Analog Circuits
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Module - 04
Lecture – 11

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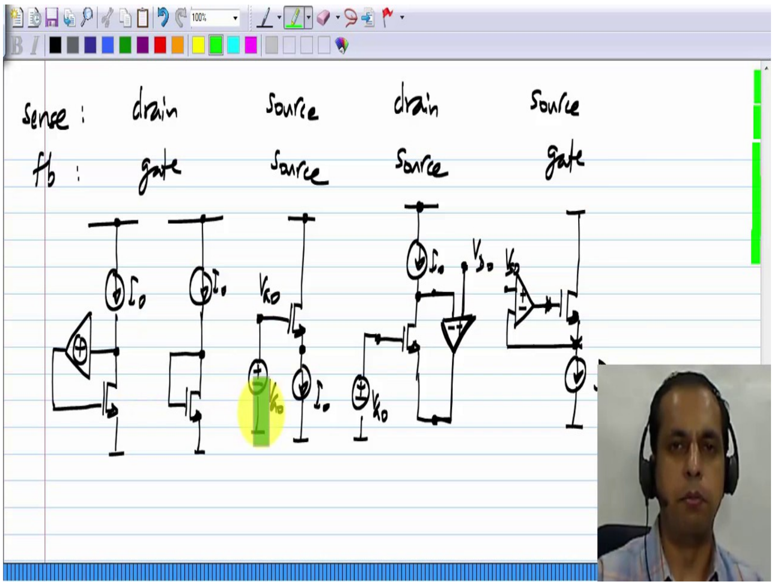

We have studied a number of bias circuits to bias a transistor at a constant drain current instead of fixing the gate source voltage. And they are all shown here. There are different choices for where you sense the current and where you apply the feedback to, based on that you get four different types of circuits. Now, these circuits, they use these current sources, which are required. Now, of course, using a current mirror, we can generate a number of current sources from a single current source, so that is possible, but these current sources are usually more easy to get when you have an integrated circuit. The economics are slightly different for integrated circuits and discrete component circuits.

When you have an integrated circuit, the number of components does not matter, it is the total area that is matter. Whether you use a transistor or a resistor, the cost is more or less the same, because it is basically based on the area that is occupied by component, In fact, that could be that in some process a resistor is more expensive than a transistor, or capacitor is more expensive than a transistor. Now, this is usually not the case when you have discrete component circuits, when you buy these components and build circuits around them. There are typically passive components like resistors and capacitors are very inexpensive, whereas, transistors are lot more expensive. So, you would not use another transistor to realize this current source. And also you may not get a sufficiently good matched transistor to realize this current sources and so on. Especially in discrete component circuits, and sometimes in integrated circuits, there is some motivation to not use a current source like this for biasing. So, let us see what else we can do. I will take one of this as example, but exactly the same principle works for anything else.

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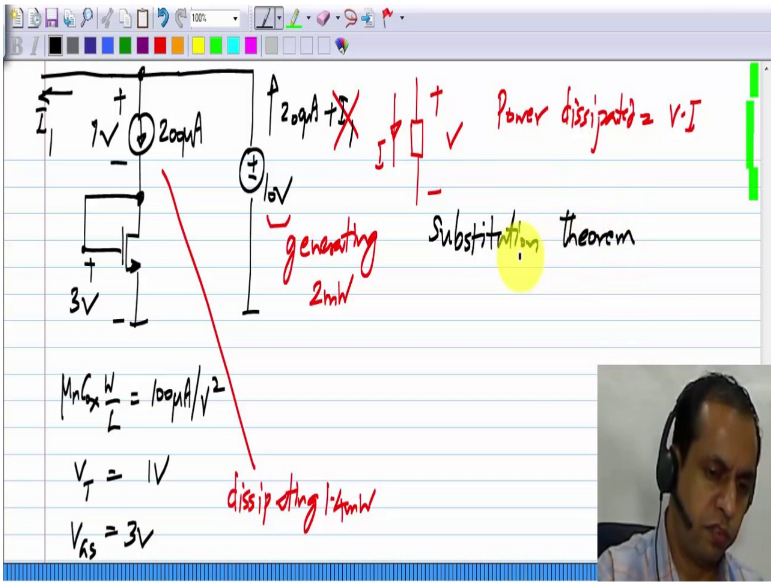

