Analog Electronic Circuits
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Lecture - 19
Robust Biasing With Source Degeneration

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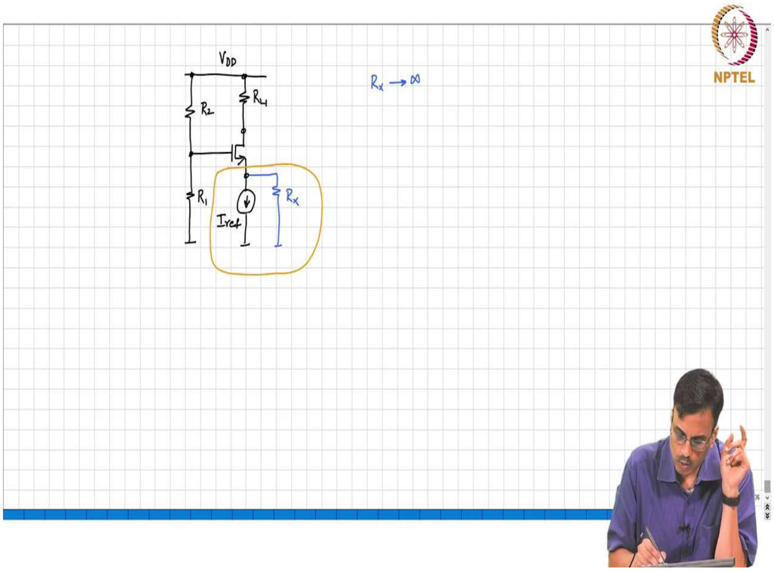

If you have a current source in parallel with a resistance what comment can you make? You can think of it as a voltage source in series with a resistor. What is the value of the voltage source? Think carefully, people. It is I_{ref} R_x.

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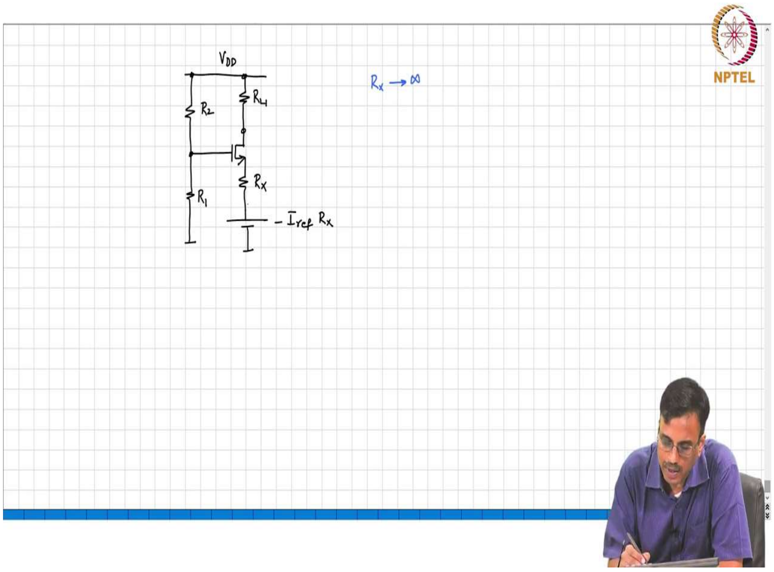

So, that is R_x and this voltage is minus I_{ref} R_x, alright. And what is the sanity check you know as R_x tends to infinity what happens? Well the impedance scene will go to infinity obviously, but the voltage is also going to infinity. So, that the current is maintained at?

At the I_{ref} pulling down pulling out of the source, correct? So, of course, we cannot get R_x to infinity, we will get R_x if you know in reality we will say R_x is large, right. So, what have we therefore done ? We have replaced a current source with a large resistor and a large

Student: Negative voltage.

Negative voltage source, correct. So, I mean now we have avoided the use of a current source and concluded that if that R_x is made sufficiently large that combination of R_x and the negative voltage source are indistinguishable from a?

