Analog Electronic Circuits
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Lecture - 27
The VCVS Continued

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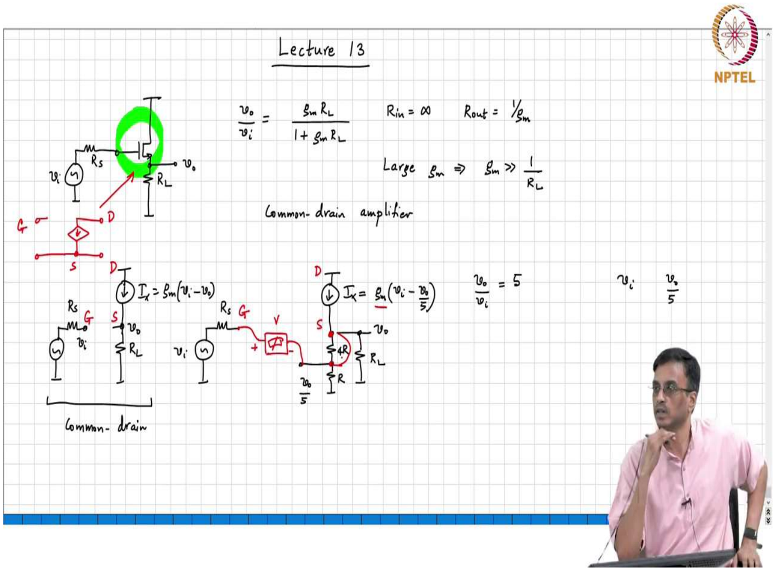

Ok, good morning, everybody, and welcome to Analog Electronic Circuits. This is lecture 13. In the last class, we started looking at how to make the various control sources using transistors in such a way that the properties of the control source, such as input impedance, output impedance, gain, trans impedance, trans conductance, etcetera, remain largely independent of the properties of the transistor.

So, we started off our journey by deriving the incremental voltage control voltage source with a gain of 1 and we said that the incremental equivalent basically looks like this. This is v_o. And the incremental gain v_o/v_i is nothing but $g_m R_L /(1 + g_m R_L)$. The input impedance is infinite owing to the 0 current nature of the MOSFET the output resistance is $1 /g_m$.

And the discussion yesterday also indicated that you know if g_m of course, tends to infinity the incremental gain will tend to 1 and that is the ideal VCVS that we wanted. In practice of course, g_m will not tend to infinity all that we can say is that we make it large and like everything else large is a context dependent thing and in this context a large g_m is 1 where large g_m means that g_m is much much larger than $1 / R_L$, alright. And towards the end of the last class we said ok, well this attempts this circuit basically called the common drain amplifier. Because the drain in the incremental network is common to both the input the source as well as the?

Student: Load.

As well as the load. Now, before closing yesterday we were also looking at you know if at all it is possible to realize a voltage-controlled voltage source with a gain greater than 1. So, we arbitrarily said 5 and the principle you know again would be the same that we have used earlier. So, we want v_o / v_i = 5 and how would we do this if we use negative feedback. We would like to compare this to v_i and this is R_S. So, we would like to compare v_o versus v_i by v_i with v_o / 5. Why cannot I compare v_i with I mean 5 v_i with v_o?

Yeah, well if I had 5 you know I mean I am not I am not asking you why we are comparing v_o with 5 v_i not v_i with 5 v_o. You understand? So, why do you not compare v_o with 5 v_i? Mathematically that seems just as reasonable. Abhishek, why are we not able to compare v_o with 5 v_i right, why are we comparing with v_i with 5, I mean v_o / 5?

Listen to the question and answer the answer. Give me the answer to the question that I asked, right? Why are we saying we are comparing v_i with v_o / 5. We could as well compare 5 v_i with v_o. Why are we not doing that?

If you have to compare 5 v_i with v_o, this is what I mean. Well, I mean, you know where you're going to get that?

Student: 5 v_i.

5 v_i that is basically the answer. So, we are comparing v_i with v_o / 5. So, to generate v_o / 5 one way of doing it is to use a potential divider. So, let us say this is R and this is some 4 R this will give you v_o / 5. And where are we going to put the voltmeter? We are going to put the voltmeter between these two terminals, alright. And where are we going to inject current?

We are going to inject the current I x here which is dependent on v_i minus.

v_o /5 the constant of proportionality must have?

Student: Trans conductance.

Trans conductance, what must be the sign plus or minus?

