Electrical Measurement and Electronic Instruments
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Lecture - 55
Difference amplifier - I

Welcome again, today we will study the most awaited Difference Amplifier. We were waiting for this for a long time.

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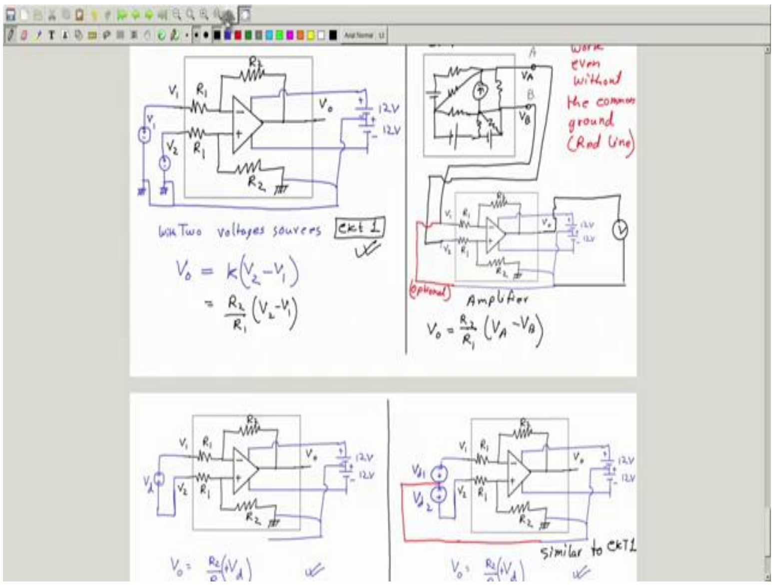

So, if you study difference amplifier, so first thing I will do is, I will draw the difference amplifier. I request you do not see my drawing, do it yourself, remember the trick to how to do it.

So, draw the op-amp 2 inputs minus plus. The rule is connecting the minus terminal to the output negative to output and positive to ground through resistances negative to output, positive to ground N O P G. Put two more resistances and then this two will become our input this will become our output. Let me put everything in a box ok. Call this V o, call these two inputs as V 1 and V 2 before we proceed with mathematical analysis.

Let us talk about how to connect this circuit in reality in lab ok. So, in lab when you are using this op-amp of. So, I do not, I never remember which pin corresponds to which pin that you see in the manual. So, IC 741 I guess this is a pin number, output is pin number 6. These are pin number 2 and 3, do not ever try to remember that those things are unimportant. You can always go to the web, nowadays it is very easy and just check the pin numbers. That is what I did actually I mean and I pause the video and just check it does never you do not have to remember these things you can also you can always check this numbers ok.

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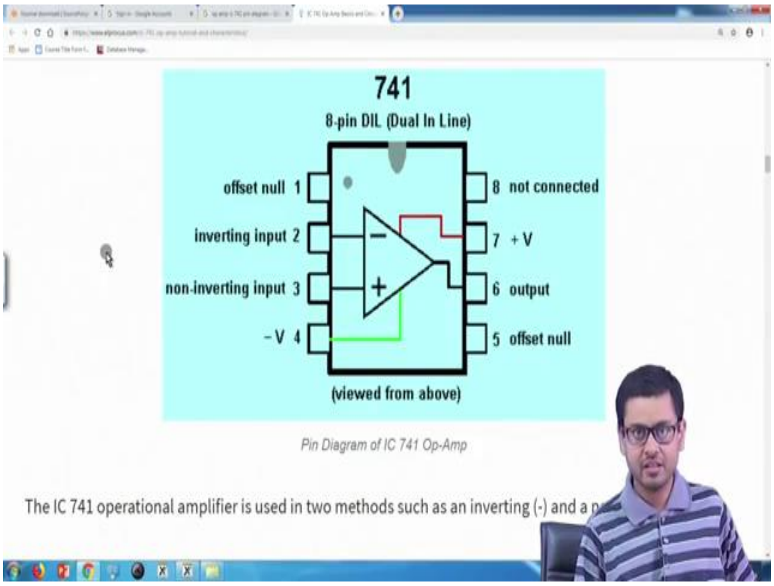

So, that is not important. What is important is that you also have to connect the two power supplies whichever pain those are; you check it in the on the web. So, connect them like this. Let me take a source say which is plus minus 12 volt or plus minus 15 volt. So, both so, I have 12, 12 in series, total 24 volt.

