Analog Electronic Circuits
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Lecture - 15
Robust Biasing - Part 1 Common-Source Amplifier with DC Drain Feedback

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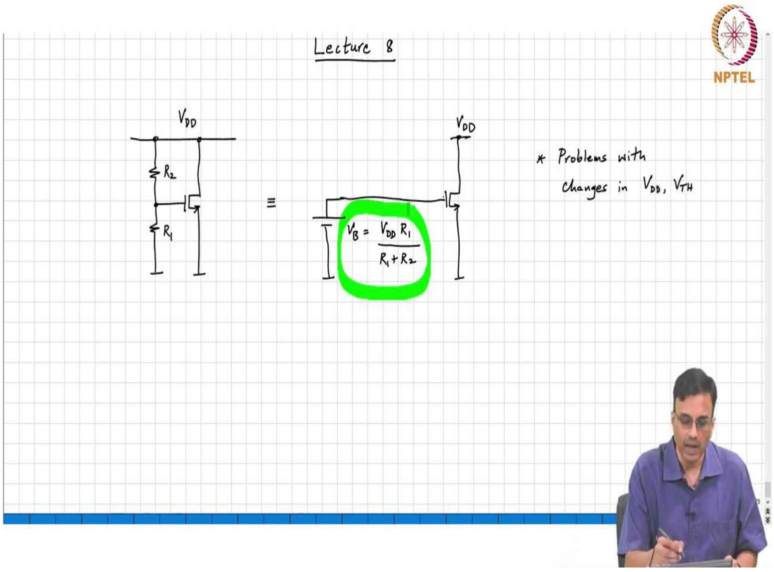

Alright people good evening and welcome to Analog Electronic Circuits this is lecture 8. In the last class we were discussing the practical problem of biasing a transistor with a gate source voltage. So, what we had was something like this, again as far as the biasing is concerned the resistor in the drain is of secondary consequence, right.

If you assume that the V_{DD} is sufficiently large then and this is R_2 and this is R_1 this is equivalent to taking a battery of voltage V_G. I call it, V_B is

$$V_B = \frac{V_{DD} R_1}{R_1 + R_2}$$

and connecting it to the gate like this, of course this goes to a sufficiently large V_{DD}. Now, what are the problems with this arrangement?

Student: We need changes after.

Yeah, so problems with changes in V_{DD} as well as V_T threshold and it also goes to say that since threshold voltage is a function of temperature. Now if the temperature changes the ambient temperature changes, then the threshold voltage changes, but the gate bias does not know anything about the threshold voltage of the device and therefore.

The operating current changes and then with it the g_m and all the other stuff ok. So, this therefore, is problematic in practice and we saw last time that you know this can make the current either you know much too large or much too small again that depends on the change in the threshold voltage.

So, the problem therefore is to figure out the root cause of the problem. We already discussed at the end of the last class and that was that the gate bias voltage V_B as you can think of it as some kind of a dumb battery, right. It does not change voltage when the threshold voltage or the μ_n c_{ox} W/L of the MOSFET changes or deviates from the nominal value and as a consequence the quiescent operating point is changing.

So, the fix therefore, is to make V_B intelligent and be able to figure out. So, basically the question we need to ask is the reverse of what we have been doing so far. So far what we have been doing we are saying here is a MOSFET whose properties are known, right, I apply a voltage V_B tell me what the current is now we have got to ask the.

The reverse question is that I want a current which is maybe 100 micro amperes or 200 micro amperes, whatever I need a current I_{ref} inside I mean flowing through the drain. What should be the gate source voltage that I should apply, so that the current in the drain is fixed, alright.

So, if I answer that question then I will be able to build a circuit to do the same thing and that basically will ensure that regardless of you know what the ambient temperature, what the threshold voltage is you get the desired current I_{ref} in the drain, right. So, in other words, imagine you are in a lab, you have all the laboratory instruments, some meters volt meters, voltage source, current source, whatever.

