Basic electronics
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Lecture- 22

Four Types of Feed Back

Hello everybody! In our series of lectures on basic electronics learning by doing we will move on to the next. Before we do that as usual we will recapitulate what we discussed in the previous lecture. You might recall as you see on the screen we discussed about the basic concepts of negative feedback in amplifiers and how there could be four different types of negative feedback circuits that we can get depending up on what we sense at the output and what we give at the input.

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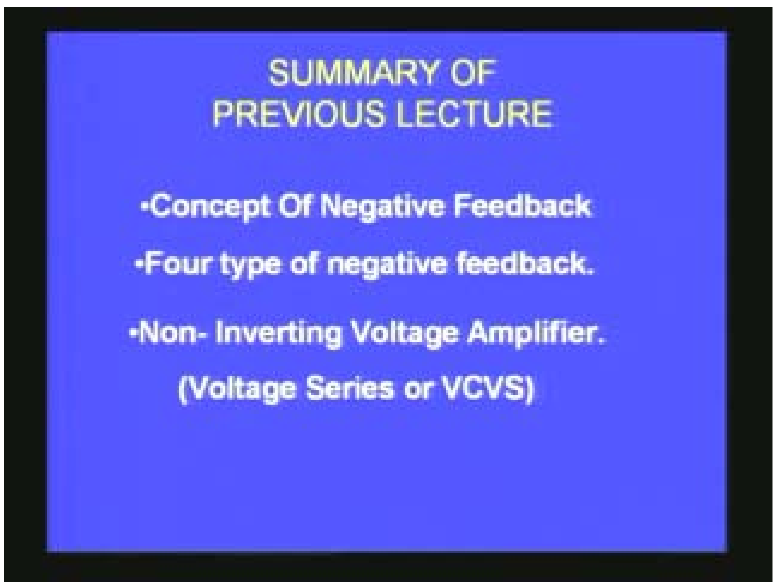

For example you can sense the voltage and give it as a voltage at the input or you can sense voltage and give it as a fed back current at the input stage, etc. So four different types of negative feedback can be constructed and these four different types of circuits will lead to four different characteristics depending on the output and input impedances. We discussed all these four types of negative feedback and then we took one typical example of one of the feedback circuit which is a non-inverting voltage amplifier where the output voltage is sensed and given as voltage in series with the input and the effect of that as you might recall is to increase the input impedance and decrease the output impedance so that it becomes much closer to an ideal voltage amplifier. An ideal voltage amplifier should have infinite resistance at the input and it should have zero resistance at the output so that you can drive different type of loads. It is also called voltage series feedback or voltage controlled voltage source circuit. This is what we discussed in the previous lecture.

In the present lecture we will move on to the next type of a feedback circuit.

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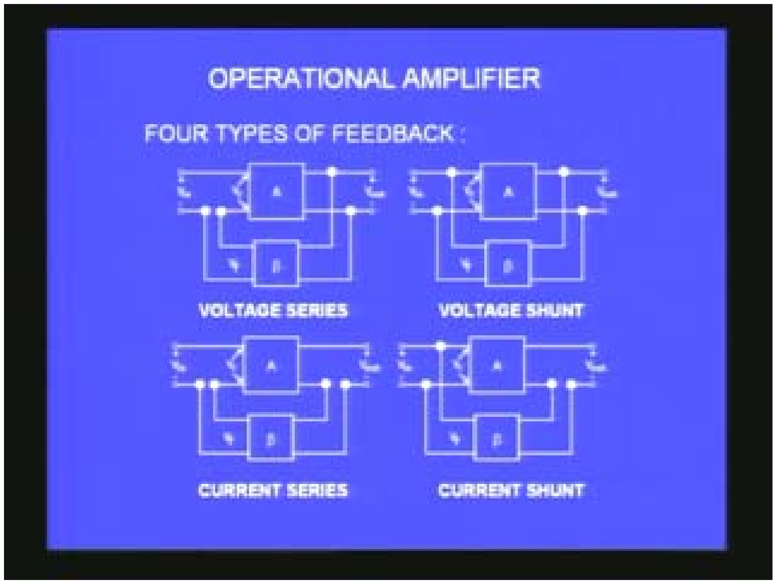

O the screen four different types of feed back circuits again are shown for clarity. You might recall we have done that in the last lecture also where voltage is sensed and given as voltage at the input, voltage sensed and given as voltage in the shunt form, currents sensed in series at the output and given as voltage at the input and current is sensed and given as a shunt at the input. These are the four different circuits and now what we are going to see is the second type where we sense voltage at the output in parallel and at the input also they give it in shunt in parallel.

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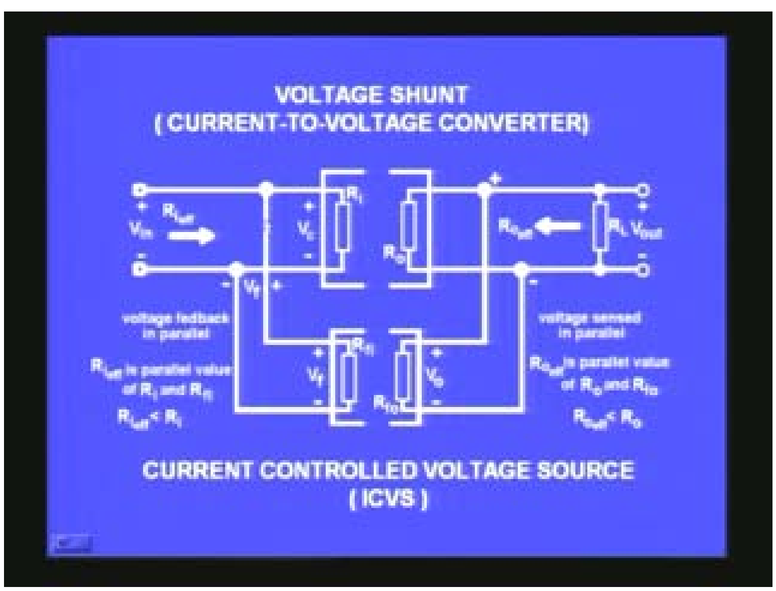

This is the feedback that we are going to discuss now. You know the effect of that on the input and output resistance of your amplifier. This block at the center is the amplifier. What is going to happen? If you look from the output side the output resistance, Thevenin's resistance of amplifier and the output resistance of the feedback network will come in parallel. When I look from here this and this will come in parallel and when two resistors are in parallel what is the effect of that? The effect of that is to reduce the effective resistance and the effect of this feedback arrangement on the output resistance is to decrease the resistance. So that is what is shown here. Voltage is sensed in parallel or output effective is parallel value of R output and R_f output where R_f output is the resistance of the feedback network; Thevenin's resistance as seen from the output side. So R out effective will be less than the previous R_o without feedback. That is the consequence of the feedback and if you look at the input this is also connected in shunt that means in parallel.

If I look from here the effect of that is also to reduce the resistance, effective resistance because voltage fed back in parallel R effective is parallel value of R …… which is the Thevenin's equivalent resistance of amplifier and R_{if} or R_{fi} which is the feedback input resistance of the feedback network. They are coming in parallel. So the input resistance also is effectively reduced. Both the input resistance is reduced and the output resistance is reduced. The effect of output resistance being reduced is to make sure that the output becomes much closer to a voltage source. It becomes a voltage output and it is a voltage source reasonably. The input side resistance increases means the input is not a voltage drive but it is a current drive. Only when the current drive is connected to a very small resistance the current cannot change significantly in the circuit and it is very useful to introduce the current at the input side. What you have at the input is a current because the input resistance is very small and what you get at the output is a voltage because the output resistance is very, very small. Input current is controlling the voltage at the output therefore current controlled voltage source.

Having looked at it we will actually look at one of the typical circuit using an op amp. The circuit is very simple as you can see. All that we have done is connected the output high point to the input high point through a resistor R_2 which is the feedback network. The feedback network is the one single resistor and the entire voltage is connected here. The feedback ratio, the fraction beta is 1 in this case because the entire voltage is given at the input. This actually is effectively a transresistance amplifier because the relationship between the output and the input is a relationship between V_{out} and I_{in} and the dimensions of V_{out} and I_{in} is resistance and this is called a transresistance amplifier. It is also called current controlled voltage source because the input current is the one which is producing the voltage output and it is also called current to voltage converter.

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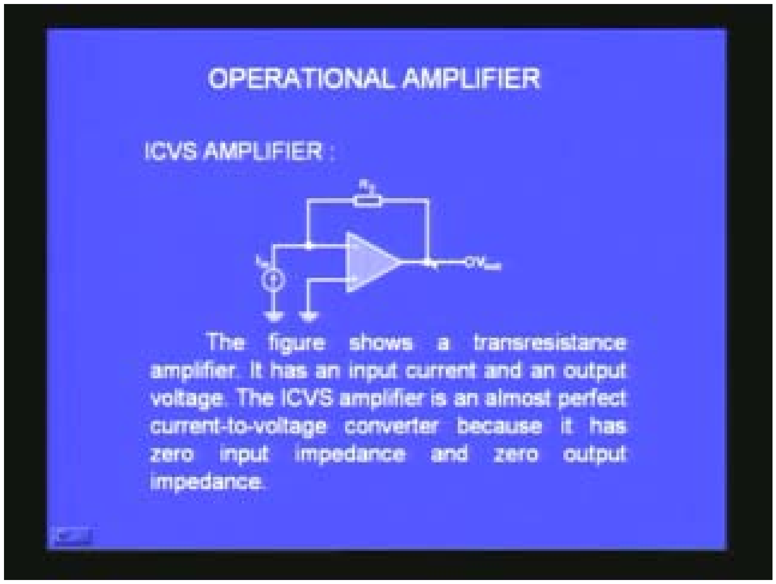

If I have some sensor or something which produces the current the best method I could use is I will connect that current to this type of a circuit so that the output becomes a voltage. The current is converted into voltage. Effectively the amplifier acts as the ideal resistance. How do we get that relationship? That exact relationship is as shown on the figure here.

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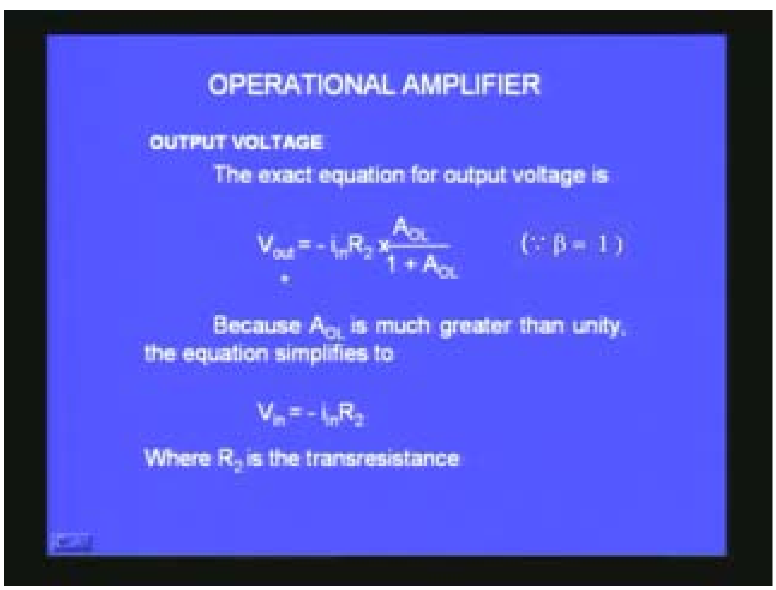

V output is equal to minus i input R_2 multiplied by A_{OL} by 1 plus A_{OL}. The beta factor is missing here because beta is 1 and therefore it is not there. But A_{OL} is a very large quantity, open loop gain about 10 to the power 5 in the case of op amp 741. This ratio is going to be almost 1 and V output is equal to minus i_{in} into R_2. That is the relationship. Why there is a minus? The minus sign shows that there is a phase inversion. The output voltage is negative. The input current is a source; you provide a current source then you get a negative voltage. If you provide a current sink at the input you will get a plus voltage. So there is a phase inversion at the output because of this and R_2 is the feedback resistance in the circuit.

