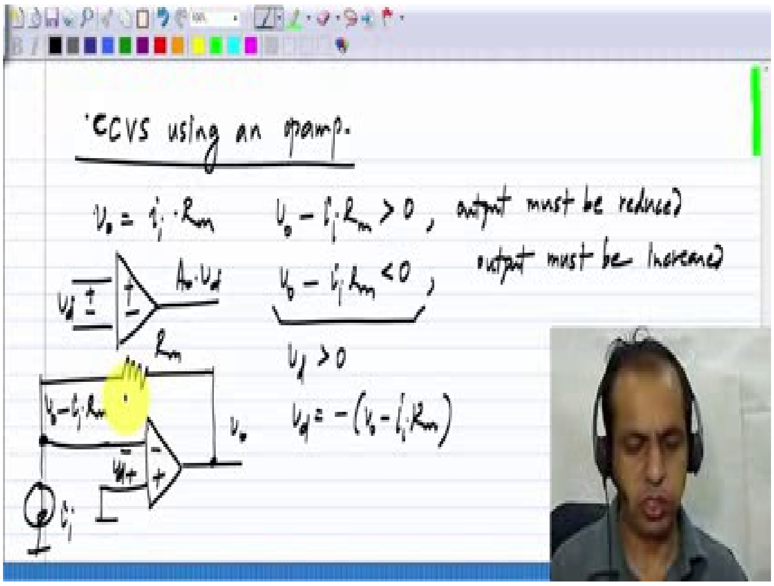
Analog Circuits
Prof. Nagendra Krishnapura
Department of Electrical Engineering
Indian Institute of Technology, Madras

Module - 06
Lecture – 06

(RefeR$_s$lide time: 00:09)

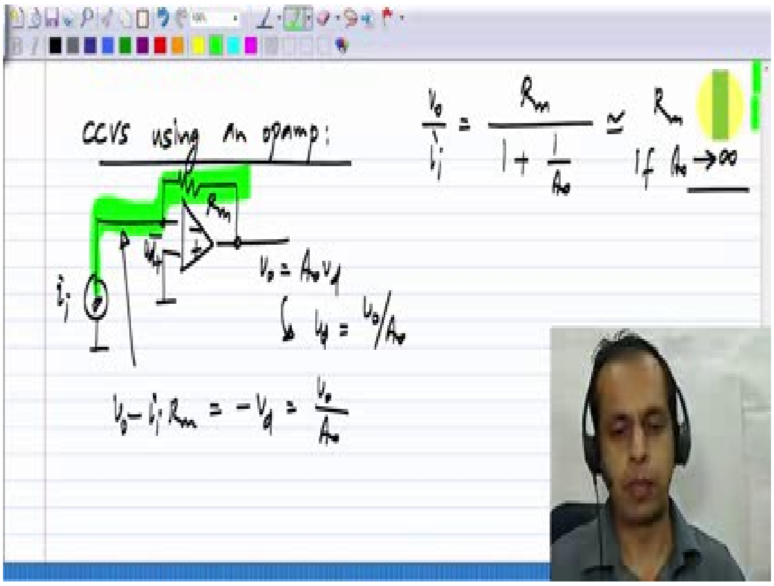


Now, we will implement a current controlled voltage source using an op amp which is modeled as a voltage controlled voltage source. A current controlled voltage source obeys the relationship output voltage $V_o = (i_i * R_m)$, which is the trans resistance or trans impedance of the current controlled voltage source. Just like in the case of current controlled voltage source using a MOS transistor, we define an error voltage $V_o - (i_i * R_m)$. And if this happens to be more than zero it means that the output voltage is higher than what is desired. The output must be reduced. And similarly, if this is less than zero, output must be increased.

