Basic Electronics
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Lecture - 16
Diode circuits (continued)

Welcome back to Basic Electronics. In our discussion so far we have considered the diode to be ideal when a reverse bias is applied; that is we have seen the diode to be off and the diode current to be 0. In this lecture we will look at the effect of reverse breakdown of a diode on its i V curve. We will also consider an application where reverse conduction of a diode is beneficial. Let us get started.

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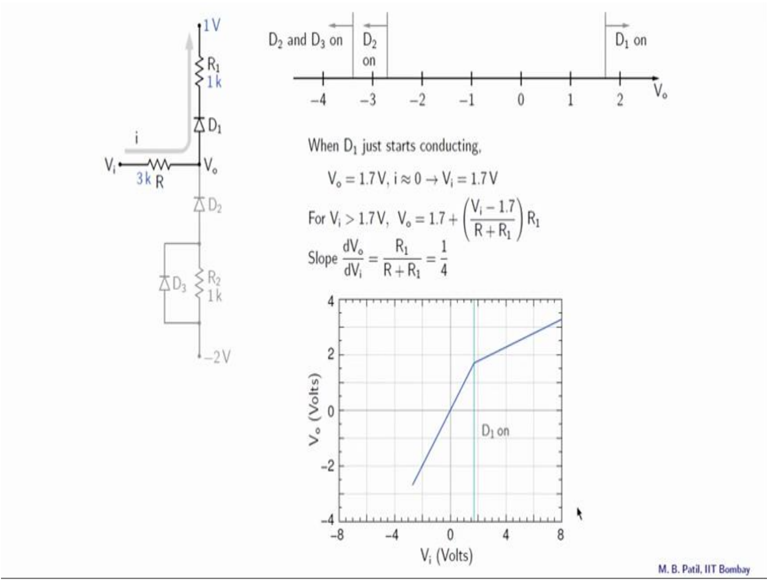

Let us look at this region now, where no diode is conducting and in that case, no current in this branch, no current in this branch and therefore the current through R is 0. So therefore, there is no voltage drop across R and V o it is equal to V i. Let us now look at the V o versus V i relationship for these two regions. Here is the plot, this region is V i greater than 1.7 volts this is 2 volts this is 1.7 volts. We have a straight line here with a slope equal to 1 by 4. In this region when all diodes are off we have V o equal to V i that is a straight line with slope equal to 1 and passing through the origin.

Note that this slope equal to 1 is not really looking like slope equal to 1, because these scales are different; here we have minus 8 to 8 volts and for the y axis we have minus 4 to 4 volts.

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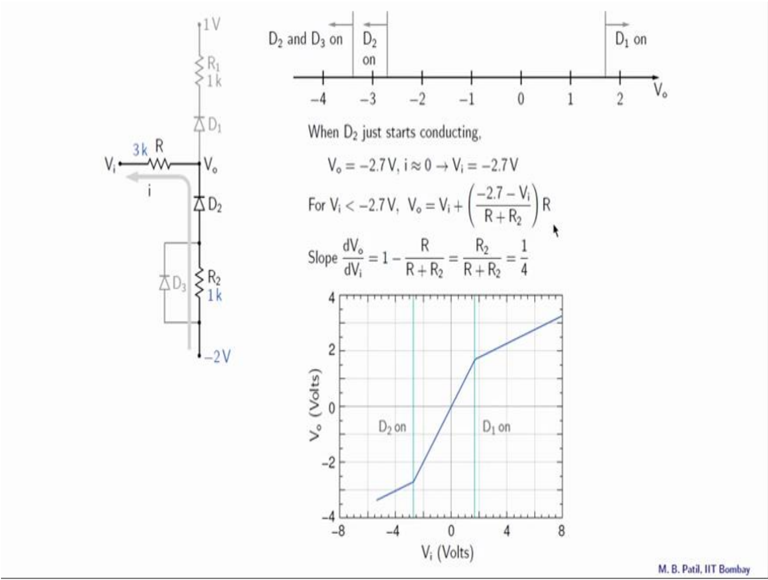

Let us proceed now with the next situation that is D 2 conducting, but D 3 not yet conducting. And in that situation the current path is like this: diodes D 1 and D 3 are not conducting and therefore they are shown in grey. Now we have seen earlier that D 2 just begins to conduct at V o equal to minus 2.7 volts. And what is your situation at this point? The current is just beginning to build up, so let us say it is still very small, so this voltage drop is small this voltage drop is also small and therefore V i would be equal to V o. So, V i is also minus 2.7 volts.

