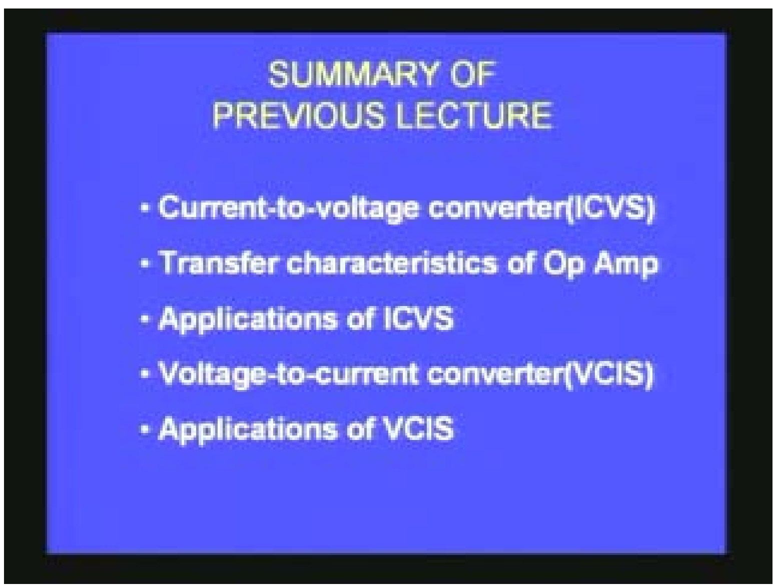
Basic electronics
Prof. T.S. Natarajan
Department of Physics
Indian Institute of Technology, Madras
Lecture- 23

Four Types of Feed Back & Mathematical Operations

Hello everybody! In our series of lectures on basic electronics learning by doing let us move on to the next. Before we do that as usual we will go through the basic topics which we dealt in our previous lecture. You might recall that we talked about the different types of feedback, negative feedback configurations and how we can get four different types of feedback configurations and we also discussed three of those applications.

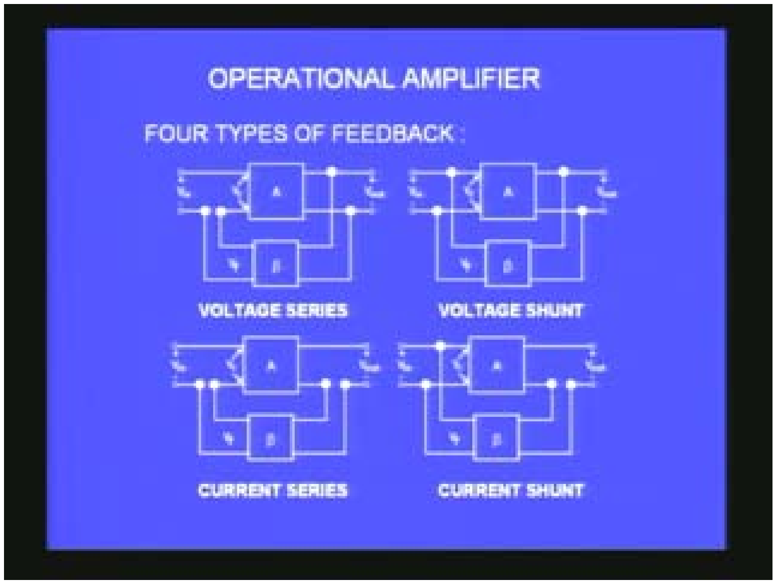
(Refer Slide Time: 2:03)



In the previous lecture we discussed about the current to voltage converter which is also known as current controlled voltage source circuit and we also briefly discussed about the transfer characteristics of the op amp in order to understand the concept of the virtual earth. You might recall that the input voltages between the two input terminals of an operational amplifier cannot be larger than plus or minus about 200 microvolt in a typical case. We also saw applications of the current to voltage converter. Then we discussed about another feedback configuration which led to voltage to current converter which is also known as voltage controlled current source and we saw some of the application circuits of voltage controlled current source. In every case you might remember we also showed a simulation experiment and then we actually went to the laboratory board and then showed the actual circuit that we discussed with multimeter and dual supply. That we will keep doing at every stage even in this lecture.

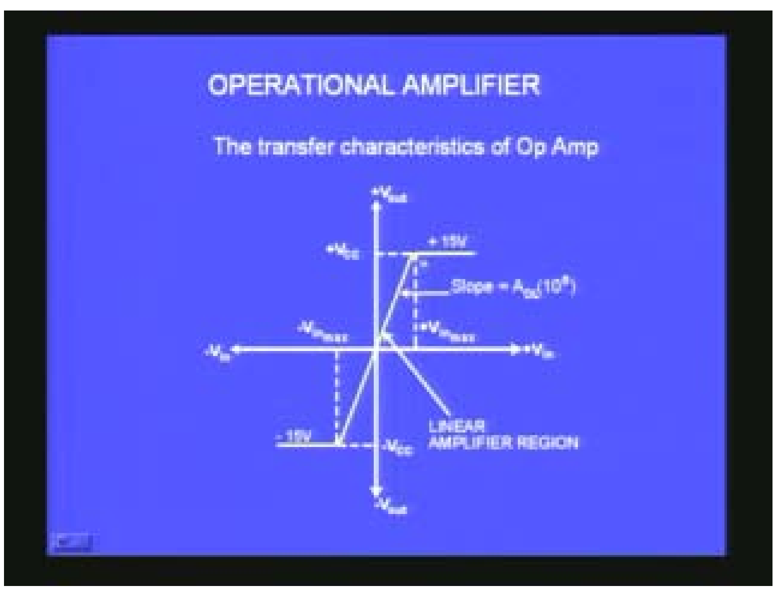
Before I do that I want to recapitulate again the basic concepts of the four configurations of the feed back that I already discussed earlier.

(Refer Slide Time: 3:42)



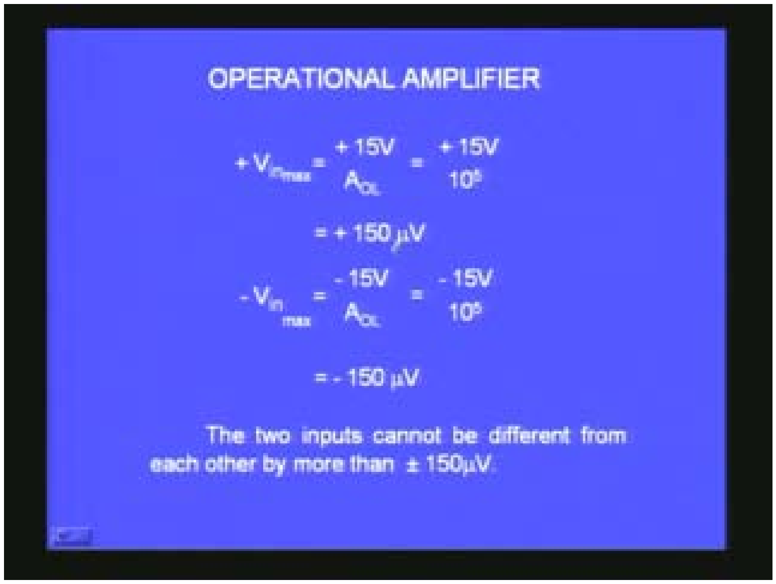
You can see the figure shows the four different configurations. We have already discussed three of them and the last one is what we are going to discuss today. I will show you the other figure corresponding to the transfer characteristics of an op amp.

(Refer Slide Time: 3:58)



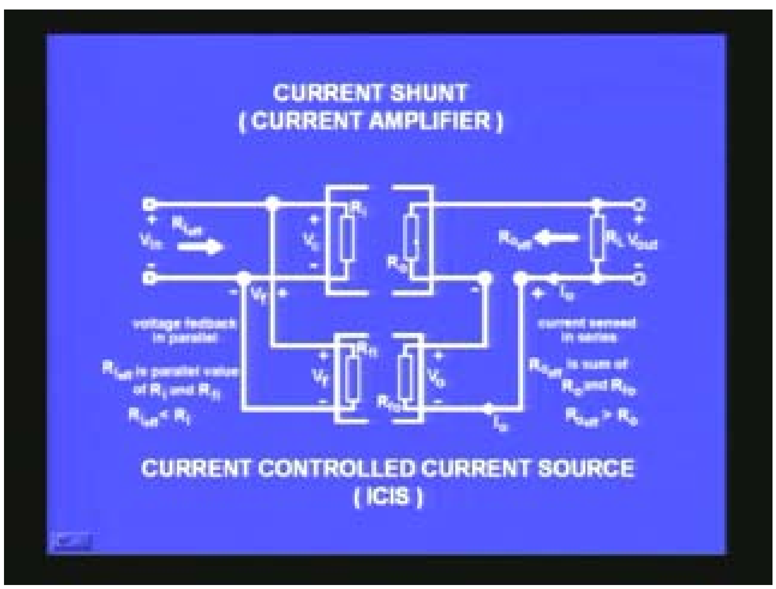
When the input voltage goes beyond the maximum voltage namely about 200 microvolts, the output becomes saturated because of the large open loop gain of nearly 10 to the power of 5 in the case of 741. Because the voltage is larger they cannot be larger than the power supply that I apply. It saturates at 15 volts at plus and minus side and you are left with only plus or minus nearly 200 microvolts or in this case 15 volts I have assumed. 15 volts divided by 10 power 5 is 150 microvolts.

(Refer Slide Time: 4:37)



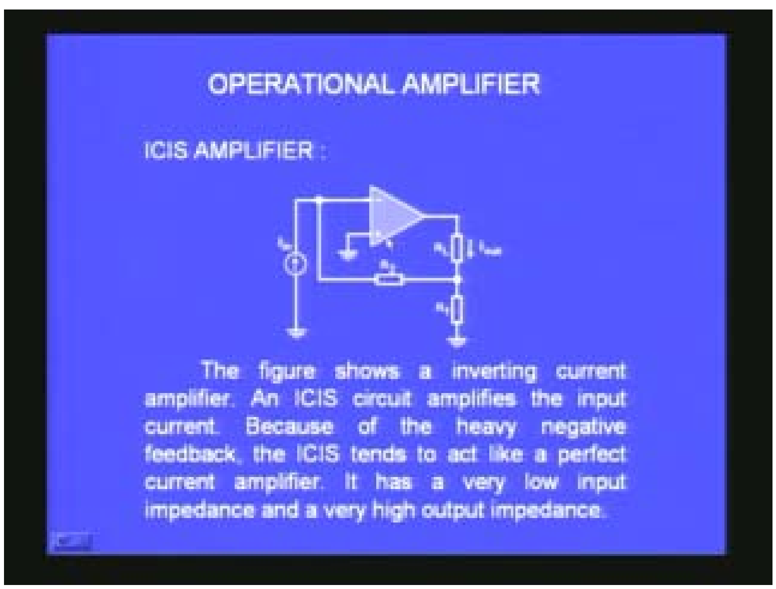
So plus or minus 100 microvolt is the difference between the two input terminals of an op amp. That you should always remember. With reference to the current amplifier or the current shunt configuration you can see this is the schematic of the feedback configuration.