You would not have understood how I obtained the relationship directly. It may be much easier to look at it in a slightly different way. The same circuit can be understood in a much simpler way.

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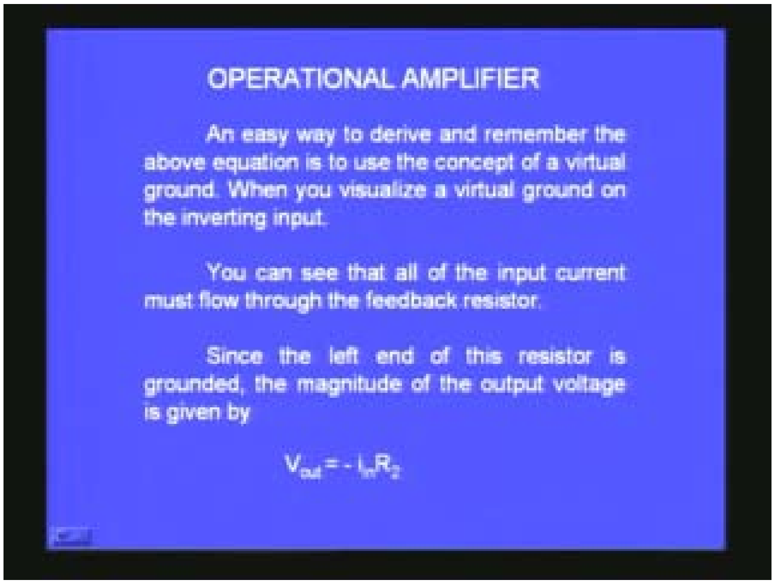

For that we have to realize the concept of virtual …… or virtual ground at the inverting input. We will try to understand the concept of the virtual ground. To understand that we should understand the transfer characteristics of an op amp. This graph that you see on the screen is a typical transfer characteristics of op amp like a 741. What do you see here? On the x-axis you have voltage input. On to the right it is + V_{in} on to the left it is -V_{in}. Similarly the y coordinate corresponds to the output voltage and above we have +V output and below you have the -V output from the origin.

If I now take an op amp, typical op amp, start applying voltage from very large negative values keep on decreasing the input voltage from -10 volts, 15 volts and then keep on going till it becomes +10 volts input what will be the output for an op amp? That is what you should worry about. That is what the transfer characteristic is and the yellow line shown here corresponds to the behavior of the op amp. I will explain to you how? If I give different voltages at the input, negative voltages the output will become -V_{cc}; -15 volts for all the negative voltages beyond some limit, threshold. Similarly on the plus side beyond certain threshold whatever positive voltage I give will result in the +V_{cc} 15 volts.

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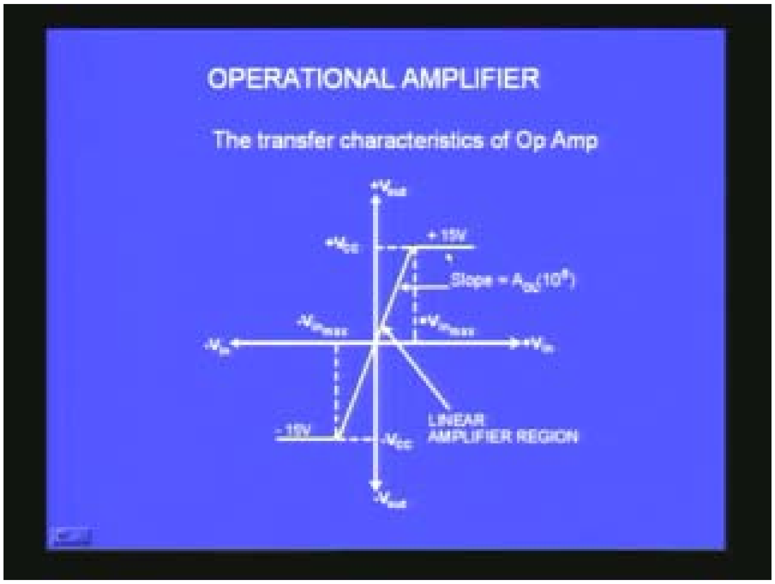

Because you have the open loop gain this is without feedback. The open loop gain here is 10 to the power of 5. Whatever voltage you give I multiply by 10 to the power of 5. If it comes larger than the power supply voltage with which we have energized your circuit then the output will saturate at +15 volts because no amplifier can amplify more than the power supply voltage that you have supplied. Here the power supply voltage is +15 and -15. The maximum voltage which will show a normal amplifier behavior is given by 15 volts divided by 10 power 5 volts at the input. That's what I have shown in the next thing.

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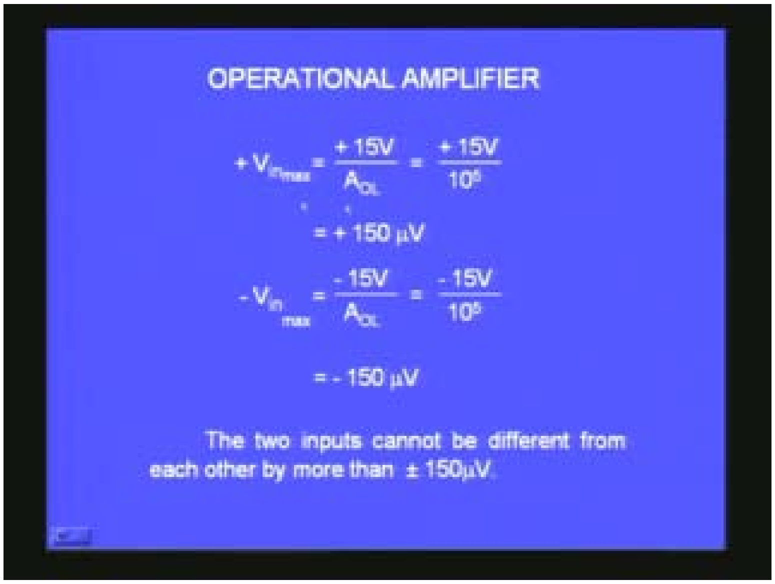

What is the maximum input voltage that can be connected between the two terminals of an op amp? On the plus side that will be equal to, at the maximum, you can get 15 volts divided by the open loop gain. That will give you the maximum voltage. In a typical case where we have taken ……… +15 volts is a power supply voltage and 10 to the power of 5 is an open loop gain. 15 by 10 to the power of 5 or I add two zeros on both numerator and denominator it can become 150 micro volt. The maximum input voltage up to which the amplifier will behave as a linear amplifier with a linear output input relationship is 150 micro volts on the plus side. In a similar way you can identify the corresponding minimum voltage on the negative side is also -150 microvolt. The two inputs of an op amp cannot be different from each other by more than plus or minus 150 microvolt. This is a very important concept which will help you to understand many of the principles of working of the circuit. At any time when an amplifier is considered for using op amp the two inputs cannot be differing from each other by more than plus or minus 150 microvolt. 150 microvolt is such a very small value that in principle you can use it as a thumb rule that in any amplifier using op amps that two inputs should be almost at the same voltage level. This is a very important concept which will help us to understand many of the things. That is what is shown here.

This V^+ on the input side and the V^- on the input side they are about 150 microvolt on either side and only between them there is a straight line and the slope of the straight line is nothing but the open loop gain. In this case typically it is 10 to the power 5. Beyond that 150 microvolt the output saturates. At +15 volts whatever input voltage you apply it cannot be multiplied by the 10 to the power of 5 because if you multiply by 10 to the power of 5 you can get a much larger number and such high voltages cannot be generated because the applied voltage itself is +15. It will saturate at +15. Similarly on the negative side -15. With this concept in background you can get the two important concepts with reference to understanding the operational amplifier circuits.

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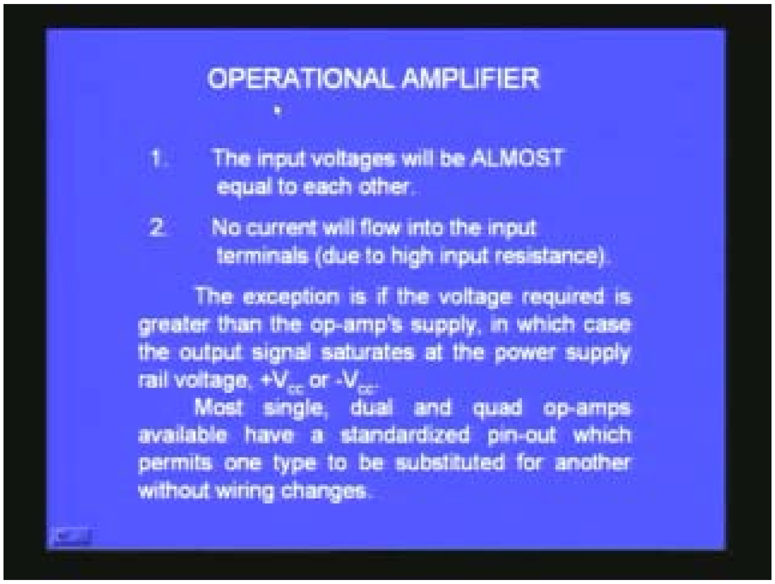

They are the two input voltages will almost will be equal to each other within plus or minus approximately 150 microvolt. The second important point is no current will flow into the input terminal ideally. This is because in general the operational amplifier input resistance is very large and there should be a finite current because the input stage, we have already discussed, is nothing but the differential amplifier and the bases of the two transistors which perform the long tail pair will be the input stage of any op amp. There should be a finite base current for a differential amplifier to work. Even though it is a finite current we know that the finite current is very, very small because it is a base current and in all practical purposes we can assume that to be too small compared to the normal current that we will be handling in such amplifiers and it is reasonably safe to say no current will flow into the input terminal even though we remember that there will be a very, very small finite current which is called the input bias current which is required to be sent into the base of the two differential amplifiers.

Having understood this concept let us look at the circuit once more. Here is the same circuit which is called the current to voltage converter.

