Electronics for Analog Signal Processing - I
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Lecture - 8
Analog Gate

We were discussing analog gate example in the last class and I had left the problem half way through. What we had was a source which was producing a triangular waveform with peak to peak value, plus 10 volts, minus 10 volts; and a triangular waveform. The control signal was at a frequency; if this is at 50 hertz, that was at a frequency which is 3 times more, 150 hertz. So, the control signal was of this time going to plus V c and minus V s, a square waveform.

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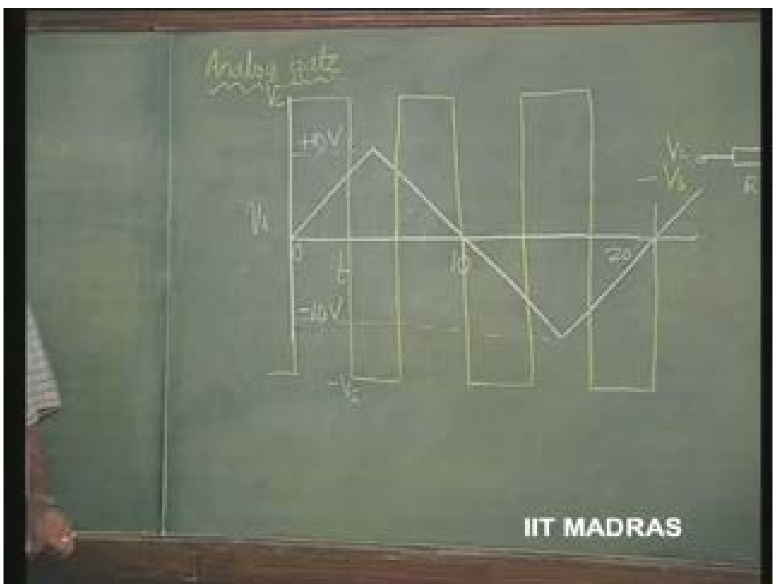

For us to design a proper diode bridge circuit as shown, wherein, the source with source impedance of 100 ohms is connected to a load of 1 kilo ohm here, this is the voltage, output voltage.

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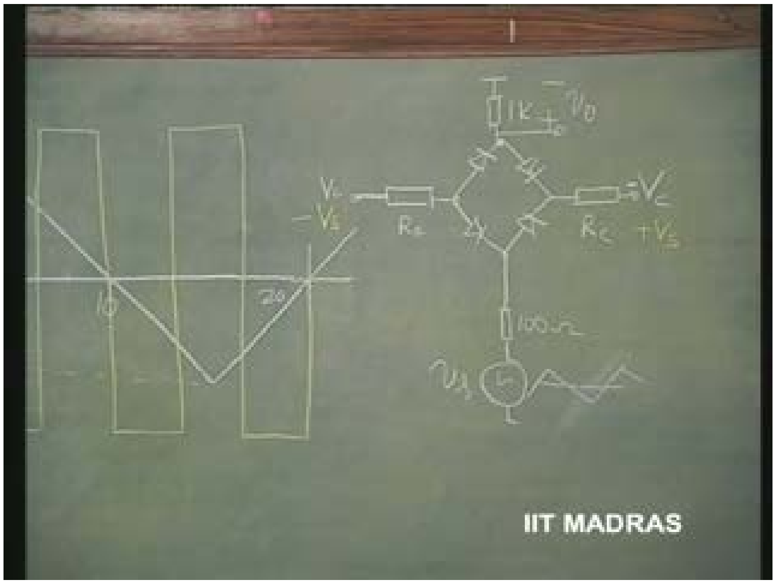

So, how to go about doing this? We have already discussed this scheme as to how it works, etcetera. When this is plus V c, this is the signal, let us say V here, they are control signal, this is how it is varying, goes to plus V c whenever we want this signal connected; and goes to minus V s whenever we do not want the signal to connect, get connected again. It goes to plus V c, minus V s, so on.

This is going to be minus V c. What we apply is going to be the other way about. Here, it will be minus V c and there it will be… That is, here it will be minus V c and there it will be plus V s, minus V c, plus V s, like that.

So, let us see what the waveform is going to be. If it works properly, then, the output waveform is something that is going to be this one that is going to be coming at this time interval. Nothing should come here. Again, this one will come at this time interval and nothing should come here and so on. This waveform is going to be there, this is not there, this waveform is going to be, this is not there, this is going to be there, this is not there; that is how it is going to appear, with an attenuation factor. What that attenuation factor depends upon how we select R c, etcetera.

Now, we have seen that the current in this is going to be V s divided by R s; plus, when all the diodes are conducting, the entire thing is going to be replaced by a short circuit. And, V c, etcetera can be grounded. V c, minus V s, etcetera can be grounded. We have seen that the resistance is R c by 2, parallel 1 K. Let us take R c. Let us just arbitrarily take R c as, let us say, 1, let us say, 1 kilo ohm. So, we have three 1 kilo ohms, coming in parallel, across 100 ohms. That means, 1 K by 3 is the resistance. That means, 1000 ohms by 3 is the resistance.

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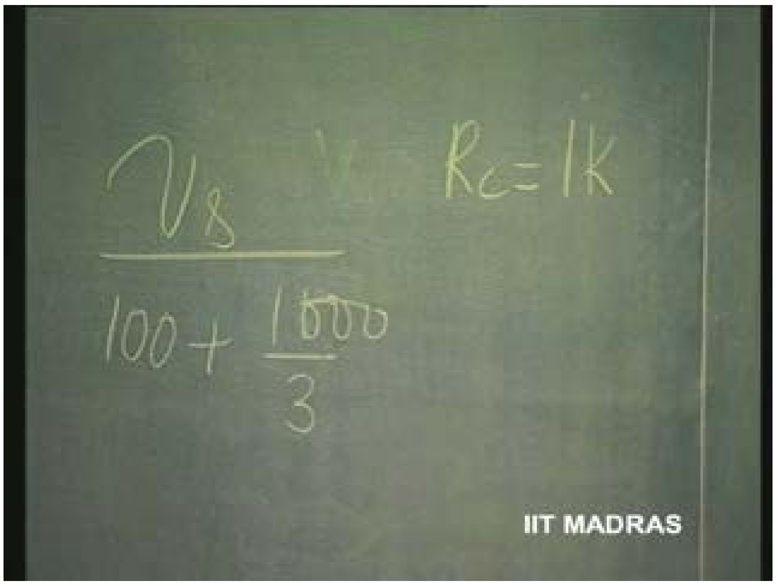

So, that is the current that is going to flow through the source and this is going to be divided equally through the diodes, in this direction, and in this direction. And that will oppose a current of - we have all under V c by R c. Here therefore, V c by 2 R c here. So, this is half the current that is flowing through the source, is going to flow through the diode; and that should be less than V c by 2 R c.

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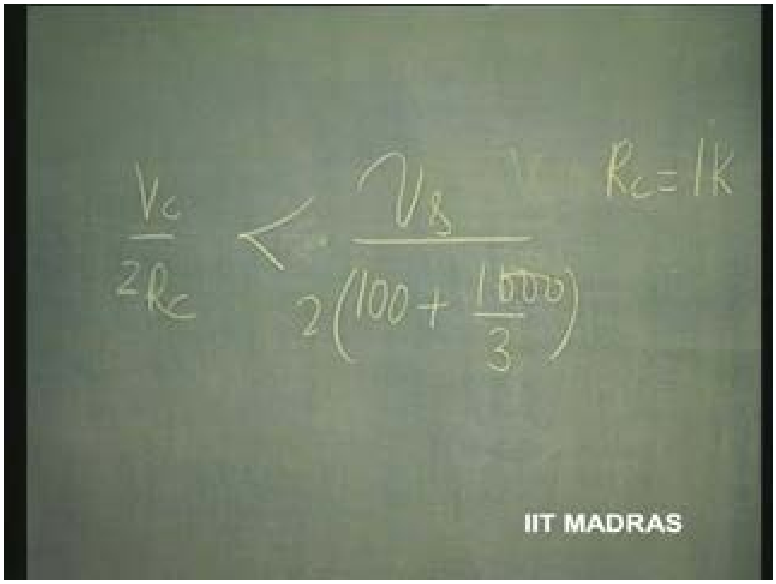

This is an important equation for the diodes to remain conducting. This, we had discussed in the last class. V c by 2 R c is the current that is going to maintain these diodes in conduction in this direction; and for these diodes, this signal current may oppose; these two diodes it is going to have.

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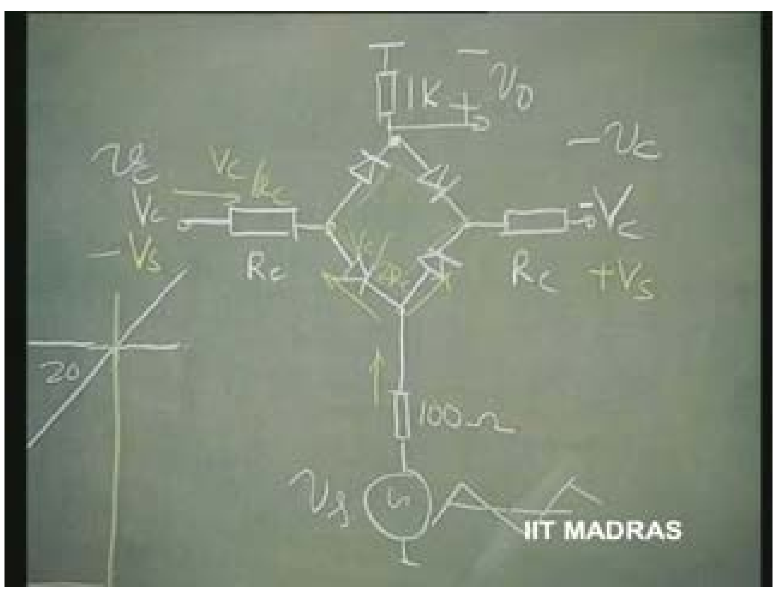

So, at any instant of time we must have V c by 2 R c magnitude, always greater than, greater than V s by 2, this one. So, V s maximum here is given as 10 volts. So, we have to consider the worst case situation; therefore, V c should be greater than 2 R c divided by 2 into 100 plus 1000 by 3. R c is already chosen as 1 K.

