Analog Electronic Circuits

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Lecture - 31
The Incremental Current-Controlled Current Source, The Common-Gate Amplifier

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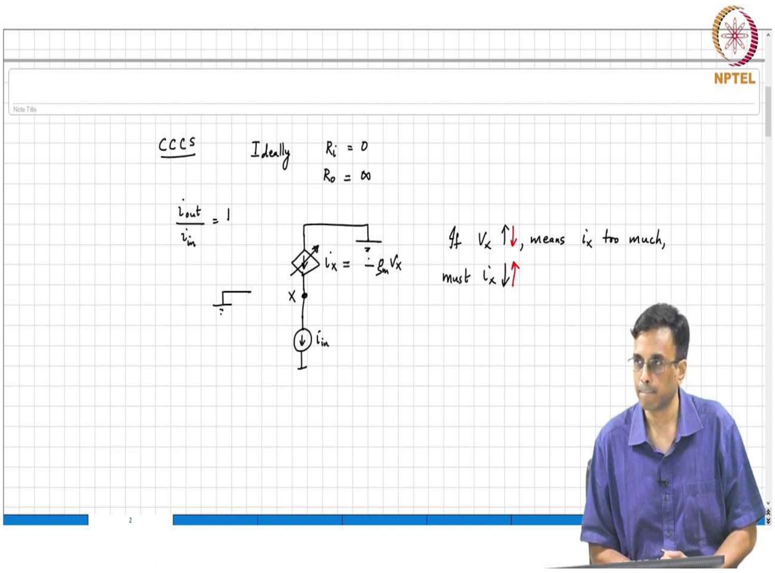

The last control source that we need to talk about is the Current Controlled Current Source. So, ideally, what comment can you make about the input resistance of a current controlled current source? Ideally, R_i must be 0. What about the output resistance?

Student: Infinite.

Infinite. And so, when you say I have a current controlled current source the only number that you need to specify is the?

Student: Gain.

Gain. And for reasons that will become apparent going forward. Let us first try and attempt to realize a current controlled current source with an incremental gain of 1, right. So, i_{out}/i_{in} must be equal to 1, alright. So, basically, we are saying here we have a current i_{in}, ok. I need to generate a current i_{out} which is the same as i, ok. Again, we go through the same process that we have done for the previous current sources. Namely, first think about what to do and then we figure out how to do it, alright. So, if you are in a lab and you want to generate another current which is the same as i_{in}, what will you do? What would you need?

We need a.

Student: Variable current source.

So, let us say we have a variable current source, alright. So, this is variable, ok. Now, what are we going to do? And remember that a current source must never be opened, just like how a voltage source must never be shorted, alright. So, we have this variable current source. So, what are we going to do?

How do you make sure that this current i_x is the same as i_{in}? And how do we take the difference? So, we want to, so we want to measure the current, we have seen this before in the context of biasing transistors. So, if you want to make sure that i_x is the same as i_{in}, what do we do? We want to find the difference. And then, so, what physical principle will be used to find the difference between two currents?

Student: KCL.

KCL. So, basically, we join the two, and we can monitor the potential of node x. So, if v_x goes up, what does it mean? It means that i_x is too much and therefore, what must you do? Must reduce i_x, alright. And on the other hand, if v_x is going down, it means that the current pumped into the node is too little compared to the current that is being or the charge being pushed into the node is smaller than the charge that is being pulled out of the node. As a result the potential of the node reduces. So, i_x must fall, I mean, so if v_x is falling it means that i_{in} is too much or in other words i_x is too little and therefore, i_x must be increased, alright.

The only circumstance when you know when i_x is equal to i_{in}, what will happen? The potential of v_x will not change, but recall that all these signals that we are talking about are incremental signals. In the incremental network you can never have a constant voltage, correct. So, any constant voltage must only be 0, right. In the real network you can have a constant voltage, but you know when you go from there to an incremental one any constant voltage becomes 0.

So, basically, what must we do? We must compare the potential of x with 0, right. It must be a constant that must be 0. So, we compare the potential of v_x with respect to ground and if v_x

increases it must decrease, and vice versa, correct. So, in other words, i_x must be a current which is proportional to, it is controlled by?

Student: v_x.

The constant of proportionality must be some conductance. What comment can we make about the sign of g_m?

Student: Negative.

Negative, why? Because if v_x is going up, it must fall down. So, this is basically minus g_m v_x, alright.

