Analog Electronic Circuits
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Lecture - 28
Introducing the Current-Controlled Voltage Source

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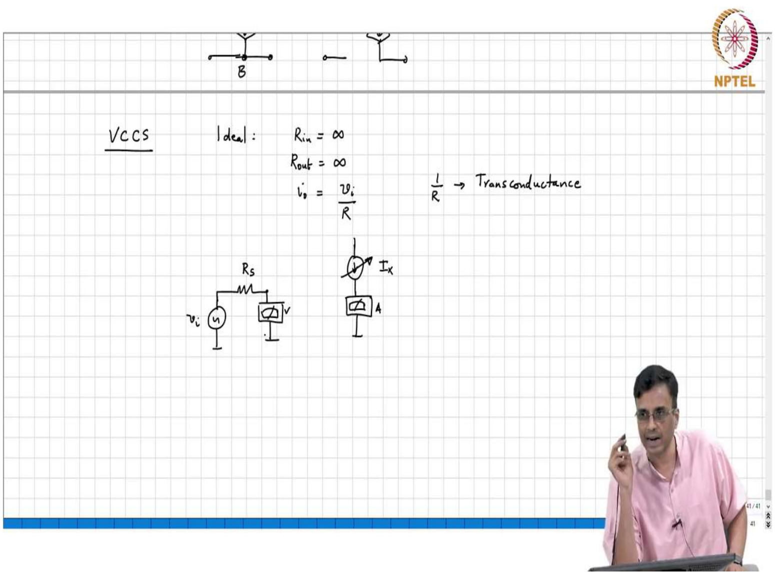

Alright so, the next Controlled Source is the Voltage Controlled Current Source, ok. And ideally quick what is the input impedance of a voltage controlled current source.

Infinite. R_{out}?

Student: Infinite.

Infinite, ok. And the only other parameter that you need to define is the Trans conductance, right. So, i_o is nothing, but some v_i/R. So, 1/R is often called the Trans conductance. So, again let us start using first principles. So, we want to generate a current i_o which is controlled by this voltage v_i. So, we have some source v_i possibly with some resistance R_S, ok.

What all would we need to realize a current which is if you are in the lab and if you want to realize a current which is v_i/R what will you do? You need a very I mean you need a current. So, does it make sense to use a variable voltage source or a variable current source?

Student: Variable Current.

We have a variable current source, ok, alright. So, this is my variable current source, alright. So, what? We have this variable current source and we have the input voltage. So, what are we going to do?

Student: Compare

Ok. So, one way of doing this is to put an ammeter here and that will measure the output current I_X you compare it. So, you need to put a voltmeter here. You know what we are going to do? We have a voltmeter, we have an ammeter, what are you going to do now? Ok. So, now you need a calculator to divide the voltmeter reading by?

Student: R.

R because you cannot compare volts with amps it is like comparing apples with oranges, correct. So, what are we going to do? We need a calculator to now do v/R, ok. Can you know somebody more come up with a more practical approach where we get it from 2 meters and a calculator. Well, the suggestion is ok, that is the earlier scheme team seems too complicated, ok.

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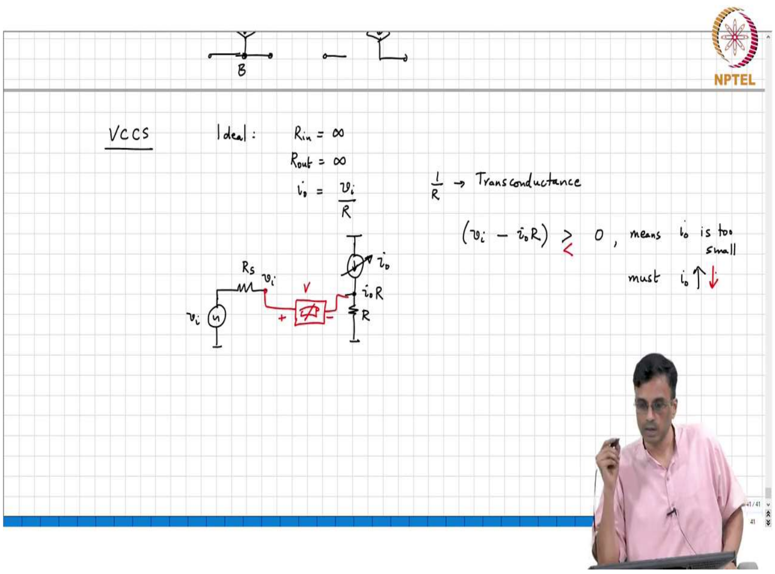

So, well to multiply I mean to divide a voltage by Resistor is equivalent to multiplying the current I mean basically comparing v_i/R with i_o is equivalent to comparing v_i and i_o R, ok. So, basically in this case or let us call this i_o this voltages I R. At least now we can get rid of the calculator. What else can we do? So, what are we comparing? We are comparing v_i with i_oR.