So, you have to connect it and then of course, this ground you have to connect to this point like this ok. So, so, and yeah and this ground is basically also a reference point I mean the point which you pick as the ground or geo fault because voltages of I mean; no, it is not really value; it is ok. So, we connect it like this ok. So, I have plus minus 12 volt supply, this is the ground just which is taken from this the center of these two batteries. Now I have to connect the inputs ok.

Now, input in this circuit can be connected in two different ways ok. The common way of connecting the inputs are to use two voltage sources. So, you can use two voltage sources like this. So, connect one voltage source plus minus the other side at ground. Ground means what basically ground means you have to short all these common grounds and take another voltage source and connect it here with V 1 plus minus the other side I can draw like this drawing like this means of course, this has same symbol. So, they are actually connected. Drawing is fine, but in the lab you of course, have to sort it ok. Notice and one is just drawing this symbol males of course, they are connected.

But in lab of course, you have to connect this ok. So, this is now so this in this way if you use the op this difference amplifier in this way then the output. So, you have two voltage sources V 2 and V 1. So, this is V 2 this is sorry this is V 1 this is V 2. So, then the output you will get that you will get is proportional to the difference of these two voltages which minus which this is connected to minus side.

So, minus V 1 this is connected to plus side plus V 2 multiplied by K. This is what you will get. What is this constant K? This depends on this resistances. So, normally we need for a normal different ideal difference amplifier we need these two resistances to be equal the two that are connected to the inputs take them R 1 and R 2. The other two also need to be equal R 1 and R 2.

$$Vo = k\,(V2-V1) = \frac{R2}{R1}\,(V2- V1)$$

This is one way you can use it. Now suppose you are using you are measuring or amplifying. So, this is an amplifier right. So, what is the purpose of an amplifier? Purpose of an amplifier is to amplify some voltage maybe because you want to measure it ok. So, to measure suppose you want to amplify and then measure because the voltage is very small ok. So, then suppose you have a network complicated network a network means a complicated circuit ok. Whatever complicated circuit you can think of. So, think of a very complicated circuit as complicated as you can think voltage source, current source.

I mean I am drawing blindly something I do not, then I mean whatever you can think of is think put too many sources whatever you would like to do we do a very complicated circuit and then suppose you want to measure the voltage between these two points. So, this is a network a complicated network. So, this is a complicated network and call this point A and point B and you want to measure this voltage. How will you do it? What do you have to do is that you have to.

So, this is a complicated network and this is the amplifier. Now I have to connect the this to the input of the amplifier ok. So, this is the amplifier part. So, what you can do? You can just connect this one terminal here and the other terminal here ok.

$$Vo = \frac{R2}{R1}(VA - VB)$$

So, this is what you will get at this point ok. Now suppose you want to measure it then what you have to do then you take an amplifier, sorry and voltmeter ok. So, this voltage you connect here this is a voltmeter, but you have to close the circuit.

So, what you can do you connect this to the ground ok. Now so you can use it in this way fine, you can also use it in this way, suppose you have a network and between these two terminals you want to measure the voltage after amplification you can use it in this way. Now if you want you can do another thing.

If so see this two circuits this network and the amplifier they do not have a common ground ok. So, if you want to have a common ground you can connect any point of this circuit whichever you want to take as the reference to this ground. This is the ground line right; this is the ground line. So, any point in this circuit you can in theory you whichever you would like to consider as the reference you can connect to this ground any point in theory.

So or even one of this point so suppose you want to make V B as your reference. So, then this is V B. So, you can connect this to the ground. Now they will have common ground. Now this particular circuit, this particular amplifier will not need this common ground that is the nice thing about this amplifier ok.

So, these are this common ground, so this red line is optional. It will work even without this red line, this common ground connection ok. So, it will work even without the common ground that is the red line ok.

