Analog Circuits
Prof. Nagendra Krishnapura
Department of Electrical Engineering
Indian Institute of Technology, Madras

Module - 01
Lecture – 09

In this lesson, we will discuss the Diode model. And the model I am referring to now is what is known as the large signal model. It simply refers to the fact that we are dealing with total quantities that is, the total Voltage across the Diode and the total current in the Diode, and not incremental values over certain operating point.

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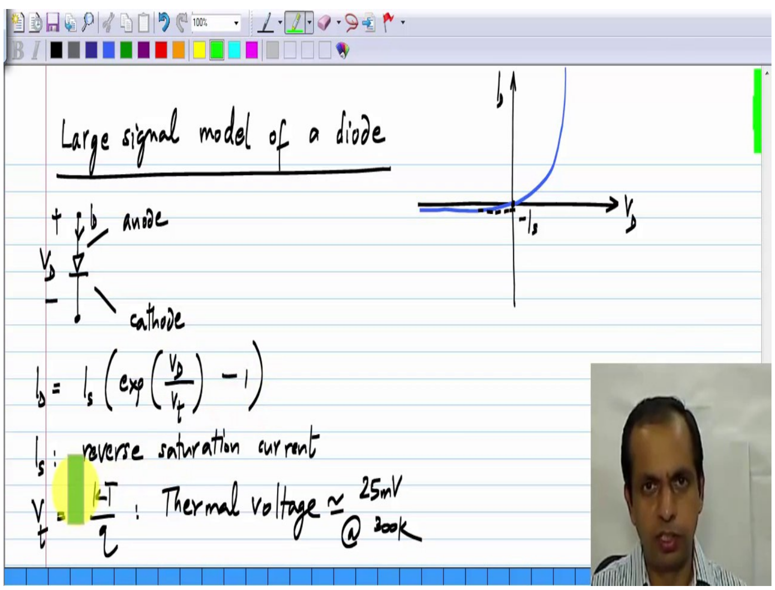

This is the Diode symbol and we have the anode and cathode. By convention I will define the Voltage across the Diode to be positive at the anode terminal, the value of V_D of course can be anything. And the current I_D will be flowing into the anode as per passive sign convention. Now we already have seen a model for this. The Diode current is I_S $(e^{\frac{Vd}{Vt}} - 1)$, where I_S is the reverse saturation current. And Vt which is KT/q is the thermal Voltage, and if you substitute the value as for 300 Kelvin or room temperature, this is approximately 25mV.And we also know what the characteristic look likes graphically; the current can be substantial, when V_D is positive; and it will saturate to - I_S, when V_D is negative. And of course, the current is zero, when the Diode Voltage is zero. Now, even with this expression for the Diode current and even for very simple circuits, evaluation becomes very difficult, because you have to solve equations numerically. So, we have a number of approximation to this, which I am going to discuss now.

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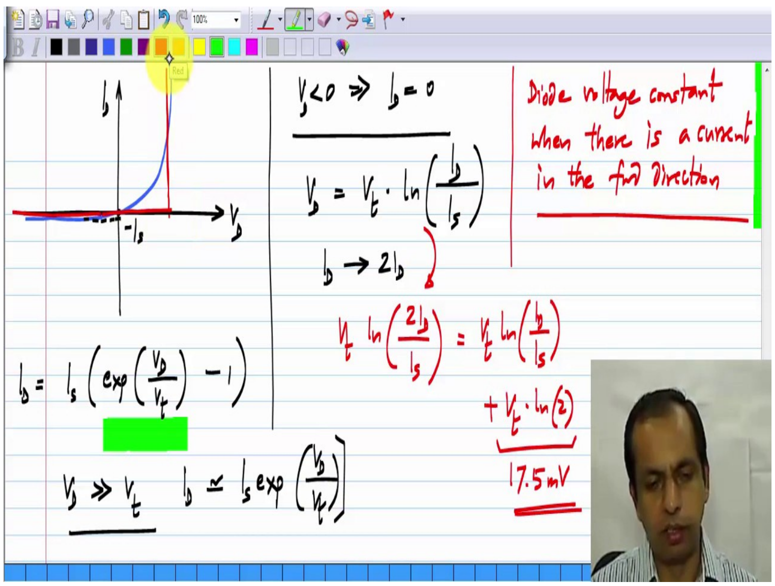

So, one of the first thing to do sometimes this is very convenient is to neglect this one, when compared to this. And of course, this works only when this term is very large, and when is it very large when V_D is large and positive. When I say large and positive V_D must be much more than the thermal Voltage. In this case, clearly the exponential of this is much more than this. For a V_D of a few thermal Voltages, this turns out to be correct right; couple of 100mV is all we need. And in this case, the I_D can be approximated to be $I_S \; e^{\frac{Vd}{Vt}}$. Of course, it must be remembered that this holds only when V_D is much more than the thermal Voltage.