So, that basically means we need one voltmeter to measure v_i one voltmeter to measure i_oR can somebody think of a smarter way of doing it?

So, basically rather than compare v_i with i_oR. We will compare v_i - i_oR with 0, alright. So, where are we going to put the voltmeter? We are going to put the voltmeter here plus minus, ok. So, if v_i - i_oR is greater than 0 what does it mean? It means that i_o is too small and therefore must increase I_o. on the other hand if it is less than 0, it means that i_o is too much and you must reduce i_o.

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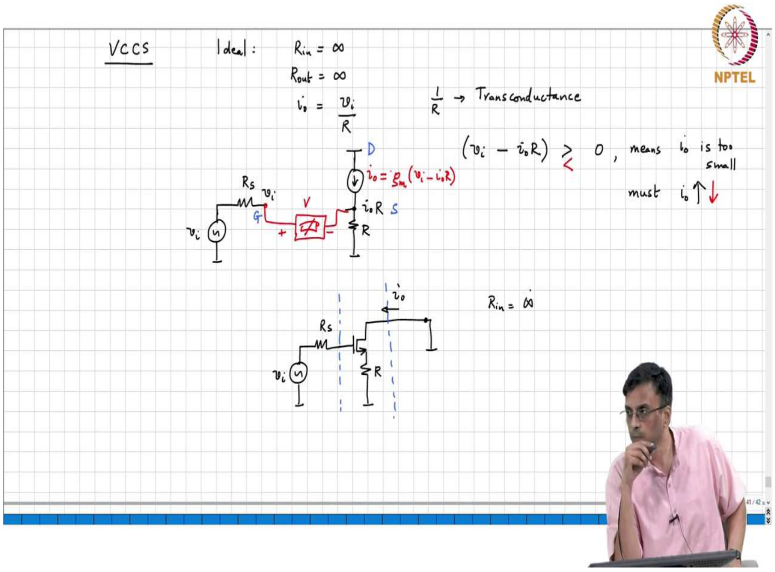

So, in other words i_o is dependent on v_i - i_oR. The constant of proportionality is conductance, and how much must that conductance be? Some g_m. And g_m must ideally be?

Student: infinite.

Why? Ideally g_m must be infinite because even for an infinitesimally small difference between v_i and i_oR the current source must kick that output node so hard that i_oR will become equal to v_i. And so, what is the sign of that g_m plus or minus?

Student: plus.

So, if v_i - i_oR is greater than 0 you must increase it. So, the g_m has a positive sign, alright. So, therefore, this is a voltage controlled current source, ok. And so, now can we identify the transistor source. So, in other words the incremental diagram is v_i this is R. And which is the output?

This is the I, alright. So, this is our voltage controlled current source, ok. So, what is R_I the input resistance? It is infinite, is that clear? What is the output resistance?

Student: Infinite.

Why?

Student: Like in incremental circuits we are not giving any input.

Ok. So, what?

Student: Like from the incremental circuit.

Ok, like the incremental circuit is here, alright, ok. So, we are trying to find the output resistance looking in here, ok.

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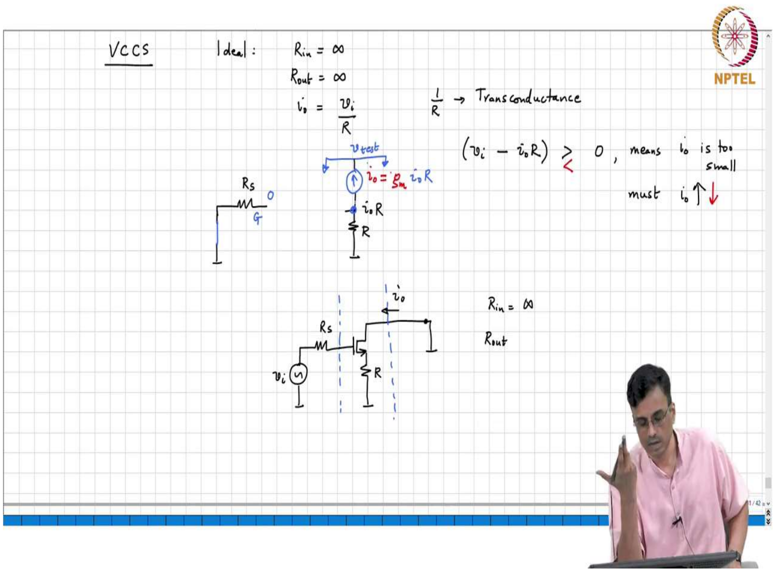

So, how will we do it? We de-energize all the independent sources so, this becomes 0. So, v_i becomes 0, alright. So, therefore, this g_m becomes g_m (0 -i_oR). So, that direction of the arrow goes the other way. So, this is g_m i_o R, ok, alright. Now, what? So, what do we do? We want to put a v_{test} here and find the current flowing, ok. So, let us do that. What is the unknown?

i_o is unknown or i_oR basically the potential of this node is unknown, ok. So, how will you find the potential of that node?