Student: Current.

Current. And therefore, for all practical purposes you know the stability of bias that the current source would also be given by this resistor, correct. Now, unfortunately there is a small problem and what is the problem now?

Earlier how many supply voltages did we have? How many voltage sources did you have?

Student: One.

One, now you have two, but the problem is?

There is basically a?

Student: Negative.

Negative supply, right. So, if you want to avoid the negative supply, what do you think you can do? This is very similar to what you do with competitive exams, right. there is negative marking, and it's very likely that a whole lot of candidates will get negative marks, but then if it comes out to the press that you know people getting zero are qualifying and you know studying in a top class institution then it will become a huge PR nightmare.

So, what will you do? You add 50 marks to everybody, right? So, the guy who gets minus 30 basically feels happy that he is at least got 20 and the guy who got 0 now all of a sudden has got 50 and then you tell everybody the minimum pass mark is 50, alright. I mean it does not affect anything right, same thing in a network. see what is the notion of I mean if you add, so basically then what is the most negative potential in this network now?

Student: - I_{ref}.

- $I_{ref} R_x$. you do not want that. So, what will you do? I mean typically you reused to the lowest potential being.

Student: 0.

Being 0 correct. And so what will happen now, what will you do? You I mean you used to the most negative potential being 0 unfortunately it is not 0. It is minus $I_{ref} R_x$. So, what will you do?

You add $I_{ref} R_x$ to all node potentials and what effect will that have on the branch currents and in the network? If I take all the nodes in a network and move all their potentials up by?

Student: Same amount.

By the same amount, what will happen? I mean it's like giving everybody in the country you know 2 crores and say you know in India everybody is rich. You understand? That is not helping anybody correct? because you know flow of money only depends on differences like flow of current alright. So, if all the voltages have gone up or gone down by the same amount, basically the currents in the branches will not change, correct. So, the question is now, if I add $I_{ref} R_x$ to all nodes what comment can you make about the lower end of that R_x?

Student: 0.

0, very good, ok.

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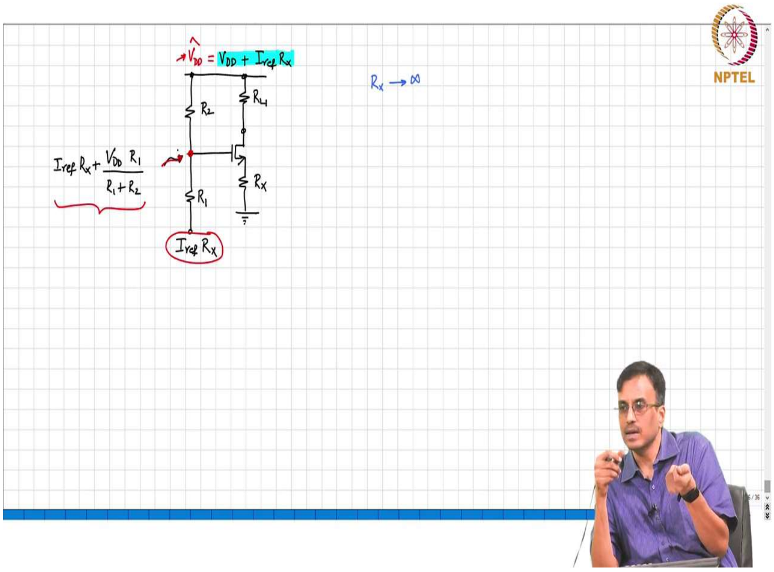

What comment can you make about the lower end of R_1, what potential must it be at?

Student: + I.

What was 0. Remember our analogy, your marks are 0, so?

Student: + I_{ref} R_x.

What should I do with V_{DD}?

Student: V_{DD} +I_{ref} R_x.

Alright. So, what comment can you make about this potential?

What was it previously? It was V_{DD}?

Student: R_1 / (R_1 + R_2).

