Analog Circuits
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Week -06
Module- 05
Limiter, Diodes

Hello, welcome to another module of this course analog circuits, so in the past module we had been talking about limiter circuits, in this module I will introduce you to another limiter circuit, so the other circuit that I was mentioning.

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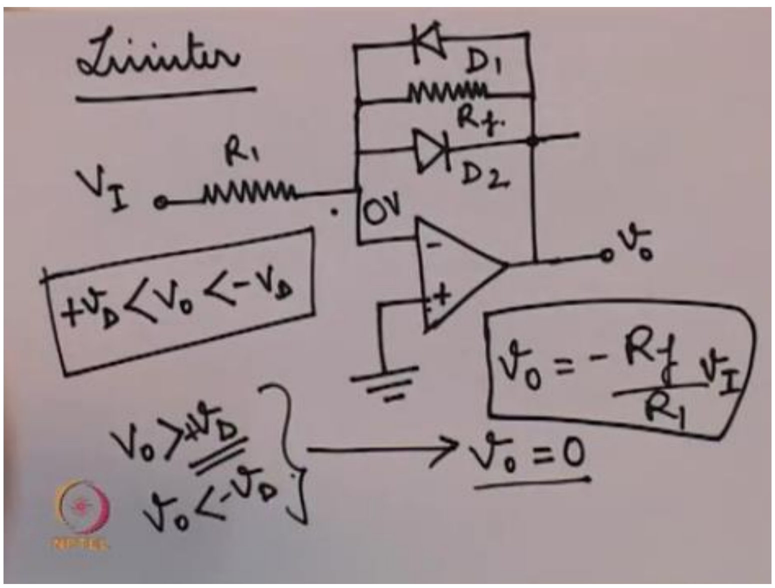

Suppose we have opamp in a inverting configuration like this assume that both D1 and diodes D1 and D2 are open then the output voltage will be given by - Rf upon R1 times Vi, now suppose for some reason now note here that this voltage will be at 0 volt okay because the non inverting terminal of the opamp is in a virtual shot suppose for some reason the voltage Vo goes on high okay it becomes higher and say Vo is greater that VD where VD is the threshold voltage of the diodes.

So if Vo is greater than VD then diode D1 will start conducting and if diode D1 starts conducting then there will be a short between these 2 terminals, if there is a short between these 2 terminals then Vo will be 0 if Vo becomes 0 then immediately what will happen the threshold voltage across diode will become lesser than VD and therefore this point and this point will again the diode will be in an open configuration that is it will not conduct there will not be the short that existed between these 2 terminals before will not exist once this V0 becomes 0 okay.

So the sequence of action is like this Vo for some reason goes above VD diode D1 starts conducting as diode D1 starts conduction Vo becomes 0 and once Vo becomes o diode D1 again becomes open and so the voltage the relationship between Vo and Vi is restored to this form, similarly if Vo is lesser than VD for some reason then also a similar sequence of events will happen first diode D2 will start conducting once that D2 starts conducting Vo will again be = 0.

So for both these can whenever these 2 conditions happen Vo will immediately become = 0 once Vo becomes = 0 this diode will again go into the open that is the cutoff stage where and these 2 terminals will be the short that existed between these 2 terminals will no longer exist.

So what you see is that I should say this is - VD this is + VD this is - VD let us make note this correction so what we see is that when this V0 is lesser than - VD and greater than + VD only then this relationship is true for other values this relationship or in other words when VI increases or decreases to such an extent that Vo exceeds this limit then you know we can no longer guarantee that Vo will continue to follow this relationship when such a condition happens that is Vi becomes so high or so low that Vo exceeds our or decreases beyond this limit then Vo will automatically go to 0.

So then this is the range where Vo can exist hence this is a limiter circuit also so that was about limiter we shall see some uses of limiter when we discuss about oscillators right now let us discuss in a little detail about the diodes, diodes are an example of what we call active circuits because they need a certain external input power for their operation unlike resistance, so just like an opamp which needs a external supply voltage in diode certain a certain bias voltage is necessary for its operation.

So you know resistance inductors capacitors they are all examples of passive components because they do not require any external power supply for their operation whereas diodes and opamps to, so let us study a little bit in detail about diodes so diodes as you know I have already given you the symbol while discussing the limiter circuits and diodes are also a prime example of non linear components, the input output relationship between inductors capacitors and resistance is linear either directly proportional or their derivatives are proportion to the input and output.