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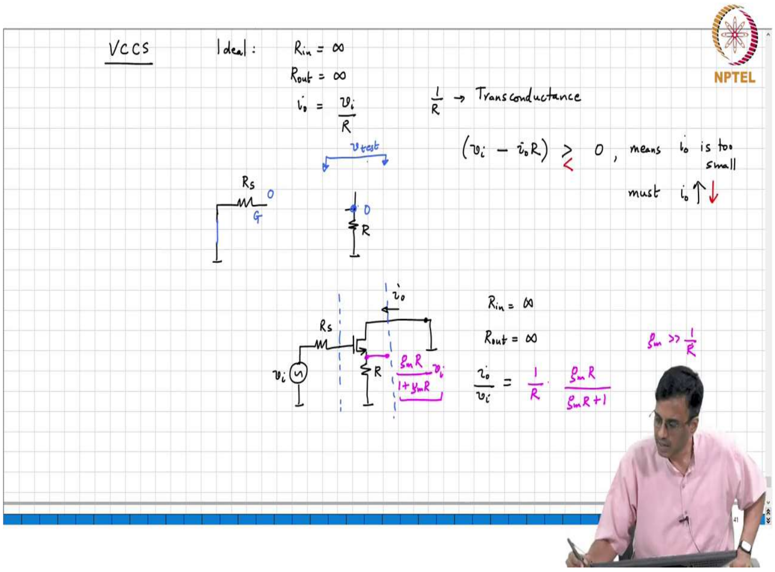

So, basically what is the voltage of the source? Ok. So, what is the i_{test}?

What is the i_{test}? So, basically i_{test} is 0. So, what is the output resistance? Now, the load current depends on v_i, right. 1 + 2 is 3. The sun rises in the east. All these are true statements, but they do not explain the fact that is my that is my trouble.

The question I am asking is, well it is true that the output resistance is infinite the math proves it, correct. But the question I am asking you is why does it make intuitive sense or does it make any intuitive sense? In a MOS transistor operating in saturation, what comment can you make about the influence of the drain potential on the drain current. That is all that you need to recognize that the output resistance must be infinite, correct, ok.

The drain current of the MOSFET is not influenced by the potential of the drain period, right. At least in our ideal model of the MOSFET which only consists of a voltage controlled current source, ok. So, what is the Trans conductance now? i_o/v_i is what? How can it be 1? i_o is in amperes and v_i is in volts, no correctly.

What is the incremental voltage of the source? I mean this does not require you to know any new analysis we have already done before. What is it?

$g_m R / (1 + g_m R) v_i$. So, what is i_o? v_i / I mean this voltage divided by R.

Ok. So, this is nothing, but 1/R times. I prefer to write it this way because it shows you something times v_i, alright. And remember that sanity check, what is the sanity check? One sanity check is when g_m tends to infinity you must get?

Student: we get 1/R.

Alright, ok. What is the other sanity check? When I put R = 0 what must you get?

Student: $g_m v_i$.

$g_m v_i$. When R = 0 the source is grounded. So, you must get it as the common source amplifier right, common source type of configuration. therefore, i_o must be $g_m v_i$, clear. Excellent. So, what does now a large g_m mean? We said g_m must be infinitely g_m evidently cannot be infinite. So, g_m must be large. So, what is it? What is the meaning of large now? g_m must be much much larger than 1/R.

And if g_m R is much larger than 1 as promised the Trans conductance which is the ratio of the incremental drain current to the incremental gate voltage is largely independent with 1/R times a large number by a large number plus 1, which basically is close to 1. So, even if that g_m changes by quite a bit you can see that $g_m R / (g_m R + 1)$ is not changing that much.

If so, say for example, if g_m R is 20, right. Then this thing is 1/R times 20 /21 which is 0.95, right. On the other hand, if that g_m goes down even by a factor of 2, which is a huge change, right. Then g_m R becomes in decimals.