If you consider an op amp, which we model as a voltage controlled voltage source, there is the input voltage difference V_d, and the output is some $A_o * V_d$, and A_o is the large number or you would like it to be a large number. Now, how does this work, if V_d is positive, the output will be driven to a large positive value; if V_d is negative, it will be driven to large negative value so that means that to reduce the output voltage, you have to make V_d more negative that is we have to reduce V_d or we have to make it more negative than what it currently is. And similarly, to increase the output V_d must be made more positive. Now, here you see that if the error voltage V_o - (i_i * R_m) is less than zero, the output must be increased. So, putting the two together, you see that when V_o - (i_i * R_m) less than zero, V_d must actually be greater than zero; V_d is the input difference voltage of the op amp with the signs define like this.

So, if this is the output voltage, and this is V_d, I would like V_d to be - (V_o - ($i_i * R_m$)) so that the action described here can happen. If V_d = - (V_o - ($i_i * R_m$)) what happens is that when V_d < 0 , the output will be further reduce to negative values, so that is not what you want. So, V_d has to be equal to - (V_o - ($i_i * R_m$)). Now how do we obtain this (V_o - ($i_i * R_m$)); just like V_d in the case of the transistor current controlled voltage source, if this is the output node, and this is the input current source then if I connect R_m like that the voltage here will be (V_o - ($i_i *$ R_m)). And we want that to be equal to -V_d. So, convenient way to do that is you connected to this ground and connect it here. So, now, you can see that -V_d equals (V_o - ($i_i * R_m$)).

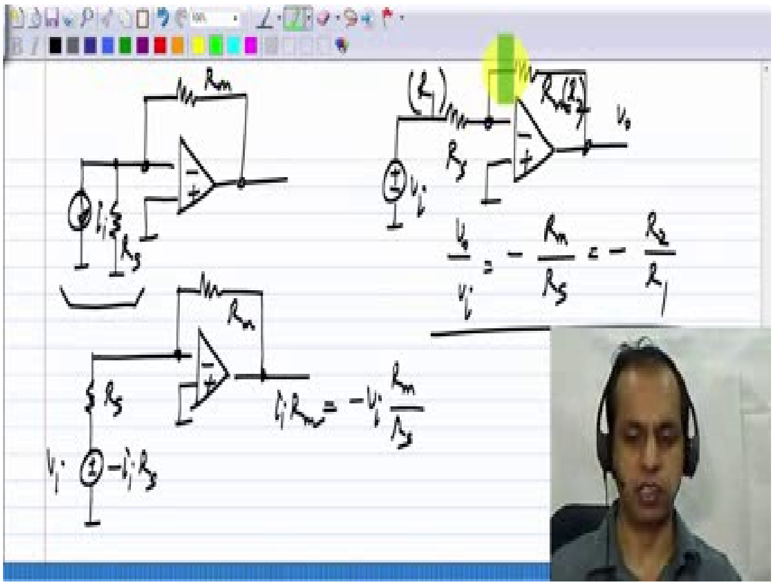
(RefeR$_s$lide Time: 04:03)



So, a current controlled voltage source using an op amp, it looks like this. So, this is V_o, this is R_m and this is i_i. Of course, the input source can have an internal resistance R_s. Now the op amp is modelled as a voltage controlled voltage source that means that if this voltage is V_d, the output voltage V_o is A_o * V_d. Let us analyse what exactly we get from this. And for simplicity, I will not include R_s, but you can include it and analyse it and see what you get out of it.

In this case, we know that this V_d here, this voltage has to be (V_o - ($i_i * R_m$)), because this current has to flow into the resistance nothing goes into the op amp. We assumes that the input resistance of the op amp itself is infinite. So, now, this is equal to - V_d and from this we can see that $V_d = V_o / A_o$ which is V_o / A_o. From this, we see that V_o / i_i equals ($R_m / (1 + (1 / A_o))$). Now, this is the desired ratio between the output voltage and the input current and we have something extra in the denominator, but the denominator reduces to unity and this ratio goes to R_m, if $A_o \to \infty$. If the gain of the op amp is infinite then we get exactly what we want. So, this is the current controlled voltage source using an op amp.