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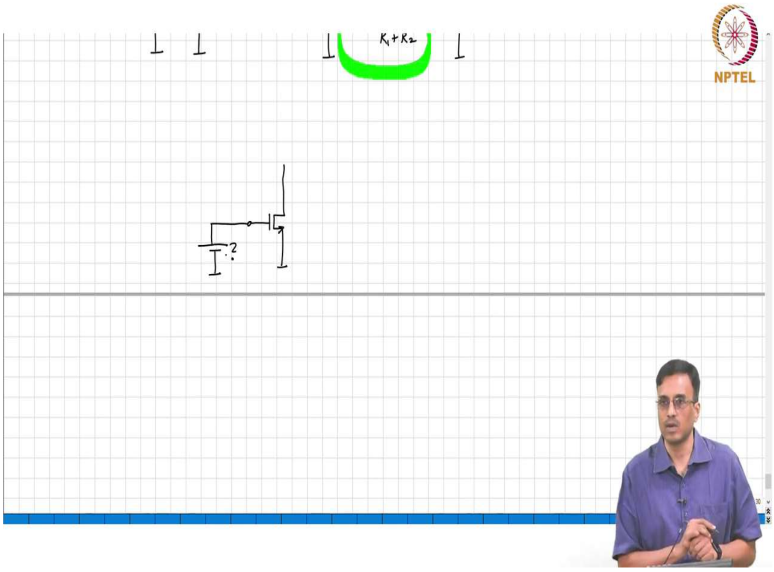

And you have a MOSFET whose threshold is unknown alright; μ_n c_{ox} W/L is also unknown, alright. Now, the question that I am going to ask you is how would you choose how would you come up with this battery voltage or what would you apply to this at the gate terminal?

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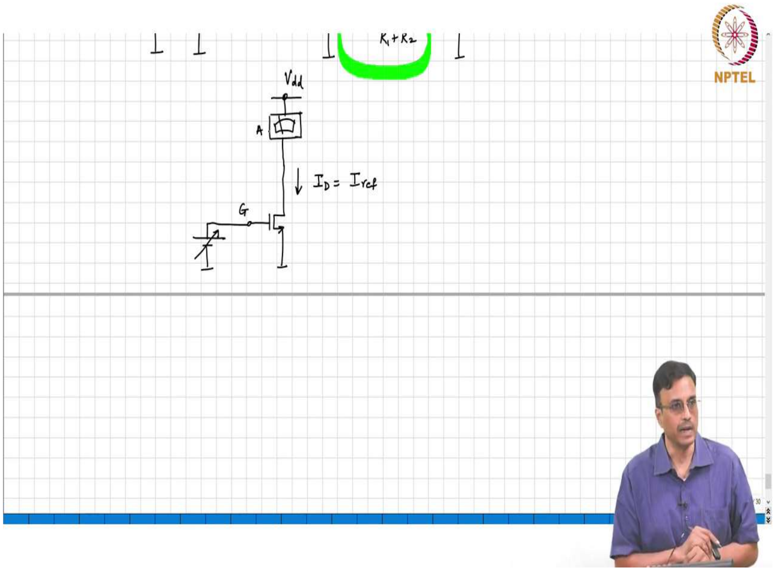

So, that the current in the drain is some desired current I_{ref}? What would you do in principle? What would you do? So, basically what he is the principle is the following: that is you therefore at the gate you have to have a variable voltage. We apply some voltage source unknown voltage to the gate, note down the current. So, note down the current is equivalent to saying that you measure the current in the?

What is the meaning of noting down? I mean you basically have to measure the current now only then you can note it down, correct. So, what do you do? You need to stick an ammeter into the drain. So, basically, we have to ensure that the transistor is operating in saturation. So, we hook the drain up to a sufficiently large voltage, so that the transistor is known to be operating in Saturation. So, basically then we have an ammeter, which shows some reading right and that ammeter will be reading I_D correct.

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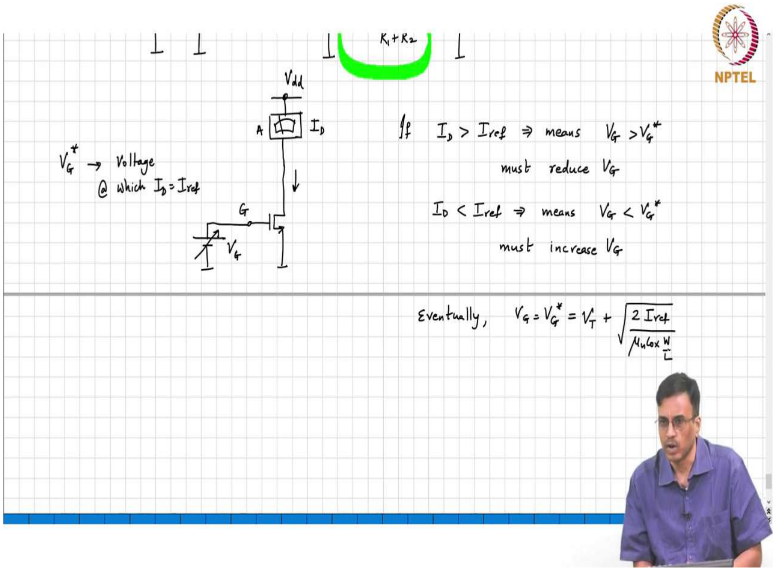

