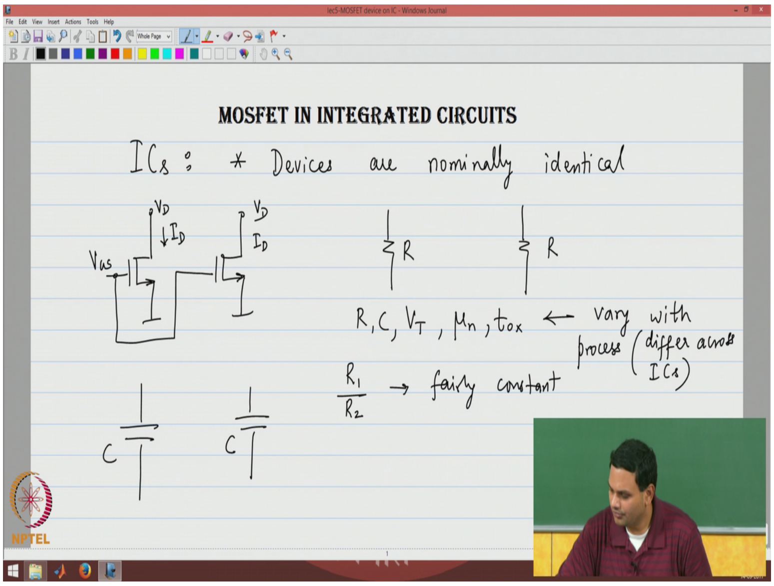
Analog Integrated Circuits
Prof. S. Aniruddhan
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture - 05
MOSFET in Integrated Circuits

In this lecture we will look at a few characteristics related to MOSFETs specific to integrated circuits. Now, what do we understand by integrated circuits? You basically have a single substrate on which several different circuits are grown and they are always tied together on the same chip.

(Refer Slide Time: 00:43)



Now, what we know for integrated circuits is that if you have two devices that have the same dimensions and are of the same type, they are nominally identical. What does that mean? If I take two devices let us say 2 MOSFETs and I apply the same gate source voltage to them and they apply the I apply the same drain voltage to them, they will have exactly the same current, they will have exactly the same current. That is what we mean when we say that the devices nominally identical they will have the same characteristics.

Similarly if I take 2 resistors and they are of the same type of resistors on the integrated circuit I use the same material to create the resistor. Remember that a resistor can be created in many different ways on an integrated circuit I can use a piece of polysilicon, I can use a metal, I can use a lightly or strongly doped resistor as longly doped piece of silicon.

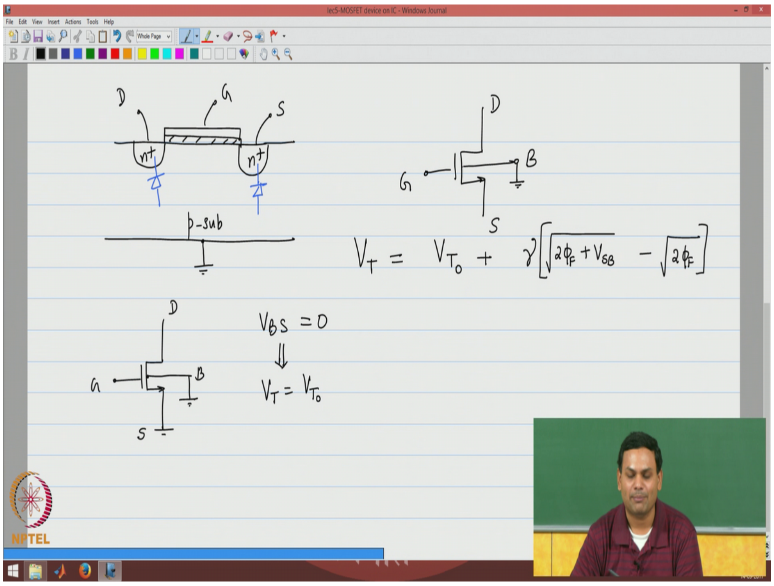
There are many different ways to create resistors if I build a resistor using a certain width and length of material on the integrated circuit, if they have the same dimensions I will assume that their nominally identical they will have the same value of resistance. What I cannot guarantee is that if I take 2 different ICs and I have the same dimensions of MOSFET or resistor or capacitor I cannot guarantee that on those two different ICs they will have the same value.

