Electronics for Analog Signal Processing - I
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Lecture - 9
Small Signal Analysis
of
Diode Circuit

In the last class, we saw how a diode, semiconductor diode in particular we have been taking now, put in series with, let us say, resistance and a battery; such a circuit can be analyzed. If this is R and this is V, the voltage across the diode, we will call it as V, and current through the circuit as i.

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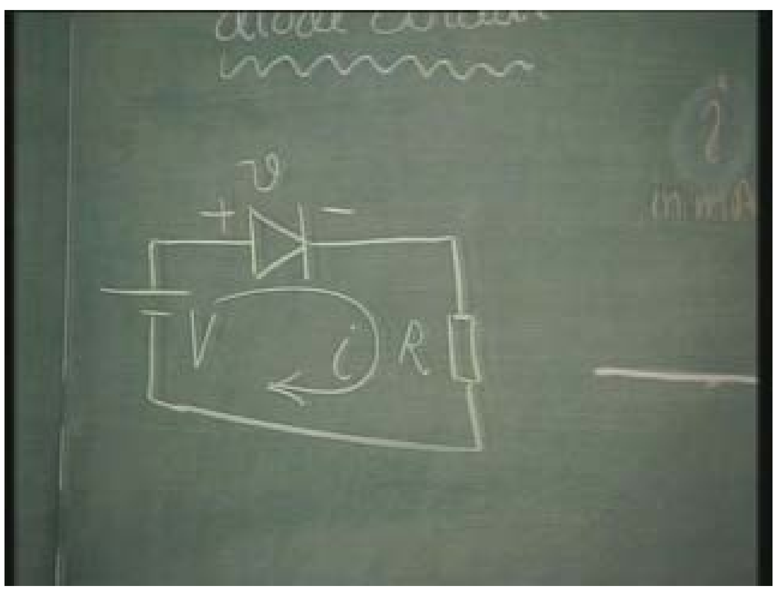

Then, we saw that the i can be written as V minus v, this V minus this, divided by R; that is the drop across the resistance. V minus v, that by R, is the current through the circuit. This is an exact equation, an important equation, which is all followed all the time. Another equation in order to evaluate i is the I V characteristics of the diode. i through the diode is equal to I s exponent v by eta V T minus 1, this we know.

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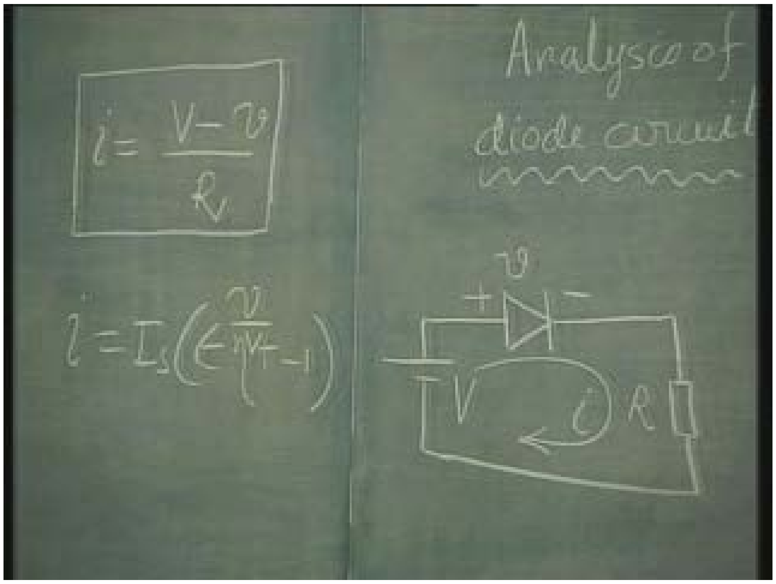

And I told you that since it is forward biased, this can be approximated as I s. I s typically, or I have told you, is of the order of picoamperes for silicon diodes and eta can be taken to be 1 to 2. So, we will take it as 1 here and this 1 can be ignored; so, this is the approximate result in the forward bias region.

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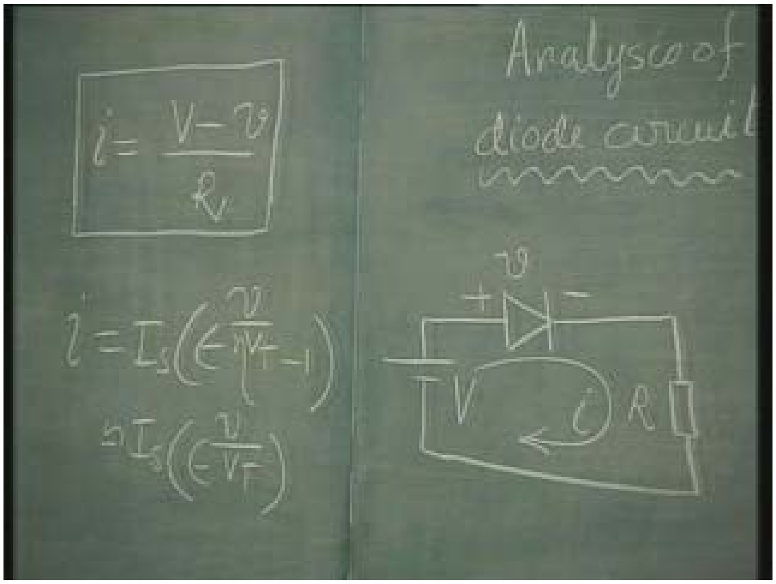

Under this condition, we would like to evaluate the current; then we can substitute here. i is equal to V minus, in fact, we can put v here which is nothing but V T log i by I s; this, we have done earlier also, divided by R.

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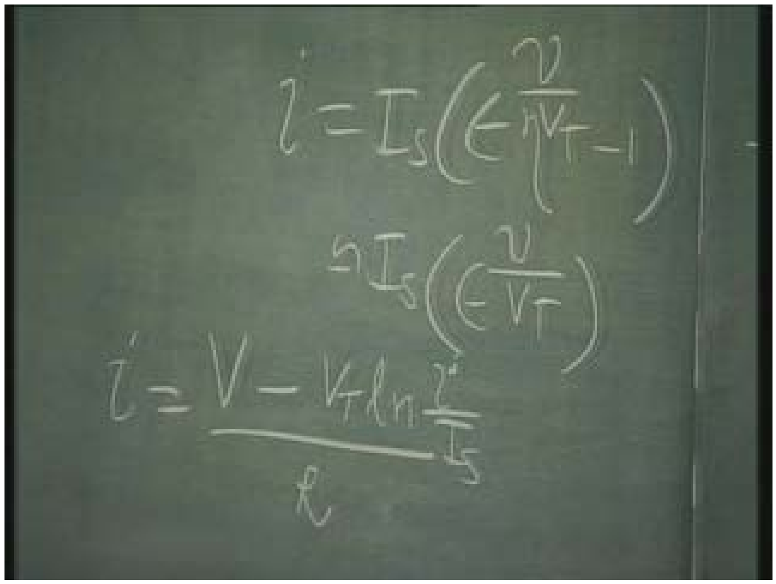

So, this is a nonlinear equation. i, that is, current that is to be evaluated, is given in terms of a nonlinear expression in current itself. So, it is not so easy to solve this exactly. One way to solve, I have suggested, analytically this whole thing, is to approximate this voltage in a ideal diode situation as zero; and first order approximation for i is simply V by R.

Then, the second order approximation is, i is approximately equal to, this we have told earlier, for silicon is typically of the order of point 5 to point 7. So, taking this as V minus point 6 divided by R, we can evaluate i. This is a pretty good approximation for i.

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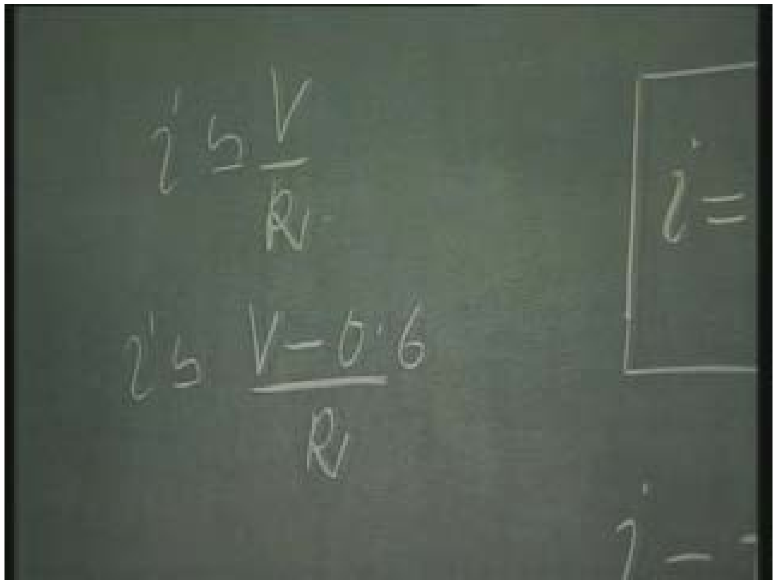

Use this i in this expression to get the value of V more exactly and then evaluate the better approximation for i. Then, use that again here; and you do this successively until the successive values of i you got are very nearly the same; to any percentage accuracy you need. This is how you can solve this analytically.

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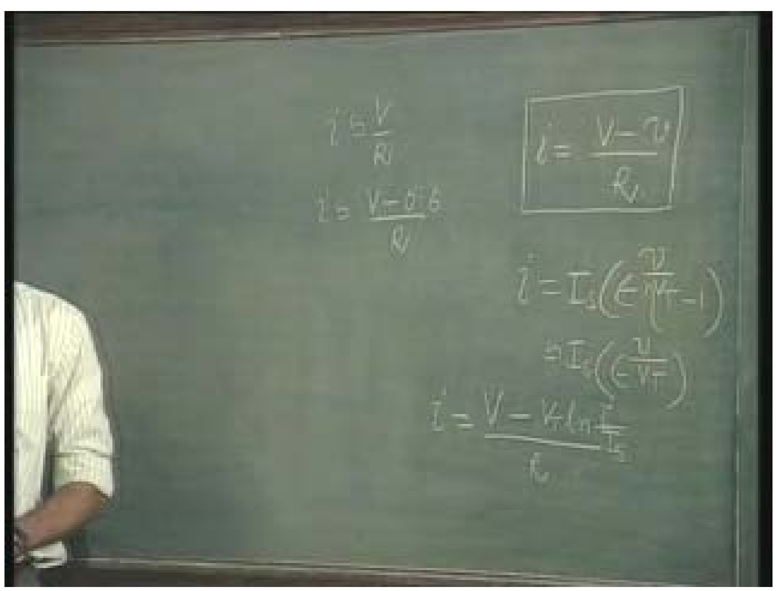

But, we would like to see whether this can be solved graphically and that is where this figure comes into picture. We have i plotted as a function of v. So, this is exponential for the diode. This is nothing but our i is equal to I s exponent v by V T approximately, let us say. Or, you can even consider this as exact because this can be plotted exactly. This is the complete characteristics of the diode.