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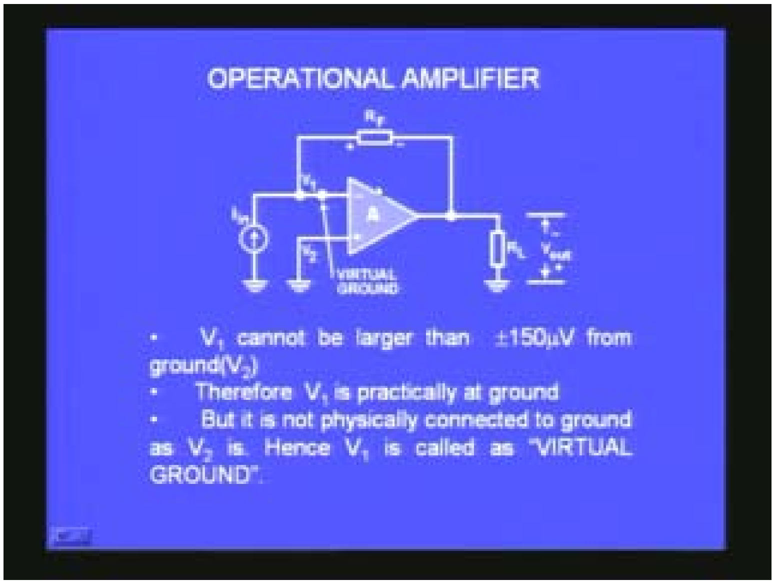

We want to understand how the output is given by minus i_{in} into R_f or R_2. One of the input terminals V_2 is connected to ground. If this is connected to ground then without looking at the amplifier you can say corresponding other input V_1 should also be very close to ground with in plus or minus 150 microvolt. V_1 cannot be different from V_2 beyond 150 microvolt on the either side. If this is ground for all practical purposes this also can be taken to be very close to ground or almost ground. This point is not directly connected to the ground but still it is very close to the ground voltage as long as this terminal is connected to ground the V_2. This point is virtually at ground potential and that's why this point is called virtual ground. You know virtual images in mirrors and lenses. The image which cannot be caught on a screen is called virtual. It looks almost real, the image that you will see in a mirror but then it is virtual. You know that you are not standing behind the wall where the image is formed and the same way even though it is very close to the ground potential it is not directly connected to ground. This is close to ground potential because the other terminal is at ground potential. This becomes a virtual ground or virtual head point. So if you realize that many of the understanding of operational amplifier circuit become rather simple.

I am now sending a current into this virtual ground point and because there could not be any current through the op amp, we have seen the bias current is going to be very, very small. Therefore the entire current which comes to this node will have to flow only through the feedback resistance. Now what is the voltage at the output? The voltage at the output is the voltage that you measure by using a voltmeter between the output point and the ground but the output point and this point is also equal because this point is a virtual ground. If you measure the voltmeter from this point to the ground it is the same as measuring this point with reference to this point. The voltage here is nothing but the I flowing through R_f. That I is the i_{in} flowing through R_f which is the feedback resistor. That is the voltage that you will get here and it is negative. Why is it negative? Because current is going from this end to the other end. Whenever a current is entering a point that point should be negative; whenever a current leaves the point that point should be a positive point. In this case the current is coming towards this end. This end is lower in potential compared to this potential and this is zero. Therefore this has to be minus. Output is given as V output is equal to minus i_{in} into R_f in this case where R_f is the feedback resistor. The output voltage is equal to minus i_{in} into R_2 or R_f as the case may be and this becomes much easier to understand because of the application of the concept of the virtual ground.

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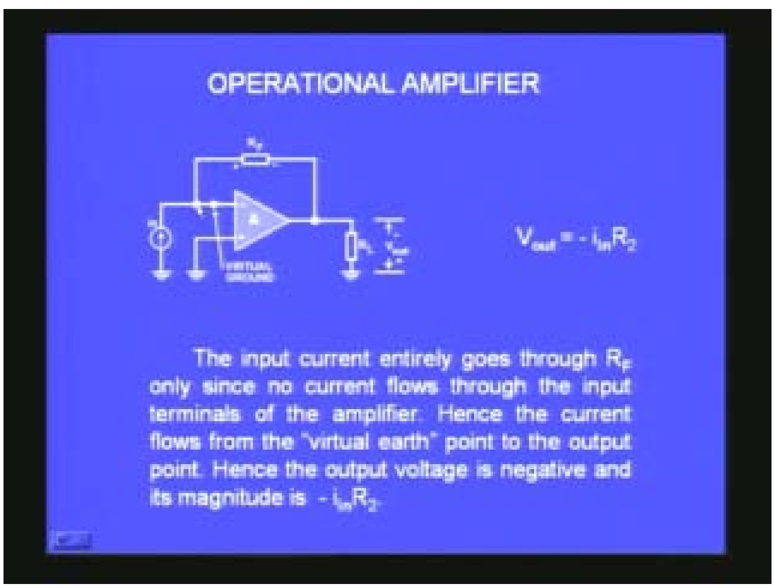

What happens to the closed-loop input output impedances? We have already seen that the effect of the feedback is to reduce output impedance; that is also to reduce the input impedance.

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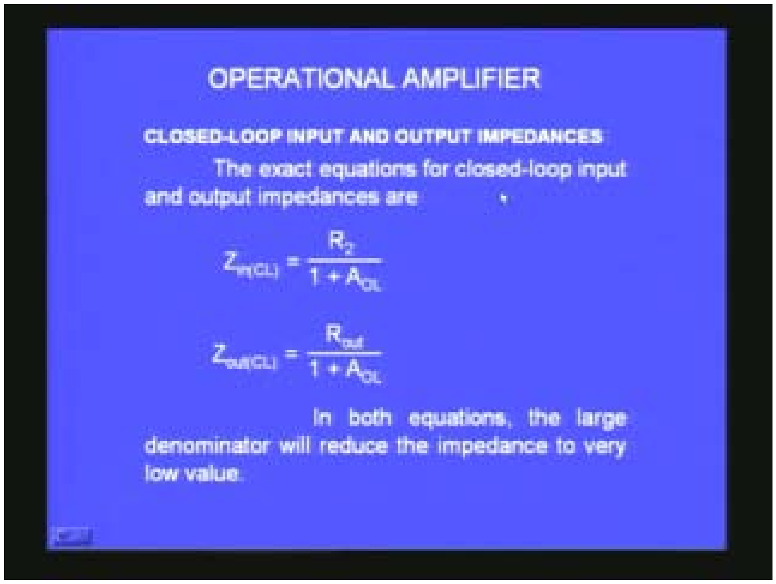

Z_{in} with the closed loop, CL means closed loop; Z_{in} with the closed loop configuration is given by R_2 divided by 1 plus A_{OL}. The beta is 1 here; 1 plus A beta is a factor, loop gain. Beta is 1; therefore it is 1 plus A_{OL} and because A_{OL} is very large R_2 by A_{OL} is going to be very, very small. The input resistance is going to be very, very small much smaller than R_2. Similarly the output resistance with closed loop configuration is R output without feedback divided by 1 plus A_{OL}. Again this is going to be a very, very small value at the output also. Both the input and output impedances will be reduced to a very low value by this feedback. Let us take an example.

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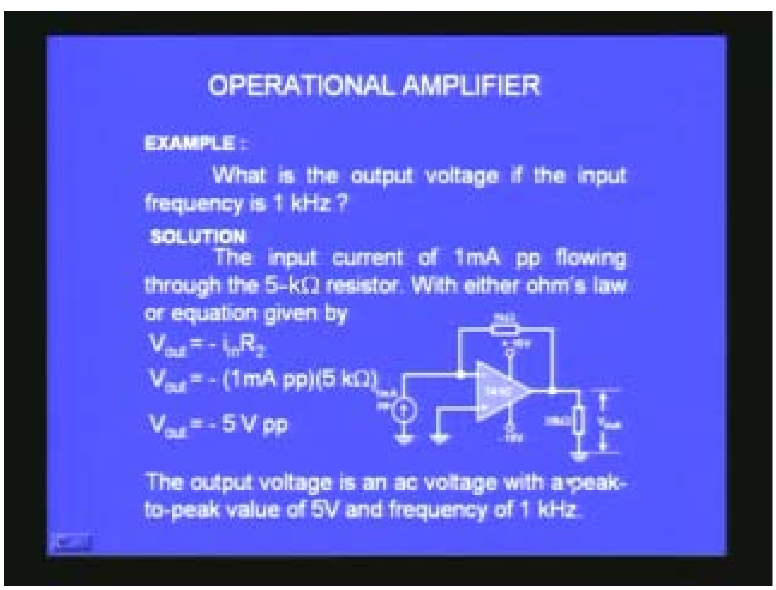

What is the output voltage if the input frequency is 1 kilo hertz? Even though we have not discussed that the input can be an ac because it is an amplifier it should have a finite bandwidth and you can apply not necessarily dc current but ac current also. What is the output voltage if the frequency of the input is 1 kilo hertz? You are applying 1 milliampere peak to peak sinusoidal current value that is connected here. What happens to the voltage? The input current of 1 milliampere peak to peak is flowing through the 5 kilo ohm resistor. So we can apply simple Ohms law. V output is equal to minus i_{in} intoR_2. In this case i_{in} is 1 milliampere peak to peak multiplied by 5 kilo ohm and that gives you 5 volt. The kilo and milli will go away. You will be left with -5 volts peak to peak. This current voltage converter will convert 1 milliampere peak to peak current to a 5 volt peak to peak voltage. But again there will be an inversion. The negative sign shows the inversion. If the current is increasing the voltage will be decreasing and if the current is decreasing the voltage will be increasing. You get a 1 kilo hertz output here.

Having seen that let us quickly see a simulation of the circuit. You can see on the screen a bread board. You have a dual power supply here plus, minus and ground with 15 volts. You have also a current source and on this side you have a digital voltmeter. Now you have to wire the circuit. You have the gate, you have the op amp and resistors. Now let us arrange for the building of the circuit. The I_c is put there; the resistor is put there and the different wirings are done corresponding to the circuit and a circuit is shown here. It is a very simple circuit two inputs and one feedback resistor between the output and input. That's all.

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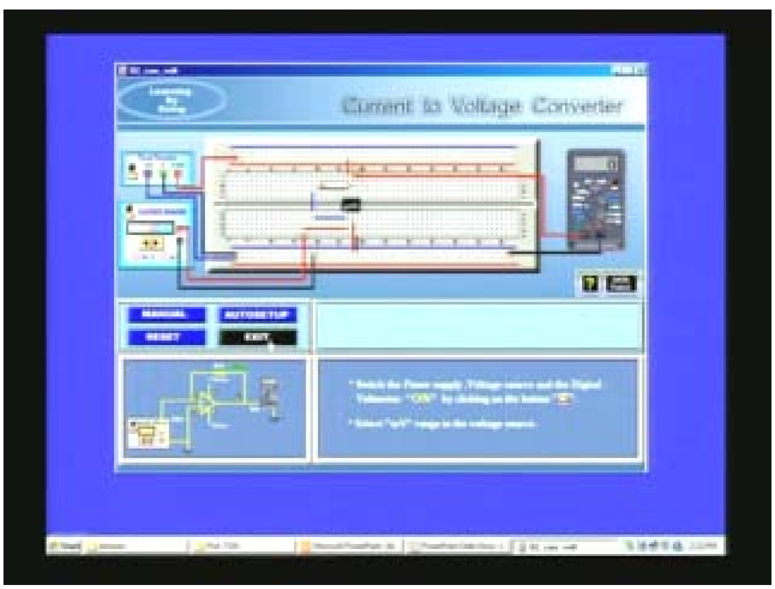

The pin number 2 is connected to pin number 6. That is the feedback loop and the value of the resistor is 10 kilo ohms typically in this case. You have the voltmeter here; you have the dual supply. We will switch on the dual power supply, the current source and the voltmeter. Now I can select either milliamperes or microamperes. Let me select microamperes and I can increase the current.

