Basic Electronics
Learning by doing
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Lecture – 30
Inverter/Non-inverter Circuits
(Switchable inverter/non inverter, sign changer, adjustable & reversible gain…..)

Hello everybody! In our series of lectures on basic electronics learning by doing let us move on to the next one. Before we do that let us recapitulate what we discussed in the previous couple of lectures. You might recall that we discussed about the various characteristics of operational amplifiers.

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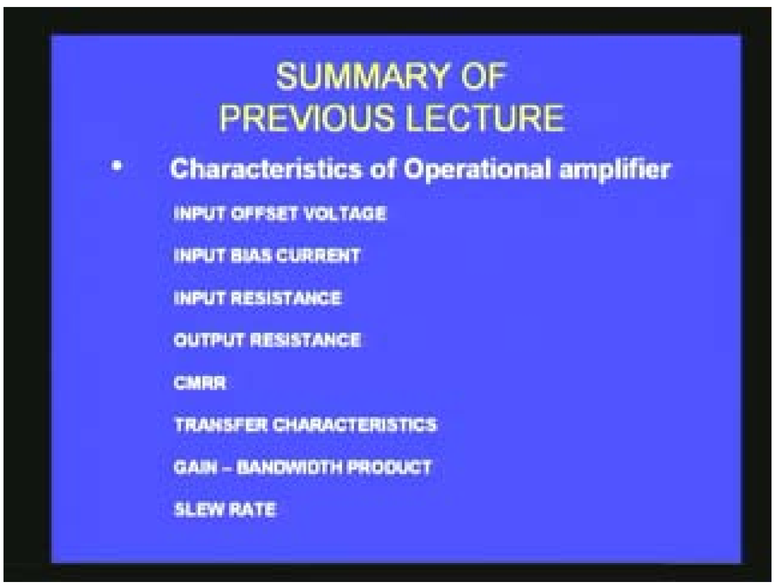

You can see on the screen I have listed them; input offset voltage, input bias current, output resistance, input resistance, common mode rejection ratio or CMRR as it is known, transfer characteristics, the gain-bandwidth product and slew rate. We also showed how these parameters can be measured in the laboratory. Now let us move on to certain applications of operational amplifier. I would like to take some simple application circuits of operational amplifier.

The first example I would like to take is an inverter/non-inverter circuit. A circuit which will be both inverter as well as a non-inverter by modifying certain things is the circuit I want to discuss now. The circuit is shown on the screen. This is a very simple circuit which may be very familiar to you because we have seen similar circuits earlier.

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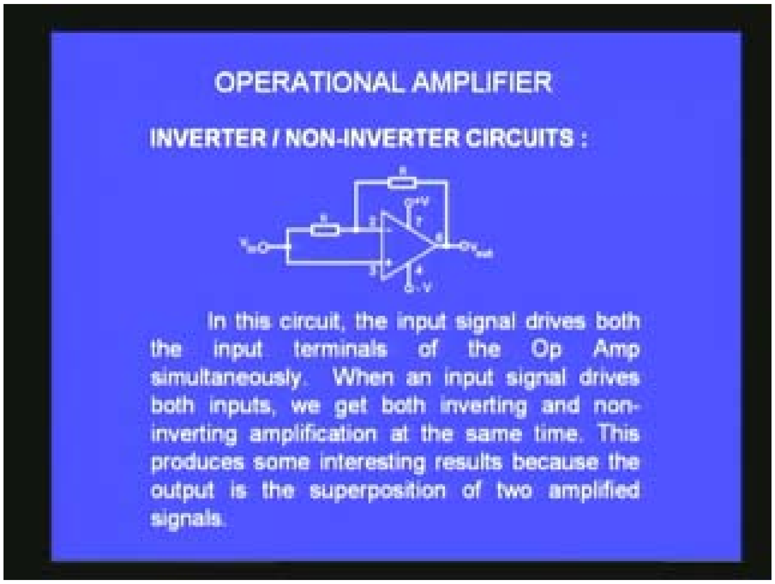

There is R and R; the feedback resistor and the R_i both are R here equal resistors and the op amp. The input voltage signal is applied simultaneously to both the non-inverting input as well as the inverting input. If I have the circuit like this and if I give V_{in} signal here what will be the output? It is somewhat tricky because the input is driving both the inputs and what will be the net output, the effective output? But I can assure you it is not going to be very difficult to understand because we have already learnt some of the theorems which will help us in understanding even complicated circuits. You might remember we discussed about the superposition theorem. Using superposition theorem we can understand the working of this circuit.

What is that we have to do? It is very simple. I assume the V_{in} is driving both the inverting as well as the non-inverting input. If I now ground this non-inverting input and apply the voltage only to the inverting input then it becomes a very simple exercise because it is a inverting amplifier and the feedback resistor is R, the input resistor is also R. The gain is -R by R that means -1. It is a very simple inversion circuit. It is inverting whatever is the amplitude at the input, correspondingly at the output. It just provides 180 degree phase shift between the input and output. When I ground the non-inverting input the amplifier becomes a very simple inverting amplifier. That is first part of the superposition theorem.

The second part I have to ground the inverting input and apply the signal only to the non-inverting input. That is the next option. When you do that the circuit becomes totally a non-inverting amplifier. I have shown here for example the total voltage gain that I get. A_v, the total voltage gain of that circuit, will be by superposition the gain of the amplifier when it is only an inverting amplifier. That means non-inverting input is grounded plus the gain of the amplifier when it is acting only as a non-inverting input with the inverting input connected to ground.

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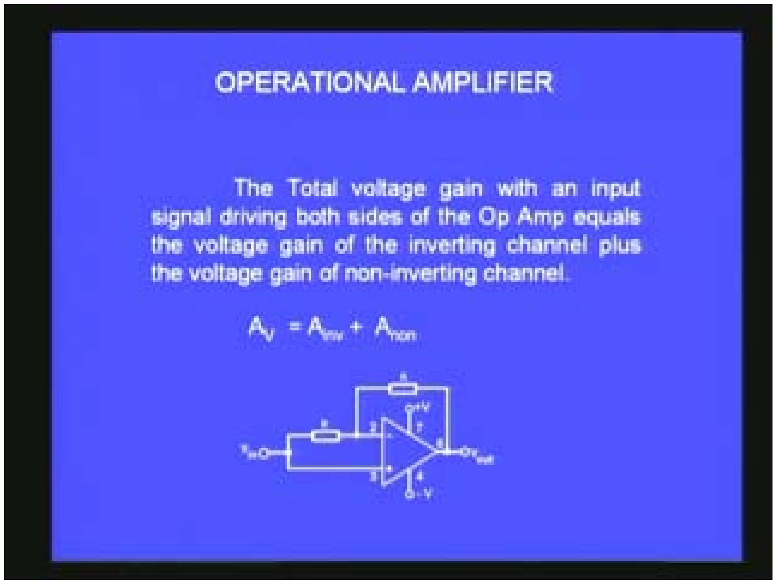

A_v the total voltage gain is equal to A inverting plus A non-inverting. That is what we want to look at. That is what I was just mentioning to you by using superposition theorem. Let us see in more mathematical terms how it is?

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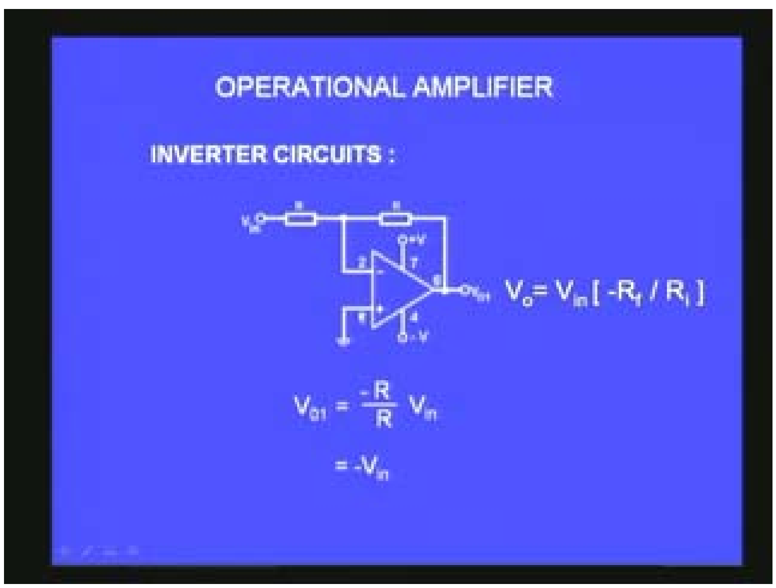

The three is grounded. This is the first part. We applied input; it is only at the inverting input and the gain is R by R therefore it is 1. But because it is inverting we have a negative sign. -R by R times V_{in} is the output voltage. V_{o1} I call it because it is a first configuration and it becomes $-V_{in}$ or if I want to look at it as gain V_{o1} by V_{in} is equal to -

1. This is very simple. Now I go to the second configuration in the superposition where I ground the inverting signal input and apply the input only to the non-inverting.

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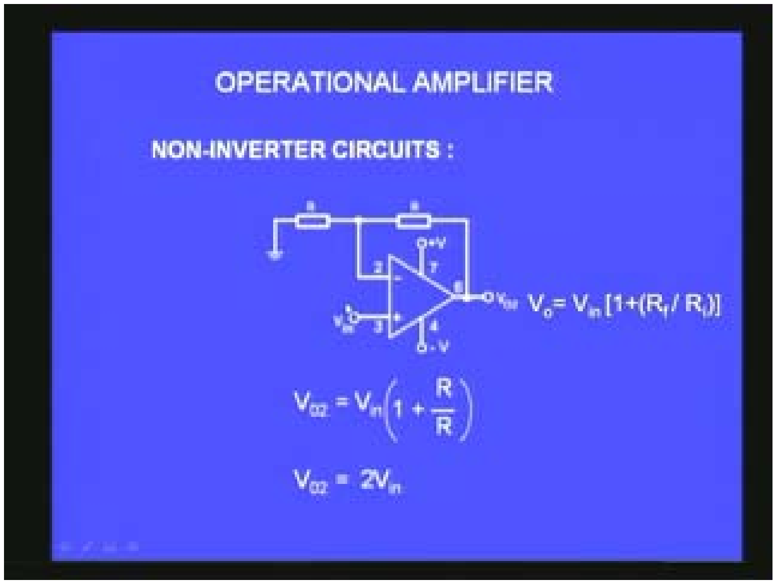

Then what happens? It becomes a very simple non-inverting amplifier and for a non-inverting amplifier output voltage, now we call that V_{o2}, V_{o2} is equal to V_{in} the applied voltage multiplied by a factor which is 1 plus R by R; 1 plus R_2 by R_1 where R_2 is the feedback resistor here. Because the two resistors are equal R and R it is 1 plus R by R and that means it is 2. V_{o2} is equal to 2 times V_{in} or the gain of the non-inverting amplifier is 2. I have found the gain of the inverting amplifier separately and the non-inverting amplifier separately. All that I have to do is I have to add them together to get the total voltage gain of that amplifier. V output is therefore is equal to $V_{o1} + V_{o2}$ where V_{o1} is due to inverting and V_{o2} is due to non-inverting. This is $-V_{in}$ as we have seen already and this is $2V_{in}$ and what I left with is V_{in}.

