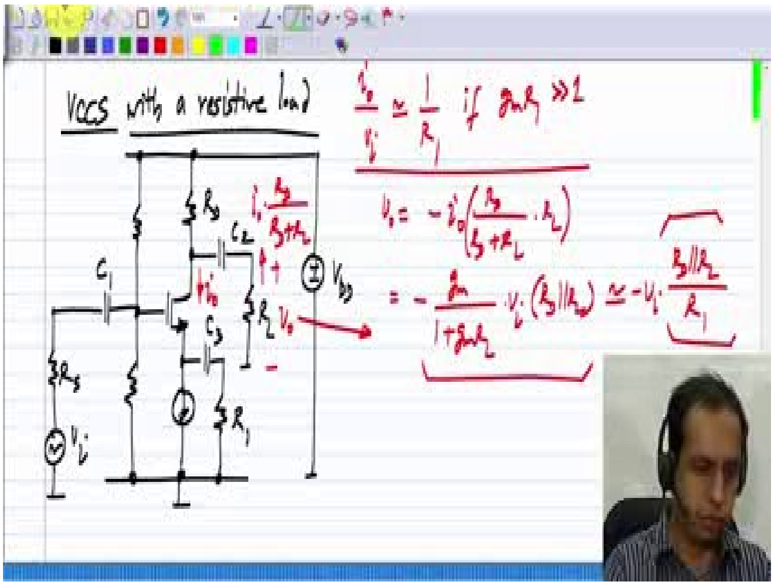

Now, our voltage controlled current source using a single MOS transistor is made like this, we bias it with a current source in the source. And most commonly used way of biasing the drain is through a bias resistor R_D, and we ac coupled the load to it, and we couple the resistor which defines the trans conductance R_1, and we also ac coupled the input. Now, the quantity that is controlled by feedback is the small signal incremental current in the drain and $\frac{io}{vi}\ \frac{1}{R1}$ if g_mR_1 >>1; and in this particular circuit, this i_o divides between R_D and R_L, an inverse ratio of their values.

So, the current that flows here is really $i_o \frac{R_D}{R_D+R_L}$. Now, it so turns out that lot of times also though this is a voltage controlled current source, it is used with the voltage output, you measure the output voltage instead of the current, and that is very easy to do. What is this output voltage after all if I define this to be v_o; $v_o = -i_o \left(\frac{R_D}{R_D+R_L} \right) R_L$. Basically this i_o is going through parallel combination of R_D and R_L, and because of its polarity we get a negative sign. And if I expand this out, I will get $-\left(\frac{g_m}{1+g_m R_L} \right) v_i \left(R_D \vee ¿ R_L \right),$ so that will be the output voltage.

And when this condition is satisfied, when $g_m R_l >> 1$, this is approximately $-v_i \left(\frac{R_D \vee ¿ R_L}{R_1} \right)$. So, the gain, the voltage gain if you think of that way is defined by a ratio of resistors and that can be defined accurately, that is more accurately than defining the trans conductance of a MOS transistor, which varies significantly with temperature and so on. Especially in an IC, the ratio of resistors can be quite accurately fixed. Although I considered the output voltage, this is not the voltage controlled voltage source, this is the voltage controlled current source with the load resistor. How do you differentiate between that two, if it were really a voltage controlled voltage source, then changing the value of the load resistance or connecting another resistance in parallel with this should not change the output voltage at all. Whereas, in this case it definitely changes the output voltage, this i_o is fixed, that is independent of what load you connect.

So, the voltage v_o will very much depend on the load resistance that you connect. So, this is really a voltage controlled voltage source with a resistive load and it is used like this and sometimes we would not discuss it, but this i_o is passed to some resonant circuit to form a resonating amplifier and so on, a tuned amplifier which is used in many RF circuits. We would not discuss those things, but this voltage controlled current source can be used with variety of loads to give you different kinds of functions.

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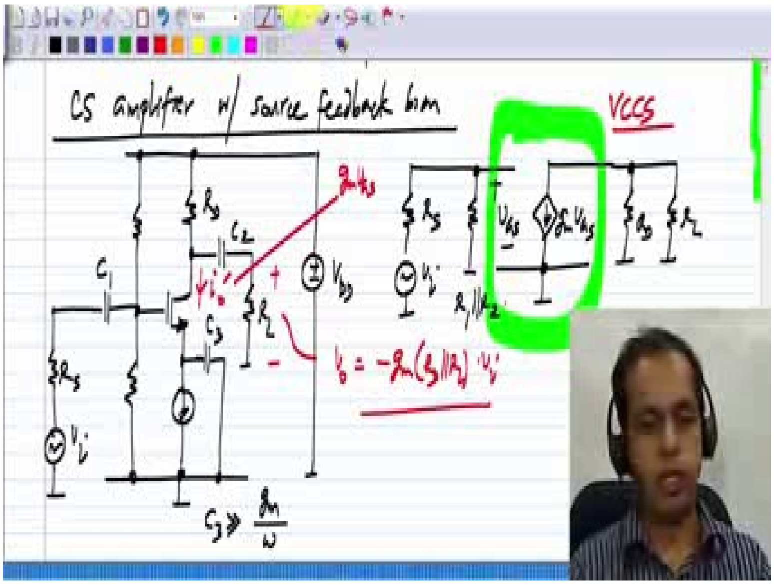

