Basic Electrical Circuits
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Lecture – 105

In this lesson, we look at how to systematically analyze op amp circuits.

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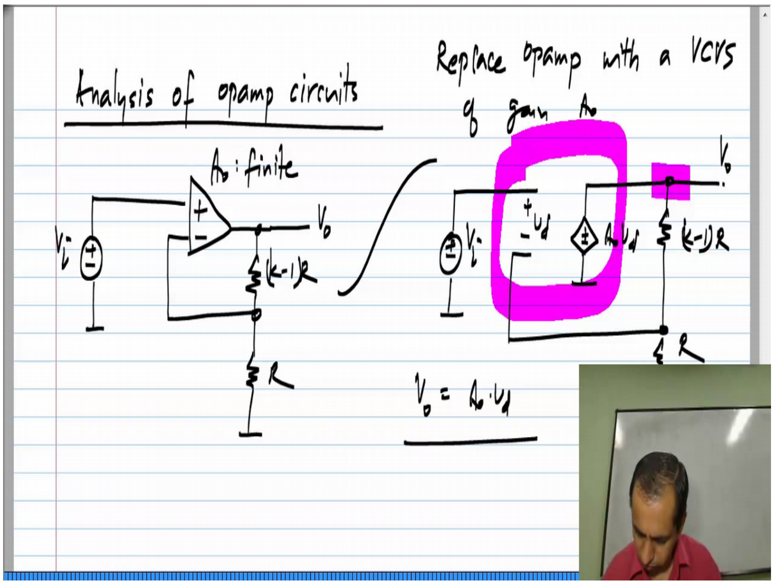

Now, if the op amp is not ideal it will have a finite gain and then, analysis has no different from what we have discussed earlier of our circuit analysis, when the circuit has control sources. Because, let us take the same circuit we been considering and let say, A naught is finite; that is, the op amp is not ideal. So, then, I mean the only thing different between this and all the circuits we analyzed before is the symbol, all we have to do is replace the op amp with a voltage control voltage source of gain A naught. So, my circuit becomes this, this is V d, this is A naught V d.

So, now we have this control source and we know how to handle voltage controlled voltage sources. We have to basically replace the voltage control voltage source with a super node and we will lose one equation, we cannot write KCL at this node, we replace that by the equation governing the voltage control voltage source. So, in this particular case we cannot write an equation, a KCL equation at this node, let say if you are doing nodal analysis, but we can do it at this particular node and then, we use the control source equation which is V naught equals A naught times V d as the extra equation.

So, we have already discussed how to do nodal analysis with voltage control voltage sources. We also know how to do mesh analysis with voltage control voltage sources. So, this is not a difficult thing at all; in fact, with non ideal op amps the analysis is easy, it is the same as analysis of any circuit with voltage control voltage sources.

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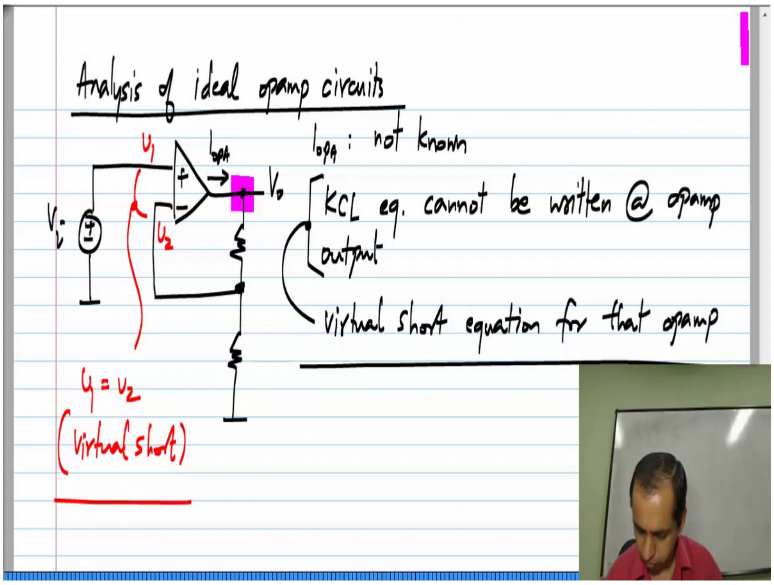

Now, as far as analysis of ideal op amp circuit is concerned, now we cannot use the previous approach, because for an ideal op amp the gain A naught is infinite. If you have multiplying factor which is infinite, we cannot write legitimate equations. So, what we do then is the following. Again, the problem is that we do not know, what is the current at the output of the op amp, if I call this I O P A, I O P A is not known; that is, it is unrelated to the characteristics of the op amp. We cannot write some equation based on what the op amp is.

