Analog Circuits
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Module - 03
Lecture – 08

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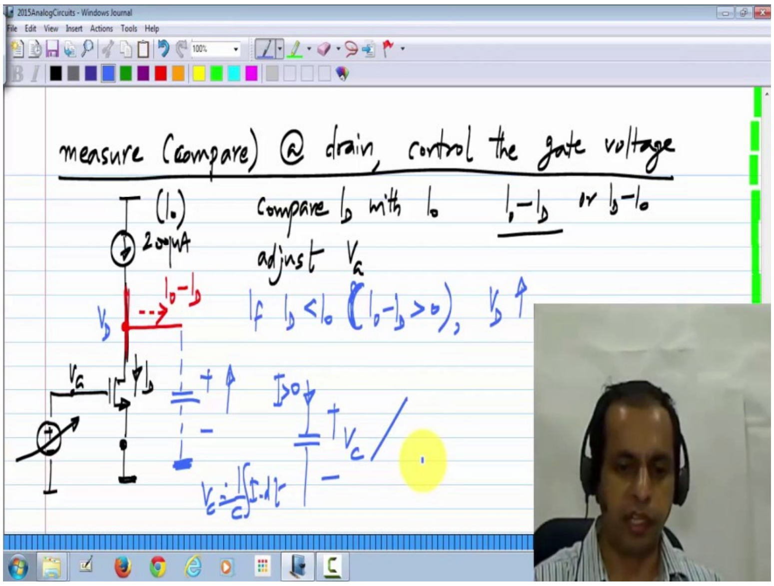

Now, when we say we have a desired current, of course, when calculating I have it in my mind that it should be 200 μA. In terms of circuits, what it means is that there is a current source of the desired value available; that means, that I have a 200 μA, let me call it in general as I_0. The source of value I_0 is available. How to make this current source? We see later because in an electronic circuit everything has to be made using transistors and there are ways of making a current source also using a transistor. So, this current source is available. And what is it that we want to do? we have a transistor and the drain current of this must become equal to I_0. Of course, directly connecting I_0 to this does not work, we saw that because the transistor is a unilateral device.

So, what we need to do is to adjust this gate source voltage. And as I mentioned here, we will control the gate voltage and keep the source voltage fixed. I can fix this to any voltage, but I will tie to ground; it does not matter what voltage I connect it to. For now, let us assume it is at ground. So, what I have to do is this is the gate voltage V_G, and I have to control that, and somehow come up with the circuit arrangement, this is not something I am doing, manually right. I am not looking at the ammeter and adjusting it. I should configure the circuit, so that finally when everything settles down this value of I_D should become equal to I_0.

So, as we described the process of negative feedback, there are two things to be done. Compare I_D with I_0, and adjust the gate voltage V_G. So, depending on whether I_D is more than I_0, or I_D is less than I_0. Now, how do we compare two currents? when we say compare, essentially I want to know whether I_D is more than I_0 or less than I_0. And one of the common ways of doing this is to look at $I_0 - I_D$ or you can also look at $I_D - I_0$. So, the sign of $I_0 - I_D$; if $I_0 - I_D$ is positive, I know that my drain current I_D is too small; and if $I_0 - I_D$ is negative, I know that I_D is too large, so based on that I can do something.

So, essentially I need to be able to take the difference between two currents or algebraically sum of two currents. I hope this part is clear. We have to compare two currents, that means, that I have to compute the difference between these two currents; in other words, some sort of algebraic sum of the two currents. And how do we sum two currents? we know that by Kirchhoff's current law, if you connect two current into a node then the current that is flowing out of that node will be the sum of these two that is if I have I_1 and I_2 flowing that way, what will be flowing out is going to be $I_1 + I_2$. On the other hand, if I had I_2 in the opposite direction, I would have got $I_1 - I_2$. So, Simply by connecting currents to a node, what tends to flow out of the node, we will have to see what happens to that, what tends to flow out of the node will be the sum of the currents, which is exactly what we want.

So, what we need to do here? Here we need to find $I_0 - I_D$. So, if I connect these two together, let me show it like that. What tends to flow out of this node, I am not connected anything there yet, so what tends to flow out of there is $I_0 - I_D$; I hope this part is clear. This is just basic Kirchhoff's current law. So, if I_0 is flowing in this wire, and if I_D is flowing there, what goes out has to be equal to $I_0 - I_D$. Now, where does it really go? Right when you do connect it up like this, and you do have two currents which are different, what happens in case of ideal current sources, we say that such a connection is not permitted. So, such a connection is not permitted, because it violates Kirchhoff's current law, but of course, nothing prevents me from taking two things like the transistor and the current source and connecting them together.

And what really happens in that case? What happens is the following, at every node, there will be some parasitic capacitance. you know that anytime you have two conductors separated by some dielectric, there will be some capacitance between them so; that means, that if we have a circuit with a number of wires, there will be capacitors from every wire to every other wire. So, you can think of this, in order to figure out what really happens when I_0 is different from I_D, you can think of this as flowing into a capacitor, the capacitor can be connected anywhere, it does not matter, but we will assume that it is a capacitor connected to ground. The result of what we are going to discuss does not change regardless of the connection of the capacitor.