$V_G^* \rightarrow$ Voltage @ which $I_D = I_{ref}$

If $I_D > I_{ref} \Rightarrow$ means $V_G > V_G^*$

must reduce V_G

$I_D < I_{ref} \Rightarrow$ means $V_G < V_G^*$

must increase V_G

Eventually, $V_G = V_G^* = V_T + \sqrt{\frac{2 I_{ref}}{\mu_n C_{ox} \frac{W}{L}}}$

So, we apply some V_G and we read some I_D. Now if I_D is greater than I_{ref} what does it mean?

Yeah let us say the magic voltage at which the drain current is I_D is some V_G star right. So, this is I_D equals I_{ref}. So, if I_D is greater than I_{ref} it means that the applied voltage at the gate V_G is it too much or too little or is greater than V_G^*. So, what must you do?

Must reduce V_G, does it make sense? On the other hand if $I_D < I_{ref}$ what does it mean? It means that the gate voltage is too little and therefore, I must increase V_G. Does it make sense? So, eventually when you are done what happens the gate voltage will be V_G^* and the current will be equal to I_{ref}, ok, alright. So, what is that V_G^*. It is,

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

So, just to take a step back, what have we done in this whole process? We did not know. Please note that we did not know either μ_n c_{ox} W/L or V_T, but still we have managed to find the exact voltage needed at the gate to be able to ensure that the drain current is equal to I_{ref}.

Is this the only way of doing things or is there you know another conceptually different way of doing things right, which we do not know. The properties of the MOSFET I mean when we say properties of the MOSFET what are we looking for?

The μ_n c_{ox} W/L and V_T, ok. So, is there any experiment you can do to measure μ_n c_{ox} W/L and V_T. You flop in 2 V_G. 2 voltages at the gate. Measure the currents and solve the equation correctly. So, once you go solve the equation. Let us say now you know both μ_n c_{ox} W/L and V_T.

Now if somebody says this is the I_{ref} I want in the drain what will you do then? You have these μ_n c_{ox} W/L you have V_T you go and do the math and then it will tell you V_G is that voltage that you must put you know 1.234 volts go and put that. Stick that voltage in there and that will also give you I_D equal to I_{ref}.

Now, if the temperature changes right or the device changes what you have to do now again?

You again have to make you know measurements again extract μ_n c_{ox} W/L and V_T again do the math and then find that V right or god forbid if you do not know how to solve the equation properly and you made a mistake and you know you missed a decimal point. Then what happens? Well you gone and done the math, you know you were careless you go and put that voltage there and the current is going to be completely off. You understand ok.

So, these are two. I mean you know the first method where we put in a voltage, keep monitoring the current and tweak the gate voltage until the drain current is, you know what is that whole mechanism. It is not trial and error. I mean trial and error is basically I will put in some voltage measure the current, well it is not what I want I am going to put in another voltage or a randomly chosen one that is trial and error. What we are doing is not trial and error. It is?

Students: Feedback

Feedback I hope you know the difference between trial and error and feedback. What we have on the board is basically feedback where we compare what we have with what we want to have and kick the system. In this case the MOSFET is in the right direction. So, that what you want is the same as what you have, ok.

The approach where you basically go and find $\mu_n c_{ox}$ W/L and V_T by using measurements or looking at the data sheet basically and then doing the math and then putting that voltage between the gate and the source, that is not feedback. It is an open loop method of doing things which is more robust, because in the open loop technique you know any error you make in either reading the data sheet or computing the computation. Basically, I mean there is no way to figure out whether what you actually achieve is what you wanted to achieve, to give you an analogy.

So, if you want to go from here to the Electrical Engineering department you know there are 2 ways of doing it. One is to put it in Google Maps and what does Google Maps tell you. It will basically say you know, walk 50 feet and then you know climb down you know 20 feet and then walk another 300 feet and then make a left and then walk another 400 feet and then you make a right and then you know that will be your Electrical Engineering department.

Now, if somebody who is doing data entry has made a mistake, then what happens? You know you walk again 50 feet, maybe it is 80 feet and then you know you are trying to walk and then you jump off the a parapet, because Google told you to do so. So, you understand and likewise if any of these measurements are in error either because your GPS is not working or there is an error in data entry.