So, which means if I so, so if I can instead of having two sources, I can also take only one source and use it in this way and call this V d then the so there you need not connect this is not required.

$$Vo = \frac{R2}{R1}(-Vd)$$

if you do not like this minus side then let me take this reference in the opposite direction then plus is to plus minus is to minus then it is plus ok. So, this is also a valid circuit. You can use it in this way and you can also use it with a common ground like this. So, let me choose to say connect it like this or you may like to choose connect it to this if it is.

So, either it is ok. So, this is also a connect circuit. So, this it is basically the point here is this difference amplifier can be used in mainly two different ways, one with a common ground and other without a common ground. So, this is with common ground. So, you can connect it here. If you can also collect it here and which also means that suppose I have two sources herein series plus minus plus minus. If I have two sources call it V d 1 and V d 2 or maybe 2 and 1; sorry 1 and 2 side 1 side 2. You can also connect this red line in between here red, this is also fine this will also work. So, this red this common ground you can connect here, you can connect here, you can connect here this will work and here there is no common ground. So, this is without common ground.

Now you just observe a small thing is that this particular circuit give it a name; circuit 1; circuit 1 this circuit and this circuit are same; convince yourself these are same similar circuits. So, if you replace V d 1 with V 1 and so that we saw you together if you replace V d 1 with V 1 V d 2 with V 2 then these two circuits are same similar ok. So, this is similar to circuit 1 ok. So, the point is essentially you can or cannot have I mean may or may not have this common ground here we have; here we do not ok. So, this particular circuit can be used even without common ground.

But essential point is that in general later on also we will see some circuits where common ground between the circuit which we are probing; that means, like this network circuit that which on which we are doing the measurement and the amplifier in general may need a common ground between them. This particular circuit this amplifier does not need it, even if you put the common ground no problem no harm is there. So, it may be in general a safe trick to always have a common ground ok.

So, this can be used in two different ways and I have shown you detailed connection with power supply etcetera everything ok. Now next so the remaining in the remaining part of this class we will do a thorough analysis of this difference amplifier with graphical method, the method we have studied so far it was good ok.

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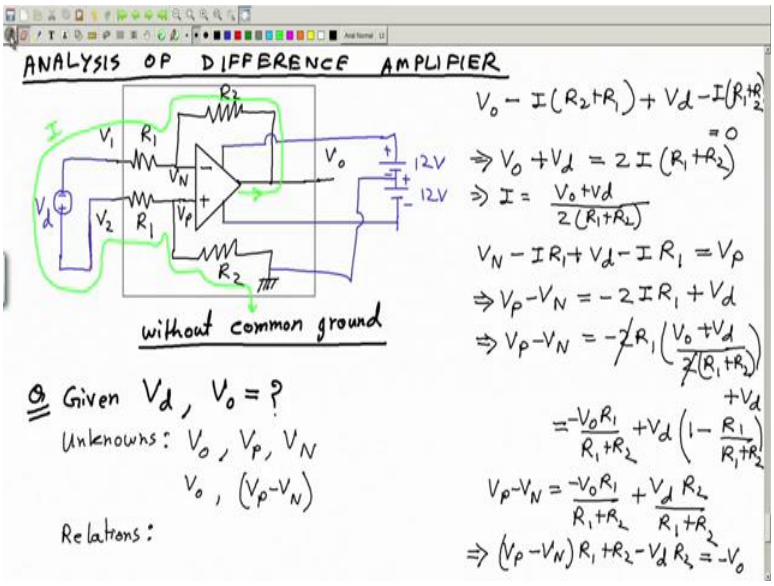

So, now we are going to analyze of difference amplifier. So, let us take this circuit first without the common ground.

Now, once again the question is what is the question given V d that is the input given V d what will be the output V o ok. So, V o is the unknown. Now so, this is what this is V P this is V N. Now unknowns are of course, output V d, but we do not know V P V N either of them. So, we have V P as well as V N. So, we have 3 unknowns, we can find three equations, three relations between them, but the problem a difficulty we will have is that we cannot draw a 3D picture 3D graph. So, it is difficult. So, what the trick that I will use I will write the V N = (V P-V d) you see this is ok.

