Basic Electronics
Learning by doing

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Lecture – 36
Logarithmic & Anti – Logarithmic Amplifier

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 let us recapitulate what we discussed in our previous lecture. You might recall in our previous lectures we discussed about how operational amplifiers can be used for generating sinusoidal waves, namely the applications of op amp in oscillations. We discussed different types of oscillators mainly RC oscillators.

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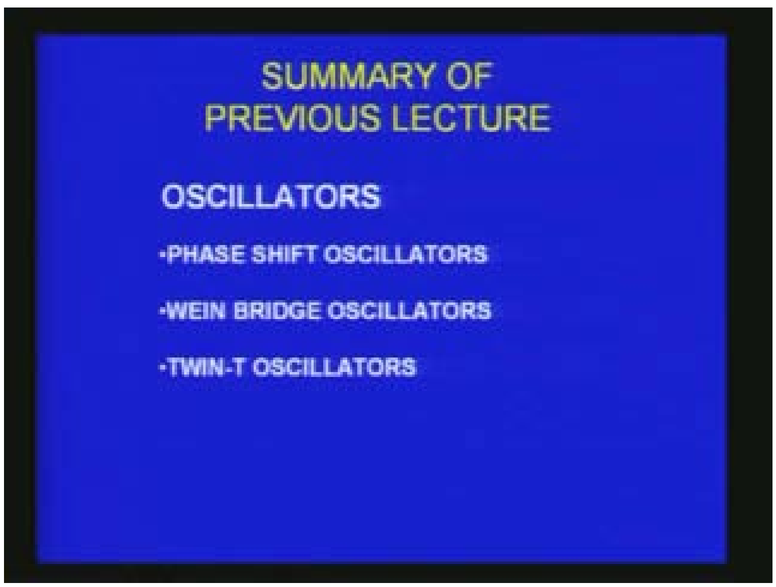

For example phase shift oscillators, Wein's bridge oscillator and Twin–T oscillators are the three different types of RC oscillators that we discussed during the last lecture. Now I want to go on to another very important application of operational amplifier especially a non-linear amplifier. This is what is known as the logarithmic amplifier. One of the most useful circuit techniques using op amps is this logarithmic amplifier. When we want dynamic range compression, when the range is going through several decades then it becomes very difficult to draw the relationship within a simple graph. Even when you want to plot for example the bandwidth of an amplifier the frequency will go from above 10 Hertz to 1 Mega Hertz. Nearly 6 orders of magnitude you have to vary the frequency from 1 Hertz to 10 power 6 and it becomes difficult to plot it in a normal linear graph. So we want to go into a logarithmic scale. In the same way when for example a sensor is having a very large dynamic range over several orders of the magnitude then it will be very convenient if I can use a logarithmic amplifier or in another case a antilogarithmic amplifier. The whole manipulation of the signal becomes much more convenient for us. Dynamic range compression raising to powers, taking roots, square roots, RMS conversion which again involves the squaring and multiplier, divider circuits where two analog voltages can be multiplied or two analog voltages can be divided as the case may be, all these circuits can be designed out of a very basic configuration which is known as logarithmic amplifier. We will discuss about the logarithmic amplifier.

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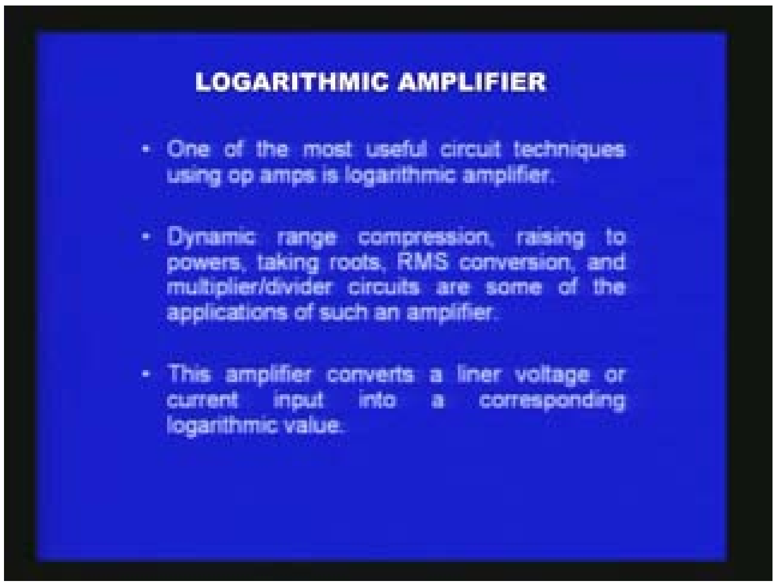

What will the logarithmic amplifier do? The logarithmic amplifier will convert a linear voltage given at the input, the current or voltage whatever that you have it can be a current or a voltage; at the output you will get the logarithm of this value. The relationship between the input, output is decided by the logarithm. If I give V_{in}, the output V output will be log of V_{in}. That is what I mean by this.

Equally important configuration is the reverse operation where you get the antilogarithmic relationship between the input and the output, antilogarithmic amplifier. In an antilog amplifier if one applies a voltage or a current at the input which is varying logarithmically, the output becomes linear. That is exactly what it does. Using such log-antilog combinations we can very easily generate multipliers, analog multipliers and analog divider circuits.

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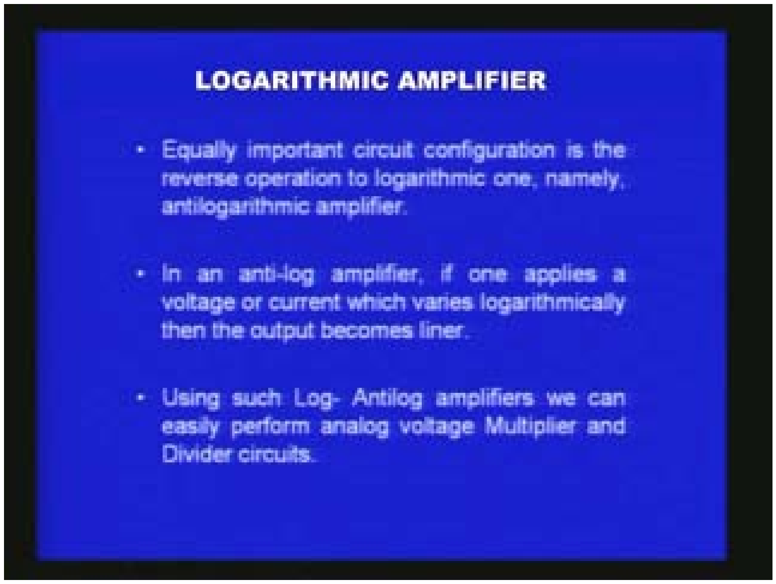

From basic principles of logarithms if I want to multiply two analog voltages, input voltages one way to do that is by taking the logarithm of the two voltages and adding them and then again converting them back to linear by using antilog amplifier circuits. From elementary logarithm ideas log AB is nothing but log A plus log B.

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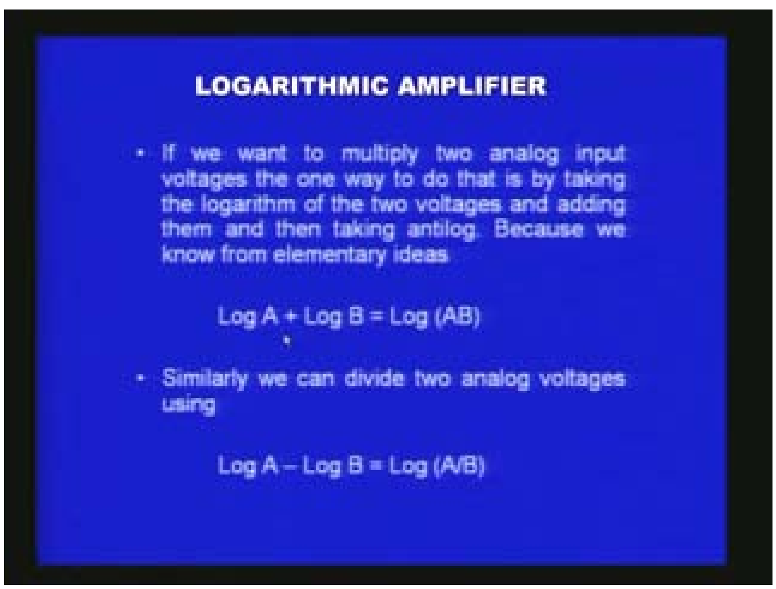

Log A + Log B = Log (AB). If I want product of two voltages then I should add the logarithm of each of this; logarithm of A and logarithm of B. Then if I now take the antilog then I will get AB, the product. Similarly if I want division Log A-Log B =Log A/B and if I use two logarithm amplifier for A and B inputs and get the difference of these two and take the antilog, use an antilog amplifier and obtain the output you will get A by B or B by A as the case may be, whatever that you want. Obtaining analog multiplication or obtaining analog division is possible by using such logarithmic amplifiers. These are some of the applications of the logarithmic or antilogarithmic amplifier. The basic device which is responsible for helping us using an op amp to obtain a logarithm or antilogarithm amplifier is a diode, semiconductor diode. It is a known fact that base emitter voltage for example V_{BE} of a silicon transistor is logarithmically related to the collector current over extremely wide range of values.

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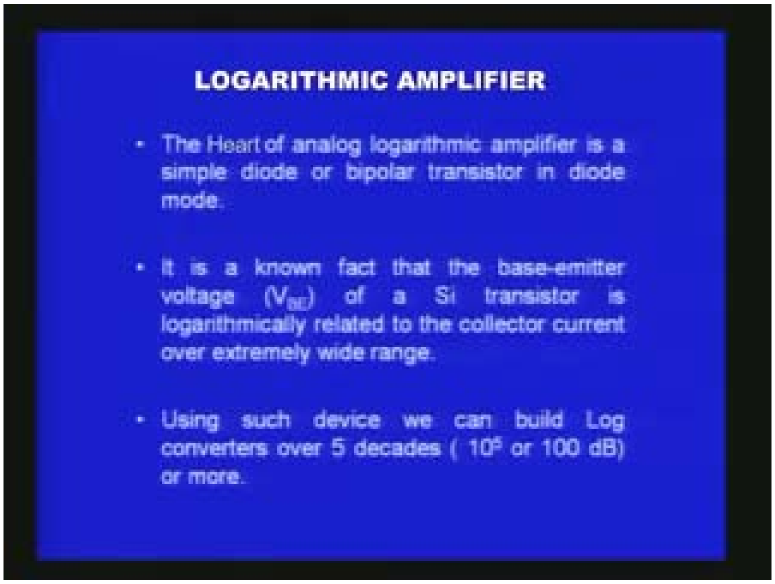

If I know use such silicon transistor in the diode mode I will be able to generate logarithmic relationship. We can use such transistor or semiconductor diode and we can build a log converter over easily five decades that is about 100 db; 10 power 5 or 100 db or more. Now I want to show you an actual amplifier. On the screen what you see looks very similar to a normal configuration of the operational amplifier. You have an input R resistor and in the feedback you have got a diode. Instead of a resistor you have a diode, silicon diode. This becomes a simple logarithmic amplifier. Just an amplifier, one resistor and one diode that is all you need. You are able to construct a very simple logarithmic amplifier.

I will explain the principle. This point is virtual earth because the other non-inverting input is grounded. This input is virtual earth and V_s by R is a current here and this is the current which is actually passing through the diode.