This is because if that two different ICs may be processed in very different ways may be the temperature of the furnace in which the substrate was baked was different or maybe the doping concentration was slightly different etcetera the actual value of device parameters such as resistors, capacitors, capacitance value or threshold voltage that doping concentration etcetera or the thickness of the oxide all these things vary with the process, in other words they are different for different ICs.

Similarly, the value of V T or mu n or the value of the resistance can be a function of temperature, if temperature increases if the resistance has a positive temperature coefficient their value of the resistance will also increase. What I am assured however, is that if the 2 resistors are on the same integrated circuit they will experience the same temperature change because they are so close to each other and they will therefore, experience approximately the same temperature change. So, in other words what I am assured of is these devices will be nominally identical they will experience identical variations.

Similarly, what you can also tell is that ratio of quantities will also be fairly constant this is because for example, with temperature if R 1 and R 2 have the same temperature coefficient if they are made with the same material then R 1 by R 2 will stay constant over temperature.

(Refer Slide Time: 04:47)



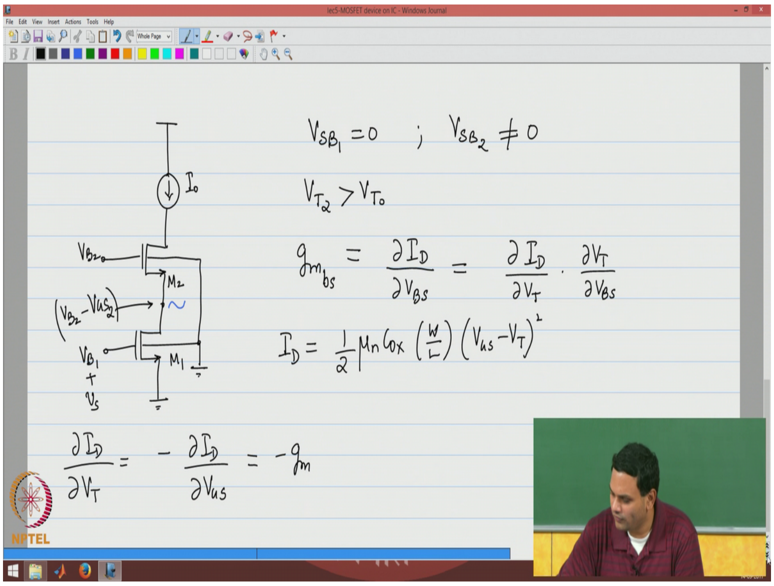
How is the device made if I were to draw the cross section of the device? If I look at the MOSFET I need the 2 drain source diffusions I will take the example of an NMOS transistor. So, they will be n plus diffusions on the p substrate, I will denote that by p-sub and I will grow the gate oxide and on top of that the polysilicon will be the gate, so I will denote these by this three the gate drain and the source.

Please note that the device clearly has a fourth terminal which is the bulk terminal. So, now, we introduce the concept of the MOSFET being a 4 terminal device I will denote that by B. Normally all NMOS devices on the same substrate will have a common bulk and to ensure proper operation you need to make sure that these diodes are always this pn junction diodes are always reverse biased and therefore, the p substrate is always connected to the lowest potential on the integrated circuit we will assume that we are working with unipolar circuits and therefore, the lowest potential circuit is ground. So, the substrate terminal is not under your control it is always connected to ground.

If I take such a device when I connect the device in the common source amplifier configuration then clearly the bulk to source voltage is 0. Now it turns out that the if the bulk to source voltage were not 0 the threshold voltage of the device will change that can be represented in this form if you want to know more about this please consult a good devices semiconductor devices text book on MOSFETs that will explain the exact dependence of threshold voltage on the source bulk voltage. I will just give you the final result.

The actual expression for the threshold voltage is V T naught which is a threshold voltage when the source bulk voltage is 0 plus some factor gamma times the fermi potential plus V SB. Please note that if the source bulk voltage is 0 then V T will be V T naught. So, for the common source amplifier the threshold voltage of the device is V T naught. Now, also note that the bulk is always connected to the lowest voltage possible therefore, normally the source bulk voltage is positive and the threshold voltage would be larger than V T naught if the source is biased data larger voltage.