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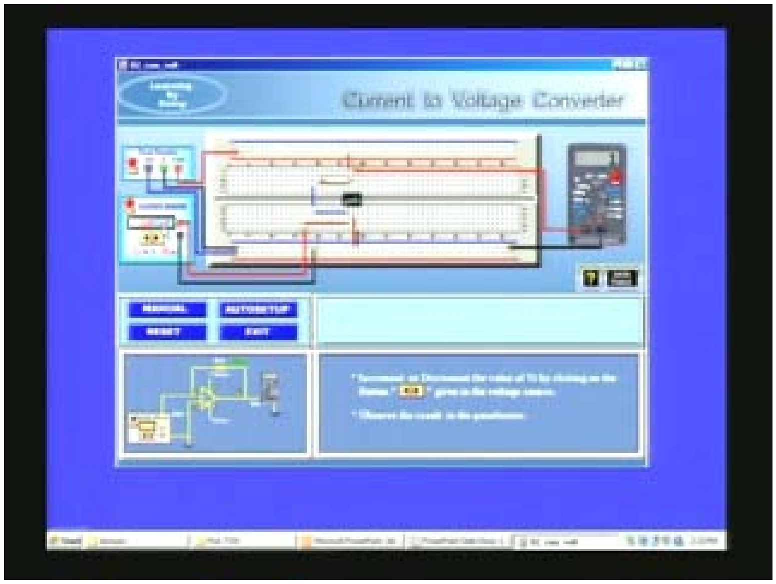

For example input is 100 microampere; this let us say. Then this 100 microamperes going through 10 kilo ohm will give me 1000 millivolt or 1 volt and that is what you see here. This is 1 volt because 10 kilo ohm resistor is multiplied by 100 microampere. If I increase the value to 200 microampere output becomes 2 volts. I can apply different currents and see the output in each case. This becomes a very simple current to voltage converter. What is the use of such current to voltage converter? The applications of these current to voltage converters are many.

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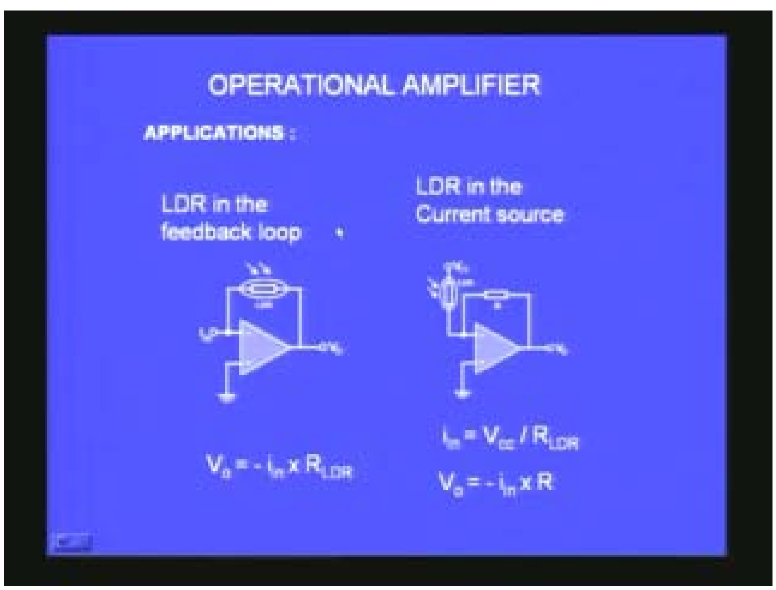

I have taken two typical examples which I would like to show to you all later on. Here what I have done is it is the same circuit; the current voltage converter basic circuit. But instead of the feedback resistor R_2 I have put a LDR, light dependent resistor. If I give a constant current i_{in} now and vary the light intensity here falling on the LDR due to the light intensity the resistance changes because it is a photo conductive cell light dependent resistor and when the resistance changes the output voltage changes because the relationship is V output is equal to minus i_{in} into R_{LDR}. Here R_{LDR} is the one which is proportional to the intensity of light falling on that. Then the V output is equal to minus i_{in} into R_{LDR} can be used to measure the intensity of light falling on the LDR. It becomes a lux meter to find out the light intensity.

There is another way in which the same circuit can be designed. For that what we do is we use the LDR in the current source path. That means you apply a voltage; usually LDR's have got very high resistance in darkness and very low resistance when it is fully bright. When it is a large resistance along with a large voltage source you will get an ideal current source, reasonably close to an ideal current source. We can try to apply a voltage to an LDR in dark so that the resistance is high, voltage can be anything and because of the large resistance of the LDR you get an almost good current source. So that is what is exploited here. The current i_{in} is now modulated according to the intensity of light falling on it. If the intensity is very high the resistance of LDR will become very small and the current will increase. If you keep it in dark then resistance is more. Therefore current will become less and output voltage will also become less. This is easy to understand I hope; these two models. There is also another circuit which you can build; same corresponding to the current to voltage converter and that is by the use of photo diode.

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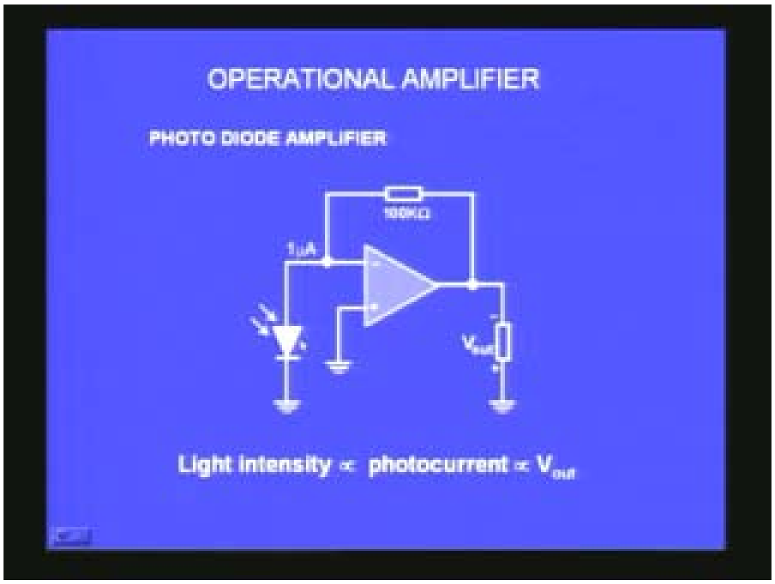

You can use a photo diode amplifier; connect the photo diode at the input stage. Photo diode basically is a current source. When light intensity comes some electrons are excited to the conduction bandwidth. This becomes closer to a current source and when I use the photo diode I should try to use a current to voltage converter rather than a simple voltage amplifier. This an essential point. Depending upon what you want to convert from one stage, the input stage to the output stage you must choose proper amplifier whether it is a transconductance amplifier, transresistance amplifier, voltage amplifier or current amplifier. In this case light intensity is proportional to photo current and that should be proportional to V output. It is a very simple circuit application of operational amplifier as a current to voltage converter.

There is also a fourth application which I would like to indicate to you and that is to construct an electronic ohm meter. An ohm meter measures the resistance.

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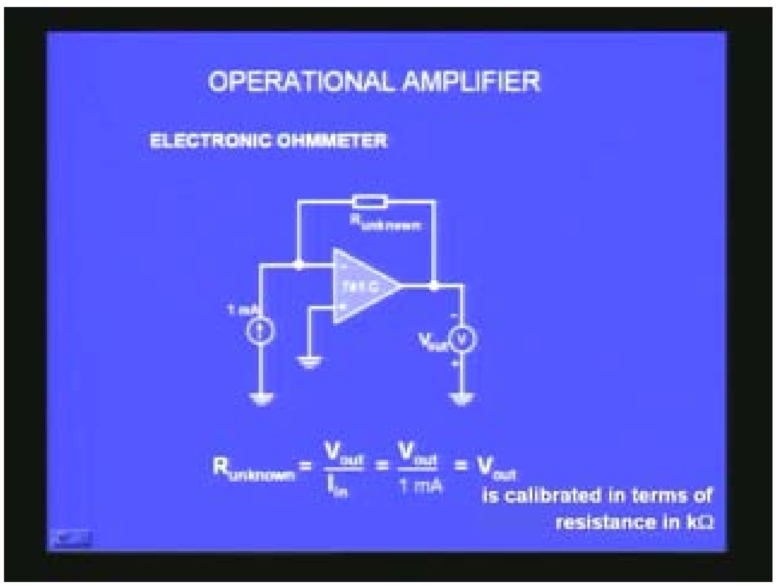

We will try to measure the unknown resistance using this circuit of current to voltage converter. If I have an unknown resistance all that I have to do is wire the current to voltage converter and replace the feedback resistor with the R unknown; the resistance given whose value of resistance is to be found. You put the unknown resistance in the feedback loop and give your input current and measure the output. The R unknown you can see is minus V output divided by i input and if I take a typical example of 1 milliampere current V output by 1 milliampere is the unknown resistance. If I take the corresponding value for the milliamps then it comes to the numerator. You will get kilo ohms. The magnitude of the output voltage itself expressed in kilo ohms gives you the value of the unknown resistors. This is one of the simple examples of application of current to voltage converter. I will quickly go to the work table and show you these three examples. We will perform the experiment and get the result. What we have on the table is the familiar dual supply. I am sure all of you are now familiar with this; we have already seen the earlier experiments. You have the bread board. In the bread board there is an op amp and there is one feedback resistor.

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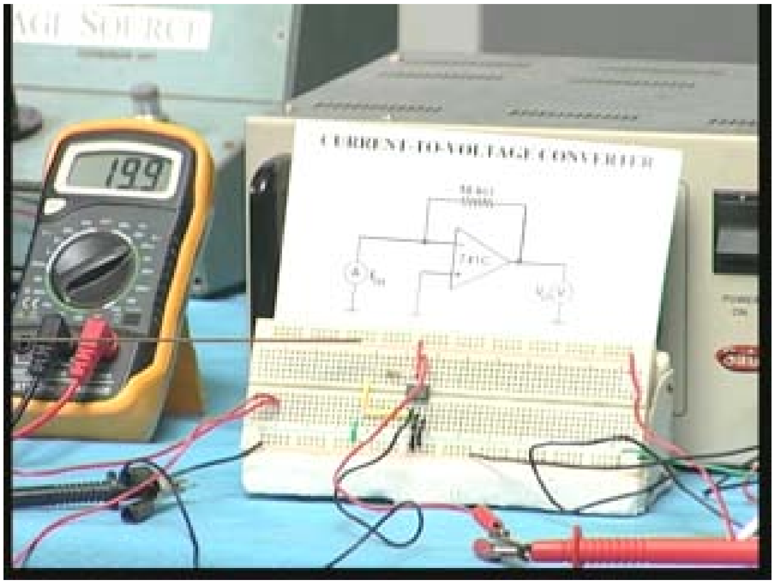

The wiring is done and the output voltage is measured using this digital voltmeter you find here. This digital volt meter which is selected for the voltage range dc voltage will measure output voltage. The circuit of whatever that we have wired on the bread board is shown on the diagram above. It is simple. You have a current source here; you connect a feedback resistor of 10 kilo ohm and you measure the output voltage using a digital voltmeter. It is a same circuit which is wired here and what I have here is a current source. It is a commercial current source.