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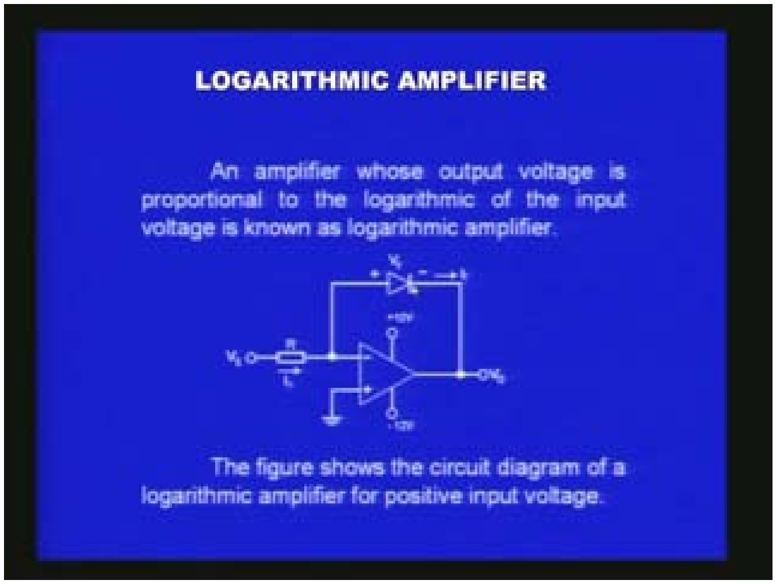

Because the input current into the operational amplifier is very, very small, negligible the same V_S by R which is actually I_s is the one which is also flowing through the diode. That is what we are going to do. I_s is nothing but I_f the feedback which is going through the diode or V_S - 0 because the virtual point divided by R is equal to I_f which is the diode current and diode current is I_o exponential eV_f divided by eta kT minus 1. This is the standard diode equation which we have also seen earlier when we discussed about diode.

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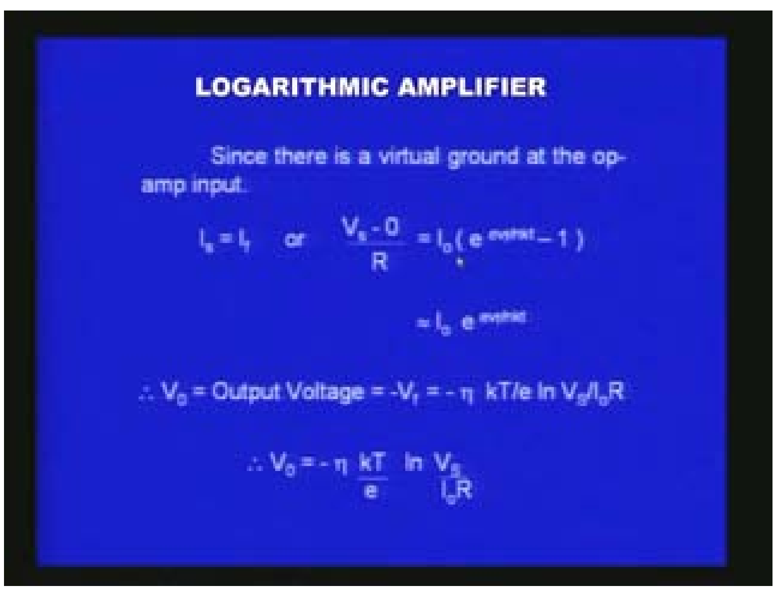

If you consider the exponent term, compared to 1 this exponent term is much larger and I can neglect the 1 term and I can approximate this to I_o exponential eV_f by eta kT where eta is a constant associated with the ideality factor as we call; is associated with the semiconductor that we use. V_o is the output voltage and that will be equal to $-V_f$. Because you are measuring the voltage, the current is flowing towards V out. Therefore it has to be a negative voltage. So V output is $-V_f$ and that is minus eta times kT by e ln V_S by I_oR from this equation that we have already got. V_o is equal to minus eta into kT by e into ln V_S by I_oR. That is obtained by taking logarithm so that we can get rid of the exponent where I_o is called the reverse saturation current flowing through the diode. Eta is 1 for germanium and 2 for silicon, capital T is the temperature in Kelvin scale, the small k is Boltzmann constant.

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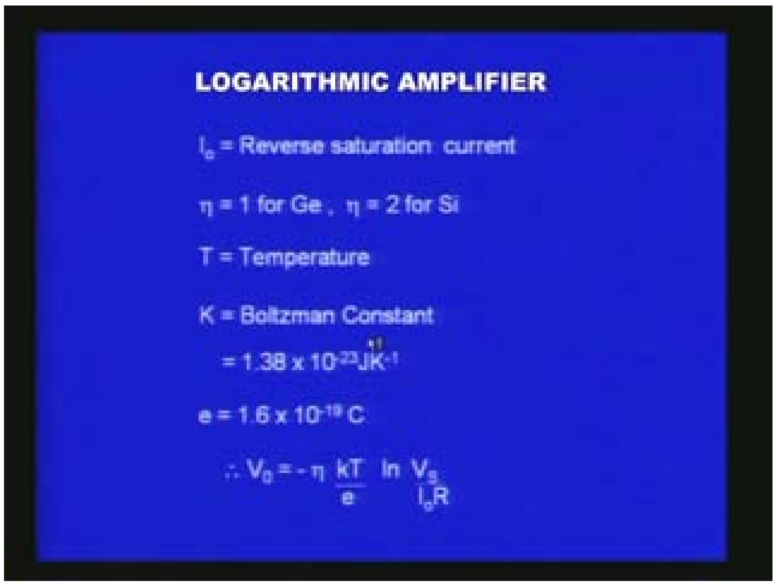

It is actually 1.38 into 10 to the power of -23 joule per Kelvin and e is the electronic charge which is 1.6 into 10 to the power -19 coulomb. All these values are known. So V_o is equal T minus eta kT by e ln V_S by I_oR. When I substitute all these values and I assume 27 degree Centigrade which is the normal room temperature approximately so that after I add 273 it becomes 300 degree Kelvin which is a very convenient number and I take 27 degree centigrade as standard. We know kT by q from diode is nothing but 26 millivolt. kT by e or q, q is actually the charge is equal to 26 millivolt approximately and if you use this value V_o becomes about 59 or 60 millivolt logarithm of I_c by I_o. I_c is the collector current, in this case the diode current. I_o is the reverse saturation current of the diode. At 27 degree centigrade the V_{BE} of the silicon transistor will increase by about 60 millivolt for each decade increase in the diode current. That is what this equation says.

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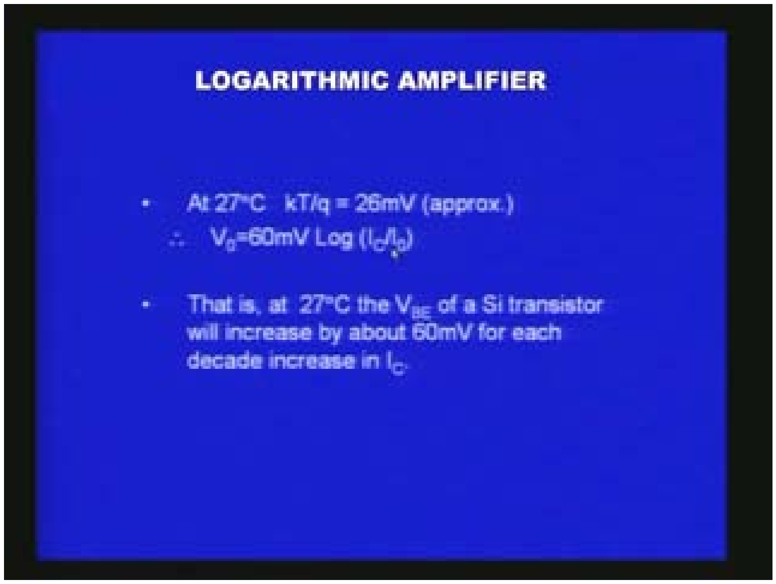

This is logarithm to base 10. Whenever it increases by 1 order of magnitude I will get an increase of 60 millivolt in the output. That is what we look at. This is the basic equation that we have. Now that is what exactly I have done. I have substituted the values for the equation.

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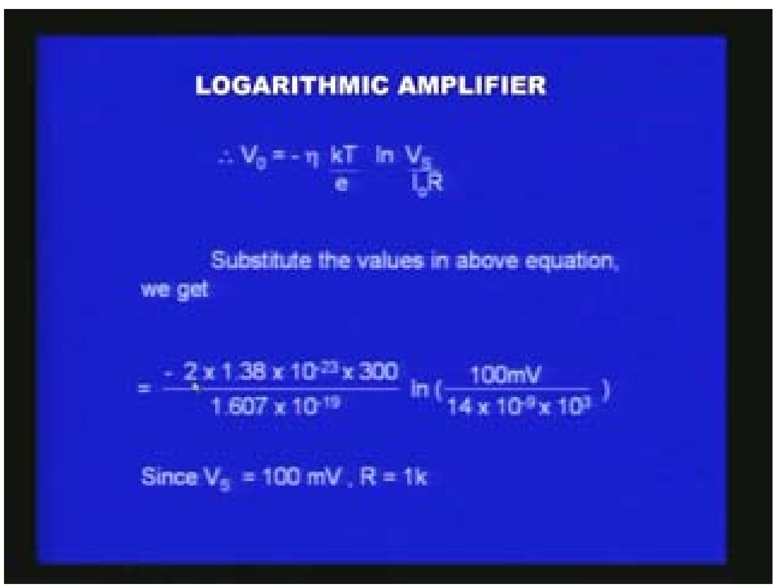

The eta is 2, k is 1.38 into 10 to the power -23; capital T is 300 Kelvin divided by e is 1.607 into 10 to the power -19 and I have assumed the input voltage of 100 millivolt. V_S is 100 millivolt I assume and I have assumed also the I_o to be about 14 nano amperes which is a typical value. 14 into 10 power -9 into the resistance which we have assumed to be 1 kilo ohm. When I substitute all these values and I am simplifying this over this. Then it is around 51.5 multiplied by 8.87. This is about 8 orders of magnitude difference and the actual value for 100 millivolts is about 0.457. That is 457 millivolts.

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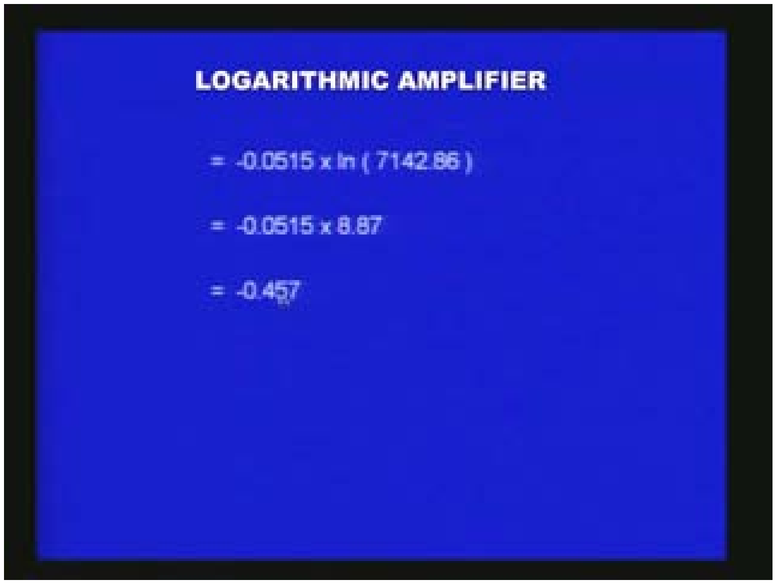

Negative sign is there. So it is -0.457 volts. I am showing the graph where we can see this variation.

