Analog Electronic Circuits

Prof. Shanthi Pavan
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Madras

Lecture - 04
Incremental Model for Common Two-Terminal Elements Passive Two-Terminal Elements

Alright. So, now, let us take a library of components that we encounter in practice and draw their small signal equivalents, right. So, that next time you do not have to keep doing these derivations all over again, when you look at the element you know what to do to get the small signal equivalents? What is, basically what it means what our theory has told us is that take every element and replace it by its.

Student: Small signal equivalent.

Small signal equivalent, correct.

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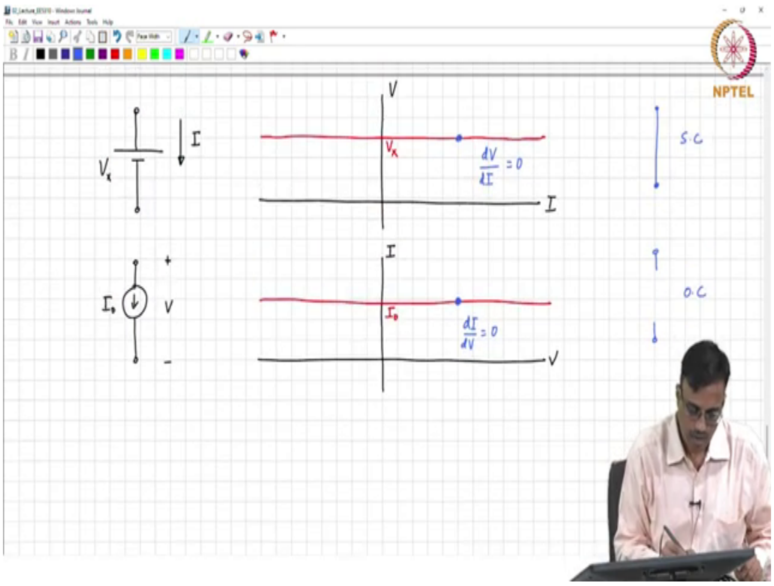

So, let us start. The first element that I would like to start with is the voltage source. Now, is this element a linear element or a non-linear element?

So, this is some voltage V_x, right. What is the I-V characteristic of a of a voltage source? What will we plot on the x axis and what will we plot on the y axis?

If I gave this to you in a box with two terminals and asked you to plot its I-V characteristics, what will you do?

So, on the vertical axis you will plot the.

Student: voltage.

Yeah, you will plot the voltage and on the x axis you will plot the current, ok. So, I will call this V. And what will I see?

Student: A straight line.

A straight line.

Student: a horizontal line.

A horizontal line, ok. And why is this a non-linear element?

Student: It does not through the origin.

It does not pass through the origin, correct, ok. So, what is the small signal equivalent? At any operating point, so let us say I pick this operating point. If I find dV/dI at that operating point, what will I get?

Student: 0.

You get 0. So, what is the small signal equivalent? It is a.

Student: Short circuit.

Short circuit, ok. And what is the definition of small signal? Yesterday, we saw that the definition of small signal depends on the operating point as well as the function itself. What comment can we make about the what constitutes a small signal? This is a non-linear element, we all agree.

Student: Agree.

So, there must be a definition for what constitutes a small signal, right? What signal constitutes a small signal or in other words how large an excitation can I put around the operating point, and expect that the small signal approximation is valid.

Student: criteria is satisfied.

You have the characteristic, you can check.

Pardon.

Yeah, in this particular case.

Student: Straight line.

It is a straight line. So, the first derivative will approximate it.

Anywhere, right and therefore, any excitation constitutes a.

Student: small signal.

Small signal. Is that clear.

Right. Here is an example where a small signal necessarily need not be small the way you imagine it, right. Any signal constitutes a small signal, you understand, alright.

Next thing I am going to do is to draw basically a current source. Let us say this is the voltage across the current source. So, when I draw the IV characteristic, how will this look like? I have plot the voltage and measure the current. And what will it be?

Student: Constant.

It will be a constant with an intercept of I_0. And what comment can we make about the small signal equivalent?