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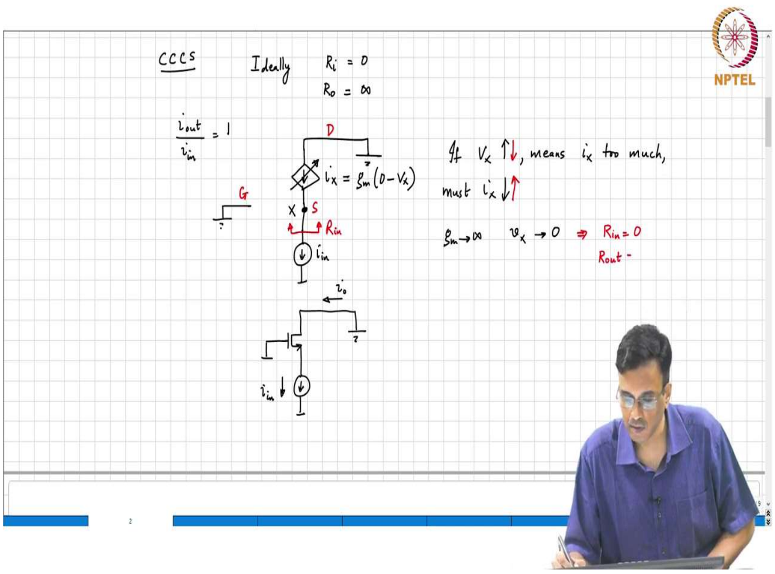

I am going to write this as g_m (0 - v_x). And now can you identify the transistor for me? Which is the term, which is the transistor?

Student: Gate.

Gate is grounded, very good.

Student: x is source.

This is the source.

This is alright. And therefore, the incremental picture basically looks like this. This is i_o, this is i_n, alright. And what do you call, ideally what should that g_m be? Ideally, you like that g_m to be infinite. So, therefore, what comment can you make about the, if g_m tends to infinity what comment can you make about the incremental potential of node x? v_x will tend to 0. So, what comment can you make about the input resistance?

Student: 0.

Why is it 0? Because, while you are pushing in current, the potential of that node is not changing at all, which implies that the input resistance is 0, correct. What comment can you make about the output resistance? Where is the output?

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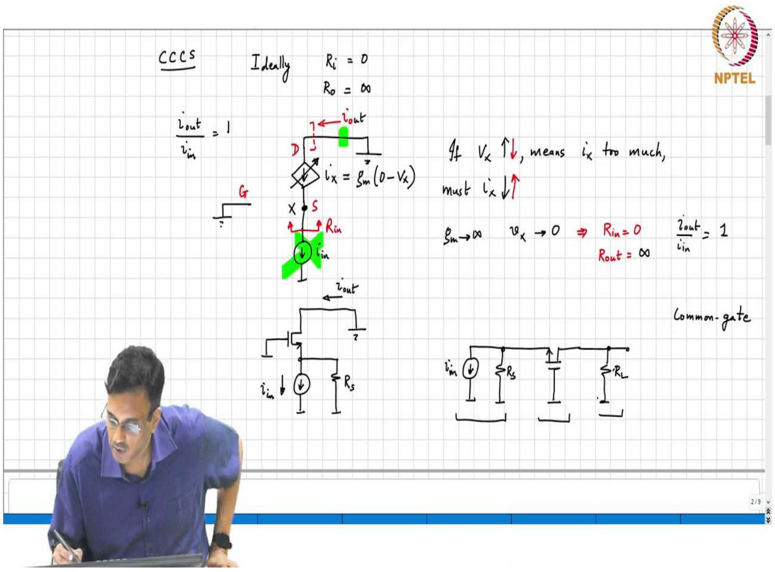

This is i_o, alright. And what comment can you make about the output resistance? We did this before.

Student: Infinite.

Why? No, it is infinite that is correct. But why?

Student: Open circuit.

Open circuit, where? Ok. So, basically, I hope you are all able to see this, right, its apparent. That, if you form the incremental circuit here what happens to the what happens to i_{in}? Open circuit. Remember, I mean if you are confused the easiest thing is to put a v_{test} and then measure the i_{test}. So, obviously, if i_{in} is an open circuit then; well, whatever you v_{test} you put here there is no current flowing, correct. And therefore, i_{test} is 0, so therefore, output resistance is infinite. And what is i_o/i_{in}? I mean we call it as i_{out}/i_{in} must be?