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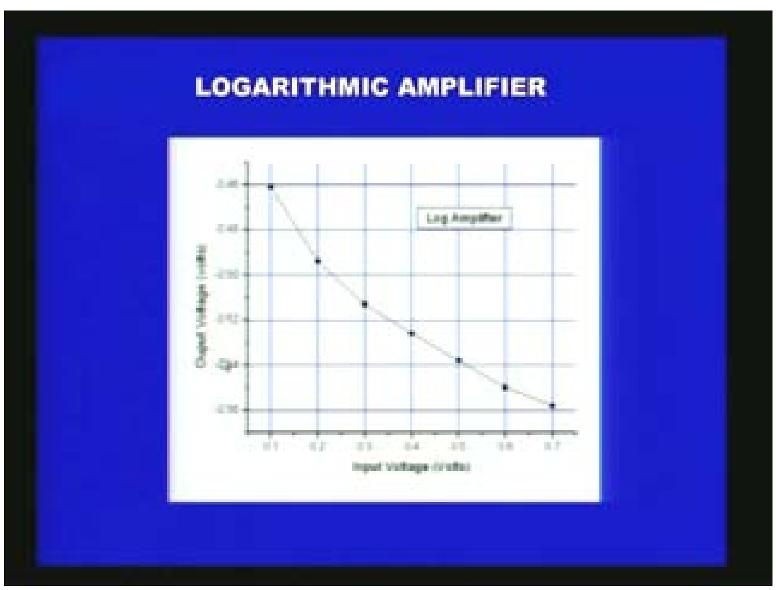

I have applied different voltages at the input 0.1, 0.2, 0.3, etc and look at the output voltage. When I applied 0.1 it is about 0.6; 0.7 we got just now and as I keep increasing the voltage because it is negative it keeps decreasing here in an exponential way. This is corresponding to the logarithm and to see whether it is really logarithm what I do is I take the logarithm of the output voltage and draw a graph between the logarithm of V_{in} versus V output. The logarithm of V_{in} versus V output; that is what I have done in the next graph.

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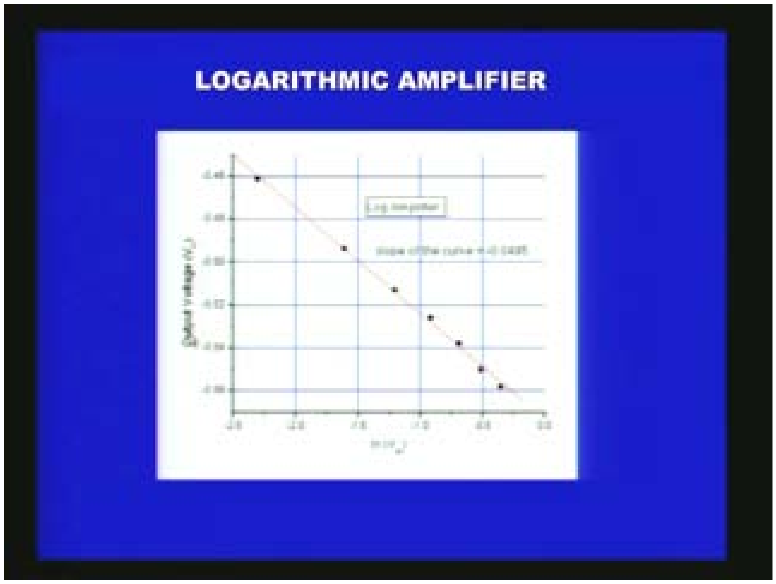

The x-axis is logarithm of V_{in} and output is directly plotted in voltage. You get a linear graph. That means this is corresponding to the logarithmic behavior and the slope of the graph is around 0.495. 0.495 is the slope of this graph. A very simple logarithmic amplifier can be constructed using a diode in the feedback. But we have to also remember the drawbacks of these logarithmic amplifiers. The temperature factor comes over here in the equations. V output is equal to eta times kT by e where T is the temperature.

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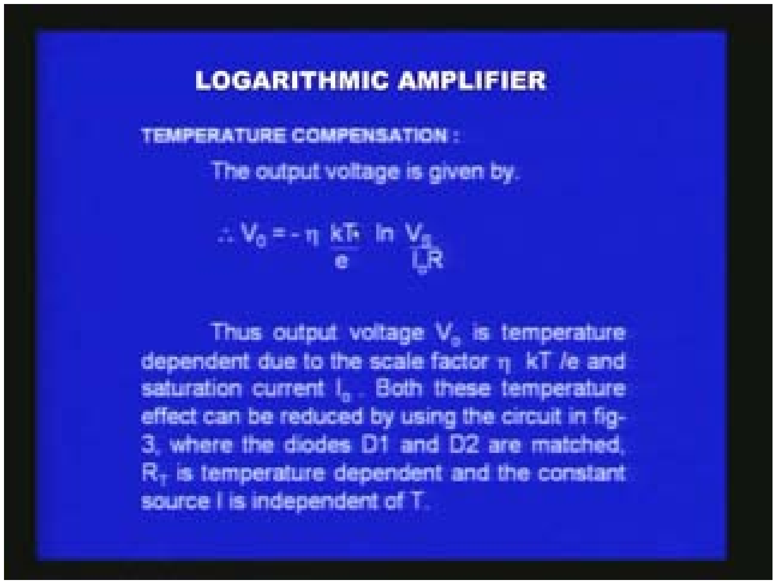

When the temperature is changing the output voltage will be dependent on temperature so that also will change and you also have another factor which is I_o, the reverse saturation current of the diode which is also highly sensitive to temperature. There are two parameters in the equation which are temperature dependent and one has to be careful when you use an amplifier. It will also have a very severe dependence on temperature. People started thinking how to overcome this difficulty? How to compensate for any variation in the temperature? What we normally do is we try to use two diodes in the configuration. The circuit that I have shown in the screen involves two diodes; D_1 and D_2.

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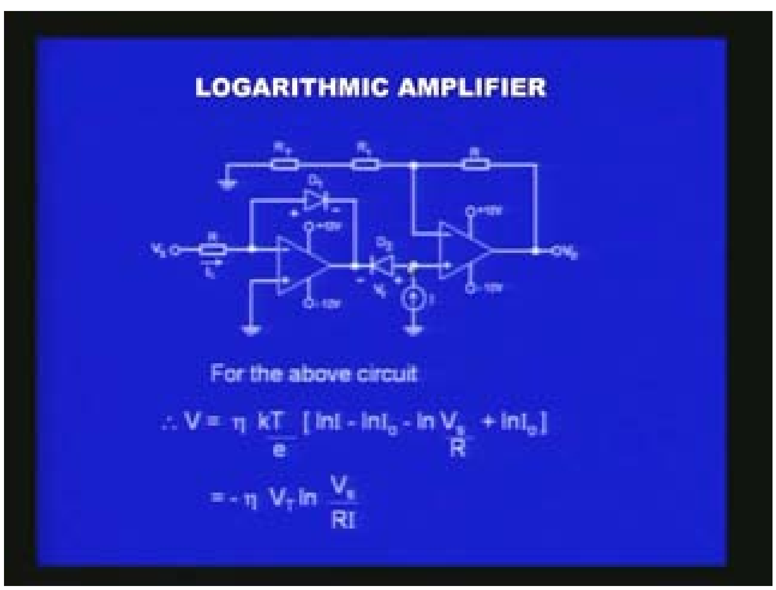

I use a current source here so that what you will measure the I_o value will be the difference between these two currents and the temperature dependents will become very less. I have written it in the equation V in this case, the output is equal to eta times kT by e within brackets ln of I which is the current through the current source minus ln of I_o which is the current through one of the diodes minus ln V_S by R as we have in the previous case which is corresponding to the current through D_1 and ln I_o which is again the reverse saturation current due to the other diode. The two diode currents ln I_o minus ln I_o will cancel each other thereby we will over come the temperature dependence of I_o which is coming in the output. The output becomes independent of the I_o independence and the V is equal to minus eta V_T ln V_S by RI where V_T is this quantity kT by e which is again temperature dependent. But this is the only temperature dependent that is coming here. We have eliminated whatever the effect of the I_o coming into the final expression by using two matched diodes. The usual way of implementing this logarithmic amplifier is not by using diode as I have shown here but actually using good transistors. Because it is much easier to get matched transistors they will use transistors in the diode mode in the feedback to obtain the actual logarithmic amplifier. The expression for the previous circuits that I showed is written here and except for V_T factor which is coming all the other things are completely eliminated.

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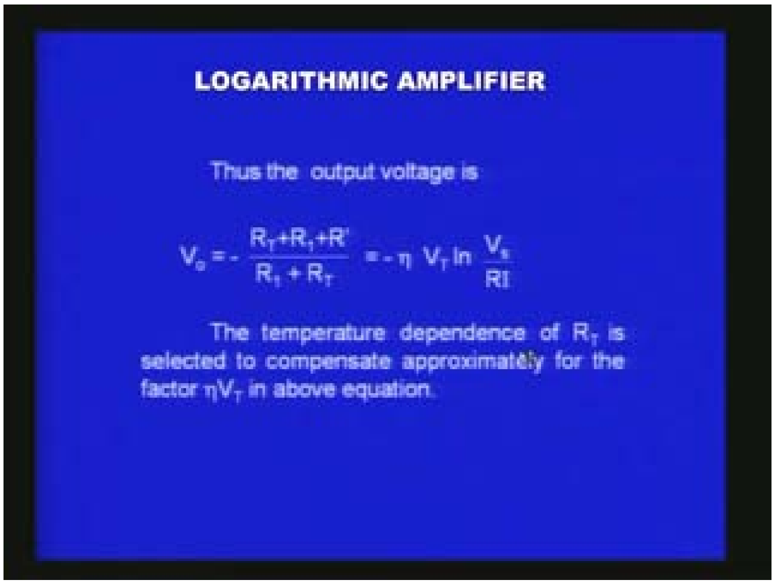

But in the circuit we also see one extra resistor which is R_T. This R_T is usually chosen in such a way the R_T takes care of the temperature dependence of V_T. You can choose the R_T suitably so that that will compensate for the change in V_T. Thereby we can eliminate both the sources of temperature variations namely the V_T factor as well as the I_o factor. The normal way of making use of the logarithmic amplifier is to make use of the transistor because in a transistor the current voltage relationship between the base and the emitter is exactly in logarithmic scale over a much wider range compared to a normal diode. Usually we prefer to use a transistor in place of a diode in the feedback scheme. I am showing you another circuit in which I have shown the diode being replaced by a transistor.

