Analog Electronic Circuits
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Lecture - 18
Robust Biasing with Source Feedback - Part 2

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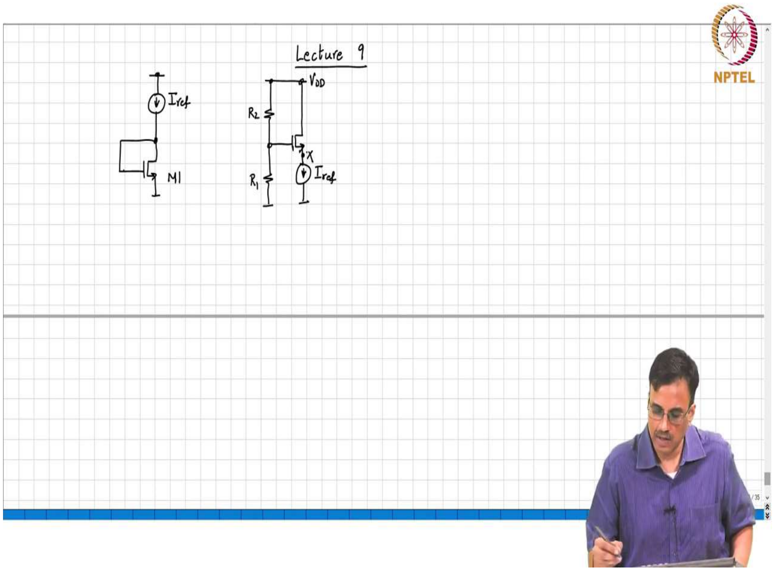

Good morning and welcome to Analog Electronic Circuits. This is Lecture 9. In the last class we were discussing bias stabilization. And the basic idea is the following. We would like to make sure that the bias current in the transistor remains equal to some reference current which is assumed to be accurate in itself. And now how we will get that accurate bias current is another matter.

We will figure that out later. But at this point let us assume that we have an accurate reference that does not change with you know temperature and with process and with supply voltage. And we would like to make sure that the bias current in the transistor is accurately equal to this reference current. And the basic idea is very simple. You check the current in the transistor, you compare it with the reference current and you vary the gate source voltage of the transistor to make sure that the drain current equals the reference current. That is all.

The principle is very simple. So, now, how we implement it is of course, you know can be done in multiple ways. We saw a couple of them and again the fact that there are multiple ways is not surprising. Because the gate source voltage can be controlled in at least two ways.

One is to keep the gate voltage fixed and vary the source or keep the source voltage fixed and vary the gate. And similarly, measurement of the current in the transistor can be done in two fundamental ways. You either stick the ammeter in the drain or you stick it in the?

Student: Source.

Source. So, if you permute these four combinations I mean these four possibilities you get at least four ways of stabilizing the bias curve. The first one we discussed was drain feedback. So, this corresponds to? So, what does this correspond to? Where are we measuring the transistor's quiescent current? We are measuring current in the drain. And varying V_{GS}, by how are we varying V_{GS}?

Keeping the?

Student: Source voltage.

Source voltage fixed, but wiggling the?

Student: Gate.

Gate. This was the first method. The second one that we discussed was where we decided to keep the gate voltage fixed. And where are we measuring the drain current now?

We have stuck the ammeter in the source, we are comparing the source current with the reference current and varying the?

Student: Source voltage.

Source voltage so that the current in the transistor is equal to I_{ref}, alright. And you know as we discussed on Friday there is nothing special that needs to be done, the very act of sticking that source to the current source in the source of the transistor. Automatically ensures that the potential of that node X will go in the right direction so as to make sure that the source current is the same as the reference current. Does it make sense folks? Alright.