Now because you moved everything up by the same amount this potential will automatically be I_{ref} R_x +V_{DD} R_1 / (R_1 + R_2).

Alright. So, now, yes if you now look at the circuit what do we see? Well, what I mean is this whole notion of I_{ref} does not make any sense at all anymore. We can call this guy we can call it instead of calling this $V_{DD} + I_{ref} R_x$ we can call this say $\hat{V}_{DD}$, ok

What comment can you make about this voltage? We want that to be this character here, ok alright. So, is there something you can think of to get rid of having to have that $I_{ref} R_x$. What can we do? We have $\hat{V}_{DD}$ here we need to get what is the purpose of that R_1 and R_2?

It is to bias that voltage properly, right. So, there is no real need for the lower end of that resistor R_1 to be at?

Student: I_{ref}.

$I_{ref} R_x$.

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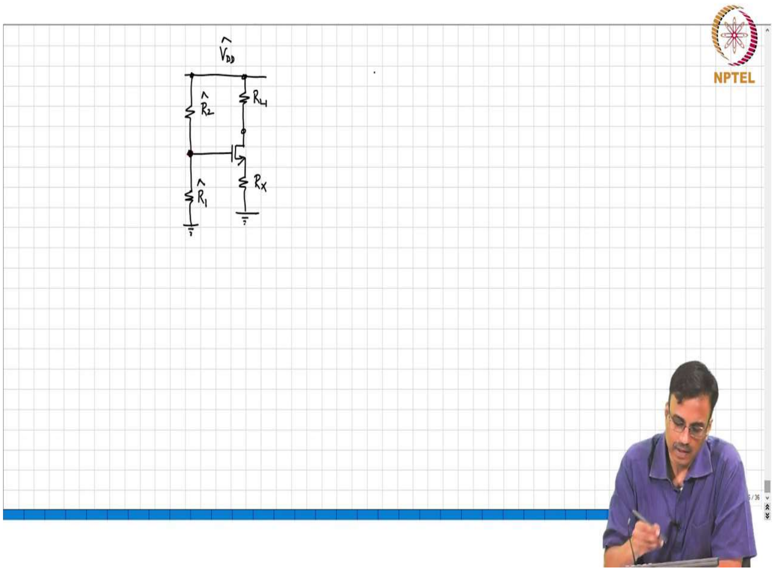

Let us say we ground this and we still want the same potential here. What will we do?

Well that is very easy. So, basically instead of R_1 and R_2 basically you say I am going to call this $\hat{R}_1$ hat and $\hat{R}_2$ where you know the hats basically go and appropriately change the resistor, so that the voltage at the gate remains what we wanted it to be.

So, now, therefore, there is no need for any of this. this is some $\hat{V}_{DD}$ $\hat{R}_1$, $\hat{R}_2$, R_x R_{L1} where the understanding is that compared to the earlier circuit with the current source what comment can we make about $\hat{V}_{DD}$?

$\hat{V}_{DD}$ should it be expected to be greater than V_{DD}. In the limit, $\hat{V}_{DD}$ should be infinite to get the same level of insensitivity to changes in supply voltage and all that stuff. Remember when we had a current source, in the source the bias current in the transistor was absolutely insensitive to? For instance, changes in the gate potential or changes in the threshold voltage or whatever, because the current in the drain would always be the same. Now, that can only be achieved if R_x equals infinity which then will mean that $\hat{V}_{DD}$ will be infinite, but of course, in reality at $\hat{V}_{DD}$ is going to be finite and so will because R_x has to be finite.