At any operating point we see that dV/dI = 0, this is dI/dV = 0. So, what comment can we make?

It is an.

Student: Open circuit.

Open circuit. And what comment can we make about the validity of the small signal approximation? In any voltage you put in constitutes a, any change in voltage constitutes a.

Student: Small signal.

Small signal. Does that make sense? Alright.

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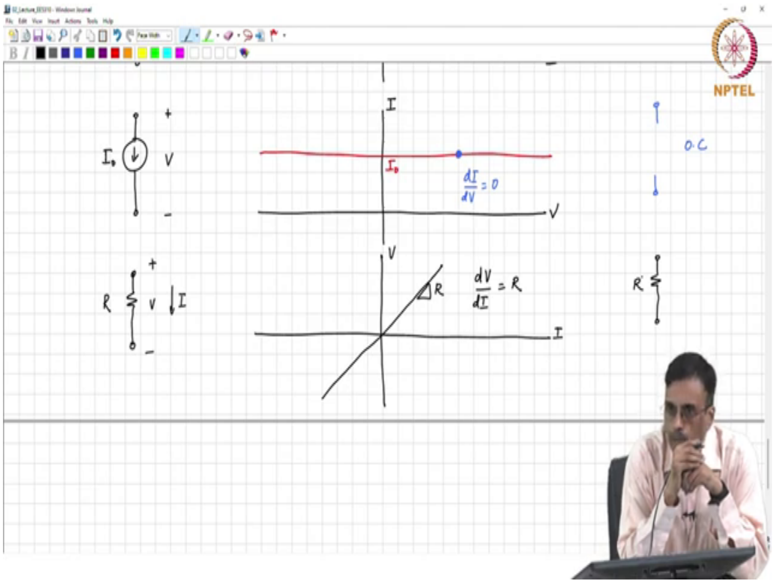

The next thing is a resistor. So, this is V, this is I, if I plot V versus I, what do we get?

Student: a straight line.

a straight line that passes through the origin. The slope is.

Student: R.

R. So, dV/dI = R. So, the small signal equivalent also happens to be the same as the element itself. That makes sense, because well the element was linear to begin with, right. And again, any signal constitutes a small signal, alright.

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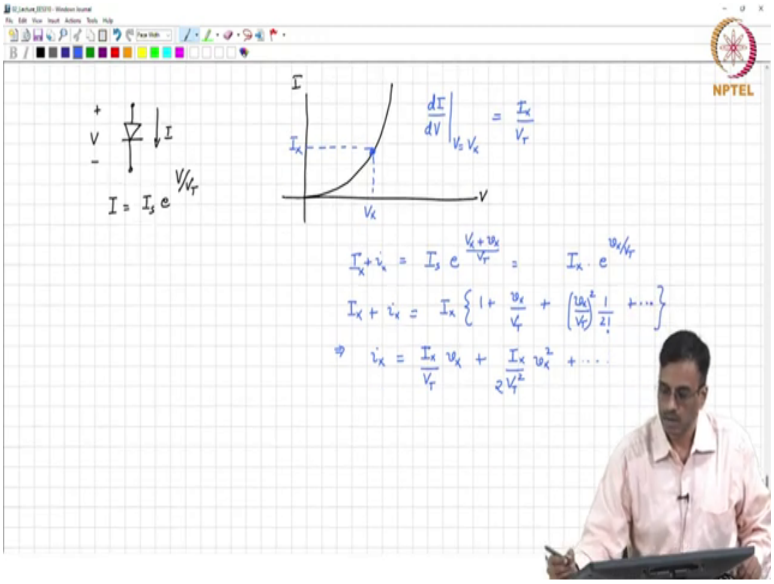

Now, the next thing I would like to do is basically let us do a diode in forward bias. So, this is V, this is I, and as we seen in this forward bias region I is,

$$I = I_s e^{\frac{V}{V_T}}$$

Ok. I am neglecting that I_s term.