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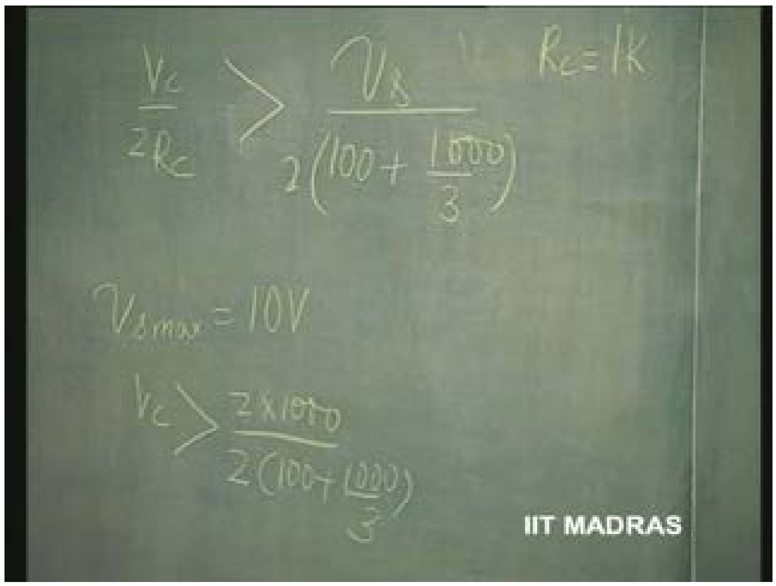

So, this is the equation. This into V s max 10 volts. So, we can see here that this is going to be the value of V c. The minimum value of V c that we should have therefore is going to be more than 10 volts, because of this factor - 1000 divided by 100 plus 1000 by 3. So, this is going to be greater than 3000 by 1300 times 10. That is the factor by which V c should be greater than 10 volts.

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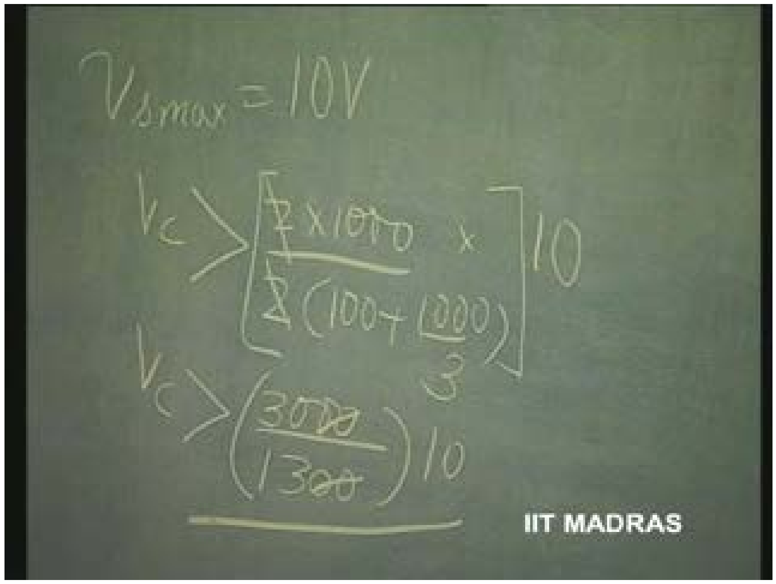

So, we should take care to see that this is the magnitude of V c that should be maintained; should be greater than this value, about 3 times this 10; that means 30 volts. And therefore, it all depends upon how you select the value of R c. Select the value of R c lower, then it is going to be lower; select the value of R c higher, ultimately, it can be three times that in this. All R cs' are made same as RL. And since RL is fixed, we do not have any other choice. So, in this case therefore, it is dependent upon the choice of R c in relation to R. So, this is the thing.

Now, if that is chosen like that, what about V s? V s is the one that prevents the diode from conducting. So V s, when you apply, all these diodes are open and V s appears here; and at that instant of time, if signal source is going to go to plus 10 volts and minus 10 volts, it should still remain reverse biased.

So, V s is very easily calculated as something which should be in magnitude greater than 10 volts; that is all. So, V s should be greater than 10 volts. So, this is the condition for our design. These are the two conditions, if R c is chosen as 1 kilo ohm.

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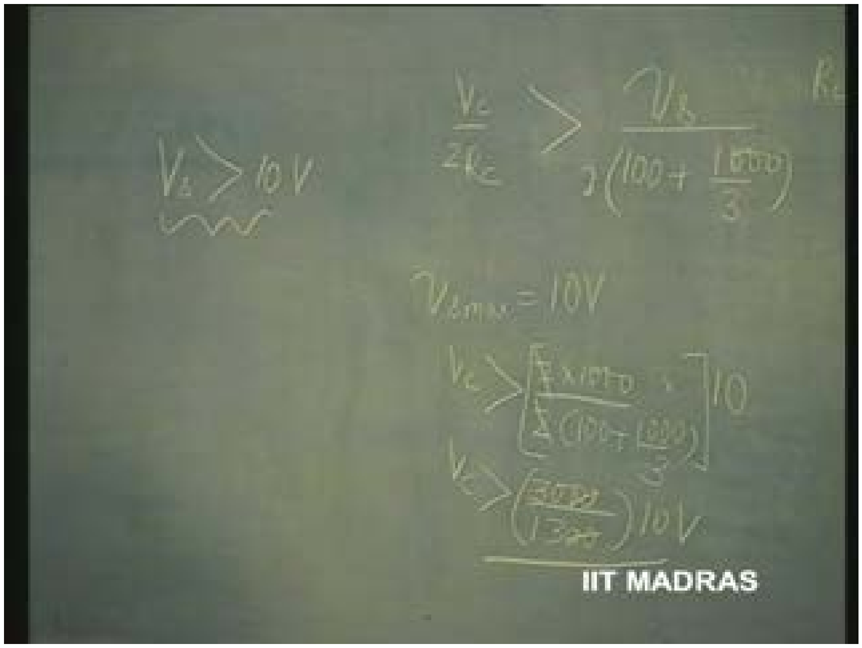

I would like you to try out by selecting R c as, select R c as point 5 K and get these two limits for the same problem. Select then, R c as 2 K and get these two limits. This limit remains unaltered; it is independent of R c. But this limit changes depending upon the value of R c chosen.

So, we can see how, by selecting now a value which is lower than this and higher than this, the value of V c is getting altered. So, please do this homework problem so as to understand how to design this important analog gate.

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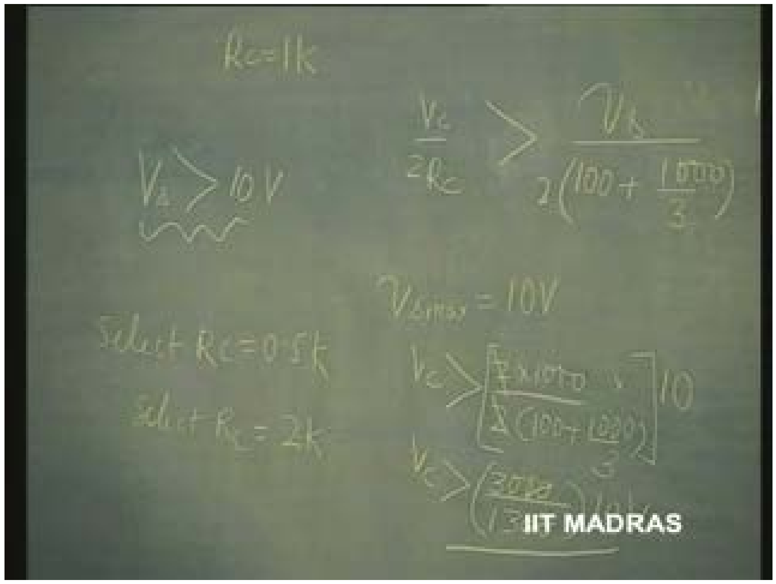

The output in the last problem is going to be therefore equal to effective resistance; that is, 1000 by 3 divided by the 100 plus 1000 by 3 times V s, after the design.

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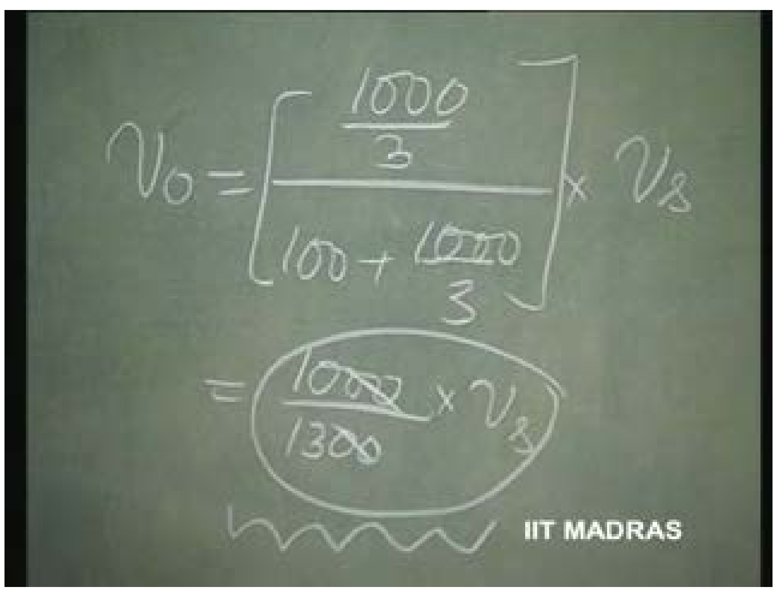

So, you are going to get this as 1000 divided by 1300. So, it is going to get attenuated to a certain extent. That is the output. It will not come as plus 10 volts, minus 10 volts; it will get attenuated, that is all. But, it is going to be connected or disconnected depending upon the control signal; so, this problem is an important aspect of analog gate.

Now, we will discuss about semiconductor diode and its characteristics with applications. So far in our discussion, we have assumed that the diode is going to be an ideal diode. What it means is, it is going to conduct in one direction and not conduct in the other direction. That means, it is a short circuit in one direction and an open circuit in the other direction.

We never bothered about the actual diode characteristics that the diode is going to have. We assumed that it is close enough to the ideal diode characteristics and analyzed all our previous applications that way. Most of the practical applications, this analysis is good enough; and you do not have to bother that the ideal diode characteristic differs from semiconductor diode characteristic.

But in the future applications that we are going to consider, I am going to exploit this characteristic for a variety of applications; this characteristic is that of the semiconductor diode characteristic.

What it is, we have already learned. What it is what it is? We will also now just remember that the current i of the diode, this is the semiconductor diode which is called a P N junction, P N junction; this way. So, positive here, this is forward biased for a current i diode and v diode. This is ((information)) (Refer Slide Time: 13:33) of current in this direction. So, P N junction diode is what we are talking about. Now, can we therefore use this characteristic for a variety of applications?

This also is very important. We have mentioned that this characteristic is going to be an exponential characteristic; that is, i versus v, i diode versus v diode. How will it look like?

