Network Analysis
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Lecture - 79
Ideal Op-Amp.

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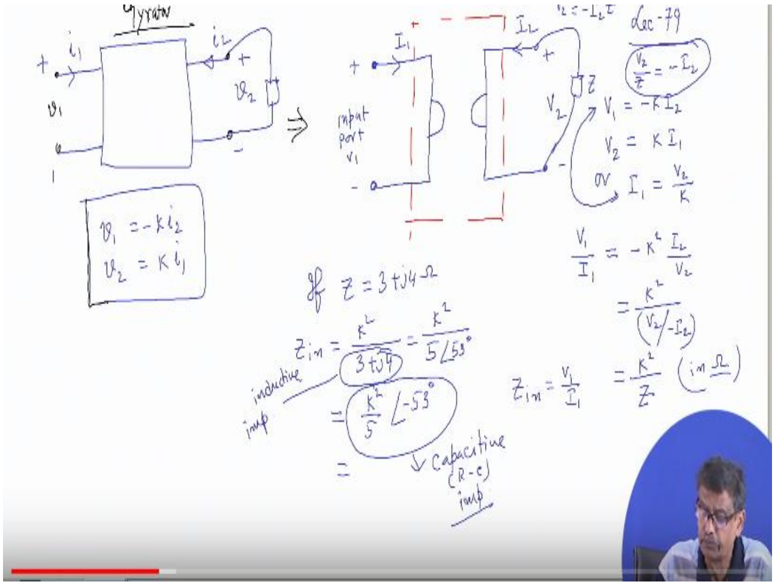

So, we have been discussing with gyrator and you are drawing it like that. These two are input port and these two are output port and relationship of the input port, voltage and currents are like this and you can always write its jet parameters or ABCD parameters, but always be careful I have been doing all these things. With this, the detection of i2, jet parameters will be absolutely fine. But ABCD parameters when you do minus i2, you replace by i2 because the fact for ABCD parameters only it is taken outside, throwing away.

In case of transformer also be careful while writing the ABCD parameters or jet parameters, because in jet parameters, i2 is assumed to enter into the circuit through the output port. Anyway, this is the thing gyrator. Now, this gyrator people use a different symbol, instead of drawing a box, so that you can easily identify it is gyrator. It is drawn like this, a single line, two ports and a thing like this.

This is how it is represented, input port, and this is V1, this is I1, and this is V2 and this is I2. This is how the gyrator is represented in this fashion to distinguish it from other two ports. Just looking at it one indicates that it is a gyrator. Then this relationship holds good. The relationships are then V1 = - K into I2 and V2 is equal to K into I1. This is the thing. We have got this. Now, that I have explained to you that how an inductor gets converted into a capacitor or a capacitor connected at the secondary port which look like a inductor.

This things we have done, but let us do it also mathematically just in one stake that this equation or this equation can be written as I1 is equal to V2 / K from this equation. Then, these two equations if you divide V1 by I1, it will become equal to how much minus K squared into I2 by V2. Suppose if you have connected any impedance, need not be inductance or capacitance here. Suppose some impedance you have connected Z; complex impedance you have connected. Then, this relation holds good.

So, this is thing, so V2 by Z, if I do, I will get minus I2. I2 is entering, V2 is this voltage, so V2 = - I2 into Z. That is the thing. Therefore, V2 by minus I2 K squared / V2 divided by minus I2 will be the thing, which is equal to K squared by Z, whatever impedance you have connected. Therefore, Zin is equal to V1 by I1 is equal to K squared by Z. K is what, K is the constant of the gyrator.

If I know this value, then I find that the input impedance is some constant by Z. Mind you, you should not consider this to be admittance or things like that. This is the equivalent impedance in ohms seen by the source. For example, if Z happens to be 3 + j4 ohm, in general, then Zin will be K squared, which is the number only by 3 + j4 which is equal to K squared by 5 angle 53 degree or things like that.

This is the impedance we have connected. So this impedance value will be K square by 5 and - 53 degree approximately. So, this is the thing. Now, what is this impedance, 3 + j4 was inductive impedance, but this one if you break it up, this capacitive impedance, that is Rc impedance. Therefore, unlike transformer it not only changes the magnitude of the impedance, but also the quality of the impedance is reversed. Because of the fact, Z comes below. It is not K square x Z as it happens in a transformer.

Therefore, this gyrator representation is like this, and you can write down the basic equations and with some impedance is connected, what is the impedance in by the input port can be easily calculated. Okay and also remember, that gyrator is not symmetric. Anyway, transformer is a symmetric and last time we discussed, if two gyrators are connected, it becomes cascade, it becomes an equivalent way transformer.

