Analog Circuits
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Module - 06
Lecture – 09

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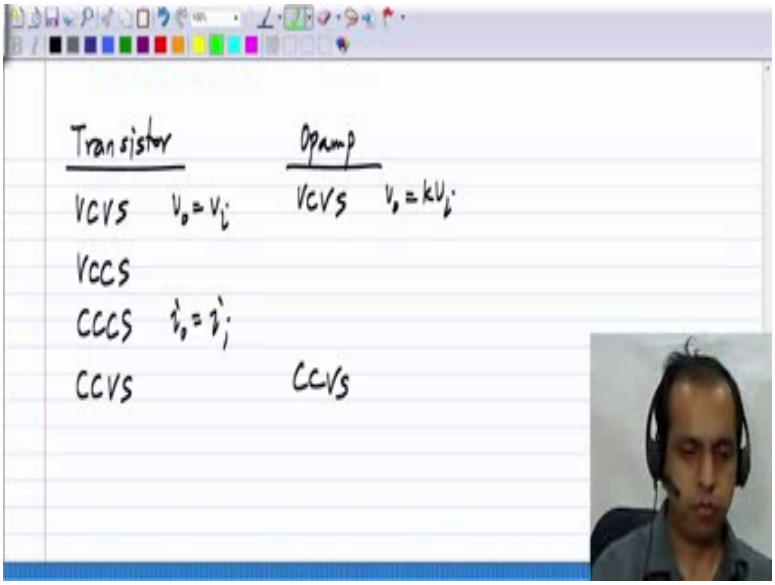

We have discussed controlled sources using the transistor as well as using the op amp. And those of you have been observing carefully will probably realise there was the some cheating involved here that is using the transistor I did realise all four kinds of control sources - voltage controlled voltage source, voltage controlled current source, current controlled current source, and a current controlled voltage source. But voltage control voltage source had a gain of one, I did not realise $V_o = k*V_i$, where k is something other than one. And similarly current controlled current source had a gain of one; I did not realise $I_o = k* i_i$, where k is something$_m$ore than one.

And in case of the op amp, I discussed only the voltage controlled voltage source and the current controlled voltage source; of course, the voltage controlled voltage source had a gain that could be anything; k can be greater than one in this case. Now, why did I limit myself to these and why did I constrain myself to a gain of one for the voltage controlled voltage source and the current controlled current source.

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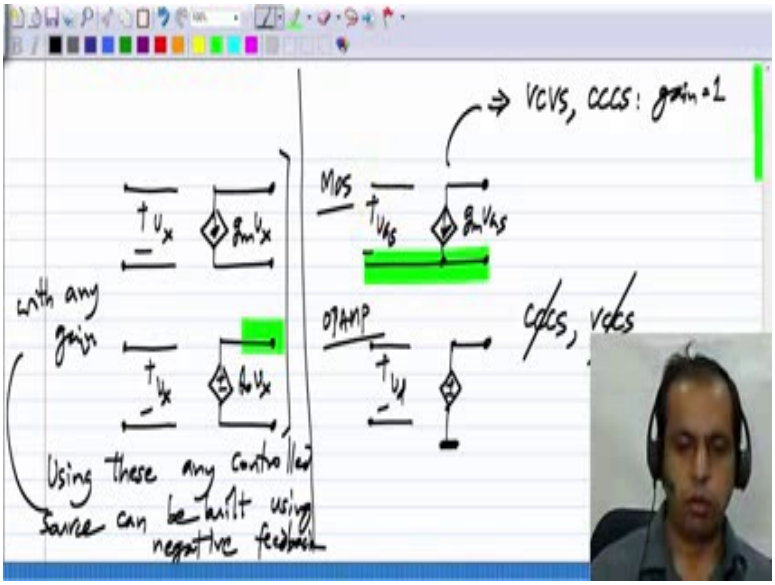

The point is let say if we had a control source like this, that is a basic control source which was like this. If there is some V_x , this gives me some g_m*V_x. Or alternatively, I could have a voltage controlled current source; if this is V_x, I could get some A_o*V_x. Now using these I could build any other kind of negative feedback controlled current sources. So, essentially using these any controlled source can be build using negative feedback. And it will have all the good stuff. If this g_m becomes very large, the transfer ratio of the controlled source becomes insensitive to the exact value of g_m, the g_m could vary by factor of 10, but the transfer ratio does not change much. But similarly, A_o has to be very large, but it does not matter whether it is 10000 or 100000 even for factor of ten change, the transfer ratio does not change very much.