But in diode as you have seen already that it is a non reciprocal that is if just because current flows from one terminal to the other does not mean current can flow from the other terminal to the previous one so it is a non reciprocal network, it is also a non linear network because in a diode for some input voltages it conducts for some input voltages it does not conduct, so it is not it does not follow the linear relationship or it is it does not follow the linearity principle.

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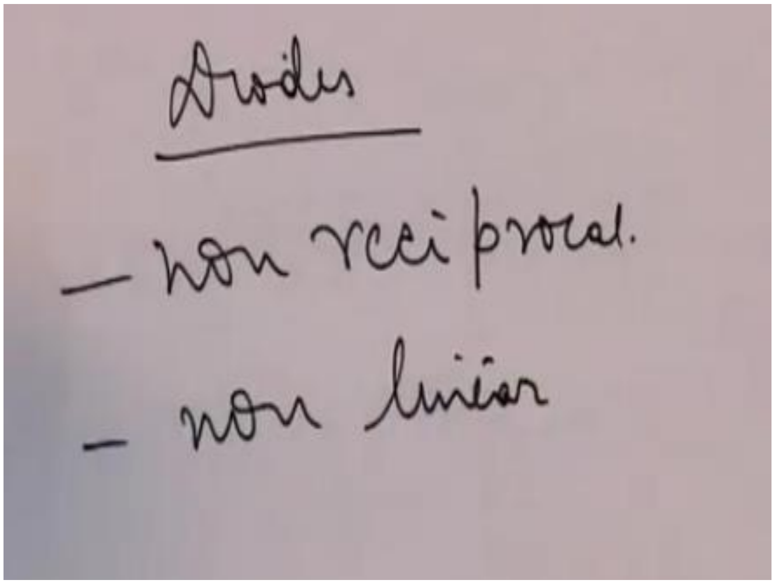

So diode is so then we can write that diodes are an example of non reciprocal and nonlinear component okay, now ideally how should a diode operate?

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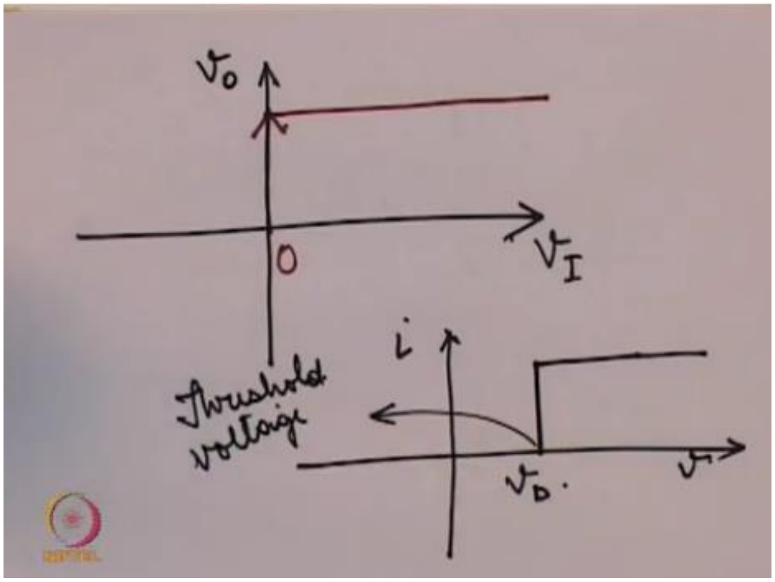

Ideally if you know, if you write the input output relationship then the ideal input output relationship between input voltage and output voltage should be somewhat like this, that is whenever Vi okay is above 0 volt it conducts and if Vi is lesser than 0 volts it does not conduct or I should say when Vi is above 0 volts there is a certain output voltage when Vi is lesser than 0 volts.

There is no output voltage that the output voltage is 0, but this kind of characteristics is quite difficult to achieve actually, because first of all see that how do we determine this output voltage where I said it should saturate that is somewhat difficult so more practical circuit or more practical achievable characteristics of a diode is somewhat like this, if I draw a graph between the current and the voltage of the diode then at a certain voltage which I call the threshold voltage it starts conducting that is there is a finite current and below this threshold voltage there is no current.

