Basic Electrical Circuits
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Lecture - 86

In this and some of the following lessons we look at a very useful circuit block known as the operational amplifier or the op amp. It is really a control source, but when it is used like an op amp it has certain properties, which makes it very, very useful and that is why it is used very widely. So, we are going to look at certain op amp circuits and also how to analyze op amp circuits in general.

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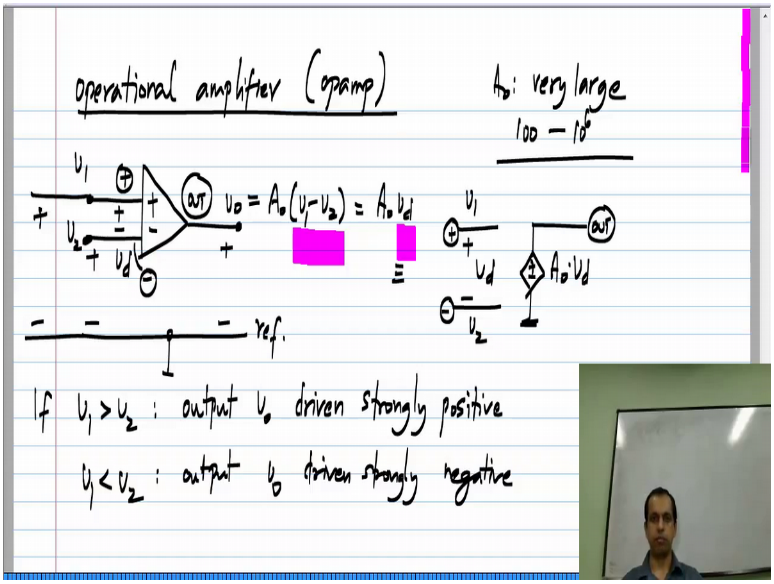

It is frequently abbreviated as op amp. So, what is it? It is denoted by this symbol, so it has two inputs; that is, if you assume that there is some reference node here, then we have V 1 and V 2 at it is two inputs; that means that, V 1 is the voltage between this point and ground V 2 is the voltage between that point and ground and V naught is between that and ground and this V naught is A naught times V 1 minus V 2.

So, typically this difference between V 1 and V 2 is denoted V d. So, V naught is dependent only on the difference voltage between it is inputs, so that is what an op amp is. Now, looking at this definition it will be obvious to many of you, that this is nothing but, a voltage controlled voltage source. Now, the voltage controlled voltage source is such that the controlling voltage between it is terminal is denoted V d and the control sources A naught times V d and one of the terminal of these control sources, the bottom terminal as I have shown here is connected to ground, which is the common reference voltage and this happens internally to the op amp, this is not a connection that you make.

So, these three terminals are available to you, this is denoted plus, that is denoted minus and this is the output. So, this is the plus terminal as it is marked inside, this is the minus terminal as it is marked inside and that is the output terminal. So, this is what an op amp is, it is a voltage controlled voltage source. So, what distinguishes an op amp from a general voltage controlled voltage source, the point is that this A naught is suppose to be very large.

So, an op amp is a voltage controlled voltage source with a very high gain. What is very large depends on the context? It could be that in some context, 100 is large enough or in some cases you need a million, so the point is that it is very large. In fact, frequently we take the limiting case of A naught being infinity and in one of the following lessons, we will deal with the case when A naught is infinity.

So, what can we do with this? What does it mean? So, this is the voltage controlled voltage source, this means that this voltage is V 1 with respect to ground, this is V 2. Now, what does it mean for us to have a voltage controlled voltage source with a very large gain? This means that if V 1 is larger than V 2; that means that this V 1 minus V 2 this is positive or this V d is positive.