(Refer Slide Time: 08:46)

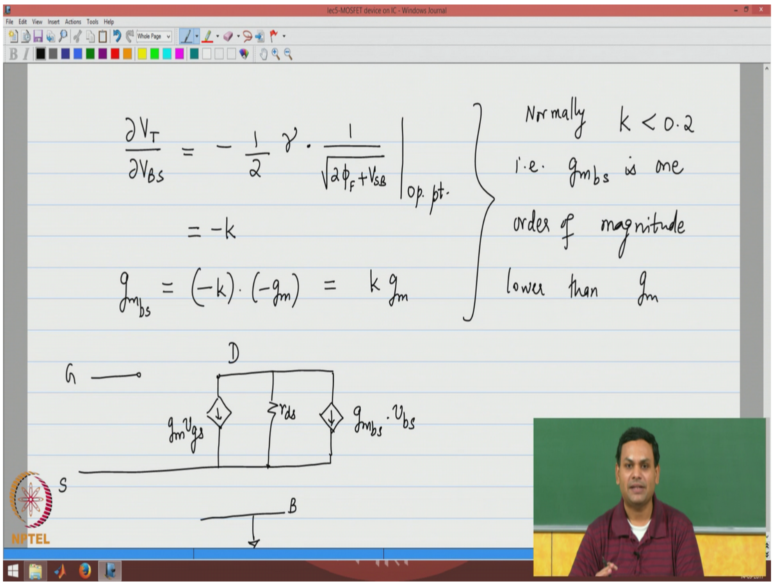


There are many circuits where this would happen I will show you what will happen if we look at the circuit which you folks would have seen before which is the cascode amplifier. Please note that the source bulk voltage for M 1 is 0, but the source bulk voltage for M 2 is not 0, it is larger because the source of the transistor will have a voltage of V B 2 minus V GS 2. Since this have a since V SB 2 is positive V T 2 is greater than V T naught the two devices will have different threshold voltages. So, any circuit where the source and bulk are not connected together will have this effect.

Now, there is one more thing to keep in mind the minute the source and bulk are not connected together we should also look at a different aspect of this particular effect. Please note that the bulk is connected to ground which is the lowest potential. So, normally the bulk is always at small signal ground whereas the source voltage need not always be at small signal ground. For example, the source of M 2 will experience a signals mean we need to quantify the effect of this clearly there will be a signal aspect to this we will represent that by a as small signal conductance a transconductance called gm bs I will call that I will represent that as gm bs which is nothing, but dou I D over dou V BS.

Clearly this is the dependence of I D on V BS is through the threshold voltage. So, therefore, this is dou I D over dou V T times dou V T over dou V BS. And now we need to calculate these two quantities let us look at dou I D over dou V T. So, I D is clearly half mu n C ox W over L into V GS minus V T the whole squared. Now please note that dou I D over dou V T is the negative of dou I D over dou V GS which is nothing, but minus gm, where gm is the transconductance of the device.

(Refer Slide Time: 12:10)



What about dou V T over dou V BS? Dou V T over dou V BS is clearly minus half gamma times this expression this is of course, calculated at the operating point, so V SB value is chosen to be the DC operating point value to calculate this expression therefore, I am going to x call this sum factor k because gm bs is finally, minus k times minus gm which is k times gm.

If I were to now draw the incremental equivalent circuit of the device I have the transconductance of the device gm times V GS, I have the small signal r ds of the device representing the dependence of I D on drain voltage. Finally, I have a third incremental voltage controlled current source which is simply gm bs time V BS where the bulk terminal is connected to small signal ground. So, if the source moved with respect to bulk you will have a third small signal component in the small signal picture.

Now the good thing about this is that normally k is less than 0.2, so that the effect of gm bs is 1 order of magnitude 0.2 or 0.1. So, the effect of gm bs is 1 order of magnitude lower than gm. So, in many cases even if the source were to move for hand calculations the accuracy may not be lost if gm bs is ignore, but this is definitely something to keep in mind because once you go to a simulator you will see this difference. So, this is one of the second order effects to keep in mind when you are designing amplifiers with MOSFETs. Now the same thing is valid even for PMOS transistors. So, PMOS transistors will also have the same effect they will also end up having the same small signal equivalent circuit.

So, with that we will assume that the most of the small signal effects in the device are taken care of, so the low frequency model of the device that we will look at will consist of the three quantities gm, r ds and gm bs.