Let me for illustration take some numerical values $\mu_n C_{ox}\left(\frac{W}{L}\right)=$¿ 100 μA/ V^2 and threshold voltage of 1 V. And let me assume that this current is 200 μA, and if you calculate V_{GS} will come out to be 3 V. This current 200 μA corresponds to V_{GS} of 3 V. Let us say the supply voltage is for illustration 10 V. Now, the question is how do I get rid of this current source. How do I_Do that? First of all, this current source, it is carrying a current of 200 μA and it has a voltage of 7 V across it in this direction. What I want to show is the distinction between this current source and this voltage source. Whereas this voltage source here is supplying 200 μA and if there are other circuits connected, they will be drawing some current I_1 and it will be supplying that I_1 as well.

The point is this current source is actually dissipating power, if you remember how to calculate the power dissipated in a two terminal element, you consider the voltage and current according to the passive sign convention that is if the voltage is defined with positive at some terminal, current should be going into that terminal. Then the power dissipated is (V * I), and the power generated by this would be – (V * I). And if you follow that you can see that this current source here it is dissipating 1.4 mW whereas, this source is generating 10 V * 200 µA = 2 mW assuming I_1 is zero.

Now, you cannot replace this voltage source, this is the source of energy whereas, this current source, although it could be a source of energy, in this particular circuit, the voltage across is such that it is actually dissipating power, it is a dissipative element. So, presumably, it can be replaced with another dissipative element and the obvious candidate is the resistor. So, now can we replaced with this resistor; I am sure you remember what is known as substitution theorem from basic electrical circuits.

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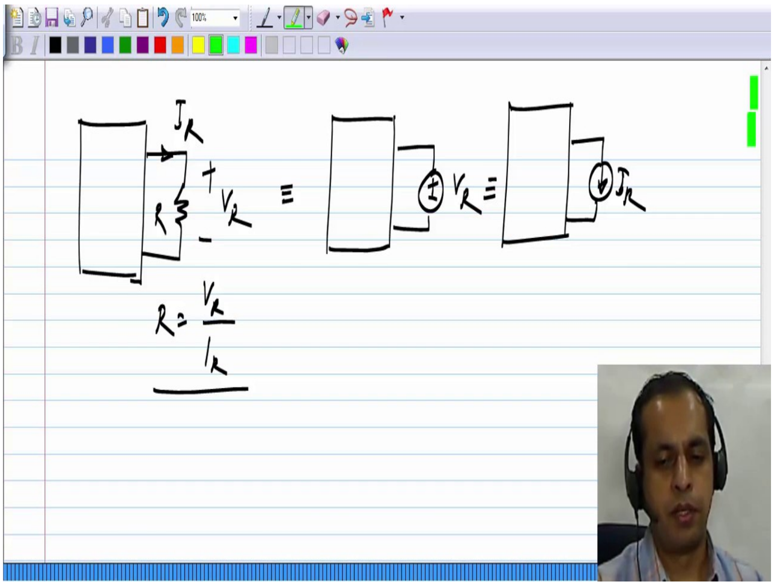

The substitution theorem says that if you have a circuit with some resistor, it has a voltage V_R across it, and a current I_R through it, and of course, R will be equal to V_R by I_R by Ohm's law then you can replace the resistor with the voltage source of value V_R, or a current source of value I_R without changing any of the node voltages or currents in the circuit. If you do not recall this, go back to basic electrical circuits and then find out about this theorem, this is known as substitution theorem. So, essentially a resistor can be replaced by another element which has the same voltage and current across it.

By the way, this is not the general substitution this is only for particular values of sources that are used in the circuit. You have a circuit with some voltage sources and current sources, they have some particular values, only for that particular set of values you could replace a resistor with a voltage source or a current source. Now, it turns out you can also go the other way around; if you have a circuit with some voltage source or a current source, you can replace the voltage or current source by a resistor provided that the source is dissipating power; otherwise, you have to replace with a negative resistance, and you could get some singular conditions. But if you have a circuit, where a current source is dissipating power, you could replace it with a resistor. And what resistor should you replace it with? It should be such that the voltage across and current through it are exactly same as in the original circuit.