When we make V i more negative than minus 2.7 volts that is V i less than minus 2.7 volts we are talking about this region now D 2 is conducting and D 3 is still not conducting. So what happens then, we this current starts increasing as V R becomes more and more negative. In that case V o is V i plus i times R; and what if i? This node is at minus 2 volts this node is at V i so the total voltage drop between these two is minus 2 minus V i. And from that we need to subtract the diode voltage drop that is 0.7 volts. Therefore, we have minus 2 minus 0.7 minus V i divided by R plus R 2. So, that gives this current i. Therefore, we have V o equal to V i plus R times this current that is V o equal to V i plus this is our i that multiplied by R.

This of course is a straight line and the slope of the straight line is given by 1 minus R by R plus R 2 like that and that is R 2 by R plus R 2: R 2 is 1 k, R is 3 k so therefore the slope turns out to be 1 by 4. Let us now look at the plot that is V o versus V i in this region; we already looked at these two regions this one and this one, and this is the new region now where D 2 is on and D 3 is still not on. So, that is the straight line described by this equation here and it has a slope of 1 by 4.

Let us now talk about the final case that is both D 2 and D 3 on. Let us first figure out at what point D 3 just begins to conduct that is this boundary here. So, what is happening as we make V o more and more negative that is make V i more and more negative. This current increases and therefore this voltage drop goes on increasing. At some point it becomes equal to 0.7 volts and that is the point at which D 3 turns on. So, let us first find that point and then we will be able to complete this picture.

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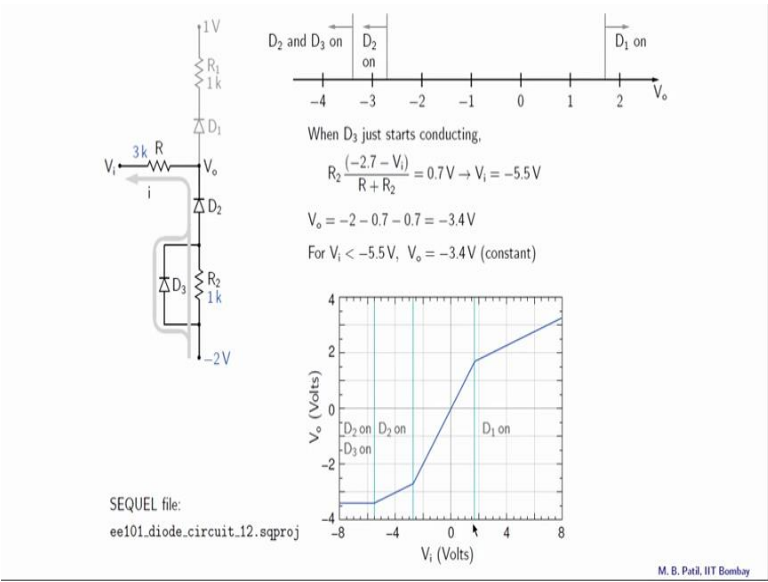

When D 3 starts conducting here two current paths: one through R 2 and one through D 3 like that. Now let us consider the case where D 3 has just begun to conduct; that means, this voltage is almost 0.7 volts, but not quite. So, this current is still 0 and this voltage drop is nearly equal to 0.7 volts. And in that case the current it is like that and we can use the expression that we derived for this current in the last slide; and that is given over here.