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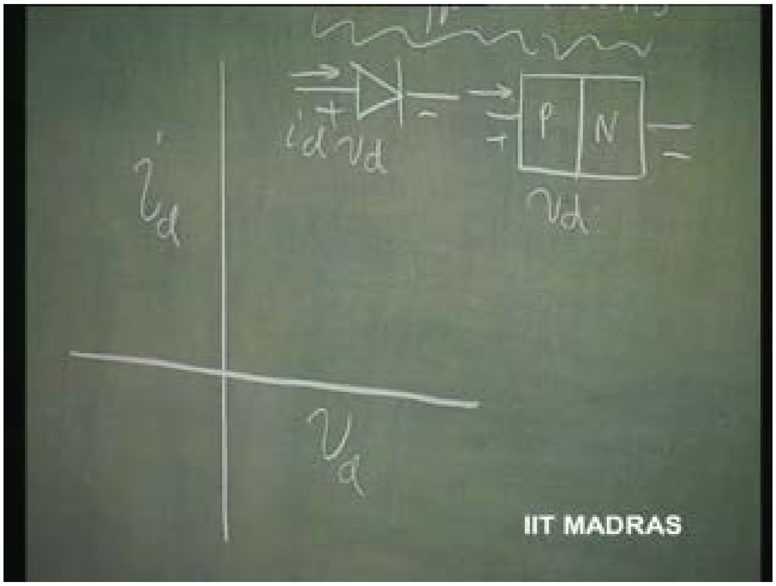

I have mentioned this. i d is equal to I s exponent v by eta V t minus one. eta is between 1 and 2. V t is 20, let us say, 6 millivolts at room temperature. This is also equal to Boltzmann's constant K into absolute value of temperature divided by electronic charge q. That is equal to 26 millivolts at room temperature of 300 degree Kelvin. So, please remember this: we do not have to bother about it. It is an absolute constant K over q; it depends upon and room temperature t.

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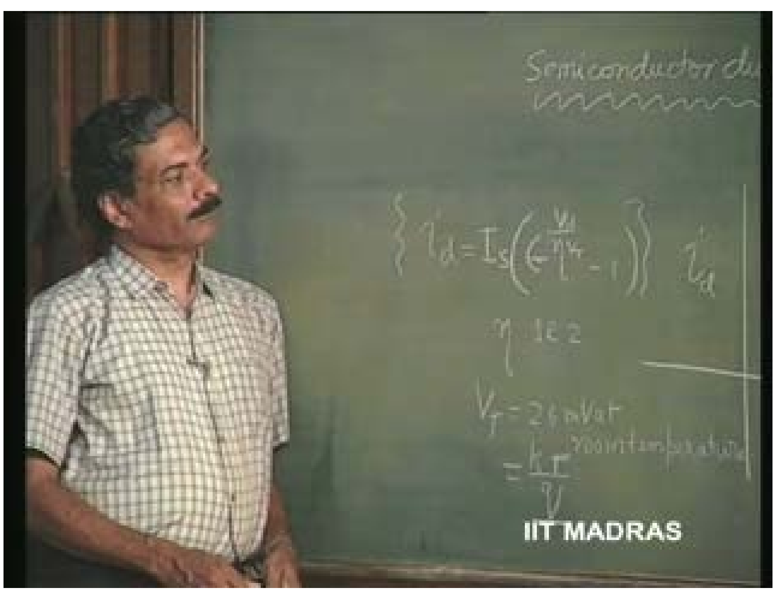

So, eta is a constant factor which is between 1 and 2. So, I s exponent v diode divided by eta V t minus one. This relationship is followed. This is the only device wherein this mathematical relationship is followed over several decades of variations of current; from micro amperes to several hundreds of milliamperes. Without any sort of problem, this relationship is followed faithfully; so, this is an important relationship in mathematics also, which can be used for signal processing.

The plot looks like … We have seen this. In forward direction, V d is, let us say, the forward voltage, it is going to be steeply rising; current is going to steeply rise as voltage goes on increasing. This region is typically of the order of point 5 to point 6 for silicon and there after it is going to be very low current.

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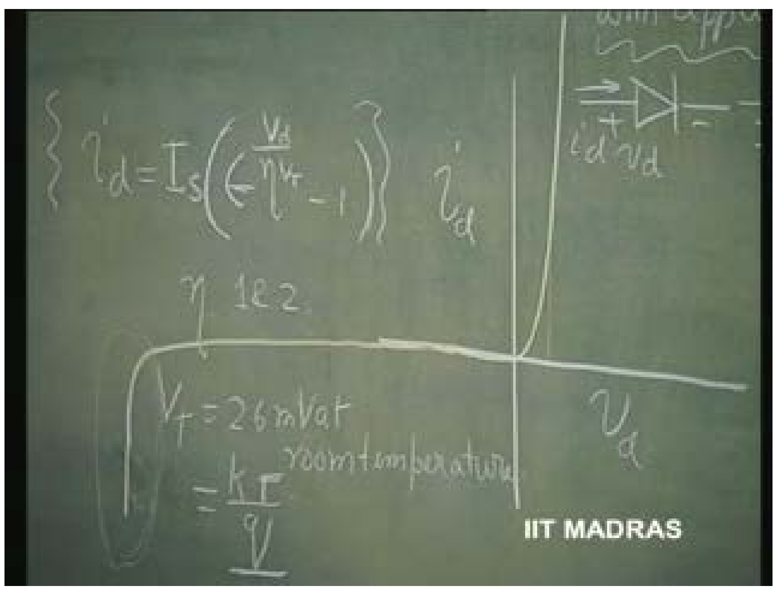

This is what is called reverse biased region; and at a certain point, may be, it is going to breakdown. At a very large voltage, it is going to breakdown. So, that also, we have discussed earlier. This region, it is called a Zener diode; breakdown may be formed by what is called an Avalanche phenomena or Zener phenomena; but these diodes which are used in this region are called Zener diodes.

The diode is, rectifier diode is, primarily used in forward biased and reverse biased region, where it does not breakdown. Earlier, we have mentioned that for our rectifier diode, the peak inverse voltage rating should be such that the diode never breaks down. Diode is always in this operating region. So, let us see how this relationship can be understood by us. If I diode is equal to I s exponent this thing, in the forward biased region, when V d is much greater than eta V T, this can be approximated; I diode is very nearly equal to I s exponent V d by eta V t.

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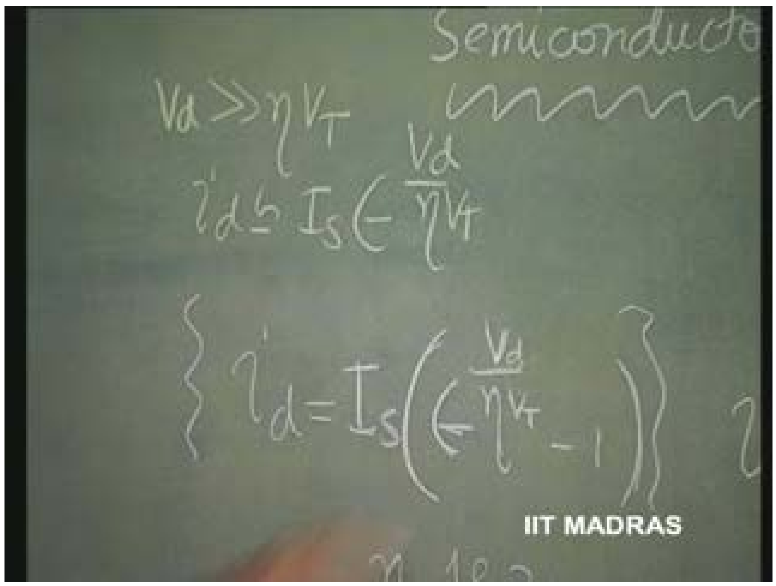

This one can be ignored compared to this exponential relation. That is why it increases enormously with current, with voltage. So, since this is of the order of 25 millivolts etcetera, by the time we have reached the V d of the order of 500 millivolts, this factor is coming out to be greater than about 20. So exponent 20 becomes very huge compared to 1; that is in the forward bias.

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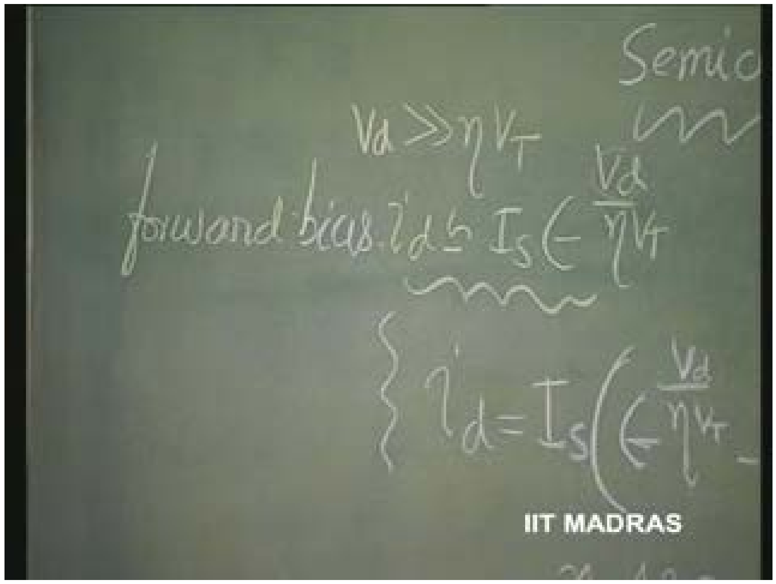

In the reverse biased region, V d becomes negative; so, exponent of a negative quantity fast goes to zero. So, i d becomes close to I s; minus I s because, the current flows in the opposite direction. This is called reverse saturation current or inverse saturation current. That means, in the inverse mode, the current gets saturated to a value of I s.

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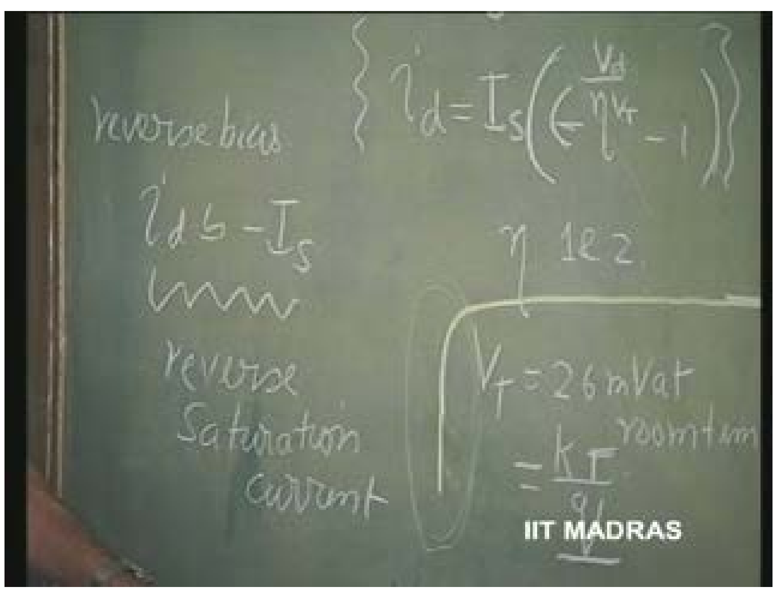

This is an important property of our semiconductor diode. That is, in the reverse bias mode, current gets saturated very fast to a value called I s, which is the reverse saturation current. Typically, this current may be of the order of picoamperes for most of the, let us say, small signal diodes, discrete diodes, this may be of the order of picoamperes.

