Network Analysis
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Lecture - 80
Examples of Ideal Op-Amp Circuits – I

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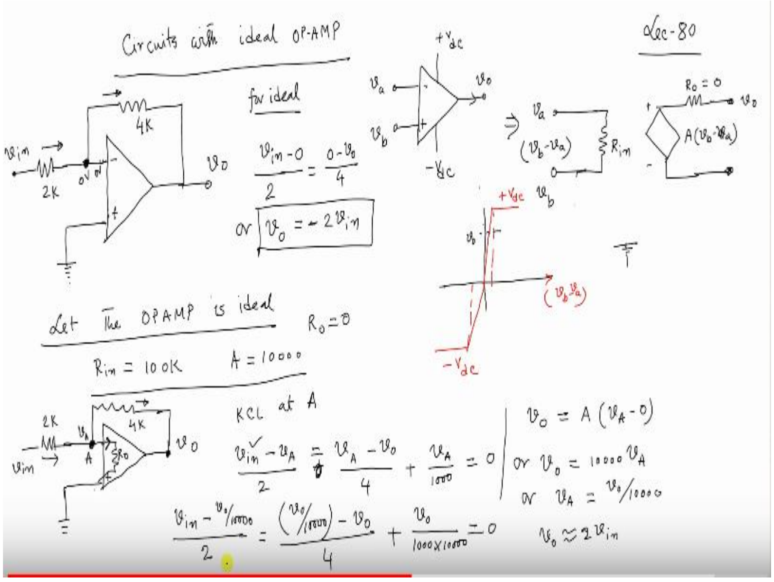

So, we have been discussing with circuits with ideal Op-Amp and negative feedback and you can amplify signals and do hundreds of other things. But, here the emphasis is, I will consider the Op-Amp to be ideal and how to analyze this circuit from circuit point of view. For example, you recall that, in the Op-Amp, there will be two signals you will be giving, one is inverting and another is output.

Here you give Va, here you give Vb, and there will be an output, but you should not forget that it is a differential amplifier, and its equivalent will be if you look at its with respect to these three points. It will be the voltage applied across these two terminals is Vb - Va. That is what I have applied here and this voltage will be amplified, okay, and in general, it can have an input impedance, this one, and the output will be the amplified signal A times Vb - Va, and there may be output resistance also.

These two terminals and what are these terminals. All these potentials are with respect to ground. So, this will be your V0 here and Va is this one, Vb is this one with respect to that common ground. How do I get this ground from the supply to this Op-Amp? Which is generally not shown in the circuit? This is to apply even. The ground of this supply is this one, with respect to this point Va is defined. Vb is defined and V0 is defined like that.

So, but the point is the gain of this Op-Amp will be very large. If you sketch here, Vb - Va, it will be like this. So, over a very small range of Vb - Va, the output voltage beyond this range will either become plus Vdc or minus Vdc depending upon who is more. Vb is more or Va is more depending on that, you will get that. So, gain is very high. It is one of the assumptions made.

Rin is also, A may be say very large means for a good Op-Amp ideal sort of thing. The gain may be 100s of 1000s to 100s into 10 to the power 6, very large. Similarly input impedance could be 100k to 10 giga ohm. Input impedance very high and output impedance is very low, may be some 10 to 100 ohms. Hundred ohms is a large resistance, but compared to this value, it is quite small. So, that is with respect to what we are discussing.

Therefore, that is very important when you neglect some terms. For example, if somebody says that I have an Op-Amp, which is not so ideal, but these values are given. Then how to solve it. For example, this circuit we have done last time. Let us take some good circuit like this. This is minus, this is plus, just to tell you what is the implication of this term. This is the thing.

Here you connect suppose 2K resistance, here we will give you input Vin, which is connected to terminal A, and this one you keep grounded, and here you connect a 4K and this is your output voltage and this is 4K. Now, if it is ideal, then what I am telling is this V0 will be this range. V0 is not negligible, it will be quite large, but to get that V0, in this linear zone, you require a very little voltage across these two terminals, that is what is important and I neglect that.

If gain is higher and higher, you will require lesser and lesser voltage existing between these two points, if the gain is very large. So in case of infinitely of large to get a finite output voltage V0, the voltage necessary will be almost 0. That was the idea and also the input impedance is very high, therefore, no current will be drawn by the Op-Amp. These are the external thing I have connected.