So, we have R 2 times i equal to 0.7 volts. And we can solve this equation for V i: V i transfer to be minus 5.5 volts. What happens if we make V i smaller; that means, more negative than minus 5.5 volts? All that happens is this current increases and the additional voltage drop appears across this resistance R. Let us now look at V o in this situation; that means, D 2 and D 3 are both conducting. What is V o? V o is minus 2 volts minus 0.7 volts minus another 0.7 volts, so V o is then minus 3.4 volts. So, in this region V o is constant and that is equal to minus 3.4 volts.

Here is the complete picture: in this region that is we are greater than 1.7 volts D 1 is on. In this region that is V i between minus 2.7 and 1.7 volts no diode is conducting and we have V o equal to V i. In this region that is between minus 5.5 volts and minus 2.7 volts D 2 is on D 3 is not on. And finally, in this region both D 2 and D 3 are on.

And this is the reason that we were just discussing. For V i less than minus 5.5 volts, V o is minus 3.4 volts and it is constant that is minus 3.4 volts. The sequel file for this circuit is available and you can play with it, you can try to change the registers values. For example, predict what should happen and then run the simulation and check whether your prediction is correct.

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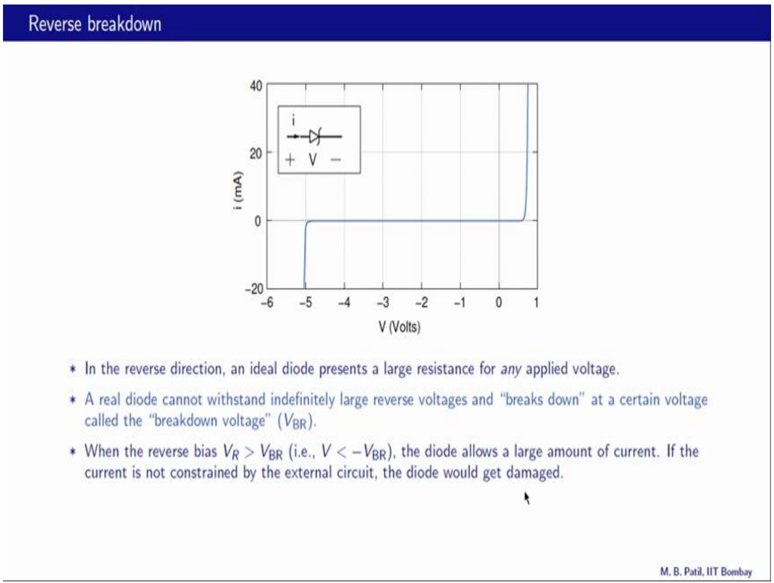

Let us now look at the i V curve of a real diode, and in particular we want to look at the reverse bias region; that means, with applied voltage less than 0 volts. In the reverse direction an ideal diode presents a large resistance for any applied voltage ideally infinite resistance and that is indeed what we have assumed so far. In all our examples this is the assumption that we have made. Now that is not quite true about a real diode: real diode cannot withstand indefinitely large reverse voltages and breaks down at a certain voltage called the breakdown voltage.

In the example shown over here this diode is seen to break down at about minus 5 volts. Now this breakdown voltage V BR is usually created as a positive number for this specific device V BR would be 5 volts and the applied voltage would be minus 5 volts. In the reverse bias V R is greater than V BR that is when the applied voltage is less than minus V BR in this case minus 5 volts. The diode allows a large amount of current, as seen over here. And if this current is not constrained by the external circuit then chances are that the diode would get damaged, because this V times i would be too large that is the power absorbed by the diode which has to be dissipated as heat, and if that heat is not dissipated effectively the diode temperature will rise and eventually the diode would get damaged.