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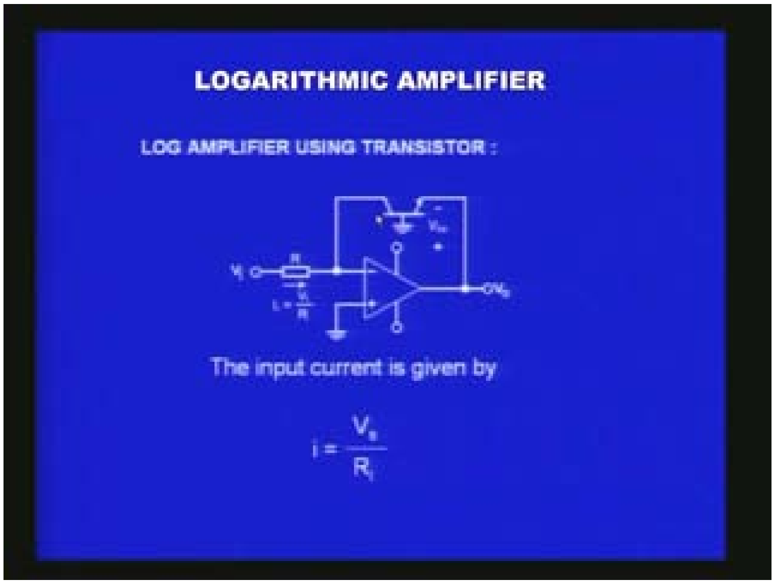

The base of the transistor is grounded and the collector comes to the virtual earth terminal and the emitter is going to the output point. You measure voltage output between the V output point and ground and the V output point and ground is nothing but V_{BE}. Basically you are measuring the V_{BE} as the output voltage and that is actually the collector current which is almost equal to emitter current and the collector current is given by V_i by R and the relationship is very similar to what we already discussed. Only difference is instead of a normal diode we are using a transistor. I have shown the equations corresponding to that and finally the output voltage is around 60 millivolt; 0.059 if you convert into millivolts it is 60 millivolts approximately, logarithm of V_i by R_i I_{EO} which we already discussed.

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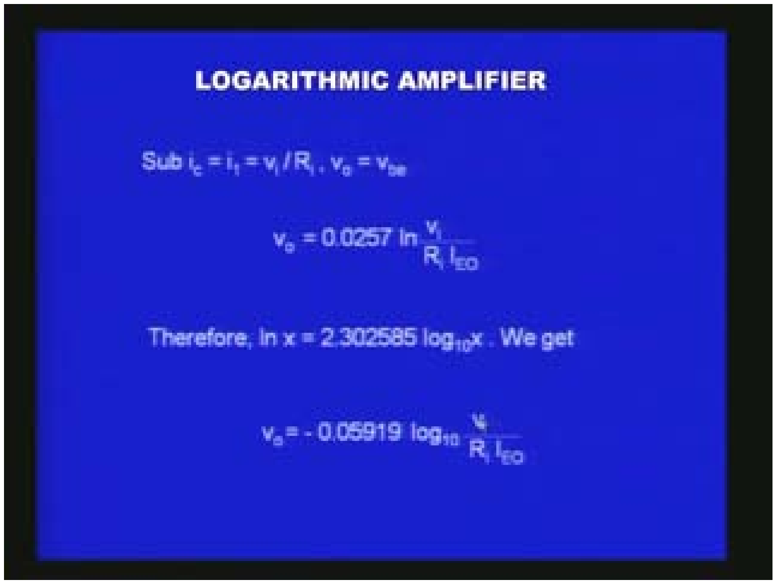

Output voltage is proportional to logarithm of V_i and the multiplication factor is around 60 millivolt which we already saw. That is exactly what I have derived here. The circuit produces a change of about 60 millivolts in the output voltage for each decade of change nearly 10 to 1 ratio in the input voltage. There is another scheme by which you can also compensate for the temperature dependence. That is what we have shown next. I will not go into the details but what we do here is we have used two matched transistors.

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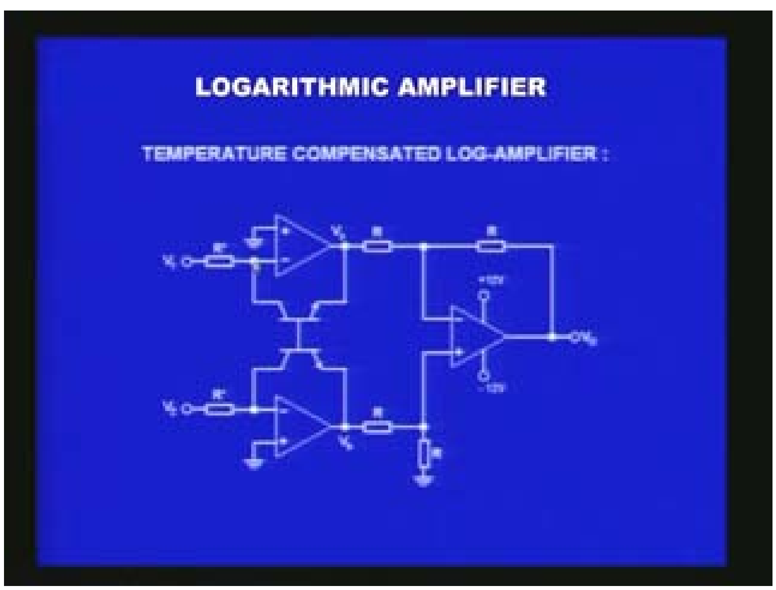

The two transistors will have almost identical I_o values. By using the configuration again the difference in V_{BE} is what you are going to measure and this third op amp is basically in the differential amplifier configuration. You are looking for a difference in the V_{BE} voltage at the two transistors and whenever you take a difference the temperature differences also will be taken care of. It will be completely removed because the temperature is constant to both and the directions of the diodes are different and in this case between the base and emitter and the base and the emitter and the I_o will get cancelled here. You will get a temperature compensated logarithmic behavior when I use this configuration.

Having seen this let me now show you a demonstration of the simple logarithmic amplifier and you must remember the slope that we got for the relationship, especially when it is a linear graph, is around 0.0495 or 0.05. That is what we got, the slope. You should remember that we will get for different input voltages approximately with these relationships. That is what I am going to show you now. You can see the circuit here.

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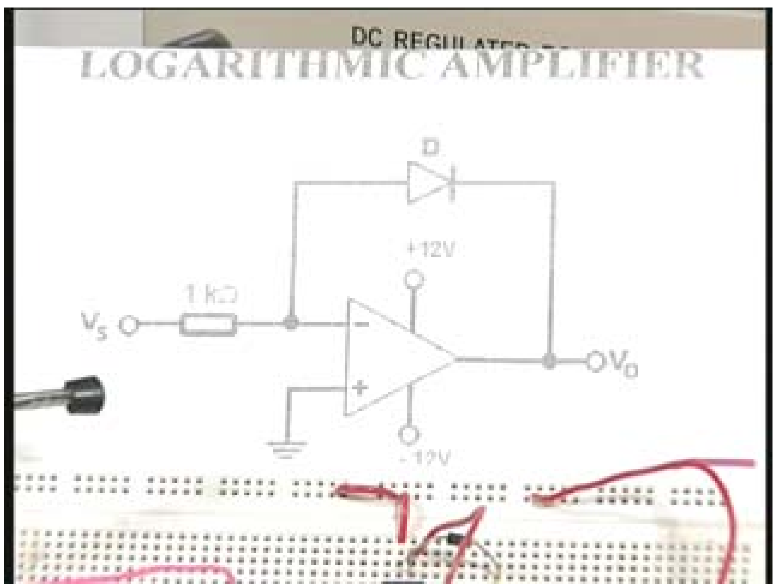

You can see there is a 1 kilo ohm resistor at the input, R and you have a diode here and you have the op amp here. The inverting terminal is the one in which we are giving the input. Therefore output should be negative of the input and because there is a diode it will be the logarithm of the input voltage. This is the circuit and you can see also in the circuit below I have not used the transistor. I have used only the diode here normal silicon 1 and 4001. Some standard diode I have connected in the feedback. It is going from 2 to 6 and you have the 1 kilo ohm resistor here which is connected to a millivolt source which we are also already very familiar. We used this many times. You have a selection range and a continuous variation here and you have a potentiometer which can vary within the range. These three knobs are used to adjust the different values of the millivolts and that input is given as input for the logarithmic amplifier. The output of the logarithmic amplifier is monitored using a multimeter. It is in the voltage range and you get a -0.48 and look at the input voltage. I will take the multimeter and connect it at the input to see the input at this stage and you can see the input is 0.09. It is about nearly 100 millivolts. Let me slightly increase it to make it 0.1. It is about 0.1.

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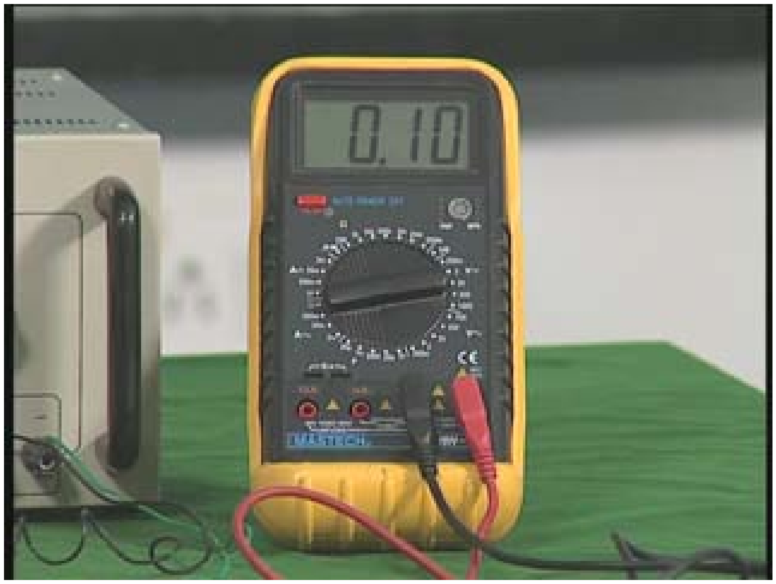

0.1 means 100 millivolts. It is in the voltage range. This is 100 millivolts. I will again change the multimeter to the output point. I have connected at the output point and the output is about 0.48. When I have 100 millivolt it is around 0.48. If you remember the linear graph that I showed you it was very close to 0.49. Now if I make it 0.2 volts at the input it is around 0.51. It is not increasing in a linear fashion.

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But the increase is only about 0.03; 0.48 to 0.51. The difference is only 0.03. If I go to 300 millivolt now it becomes only 0.52 or 0.53. It keeps on decreasing It is not in a linear fashion. That is what I want you to recognize. Now it is 400 millivolt. For that it is 0.54 and if I go to 500 it is 0.55. The output voltage is increasing very slowly whereas the input is going in steps of 100 millivolt and if you take the set of readings and if you take the logarithm of 100 millivolts, logarithm of 200 millivolts, etc with reference to base 10 and plot the output voltage you will get a linear graph, a straight line. When the input is changing in large amounts the output is changing only very, very slightly. That is exactly what is known as compression. Several orders if you vary the input, the output varies only in a linear fashion. The input is varied in a logarithmic fashion and the output is varying in a linear fashion. That is exactly what we wanted to achieve by using the logarithmic amplifier. When I have 100 millivolt approximately you get a 0.48. This is for 200 millivolt, etc and this follows a simple linear graph and if input voltage and output voltage are in linear scale for 100 millivolt you get 0.6.

