Basic Electronics

Dr. Chitralekha Mahanta
Department of Electrical Communication Engineering
Indian Institute of Technology, Guwahati

Module - 4
Operation Amplifier (Op-Amp)
Lecture - 4
Op Amp Applications Part 2

In the last classes we have studied about the application of op-amp and we have seen application of op-amp in various arithmetic circuits like logarithmic, exponential as well as precision half wave rectifiers, etc. Today we will study about the application of op-amp in control sources. What is a control source? Control source means we can control the output with a control input. That is suppose we want to vary the output current of a circuit by varying the input voltage or suppose we want to vary the output voltage by varying the input voltage or suppose we want to vary the output current by varying the input current; so the different examples of control sources are there. Here the source means a voltage or a current source and that voltage or current source which we will get are in fact obtained by input voltage or current sources. A typical example which we earlier studied was that of a transistor.

If we consider a transistor, we get at the output a control source or a dependent current source because if we consider a common emitter transistor, the output current is the collector current and that collector current I_C is equal to beta times of the base current. This example is nothing but that of a current controlled current source. Here we are controlling the output current I_C by controlling the input current I_V. Similarly using op-amp also we can have the control sources and that we will discuss today and the control sources are having various configurations like voltage controlled voltage source. It is called VCVS, then voltage controlled current source, VCCS it is in short called and current controlled voltage source that is CCVS or current controlled current source that is CCCS. These different types of control sources we can have by using op-amp.

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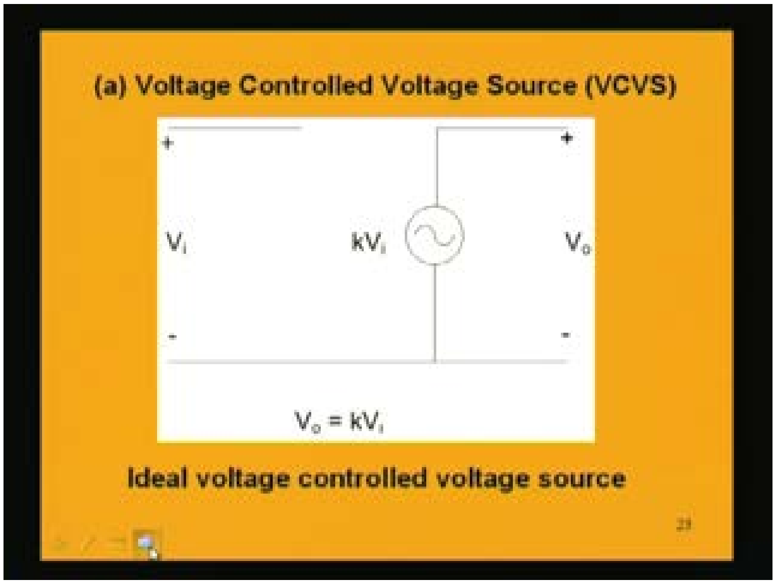

Let us take a schematic diagram of a voltage controlled voltage source or VCVS. If we consider a block of a VCVS, the input is V_i that we are giving. We have to give an input and as it is controlled by voltage, input will be a voltage and that is V_i and the voltage source at the output or the control source which we will get at the output is also voltage and that is V_O. The main thing here is that V_O is controlled by V_i. That is we will get V_O, which is controlled or affected by V_i and that is equal to k times V_i we are writing in order to express that relationship between output voltage and input voltage. Here this k which is a constant, it will relate the input voltage and output voltage. If we vary this input voltage, output voltage here will accordingly vary. This is a block diagram for representation of an ideal voltage controlled voltage source.

Here we are using the term ideal because we are not considering the practical parameters which exist. For example we know in an op-amp there will be input impedance, there will be output impedance. But in this ideal consideration, we are not considering those or we are simply ignoring those and an ideal op-amp consideration still we are using ignoring the input impedance and output impedance.

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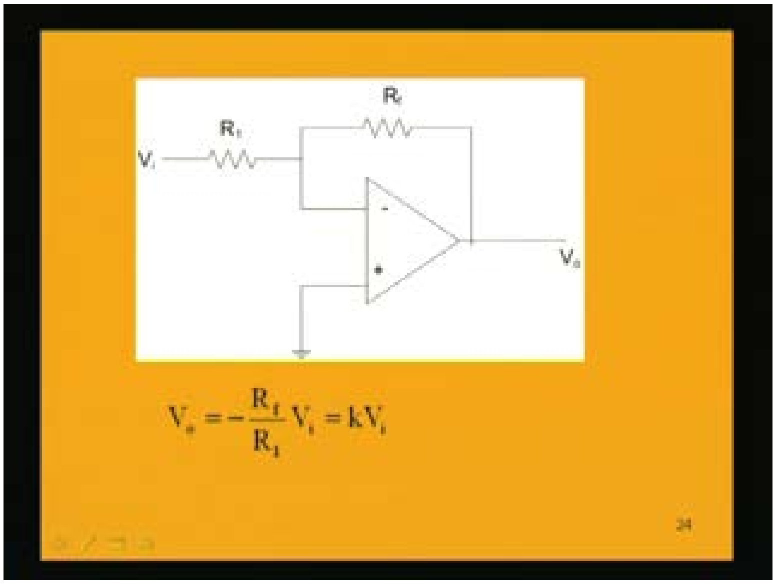

Let us consider a practical circuit. This circuit is a very familiar circuit. We used it when we were discussing about the inverting op-amp; inverting amplifier when we discussed earlier, the same circuit configuration we have used. Input voltage V_i is having an input resistance which is connected that is R_1 and the feedback resistance is R_f and the non-inverting terminal is grounded. What will be the output voltage V_O and from our earlier study we already know V_O equal to minus R_f by R_1 into V_i and R_f by R_1 for a circuit once we design it, suppose we are not varying it, we can name it as k. k being the ratio between R_f and R_1 that is the feedback resistance and the input resistance and that k is relating the input voltage with output voltage. That means we are controlling the output voltage V_O with an input voltage V_i. The output and input both are voltage sources. This is an example of a controlled voltage source and this voltage source which is controlled is by another voltage source only at the input.

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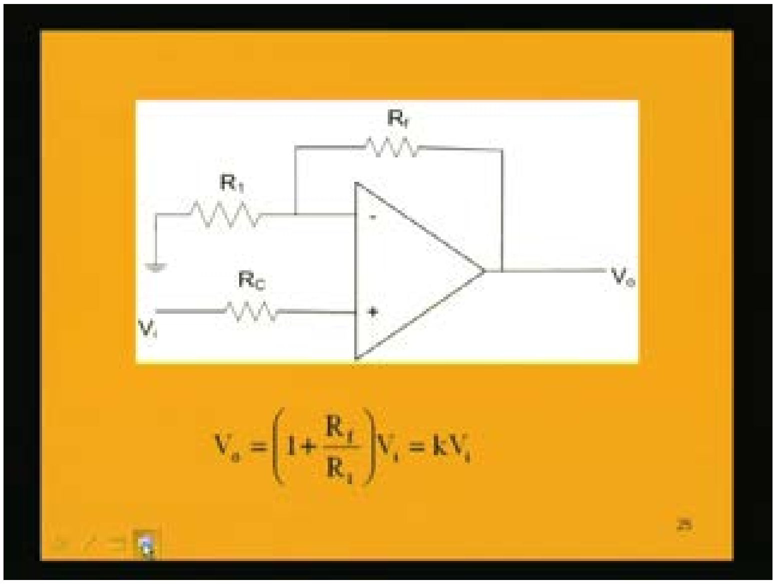

Similarly the non-inverting op-amp example which we are discussing earlier is also an example of voltage controlled voltage source. Because if we see in the circuit we are connecting a voltage V_i at the non-inverting terminal and there is a resistance R_C. This R_C resistance is there but it is not going to affect the overall expression of the output voltage V_O. Because if we want to find out what is the output voltage V_O, V_O is here and if we see the side where V_i is connected, this R_C is there, but there no current into the op-amp. If we name this current, which we have flowing through this R_f, the same current will flow through this R_1 and this example and the non-inverting terminal op-amp which we were discussing earlier does not have any difference in analysis because this presence of R_C is not going to affect anything.

