Basic Electronics
Prof. Mahesh Patil
Department of Electrical Engineering
Indian Institute of Technology, Bombay

Lecture - 15
Diode circuits (continued)

Welcome back to Basic Electronics. Last time we looked at a diode circuit with two diodes in this lecture we will continue with that example and consider some specific cases. We will consider two other diode circuits and obtain the V o versus V i relationship for those circuits. We will also check over analytic results against circuit simulation results. So, let us begin.

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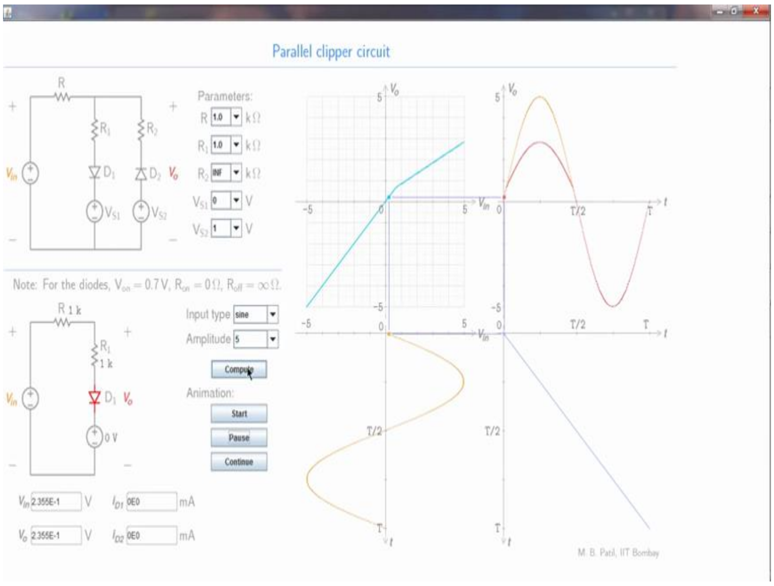
Parallel clipper circuit

Parameters:
R 1.0 kΩ
R_1 1.0 kΩ
R_2 INF kΩ
V_{S1} 0 V
V_{S2} 1 V

Note: For the diodes, $V_{on} = 0.7\,V$, $R_{on} = 0\,\Omega$, $R_{off} = \infty\,\Omega$.

Input type sine
Amplitude 5

V_{in} 2.355E-1 V
I_{D1} 0E0 mA
V_o 2.355E-1 V
I_{D2} 0E0 mA

Let us now look at some other configuration: first let us remove this branch by making R 2 equal to infinity. So now, we have only this circuit, and to begin with let us make V S 1 equal to 0. So now, this is our circuit this second branch is gone and the V o versus V i relationship is as shown over here. It has only one big point somewhere here and let us now try to understand this V o versus V i relation.

Let us first figure out where we expect, this breakpoint to be that breakpoint corresponds to the situation in which the diode just begins to conduct; that means, we have about 0.7 volts here and this current through the circuit is still very small let us say 0, where 0.7 volts 0 volts here, and the voltage drop across R R R 1. So therefore, V in is also 0.7

volts. So, we expect the breakpoint to be at V i equal to 0.7 volts and that is what this shows over here. If V i is less than 0.7 then the diode is off, and therefore no voltage drop here and V o is then equal to V I; that is this line here with a slope equal to 1 and passing through the origin.

When the diode does conduct that is when V i is greater than 0.7 volts you can work out the relationship between V o and V i following the method that we discussed earlier. The important thing is the slope of the V o versus V i line in that region. And that would be given by R 1 divided by R plus R one, in this case R and R 1 are equal; so therefore the slope will turn out to be 1 by 2. So, that is the slope here.

Let us continue with the animation; and notice how this V i of t is being traced and with the help of V o versus V i and this t versus t graphs; V o as a function of t gets constructed. The diode is off in this region and that is why it appears in red. So, that is the end of one cycle.