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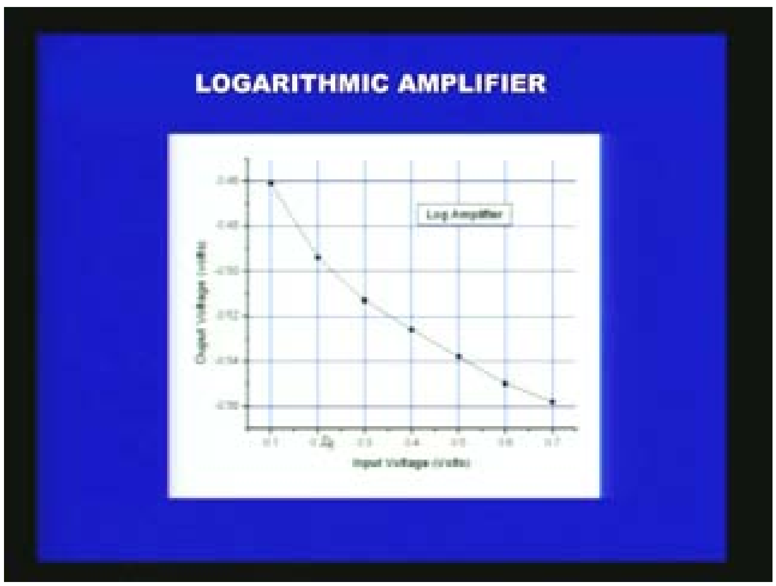

For about 0.2 it is about 0.51 and 0.3 it is around 0.53. It is exactly the way we got in the multimeter. Having seen the logarithmic amplifier now we will move on to the next which is the inverse operation which is anti-logarithmic amplifier. How do we get an anti-logarithmic amplifier? If you recall integrator and differentiator circuits made using op amp, for an integrator you will use the capacitor in the feedback loop and the resistor in the input side and if you want to differentiate you will just invert the two. You will put the capacitor in the input side and the resistor in the feedback loop then you will get a differentiator circuit. In the same way if I put the diode or the transistor in the diode mode in the feedback loop for getting a logarithmic amplifier, for an anti-logarithmic amplifier we should put the diode in input circuit and the resistor in the feedback loop. It is as simple as that. In the circuit that I have shown here I have used the resistor in the feedback and I have used the diode in the input side. Other than that there is no other change. I have swapped the two components.

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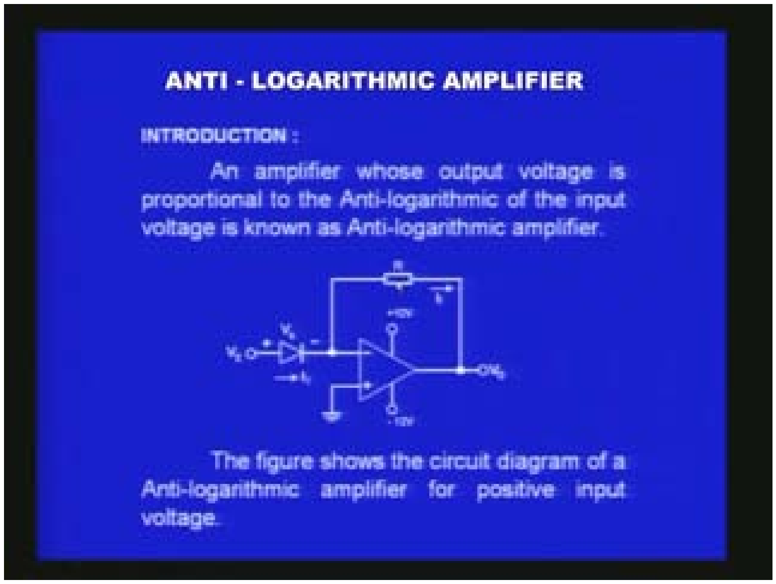

The resistor is now in the feedback and the diode which was at the feedback previously is now in the input side. This provides you with the anti-logarithmic amplifier. The equation is very simple. You get $-V_o$ by R. Because this is a virtual earth point this is $-V_o$. $-V_o$ by R will be the current which is flowing into the output terminal and that is equal to the diode current I_o exponential eV_f by eta kT minus 1.

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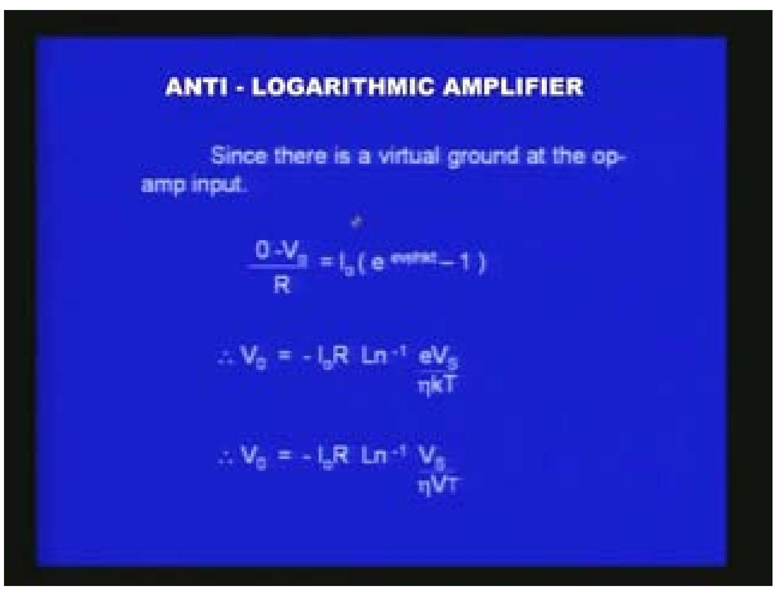

This we have seen and we neglect the -1 here and we get V_o is equal to $-I_o$ into R exponent is nothing but inverse of logarithm and e V_S by kT. V_S is the input signal that we applied by eta kT and when you substitute the various constants for silicon diode eta is 2 and kT by e, the Boltzmann constant, you get about 300 millivolt when I apply around 0.2 volts.

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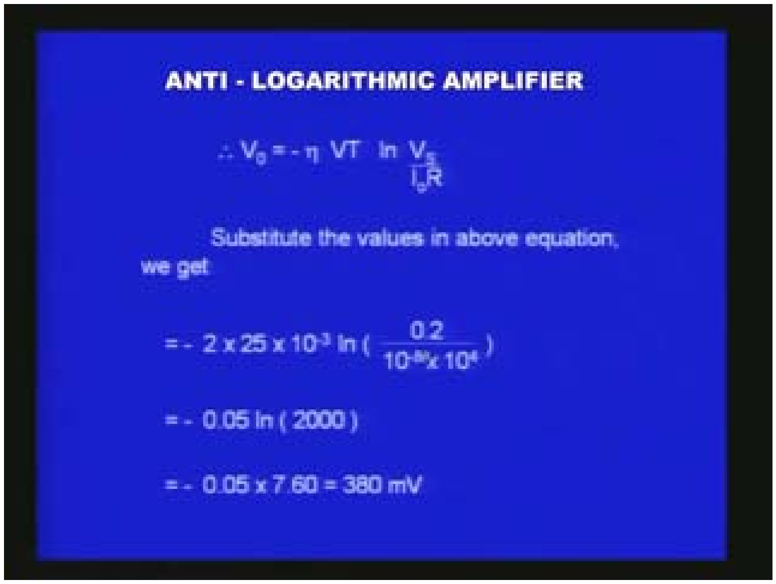

When I apply about 200 millivolts I get about 300 millivolts at the output when you simplify the numbers. I have also shown a graph here which is a graph between input voltage versus output voltage.

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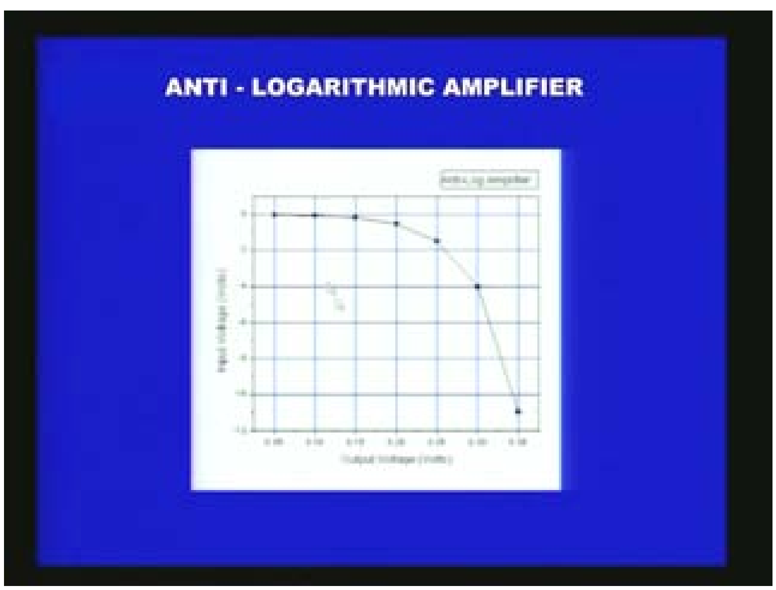

Previously it was like this. Now the input voltage is in the y-axis, the output voltage is in the x-axis. It is following an exponential behavior and I have not shown you the linear graph in this case and this also can be implemented. Instead of using the diode you can make use of a transistor. So you are using a transistor here and the input voltage is actually the V_{BE} voltage of the diode between the emitter and the base.

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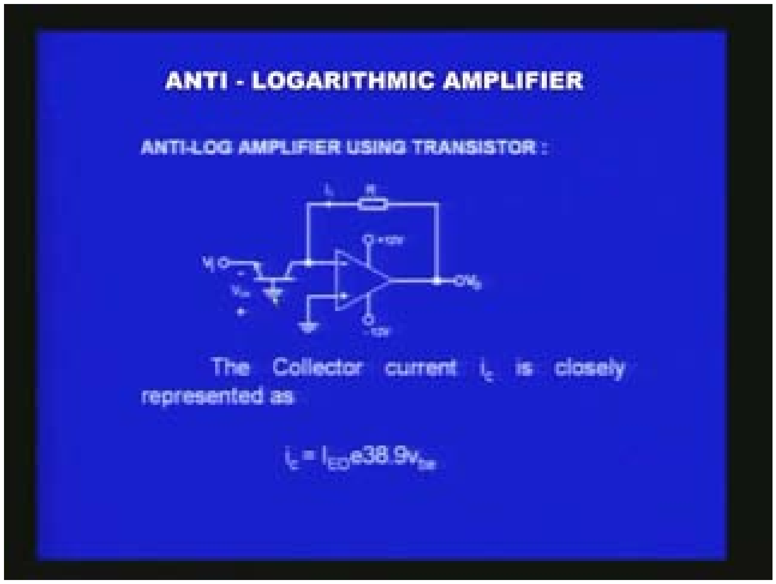

The base is grounded here. So what you apply will be the V_{BE} voltage. Because of this there will be a current generated i_e and that i_e is the one which is also flowing through R and the relationship can be obtained and when you actually simplify and use, the i_e or i_c both are almost equal and i_c is equal to I_{EO} e power 38.9 V_{be}. This is the relationship that I get.

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V_{be} is nothing but V_i and it becomes e exponential 38.9. The quantity is now expressed in this form. This is the relationship between the input and the output and I will now show you the demonstration of the anti-logarithmic amplifier.

In the circuit which is shown here the diode is in the input circuit of the operational amplifier and in the feedback I have the 1K resistor. Previously for the logarithmic amplifier they were interchanged. The diode was here and the resistance was here. Now for anti-logarithmic the diode has come here and the resistor is here and there is nothing else except for the op amp. When I give input voltage I give dc voltages from the millivolt source which we have used even earlier and the output can be varied in 100, 200, etc millivolt. I have now kept it in millivolts 1, 2, 3, 4 means 100 millivolt, 200 millivolts, etc. This is the minimum position. The input voltage is actually connected at the diode. You can see the circuit here.