Student: 1.

1, alright ok. Now, if I draw the picture in a slightly different way, alright. So, now before I do that, what comment can I make if the source is not the current source, not ideal, but has some source resistance R_s, what is i_{out}? Ok. So, if g_m is infinite, what comment can we make about i_{out}?

Student: It does not change.

It does not change, why? Well, the incremental voltage at x is 0. So, the current flowing through R_s is?

Student: 0.

0. So, all the current i_{in} flows through the transistor into the drain. So, basically, i_{out}/i_{in} is 1, alright. So, this is you know this is simply you know current control current sources is, it is basically taking the poor current source and making it look like a?

Now, what is the point in having a current control current source? What is this, I mean, why do we I mean, why do we, if i_{out} is the same as i_{in}, why bother having you know a current control current source. Why do not we just take that input current and connect it to the output of the wire. Why do we need this whole transistor and all that?

The idea behind using a current control current source is that it can take a bad current source. What is a bad current source? A bad current source is one whose output resistance is?

Student: Infinite.

Not infinite, it is finite, ok. So, if you connect a bad current source to a load, ideally you would expect that all the current provided by the current source must go in through the?

Student: Load.

Load. But unfortunately, because the current source is bad and it has some internal impedance of its own, alright, all the current will not flow, only a fraction of it will flow through the load, correct. Yeah, this is pretty much like having to pay a bribe, you understand, right. You need to get a big loan from a bank, right? Of course, you know your financials are all very you know very shaky, alright. But you know if you say you know, I will give you to the manager and say I will give you say 10 percent of the money, that is like you know poor output impedance, right, ok, alright.

So, you know if more money is there you lose he gets a bigger cut, right. There is only a fraction of that current that flows through that the recipient, the other 10 percent is lost, ok, alright. So, the current control current source job is to basically make, is to isolate.

You can take a bad current source and make it look bad or make it look great, right. And make it look like an ideal current source with an infinite output resistance. So, if I redraw this picture slightly differently, you will get an idea of why it is called what it is called. So, this is i_n, this is R_s, there is a current source, I mean let us say I push it into a load, alright. So, it is the same circuit, except that I have inserted a load in the drain. I am sure this is familiar to all of you, correct. What is this? Here, we see that the gate terminal of the transistors is common to both the input source and the load and therefore, this is called the common gate, ok.

Another way of looking at it is that this is not an ideal current source. This is the institute, right, ok and you know this is the external volt. So, this is the common gate amplifier, ok. Now, again you know the same volt, same volt, of course, before we go there we must figure out what happens when the transistor's g_m is is finite, right. What do we do? We have done this multiple times before.

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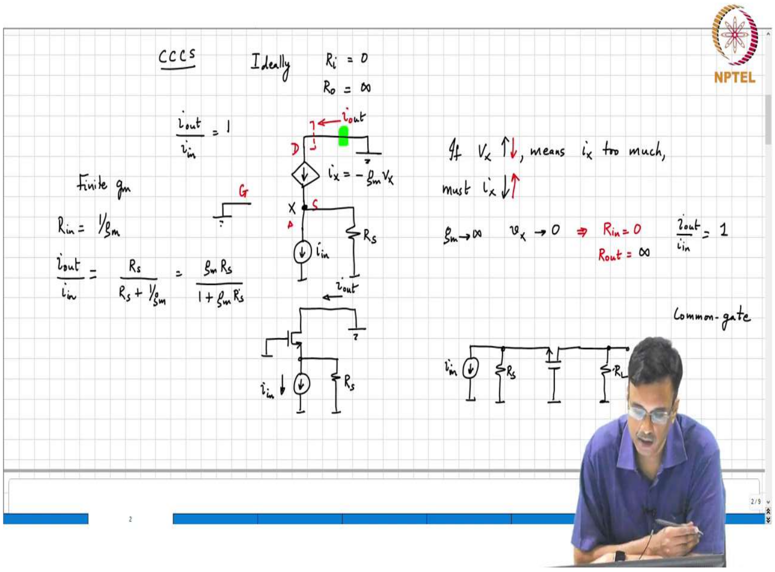

So, what do we do? Well, i_x is nothing but - g_m v_x. And so, what comment can we make about R_{in}? So, R_{in}, is what? It is $1/g_m$, correct. Now, let us now put in a source or frame the source resistance, alright. So, what comment can you make about the i_{out}/i_{in}? The input resistance of the common gate amplifier is, as we just saw, what is it?

