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

Lecture - 08
IV Characteristics of a Nonlinear 2 - Port with Incremental Gain

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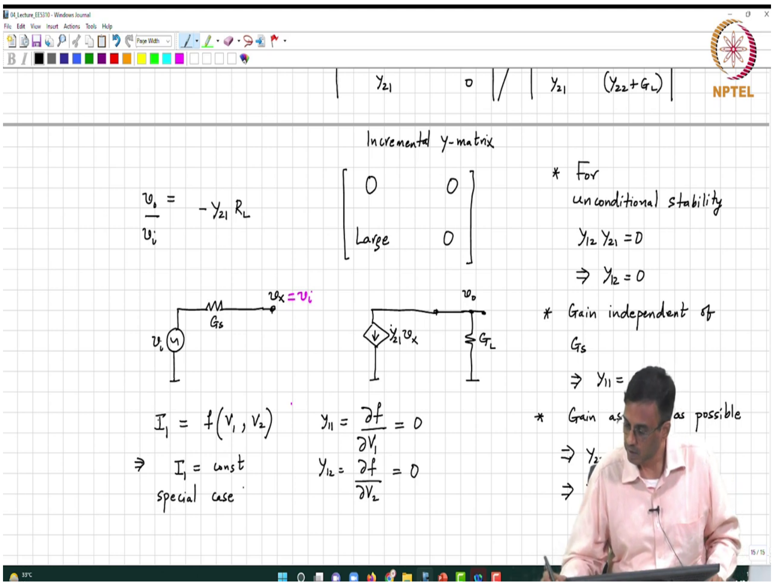

So far, we have taken some two port and then found the formula for its incremental Y parameters. Now we are trying to figure out what the characteristics of the device must be, of that box must be, the IV characteristics must be, so that the incremental parameters look like this. Does it make sense, right?

So, in other words, remember that if you had a general non-linear two port, the current in port 1 was some function $f(V_1,V_2)$, what we are saying now is that and what was Y_{11}?

$$Y_{11} = \frac{\partial f}{\partial V_1} = 0$$

And we want that to be equal to what do you want that to be?

Students: 0.

0. And similarly Y_{12} which is,

$$Y_{12} = \frac{\partial f}{\partial V_2} = 0$$

must also be equal to 0, correct. So, what is one function that satisfies this? Well, I_1 is a constant and what is the simplest constant that you can choose? Actually, it can be any constant, but specific special case is when I_1 = 0, ok. It is just a special case. It could be any constant, alright?

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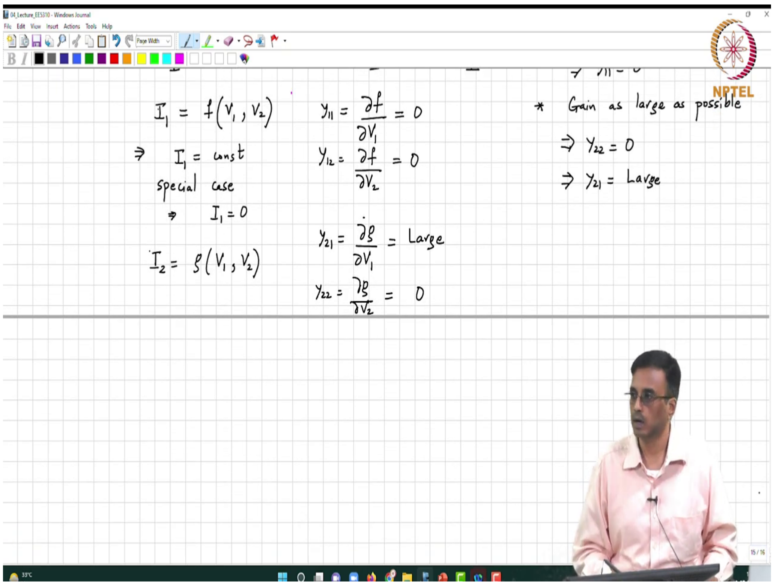

So, what comment can you make about the input characteristics?

I mean it is either a constant, and the constant can be 0. I mean there is no fun in drawing a constant straight line. So, I mean there is no point in drawing the input characteristics, right? I mean it is a constant, I hope that you know after people as old as us should be able to imagine a constant without having to show a picture, correct, ok.