So, what we will do we will; no, not this I mean we will write; we will find some relation between V P and V N from this part of the circuit ok. So, what can be that relationship? So, you see that the current here is 0 in this branch ok. Here no current can go into the op-amp. So, this is crossed, similarly no current can go here I mean into or out of the op-amp ok. So, there is no current there.

So, therefore, the current must flow if any current flows it will flow like this like this ok. From here it will completely flow in this path or in the opposite path ok. It cannot get into the op-amp ok. So, let me write let me take this current in this direction starting from here ok. So, this is the way the current flows and if you want to continue this line further this will flow like this.

So, out of the op-amp it starts from here and it goes like this and it goes to the ground, starts from the op-amp and it goes to the ground and if you ask how is this circuit closed? You see that this ground I mean the; I mean once it goes to the ground it basically is connected to this point and then these two points are connected here. This way you can also think about the conservation of charge if you are really that much keen about it, but this is the path of the current we are going to consider. This current let me call it I ok, but if we can write the 2 unknowns as V o is 1 of course, this is output another V P - V N ok. So, if we write these two as two variables; two unknowns then with a 2D graph we can solve it ok.

So, let us find the relationships between these quantities ok. So, relations or equations so, first let us consider this part of the circuit ok. This part of the circuit once so, let so, you know that the current if there is any current that will not flow in this branch here, it will not flow even in this branch because no current can go in or out through the input terminals of an op-amp. So, current can only flow like this starting from here it goes like this and to the ground ok. So, this is the way the current will flow like this and no current can flow here or here.

$Vo - I(R1 + R2) + Vd - I(R1 + R2) = 0$

$Vo + Vd = 2I(R1 + R2)$

$I = \frac{Vo+Vd}{2(R1+R2)}$

$VN - IR + Vd - IR1 = Vp$

$Vp - VN = -2I\,R1 + Vd$

$Vp - VN = -2\,\frac{Vo+Vd}{2(R1+R2)}\,R1 + Vd$

$Vp - VN = \frac{-Vo\,R1}{R1+R2} + Vd\,\frac{R2}{R1+R2}$

$(Vp - VN)(R1+R2) = -Vo\,R1 + Vd\,R2$

$-(Vp - VN)\left(\frac{R2+R1}{R1}\right) + Vd\,\frac{R2}{R1} = Vo$

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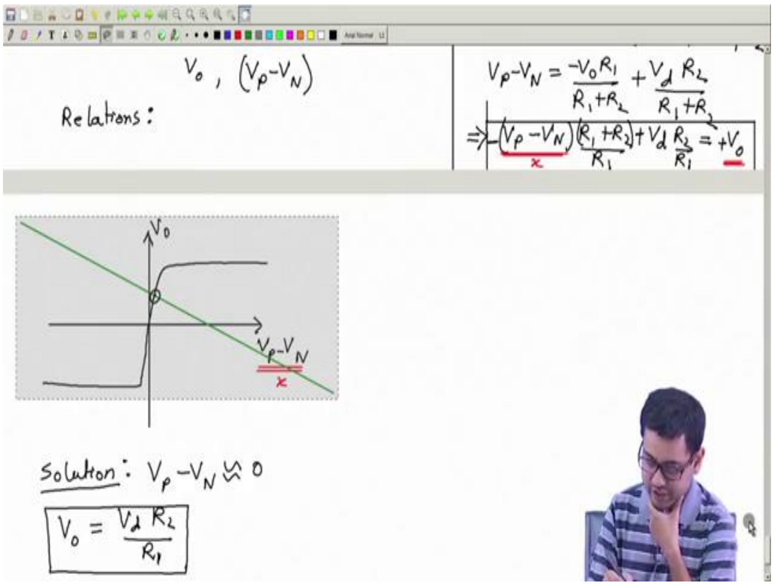

So, let us now draw these two relationships on a common graph. So, x axis is V P - V N, y axis is the output V o. Now the static characteristic looks like this and so this is one relationship, another relationship comes from this ok. Here this term is the y axis y value, this is the x value.