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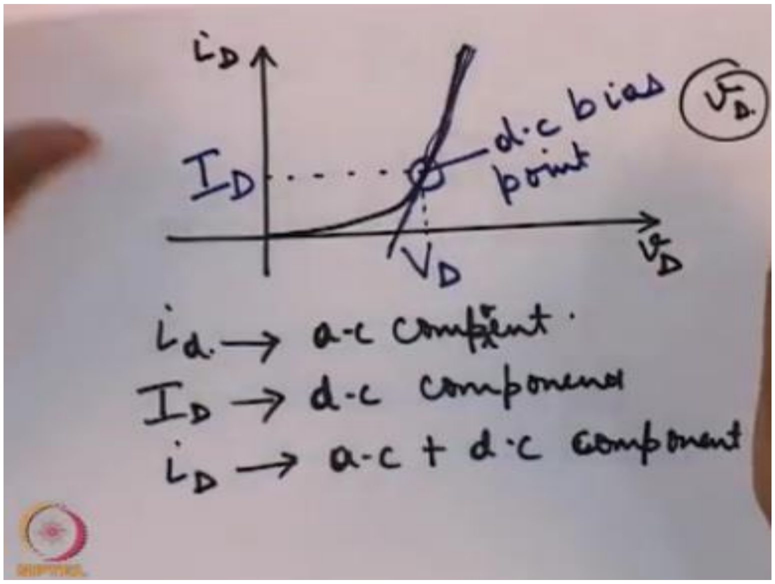

Now even this is somewhat difficult to achieve actually what we do get in reality is something like this, the diode that we actually get in the market has a characteristic somewhat like this, now I shall write this term VD this is not the same as the VD the threshold voltage that we had been discussing this, you know I will just give you some of the nomenclature that I am using in this course.

I will just mention if I write a term like this like this and like this what is the difference between these 3 quantities when I write with a small D this refers to just the AC component or the non DC component or the time varying component of the current with the capital I with a capital D this represents the DC component or the non time varying component and small i with a capital D this represents the AC + DC.

So here when I am drawing the characteristics of the diode I am representing the Y axis with small I capital D and the X axis with small v capital D both representing the AC + DC component now the equation governing the voltage and the current of a diode at any particular point on this graph is given by what is known as the Shockley diode equation.

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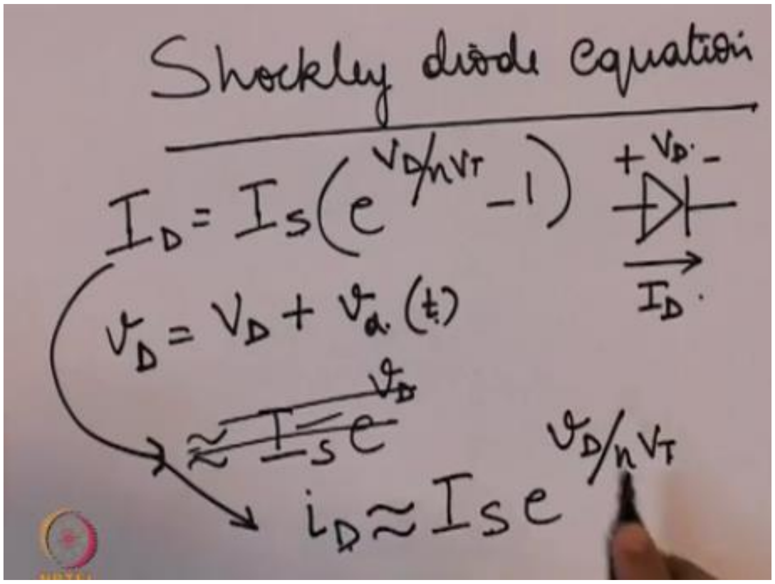

Here this is the DC component and this is also the DC component of the voltage what this equation gives is that suppose the voltage across the terminals of a diode is kept at VD okay then what will be the ID flowing through it, so this is the steady state or DC characteristics of course we are here assuming that when the voltage across the diode falls below 0 voltage then current will be 0 so that is not entirely true but for this particular case for now we will be assuming that the current is 0.

You know this AC + DC component of the voltage across the diode can be given as the sum of the DC component and the AC component this equation can also be simplified like this here this capital I capital S is a constant so this for you know even moderate values of VD can be given like this.

This equation if I now represents in place of capital I capital D that is instead of the DC current I represent the AC + DC component then this will approximately be given as Ise raise to the AC + DC component of the voltage across the diode like this here we are ignoring this one because even for small values of PD this exponential term will be much larger than 1 so then I can write my IDT like this.