Yeah, I mean whatever g_m R becomes 10, 10 / 11 = 0.91, ok. So, even though you have a 100 percent change in g_m, the change in gain is only less than you know is about 4 percent, right, ok. So, this is the incremental network. So, now I mean now you are all experts at biasing the transistor and making it work.

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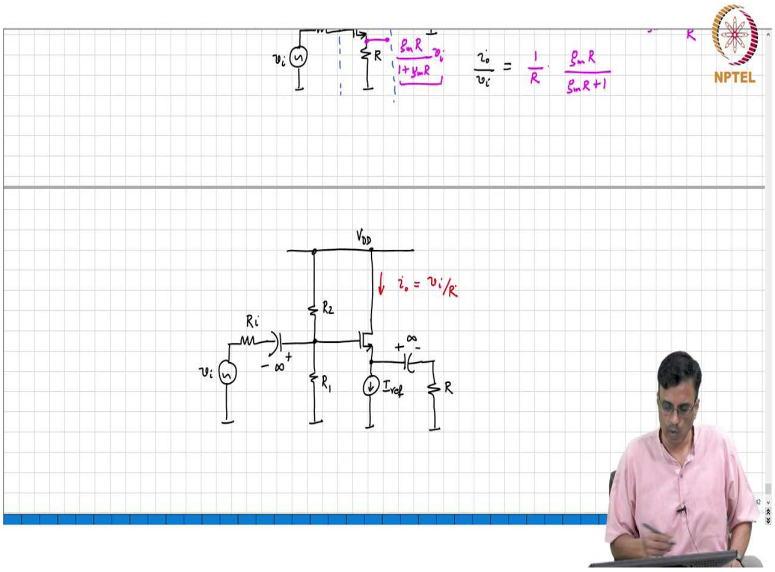

So, what do you think? What is your favourite way of biasing the transistor? You hold the gate at some R_1, R_2, alright. And what is now the resistor ladder is done. What am I doing with the transistor? So, you want to put a current source fine, alright. What is the drain doing? What should I do? What do we do here? Around it, in the real circuit. Connect to V_{DD}, ok, alright. And then what are we going to do now? Connect an R parallel to I_{ref} ok, one suggestion is to do this, with a growth capacitor, ok. And why do we need the infinite capacitor? So, that we do not mess with the operating point. An alternative thing to do would have been to remove the I_{ref} and put the?

Student: R.

So, R basically not only appears in the small signal picture but also appears in the quiescent operating, ok, alright. Then what else? So, again we have our input Ri v_i this is the infinite capacitor. And therefore, if g_m is large what comment can you make about the incremental output current? If g_m is large the incremental current is approximately v_i/R.

Of course, there is no point in generating an incremental I mean a current in dumping it into the supply voltage. A current is useful only when it is just like voltage. It does not make sense to have a battery and not load it at all, correct, ok. You are not going to look at the battery and admire it, you need it to power a circuit, right. So, similarly you need this current to do something and what is that something you should?

You should connect a?

Student: Load.

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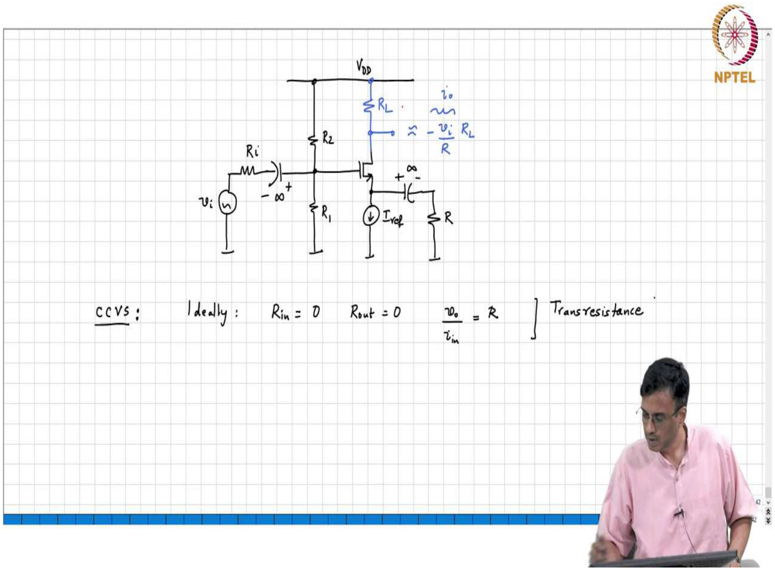

So, basically some R_L here. And what comment can you make about the incremental voltage across the drain of the transistor? Yes. What is the incremental voltage at the drain of the transistor? - i_oR_L which is known to be minus approximately $-v_i/R$ - i R_L. So, this is nothing but the incremental current i. So, does it make sense to people? Alright, ok. So, the next controlled source is the current controlled voltage source. Ideally, what is the input impedance? 0. Output resistance is0. What is the only thing that we need to specify therefore?