$1/g_m$. So, how much of the current will i_{in} will flow into the transistor now? It is $R_s/(R_s + 1/g_m)$ which can be rewritten as g_m $R_s/(1 + g_m$ $R_s)$ and that current will flow out. So, as you can see, the current gain is not exactly 1. It is g_m $R_s/(1 + g_m$ $R_s)$. What comment can you make about the output resistance with finite g_m? Ok. Let us apply v_{test} and then find what i_{test} is?

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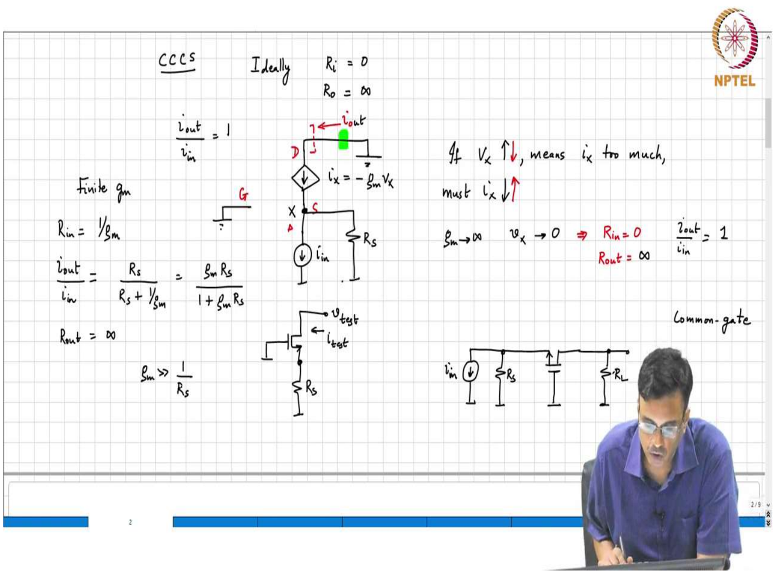

R_s is there. We have, in fact, now this should bring a bell because we have done this analysis before. This is R_s, we are applying a v_{test} here. What is i_{test}?

Student: i_{test} is 0.

i_{test} is 0, why? Which one? So, in our model for the transistor we assume that the drain source, the current in the drain, is independent of the drain potential. So, basically, you know you wiggle the drain there is no change in the current and therefore, i_{test} is 0. So, the output resistance still remains infinite even though the g_m is finite, ok, alright. So, R_{out} is infinite. Now, what comment can we make about therefore, when we say we want g_m to be large we know that we cannot make g_m infinite, we can only make g_m large.

Now, the question is, how large and now we should be able to answer that question. What is it? So, g_m must be much much larger than $1/R_s$, alright. Now, why do you think the current controlled, I mean we said that the current controlled current source that we are going to attempt is going to have an incremental gain of 1. You know, why cannot we make an incremental gain of 10? The reason is exactly analogous to what we saw in the, which case?

Student: Voltage controlled Voltage source.

Voltage source, where also it was only possible to make an incremental gain of 1, reason being the transistor is a 3 terminal voltage controlled current source. Is that clear? Alright.

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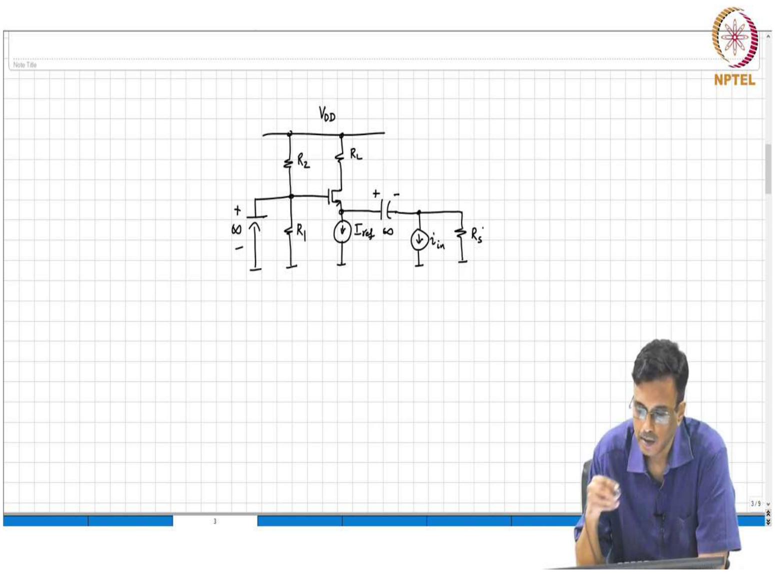

