Analog Circuits
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Module - 06
Lecture – 05

We now know how to implement all four types of control sources using a MOS transistor. The MOS transistor by itself is a Voltage controlled current source those proportionality constant is g_m trans conductance. And all these controls sources behave ideally if this g_m which is used to realize the control sources tends to infinity. Now we will see you how we can realise such control source when the basic device that we have is a Voltage controlled Voltage source.

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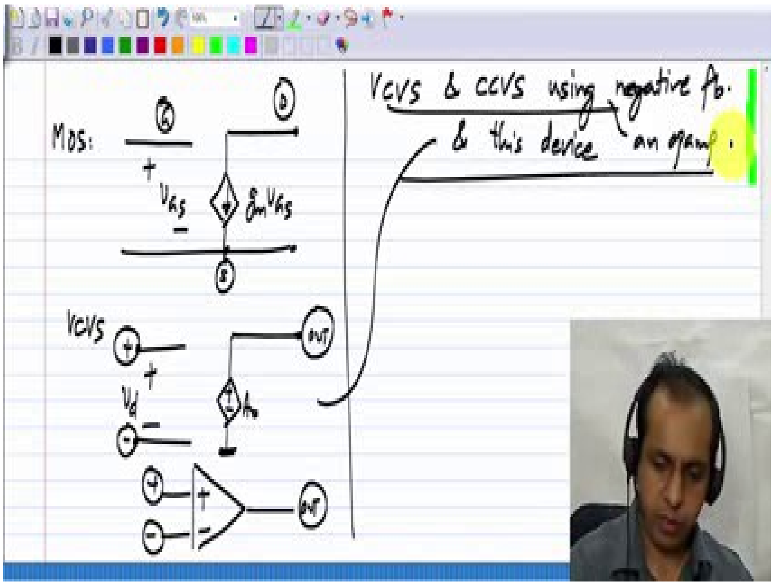

A MOS transistor as we know, it is a Voltage controlled current source. The current is g_m times V GS, where V GS is the gate source Voltage. Now, imagine that instead of this Voltage controlled current source, we had a Voltage controlled Voltage source to begin with. And let me say that the model looks something like this. There is a Voltage V_d between these two terminals, I will call them plus and minus. And one side of the control source is connected to ground; the other side is the output. This is a Voltages controlled Voltage source with some restriction this one side connected to the ground and so on. So, now instead of using the MOS transistor, we can try to use this basic device and implement our control sources using negative feedback, so that is we will implement a Voltage controlled Voltage source and a current controlled Voltage source using negative feedback and this particular device.

This is already a Voltage controlled Voltage source, you may be asking why I need to implement Voltage controlled Voltage source using negative feedback around this one. It exactly is same as why we implemented a Voltage controlled current source using the MOS transistor when it is by itself a Voltage controlled current source. The point was a following g_m of the transistor which is the parameter of an active semiconductor device, it vary substantially with temperature; it varies from MOS transistor to MOS transistor. Whereas, the Voltage controlled current source we realized using this, had a trans conductance which was defined by a resistance which can be much more accurately set. Similarly, here this I naught when it is realised using a semiconductor device can vary widely, we want to have a Voltage controlled Voltage source whose gain is determined by not a semiconductor device, but something like a resistor. So, we will try to do this.

Now of course, I do not need to make this any more mysterious than it is. You know what this is the model of, it is the model of what is a very popular device the operational amplifier or the op amp. This is the output, this is the plus terminal, and this is the minus terminal. So, essentially what I am saying is we will try to realise the Voltage controlled Voltage source and current controlled Voltage source using an op amp in negative feedback.

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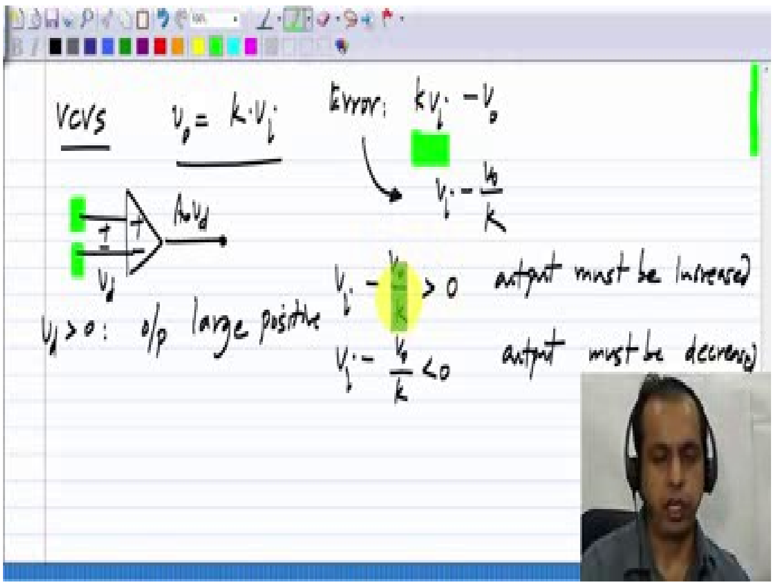