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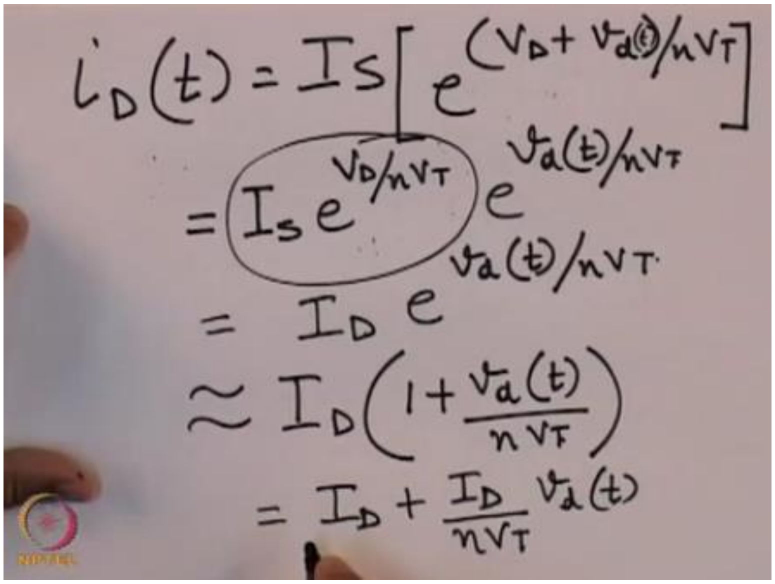

Now okay, so here I have simply in place of the AC + DC components I have substituted with that DC + the AC component, so I can write a small t showing that this small V small D is a function of time so this becomes now this if I consider this whole thing as a constant I am assuming here that the DC voltage across the diode (Refer Slide Time: 16:00) that is we are operating at a particular point in the graph where the DC voltage is capital V capital D and the DC current is capital I capital D.

So at this point if we you know are seeing the applying a signal around this particular DC bias point as I said this I will the DC bias point why DC bias point because the changes that we shall be observing are about this point okay, so around this point what is the if we apply a small AC signal about the DC voltage or a small AC voltage about the DC voltage capital V capital D, then what will be the small AC current?

We will be observing about the current capital I capital D so let us assume that this is a constant this capital I capital S e raised to VD upon nVT and let me call this as ID I capital D this representing the DC component of the current ok now if this exponential term is quite less then we can simply use the exponential expansion and consider only the first term of the exponential expansion, so this becomes = and this can be further expanded as.

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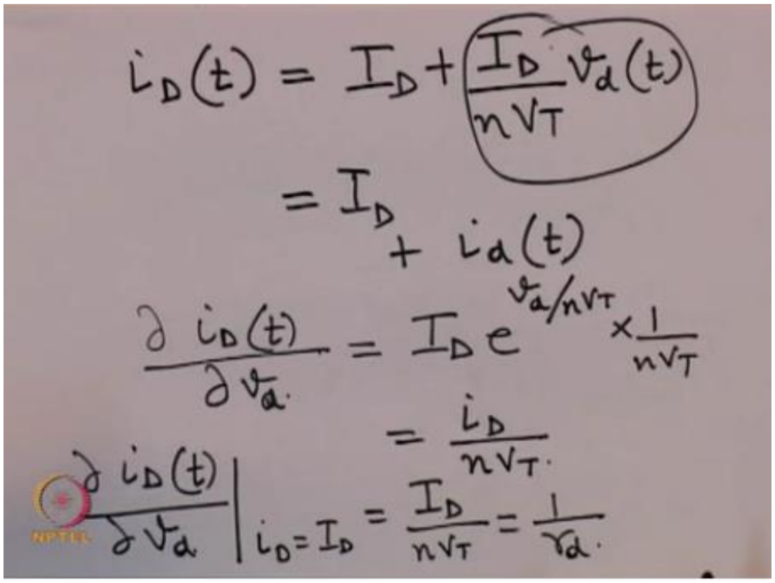

So we have small I capital DT is = ID + ID upon nVT into VD of t and this I am representing this whole quantity by idt ok, so this is the DC component of the output current of the order of the diode current and this is the AC component which I am representing by small i small dt, so what I have effective done here is that now see fundamentally the diode characteristics is non linear isn’t it, the ID versus VD as you can see it is a curve but about this point I am linearized.