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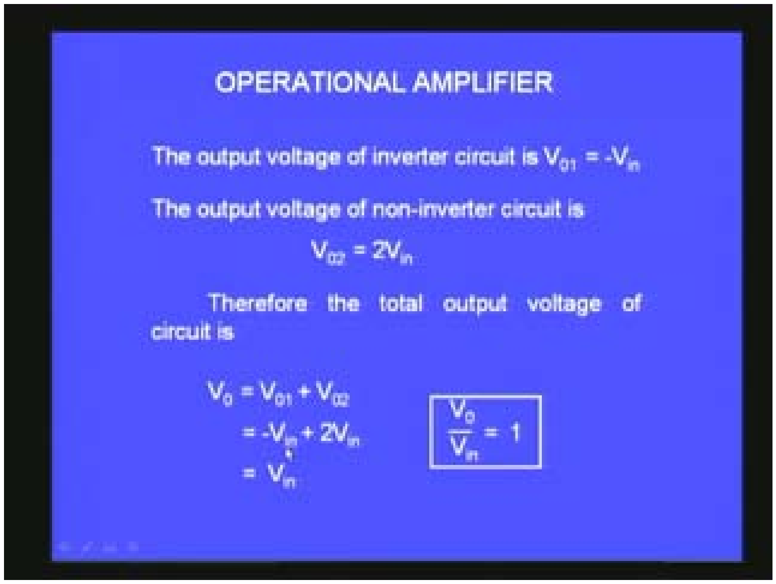

V output is equal to V input. That means it is a non-inverting amplifier effectively and the gain is 1; V_o by V_{in} is the gain and that is equal to 1. When I have simple configuration like the one I showed you at the beginning and if I have the circuit with the two resistors equal and apply the input voltage here I would exactly get the same voltage at the output. But if I disconnect this and connect it to ground it becomes an inverter and the gain becomes -1. This circuit can easily be used to switch between inversion and non-inversion. That is what I want to show you as a next application. By using the superposition theorem in the earlier circuit I can now have an amplifier which can switch between inverting amplifier and a non-inverting amplifier. If I want inverting amplifier it is very simple. I have replaced one of the wires that you saw in the previous circuit with a switch here.

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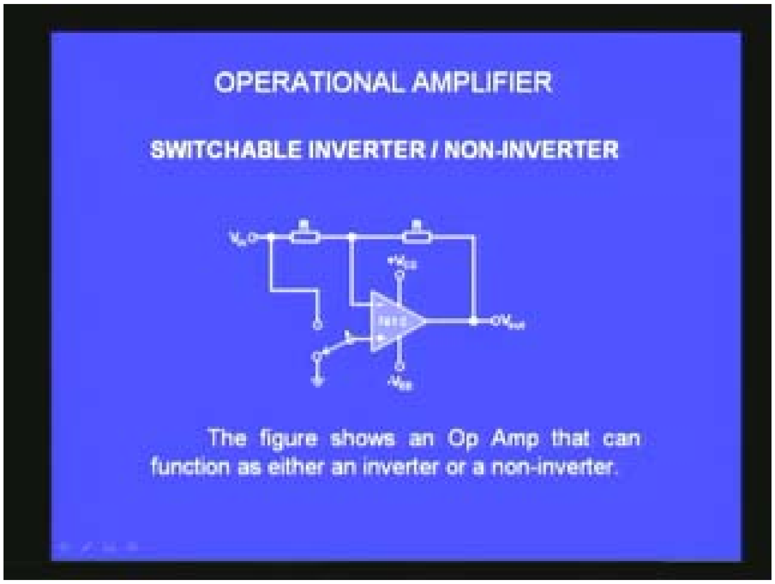

It is called single pole double throw key. You either connect this terminal three to ground or you can connect it to the input V_{in}. When I connect it to ground it becomes a very simple inverting amplifier because the R, R are equal and you are giving the input at the inverting terminal and the gain will be -R by R and that means -1. It is a simple inverting circuit when I put the switch to the ground with reference to the non-inverting terminal connected to the ground. But I want the other configuration that I have shown here. A_v for this configuration is -R by R. That is equal to -1 because R is equal to R.

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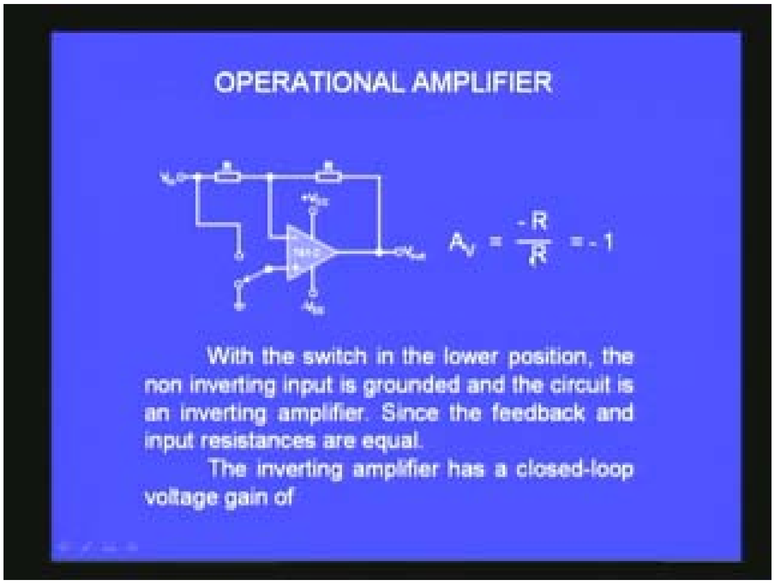

If you want a gain you can always put the feedback resistor 2R, 4R, 10R and correspondingly you will get the gain. But here you just want an inverting or a non-inverting amplifier selectable by a simple switch. We have kept the resistors equal so that we don't get any gain. We just get an inversion or a non-inversion. This is the first part where it becomes a simple inverting amplifier. The two resistors are equal and you are only operating the inverting mode and the non-inverting terminal is connected to ground. The gain is -1. Now I have switched the non-inverting input to the input voltage rather than to the ground.

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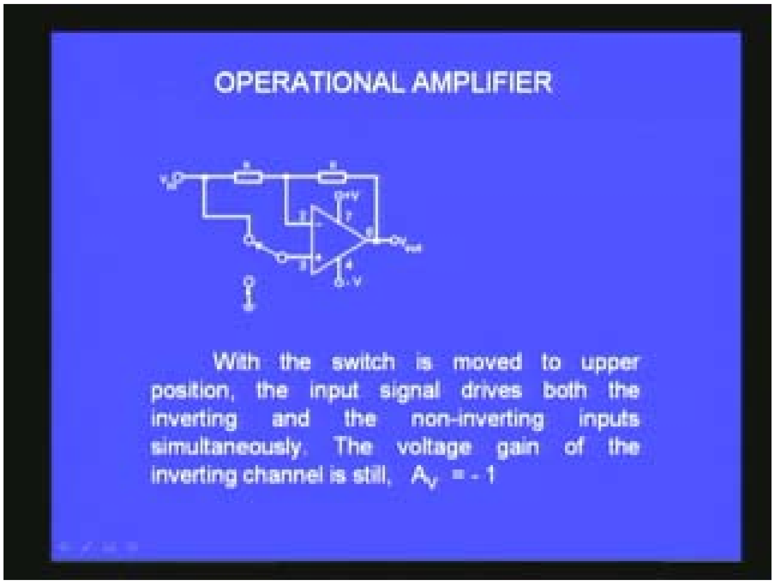

Previously it was here. Now I have shifted it to the input in this configuration. It is the same as the circuit which just now we discussed by using superposition theorem in two stages and the gain of this circuit is +1. By super position theorem the gain of the non-inverting amplifier is 2; the gain of the inverting amplifier is -1. When I add them together 2-1 gives me 1. It becomes a simple amplifier with a gain of 1. It is a non-inverter; whatever input I give V_{in} I get at the output. By selectively choosing the two terminals corresponding to the non-inverting terminal of the op amp whether I connect it to ground or to the input voltage I can switch the amplifier to be an inverting amplifier or a non-inverting amplifier with a gain of 1. That is exactly what I have shown on the screen. A non-inverting is R by R plus 1 that is equal to 2 and the algebraic sum is A_v is equal to A inverting plus A non-inverting. That is equal to -1+2 is equal to 1.

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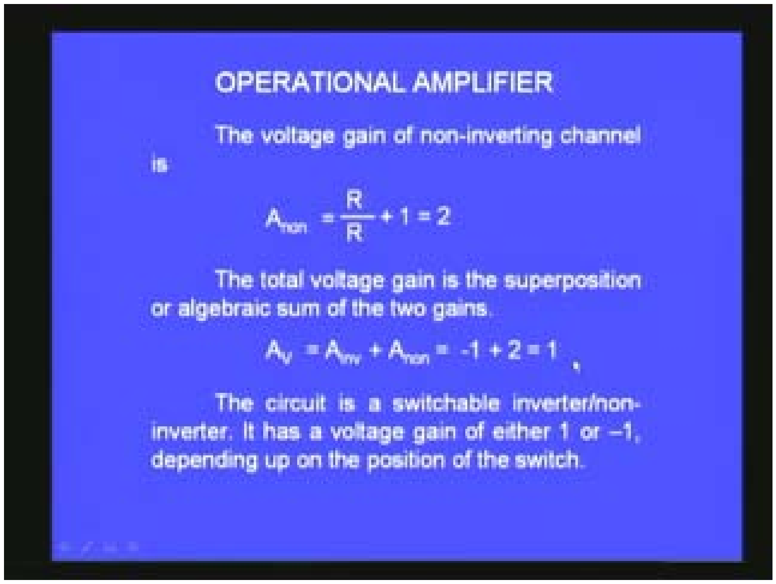

The circuit is a switchable inverter/non-inverter circuit and it has got a gain of either 1 or -1 depending up on the position of the switch. It will be very useful in different applications. I will show you the same circuit wired on the bread board and I will show you how this can be very easily switched. Instead of using a switch I will use the same wire; one single wire which is connected to the non-inverting terminal. I will either connect it to ground or to the input of the inverting terminal. Thereby I will show you what happens to the gain at the output. The circuit here is same as the one which I showed you just couple of minutes ago.

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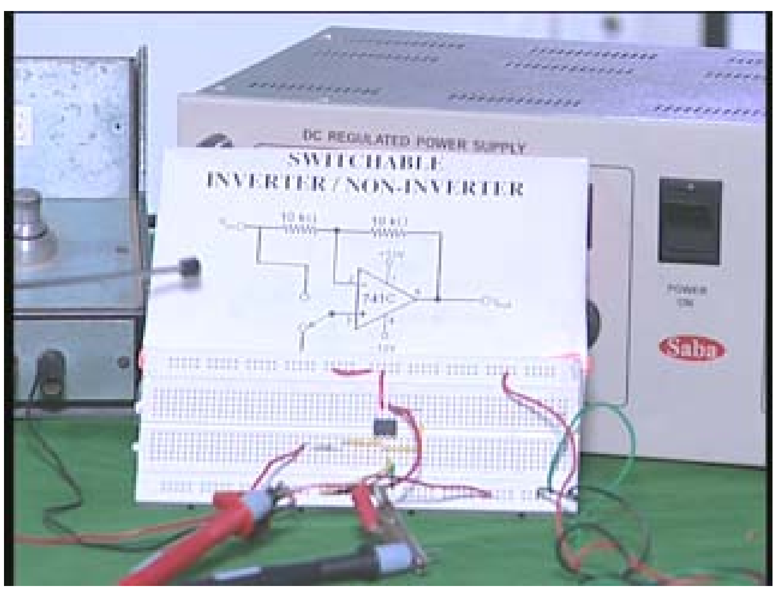

There is an operational amplifier 741 at the center. There are two resistors which are called R and R in our circuit. This is 10 kilo ohm; this is also 10 kilo ohm and the non-inverting input can be either connected to the ground or connected to the V_{in}, input by using this switch. Instead of the switch I am going to use a wire which can be connected either to this end or this end. That is the only difference. The same circuit is wired here. I am sure you can see the operational amplifier here at the center and this is the power supply. This is +12 volts line and similarly at the bottom you have the -12 volts. The green wire shows the -12 volts and the black wire corresponds to the ground connected to the dual supply that I have at the back. Now it is actually connected to the ground. This input is exactly in the same way as it is shown in the circuit. It is connected to the ground this yellow wire and for the input I am using a millivolt source which is also very familiar to you. We have used this in the earlier experiments also. This is the millivolt source and the output of the millivolt source is connected as the input and the output of the operational amplifier is connected to a multimeter which is in the voltage scale and it is now reading -1.01 which is the output voltage.

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The output voltage for this circuit is -1.01. Now let me take out the multimeter from the output and connect it to the input and at that time you observe what the multimeter reading is. I have removed the multimeter from the output pin number 6 and connected to pin number 2 to the inverting this end; I have connected the multimeter here. What it is now measuring is the input voltage from the voltage source and I want you to observe the multimeter. It is showing +1.01. The input voltage is +1.01 and the output voltage we measured is -1.02. There is only a simple inversion.