What will happen if we change this 0 volts to 2 volts in that case for the diode to turn on we require 2 volts plus 0.7 that is 2.7 volts as V i; for V i greater than 2.7 the diode would conduct otherwise it would not conduct. So, what we expect is that this breakpoint we will shift to 2.7 volts somewhere there. Will this slopes change? The slope of course does not depend on any resistance values, it simply represents V o equal to V i. What about this slope? This slope is given by R 1 by R plus R one. And since you are not changing the resistance values that slope would also remain the same.

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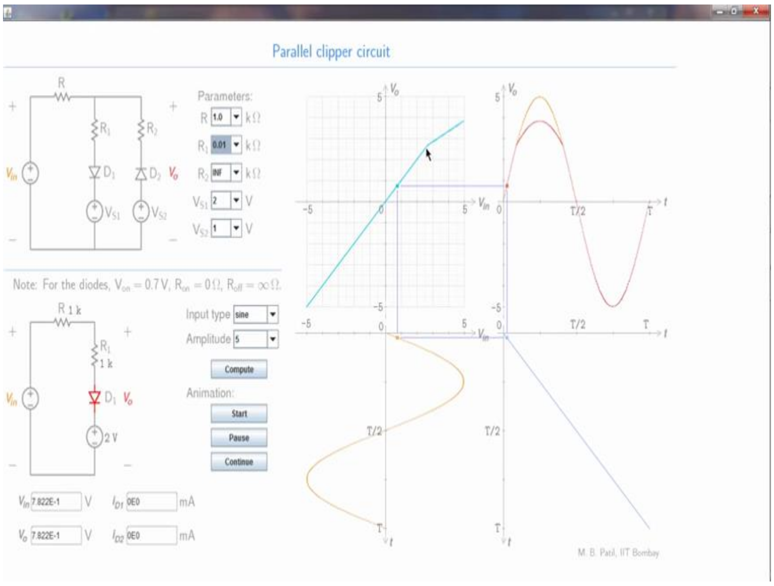
Parallel clipper circuit

Parameters:
R 1.0 kΩ
R_1 0.01 kΩ
R_2 INF kΩ
V_{S1} 2 V
V_{S2} 1 V

Note: For the diodes, $V_{on} = 0.7\,V$, $R_{on} = 0\,\Omega$, $R_{off} = \infty\,\Omega$.

Input type sine
Amplitude 5

V_{in} 7.822E-1 V I_{D1} 0E0 mA
V_o 7.822E-1 V I_{D2} 0E0 mA

So let us see if that happens: and we observed that the breakpoint has indeed shifted to 2.7 volts and the slopes are not changed. Next let us look at the situation in which V S 1 stays at 2 volts, but R 1 is made very small say 10 ohms, so this is 10 ohms now. What would happen now? The breakpoint would not change because we are not changing this voltage, but this loop will change; that slope is given by R 1 divided by R plus R 1. Now this R 1 is changing from 1 k to 10 ohms, so the new slope would be 10 ohms divided by 1000 plus 10 that is 1010 ohms. So, this 10 divided by 1000 that is a very small slope so we expect that this line would appear almost as a horizontal line.

So, let us see whether that happens there. Now notice that the output voltage has got clipped at this point and that is why this circuit is called a clipper circuit. Let us do another experiment; let us now keep this branch and remove this branch form the circuit. So, let us make R 1 equal to infinity and R 2 equal to 1 k to begin with, V S 1 does not matter anymore because this is an open circuit and V is 2 could be 0 volts first we can change it later.

