Basic Electronics
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Lecture - 14
Diode circuits (continued)

Welcome back to Basic Electronics. We looked at a simple diode circuit in the last class; we will now look at the similar problem, but with two diodes. We will first obtain the V o versus V i relationship for the circuit and then use it to plot the output voltage as a function of time for a specific input voltage wave form. So, let us start.

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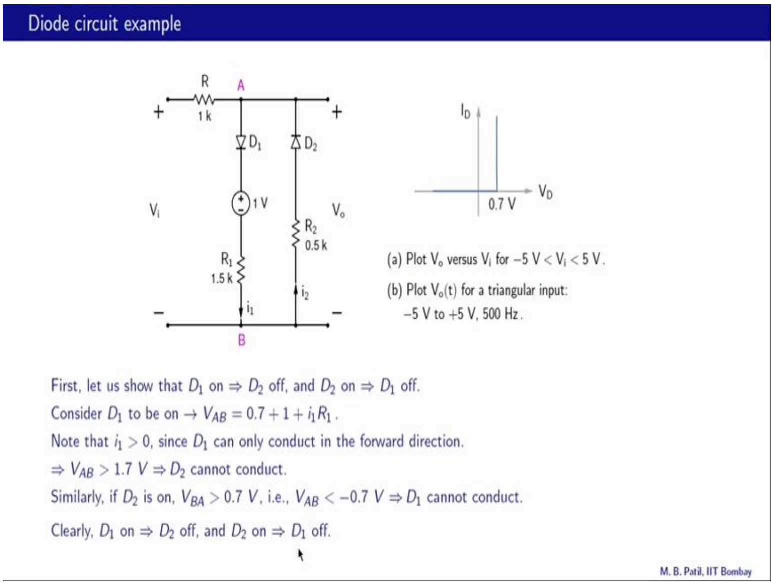

Here is our next example and it is a little more complicated than the previous example, because we have two diodes now D 1 and D 2. And we want to plot V o this voltage here as a function of V I, this voltage with V i in the range minus 5 volts to plus 5 volts. Once we do that we want to plot V o as a function of time for a triangular input going from minus 5 volts to plus 5 volts with a frequency of 500 hertz. And the diode model that we want to use is the same as the one that we used in the previous example; that is if the diode conducts then the voltage across the diode is constant 0.7 volts and if the voltage is less than 0.7 volts then the diode does not conduct.

Now this example does look more complicated than the previous one, but let us show that if D 1 is conducting then D 2 cannot be conducting and vice versa, and once we show this then the whole problem becomes much simpler. Let us suppose that the diode D 1 is conducting in that case as we go from A to B we have a voltage drop of 0.7 volts here across D 1, then this voltage drop of one volt. And after that we have a positive voltage drop across R 1, because this current i 1 can only be positive since the diode can only conduct in that direction.

So the voltage difference between A and B that is V A minus V B or V A B must be greater than 0.7 plus 1 that is 1.7 volts, because this voltage drop can only be positive. So, what it means is that for D 1 to conduct we must have V A B greater than 1.7 volts. Let us now take the next case that is D 2 is conducting: if D 2 is conducting we have a voltage drop of 0.7 volts in that direction and also we have a positive voltage drop across R 2 in that direction, because this current i 2 can only be positive since D 2 can conduct only in that direction.

So what it means is V B minus V A must be greater than 0.7 volts now, because this voltage drop i 2 R 2 can only be positive. In other words for D 2 to conduct we require V B A to be greater than 0.7 volts and what that means is V A B must be less than minus 0.7 volts. So, we require V A B to be greater than 1.7 for D 1 to conduct and we require V A B to be less than minus 0.7 for D 2 to conduct. And clearly these two requirements are contradictory, so therefore we can have either D 1 conducting or D 2 conducting.

The arguments that we just represented are summarized over here, and the conclusion is that if D 1 is on then D 2 must be off and if D 2 is on the D 1 must be off.