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But one can also do with simple circuits in the lab to generate constant currents and this is capable of producing currents to very large ranges starting from nano amperes to several hundred milliamperes by using the dials. Right now I have kept it in stand by mode. The current source is connected to the input and that current flow into the pin number 2 of the amplifier and the output is monitored here. To measure the current I have introduced a current meter another multimeter.

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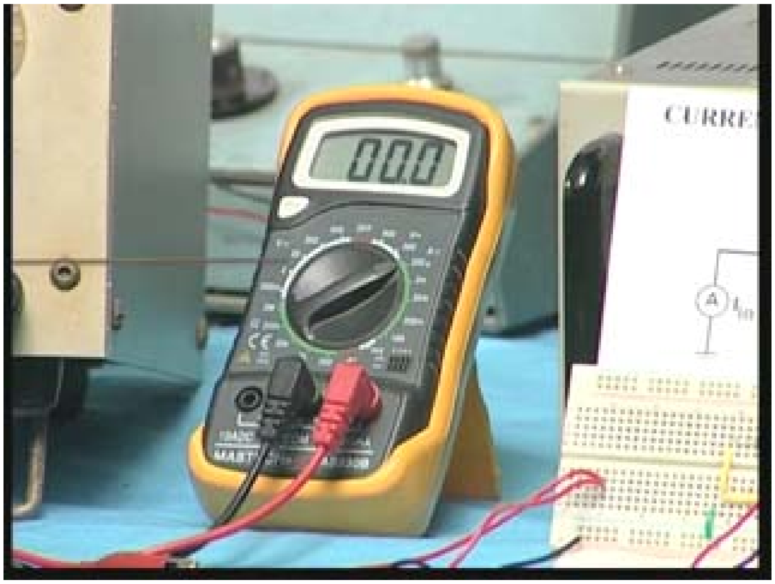

I have selected 200 microampere range here and what it measures is the input current. This comes in series with the current source and then it is applied to pin number 2. This black wire is connected to the pin number 2. These two are connected in series at the input. This is the current source. This is the current meter which is measuring the magnitude of the current and the voltage is measured using the output voltmeter. Let us try to apply the current. I don't know whether you are able to see the dial. It is 2 here; it is 0 here and this is the dot decimal and therefore 20.0 microamperes. So it is 20 microamperes and that is the current and you can see here it is in 200 microampere range and it reads 20 microampere. 20 is the reading here.

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This and this are perfectly matching. You are applying 20 microamperes and you are also reading 20 microamperes in the multimeter and that is being applied here. You have a 10K resistor. So multiply 20 microampere by 10K. That will be 200 millivolt. The K and the micro will make it milli. So 200 millivolt should be the value of the voltage. I have to switch on the dual supply and if you observe the multimeter, it reads 206 millivolt.

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So this is a very neat presentation; you can see that. Now what I am going to do is I am going to increase the current. From 20 let me increase to 30 micro amperes. You can see this current meter reads 29.9 which is 30 microampere; close to that and correspondingly if you now observe the output voltage it will be very close to 300 millivolt.

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Now I keep moving to another current 40 microamperes; 39.8 is the reading here.

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You multiply by 10K. There it is about 0.406 millivolt. You can see this current is converted into voltage. Now if I change the range for example I will bring this to zero and have 1 or 2 micro ampere. For example I have kept 2 microampere here. 2 microamperes multiplied by 10K should give me 20 millivolt. What you get on the millivolt range is about 21.4. There is a slight variation.

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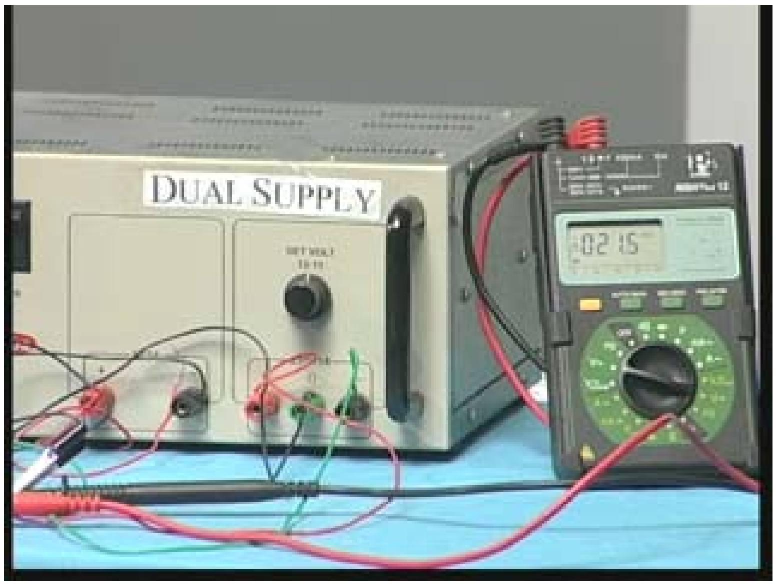

It is not perfectly 20 because this 10K resistor is what I read from the color code. But the actual resistance can be slightly different from 10K; may be 9 or 11. There is a 10% tolerance and it can be slightly different from 10K. If I want to change the conversion factor, the conversion factor is basically the 10 kilo ohm that is the transresistance amplifier. If I change it to 100 kilo ohm here, the same current will be multiplied by 100K and you will get the corresponding output voltage here. So you can increase or decrease this resistance here and get a voltage proportionally at the output. Therefore it is a very, very simple and useful circuit especially when you have number of different sensors. I also told you that we will show you a simple application circuit using LDR. Now you can see the two circuits which I already showed you on the computer screen. There is one current to voltage converter where the feedback resistor is now replaced by a light dependent resistor, the LDR.

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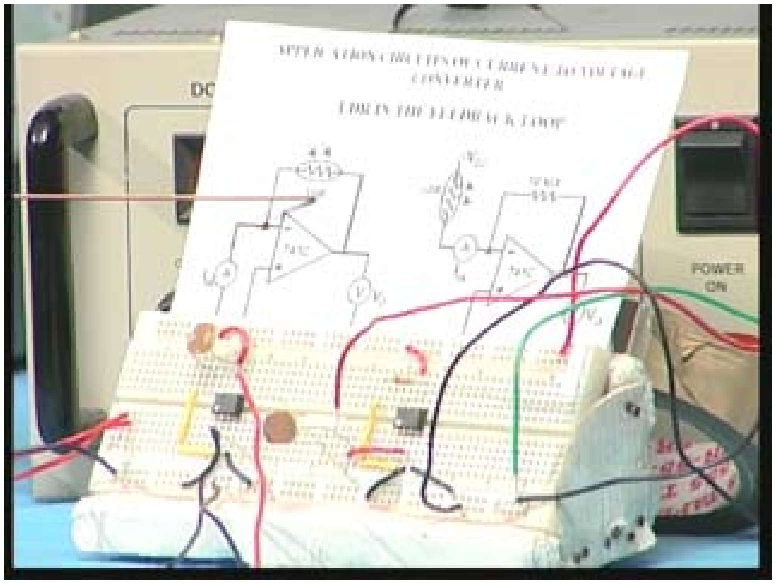

The corresponding circuit is here. You can see the op amp; you see the LDR here and that is in the feedback network and the current source is still here and current meter is also here and output is monitored by the voltmeter here. Everything is same except that in the feedback instead of the normal resistor I have replaced by a light dependent resistor. Now let me apply the current. The current here is about 10 microamperes as read from the multimeter here. It is 10 microamperes and here also it is one zero point; so 10 microamperes and now please observe what is the output voltage you are getting? You are getting something around 33.4 millivolts; around 33 or so. This is corresponding to the current that is generated due to the LDR present here.

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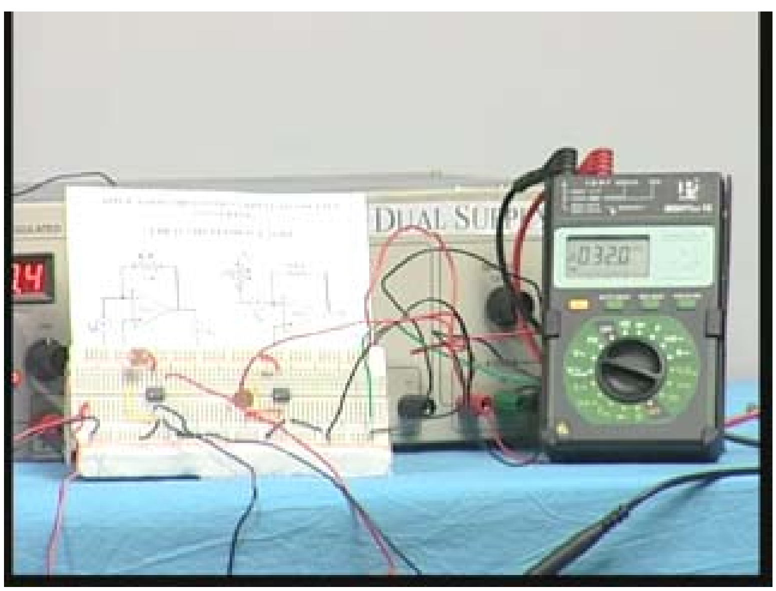

If I close the LDR using a small cardboard the resistance will increase and the current to voltage converter output also will increase. Because R increases i into R should also increase. Keep observing the multimeter reading as I bring the cardboard and hide the LDR. Now I have closed the LDR. The voltage is somewhere around 180 or so.

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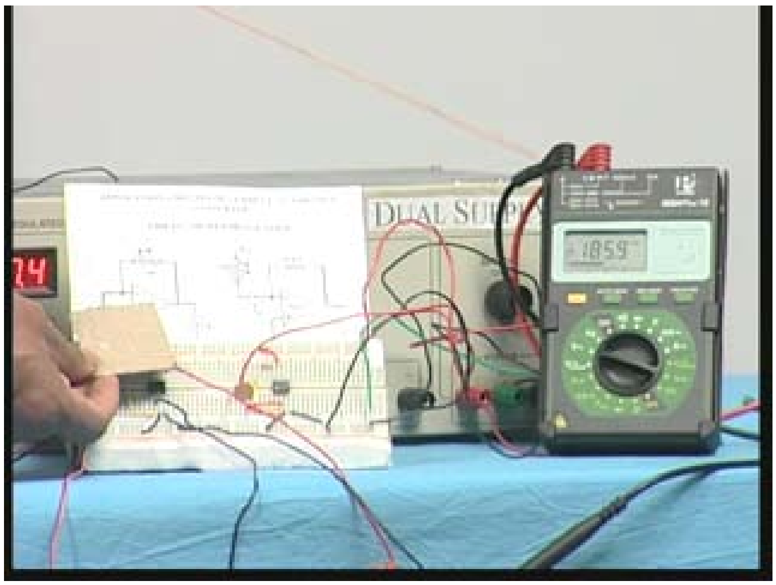

When I remove it again it comes to around 30 or something.