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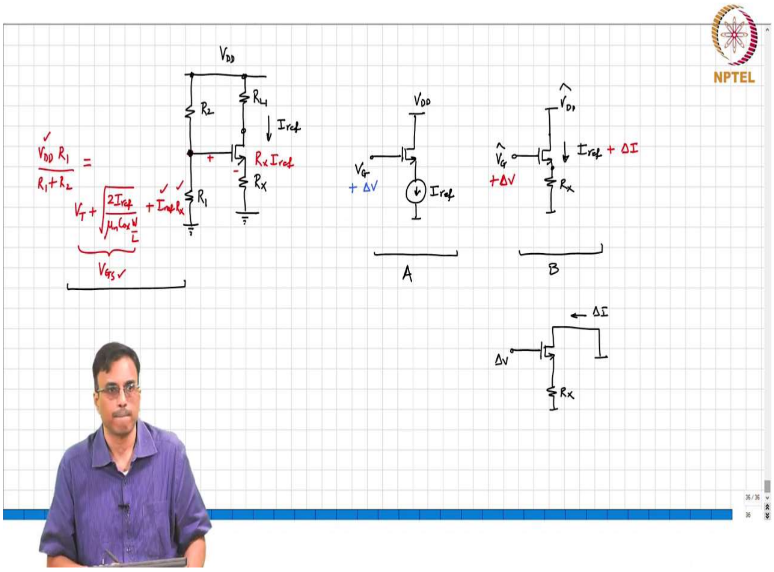

And therefore, actually then the next step is to say let us dispense with this hat where here now it is understood that V_{DD} R_1 and R_2 are chosen appropriately, so that the current flowing in the transistor. Let us say you want a current I_{ref} in the transistor. How will we go about choosing you know R_x, R_1, R_2 and V_{DD}? We want a current I_{ref} in the transistor. What do we do? Let us say we have chosen R_x how will we figure out what R_1 and R_2 must be for a given V_{DD}, what is the source potential?

Student: R_x I_{ref}.

That is the R_x I_{ref}, what is the gate voltage?

V_{DD} R_1 /(R_1+R_2) which must also be equal to?

How is it related to the transistor? I mean, how will you find it? We need I_{ref} in the drain. So, how will you choose R_1 and R_2 given V_{DD}. So, what is the gate voltage? It is of course, V_{DD} R_1 /(R_1+R_2) must be equal to the gate source voltage of the transistor plus I_{ref} R_x. Is this clear? So, basically, what is V_{GS} of the transistor? What is the current flowing through the transistor?

So, what is the gate source voltage? So, we that is nothing so gate source transistor voltage of the transistor is nothing but,

$$= V_T + \sqrt{\frac{2 I_{ref}}{\mu_n C_{ox} \frac{W}{L}}} + I_{ref} R_x$$

So, I_{ref} is known R_x is known and the transistor properties are known, so V_{GS} is known, V_{DD} is known. So, we know from this you can go and find the ratio between R_1 and R_2 and as usual we will choose the parallel combination of R_1 and R_2 to be much larger than R_x, alright. So, now, if you want this circuit to I mean. So, staring at this picture, how do we convince ourselves that R_x actually helps in stabilizing the bias current? So, remember I mean think about it this way if I_{ref} attempts to increase for some reason right what comment can you make about the source potential?

Student: Increase.

It will increase thereby Reducing V_{GS}. And therefore, will act in a way as to reduce I_{ref}, does it make sense?

Student: Yes.

Alright. So, now, the question is, we know that if this so -called scheme has to be effective that R_x must be large, right? So, now, the obvious question is?

Student: How large?

How large? So, how do you figure that out?

Student: Cut off.

So, earlier remember we were keeping V_G fixed this was V_{DD} and we had put I_{ref} in the source. Now, we have some other V_G which we call $\hat{V}_G$, alright. We have some R_x and this is going you know to some large voltage $\hat{V}_{DD}$ and let us say this is also drawing I_{ref}. So, how will we know if you are in the lab? How will you figure out if R_x is a you know what experiment can we do to understand if that R_x is large enough?

Look at this guy here. How will we convince ourselves that this I_{ref} stabilizes the bias? If you are in the lab what will you do?