So, first let us consider the Voltage controlled Voltage source. The output Voltage V_o should be equal to k times the input Voltage, where k is some gain. In other words, now for us to realise this using this negative feedback, we have to define some error and based on that error, we have drive the output up or down. Now what does our op amp do, this Voltage is V_d and the output is some A_o*V_d. So, if this Voltage is small or if it becomes negative, it drives the output also negative; and if this input Voltage is large, it drives the output to large positive values. So, what we have to do is we have to define some error between desired and actual quantities, and feed it to the input of the op amp, in the correct sense such that the output is driven to the desired value.

So, what is the error, the desired quantities $k*V_i$ and the actual quantities V_o. So, we can define the error presumably as ($k*V_i - V_o$). So, that is the op amp input Voltage, the op amp reacts to the input Voltage, so its input Voltage should be related to this error, but this clearly has the problem where do we get $k*V_i$ from that is in fact what we are trying to find. If we already had $k*V_i$ we would not be building this amplifier in the first place, but exactly the same information can be had by dividing this entire quantity by k. So, I will redefine the errors as $V_i - (V_o/ k)$. You can clearly see that if the output Voltage is the smaller than required then this error will be positive; and if the output Voltage is much more than required then this error will be negative. Now this is ok, we do not need $k*V_i$, we just need V_i which is the input Voltage which of course is available.

Now, what should happen is that if $V_i - (V_o / k)$ is positive, output must be increased; and if $V_i - (V_o / k)$ is negative, the output must be decreased. And what is the op amp do, if V_d is positive, the output is large and positive, and the more positive V_d becomes the higher the output Voltage will be it will increase the output Voltage that is positive values of V_d will tend to increase the output Voltage and negative values of V_d will reduce the output Voltage to large negative values. So, it is clear that this $V_i - (V_o / k)$ should be the difference Voltage of the op amp, the input Voltage of the op amp. In order to be able to implement this, we need V_o / k where of course, k is more than one because this is an amplifier and that is very easy to obtain how do we obtain (V_o / k).

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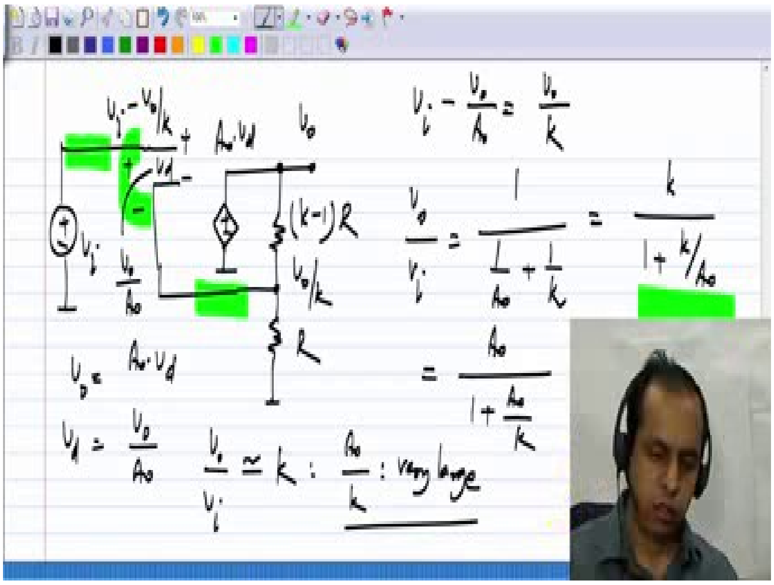

If you have V_o here, so let say we have V_o there, we can obtain V_o / k by having a resistive divider of this ratio (k-1)R and R. So, this gives me V_o / k and I have my input source V_i. The op amp has two input terminals, so if I connect V_i to one of them, and V_o by k to the other, we get V_i - (V_o / k) . So, this does appear to be in the correct direction if V_i is more than V_o / k then this positive value will drive up the output of the op amp. And similarly, if V_i is less than V_o / k, the negative value will drive down the output of the op amp exactly as you want.