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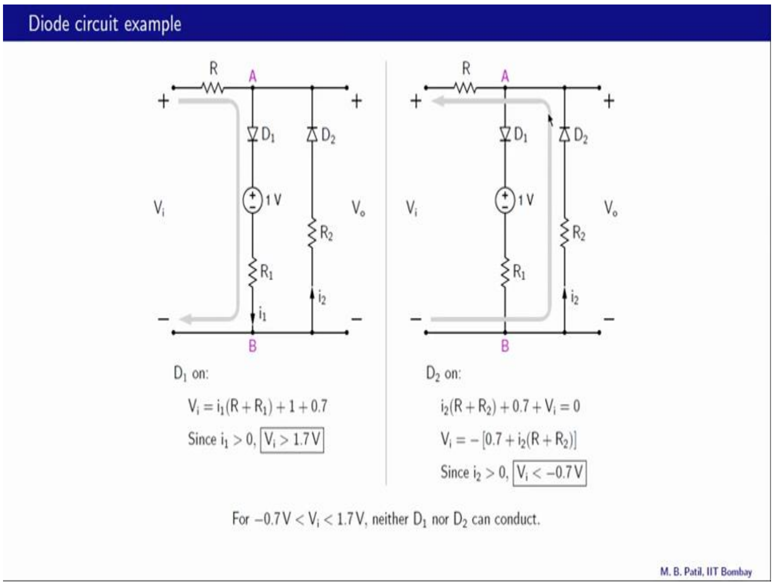

Let us now look at these cases one by one. Here is the case where D 1 is conducting and D 2 is not conducting, and then the current path is like that. And in this situation the input voltage V i is given by KVL it is equal to this voltage drop plus 0.7 plus 1 plus this voltage drop across R one. Now this voltage drop across R is R times i one, because the same i 1 is flowing through R as well. So, we have i 1 times R plus 1.7 plus R 1 times R 1. So, that is our V i. And what it means is that V i must be greater than 1.7 volts, because this term can only be positive because the diode can only conduct in that direction; so therefore, R 1 must be positive.

Here is our second case in which D 2 is conducting but D 1 is not conducting. And let us obtain V i in this case by writing the KVL for this loop. Let us start from this point we go down like that come across a voltage drop of V i, so that we take as plus V i then we come across a voltage drop of R 2 times i 2 then a voltage drop of 0.7 across D 2 and then a voltage drop of R times i 2 across R. So these voltage drops when added must give us 0 and that is this equation here. So, that gives us V i that is minus 0.7 plus i 2 times R plus R two.

Let us look at this number in the brackets here, it is 0.7 plus i 2 times R plus R 2. Now i 2 can only be positive, because D 2 can only conduct in that direction and therefore this number is always larger than 0.7 volts. So, what it means is V i must be less than minus 0.7 volts for D 2 to contact. So, we have V i greater than 1.7 volts when D 1 conducts and we have less than minus 0.7 volts when D 2 conducts. And in between these two limits that is for minus 0.7 volts less than V i less than 1.7 volts neither D 1 nor D 2 can conduct.

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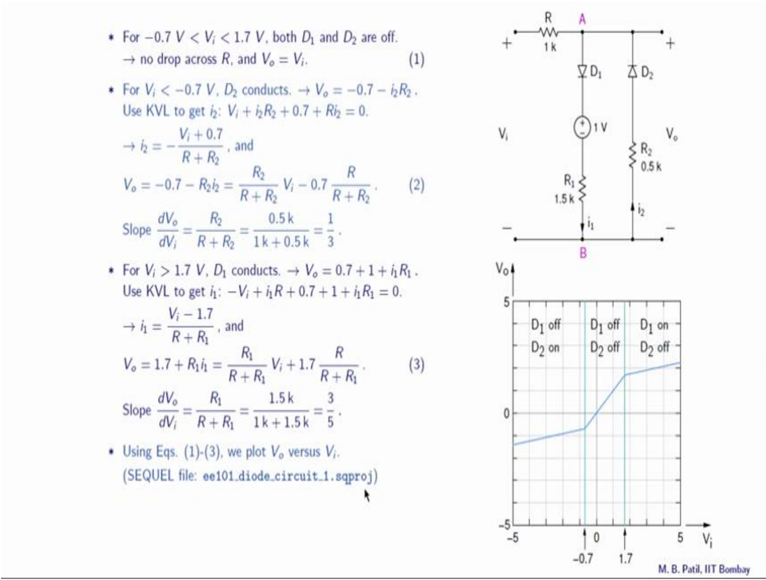

