Basic Electronics
(Module – 1 Semiconductor Diodes)

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Lecture - 5

Zener Diode and Applications

Today we will discuss about a special diode known as Zener diode. This Zener diode is very much used in voltage regulator to maintain a constant voltage across a varying load. In order to understand Zener diode operation let us first recall the VI characteristic of a PN diode. The VI characteristic of PN diode as you can see here is in two regions. One is the forward biased and the other one is reverse biased.

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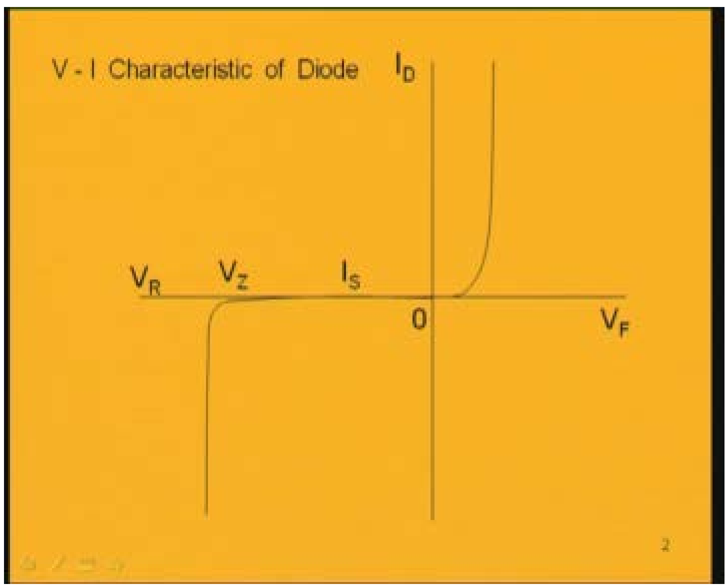

In the forward bias region the current rises sharply after crossing the threshold voltage which is around 0.7 volt for silicon and 0.3 volt for germanium. Let us concentrate in the reverse bias condition. When the reverse bias voltage that is applied across the PN diode is increased current does not increase significantly. Whatever little current flows that is called the reverse saturation current I_S and this is due to the minority carriers present in the diode. Even though we increase the reverse bias voltage the current does not rise significantly. If we go on increasing the reverse bias potential then if it is sufficiently large after a point we see that there is sharp increase in the reverse current I_R. That means here the voltage which is to be reached before the breakdown condition that voltage is known as breakdown voltage and the breakdown in a PN diode occurs generally due to two phenomena. One is called the avalanche breakdown. That is because when the applied reverse bias potential across the diode is very large then the electrons get sufficient kinetic energy to break open the covalent bond and in the process they release other electrons and these electrons also get the energy to knock out other electrons from near by covalent bonds.

This process is actually a cumulative process. There will be an avalanche of carriers present and that is why there is a large rise in the current and this process is the avalanche breakdown. But this avalanche breakdown phenomenon generally happens for lightly doped PN diodes. If we increase the doping concentration in P and N type, then we can get the breakdown occurring at even a lower potential. If the doping is high then we could get the breakdown occurring as low as at even -5 volt. That phenomenon for heavily doped diode is known as Zener breakdown.

There is a fundamental difference between avalanche and Zener breakdown. What is Zener breakdown? Because of the reverse bias potential being high there will be strong electric field present across the junction. Due to this high field intensity, the rupturing of the covalent bonds will occur and whole electron pairs will be generated. Here tearing of the covalent bonds occur because of the high electric field across the junction, because of the application of a high reverse bias potential. This breakdown is called Zener breakdown. This Zener breakdown will have a sharp rise of the reverse current in the diode. That means this current will suddenly very sharply rise after crossing this Zener breakdown voltage, V_Z. The major reason for the Zener breakdown is because of this rupturing of the covalent bonds.

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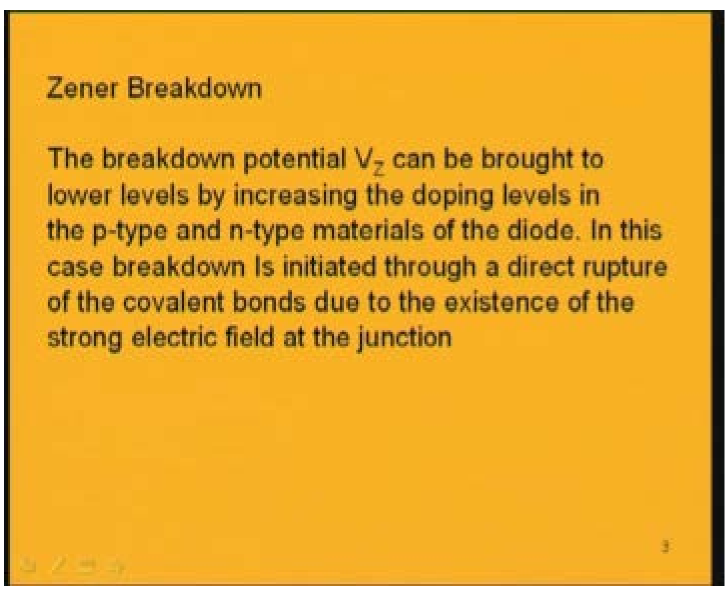

This breakdown potential V_Z can be brought to lower levels by increasing the doping levels in the p-type and n-type materials. These Zener diodes exploit this breakdown phenomenon which is effectively used for some special applications. For example a common application is the voltage regulator.

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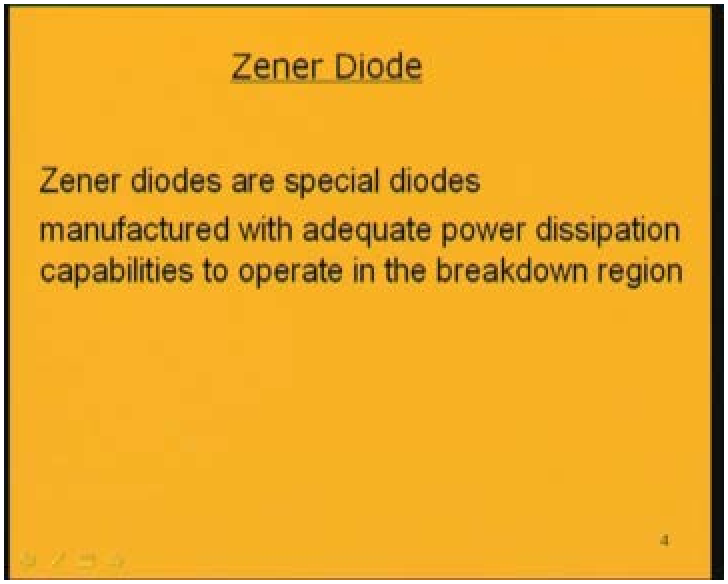

This Zener diode is manufactured with adequate power dissipation capabilities so that they can operate in the breakdown region. Normal diodes we cannot operate in breakdown region because of this danger of degrading the characteristic of the diode if the power dissipation capability is not high and normal diodes do not have the high power dissipation capability. That is why it is dangerous to use in the breakdown region. But the Zener diode has higher power dissipation capability so that they can be used in the breakdown region without any danger of degrading their properties. These Zener diodes are special diodes which are effectively utilized in the reverse breakdown region. It does not mean that the Zener diode is only operable in the reverse breakdown. It can be used in the forward region also.

In the forward characteristic it will be similar to the VI characteristic of normal diode. If we consider the V-I characteristic of the Zener diode in the forward region, the current versus voltage is like a normal diode. In this region we can equivalently express the Zener diode by a source 0.7 volt across this diode which is due to the threshold voltage and the resistance of the diode which is very small in the forward bias condition. This Zener diode in this region will clash across this P and negative of the terminal of the battery across the N of the diode since it is forward bias condition. The equivalent circuit for this Zener diode in the forward bias condition is like a normal diode having 0.7 volt drop across the diode and resistance R_Z is the resistance of the Zener diode in the forward bias condition. But as this R_Z is very small we can effectively express this equivalent circuit by another approximation keeping the 0.7 volt battery that is expressing the voltage drop across this diode. This equivalent circuit is having this voltage drop 0.7 volt for silicon and this characteristic in the forward bias condition is similar to your normal PN diode.