Now, what is Y_{21}? Remember some other non-linear function g (V_1,V_2), alright? And so, Y_{21} is nothing,

$$Y_{21} = \frac{\partial g}{\partial V_1} = large$$

We want this to be?

Student: Large.

Large. Aand Y_{22} which is,

$$Y_{22} = \frac{\partial g}{\partial V_2} = 0$$

must be 0, alright? So, what comment can we make about the function of.

Students: V_1

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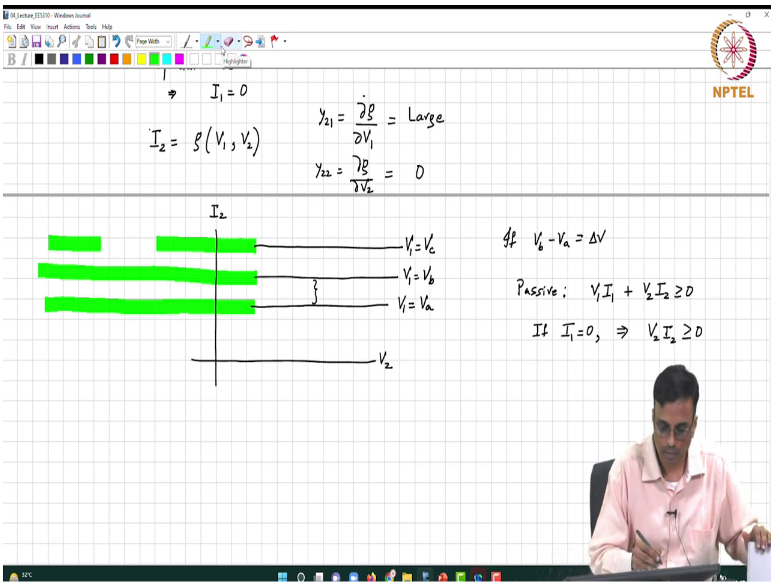

Very good. So, now, we should draw the output characteristics, ok. And the output characteristics remind me again what are we trying to draw?

I_2 on the.

Students: y-axis.

y axis and V_2 on the.

Students: x axis.

x-axis. It is telling us that the incremental $Y_{22} = 0$. So, for a given value of V_1, what comment can we make about the output characteristic? What are the output characteristics? I_2 versus V_2 for? It is a family of curves each curve is for a specific value of, Students: V_1.

V_1. And we vary V_2 and measure.

Students: I_2.

I_2. So, for a specific value of V_1, if the incremental $Y_{22} = 0$, what does it mean?

The output current does not change if you change the output voltage, ok. So, basically I_2 is independent of V_2, ok. This is for some specific value of V_1. Let us call it V_a.

For another value V_b of V_1what do we expect to see?

Students: straight line.

Another straight line which is parallel to this line, ok. Let me call that and for yet another V_1 which is equal to V_c you see yet another parallel, correct? Ok, now, if the difference between V_a and V_b was very very small, where again we will come back later and qualify what that meaning of small is, then what comment can you make about the spacing between these lines. So, in other words if V_b - V_a was a small signal, what does the distance between these two parallel lines? what does that quantify?

Students: Y_{21} x ΔV.

Is that clear? So, as you keep changing the absolute voltage at port 1, you get a family of curves in the output characteristic and ideally for a small change in V_1, you would like this spacing between the characteristics to be.

Students: Very large.

Very large and that indicates a large?

Students: Y_2.

Y_2, is that clear? Alright?

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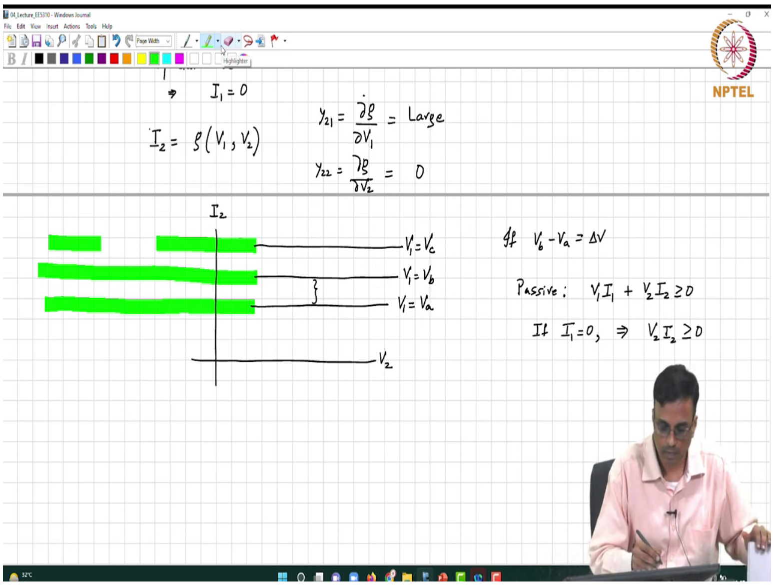