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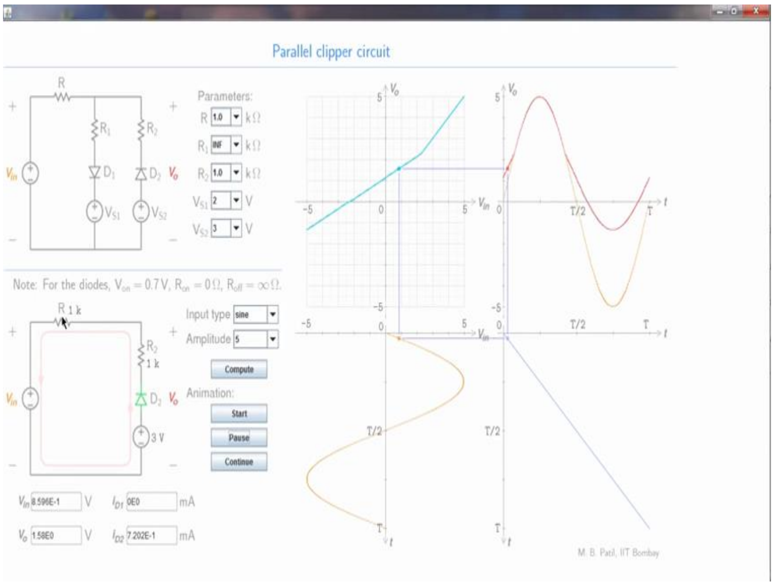
Parallel clipper circuit

Parameters:
R 1.0 kΩ
R_1 INF kΩ
R_2 1.0 kΩ
V_{S1} 2 V
V_{S2} 3 V

Note: For the diodes, $V_{on} = 0.7\,V$, $R_{on} = 0\,\Omega$, $R_{off} = \infty\,\Omega$.

Input type sine
Amplitude 5

V_{in} 8.596E-1 V
V_o 1.58E0 V
I_{D1} 0E0 mA
I_{D2} 7.202E-1 mA

Now, what do we expect to happen? So, this branch is not there and V S 2 is 0, so therefore this is a short circuit. And now D 2 will conduct if V i is less than minus 0.7 volts. Therefore, the breakpoint is given by V i equal to minus 0.7 volts. And V i is less than minus 0.7 volts a current will flow like that and you should a derive the V o versus V i relationship in that case and show that the slope would be given by R 2 divided by R plus R 2. When V i is greater than minus 0.7 volts D 2 will not conduct; no current and therefore this voltage drop is 0 and then V o would be equal to V i.

So, let us check that out. Here is the V o versus V i relationship, this is the breakpoint and that is at V i equal to minus 0.7 volts. In this region V i is less than minus 0.7 volts the diode conducts and the slope would be given by R 2 by R plus R two. Since R 2 and R are equal the slope would be 1 by two. In this region D 2 does not conduct and therefore, we have V o equal to V i.

What would happen if we change this V S 2 to 3 volts? Let us take this as the reference node for convenience then if D 2 is conducting then we have 3 volts minus 0.7 volts, so this node would be at 2.3 volts. And if D 2 is just about to conduct then these voltage drops are 0, and therefore V i would be 2.3 volts. So, that will be the breakpoint and these slopes are not expected to change because we are not changing the resistance values. So, let us check that out.

So, here is the breakpoint now; the slope is still 1 by 2 this slope is still 1 and the breakpoint has shifted to 2.3. What if we change these 3 volts to minus 2 volts? Then we would have with respect to this reference node minus 2 volts here and minus 2 minus 0.7 that is minus 2.7 volts at this node. And V i equal to minus 2.7 volts is then the breakpoint. So, we expect the breakpoint to shift to minus 2.7 volts, and if you do not change these resistance values we do not expect the slopes to change.

So, let us check that out. So, here is our breakpoint and that is indeed at minus 2.7 volts.