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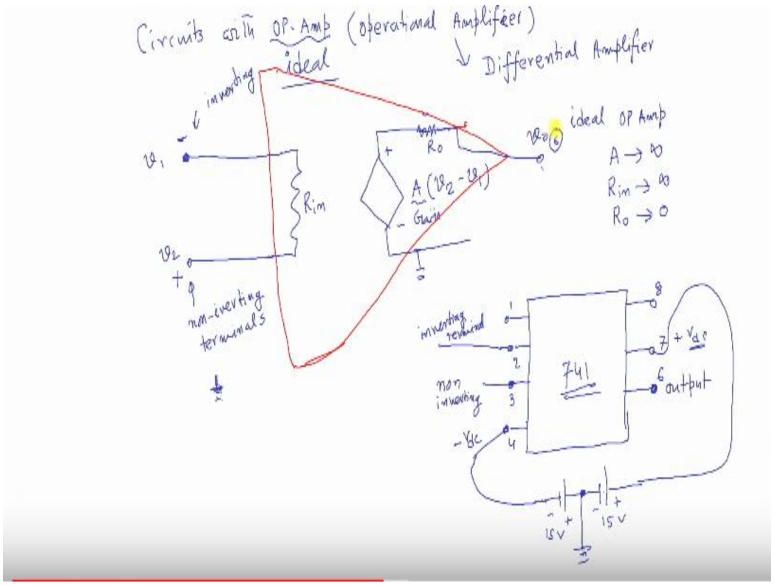

Anyway, today what we will be doing that is we will be studying now, whether okay it is such a circuit, how to realize this kind of two port network or things like that. We will not go deep into that, but using some Op-Amp circuits, it can be realized, such a relationship you can make it to happen, by using some operational amplifiers. Now, today what I will be doing here is we will give you some idea of solving a circuit having some Op-Amp present in the circuit. Okay. Circuit with Op-Amps called operational amplifiers.

Simple circuits and you will be able to solve, no matter how the Op-Amps are connected to the various resistances and things like that, but our discussion will be limited to the study of the ideal Op-Amps, also indicate how to handle situations when the Op-Amp is not ideal, but in most of the cases, ideal wave Op-Amps circuits, if you know, we will be able to face even the operational amplifier is not an ideal one.

Now, the question is what is an Op-Amp. Op-Amp is actually an amplifier as the name indicates, the question is what does it amplify. There will be two input terminals of an Op-Amp, can be considered to be input ports, and this voltage, which you apply V1 here, is often called like this. Two input points where input signals can be connected, and this is called inverting terminal and this is non-inverting terminals, and to this it has got an input impedance connected to the source.

Now, what an Op-Amp is actually called a differential amplifier. What it does is that, if you connect a signal V1 with respect to some common point V1, and if you connect another signal V2 with respect to the same common point, then what it does is that, it will amplify this signal whatever is the voltage with respect to that ground, this point is also grounded and this is the output voltage. So output voltage will be proportional to the difference of the input signals multiplied by a gain of the Op-Amp. Okay.

Now ideal Op-Amp means the gain tends to be very high, very large. This input impedance is also very large and if there is an output impedance that is very low. These are the qualities of the Op-Amp. I will explain to you what do they all mean. Okay. So, this is the Op-Amp. Some people will draw like this. These are the output terminals. Okay. This is how it will be shown. Input terminal, output terminal and this is the output terminal if you want to show it like this.

Output terminal is this one, and all voltages are measured with respect to the common ground. With respect to this, you apply a signal here, with respect to this you apply a signal here, and so on. Now, I will just tell you a very popular Op-Amp chip is available with respect to 741. To understand what are these terminals, it is some 8 pins will be there, 8 connections you can make, one terminal is one, two, three, and then four and here it will be 8, 7, and 6.

It is this terminal 6 where output is connected. Now this pin that is pin number 3, 3 is the non-inverting terminal, 2 is inverting terminal and apart from this, there is two terminals for connecting supply, that is here minus Vdc, connect some battery connection is necessary for this chip to work and 7 is plus Vdc. Okay, and to the terminal 8 nothing is connected, 1 is for some other purpose, generally not connected.

So, out of this 8 terminals, let us identify with this circuit what are these terminals are. Because the rest of the things are not difficult, only thing just to give you a feeling that how things work, what you require is a battery. Suppose 15-volt supply is necessary, this is suppose 15 volt, this is suppose 15 volt. Then, what you do this 15 volt minus you connect it here, and +15 volt you are connecting there and this point is the ground point.