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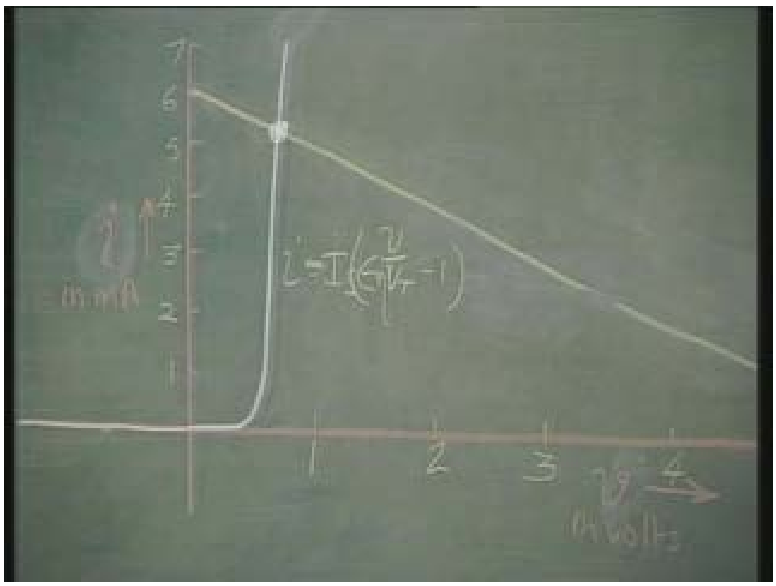

Now, in this characteristic, we would like to represent this equation which is also valid at all times. So, let us plot this along with this. So, this is the equation of a straight line: i as a function of v with the slope equal to minus 1 over R. So, you can see that v for v equal to zero the value of i is V by R.

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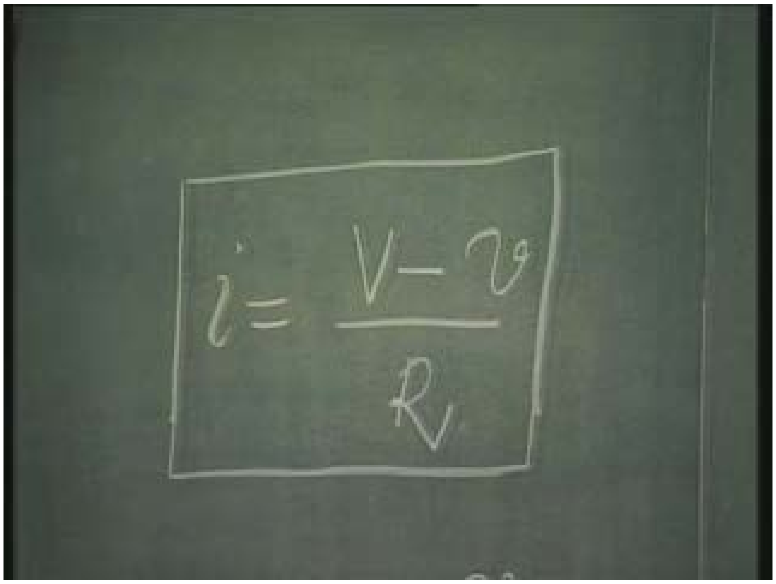

So, this is the value of V by R, where, this is the value of V; where, i is zero, V is equal to V, capital V. So, these are the two points through which this line goes; and this line, when it intercepts this axis, is the solution for simultaneously satisfying these two equations.

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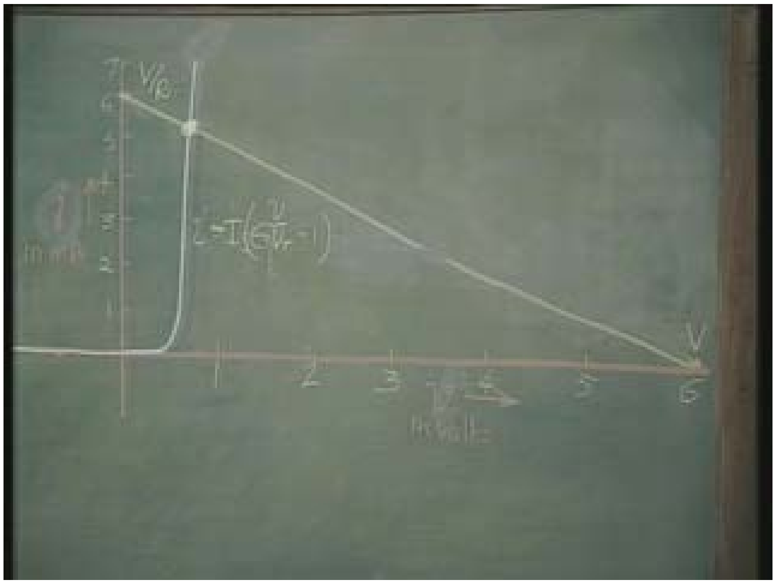

These are the two equations which have to be simultaneously satisfied. One equation is plotted here like this; the other one is a straight line. The intersection of this will give us the value of i and V; that is this. So, this can be, this as you see, is very nearly equal to point 6 itself because, this steeply rises. So, this is very nearly equal to point 6. The exact value of this can be obtained by noting the intersection and also noting the current at that point. So, these two values will be the exact solution for this circuit.

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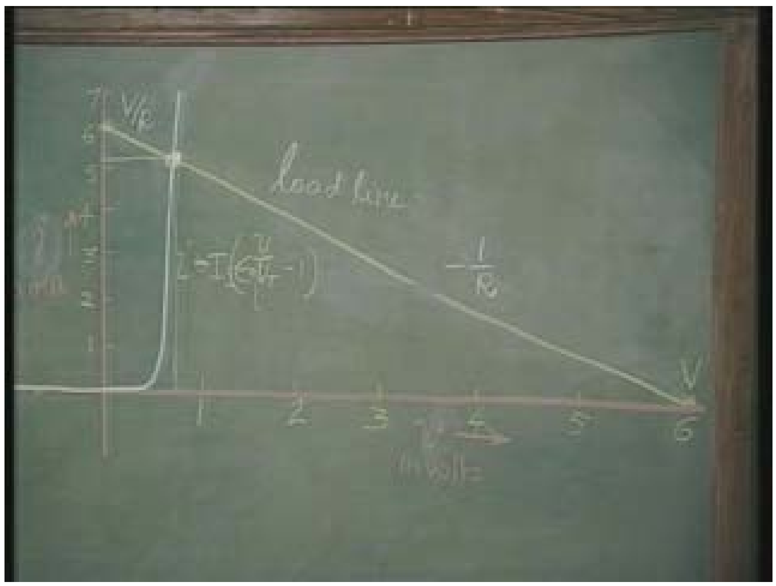

This line is called, we can call it as load line; this is the terminology that is adopted; load line, assuming that this is a diode circuit feeding on to a load like this, its current. So, this is the load resistance and the slope of this is minus 1 over R.

So, let us consider a numerical example; V in this case is equal to, let us say, 6 volts and R is equal to 1 Kilo ohms, then, we know that one intercept here occurs at 6 volts by 1 Kilo ohm, which is 6 milliamperes and the other intercept is at 6 volts. So, if you join this line, it will intersect at this point which is very nearly about 5 point some value.

We would have got this approximate current here, for this example chosen. V is equal to 6 volts, R is equal to 1 K, the current is very nearly equal to 6 milliamperes. It is not so; it is less than 6 milliamperes. 6 milliamperes is this, assuming that the diode drop is zero.

So, this value, we would have got of current if we had gone for the second approximation, which is, V is equal to 6 volts minus point 6. I am arbitrarily assuming that it is between point 5 and point 7; which is point 6 divided by 1 K which is equal to 5 point 4 milliamperes.

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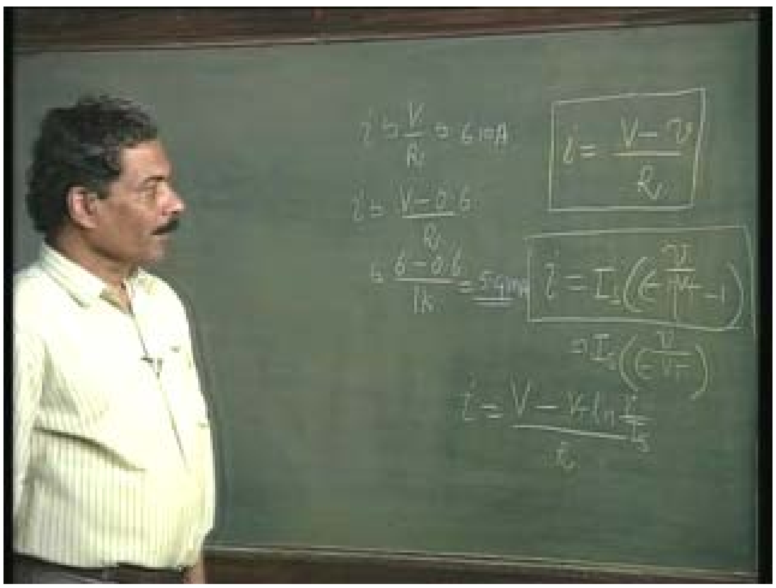

So, this is what you are going to get; very nearly 5 point 4 milliamperes is the current, which will get more exactly, if you draw the graph or solve it using this equation.

So, we will treat it as an example now. The same problem of a diode is connected to a resistance of 1 Kilo ohm through a battery 6 volts. Determine the current through the diode and the voltage across the diode. So, if such is the problem, the circuit is given here. A diode is connected to a load resistance 1 Kilo ohm and a bias voltage of 6 volts. Determine i and v.

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So, we have seen how to proceed. Let us now repeat the thing. Approximately, the current is going to be, assuming that the diode is ideal, V by R, which is going to be 6 volts by 1 K, which is 6 milliamperes.