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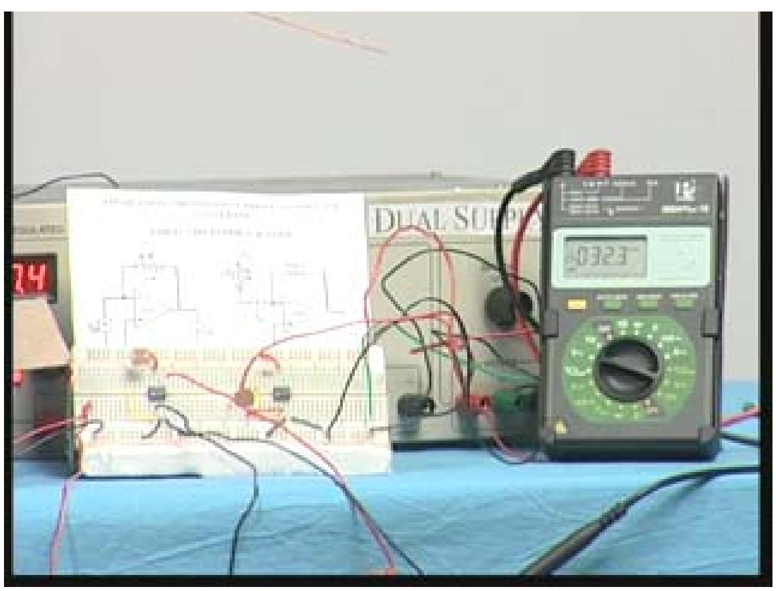

When I close it completely it can go to very high values 200, 300 millivolt. That is because when the light is stopped from the LDR the resistance of the LDR increases. This can be used to detect light intensity. When I close the LDR the resistance increases, the output voltage increases. When I remove the lid then the LDR is exposed to lot of light and therefore resistance is small and the voltage is also small.

There is also another way to get the circuit and that is instead of putting it in the feedback I am using the LDR itself as a current source. That circuit is shown in the next part of the bread board. You see another circuit here. You have the LDR now connected to some 5 volts supply.

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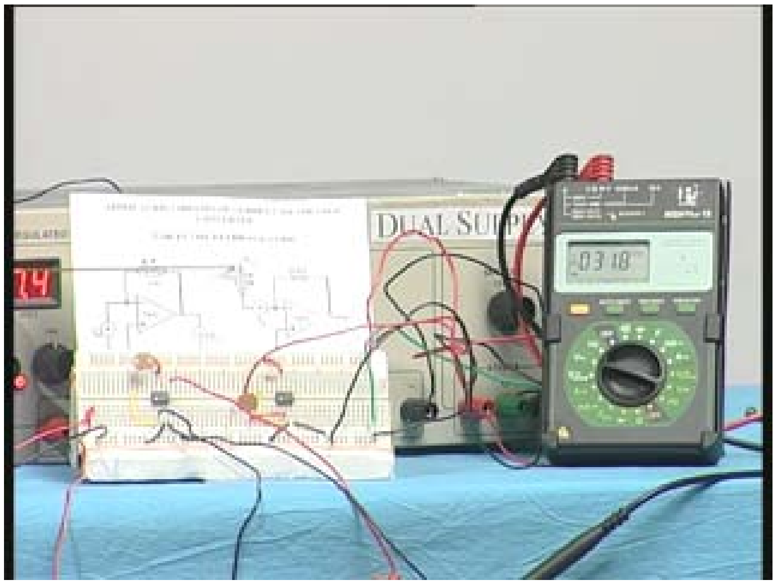

The 5 volt supply with LDR becomes a current source in effect and that is connected at the input and I have put a fixed resistor of about 10 kilo ohm in the feedback here which you can see. This is the op amp; this is the 10 kilo ohm resistor. This LDR is here and one end of the LDR is connected to the op amp. The other end is connected to +5 volts and therefore it is energized with 5 volts. Now I will quickly change the multimeter from here to the next circuit. Now you can see I have connected the multimeter to the second circuit; at the output of the second circuit in number 6 of the second op amp and the current source is due to this LDR which is now exposed to lot of light and the resistance is very small. You have large current and the voltage here is around 0.538 volts.

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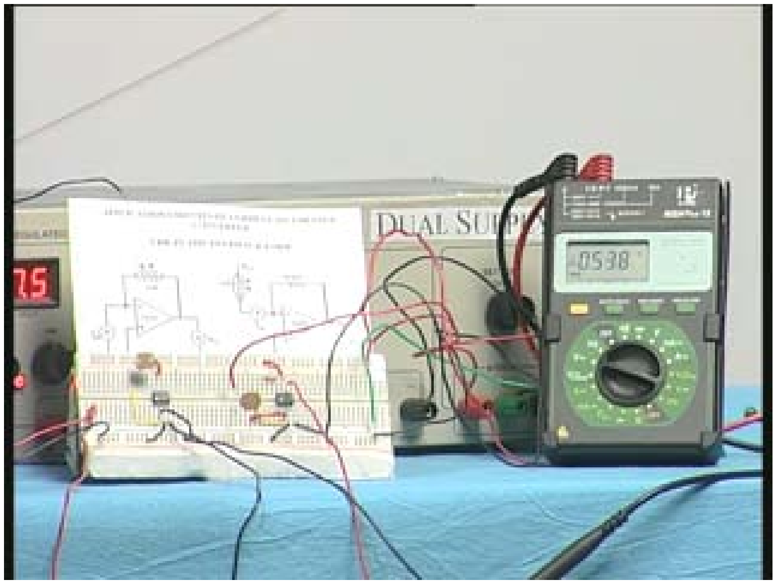

It is in volts. Now if I cover the LDR the resistance will increase, the current will start decreasing. Because it is forming part of the current source when I close that, current will decrease and the output voltage comes to millivolts 147 or something.

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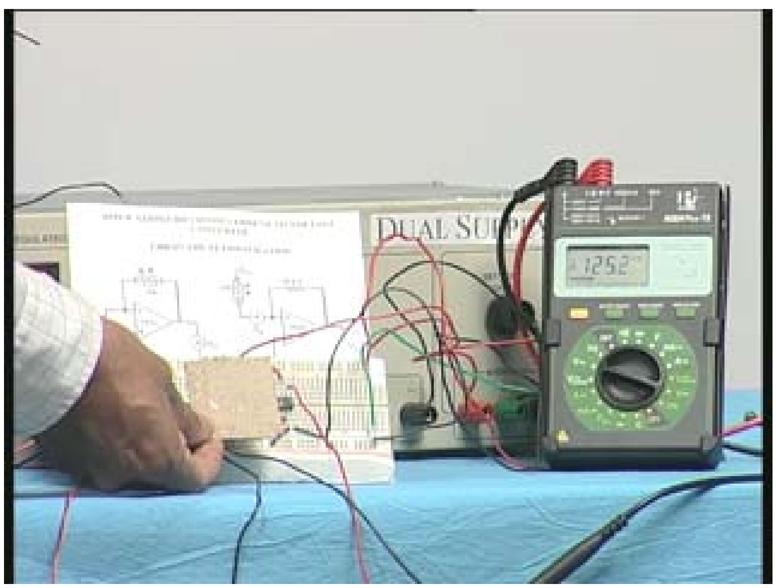

If I remove it again it comes to 0.5 volts or so and when I close it, it comes to few hundred millivolts or so. This also can be used as an optical detector for detecting light intensity. This LDR can be used by making use of the simple current to voltage converter.

We will move on to the next feedback configuration. You can see that here the output is connected in series with the feedback network and it is sensing the current output. It is sensing the current here and it is also given as a voltage here in series at the input.

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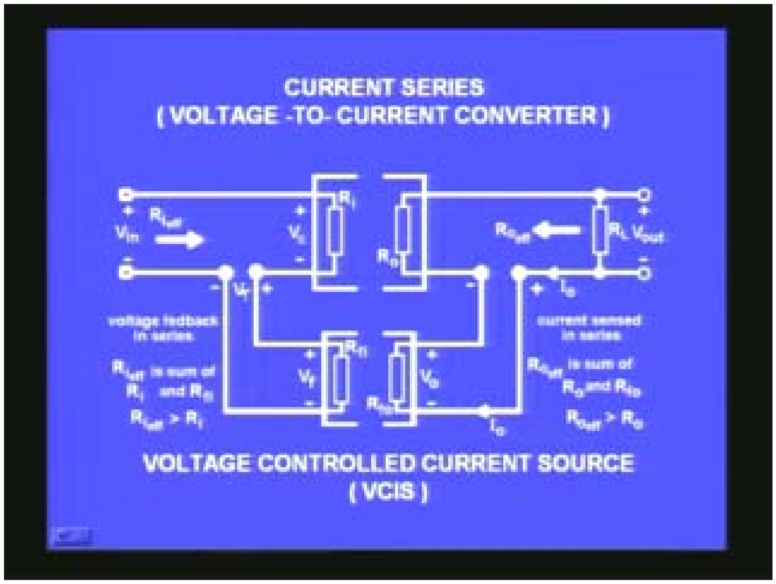

The effect of connecting something in series at the output is to increase the total resistance. Now it is R_0 plus R_{f0} and the effect is to increase the output resistance from this side and the effect of giving voltage in series with the input is basically again to increase the input resistance. The input resistance is also increased the output resistance is also increased by this configuration in this feedback. What is the effect of this? Because the output impedance is increasing then this becomes a current source. It is not a voltage source because only for a current source the output impedance is very, very large. Usually for an ideal current source it is infinity and at the input, the input resistance is increasing. That means input will have to be a voltage. You have a voltage at the input with a large input resistance for the effective amplifier and you have large output impedance corresponding to a current drive at the output and it becomes a voltage to current converter. Input voltage will be converted into a current by this feedback arrangement or it also can be called as a voltage controlled current source, VCIS and now let us try to look at some circuits based on this.

What you see on the screen is a very simple op amp voltage to current converter. This is a negative feedback. You have a R_1 and a R_2. Whatever current that is flowing through R_2 that and R_1 a potential divider and this voltage is applied here in series with the input voltage and this is exactly same as what we discussed a moment ago. What about the input output relationship? You can understand this in a very simple way. Because you are giving the input voltage here, this is V_{in} and this voltage cannot be different from V_{in} by more than plus or minus 150 microvolt at any instant and this voltage will also have to be V_{in} at this point.