So, this is x right x coordinate this is the x coordinate. So, you see y is equal to minus mx plus something. So, how will they curve look like? It will be a straight line with negative slope and the intercept will be positive. So, it will be a line like this ok. So, the intercept is positive because this value is positive assuming V dp is positive ok. Resistances are of course, positive and then slope is negative because of this minus sign let me highlight this. This is there is a minus sign here ok. So, this will be the solution therefore and so; the; what is the solution then?

So, the solution; so at this solution you see that with the x axis the value of x that is VP - V N is 0; ideally 0 because ideally this part should be almost vertical. So, we can write V P minus V N is almost equal to 0 and what is the y value V o. Now V o let us take this equation and put the value of V P minus V N is equal to 0. So, from this equation then we can write V o is equal to this part is 0.

$$Vo = Vd\,\frac{R2}{R1}$$

So, the analysis is now quite straightforward. We have done so many similar things, so many practices. It is now should be very simple but what comment can we make from this.

So, see the output is proportional to V d. What is V d? V d is nothing but this voltage which is nothing but V 2 - V 1. So, the output is proportional to the difference of these two voltages. So, you can connect a voltage in this differential form like this ok. So, and the output will be therefore, proportional to this V d ok. Now is the and how many solutions can we have?

We can have only one solution because there is only one intersection. You can now change the value of say the position of this green curve. This green curve comes from this relationship where you can change the value of Vd, do not change any resistance only change the input then the slope of this equation will remain same but the intercept will become more or less.

So, if we increase V d this curve goes up and after some point you see it will be like this. So, the solution will be here. So, we output will not increase further ok. So, that is the saturation region, but if you decrease V d it goes down and here and after this point again a saturation will occur if you bring V d further down. Normally it is I keep it here.

For some value of V d which is positive and what else can you see ok? So, then if V d is within the limit of saturation then V P minus V N is equal to 0 right. If it goes beyond saturation then V P - V N will be this much. So, that will not be 0, but within the limit of saturation this is almost equal to 0. So, we can say that virtual shorting is working, it is true.

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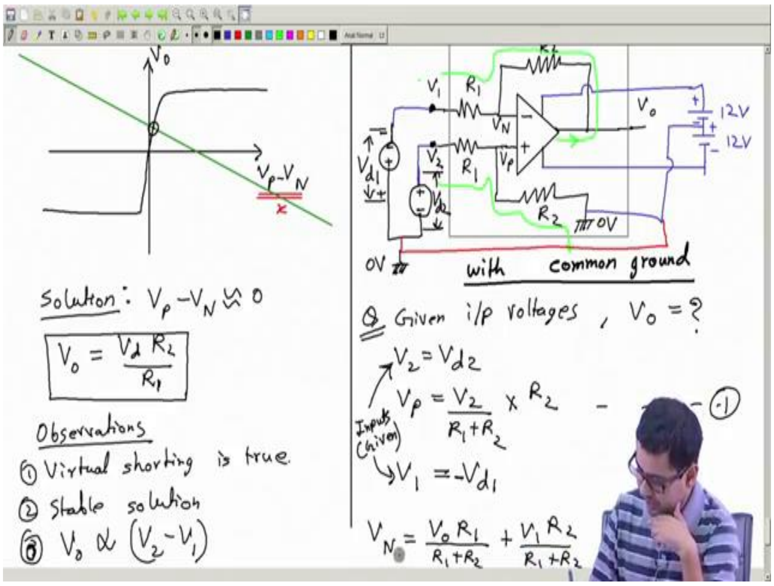

So, comments or observations virtual shorting between V P and V N is true ok. What else the solution you can test? The solution point will be a stable point stable solution you can test it yourself like the way we did in the previous class and output is proportional to the difference between V 1 and V 2 because V d is V 2 - V 1. So, we can write this is basic this is the; I can write this is point number 0 ok. So, output is proportional to V 2 - V 1.