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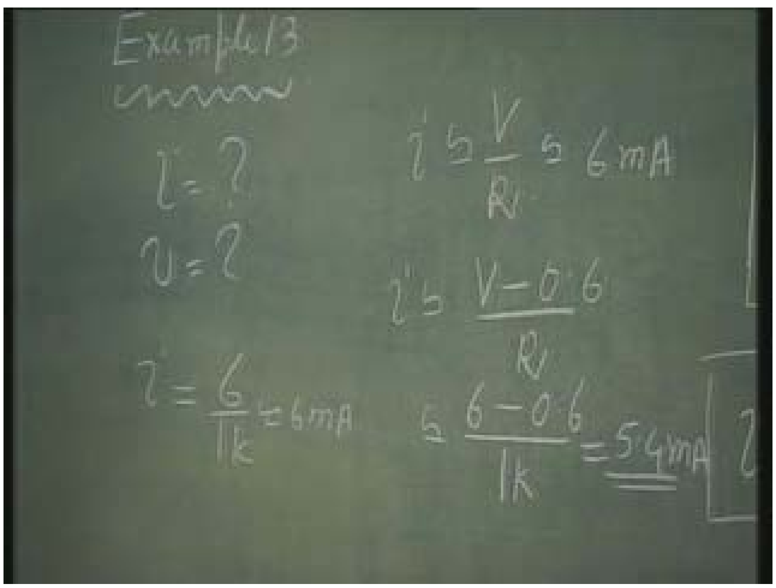

A better approximation would be to take the voltage across the diode, not as zero, but as point 6 volts, because we have predicted that it lies between point 5 to point 7 for most of the diodes which are operating around milliamperes of current. We will examine it whether this is true later, but for the time being, we will assume it to be point 6. So, the current, a better approximation is 6 minus point 6 divided by 1 K, which we have got as 5 point 4 milliamperes.

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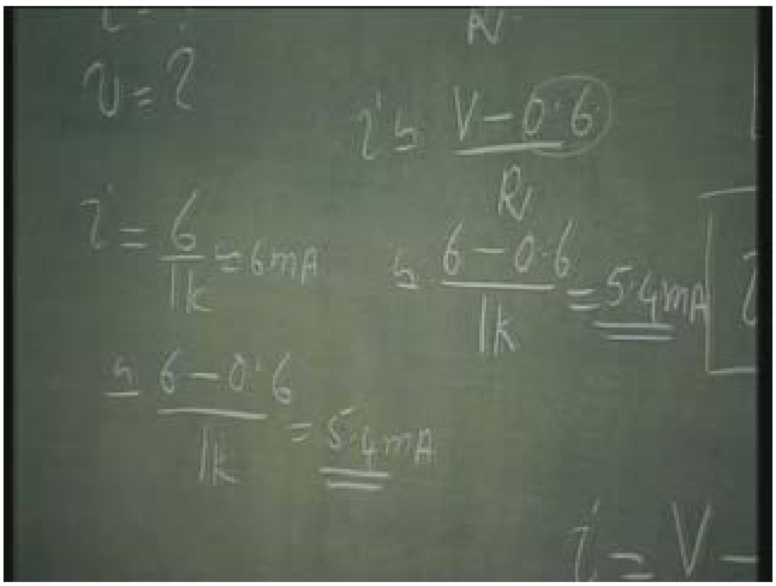

Now, I want you to understand what is meant by solving this nonlinear equation. i is equal to V minus v, voltage across the diode, divided by R, R being 1 K. So, I had taken this as point 6; but it is not point six. How much is it? Let us take as i is equal to 6 milliamperes; I s for the diode is 10 picoamperes.

So, for such a diode with I s equal to 10 picoamperes, the characteristic may be known. So, v is equal to V T log 6 into 10 to power minus 3, 6 being the operating current, assuming that it is operating at 6 milliamperes which is the first approximation; 6 into 10 to power minus 3 divided by 10 picoamperes, which is 26 into 10 to power minus 3. V T, we know is K T over q which is assumed to be 26 millivolts at room temperature, this we know earlier. log 6 into 10 to power 8 which comes out to be 525 point 5 millivolts.

What did we assume it as? We had only assumed it as 600 millivolts; so our approximation is pretty close to the very near correct value which is 525 point 5 millivolts.

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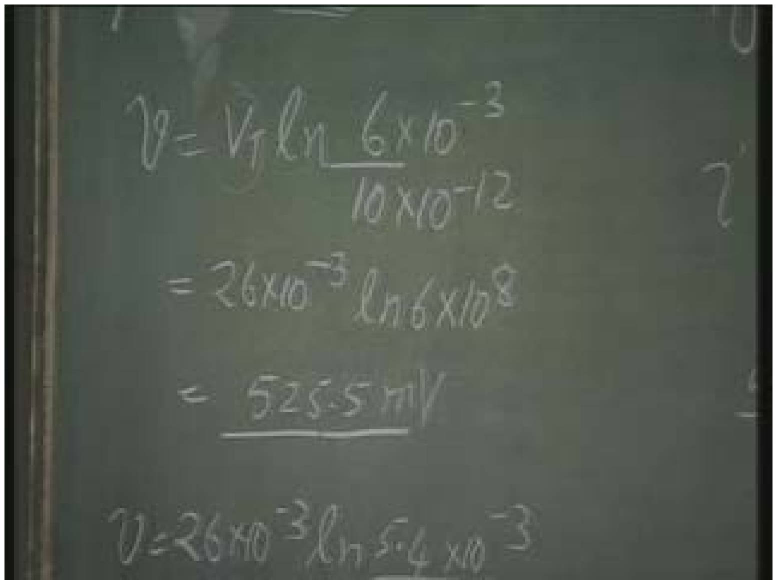

So, this is not 600 millivolts, but 525 point 5 millivolts. If it is 525 point 5 millivolts, we can again evaluate the current.

But, let us see what this approximation will give us. Assuming that i is 5 point 4 milliamperes, instead of 6 milliamperes, which is a better approximation, we can say that v is V T, which is 26 millivolts, log 5 point 4 milliamperes divided by 10 picoamperes, which is coming out to be 522 point 78, which is pretty close to the voltage that we have already evaluated, assuming that it is 6 milliamperes.

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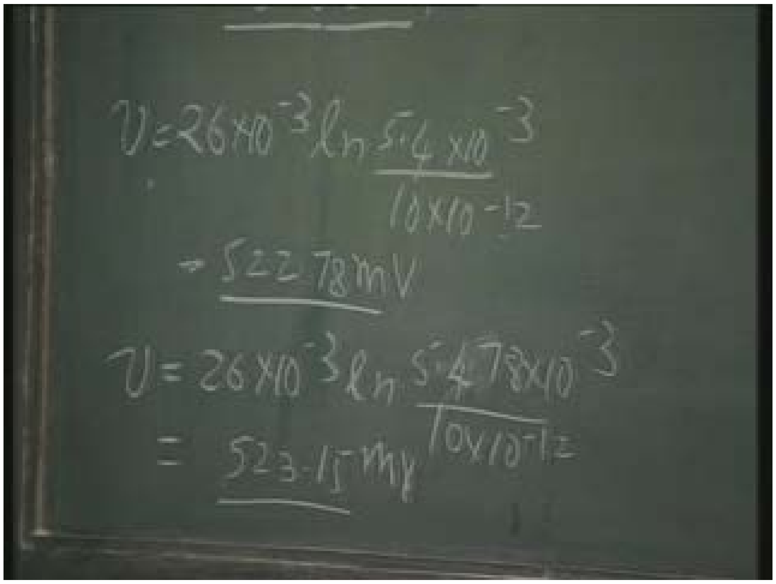

So whether we take it as 6 milliamperes or 5 point 4 milliamperes, we see that the results are pretty close to one another; one is 525 point 5 and another is 522 point 78. So, now, assuming that it is about 520, 2, etcetera, we can again recalculate the whole thing, the voltage. If it is 522, current is going to be 5 point 478 milliamperes divided by 10 picoamperes, which is going to give you a re so (Refer Slide Time: 14:27) evaluated value for the voltage v as 523 point 15, which is again pretty close to this; which is more correct than any of these values.

So, this is the way it is going to approach the correct value of v. If we keep on using the same information again and again, now, the if we use this information in order to reevaluate v, again, we will get a value which is pretty close to this. Therefore, there is no point in proceeding further. We can take this as very nearly the correct value for the voltage v.

So v is going to be approximately 523 millivolts and i is therefore, 6 minus point 523 divided by 1 K, which is going to be 7, 7, 4, 5, point.

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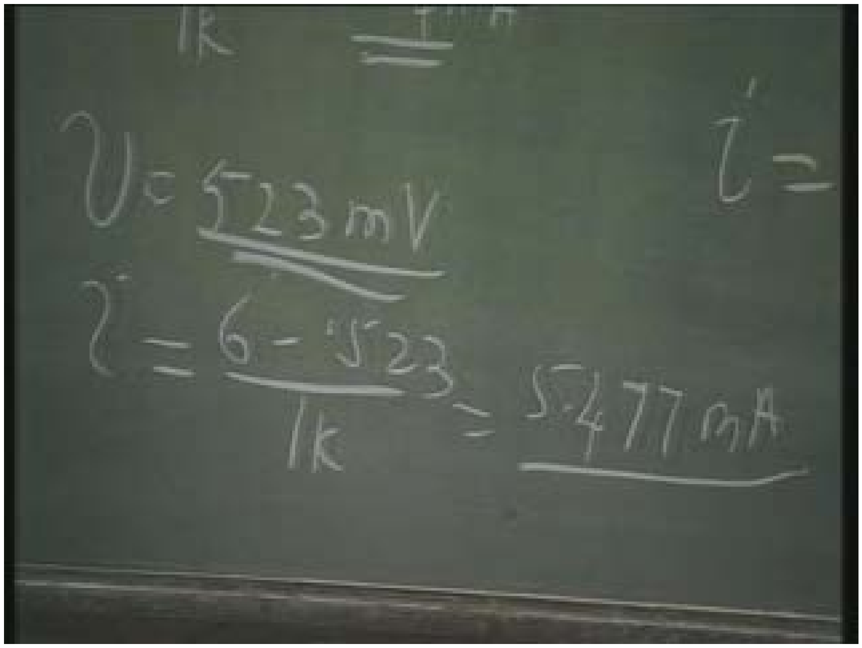

So, this is pretty close to realistic value of current. We had only made the approximation and we got it as 5 point 4 which is close to 5 point 477 milliamperes. So, you can see that in most of our applications, it is not necessary to either do it graphically or solve this complex equation. It is possible to arrive at the value of current pretty close by 1 or 2 iterations; these are called iterations.

So, this kind of analysis is what you would be encountered with in diode circuits wherein you have to evaluate the current in the diode circuit using the exact relationship for the diode; that is, exponential relationship. Just now, we had seen how, in a diode circuit, wherein, the diode has a complex nonlinear relationship between i and v, the currents and voltages can be evaluated pretty easily. This method, graphically as well as analytically, we had shown.