Linearized it means I have just assumed or developed a relationship which shows that for small variations of the AC voltage about the DC bias point capital V capital D and the output current that we will get for small AC variations the small AC diode current that we will get is also is linearly related to the AC voltage variation and that is given by this relationship, so ID i small i small dt is given by this relationship which shows that the AC current across the through the diode is linearly related to the AC voltage across the diode, now so we had the expression for ID I capital D like this if you differentiate this equation.

Let us see what happens, so I am differentiating the AC + DC current with respect to the AC voltage and what I get is the DC bias point, so this and say this I call as 1 upon rd so this is the AC resistance the AC resistance is the instantaneous or the dynamic resistance offered by the diode to any variation in voltage ok.

So the small change in the current about the bias point due to a small change in the voltage about the bias point is what is measure is what is given or the factor that controls this change of current with respect to small changes in voltage is given by this rd so this is known as the AC resistance and it is given by the inverse of this quantity so then again if you go back to the characteristics for a moment what we did was we linearize this point ok.

So we drew a straight line about this point and the straight line also kind of this blue line kind of closely follows the curve also and if we extend this line so that it touches the X axis and suppose we the point where this line this blue line touches the X axis is VD0 then what will be the equation of this line.

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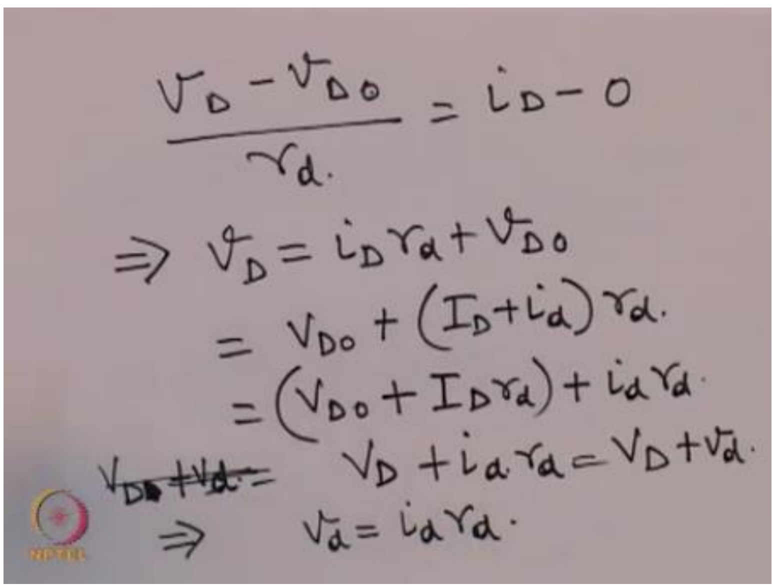

So the equation of this line will be VD - VD0 upon rd, since rd is the slope will be = ID - 0 so from here we get VD that is the AC + DC voltage is = ID rd + VD0 from which we get VD0 + ID + ID rd and from which we get this represents the DC component and this represents the AC component okay.

Now if we also write our VD this V AC + DC voltage as VDD + VS or simple I can write VD + VS ok were VS is the AC input okay or you know I will just follow the convention I will just write it like this is = VD + small vd small v small d so this is capital V capital D + small v small d then this VD is = Id into rd now let us consider a circuit with the diode in it.

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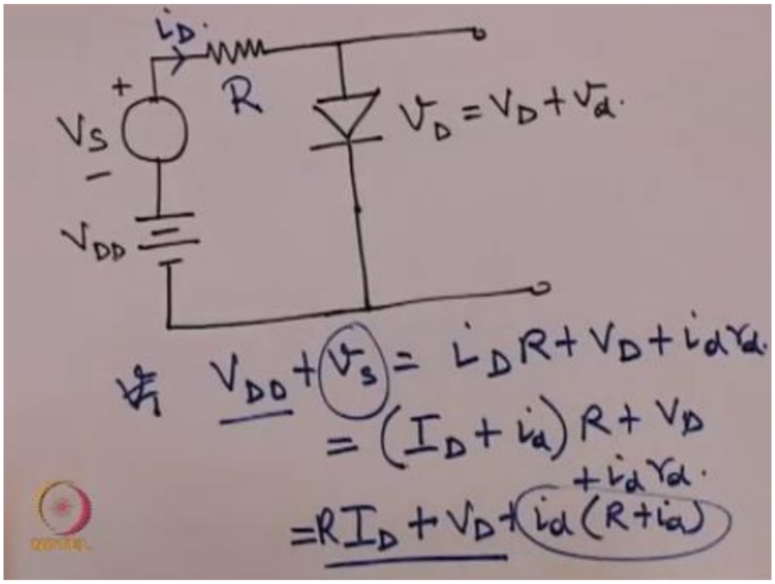

