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.
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.
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.
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 $1 + \frac{R_f}{R_1}$ 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 $V_i$. 

\[
V_o = \left(1 + \frac{R_f}{R_1}\right)V_i = kV_i
\]
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.
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 \( V_i \).
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, \( V_i \) 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.
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 \( V_i \).
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.
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 $V_0$ 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 $V_0$ 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 $V_i$ 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 $R_2$ 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 \( I_0 \).

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 \( I_0 \) equal to zero.

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If the right hand side of this \( V_i \) by \( R_2 \) plus \( I_0 \) is zero that means we get \( I_0 \) 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 \( I_0 \) 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.
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.
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, Rs. 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 $I_0$ 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 $I_0$? 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 $I_0$. So $I_1$ is basically $I_0$ plus $I_2$. So $I_0$ 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 $I_2$. 

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Simplifying further, taking $I_1$ common I get $1 + \frac{R_1}{R_2}$. So $I_O$ is equal to $1 + \frac{R_1}{R_2}$ 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 $V_0$ 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 $V_0$ 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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![Diagram](image)

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 milliampere 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.