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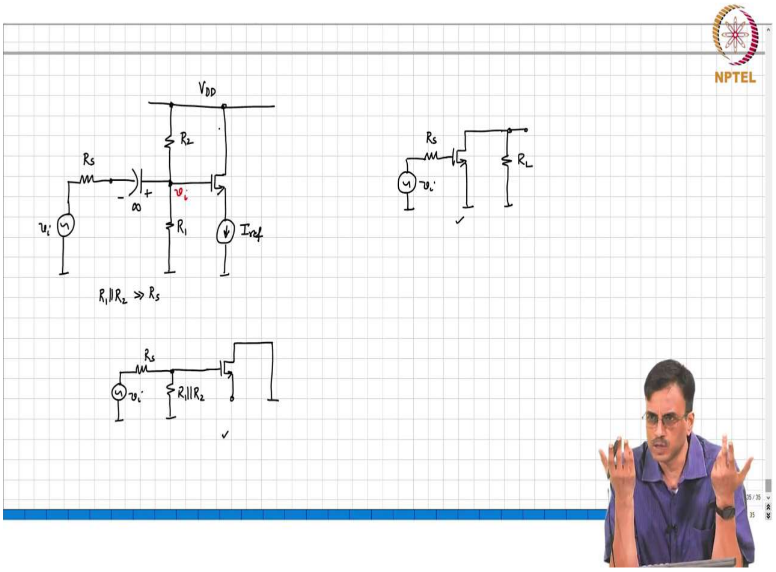

And so this is the bias network. So, now, let us complete the picture and then make the common source amplifier. So, this is the biased picture, this is V_{DD} this is R_1 this is R_2 and this is the current source, alright. Now for incremental signals we need to make the system look like this. So, this is R_S this is the transistor assumed to be operating in saturation and we need the incremental network to look like this. This is the model for the common source amplifier. So, what do we do?

Student: source.

Yeah, where do we put it? here is the common. So, basically what you need to do is mentally draw the small signal equivalent of the network on the left. If you do that what happens to the to V_{DD}?

Student: ground.

Ground. And what happens to the current source? So, basically what happens therefore is what we have right now? What happens to R_1 and R_2?

Very good, R_1 parallel R_2 and the transistor is here. What happens to the source?

Student: Open circuit.

The source as it stands is an open circuit. And what happens to the drain?

Student: Ground.

Has gone to ground. So, this is an open circuit. We want to make this guy. Here, we want to make it look like that. So, clearly what is missing? One thing that is missing is v_i and R_S.

So, we add v_i and R_S. Can I directly hook on the source to the gate node? We cannot do that because that disturbs the operating point. So, we add our usual infinite capacitor. And how would we give R any choices of R_1 and R_2? What are the design considerations for R_1 and R_2?

To establish the voltage only the ratio is needed, correct? But beyond that?

Student: R_1 parallel R_2.

If we got to make sure that R_1 parallel R_2 is much larger than?

Student: R_S.

R_S. So, this way the incremental voltage at the gate is approximately v_i, very good. So, we have added R_S and v_i. So, the input part seems, what else is there in the small signal stuff which is the desired small signal equivalent that is not there in the actual circuit load.

So, what do you suggest I do? Again, there are multiple ways possible. One way is to?

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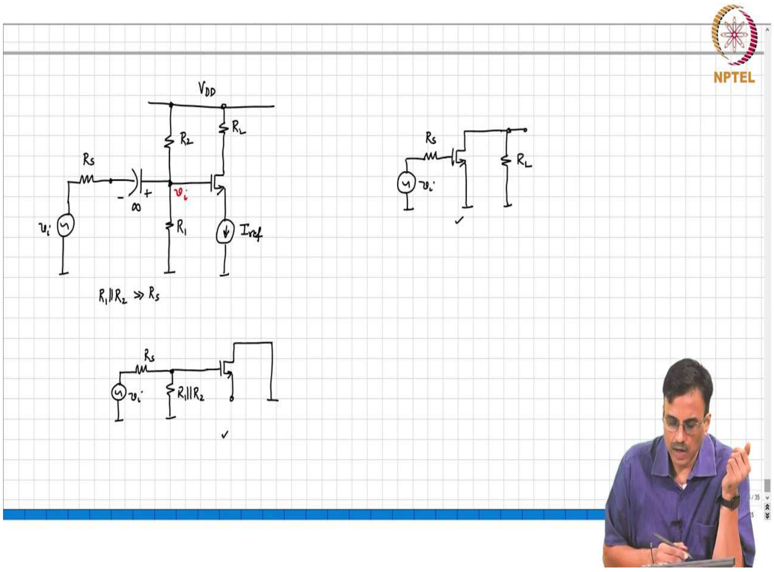

