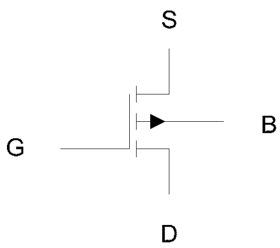
Small Signal Analysis of a PMOS transistor



Consider the following PMOS transistor to be in saturation. Then,

$$I_{SD} = \frac{1}{2}\mu_p Cox(V_{SG} - V_{tp})^\wedge 2(1 + V_{SD}\lambda)$$

From this equation it is evident that I_{SD} is a function of V_{SG}, $V_{SD,}$ and $V_{SB,}$ where V_{SB} appears due to the threshold voltage when we have to consider the body-effect.

Therefore, if we are interested in small changes in the source to drain current of the transistor, as we are in small signal modeling, we must consider how the current changes with respect to each of these voltages independently. In particular,

$$i_{sd} = \underbrace{\frac{\partial I_{SD}}{\partial V_{SG}} \cdot v_{sg}} + \underbrace{\frac{\partial I_{SD}}{\partial V_{SD}} \cdot v_{sd}} + \underbrace{\frac{\partial I_{SD}}{\partial V_{SB}} \cdot v_{sb}}$$

Small change in source-drain current brought about by v_{sg}	Small change in source-drain current brought about by v_{sd}	Small change in source-drain current brought about by v_{sb}

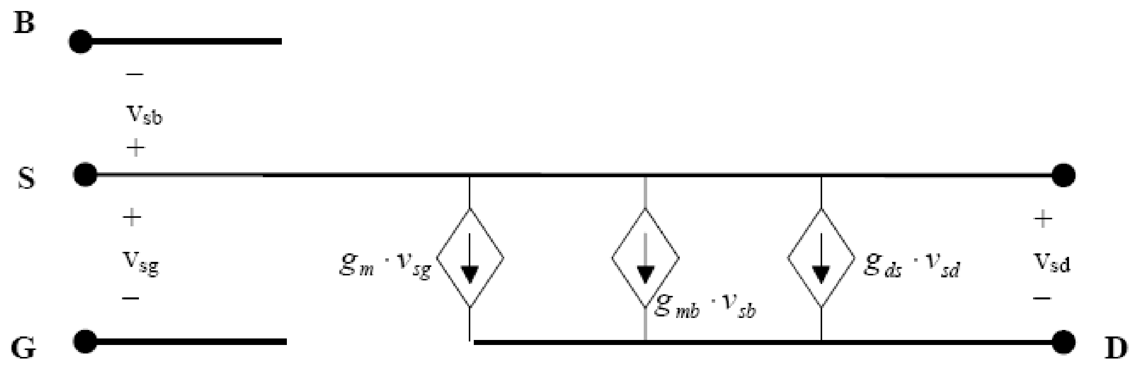
where each of the partial derivatives are given special names.

$$\frac{\partial I_{SD}}{\partial V_{SG}} = g_m, \qquad \frac{\partial I_{SD}}{\partial V_{SD}} = g_{ds}, \qquad \frac{\partial I_{SD}}{\partial V_{SB}} = g_{mb}$$

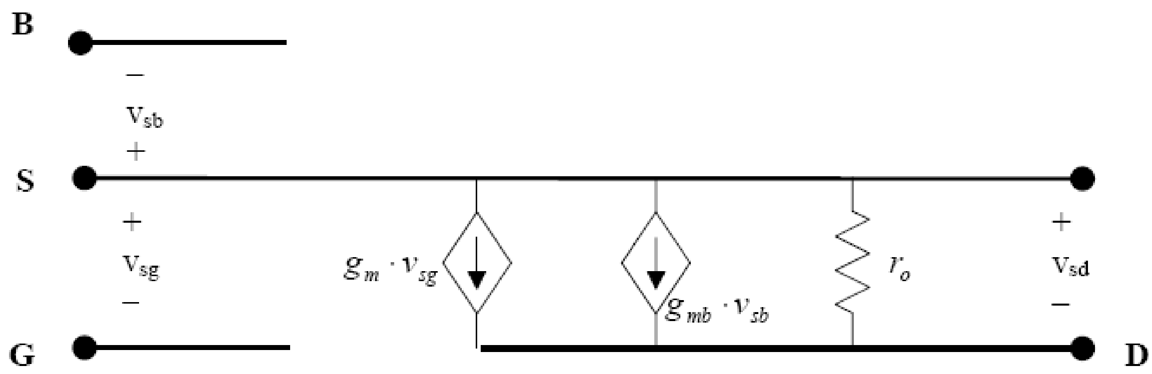
Here we refer to:

gm as the transconductance,
gmb as the backgate transconductance
gds as the outputconductance