Now, you can therefore imagine that this current, if it is of the order of milliamperes, this one can be clearly ignored; and, you can also say that for all practical purposes, almost low current source when the diode is reverse biased. When it is forward biased, we have i d equal to I s exponent V d by eta V t. You take log i; therefore, exponent V d by eta V t equals i diode by I s, in the forward biased region. Therefore, if I now take log, natural log, V d divided by eta V t is equal to log i d by I s.

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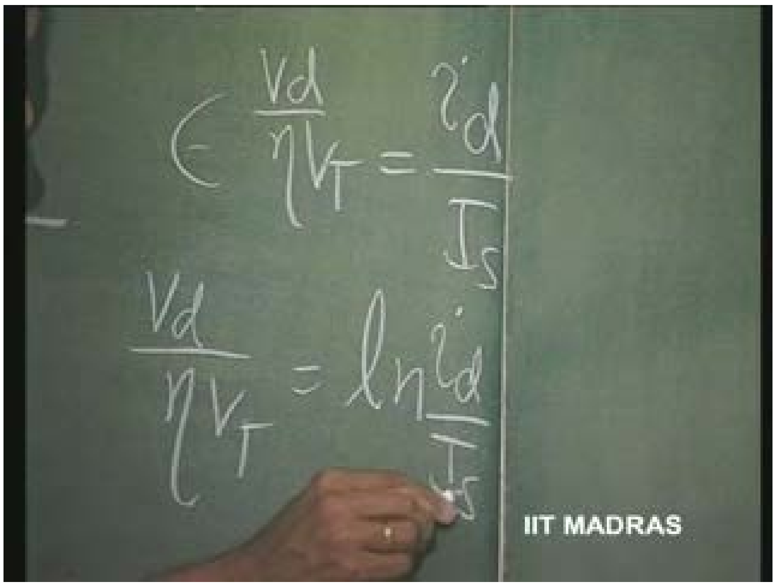

Or, V d, voltage across the diode, can be expressed in terms of eta V T log i d by I s. So, it can be used for logarithm operation. This is an important device whose current and voltage are related by natural log. So this can be used for log operation. So, this is one of the important application of the diode, since the diode of the voltage is logarithmically related to diode current in the forward biased region; please remember this.

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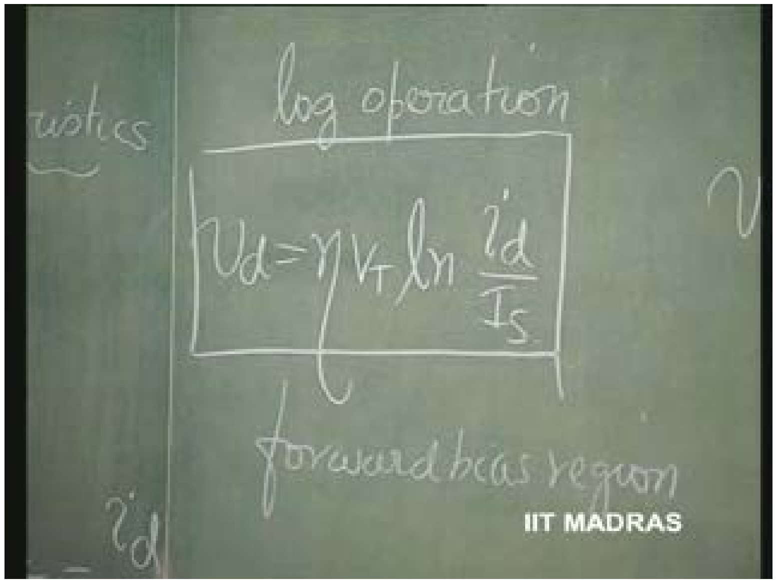

This property is also used for what is called data compression. Now therefore, the current can vary by a huge magnitude from microamperes to milliamperes, the voltage only changes by few hundreds of millivolts. So, the data can be compressed. So, this is also used for data compression. The log operation is suitable for data compression.

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Then, after doing data compression and then processing the signal etcetera, you would like to bring back the data to original state. That can be done by antilog operation, which is, i d equal to I s exponent V d by eta V t; this is nothing but antilog operation.

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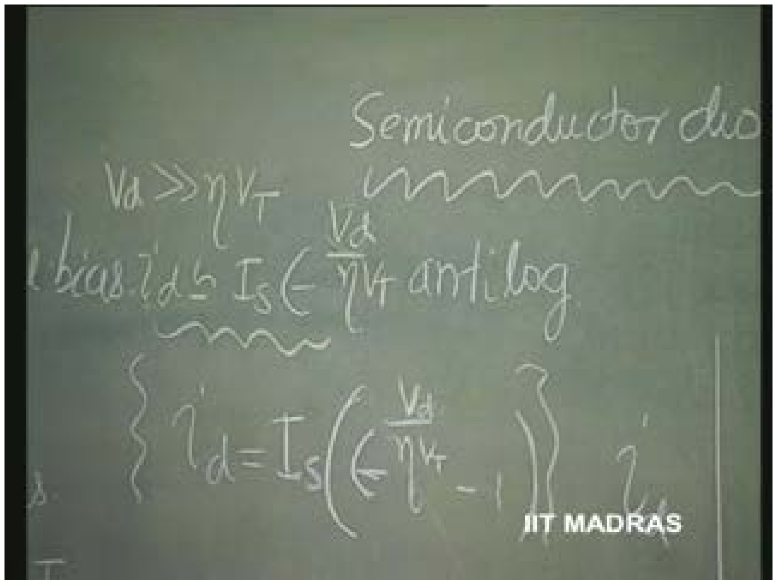
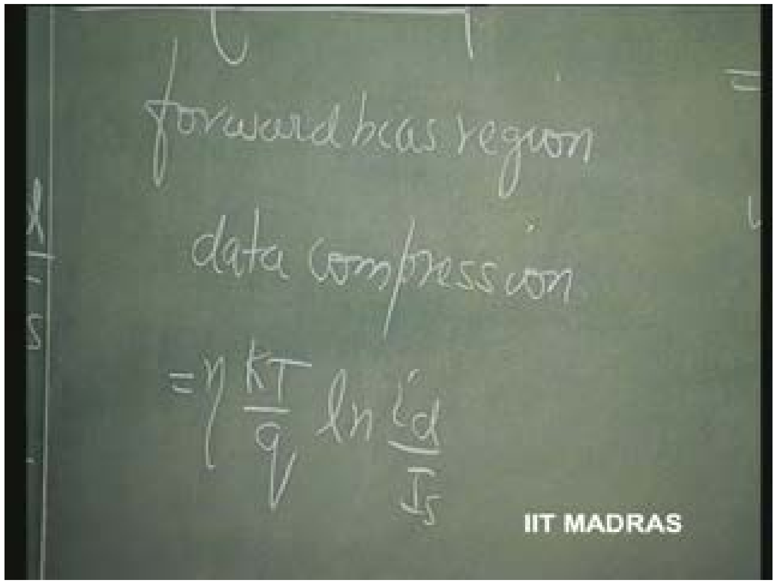


So, log operation and antilog operation can be easily performed by this famous element which is the semiconductor diode; one of the most important applications of the diode, semiconductor diode.

Next, let us look at this. V d is equal to eta V t log i d by I s. So, V t is nothing but K t over q.



If I use two identical diodes, then, we will have V d 1 equals eta K T over q; this is same for both the diodes; then, log i d 1 by I s. Identical diode means what? They have identical values of I s, reverse saturation current; then, the second diode will have V d 2 equal eta K T by q log i d 2 by I s.

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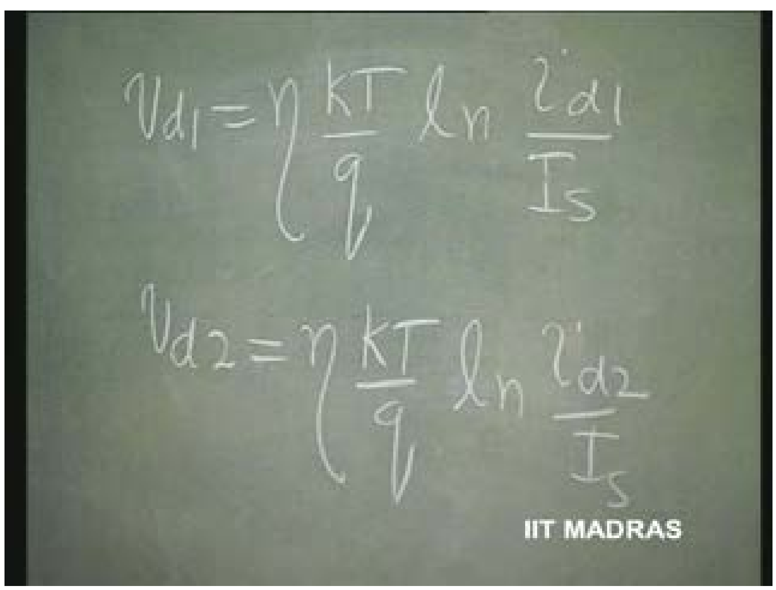

So, these two values of I s remain the same because they have identical characteristics. Such a feature is possible in all integrated circuit components. You subject the diodes manufacture to same operating conditions, same sort of temperatures and same process conditions, etcetera; so the manufacture diodes have I s perfectly matched. Then, if they are operating at two different currents, the voltages will be V d 1 and V d 2.

If I now take V d 1 minus V d 2, then, you will get this as eta K T over q log; this minus this, which will be i d 1 by i d 2. log x minus log y is log x by y; so log x minus log y, because, eta K T by q is common; log x divided by y is – I s I s gets cancelled; so, it is only dependent upon the operating current.

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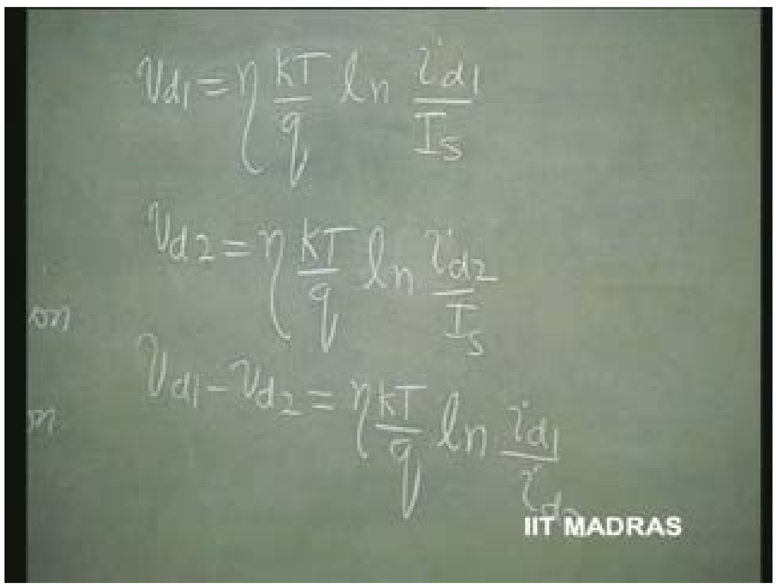

So, if I operate one diode at 1 milliampere, another diode at point 1 milliampere, I can have this as a constant; eta K T q divided by log 1 milliampere by point 1 milliampere, log 10.