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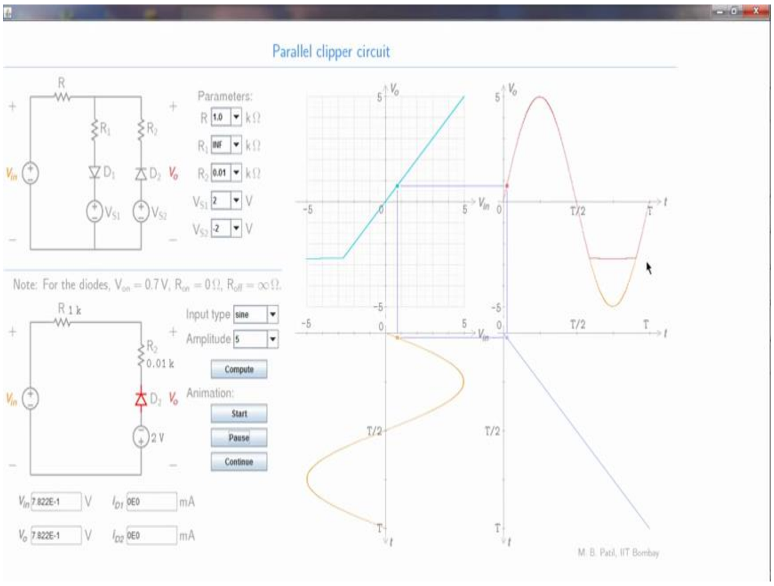

Parallel clipper circuit

Parameters:

R 1.0 kΩ

R_1 INF kΩ

R_2 0.01 kΩ

V_{S1} 2 V

V_{S2} -2 V

Note: For the diodes, $V_{on} = 0.7\,V$, $R_{on} = 0\,\Omega$, $R_{off} = \infty\,\Omega$.

Input type sine

Amplitude 5

V_{in} 7.822E-1 V

I_{D1} 0E0 mA

V_o 7.822E-1 V

I_{D2} 0E0 mA

Next let us change this R 2 from 1 k to some very small value like 10 ohms leaving this V S 2 at minus 2 volts. In that case we do not expect the breakpoint to change because that is determined by the V S 2 and this voltage drop across the diode, but this slope will change because that is given by R 2 divided by R plus R 2.

Let us check whether that happens. So, we will make R 2 equal to 0.01 k that is 10 ohms, compute and now we see that the breakpoint has not changed it has remained at minus 2.7 volts, but this slope has become nearly 0. And as a result of that notice that the output voltage has got clipped over here, and therefore this circuit is also a clipper it clips in the negative direction.

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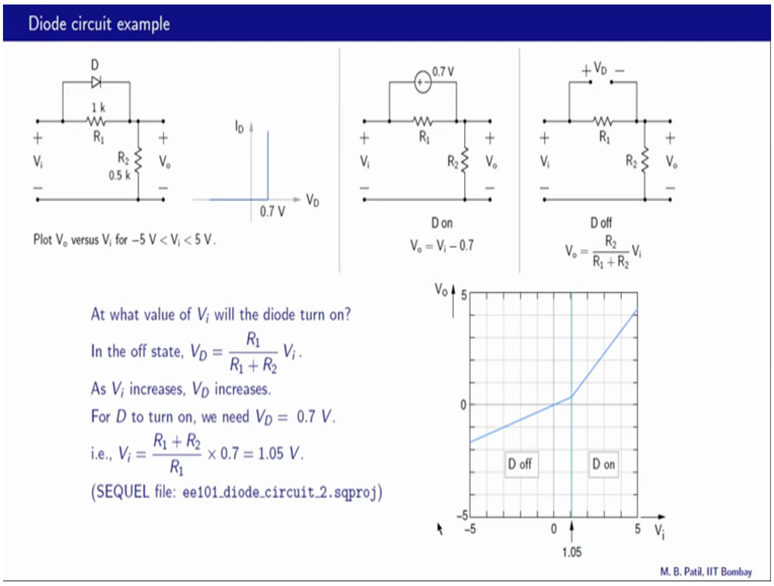

Diode circuit example

Plot V_o versus V_i for $-5\text{ V} < V_i < 5\text{ V}$.

D on

$V_o = V_i - 0.7$

D off

$V_o = \frac{R_2}{R_1 + R_2} V_i$

At what value of V_i will the diode turn on?

