Analog Circuits

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Module - 01
Lecture – 04

Previously we saw that in order to have power amplification or power gain, we need to have a nonlinear circuit and we also need an additional source, because every element is passive. If you just have a single source which delivers the signal power then what comes out, the power that comes out is going to be smaller than the input signal power. So, we need to have a nonlinear device as well as two sources; one is the source which provides the desired signals and also another is sort of a power supply usually it is a dc source. And somehow some of the power that is taken from the dc source will be converted to useful form in the form of the signal. So, that is how we get power gain.

Now, before we can discuss amplifier devices, we have to learn how to analyze nonlinear circuits,because this is usually not what is taught in basic circuit classes. So, we will go step by step and the analysis of nonlinear circuits is not as easy as linear circuits, but we can make some approximations and make some progress with analyzing nonlinear circuits.

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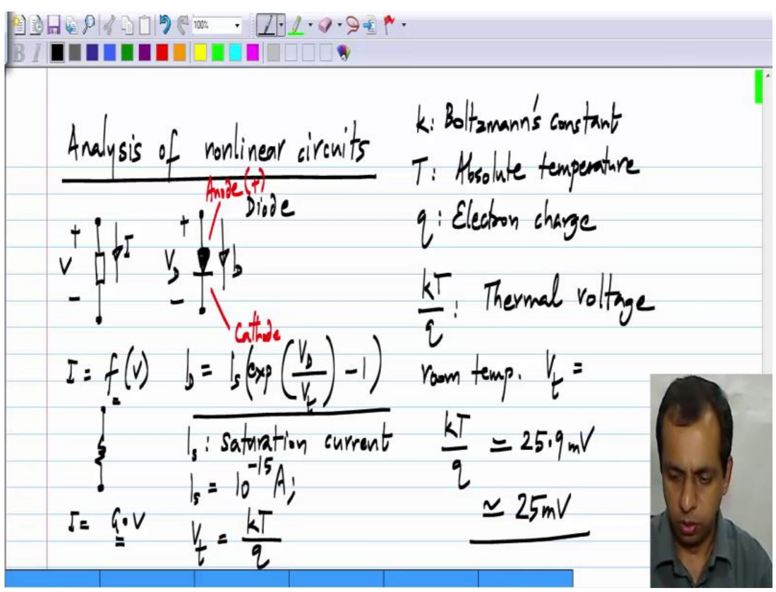

Now, eventually we want to have two port elements that is an element where you can provide an input from one side and take the output from the other side. But because we are yet unfamiliar with nonlinear circuits, we will first consider nonlinear one port and then go to nonlinear two ports. But the general method of analysis shown with the nonlinear one port will also be applicable to nonlinear two ports. Now, I will represent a general nonlinear one port like this. If it has voltage V across it, it has certain current I through it;and I will be some function of V where this f is nonlinear. Of course, in case of resistor,which is linear we have a similar relationship where I is G times V where G is the conductance. So, the single number conductance is describes the resistor; and in case when nonlinear element the function f describes the nonlinear element.

Now of course, we can talk in abstract terms about a general nonlinear element but it is also useful to learn about a very frequently used one port nonlinear element which is the Diode. So if the voltage across this is V_D, the current I_D through it will be given by some nonlinear function. I am going to show that in a moment, but one thing I have to show is the diode is represented by a symbol like this and it is asymmetrical. So this side is known as the anode or the plus terminal and that side is the cathode. And while describing the characteristic, this V_D is defined with the anode being positive and I_D is defined with the current going into the anode,so that's the usual passive sign convention. So with this polarity, this $I_D = I_S \ (e^{\frac{Vd}{Vt}} - 1)$. Now this I_S is called the saturation current, it is some property of the diode; it is somewhat similar to the conductance of the resistor. So you can have a resistor with different conductance similarly you can have diodes with different saturation currents. And the saturation current can vary widely just like you can have one ohm resistor or one mega ohm resistor, but I just give you some value which you can find this I_S itself will be a very small number 10^{-15} A.

And there is another constant here which is V_t, and this is not really a property of the diode, but it is the fundamental constant and it is given by kT/q , where k is Boltzmann's constant you would be familiar with this and T is absolute temperature and q of course is the electron charge. And this number kT/q , this is known as the thermal voltage, obviously it has dimensions of volts and you have see that it must be like that to balance the dimensions here, because V_D is volt, V_t also has to be in volts so that the argument of this exponential is dimensionless. Now of course this is something that is directly proportional to the absolute temperature and it turns out that at room temperature, this V_t is kT/q and which equal to 25.9 mv. And we will frequently approximate it with just 25 mv. So this is the number worthwhile remembering, the thermal voltage V_t is 25 mv at room temperature. So sometimes it is approximated to 26; or sometimes, we use 25.9, but this is good enough 25 mv.