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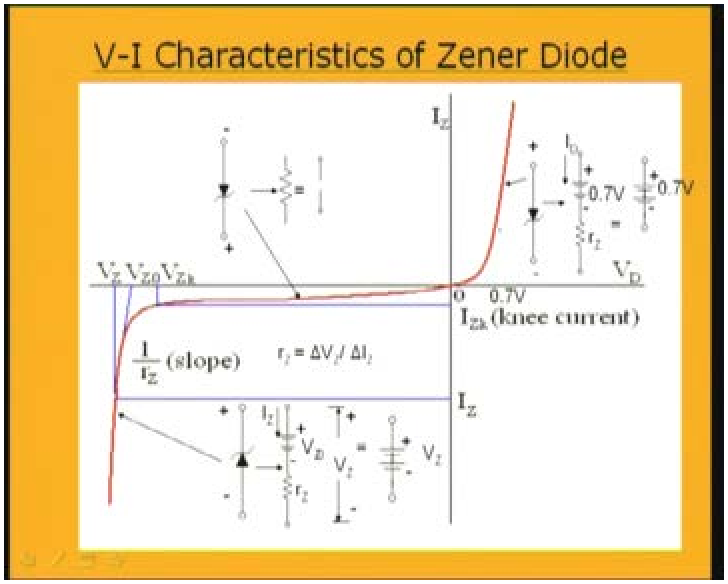

Now let us concentrate in the reverse biasing condition. When the reverse bias voltage is low even in the case of increasing the reverse bias potential the current will be low because this current which is the saturation current is due to the minority carriers only. The current is very small and in this region even if you go on increasing the potential we will not be getting rise of current. If we go on increasing the reverse bias potential even further then we will see that after a point the current is rising sharply but the voltage is almost same. That is the voltage is maintained constant but the current is rising significantly. That means here the Zener breakdown is occurring. Till the point when the breakdown does not occur, this region as it is having very less current the resistance in this portion is very high. That is very clear if we find the slope of the curve and the in inverse or the reverse of this slope is the resistance. The current change is very small even though change of this voltage is very high. We infer that the resistance is very high in this region. This Zener diode in the reverse bias condition the negative of the terminal of the battery applied to the Zener diode is connected to P and N is connected to positive. This is the symbol of the Zener diode. It is a crooked N to differentiate it from normal PN. This region can be equivalently expressed by only the resistance which is very high.

As the current is almost zero if we ignore this minority current which is very small we can approximate it as an open circuit. That is current is almost zero in this region as compared to the current which flows after breakdown. When this point of breakdown is reached, after that point the current rises very sharply. This is almost linear region so that the slope of this region, inverse of this slope will give the resistance. That resistance is very small, only a few ohms after breakdown. This dynamic resistance is given by del V_Z by del I_Z. If we consider two points in this region, find out the change in the voltage and corresponding change in the current this curve is almost vertical. The change of the voltage is very small but change of current is very high. So the resistance will be very, very small. The dynamic resistance which is obtained in this way is very, very small. In this region as this voltage across this diode is almost constant we get a constant voltage and apart from that constant voltage across the diode we have small resistance. There is a point called the knee current. In the current axis if we see the current I_{Zk} is the knee current and what does it mean? If we consider the knee region of this curve, center of this knee region is corresponding to this point I_{Zk}. That means below this knee current there is no breakdown. That means from this point to this point, up to the knee point this resistance is very high and it is almost like open circuit.

This Zener diode is almost like open circuit and the corresponding voltage is V_{Zk} for this knee point. The center of this knee point is corresponding to I_{Zk} V_{Zk}. Actually that point is significant in the sense that before this point is reached the reverse breakdown phenomenon is not occurring and the Zener diode is only having the reverse saturation current which is very, very negligible. The resistance is very, very high. After this knee point is reached this current is rising very sharply. If we extend this linear region of the curve it will be intersecting the voltage axis at point V_{Z0}. This V_{Z0} and V_{Zk} this difference is very, very small and almost these two points are very, very close. We take any point on this reverse breakdown region and find out the voltage at this point and current at this point. For example we are taking this point which has a current I_Z and the voltage V_Z. This voltage V_Z actually is the voltage V_{Z0} plus this voltage. This voltage is nothing but I_Z into R_Z that is the drop in the Zener resistance. V_{Z0} plus I_Z R_Z will give you the voltage across the Zener diode at that point of operation.

We can now consider the Zener diode in the reverse breakdown as having a voltage drop which is V_{Z0} and having a resistance R_Z. The overall voltage dropped across this Zener diode is V_Z which is equal to V_{Z0} plus I_Z into R_Z. Again R_Z is very small because if we consider this linear portion this resistance will be very small as there is very, very less change of voltage for a considerably large change of current. We will not be wrong if we approximate it to have only the voltage drop V_{Z0} and ignore this part I_Z into R_Z. This drop will be very, very negligible. Ultimately we have this model of the Zener diode in the reverse breakdown condition as having the voltage V_Z which is equal to V_{Z0}. This part can be neglected. What we get across this Zener diode after Zener breakdown has occurred is that a constant voltage drop V_Z is maintained even though current can change. This particular phenomenon is very, very effectively utilized. That we will see later.

Once this reverse breakdown occurs then the voltage across the Zener diode will be locked at the voltage V_Z. This V_Z that is the Zener voltage for Zener diode is specified in the data sheet for a particular Zener diode that you are using. It can be a 3.9 volt Zener diode also and it may be even brought further less and higher voltage Zener diodes also are available. There are a variety of Zener diodes having different Zener voltages which will be known from data sheet. In the Zener diode you are particularly using, how much is the Zener voltage that will be specified in the diode. The Zener voltage of the particular Zener diode that you are using will be specified in the diode. Apart from that specification another specification which is very important is the power dissipation. The Zener is having a particular maximum power dissipation capability that is also specified in the data sheet. For a particular Zener diode what is the maximum power that it is able to dissipate? That rating will have to be always remembered because we cannot exceed that power rating. One rating is the Zener voltage and other is the power dissipation.

These two are important parameters of the Zener diode which is specified in the data sheet. Keeping these two parameters in mind we have to design Zener circuits for regulation of or for other purposes. When use practically these two points that is Zener voltage and power dissipation are to be kept in mind and this power dissipation is higher than compared to the normal diodes because the Zener is particularly designed for use in the reverse breakdown condition. It will have higher power dissipation than the ordinary or normal PN diodes which are generally operated in the forward bias condition. After this we can see that the voltage across Zener diode will be locked to a voltage which is specified in the data sheet. That is known as the Zener voltage or breakdown voltage and along with it the power dissipation capability of the Zener maximum power dissipation rating that is also specified. The symbol of the Zener diode is this one.

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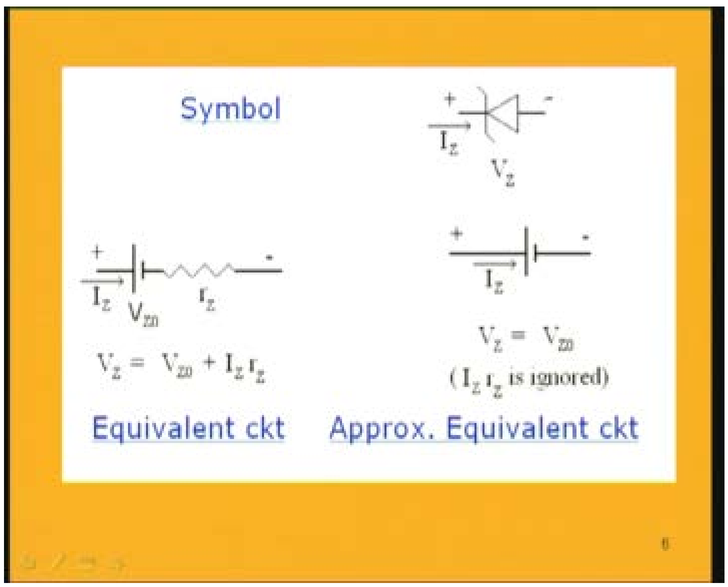

This PN N is a little tilted than the normal diode symbol and we always operate that Zener diode generally in the reverse breakdown. That is why last of the battery terminal is connected to N and negative of the battery terminal is connected to P and this voltage V_Z is specified and the current flowing through the Zener diode is I_Z and you have to notice the direction of the current because the Zener diode will be reverse biased. Positive of the battery terminal will be connected to N. The current direction will be the conventional current direction from positive of the battery terminal to the negative. That is why the current direction is I_Z as is shown in the diagram. This is the symbolic representation of the Zener diode.