Suppose we have a source an AC source Vs and a DC source VDD with a diode like this whose AC + DC voltage is given like this now here if we write the Kirchhoff's voltage equation what we get is V sorry VDD + Vs is = because the current is id, so this is the AC + DC component of current so this is ID into R + VD + ID in to rd from which we can write it as now this small i capital D is the sum of the DC component + the AC component + VD + ID rd which in turn is = Capital I capital D + so R into Capital I capital D + VD + ID into R + id.

See here this part that we obtained is there is dependent only on DC currents and voltages this part the voltage side left hand side is also dependent on DC component but this component and this component is dependent on the AC currents and voltages.

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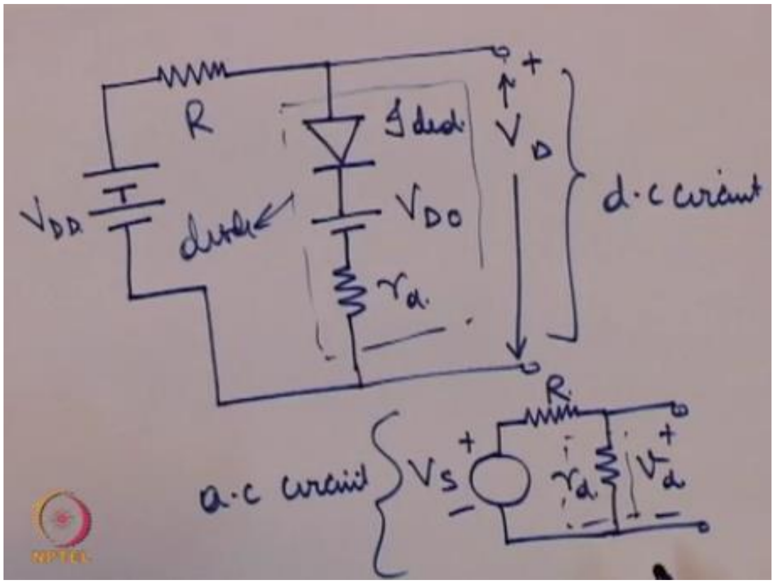

So the circuit which we were given initially can now be divided into 2 components, one is like this and another circuit like this, this circuit is called the AC circuit this circuit is known as the DC circuit, note that both these 2 circuits operate only in the positive bias mode that is when the diode is conducting for when the diode is not conducting of course these 2 circuits will not be valid.

Now coming back to this circuit see this is the DC circuit what it means is if we want to find out the DC operating conditions of this diode then we if we find a solution of this circuit we will know exactly what is the voltage across the diode the diode node consists of this entire all these things here on the AC circuit however the diode is limited to this part so this is entire thing is our diode this is an ideal diode means whose threshold voltage is 0 and since in our diode the threshold voltage is not 0 it is replaced by this VD0.

Now well when finding out the DC operating point of any diode which is frequent exercise that engineers have to do you know you are given a circuit what is the DC input and output voltages of a diode, so there this circuit is useful as we have seen and note that this VD0 that we are using is not a point on the IV characteristics of the diode it is simply a point on the X axis where the straight line that we used for linearizing the diode meets the X axis.

So this is very important you know this threshold voltage that we use while obtaining the DC solution of any circuit VD0 is not a point note this very careful is not a point on the IV characteristics of this curve isn’t it VD0 is a point on the X axis you see nowhere on the characteristics it is just the point where the line or the linearization line used for linearizing this diode circuit about its bias point meets the X axis.

So note this carefully the AC circuit on the other hand is quite simple it just consists of an RD small R small D there are no diodes or threshold voltages of course keep in mind that this circuit will be applicable only when the diode is conducting that is in the forward bias what we also know as, so when the diode is not conducting this circuit will not be valid.

So I hope I was able to explain in a little detail about the operation of a diode when we try to find out the important point about diode is that there is a threshold voltage when we try to which we have to consider while trying to find out the DC solution of a diode and this threshold voltage it derives from the linearization that we do on the diode not from any point on the IV characteristics of the diode. So thank you very much for attending this module, see you in the next module, thank you.