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I give 1 volt here I get -1 volt at the output. I will again quickly take it out and connect it to the output once again. Now I have connected to the pin number 6 again the same multimeter and I want you to observe the multimeter. It shows -1.01. There is inversion nothing else. It acts as an inverter because I have connected the non-inverting terminal to the ground. What I am now going to do is remove that wire and connect it to the input. It is equivalent to having a switch. I am switching it off on the other side; pushing it on to the other side. I am going to take out this yellow wire and connect it to the input and let us now see again what is the input and what is the output?

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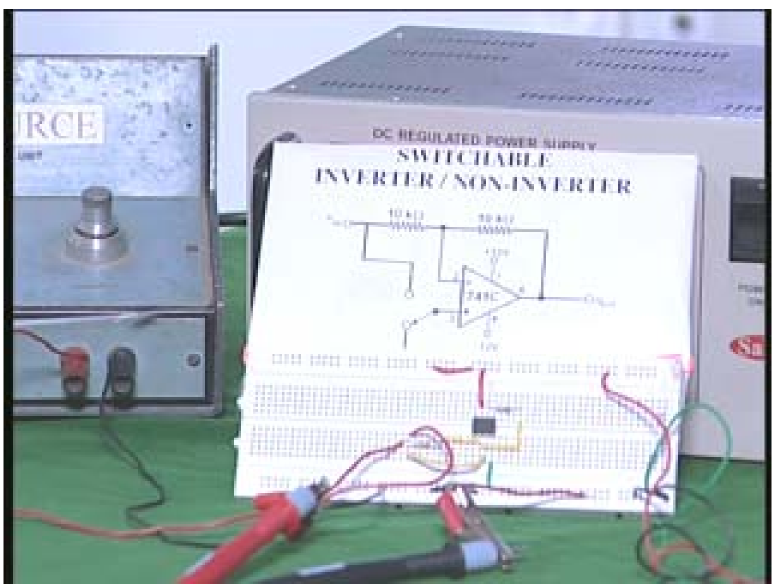

I have now switched the yellow wire from ground to the input terminal and I am now monitoring the input voltage using the same multimeter. I want you to see the multimeter. When you look at the multimeter the multimeter shows 1.02 volts.

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That is the input voltage, positive voltage because I have connected the multimeter now at the input. I am going to take out here and connect it to the output terminal and again look at the multimeter output. Now I have switched the multimeter to pin number 6 as usual and now multimeter will be measuring the output voltage and the output voltage is also +1.02. That means there is no inversion and the same voltage which is given at the input is measured at the output. It acts as a non-inverting amplifier with a gain 1. Previously it acted as an inverting amplifier with a gain -1. I will able to switch the amplifier to non-inverting or inverting by just switching this wire between the ground and the input.

We have seen a very simple demonstration of the switchable inverter and non- inverter circuit. The same thing can also be done using some device. The next one I wanted to discuss is a JFET controlled switchable inverter. JFET means junction field effect transistor. Junction field effect transistor controlled switchable inverter is what I wanted to show you and the input signal drives again both the inputs of the op amp simultaneously; the inverting as well as the non-inverting.

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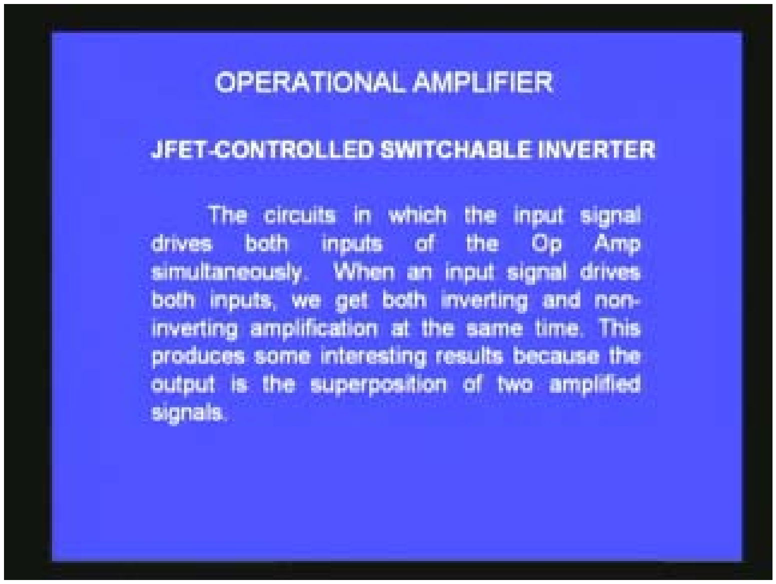

We will get an amplification corresponding to the inverting amplifier as well as a non-inverting amplifier and the effective output will be the superposition of these two. We will get a very interesting result here also. In the circuit which is shown on the screen this symbol is the junction field effect transistor and I give a pulse here.

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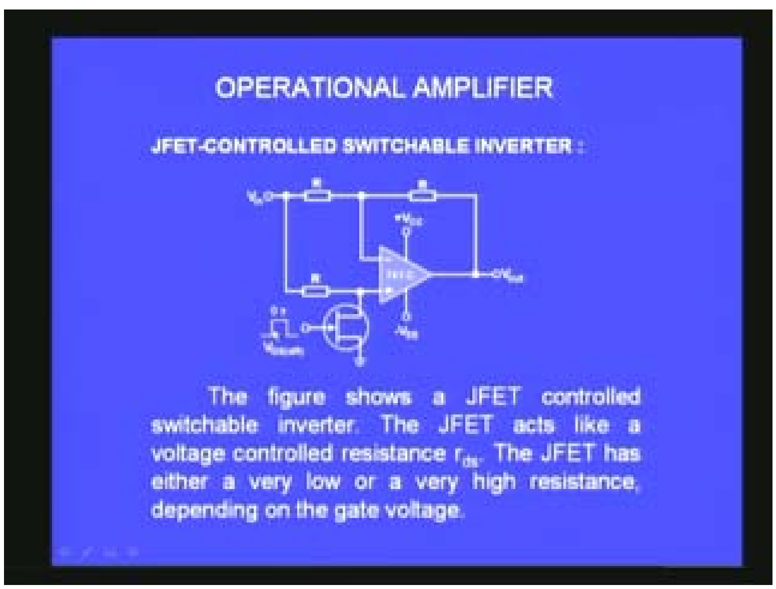

The pulse is from 0 to 6 volts. When it goes from 0 to 6 volts when it is positive this FET will be conducting and when it is ground it will be non-conducting. The JFET acts like a voltage controlled resistance in principle. Depending up on the voltage you apply at the gate the resistance between the drain and the source can be very low or very high. What is going to happen when the gate voltage is low? That means I have 0 volts at the gate. JFET will become open; the resistance of the JFET when there is no gate voltage will be very, very high. It is like an open switch.

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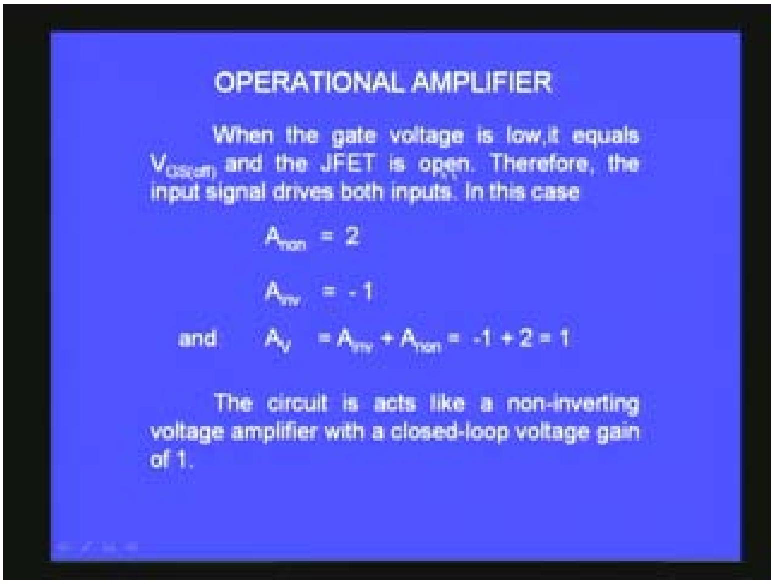

When that happens this is open here this terminal and that means the input voltage is driving both the inverting and the non-inverting input simultaneously and the values of resistors are the same. If that is the case what is the total voltage gain? We have seen it earlier also by using superposition and the total voltage gain is 1. When the gate voltage of the JFET is 0 you get a very simple non-inverting amplifier with a closed loop gain of 1. Similarly when I have the high then this will become on. When this becomes on the JFET offers very low resistance at this end. That means it is almost connected to the ground. When this is connected to the ground the non-inverting input is connected to the ground. When that happens only the inverting input is driving the amplifier and the gain will be -R by R that is -1. By using this square pulse I can switch back and forth as an inverting or a non-inverting amplifier. The same thing I showed as a demo except that I was manually switching. I was taking the wire and connecting to the ground and then connecting the same wire to the input terminal. The same thing can also be done electronically by making you use of FET as a switch here. When I apply a low voltage at the gate the FET is open. When I apply high voltage at the gate the FET is on like a switch and I can switch by sending a square pulse on or off and thereby I convert the amplifier as a inverting or a non-inverting amplifier. You can also electronically select whether you want +1 or -1 as the gain. That is the advantage of the circuit.

There is also another variation of the circuit similar to what we have already seen. That is an inverter with adjustable gain. You can change the gain of the inverter from some low value to a very high value whatever value you want.

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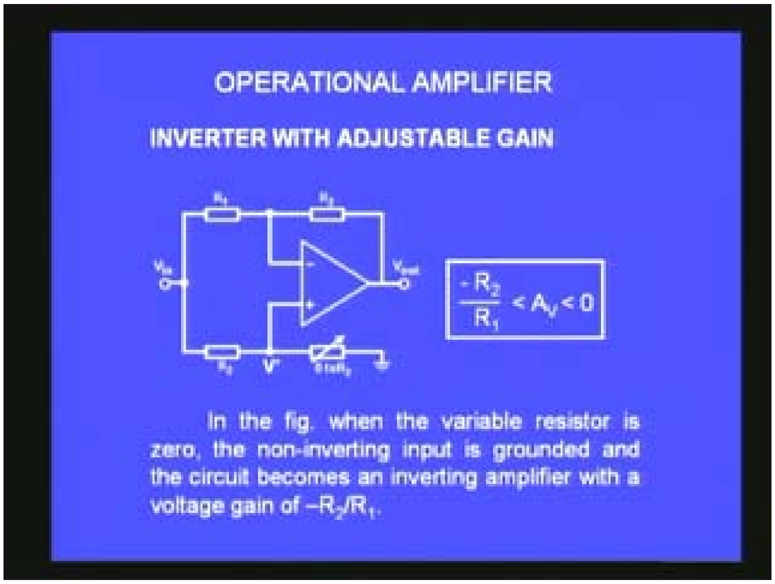

I am showing another application circuit of the operational amplifier which is an inverter with an adjustable gain. What you have here is a very simple circuit which you can very easily recognize. I have R_2 and R_1 as the feedback and the input resistance for the inverting terminal and for the non-inverting terminal again I have a potential divider. I have an R_2; R_2 which is a variable. That means it is 0 to R_2 variable resistor and that is connected to the ground. How do I analyze the circuit? What will be the gain of the circuit for different variations of the value of R_2 here at the non-inverting terminal? From 0 to a maximum value R_2 if I vary how will the gain change? That is what we are interested in.