As we have seen and understood in the V-I characteristic of the Zener diode in the reverse breakdown condition we approximately model the Zener diode as this circuit having the voltage drop V_{Z0}. Along with it there is a resistance r_Z in the reverse breakdown. Basically the voltage across the Zener diode V_Z is equal to V_{Z0} plus I_Z r_Z. If I_Z varies this drop is variable. This part is this. V_{Z0} is constant because this is the point where the linear characteristic intersects the voltage axis. But for different operating points on the reverse breakdown this current I_Z will vary. So the dropped I_Z r_Z will also vary. That is why basically the whole drop is V_{Z0} plus I_Z r_Z. But as this r_Z is very small this whole drop I_Z r_Z which is exactly actual variable we can approximately ignore this drop. As this r_Z is small this drop will be small. This variable drop can be neglected all together and then we will have V_Z equal V_{Z0}. That is the practical model which is used for Zener diode in reverse breakdown. That is equal to V_Z. This drop is equal to V_{Z0}.

This is the approximate equivalent circuit and this circuit will be frequently and mostly used unless and until you are specified that you have to take into consideration that resistance also. But for our discussions we will be generally neglecting this drop. This V_Z is a battery. It is shown like a battery. So this drop is constant. That is why it is shown like a battery. That is the drop across the Zener. The Zener voltage or the breakdown voltage is sensitive to the temperature also.

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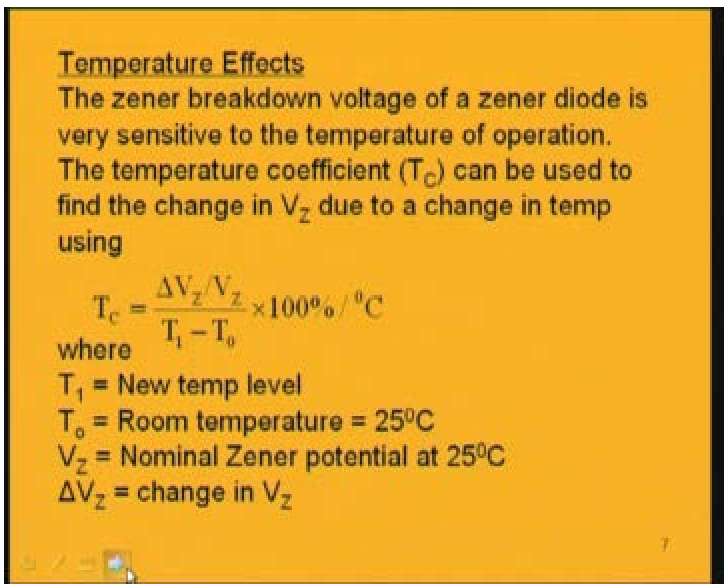

The temperature at which you are operating the Zener diode has an effect on the breakdown voltage. That effect is generally expressed by temperature coefficient T_C and this temperature coefficient is used to the find the change in the Zener voltage V_Z or breakdown voltage V_Z which arises due to the change in the temperature of operation. The expression which is used to find out this temperature coefficient is T_C is equal del V_Z by V_Z divided by T_1 minus T_0 into 100% per degree centigrade. What is this del V_Z? This is the change in V_Z due to temperature change. T_1 is the new temperature level and T_0 is the room temperature. Generally this is nominal temperature at which we do our calculations. This is 25 degree centigrade. Room temperature is taken as nominal temperature and at that temperature 25 degree centigrade, the Zener voltage is V_Z. If we have change from 25 degree centigrade that is T_1 and with this expression we can calculate what is the change in V_Z from the nominal V_Z? That is Zener voltage at 25 degree centigrade. From that what change occurs due to the change in temperature that can be calculated from this and if we know del V_Z we can find out what is new V_Z. That is equal to old V_Z plus this delta V_Z. So temperature has an effect on the Zener voltage.

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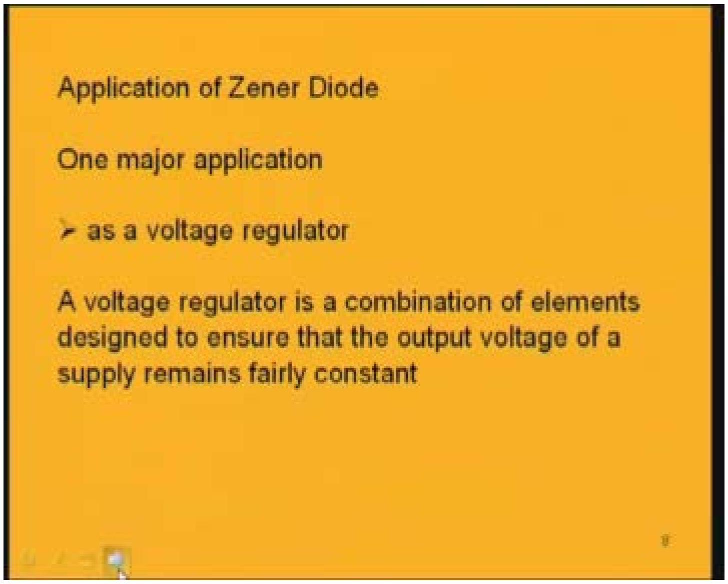

Main application of Zener diode as I have indicated is in voltage regulator circuits. A voltage regulator is a combination of elements which are designed to ensure that the output voltage of a supply remains fairly constant and if we recall the rectified circuits which we discussed earlier we had a block diagram representation which gave the various stages of rectified circuits. Starting from a sinusoidal AC voltage we first rectified it using half wave or full wave rectifier which is with a capacitor filter to smoothen out the DC voltage but finally even after using the filter capacitor we got a DC voltage which had ripples. These ripples are present in the DC voltage. That can be removed if we now use a Zener regulator. That is finally after rectifying it with filter capacitor we can further rectify and find the final constant DC voltage if we use Zener voltage to maintain a constant output voltage. Finally we can get a constant output voltage from the DC having ripple part.

How is that obtained? The main principal is that if Zener diode is a diode which is used in the reverse bias condition where after breakdown the voltage across the Zener diode locks to a constant voltage. That principle will be used. We will see that even if there is change in the load current or there is change in the input voltage we still get an output voltage which is constant. We will be first considering the Zener regulator circuit, a simple basic circuit. Just to show how this regulation of voltage occurs we will be taking help of a simple circuit. In this circuit both input voltage and the load resistance are first fixed. Let us first discuss how the regulation takes place and then we will practically see what happens when the input voltage and load resistance changes.

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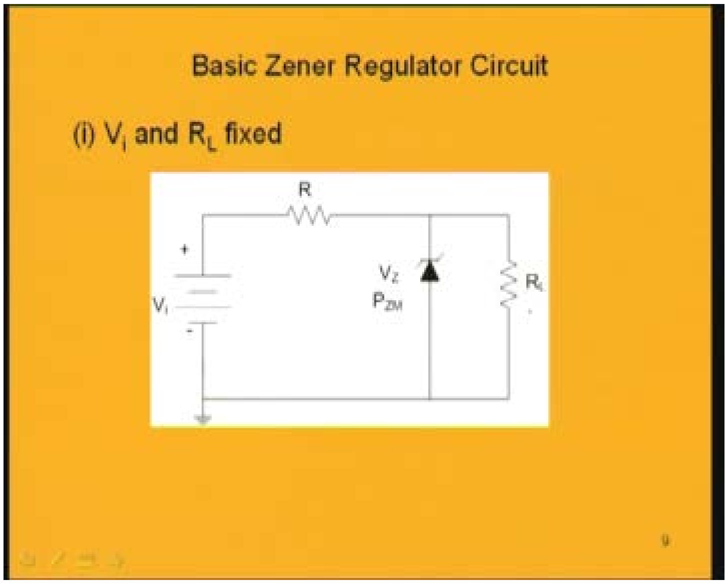

Here for this case let us start with constant voltage V_i as the supply voltage to the circuit and load resistance R_L is fixed. This Zener diode is having a constant voltage V_Z after breakdown and maximum power dissipation capability is P_{ZM}. These are specified in the Zener diode. This R is there to limit the Zener current after breakdown. This is called current limiting resistance. It is in series in the circuit. It will be limiting the Zener current which flows enormously after breakdown and that can be limited by using a resistance in the circuit. First of all we have to find out that condition under which the breakdown in Zener diode occurs. That is when the reverse breakdown will be occurring? When the voltage across this Zener diode that is load voltage is greater than or equal to the limiting condition at that condition the Zener will break down, reverse breakdown will occur. First of all in this circuit we must ensure that the voltage applied across this Zener diode is greater than or equal to the Zener voltage. The voltage that is across this Zener diode has to be found out.