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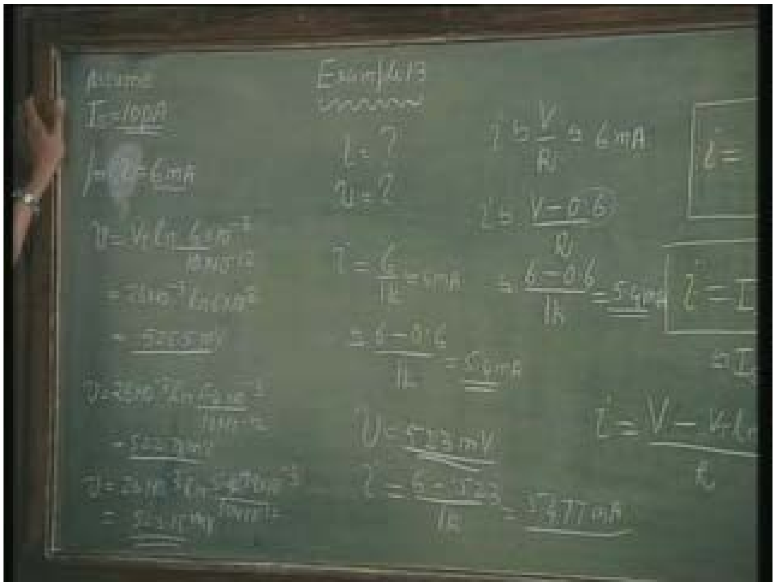

Now, Example 14 let us consider. In the diode circuit shown, the same circuit as previously shown, same circuit we will take, with v equal to 6 volts connected to a resistance of 1 K. In the diode circuit shown, v is changed from 6 volts to 6 point 06 volts. So, the voltage v that we have applied is changed from 6 to 6 point 06 volts. Determine the change in diode current as well as diode voltage; this is the question. What is it? When this v voltage is changed from 6 to 6 point 06, what is the change in current i?

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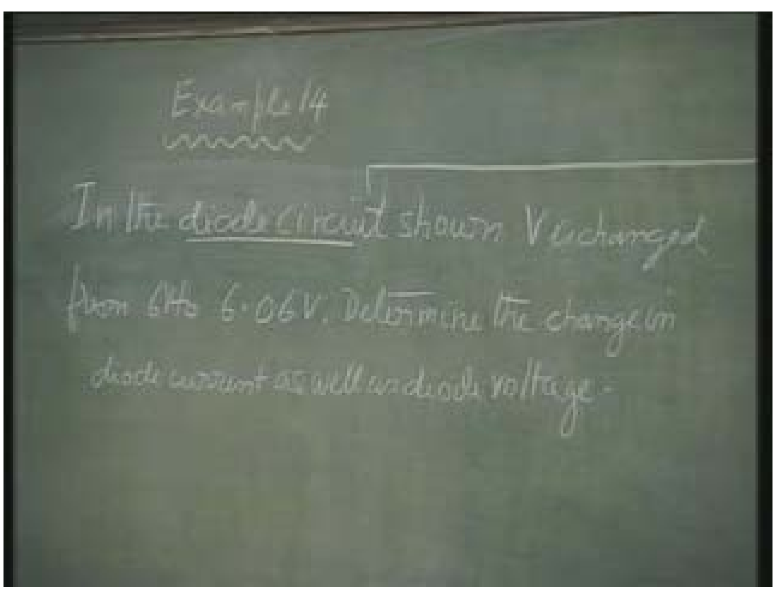

i might change from its value which has been already evaluated to some other value; and V also will change from what has been already evaluated to some other value. It is this change that I am interested; I am not interested in the absolute value of these currents, but only interested in the changes.

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This is an important aspect of electronics. The diode which is forward biased this way is to be operating at a certain current, which we have already evaluated; which is, V minus v divided by 1 K. That current is the operating current here. So, this is the operating point where there is a certain current flow through the diode that is given by this; and certain voltage across the diode.

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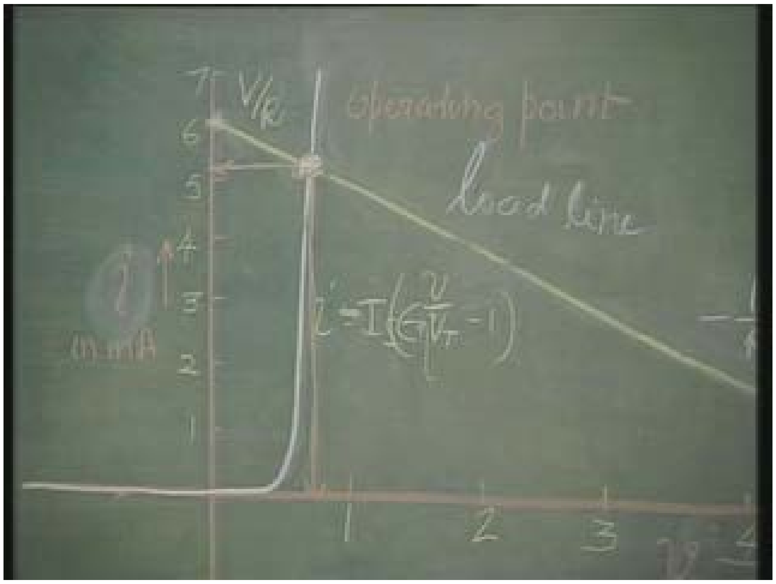

This is about 5 point 4 milliamperes approximately; and this is about point 5 five or so. So, this is the situation that we have already evaluated earlier. Now, what we are interested in is, the voltage is changed from 6 to 6 point 06. That can be depicted by drawing a new load line now. You can draw the new load line because the resistance has not changed; the slope remains same as 1 minus 1 over R. Only, this voltage has changed from 6 to 6 point 06; which may be in that, we will intersect this whole thing at 6 point 06, which may be very close to this, because this is 6. This may be 6 point 1. So, we will see that it is going to be some line which is pretty close to this, in parallel to this original line, intersecting this at 6 point 06.

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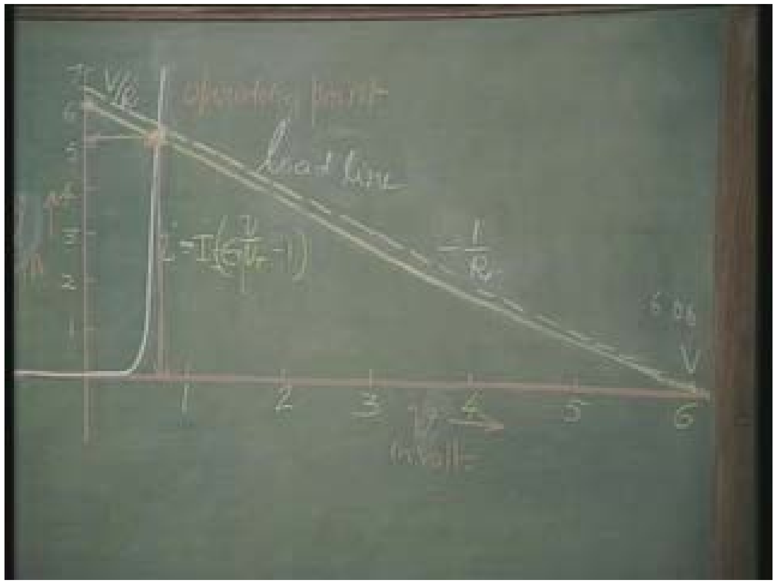

And, where will it intersect this? It will in turn intersect this at 6 point 06 milliamperes, by our definition of intercepts. What I am interested is not these intercepts; these are already known to us. What is the change, new change that this has brought about? From here, the operating point has shifted to this. This operating point also is called Q point. What is Q? Q is quiescent; it is remaining like that until you disturb it.

So, you can say that this is the disturbance; otherwise, it would have remained quietly at this point. That is called Q point, quiescent point, operating point. These terminologies become quite important whenever we use these devices: diodes or transistors. We make these devices operate at a certain point, so that, we can use, exploit, their characteristics around this operating point.

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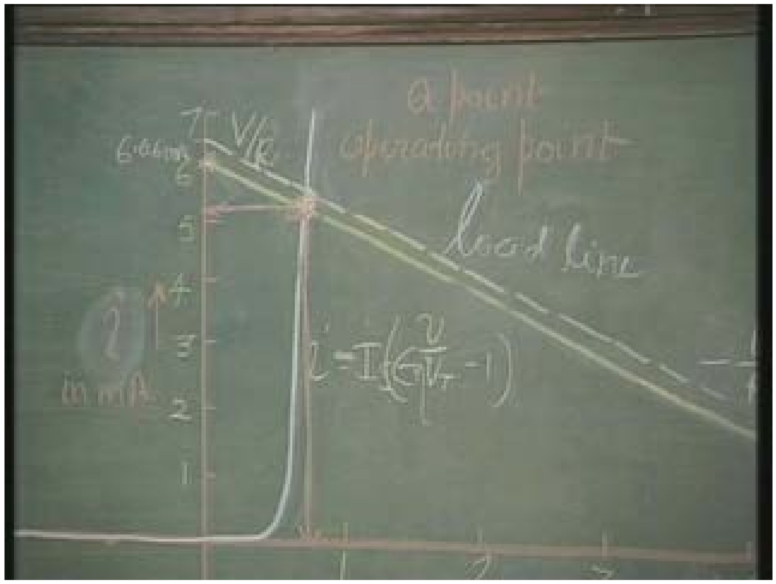

So, this diode is said to have an operating point of about 5 point 4 milliamperes and correspondingly, about, near about, point 6 volts. I am interested in the change that has taken place in both the diode current as well as the diode voltage. Diode voltage will change by a small amount; diode current also will change by a small amount. What is the change? How do you evaluate this change?

This is where we come into what is called small signal equivalent circuit, small signal. This is important. Small signal equivalent circuit for the diode. What is the small signal equivalent circuit for the diode? When it is operating at a certain operant point and it is disturbed by a certain signal; now the signal is this. This voltage is changed by some amount, Delta V. So V is changed from V to V plus Delta V. So, let us say, V is changed from V to V plus Delta V. Then, we must have i changing from, let us say, I, original current, operating current, plus Delta I; some change in current.

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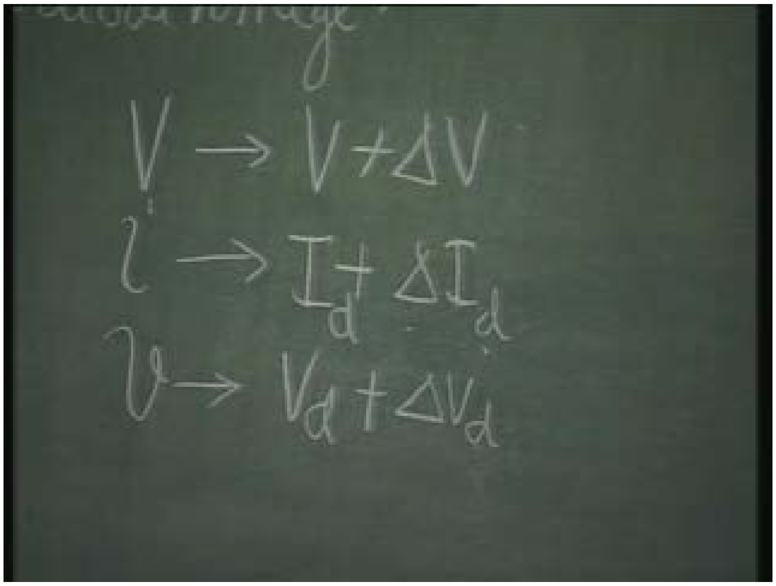

It is this change that we are interested in. And correspondingly, v is changing from original voltage across the diode, V diode, this is I diode plus Delta V diode. So, what are these changes? Delta I d and Delta V d is the question.