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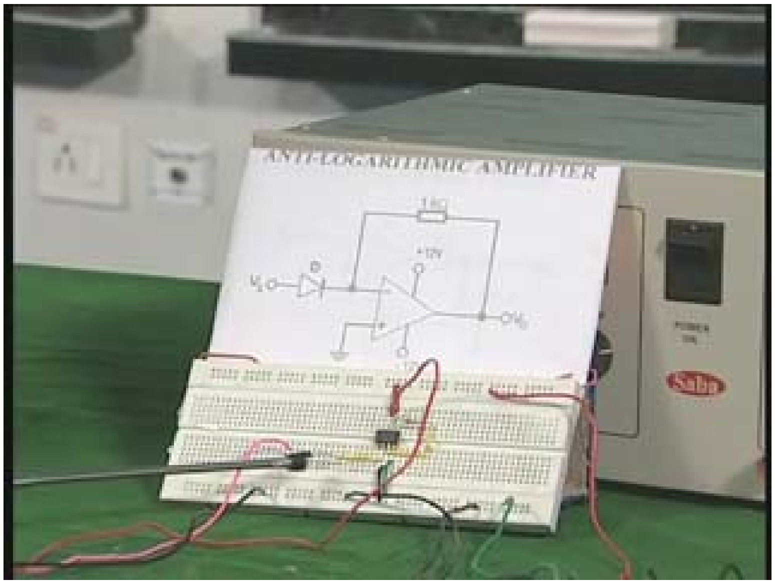

The diode is at the input circuit and this is the op amp and in the feedback I have got the 1K resistor. From the color code you can see brown, black and red. This is 1K resistor. This is a very simple circuit and the output is connected to the pin number 6 to a multimeter. The multimeter now reads 1.55 volts when I give 100 millivolts.

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You get a very large output. Previously if you remember when I change from 100 to 200, 300 millivolt it was changing from 0.48 to 0.51, 0.53. It was changing very slowly at the output compared to the input. Now what is happening? For a change in the input there is a very large change in the output, exponential increase in the output because it is an anti-logarithmic amplifier. To see the input that I have given, I take the multimeter and connect it at the input terminal. When I connect the multimeter at the input terminal the multimeter shows 1 volt.

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It shows 1 volt. Now I will make it 100 millivolt. This is 0.1 volt that means 100 millivolts. When I have 100 millivolts at the input I take out again and connect the multimeter at the pin number 6 of the op amp and it is around nearly 1 volt.

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100 millivolt comes nearly around 1 volt. When I increase it to 200 millivolt, when I increase the input voltage to 200 millivolts I get about 1.03. I change it to 300 millivolt. Now it is 1.12. It has come to volts now and when I go to 400 millivolt it is 1.17. If you actually take the output it will be related to the input through the logarithm. That means logarithm of the output voltage will be equal to the input. It is the reverse operation. That is what we should remember. The output voltage will be exponent of some value into the input voltage. That is what we have already shown when we discussed the corresponding equation. This is the antilogarithmic amplifier where the diode is in the input circuit and the resistor is in the output circuit. We are making use of the relationship of the current through the diode which is I is equal to I_o exponential. This is what is being made use of in this configuration for generating the logarithmic relationship.

Having seen the logarithmic and anti-logarithmic amplifiers and also the actual demonstration of the circuits using logarithm and anti-logarithm what are the applications? Log antilog amplifiers can be used for multiplying two analog voltages. There are analog multipliers available in the integrated circuit form. You can buy four quadrant, etc. But then the simple principle behind that is to make use of the logarithmic and anti-logarithmic amplifier. What is a multiplier? In an analog multiplier the output voltage at any time is proportional to the instantaneous product of the two separate input wave form. That is what I mean by multiplier.

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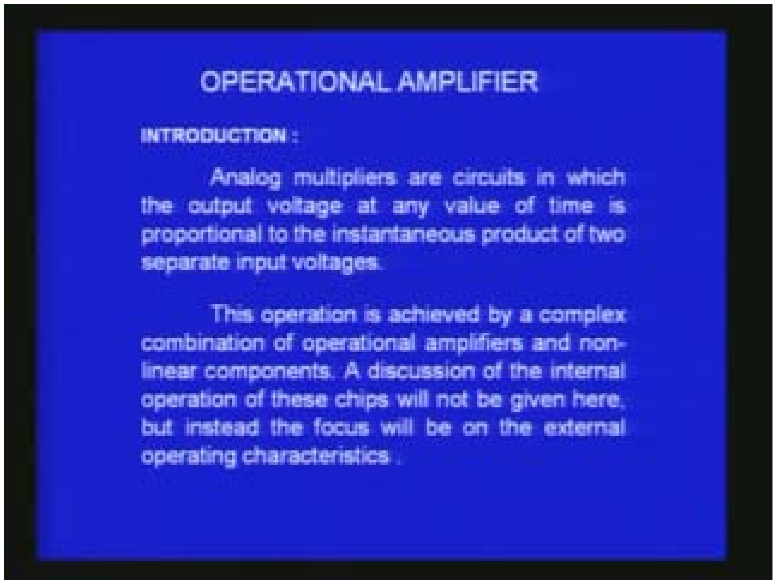

The operation is achieved by a complex combination of operational amplifiers and non-linear components like the diode. Now what I am going to do is I am going to show you a block diagram of a multiplier.

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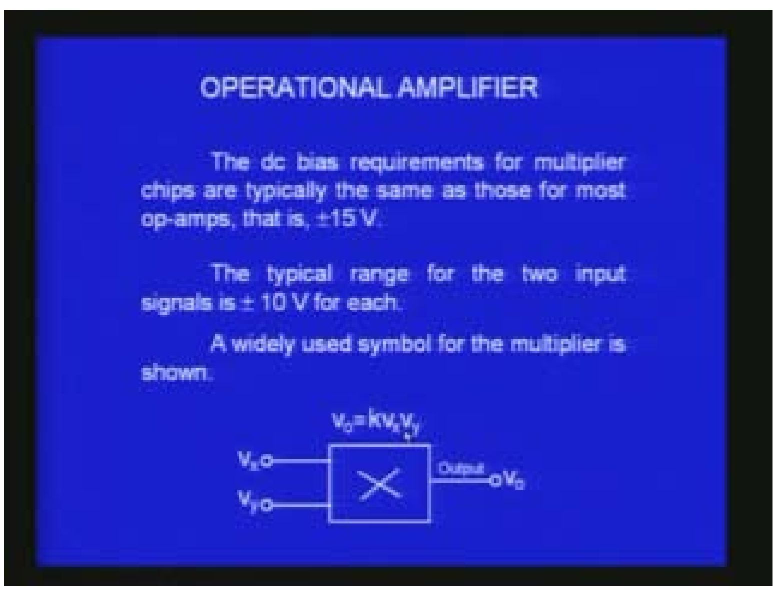

We have V_x and V_y as the two inputs and you get an output V_o. The cross here shows that it is a multiplier. V_o is equal to some constant times V_x into V_y. This is the characteristics of a multiplier. The output is the product of the two inputs V_x and V_y multiplied by some constant factor, k.

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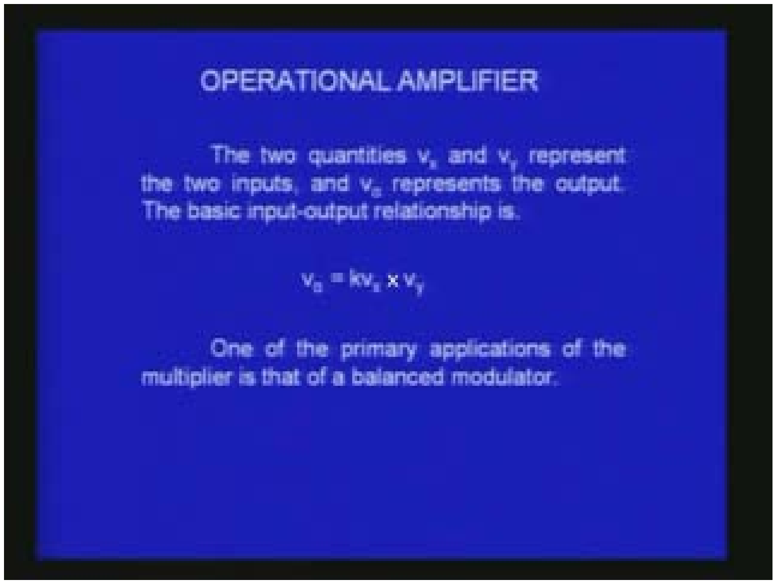

The quantity V_x and V_y represents the two inputs and V_o represents the output and V_o is equal to k into V_x into V_y. One of the important applications of the multiplier is the balanced modulator. When do modulation you should have a multiplier so that you can get a sum and difference frequencies corresponding to the inputs. How do you achieve division? If I have a multiplier how to get a multiplier that I already explained to you. You have V_x and V_y initially applied to a logarithmic amplifier so that the output will be log of V_x and log of V_y. Then you use a summing amplifier add log V_x and log V_y. The output is going to be log V_x plus log V_y which is nothing but log of V_x V_y. Now if you put another antilog amplifier at the output then you get back your V_x V_y with a constant factor k and that is the principle of a multiplier basically. Now how do I achieve division?

You can use the same multiplier to achieve division by using op amp. That is what I wanted to show you. You can also use logarithmic and anti-logarithmic amplifiers and achieve division by subtraction; not by addition. In the previous case you did addition because log a by b is log a minus log b. You can use that principle also and obtain division. But here what we are going to do is use a basic multiplying circuit. As you can see in the screen we use a multiplying circuit and one input of that you give V_D which is the denominator voltage and the actual input of the op amp is V_N which is the numerator voltage.

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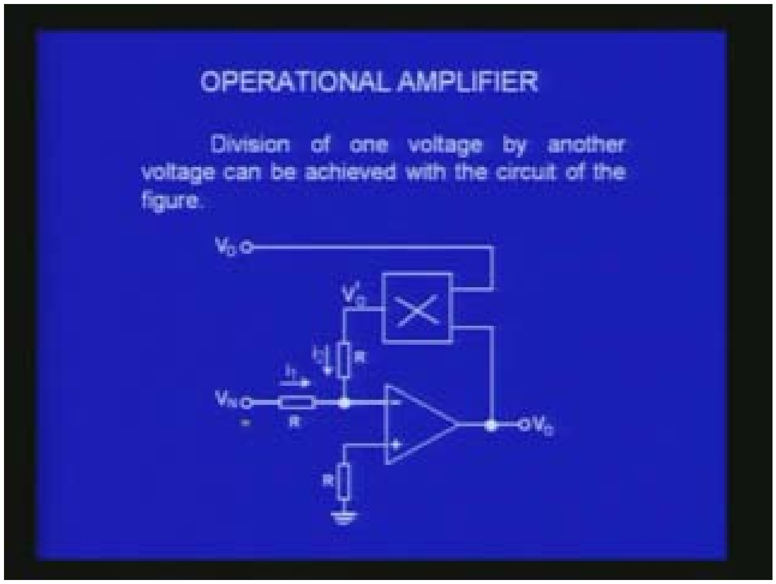

You use two R's here R and R. They are equal. This is the configuration you will use to achieve division using multiplier. Because multipliers are available readymade in the market you can use multiplier and achieve all other mathematical operations that you want like multiplication, squaring, division, square root, etc. That is what I am trying to show you in principle. I am not going to show any demo of this and I am only showing you the basic principle behind the multiplier and how the applications of multiplier can lead to different useful circuits. V_D is connected to one of the inputs of the multiplier. The V output is the other input of this multiplier and the multiplier comes in the feedback loop and the V_N, the numerator voltage is connected at the input of the op amp in which this is connected as the feedback device. What is V_o prime, output of the multiplier? The output of the multiplier is k times, where k is a constant, the two inputs. The two inputs are V_D and V_o. V_o prime which is the output of the multiplier is equal to k times V_o into V_D which are the two inputs of the multiplier and this current which is V_N by R is the same which is flowing into this and V_o prime by R should be equal to V_N by R except that the direction of the current as shown in the figure are opposite. i_1 and i_2 are opposite in direction. That is exactly what is shown here.