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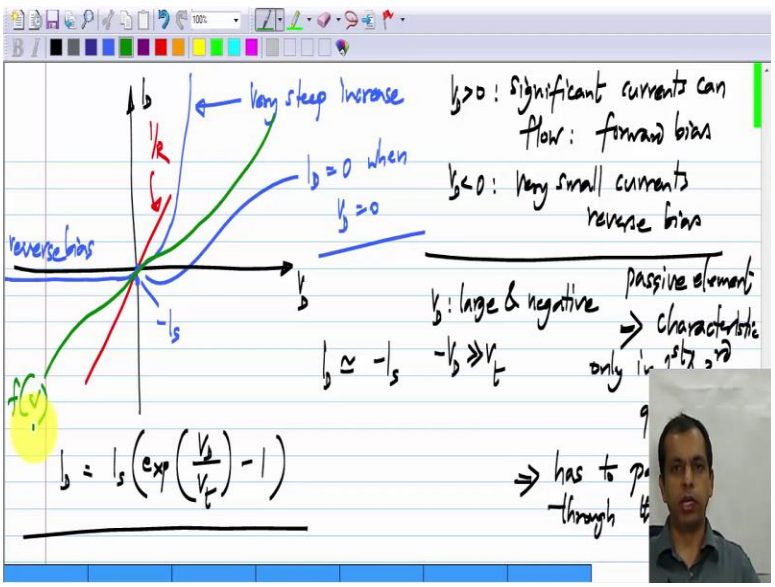

So now let see what this characteristic looks like. As usual as for any element, we can also graphically depict the characteristic, I_D v/s V_D; and we said I_D is I_S $(e^{\frac{Vd}{Vt}} - 1)$ .It is some nonlinear curve, but we can see how it behaves. So first of all, when V_D is very negative that is V_D/V_t is large negative number. This exponential of large negative number is close to zero; of course, it will never be exactly zero, but it will be very small. So in this parenthesis, you will just have minus 1, so I_D will be approximately $-I_S$ when $-V_D$ that is the negative value of V_D is much more than V_t. So what I am saying here is V_D is large and negative. So I_D approximately $-I_S$, it means that I_D will be something like this, when V_D is large and negative, and this number is $- I_S$. So what it means is in this region when V_D is negative by the way that region is called reverse bias,the current will be almost constant and it will be equal to $- I_S$. And in fact this is the reason why I_S is called the saturation current or the reverse saturation current.

Now when V_D equal zero,this number is one, and I_D will be equal to zero, so that means that this I_D will be zero when V_D is zero. And as V_D becomes positive, this exponential grows rapidly with V_D, and the current increases rather steeply,something like this. So this region where V_D is greater than zero, significant currents can flow and this is known as forward bias. And V_D less than zero, the current is very small; we saw that I gave you typical value of I_S which is 10^{-15} A, so it is very small and more than the absolute value of that the significant thing is that when V_D is more than zero the current is much, much more than when $V_D < 0$.So when we say small and large currents, we have to relate it to something, what we mean is that the reverse bias currents are much smaller than forward bias currents. This is reverse bias.

And for V_D equal to 0, I_D will be equal to 0.In fact, this is the condition that is necessary for passivity. We of course know that resistor characteristic would look like this right, it will be a straight line passing through the origin and it will have the slope of conductance or the reciprocal of resistance, and it is passive. Now you must know this from your basic electrical circuit courses. If the I_D characteristic of a one port or a two terminal element is in the first or third quadrant, it is dissipating power, because v times is positive. Here in the first quadrant both v and i are positive; in the third quadrant, both v and i are negative. So in both of these, it will be dissipating power. In these quadrants – second and fourth quadrants v times i will be negative and the element will be generating power. So if you have a passive element, it cannot have any part of its characteristic in either the second or fourth quadrants.

So passive element means the characteristic only in first and third quadrants; and this of course implies that it has to pass through the origin. So now this is for a diode and in summary, diode has a very small current in reverse bias that is when the diode voltage is smaller than zero and note that the diode voltage is defined with the specific polarity and the symbol of diode is asymmetrical. So please keep that in mind while figuring out forward and reverse bias. And when it is in forward bias, it can have significant currents. Now of course, in general nonlinear element can have arbitrary characteristics, but if it is a passive nonlinear element, it is going to have characteristics which are going to pass through the origin and be only in the first and third quadrants, it can be anything, some general f(v). So this is just an introduction to a two terminal nonlinear element, and we have seen the characteristic, we can describe it with an expression or we can draw a graph.