So, now we need to insert the model of the op amp which is the Voltage controlled Voltage source and see what exactly the output Voltage will be. If you do that this is V_d and you know that the model for the op amp is A_o*V_d. So, V_o is A_o*V_d or V_d is V_o/ A_o. So, this number here is V_o/A_o. Now all I need to do is to write one equation this Voltage is V_i, this Voltage is a V_o/A_o and this Voltage is V_o/k. So, V_i - (V_o /A_o) = V_o / k, so it is very easy to see that V_o / V_i = (1 / (1 / A_o) + (1 / k)). You can also be written as k / (1 + (k / A_o), and it can also be written as A_o / (1 + (A_o / k))and on so on.

If you are familiar with the op amp circuit, you would have probably seen all these forms. I will use this form, and in this you have k that desired gain in the numerator. And something in the denominator, and you can see that the denominator approaches one if this k / A_o goes to zero or A_o goes to infinity. So, V_o/V_i is approximately k, if A_o/k is very large.

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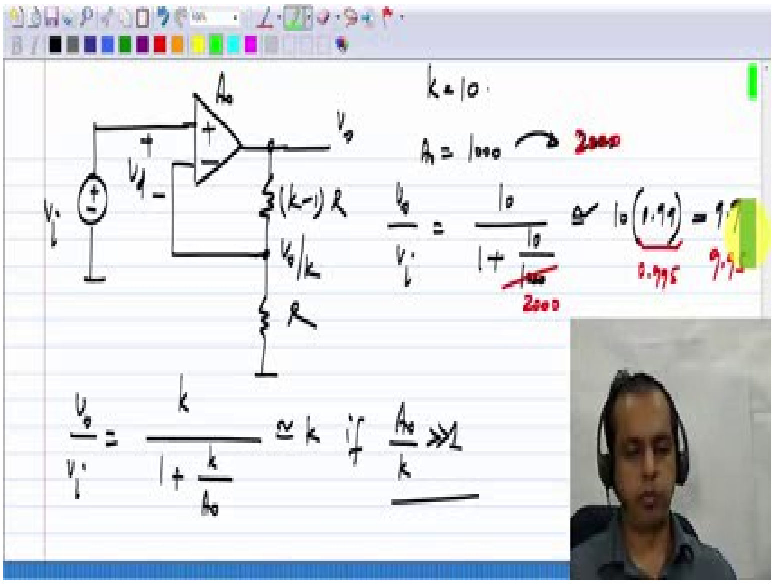

So, this circuit here using an op amp, which we model as a Voltage controlled Voltage source and that is how it is conventionally model frequently. We can divide the output Voltage using a resistive divided and the input is compared to the divided Voltage and output is driven based on comparison, so that is V_d and that is V_i. And if the op amp gain is A_o that is if the Voltage controlled Voltage source inside the op amp has a gain A_o then V_o/V_i equals $k/(1 + (k/A_o))$, and this will be approximately k, if $A_o/k >> 1$. Essentially A_o the gain of the op amp has to be very, very large.

Now, this of course is probably familiar to you and also I am going rather quickly through this, because this is a treated in courses like basic electrical circuit. If you are not familiar with this please go back to these lectures and brush up yourself. The bottom line is we can realise a negative feedback amplifier, negative feedback Voltage control Voltage source using an op amp which is by itself a Voltage controlled Voltage source, but the important thing here is that even if A_o changes by some amount, let us taken example where k=10 and let say A_o=1000 then V_o/V_i will be 10/ (1 + (10 /1000)) which approximately is 10*0.99 or 9.9. And let say A_o changes to 2000, what happens then instead of this 1000 here, you have 2000; and instead of this 0.99, you will get 0.9995, so the gain becomes 9.95.

So, this is the advantage of negative feedback. You may be wondering why I realised the negative feedback control Voltage controlled Voltage source using an op amp which is by itself a Voltage controlled Voltage source, this is the reason the parameter of the Voltage controlled Voltage source within the op amp, the again of the op amp can vary by quite a bit, it can vary by factor of the two. But you can see that V_o/V_i the closed loop ratio of the Voltage controlled Voltage source is changing from 9.9 to 9.95, changing very little. So, negative feedback circuit have this advantage of having low sensitivity to amplifier parameters and amplifier parameters tends to vary a lot because they are based on semiconductor devices. So, if you realise these things using negative feedback, you can have very well controlled parameters that is the idea. So, this is a Voltage controlled Voltage source using an op amp.