To find out voltage the across this Zener diode we will be using Thevenin's Theorem; open circuit this diode and find out the voltage looking from these two terminals. In the next step from this diode we will be removing this diode. Open circuiting this find out the Thevenin's voltage, V Thevenin across these two terminals. That is the way we have to find out the voltage across the Zener diode. First of all let us find out V Thevenin. What is V Thevenin; this voltage across these two points after open circuiting this diode using Thevenin's theorem. The voltage across these two points is V_i into R_L by R plus R_L. That is the voltage division taking place across these two resistances of this voltage will be found out. If this voltage, V Thevenin is greater than equal to V_Z that is Zener breakdown voltage for this particular diode which we are considering, then the Zener diode will be in the ON condition; means breakdown will occur and we can approximately replace this Zener diode by its approximate equivalent circuit.

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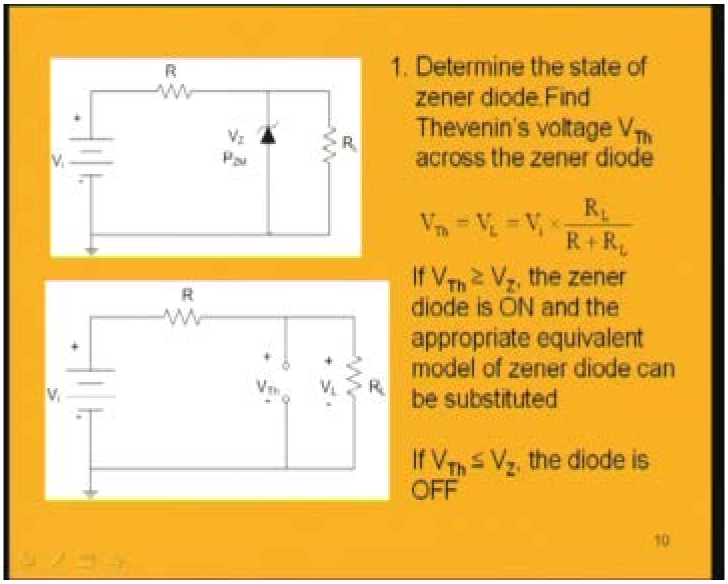

If this voltage across this Zener diode that's open circuited voltage V Thevenin is less than V_Z then the Zener diode will be not ON. First of all we must ensure whether the Zener diode is ON that means whether breakdown is occurring or not. That means we must first ensure that the open circuited voltage across the Zener diode must be greater than the Zener voltage for that diode. If this condition is met that is V Thevenin is greater than equal to V_Z then we will be replacing the circuit by its equivalent circuit which is nothing but drop V_Z.

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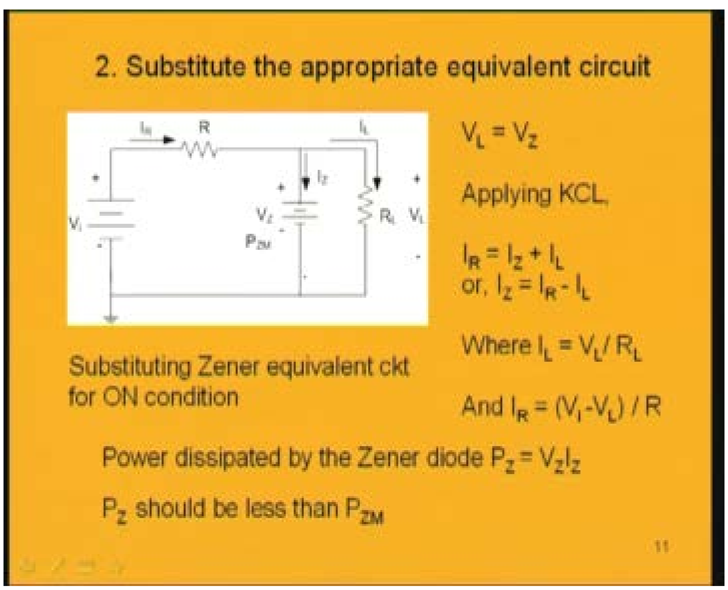

This battery is expressing that a constant voltage drop is occurring across this Zener diode after breakdown. Substituting this equivalent model now, we get this circuit. It is an electrical circuit. We can find the different currents and voltages in the different components of the circuit. The voltage V_Z is constant even though currents may change. That means the current I_L may change if we change R_L but V_Z will be constant. But in this case we are keeping this R_L constant. What is the voltage across this R_L? That is V_L, load voltage this voltage at these two points is nothing but this voltage V_Z. So V_L is equal to V_Z. At this point we can now apply the Kirchoff's current law. The algebraic summation of the currents at this node is equal to zero; that is Kirchoff's current law. Using Kirchoff's current law I_Z plus I_L are outgoing; I_R is incoming. Incoming current is equal to sum of the outgoing currents I_Z plus I_L. I_R is equal to I_Z plus I_L.

You can find out I_Z, the Zener current that is equal to I_R minus I_L. What is I_L, load current? V_L by R_L; V_L is nothing but V_Z. We will be also able to find out I_R. The current flowing through this resistance R_i is nothing but the potential across these two points divided by resistance. Difference of potential across these two points is V_i minus V_Z. V_i minus V_Z divided by R is I_R and after knowing all these currents and also we have known the voltages across the different components we can also find the power dissipated by the Zener diode. The power dissipated by the Zener diode is the product of the volatge and and current flowing through it. P_Z equal to V_Z is the voltage across this Zener diode and current flowing is I_Z. V_Z into I_Z will give you the power dissipated in the Zener diode and it should be less than the maximum power dissipation capability of the Zener diode which is equal to IP_{ZM}. P_{ZM} is defined. What will be that value? You know that. P_Z should be less than P_{ZM}.

This is a case where you did not have a variable voltage or a changing load. But now let us consider the variable load and fixed V_i. That is the voltage is kept constant; input voltage or supply voltage V_i is kept constant but the resistance is variable. You can change the resistance and consequently you can change the load current. Let us consider that type of the circuit. In this circuit this load is variable. That is why a variable symbol is used for this load resistance R_L. How much variation can this load resistance have in order to turn the Zener diode ON? Because you can change this load resistance how much change you can make? How much minimum value and up to what maximum value we can change the load for Zener diode to turn ON? Because there will be a range you cannot go on arbitrarily changing the load resistance; that will be clear. Because the first and foremost condition to be satisfied is that the open circuited voltage across the Zener diode must be greater than V_Z. So that will be putting a limit on R_L. What will be that R_L? Let us find out the maximum and minimum values.

If we change this load resistance to very small value we will be having a Thevenin's voltage across this Zener diode which will be less than V_Z and then the Zener diode will be OFF. First of all let us find out that minimum load resistance R_L which will turn ON the Zener diode. Assuming that the Zener diode is turned ON by that resistance R_L minimum, what will be the minimum value of R_L?

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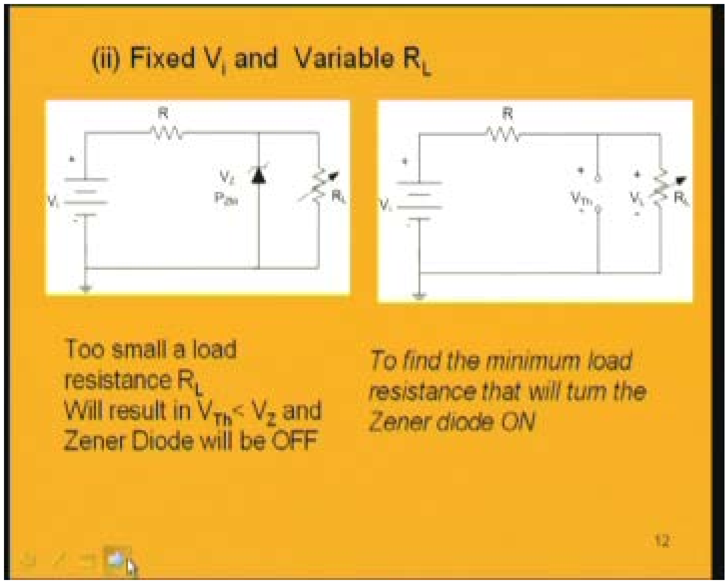

In order to calculate that value of R_L minimum let us consider the Zener diode ON and find out. If Zener diode is ON, for this V_L will be equal to V_Z. What is this voltage across this Zener diode? Thevenin's open circuited voltage is V_i into R_L by R_L plus R and that must be equal to V_Z. Actually it is greater than V_Z but let us take the limiting condition to find out that limit. V_L is equal to V_Z equal to V_i into R_L by R plus R_L. If we simplify this expression and solve for what will be R_L, then we get that value of R_L is equal to V_Z into R by V_i minus V_Z. That means the resistance value should be at least equal to V_Z into R by V_i minus V_Z. We are not changing R. R is constant. Once you decide R, we are not changing V_Z is the voltage, Zener voltage for that particular Zener we are applying. V_i is constant. This expression will give you the minimum R_L which will make that diode, Zener diode ON. If it is less than that, this voltage will be not sufficient to make the Zener diode ON.