What will be the output voltage V_O? V_O is again 1 plus R_f by R_1 into V_i only. This example is also an example of a voltage controlled voltage source. The output voltage V_O is controlled by the input voltage V_i.

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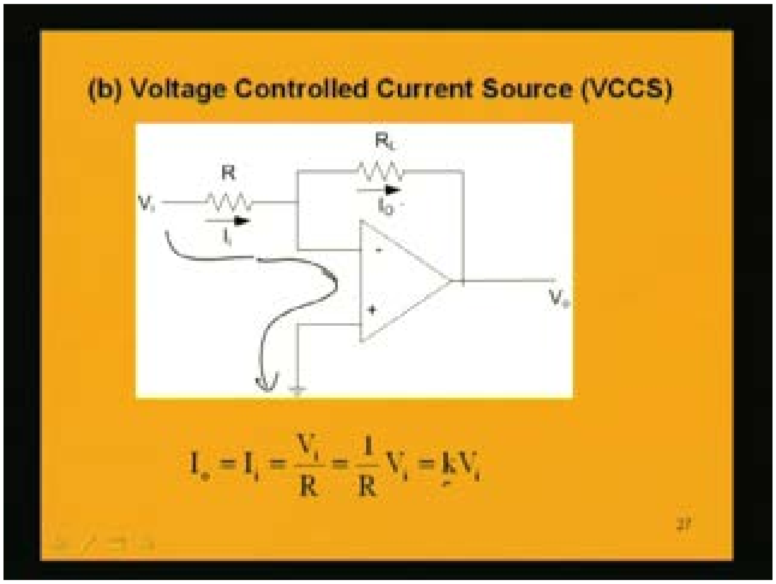

Another control source is voltage controlled current source and in short it is known as VCCS. As the name suggests voltage controlled current source means the output source will be the current source, but it will be controlled by an input voltage. Here is the circuit of a voltage controlled current source. We are having a voltage at the input which is V_i and if we now denote the current flowing in this resistance R, this is I_i. We are naming it I_i. The same current will also flow through the resistance R_L because there cannot be any flow in this op-amp. Current flow cannot enter in the op-amp; whatever current is flowing from this V_i must flow through this R_L. So the current I_O is same as I_i and what is I_i? This is nothing but V_i by R only because we will go by this loop. So V_i minus zero by R that is I_i and it can be written as 1 by R into V_i; this 1 by R, let us name by k. So what do we get at the output? Here, the current I_O we are getting from V_i with a relation that is k times of V_i or k is equal to 1 by R or 1 by R times V_i is equal to I_O. If we vary this V_i, the output current will also vary.

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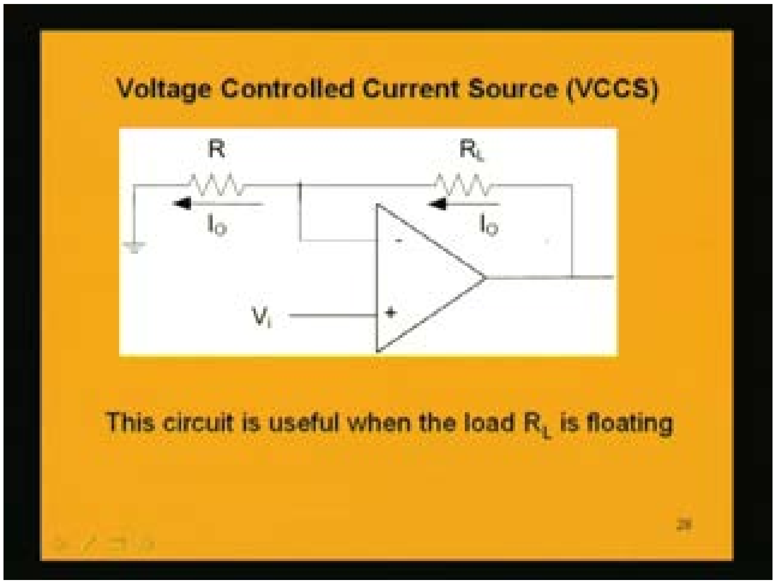

Another example of voltage controlled current source can be this example where we are having a V_i at the non-inverting terminal and we are having resistances R and R_L connected in this manner, R_L being the feedback resistance. This circuit and the earlier circuit (Refer Slide Time: 9:32) have a difference. Where is the difference? Here we are having a R_L in this case which is floating. Floating means it is not grounded. If you see both the sides, this side is connected to R and this side is connected which is the output voltage V_O. This point is not ground; so, this is called a floating resistance or floating load resistance R_L. But here in this circuit when the load is floating we will have this control source, which is same as the example which we were considering earlier which is also nothing but a non-inverting op-amp circuit. We will discuss a circuit which is having a floating resistance and a circuit which will have a non floating resistance; in both the cases we can use actually a voltage controlled current source. In this circuit we are having the output current I_O which is effected or which is controlled by the input voltage source V_i.

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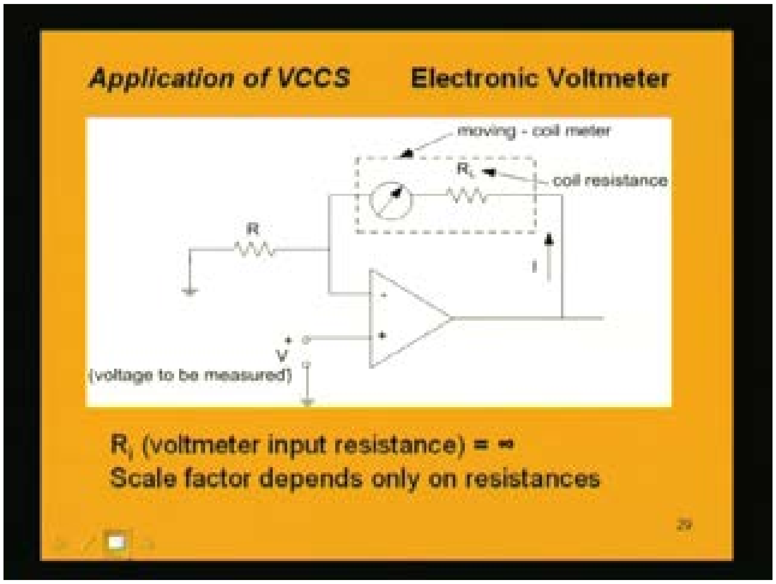

The voltage controlled current source that we are considering right now, finds application in electronic voltmeters. If we consider electronic voltmeters circuit, electronic voltmeter is basically a voltmeter which should be able to measure even very small voltages and if we want to find the measurement for a voltage we must have a considerable deflection in the meter and we may also want that a full scale deflection should occur for a specified voltage which is to be measured. In those cases, we will use a voltage controlled current source like the example which we discussed just now. Here these examples show a moving coil meter, the basic component in an electronic voltmeter and this coil resistance is R_L. We want to measure a voltage which is V. We are using it with an op-amp that means we are not using this electronic voltmeter alone. This moving coil meter, which we are having for measurement we are not simply using it and measuring any voltage, we are combining it with an op-amp.