We know a lot of things about the problem now and let us proceed to obtain V o as a function of V i. Let us start with this situation that is V i between minus 0.7 volts and 1.7 volts, and as you saw on the last slide for this case both D 1 and D 2 are off; that means, there is no current in this branch no current in this branch. Therefore, there is no possibility of any current through R. So, what it means is this output voltage V o must then be equal to V i because there is no voltage drop over here like that.

Here is a plot of V o versus V I, and the situation that we just discussed is right here V i between minus 0.7 and 1.7. And the V o versus V i relationship in this region is given by this straight line over here which is represented by V o equal to V i. So this is a straight line with slope equal to 1 and passing through the origin like that. And in this situation D 1 is off and D 2 is also off.

Next let us take V i less than minus 0.7 volts, and for this range as we saw in the last slide D 2 conducts D 1 does not conduct. And what is the output voltage in that case? Let us start with this voltage drop V B minus V A, so that is i 2 R 2 plus 0.7; and what is V o? V o is just negative of that, so V o is minus 0.7 minus i 2 R two. Let us now find this current i 2 and we will do that by writing the KVL equation for this loop here. Let us start at this point we go down first then across a voltage drop of V i, we take that as plus V i, then we come across a voltage drop of i 2 R 2 then a voltage drop of 0.7 and then a voltage drop of R times i 2. And these voltage drops must added to 0 and that is this equation here.

Now from this equation we can obtain i 2; i 2 turns out to be minus V i plus 0.7 divided by R plus R 2. Let us substitute this i 2 now in this equation for V o and that gives us V o equal to R 2 by R plus R 2 times V i minus 0.7 times R by R plus R two. The slope d V o d V i is given by this factor here R 2 is 0.5 k R is 1 k. So therefore, the slope turns out to be 1 over 3.

Let us look at the plot now we are talking about V i less than minus 0.7 volts, this region here. D 2 is on D 1 is off, and we have a straight line describing V o versus V i and that line has a slope of 1 over 3. Note that the V o versus V i relationship is continuous as we go from this region to this region. And that can be seen also from equation 2 here. At V i equal to minus 0.7 volts equation 1 predicts that V o should be minus 0.7 volts and let us see what equation 2 predicts. Let us put V i equal to minus 0.7 here and then we have minus 0.7 times R 2 plus R divided by R plus R two so that gives V o and that also will turn out to be minus 0.7 volts. Therefore, there is continuity over here.

Finally, let us take this case where V i is greater than 1.7 volts for this range D 1 conducts and D 2 does not conduct as we saw earlier. And what is V o in this case? V o is 0.7 plus 1 plus i 1 R 1, this equation here. And now let us obtain i 1 by writing the KVL equation for this loop. So, let us begin at this point we go up first we come across the rise of V i so that we write as minus V i, then we come across a drop R 1 times R then 0.7 then 1 then another drop i 1 times R 1. When we add all of these terms we get 0 and that gives us this equation here.

And we can solve this equation for i 1: i 1 turns out to be V i minus 1.7 by R plus R 1 and we can now substitute this i 1 back over here and get V o. So, V o finally is R 1 by R plus R 1 times V i plus 1.7 times R by R plus R 1. Now the slope in this region d V o d V i is given by this factor here R 1 is 1.5 k R is 1 k, so therefore the slope turns out to be 3 by 5. Here is the V o versus V i relationship for V i greater than 1.7 volts, and it is a straight line with a slope equal to 3 by five. And you can verify that there is continuity at

V i equal to 1.7 volts. So, our V o versus V i relationship is given by combining these three pieces together and that is what we get.

The sequel file for this circuit is available. So, you can run the simulation and check out the results.