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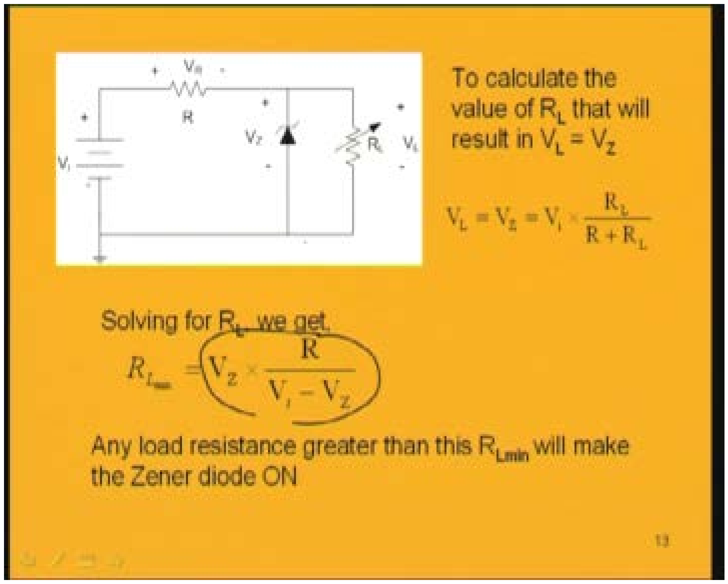

You should have any load resistance greater than this value of R_L minimum to make the Zener diode ON. If R_L is minimum I_L will be maximum. When I_L is maximum, that I_Z will be minimum because I_R equal to I_L plus I_Z. This I_L is maximum because we are having a load resistance which is minimum.

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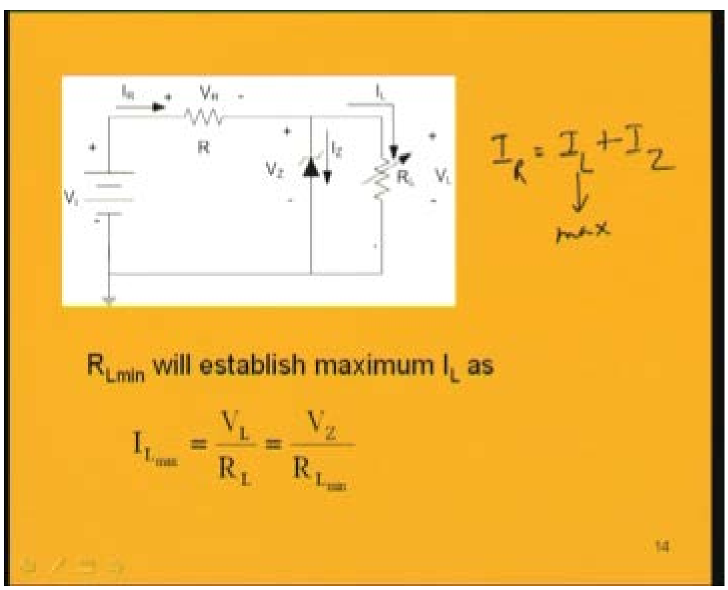

I_L maximum will make I_Z minimum because I_R is constant. We have now a condition for I_L maximum which is obtained V_L by R_L that is equal to V_Z by R_L minimum. The minimum resistance which you have just now derived that will be giving you the maximum load current and that will be giving you the minimum Zener current.

What is the I_Z minimum that we can find out because I_Z minimum is equal to I_R minus I_L maximum and we know I_R. I_R is equal to this current is equal to V_i minus V_Z by R.

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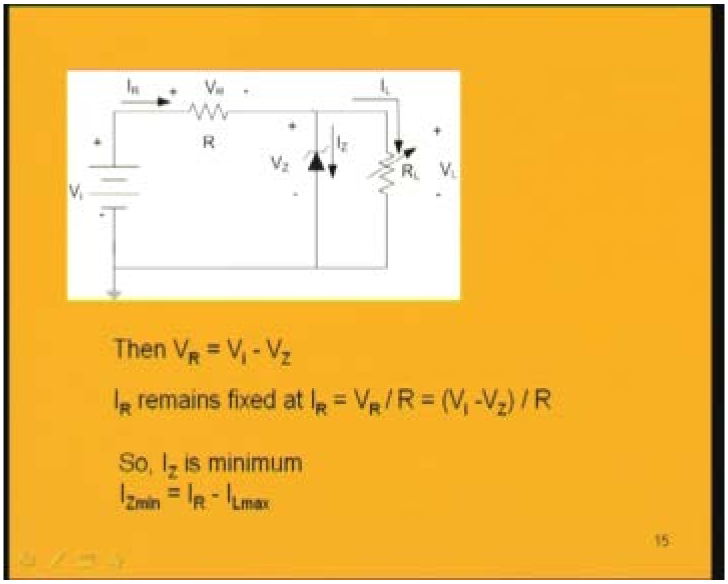

This is one condition where you will be getting the maximum load current, correspondingly minimum Zener current. Let us find out the maximum load resistance. When you have maximum load resistance then load current will be minimum because I_R is equal to I_Z plus I_L. When R_L is maximum this I_L, load current is minimum. As load current is minimum, I_Z is maximum. But I_Z has rating. Maximum Zener current is specified in the diode. That maximum Zener current I_Z will be causing load current to be minimum.

What is that minimum load current? I_R minus I_Z max; corresponding to this minimum load current we have the R_L max that is equal to V_Z by I_L minimum. In this circuit V_L by R_L minimum is I_L maximum as well V_L by R_L maximum will give you I_L minimum. I_L minimum will give you I_Z maximum. This I_R we know because I_R is equal to V_i minus V_Z by this resistance R. Once you fix this I_R we can find this maximum Zener current. Maximum Zener current means I_L minimum. You have now obtained conditions for R_L minimum and R_L maximum. Within this range you can vary this load resistance to get a constant Zener voltage and this maximum condition we will be getting from the Zener current maximum rating of the diode.

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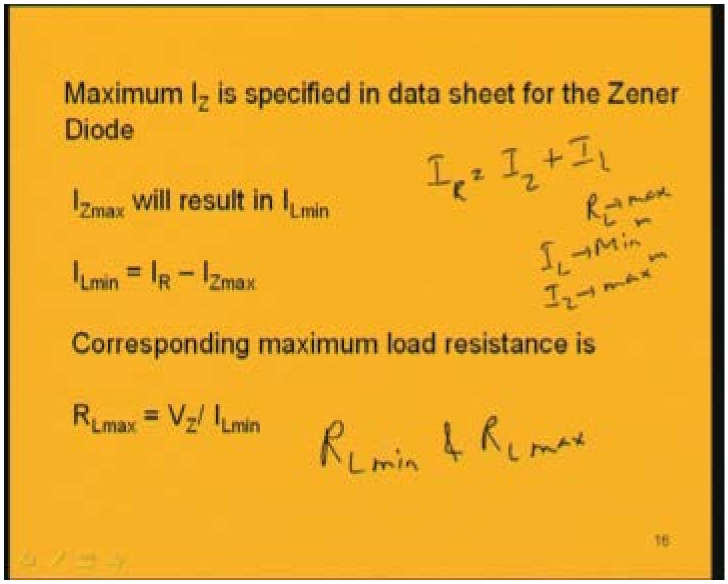

Another condition may happen when the input voltage V_i is variable but R_L is fixed. Suppose supply voltage is variable. Then in order to find out V_i minimum and V_i maximum rating how much change can be allowed for the input voltage V_i or source voltage V_i in order to get a constant voltage drop V_L? That is the problem. How small V_i may be in order to turn ON the Zener diode? That condition we will find out from the fact that V_i must be sufficiently large to cause the Zener to go into the breakdown state.