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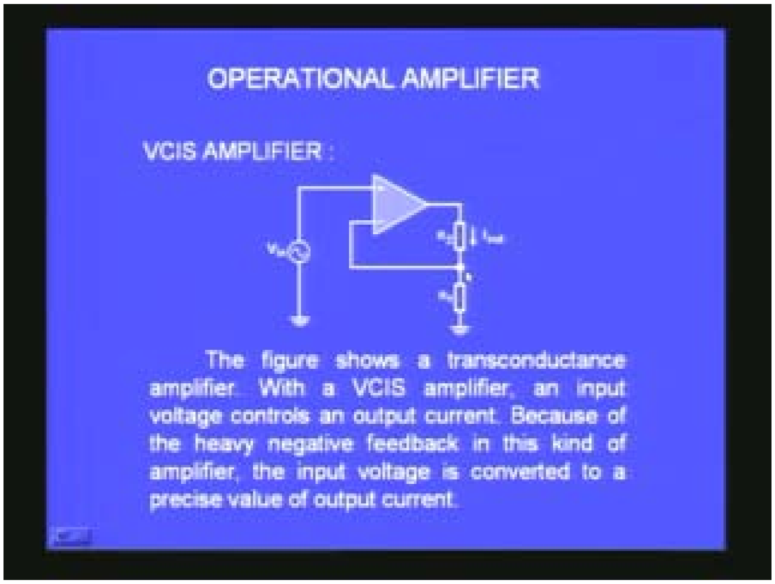

If this is V_{in} this current through that will have to be V_{in} by R_1; voltage divided by resistance is current by Ohm's law. So V_{in} by R_1 is the current and that will have to be the same current which is flowing also from the output of the op amp. Because there is no current which is flowing in this direction all the current will have to flow through this and the relationship is i output is equal to V_{in} divided by R_1. That is a very simple relationship. So i output is equal to V_{in} divided by R_1 and the input output relationship is output by V_{in} is equal to 1 by R_1 from this equation and 1 by R_1 is nothing but conductance.

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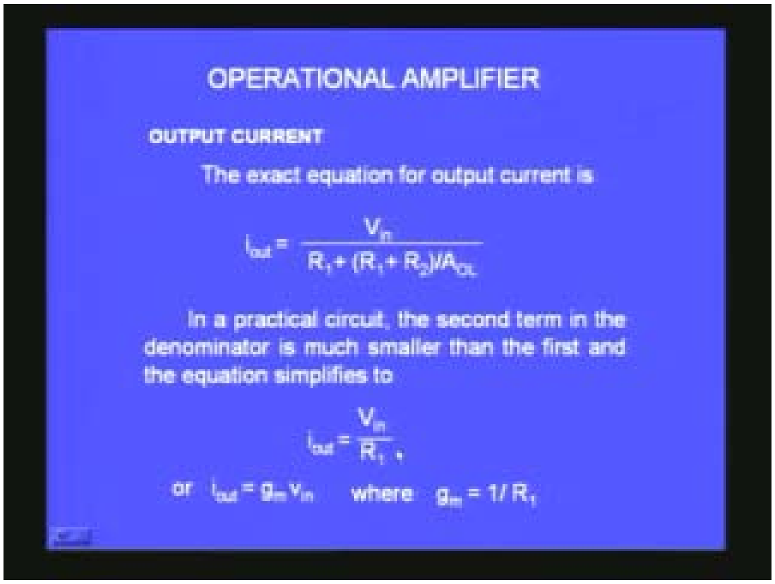

Inverse of resistance is conductance and i output is equal to g_m into V_{in} where g_m is the transconductance and this amplifier is also called transconductance amplifier and in this case g_m is actually 1 by R_1. The exact equation i output is given by V_{in} by R_1 plus R_1 plus R_2 divided by A_{OL} and because A_{OL} is much larger this term can be ignored and what you are left with is only by V_{in} by R_1. This is also a very simple circuit which will provide you with a conversion from voltage to current.

For example I have a thermo couple. If I have a thermo couple it produces a voltage thermo emf corresponding to the temperature difference between the hot and the cold junction. This voltage I want to measure in terms of a current so that I can have a thermometer, electronic thermometer. All that I have do is connect a voltage to current converter and connect a simple current meter, a milliampere or microampere meter as the case may be and when you put the two junctions in two different temperatures that will produce a thermo emf that thermo emf will be converted into corresponding current by a proper choice of R_1 and you get an output current which is proportional to temperature. I can calibrate the current in terms of temperature and then it becomes a very simple inexpensive electronic thermometer. I have given an example here.

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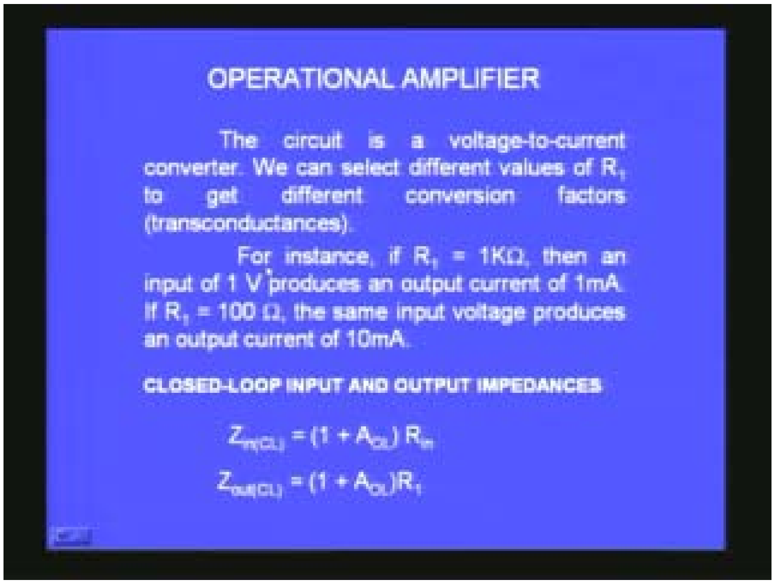

If R_1 is equal to 1 kilo ohm, an input voltage of 1volt will produce a current of 1 volt by 1 kilo ohm. V_{in} by R; R is 1 kilo ohm. That is equal to 1 milliampere. You get a 1 milliampere current at the output and if I have 100 ohms instead of 1K the output current will be 10 times more. It will be 10 times 1 milliampere or 10 milliampere and correspondingly in all the cases the input resistance of the closed loop will be 1 plus A_{OL} times R_i. It increases the input resistance by a factor which is 1 plus A beta and the beta here is also 1; 1 plus A_{OL} into R_{in}. Z output is also 1 plus A_{OL} into R_1. Both the input and output resistance are increased here and that is why it is a voltage to current converter or the transconductance amplifier.

I have got here a small example. What is the output current in the figure? We have used an op amp LM 12 plus or minus 15 volts.

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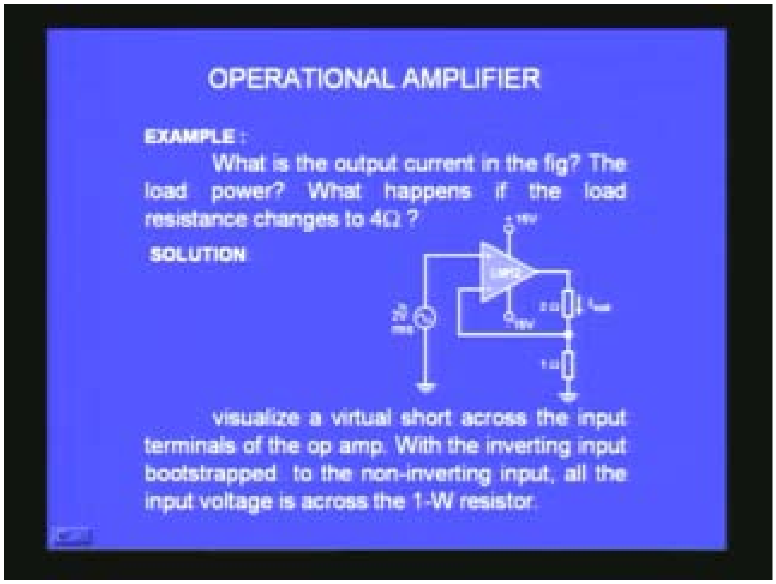

I apply 2 volts rms voltage at the input and I have 2 ohms and 1 ohm in series here and what is the load power? What happens if the load resistance changes to 4 ohms; from 2 ohms to 4 ohms. In principle it should not matter because the current is decided only by the 1 ohm. We will try to see that. 2 volts divided by 1 ohm is equal to 2 amperes. That is the current output.

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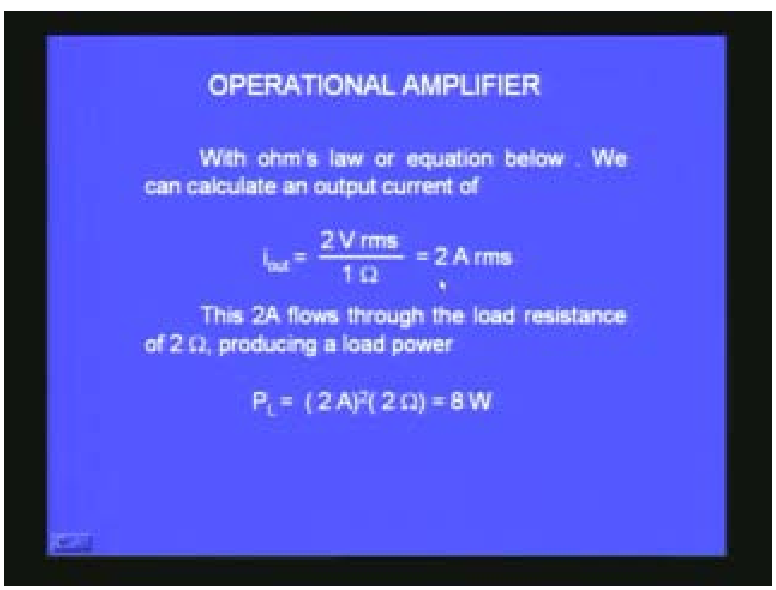

2 amperes will flow through the load resistance 2 ohm producing a load power. i square R; 2 ampere whole square into 2 ohms that is equal to 8 watt. This is the power dissipation of that particular load resistor.

If I make it into 4 ohms the current still will be 2 amperes because the current is decided only by the 1ohm resistor and multiplied by 4 ohm gives me 16 watts.

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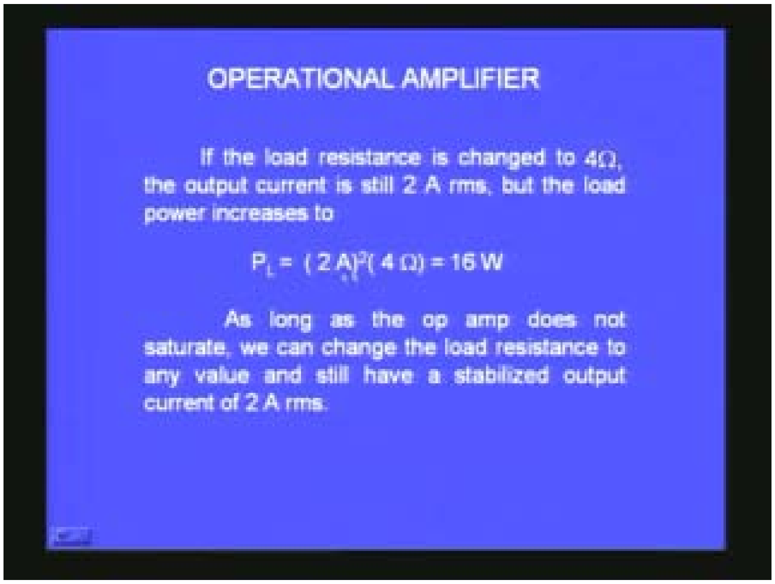

The output power is increased because the value of the resistance is double; the output power is also double. As long as the op amp does not saturate we can change the load resistance to any value with the stabilized current of 2 amperes. This circuit is also very useful in number of applications.