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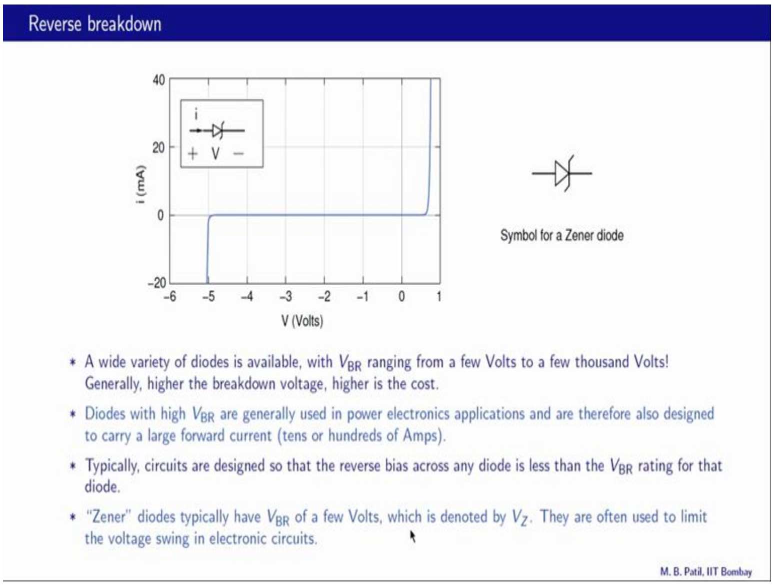

Let us make a few comments on the reverse breakdown. A wide variety of diodes is available with the breakdown voltage ranging from a few volts as in this case to a few thousand volts; that is a very large breakdown voltage. And generally higher the breakdown voltage higher is the cost, because if you want to make a diode with breakdown voltage of a thousand volts for example, the manufacturing process that it requires is very stringent and that adds to the cost. Diodes with high breakdown voltage are generally used in power electronics applications, and are therefore also designed to carry a large powered current how large it could be tense of amperes or even hundreds of amperes.

And when a diode carries a large current of that kind it generates heat which must be effectively dissipated and that is why these high powered diodes look very different than diodes that we use in electronics labs.

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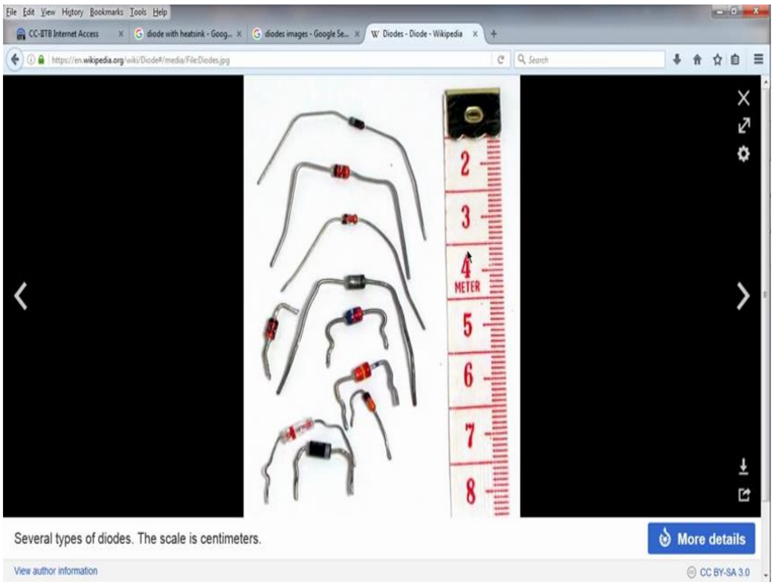

Let us look at some images. Here are some low power diodes that one would use in an electronics lab; the scale is centimeters, so this is one centimeter. So, we see that they are fairly small.