The reason for this combination with an op-amp is that we want to have a specified deflection in this meter with respect to a particular voltage being applied at the input. Suppose we are measuring a millivolt range of a voltage and we want to have a full scale deflection in the moving coil meter which will be basically dependent upon the current flowing through it. The current which will flow if we denote by I that is the current which is flowing through this moving coil meter having the resistance R_L. This current should produce that much of deflection. Suppose if we want to have a deflection of 100 milliampere for a millivoltage range which is specified then how we can achieve this, is dependent upon how much resistance we will connect at R, because this circuit and the circuit (Refer Slide Time: 11:30) which you discussed which is voltage controlled current source are typically same because there we were using a feedback resistance which is R_L. This R_L is now the resistance of the coil resistance of the moving coil meter. Here the voltage which is to be measured is given at the input, non-inverting terminal. The current which is flowing through this coil or the moving coil meter is I. So this current is equal to, from the earlier consideration we have seen, Vi by R.

R is the key element which will decide the current and in order to have a specified value of current for a specified amount of voltage at the input, we must connect that R which will give our requirement. This is a very important example of application of voltage controlled current source and here one thing that is achieved by combining it with an op-amp is that the voltmeter input resistance is almost infinite we are getting and that is very useful. Also another factor is that the scaling factor will only depend upon the resistances because here whatever the output current must be that is decided by the resistance and that is why we use this type of VCCS in electronic voltmeters where we can even measure very small millivolt range of the voltage very accurately.

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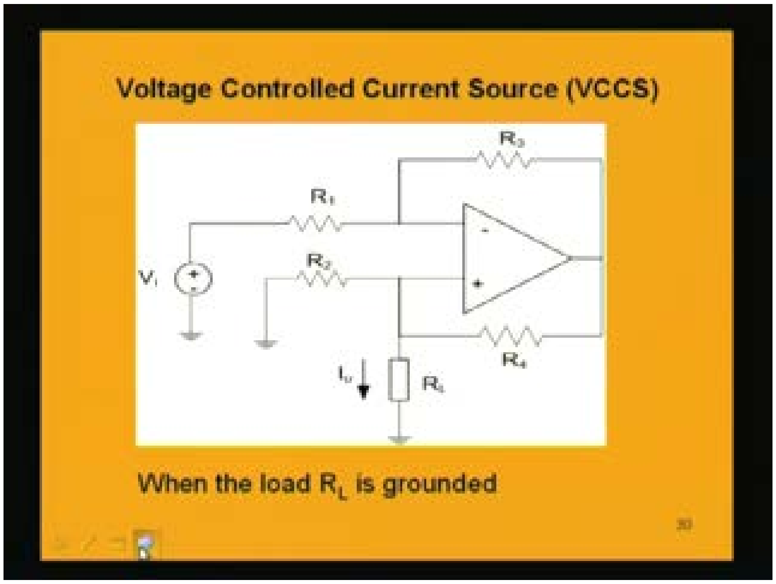

If we consider this example a voltage controlled current source, here we are having a same VCCS that is voltage controlled current source which is the similar example as the earlier case. But there is a difference here. In this case we see that the load resistance which is connected is grounded. In the earlier cases, here (Refer Slide Time: 11:30) as well as here also (Refer Slide Time: 9:32), the load resistance is not grounded, but here the load resistance is grounded. This is also an example of a voltage controlled current source. The output current I_O is the current of interest. That is we want to find out what will be this I_O? But our input is a voltage which is V_i.

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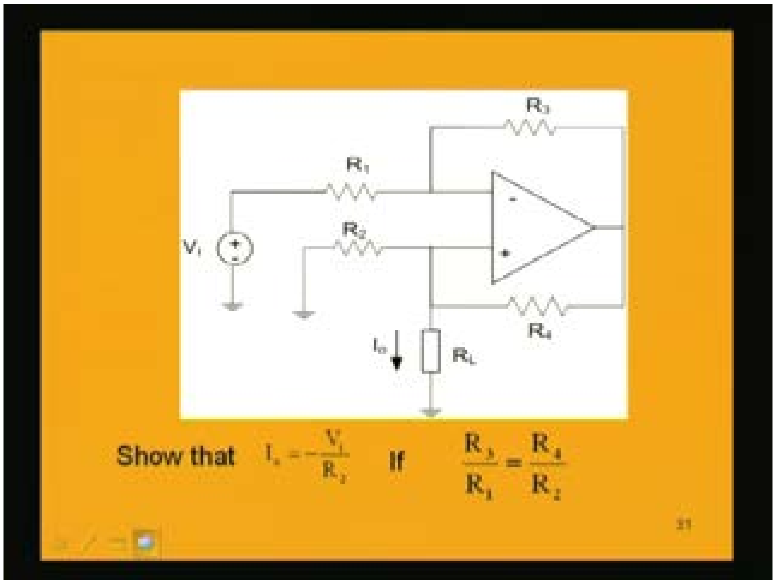

In order to know what is I_O let us first assume one thing, before finally analyzing the circuit, that R_3 by R_1 the ratio between these two resistances is equal to R_4 by R_2 that is maintained and if this resistance ratio is maintained then we can show that I_O which will be finally flowing at the output is equal to minus V_i by R_2, V_i being the input voltage. We can show that the current at the output I_O is equal to minus V_i by R_2 if R_3 by R_1 is equal to R_4 by R_2.

Let us do this example. We will try to show that I_O is equal to minus V_i by R_2. Drawing this circuit again, let us name the currents which are flowing.

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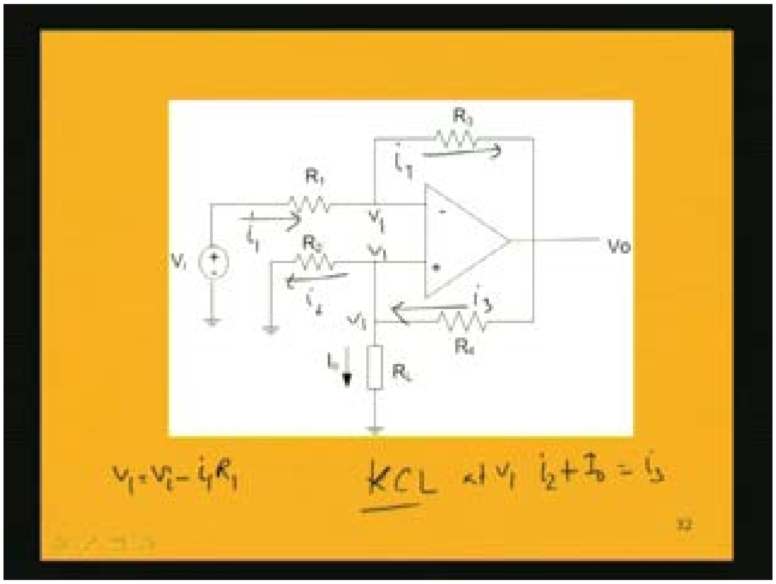

The current which is flowing through R_1 is i_1 and the same current i_1 will also flow through R_3 that is also i_1 because there cannot be any flow of current into the op-amp which is the condition or which is the assumption which we have been following, following the ideal op-amp consideration. What will be the current I_O, we have to find and for that let us name one node voltage V_1 which is here. Let us name this node voltage as V_1. If this is V_1, this node voltage is also V_1 because of this op-amp being ideal. This voltage will be also V_1 that means this voltage is also V_1. This point and this point are same.