Then an open loop technique as you can probably understand will basically lead to error. On the other hand, the other way of giving somebody directions is the most natural way of doing things. It is to say keep walking, find the first step of the first flight of stairs, go down 2 flights then keep going straight and the first building you will see is EED.

Now, here there is no notion. there is no notion of accuracy, nothing, right. So, you keep walking and the first landmark you are looking for are the stairs. So, you keep walking and at every point in time you are measuring the error between your location and the location of the stairs that is what you are doing right though you may not realize it is correct, ok. And then you find the stairs and then keep going down and so on.

Now, since you are used to Google Maps. You think that open loop stuff is ok, but most of what we do in daily life is all governed by feedback. For example, even something as simple as taking a spoon and putting food from your plate and putting it into your mouth.

The Google way of doing it would be to say well apply you know 3 newton meters of torque on the spoon and lift the stuff up and then you know go up for 32 centimetres and then make an angle of 46 degrees and then you know push the spoon towards your mouth and if any of those numbers are wrong it will be like that Charlie Chaplin movie modern times where you know the stuff comes and hits your face.

So, close to every day when we are eating we are never making any of these calculations, whether the spoon is heavy or light, whether the food is dense or not, whether your eyes are open or closed, miraculously the food reaches your mouth without any error.

Why is this? You see at every time you are basically sensing the difference between the position of your mouth and the position of your hand and making sure that the tip of the spoon enters your mouth. Now, if you do not believe me you try to close your eyes and then try to feed a friend.

So, you can see that everywhere where you want robust performance independent of within quoted device characteristics, namely the spoon you know, namely the kind of shoes you are wearing. All that is basically independent of all these device characteristics robust performance is often only possible through the use of feedback.

Like in this experiment the properties of the mass transistor were completely unknown, I just gave you a three terminal device and said go figure it out and quite naturally we did. So, anyway everything robust in circuits as well as in the world is all because of negative feedback. So, now, we know the basic idea or next job is for us to translate this into a circuit.

That is easy enough once you figure out once you know what you want to do with circuits. So now, let us get to that. So, what we are trying to do is we need to compare therefore, we need to compare the current in the transistor I_D with the drain current with the desired current I_{ref}. What is the meaning of comparison, what is comparison?

Students: Subtraction.

A subtraction right. So when you compare your marks with the neighbours you are basically saying you know I got 2, you got 4, right? So, comparison is nothing but?

Students: Subtraction.

Subtraction, right. So, you want to compare current, so you want to subtract currents. So, what physical principle will be used to subtract currents god given?

Students: KCL.

KCL, right, ok. So, if you want to subtract 2 currents it's very straightforward. You make the 2 currents fight and then the difference will come up. So therefore, we want to compare a reference current.

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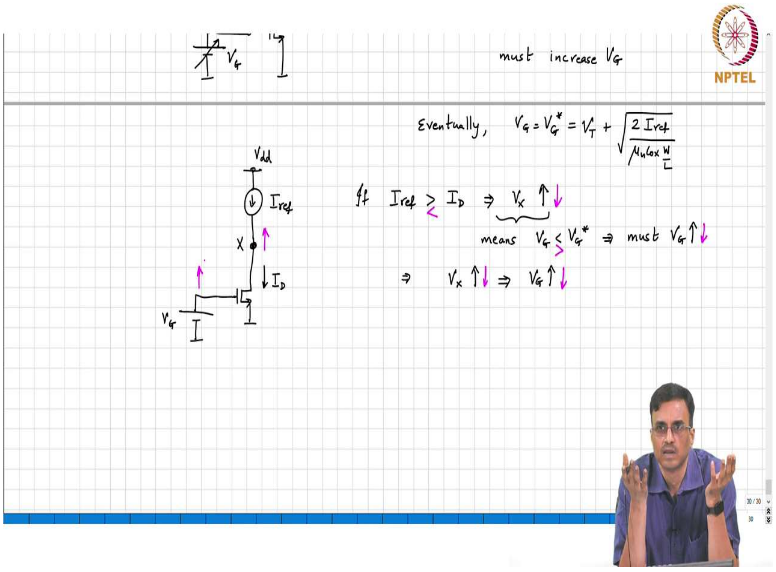

must increase V_G

Eventually, $V_G = V_G^* = V_T + \sqrt{\frac{2 I_{ref}}{\mu_n C_{ox} \frac{W}{L}}}$

If $I_{ref} \underset{<}{>} I_D \Rightarrow \underbrace{V_x \uparrow}\downarrow$

means $V_G \underset{>}{<} V_G^* \Rightarrow$ must $V_G \uparrow\downarrow$

$\Rightarrow V_x \uparrow\downarrow \Rightarrow V_G \uparrow\downarrow$

So, let us assume that the reference current is available as a current source. And we want to compare the reference current with the with I_D, the drain current of the transistor. So, how do we subtract these 2 currents, how do we get the difference between these 2 currents? You make you connect the two together and this is I_D.