So, if V 1 is more than V 2, it means that the output V naught this voltage is driven strongly positively. Because, A naught is very large for a small positive difference V 1 minus V 2, you will have a very large positive output. So, for now I will described it as the output V naught driven strongly positive. Similarly, if V 1 is smaller than V 2, then this difference V 1 minus V 2 is less than 0, this V d is less than 0 and the output V naught is driven strongly negative. So, this is an important feature of the op amp and this is what we will use to realize the very useful class of op amp circuits based on negative feedback.

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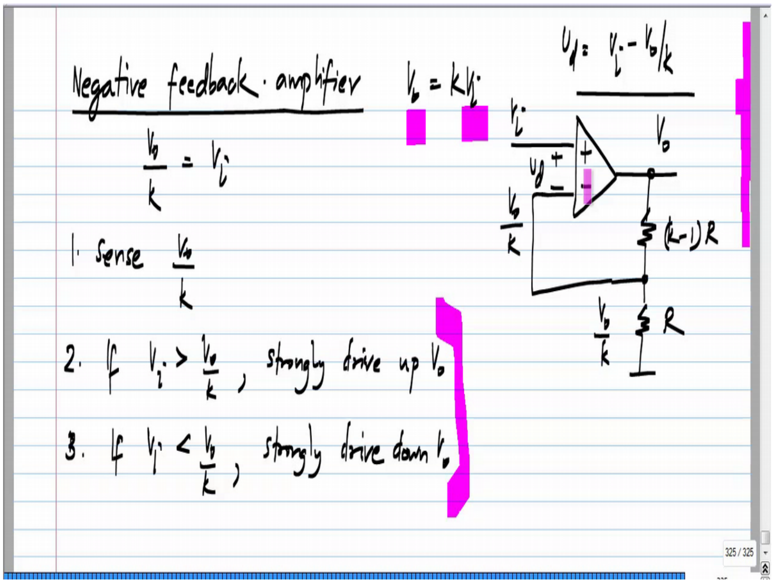

So, what does negative feedback mean? First of all feedback means that, you somehow drive the output, after looking at the output comparing it with some desired value and making some computations; that is, what is the meaning of feedback. Feedback means that you look at what the output is before you do something to change. The contrast to this is open loop control, where you set the input to something without looking at the output.

So, I will give you an example of driving a car, an open loop control is when let say you do not have a speedometer at all. So, you have some strange vehicle without a speedometer, then toward a certain speed you have some vague idea of the speed you want to go to and then for that, let say you press the oscillator down to certain extent, may be half way down. Now, you have no idea what the speed is, you just get whatever the vehicle gives you, if you press the oscillator half way down it will go out certain speed and that will depend on the properties of the vehicle may be of the road, the fiction, the oscillator and all of that, that is all.

Now, in contrast to this closed loop control is one you are actually measuring the speed; that is, the normal thing where you have a speedometer which tells you what a speed the vehicle is going at. So, you look at the speedometer and then you make adjustments to the oscillator, you adjust how for you press down. So, that it goes at a desired speed, let say 50 kilo meters an hour. So, clearly in one case you are looking at the output; that is the second case when you are looking at the output you are operating in feedback, whereas in the other case where you did not have any idea of what the speed is, you just press down the oscillator half way down, you are an open loop system.

Now, it is very clear that if you have feedback, you can set the speed lot more accurately then if you have an open loop system; that is the motivation for realizing negative feedback systems, I mean in our case we want to make an amplifier let say. So, in my case I want to make an amplifier using negative feedback, let me set V naught should be equal to k times V i. I will just recast this relationship as V naught by k should be equal to V i.

Now, how does the op amp help me? What I will do is the following. I sense V naught by k, how I will do it, I will show it to you in a short while. If V i is more than V naught by k, I strongly drive up V naught, V naught is the quantity I want to control, it is my output, whereas V i is the input. So, if V i is more than V naught by k; that means, that V naught is too little. So, I will strongly drive it up, so that it goes in the right direction and if V i is smaller than V naught by k, I strongly drive down V naught.