So, this is a nice technique of measuring temperature very accurately, because, K over q is constant, eta is a constant; T, if it now starts varying, you can use this as a thermometer, a very accurate thermometer to measure temperature. So, in integrated circuits, this method is used for obtaining what is called temperature transducer.

You can put this i c containing nothing but two diodes with amplifiers, etcetera. We can amplify this by a factor of 100 or so, so that, its sensitivity is increased. So, this i c is placed on your forehead; it will read the temperature directly. So, this kind of structure can be sort of established by just using two diodes which are biased to operate at two currents.

Let us see how the circuit arrangement looks like. So, this diode has a current of, let us say, 1 milliampere and this has, let us say, point 1 milliamperes current; then, the voltage across this is V naught, which is this. This is going to be eta K T over q log 10. It is a nice thermometer for you and therefore this diode as a thermometer is quite commonly used in instrumentation applications, etcetera.

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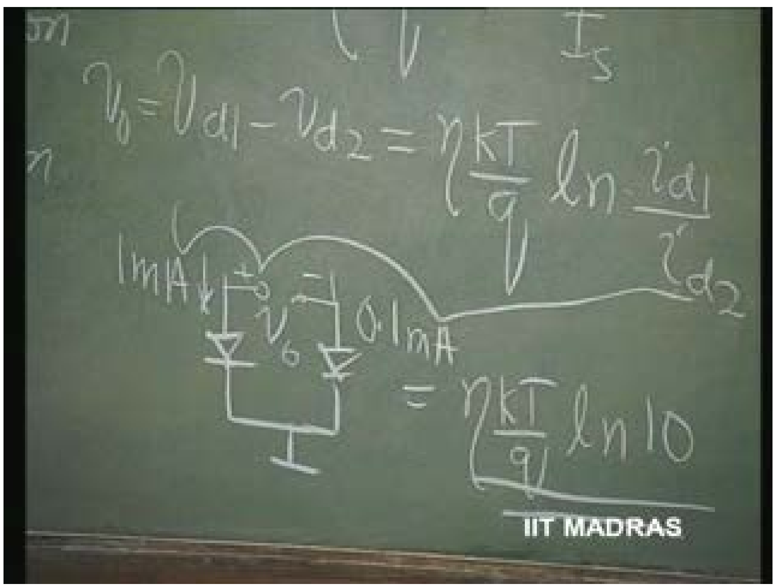

And we can see, the simple application, merely based on the exponential relationship of the semiconductor diode.

Now, let us try to understand the principle of the diode temperature transducer by working out an example.

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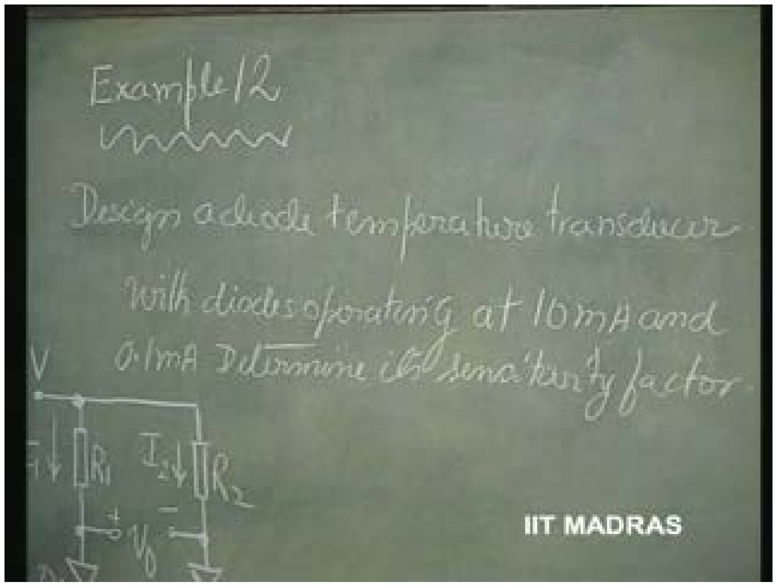

Design a diode temperature transducer with diodes operating at 10 milliampere and point 1 milliampere. Determine its sensitivity factor. So, this illustrates how one can go about designing such temperature transducers or thermometers very easily by using a pair of diodes which are having identical characteristics. These kind of diodes are easily available nowadays because we have matched pairs of transistors available; and the transistor’s base to emitter junction itself is used as a diode.

So, let us assume that we have two diodes whose characteristics are taken to be identical; that means, they have the same value of I s, reverse saturation current, and both of them are forward biased by means of a voltage, v positive; this is a positive voltage.

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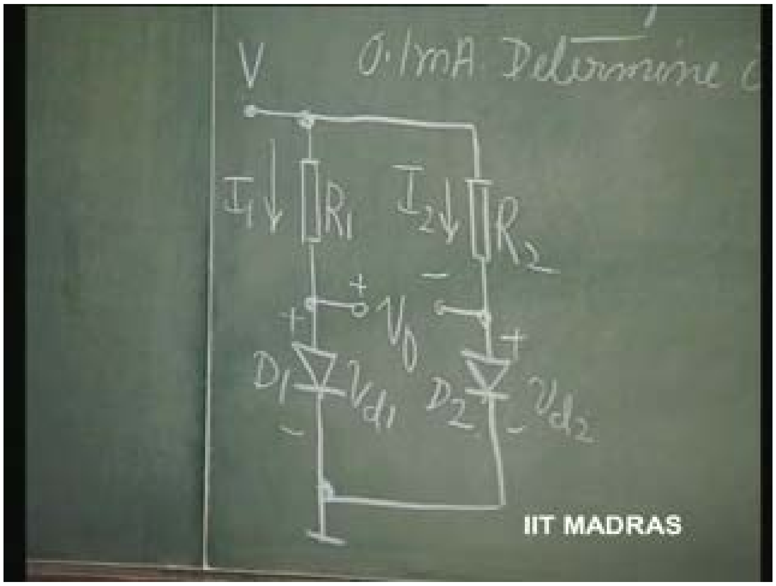

So, the current in this diode D 1 is I 1 and current in this is I 2. So what is I 1 equal to? I 1 is equal to, let us say, V minus V d 1; that is, the voltage across the diode is V d 1, and this is V d 2, V minus V d 1 divided by R 1; that is current I 1. Current I 2, once again is, V minus V d 2, that is, the voltage across R 2; V minus V d 2, divided by R 2.

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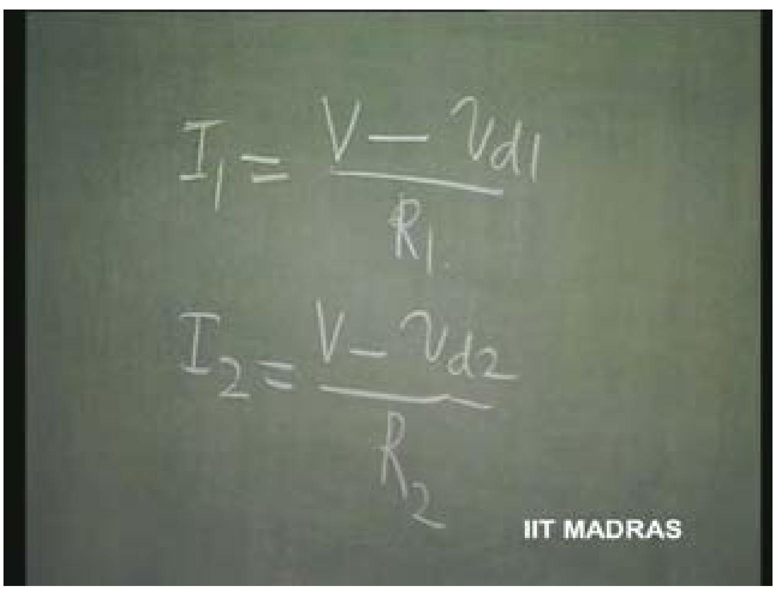

So, now, we are in a position to find out V d 1, is going to be equal to, we have from our earlier this thing, eta V T log, current through the corresponding diode I 1, divided by I s. V d 2 is going to be therefore, similarly, eta V T log I 2 by, the same value of I s, because they are identical.

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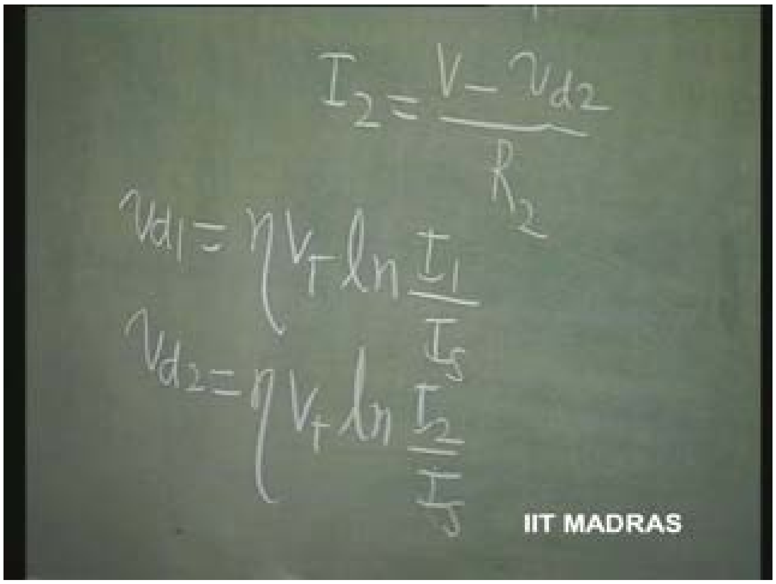

So, V d 1 minus V d 2 is nothing but V naught. This V d 1 minus this V d 2 is V naught, which can be measured by any differential amplifier; we will see how such things can be designed later. eta V T log I 1 by I s minus eta V T log I 2 by I s, which is eta V T log I 1 by I s minus log I 2 by I s, which is, eta V t log I 1 by I 2; I s, I s, getting cancelled here.