Thanks to superposition we can simply model each of the three components in the above i_{sd} equation as dependent current sources, which are dependent on the three small-signal voltages and connect from the source to the drain of the transistor. Pictorially,



One thing to notice is that the dependent current source caused by the v_{sd} voltage is dependent on the voltage across it (i.e. a resistor). Therefore, we make a small modification to the following model as follows:

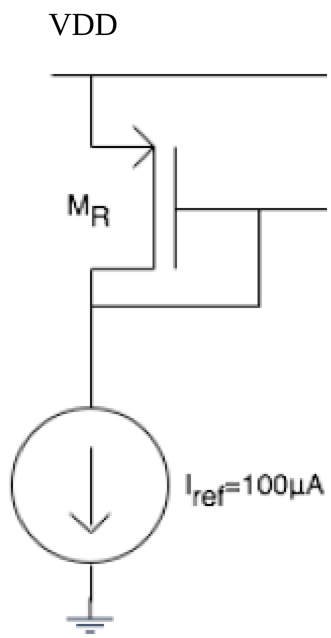


Where r_o is nothing more than $1/g_{ds}$. Another observation to make is that if the source and bulk of the transistor are tied together we can neglect the $g_{mb}v_{sb}$ current source since v_{sb} = 0.

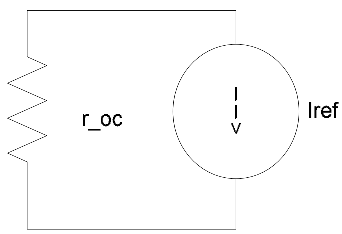
To further understand small signal modeling lets consider a couple of examples. In particular, the following two examples will show you how to set up the small signal model of a couple useful circuit configurations used in amplifers.

<u>Example #1:</u> Small Signal analysis of a diode connected transistor

Consider the following circuit:



The first thing to point out is that there is no such thing as an ideal current source. However, we can model a realistic current source as an ideal current source in parallel with a resistor, as shown below.



With this in mind the question is how do we set-up the small signal model of the above circuit.

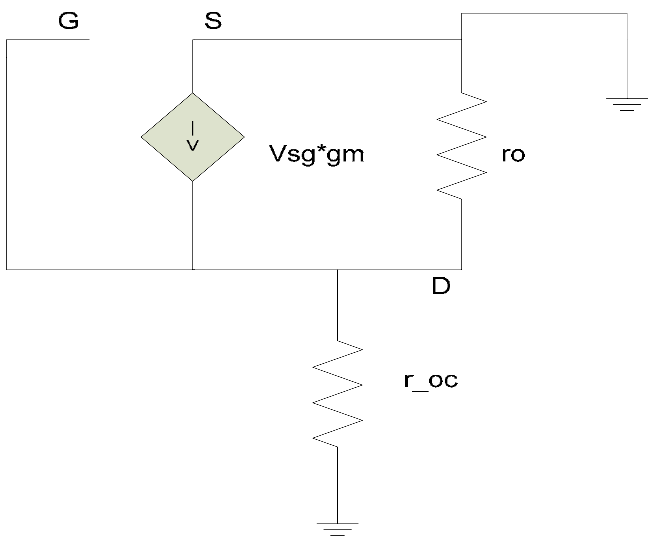
Step #1: We want to remove all DC sources.