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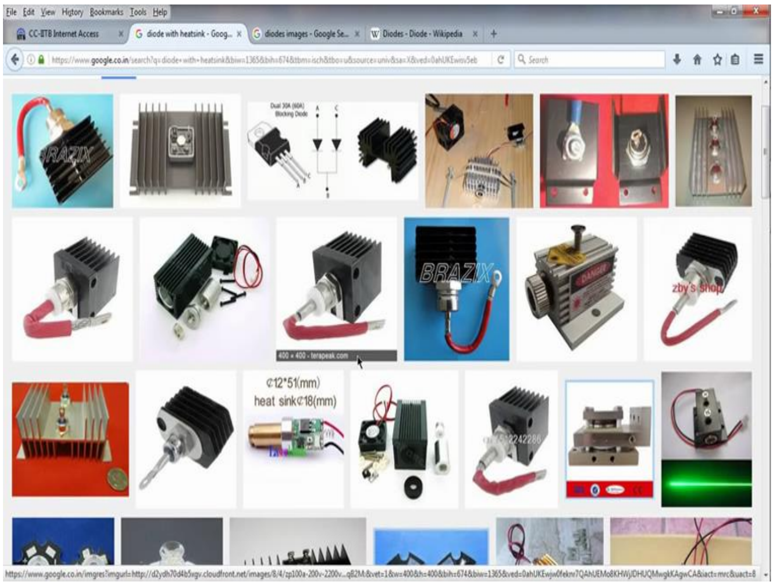

And here is the high power diode; notice that this cable is much thicker because it has to carry a large current and notice also this heat sink which has to dissipate the large amount of heat that is generated by the diode.

Now, typically circuits are designed so that the reverse bias across any diode is less than the breakdown voltage rating for the diode. And in the examples that we have seen so far of diode circuits this has been the case. So therefore, we did not worry about a diode breaking down in those examples.

However, there are diodes which are supposed to operate in this breakdown region and those are called Zener diodes. So, Zener diodes typically have V BR of a few volts and that is denoted by V Z. And these Zener diodes are often used to limit their voltage swing in electronic circuits; a little later we will see an example of an electronic circuit which knows exactly that. Here is the symbol for a Zener diode; it looks very much like the ordinary diode except it has these little line segments over here.

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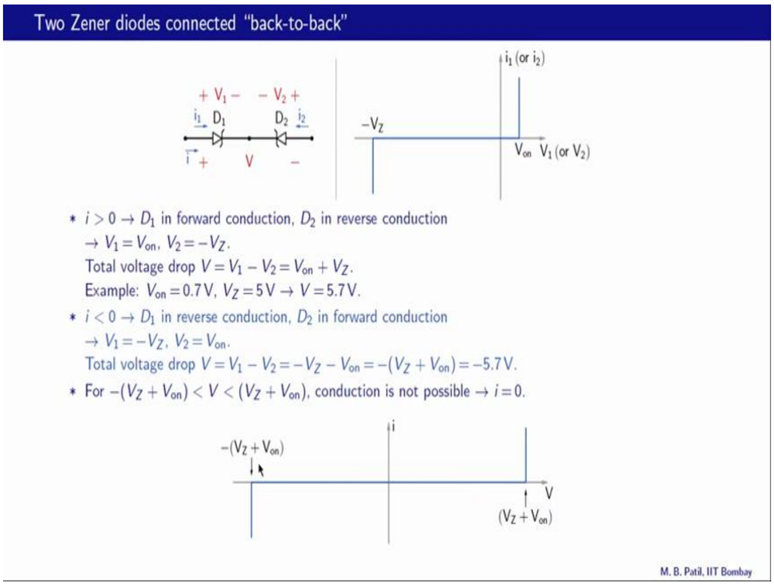

Let us look at this commonly used configuration with two Zener diodes connected back to back; that is the n of this D 1 is connected to the n of D 2 so they are pointing in opposite directions. And we want to know what i is the current here as a function of the total voltage drop V shown here. And we will assume that for each of D 1 and D 2 we have the i V relationship shown in this graph. So, this could be i 1 versus V 1 i 1 versus V 1 or it could be i 2 versus V 2. Remember i 2 has to point the other way from p to n of D 2 and V 2 also as the opposite polarity as compared to D 1.

So, we assume that in the forward direction the diode starts conducting at V equal to V on and it has 0 all resistance. And then in between that is between V on and minus V Z the diode process no current, current is 0 and it breaks down at V equal to minus V Z. And we will assume this breakdown to be sharp and that this resistance when the diode does conduct in the reverse direction is again 0; so 0 resistance infinite resistance and 0 resistances again.