So, this works as a difference amplifier, an amplifier which amplifies the difference between two voltages. So, this is how it works ok. Anything else I think this is that is fine ok. So, now, if you have understood this much it will be great. Next we will see briefly the situation where we have a common ground. So, previously we have said that we can use this difference amplifier in two different modes without common ground ok. So, and here with a common ground ok. So, the analysis that we have done is for the case without common ground. Now, how will it be if we have a common ground. So, let me just copy this circuit and now I reconnect this circuit with a common ground and two voltage sources you can think of ok.

So, let us connect two voltage sources in series ok, call this plus minus this is V 2. So, this value is V 2. So, I can write V 2 here and this value so let me call this. So, plus minus plus minus they had in series, series addition and from this middle point I take the common ground ok. So, this big this is with common ground and let me write V 2 here only. So, the potential at this point is V 2. Let me call this as you can call this as V d 2 if you want and you can call this as V d 1 right; and this point is so the absolute potential here is V 1 and this is the difference between these two terminals. Also this is the difference between these two terminals ok.

So, the source has a value of V d 1 this source has an emf of V d 2. The absolute potential here is denoted with V 1, the absolute potential at this point is denoted with V 2. We have a common ground here. So, this potential is 0, 0 volt ok. Now we have to do the analysis for this circuit. So, what do you have to do? We have to find the answer given input voltages V d 1 V d 2; that means, V 1 V 2. What will be the value of the output? This is the basic question we always ask given the inputs what will be the output ok.

And now to begin with so this point is at 0 potential so; that means, this point is at a potential V d 2. So, V 2 will be equal to V d 2 this is 0, 0 plus V d 2 is V 2 ok. So, if this is V 2. Now current can flow like this ok, but no current can go in this branch through the op-amps input terminal. So, the current goes only like this, this point is at V 2 this point is at 0 volt. So, what will be the potential here V P how much? Potential divider rule.

$$Vp = \frac{V2}{R1+R2} R2$$

This is one thing. Now what can we say about V N? Now before that what can you say about V 1? V 1 is nothing but equal to minus V d 1 because this side is plus, this side is minus. So, this is plus minus. So, there and this so starting from 0; I have a potential drop.

So, V 1 is minus V d 1 ok. So that means, given V 2 given V d 2, V 2 can be computed directly similarly given V d 1 V 1 can be computed directly. So, these are inputs. So, this is one input, this is another input these two are given. V P is found like this. Now V N ok, V N is how much? So, let us see that there is no current here right. No current at this point. This point is at value V o. So, current can flow only like this nothing can get bypassed here this is at V o this is at V 1.

V1 = -Vd1

VN = $\frac{Vo\ R1}{R1+R2} + \frac{V1\ R2}{R1+R2}$

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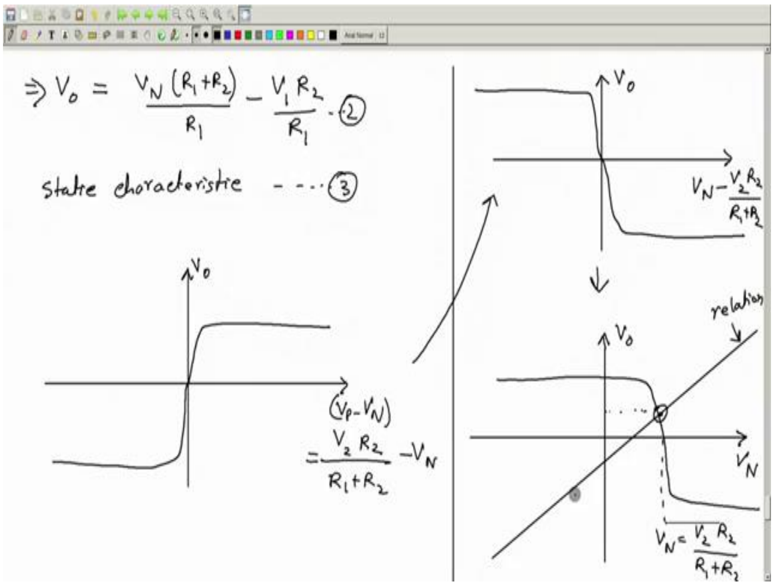

Vo = $\frac{VN\ (R1+R2)}{R1}$ - $\frac{V1\ R2}{R1}$

So, this is another equation that we have and the 3rd relationship is the static characteristic. So, now, let us use all of them together and find the solution V P minus V N V o ok. Now the static characteristic is of course, like this.