I assume that the variable resistor is zero. That means the potentiometer I keep in zero value. If I do that it is equivalent to saying this terminal is connected to ground. When this terminal is connected to ground, the non-inverting input, the circuit becomes a simple inverting amplifier and the gain of the inverting amplifier is $-R_2$ by R_1. That is what we have shown here. The maximum gain that you can get is $-R_2$ by R_1 when this potentiometer is having a value zero resistance. But when I make this resistance maximum that is corresponding to R_2 then what will be the gain? When this resistance becomes R_2, V_{in} is applied Between the ground and V_{in} you have two resistors connected in series, both of them are equal. Assuming the input resistance of the operational amplifier to be very, very large compared to these resistors these two resistors are going to divide; potential divider circuit. It is going to divide the V_{in} so that the V prime which is actual voltage at the non-inverting terminal will be V_{in} by 2. Because the two resistors are equal they will divide into half and V prime will be V_{in} by 2. The effect of having these two resistors is when I have R_2 full value, the potentiometer- ? I will only apply half of the input voltage at the non-inverting terminal. When that happens what is the voltage gain? The voltage gain for the non-inverting amplifier is 1 plus R_2 by R_1 times V input.

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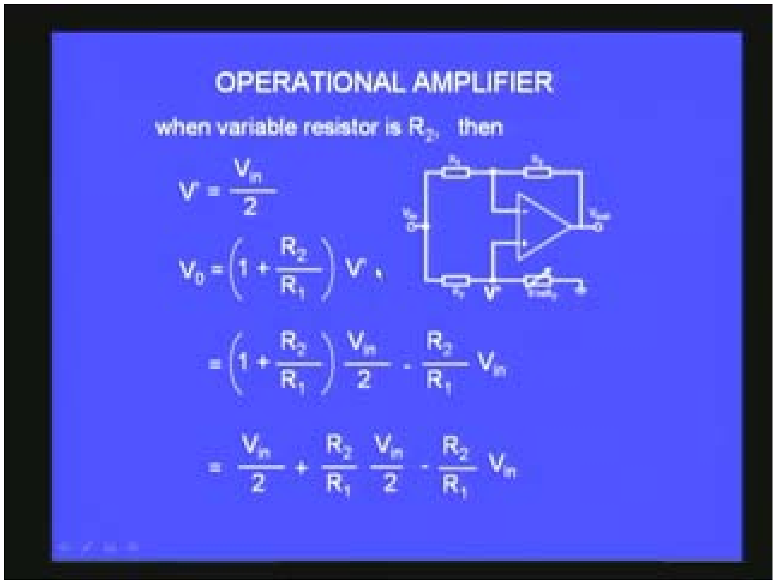

The V input here is not the actual V input that we have applied but V prime which is the effective voltage after the potential divider is applied at the non-inverting terminal and V prime is V_{in} by 2. If I substitute that and simplify this expression for a superposition then this is the gain corresponding to the non-inverting and there is also inverting terminal always present. That will give $-R_2$ by R_1 times V_{in}. The total gain of the amplifier will be when you simplify this, this becomes V_{in} by 2 into 1 minus R_2 by R_1 and if I make R_2 by R_1 equal to 1 then V_{in} by 2; 1-1 = 0.

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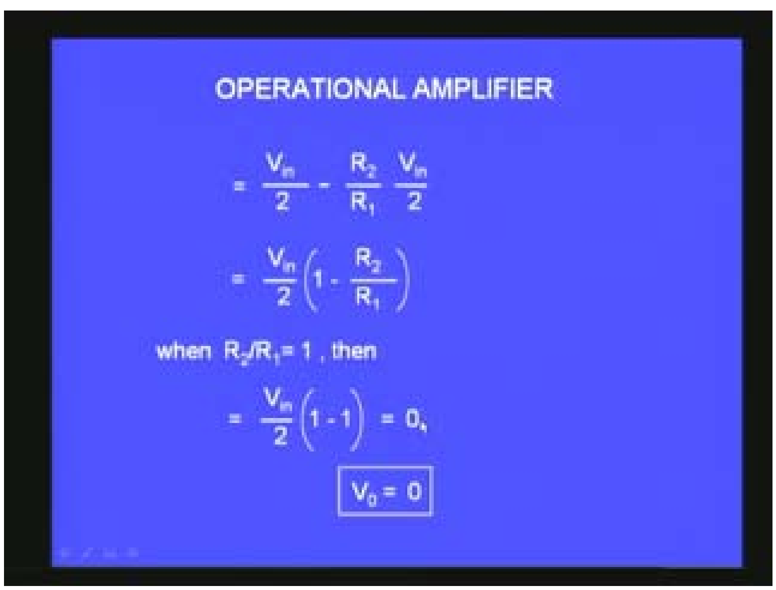

The minimum gain is 0 and whatever is the maximum gain you can get $-R_2$ by R_1 when you have only the inverting amplifier. You can vary the gain of this amplifier from $-R_2$ by R_1 to 0. The total voltage gain of this amplifier can be varied over a range by using this type of a configuration. This may be another useful circuit. I will show you demonstration of the circuit also.

The circuit here is same as the one I showed you just few minutes ago.

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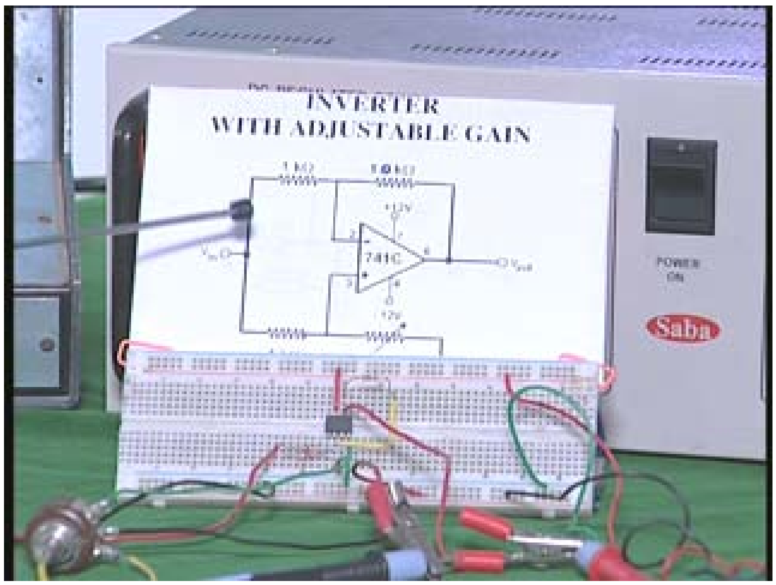

You have an operational amplifier 741 and you have a 1K resistor here. Here also 1K. This is1.0 K; this is also 1K. Both are equal and I have a 1K resistor here and also I have a variable resistor potentiometer here and when I vary the potentiometer from 0 to a maximum value the gain should go from $-R_2$ by R_1. In this case it is -1 to some different values. I can vary by varying this potentiometer. That is what I wanted to show you. You can vary the gain by changing this potentiometer. Here the input is again from a voltage source and I have not changed the output. It is about nearly 1 volt. That is connected at the input of the circuit and now I am measuring the output of the circuit. From the 6 I have connected the multimeter and the multimeter shows 0.85 with the potentiometer in zero position. The potentiometer is here. I have taken only one end and the middle and that is what I have connected in the circuit. When I put it at the extreme end it is zero resistance. When it is zero resistance the multimeter shows -0.85 volts.

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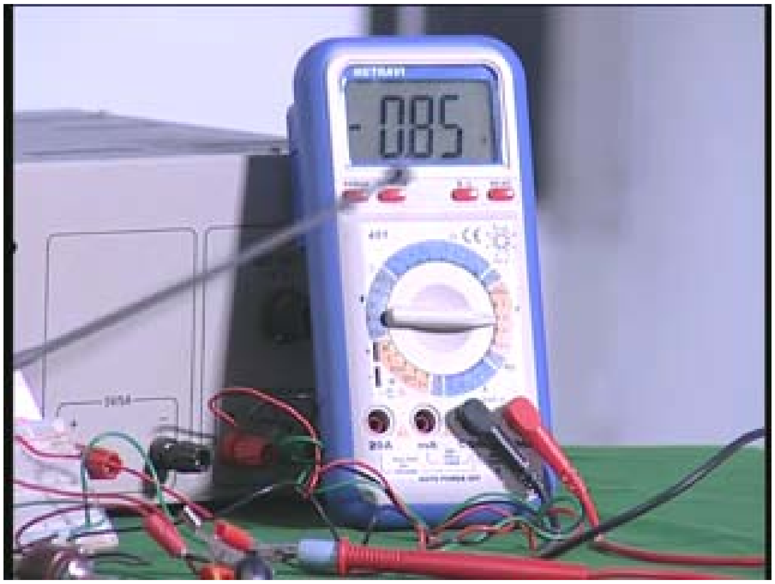

That is the output voltage. Let us see what is the input voltage? I will vary the multimeter connection and connect it at the input. If you look at the multimeter it is +0.84.

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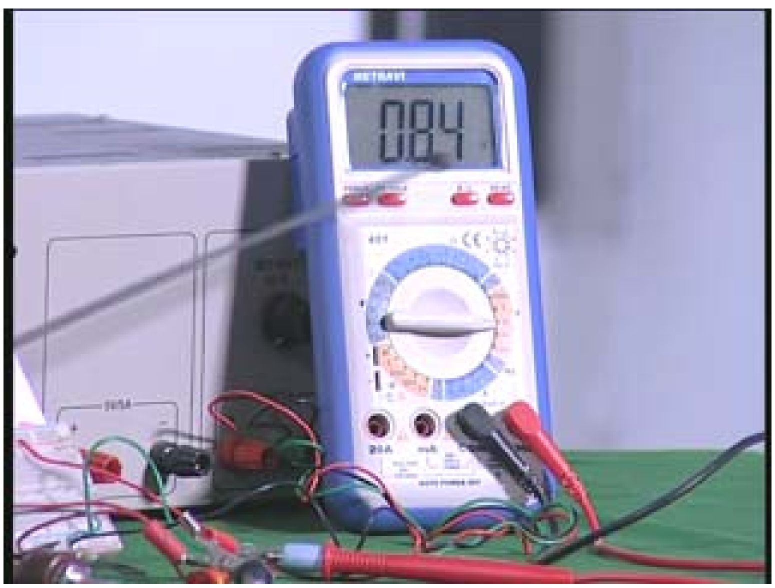

The input voltage is 0.84 volts and the output voltage was -0.85 volts. The gain is -1 in this configuration when the potentiometer is maintained at zero position corresponding to this connection going to the other end. Non-inverting input is connected to ground when this is zero. When I increase the resistance I would like you to observe the multimeter after I connect it to the output terminal. As I move the potentiometer the output voltage is decreasing. From 0.85 it has come to 0.33 and I keep on going till I get zero which will be corresponding to potentiometer corresponding to 1K. The output voltage can be varied by varying this potentiometer and that means I can vary the gain of the amplifier by using this potentiometer from a minimum 0 to the value of $–R_2$ by R_1. It is on the inversion side. $–R_2$ by R_1 will be the gain. In this case both are equal. Therefore I get a gain of 1. This is a very simple circuit corresponding to an inverting amplifier with a variable gain, with an adjustable gain. We saw how an inverter with a gain which is adjustable using a potentiometer can be constructed in a very, very simple scheme by using the operational amplifier.

Let me move on to the next application circuit which is a sign changer. We have already seen something very similar to this. When you get an inverter/non-inverter +1 to -1 that is again a sign changer if I get a gain a 1. But there is a slight variation between this circuit which I am going to now discuss and the earlier circuit which I discussed. What I have done here is I have now replaced the R_1 R_2 that you saw in the previous example. I used two resistors. I had one resistor here R_2 and I had another potentiometer here which can go from 0 to a maximum value of R_2.