So, what comment can you make about the picture? In forward bias, if I plot I on the y axis and V on the x axis, you will get something like this. And at the operating point what comment can we make? dI/dV is nothing but at an operating point say V_x, what comment can we make? This is nothing, but I_x over V_T and in given V_x you can find I_x, alright.

So, the operating point is basically, this combination of V_x, I_x is basically what forms the operating point. I have given one you can find the other because you know the curve, alright. And what constitutes small signals?

Let us do that. So, I as you know is,

$$I + i = I_s e^{\frac{V_x + v_x}{V_T}}$$

which is nothing, but,

$$I + i = I_s e^{\frac{V_x+v_x}{V_T}} = I_s e^{\frac{V_x}{V_T}} . e^{\frac{v_x}{V_T}}$$

This of course, is nothing but $I_x e^{\frac{v_x}{V_T}}$. So,

$$I_x + i_x = I_x \left\{ 1 + \frac{v_x}{V_T} + \left(\frac{v_x}{V_T}\right)^2 \frac{1}{2!} + \dots \right\}$$

Ok. Which means what? i_x is nothing but,

$$i_x = \frac{I_x}{V_T} v_x + \frac{I_x}{2V_T^2} v_x^2 + \dots.$$

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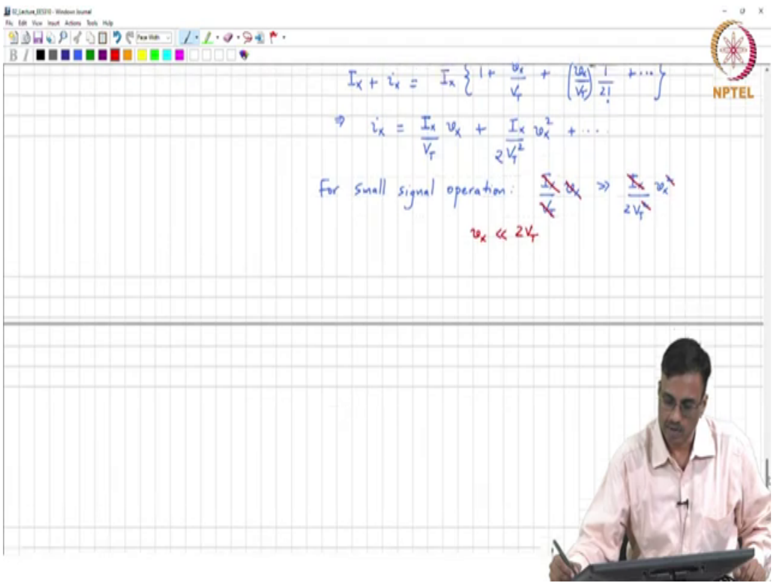

So, what comment can we make for small signal operation?

For small signal operation

$$\frac{I_x}{V_T} v_x \gg \frac{I_x}{2V_T^2} v_x^2$$

Which basically means that the i_x goes away, one V_T goes away, one v_x goes away, which means $v_x << 2 V_T$. Does it make sense? Right. So, that is what it means to say.

Student: Small signal.

Small signal, ok.

The next thing I would like to draw attention to, next element I would like to consider is the following. So, we already saw that the small signal equivalent of a voltage source or equivalently a battery is simply a short circuit, ok.

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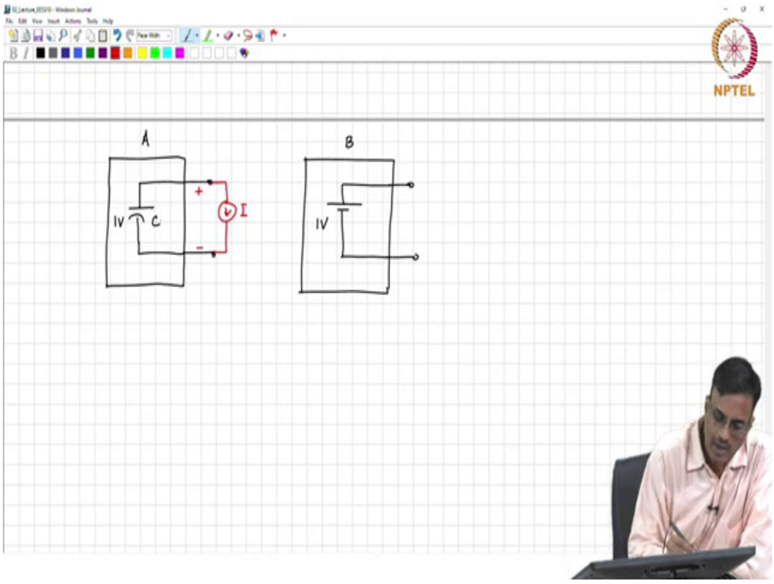

