Analog Circuits
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Module - 01
Lecture – 12

We are now familiar with analysis of circuits containing one port nonlinear elements that is a two-terminal nonlinear element like a Diode. When we want to make something like an amplifier, it is preferable to have two ports; one port to feed the input and another one to take the output from. So we will look at two-port nonlinearities and the basic principle is exactly the same as what we did for single port nonlinearities. Just a minor extension and it could be further extended to higher number of ports.

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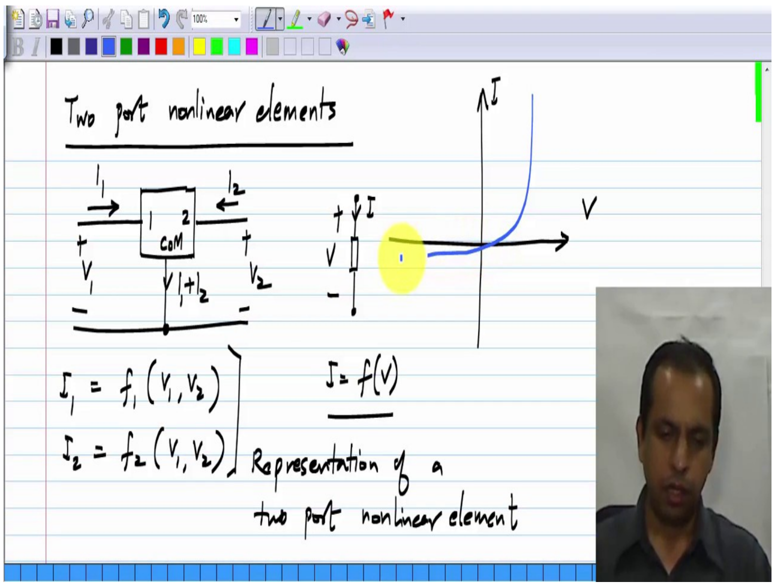

For simplicity, I will consider three terminal two-port that is there is a terminal which is common to the two sides, this is port one and that is port two so, it is denoted like that. So this common means that it is common to the two sides. Now as usual, we define voltages and current as per the passive sign convention, because it is a two-port, we have a two voltages V_1 and V_2; and currents in this direction I_1 and I_2. And just for comparison, I will show the single port or a two terminal nonlinearity here; we have a single voltage and a current. Now in case of a single port or a two terminal nonlinearity, we could define I as a function of voltage. Of course, we can also do the other way around define the voltage V as a function of current, but we choose this representation. And in this case, we will say that I_1 is some function of both V_1 and V_2; all it says is that the current going into this depends on both V_1 and V_2 that's all.

And similarly I_2 is another function in general it different one of V_1 and V_2.And by Kirchhoff's current law around this entire element we know that the current coming out of this has to be equal to $I_1 + I_2$. Again many other possibilities exist we could define the voltages as functions of currents or this voltage as the function of this current and that voltage and so on. You are familiar with linear two-port and all the possible two-port parameters which can be used to describe them; exactly the same thing can be done for nonlinear two-ports, the relationship will now be nonlinear that' all. So all the choices of dependent and independent variables you saw earlier can also be used here. We will use currents as functions of voltages, because the devices that we have now this is the most relevant representation. so that's the representation of a two port nonlinear element, two port nonlinearity.

Now for single port nonlinearity, we could give this expression; we could also draw a graph I versus V and for the particular example of the Diode, it happen to be like that, although we can have anything that we want.

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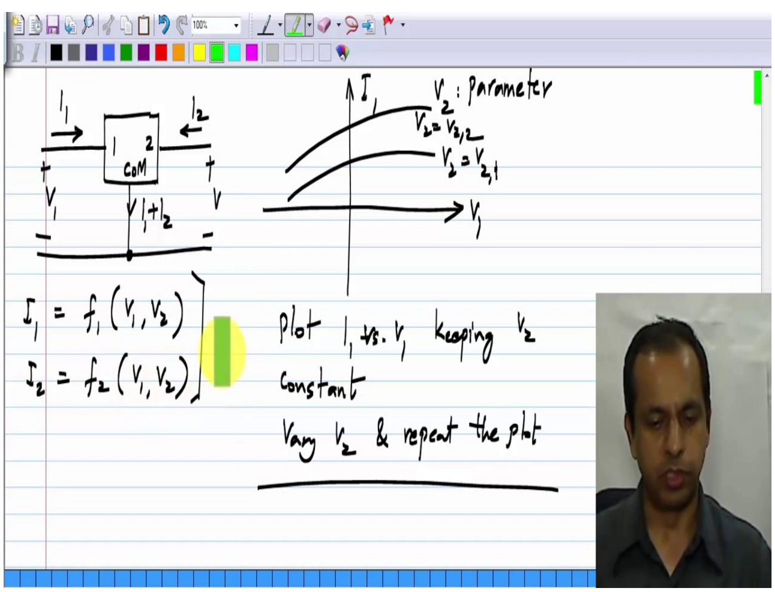