Now, how do we do it analytically, let us see. Graphically, you know the slope has remained the same. So, if I redraw this line from 6 point 06 with this intercept, I have 6 point 06 milliamperes. Where it intersects, that is the new operating point. The change can be easily evaluated graphically. But, it is so close to that, it may be difficult to read the changes that are taking place.

Can we do this analytically by using certain approximation? The approximation is that around this operating point, everything is linear; the characteristic is linear and therefore, we can say, we can replace the diode by an equivalent circuit or a resistance.

So, how do we go about understanding it in terms of characteristics? i through the diode is I s exponent voltage across the diode by V T, approximately. So, we can say that this i is equal to original I that we have evaluated. When it changes to I diode plus Delta I diode, this gets changed to… This remains same as I s exponent, V diode plus Delta V diode. It is an exponential relationship.

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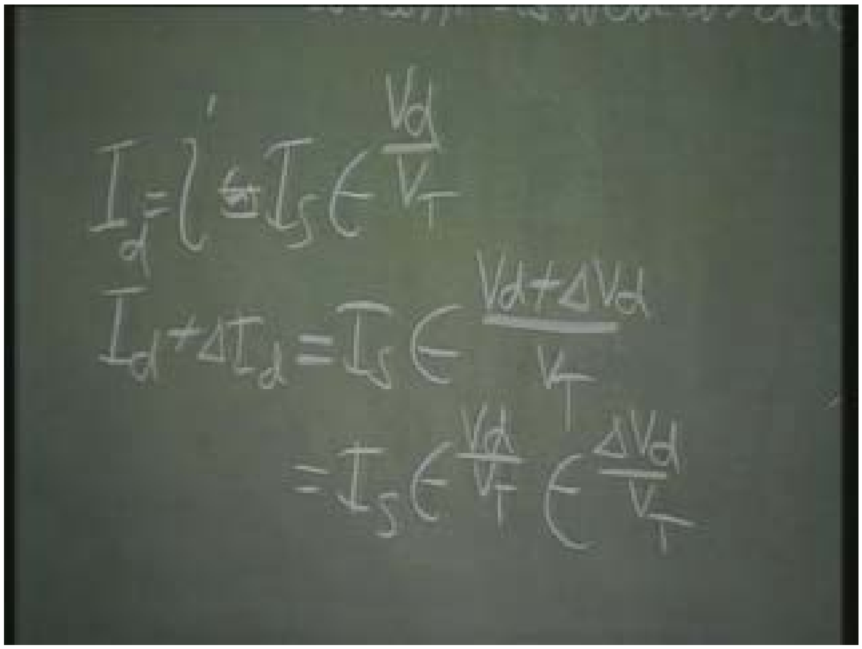

If this Delta V diode is very small compared to V diode, that is the case in our graph also, then, I can represent this as I s exponent V diode by V T exponent Delta V diode by V T. So, this is nothing but original I diode itself. I diode this is I s exponent V diode …I diode (Refer Slide Time: 25:25) itself, the exponent Delta V d which is a very small thing compared to V T. That means, assuming that Delta V d by V T is much less than 1, this we can expand. This, we had done in our earlier situation of exponential fall off of voltage across a capacitor also. E to power x is approximated as 1 plus x.

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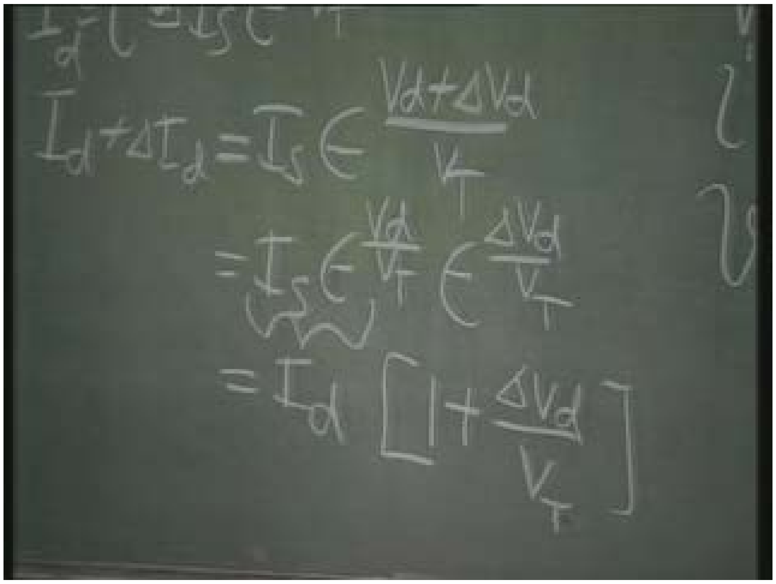

So, you can now see that Delta I diode from this, if this approximation is valid, is nothing but, I d plus Delta I diode is equal to I d plus I d Delta V diode by V T, which is nothing but… Delta I diode becomes equal to Delta V d, that is the change in voltage across the diode, divided by V T into I diode. So remember, this is coming about by an approximation to the exponent when Delta V d by V T is much less than 1; that is the linear approximation.

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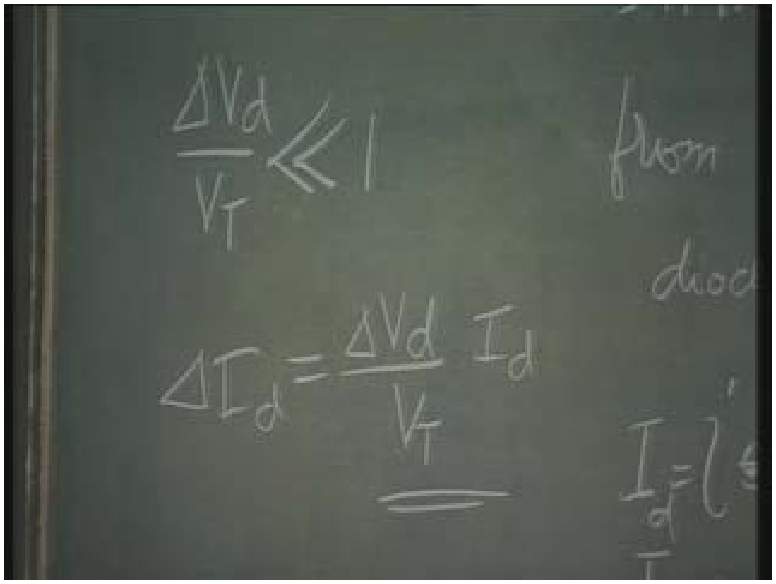

That means, the diode becomes equivalent to, Delta V diode divided by Delta I diode is equivalent to, r diode. This is the voltage divided by current relationship; but change in voltage across the diode, by change in current through the diode, is the incremental equivalent resistance; incremental equivalent resistance of the diode, around the operating point.

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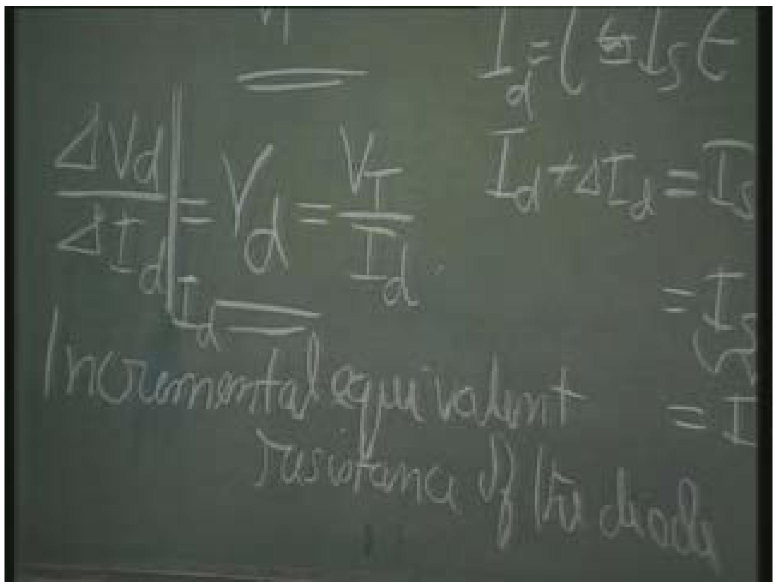

So, this is evaluated around I diode. What is this - Delta V d by Delta I diode, from graph we can see, is nothing but … This is Delta V d and this is Delta I d; so, it is nothing but inverse of the slope at this point for the characteristics.

So, this is the slope at this particular point for the characteristic. Incremental equivalent resistance of the diode can be evaluated around the operating point, I diode. So, that is equal to V T divided by I diode. So, if V T is 26 millivolts and I know I diode, then, I can easily evaluate the resistance, incremental equivalent resistant for the diode.

Let us consider for this case. V T is given as 26 millivolts; I d for the diode is 5 point 4 milliamperes, which we have evaluated. So, we can find out the incremental equivalent circuit for the diode r d as 26 divided by 5 point 4 milliamperes, 26 millivolts by 5 point 4 milliamperes, which is nothing but 26 divided by 5 point 4 ohms.

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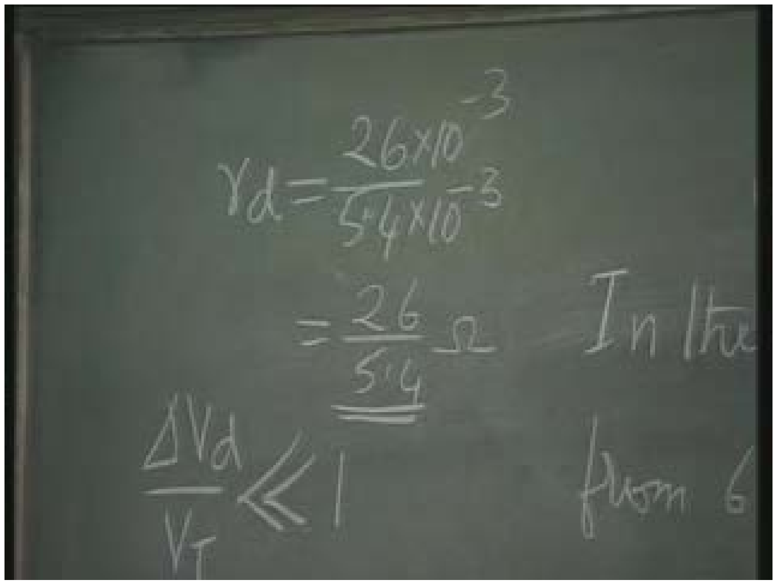

So, this is the resistance of the diode, which is of the order of few ohms, less than about 4 ohms or so; around over 4, around 4 ohms, less than 5 ohms. So, this is the way we can evaluate the small signal equivalent circuit for the diode.