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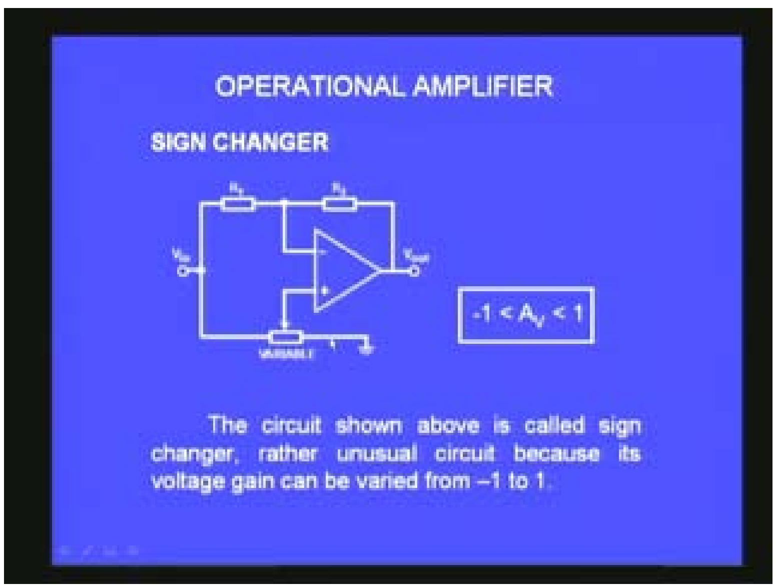

Instead what I have done here in the circuit is I have used one single potentiometer. The wiper can be connected to the non-inverting input and this wiper can be at this end. When that happens I get the full resistor here connected to ground and the input is connected to V_{in} and when I take the wiper to the other end, this end is connected to ground that means the non-inverting amplifier is connected to ground. It becomes an inverting amplifier. When I have very simple potentiometer without having a switch I can vary continuously the gain from -1 to +1. It is a modification of the switchable gain. In the switchable gain I had only two gains either it is +1 or it is -1. There is no other value in between whereas here I can go from -1 to +1 by modifying, very simply replacing the switch by a potentiometer and making use of all the three terminals of the potentiometer. One end I connect to the input, the other end I connect to ground and the variable end I connect to the non-inverting terminal of the operational amplifier. When I do that I will be able to vary the gain from -1 to +1 continuously by changing the position of the potentiometer, varying the value of the variable resistor.

Let me try to understand the operation. When the wiper is all the way to the right, the right end here that means you have the non-inverting terminal connected to the ground. The non-inverting input is grounded and the circuit has a voltage gain of $A_v = -1$. It becomes a very simple inverting amplifier. But when the wiper is all the way to the left the input signals drives both the inverting and the non-inverting input.

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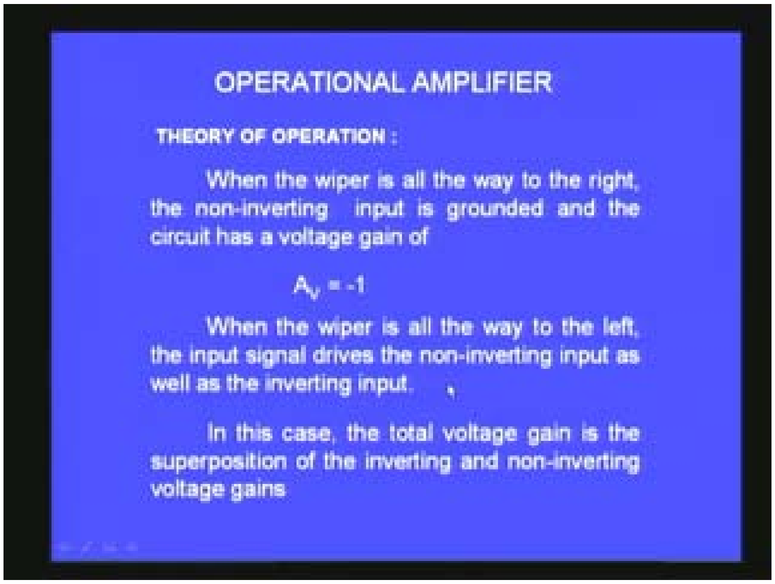

In that case the total voltage gain is a superposition of the inverting and non-inverting voltage gains. Let us try to look at that. We have already seen that earlier in the beginning also. The non-inverting gain is 2 the inverting gain is -1. Therefore total gain is 1.

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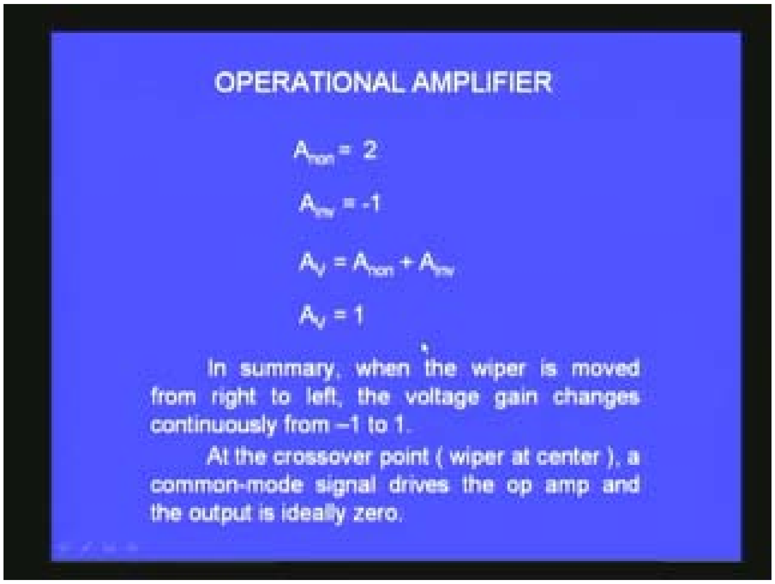

These are all known. What is the only difference? I am not just switching but I am using a potentiometer and going from the ground to some value and the gain is going to vary from -1 to +1. That is all; a very simple gain. As the wiper is moved from right to the left the voltage gain changes continuously from -1 to +1. At the cross over point when it is exactly at the center approximately a common mode signal drives the op amp and the output should ideally be zero. But it can have some millivolts which are due to the offsets of the current and voltage.

Now I will show you a demonstration of the sign changer and later on we will take one more example of an application circuit. What I am going to do is just replace the two resistors that I had previously and use only one single potentiometer and then show you that the gain can be varied from -1 to +1 continuously. The same circuit I have drawn here. You have the operational amplifier. You have the two resistors both are 1K and 1K and you have a potentiometer here with the three terminals; one terminal connected to the ground, the other terminal connected to the input and the third terminal which is the wiper connected to the non-inverting input.

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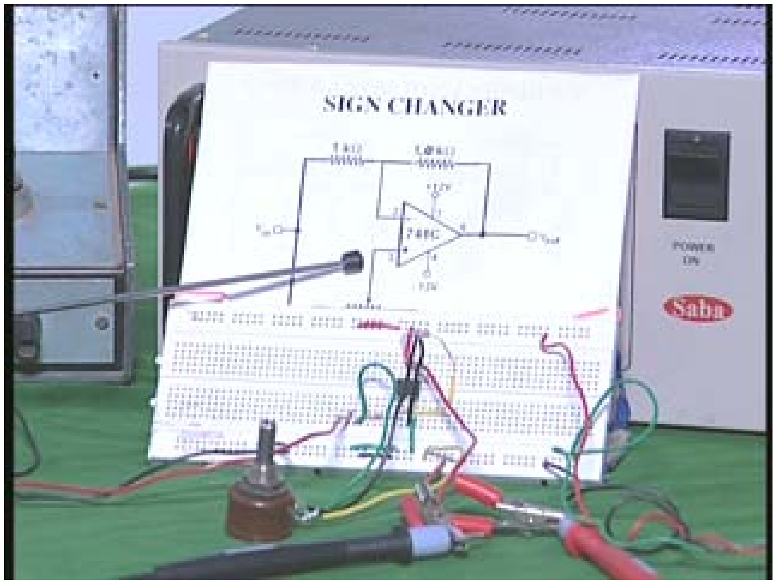

This is the same circuit which I now discussed and the same thing is wired here. You can see the op amp and the various connections made there and you can see the potentiometer here with the three wires the green, the black and the yellow. The yellow is connected to the ground, the black is connected to pin number 3 and the green is connected to the input. The input is from the voltage source which we have already seen and I have not disturbed the voltage and that means it is still 1 volt. From the beginning for all the demonstrations I have used this voltage source to be the same 1 volt and it is now the same 1 volt. I have connected the multimeter at the output of this amplifier. At this point I have connected the multimeter. If you see the multimeter output it is 1 volt.

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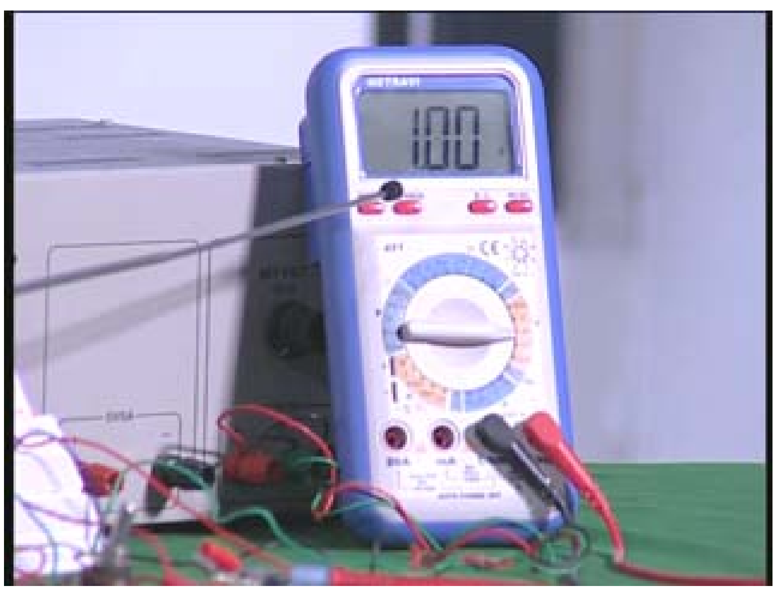

That means when the potentiometer is in the maximum position then the corresponding gain is 1 and when I give 1 volt I also get output 1 volt. When I change the potentiometer this should go from +1 to -1 continuously. I am going to now vary the potentiometer and see what happens to the gain. The gain now starts coming down. As I increase the potentiometer the gain keeps coming down, the output voltage keeps coming down and then almost I come to zero and then I keep increasing. The gain starts increasing on the negative side; -3, 5, 6, 7, etc. When I go to the maximum it has come again to nearly 1 volt; -0.91 which is close to -1 volt.

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I have changed from +1 to -1 continuously the gain by changing the potentiometer from zero value to a maximum value. This is what we call a sign changer. We can change the sign of the amplifier by continuously varying this from -1 to +1 or +1 to -1 by using the potentiometer. This is again a very simple and useful circuit for applications.

We have seen different circuits. One is just switchable from -1 to +1. By changing one wire or a switch you can change the gain of the amplifier from -1 to +1. Then we also saw another circuit where you can vary the gain from some low value for example zero to some $-R_2$ by R_1 where R_2 by R_1 can be 1 or 10 or any number depending upon the ratio R_2 by R_1. We also saw how you can have a variable gain amplifier and the third circuit you saw how you can go from -1 to +1 continuously by using a potentiometer. There is another variation of the circuit where you can go from -n to +n where ‘n’is some number; may be 10, 8, 5, 20, etc. Is it possible to design a circuit which will provide me with a continuous variation of the gain from a -n value to a +n value? This is called adjustable and reversible gain. The gain is adjustable as well as reversible. You can go from plus to minus as well as from some zero to a large value; both are possible. One such circuit is shown on the screen.

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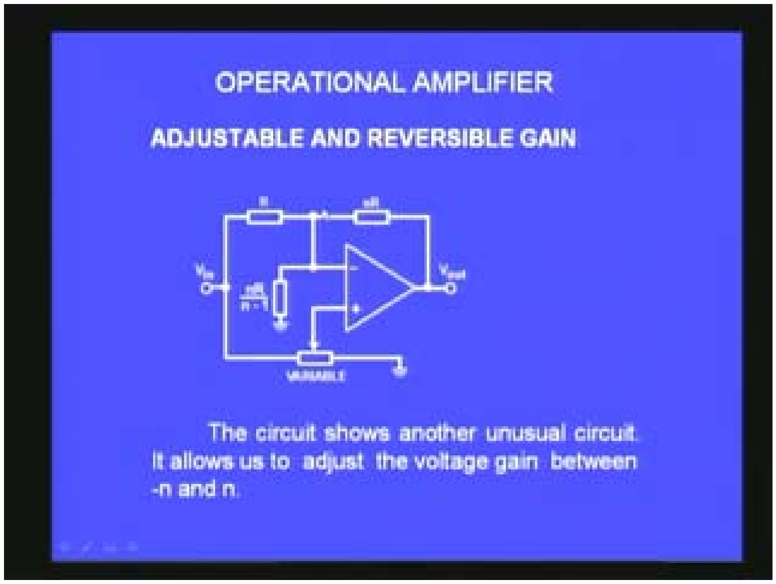

What I have done here is I have generalized a circuit. I have put a R here at the input and I put a nR; n times R and that is the feedback resistor and at the inverting input I have used another resistor whose value is n by n minus 1 times R. The product here is n by n minus 1 or the value is nR by n minus 1. I also have a variable potentiometer as I had in the previous case here. Let us try to understand how the circuit works and what it is going to do is it is going to give us a adjustable voltage gain from -n to n. It is similar to the type of the amplifier that we saw which we call sign changer.