One way is to directly connect the resistor R_L.

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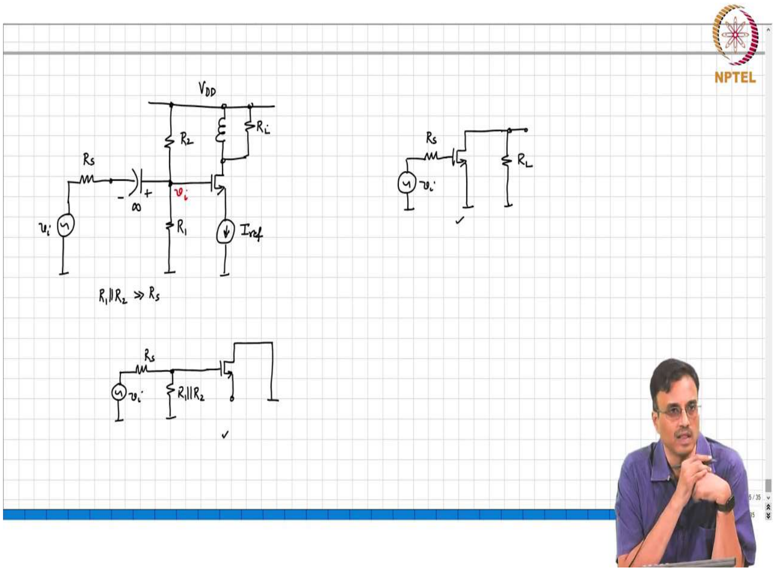

Another way is to put an infinite inductor here, and?

Student: Capacitor.

So, if you do not want to add an extra capacitor, fine this is another possibility, correct.

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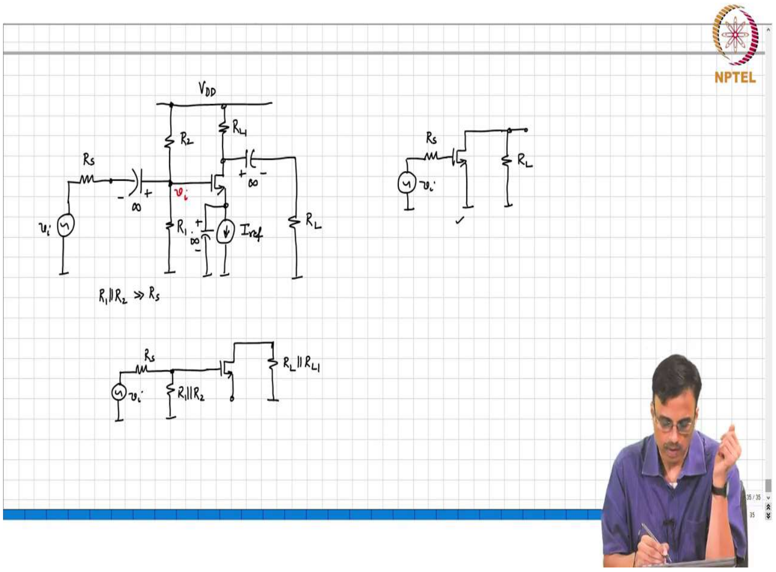

A third possibility is to say you put R_{L1} on a large capacitor and you put R_L here. And the price you pay for the freedom you get in the sense that one end of the resistor is grounded and the other? And what is the other unique feature of grounding the load through a capacitor?