(Refer Slide Time: 4:56)



At the output side you sense the current because you are connecting the network in series with the load; output R_o, output resistance of the amplifier. This is amplifier and this is a feedback network. They come in series. That means the same current flows through also the resistor which I have in the feedback network and what I sense here is some voltage proportional to the output current and then that in the input side is given as a voltage in parallel to the input voltage and in phase opposition. When I have two parallel resistors coming, if I look at the effective resistance at the input side it is the parallel resistance values of R_i and R_f. This is the input resistance R_i and R_f the feedback resistor. Any parallel resistance will have effect of reducing the effective resistance and the input resistance has effectively decreased due to the parallel combination, due to the type of feedback that I have given at the input. At the output because the two resistors come in series the effective resistance is increased with reference to R_0. This is what you should understand; the input resistance decreases, the output resistance increases. When that input resistance decreases the input will have to be current and not voltage. When the output resistance increases the output is basically a current. It becomes a current source. That is why it is called current controlled current source. The input is current which controls the output current and it is called current controlled current source, ICIS where I corresponds to current. Current controlled current source or basically this is also called current amplifier because effectively you will get a larger current corresponding to the input current that you give at the two input terminals and the actual circuit with a 741 or similar typical operational amplifier is shown on the screen.

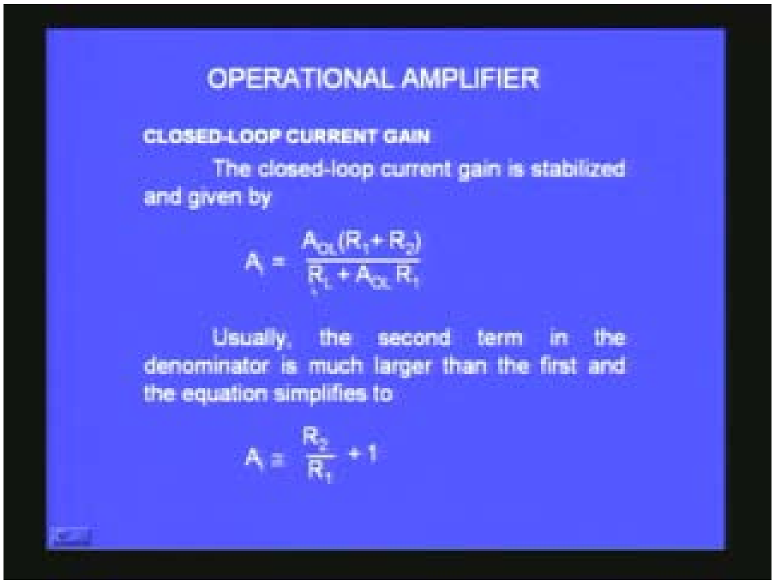
(Refer Slide Time: 7:08)



The current is sensed. The R_L is in series with the feedback network. R_2, R_1 are the feedback; part of the feedback network. R_1 gets the current which is part of the I_{out}. This voltage will have some influence through this resistor at the input. This is the feedback path that you have here and this is a current source that I have connected at the input. We should now find a relationship between I output, the current output and the i_{in}, the input current. Already I told you because of the configuration, the input resistance is reduced.

Because along with the input resistance there is another network R_2 and R_1 coming in parallel the effect of parallel resistance is to reduce the input resistance. With reference to output along with R_o that R_L is also coming. There is the R_1. There is a series resistance coming in series with the output resistance. The output resistance is effectively increased. That is the effect of the feedback here and if you look at the closed loop gain, the closed loop gain will have to be A_{OL} multiplied by R_1 plus R_2 divided by R_L plus A_{OL} into R_1.

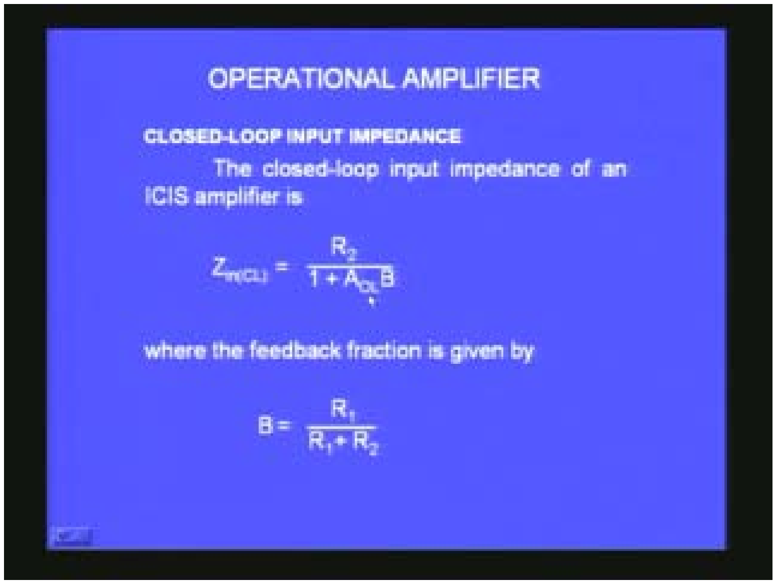
(Refer Slide Time: 8:34)



But in this $A_{OL}R_1$, A_{OL} which is a large number multiplied by R_1 will be a very, very large number compared to R_L and I can neglect the effect of R_L and then the A_{OL} will cancel and what I get will be R_2 divided by R_1 plus 1. That is R_1 plus R_2 by R_1 which I rewrite like this R_2 by R_1 plus 1. The gain of the amplifier in this case the current amplifier is 1 plus R_2 by R_1 similar to the non-inverting amplifier that we discussed earlier. We also got the amplification factor in an approximation is 1 plus R_2 by R_1; V output is equal to 1 plus R_2 by R_1 times V_{in}. Here I output is equal to 1 plus R_2 by R_1 times i_{in} for this circuit.

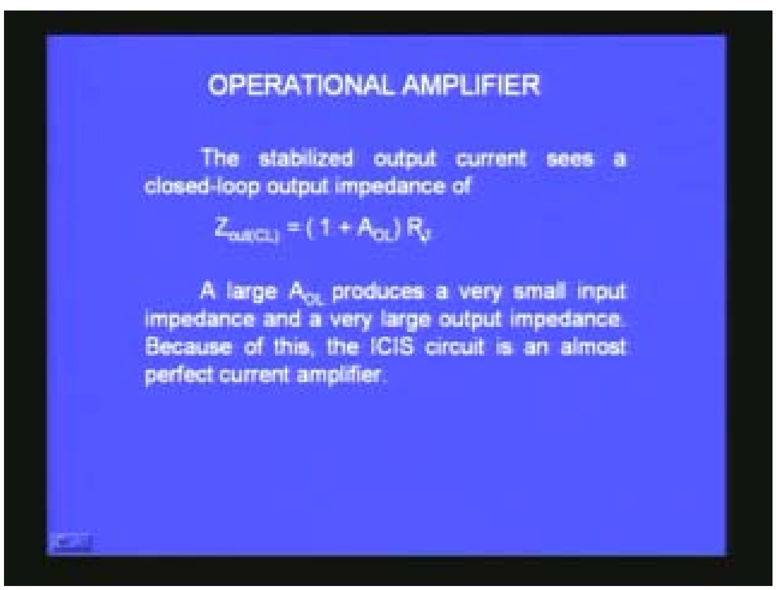
We also know this input feedback configuration will have effects on input resistance, output resistance, etc. In this case the input resistance with the closed loop feedback will be R_2 divided by 1 plus A_{OL} B where B is actually the beta, the feedback ratio R_2 divided by 1 plus A beta where A is the open loop gain here we have designated as A_{OL}.

(Refer Slide Time: 10:01)



Because the feedback fraction is given by beta is equal to R_1 by R_1 plus R_2 that is the ratio of the fraction of the output which is fed at the input and the effective input resistance is going to be less now. A beta is a large value. So R_2 divided by A beta can be very, very small. The effective input resistance is reduced. Similarly if you look at the output resistance of the closed loop configuration it will be multiplied by the factor 1 plus A_{OL} into R_1.

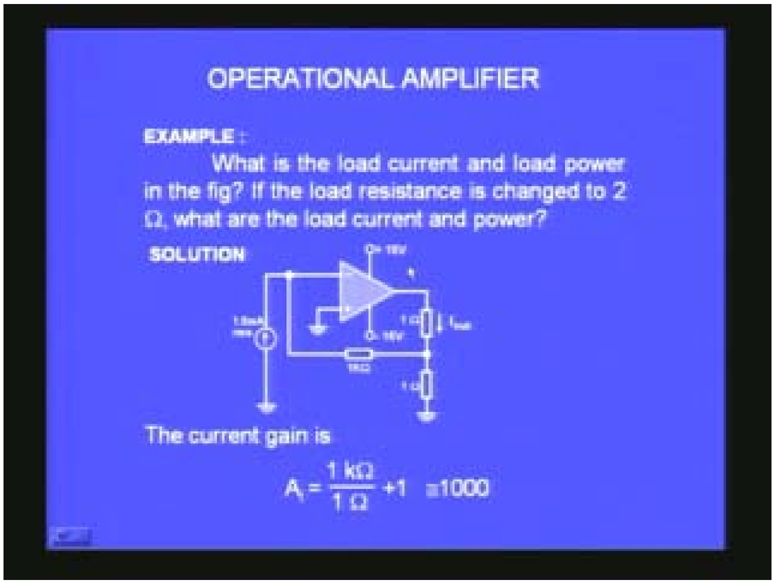
(Refer Slide Time: 10:42)



R_1 is a normal thing that you will get is multiplied by this large number. Therefore output resistance effectively is increased and the output acts as if it is a current source. That is why it is called current controlled current source. It has got small input impedance and large output impedance which is a characteristic of a current amplifier.

We will take a small example. What is the load current and load power in the figure for a given op amp if the load resistance is changed to 2 ohms? Now it is 1 ohm. If I change it to 2 ohms what are the load current and the power?

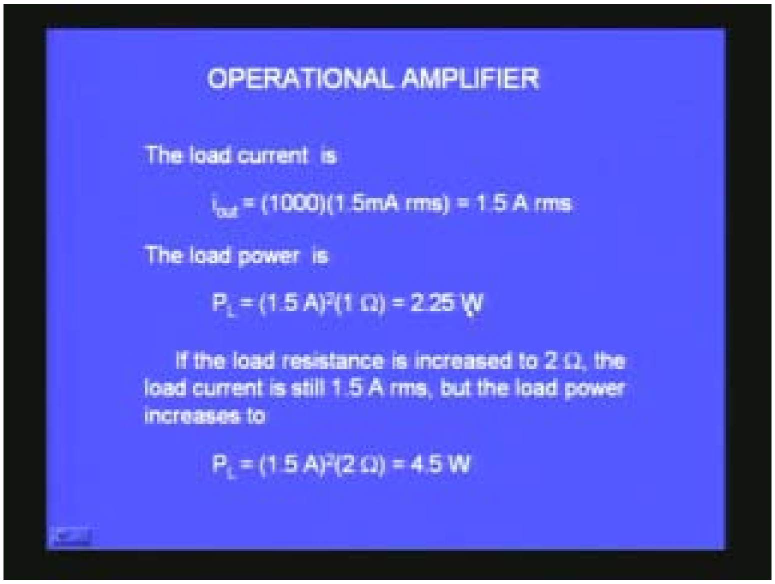
(Refer Slide Time: 11:21)



The input is an ac current; 1.5 milliampere rms and it is powered by plus or minus 15 volts and the feedback is actually 1K and 1 ohm. These are the R_1, R_2 values. What is the current gain? Current gain is equal to R_2 divided by R_1 plus 1. R_2 is 1000 ohms; 1 kilo ohm divided by R_1 is 1 ohm plus 1. 1000 ohm by 1 ohm is 1000; plus 1 it is almost equal to 1000. The current gain of this amplifier is 1000 and the input is 1.5 milliampere. So what will be the output current? 1000 times the 1.5 milliampere. So I output is 1000 times 1.5 milliampere rms. That is equal to 1.5 ampere rms. This is a power operational amplifier. It can handle higher currents; 1.5 amperes.