And now, what do we get? Therefore, I can replace the entire circuit by the small signal equivalent circuit for the diode if it is assumed to be linear around this. So, if this is changing from V to V plus Delta V, this is going to be indicated by Delta V alone, and then, this is going to be replaced, diode is going to be replaced by, r diode; and then the resistance is going to be 1 K there.

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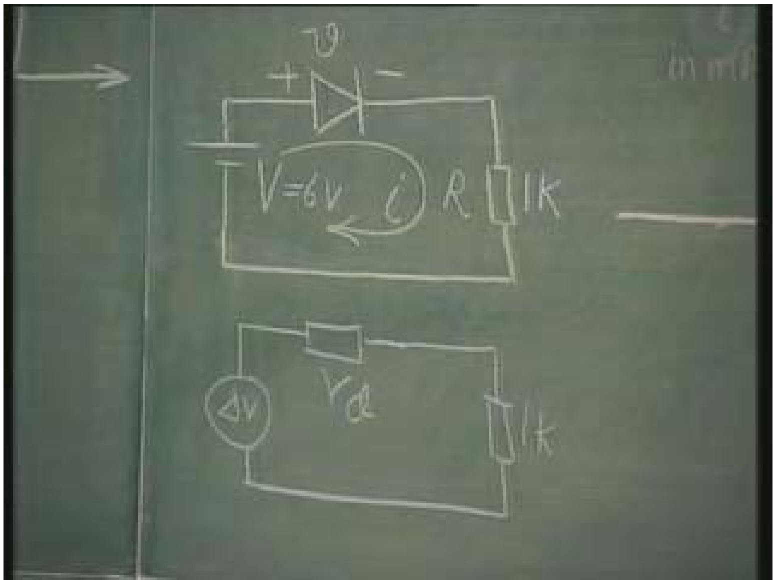

So, the current through the diode can be evaluated, change in current. What is that - Delta I diode. Delta I diode therefore is equal to Delta V, which is whatever we mentioned; it is changing from 6 to 6 point 06 volts; which means, it is going to be 60 millivolts change. So, that change divided by Delta V, divided by r diode plus 1 Kilo ohm.

So, since r diode is of the order of 5 ohms or less, this can be ignored; and therefore, this is nothing. But the current is now determined purely by 60 millivolts divided by 1 K, which is nothing but 60 microamperes; very close to the actual thing; because we have ignored only resistance of the order of 5 ohms compared to 1 K.

So, the current through the diode is still determined by 1 K, not by the diode resistance at all; because it is of the order of few ohms. So, 60 microamperes is the change in current in the diode for a change in voltage of 60 millivolts here.

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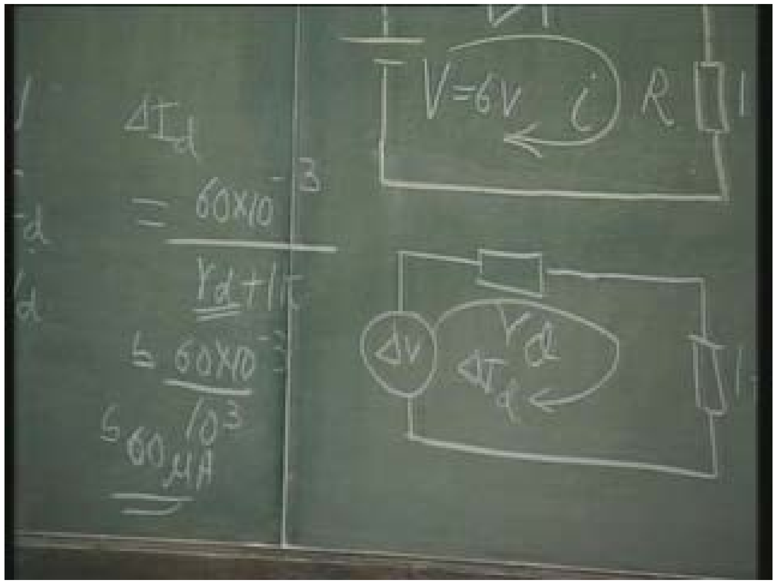

Now, what is the change in voltage across the diode? The original voltage itself is very small. What is the change in voltage? That can be easily evaluated. That is, Delta V diode is nothing but… Because we know, once you know the change in current, Delta I diode, Delta V diode is going to be given by r diode into Delta I diode.

So, r diode into Delta I diode; so, r diode is already given as 26 by 5 point 4. This, into change in this thing; that is, 60 microamperes. So this is going to be 60 into 10 to power minus 6. So, the whole thing is Volts. So, it is going to be 26 into 60 by 5 point 4; so many micro volts.

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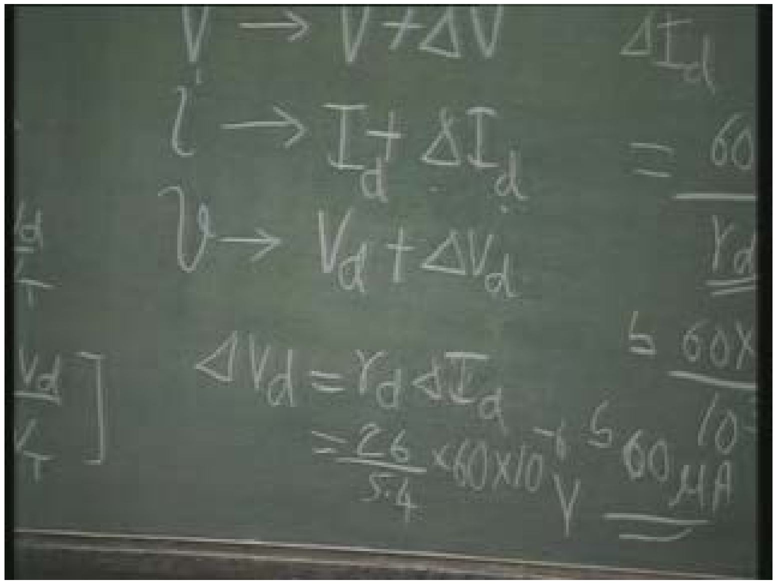

So, such is the accuracy of the small signal amount analysis that you are now able to find out the change which is going to be extremely small; very accurately by this method of equivalent circuit for the diode. So, that change is fairly accurately evaluated here, as this is 10 times; this is point 10 times. So, this is going to be around 260 divided by point 9 microvolt. So, the answer is, Delta V diode is going to be 260 or 2600 by 9 microvolts; around 300 microvolts.

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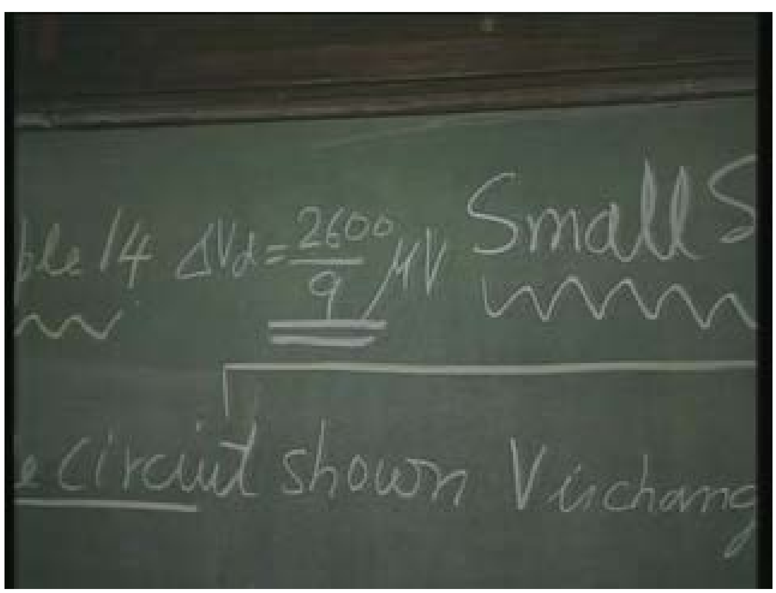

So, that is the answer to the problem in the diode circuit shown. When V is changed from 6 volts to 6 plus 60 millivolts, determine the change in diode current as well as diode voltage. So, we have evaluated the change in diode current by replacing the diode by means of its equivalent resistance; this is the forward resistance for the diode, incremental forward resistance for the diode. That is always evaluated around the operating point and that is equal to V T divided by I d.

So, the moment I know the operating current, by an approximation, as 5 point 4 milliamperes, I know the value of r diode as 26 divided by 5 point 4; which I use in that equivalent circuit, in order to evaluate the current through, the change in current through, the circuit and then, use that change in current to evaluate the change in voltage using the linear equivalent circuit.

Now, let us understand whatever we have illustrated for this small signal equivalent circuit for the diode in terms of the graph. It is always better to understand both graphical as well as analytical methods of evaluation of all these things. The same thing that we have been talking about when the change has occurred, I am expanding this area; this portion of the diagram, because it has a very small change. Assume that this has been magnified considerably.

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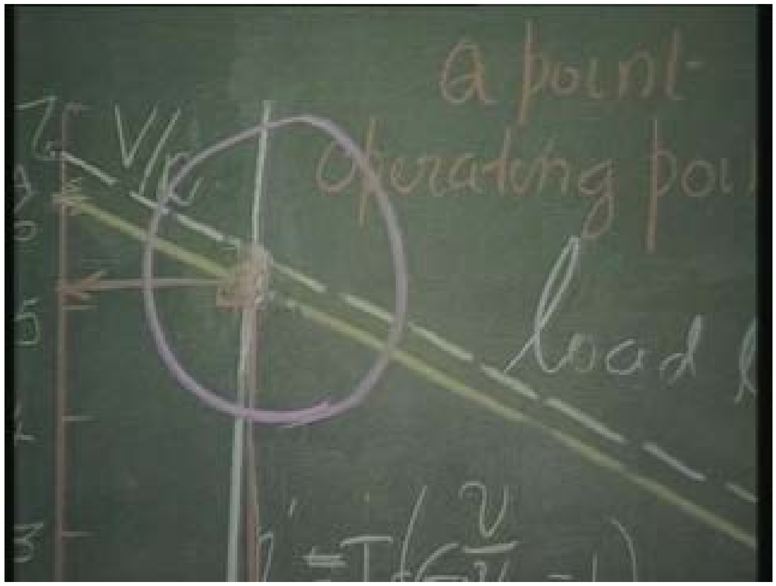

This magnified portion is indicated here; so, this is the same as that. So, we were originally at an operating point which is I diode, v diode; and we shifted because of change in voltage of voltage V; from V to V plus Delta V.