The load does not have to deal with any?

Student: DC curve.

DC curve. And the price you pay for that is the incremental gain?

Small, alright. So, any of them is fine. So, the load resistor is now there. Are we done or do we need something else?

In the circuit that we now have R_L parallel R_{L1}. The only difference between what we have and what we want is the source terminal going to be floating versus going to ground, right. So, what do you suggest we do now?

Student: Parallel.

In parallel with?

Student: current source.

The current source: what do we need to do?

Student: Capacitor.

We need an infinite capacitor, alright.

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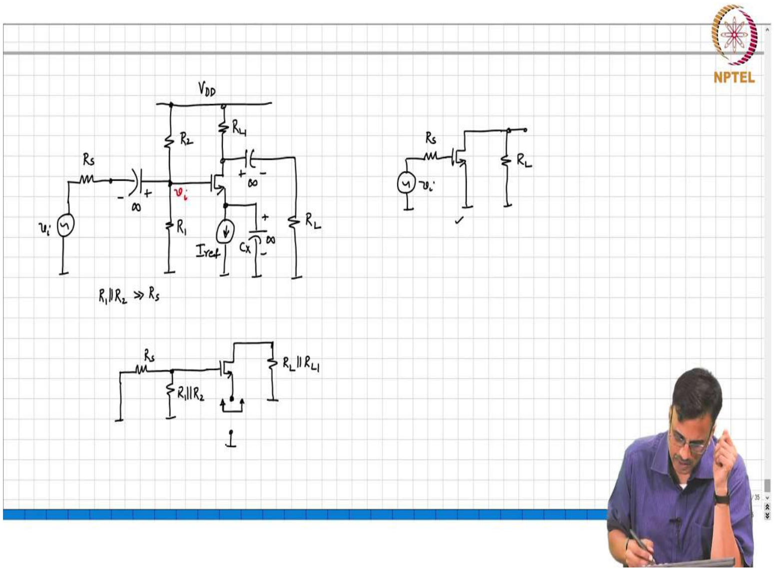

So, well I_{ref}s, alright. So, quick question for this capacitor C_X when you say it is an infinite capacitor of course, we know that you cannot make an infinite capacitor. So, what do you think we will do? Yeah, so to make sure that C_X is for all practical purposes behaving like an infinite capacitor what do we need to do? I know you know it, but please tell me carefully step by step what you will do.

So, the first step is to find the v Thevenin. The v Thevenin is not really relevant; we only need to find the?

Student: $R_{Thevenin}$.

Thevenin. What is the $R_{Thevenin}$ looking into the source of the transistor? How will we find out? We do not know. So, basically we will figure it out. So, what do we do? To find the Thevenin resistance what should we do?

Well you de energize all the independent sources, correct. So, that basically means that this becomes ground. Then what? We want to find the Thevenin resistance looking in here. So, what will you do? Between that terminal and ground that is what it means. If you want to find a way out guys you have a box with two terminals coming out, you want to find the resistance what will you do?

There are multiple ways of doing it. One way is to apply a voltage measure to the current. The other one is to?

Push current measure?

Student: Voltage.

Voltage. So, let us try.

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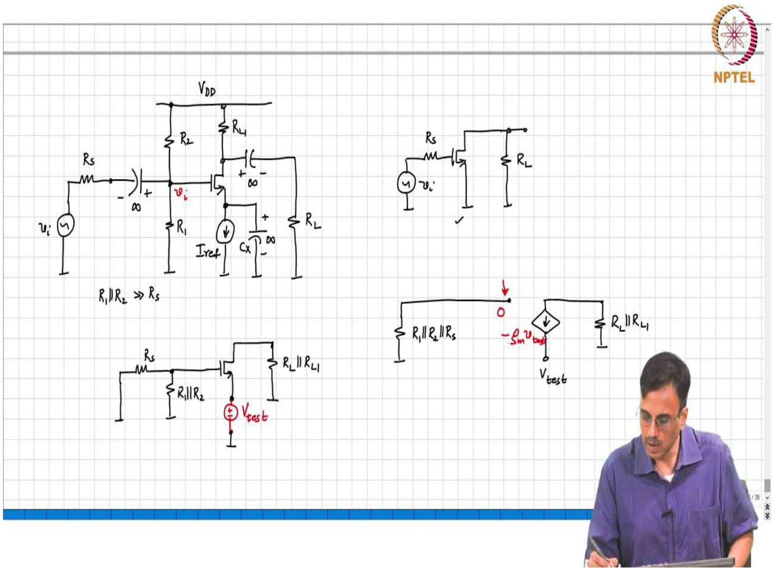