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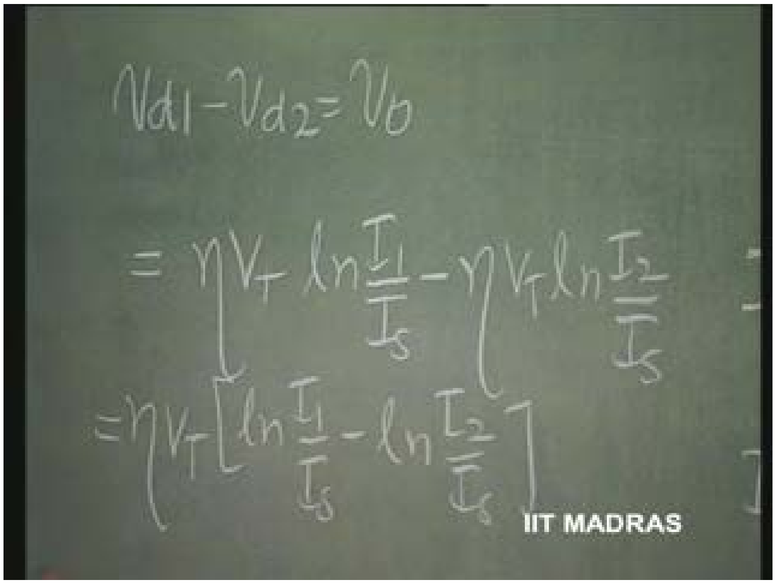

So, this is the output voltage. So, this is eta into K T over q, V t being K T over q, log of… Let us now see what I 1 is. V minus V d 1 by R 1; that divided by I 2 which is V minus V d 2 by R 2…

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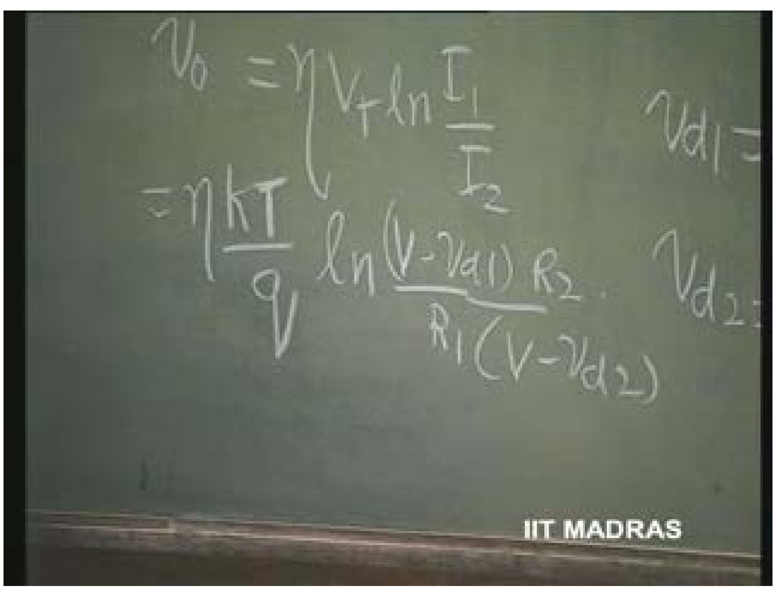

…which is now therefore going to give us V naught, which is eta K T by q which is good, proportional to temperature, into, log of R 2 by R 1, plus the ratio of the resistance which we can fix depending upon what we want, plus, log of V minus V d 1 by V minus V d 2.

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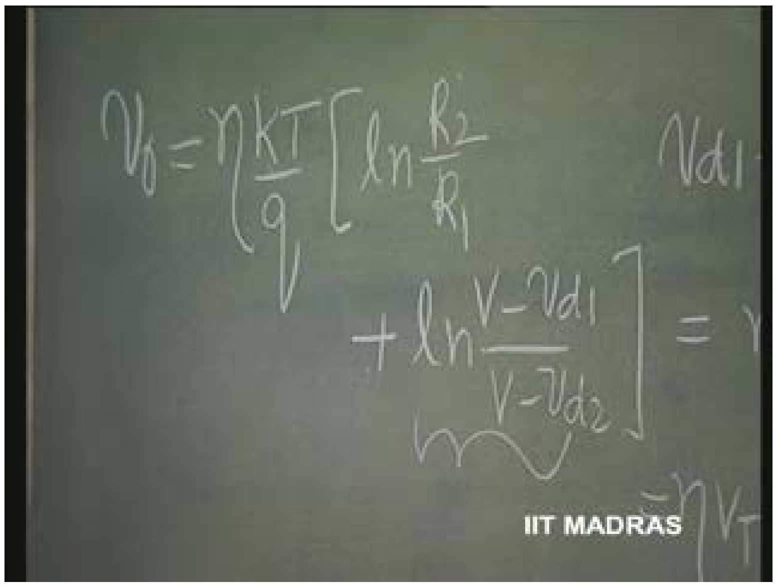

It is important to remember that if V is chosen to be very high, V is chosen to be very high compared to V d 1, what is the order of V d 1 and V d 2? I have told you earlier that the diode gets forward biased and the order of this forward voltage for silicon diode is typically between point 5 to point 7. So, that is called as the cut-in voltage, V gamma, is going to be between point 5 volts to point 7 for silicon; who so ever manufactures this, this is the order of voltage, forward bias voltage, of a diode.

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So, you can see that if I make, select the value of V, something which is greater than even 10 times that, about 5 to 7 volts; so, let us say, V is made equal to 10 volts. Then, this is 10 minus point 5 divided by 10 minus some point 51 or something, which may be slightly different. That means, it is close to this ratio; it is close to one; that means, this is close to zero already; log of 1 which is zero. So, you have this very neatly coming as… So, that is the output voltage; ratio of resistance to eta K T by q.

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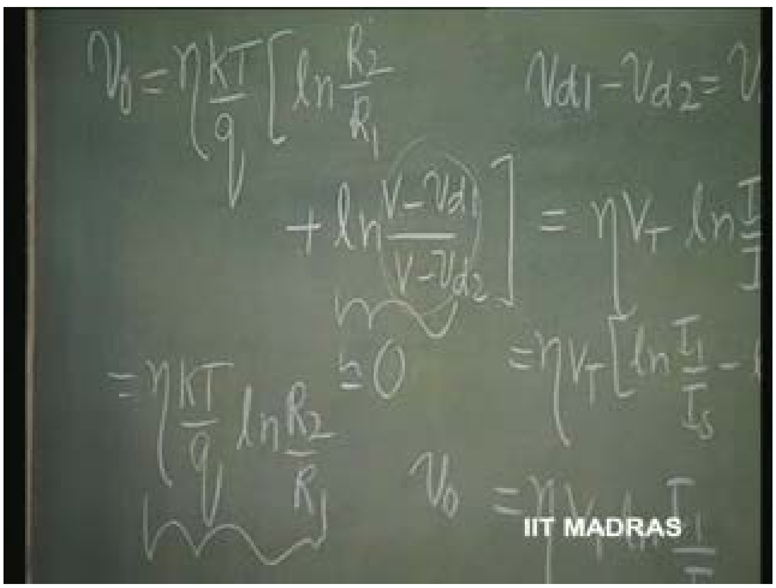

What is the sensitivity? Delta V naught by Delta T is called the sensitivity of this transducer to temperature variation. This is nothing but eta K over q into log R 2 by R 1.

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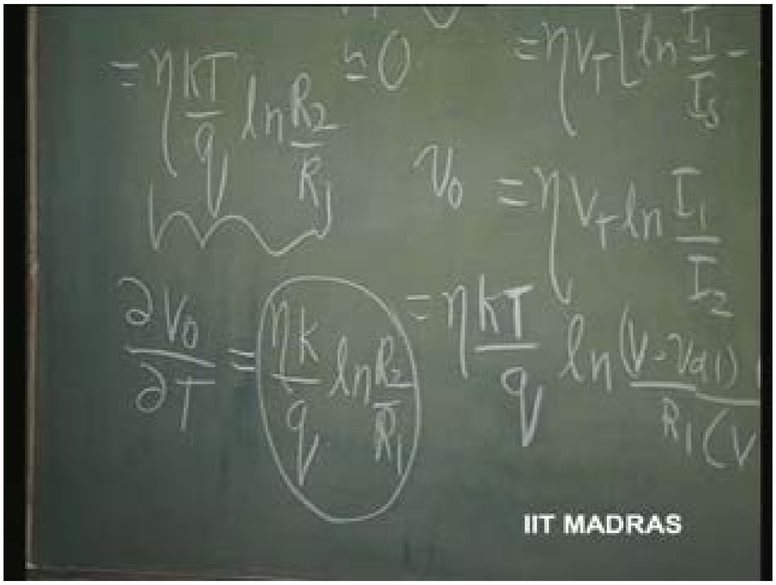

So, this is an important factor which you can fix depending upon what you want by selecting R 2 by R 1 appropriately; you can fix the sensitivity of this as a very good temperature transducer.

In this problem, let us see. What do we want? We want to fix the current in one diode as, let us say, 10 milliamperes; in the other as point 1 milliamperes. We can ignore this, as long as we select this, greater than, much greater than point 5 to point 7 volts, which is the cut-in voltage of the diode.

So, we have selected, for example, this as 10 volts. So, if this is 10 volts and I want a current of, let us say, 10 milliamperes flowing in this; if I ignore this, current is 10 volts by R 1; so, 10 by R 1 is approximately equal to I 1, and that is going to be equal to 10 milliamperes, let us say. So, R 1 is going to be 1 Kilo ohms. Design is over.

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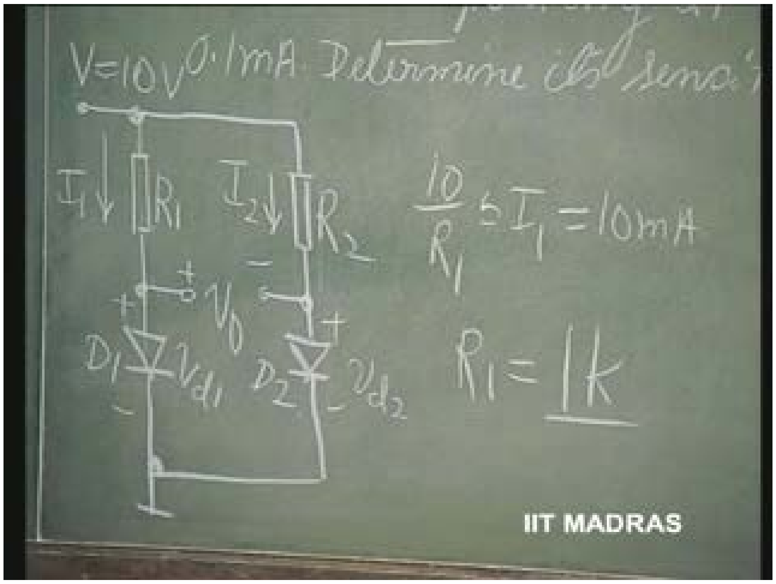

Next, I 2 has to be again fixed. Again, 10 minus V d 2, which is negligible compared to 10. So, 10 by R 2 is approximately equal to I 2; and that is equal to point 1 milliamperes; which means, I, R 2 is equal to 10 by point 1 K, which is 100 Kilo. So, the design is simply over.