So, it flows into a capacitor; this capacitor can be arbitrarily small, it does not matter. That only says how fast the voltage here changes. Just to be able to satisfy Kirchhoff's current law, this current has to flow somewhere. And it will flow into the parasitic capacitance associated with that node. So, again I hope this part is very clear; otherwise, please go back and think about it. If you have two currents coming into a node, and those two currents are unequal, the difference will flow into a parasitic capacitance. So, what happens because of that, it is very clear if I_D is smaller than I_0 this means that I_0 - I_D is more than zero. So, current is being pumped into this capacitor, the voltage across this capacitor goes up. And what does it mean, this is ground, this is the drain voltage V_D, the drain voltage V_D increases.

Again this is basic behavior of the capacitor. If you are measuring the voltage of the capacitor like this, and if you pump a current, positive current in that direction, what happens is this V_C will go on increasing that is because V_C ¿$\frac{1}{C}\int I\,dt$. We do not have to worry about exactly the shape of the current or the voltage. All we need to know is that if the current is positive, the voltage will go on increasing.

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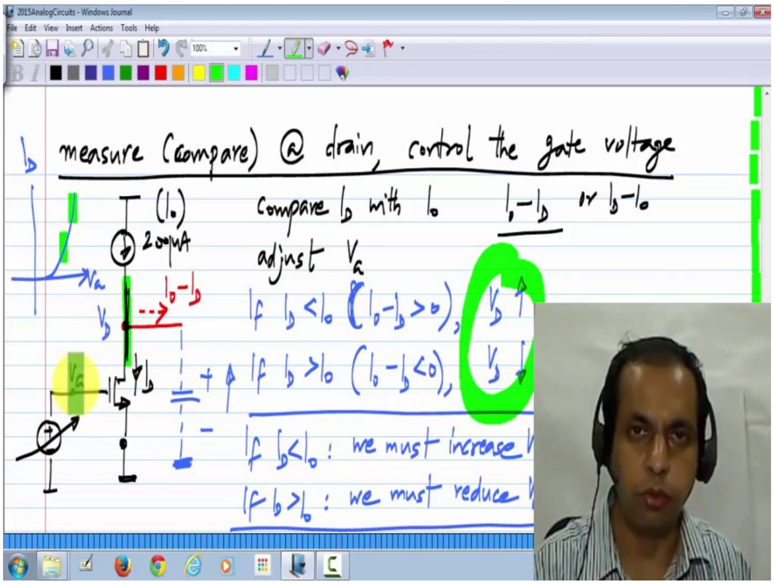

Now, conversely if I_D is greater than I_0; that means, that more current is flowing down than what is being pumped in, so this current will be negative, current will be actually drawn from the top plate of the capacitor, V_D falls – the drain voltage falls, that is if you have a capacitor, you are measuring the capacitor voltage like this, and if you have a current in this direction, this V_C goes on decreasing, because you are taking charge out of the upper plate. So, this is what we need to know, we need to know that V_D increases or decreases based on whether I_0 is more than I_D or I_0 is less than I_D. Now, what is it that we need to do? Earlier I was looking at the ammeter and doing this, but now I need this circuit to automatically do this.

What should happen if I_0 is more than I_D, if I_D is smaller than I_0, what should I do, I know that I_D is too small, I have to increase the value of I_D. so, that means, I have to increase the value of V_G, because I_D is an increasing function of V_G. We know that I_D versus V_G, it is the square law, it looks like that. So, if I have to increase I_D, I have to go from there to there, I have to increase the value of V_G. If I_D is smaller than I_0, we must increase V_G, and if I_D is greater than I_0, the opposite; that means, that I_D is too large, we have to make it smaller, so the way to make it smaller is by reducing the value of V_G. So, this is the action we need, this is the feedback action we need.

Now, how do we configure the circuit, so that this automatically happens? If you look at it, look at what the drain voltage is doing, if I_D is smaller than I_0, V_D is actually increasing, that is because this difference current flows into the parasitic capacitor and tends to increase that.

And it is exactly the same as what we wanted for V_G. Similarly, if I_D is greater than I_0, V_D goes on decreasing and if I_D is greater than I_0 we actually want to reduce V_G. In other words, what we want to happen for V_G is already happening at the drain, what we must to do the gate voltage is actually happening to the drain voltage simply because of this connection. So, now the solution is pretty obvious, all we have to do, or one of the ways to do it is to somehow transfer this V_D to V_G.