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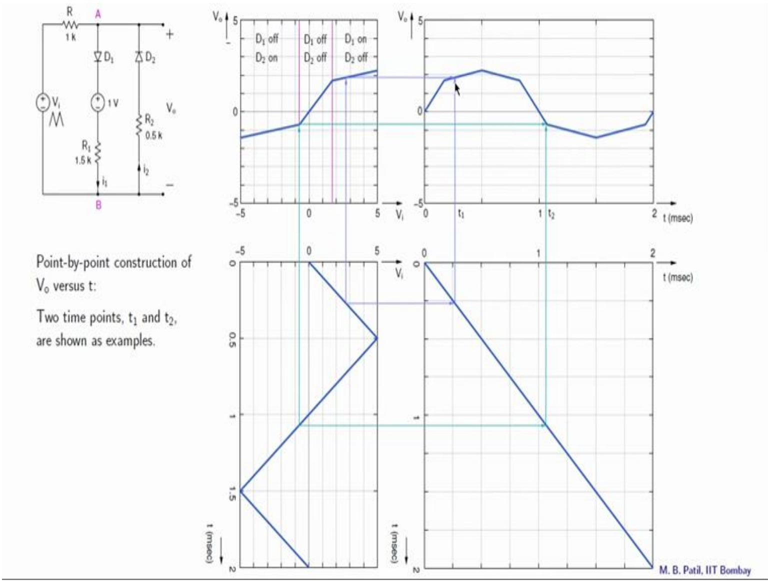

The next part of our problem is to find the V o as a function of time given a triangular input voltage varying from minus 5 volts to plus 5 volts with a frequency of 500 hertz. So, here is our input voltage wave form, this is the V i axis, this is the time axis: V i vary between minus 5 and 5 volts. And what we have shown here is 1 cycle since our frequency is 500 hertz the time period is 2 milliseconds and that is what we have over here 0 to 2 milliseconds.

Here is V o versus V i as we obtained earlier. So, what we want to do now is to use these tools to obtain V o as a function of time. And to do that we will use this plot here: this plot is time versus time that means, it is of the form y equal to x which is the straight line with slope equal to 1 and passing to the origin like that. And as we will see this graph is going to help us to map V i of t to V o of t. Let us show that using an example let us consider this particular point on the V i of t graph and let the time here the v t 1; so that is given by whatever this number is and let the V i value be given by V i 1 so that means this number. So, this point here is t 1 V i 1. Now corresponding to this point we want to find t 1 V o 1 in the V o of t graph.

This is our V o axis and that is our time axis for the V o of t graph and we are looking for this point over here which we find by this construction here, and at this point we have t equal to t 1 and V o equal to V o 1 and that corresponds to this point on the input graph; and let us see the correspondence between these two.

Now this is t 1 and because this graph represents t equal to t this must also be t 1. And therefore, this vertical line here it represents t equal to t 1. So, that takes care of the time part in the V o of t graph let us look at the V o part now. What is the input voltage? The input voltage is given by this number here. So, this vertical line represents V i equal to V i 1 and the intersection of this V i equal to V i 1 line with this V o versus V i relationship gives us the corresponding output voltage and we will call that V o 1. So, this horizontal line represents V o equal to V o 1. As we saw earlier this vertical line represents t equal to t 1, and therefore the intersection of these two lines gives us the required point in the V o of t graph.

This process can be repeated for other points in the V i of t graph. For example, let us consider this point here call it t 2 V i 2; this horizontal line as well as this vertical line represent t equal to t 2; this vertical line represents V i equal to V i 2 and this horizontal line represents V o equal to V o 2; where V o 2 is the output voltage corresponding to V i two.

And finally, the intersection of this V o equal to V o 2 line and t equal to t 2 line gives us the point that we are looking for in the V o of t graph. And we can repeat this process for all other points in the V i graph and that gives us V o of t like that. Let us now look at some animation and that will make this clearer.