What is the load power? Load power is given by I square R. I square is 1.5 amperes whole square into R_L is 1 ohm. The total is 2.25 watts.

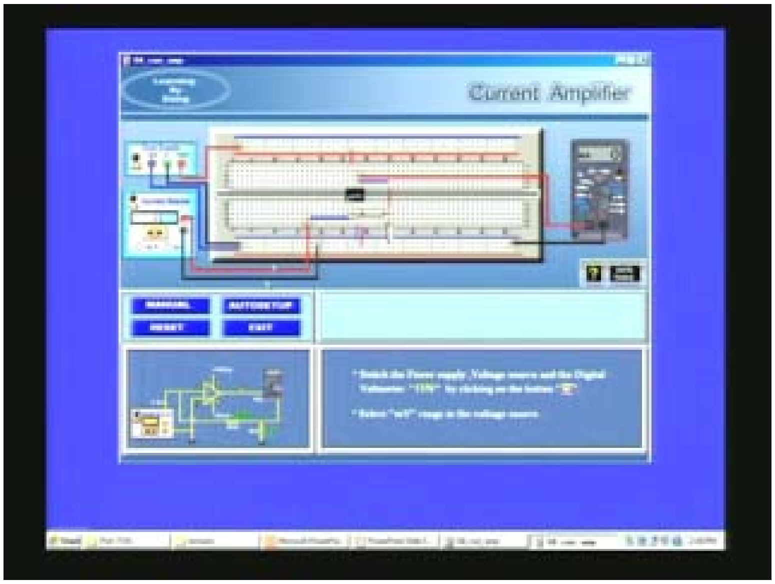
(Refer Slide Time: 12:28)



If the load resistance is changed that is doubled from 1 ohm to 2 ohm what will happen? The load current is still 1.5 amperes because the load current is not controlled by 2. It is controlled by R_1 and R_2 and they are the same. It is same 1000 times input current. Therefore 1.5 amperes will remain as such; load current. But the load power 1.5 amperes square into 2. It becomes twice. When you double the load resistance the power also doubles. From 2.25 it has now become 4.5 watts. This is a very typical simple example of a circuit. They can calculate the output current and the wattage, corresponding output power.

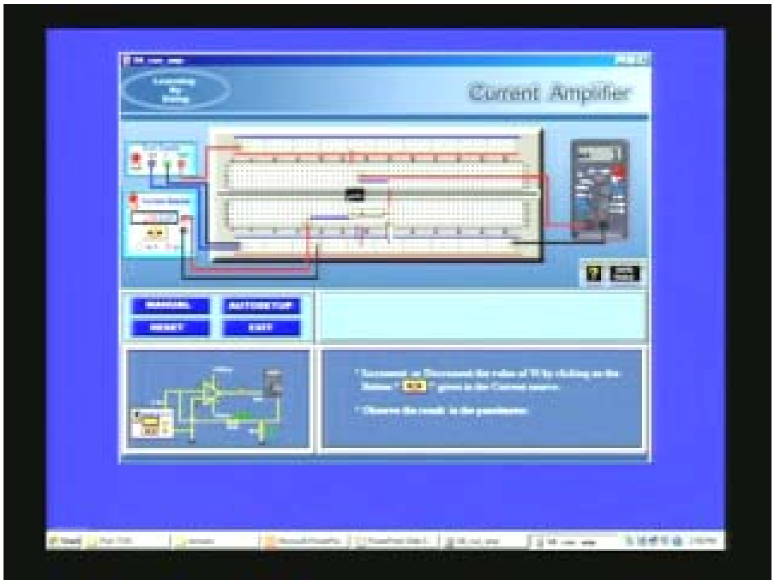
Let me quickly show you a simulation of the circuit. You have a bread board here. You have a dual supply here. You have a current source because you want to give a current input. You have a current source here. You can give currents in the order of milliamperes or microamperes by increasing the values and you have a multimeter here which is already set in milliampere so that it can measure currents in milliampere. You have the op amp and the resistors. Let me just form the circuit. The op amp goes over here and wiring is done. This is the circuit that you have here. Instead of the load resistance I have put the multimeter. The multimeter forms the load. This R_2 is 10K; R_1 is 1K. The gain is going to be 1 plus R_2 by R_1. 1 plus 10K divided by 1K; 10K divided by 1K is 10. 1 + 10 is 11. Therefore the gain of the amplifier is 11.

(Refer Slide Time: 14:16)



You can also see here this is 10K which is coming from 6 to 2 terminal. That is the feedback loop. Pin number 6 is the output; pin number 2 is the input, inverting input. You put a negative feedback connecting these two through the resistor 10K and you have the other resistor here which is the 1K resistor. This is the 1K and so the gain will have to be 11. Now I switch on the power supply, dual supply and the multimeter. I can start giving the voltages. Let me start from microamperes. If I increase here now it is 100 micro amperes. As you can see the current input is 100 microampere and if we multiply 100 microampere by 11 it will be 1100 microampere or 1.1 milliampere. The reading is around 1 milliampere.

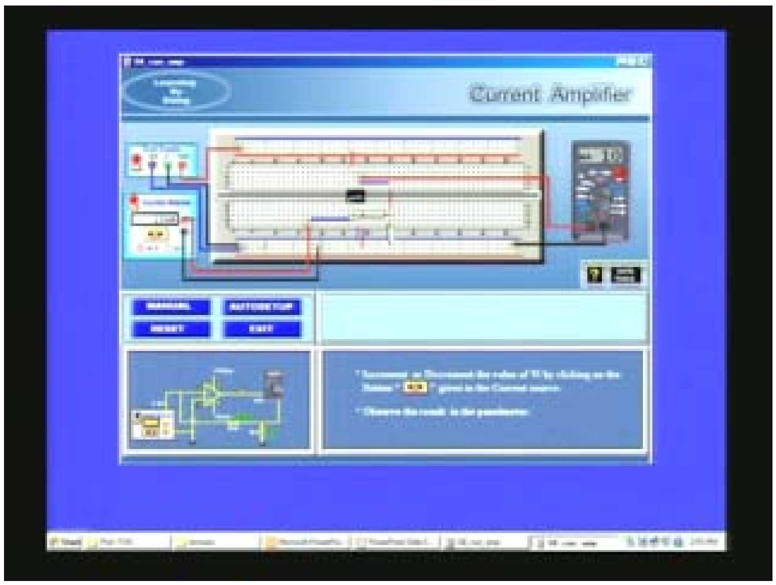
(Refer Slide Time: 15:13)



If I increase to 200 it will be 2.2 milliampere actually. As you increase the current you can see the output current also increases nearly 10 times; should be actually 11 times. It depends on the actual values of the resistors. There are some variations because after tolerance this factor cannot be exactly 10. It can be slightly less or more. That is the reason that why you are getting only 10 times and not 11 times. It depends on the typical actual values of the resistor which has to be measured using a multimeter.

Let me go to milliamperes. Let us give milliamperes. I give 1 mill ampere and the output current is 10 milliamperes.

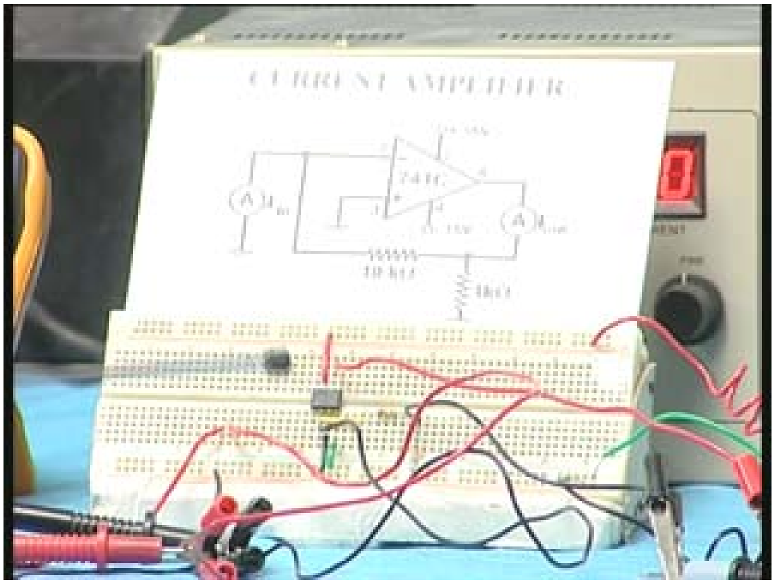
(Refer Slide Time: 16:05)



If I now go to 2 milliamperes it is 20 milliamperes; 3 milliampere means 30 milliampere. The output current is increasing nearly 10 times which is given by 1 plus R_2 by R_1 approximately. This is an example of a current amplifier constructed with the op amp and the wiring is very simple. This is the ground, the top one and this is $+V_{cc}$ and this is $-V_{cc}$, the blue line and the pin number 4 is connected to the bottom which is the $-V_{cc}$ and the pin number 7 is connected to $+V_{cc}$ and you have the input current here, the feedback loop, etc. The wiring is exactly same as what you have here and this is a current amplifier.

Now we have to perform this experiment on the experimental table. We will do that. This is the bread board on which the circuit has been wired.

(Refer Slide Time: 17:09)



You have the op amp, you have the feedback loop, you have the two resistors R_1; this is 1K and this is 10K and the power supply lines are exactly similar to the simulation. This is the $+V_{cc}$ and the black is the ground and green is the negative that is connected here in this place. This is the dual supply. The three lines plus, ground and minus are connected here and this multimeter measures current 2 milliampere range. This is measured in current and there is one more multimeter at the input which also is connected to 2 milliampere. This measures the current at the input side. So there are two multimeters connecting at the input and the output both measuring currents. You have here a current source and these are the decades. The dot here, the light here, is the decimal point. Here it shows one, zero point zero. That means 10 microamperes. So 10 microamperes is the current. Now it is in standby position. Now I apply the current to the circuit. The current applied is 10 microamperes.