So, we apply some arbitrary V_G here. We do not know what at this point. We do not know what it is. So, there will be some I_D in the transistor and we compare it with I_{ref} and let us look at the potential of node x. If $I_{ref} > I_D$ what comment can you make about the potential of node x.

If I_D is smaller than I_{ref} or I_{ref} is greater than I_D what comment can we make about the node potential, potential of node x. A node is nothing but a small bucket which holds charge. Infinitesimally small bucket which holds charge. If more charge is pumped into a node and then it is being removed from a node what comment can you make about the potential?

Student: Increase.

It will.

Students: Increase.

Increase, is that clear?

Student: Yes sir.

Ok. Alright then. So in other words if $I_{ref} > I_D$ then V_X will go up. On the other hand what does this mean if V_X is going up therefore, it means that I_{ref} is greater than I_D, which in turn means that what comment can we make about V_G?

What we should do is another matter. What does it mean first do not jump steps? What does it mean? V_G it means that V_G is less than V_G^*. I basically mean that if V_X is going up it means that I_D is much too small which in turn means that the V_G that we have applied is not enough. So, I must increase V_G.

So to summarize therefore, if V_X goes up I must increase V_G, alright. Now, likewise if I_{ref} is less than I_D what comment can we make about V_X? V_X the potential. The potential V_X of the node x will tend to fall. And that basically means that the drain current therefore, if V_X is falling it means that the drain current is more than the desired one. So, that basically means that V_G is greater than the magic voltage V_G^*. We must reduce V_G. So, if V_X increases we must increase V_G. if V_X decreases we must decrease V_G, alright. So, in other words if this goes up we must push V_G up. If X goes down the gate must be pulled down. So, what is the simplest way of doing this short which what.

Well the easiest way to do this is to simply short the gate to the drain, alright, ok.

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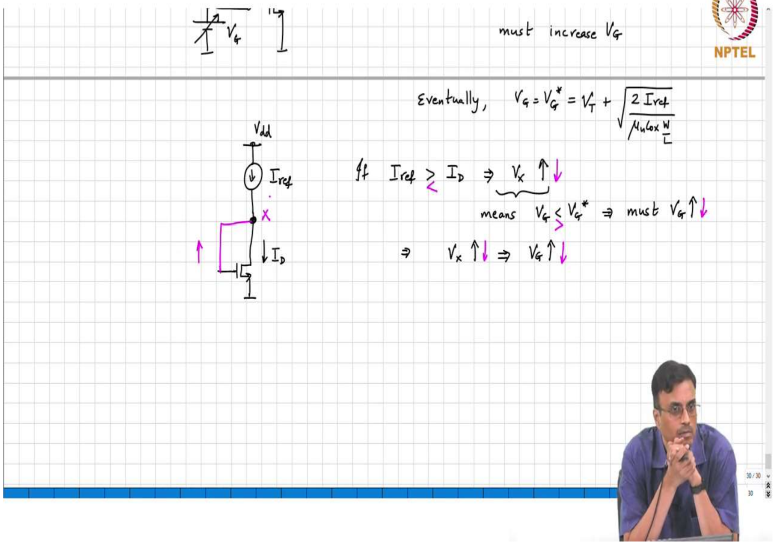

must increase V_G

Eventually, $V_G = V_G^* = V_T + \sqrt{\frac{2 I_{ref}}{\mu_n C_{ox} \frac{W}{L}}}$

If $I_{ref} \underset{<}{>} I_D \Rightarrow \underbrace{V_x \uparrow}\downarrow$

means $V_G \underset{>}{<} V_G^* \Rightarrow$ must $V_G \uparrow\downarrow$

$\Rightarrow V_x \uparrow\downarrow \Rightarrow V_G \uparrow\downarrow$

So, in steady state therefore, when the I_{ref} will be exactly equal to I_D and therefore the voltage developed at the gate is exactly that needed to make sure that the current in the drain is equal to I_{ref} irrespective of the properties of the transistor. Does it make sense people? Alright.