Then to calculate, the relationship between output and input voltage, you just apply KCL here. If this is 0 volt, I will immediately say for ideal Op-Amp, I will say this is 0 volt. So, this is also 0 volt. Nothing doing, almost 0 volt and ideal Op-Amp 0 volt. So, what will be this current. Just one-line calculation. Vin, voltage across the resistance will be Vin with respect to ground all potentials are calculated minus 0, potential of this point with respect to ground. I have indicated arrow this way.

So this divided by 2K. If V is in volt and resistances are could be ohm, the currents will be in milli-ampere. Okay. Then, what will be the current this way. This current will be potential of this, which is 0 volt with respect to ground. Potential of output, in any case, I have defined it to be V0 with respect to this ground, therefore, voltage will be this current, then V will be equal to 0 - V0 by 4K and as you can easily see, V0 will be equal to - 2 Vin.

So, it will amplify the input signal. If it is sinusoidal with 1 volt peak value, it will become also sinusoidal peak value will be 2 volt, but it is reversed inside. There will be 180 degree phase difference. That is okay, but it will nonetheless amplify this signal. Now, suppose let us say that this Op-Amp, this same circuit, I will give you some numbers say let the Op-Amp is not ideal, and it has got this thing, suppose, this Rin of the Op-Amp is say 1000K or 100K, let us say, and gain is suppose 10,000 quite large gain, and let us assume, but let us assume the output resistance, this is 0. I do not want to make it more complicated.

Complicated means nothing like what you have to do now. In that case, if these two information are there with R0 = 0, then I cannot claim that the current drawn by Op-Amp through this path is 0. So, what will be KCL at this point. So, it is now like this. This point need to be emphasized. This is grounded plus and here there is a 2K resistance, and here I am giving you Vin. That is there.

But between these two points, there is now a resistance I am telling, input resistance and between these two points, of course, 4K is connected, it is like this. Now, while writing down KCL at this point, KCL at A, my goal is to find V0, what it will be. I will say, this voltage I cannot say it is 0 volt now. Let us say that voltage is Vin. I will say Vin - VA divided by 2K, current this way, it comes here, then current goes this way + Va - V0 divided by 4K, this is the current going this way, this I have calculated plus this current also, that is + VA by R0 and R0 value is 100K, suppose, I have assumed like that and this is equal to 0, got the point.

So, Vin and VA, this will be the thing. Okay, I want to find out V0. What are things known here. Vin is known. VA and V0 are the unknown things. Now, the question is what is VA. If you see, this VA is the current drawn into R0. I have to generate another equation, to solve for another equation I have to find out. What will be that equation? So, what will be the second equation. Second equation will be, a factor will come because this is the equation, I have to go through this.

So, this voltage V0 here, is A times Vb - Va. So, the second equation will be V output is equal to A times Va - 0, this is the other relationship. Now, what is this thing, V0, is equal to, A I have been told that is 10,000 into VA. This is what has been given to me. Therefore, if you want to calculate VA, V0, so, you can do that or VA is equal to V0 by 10,000. So, I will put that in. So, let me just write down.

It will become slightly more involved in calculations. Nothing else. So, Vin by 2 and for VA, I will substitute, VA I will remove, so V0 by 1000 + V0 by 1000 here, I have assumed to N to be like that minus V0 by 4 + VA. So V0, 1000 by 10,000. This will be equal to 0. Now, V0 can be solved. I am not going to solve, but I can easily solve V0. It is a single equation with single variable.

What I am telling, V0 will be very close to 2 times Vin. I assume Vin to be 1 volt, it may be 1.99 volts. Therefore, even if the input impedance value or gain is known, but if it is really large, we do not care. So, we will be henceforth assuming the Op-Amp to be ideal. Okay. Let us take few more examples. One example is this one.

