Analog Electronic Circuits
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Lecture - 21
The Ideal Operational Amplifier

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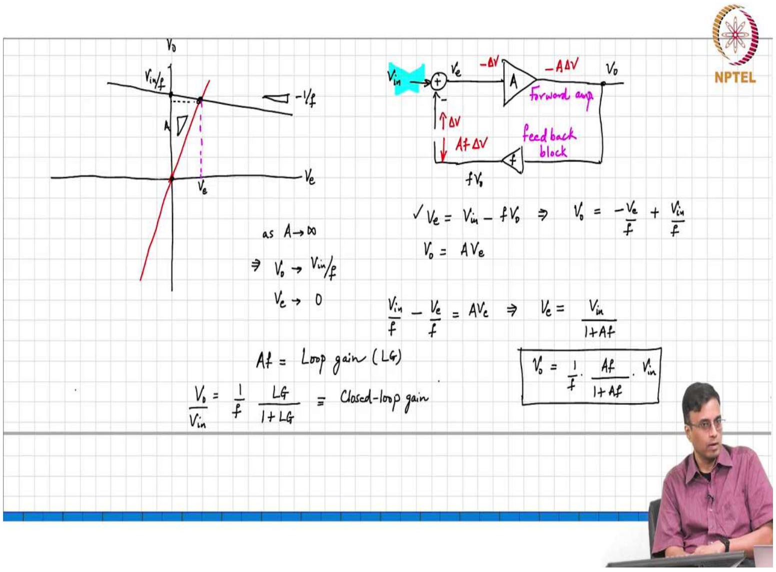

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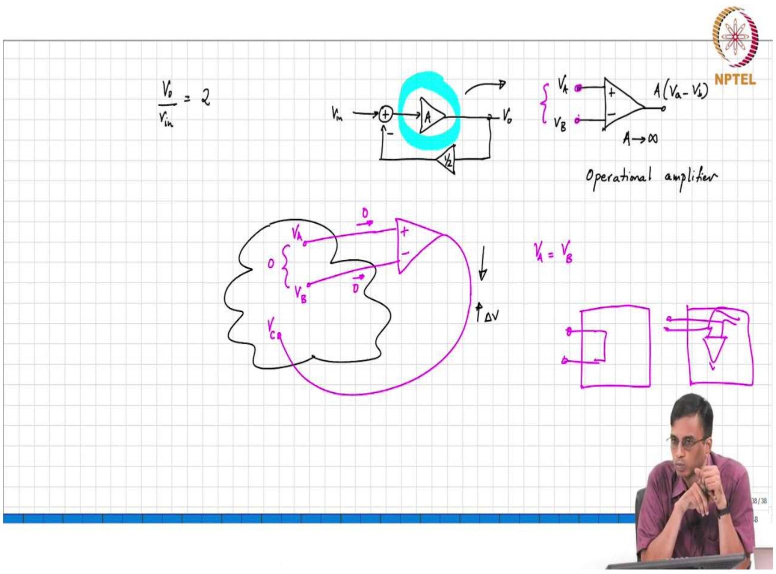

Alright, now let us apply this to some circuits that you know very well. So, the simplest thing is let us say we want V_o by V_i to be equal to 2. So, what do we want f to be?

Remember that V_o/V_i is now A. If the loop gain tends to infinity, V_o/V_i must be equal to 1/f which is in this particular case?

Student: 1 by 2.

1 by 2. So, this is V_i and this is half and this goes to an amplifier. Ideally what do we want A to be? Ideally, we want A to be infinite, but in practice, please recognize one thing, nothing in the world which is supposed to be infinite will be infinite. Nothing in the world which is supposed to be 0 will be?

Student: 0.

0, alright. So, as A tends to infinity clearly V_{out} equal to twice V_i. Now this as you know. So, now, if somebody wants a gain of say 5, what will you do?

The only thing that needs to be changed is assuming that A is very very large then if you want to get a different gain, the only thing that needs to be changed is the feedback factor. You change it from 1/2 to 1/5.

So, now, if you are a company building amplifiers. This is a great business opportunity because, what will you do? What will you sell? One thing you can do is you set up a website where somebody keys in the gain that they want and all of a sudden you have a technician here who goes and finds some appropriate feedback factor and then builds the part and then ships it out.

Is there a smarter thing to do? So, if you want a job you apply to him, ok. So, the thing to do is basically say forget about I am not going to be in the business of figuring out what value of resistors I must use to get the appropriate feedback factor. What I am only going to sell is that block in blue, whose job is to take. What is that block in blue doing? It is finding that it is amplifying the difference between?