So, this is from relation or equation two which is here ok. So, what will be the solution? The solution is this. So, this is the solution right and now what can you say about the solution for an ideal op-amp this is a fact almost a vertical line. Therefore, we can write V N is this much.

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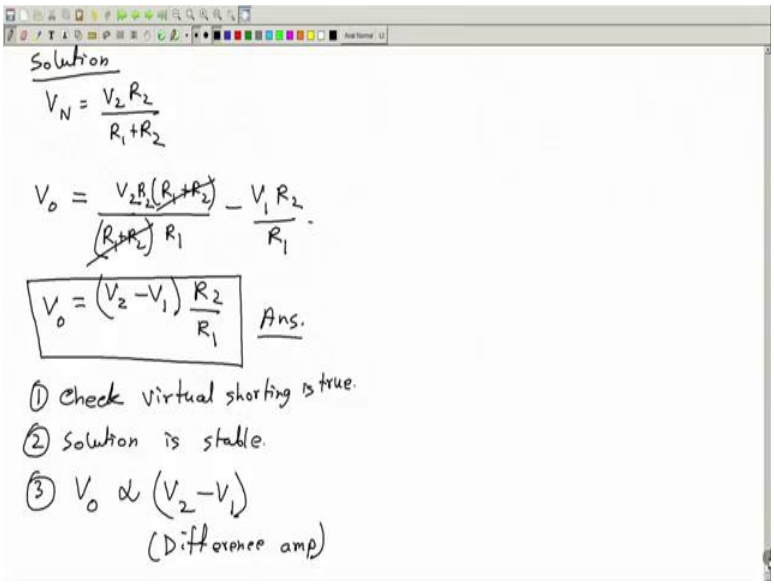

So, solution at the solution V N x axis is this much,

$$VN = \frac{V2\ R2}{R1+R2} - VN$$

Now, great; so I just give you some small task without doing it myself ok. You do it you, so this thing yourselves ok. So, check that virtual shorting is working; is true; then the solution point is stable check it ok. Do it, try it yourself and if you need any help you can ask us in the forum. What else the obvious thing is that the output is proportional to the difference between two inputs so that means, this is a difference amplifier which amplifies the difference of two voltages two inputs V 2 and V 1 which are applied like this one here V 1 another here V 2 ok. So, that is I guess simple. Another small exercise that you do yourself is that analyzed in this graph how will the solution change if you change either of the two inputs V 1 or V 2?

So, if you change V 1; that means, V d 1 or V 2; that means, V d 2, if you change either of these two inputs how will these two graphs will change ok? So, just think of it yourself. I am just giving you a small clue. So, this graph you see this crossover point depends on the value of V 2 ok, therefore, this graph will change its crossover point depending on the value of V 2 like this.

Say if you increase V 2 and if V 2 is positive then this curve will move like this and if you decrease with ok, if you increase it further then at some point saturation will take place. Similarly if you decrease V 2 this comes to the left side and then so at this point the output is output is negative because if you are decreasing V 2 because the output is proportional to V 2 - V 1. So, if you decrease V 2 you know our output is going to become negative at some point.

So, here the output is negative. You bring it further down then saturation takes place ok. So, output does not go down any further and for a normal positive value of V 2 I keep it here. Similarly if you now change V 1 this curve is not going to change, but this curve is going to change; why? Because this depends so this is actually this is from relation number 2, this equation relation 2. So, if you change V 1 it the slope will remain same but the y intercept will go up or down.

So, if you say for example, increase V 1 then if you increase V 1 then this curve goes down and then at some point the output becomes negative. If you bring it further down then saturation takes place. If you decrease V 1 it goes up; up up up; then it becomes positive and then if you bring it further up then once again saturation takes place and let me just keep it here for a normal positive value of ok. So, here the y intercept is negative so that means, V 1 is positive.

Thank you.