This is similar to, how when we had voltage sources either independent or controlled, we could not write an equation for the current through the voltage source from the property of the voltage source. So, that is determined by what is connected do it, so we replaced it by some other equations. So, in case of the ideal op amp also we will not be able to write KCL equation at the output node of the op amp. So, instead we have to use the virtual short equation. So, this is V 1 and V 2, V 1 equals V 2 and this corresponds to the virtual short.

So, bottom line is KCL equation cannot be written at op amp output. So, for each op amp, so far we have been considering only circuits with single op amp, if you have multiple op amps, the principle is the same. So, in KCL equation add the op amp outputs is replaced by virtual short equation for that op amp. So, that is the way we analyze op amp circuits in general.

Now, you have to always keep in mind that this virtual short applies, only if the op amp is negative feedback that has to be check separately using ideas we have discussed earlier, that you have to check that every op amp is negative feedback. But, once it is a negative feedback, the inputs are virtually shorted and you can use this for analysis of circuits with ideal op amps.

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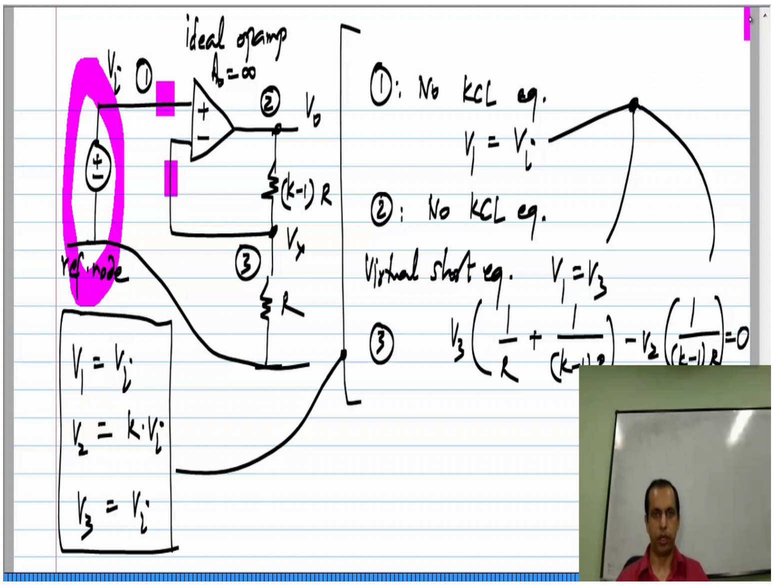

So, just for completeness let me analyze this circuit, we already know the result, but I systematically put down the nodal analysis equations. So, now we have an ideal op amp and there are three nodes 1, 2 and 3. Now, we will try to do nodal analysis, which means that we should try to write Kirchhoff's current law equations at all the nodes. The reference node; of course, is the ground, this is the reference node. Now, if you look at node 1, there is a voltage source there so; that means, that we cannot write KCL equation over there. Instead of that, we have to essentially write the consistent for this voltage source.

What you do is really is you form a super node with node 1 and the reference node, because you do not write any equation for the reference node, you cannot write any equation for this super node either. Instead of that, you simple have the constraint imposed by this voltage source, which says that V 1 the voltage at node 1 equals V i, the source voltage. Similarly 2, we cannot write the KCL equation, this node is connected to the op amp output. So, we do not know the current flowing out of the op amp.

So, no KCL equation there, instead of that we write the virtual short equation. What is the virtual short equation say? It says that this node voltage and that node voltage are the same; that is, V 1 equals V 3 and finally, at node 3 we can write the KCL equation. So, that is V x which is the same as V 3, so let me use my usual notation, which is V 3 times the sum of conductance's, which is 1 by R plus 1 by k minus 1 times R minus V 2 1 by k minus 1 times R equals the total independent current source being inducted in to this node, which is 0.

So, if I solve with these three equations, this one, that one and that one, so essentially I will get the solution, which is that V 1 equals V i, V 2 equals k times V i and V 3 equals V i. So, this is the solution to these three equations. So, if you have a complicated circuit with many op amps, again you replace, you cannot write Kirchhoff current law equations at the op amp outputs. So, you forget that, you instant write the virtual short equation for that particular op amp.

Clearly, this method applies only when all the op amps in the circuit are in negative feedback, which has to be checked separately. So, then you will have as many equations as you have unknowns. If you have other voltage sources in the circuit, you have to use the super node concept, I am assuming you will do nodal analysis, but whatever we discussed for mesh analysis also applies here. Similarly, if we have controlled voltage sources, then we again have to form super nodes and so on. So, everything else remains conventional. The op amp, the equation at the output node is replaced by virtual short equation at the op amp inputs.