Student: Two voltages.

Two voltages, right. With a gain equal to ideally infinity, but in practice as large as I can get. So, it's a voltage-controlled voltage source with two inputs. So, that is basically I have 2 terminals V_A and V_B and put out an output voltage which is A times?

Student: V_A minus V_B.

V_A minus V_B, where A tends to infinity, ok. So, if you go and buy an off the shelf contraction like this that will be 10^7, 10^8 whatever. So, this way I do not have to bother with anything I just keep selling this as a general-purpose building block. He wants a gain of two. Will he put a feedback factor?

Student: 1/2.

1/2. If somebody else wants a feedback gain of 2.42 he or she will put a feedback factor of 1/2.42, right. So, the user basically decides what feedback factor he or she wants, ok. The only thing that the company sells is this box which simply gains up the difference between two voltages by a large number, correct.

So, this is called the operational amplifier. And if the operational amplifier is embedded inside a negative feedback loop. So, let us say there is some network. So, $V_A V_B$ and some V_C, ok. And first of all how will we figure out if there is negative feedback around? If this op-amp is part of a negative feedback loop how will we figure that out?

Student: Break the loop.

Well, we do the same thing that we did before, namely you break the loop. You yank one side up like this some ΔV. You go through the network and then come see what comes back. What if what comes back is in the opposite direction of what you put in right then?

Then the operational amplifier is embedded inside a negative feedback, correct. Now if the op-amp is embedded inside a negative feedback loop and the gain is infinite. Let us assume that the op-amp is ideal for the time being and that the gain is infinite. What comment can you make about the error voltage? For example, there is a look here that A is infinity, right. And the circuit is working. When you say circuit is working what does it mean? No quantity inside the loop becomes? No voltage or current becomes? No voltage or current will become infinite. Do you understand this much or no?

Student: Understood.

So, if the output voltage V_o is finite and if the gain A is infinite what comment can you make about the difference? Between the input and the output the error voltage must be?

Student: 0.

0. If somebody told you that the circuit works and A is infinite. Even if you did not understand why the circuit should work. If something is working it means that it has not gone up in flames right, and it will not go up in flames. It will go up in flames only if some voltage or current has gone to infinity.

So, if it is not gone up in flames, that means, V_o is finite. If V_o is finite and A is infinite it must follow that that error voltage driving that infinite gain must be?

Student: 0.

0, is this clear?

Student: Yes.

So, therefore, if an op-amp is a part of a negative feedback loop, then it must follow that the assumption is that the op-amp is ideal, so that its gain is infinite. Then what comment can we make? So, that basically means that the op-amp is in a negative feedback loop and the gain is infinite then it must follow that the error voltage which is the difference between in this particular example it is the difference between?

Student: V_A and V_B.

V_A and V_B. This must be equal to.

Student: 0.

0. Does it make sense? And of course, the op-amp is a voltage controlled voltage source. So, what comment can you make about the current flowing in?

Student: Infinite.

Infinite. So, what is the current flowing there?

Student: 0.

0, alright. So, therefore, if the op-amp is embedded in a negative feedback loop then the potential difference between the two inputs of the op-amp is 0, ok. And the current flowing in is?

Student: 0.

0. If the voltage difference between two nodes is 0 what do you call that?

Student: Short circuit.

A short circuit, but what is the difference between a short circuit and a between nodes A and B.

Student: they are not connected.

They are not connected, alright. Yeah. So, what is the difference? I will give you an example, right? So, if two nodes are coming out of a circuit, their potentials are the same. In one box there is an op-amp embedded inside a negative feedback loop. So, I am bringing these two terminals out. So, the terminals are going inside somewhere, but I am just bringing these two terminals out in another case, I have a real short circuit. So, what is the difference between the two?

So, what is the definition of a short circuit? Two nodes are a short circuit if the potential is the same and the potential you can pump in whatever current you want. And what is a short circuit? In this case between these two nodes can you push in whatever current you want?

Student: No.

You cannot. There is no current, ok. The voltage is the same, but there is?

Student: No current.

No current. So, this is like a short circuit, but not a short circuit. So, this is what is called a virtual short, and. So, the key point is that a lot of people have this conceited notion that if you take an op-amp the difference between the two input voltages is 0, is that correct or wrong?

Student: Wrong.

What is wrong about it? Only if the op-amp is part of a?

Student: Negative feedback.