There is no ground point within the chip with respect to this ground point is this, what I am telling. With respect to this, I will measure the inverting terminal voltage where I will apply signal, non-inverting terminal voltage where I will apply some signal and output will be available from this terminal, which is marked 6, but that signal will also be measured with respect to this ground. So, what is this ground, the external DC supply whatever you will be connecting to the chip. The common point of that.

So, here minus Vdc is applied minus 15 volt. Here, plus Vdc is applied and this is how we identify this terminal. Okay, so operational amplifiers is nothing but a differential amplifiers. It amplifies what. It amplifies the difference of these two signals, that is V2 - V1, V2 you apply with respect to the ground. Where is that ground, no point in this chip? Ground is with respect to you have created while giving supply to this Op-Amp.

We will not go deep into this, that is how it is realized with the help of transistor. This is outside the scope of this one. We would like to know, okay, this Op-Amp circuit are so popular whether after learning circuit clearly, can I quickly find out or analyze the circuits efficiently. That is what the goal will be. So with this in mind, I will now discuss about this operational amplifier a little more.

So, it amplifies this signal and this V 0 is terminal 6, mind you. This V1, negative inverting is terminal 2 and non-inverting terminal 3. Got the point. So, this is how things will go. Now, let us come here.

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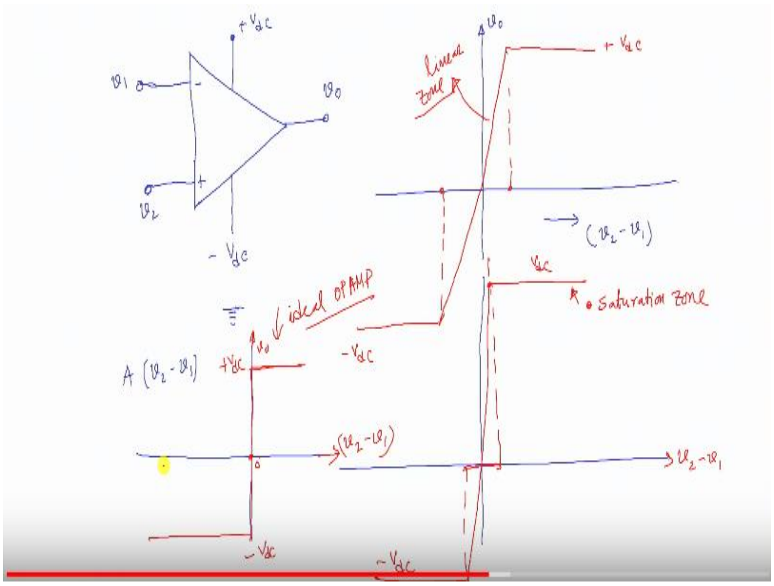

Suppose, this Op-Amp will be represented like this. Not those all the pins you show. Here only, you show the supply connections plus Vdc and minus Vdc. Those two batteries and common point of those batteries is the ground, and here it is minus inverting terminal, and plus these are two points and here is your output pin 6, that is also not written while drawing this circuit. This is output voltage; we call it V 0. Got the point.

So that is the thing and ground point exist at the center of the battery with respect to which I measured this voltage. I measured this voltage and I measured this voltage. That is the all thing. Now, suppose this voltage I call V2 and this voltage I call V1 with respect to this ground and I want to sketch the output voltage V 0 as the difference of these two voltages, V2 - V1. Against this V2 - V1, how the output voltage changes.

Now, as I told you this output voltage is a gain of this Op-Amp and the value of this is A times V2 - V1. In the last page I told you, this is the output voltage, which is equal to A into V2 - V1. This output characteristics will be very interesting. If you sketch it, what is Vdc, this one. This is the output voltage. Now, what is the gain. Gain, I told you infinitely large. Okay. This relationship will hold good between these two points and this curve will be steeper and steeper, if the gain is higher and higher. Got the point, minus Vdc, plus Vdc.

This zone, we will say, Op-Amp operates in this zone, so V2 - V1. If this value is outside this range and this range is very small because the gain is very high and this relationship only holds good between these two range. Beyond these, what we say Op-Amp is saturated. Saturation zone and this portion is the linear zone. May be in a practical Op-Amp, this may be spanning over some microvolt level, very steep and for an ideal auto-transfer Op-Amp, it will be like this.

It will be almost like a vertical line, ideal Op-Amp. This is plus Vdc, and this is minus Vdc. This will be the thing and here you are sketching V2 - V1. That is a slight voltage difference V2 - V1 and this is what we are sketching, output voltage. You are output voltage will be plus dc and if it is less than that, it will be minus Vdc.