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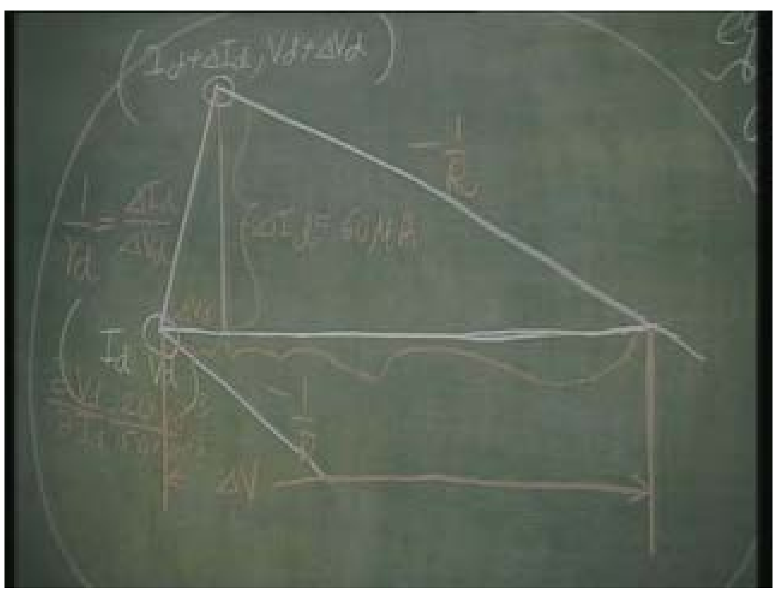

So, Delta V is the change in the X axis. X axis, the change is from here to this point. These are two parallel lines with slope equal to minus 1 over R, this is the slope.

So, the intersect here changes by Delta V. So, this base is changing by Delta V. This slope here is minus 1 over R, and minus 1 over R. This is the diode characteristic which is really exponential, which has been assumed to be linear. So, if it is linear, then, it forms a triangular structure like this. I diode has changed to I diode plus Delta I diode. V diode has changed from V diode to V diode plus Delta V diode. So what does the total change represent in terms of the graph?

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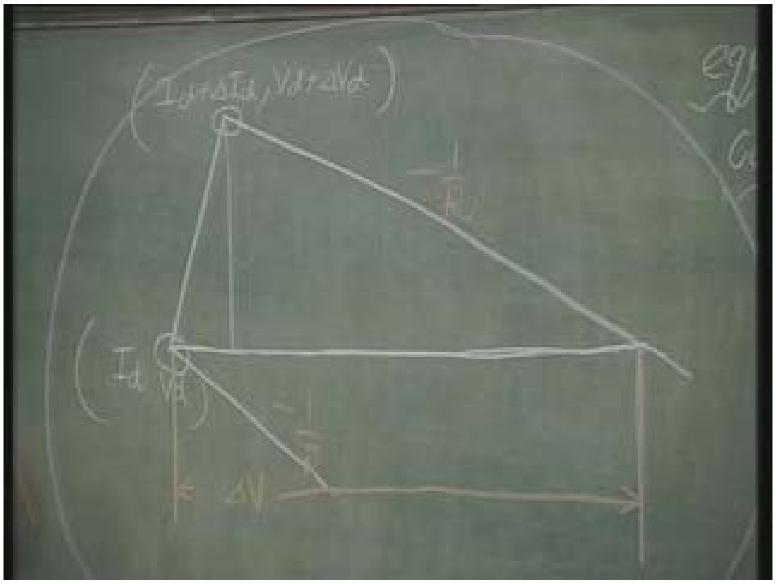

Now, the total change that has occurred is Delta V. If I now draw a line like this, this change is due to the diode and this change that has occurred is due to the resistance R; because, that is very clear; this one, minus 1 over R. So, the voltage across the resistance, change in voltage across the resistance is this; and change in voltage across the diode is only this. So, this is Delta V diode, this is Delta I diode.

So, if you assume this to be linear, then the slope here is nothing but Delta I diode divided by Delta V diode, which is the slope here; which is given as 1 over r diode by us; the equivalent resistance. So, one, when it is linear here, this can be approximated as a resistance whose magnitude can be evaluated as V T divided by I d. That is what we evaluated in our analytical model.

So, this is Delta V d, this is Delta I d; this is the Delta voltage across the résistance and this is the total voltage across this. And we have seen that Delta V is very nearly the Delta V across the resistance. Therefore, the change in current is simply Delta V divided by R. So, if it has changed by 60 millivolts and R is 1 Kilo ohms, then, this change in voltage is very nearly equal to 60 millivolts; because this is very small compared to this; that is the assumption.

So, the change in current, Delta I d is nothing but Delta V divided by R. So, that Delta V was 60 millivolts and this Delta I d came out to be 60 microamperes. Once this is known as 60 microamperes and r d is known as V T divided by I d, which is 26 divided by 5 point 4 milliamperes, that is the slope around this point, it is nothing but Delta V diode divided by Delta I diode; is nothing but the slope at this point. So, this is going to be 26 millivolts divided by 5 point 4 milliamperes.

So, we had evaluated this as 26 by 5 point 4; so, that is the resistance. So, that will determine the Delta V d, which is, Delta I d is 60 microamperes. Delta V d therefore is equal to 60 microamperes into r d which is given as 26 by 5 point 4. So, that is the answer that we got in the analytical expression also.

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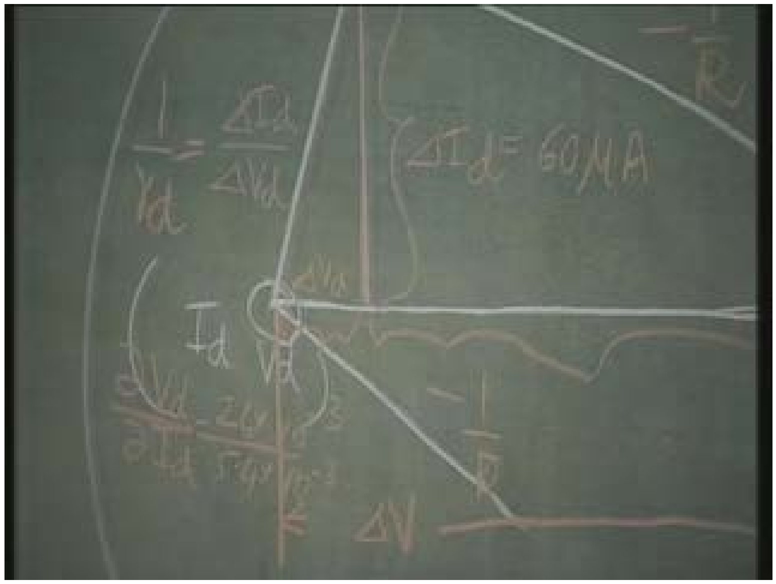

Please, therefore remember, that all these things can be also graphically got if you really expand the characteristic around that operating point. So, what we have learnt today is to represent the diode by means of its small signal equivalent which is a resistance in the forward direction; and that resistance is dependent upon the operating point; specifically, we can express it in terms of the operating current always. So, given the current, we can always analytically obtain the value of the resistance as 26 millivolts divided by the current, operating current.

So, if the diode is operating at 1 milliampere, it is 26 ohms; if it is operating at 2 milliampere, it is 13 ohms; so, if it is operating at 4 milliamperes, it is 6 point 5 ohms. So, you can easily evaluate the small signal resistance without really knowing anything about the diode characteristic at all.

So, this is a very useful information regarding the diode and its small signal property. This can be usefully utilized later when we use diode in its forward biased mode and fix the operating point; such a utility comes into picture when the diode is becoming part of a transistor. A forward biased diode becomes a part of the transistor and we will later see; most of the time, that particular diode is always forward biased so as to maintain the transistor in the active region. So, it is at that point, this knowledge about small signal equivalent circuit becomes useful for us; not for any other diode circuit that we have discussed so far and that we will be discussing later also. Other than the transistor circuit where the base to emitter junction of a transistor is a forward biased diode and it is kept in forward biased mode most of the time, this kind of equivalent circuit can be used.

So now, can we use this diode for a voltage source? So, diode as a voltage source - this is an important application of the diode and particularly, such a design is utilized in integrated circuits. Diode is forward biased and we have already established that this forward biased voltage is around point 5 to point 7 for most of the power small signal diode application; we can take this.

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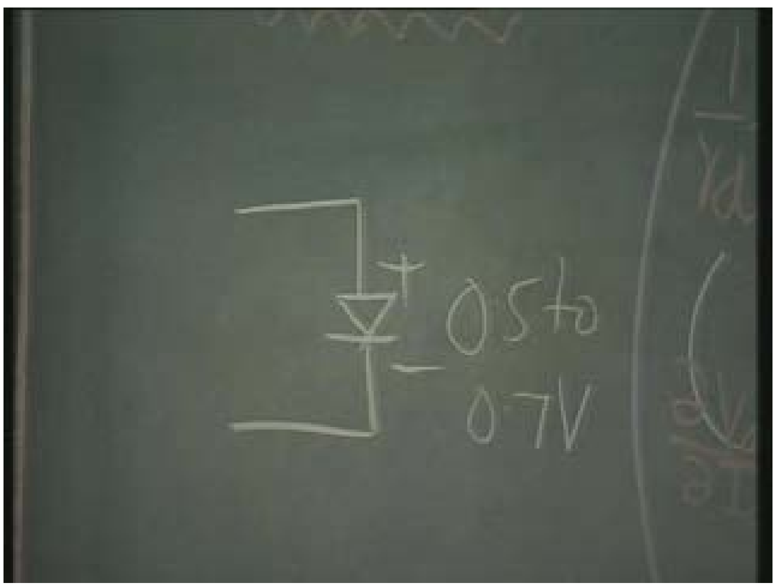

So, can't we therefore use it as a fixed voltage source with this drop? Let us say, it is equal to point 6 volts at a certain current. It does not change much with respect to current that we have seen. Suppose I put one diode. Then, this is a voltage source with point 6 volts; and even if this current changes, the voltage does not change much. But, if I want to know how much it changes, I can always find out that change by assuming that it is not only a voltage source, which is V gamma, that is point 6 volts, but also an equivalent resistance which we have put as r diode. So, this is essentially the equivalent circuit for the source; which means, this r diode is nothing but VT divided by I diode, where I diode is the current through the diode.