Negative feedback loop, ok. If there is no negative feedback then you know then this will not be true. Now let me ask you another question.

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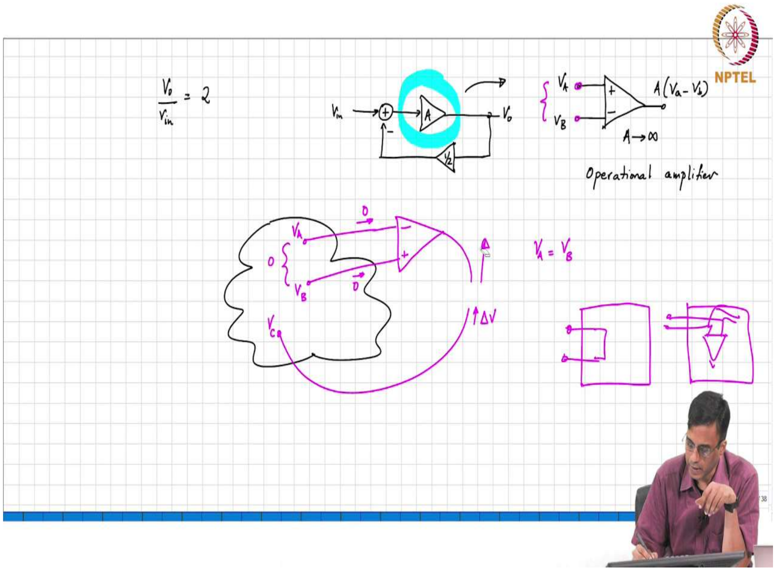

So, let us say we break the loop somewhere, say here and we apply a voltage in that direction. We apply a voltage ΔV_i that direction. What comes back is a voltage going in the same direction at the other end of the loop, right. What does this mean?

Student: Positive feedback.

It is positive feedback, alright. And so, if you want to give it negative feedback what will you do?

Student: Must change the sign.

Change the sign of the op-amp right, by flipping the input connections, right.

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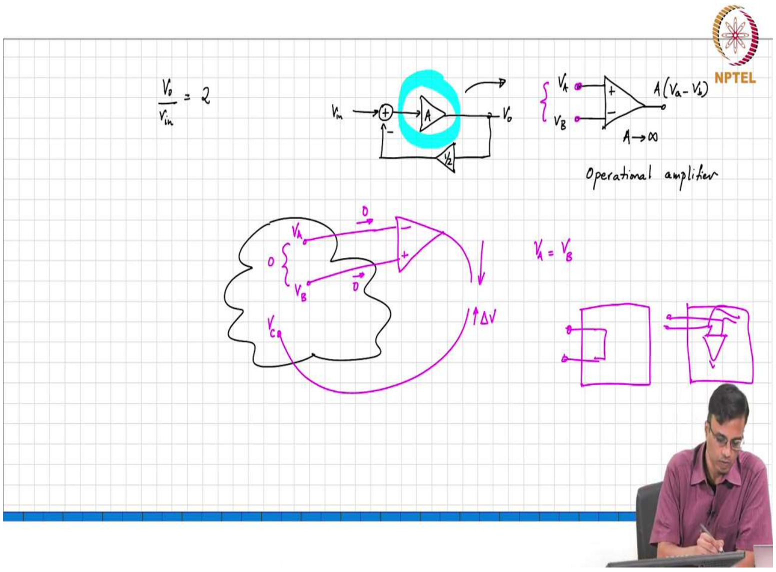

And in which case you will get the output going in the opposite direction. Because many times in a circuit it will not be as I said life does not come in block diagrams, right. So, it is not that when you are designing circuits you will see some square coming up in front of you saying forward amplifier another square coming up triangle coming back saying feedback block and something sticking out saying error voltage, ok.

You have to look at the circuit and figure out what is what. And make sure that there is negative feedback. Of course, in all the simple circuits that you have done you most likely mucked up the science, ok. Because that is what is there in the textbook, ok. But in reality, when you are going to be inventing new circuits all the time, right.

And that means, it is not there in the textbook which means you have to go and figure out what the designs of the op-amps should be, ok. And the recipe is very straight forward, you break the loop, you yank one side up to see what comes back if what comes back is in the same direction as what you put in it means that there is positive feedback. So, you flip the signs of the op-amp.

So, you assume some arbitrary science first to see what comes back. If what comes back is the same as what you put in, that means, that there is positive feedback otherwise there is negative feedback, alright, ok. So, with that I will stop. We will continue tomorrow.