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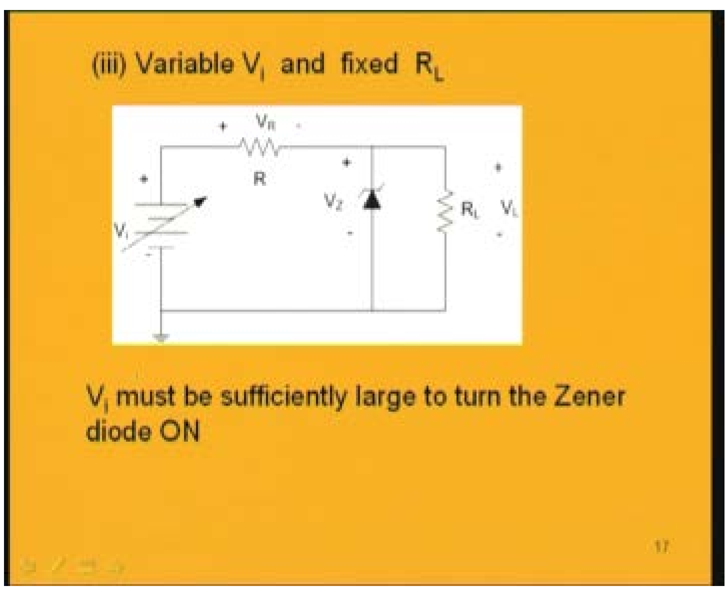

But that will be found out from the voltage across this Zener diode which is V_i into R_L by R plus R_L; that must be greater than V_Z. Putting the limiting condition here we get V_L is equal to V_Z is equal to V_i into R_L by R plus R_L assuming that the Zener diode is ON.

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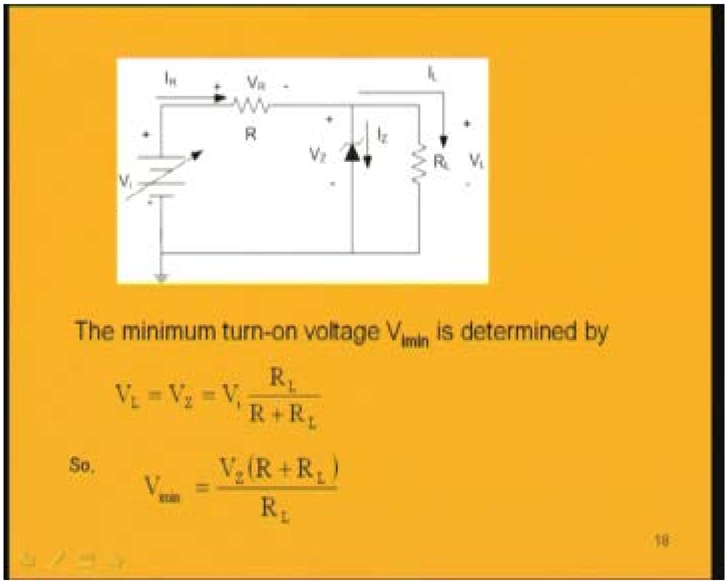

For Zener diode to be ON we are finding out what will be the corresponding V_i? Cross multiplying from this expression, we get V_{imin} is equal V_Z into R plus R_L by R_L. Minimum value of voltage input must be this one and what about the maximum value of V_i?

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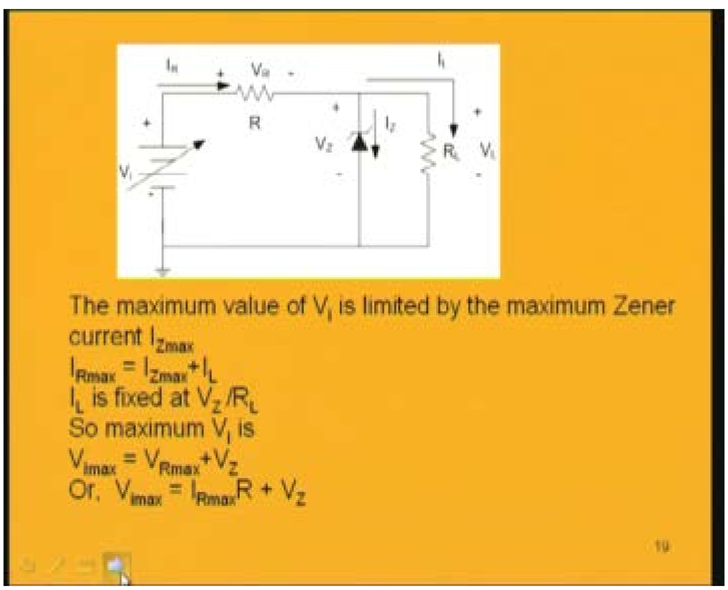

How much you can go on increasing V_i in order to make the Zener diode ON? We keep within the limit of the Zener diode specification because we have a maximum Zener current rating. If you go on increasing V_i, Zener diode current will be going on increasing. But we cannot go on increasing so much because there is a limiting condition which is specified in the data sheet of the Zener diode given by I_Z max. For the I_Z max what will be the I_R max? That is the maximum current I_R will be I_Z max plus I_L. Since this voltage is constant, resistance is also constant. V_L by R_L is constant. We are not changing the load. I_L is constant. So I_R max is equal to I_Z max plus plus I_L. As I_L is fixed maximum V_i is equal to V_{Rmax}. That means the maximum voltage across this resistance plus V_Z. Maximum voltage across this resistance means when maximum I_R flows that is I_R max into R. I_R max into R plus V_Z will be the V_i max.

What is I_R max? I_R max is equal to I_Z max plus I_L. I_Z max is given by the specified data sheet. So we have a limiting condition on V_{imax}. V_{imin}, V_{imax} we have found out those conditions. R_{Lmax} and R_{Lmin} also we have found out. With the variation in V_i or the variation in R_L still we are able to maintain the voltage across the load at a constant voltage V_Z and that is the usability of this Zener diode. The effective use of this Zener diode is this type of problem where you want to maintain a constant output voltage; that is in voltage regulator circuits. Let us try to solve an example.

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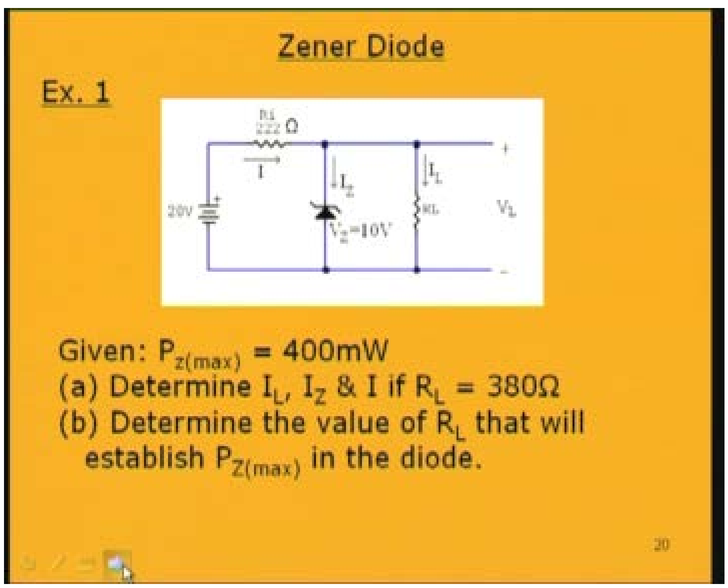

In this circuit utilizing Zener diode you are having the input resistance R_i. That is series resistance connected in the circuit is 220 ohm. The Zener diode is having a Zener voltage of 10 volt. This is the load resistance R_L which is the fixed load resistance; it is not varying. Input voltage is also fixed at 20 volt. Given that maximum power rating of the Zener diode is 400 milli watt, maximum Zener diode rating is specified. You have to find out in part a, the current I_L load current, Zener current I_Z and this current through this resistance R_i, the current I if the load resistance is given as 380 volts and part b, determine the value of R_L that will establish the maximum power P_{Zmax} in the diode. That is resistance R_L will cause this maximum Zener power 400 milliwatt maximum power dissipation. In order to solve these two problems first part of the problem you have to find out this current I_L, I_Z and I.