Now this circuit you see is very similar to, let me copy this over, I have copied over the same circuit, and what I want to highlight here is the similarity to a common source amplifier with source feedback biasing. Now, let me go back to that circuit common source amplifier with source feedback bias. What did we have in that case, the only difference between this and that circuit was this R_1 was not their it was short circuited and C_3 was connected directly to ground, you choose C_3 such that its reactance is much smaller than $\frac{1}{g_m}$; in other words,

$$C_3 \gg \left(\frac{gm}{\omega}\right)$$, where ω is the signal frequency.

Now, we know the result for this case, this is also a voltage controlled current source, let me call this i_o'. What is the small signal equivalent after all, it is the input source, and let me assume the capacitor to be a short circuit, we have R_1 parallel R_2 and we have the transistor with it is source grounded. This is the way we use the transistor amplifier. We have v_{gs} and $g_m v_{gs}$ is the incremental drain current. So, this i_o' is nothing but $g_m v_{gs}$ and that goes into parallel combination of R_D and R_L. Now if you look at the output voltage here v_o, we know what it is, we calculated it

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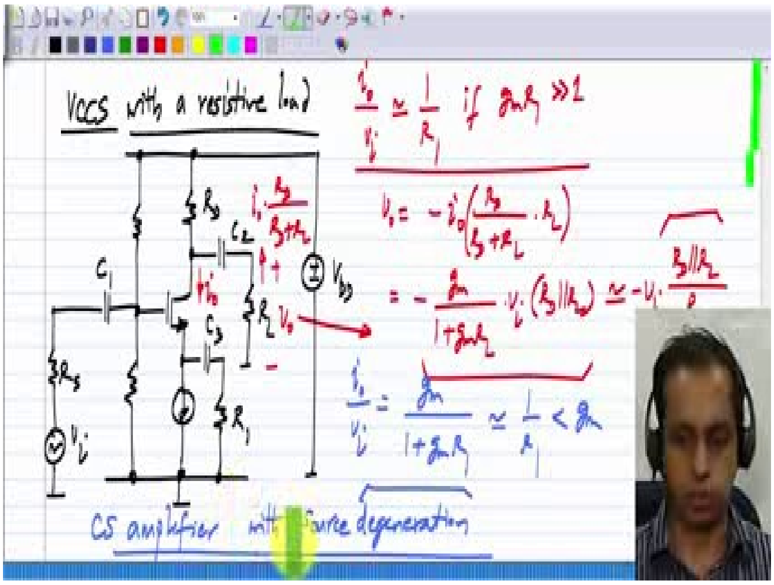

so many times, it is $-g_m(R_D||R_L)v_i$. So, this is the common source amplifier and this is a voltage controlled current source with resistive load. In fact, this is also a voltage controlled current source with a resistive load where the voltage controlled current source is just the MOS transistor by itself. This is also a voltage controlled current source, the only difference between these two is that in this case the ratio output current to input voltage is defined by the MOS g m, whereas here, if you chose g_mR_1 >> 1, the ratio of output current to the input voltage is defined by this resistor R_1.

So, they are very similar in functionality and for that reason many times this particular amplifier is also called common source amplifier with source degeneration. Degeneration means something is degenerated or reduced. And in this case what is reduced is the trans conductance. In this case $\frac{i_o}{v_i}=\frac{g_m}{1+g_m R_1}\ \frac{1}{R_1}<g_m$. And this is definitely going to be small than the g m of the MOS transistor, in fact you choose the g_mR_1 to be quite large, so this number here is going to be quite a bit smaller than g_m which is just the trans conductance of a MOS transistor whereas this is the original common source amplifier. So, it is said that the g_m of the transistor is degenerated by placing a resistance in series with the source and this becomes clearer if we draw as a small signal picture. I will omit the bias resistors R_1 and R_2 for simplicity and I will also assume that all capacitors are short circuits.