We now apply Kirchhoff's current law, KCL at this node V_1. One current is I_O, which is outgoing and let us also assume the current which is flowing through R_2 that is also outgoing and the current which is flowing through R_O is say incoming. This again is our assumption. You can also assume it as outgoing or this is incoming as you wish because ultimately we will get same expression only if we follow Kirchhoff's current law. Let us name it as the current here is say i_2. This is i_3. If we apply Kirchhoff's law at V_1, we get the sum of the incoming current is equal to the sum of the outgoing currents. Here the outgoing currents are i_2 plus I_O that is equal to the incoming current i_3. What is i_2? i_2 current is nothing but V_1 by R_2 and what is i_3? We can find out i_3 because i_3 is nothing but the difference in potential between this point and this point which is V_O minus V_1 divided by R_4.

Using this result that is V_1 by R_2 plus I_O these are the outgoing currents, we have denoted like this and equal to incoming current which is equal to V_O minus V_1 by R_4; that is the Kirchhoff's current law being applied at node V_1. You will further simplify because we know what is V_1? If we find out V_1 from this input side, what is V_1? This voltage is nothing but V_i minus this drop which is i_1 into R_1. So V_1 equal to V_i minus i_1 into R_1; we will use that here.

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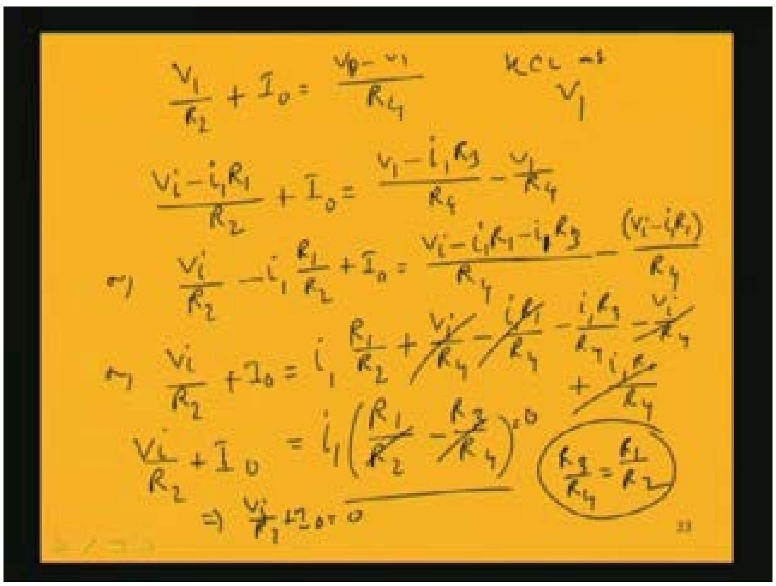

Instead of writing V_1, we will write V_i minus i_1 R_1 by R_2 plus let us say keep I_O, as it is because we want to find out I_O and from the figure what is V_O? We can write V_O in terms of V_1 as V_1 minus i_1 R_3; this drop when you subtract from V_1 that will be V_O. That is V_O can be written as V_1 minus i_1 into R_3 by R_4 minus V_1 by R_4 let us separate. We are keeping V_1 in all the expression and if we now separate out some of the terms, V_i by R_2 minus i_1 into R_1 by R_2 plus I_O equal to again V_1 can be written as V_i minus i_1 R_1 by R minus i_1 R_3 by i_1 R_3 by R_4 minus again V_1 we can write V_i minus i_1 R_1 be careful about these signs plus and minus. This is the expression. Now we write as V_i by R_2 plus I_O and transfer all the other terms to the right side. If I transfer these terms to the right side that means i_1 into R_1 by R_2 will be positive plus what we will have here is V_i by R_4 minus i_1 R_1 by R_4 minus i_1 R_3 by R_4 minus V_i by R_4 plus i_1 R_1 by R_4. If you look into this expression, there will be some terms which will cancel out; this one and this one V_i by R_4 and this V_i by R_4 minus will cancel out and i_1 R_1 by R_4 and minus i_1 R_1 by R_4 will cancel out. So we are left with these two terms in the right side, which is equal to i_1 into R_1 by R_2 minus R_3 by R_4 and that is equal to left side which is V_i R_2 plus I_O.

Now look into the right side because we are using an assumption which is given to us that is R_3 by R_1 is equal to R_4 by R_2. We will use that; R_3 by R_4 is equal to R_1 by R_2. Using this expression we will now have these two cancel out, so these two will cancel out. We will get here zero that means V_i by R_2 plus I_O equal to zero.

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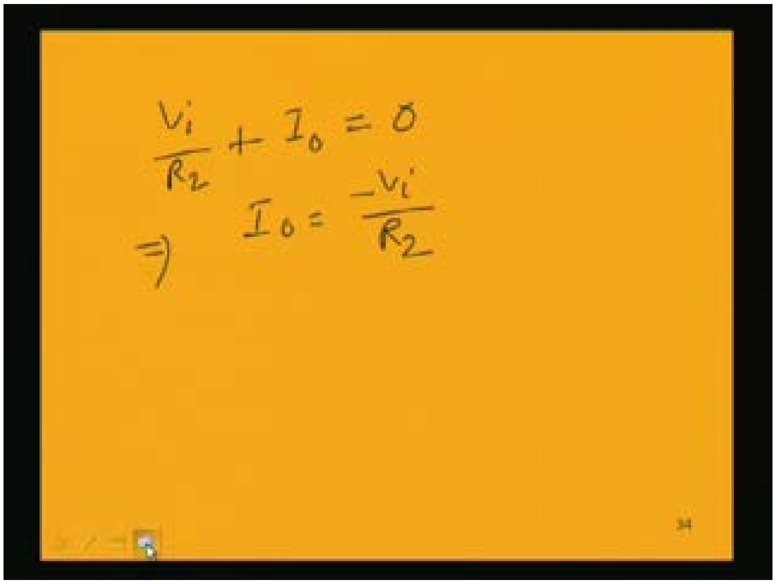

If the right hand side of this V_i by R_2 plus I_O is zero that means we get I_O equal to minus V_i by R_2. That means we can show that the controlled source current or current source which we will get at the output which is I_O that is equal to minus 1 by R_2 into input voltage V_i. Our result is now obtained which you have been asked to get by using this law or by using this relation actually. This example was an example of a voltage controlled current source.