Before finding out the currents we must first ensure whether Zener diode is ON or not; that is whether breakdown is occurring in this Zener diode or not that has to be found out. For that we will be proceeding to find out the open circuited voltage across this Zener diode, Thevenin's voltage which is 20 volt into R_L by R_L plus R_i. Our next step is to find this Thevenin's voltage across this Zener diode. This voltage we will find out after open circuiting this Zener diode. Next we will be open circuiting these two points. Here this is resistance R_i and this is the voltage 20 volt and across these two points what will be V Thevenin? You have a resistance R_L. This voltage is nothing but 20 into R_L by R_L plus R_i and that is equal to 20 into 380. R_L is 380 by 220 plus 380. That comes to 12.67 volt and our Zener diode is having a Zener voltage of 10 volt. Definitely it is greater than P_Z. Zener diode will be turned on, break down will occur.

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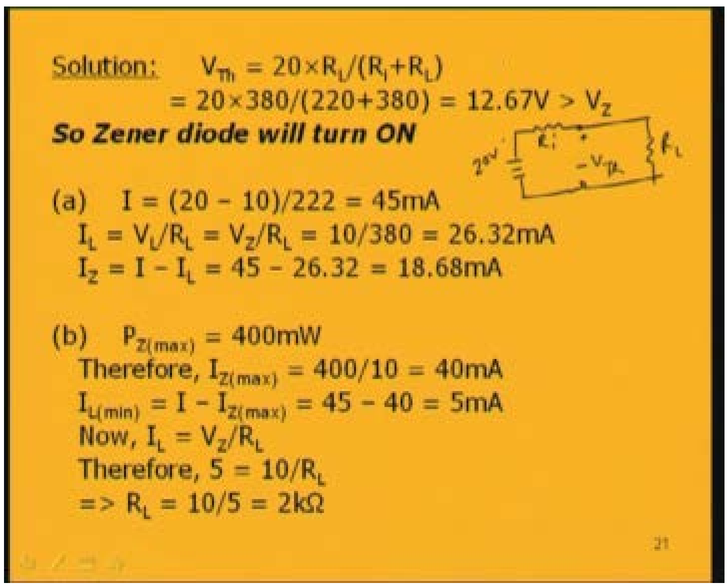

The Zener diode will turn on. If the Zener diode turns on, this voltage across this Zener diode will be locked to the voltage, 10 volt V_Z. This voltage is constant. So this loaded voltage V_L is also constant. We can very easily solve for this currents. What is this current I? This I is 20 minus 10. This V_Z is now 10 volt. It is locked. So 20-10 by R_i; it is 222 ohms. That is 45 milliampere is the current flowing in this circuit, I current. I is equal to 45 milliampere. Whatever this current I_L, I_L is equal to the voltage across this load resistance. This voltage across this load resistance divided by the load resistance R_L is the I_L current.

What is this voltage? After Zener breakdown, this voltage is constant at 10 volts. This voltage is also 10 volt. 10 volt divided by load resistance 380 ohm will be the current I_L. V_Z by R_L 10 volt divided by 380 is 26.32 milliampere is I_L current. What is current I_Z? I_Z equal to I minus I_L; I is 45 we have found out. I_L is equal to 26.32 milliampere. That gives 18.68 ampere as the current flowing through the Zener diode. All the currents have been found out in part a, whatever we are asked.

In the second part determine the value of R_L that will establish maximum power dissipation that is 400 milli watt in the diode. In part b that means you are given that the power dissipation in this Zener diode is maximum which is 400 milliwatt and what is this power dissipation? V_Z into I_Z; V_Z is 10 volt. That is Zener volt is constant. I_Z max we can find out. V_Z is 10 volts. So P_Z max divided by V_Z will be the I_Z max, the maximum Zener current that flows in the Zener diode and that is equal to 400 divided by 10 that is 40 milliampere. When the Zener diode current is maximum then this current will be minimum since this is constant. That minimum load current we can find out which is equal to I minus I_{Zmax}. I is constant which is 45 milliampere; we have already found out in part a. 45 minus I_{Zmax} 40 that gives 5 milliampere as the load current. The load current we know. We know the voltage across this load is nothing but V_Z. So V_L is equal to V_Z. So load resistance we can find out.

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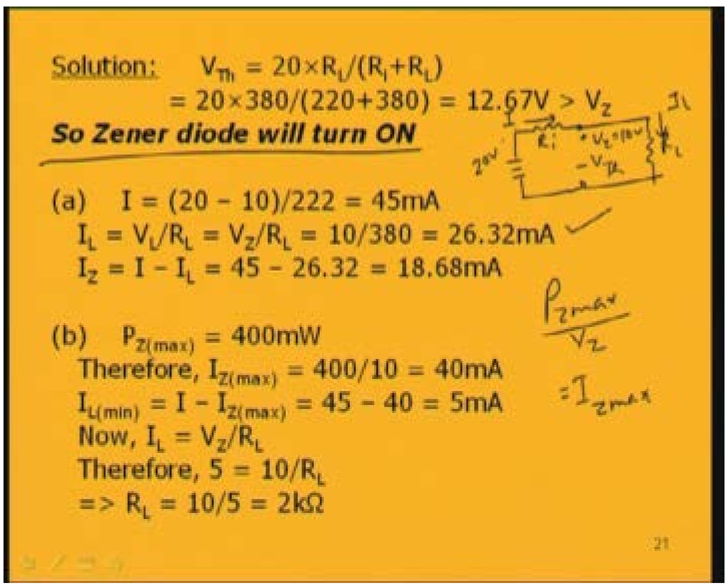

Load current 5 is equal to V_Z by R_L. V_Z is 10 volt by R_L. R_L we have to find out. So R_L is equal to 10 by 5 which is 2 kilo ohms. Since 5 is in milliampere, it will be order of kilo ohms. We get 2 kilo ohm load resistance for which the maximum power dissipation will occur in the Zener diode. This is one example where we have seen that you have this constant voltage drop and that will not change even under the condition that maximum Zener current occurs which is what we have got in this particular case 40 milliampere. So maximum power dissipation is 400 milli watt. For that we have found the load resistance which will cause the maximum power dissipation in the load.

Similarly another problem we can try. For this circuit where the load resistance is variable find the range of R_L and I_L.
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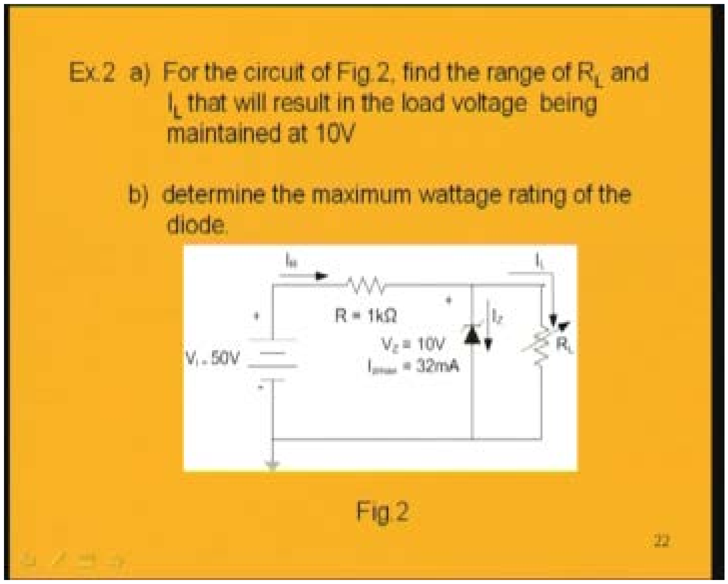

That is what will be the maximum and minimum values of R_L that will result in the load voltage being maintained at 10 volt and second part determine the maximum wattage rating of the diode. In order to solve the first part let us draw the circuit again. This is 1 kilo ohm and this is the Zener diode which is reverse biased because this voltage is plus minus 50 volt. V_i is 50 volt and this is the load resistance which is variable R_L. This is the Zener diode having the rating of V_Z is equal to 10 volt and I_Z max is given. I_Z max equal to 32 milliampere it is given in the circuit. This will be the load current I_L. This is the Zener current and this is the I_R current. First we have to find out whether the Zener diode will be turned ON or not. V_i into R_L by R plus R_L; R means this one is R. That is equal to 50 into R_L minimum that we have to find out. What is the minimum resistance in the load that will be causing the Zener diode to turn ON? Then 1 kilo ohm is R. Let us keep it in kilo ohm order. The final answer that will be in volt if resistance is in kilo ohm and current will be in milliampere. R_{Lmin}. That should be equal to the Zener voltage which is 10 volt; that is limiting condition. In fact this will be greater than 10 volt.