Now, I do not know if you remember, but what did we say about this box I mean where are the energy sources are they inside the box or are they outside the box?

Students: Outside the box.

They are outside the box. So, this box is a?

Students: Passive.

Is passive, correct. So, it cannot be generating any energy. So, what must be satisfied? What are the constraints if that box is passive, what comment can you make about the port voltages and port currents?

$V_1 I_1 + V_2 I_2 \geq 0$. In the special case that, I_1 is 0, what comment can we make?

Students: $V_2 I_2$.

So, $V_2 I_2 \geq 0$. In other words, the output characteristics, must lie in the?

Students: First.

First and?

Students: Third quadrant.

Third quadrant, ok. So, now, we are looking at the first quadrant, alright? So, now, can these lines extend? We said they have to be parallel to the x-axis, correct? Can they extend like this into the second quadrant? Why?

If they extended into the second quadrant, then the device would become.

Students: Active.

Active, which means there is a source of energy inside which basically we said is not the case. So, since this device this box is passive it follows that these lines cannot remain parallel to the x-axis for all values of V_2, right? They can only be in the second quadrant or the I mean in the either in the.

The characteristics can only be in the first quadrant or the.

Students: Third quadrant.

Third quadrant, right? and they cannot be parallel to the x-axis for all values of V_2. So, these characteristic therefore, will have to dive into the?

Students: Third quadrant.

Third quadrant and what do you think a reasonable way of doing that is?

Well, you know one way of that happening is basically doing something like this, right?

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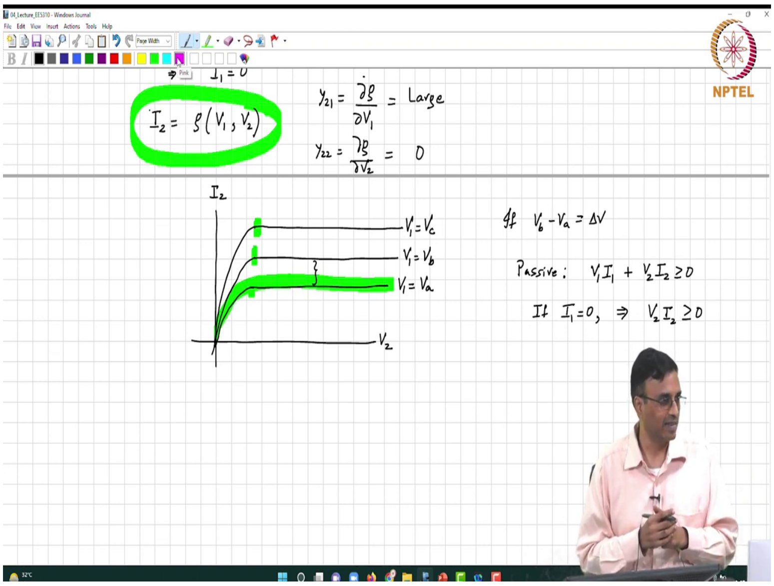

And, the same thing holds for all this characteristic, correct? And, it is not necessary that I mean this knee point is the same for all curves, it is just something that I have drawn here right?, but for a given V_1 eventually the characteristic has to dive into the third quadrant, right?, ok.

So, if you want to have any amplifying two port, the characteristics that you see must look like this, ok. And, all that we have used this. I mean this does not depend on whether there are electrons, whether they are holes whether there is I do not know I mean there is molten ion inside the device, ok. This is if we want to have a device or a two port that amplifies, these will be the characteristics.

And, this just is plain conservation of energy and basic arguments are enough to establish that these must be the characteristics. Does it make sense, right?