Student: Plus.

Plus. Why? The only thing that you can do is adjust v_o, right. So, should the sign be plus or minus?

Student: Plus.

If v_i minus v_o /5 is positive it means that v_o is not enough and must be?

Student: Increased.

Increased. So, that I_x must be positive. Does that make sense to people?

Student: Yes.

Alright. So, that is what I mean. So, what must be the value of g_m? What would you like a g_m to be? Ideally it must be?

Student: Infinite.

Infinite, because even for a small difference between v_i and $v_o/5$ you must go and kick that node so hard that the two output voltages would be the same, correct. Now with all this background can you tell me if it is possible to realize this using a single transistor? So, this again you see that this is a what kind of control source is that?

Student: Voltage control Current source.

Even when we looked at the common drain amplifier we needed a voltage control current source. So, do you think it should be? I mean do you think it is possible to realize a gain of 5 using a single transistor? What is the difference that you see between this voltage control current source here and that in the common drain amplifier?

Look at it carefully and maybe I will draw the picture of the common drain amplifier just so that it helps you. Everything looks almost exactly the same. This is g_m (v_i -v_o) and this is R_L, alright. So, this is v_i this is v_o. And this is the common drain amplifier, ok. Stare at this picture, how did we choose the terminals of the transistor?

Student: Gate source and drain.

Gate.

Student: v_o is a source.

v_o is a source and this is the drain, ok, alright. And why? Because the transistor is incrementally equivalent to this gate, source and drain, alright. Now staring at these pictures can you tell me whether it is possible to realize a gain of 5. It is possible, ok. If it is possible then tell me which is the which must be the source, which must be the drain of, which must be the gate? R_S that is the gate ok, alright, but then it seems like the transistor this g_m is basically comparing which two voltages?

Student: v_i and v_o / 5.

No, it should be comparing v_i with v_o / 5, but if this is the source what will it compare what is that?

Student: It will compare v_i and v_o / 5.

It will compare v_i and v_o?

Student: v_o / 5.

Not v_o / 5. So, I mean ideally we would have liked the source to be at R.

Student: Yes sir.

But then where are you going to connect the load resistor then. If you connect the load resistance here then that becomes? That becomes the output, Yes. Two people said they could not do it. I mean they said it is possible they could not do it. So, the answer is 'not possible'. But why is it not possible to see now?

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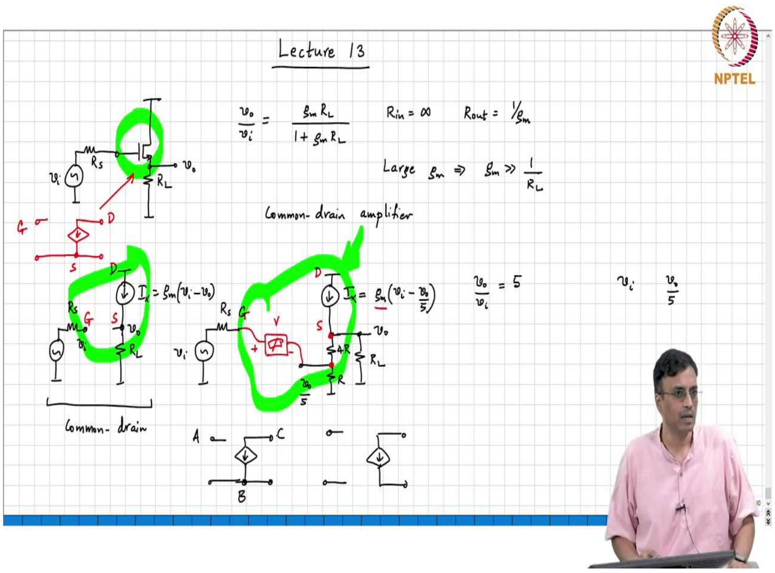

Now my first answer to everything is yes, it is possible, right, ok. And figure it out if it is not possible then you learned something, ok. There is no point in being defeated resisting saying nothing is not possible, you understand? Right. Then you never progress, ok.

So, we said yes, it is possible. We looked at it and then you know oops you know maybe perhaps it is not possible after all right, alright. Now, why is it not possible? Can you now take a look at these two pictures and tell me why it is not possible? Ok, alright, but what is the root cause?

Student: Source and the output voltage.