So, let us apply a voltage Test. And find what the current is. So, if you draw the incremental equivalent how will it look like? So, we replace the transistor at the gate now. There is R_1 parallel R_2 parallel R_S. This is the transistor, that voltage is V_{test} that is R_L parallel R_{L1}. And what are we interested in finding?

So, what is this voltage? What is that voltage? That voltage is 0, very good. So, what is this current source?

Student: g_m.

g_m times incremental V_{GS}. So, what is the incremental V_{GS}?

Its g_m times minus V_{test}, which is equivalent to saying I will turn the arrow the other way.

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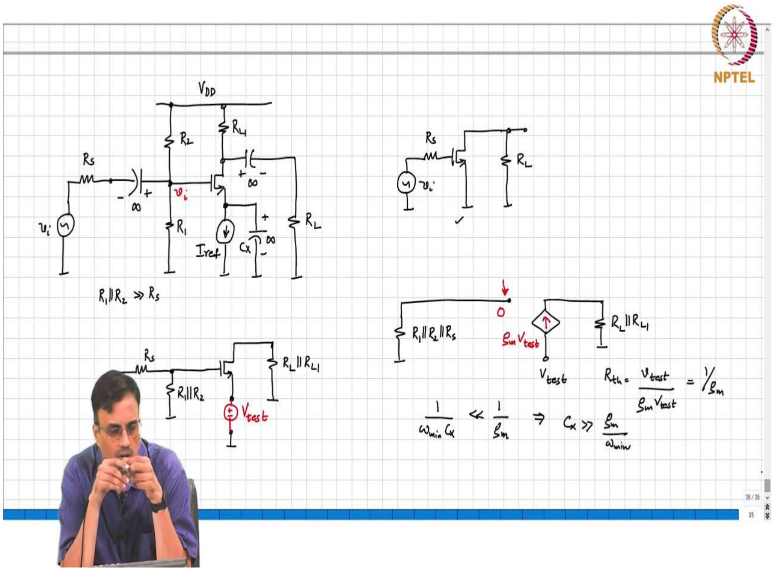

And that current is g_m V_{test}, alright. And so therefore, what comment can we make about the Thevenin resistance?

Student: $1/g_m$.

1 over g_m because we are applying a voltage V_{test} and the current flowing out of the test voltage is g_m V_{test}. So, that basically means that

$$R_{Thevenin} = \text{Test} / g_m.$$

V_{test} which is 1 over g_m, very clear. So, now, when we find the Thevenin voltage, what do we do next? So, what constitutes a large capacitance C_X? The impedance of the capacitor must be?

Student: Much smaller than $R_{Thevenin}$.

The Thevenin resistance looking across the capacitor and at what frequency evidently the impedance offered by the capacitor is a function of frequency? So, what comment can we make at what frequency should we evaluate this?

See you are never going to be amplifying a sine wave, correct. Do you understand or not? What is the point of amplifying a sine wave if there is no information that sine wave we are going to always be amplifying range of frequencies.

So, what comment can we make? At what frequency should we evaluate? So, what frequency will we be evaluated at?

At the lowest frequency intended to operate the amplifier. So, basically one over omega C_X or omega min times C_X must be much much smaller than 1 over g which implies C_X must be much much greater than?