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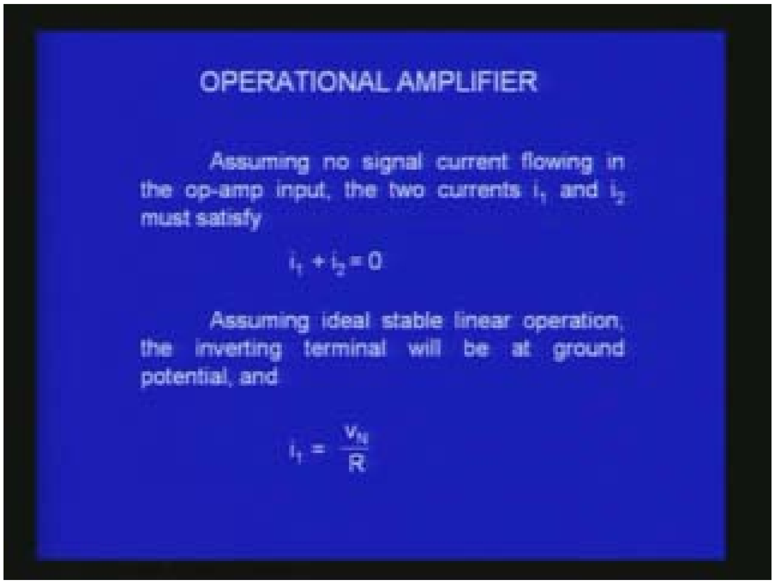

The i_1 plus i_2 should be equal to zero. Now assuming stable ideal linear operation for the multiplier, inverting terminal will be at the ground potential. Therefore i_1 is equal to V_N by R, i_2 is V_o prime by R.

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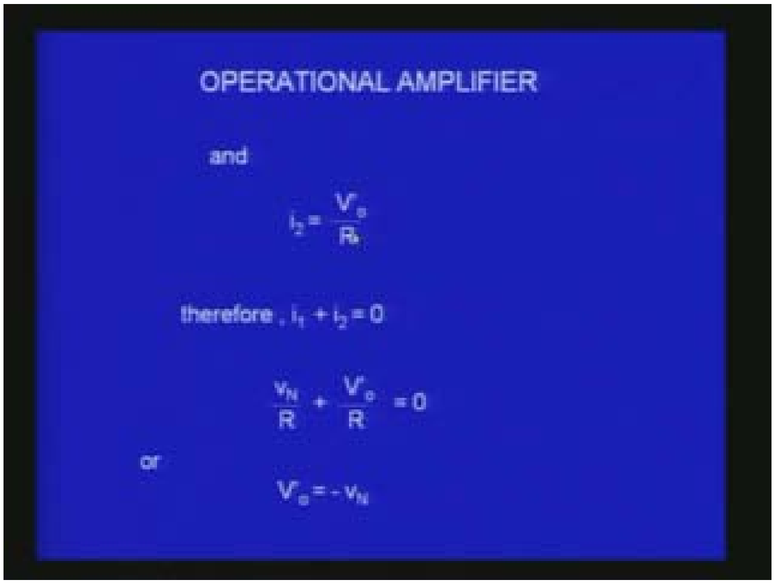

$i_1+i_2 = 0$; we have already discussed. That means V_N by R plus V_o prime by R is equal to zero or V_o prime is equal to $-V_N$. That is what we get. If I now substitute for V_o prime this will be $-V_N$. $-V_N$ is equal to k times V_o V_D and V_o which is the output voltage that we measure in the op amp is equal to minus V_N by k times V_D.

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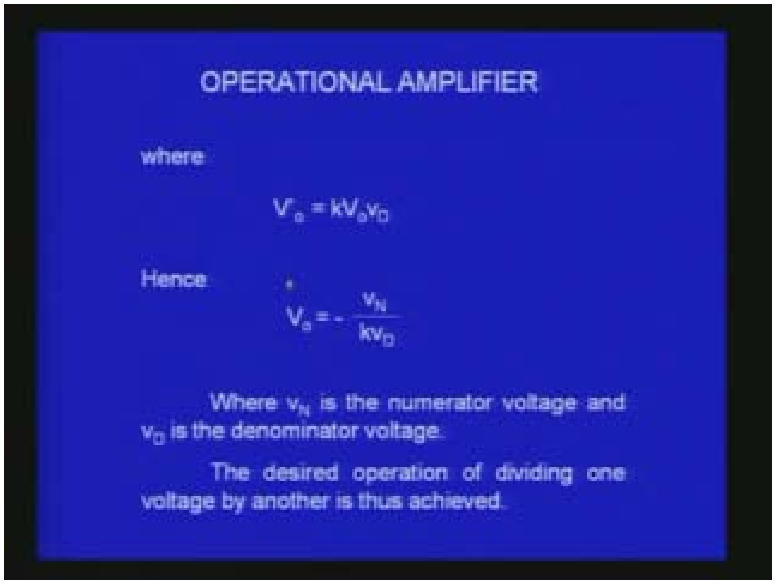

Output voltage is nothing but V_N by V_D. Output is proportional to V_N by V_D and the proportionality constant is -1 by k where k is the factor corresponding to the multiplier that we used. V_N is the numerator voltage, V_D is the denominator voltage and the desired operation of dividing one voltage by another is achieved here; numerator by denominator. If you want two voltages to be divided V_1 and V_2 you should correspondingly apply the input as shown in the earlier picture that I showed. That way you can get division. You already got a multiplier. From the multiplier by using an op amp you have now achieved a division. How do I get square root operation? How do I apply a square operation? That is very simple. The two inputs of the multiplier are connected together. If I give V_i the output is k times V_{in} into V_i; k times Vi square. So squaring using a multiplier is a very, very simple elementary operation. There is no difficulty. But how do I get a square root using the multiplier?

For that I have shown you another circuit here. A square root operation can be achieved by again having the multiplier with the feedback loop but connecting the two inputs together connecting to the output and the input is as usual in the previous case we had for the division the same way you have. V_o prime is equal to k times V_o square because both the inputs are now V_o for the multiplier. Therefore k times V_o square and V_i by R is equal to -V_o prime by R. That also we saw previously. Vo prime will be -V_i. You get -V_i or Vi will be -k times V_o square or V_o will be root of -V_i by K.

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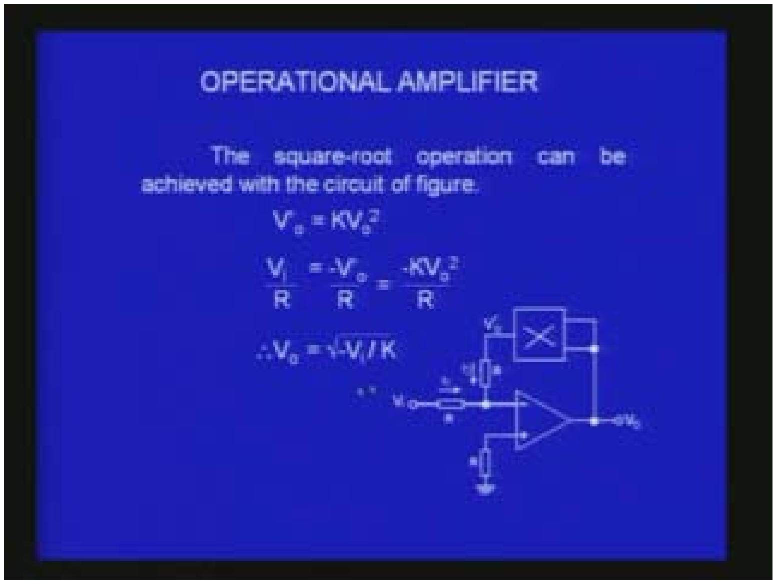

The output voltage is square root of V_i the input voltage. There is a factor k which is coming in the denominator which is corresponding to the multiplier relationship and there is also a negative sign. You can apply negative voltages and obtain positive values for this. By using this configuration square root of the given voltage can be obtained at the output. This amplifier is a square root amplifier. If I give a V_i the output is root of V_i, proportional to root of V_i. That is what I get.

So far I have explained to you how a logarithmic amplifier can be constructed using a diode and how an anti-logarithmic amplifier can be constructed by replacing the diode and switching the diode and the resistor in the feedback network and then I also told you how we can achieve multiplier using antilog, log amplifiers and using multiplier how we can achieve squaring, division and also square root. I would like to give you one more application of the operational amplifier with reference to the diode, absolute diode that we already discussed in one of the earlier lectures that is to form ac millivolt meter using an operational amplifier and a bridge configuration of the diode. That is what I wanted to discuss today.

I have shown the circuit here. It is almost clear to you. We have discussed this earlier. What I have done now is I have used a bridge rectifier. This is a bridge rectifier many of you are very familiar already. The output of the bridge rectifier I connect a milli ammeter, current meter and the other ends of the bridge rectifier are connected in the feedback of an operational amplifier and I have a R at the input which is connected to ground. It is in the non-inverting mode with the diode bridge in the feedback loop and the output of the diode connected to the milli ammeter the other ends of the diode bridge is connected in the feedback area.

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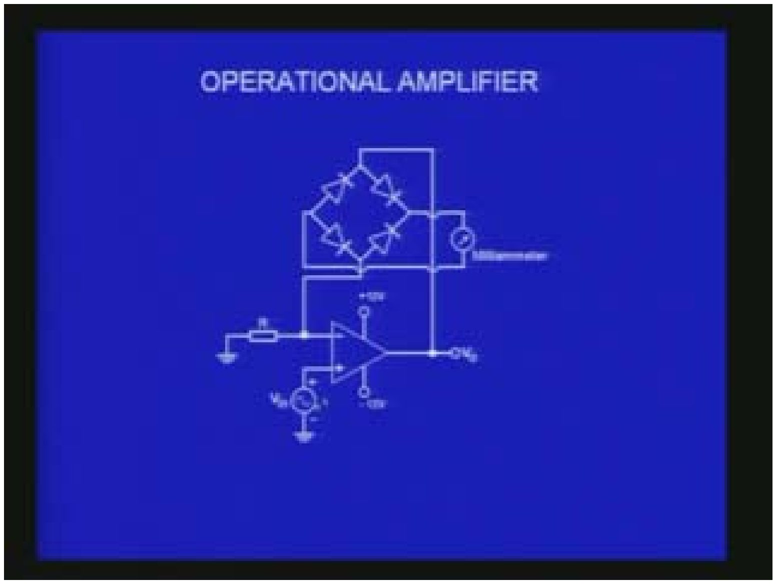

This is the V_{in}, input voltage that I give. We already saw the advantages of using operational amplifier along with the diode. When I use an operational amplifier along with the diode, normally the diode if it is a silicon diode, the cutting voltage is around 0.65 or 0.7 volts which is 700 millivolts. That means if I give a very low ac signal about 200 millivolts peak voltage then what is going to happen is even to make the diode conduct you require about 600 to 700 millivolts and there will be nothing which is coming out of the diode and because of that the diode will not be conducting well at the very low voltage. But if I use an op amp in the feedback and put the diode in the feedback then I can have reduction in the cutting voltage which will be 0.7 by A_{OL} which is the open loop gain of the operational amplifier. If it is 0.7 volts for silicon 0.7 divided by 10 to the power of 5 or 100 kilo thousands, which is a typical value of the open loop gain of the operational amplifier, then you get about 7 micro volts only as a cutting voltage. This is the same principle I am using in this case to form an ac milli voltmeter or microvolt meter. When I have very small voltages of the order of millivolts if I put the diode bridge then in the diode bridge you have two diodes conducting for one side of the ac, one half of the ac signal and the other two diodes are made use of during the other half cycle and because the diodes are coming in the feedback loop of an operational amplifier the cutting voltage of the diodes will be 7 micro volts each. 7 + 7 = 14 microvolt will be the voltage that will be lost to make the diode conduct in either direction and whatever input voltage I give will be available at the output with the corresponding gain factor corresponding to the non-inverting amplifier because the configuration that I used here is non-inverting amplifier. This R is there; the feedback effective resistance of this will come into the game and what you will see will be a very nice ac milli voltmeter made out of a basic operational amplifier and a diode bridge in the feedback. I have shown you a typical reading that we have taken using such a circuit. You have the input voltage which is varied from 100, 200, etc millivolts and the output current we have measured and when we draw a graph you get a linear graph.