Exactly in other words realizing this is not a kind of control source needs a voltage controlled current source where there is no common terminal between the input and the output. What is the difference between this volt I mean this is also voltage controlled current source correct. This is also a voltage controlled current source, correct. What is the difference between the two? This voltage controlled current source on the left side is like this voltage controlled current source on the right side is like this, right.

So, this was a terminal A terminal B terminal C, you can see that in general a voltage controlled current source must have independent controlling voltages and is basically a four I mean a generic truly general voltage controlled current source is a how many terminal elements?

Student: Four terminals.

It is a?

Student: Four terminals.

Four terminals, right. But what is the transistor? The transistor operating in its saturation is a voltage controlled current source but?

Student: Three terminals.

It is a?

Student: Three terminals.

Three terminal elements where you know one terminal is common to both the?

Student: Input and Output.

Do you understand? So, do you think that is more restrictive than having a generic VCCS or is it less restrictive?

Student: Less restrictive.

Obviously if you take two terminals and join them together, right. It is like saying you know I mean technically your two hands and your two feet can go in you know any direction, right. Now if I take your hand and tie it to your leg. Obviously, there are some things that you can do with all four of our limbs going in arbitrary directions right, when compared to if you tie one of your legs to one of your hands, correct. So, obviously, it is the fact that you shared one of the terminals between the input and the output port of the controlled source is more.

Student: Restrictive.

Restrictive. So, it is reasonable that you cannot do everything that you can do with a generic completely unrestricted voltage controlled current source. So, because the gain of greater than 1 needs the input port of the voltage controlled current source to have different terminals when compared to if you want to gain greater than 1 the two input terminals of the voltage controlled current source must be separate from the two output terminals, correct, ok. And that is not possible with a single transistor. So, it is not possible with a single transistor it is not possible to realize a gain greater than can somebody guess you know if I say it is possible to do what you think you can do? Can you think of any other passive element you can put to make sure that that is possible? Transform, right.

So, if you put a I mean the problem with the voltage divider is that it is giving you a you know the v_o / 5 at a different terminal if you want v_o / 5 at that you know. So, basically one way of fixing that problem would be to do this, right?

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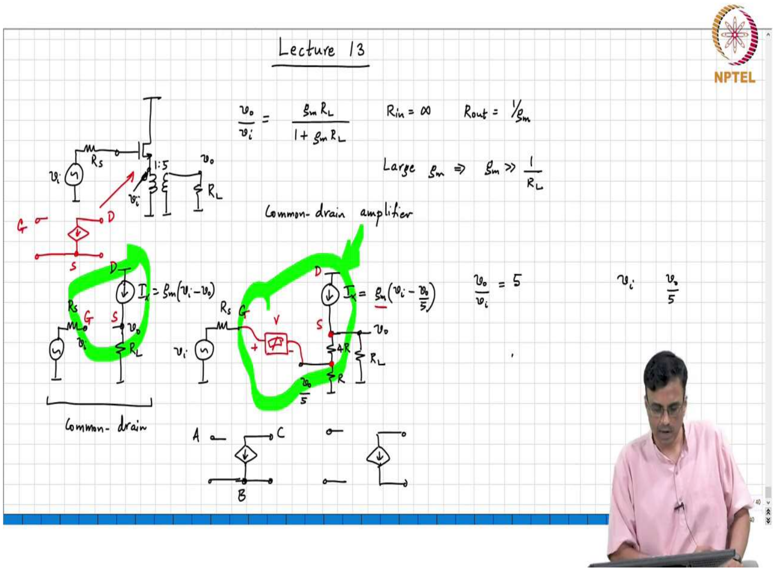

And this is a 1 : 5 transformer. So, by the definition of the transformer if this is v_o what is the input?

Student: v_o /5.

You compare finally, this is still going to be equal to what is that still going to be? With g_m tends to infinity. What is that node voltage going to be?

Student: It will be v_i.

It will be v_i, ok. So, that is not changing. The transformer is simply taking that voltage and making it, but I mean a transformer is basically problematic to realize. So, but in principle that is you know one way around anyway. So, that completes our discussion about the voltage-controlled voltage source. So, which is what I mean. So, in your prior classes you have seen the common drain amplifier correct, and it is a voltage-controlled voltage source.

But you might have wondered why the gain is only I mean if it is possible to realize gain greater than 1 with a single transistor it is not possible. And the fundamental reason is that while it is true that the transistor is a voltage controlled current source it is not a truly generic voltage controlled current source in the sense that the input and the output terminals are there is one shared terminal which restricts the kind of circuits that you can realize.