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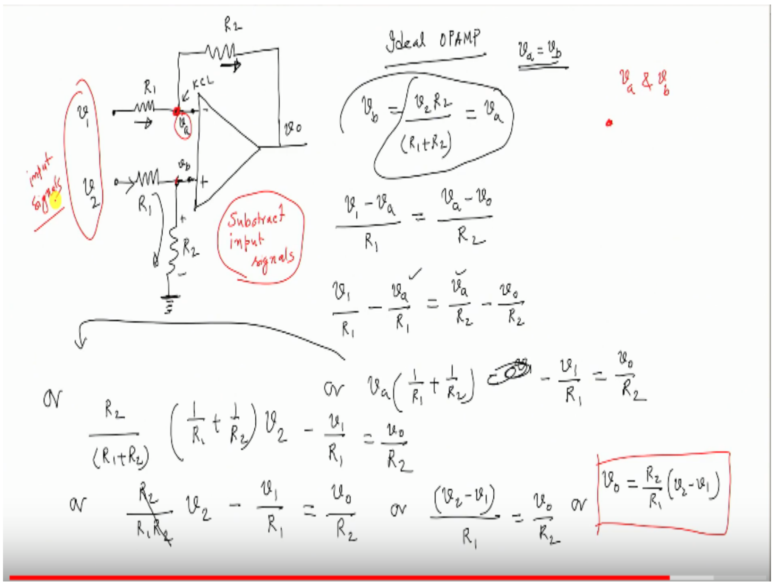

Suppose, you have got a circuit like this. It is all more and more problems. So, here it is inverting, here it is non-inverting, and the values of this resistances, this is R1, this is R1, and here is a point R2 and this is grounded. Okay and here is a negative feedback. Negative feedback is necessary through a passive element, either RL or C, there should not be any source here. Okay.

This is output voltage V0. Ideal Op-Amp and this resistance is also suppose R2, and here I will connect a signal Va and another input signal Vb, so, two inputs to be connected, it is connected like this. This is R1. Now how to analyze this circuit. Very quickly we have to do it. First thing, this is an ideal Op-Amp. So, it input impedance is very large. Therefore, there will be no practically current drawn by the Op-Amp.

There will be no current here in this branch or in this branch. That is what I will assume and also if no current flows. Therefore, the potential between this point and this point, that is the thing which gets amplified, this potential of this and this points has to be same. But note that, this point is not now grounded, so I cannot say this is at 0 volt, this is at 0 volt. So, what I have to do. Let me put it, so that in the context, let this signal be V1 and this signal be V2, and these are the input signal to the Op-Amp, Va and Vb.

That is what we are doing. Now, since no current is drawn, therefore what will be Vb. I will calculate fast. Because I am sure Vb will be equal to Va. Va and Vb has to be same. There will be no drop taking place here practically because to get a finite output voltage, the difference of this voltage Va - Vb, this difference will be very small. Ideal Op-Amp it is 0.

Therefore, potential of this point has to be equal to potential of point a, another input point. Now, what is Vb. Vb is, you see, if some current flows here, this current comes here. This current cannot be entered. Op-Amp will not draw any current. No current can exist. Therefore, the same current has to flow like this. So, what will be Vb then. Vb will be this current, which is independent of this thing.

Nothing is connected because no current is drawn here. So, V2 divided by R1 + R2, this will be this thing, into R2. The potential drop between these two points is your Vb with respect to this point. If this is Vb, I will say, this is also equal to Va and you are done. Therefore, the moment I know this potential, then I will write KCL here. KCL at this point. What is KCL, this current is V1 - Va, divided by R1, and what is this current.

This current will be Va - V0 divided by R2. Look at these arrows I have given. So, Va - V0, I have to do before dividing R2 to get this left to right current. Similarly, left to right current V1 - Va, all potentials are with respect to this common ground point. So, this will be the thing. What is our goal. Our goal is to obtain V0. Therefore, let us calculate that. So, Vb is this one, which is equal to this.

So, here you get V1 by R1, let us separate them, by Va - R1, is equal to Va by R2 - V0 by R2, if any missed out point or I will say Va into 1 over R1 + 1 over R2. That is these two terms. These I have taken to this side will be equal to V1 and I will keep V0 on one side. So, I have taken this term to this side and say minus V1 by R1, and this will be equal to V0 by R2. I can do that and then this is the thing, but Va is equal to this because input signals are V1 and V2, so V1 is there, I am happy, Va is there.

That should be expressed in terms of input voltages, and this I have already found out. This is the thing. Va is equal to from this to this, if you do Va is R2 by R1 + R2. For Va, I am writing into V2, and this is 1 over R1 + 1 over R2 is already there, into V2 and this one is minus V1 by R1, is equal to V0 by R2. This will be the thing. So, the important point is potential of this point and this point are same.

If it has got a negative feedback, and Op-Amp is ideal. That is the Op-Amp is non-saturated zone, linear zone it is operating. Therefore, there will be practically no voltage difference between these two points. It will be like this. So this one, if you calculate, this will be R2.