So, all controlled sources can be realised and you will not even have the restriction of unity gain. Any controlled source also with any gain, it can be realised. Now, what is it that we do have, we have a MOS transistor which is the voltage controlled current source and it looks like this; V_{GS} , g_m V_{GS}. Now what is the difference the obvious difference you see is that here the controlling nodes are completely separates from the controlled nodes; whereas here one of the controlling nodes and one of the control nodes is common, it is the source of the transistor. This is the reason why we cannot make voltage controlled voltage source or voltage controlled current source with gain more than one, because it is already tied here. So, these two have unity gain.

So, with this anything can be made, but it is almost like we are given controlled source, but with these two tied permanently together. So, we cannot break that of course, it is part of the transistor. So, we cannot realise gain more than one, and the op amp while it is voltage controlled voltage sources is also not like this, it is not like this one here. So, what we have is this and this is separate from the control side, but on the control side one side is implicitly grounded, this will be the common reference node in the circuit. So, you cannot lift this terminal off the ground, it is part of the op amp.

And we have only this terminal that is free and this is why we cannot realise the current sources either the current controlled current source although voltage controlled current source, we cannot do this. Because when you realise the current source, you need two terminals that is let say you provide the current output from there to sense the current output you need the other terminal, because some current flowing from here to there, you sense it at this terminal and you provide the current output at that terminal. Both terminals have to be free for a current output device, like a current controlled current source or a voltage controlled current source. Now, because we do not have access to the both terminals, we cannot obtain a current output from an op amp. So, this is why essentially I let the discussion to whatever we can realise.

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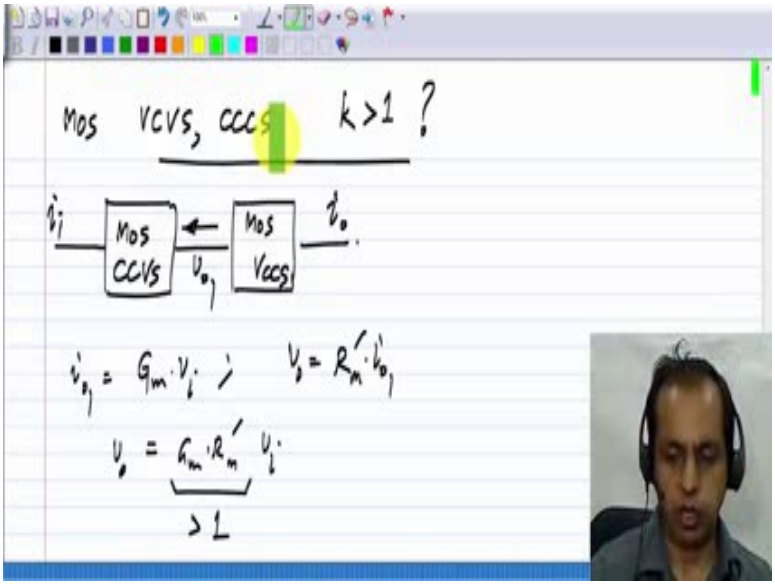

Now, how would we go about realising gains more than one using $_{m}$OS circuits, MOS voltage controlled voltage source or a current controlled current source with k greater than one. Can

we do this? Please think about it, may be pause the lecture, and think about it, it turns out that knowing what we do now we can still do this. One easy way to do it this, you have a MOS voltage controlled current source and follow that with MOS current controlled voltage source. I will show it schematically like this if this V_i, I will get something here which is I_{o1}, and I will get something their which is V_o, and I_{o1} will be some g_m*V_i and V_o will be some $R_m'*I_{o1}$; together will get a gain of $g_m* R_m'$ which can very much be set to greater than one.

And if you want to realise the current controlled current source, you simply reverse the order of cascading. You first have a current controlled voltage source and after that a voltage controlled current source. If you have an input current, you will get V_{o1} from that and you will get I_o from there. And again the gain can be adjusted to be more than one. Now this is possible; it is very much possible to realise gains more than one for a voltage controlled voltage source or a current controlled current source using only MOS transistors, but one thing here is that there are two separate feedback networks one to realise this stage and another one is to realise that stage. It turns out that you can also do these things using MOS transistors with a single feedback circuit. Again these are not things I am going into in great detail, but I will just suggest is as an exercise, you can try to do it yourself it actually quite fun.