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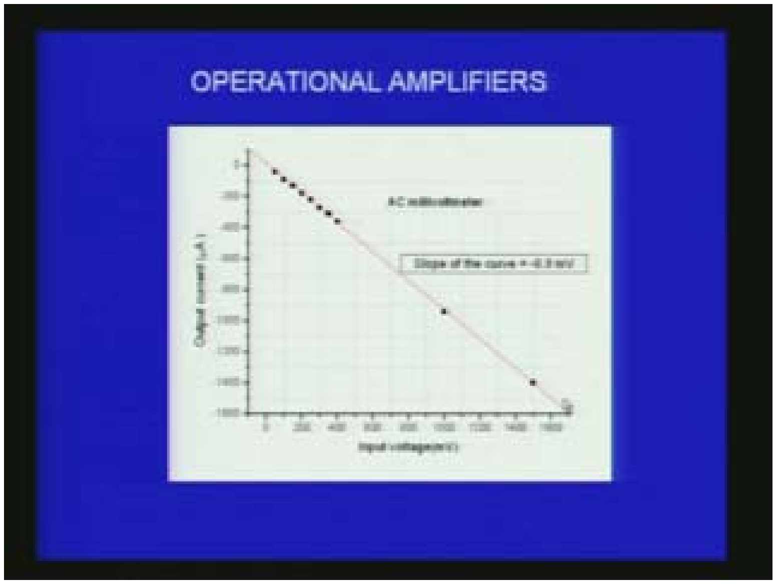

That means the output current meter can be directly calibrated in terms of the input millivolts that you want to measure. This becomes in that sense an ac milli voltmeter and we have done that in a very inexpensive way by using the operational amplifier which is not very expensive these days and the diodes which are also very, very cheap. By using this you will be able to have a very nice ac milli voltmeter constructed for our purpose and if you look at the slope of the graph, the red line that you see on the screen is actually the fitted line using the standard software. The points are all lying on the same straight line and the slope is around -0.9 millivolt. That is what I get in this typical case. You can try this type of circuit easily and then construct a very nice ac milli voltmeter. Now I would like to show you a demo of ac milli voltmeter.

I want you to see the circuit here. This is the bridge rectifier that I already mentioned to you using four diodes and that is coming in the feedback loop of the operational amplifier and you have a 1K resistor and it is grounded at the inverting terminal and the output of this bridge rectifier the two ends we connect a milli voltmeter. This is the milli voltmeter. This is the op amp and the input is given at the pin number 3 corresponding to the non-inverting. You see here the 4 diodes connected in the bridge configuration, the operational amplifier and this one k resistor which is connected to the ground.

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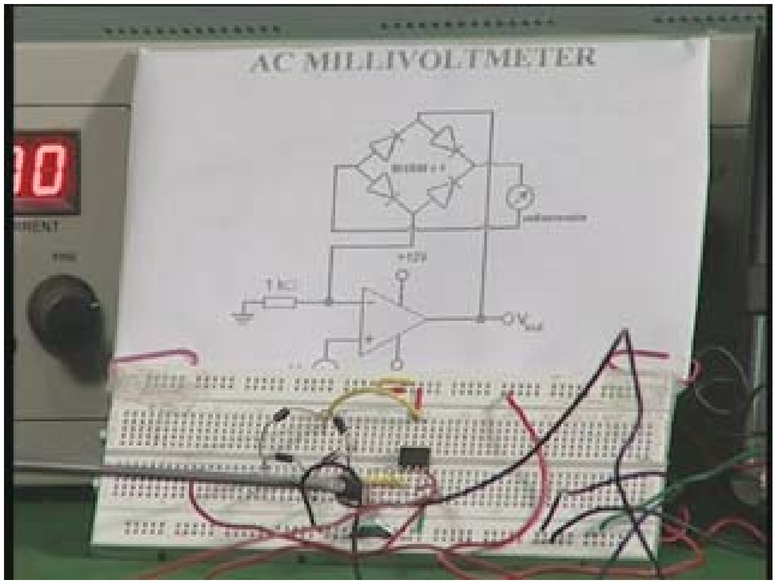

The same circuit is wired here and the multimeter here is in the current mode and it is in the milli ampere mode and it is in dc. Because output is going to be a dc this is the dc milli ammeter that is connected here. Multimeter is connected as the dc ammeter and on this side you have the voltmeter which is kept in the ac range and I have a signal generator which is now maintained at 100 Hertz approximately; 0.1 kilo Hertz that is 100 hertz and you can vary this output voltage and these are all for offset. We are going to use only this. This is for changing the amplitude and this is for changing the frequency. I am going to change this. I want you to see here at the input and correspondingly the output at the current meter. Let me know first increase it to bring it to about 100 millivolts approximately. This is about 100 millivolts. I have kept around 100 millivolts, 0.1 volt ac from the function generator at hundred hertz frequency.

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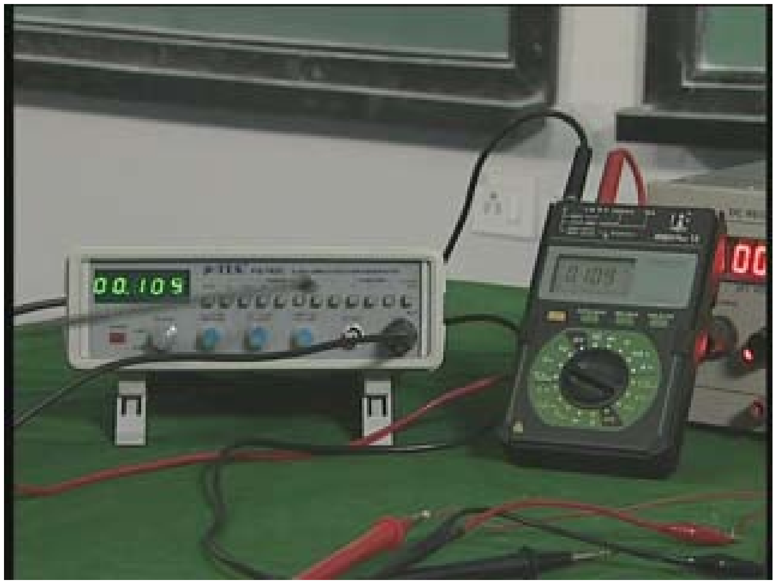

Let us see what is the output? The output is about 0.74 milli amperes.

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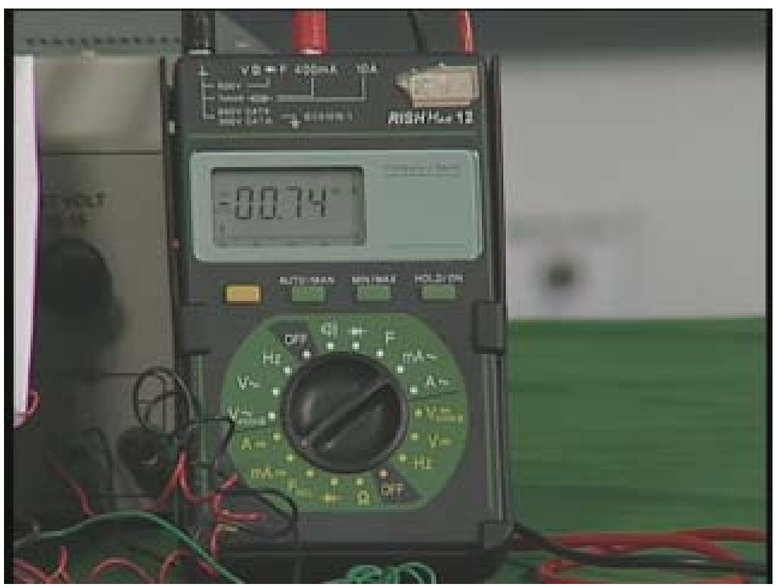

Now I increase the input to 200 millivolts let us say; this is about 200 millivolt and it is not changing. I have here 200 millivolts as the input ac and the corresponding output is about 0.18. That relationship is around 0.9. So 200 into 0.9 is about 180. That is what is shown here, 0.18. Now I increase it to 300. It is about 300; 300 into 9 it is around 27. It is about 0.278 here. I go to 400 millivolts or 500 millivolts. This is around 500 millivolts. It should be around 45 or 0.48 that you are getting. There is a relationship of about 0.9 between the input and output which is decided by the effective resistance of this 1 plus R_2

by R_1. That is the non-inverting amplifier gain. Even for 0.5 volts you are able to get output current which can be calibrated in terms of the input millivolts. I increase to 600 millivolts or 700 millivolts let us say. This is about 700 millivolts and that is around 60 milli ampere current. 0.60, that means 600 micro ampere current is what I get here. For very low voltages also you are able to get significant current which can be calibrated in terms of the milli voltmeter. This becomes an ac milli voltmeter making use of an op amp and a simple diode bridge. Using an op amp and the diode bridge we are able to make an ac milli voltmeter which otherwise will be very, very expensive equipment when you want to buy commercially. But if you slightly improve the performance by adjusting the offset you can get a very reliable performance of your ac milli voltmeter and it is very, very inexpensive and you can make it in a very easy method.

What we have seen in this lecture is three different aspects. One is a basic logarithmic amplifier and the other one is an antilogarithmic amplifier and I also showed how the logarithmic amplifier and antilogarithmic amplifier can be used for obtaining analog multiplication, squaring of the input voltage or square root of the input voltage or division of the input voltage and I also showed you the actual demonstration of an antilog and logarithmic amplifier. Finally I also showed one other application of the operational amplifier basically with reference to measurement of very low ac signals of the order of millivolts by using very simple configuration of a bridge diode as well as an operational amplifier. Using a bridge diode configuration in the feedback of an operational amplifier I showed you that we can construct a very simple ac milli voltmeter. When the input voltage is in very low voltages millivolts and micro volts the output can be a significant current and it can be calibrated that in terms of the ac millivolt and you can get a very inexpensive ac milli voltmeter made out of an operational amplifier and a diode bridge.

In the next lecture I would like to discuss about some of the filters that can be configured using operational amplifiers. They are called the active filters. We have already discussed the applications of filters when I discussed about the RC network earlier. You have simple RC networks and they can be used as filter but they are called as passive filters. You can also have active filters made out with the help of operational amplifiers. We will discuss the different configurations of the filter circuits using operational amplifiers in my next lecture. Thank you!