(Refer Slide Time: 18:28)

That is read by this current meter. It shows point zero one zero milliamperes. Point zero one zero milliampere is nothing but 10 microamperes. 10 microampere if you divide by 1000 you will get milliampere; 0.010 milliampere. This is 10 microampere basically and the gain is 11; 1 plus R_2 two by R_1. R_2 is 10K, R_1 is 1K as you can see in the circuit at the top. So 1 plus R_2 by R_1 is 11. 11 times 10 microampere is 110 microamperes and if it is milliamperes it should read 0.11 milliampere and you can see it reads 0.11 milliampere. There is a decimal point here.

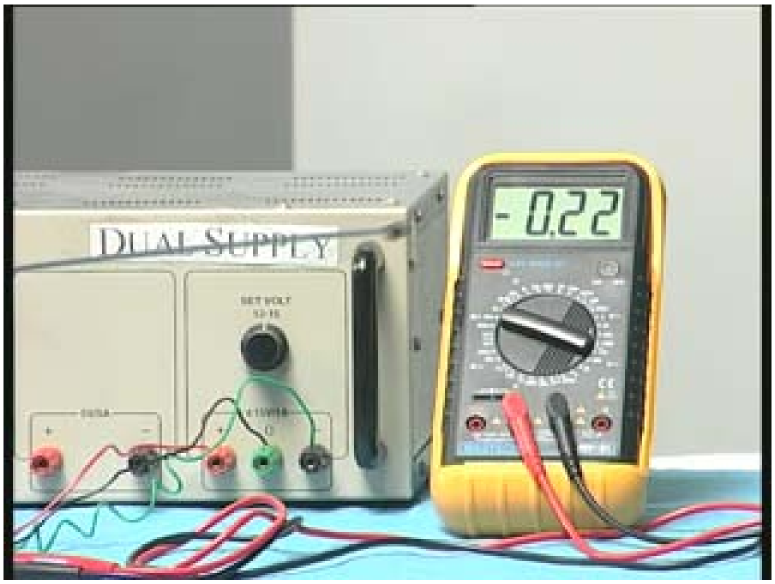
(Refer Slide Time: 19:19)

It is exactly multiplied by 10 times with reference to the input current. I am going to change this dial to 20 microamperes and you see what the input current meter reads. It reads 0.020 which is actually 20 microamperes.

(Refer Slide Time: 19:41)

When I apply a 20 microampere current I want to see what is the output current? In this multimeter I measure the output current. It shows 0.22 which corresponds to 220 milliampere.

(Refer Slide Time: 19:56)



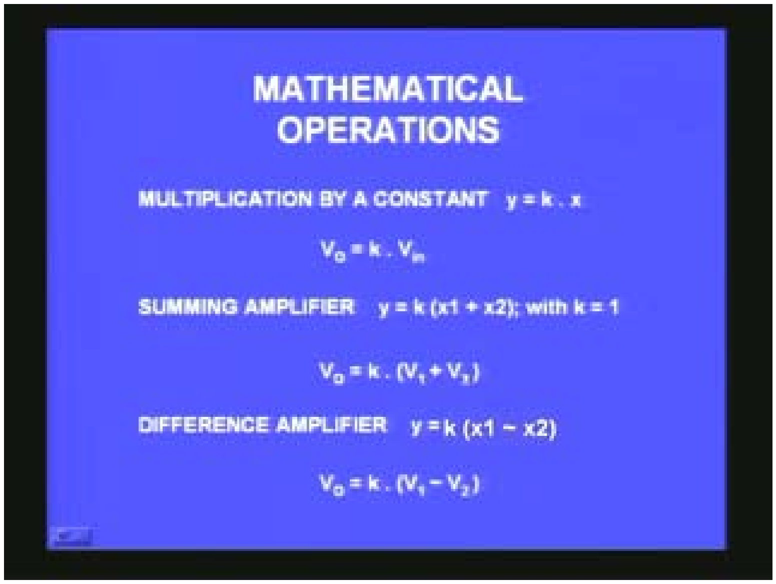
So 20 multiplied by 11 is 220 microamperes and that is 0.22 milliamperes. If I again increase the current to 30 you can see it is reading 30 and correspondingly at the output you have 0.34; 340 microamperes. So 11 times it is multiplied; slightly more than 11 times. I already mentioned to you that the small variations that you get it is because of resistances not being exactly what we thought it should be. If you actually take the resistors and measure using multimeter and use that in this calculation they will match with the corresponding readings here. But you can see as I keep increasing the current the output current also increases every time in a linear fashion multiplied by the factor 11 because this is a current source. I will do an additional value. For example I have now put 60 microamperes as you can see here 0.062. So this is 62 or 63 microampere. That is what it reads here multiplied by 11 should be around 66 or so and the output is around 69 or 68. The output current is multiplied by 1 plus R_2 by R_1 which is the gain factor here.

Having seen the four configurations, the four configurations actually give you four different circuits. They gave you the following important circuits; voltage amplifier, current to voltage converter, voltage to current converter and current amplifier. The four different feedback configurations give you four different circuits which are almost close to ideal situations. All that you have to do is just use either 1 or 2 resistors, maximum, in the feedback configurations by which you will be able to get with the simple op amp like the 741, four different excellent amplifiers. The voltage amplifier, the transresistance amplifier, transconductance amplifier and current amplifier are the four different circuits that you got.

W will move on to the next set of experiments which are very important with reference to operational amplifier. Why is the name operational amplifier? You might recall at the introduction I mentioned to you that operational amplifiers are known as operational amplifiers because they can perform different types of mathematical operation. What are the mathematical operations that op amps can perform? I have taken few typical examples on the screen. You can see the different mathematical operations that one can perform. Number one is multiplication by a constant. That means what? y is equal to k x where k is a multiplication constant. Y and x are related by a multiplication constant; a linear relationship, y is equal to mx plus c. Y is equal to kx. In terms of the amplifier, the output voltage of an amplifier when it is multiplied by a constant factor of the input voltage that you apply this becomes a multiplication by a constant. This is nothing but an ordinary amplifier. In any ordinary voltage amplifier the output voltage is some constant factor of the input voltage. The multiplication constant is a very trivial example of a mathematical operation that amplifiers can perform because almost all amplifiers perform this work. Output is some constant times the input.

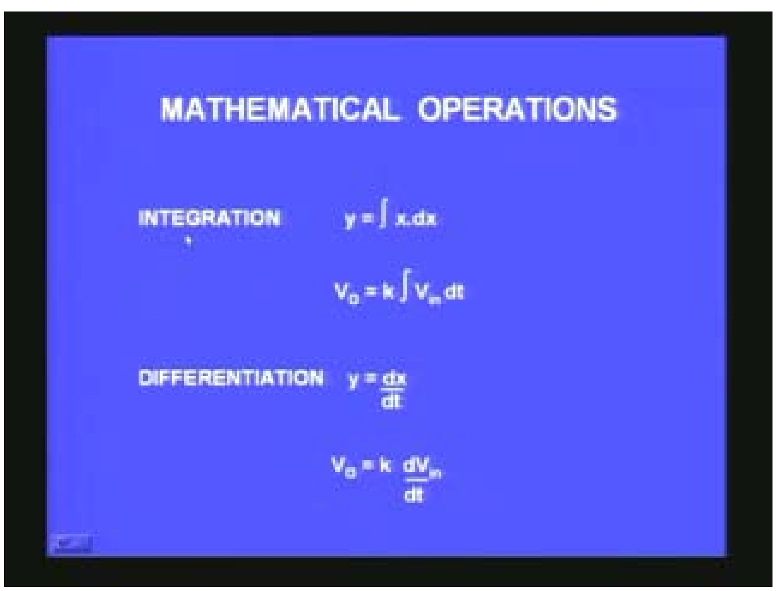
Apart from this multiplication by a constant you can also get other circuits. One of the important circuits that you can get is a summing amplifier. y is equal to k times x1 plus x 2 for the case of two inputs. With the value of k is equal to 1 this becomes y is equal to x1 plus x2 a simple summation. Correspondingly you can think of an amplifier which will give an output voltage which is some k times V_1 plus V_2 where V_1 and V_2 are the two input voltages. If I choose the value of k, the gain to be 1 then it becomes a simple summing amplifier. V output is nothing but some of the two inputs V_1+ V_2.

(Refer Slide Time: 25:01)



Similarly you also can have a difference amplifier or a differential amplifier. What is the difference amplifier? y is equal to some constant times x1 difference x2 or when the k is equal to 1, y is equal to x1- x2 or x2 – x1 as the case may be depending up on which is higher. You can also think of an amplifier where the V output voltage is the difference in the two input voltages multiplied by a constant factor. The constant factor, when it is 1 this becomes a simple difference amplifier V_o not is equal to V_1- V_2 or V_2 – V_1 as the case may be. The sign will change accordingly depending upon which is larger. This is an example of a difference amplifier. You also have another operation which is much more complex which is called integration.

(Refer Slide Time: 25:55)

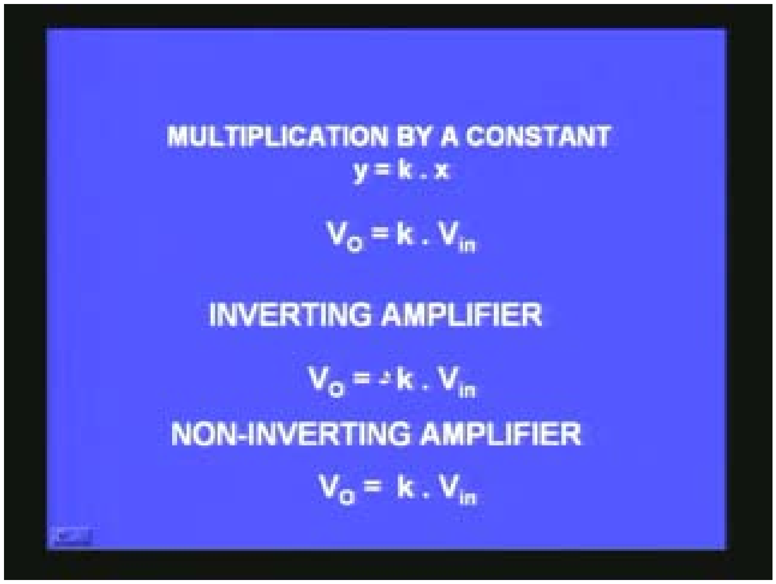


You can perform an integration y is equal to integral of xdx or xdt depending upon whether you are integrating with reference to time or the space variable. I have a circuit where the output voltage is k times integral of V_{in}dt. V_{in} is the voltage input. It is the integral of the input voltage which is related to the output voltage by a factor k. Then this circuit performs integration of the input voltage. The output is the integral of the input. Similarly you can also think of another circuit which will perform differentiation; y is equal to dx by dt. So V_o in this case, output voltage will be k times dV_{in} by dt. What is dV_{in} by dt? It is a differential with reference to time of the input voltage dt. This is also another circuit. So we have five different types of mathematical operation to start with, which will be discussing here. One is the multiplication by a constant where V output is k times V_{in}. Second one is summing amplifier where V output is proportional to $V_1 + V_2$; sum of the two inputs and difference amplifier where the V output is proportional to the difference in the two inputs and you have an integration circuit where the output voltage is integral of the input, time integral and differentiation circuit where output voltage is differential of the input voltage V_{in}. These are the five different circuits.