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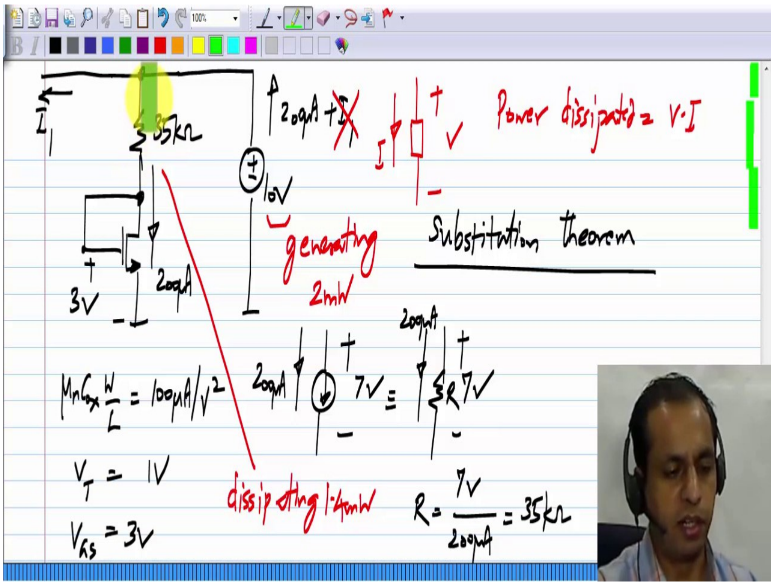

So, for instance in this case, in this operating point remember this substitution theorem is true for a particular value of source voltages that is at a particular operating point. So, at this point, we have 7 V across it and 200 µA through it, and we want to replace it with a resistor, and the resistor also must have 7 V across it, and 200 µA through it. But of course, resistor is governed by Ohm's law, so if a resistor has to have 7 V across it, and 200 µA through it, the value of the resistance has to be 7 V divided by 200 µA, which is 35 kΩ. So, what you can do is you can get rid of this current source. And replace it with the resistance of 35 kΩ, and you will get exactly the same current.

Now, if these problems are given to you as an analysis problem. In fact, I would encourage you to solve it for like that. You would just take this circuit, let us pretend that you do not know what the current is solve for the current. You have to solve a quadratic equation and it comes out quite easily, and you will see that will be 200 μA. So, whether you had a 200 μA current source here or 35 kΩ resistor, you will get exactly the same current. So, this is used many times.

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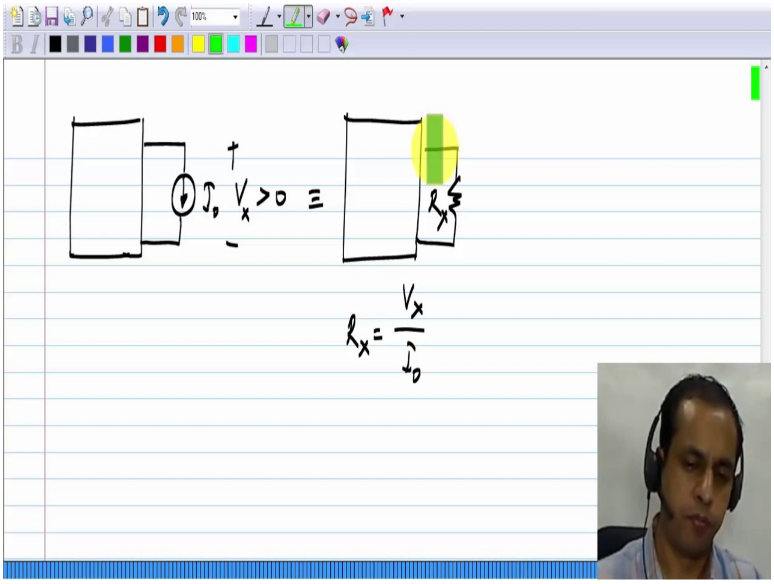

In this particular context, we are looking at replacing current sources by resistors. So, let us say you have a circuit and you have a current source of value I_0 somewhere and the voltage across that is some V_x, let us say, and V_x. > 0. It is only in that case that this will be dissipating power, and you can replace it with a resistor. Then you can replace the current source by a resistor R_x and the value of R_x of course, has to be equal to V_x divided by I_0 and the conditions in the circuit that is the voltages and currents in the circuit will remain exactly the same. And this can be done for any circuit, all of the biasing circuit that we discussed earlier for particular values of supply and so on, you need to know the numerical values of everything then you can replace the current source in those biasing circuit with the resistor and the bias condition will remain exactly the same.