So, if V i is smaller than V naught by k, it means that V naught is too high, so I have to drive it down. Earlier I described the op amp as something that strongly drives the output positively, if V d is greater than 0 and negatively, if V d is less than 0. You see that, it essentially accomplishes what we are looking for over here. So, an op amp which is the voltage controlled voltage source with a very high gain can be used to realize this amplifier.

So, how do I do that? The output of the op amp must be V naught and it must be driven up strongly; that it is must be driven strongly positively, if V i is more than V naught by k. So, I have to apply V i to one terminal and V naught by k to the other terminal. So, with this polarity the op amp response to V i minus V naught by k. My difference input voltage V d is V i minus V naught by k and similarly, if V i happen to be smaller than V naught by k, the op amp will strongly pull down V naught, it will drive it strongly negatively.

So, this is exactly what we want. The only thing we need to do in order to complete the circuit is we have to somehow obtain this V naught by k, which is the fraction of V naught. Remember, we are realizing an amplifier, so this case more than one, so V naught by k is smaller than V naught. Now, it is very easy to derive a smaller voltage from a larger voltage, you can do that using a resistive divider. So, if I realize the resistive divider like this, where the upper resistor is k minus 1 times the lower resistor, the voltage that I get over here is V naught by k, so that I take and connect over there, where I wanted V naught by k, so this completes my circuit.

So, I derive the circuit from the idea that if V i is more than V naught by k I should drive up V naught strongly and if V i is smaller than V naught by k I should derived on V naught strongly and I had a block and op amp, which is the voltage control voltage source with a very high gain, which does this business of strongly driving up or strongly driving down the output, so I have realize it like this.

So, now, we can use your circuit analysis machinery to see exactly what this does right now I diverted based on some intuition and negative feedback, but we can use or knowledge of analyst to figure out what it does.

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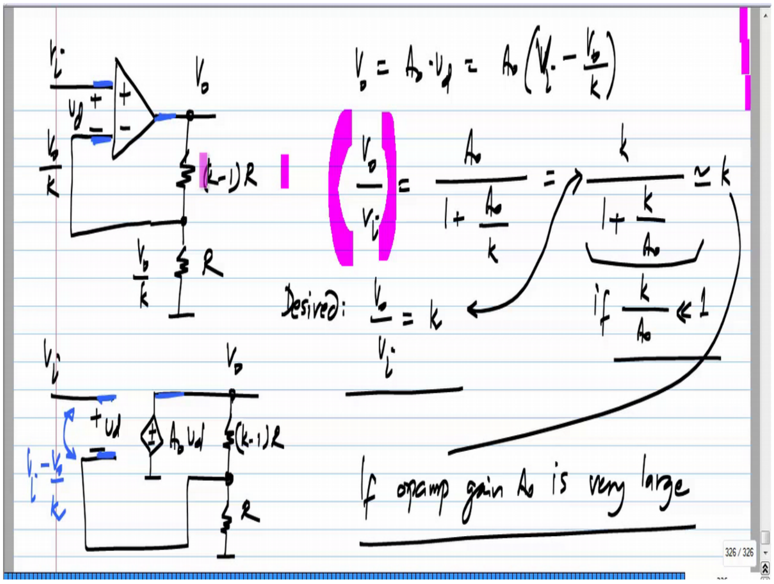

Initially, if your little bit confused with the op amp symbol, you can substituted with control source symbol, this is A naught V d and this voltages V d I have not the anything here, if simply substituted the op amp with the control source the three terminal. So, the op amp here, here and there correspond to this one, that one and that one respectively very, very simple circuit analyze. The output voltage here V naught is A naught V d and V d is the unknown, but V d V know is V i minus V naught by k. So, this difference here is V i minus V naught by k.