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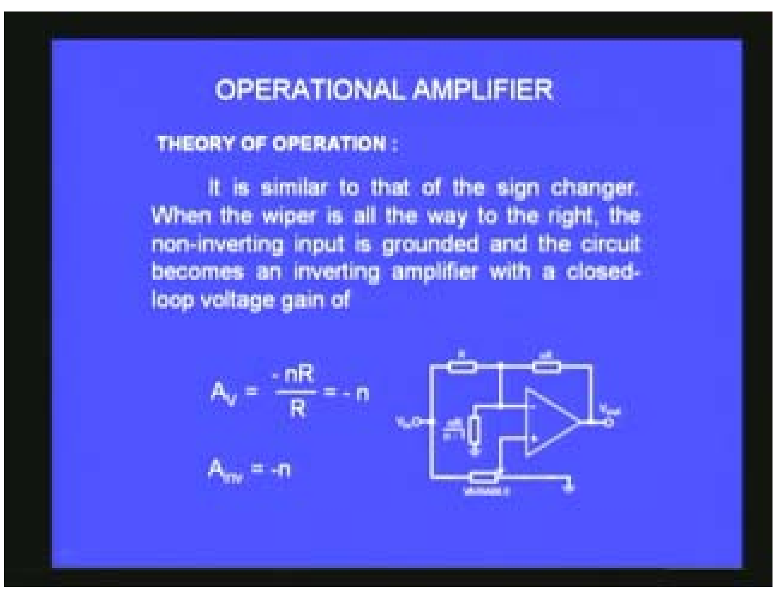

The sign changes from -1 to +1 continuously by using the potentiometer. A very similar circuit is seen. Here also we are using the potentiometer in a very similar fashion. But apart from that we also have got the feedback resistor n times more R and nR. Let us look at this circuit. When the wiper is at the bottom end, the right end the non-inverting input is connected to the ground and the input is only applied at the inverting terminal and the feedback resistor is nR. The gain is -nR by R and that is –n. We have already seen except that in the earlier case we have not used nR. We have just used R. The gain was -1. Here I have used nR. The gain is –n. That is all the difference. The gain of this amplifier is –n; -nR by R and therefore –n when the wiper is at the lower end corresponding to the ground. What happens when the wiper is at the other end, maximum end when the value of the variable resistor is included in the circuit corresponding to the non-inverting terminal?

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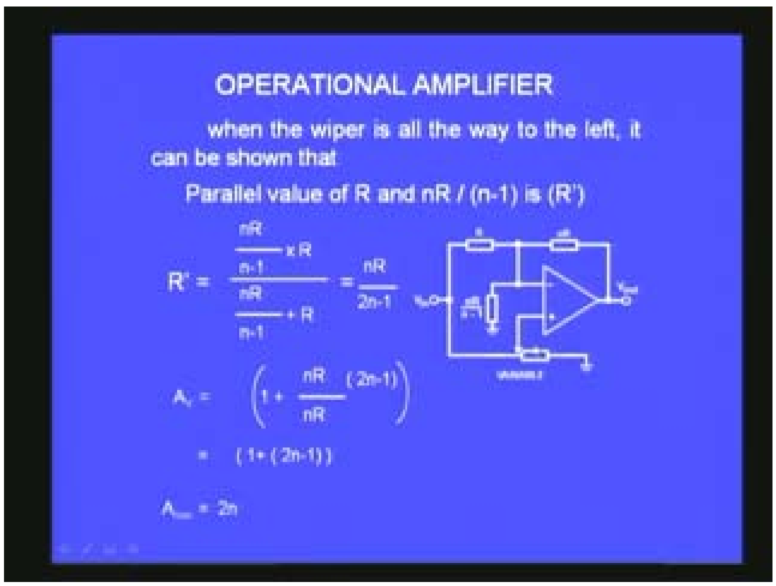

When this happens what will be the effective gain? To find the effective gain by superposition if I assume it to be a non-inverting amplifier the V_{in} is connected to the non-inverting amplifier by superposition. At that time I should ground this terminal and then calculate what is the gain? After that I should ground the non-inverting terminal and assume only these resistors are present and the input is driving only the inverting terminal and find out what is the gain and I should add the two to get by superposition theorem the overall gain of the amplifier. Before I do that what I have done is if I ground this terminal then I have two resistors connected to the ground in parallel at the inverting input. Then what will be the effective resistance of these two resistors? I call them R prime and I have calculated that. nR by n minus 1 multiplied by R divided by nR by n minus 1 plus R. R_1 into R_2 divided by R_1 plus R_2 is the effective resistance of two resistors R_1 and R_2 connected in parallel. We have already discussed that very long back and nR by n minus 1 into R divided by nR by n minus 1 plus R is the effective resistance of these two and that when I simplify becomes nR by 2n minus 1.

Now when I have the non-inverting amplifier the gain will be 1 plus R_2 by R_1. 1 plus R_2 is nR. R_1 is this effective resistance. Because both the resistors will come in parallel connected to ground and I have used that value nR by 2n minus 1 as the denominator. nR is in the denominator 2n minus 1 comes into the numerator and the value of the non-inverting amplifier becomes 1 plus nR by nR into 2n minus 1. That is nothing but 1 plus 2n minus 1; therefore 2n. A non-inverting input is 2n and A inverting is –n. When I connect both of them together the total value will be A non-inverting plus A inverting; 2n plus minus n; therefore it is n.

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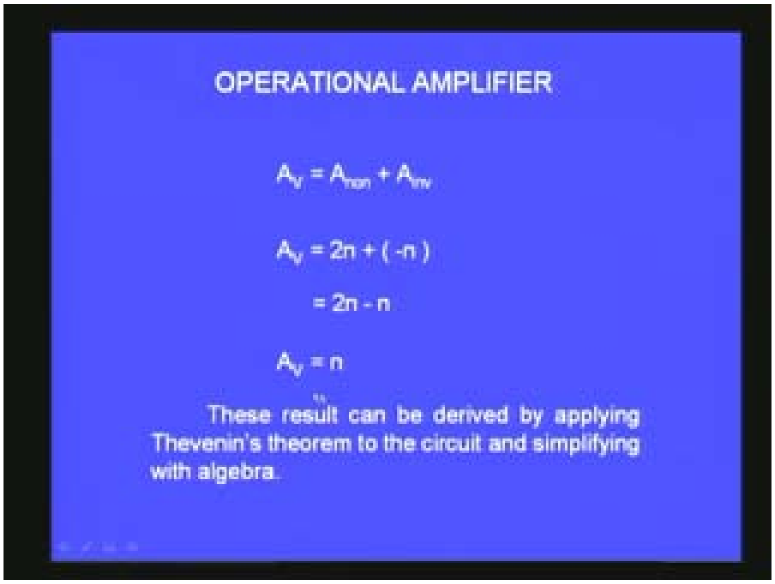

When I have the wiper to the ground it is only an inverting amplifier with a gain –n. When I have the wiper to the left extreme point then I have a gain of n. When I change the potentiometer from the minimum value zero to a maximum value the output gain should vary from -n to +n. This is an adjustable gain amplifier where the gain could be chosen by choosing the value of the resistors nR and …….

I am going to demonstrate the circuit now. where i will show you the various things. What I have done is I have chosen n to be 10 for example for simplicity. R is going to be 1K; nR is going to be 10K. If this is the case then what will be the nR by n minus 1. n is 10. Therefore 10 by 10 minus 1 is 10 by 9 times R. 10 by 9 is almost equal to 1. Therefore I will make this also equal to 1K. I have 1K here. I will have 1K here and I will have 10K here and I have a potentiometer to be 1K or 5K. doesn't matter

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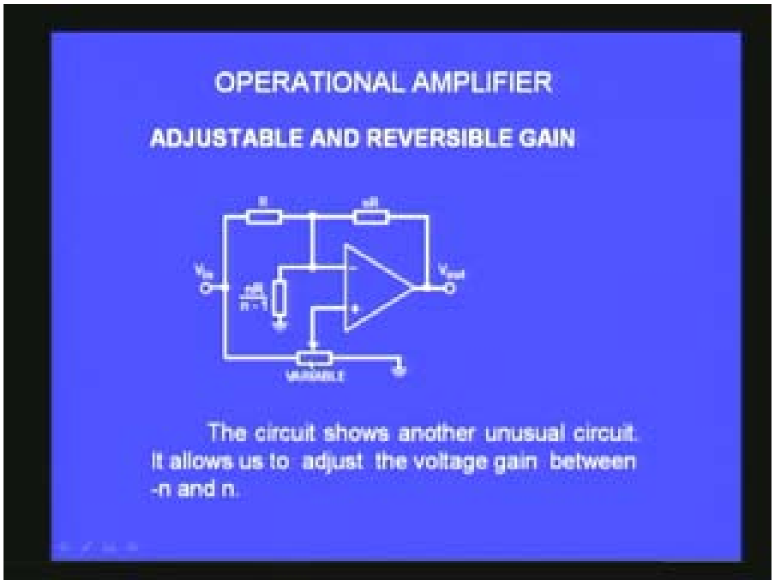

When I put it at this extreme end I will get a gain of -10 because nR by n minus n and when I put the potentiometer to the left extreme on the screen then the gain will be +n. That this +10. I should have a gain of -n to +n as I vary the potentiometer in the circuit. This is what I want to demonstrate to you now.

You can see the circuit here is the same as what I have shown you earlier.

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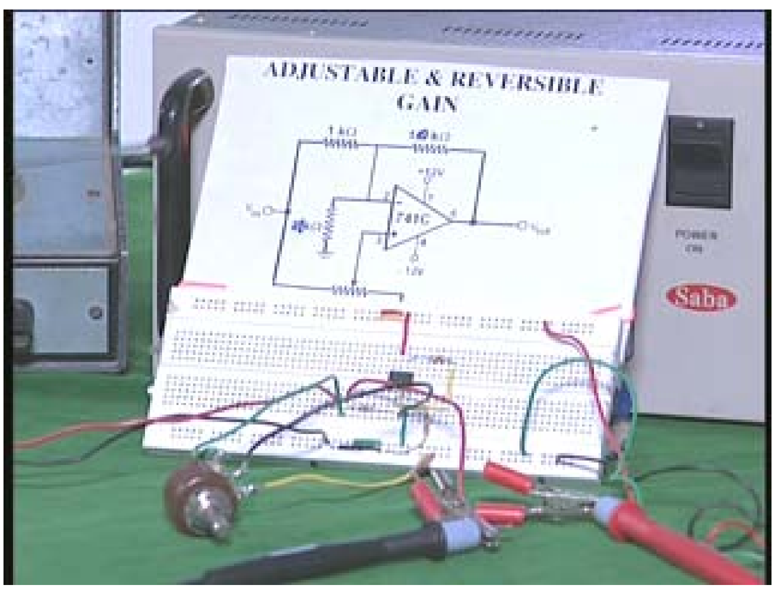

I have nR is 10K. The R is 1K. Therefore n is 10. This is 10K resistor; this is 1K resistor and this is n by n minus 1 times R and because n is 10, 10 by 10 minus 1 is 9. 10 by 9 times R; R is 1K. Therefore 10 by 9 is nearly 1K. I have put it as 1K. This is 10K. This is 1K. This is 1K also and here I have a potentiometer which can vary from zero to some value. Usually it will be 1K or 2K resistor. What will happen to the gain when it put it to the minimum? I have now maintained the potentiometer to the minimum position already and at the minimum position it becomes grounded and it becomes a simple inverting amplifier. For an inverting amplifier the gain should be -10; minus n. n is 10 here.