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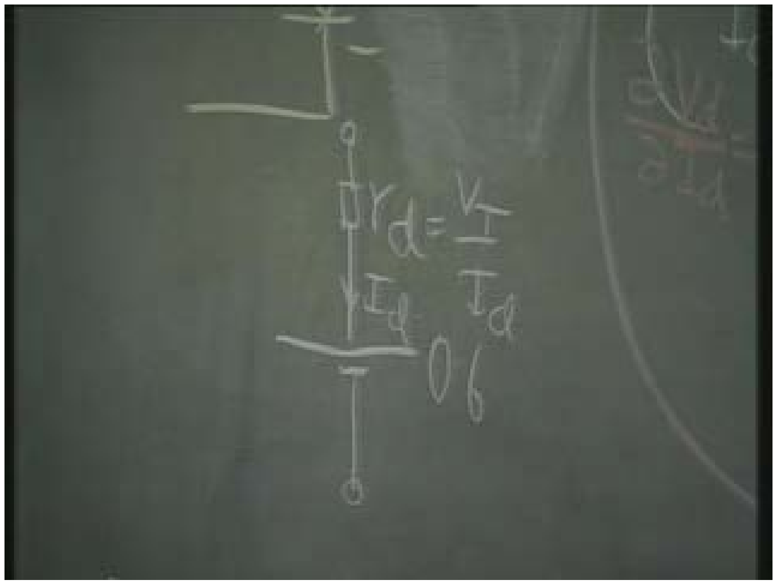

So basically, this is equivalent to a battery of point 6 volts and a small series resistance of the order of few ohms, for currents of the order of milliamperes; that we have established. So, it can be definitely used as a secondary source for biasing, etcetera.

So, this kind of application will maintain this voltage very constant. That means, if I apply a voltage here which is varying, the current only varies; the voltage across this remains constant at point 6, around point 6. So, this is called a voltage regulator; important application of a diode.

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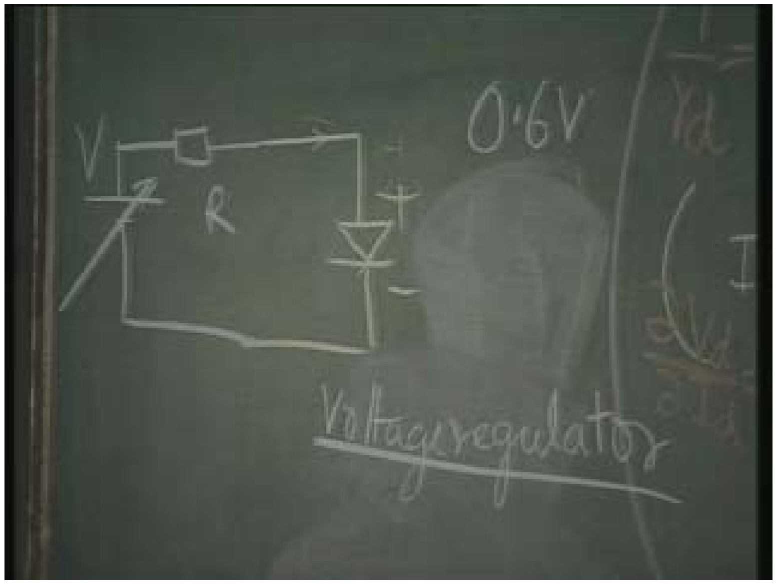

Suppose I want to regulate the voltage at a constant value, irrespective of the change in voltage here, V; then, I can use this diode. You might say that point 6 voltage is too small. So, what should I do? No problem. You will connect diodes in series, very large number of diodes in series; let us say, n such diodes. Then, the voltage that becomes available is n times point 6.

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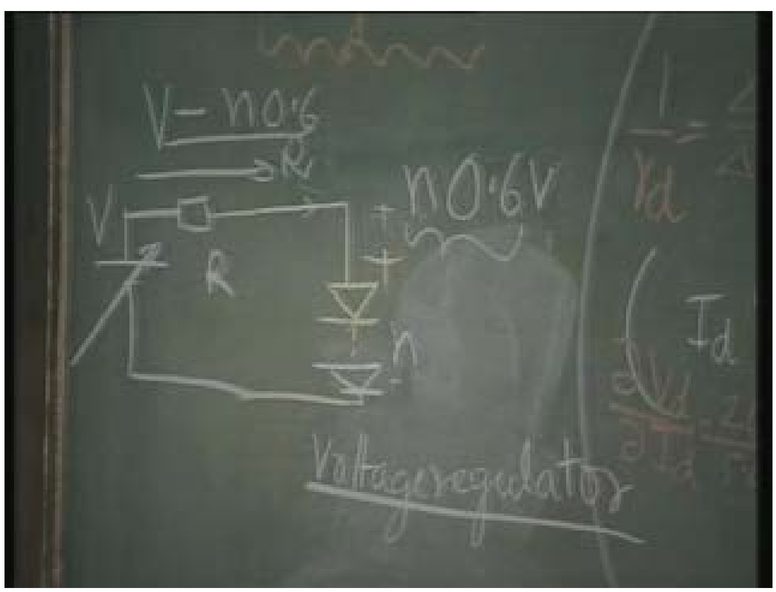

Suppose you use 10 such diodes in series; then you will get, n into point 6; that is, 6 volts; 10 into point 6; 6 volts across this. If you use 20 such diodes, you can get 12 volts constant, irrespective of what this voltage is, as long as this voltage is greater than 12 volts so as to forward bias that, all the diodes, because all the diodes will get forward biased when the cut in voltage of all these totally get exceeded. That means, this voltage should be necessarily greater than n times point 6. Then it will forward bias all these diodes and the current is limited by this resistance R. So, what will be the current in this? V minus n times point 6 divided by R.

So, I fix this current at, let us say, 1 milliampere or so; then, this voltage remains constant. I can use this arrangement, which is called a string of diodes for regulating the voltage at a constant value like this or I can use what is called as a Zener diode.

The diode we have seen breaks down at a certain point. This characteristic, we have seen; this is called the Zener voltage, V z. Under normal circumstances, this has to be greater than the peak reverse voltage that is coming across the diode. But, when it is being used as a Zener diode, this is precisely sort of monitored; and therefore, you have Zeners which are available from few volts up to hundreds of volts.

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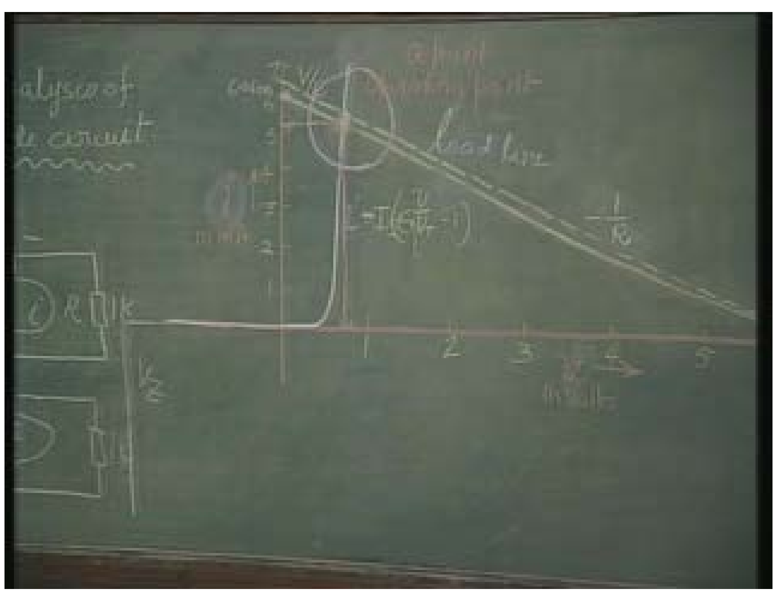

So, this breakdown region, you can see, that is similar to this kind of current increase exponentially; so, the current increases drastically for the same voltage. So, that characteristic of the diode can be definitely used. So, the entire region can be used; instead of using a string of diodes, we can use a Zener diode.

The symbol for Zener diode, the same diode used in the reverse bias mode, but in the breakdown region. So, we have this breakdown region indicated by this symbol. So, this is the Zener diode and the Zener breakdown voltage is V z. So, it is this V z that is being used for voltage regulator application, when the Zener voltage has to be very high. Instead of putting large number of diodes in series, to get this effect, we can just use a single Zener diode.

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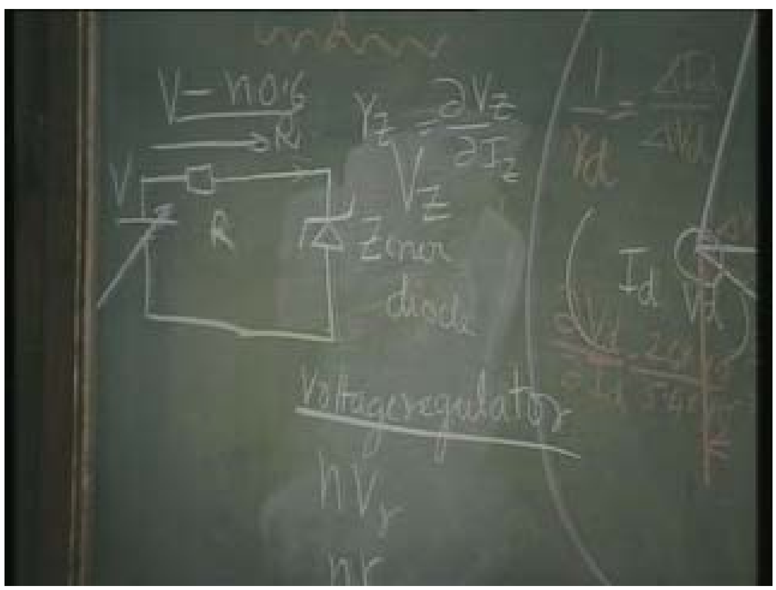

The advantage is, when you put diodes in series, the resistance of this, this is n times V gamma is the voltage, but the resistance is n times r diode; that increases. So, it is not equivalent to a good battery because resistance in series increases. So, the terminal voltage keeps changing as current changes; whereas, in the case of a Zener diode, the Zener resistance is of the order of tens of ohms; that is called Delta V z by Delta I z. When there is a change in current through the diode, Zener diode, the change in voltage is extremely small; and that again can be put as an equivalent r z, small signal equivalent circuit for the Zener r z, which is of the order of few tens of ohms. So now, we have represented the forward bias diode, a string; or, the reverse bias diode under breakdown can be used for what is called Zener voltage regulator or diode voltage regulator, to maintain voltage constant, irrespective of the current through it.

So, in the next class we will learn how to design such voltage regulators for maintaining the voltage constant when the DC voltage here varies.

This is the problem with most of our supplies here. The DC voltage which you derive from rectifier filter combination that we had discussed earlier keeps changing, depending upon the AC voltage that is applied to it. So, when that voltage varies, we do not want our bias voltages to change. So, we put a Zener diode to maintain the voltage constant at V z and then you can connect the load across it. So, how to design such Zener regulators will be the topic of our next class.