In the off state, $V_D = \frac{R_1}{R_1 + R_2} V_i$.

As V_i increases, V_D increases.

For D to turn on, we need $V_D = 0.7\ V$.

i.e., $V_i = \frac{R_1 + R_2}{R_1} \times 0.7 = 1.05\ V$.

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M. B. Patil, IIT Bombay

Here is our next diode circuit example, this is our input voltage V i that is the output voltage V o and we want to plot V o as a function of V i for V i varying from minus 5 volts to plus 5 volts. And this is the I D V D relationship for the diode that we will use, and it is of course the same as what we used previously.

To begin with let us consider the circuit with the diode D conducting. And in that case we can replace the diode with the battery 0.7 volts as shown over here. And now let us write KVL equation for this loop here; what do we get we go from here to there we come across the rise of V i so that comes as minus V i, then we have a drop of 0.7 volts; so that is plus 0.7 volts and then we have a drop again. So, that is plus V o and now we are back to the beginning. So, these three must add up to 0, and that gives us V o equal to V i minus 0.7.

So, when the diode is on that is the relationship between V o and V i that they would expect. We could of course, get this by inspection let us take this node as the reference node that is 0 volts, with respect to this reference node this node is at V I, this node is at V o and then we have V o equal to V i minus 0.7. So, sometimes it is much easier to just get things by inspection rather than writing KVL worrying about signs and so on.

Let us now look at the second case that is the diode not conducting, and in that case we replace D with an open circuit as shown here. And in this case the output voltage is given simply by voltage division that is R 2 divided by R 1 plus R 2 times V i like that.

So, we know what happens in these two cases: that is when the diode is conducting and when it is not conducting. Let us now worry about the input side, and the question we want to address now is at what value of V i will the diode turn on. Let us start with V i equal to 0 and in this case obviously the diode cannot conduct because it does not have the 0.7 volts it requires and therefore we are looking at this circuit here.

Now, imagine that we start increasing V i as a result this current will increase and the voltage across R 1 will start increasing. Now the voltage across the transistor R 1 is nothing, but the diode voltage V D and when this voltage reaches 0.7 volts that is when the diode will start conducting. And what is this voltage when the diode is not conducting? That is given by voltage division. So, V D is R 1 by R 1 plus R 2 times V i this equation here.

As V i increases V D increases and for D 2 turn on we need b D equal to 0.7 volts, so we put this equal to 0.7 volts and that gives us the condition for V i at which the diode will turn on. And that is given by this expression here and when we substitute values for R 1 and R 2 we get V i equal to 1.05 volts. So, if V i is 1.05 volts or greater than the diode conducts otherwise it does not conduct.

We now have the complete picture: if V i is greater than 1.05 volts then the diode conducts and V o is given by V i minus 0.7 volts, if V i is less than 1.05 volts the diode does not conduct and V o is given by this expression here. And now we can put all of these things together and plot V o as a function of V I, as shown over here. So, this is the region V i greater than 1.05 in which the diode is on and in this region the diode is off. When the diode conducts D V o D V i is simply one, and that is what we observe over here. And when the diode does not conduct the slope is R 2 by R 1 plus R two; R 2 is 0.5 k R 1 is 1 k, so this is 0.5 k divided by 1.5 k that is 1 by 3. So, this slope is 1 by three.

One might wonder at this point whether the circuits we are looking at are practically relevant; do they have any applications in practice. The answer to that question is maybe not; maybe not directly but in the process of looking at these circuits and analyzing them we are definitely learning many useful techniques, and these techniques will surely be very useful when we look at some practical applications.

So, hold on and very soon we will come across circuits which are practically relevant interesting useful and so on.