Let us consider the case in which i is positive let us say 1 milliamp. So, 1 milliamp is flowing from this node to this node. And how is that possible it is possible only if this diode conducts in the forward direction and this diode conducts in the reverse direction. So, for this diode we have a forward current of 1 milliamp; let us say 1 milliamp is somewhere here and we are on that curve i 1 versus V 1. For D 2 the reverse current is 1 milliamp and so therefore we are somewhere here. Therefore, it has a voltage drop of minus V Z across it and let us see what the complete picture looks like.

So, D 1 in forward conduction D 2 in reverse conduction, V 1 is V on V 2 is minus V Z. And our interest of course is what is this total voltage drop. So, the total voltage drop is V 1 minus V 2 and that is V on minus minus V Z so that turns out to be V on plus V Z. Let us take an example if V on is 0.7 volts and we Z is 5 volts that is this minus V Z is minus 5 volts, then the total voltage drop V would be 5.7 volts.

And the other situation is completely analogous, let us now consider i less than 0 and that case the current goes in that direction. D 2 is now under forward bias and D 1 is under reverse breakdown. And V 2 this voltage is therefore V on and V 1 is minus V Z. Now once again we can find the total voltage drop. What is the total voltage drop is V 1 minus V 2 as before V 1 is minus V Z V 2 is V on, so V 1 minus V 2 is minus V Z minus V on or minus V Z plus V on and brackets. So, that for our example here turns out to be minus 5 0.7 volts.

And for any voltage between these two limits that is 5.7 and minus 5 0.7 volts no conduction is possible, and therefore the current is 0. So, putting all of this together we get the i versus V relationship for this entire combination as follows. So, that is i, that is V, no current between these two limits and at V equal to V Z plus V on the combination it starts conducting in the forward direction. For V equal to minus V Z plus V on it starts conducting in the negative direction.

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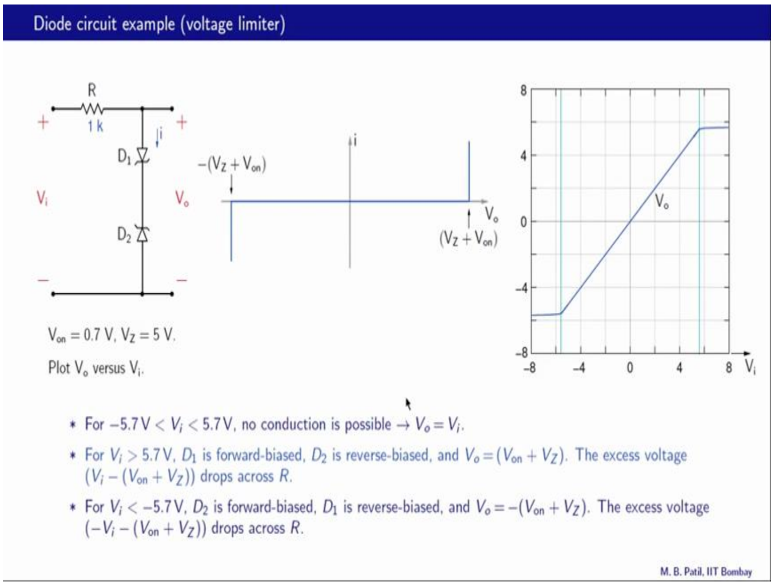

Here is a circuit in which the Zener diode pair that we saw in the last slide has been used. This is the input voltage, that is the output voltage and we want to plot V o as a function of V i. And then we will figure out what function this circuit is performing. Let us take V on equal to 0.7 volts for each of these diodes; that means, when they conduct in the forward direction the voltage drop across the diode is 0.7 volts. And let V Z be 5 volts; that means, if the diode conducts in the reverse direction then the voltage drop across the diode is minus 5 volts.