Before we go to that we will try to look at one of the first circuits which is actually a multiplication by a constant which is nothing but a normal amplifier. But there is a difference. You have already seen one amplifier which can be treated as an amplifier which can produce multiplication by a constant factor. That is a non-inverting amplifier which we have already discussed. V output is equal to 1 plus R_2 by R_1 times V input where 1 plus R_2 by R_1 is our k factor, the gain factor; the multiplication factor. You can choose the R_2 and R_1 corresponding to the value of k that you want. It becomes a simple multiplication by a constant factor amplifier. But there, there was no phase change. You can also design a very simple circuit for producing a negative multiplication of a constant. That is called an inverting amplifier.

Let us look at an inverting amplifier. Again I recapitulate here y is equal to kx or V output is equal to k times V_{in} and the inverting amplifier will have V output is equal to minus k into V_{in} where the minus sign comes because of the phase inversion. If I give a sine wave it will become a cosine wave. It will be inverted by 180 degrees.

(Refer Slide Time: 28:56)



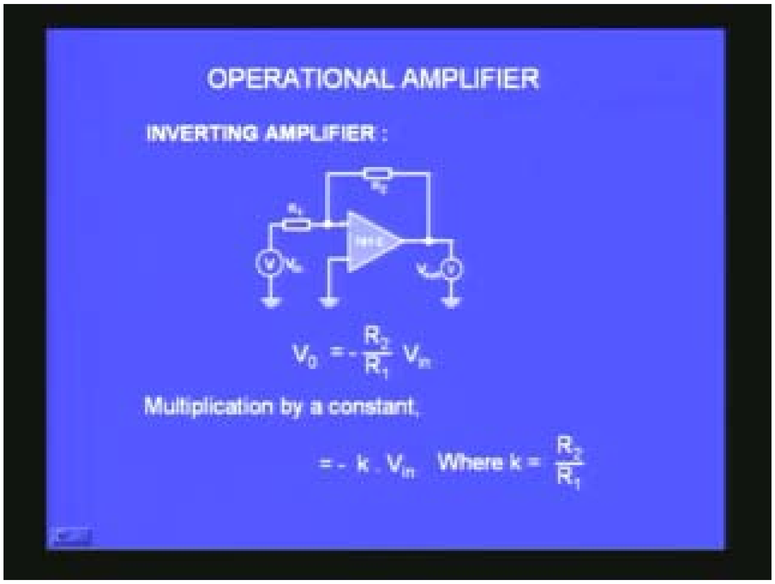
Non-inverting amplifier also can go as an amplifier which will perform multiplication by a constant. That I already mentioned to you. V output is equal to k times V_{in}. Because we discussed this non-inverting amplifier already let me take the example of the inverting amplifier and show you a very simple circuit which will perform this inversion.

(Refer Slide Time: 29:18)

In many of the books inverting amplifier will be given as the first circuit; most basic circuit in the op amps. Because you also have here negative feedback, the negative feedback stabilizes the performance of the amplifier. When you have negative feedback the amplifier performs much more reliably. Because the open loop gain can be different starting from some 20,000 to some 200,000 you can have variation depending upon several other parameters of the amplifier. Then it is becomes unpredictable. What be will be the output voltage? But by giving negative feedback you try to stabilize the amplifier and the amplifier becomes much more reliable. That is the advantage of introducing negative feedback.

Now I have here a very simple circuit which you might recognize as part of the old or whole? circuit that we already discussed.

(Refer Slide Time: 30:19)

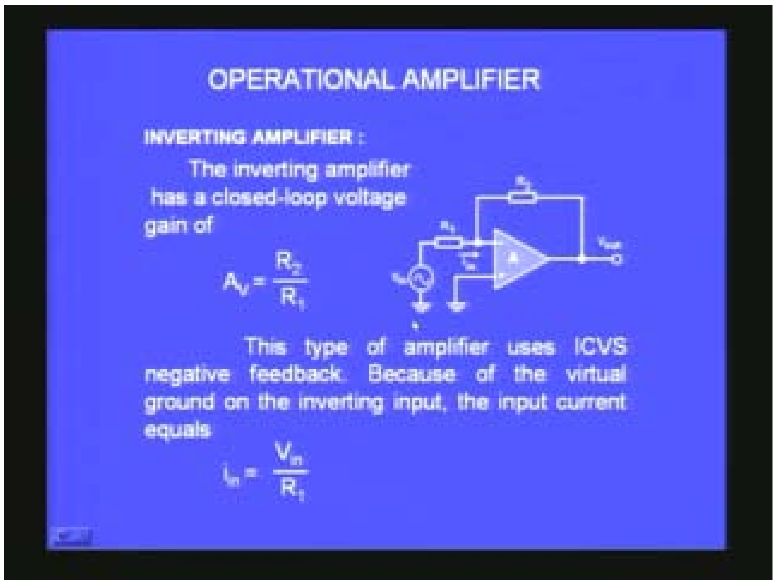


Here what is happening? There is a feedback resistor R_2 and R_1. This is actually minus and this is plus. This is not seen here; minus and plus. The feedback is negative because the output is connected to the negative input and it is a negative feedback using two resistors R_1 and R_2. What is the output voltage in terms of the input voltage? The expression is V output is equal to - R_2 by R_1 times V input. The multiplication factor now is given by R_2 by R_1. If I have R_2 10K and R_1 1K I will get 10 as the multiplication factor k. V output is – R_2 by R_1 times V_{in} where the k factor is basically R_2 by R_1. How do I get this R_2 by R_1 expression?

Without this part which is connected at the input which shows the R_1 you can identify this circuit to be a simple current to voltage converter. If I give a current here the current cannot pass through the amplifier because of the high input impedance of the amplifier. So the entire current will have to flow only through R_2 and therefore output voltage is given by R_2 times i_{in} because this point is a virtual earth. This voltage will have to be negative with reference to the earth. Because the current is flowing towards that terminal it is a negative voltage. So V output is nothing but i_{in} into R_2 with a negative sign; $-i_{in}$ into R_2. But what is i_{in}? i_{in} is now generated using a voltage source and a resistance. Because this is a virtual earth that input current will have to be V by R by Ohms law; V_{in} divided by R_1. V_{in} divided by R_1 here that you see in the expression is nothing but i_{in} multiplied by R_2; gives me the output voltage. The negative sign comes because the current is flowing towards the output terminal from the ground and therefore it is negative. This expression can be very easily understood from this argument.

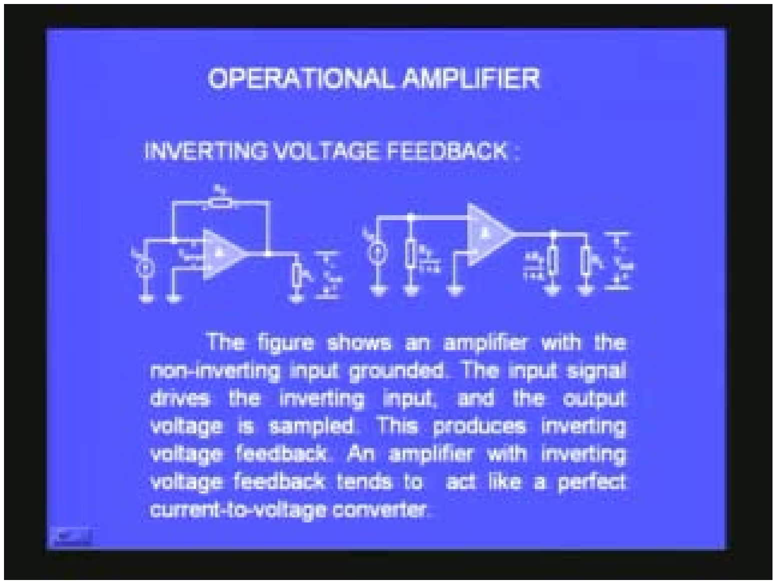
The voltage gain, the closed loop voltage gain of an inverting amplifier is R_2 by R_1 and it is inverting. That means there is a phase inversion between the output and the input.

(Refer Slide Time: 32:58)



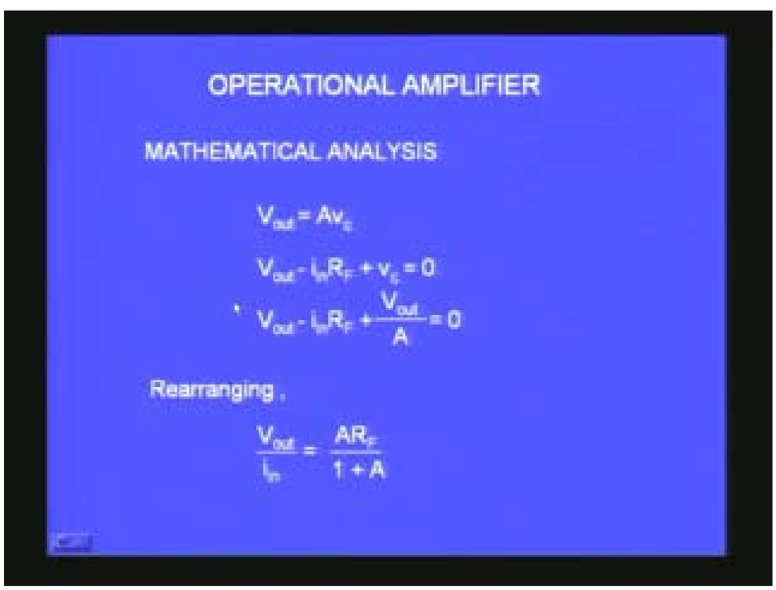
This is very similar to the current controlled voltage source amplifier, negative feedback that we have employed. We already discuss that earlier. It is actually a current to voltage converter. That's why I have shown here i_{in} is nothing but V_{in} by R_1 and V out is nothing but R_2 into i_{in} with the negative sign. Therefore you get the factor R_2 by R_1. This circuit with the feedback resistor can also be analyzed from a known theorem that we already discussed earlier. You might recall the Miller's theorem. The Miller's theorem helps you to split the R_f which is the link between the output and the input; the feedback resistor into two components exclusively one at the input and one at the output. When I split this R_f and put here as a shunt resistance at the input and the output, the shunt resistance at the input will be given by R_f divided by 1 + A where A is the gain of the amplifier. The resistance at the input will be divided by 1 + A. Because A is very large R_f by A will be very, very small. This comes in parallel to the input resistance. The effect is to reduce the input resistance enormously. At the output side the Miller's resistance will be A times R_f divided by 1 + A_f. Because A is very large compared to 1 this is almost equal to 1 and it will continue to remain as R_f. The entire R_f will approximately come in parallel at the output along with the load and the output resistance is reduced effectively because it is a parallel value.