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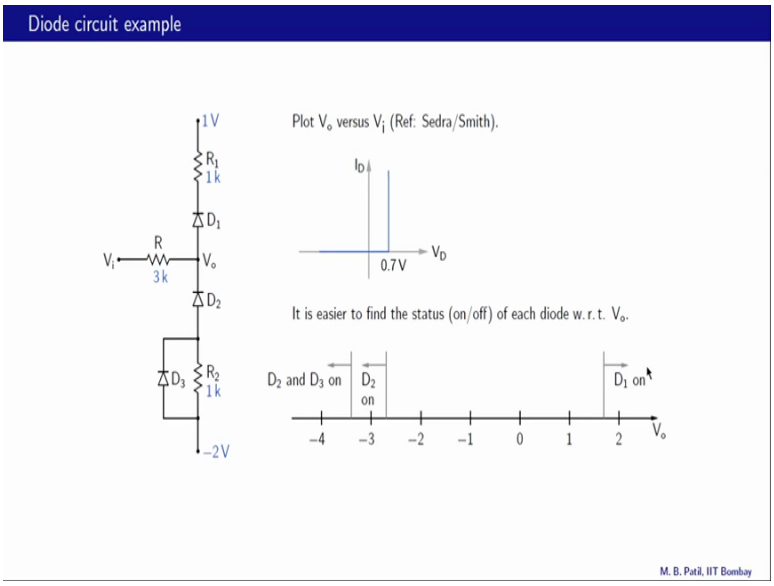

Diode circuit example

Plot V_o versus V_i (Ref: Sedra/Smith).

It is easier to find the status (on/off) of each diode w.r.t. V_o.

M. B. Patil, IIT Bombay

Here is our next example taken from this book by Sedra and Smith, and there are several other interesting diode circuits given in this book so therefore it should definitely look it up. Let us look at this circuit now; this is the input voltage V i with respect to ground that is the output voltage. This node is sitting at 1 volt with respect to ground which is not shown in this circuit, and this node is sitting at minus 2 volts. We have three diodes: D 1, D 2, D 3, so the circuit definitely looks very complicated, and let us see how to go about analyzing it.

Since we have three diodes here there are eight possible states for this circuit, this t 1 can be on or off D 2 can be on or off and D 3 can be on or off. So therefore, there are 2 raise to 3 or 8 possible states. And therefore the circuit analysis surely looks very very complicated. But once we realize that it is much easier to find the status of each diode with respect to V o then things are much simpler. And what do we mean by that? If V o is known then this voltage difference is known, and therefore we can figure out whether D 1 is conducting or not conducting. And similarly, this voltage difference is known and then we can figure out whether D 2 is on D 3 is on or D 2 is off D t is off or just one of them is on.

So, if we start our analysis with respect to V o then we find that it is much easier. Here is our V o axis; this is V o equal to 0 1 volt 2 volts minus 1 minus 2 and so on. And to begin with let us figure out for what value of V o or for what range of V o D 1 is equal to conduct. When D 1 conducts it can only allow current in that direction, and therefore this voltage drop across R 1 with plus here and minus here would only be positive. And as we go from this node to this node the total voltage drop would be 0.7 plus some positive voltage drop.

Let us say that this diode D 1 is just turning on; that means, the current is just starting to build up and let us say that the current is very small so that this voltage drop across R 1 is negligible. In that case between this node and that node we have only 0.7 volts and if this is 1 volt V o must be 1.7 volts.

In other words V o equal to 1 0.7 volts represents the boundary between D 1 conducting and D 1 not is conducting; any value of V o greater than 1.7 volts means that D 1 would conduct. And this observation is marked in this figure like that, this is 1.7 volts for V o greater than 1.7 volts we can say that D 1 is on.

Let us now look at D 2: when D 2 just begins to conduct this current is still small and we do not have any voltage drop here and then the total voltage drop between this node and that node is 0 plus 0.7 that is 0.7 volts. And that would happen if V o is 0.7 volts lower than minus 2 that means, V o must be minus 2.7 volts. And any value of V o lower than minus 2.7 volts would also mean that D 2 conducts. So, that is indicated over here this is minus 2.7 volts and for V o less than minus 2.7 volts D 2 conducts.