Now, that we know these characteristics, we go to our device colleagues and say you know can you make device like this and they say sure enough, and you know not merely one kind we can make all kinds of devices. All of them, but all of them will eventually end up having characteristics like this, right? How many of you have seen characteristics like this before?

Students: Transistor.

Transistor, right? and how many kinds of transistors are you familiar with?

You are familiar with the bipolar junction transistor, you are also familiar with the?

Students: MOS transistor.

MOS transistor, right? and you know, I do not know how many of you are familiar with the JFET, heard of something?

Students: Yes, sir.

Yeah and its characteristics also look similar, right? There is also transistors you can make with gallium arsenide right? it is called the GaAsFET, right? That also has got characteristics which look like this and forget about silicon or semiconductors like you know long back before even before your grandfathers were born, there was an active device called the vacuum tube, right?

The characteristics of vacuum tube also look like this, except that those you know those variables are called something else there. One is called plate voltage something, right?, but the output characteristics of that vacuum tube also look like this and the vacuum tube has got nothing to do with you know diffusion, drift all that stuff. It is pretty much you have a plate you heat the plate and then you boil electrons off, the plate then they go from place A to place B, ok.

So, the physical phenomena involved in in carrier transport are extremely divorced from what you can see in semiconductors, right? and even in semiconductor devices you know all of you probably know from your device classes that the bipolar transistor for instance you know it operates its a is it a diffusion device or a drift device?

Student: Diffusion.

It is a diffusion device. MOSFET on the other hand is a?

Student: Drift.

Drift device, right? So, the physics of operation of the two devices are completely different, right? Bipolar is something you know you inject some carriers into the base and then some recombination all sorts of fancy stuff whereas, MOSFET is you know you apply a voltage electricity, attract some electrons to the interface and then apply voltage across the drain and source, right?

But, you know if you look at this, you can see that all that stuff they are all details which are irrelevant as far as the as the basic box is concerned. Tomorrow, I mean you know 10 years or 15 years from now if some new device is invented with quantum, tunneling this thing that thing all that you do not have to worry because?

The characteristics will have to be something like this, right? The only thing that will change is the formula that what is the only thing that is left to be described here?

I mean what the exact function that does this is the only thing that remains to be described and that is going to be a function of how you make the device you know whether you make it with semiconductors or whether you make it with cement or whether you make it plastic you know it does not matter. That is only going to alter the nature of that equation, but the fundamental nature of these characteristics are going to be the same right? ok.

Which is why to be a good circuit designer you really do not need to it is not as if you know you need to go deep into you know how electrons are jumping how for you know Fermi levels energy density you know all that stuff. That is all good stuff that you know is fun stuff to learn, but that is got nothing to do with your competence as a circuit design, right?

It is like a civil engineer, right? I mean this it is true that the building is made of bricks, correct? And it is made its got iron in it, right? to hold the structure. But, I mean you know as a civil engineer do I really care whether the iron was treated at you know was brought from Bihar or whether its bought from Germany or whether it is heated in blast furnace or whatever I do not know. I do not care, right? as long as the iron does not you know bend over and break ok, I am good to go, alright.

Same thing with the brick I do not need to know the details of it was boiled at this I mean it was cured at this temperature it was it was mined at this place all that stuff they are all irrelevant details. All that I need to know is will you know how heavy the brick is, will it be able to withstand this load and all that stuff, right?

So, as long as the input output characteristics of the brick is known, the details of you know the chemical phenomena or the physical phenomena occurring inside are completely irrelevant to me. Likewise, if we know the characteristics of the transistor, I mean of this of this box which you know is the transistor from an input output terminal point of view in other words if we know the expression for this current, this I_2 basically the only thing that we need to know is this function g, right?

Once you know that function g, the rest of it is you know is not allowed, right? whether it is diffusion, drift, you know tunneling, this thing, quantum, you know whatever right? none of that stuff is relevant as a circuit design. If you trying to build devices of course, that is the bread and butter, but if you are trying to build circuits you do not need to worry about it ok, alright.

So, having said that, so, we go to the device folks and basically say, well can you give us a device like this and they say yeah, sure. Here is one possible device. And I mean many possible devices and then you know depending on economics and all that you know we pick one device and use that in our example to illustrate circuit design, right? The examples with minor modifications would be applicable to any device, alright?