(Refer Slide Time: 34:43)



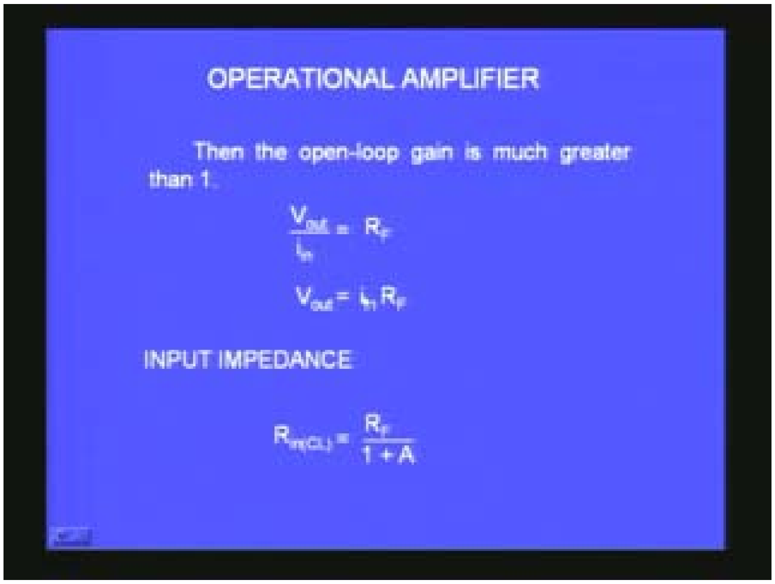
Using Miller's theorem we can split the feedback resistor into two components, one at the input one at the output. The input component is almost neglible because it is R_f divided by 1 + A and the output component is almost R_f because A by 1 + A is almost equal to 1. This way also we can discuss the circuit and the output is A times V epsilon where V epsilon is the small error voltage between the plus and minus terminals and V output minus i_{in} R_f plus V epsilon is zero by applying Kirchhoff's law. For the circuit here V output is the i_{in} R_f. This is the V epsilon.

(Refer Slide Time: 35:33)



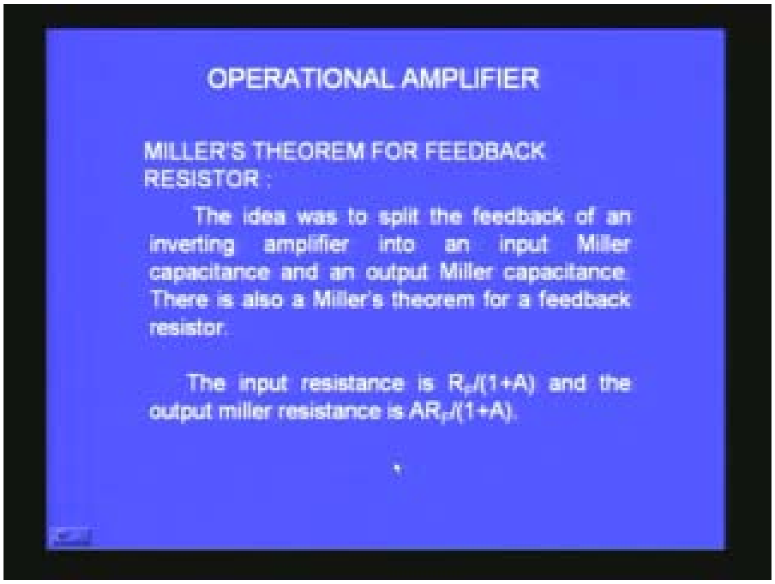
This V epsilon is nothing but V output by A. So I substitute in the next line V output by A and I can rearrange in terms of the V output. So V output by i_{in} will be equal to A times R_f divided by 1+ A which when A is very large is going to be almost R_f or V output is equal to i_{in} into R_f which is what we know. If it is a basic current to voltage converter output voltage is equal to i_{in} into R_f except for a negative sign here. So V output is equal to i_{in} into R_f is the output in terms of the input.

(Refer Slide Time: 36:14)



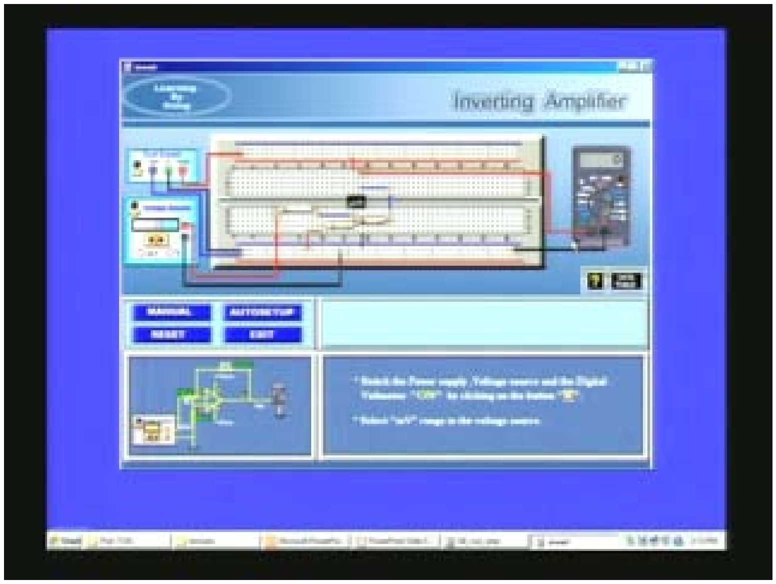
This i_{in} now because of the virtual earth we are generating using a voltage source and a series resistance R_1 and you get corresponding V output is equal to R_2 divided by R_1 times V_{in} with a negative sign. The input impedance of the amplifier will be reduced; R_f divided by 1 + A. That is what we saw from the Miller's theorem also that it is the effective resistance which will decide. All the other resistances are larger value.

(Refer Slide Time: 36:42)



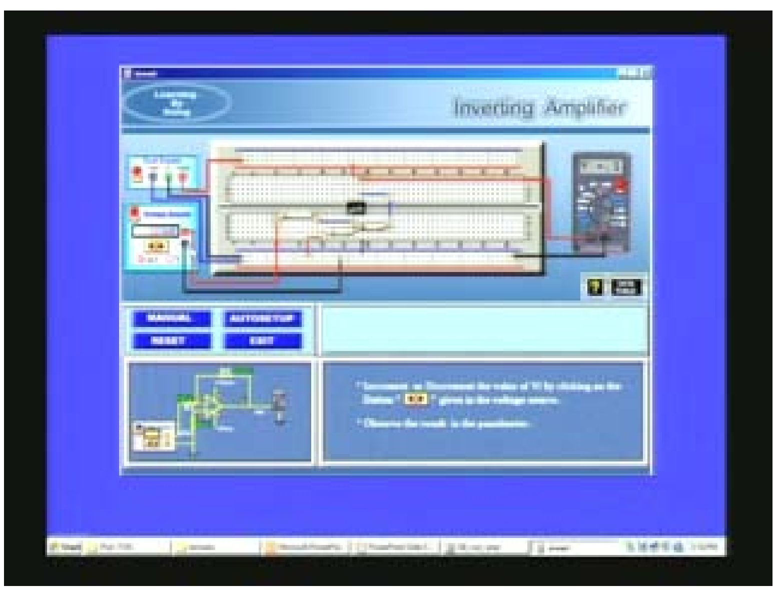
The parallel value will always be very close to the smaller value. Miller's theorem helps us to analyze the circuit easily. Now let me do a simple simulation of the inverting amplifier. Again see on the screen the bread board is coming. You have a dual supply. I switch the dual supply. Before that I will form the circuit. The circuit is simple. You have a 741 op amp and you have a feedback resistor of 10K and you have an input resistance of 1K which is connected to the voltage source. Let me do auto set up. Then all the IC's and other things will go and sit in the proper place. This a dual supply that is being wired. The top one is the negative supply. Then the ground and the V^- are connected at the bottom. There is a voltage source. The output in the voltage source is connected between the input terminals; connected to the resistor which is connected to pin number 2 of the op amp and the ground. The value of the input resistance is 1K; the value of the feedback resistance is 10K and the value of the resistance which is connected to the ground is also 10K approximately which will be a parallel value of these two resistors. The wiring is completed.

(Refer Slide Time: 38:08)



The multimeter is connected at the output in voltage mode and let us switch on the power supply. I switch on the power supply; all the three power supplies. Now I can give the input voltages. The input voltage I have a choice. I can give in millivolts or in volts. Let me give it in millivolts. I increase it. 10 millivolt is the input multiplied by 1 plus R_2 by R_1; 100k by 10K which is 10. So 1 + 10 is 11. 11 times 10 millivolt is about 110 millivolts. That is 0.1 volts. That's what you see here.

(Refer Slide Time: 38:47)

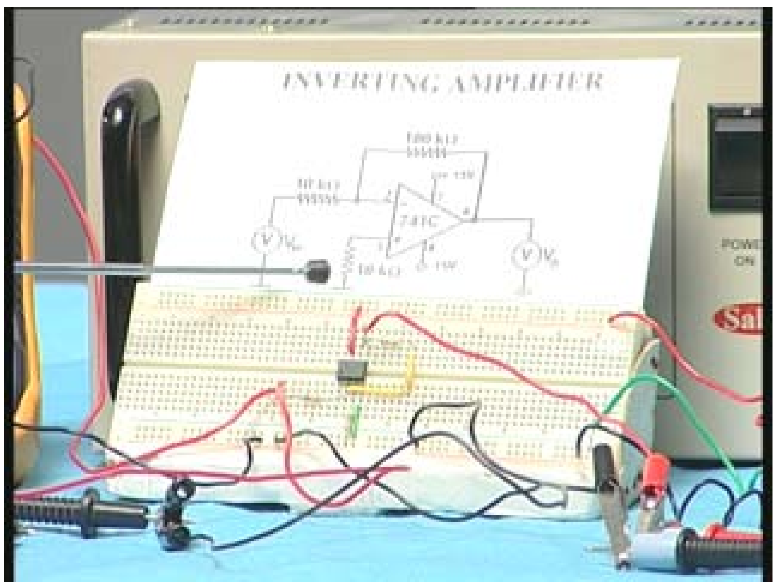


I can apply 20 millivolt. Then the reading becomes -0.2 volts or 200 millivolts. 30 millivolts means 300 millivolts; 10 times more. 40 millivolts gives me 400 millivolts or

0.4 volts. If I keep on increasing to larger value then it can also saturate at some stage because the output voltage cannot be more than the power supply voltage. This is the inverting amplifier. Also the voltage is negative.

Having seen this, let us move to the demonstration. We will see the demo. You have the inverting amplifier. You have the 10K at the input along with the voltage source and you have the feedback between the two and six terminals of the op amp the 100K resistor and at the three input it is grounded through a 10K resistor. This is meant to balance actually to take care of the differences in the input bias current about which we will discuss at a later time.