Now, if you do plot this, what happens is in this region where the current it substantial, you will get approximately the same value. One crucial difference between the exact expression and this is that a new expression does not go to zero when V_D equals zero. So, this means that if you plot this characteristic, there will be a part in the second quadrant which means that the devices is not passive. Of course the reality is that near the origin, near V_D equal to zero, this expression should not even be used; it is only an approximation.

And another approximation frequently used is that because the reverse bias current is so small, this value of I_S is quite small and again when I say small compared to currents you normally see in forward bias. Then you assume that there is no current flowing through the Diode, that is in reverse bias there is no current in the Diode. This is one of the approximation that is frequently used. Of course, we have still left with the nonlinear equation and this is useful for certain classes of circuits, but still even for simple arbitrary circuits, you have to solve nonlinear equations, and we would like to avoid that for hand calculations.

So, the next approximation that you see is that if you look at this part of the curve, curve is quite steep. I am plotting I_D versus V_D and curve is very steep. So, what you can say is that in this part of the curve, the Diode Voltage does not change much, it of course changes. In fact, I will use this approximate expression to find the expression for the Diode Voltage. So, V_D will be the thermal Voltage times the natural logarithm of the Diode current by the saturation current. So, now let say I_D is doubled, I_D becomes 2 I_D then this changes to V_t ln $2Id/Is$, which is basically the old value of V_t ln I_D/Is + V_t ln 2. And if you calculate this, it will come out to be approximately 17.5mV. So, even doubling the current, changes the Diode Voltage only by something less than 20mV.

So, we can make a reasonable approximation that for a range of currents the Diode Voltage is constant that is we assumed the characteristic to be exactly vertical where the Diode Voltage is not changing at all. Of course, this gives you very bad errors when you come close to the origin but that is ok; we assume that the Diode is operating somewhere here. So, we say essentially the next level of approximation is to say that the Diode Voltage is the constant when there is some current flowing in the forward direction. And also we know that the current is very small in the reverse bias region and we already approximated that to zero earlier, that is we assumed characteristic of this type and we can continue that all the way till here. So, we assume that there is zero current up to this point, and at this point, the Voltage will be constant and it can carry any current.

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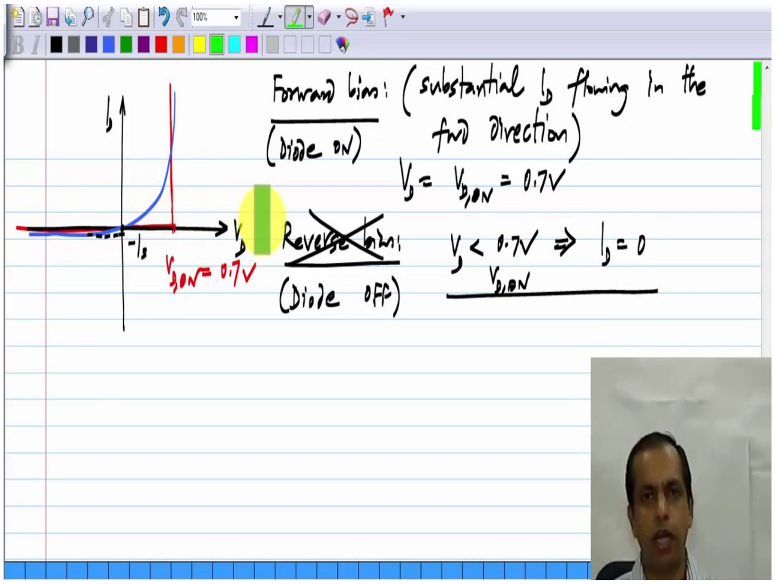

So, the next level of approximation is as follows. Forward bias which means that substantial I_D flowing, of course in the forward direction. In the reverse direction, substantial current cannot flow in the Diode at all. So, in this case, what happens, V_D is some constant, which is denoted by V_D ON. And what is the value of this constant, essentially the way you work out this constant value is you have certain types of Diodes that you normally use, and you have certain range of currents that you normally operate at, and for that you just look for a reasonable value. And it turns out that the reasonable value for this is 0.7 V. Now, this does not have to be the case, if you operate Diodes with very small currents, it could be smaller than this; and also in Diodes, which carry very large currents, it could be more than this even as much as 1 V. But we will assume that it is 0.7 V. But the important thing is that it is assumed to be a constant regardless of the value of current.

And then I will call it reverse bias, basically when the Diode is OFF. By the way, I refer to this as the Diode being OFF, and I shouldn't really call this reverse bias, because V_D is not necessarily negative, it also includes V_D less than 0.7 V. So, this means that if V_D is less than 0.7 V, this means the current will be zero. If V_D is less than V_D ON, the current will be zero. The forward bias is when the Diode is ON, but it looks like some kind of switch where you can go from OFF state, where there is no current; to ON state, where the Voltage is constant and it can support any current. Now this is fine, this is in fact what we will use for our large signal calculations.