I will show you a simulation of the circuit here. On the screen you have a voltage source; you have a dual supply and multimeter and this is a circuit. Instead of the load I connect the voltmeter itself as the load. Now let me do auto setup. All the IC's are going there and the corresponding wiring is coming out. The dual supply is connected. Now the voltage source is connected to the input and then the multimeter will be connected. Once it is done let us switch on the power supply, multimeter and I give some millivolts. When I give about 100 millivolt this resistance is about 10 kilo ohms. 100 by 10 kilo ohm should give me about 10 volts.

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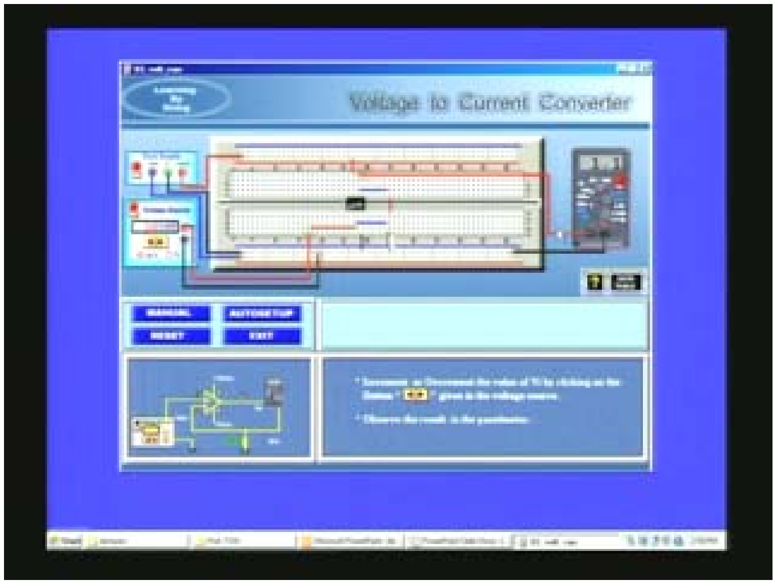

You would find the reading is corresponding to that and I can increase the voltage here and correspondingly the output also changes in a linear fashion. The conversion factor is the 10 kilo ohm resistor that is coming into …?... V_{in} by 10 kilo ohm should be the current that I am getting at the out put.

I will quickly go to the table and show you the demonstration of this voltage to current converter circuit. Here you have the voltage to current converter.

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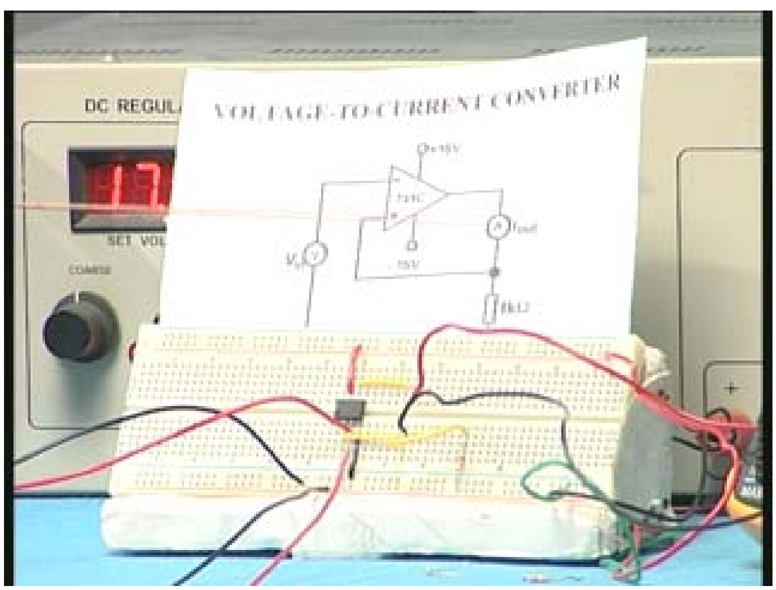

The same circuit is shown here and you can see the op amp here and I have connected 1 kilo ohm resistor and this is the current meter which is connected here and the voltmeter is here. This is the voltage source, dc voltage source which is connected at the input and this voltmeter measures in parallel the voltage I connect here and load is actually the current meter which is connected here. If you observe, the voltage source I have kept at 10 millivolts as you can see from the reading on this multimeter. It shows 100 millivolts here and 100 millivolts divided by 1 kilo ohm gives me 0.1 milliampere. This is 0.1 milliampere, 100 microampere.

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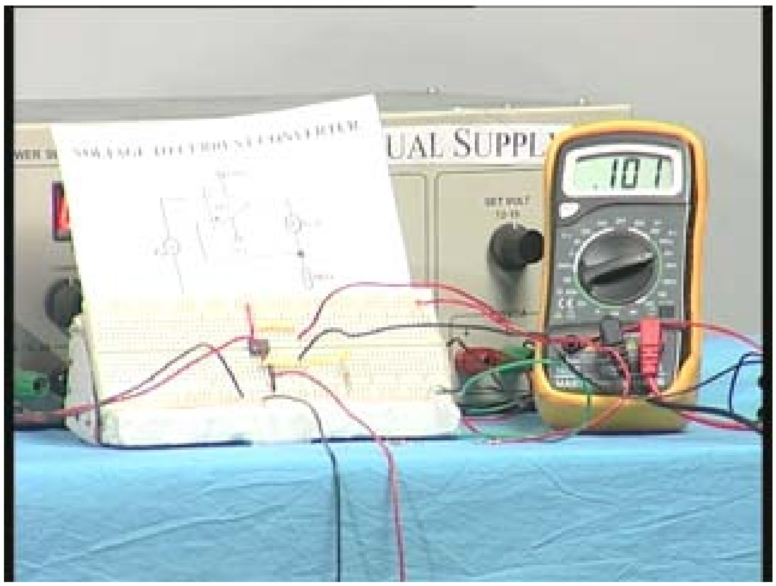

100 millivolt divided by 1 kilo ohm gives me 100 microvolt or 0.1 milliampere. That is what this meter reads. If I increase the input voltage to 200 millivolt this is reading 200 millivolt here approximately and you can see it is now 200 microampere or 0.2 milliampere at the output stage. Now if I increase to 300 millivolt, this multimeter again reads 300 millivolt and a corresponding output current is 0.3 milliamperes or 300 microamperes. Corresponding to every voltage here a corresponding current is obtained by the feedback network that you have here and the circuit is converting this voltage into a corresponding current. So this is the voltage to current converter circuit.

There are several applications that one can think of for such a circuit which is basically a voltage to current converter. The circuit provides very large input impedance and it has got larger output impedance that makes it a current output. Can we build a good electronic volt meter which is not very expensive by making use of a single op amp and a current meter 0 to 100 microampere full scale current meter? If I have a 0 to 100 full scale current meter I connect it in the circuit. Then I connect for example 10 ohms. 100 microampere into 10 ohms gives me 1000 microohms or 1 millivolt.

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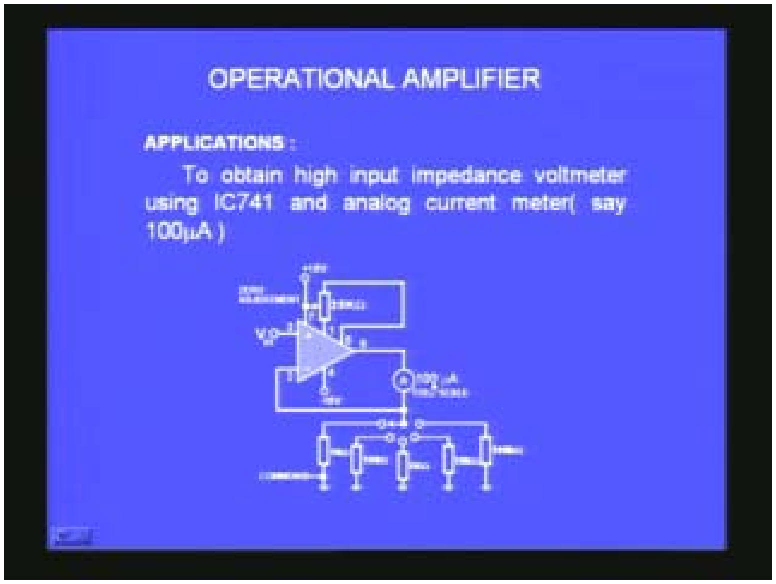

If I apply 1 millivolt here it will correspond to 10 ohms and 1000 microvolt or 1 millivolt. When I give 1 millivolt here that will correspond to 1 by 10 current which is 0.1 milliamp which is equal to 100 microampere full scale. This becomes a 1 millivolt meter. This 100 microampere current meter is now converted into a voltmeter along with the op amp. It becomes 0 to 1 millivolt range. It will show a current from 0 to 100 microamperes. Now if I switch the resistor from 10 ohms to 100 ohms then for 10 millivolt you will get 100 microamps. When I switch this to 1000 ohms then this becomes a 0 to 10 millivolt voltmeter. It can measure 0 to 10 millivolt; correspondingly a current of 0 to 100 microampere. If I now remove the dial of the 100 microampere meter and put it in terms of volts this becomes a typical electronic voltmeter. Like that I change the value of resistors every decade?. For example 1 kilo ohm, 10 kilo ohm, 100 kilo ohm; correspondingly I can go for 100 millivolt, 1 volt, 10 volt, up to 10 volt I can go. This becomes a multi range electronic voltmeter. It is a very good electronic voltmeter because the input impedance is very high and the output impedance is also very high in this feedback network and I just connect a normal current meter, panel meter which are not very expensive and op amps are also not very expensive. You can combine them with a few resistors and build your own very high resistance electronic voltmeter.

You may be wondering what will happen to the dual supply? This dual supply can be very easily obtained by using two 9 volts batteries. Connect them in series and keep the center tab to the ground. You will get a dual supply. +9 and -9 and you can use this and because the current involved is 100 microampere this battery will come for long time; may be few months, several months and you will have no problem and it can be put in a very small compact box your PCB, your two batteries connected as a dual power supply everything can be enclosed behind the panel meter and just take the two leads which are corresponding to the input leads and that can become a very good voltmeter, electronic voltmeter. You can have a small band switch connected corresponding to these resistors so that by switching the resistor you can switch the range of the electronic voltmeter from

0 to 1 millivolt, 0 to 10 millivolt or 0 to 100 millivolt; up to 0 to 10 volts all will give full scale of 0 to 100 microamperes and you can construct a very nice electronic voltmeter. There are several such applications that you can think of for these type of circuits.

What we have seen today is that the two different types of feedback configurations will give two different circuits. One will be a current to voltage converter and the other is the voltage to current converter and both of them can be used for several simple applications in normal electronic fields. Next time we will see the next feedback configuration which will lead on to a current amplifier and then we will go further. Thank you!