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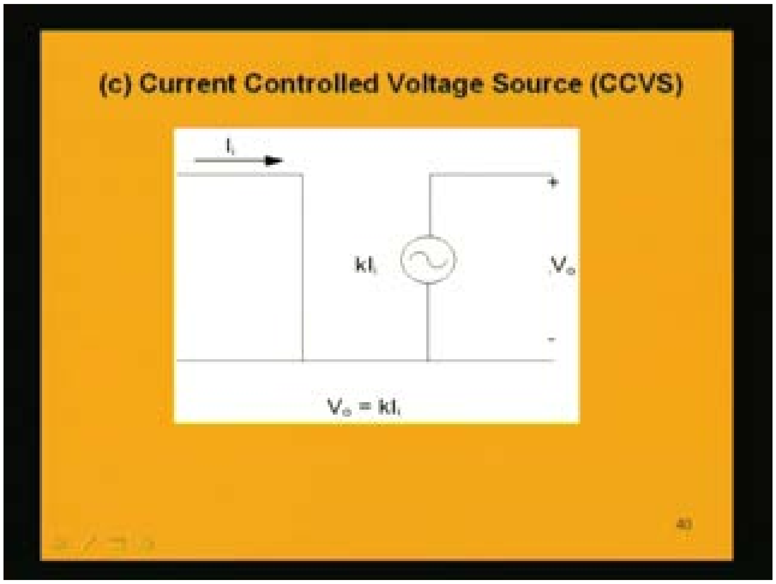

Another source which is a controlled source is current controlled voltage source. So far we have discussed about voltage controlled voltage source as well as voltage controlled current source. Now we will discuss current controlled voltage source and current controlled current source. Current controlled voltage source or CCVS, as it is named, is having this diagram which is an ideal block diagram form of a current controlled voltage source. Here the input is a current. I_i is current and at the output we are getting a voltage which is V_O and V_O is a voltage which will be controlled by the input current I_i according to the law k times of I_i; k is actually a constant.

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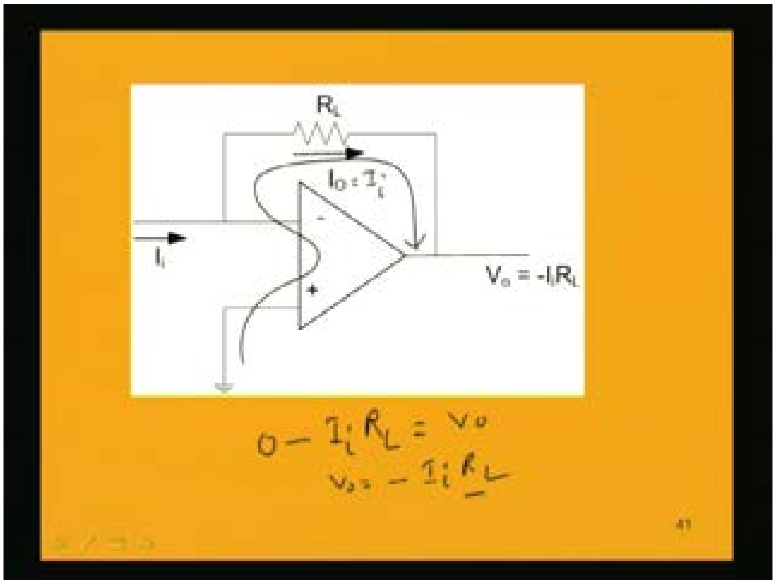

For example we have this circuit where we are having an input current I_i and the voltage at the output if we want to find out what is this V_O? V_O is found out by flowing in this loop starting from ground which is zero minus I_O into R_L is equal to V_O or I_O we can just write as I_i. Because I_O is equal to I_i there cannot be any current flow in the op-amp. So zero minus I_i into R_L is equal to V_O. So that means V_O is equal to minus I_i into R_L. Here the k which we are writing here is this resistance R_L. This example is a very simple example of the current controlled voltage source.

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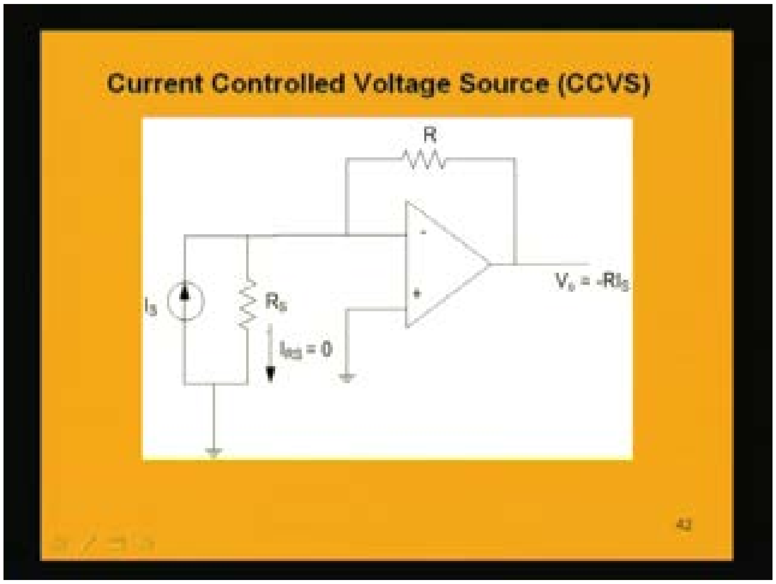

Basically in the example which we have shown here, input is having a current source. But if we think about a current source, basically a current source is having actually an infinite resistance ideally, in parallel, and as larger value that parallel resistance has, it is more and more towards an ideal current source. Because we know that along with the voltage and current there will be series resistance in voltage source and current source will have a parallel resistance. An ideal voltage source is when the series resistance is zero and an ideal current source is when the parallel resistance is infinite. But practically we never get an infinite parallel resistance with a current source and that is why even if we want that the input current should pass on to the load wholly, that means 100% of the current available from the current source must be available for the input circuit, that does not happen because a part is lost as the current through the parallel resistance which is along with it.

This is a current source. Basically a practical current source will have this resistance, R_S. We apply directly a current source in a circuit. In this circuit whatever we have shown, it is a current source just applied in this circuit; but then the current source is having a resistance that was not shown in this case. But because of this fact that it has a resistance which is parallel to it and which is to be avoided and because we want that the resistance should not draw any current so that the whole source current must be available in the circuit, we are combining it with an op-amp. What will we gain? We now see what part of the current will flow through this resistance? In this resistance, this point is the negative or inverting terminal of the op-amp and its positive is grounded. We are having an op-amp. These two points are having the same ground voltage. This voltage is also ground voltage and at the other point of this source resistance, this is also ground. There cannot be any flow of current through this resistance R_S because both the points are at ground because of the connection through an op-amp. Our aim that there should not be any current flow in the parallel resistance of the current source is being achieved and so the current will be flowing wholly through this R and so the output voltage we will get minus R into I_S. This is an example of the current controlled voltage source because we are getting an output voltage V_O which is controlled by the current source I_S.

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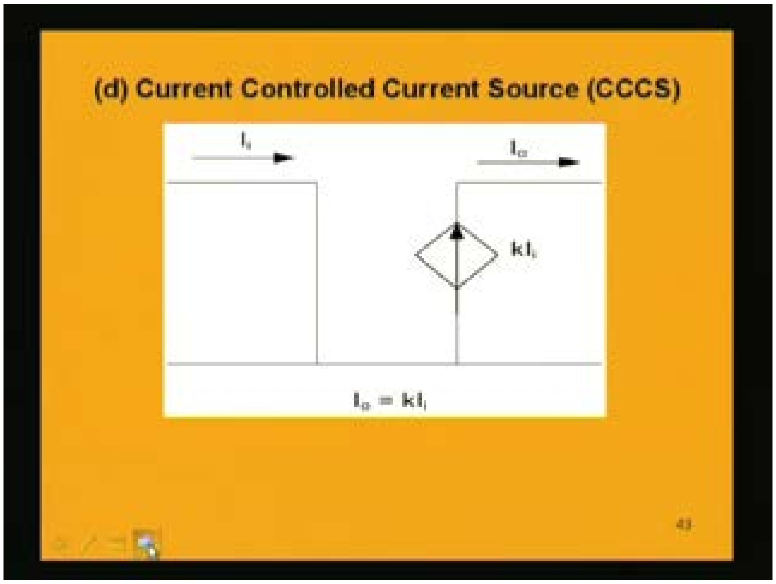

Now current controlled current source is another example of control source driven by an input current and here the output is a current. Earlier case we got a current controlled voltage source but here the current controlled current source we are getting. This is the ideal block diagram representation of this current controlled current source. This is the model of the current controlled current source. Here this is the dependent current source at the output which we obtain from the input by this relation that I_O is equal to k times of I_i. Let us now see the practical implementation of a current controlled current source.