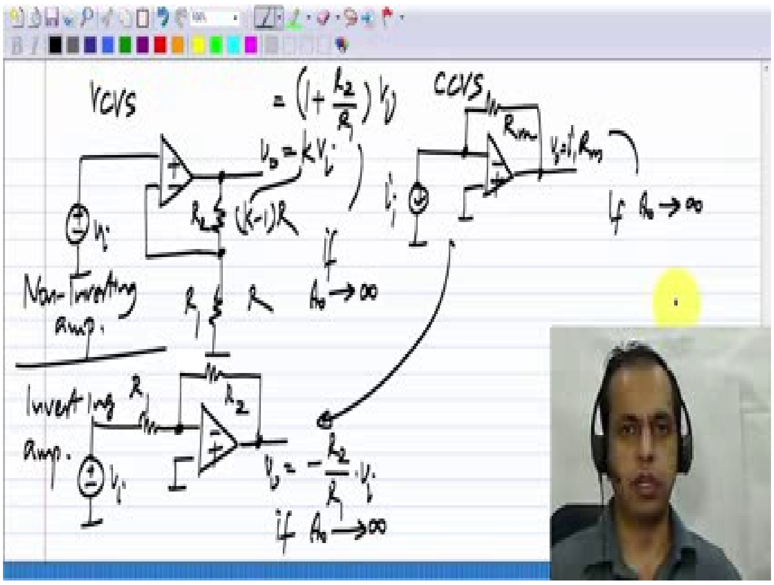
(RefeR Slide Time: 06:39)



Now, just like in many other current controlled devices, many times such a device is used actually with a voltage input that is imagine that we had the current controlled voltage source R_m, and this is the source resistance R_s. We can convert the parallel combination into a series combination of R_s and a voltage which is - $i_i R_s$, and this drives current controlled voltage source. Now, once we have the circuit, we can forget that we ever started from a current source; we can just things of this as the voltage source V_i. And draw it like this, where we have some resistance R_s in series with input source. Now, we can forget about the factor this was the internal resistance of the current source. We have some voltage source, and we have resistance here in series and we have some resistance R_m over there. The output voltage here is $i_i * R_m$ which can also be written as - $V_i * (R_m / R_s)$.

So, if this is V_o, V_o / V_i will be - (R_m / R_s).Of course, usually these are not denoted R_m and R_s if you are not using them as a trans impedance amplifier. We just call them R_1, R_2 in that case they become - (R_2 / R_1). So, this is nothing but a current controlled voltage source driven by a series combination of voltage source and resistor. Many times it is use like that. In this case, you do see that a gain depends on R_s, which is in series with voltage source. This is not a voltage controlled voltage source, because in a voltage controlled voltage source the gain V_o/V_i should not depend on the internal resistance of V_i. Now for instance, if there is another resistance here that appears in series with this and the gain will depends on that resistance. So, this is the current controlled voltage source driven by a voltage source in series with its internal resistance.

(RefeR$_s$lide Time: 09:24)



So, now we have seen two circuits - voltage controlled voltage source using an op amp which looks like this, and the current controlled voltage source using an op amp which looks like that. And in case of voltage controlled voltage source, the output will be exactly k * V_i; where this k is given by the resistor ratio. If this is (K - 1)*R and R, K is what appears there. or , if you call these R_2 and R_1, this will be $(1 + (R_2 / R_1)) * V_i$. In this case, the output voltage will be $i_i * R_m$; now these are true if the gain of the op amp goes to infinity.

So, an op amp whose gain is infinity, it is known an ideal op amp. And in case of an ideal op amp, the gain of this will be $(1 + (R_2 / R_1))$, the gain of this will be R_m. And a variant of this which can be driven with voltage source is V_i R_1 R_2. Here the output will be $(R_2 / R_1) * V_i$, if the gain of op amp is infinite. Now of course, these two circuits are very likely very familiar to you and they are nothing but the classic non inverting amplifier, and the inverting amplifier, so that is how we can realise control sources using an op amp as well. So, we can also realise control sources using an op amp; we have seen how to make a voltage controlled voltage source as well as the current controlled voltage source.