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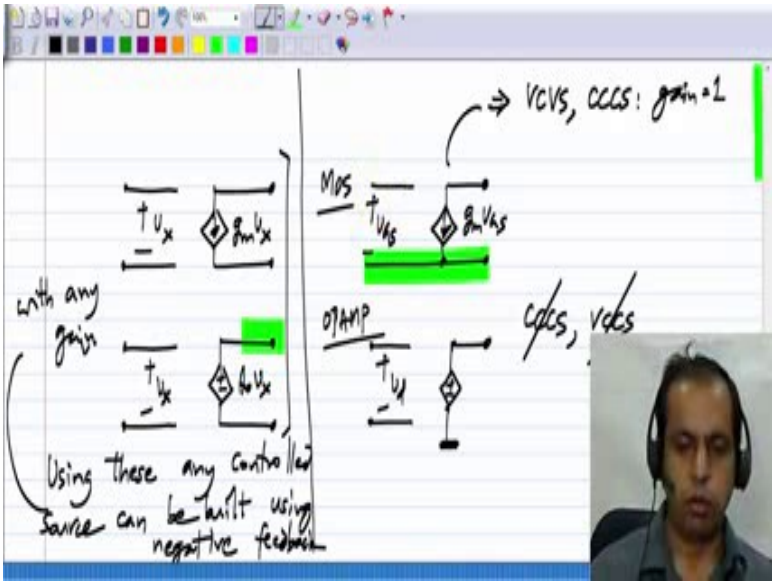

In fact I would encourage you to use either of these current sources and synthesize all four kinds of controlled sources using negative feedback. It is similar to what we did for in the

cases earlier that is four controlled sources with MOS transistor and the two with the op amp. But now if you do have all four terminals free, you can realise everything. So, you can try to do that. Now how can I do that in practice, one possibility is to not just you single transistor everything we tried so far is with two transistors. So, again I will show schematically the picture, I am not going to show biasing and so on.

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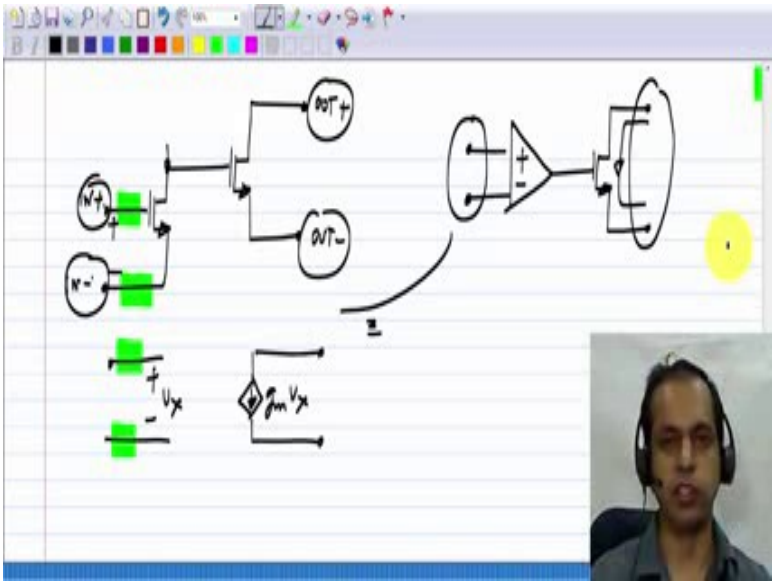

So, let say this is the input you have to replace the incremental equivalent and carry out the analysis and so on. And these two are the outputs; this is in plus and in minus, and this is out plus, and out minus. So, we do have four distinct terminals two terminals for the input and two terminals for the outputs. Of course, you first synthesize the signal picture using this and add biasing to get the complete circuit. This is still not exactly equivalent to this one, because in this case no current flow in this or that terminal, whereas in this case no current flows in that one, but some current does flow in that one. So, it is not exactly equivalent but you can still work with this.

And another combination which will let you make all four controlled sources is to combine an op amp with a transistor. So, you have the two input terminals over there and two distinct output terminals over there. Whatever current goes in here and comes out there, so you can sense the current as well as provided to some other circuit. And using this, you can realise all four kind of sources and this is roughly equivalent to that one. So in fact, I would encourage you to try this out, try to synthesize these things, and it will actually help you great deal in

your understanding of circuits. So, with these you can in fact, synthesize all four kinds of controlled sources with no restriction on gain.