So, now the last thing to do is again come up with the real circuit. Again, we can pick our favourite bias scheme. I am picking something you know is terribly boring to keep working on the same thing all the time. But I am going to leave you to do it. This is sum I_{ref}, this is R_L, and this is V_{DD}, alright. So, I have biased the transistor, now what? What should we do to make it a common gate amplifier?

Student: capacitor gate.

Capacitor gate, alright. Very good. What else? Alright. That is R_s, ok.

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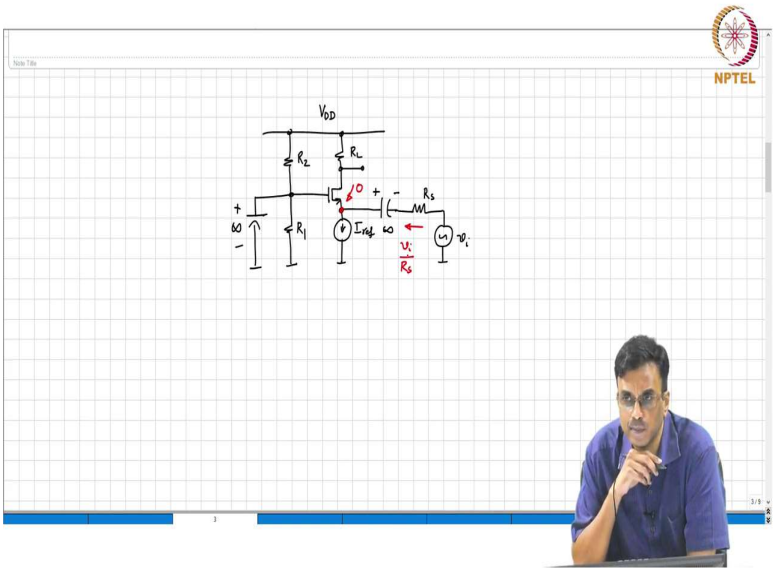

Now, if I remove this and this is v_i, let us say this is R_s, what comment can you make about the incremental voltage at the drain? So, another way of thinking about it, if you did not want to go back to the Norton equivalent, what is the incremental voltage there? What is the incremental voltage there?

Student: for infinite g_m it is 0.

So, what is the incremental current flowing there?

Student: v_i/R_s.

So, where does that current flow?

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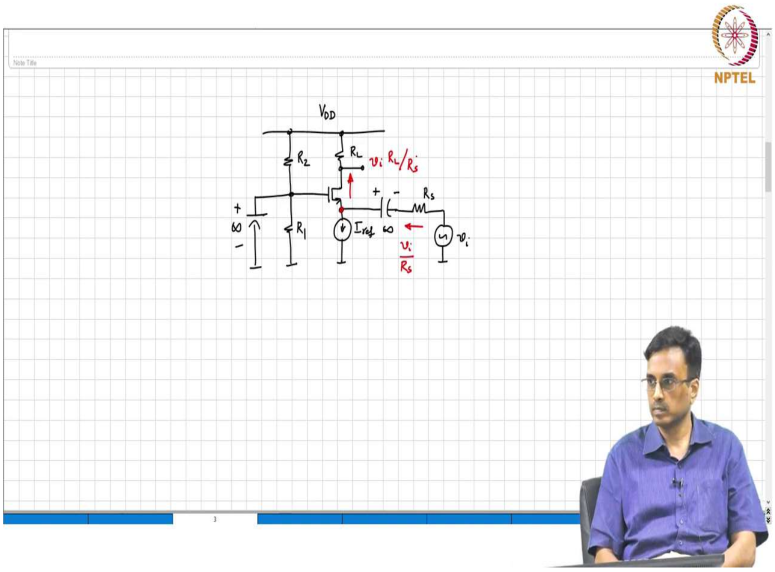

I_{ref} is an open circuit in the incremental network, so that it will flow through the R_L. So, what comment can you make about the incremental voltage at the load?

Student: v_i R_L/R_S.

v_i R_L/R_S. Again, you can just look at it, and then there is the answer.