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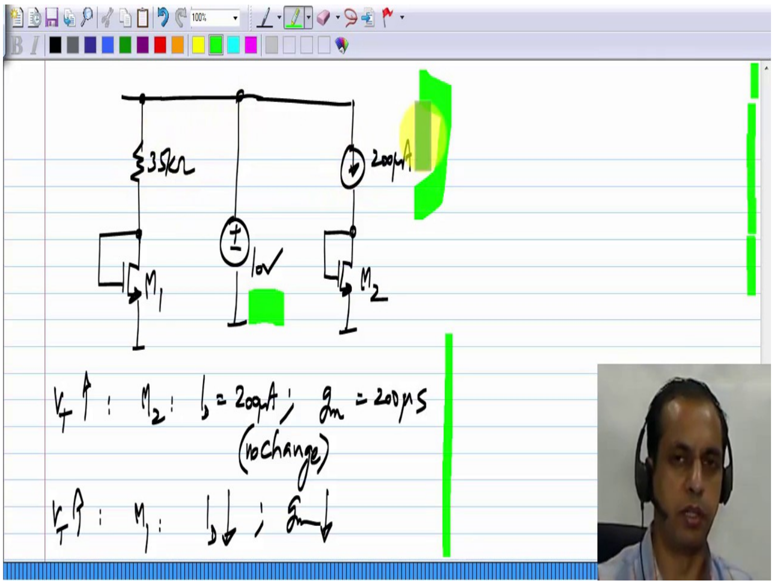

$V_T \uparrow$: M_2 : $I_D = 200\mu A$; $g_m = 200\mu S$
(no change)

$V_T \uparrow$: M_1 : $I_D \downarrow$; $g_m \downarrow$

Now, if a resistor is as good as the current source then why would you ever would not use a current source; now not everything is not exactly the same. For instance, let me take the circuit again, so I had a 10 V source and a 35 kΩ resistor. And I have my original circuit with a 200 µA current source. So, now let me call this M_1 and M_2, remember the whole idea of using constant current biasing was to reduce the sensitivity of the transistor transconductance to the parameters of the transistor such as the threshold voltage and current factor.

Now, that sensitivity will be different for this circuit and that circuit. So, let us say the threshold voltage of M_2 changes by some amount, the current through it will still be exactly 200 µA. So, the trans conductance of M_2 does not change at all. This is the easiest example to consider. So, let us say V_T increases, M_2 has a current of 200 µA and g_m is 200 µS. Basically neither of these changes. Whereas in this case, if the threshold voltage increases, and if you carried out that earlier exercise I mentioned of trying to solve for the current here, you will see that the current will change. I_D will actually reduce slightly and g_m also reduces. It is still very likely to be much better than constant V_{GS} biasing, but it is not as good as biasing it with an actual current source. So, resistor is really a poor man's current source, but sometimes just for the sake of convenience, you can use that.

And as you can guess the equivalent resistance, the incremental resistance of the current source is infinity, so the larger the value of this resistance the more closely it approximates the current source. Now, for instance, that you also know from Thevenin and Norton equivalents, if you have a large voltage and a large resistance in series with it then it behaves more or less like a current source for small values of load resistance. So, exactly the same thing works here. If this resistor happens to be very large and if this voltage is very large, then it will tend to behave like a current source, so that is one difference. The sensitivity is actually worsened when you use a resistor, and also there is additional sensitivity to something else. If you change the supply voltage ten V, what happens to M_2, absolutely nothing because it does not even see the change in that voltage, all of that change will appear across this 200 µA current source.

So, there will be no changes in current or trans conductance of M_2. Whereas, if you change the voltage to M_1, I mean if you change the supply voltage, M_1s currents will change. If this becomes 12 V instead, the current in M_1 will increase. So the sensitivity to supply voltage will be zero in this case, and non-zero in that case. So, this is inferior to having a constant current source, but it is superior to having a constant V_{GS}. The motivation to use this is simply to avoid current sources especially in case of discrete circuits. The analysis of sensitivity and so on you can carry out in activity and assignment problems then you will clearly understand and by how much this is worse than that one.