Now, let me ask you a question therefore, lead you to the answer. So, let us say I have a black box. And I have black box A, where I have a capacitor C, charged to a voltage of 1 volt. This is box A. Now, I have box B, where I have a battery which is charge to which is whose voltage is 1 volt. How will you figure out which one contains the capacitor and which one contains the battery?

Student: Connect a load.

Pardon.

Student: Connect a load.

You connect a load and what happens?

Student: The voltage will reduce.

Yeah. So, well the idea is that well if you connect a resistor across both the across both the boxes then in one.

Student: The voltage will decrease.

The voltage will decrease, in the other.

Student: will remain same.

The voltage will remain the.

Student: Same.

Same, ok. And why will the voltage here decrease?

Student: Draws some current.

Let us say you draw some current I, then the voltage here is going to be some C times 1 volt was the charge on that capacitor. And as you keep drawing current out that basically means you are removing charge and therefore, the voltage across the capacitor plate is reduced, ok.

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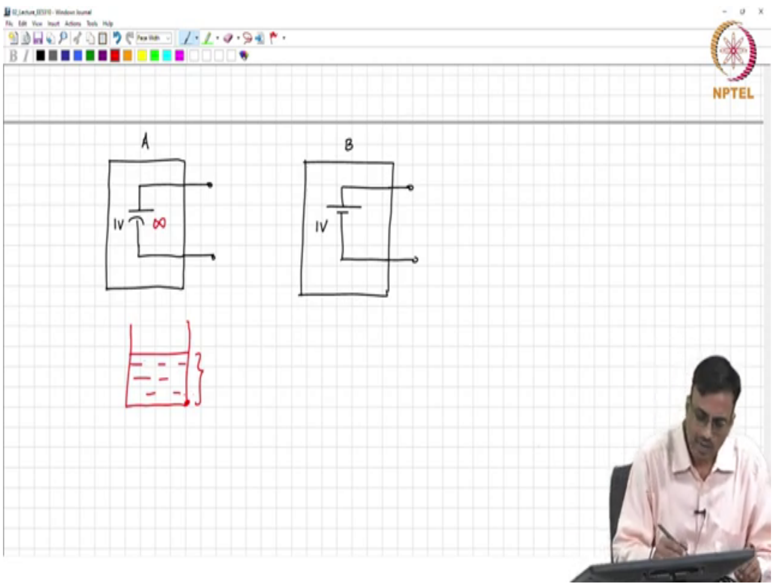

Now, if I make this capacitor larger and larger, let us say in the limit if I make this capacitance infinite, what comment can you make?

Student: It holds the infinite charge.

Yeah, ok, it holds infinite charge. So, what comment can you make therefore? Can you distinguish between boxes A and B now?

Now, the question is the capacitance is infinite, but charged to 1 volt, ok. Now can you make a distinction between boxes A and B?

Student: No.

No. Why?

Student: dy/dt will be tend to 0.

Yeah. So, this is infinite charge, right and therefore, if you keep drawing charge, it does not change the voltage across the capacitor, right. Please remember that capacitor is nothing but a bucket which holds.

Student: Charge.

Charge, right. So, if you have a bucket like this and then think of it as a as water inside, the area of the bucket is analogous to.

Student: Capacitance.

The area of the bucket.

Student: Capacitance.

Is the capacitance. The height of the water inside the bucket is equivalent to.

Student: voltage.

Voltage. And the volume of water inside the bucket is equivalent to.