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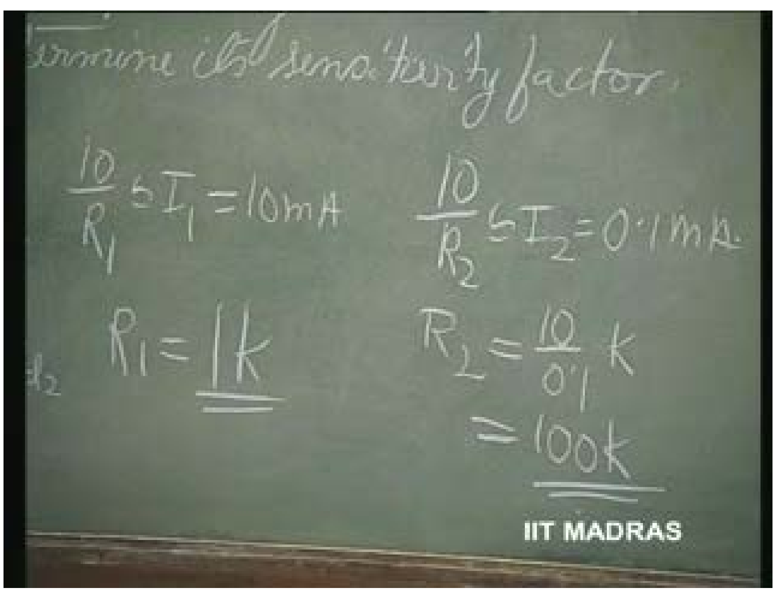

If I make this, R 1 equal to 1 K and R 2 equal to 100 K; so, this sensitivity Delta V naught by Delta T is going to be eta K by T log of R 2 by R 1, which is 100 divided by 1. So, this is eta K by q which is nothing but, you can write this, rewrite this as eta K T by q. eta K by q can be written as eta K T by T into q; which itself is going to be nothing but eta V T by T into log 100.

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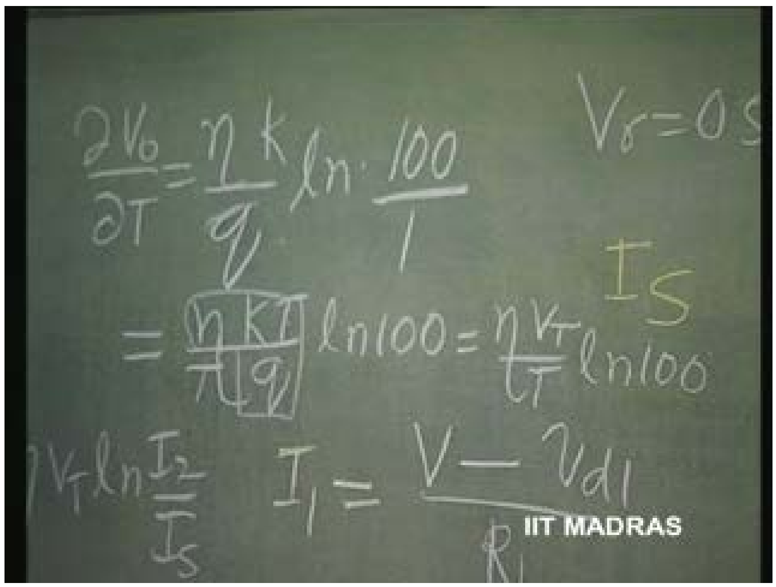

So, V T at room temperature is known to you, 26 millivolts; T - 300 degree Kelvins; eta is ((1 or 2)) (Refer Slide Time: 37:19); log 100 is the sensitivity factor. You can evaluate this mathematically as equal to 1 to 2, let us say 1, into 26 millivolts, log 100 divided by 300 degree Kelvins. This is the sensitivity factor, numerically. Please evaluate this and see for yourself how much it is.

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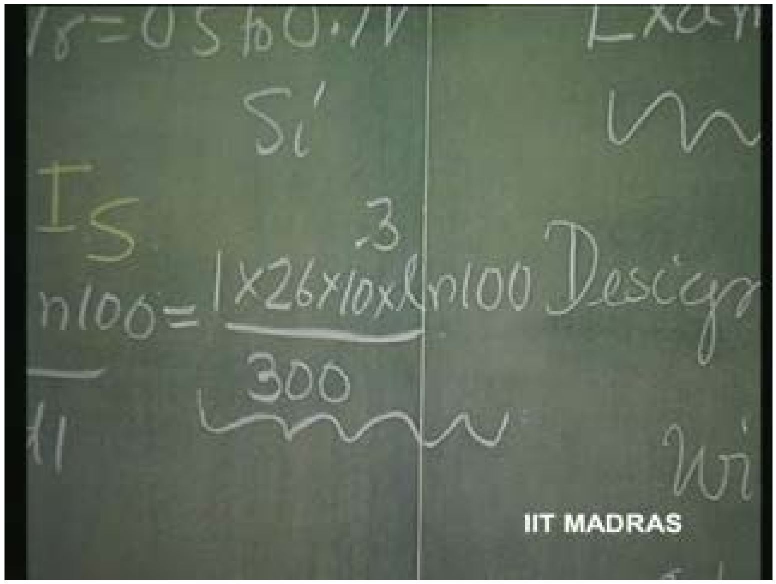

So, the problem is neatly solved in terms of a circuit that comprises of a pair of identical diodes with R 1 equal to 1 K, R 2 equal to 100 K, with a sensitivity factor of this much.

Let us now focus, further our discussion into the forward biased region of a diode. That is why I am expanding that region. This region is the region where it is following the exponential law, where we can make an approximation that I diode is equal to I s exponent eta V T; that is, V diode by eta V T; that one can be ignored. And in return, we can rewrite this waveform, this voltage, as V diode is equal to eta V T log I diode; either this or this.

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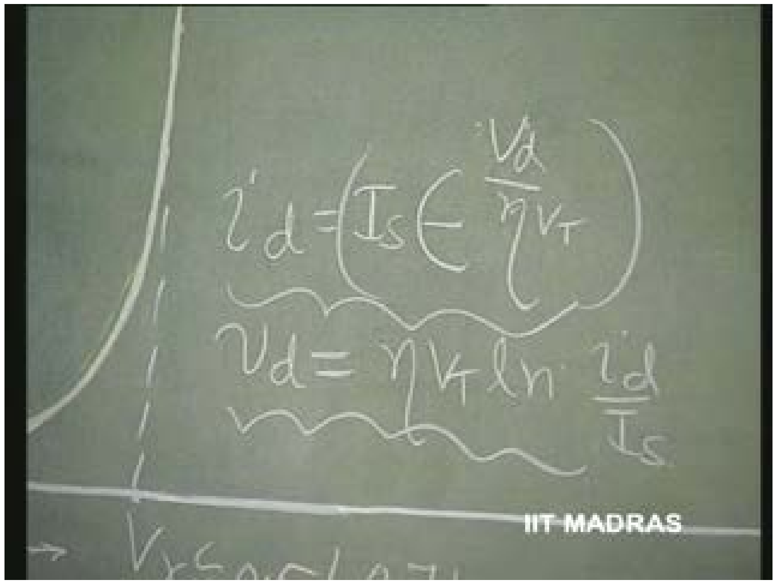

This we have understood; and we have seen some of the applications. Let us now further see other uses of this diode. When it is forward biased, we say that the voltage across the diode is eta V T log i d by I s. But, I s delivers current or inverse saturation current, we have called this. This is heavily dependent upon temperature. That is why people say that it doubles for every 10 degrees rise in temperature; that this I s doubles for every 10 degree rise in temperature.

So, if you look at the diode characteristic, therefore, since I s doubles for every 10 degree rise in temperature, we can say that, the voltage characteristic, now this, it is dependent upon I s, into exponent V d by eta V T. For the same voltage, I can get higher current; for the same V d, eta V T remains constant. Since I s doubles for every 10 degree rise in temperature, for a higher temperature, if I draw the characteristic, it will be almost, it is not seen here, but in the forward characteristic, it might go like this.

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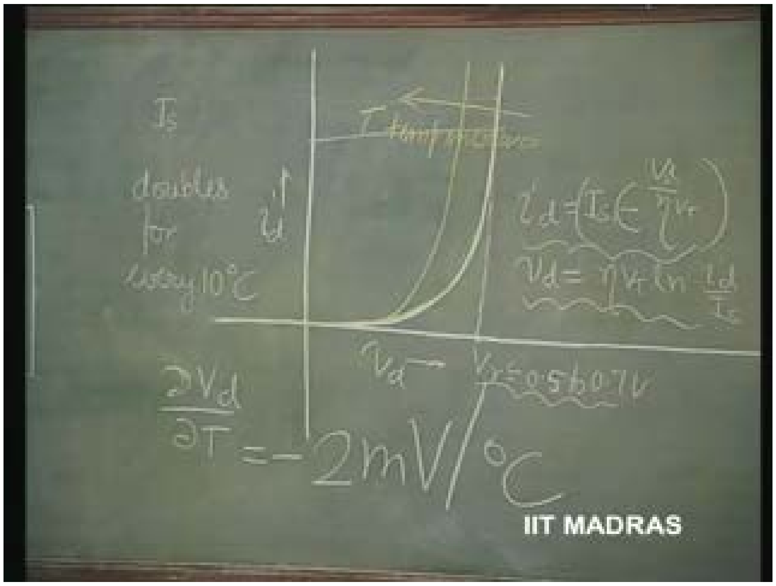

So, as temperature increases in this direction, this characteristic moves. So, it is the diode voltage, if the current is maintained constant, let us say, current is maintained constant, then, the voltage across the diode is going to shift towards the y axis. And this temperature coefficient, this is Delta V d by Delta T. For silicon, diode is equal to, it is an important thing, minus 2 millivolts per degree centigrade rise in temperature, minus 2 millivolts; 2 to, minus 2 to minus 2 point 5 millivolts degree, per degree centigrade rise in temperature. This itself therefore can be used for temperature measurement.

And this is used again for scientific application, particularly at slope in temperatures, because this diode cannot be used for very high temperatures anyway because silicon material itself cannot be used. Therefore, for low temperature measurement, this can be very nicely used; just a diode, because its temperature coefficient is going to remain almost constant and it is about minus 2 millivolts per degree centigrade.

That is the temperature coefficient of a diode which is biased at constant current. So, it is going to shift; characteristic is going to shift this way. Please remember this. This is also used for temperature measurement and control applications.

So, I s doubles for every 10 degree centigrade; because of this, the diode which is biased at a constant current has its forward voltage v d changing with respect to temperature with a negative temperature coefficient of 2 millivolts per degree centigrade.

Now, the cut-in voltage; that is, if extend this exponential thing like this, it almost is a straight line and it cuts this axis. This voltage is called cut-in voltage; for silicon diode, it is about point 5 to point 7.