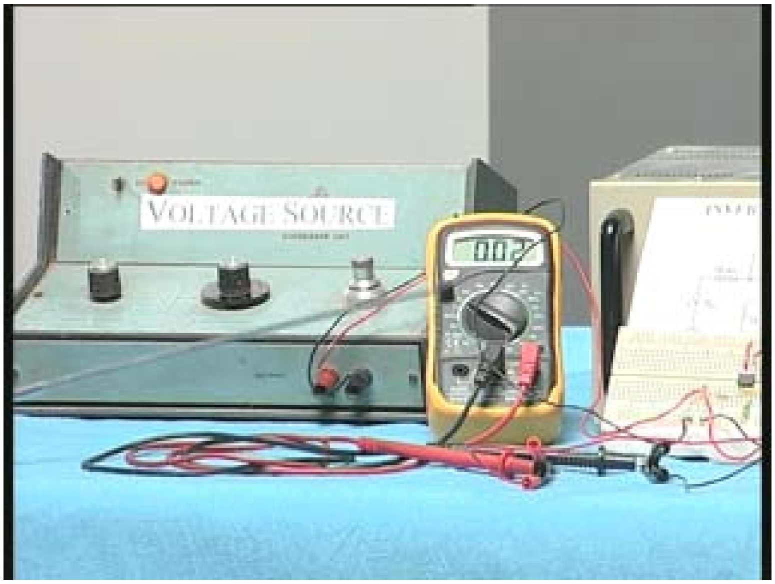
(Refer Slide Time: 40:02)



I have put a 10K resistor which is almost the parallel value of 10K and 100K. It is about 9K. I have put the nearest value 10K here. This is the output voltmeter. Here this is a op amp. The seven is connected to the rail voltage which is connected to +15 and the bottom black is a ground and the green is the -15 volts and you have the two resistors the 10K and the 100K resistors connected in the feedback and there is a 10K resistor which is coming from the pin number three. This is a voltmeter. It is measuring volts and this is a voltage source which we have seen in the earlier experiment. I can change the dials and change from millivolts to volts and that is connected to the input of the amplifier between the terminal two of the resistor that I have between this point and the ground. That is what I have connected here. This voltmeter measures in parallel. I have connected the voltmeter in parallel to the voltage source so that I know whenever I change the voltage I will measure the voltage I am applying at the input. At the output I have connected this voltmeter which is again a multimeter in the voltage range.

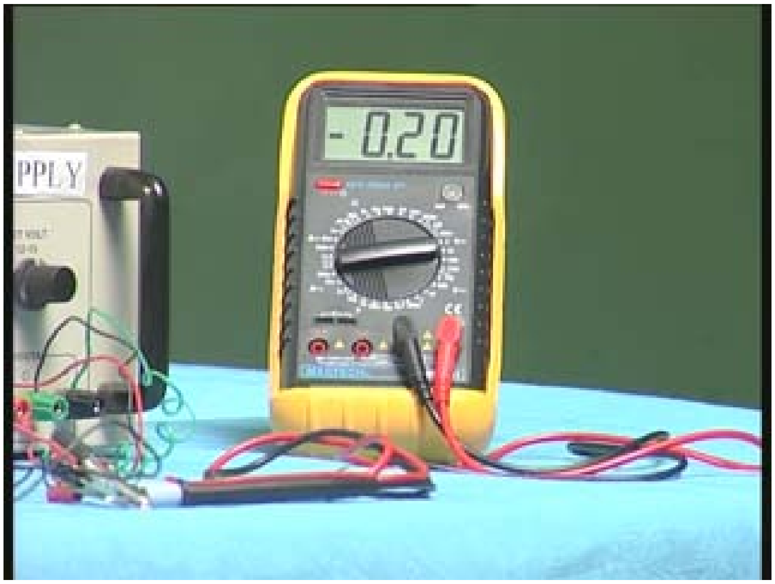
Now I have got here 100 millivolts. The gain is 100K divided by 10K. That means 10 times. It is actually 10 millivolt. I will come to a lower range. It will be better. So I have kept it here in 2 position. That means 20 millivolts I am applying. So the reading here is 0.02 volts. This is in volts range.

(Refer Slide Time: 42:03)



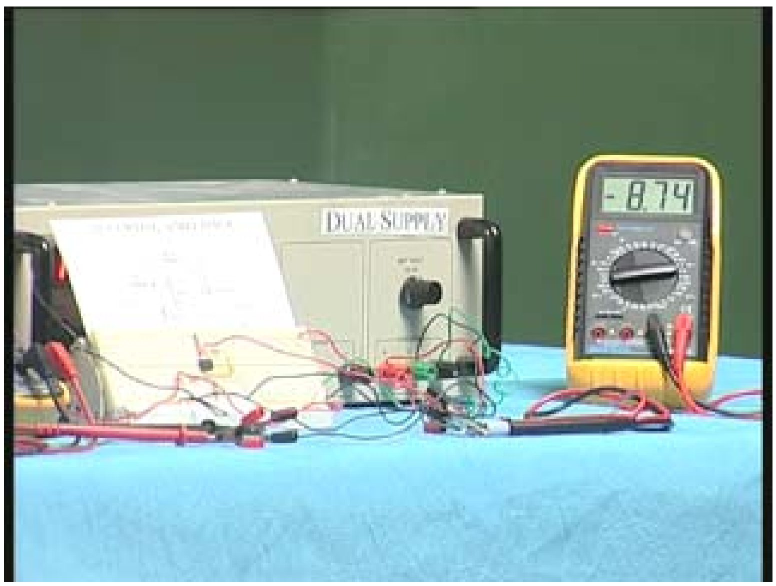
0.02 means 20 millivolts. If you multiply by 1000 you will get it in millivolts. 0.02 if you multiply by 1000 it is 20 millivolts. 20 millivolts multiplied by 10 should be 200 millivolts and what I get in this power supply is 0.20 volts. That means 200 millivolts.

(Refer Slide Time: 42:23)



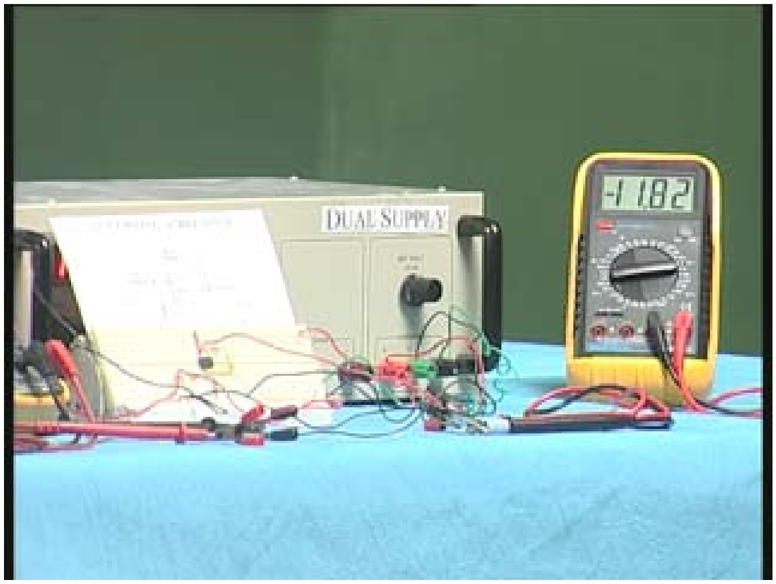
0.02 is coming as 0.2; multiplied by 10 times. If I put 0.3 here, 30 millivolts you get 0.3 volts at the output correspondingly. If I make it 40 millivolts, 0.04 and the output voltage is 400 millivolt or 0.4 volts. Now what I will do is I will increase it in hundreds. I increase to 100. Now it is in two position. That means 200 millivolts that is shown as 0.19 or 0.2. This is 0.2 means 200 millivolts multiplied by 10 should be 2 volts. That is why 1.95 you are getting. If I change it to 300 millivolts I get 3 volts nearly. If I change it to 400 millivolts I get nearly 4 volts or 3.89. The difference as you can see is because the resistors are not precise. If I take 1% resistor and try the 100K, 10K etc you would find very close to the exact number that you think. If I keep on doing it you might ask what will happen if I go to very high values. For example now I apply 900 millivolt. You can see that 0.87 multiplied by 10 is 8.7.

(Refer Slide Time: 43:52)



Now what I am going to do? 8 volts I am getting. I will increase this still further to 1 volt at the input. I have 1 volt here. This is 0.97 volts multiplied by 10 is 9.7 volts. That is what you are getting. If I put here 2 volts what will you get at the output? You will say 2 into 10 should be 20 volts. Let us see whether you get 20 volts. I have put here 2. It is now 1.95 volts and the output is 11.82 only. I go to 3 volts; here it shows 2.93 nearly 3 volts. But the output still remains at -11 volts. Why?

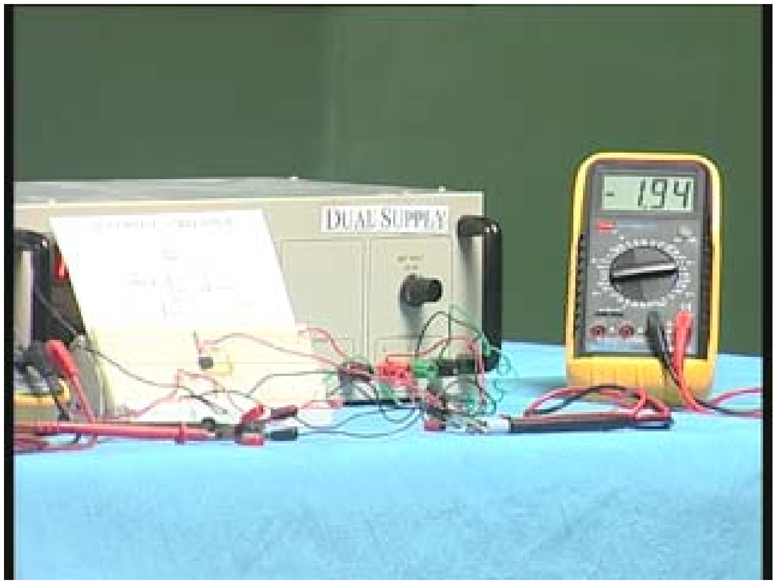
(Refer Slide Time: 44:39)



We say the op amp is now in saturation. Because the input voltage is very large multiplied by the gain factor if it exceeds the supply voltage which is in this case plus or minus 12 volts; 11.8 is corresponding to the power supply voltage; -11.8 and it has come to saturation. If I come to 2 volts also it is still 20 volts. It cannot be shown because it is larger than 12 volts that I have applied to the op amp. So it only shows -11.82. If I come to 1 volt then I am below the saturation limit and 1 multiplied by 10 you get 9.76. I cannot increase the voltage at the input larger than 1.2 volts because when I multiply 1.2 volts by 10 I get 12 volts and 12 volts is the maximum that I get from the power supply. I cannot get any output voltage larger than the power supply voltage. That is the idea I wanted to explain.