DC voltage sources become short circuits
DC current sources become open circuits

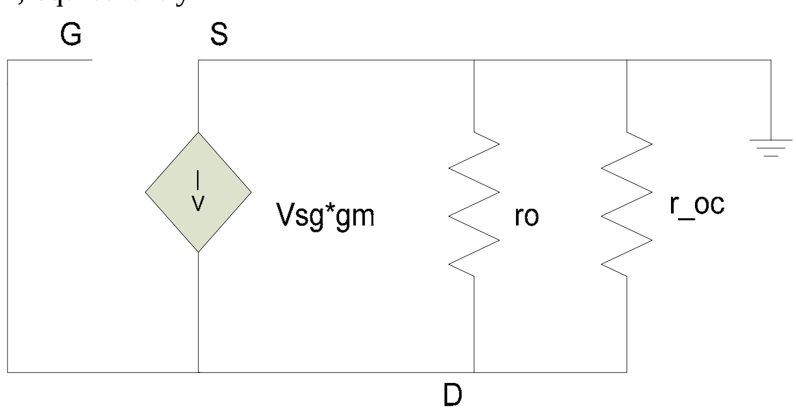
Why? Recall small-signal models are used to examine small changes in voltage/current. A DC voltage source is an electrical element that forces a particular node in the circuit to a certain voltage. Thus, a DC voltage source does not allow the voltage to change (even by a small amount). An element that realizes this is a perfect wire, since a wire indicates no change in voltage regardless of the current through it. Hence, a DC voltage source is modeled as a short circuit. Similar reasoning will indicate that a current source is modeled as an open circuit.

Step #2: Draw the small signal model of the transistor with all nodes connected as they are in the circuit.

For example, here we see that the drain of the transistor is connected to the gate. Similarly, r_oc is connected to the drain. Therefore, we come up with the following small signal model realizing that the source and bulk are tied to the same potential thus removing the $g_{mb}v_{ds}$ current source.

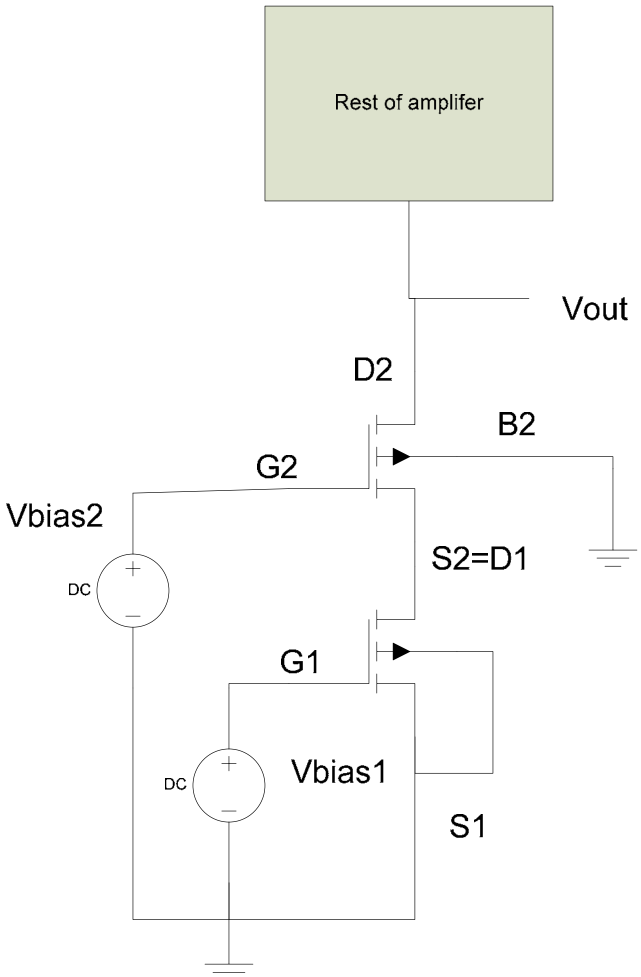


Or, equivalently



Example #2: A cascode current source.

As you will learn later in the semester one way to increase the gain of an amplifier is to set up a cascode current source. Therefore, it is important to understand how to set up the small signal model. Here we have two transistors, M2 and M1 connected in series. For this example, the body of M2 is not connected to the source of M2. Therefore, we must consider the body effect.