For this limiting condition what will be the Ri R_{Lmin} that can be found out. If you cross multiply 50 into R_{Lmin} equal to 10 plus 10 R_{Lmin}. So 50-10 is 40; 40 R_{Lmin} is 10. So what is R_{Lmin}? R_{Lmin} is equal to 10 by 40 which gives 0.25 kilo ohm.

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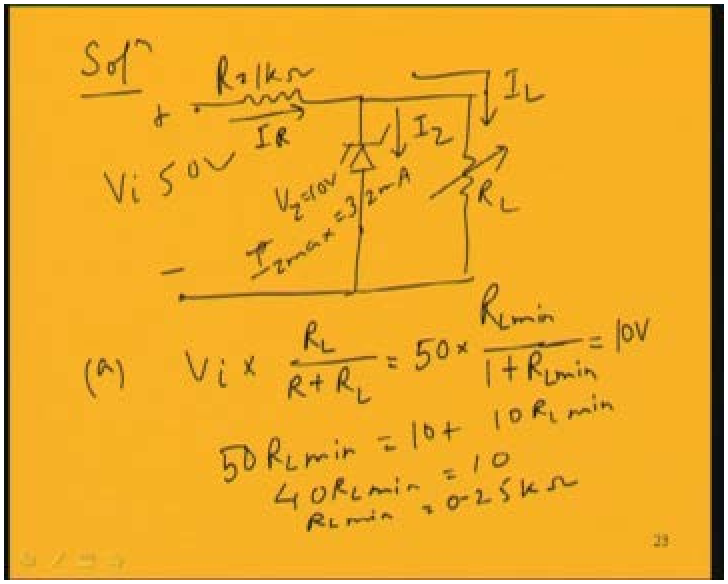

0.25 kilo ohm should be the minimum resistance of this load in order to cause Zener to breakdown and for that condition we will get maximum load current and maximum load current is V_L by R_L minimum. V_L is nothing but 10 volt V_Z by R_{Lmin}. R_{Lmin} we have found out to be 0.25 kilo ohm. 10 divided by 0.25 kilo ohm gives 0.04 ampere or 40 milliampere. 40 milliampere is the maximum load current and for maximum this is the R_L minimum. R_L we have found out to be 0.25 kilo ohm or 250 ohm and for maximum R_L, I_L is minimum. So I_Z will be maximum. What is that I_Z maximum that is given in your rating? I_{Zmax} equal to 32 milliampere. This is the rating of the diode; it is given.

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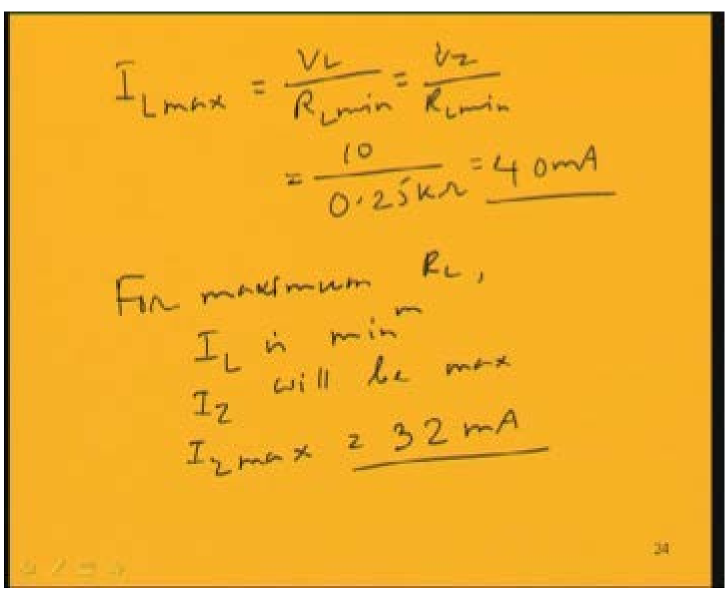

For that particular I_{Zmax} we can find out what is I_{Lmin}? If we consider this current I_R is equal to V_i minus V_Z by R. V_i is 50, V_Z is 10, R is 1 kilo ohm that gives you 40 milliampere. We have to find out what is the I_L minimum for that maximum load resistance? I_L minimum for maximum I_Z that is I_R minus I_{Zmax}. I_R is equal to 40 and I_{Zmax} is 32; so 8 milliampere is the minimum load current. Correspondingly we get R_{Lmax}. R_{Lmax} is V_Z by I_{Lmin}. V_Z is nothing but V_L which is the load voltage across this resistance. That is equal to 10 volt divided by I_{Lmin} we have 8 milliampere; that is 1.25 kilo ohm will be the maximum load resistance.

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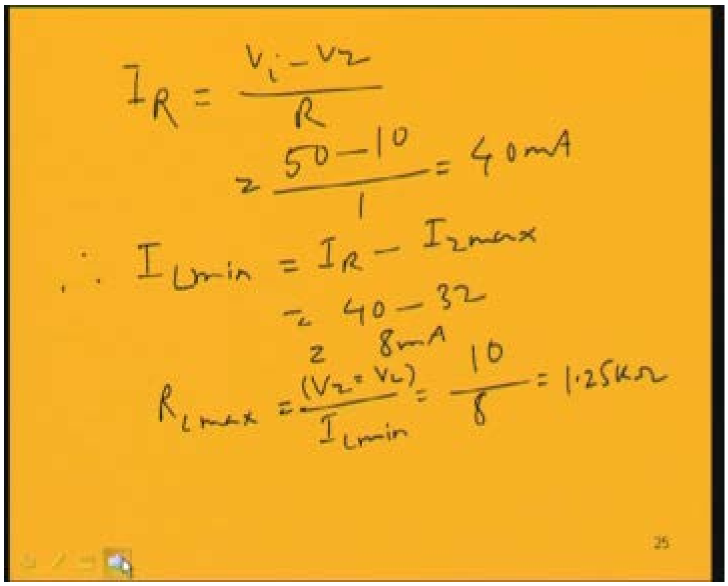

That means for these two conditions, minimum load current 8 milliampere and maximum load current 40 milliampere we get constant voltage V_Z which is 10 volt. Second part, b part is maximum wattage rating; maximum wattage rating of the Zener diode is to be found out. What is the maximum wattage rating? It is given by V_Z I_{Zmax}; V_Z is 10 volt, I_{Zmax} is 32 milliampere which we have been provided in the data sheet. 320 milliwatts will be the maximum power rating of the diode.

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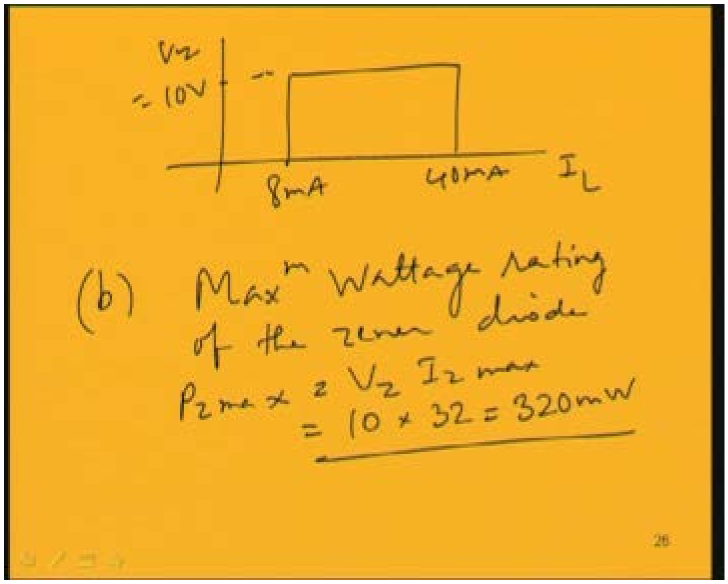

In this way we have seen the application of the Zener diode in the voltage regulator circuit and the Zener breakdown phenomenon maintains a constant voltage drop across the Zener diode at the Zener voltage V_Z. We can have a constant voltage across a load resistance even when the load resistance varies. That means the load current varies or there is change in the input voltage. Because input voltage may change there may be fluctuation in the input voltage which we face. Very often in our domestic house hold applications we see that the supply voltage varies. Even though supply voltage varies we can maintain almost a constant voltage across the load and that is the major advantage which this special purpose diode known a Zener diode has and that phenomenon is very effectively utilized in voltage regulator circuits.