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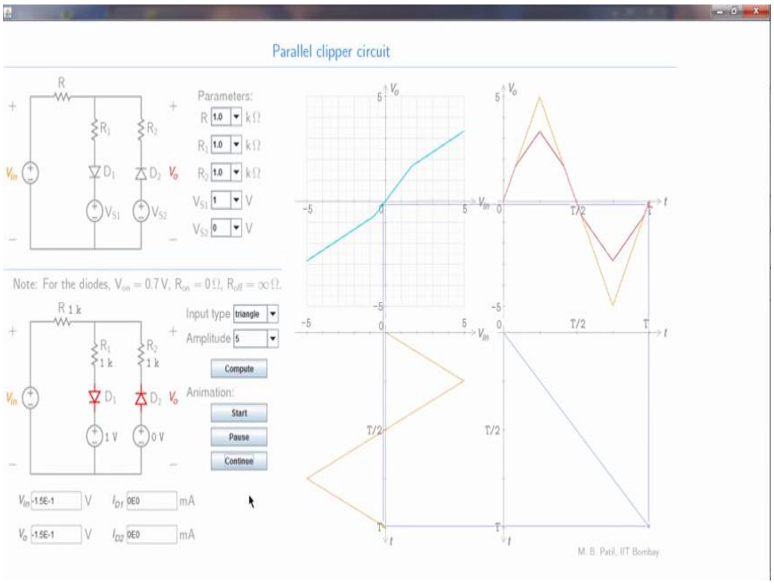

So, here is a circuit that we were just looking at the component values such as R R 1 R 2 can be selected over here for example, R can be 0.5 k 1 k 2 k or 5 k R 1 can be 0.01 k very small resistance that is 10 ohms our point 1 k or 0.5 k 1 k 2 k 5 k or it could even be infinity. Now when we select R 1 equal to infinity what we are doing essentially is to remove this branch from the circuit, because we have an open circuit instead of R one. Similarly R 2 has the same options V s 1 can be minus 5 volts or minus 4 minus 3 etcetera up to 5 volts. And V s 2 also has those same options.

Let us choose V s 2 to be 0 volts, because if you recall we did not have a voltage source over here in our example and by making V s 2 equal to 0 volts we are going to make this a short circuit. Let us choose R R 1 and R 2 to be 1 k h these values are a bit different than what we had in our example, but that would not make too much difference 2 over V over 6 V i curve. It will only change the slope values, but not the break points.

Let us now compute the V o versus V i relationship; and this is what it is this axis is V i going from minus 5 to plus 5 volts this axis is V o again going from minus 5 to plus 5 volts and that is our V o versus V i characteristic. Where are the break points one big point is here the other big point is here; between these two big points we have a straight line with a slope equal to 1 and passing through the origin as we would expect. There is this big point, this is 1 volts this is 2 volts and this is 1.7 volts as we had computed. What about the second break point? This is 0 this is minus 1 and the second big point is at minus 0.7 volts.

Let us choose the triangular input option, because that is what we considered in our example and compute again. So, this is our input voltage that axis is V in and this one is time. So, the input voltage is going from minus 5 to plus 5 and the period is denoted by t over here. Now this input voltage is repeated in this plot over there, the yellow one and the red one is the output voltage as a function of time. What is this graph here? It is t versus t; that is time versus time and as we saw in our slides it is a straight line with a slope equal to 1 and passing through the origin.

Let us now start the animation and then we will be able to observe how this V i of t graph gets mapped into the V o of t graph here. And as we discussed that is done using this graph of t versus t and the V o versus V i relationship. Let us start the animation; pause now at this point D 1 and D 2 are not conducting and therefore they appear in red. Let us continue pause again at this point note that D 1 conducts and D 2 does not, so therefore D 1 has appeared in green color now, whereas D 2 continues to be in red. Notice also that the conduction path is shown over here and if you observe carefully that will keep changing. Continuing; so no diode is conducting now, now D 2 has started conducting also the current path has changed and that is the end of the simulation.

In summary we looked at a circuit with two diodes; figured out conditions for each diode to be conducting, and then looked at the implications for the V o versus V i relationship. We then use the V o versus V i relationship to map a given V i of t to V o of t. We have also used animation to illustrate this mapping process. That is also now, see you next time.