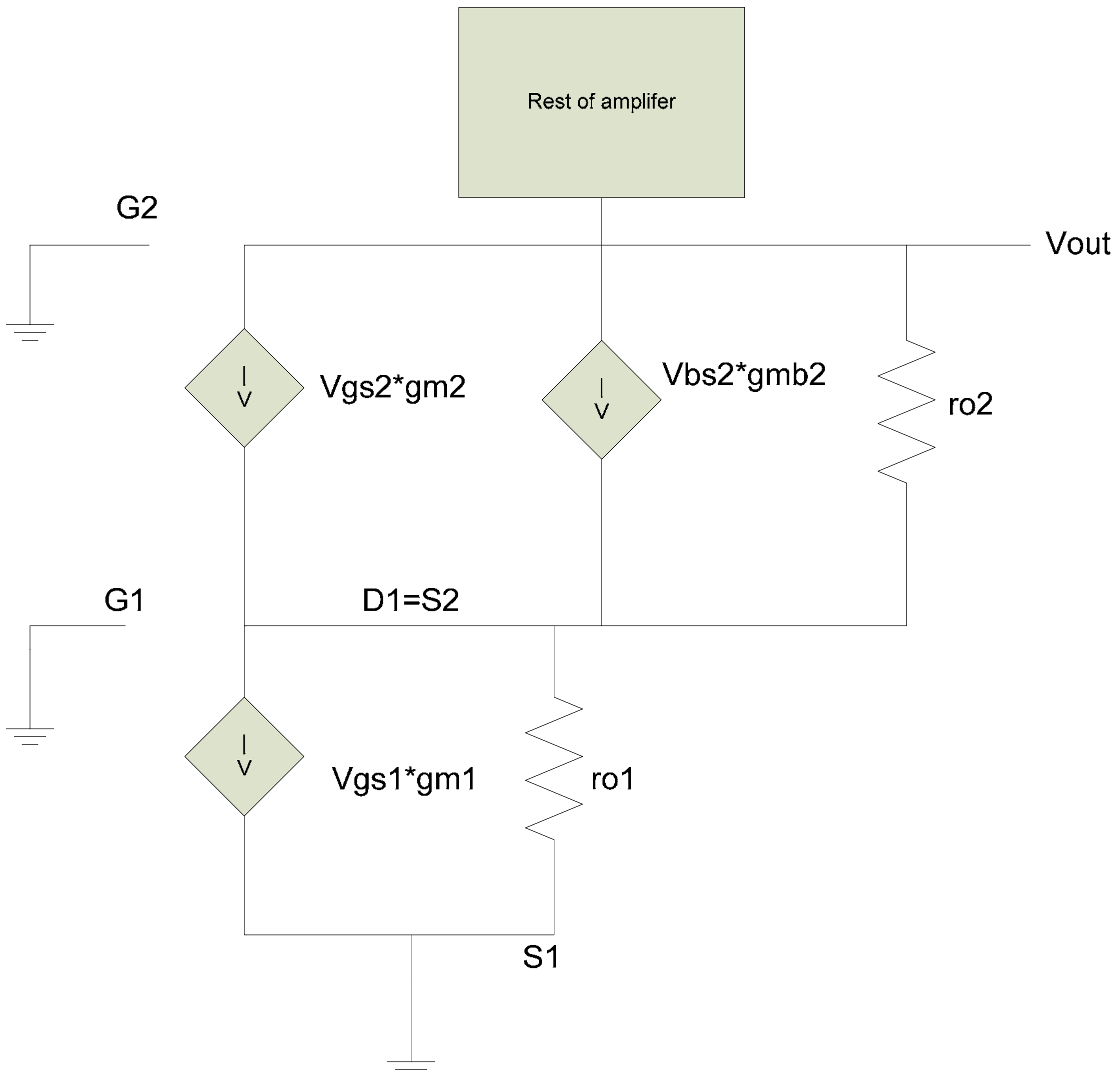


Step #1: Remove all the DC sources.

Here we see both the gates are set to DC biases, which are actually just diode connected transistors. Therefore, the will want to short circuit these components to ground.

Draw the small signal model of the transistor with all nodes connected as they are in the circuit.

Here we see that the drain of transistor M1 is connected to the source of M2. Also, the source of M1 is connected to ground and the drain of M2 is connected to the output. Furthermore, since the body of transistor 1 is tied to the same potential as the source of transistor 1, the $g_{mb1}v_{bs1}$ current source is zero and not included. With these connections we come up with the following small signal model.



I hope these examples help you learn how to set up small signal models. It is important that you understand these concepts, because as you begin to examine amplifiers you will use small signal modeling extensively to solve for quantities such as voltage gain, current gain output resistance, input resistance, etc.