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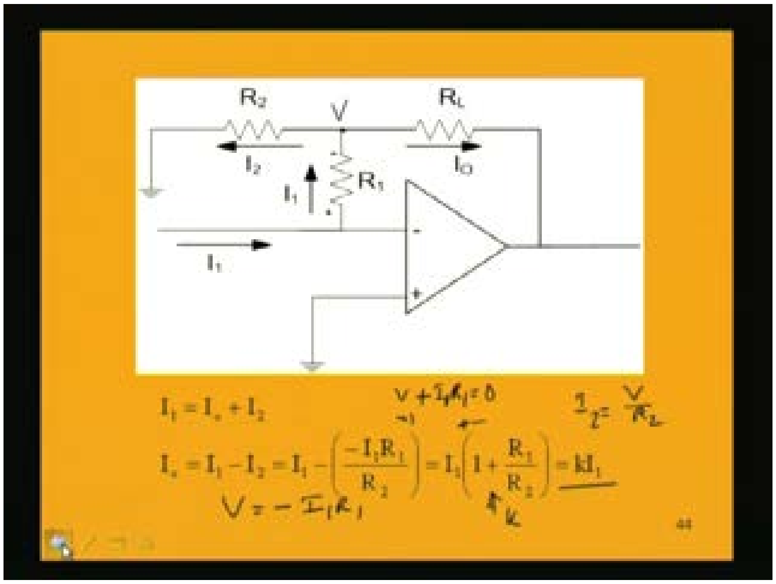

This is an example of a current controlled current source. Here we are having an input current and we have to find out what will be the output current I_O? There is this op-amp and positive or non-inverting terminal is grounded and we are having resistive network having the resistances R_1, R_2 and R_L. The current if we denote at the input as I_1, this I_1 will flow through R_1 as there cannot be a current in the op-amp and at this point, one part of the current will be say I_2 and the other current is I_O. So I_1 is basically I_O plus I_2. So I_O is I_1 minus I_2. This current I_2 we can find out. If I name this voltage as V, the current I_2 is nothing but V by R_2; this is I_2. Now what is V? Suppose we use this loop; this current is flowing. This point is plus, this point is minus. So V plus I_1 R_1 is equal to zero; because I am coming from this point downwards, minus plus is raising voltage, so V plus I_1 into R_1 is equal to zero. This is ground. From here I get what is V? V is equal to minus I_1 R_1. I am replacing this minus I_1 R_1 here. In place of I_2 I am writing minus I_1 R_1 divided by R_2. That is the expression for I_2.

Simplifying further, taking I_1 common I get 1 plus R_1 by R_2. So I_O is equal to 1 plus R_1 by R_2 into I_1. This can be written as k. This is the ratio R_1 by R_2 plus 1. This is a constant. That means we get this expression of this I_O as k times of I_1 and this is the form of a controlled source which is a current source driven by input current. This is an example of a current controlled current source, CCCS. We are controlling the output current by an input current. Example of control sources we have taken up today. We have seen different forms of control sources; voltage controlled voltage source, voltage controlled current source, current controlled voltage source and current controlled current source.

Let us now try to solve one or two examples which are based on these op-amp circuits. Using that ideal op-amp consideration, now let us find out a voltage V_O given in a circuit like this.

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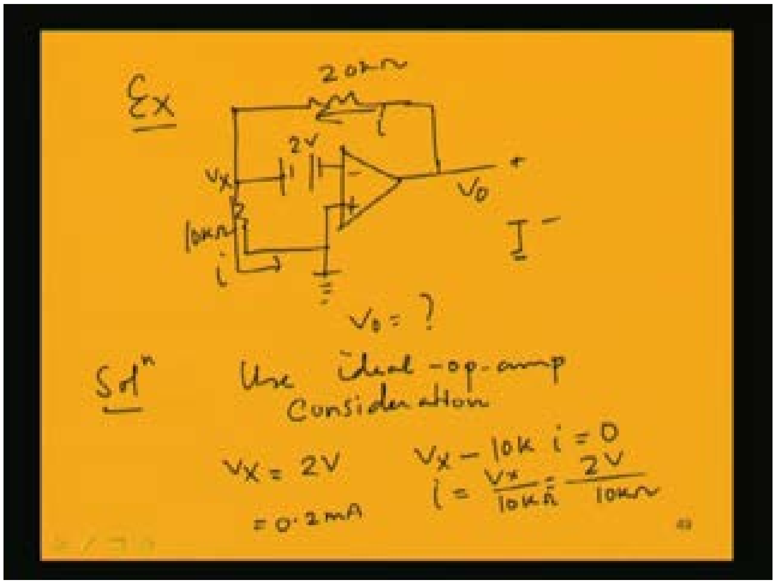

We have an op-amp and we are having a source applied to it say minus plus, minus plus 2 volt and this resistance, if this one is 20 kilo ohm, V_O is to be found out and the positive terminal is grounded but the point here is connected to this positive terminal and this resistance is 10 kilo ohm. Note this circuit using this op-amp. We have to find what will be the value of V_O? In all analyses we use ideal op-amp consideration; that means we will use that property of ideal op-amp. In order to find out V_O, let us name this node voltage as V_X. What is V_X? If we come down from this point to ground V_X minus 2 volt is equal to zero. So V_X is equal to 2 volt and let us name the current as i, which flows through 20 k. I am showing the direction like this; intuitively I am assuming that this is flowing to ground, so it will be in this direction. But there is no hard and fast rule. We can take the direction from left to right also; that will not harm.

We now find out what is I? I, current can be found out if we come from the V_X to ground through this resistance. The current i, which is flowing will not go through this part because then it will have to enter the op-amp. So it will flow down like this. This current i and this current i, which flows through k, 10 k is same. So now I can write V_X minus 10 k into i minus zero equal to zero. So what is i can be found out; V_X by 10 k ohm and we know V_X is 2 volt. So 2 volt by 10 kilo ohm is the value of this current. That means it is 0.2 milliampere.