Student: g_m/ω.

g_m/ω. So, as I said this is you know again yet another common source amplifier. And if you put the earlier picture I mean earlier circuits that we had and compare it with this on the face of it looks as if this is a completely different circuit. I mean there are the connections. You know there are all sorts of components, there is no current source.

But there is basically a big I mean as far as the incremental picture is concerned the underlying circuit is still the same, alright. See the only drawback of the circuit you know if any is the fact that know again if you are building this on an IC then there is really no issue because even if you want to build a hundred amplifiers you need hundred reference currents copies of the reference current. So, how will you get hundred copies of the reference current?

We already know how to make a current mirror. So, you can take one master current and then make as many copies of it as we want. So, in reality, I_{ref} could be the output of a current mirror. Is that clear to everybody, yes, or no?

Student: Yes sir.

Yes. So, but if you are trying to build discrete circuits on a PC board or a breadboard you know as you know many of you have probably done in your labs, Then you know the current source may not be you know a great thing to use simply because it involves you know more complexity. Remember on an IC you know using a lot of resistance and a lot of capacitance is actually a bad thing.

Whereas, transistors are free pretty much. So, if you can replace a resistor by half a dozen transistors you know often that will be the better thing to do right because transistors are small and they all match and so on. On a breadboard or in discrete circuits often the active components are expensive whereas the passive are cheap. So, there the design paradigm is the opposite, where you basically try to minimize the use of

Student: Transistors.

Transistors. So, for example, you know this I_{ref} here basically would have to use some kind of active device to make the current and that is basically a problem. So, it would be nice if we could avoid the use of the current source. While still, what is the role of that current source in this whole scheme of things?

Is stabilizing.

Student: Source.

Then you know the bias current of the transistor making it equal to I_{ref} no matter what. For example, if the threshold voltage changes, what happens? if suddenly the threshold voltage of the transistor changes what happens?

The source potential will adjust itself. So, that the current is exactly equal to?

Student: I_{ref}.

I_{ref}, alright. So, now, the question is what do we do?

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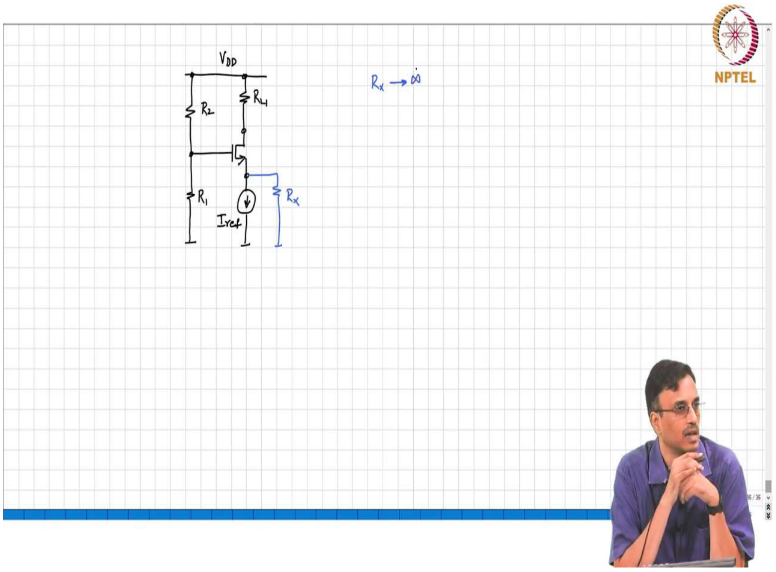

Let me again get rid of the incremental part just to focus on the bias arrangement. So, this is I_{ref} and. So, of course, an ideal current source what is the output resistance of an ideal current source? Infinity. So, in practice, of course, the resistance of the current source will not be infinite, it will be large. So, you can think of it as some R_x, where R_x ideally should tend to infinity, correct? Now what I am going to do is recognize that.