I have taken the input from the voltage source here which we have already seen and what I have done is I have reduced the voltage by 10 times to the previous value. Previously it was 1 volt in the earlier experiment. Now I have kept it as 100 millivolts; 0.1 volt or 100 millivolts. That is what you will observe now because I have connected the multimeter at the input terminal. If you look at the multimeter output now it shows 0.11. That means 0.1 volt or 110 millivolts. This is 0.11 volt or 110 millivolt approximately.

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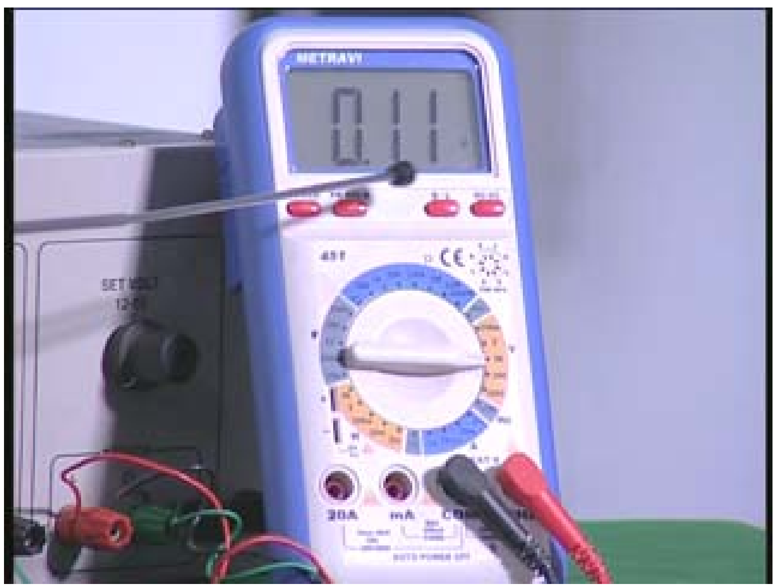

That is the input voltage. What I am going to do is I am going to take multimeter from the input and connect it to the output. See what happens?

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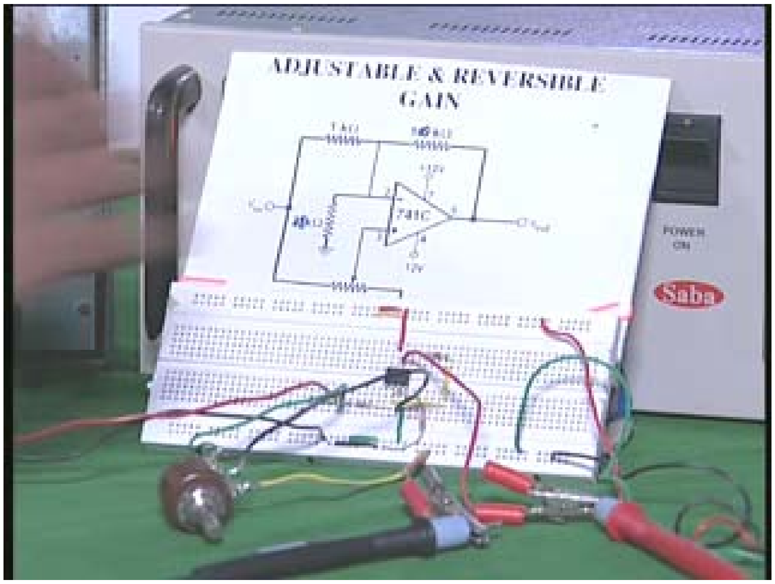

I have taken the multimeter and connect it at the pin number 6 with this circuit wired here. What will be the output? Because the potentiometer is in the minimum position the gain now is 1.01. 1.01 is what you measure at the output voltage of the multimeter.

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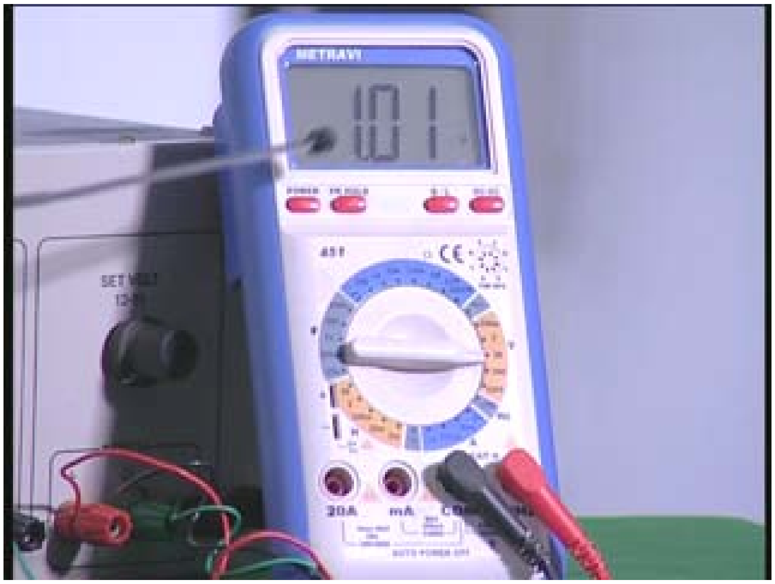

1.01 divided by 0.1 which is the input gives me 10. The gain is 10. If I vary the potentiometer I must vary the gain to -10. That means the output voltage should become -1 volt. From +1 volt it should go to -1 volt as I vary the potentiometer. That is exactly what I am going to do now. The potentiometer now is +1. As I change the potentiometer the output voltage keep decreasing; 0.7, 0.6, 0.5 it keeps on decreasing still and it comes to nearly zero and then it has come to minus; -2, -3, -4. I will keep moving in the same direction of the potentiometer minus eight and finally when I come to the complete 1 it becomes -1.01.

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-1.01 divided by the input voltage which is 0.1 gives me the gain and the gain is -10. All that you have done is vary the potentiometer from the minimum value to the maximum value and the gain goes from -10 to +10 as I vary this. It is a very simple configuration with only four resistors; three of them are fixed resistors and one is a variable resistor and by changing the value of the potentiometer I am able to vary the gain of the amplifier by +10 to -10. I have used here n to be 10. If you want to change the gain to some other number you can very easily do. For example I can put here 50 kilo ohms. Then I can have this also nearly 1K. There is no need to vary this and then by changing the potentiometer I will be able to vary the gain of the amplifier from +50 to -50 continuously using the potentiometer. You can put different resistors and it is very simple. There are no complicated things involved here. It is very understandable and reasonably very straight forward and as soon as you wire the circuit you will be able to get the output voltage. That provides a lot of confidence for us to build different types of amplifiers. The variable amplifiers are always very useful because we do not know the signal level. If the signal level is varying from very low voltages to very high voltages then you must also be able to vary the gain correspondingly. When it is very low value of voltage input then you should increase the gain and when the voltage becomes very larger at the input you should reduce the gain. In several applications the variable gain amplifiers will be very, very useful and you can make use of this configuration for achieving such variable gain amplifiers.

We have seen the adjustable and reversible gain amplifier. The demonstration also we have seen; the theory also we discussed. Next application circuit I want to show you is a very small variation of the same circuit which is called a phase shifter. There are several applications where you would like to vary the phase of the output with reference to input without changing the amplitude that means without changing the gain. It is possible to do that using a single op amp in a very, very simple straight forward manner. In the circuit shown on the screen you have got the two resistors R and R prime. Both are equal R prime and R prime and in the other circuit I have an R and a C. R is a variable resistor and C is the capacitor that is connected at the non-inverting input.

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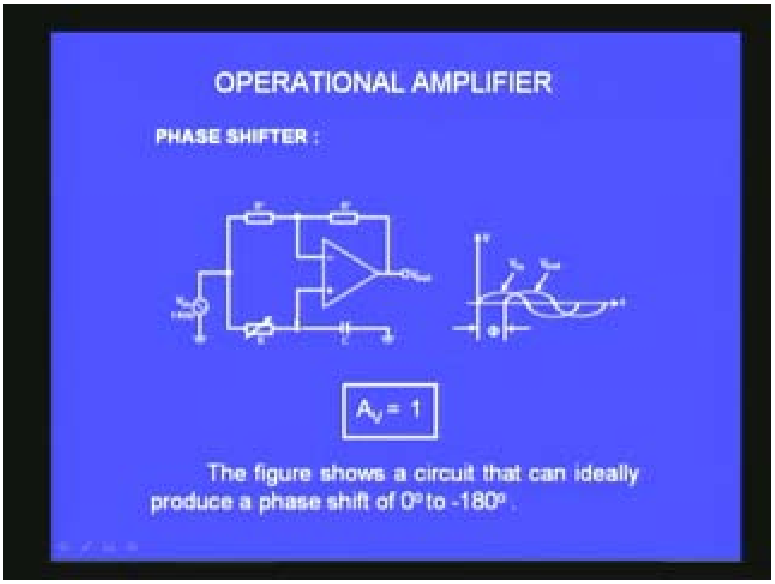

When I have a configuration like this and apply a sine wave input at different frequencies or any finite frequency then the output phase can be varied with reference to the input phase by changing the value of the R having the gain 1 because R prime and R prime beside the gain they are equal the gain is only 1. The gain is 1 for this configuration. But what is the advantage? The advantage is the phase can be changed from a value zero to a value 180 degrees; zero to -180 degrees you can change. When I have the input frequency much lower than the cut off frequency f very, very low compared to f_c the capacitor appears to be open.

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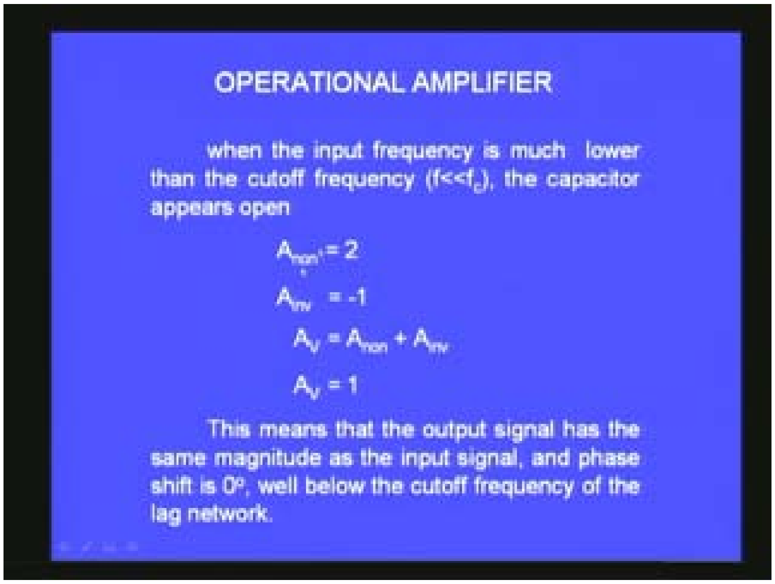

In that case the total gain is due to both inverting and the non-inverting and A_v is equal to 1. This means that the output signal is having the same phase or zero phase with reference to the input and the gain is 1. When the input frequency is much greater than the cut off, f very, very large compared to f_c the capacitor appears shorted and in this case the non-inverting channel has a voltage gain of zero.