This R1 + R2 will cancel out, divided by R1 and R2 into V2 - V1 by R1 into V0 by R2. I want to calculate this difference in voltage. So, this R2 cancels.

So, you will have V2 - V1 divided by R1, is equal to V0 by R2, or I will say that V0 is equal to R2 by R1, into V2 - V1. That means, that this network is what is going to do. It is taking the difference of two input signals and amplifying it. If R2 is equal to R1, it will simply subtract that circuit. Two signals in signal processing, you often require two add signals, subtract signals, things like that.

So, here is a circuit, which subtracts input signals. Very interesting circuit. So, what is this tape involved. First take whether there is a negative signal, then it is in amplifier mode, and then this voltage. These two should be equal for the finite output voltage and you write KCL at this point. You write down KCL, and that will be one equation and then what is Vb. The current, this current has to be 0.

If that is to be 0, then in this circuit, I can calculate Vb in terms of input signals. So, Va and Vb should be expressed in terms of V1 and V2. That is all. That is what we have done. Okay. So, express this input voltages in terms of, these are the input signals, not Va, Vb input signals. I think we have understood this. So, this is called a subtracting two signals.

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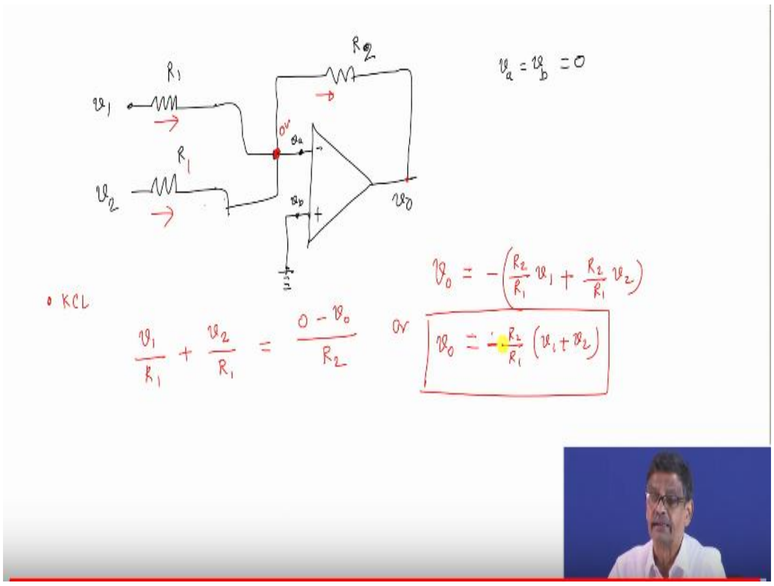

Similarly, you can easily see, you can add these two signals. For example, if you have two resistances, the calculations are very simple. One idea is there. Suppose, you have these two and this is grounded, and this is your output pin where you give a negative feedback with resistance. Say R2 and let us say this is R1 and this is R2, and here I will connect a signal V1, and I will give a signal V2, all with respect to this ground, and that is it, V0, R1, R2 and this potential and suppose this Op-Amp is ideal, and it is operating in linear zone, then I will say potential of this is a, this is b, this is the clue, Va must be equal to Vb, but this time, Vb is equal to 0.

That is all grounded. Then you write KCL at this point, red terminal. KCL is very simple because this is 0 volt, you write down, so this current is V1 - 0 by R1 straight. This current, plus V2. This is also let us say R1, corrected. Suppose, these two resistances are equal, so V2 - 0 by R1. This current. What will be the current? This branch 0 because it is an ideal Op-Amp. It is not drawing any current.

The sum of the current must draw through this point. So, this plus this must be equal to 0 and this potential is V0 with respect to this. So, 0 - V0 by R2, it will become or I will say V0 is equal to minus of if you bring all this thing this side, R2 by R1 into V1 + R2 by R1 into V2, this will be the thing. Bring R2 this side appropriately, so this is equal to - R2 by R1 into V1 + V2.

So, this signal, so this circuit adds two signals provided here. You could have more signal V3, that will also get added up. If R1 equal to R2, it will be simply adding the signals, otherwise, the signals will be added and will be amplified by this factor, and do not forget about the negative sign, it will reverse the 180 degree phase sheet. Okay, it will add two signals, multiply it with the amplification factor and then reverse its sign. Anyway, thank you, we will continue with this.