So, the output voltage V naught is A naught times V d which is A naught times V i minus V naught by k. So, while taking terms containing V naught to the other side I get this ratio V naught by V i to be A naught by 1 plus A naught by k which can also be written as k by 1 plus k by A naught. Now, what did I want my original goal was to realize an amplifier of gain k so; that means, that the desired function is V naught by V i equals k.

Now, what I have is not exactly this, but that one, but by inspection you see that this will be approximately equal to k, if k by A naught is much smaller than one. So, this is where the significance of A naught being very, very large comes in, the op amp has a very large gain A naught. So, this k by A naught is much smaller than one, if k is some modest value let us say A naught is 1 million and your k is 100. So, k by A naught is 1 by 10,000 which is the very, very small value compare to one.

So, in that case the gain of this amplifier V naught by V i which is k divided by 1 plus k by A naught can we approximated by k. So, this is true if op amp gain A naught is very large. So, this is the reason we need a very large gain in the op amp, then the gain of this amplifier is k which depends only on ratio of resistance it is depends on this resistor and that resistor. So, this is an amplifier using negative feedback using an op amp and it gives us feedback control amplifier of a gain which is very, very close to k.

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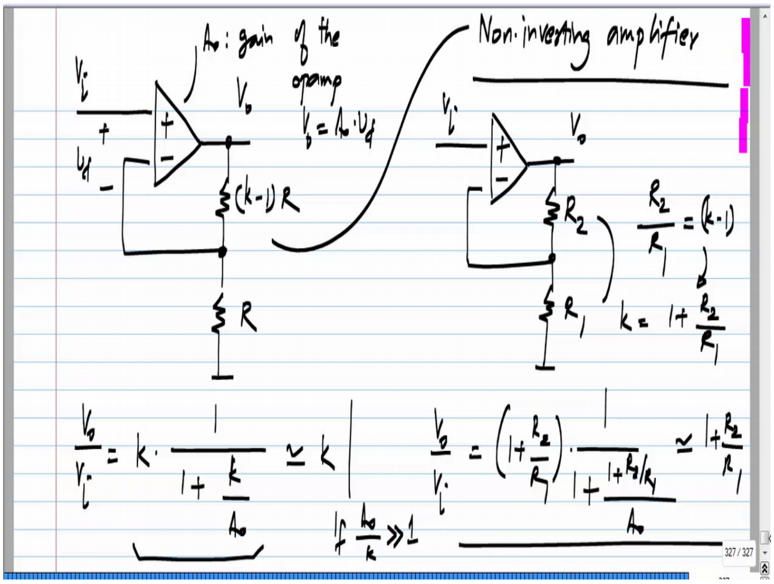

So, some quick comments on this circuit have set the resistance value the upper one to be k minus 1 R, the lower one to be R and the actual gain of this is k by 1 plus k by A naught, where A naught is the gain of the op amp, it means that if this difference voltages V d the output V naught will be A naught times V d and if A naught is very, very large this gain is approximated by k, this is if A naught by k is much more than one.

So, in that case the denominator becomes approximately one and the gain is just k, this particular circuit it is a classic op amp circuit known as a non inverting amplifier and very frequently you seat in textbooks with a slightly different notation for resistors, this is called R 2 and R 1, the circuit is exactly the same. So, R 2 by R 1 is nothing but, the ratio of this resistor to that resistor which is k minus 1.

So, the gain of this non inverting amplifier when I denoted the two resistors as to R 2 and R 1 is V naught by V i the same formula holds early thing is I would express k in terms of R 2 1 R 1. So, clearly from this we see that k is 1 plus R 2 by R 1, so the gain is 1 plus R 2 by R 1 times 1 by 1 plus 2 by R 1 divided by A naught which is approximately equal to 1 plus R 2 by R 1 if the op amps gain A naught very large, some of you who are familiar with op amp circuits would already be familiar with this formula, what I showed you is, how this negative feedback circuit is derived it operates based on sensing the output, sensing a fraction of the output comparing in to the input and driving the outputs strongly upper down based on the difference.