And as we saw in the last slide here is the i versus p relationship for this diode pair. The current i is on this y axis here and the voltage across the diode pair in this case is V o, so V o is on the x axis. Now if the diode combination conducts in the forward direction; that means, if the current is positive then we know that the voltage across the diode pair that is V o must be equal to V Z plus V on. In this case 5 plus 0.7 that is 5.7 volts. And when the diode combination conducts in the reverse direction; that means, when that current is going like that then V o would be minus 5 0.7 volts.

What is the condition on V i for the diode pair to conduct in that direction? In that situation V o would be 5.7 volts and this voltage drop would be positive, because the current is going like that. And therefore, V i would be 5.7 volts plus this voltage drop. And therefore, clearly V i must be greater than 5.7 volts.

Let us now consider the other situation in which the diode pair is conducting in that direction, and when that happens we know that V o would be minus 5 0.7 volts. For convenience let us take this node as the reference node. So, we have 0 volts here with respect to that reference node this node is at minus 5 0.7 volts, and the current is going in that direction this node is at V i. So, the voltage here is equal to V o minus this voltage drop and that is clearly less than minus 5 0.7 volts.

To summarize we need an input voltage greater than 5.7 volts for the diode pair to conduct in that direction, and we need an input voltage less than minus 5 0.7 volts for the diode pair to conduct in the opposite direction. Let us now put all these observations together and plot V o as a function of V i. Here is the plot of V o versus V i and let us make sure now that the features in this plot are consistent with our observations.

For V i between minus 5 0.7 volts and plus 5.7 volts no conduction is possible as we argued earlier. If no conduction is possible there is no voltage drop across this resistance and therefore V o is equal to V i. And this equation represents a straight line with a slope equal to 1 and it passes through the origin like that. Point number two: for V i greater than 5.7 volts D 1 is forward biased D 2 is reverse biased the current flows like that and the output voltage is V on plus V Z that is 5.7 volts as shown over here. And of course, it is constant.

The excess voltage that is the difference between V i and output voltage that is the V on plus V Z drops across R. As an example let us say V i is 10 volts of this 10 volts 5.7 volts will drop here and 4.3 volts will drop across R. And similarly for V i less than minus 5 0.7 volts D 2 is forward biased, D 1 is reverse biased that is its in the reverse breakdown, the current flows like that. And V o in this case is minus V Z plus V on that is minus 5 0.7 volts. And that is shown in this part of the graph. Once again the excess voltage, that is the difference between V i and minus 5 0.7 drops across R.

So, we observed that as long as V i is in this range that is from minus 5 0.7 volts to plus 5.7 volts V o is equal to V i, but if V i exceeds 5.7 volts then V o gets limited to 5.7 volts. Similarly, if V i becomes less than minus 5 0.7 volts V o gets limited to minus 5 0.7 volts. So, this circuit serves to limit the output voltage, on the positive side the limit is 5.7 volts and on the negative side it is minus 5 0.7 volts. And that is why it is called voltage limiter.

One question that we now want to address is how to choose this resistance value; here we have 1 k could that be 10 k or 10 ohms how do we go about selecting this value. Now notice that if we are in this region, if V i is between minus 5 0.7 and plus 5.7 then this diode pair does not conduct there is no current through this resistance and in that case it does not really matter whether it is 1 k or 10 k or whatever.

But when V i exceeds 5.7 volts; for example if V i is 10 volts then there is a current through R. Now out of this 10 volts 5.7 will drop here 4.3 will drop here, so the current in this case would be 4.3 divided by 1 k that is 4.3 milliamps. Now if we make these 10 ohms for example, then the current would be 4.3 volts divided by 10 ohms. So, that is 0.43 amperes. And that is another large current and this voltage source may not be able to supply that current. So, this current limiting functionality is what we need to consider when we select this resistance value.

In conclusion we looked at how reverse breakdown of a diode changes its i V relationship. We studied the i V curve or a pair of Zener diodes connected back to back. We also looked at an application based on this back to back pair. We will now move on to some more diode applications in the next lecture, until then good bye.