Now, as we increase V o in the negative direction like that what happens is this current starts increasing and therefore the voltage drop across R 2 starts increasing, and at some point that would become 0.7 volts and at that point D 3 would start conducting. We will calculate that the value of V o a little later. And the value of V o at which D 3 turns on it is indicated over here.

So, as V o is reduced that means, increased in the negative direction first D 2 turns on and after some point D 3 also turns on. So, in this region we had both D 2 and D 3 conducting, here we have only D 2 conducting in this region one of the diode is conducting and in this region only D 1 is conducting. Let us now look at this region and find the relationship between V o and V i for that region.

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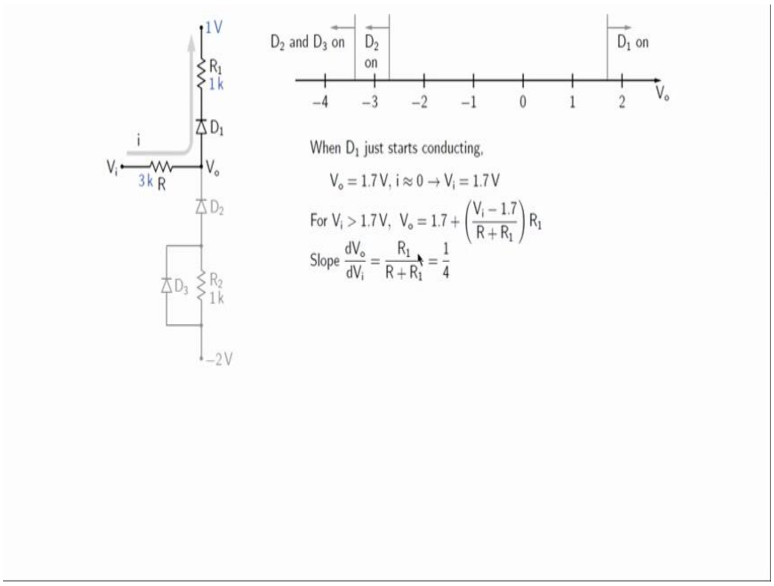

When D_1 just starts conducting,

$V_o = 1.7\,\mathrm{V},\ i \approx 0 \rightarrow V_i = 1.7\,\mathrm{V}$

For $V_i > 1.7\,\mathrm{V}$, $V_o = 1.7 + \left(\frac{V_i - 1.7}{R + R_1}\right) R_1$

Slope $\frac{dV_o}{dV_i} = \frac{R_1}{R + R_1} = \frac{1}{4}$

When D 1 conducts the current path is like that and in this situation D 2 and D 3 do not conduct, there is no current in this branch and therefore we have shown that in gray. Now as we have seen earlier D 1 starts conducting when V o becomes 1.7 volts. So, V o is 1.7 volts when D 1 just starts conducting and this current is still small so therefore this voltage drop is nearly 0. And in that case V i is equal to V o that is 1.7 volts, like that

When V i is increased beyond 1.7 volts this current starts increasing and then let us see what V o is. V o is 1 volt plus 0.7 volts here plus this voltage drop; that means, i times R 1: and what is i? I is given by V i minus 1 volt minus 0.7 volts divided by R plus R 1. So, we get V o equal to 1 0.7 plus V i minus 1.7 divided by R plus R 1 multiplied by R 1. So, that is the V o versus V i relationship in this region where and what is the slope of this straight line it is R 1 divided by R plus R 1 with R 1 equal to 1 k and R equal to 3 k this slope turns out to be 1 by 4.

In summary you have considered a few diode circuits and seeing how they can be analyzed systematically. With this experience you would be able to work out the V o versus V i relationship for other circuits of this kind and it is a good idea to take up some diode circuit problems say from a textbook figure out it is V o versus V i relationship and then check your results with simulation. See you next time.