You wiggle V_G and see how much I_D changes, right. So, if you did that experiment for the circuit on the left circuit A what will you see? If I wiggle V_G by a small amount, so in other words if I change it by ΔV what comment can you make about the current in the transistor in circuit A.

It will not?

Student: Changes.

It will not change. Is that clear or is it not clear?

Student: Clear.

Understand, alright. So, now, what should we do now? So, now, based on this discussion can you tell me what we should do? How will we figure out if a certain R_x qualifies as a large R_x?

We changed V_G by a little bit and observed the change in?

Student: I_D.

I_D right. And when we say the current does not change what it basically you know it does not make sense to talk about the absolute change in current. It only makes sense to talk about a relative change in current. So, now, what comment can you make about circuit B, how will we figure out whether R_x is large or not?

Changed V_G by a small amount ΔV and saw what happens to the current and what did we find ΔI was?

Student: 0.

So, now, for circuit B what will we do?

We will vary Gate voltage by a small amount ΔV and just look at the change in the.

Student: Current.

The current, alright. So, this current will change by some amount ΔI and all that we are interested in is that?

Student: ΔI.

ΔI, ok. So, how will you figure out that the change in current is due to a change in the gate voltage by a small amount ΔV? One way is to write out the equations and solve the quadratic and so on but because Δv is a small change in the gate voltage. We can linearize the circuit about the operating point which we already know. So, in the small signal equivalent what happens what should we have at the gate?

You should have ΔV. What do we have in the source?

Student: R_x.

Alright. What should we have for the drain?

Student: Ground.

Ground very good and what should we have as the drain current? ΔI, alright. We replace the transistor by its incremental equivalent.

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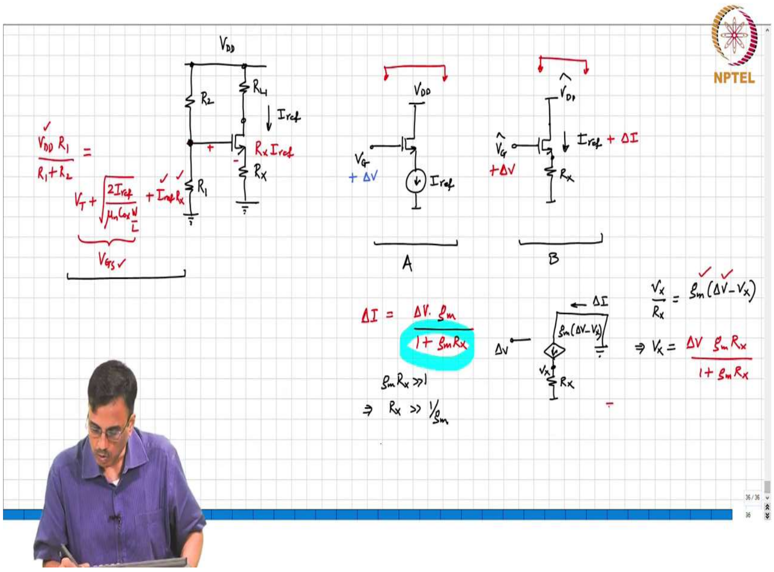

So, what is the control source? Let us call that V_x. What is the control source?

It is ΔV - V_x. So, now, help me figure out ΔI. So, what is the unknown that we are trying to find out?

Student: V_x

Vx. So, how will we find V_x?

So, basically you write KCL at node V_x. So, basically V_x / R_x must be equal to G_m ΔV-V_x ok. So, what does this mean? What is V_x?

What is known and what is unknown in that equation? 1+G_m R_x, alright. So, what is the ΔI therefore? You know V_x. What is the ΔI?

Student: V_x / R_x.

So, that basically is nothing but,

$$V_x = \frac{\Delta V g_m R_X}{1+g_m R_X}$$

Sanity check is to look for R_x, If it is equal to infinity and then what happens?

ΔI should be?

Student: 0.

0, why does that make sense?