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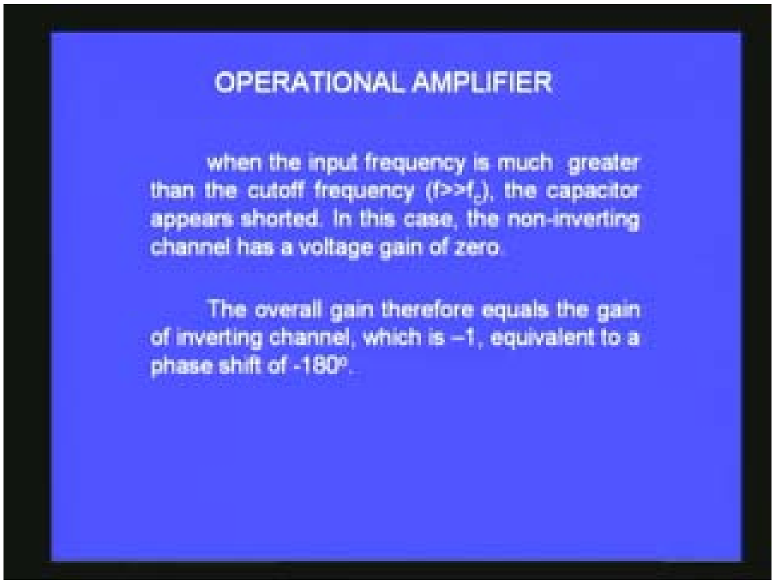

The over all gain is equal to the gain of the inverting channel which is -1 and the minus shows that there is a phase of 180 degrees.

What we have now is the same circuit with a potentiometer here and we can shift the potentiometer from this end to that end. Thereby I will be varying the phase of the amplifier from 0 to 180 degrees.

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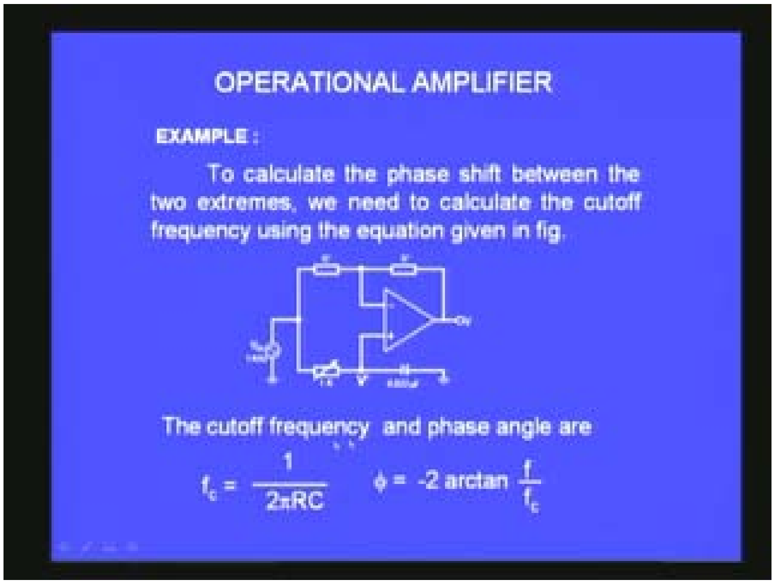

The cut off frequency for this is decided by the two resistors RC combination that I have here and I have used here 1K and 0.022 microfarad. f_c is 1 by 2 pie RC. This is a well known formula and the phase angle is given by -2 arctan f by f_c. f is the applied frequency, f_c is the cut off frequency obtained from this formula 1 by 2 pie RC. By using this for the values that I have shown in the circuit 1 by 2 pie RC, R is 1 kilo ohm; C is 0.22 micro farad and you get the cut off frequency of 7.23 kilo hertz.

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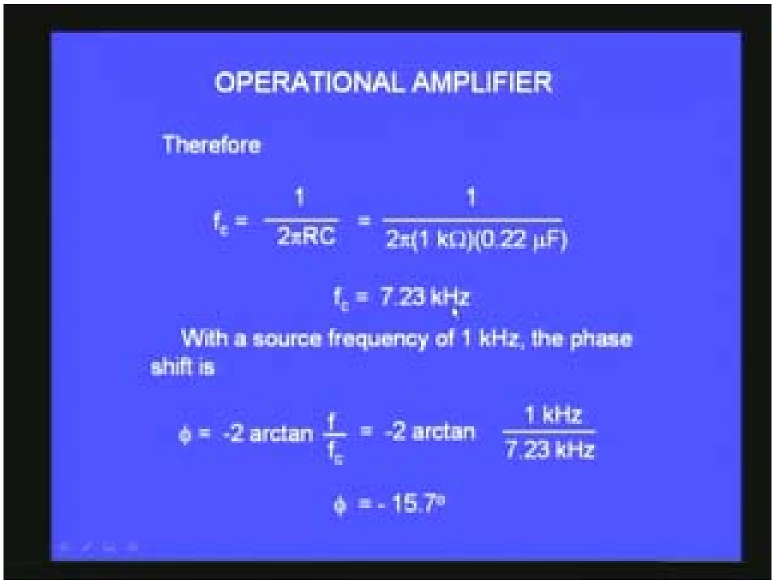

When I have about 1 kilo hertz the phase shift will be 1 kilo hertz by 7.23 kilo hertz that is -15.7 degrees. If I increase to 10 kilo ohm then the corresponding phase shift can be calculated because the cut off frequency will now vary to 723 kilo hertz and 1 kilo hertz by 723 will become 108 degree and when I change to 100 kilo hertz then it becomes 72.3 kilo hertz and the phase angle is 172.

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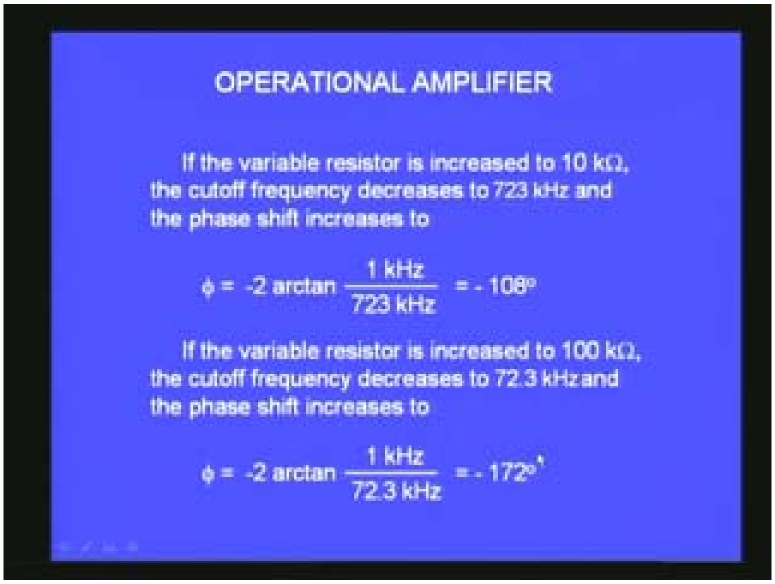

By changing the potentiometer, the RC value, R value the phase angle can be varied by a whole range from almost zero to 180 degrees. I will show you the demonstration of this phase shifting amplifier.

You observe the circuit. I have a 1K here and I have a 1K here. R prime as I have shown in the picture and this is the potentiometer and I have a capacitor which is about 0.22 microfarad. The input here is from a function generator with a sine wave oscillator output.

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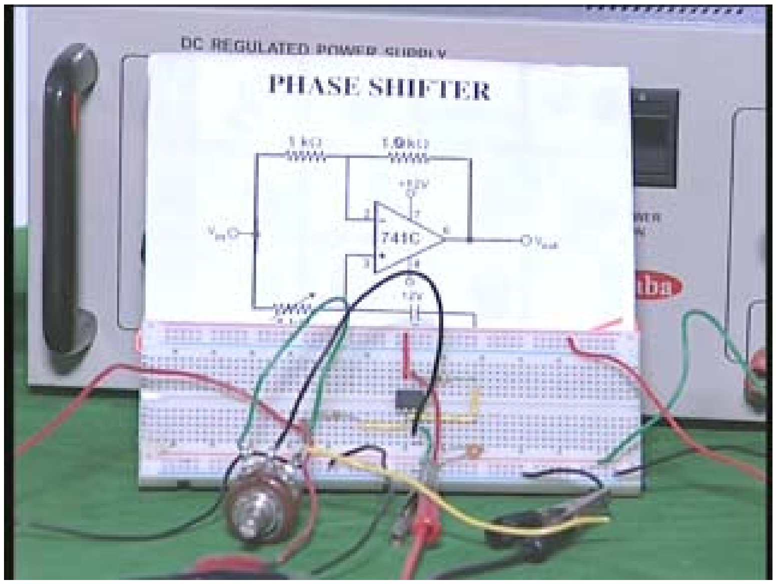

You can see here the function generator to the left of the screen. I have chosen 1 kilo hertz as the frequency; 1.14 kilo hertz and the output is connected at the input of the amplifier here and the output of the amplifier is monitored using an oscilloscope. The two traces are basically the input and the output both together. They are in phase. When the input is going down the output is also going down. So they are in phase.

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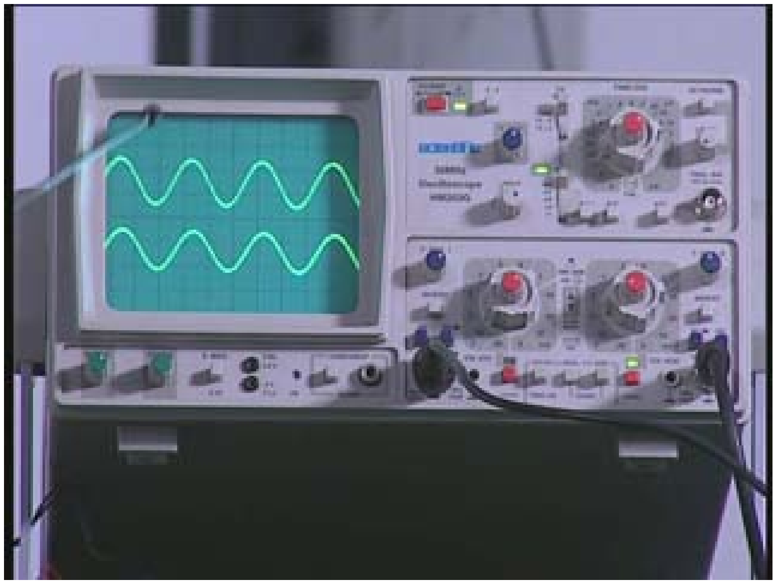

But when I change the potentiometer one of the traces, the output trace will show a shift that corresponds to the phase shifting that I am talking about for the same RC network. If you change the value of R and C you will get different phases. The shift in the phase, as seen by the shift in the trace you see on the oscilloscope. Now I want you to observe the oscilloscope while I change the potentiometer and you would find the trace slowly moving away to the right. You can see that the trace starts moving to the right and then I can go almost up to 180 phase shift corresponding that I come back now. Now it is in phase. As I move that you find it is shifted towards the right and the phase can be continuously varied from 0 to 180 degrees.

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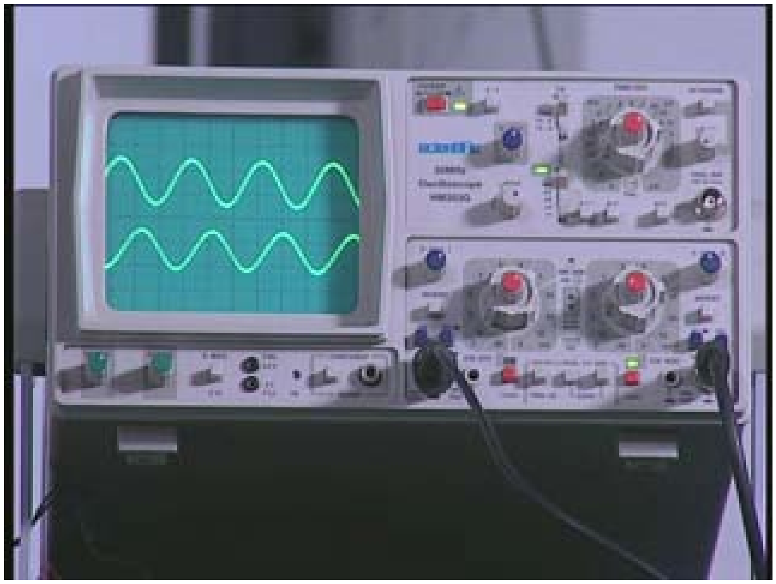

This is a phase shifting circuit and all the five different circuits that I have discussed are very simple to construct and I have also shown a demonstration how they can be used in different applications. Thank you!