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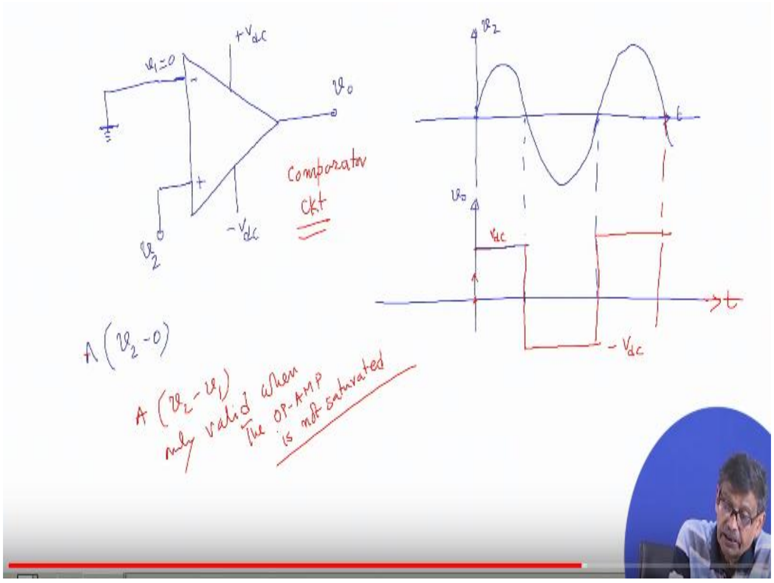

So, Op-Amp ideal circuit, if you just use in this form, this circuit can be used as, for example, what I mean to say, suppose I have an Op-Amp circuit like this, this is your output, this is the thing. Suppose, if you make this point grounded and here you have applied a voltage V and suppose this applied voltage is sinusoidal model, what I am telling. That is the V2 signal. What is V1. V1 is equal to 0 because with respect to ground, all the potentials will be measured. So, this is V2. This is mind you time.

Then, what I would expect at the output. My question is this. Suppose, it is an ideal Op-Amp, a slight increase V2 - 0 volt into the gain, but that zone is very little. So, V2 is greater than V 0 means, it will immediately go to high plus Vdc. Vdc of what. Vdc of the Op-Amp. Two supply you will connect, it will saturate. Because this voltage, a slight value of this voltage, may be of the level of microvolt level here, this is much voltage, immediately saturates.

For ideal transformer, this V2 greater than 0, it saturates. It starts from here and during this zone, V1 is 0 and V2 is negative. Therefore, it will be negative excursion. So, this output voltage will be like this. Therefore, with this circuit, of course, you can convert a sinusoidal voltage to a square wave voltage, or you can such a circuit is called a comparator circuit. No feedback is used. Comparator circuit, very much used.

To get the idea of zero crossing of this signal, it could be any other signal, but whenever this will go positive, it will become like this and if it goes negative, it will become saturated to negative value. That is the thing. What is this axis? Time. So, any difference in voltage V2 and V1, will make the output either go to a plus Vdc or minus Vdc.

So, in such operations, the Op-Amp will operate under saturated condition and no point in trying to tell that Vdc by this V2 is your A. That relationship is only true, A into V2 - V1. This is only valid when the Op-Amp is not saturated. So this is the thing. Now this is one of the just no feedback, nothing used and you have connected like that. However, you can make much more interesting circuit with the property of this Op-Amp, for example, one like this.

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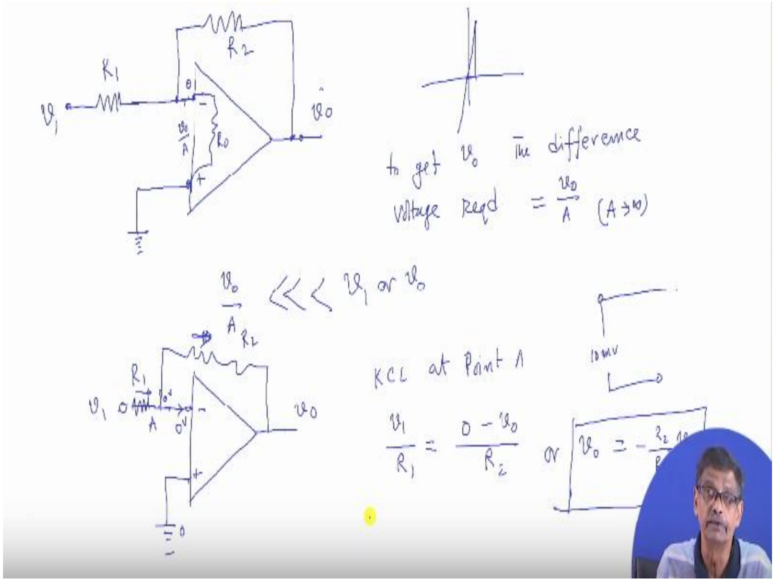