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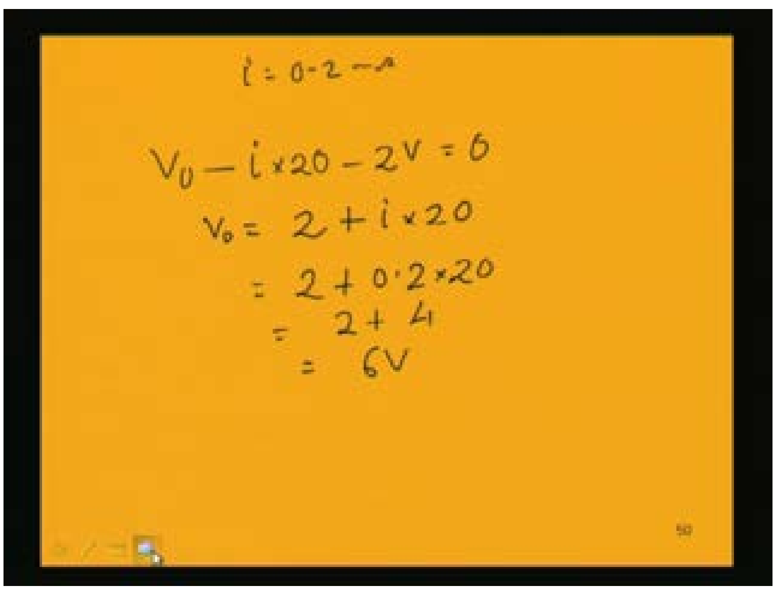

We got the current i is equal to 0.2 milliampere. We are interested in finding out V_O. How we can find out V_O? V_O can be found out if we flow from this point V_O minus 20 into i minus 2 volt is equal to zero. The voltage V_O can be found out using this expression or KVL; V_O minus i into 20 this drop minus 2 volt to ground if we come. V_O is equal to 2 plus i into 20; 20 is in kilo ohm and i we have found out in milliampere. So it will be in volt only; 0.2 milliampere into 20, so 2 plus 4 which is 6 volt is the voltage V_O. This is an example of a simple circuit. Similarly we can proceed to find out actually different parameters in a circuit.

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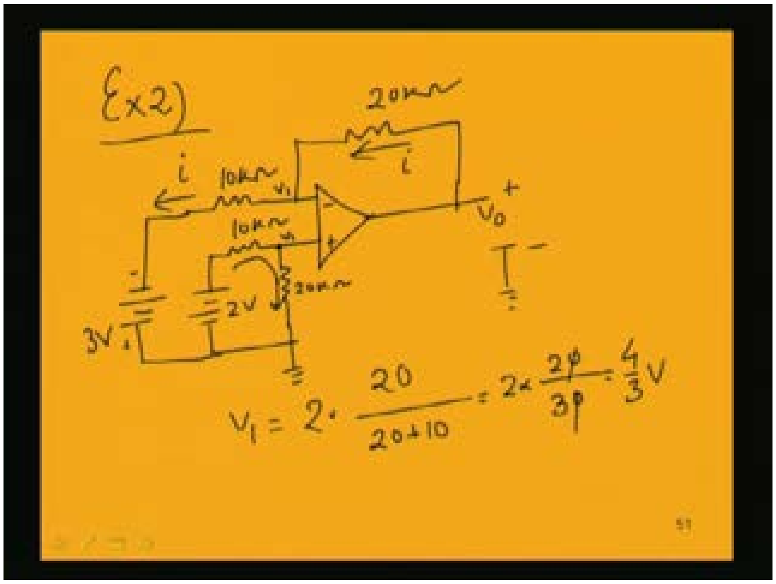

Another example let us do to find out the voltage in this circuit. If we have a circuit having say a resistance is connected here which is 10 kilo ohm, another resistance is here which is also 10 kilo ohm then this resistance is 20 kilo ohm. There is a source or a battery 2 volt. This point is ground and another source is in the opposite direction of polarity. This is 3 volt. Another resistance is there in the feedback part which is having 20 k ohm. We have to find out what is this voltage V_O? To solve this example, let us name the node voltages as v_1 here. If this is v_1, this is also v_1 according to the ideal op-amp assumptions or ideal op-amp properties and let us name the current also. This current is i let us name it and the current which is flowing through this 10 k ohm must be also equal to i. We have to find out what is V_O and for that let us first find out what is this node voltage V_1?

If you see this circuit, we want to find out the voltage at this point. The other point is grounded. This is a circuit where we can find out the voltage V_1 simply by following the voltage division law. So V_1 is equal to 2 into 20 by 20 plus 10; kilo ohm I am omitting because all are in the same unit. So we get 2 into 20 by 30. That means we are getting a 4 by 3 volt at this node which is same as this voltage. V_1 is equal to 4 by 3 volt. We can now apply the Kirchhoff's current law at this node V_1. If we apply Kirchhoff's current law, at this node V_1 the current incoming is i, which is equal to V_O minus V_1 divided by 20 k and that is equal to the current outgoing which is equal to V_1 minus -3 because this polarity we have to be careful. This is minus, this is plus, so if I find out the potential difference between these two points, this point is grounded and this point, V_1 minus this voltage but this voltage is -3; so V_1 plus 3 divided by 10 k that is the outgoing current. This expression can be applied here at V_1 of the Kirchhoff's current law at node V_1.

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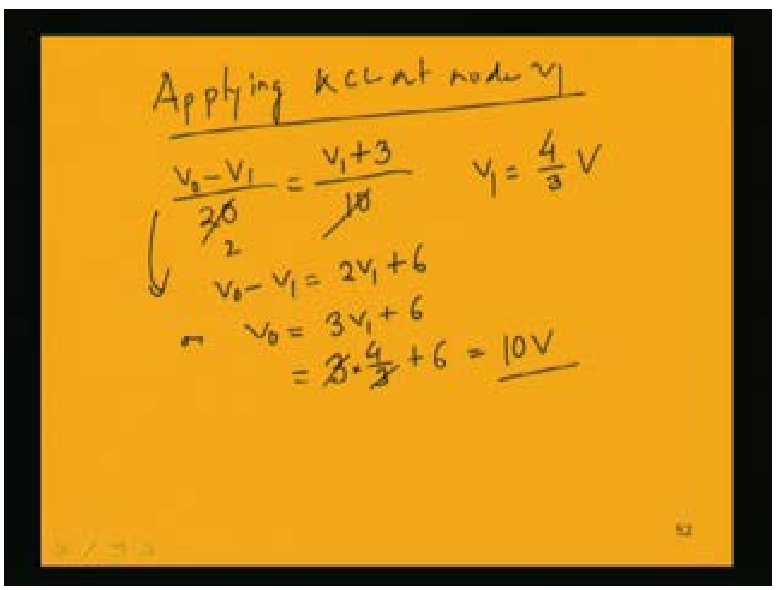

KCL, Kirchhoff's current law we are applying at node, which has a voltage V_1. So that gives us the incoming current i is equal to the outgoing current, same current but we will find out this expression from the node voltages V_O minus V_1 by 20 k. Omitting this k because both sides will have the same unit equal to as I have said V_1 minus -3 that is V_1 plus 3 by 10 and we already have known what is the value of V_1. V_1 is equal to 4 by 3 volt. So this is 2; so from this relation we get V_O minus V_1 equal to 2 times V_1 plus 6 or what is V_1 can be found out? V_O is equal to 3 times V_1 plus 6. So replacing this value of V_1 by 4 by 3 what we get at the output is 10 volt. The output voltage V_O is 10 volt that we have got here in this example following the principal of ideal op-amp.

In another example let us try to find out the power in a circuit.