Student: Because R_x is current flows.

So, basically if you look at the incremental equivalent of this guy here that is equivalent to this circuit with R_x equal to circuit. The incremental equivalent of circuit A is the same as that of circuit B for R_x equal to how much?

Student: Infinite.

Infinity and we know that in circuit if you change the gate voltage, the drain current does not change. So, the sanity check is that if you set R_x equal to infinity in the expression, we must get

Can somebody think of another sanity check, R_x is infinity is one choice what is the other easy thing to check?

Student: G_m R_x.

One sanity check was as all of you suggested R_x is infinity, what are the other sanity checks that you can do?

Student: $R_x = 0$.

$R_x = 0$ ok. If you put $R_x = 0$ what ΔI do you get?

Student: G_m.

The math is telling us it is G_m ΔV, does it make sense or not?

Student: Yes

Yes, why?

Well, if $R_x = 0$, then it is a common source amplifier. If you have wiggled the gate by ΔV, the current will change by G_m ΔV. The process of adding that resistor R_x in the source is reducing the change in current from what would have originally been?

Student: G_m.

G_m ΔV by a large factor. Or by a factor $1+G_m R_x$, alright. So, now, based on this discussion can you tell me what it means to have a large R_x? What does it mean to have a large R_x. What constitutes a large R_x?

Without R_x the change would have been G_m ΔV, what is the job of R_x?

Student: Reduce.

To reduce that change. I am telling you or the equation is telling you that if I plop in an R_x the change in current is going to be G_m ΔV which is the change without R_x divided by this factor $1 + G_m R_x$. This is valid for all values of resistance R_x. So, now, the question I am asking you is what constitutes a large R_x?

So, basically that number $G_m R_x$. So, this change in the current will be very small if $G_m R_x$ is much much larger than 1 which is equivalent to saying that R_x must be much much larger than $1/G_m$. Let me just finish this in a couple of minutes.

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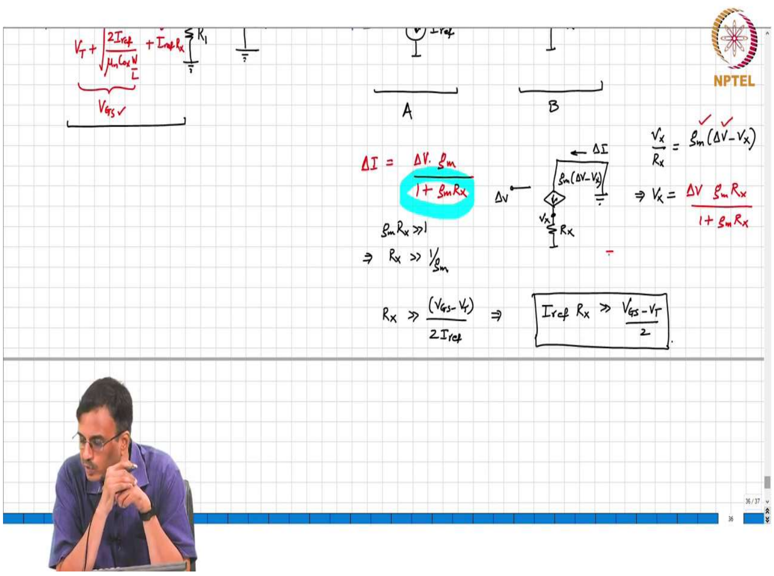

So, what is G_m in terms of the bias current? What is 1, what is G_m? Its $2 I_{ref} / V_{GS} - V_T$.

That must be much smaller than R_x. So, which is equivalent to say that $I_{ref} R_x$ is much much greater than?

Student: V_{GS}.

$(V_{GS} - V_T)/2$. So, saying $G_m R_x$ is much much larger than?

Student: 1.

1 is equivalent to saying that the voltage drop across that resistance R_x must be much much larger than $(V_{GS} - V_T)$. The larger the better.