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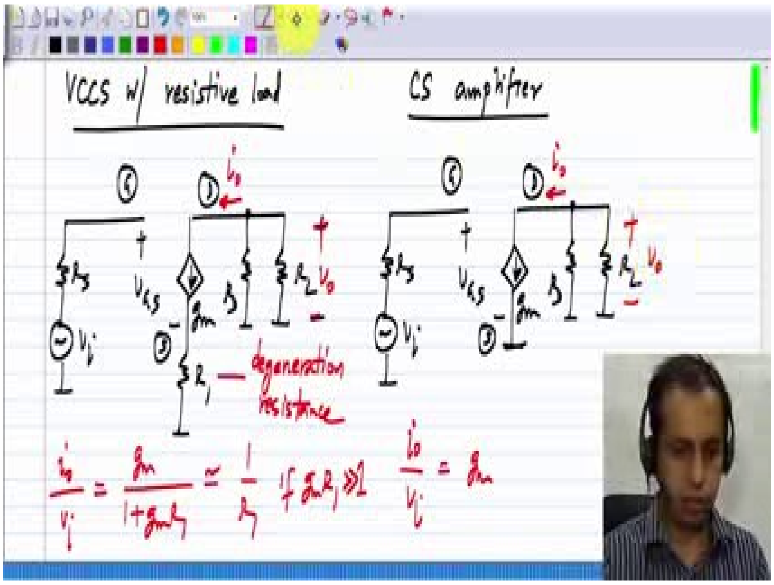

A voltage controlled current source with resistive load, this is used with the voltage output as I mentioned, it looks like, this is g_m and this quantity is v_{gs}, these are the drain, gate and source terminals of the MOS transistor. And the common source amplifier is very similar of course, except that the resistance is not there and the source is connected to ground. So, if I call this i_o here and there $\frac{i_o}{v_i} = \frac{g_m}{1+g_m R_1}$ $\frac{1}{R_1}$ if $g_m R_1 >> 1$, and in this case $\frac{i_o}{v_i} = g_m$. So this has a smaller trans conductance i_o by v_i and it is referred to as degenerating the transistor by connecting a resistance between the source terminal and ground, what happens is the effective gate source voltage here is smaller than v_i whereas, the gate source voltage here is exactly equal to v_i.

So, the trans conductance is reduced, but why we do this, why do we reduce the trans conductance. First of all, it become independent of g_m which has some desirable properties because g_m is very sensitive temperature and so on. And another aspect which we have not discussed so far, this circuit is more linear compared to this one, that is you can apply a larger signal, larger value of V i to this without driving the MOS transistor into very severe non-linearity compared to this circuit. That is another feature of negative feedback, of course I have only stated it vaguely because to specify it exactly you have to also make quantitative comparisons, the trans conductance here is smaller than this and so, on, but in general the circuit is more linear than that and this is used for that purpose, degenerating the transistor and this resistor is sometimes called the degeneration resistance. And instead of the output current you look at the output voltage v_o like this then

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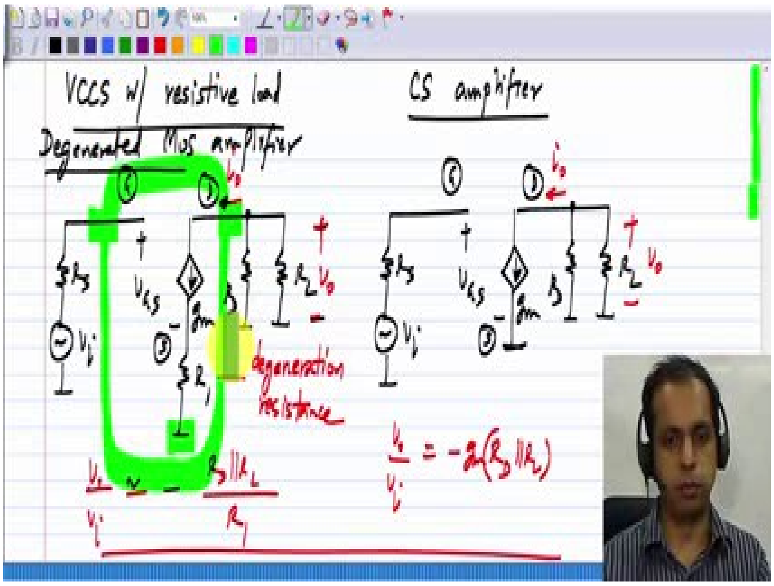

we will have $\frac{v_o}{v_i} \; -\frac{R_D \| R_L}{R_1}$ in this case, again under this same condition this $g_m R_1 >> 1$

and $\frac{v_o}{v_i} \; -g_m (R_D \| R_L)$ in this case, So, many times you see this terminology, degenerated MOS amplifier, and this is what it means, if you have resistance in the source then you can think of this entire block, these three terminals, this, this and this one as a three terminal limit whose g m is much smaller than that of the MOS transistor by itself. So, that is what degeneration means, and this circuit is also very widely used basic building block.