We can make a similar graphical representation for the two port. Now first of all, we have two quantities here, I_1 and I_2; and we have to draw graphs for both of them. Now I_1 is the function of two variables V_1 and V_2, and you can imagine a three dimensional graph that is you have I_1 as a function of V_1 and V_2 which are two dimensions by themselves. Basically a 3D plot but such a plot is very hard to read an interpret, so normally what you do is instead draw a number of two-dimensional graphs that is we plot I_1 versus V_1 with V_2 being constant. And you must be familiar with this; in this case, V_2 is called the parameter, and it can be anything. I will just show some arbitrary example, I_1 versus V_1 could be something like that for a particular value of V_2. For another value of V_2, it could be like that and so on.

So basically plot I_1 versus V_1 keeping V_2 constant so that's the two-dimensional plot, one variable versus another variable, and then vary V_2 and repeat the plot. So basically you get a family of curves. And exactly the same thing can be done, and clearly you can see that there are four possible plots – I_1 versus V_1 with V_2 being constant, I_1 versus V_2 with V_1 being constant, similarly I_2 versus V_1 with V_2 being constant and I_2 versus V_2 with V_1 being constant.

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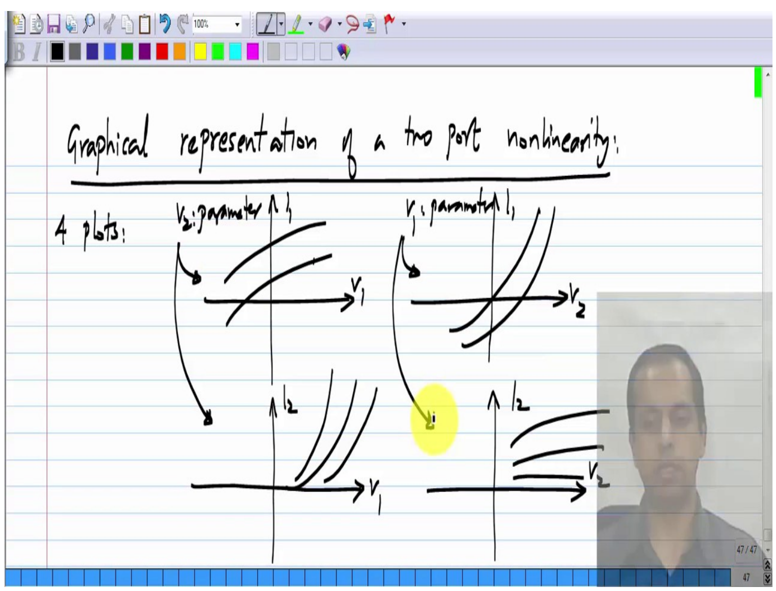

So, you will have I_1 versus V_1, I_1 versus V_2, I_2 versus V_1 and I_2 versus V_2,and they could be anything. I will just show some representative example. So in this plot, this plot for instance, V_2 is the parameter, so what it means is for each of these curves, V_2 is the constant; and for different curve, we choose different constant values of V_2.And similarly for this one, we will have V_1 as a parameter, and it could be anything, it could be something like that. And similarly I_2 versus V_1 could be something like that; and I_2 versus V_2 could be something like that. So V_2 is the parameter in these two plots, and V_1 is the parameter in those two plots. So this is how we can graphically shown the relationships - the current-voltage relationship of a nonlinear two port or any two port. We can also do it for a linear two port; in case of linear two port, these curves will be straight lines that's all. This is just like the I-V characteristic of a resistor which will be a straight line; I-V relationships of two port will also consists of four plots, but all plots will consist of straight lines.

Now when you have a nonlinear two port embedded in a circuit, you have to write the circuit equations and you will have nonlinear equations because of the nonlinear nature of the two port and then you have to solve the nonlinear equation numerically this is what we will have to do in order to solve for the operating point. And right now we have not consider any specific nonlinearity, but a general one in the form of f1 and f2,but you know that given the nature of the nonlinearity given the definition of f1 and f2, you can solve the nonlinear equation, so we won't deal with that aspect any further here. We will assume that you will be able to solve for the operating point. What we have more interested in is in the incremental analysis when you have a nonlinear two port, because when we vary the signal when we vary the voltages or currents in a circuit what happens is we treat them as increment over the operating point in order to do that we have to be able to do incremental analysis of nonlinear circuits. And it is only in the incremental sense that nonlinear device will have power gain.