I will only tell you the concept. Generally, people will draw like this. This is minus inverting terminal; this is plus terminal. Okay and suppose you connect one, this is called negative feedback. This is output voltage and Op-Amp circuits will mostly operate on negative feedback circuits. Suppose, I have connected, one resistance R2 here and another resistance R1 here and this point, I have grounded. This is what I have done. I have made a simple circuit like this.

Now, here you see I have used a negative feedback. The output voltage is fed back to this point here. Now, in this case, this is not Vdc, because it is negative feedback is there. If it is some finite voltage and the Op-Amp is operative in the linear zone, now the Op-Amp will operate in the linear zone meaning that, the voltage required to get V 0 here, how much will be this. This voltage will be V 0 by A, that is what will exist. Because differential amplifier between these two points, whatever is the voltage that gets amplified.

So, this operational amplifier will now operate in the linear zone with very high gain. So, if you get some finite output voltage, the input voltage required between these two points will be V 0 by A and A is very large, so a little voltage here, will cause a finite output voltage 2 ampere in this circuit. So to get V 0, the difference voltage required will be equal to V 0 by A with A tends to infinity. For ideal Op-Amp, it is infinity.

Therefore, how much will be the voltage between these two points, practically 0, compared to whom, compared to the finite voltage, with which we are working. I will give some input signal here, for example, you give V1 here, the level of say millivolts, but this zone as I told you it is microvolt, less than that even this linear zone. Therefore, the voltage existing between these two points compared to this V1 or V 0 can be neglected.

So, V 0 by A will be much smaller than your input signal or output signal. Therefore, voltage difference will be changed practically, not existing between these two points and also the input impedance between these two points is very high, therefore, no current will be drawn by the Op-Amp. This side, there will be practically no current. Yes, there will be current, how much that current will be, this small voltage denoted by A, divided by this R 0, but what I am telling R 0 is very large and V 0 by A is also a small number.

Therefore, this current will be 0. So, when this Op-Amps will be used in this sort of negative feedback, one conclusion is that, potential difference between this point and this point will be 0. That is potential of this point and this point can be considered to be same, and this potential is 0, therefore, this potential can also assumed to be 0 and it is called then a virtual ground. Now, let me do one step, then you will understand and we will discuss it further. For example, I want to find out and analyze this circuit.

So, I will say that look here, and let us assume it is an ideal Op-Amp. So this is the circuit. This is R2. This point I have grounded and this is my output voltage and here I will connect my input signal V1. What is the consequence of this ideal Op-Amp? Can it draw any current? No, input impedance is high and for an infinite voltage, you have very little voltage here compared to be V1, which can be assumed to be 0.

What is the point in a circuit if you are applying say 10 millivolt and you are saying that in this branch here no current is flowing and voltage existing is very zero. Therefore, no current flows here. Current here in this path is 0. Input impedance is higher, infinitely large. This fellow will never draw any current or very little current, which is of no consequence to the practical situation here. Now, this voltage is V1, clear.

Therefore, what is the voltage here, 0 volt. So at this point, because the voltage does not exist here, so here also 0 volt. It is almost connected to the ground. No voltage drop here. So, write KCL at this point, say A. What will be the case here and also connect A resistance here, for this side, V1. Therefore, what will be the current in this path. This current will be V1 by R1. Why V1 with respect to this point, this is the potential, but this point is also here, because no drop takes place here.

Potential difference between these two points is also 0, therefore V1 - 0 volt here, divided by R1 is what current coming and then the current leaving. This current is 0 and this current will be how much, going this way. We know from the circuit analysis; it will be V1 - V 0 by R2. KCL at this point A. V1 by R1, and the current in this branch, this will be how much. Potential difference between these two.

It will be 0 minus this potential is 0, and this potential with respect to V 0 and current detection this way I am calculating. So, 0 - V 0 + R2 and these two should be same or you will get V 0 = - R2 by R1 into V1. That is all. So, here nothing like saturated voltage will appear across the output. What you get in a sense, is an amplified version of this signal V1. If R2 is greater than R1, suppose R2 is two times R1, whatever is the input voltage, it will be twice appearing in the output with an inversion of sign. Anyway, we will continue our discussion in the next two lectures. Please be with me. Thank you.