Student: Charge.

Charge, right. If you have a wider bucket, for this if you pour the same amount of charge, what comment can you make?

Student: height will reduce.

The height will reduce.

So, basically for the same charge if you have a larger capacitance the voltage will be small, correct. And if you draw a water out of the; out of the bucket by making a hole here for instance, then if you have a finite bucket then if water keeps flowing out.

Student: The voltage will reduce.

The voltage will fall, right. Now, if you have an infinite bucket like the sea, right and you go on removing water from it, if you leak water from it, what will happen?

Student: No change.

The level of the sea is not going to change, correct, ok. So, likewise an infinite capacitor charge to voltage V is indistinguishable from a from a ideal voltage source which has the same voltage. Does it make sense? Ok.

So, now, with this background can you tell me what the incremental equivalent of between these two terminals is?

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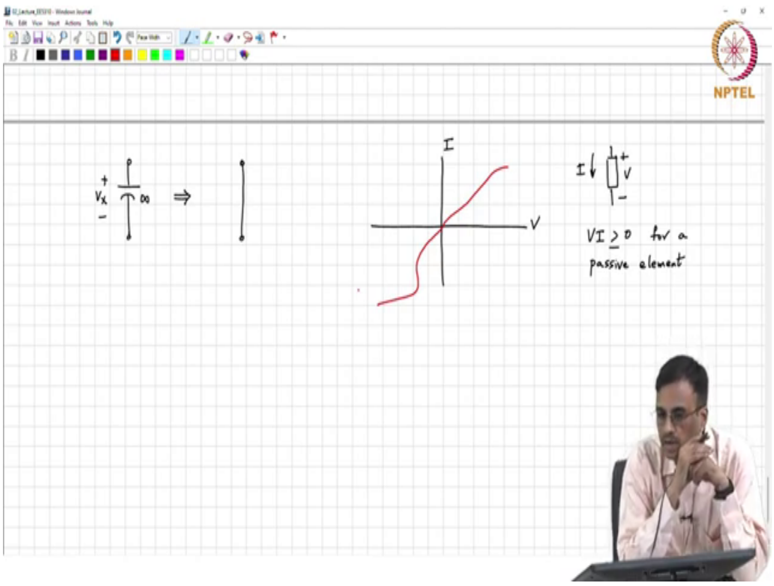

So, an infinite capacitor charged to a voltage V_x.

What is this?

Student: Short circuit.

It is a short circuit, ok. And you may be wondering why this makes sense at this point in time, but going forward we will use this observation, ok.

So, to summarize our discussion so far, we have looked at what happens when you have a non-linear network which is general and we concluded that finding the operating point has to be done numerically.

Having found the operating point a change in the branch voltages and the branch currents can be related to each other using a linear network. And it is not necessary to write out the equation, subtract them and then come up with the network after all, right.

We saw that you can simply looking at the original network, one can draw the incremental equivalent by replacing every element in the network by its.

Student: Small signal.

Small signal equivalent where the small signal equivalent is found from the characteristics of the non-linear element as well as the.

Student: Quiescent operating point.

Quiescent operating point, ok. And then we saw some commonly used elements that we will come across in our examples. And basically, found their small signal equivalents, ok.

Now, another quick piece of information, right. Any two-terminal element without any energy source in it is called a passive element, right. Does passive mean linear?

Passive, passivity and linearity have nothing to do with each other. A passive element is simply one which cannot generate energy, ok.

So, if you take a memoryless passive element and if you plot its IV characteristics what comment can you, I mean remember that the convention is always that if you have a voltage here, the current must flow in this direction. So, what comment can we make about?

Student: V x I.

Pardon.

Student: V x I.

V x I must be positive for a passive element.

Must be greater than or equal to 0 for a passive element and consequently.

The characteristic can only lie in the.

Student: First and third quadrant.

First and third quadrant, ok. So, the moment the characteristic goes into the second and fourth that there is some source of energy inside, ok. So, that basically finishes the discussion on a non-linear element, I mean a basic discussion or review of networks with non-linear elements.