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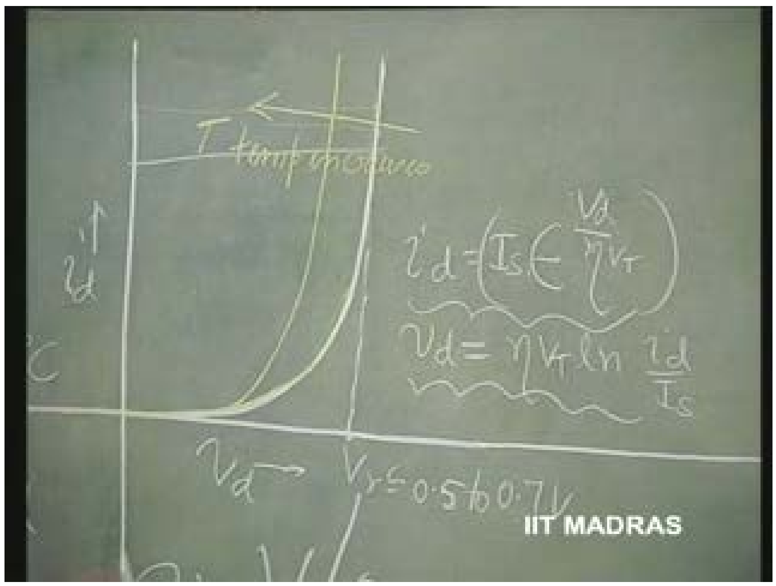

That means, I can assume that diode is almost conducting fully; that it is short circuit; really not a V d equal to zero but at a voltage of about point 5 to point 7 volts. Until point 5 to point 7 volts is reached, current is not substantial; thereafter, current is going high, which means, I can make another approximation to a diode saying that up to point 5 to point 7, current is almost negligible, and thereafter, current is increasing very fast. Therefore, it is a short circuit after point 5 to point 7 volts is reached; that is, the cut-in voltage.

These are the important parameters that you should remember for silicon diode and therefore, suppose therefore I say that voltage v of a circuit connected like this with a resistance R in series with a diode which is forward biasing; the diode is given to you. Let us say, voltage V is 5 volts and resistance R is 1 Kilo ohm and I am connecting a diode whose characteristic is like that. Determine the current through the diode.

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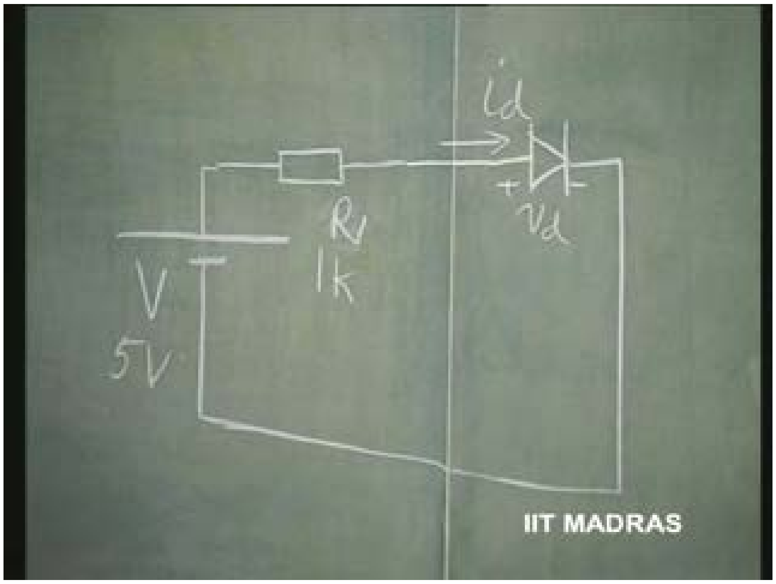

How will you go about doing it? Now, let us follow this very strictly. I say that it is not a semiconductor diode; it is an ideal diode. Then I know that whenever it is forward biased, v d is zero.

So, then, current in the circuit, I diode is therefore approximately equal to 5 volts by 1K, which is approximately equal to, this is approximately equal to, 5 milliamperes. This is first order of approximation in a diode circuit, which is forward biased. What it says is this diode dropped is that of the ideal diode and therefore it is zero.

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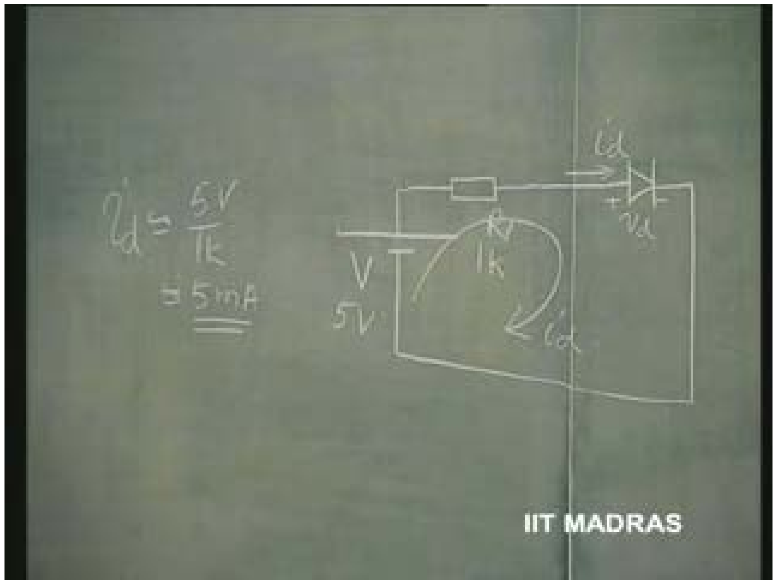

Then, I say that it is a semiconductor diode. Then, immediately, it comes to our mind that it is between point 5 to point 7; so, let us assume it has point 6 volts.

So, V gamma is equal to point 6 volts. So, let us therefore now evaluate the current. So, it is 5 volts minus point 6 divided by 1 K. This is the diode current, second approximation, which is nothing but, 5 minus point 6 is 4 point 4 milliamperes. So, this is more accurate than this; but anyway, an idea about the current is already got here as 5 milliamperes. This is more accurate in this case because it is coming out as 4 point 4 milliamperes.

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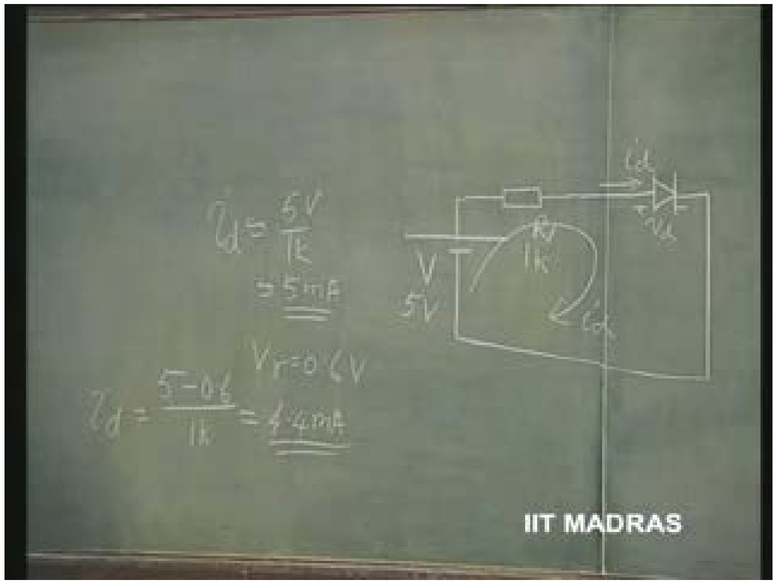

I want the current very accurately. So, what do I do now? I know that the diode characteristic follows this. So, i d is equal to I s exponent V diode by V T; this is known to me. I s, if it is given, I can find out what this is going to be, this is the characteristic given.

So, and also, we know that V minus v diode, whatever it is, which we have taken here as point 6, here as zero; it is not exactly zero, it is point 6, but not exactly point 6; it depends upon this equation. So, this is the actual current; V minus v d divided by R; that is the actual current. And v d is nothing but V minus, we know that, let us say, we can even put eta, eta V T log i d by I s divided by R.

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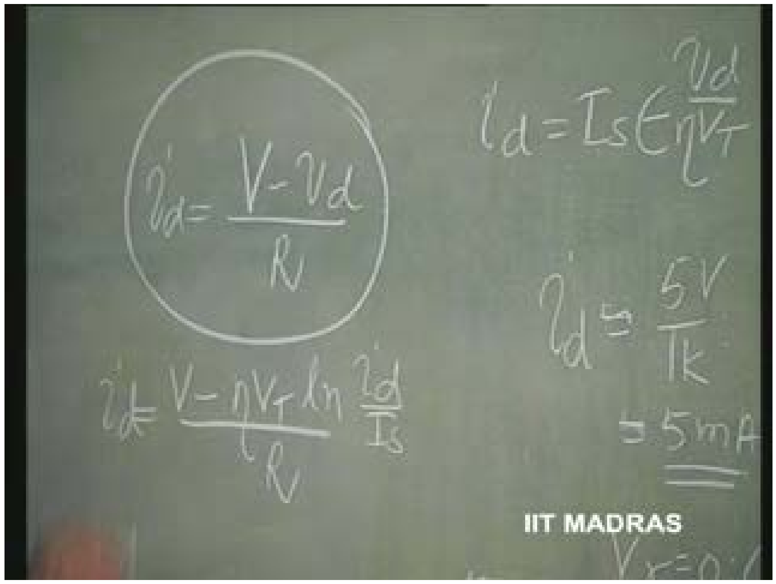

This is a very complex equation, we can see here. i d, we want to determine; it is V which is known to us; eta, may be, known to us; V T is known to us; R is known to us. Again, i d is not known to us; I s may be known to us. So, something to be found out is to be evaluated only if we know this; that is to be found out, though this is a complex nonlinear equation which cannot be solved easily.

So, how do we really get the exact solution for this? This can be done by what is called as repeated usage of; that is how computer also solves this nonlinear equation. First, we put the value of i d as 5 milliamperes; that is, this approximation, let us say, or this approximation, which is a better approximation? 4 point 4 milliamperes here and evaluate this as i d, then, use this i d here and again next evaluation. So, in successive steps, we will be approaching the actual value of i d.

So, once again, let us see. id is equal to V minus eta V T log; this i d value will take this approximation, which is a better approximation. 4 point 4 divided by I s; I s given to us. So, this whole thing is known exactly and we can find out I d. Now, this value is again used upon this side; repeated usage of this.

Ultimately, there will be very little difference between one value and the successive value of the I d that we evaluate. When the error becomes very small, we can say that the final value of I d is reached.

So you can see the complex way the solution has to be obtained here, simply because, the diode is a nonlinear element. Now, this can be done graphically. We will discuss in the next class, how this can be done graphically by what is called, by using this equation only, concept of load line. So, this whole thing, which is to be solved by using this nonlinear equation, this can be done graphically there by plotting the characteristic of the diode and this equation in the same curve.

That line that we draw here corresponding to this equation is called the load factor. Where the intercept occurs is the operating point. So, these concepts will become clear; and why we should go for such graphical concept only becomes clear, when you are confronted with the problem where in nonlinearity exists. This, therefore, has to be solved by successively assuming some approximate value for the unknown and calculating the unknown and then repeating this several times until the error becomes very small.