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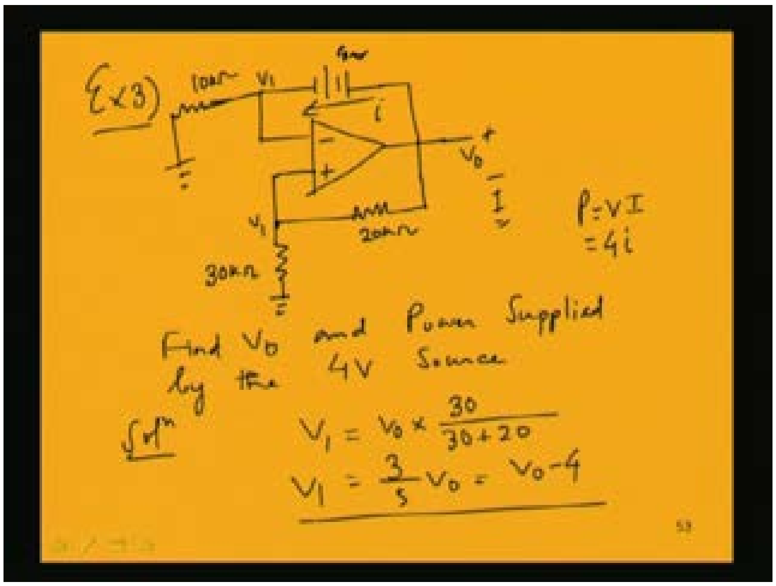

For example we have a circuit having an op-amp here. We are having this battery here minus plus minus plus 4 volt. 4 volt battery is applied in the feedback part and we are having in the non-inverting terminal, a resistance which is 30 kilo ohm and another resistance is connected which is 20 kilo ohm and here there is a resistance which is 10 kilo ohm to ground. This is the circuit. We want to find out the output voltage. Find V_O as well as the power supplied by the 4 volt source. In order to find out the power supplied by the 4 volt source, we must also know the current flowing through it. Because power is equal to voltage into current, we must know the current which flows. Let us name it by i. So we will have to find out the current through it because then only we can find out what is the power supplied by the 4 volt source. Power supplied by the 4 volt source will be 4 into i.

So i we need to know. In order to solve this following similarly let us name this node voltage here as v_1 which is same as this point voltage which is V_1 only; these two voltages are same. We now find out what is? We can find out V_1 in one way just by finding out this voltage which is that portion of the voltage available from V_O. We do not know V_O but then we will be solving following this relation. What is V_1? V_O into 30 k divided by 30 plus 20 k; because if we consider this as a source this is ground, this is the part. The voltage here into this resistance by this resistance plus this resistance; this is the voltage division principal we are applying. We are interested to know this voltage. We are finding out V_O into 30 by 30 plus 20; so 3 by 5, 30 by 50 is 3 by 5. So 3 by 5 V_O is equal to V_1. We have found this voltage, here as well here. This is the same voltage 3 by 5 into V_O and so this can be written in another way V_O minus 4 volt is equal to again V_1 that is equal to V_O minus 4 volt. Using these two relations we can find what is V_O?

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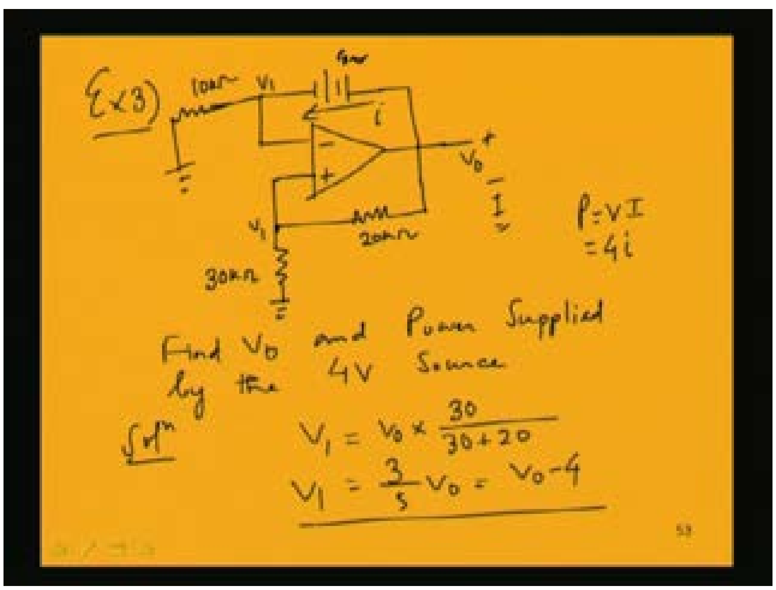

So V_O minus 4 is equal to 3 by 5 V_O or we can find what is V_O? V_O is equal to V_O into 1 minus 3 by 5 equal to 4 V_O into 2 by 5 is equal to 4. So V_O equal to 10 volt. We have known 10 volt is V_O. If we know V_O, then V_1 we can find out. V_1 is nothing but V_O minus 4; the voltage here is V_O minus 4. 10 minus 4 is 6 volt. We know what is V_1 and so we can now find out what is the current flowing i? i, this current is nothing but the same current; this current is same current i, so V_1 by 10 k. V_1 is 6 volt so i is equal to V_1 by 10 k; 6 by 10 is 0.6 milliampere which is i. The current which flows here is 0.6 milliampere. 0.6 milliampere is the current which is flowing; i is equal to 0.6 milliampere, the current we know. We know the voltage which is 4 volt; so, we know the power supplied by the battery is 4 volt.

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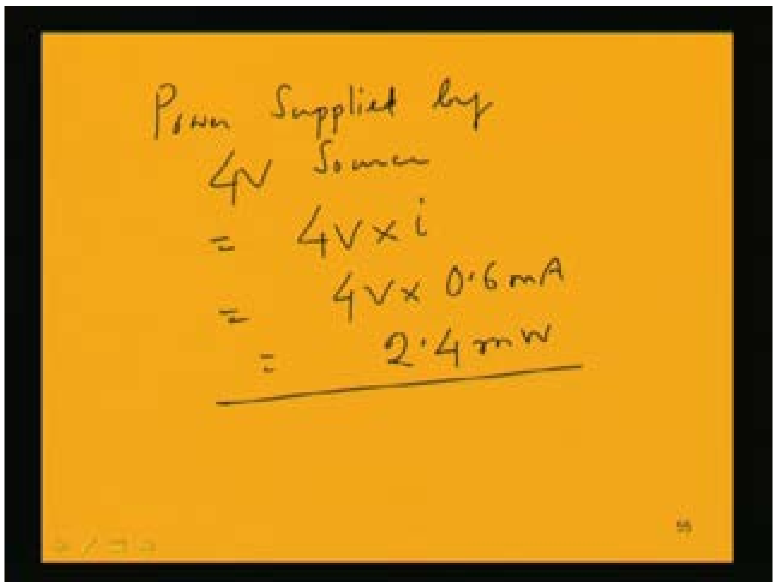

The power supplied by the 4 volt source equal to 4 volt multiplied by i and 4 volt multiplied by i, we have found out to be 0.6 milliampere and that gives us 4 into 0.6 which is 2.4 milliwatts; volt into ampere is watts. So miiliampere into volt is milliwatt. That means we have found out the power supplied by the 4 volt source which is 2.4 milliwatt and for that we have to find out the current flowing through that circuit or we have to know the current supplied by the source 4 volt actually. In this example we have seen that power can also be found out if we know the current as well as the voltage. These are some of the examples which we have solved today by following the same analysis of op-amp being ideal. In the whole analysis or in all the examples we have solved till now we are following only the ideal op-amp consideration. In order to solve such problems we have to know the ideal op-amp consideration only and then we can apply Kirchhoff’s voltage law as well as current law and we can find out the required quantities whether it is voltage or current in the circuit.

In today’s discussions we have seen the control sources being built up using op-amp and the four different variations of the control sources we have studied today. These four variations of control sources are voltage controlled voltage source, voltage controlled current source, current controlled voltage source and current controlled current source and these are extensively used. Mainly in instrumentation circuits also you will find applications of these control sources and also we have seen how we can solve numerical examples using ideal op-amp considerations and the KVL, KCL, etc to arrive at the required solutions.