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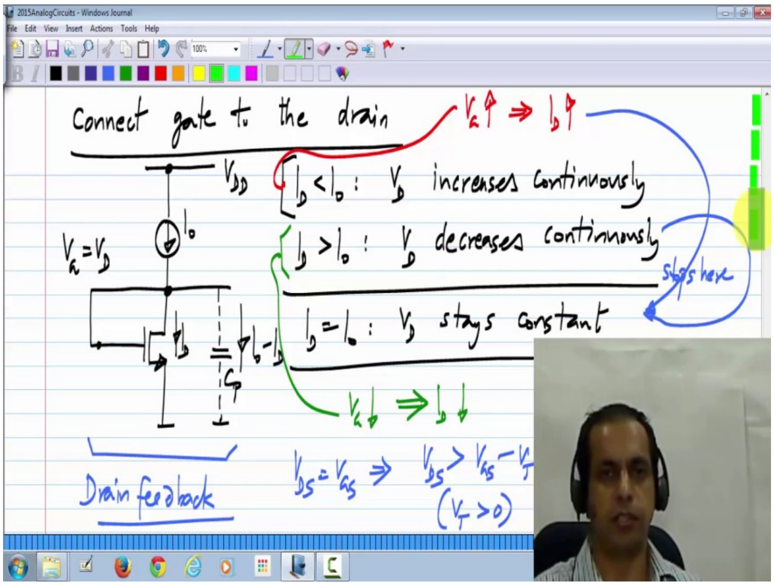

And the easiest way to do that is to connect the gate to the drain. Again what we desire for V_G, the kind of variation we want for V_G is happening at the drain. So, the easiest thing to do is to make $V_G = V_D$. That gives us the first type of circuit, this will be connected somewhere. I will assume that it is connected to some supply voltage V_{DD}, this is the current I_0, and this is the actual drain current I_D, I_0 - I_D will flow into this capacitor C_p which is the parasitic capacitor; do not worry about its size, it is just to imagine the kind of voltage variation, you get at the drain. And lets say we connect the drain to the gate, because of this connection we make V_G equals V_D.

What happens now? if I_D is smaller than I_0 some current will be flowing into this capacitor, and this voltage will go on increasing. On the other hand, if I_D is more than I_0, some current will be drawn from the upper plate and this voltage will go on decreasing. And if I_D is greater than I_0, V_D decreases continuously. Now, when does V_D stay constant? V_D will stay constant only if I_D exactly equals I_0. Now, lets see what happens because of this connection, lets say I_D

initially was smaller than I_0, when you start of maybe it starts with zero current, then the drain voltage goes on increasing. Now, what happens in that case, the gate voltage also goes on increasing, so this increases the value of I_D. So, I_D is smaller than I_0, so this I_D will go on increasing because of this feedback, so it is exactly what you want. Or if I_D is too much, if I_D is higher than I_0, then the V_D will go on decreasing, which will, in turn, reduce the gate voltage, which will, in turn, reduce the drain current.

So, in other words, if in this particular case, what happens is V_G increases which implies that I_D also increases. And in this particular case, V_G falls down, which implies that I_D also falls down. In either case, what will happen is both of them will end up at this state. So, in this case, because of the feedback I_D will go on increasing, we do not have to worry about whether it is slow or fast, it will keep on doing that until I_0 becomes exactly equal to I_D. So, in that case, it will stop. And exactly the same thing happens in this case as well. In this case, I_D will go on decreasing until it becomes exactly equal to I_0.

Now, if it is not equal to I_0, we know that the circuit would not reach steady state, because this voltage will go on increasing or decreasing. Finally, when this voltage becomes constant, we guaranteed that I_D is exactly equal to I_0, that is simply by Kirchhoff's current law. So, this is the most basic way of biasing a transistor, and this is known as drain feedback. What it really means is that the drain source voltage is feedback to the gate source, the gate source voltage equals the drain source voltage in this case. So, the drain voltage is somehow fed back to the gate, and finally, steady state is reached where the drain current of the transistor equals the desired current I_0.

What I want to emphasize very strongly is that if you look at this circuit, do not think of it as I_0 being somehow applied to the transistor, this is the feedback circuit. The difference between I_0 and I_D triggers some feedback action that controls the gate voltage. It is only by controlling gate voltage that I_D can change, so this is the feedback circuit, in which things are arranged in such a way that V_G will go on changing, if I_0 is different from I_D, and V_G will remain constant only if I_0 equals I_D, and the circuit will finally, reach that steady state. So, it is a feedback circuit.

Now, there are other variants of this that is we do not have to connect V_G to V_D directly, all we want is this kind of variation V_D increasing to be transferred to V_G in some way; there are many ways of doing it, so that we will study. And also another thing to look at is whenever we invent a circuit like this, whenever we come up with bias circuit, we have to make sure that the transistor remains in saturation, because that is the desired operating point for an amplifier. So, we have to check that as well. Actually, in this case, it must be pretty obvious to you, because V_{DS} equals V_{GS}, so this automatically means that V_{DS} will be greater than V_{GS} - V_T as long as V_T is positive. So, if we have a positive V_T transistor, this connection ensures that the transistor remains in saturation region. So, we will use this to make amplifiers, we will see variants of this in the following lectures.