Student: Trans resistance.

Trans resistance. So, v_o / i_n must be some R and this is also called either the Trans resistance or the Trans impedance it does not matter. And why Trans because? I mean voltage by current at the same port is basically resistance here voltage is somewhere current is somewhere else. So, it is transfer resistance or Tran's resistance, alright.

And so again we get back to our you know good old you know common sense approach if you are in a lab you want a voltage source you want an output voltage across some load which must we want it to be equal to i_n times R.

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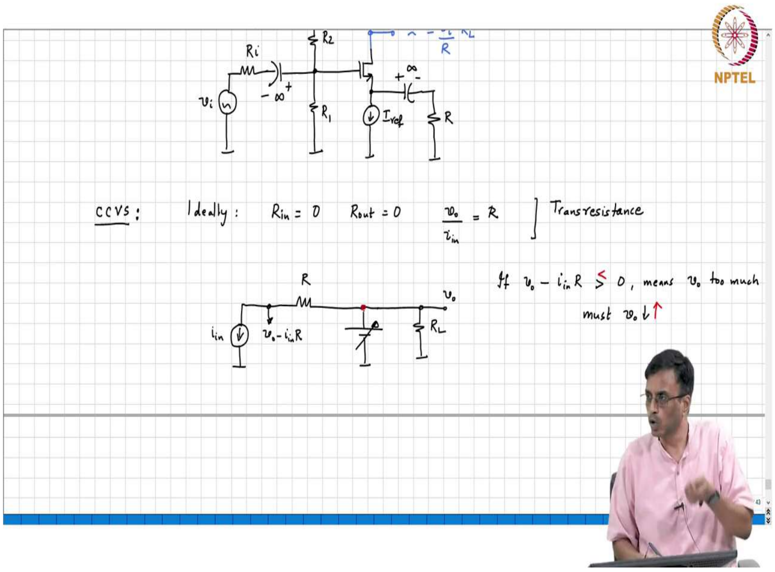

We have seen this before in the Op-Amp network, correct, alright. So, how did we do that before? What did we do earlier? Ok. So, we said we are going to have a variable voltage source in a way that the method to vary output voltage and we are going to compare i_n R.

So, we need to compute we need to compare v_o - i_nR with 0, right. So, if v_o - i_nR how do we generate v_o - i_nR?

How do we generate v_o - i_nR? We discussed this before. So, this is R this is i_n. So, what is that voltage? v_o - i_nR and if that is greater than 0, it means v_o is too much and therefore, must be reduced alright. and if it is less than 0 the v_o must be pushed up, alright. So, in other words this v_o is controlled by the voltage i_n R. So, but unfortunately a transistor is not a voltage controlled voltage source it is a?

Student: Current source.

Voltage controlled current source. So, in other words rather than change the potential of node v_o by using a variable voltage source we have to use a variable current source.

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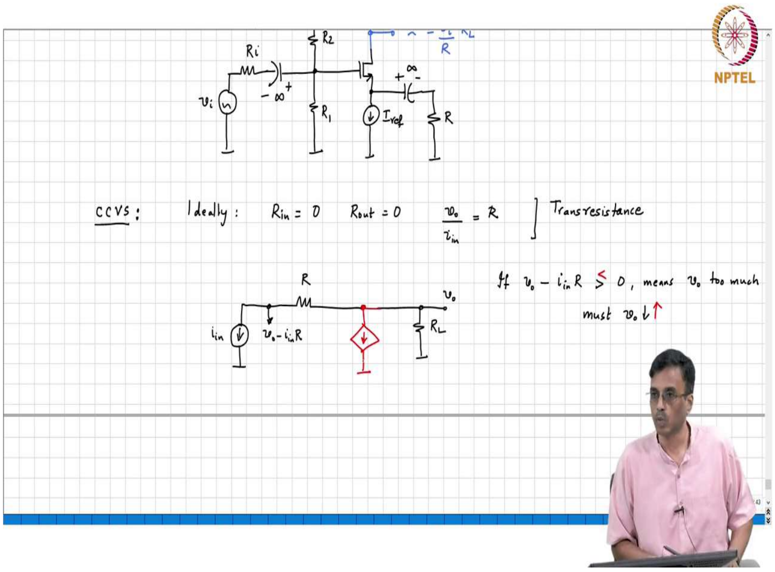

So, basically, ok, alright. So, I think it is late. We will continue with this tomorrow.