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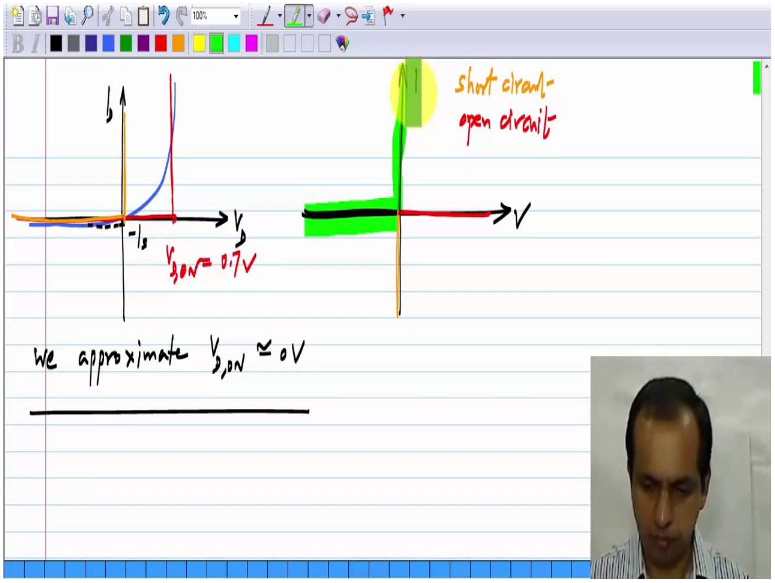

And there will be some cases where we can approximate this even further, let say we have circuits where the Voltages are much larger than 0.7 V, it turns out that you can approximate this as having zero current when V_D is negative. And having a zero Voltage, when there is any current flowing through it that is we make an even make a cruder approximation for V_D ON by setting it to zero V that is the Diode behaves like a short circuit when there is a positive current flowing and the Diode behaves like an open circuit, when a reverse Voltage is applied. If you remember I versus V of a short circuit, is as follows. It is this, it will have zero Voltage regardless of the current that is flowing, and the I-V characteristic of an open circuit, it is like that. It will have zero current regardless of the Voltage across it.

Now the Diode is the combination of these two. It is an open circuit in this part in reverse bias region; and a short circuit in the forward bias region, so that is another approximation to the Diode characteristics.

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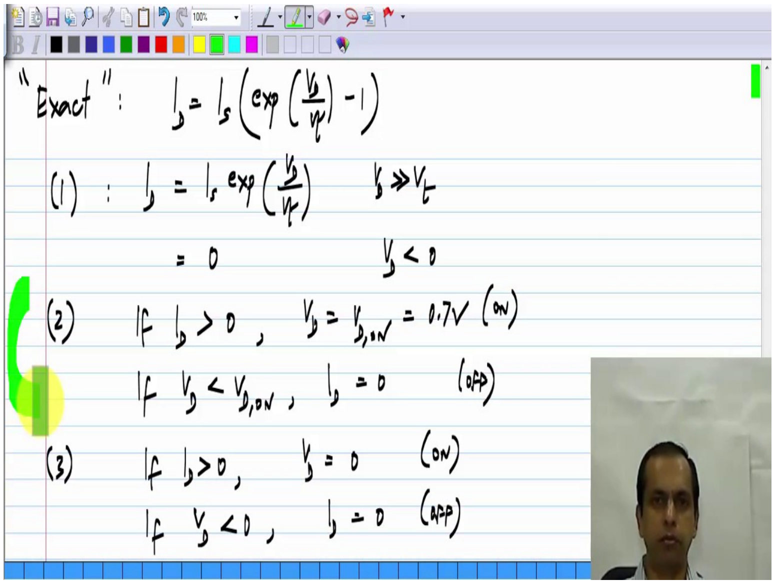

So, to summarize, we have the exact characteristics of the Diode; and this exact, I will put in quotes because this is still an idealize version of the Diode characteristic. And in a practical Diode, you will have other non-ideal features, but as far as we are concern this is the exact characteristics. And this is valid for all values of V_D, and then we have the first level of approximation where we say that I_D is just the exponential without this minus one term, when V_D is much more than Vt; and it is zero, when V_D is less than zero. And we have a second level of approximation where we say that if there is current flowing through the Diode at all, forward current flowing through the Diode, then the Diode Voltage is some constant V_D ON, which we will take as 0.7 V.

And if the Voltage happens to be less than V_D ON, then the I_D will be exactly equal to zero; and in this model that the Diode Voltage cannot be more than V_D ON. And in even cruder version of this is to say that if I_D is more than zero, V_D is zero; and if V_D is less than zero, I_D equals zero. So, this is the ON Diode, and that is the OFF Diode. In this course, and generally in many courses for hand calculations, you will end up using this as a reasonable approximation.