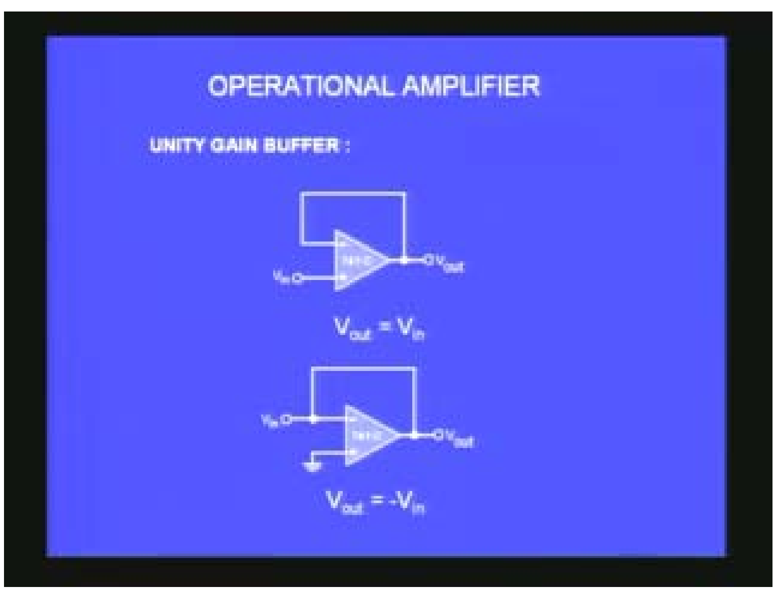
Another very important thing; for example I am again giving 200 millivolt 0.2 volts and the output is 2 volts nearly 1.94. But what is more important is I am applying the red to the input, the black to the ground. That means I am applying positive 200 millivolts and multiplied by 10 I should get -2 volts and you can see there is a minus sign here. This is actually -1.95 volts.

(Refer Slide Time: 46:12)



Whenever I increase the input voltage the output voltage is always negative. That shows it is an inverting amplifier. The positive voltage is converted in to negative voltage. These two points are to be borne in mind. Having seen the inverting amplifier now we can also see a small variation of the inverting amplifier and the variation of the input inverting amplifier is a very, very useful circuit which is useful in many buffer applications. For example I have shown on the screen two circuits.

(Refer Slide Time: 46:49)

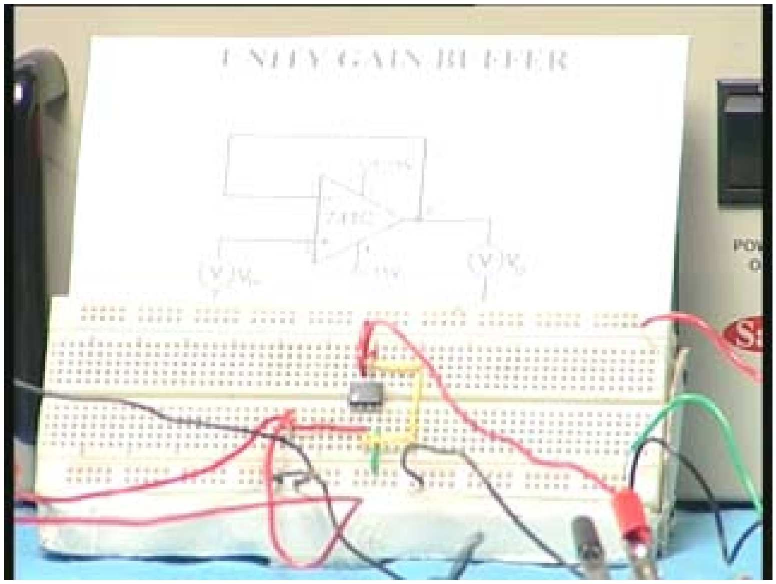


In one circuit the output is completely connected to the input without any resistor. There is no resistor. Output is connected to input and the input voltage is now given to the non-inverting input terminal. So $V_{in} = V_{out}$. The feedback is 100%. When the feedback is 100% the gain becomes 1. Beta is 1. So A by 1 plus A beta is nothing but A by A which is almost equal to one because A is very large. So you have gain of one. But then if there is no gain why do you talk about this amplifier? We talk about this amplifier because the gain is 1 alright but then the input impedance has increased by enormous value. The 10 power 5 factor and the output resistance is decreased by 10 power 5 factor because I have scarifies the entire gain in the feedback and it improves every one of the characteristics by that factor. If it is a 1 meg ohm input resistance it becomes 10 power 5 meg ohm which is very large value and the output resistance is 75 divided by 10 power 5 which is again a very, very small value. It becomes an ideal voltage amplifier with a perfect high resistance at the input, low resistance at the output. This can be used as a buffer amplifier. So this circuit is very, very useful as a buffer to isolate an input and an output stage. Because this has got high input impedance it provides isolation between these two. This is a very, very useful circuit; unity gain buffer. That's why it is called unity gain buffer.

You can also have a small variation of the output of the circuit where the input is given to the inverting and the other input is grounded. Here you get output $-V_{in}$. In the previous circuit V output is $+V_{in}$. That is non-inverting buffer. This is an inverting buffer. The two different circuits are both very, very useful. They provide you as a buffer; the more important circuit is this unity gain buffer with non-inverting configuration. This provides perfect isolation. This is also very, very useful. It is a variation of the inverting amplifier and non-inverting amplifier that you have already seen. What we have done is we have eliminated the resistor and we have given 100% feedback. That is why you have this.

Having seen that we will go down to the table and we will see the last demonstration of this unity gain buffer where the output is exactly same as the input. There is no difference but the amplifier is useful because it provides very large input resistance and very small output resistance. It is used as buffer stage between different stages of amplifier. Here you can see the unity gain buffer. The output is directly connected to the input and the input is given to the non-inverting terminal and the output voltage is measured at pin number 6.

(Refer Slide Time: 50:13)

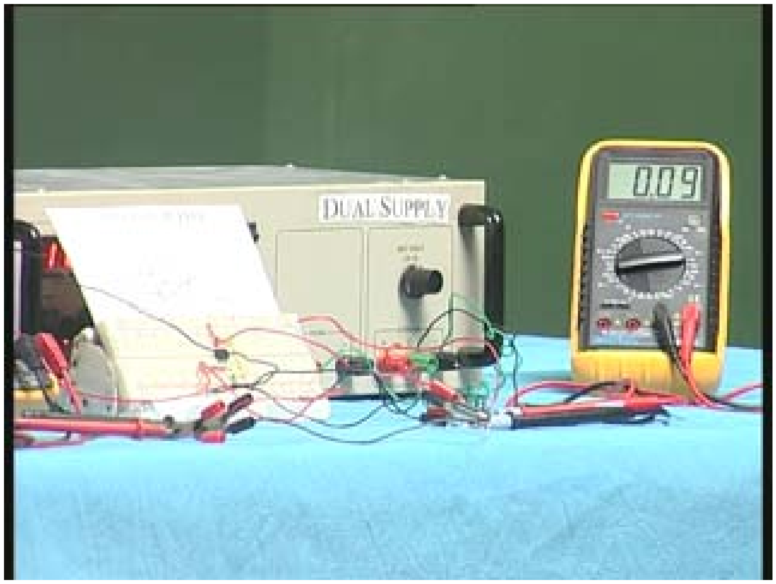


The circuit is shown here. There is a feedback loop here and this voltage source is connected at the input and this voltmeter reads the voltage input here. In the similar fashion at the output you have a one more voltmeter which measures the output voltage. It is in the volt range dc volts and you have the bread board connected to the dual supply; the red, the green and the black. This is +12 volts, ground and -12 volts. The three wires are connected very similar to what you saw already and you can now see the output and the input. Now what I have done is I have given 100 millivolts. This is in 100 millivolt position. So I am giving 100 millivolt which is read by this multimeter as 0.10 volts which is correct. 100 millivolt is 0.1 volt.

(Refer Slide Time: 51:12)

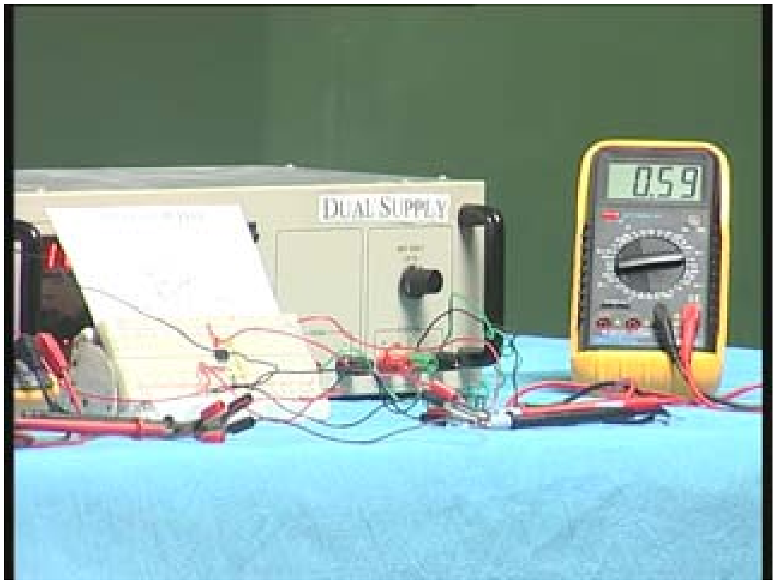
What should be the output? Because there is no R_1 R_2 the feedback is complete; 100%. Therefore the output is also the same as that. Instead of 0.1 it is 0.09 because it is exactly not the same as the input; slightly less.

(Refer Slide Time: 51:32)



If I put it in 2 that means I give 200 millivolts output is also about 0.19; 300 millivolts output is also about 0.29. There is no difference between the input and the output. They are almost equal. The input is 0.39 here the output is also 0.39 nine here and the polarities are the same. Output is also positive and the input voltage is also positive because it is a non-inverting amplifier. There is no gain. That is what you should recognize. There is no gain here but still you gain in terms of other features like the input resistance and output resistance and this unity gain buffer is very, very useful circuit in number of applications; for impedance matching, etc. Now you might be wondering when I go to higher values now it is 0.49 the output also is exactly 0.49. If I go to 0.6 that is 0.59, the output also is 0.59.

(Refer Slide Time: 52:36)



But when I come to lower values for example 0.2 or 0.1 here you find it is only 0.09. It is not exactly 0.1. Why is it so? That brings us to a very important idea that when I have zero for example even though it shows zero it will still have some small residual voltage which we call off set voltage. Even when the input is zero there could be very small off set voltage and that is the reason why at very low voltages you don't get exactly the same value at the output as the input. We will discuss about this offset voltage and other characteristics of the op amp in one of the later lectures.

What we have seen today is basically the current amplifier. We also saw the circuit. I explained about the working of the circuit and then I also showed you a simulation and an actual demonstration of the circuit with all the input current source and output current meter and we also discussed about the different mathematical operations that can be performed using the operational amplifier and we took one example of multiplication by a constant, which can be either a non-inverting amplifier or inverting amplifier. We also discussed about the inverting amplifier and we saw the simulation as well as the actual demonstration of the inverting amplifier. Then a variation of the inverting amplifier is the unity gain buffer where you can have 100% feedback from the output to the input. With that you get very high input resistance and very low output resistance. They can be used for isolation in buffer stages and that is another circuit. The gain in that case is only unity. Even if it is unity it has got other characteristics and it is very, very useful. Three different circuits were discussed and the circuits were also demonstrated to you. We will discuss about the rest of the mathematical operations that can be performed like the summing amplifier, the difference amplifier, the integration circuit, the differentiation circuit, etc in the next lecture. Thank you!