Large-Signal & Small-Signal Operation

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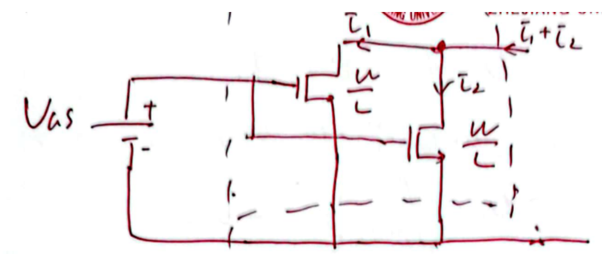
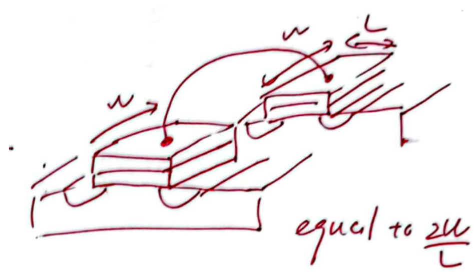
MOS in Parallel



If we place two MOS in parallel as a new MOS, what is the I/V characteristics of new MOS? Let's look at it in 3D diagram.



Obviously, the new MOS has a double W/L. Now we derive it in math.

$$I_1 = \frac{1}{2}\mu C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2$$

$$I_2 = \frac{1}{2}\mu C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2$$

$$I_{newMOS} = I_1 + I_2 = \frac{1}{2}\mu C_{ox}\frac{2W}{L}(V_{GS} - V_{TH})^2$$

That is, the W/L of the new MOS is twice that of the original.

$$g_{m1} = \frac{2I_1}{V_{GS} - V_{TH}}$$

$$g_{m2} = \frac{2I_2}{V_{GS} - V_{TH}}$$

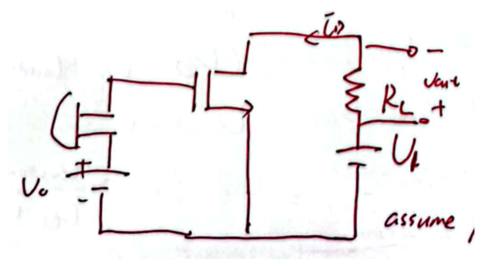
$$g_m = g_{m1} + g_{m2} = \frac{2I_1 + 2I_2}{V_{GS} - V_{TH}} = 2g_{m1} = 2g_{m2}$$

The transconductance of the new MOS is also twice that of the original.

Let's build an amplifier

Last day we didn't take V_{DS} into consideration. In the case we designed yesterday, the MOS didn't work in the saturation zone, which means the amplification circuit fails.

Actually, we also need to add a bias voltage to the Drain.



Add a bias voltage to the Drain

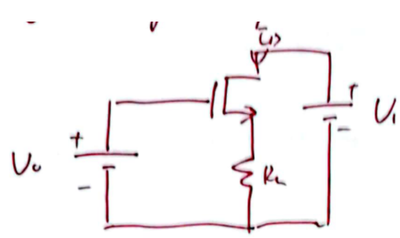
Assume that $V_D = 0.9V$, $V_{TH} = 0.5V$, $I_D = 1mA$, $R_L = 1k\Omega$.

If $V_{DS} \geq V_0 - V_{TH} = 0.4V$, the MOS is in saturation zone.

So if we let $V_1 \leq I_{Dmin} * R_L + V_{DS} = 1.4V$, the MOS can work in saturation zone.

In this way, we build an amplifier successfully.

Large-Signal Operation



Large-Signal Operation

We have:

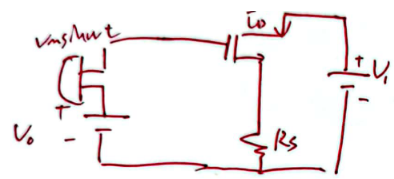
$$I_D = \frac{1}{2}\mu C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2$$

$$V_{GS} = \sqrt{\frac{2I_D}{\mu_n C_o x \frac{W}{L}}} + V_{TH}$$

Then we can get:

$$V_0 = V_{GS} + I_D * R_L = \sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}} + V_{TH} + I_D R_L$$

Let's add a signal

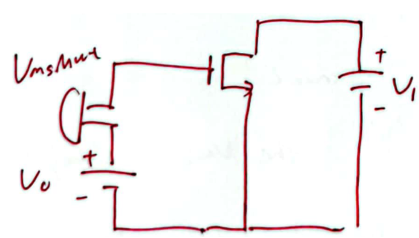


Large-Signal Operation

We assume that V_m is not "small".

$$V_0 + V_m sin\omega t = V_{GS} + I_D * R_S = \sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}} + V_{TH} + I_D R_S$$

Small-Signal Operation



Small-Signal Operation

Now we assume that V_m is small, V_{GS} is almost a constant.
In this case, I_D is almost a constant, we can ignore the R_s too.

$$I_D = \frac{1}{2}\mu C_{ox}\frac{W}{L}(V_0 - V_{TH} + V_m sin\omega t)^2$$

Because $V_{GS} - V_{TH} \geq V_m sin\omega t$, we have $(1+x)^2 \approx 1 + 2x$.
Then:

$$I_D = \frac{1}{2}\mu C_{ox}\frac{W}{L}(V_0 - V_{TH})^2(1 + 2\frac{V_m sin\omega t}{V_0 - V_{TH}})$$

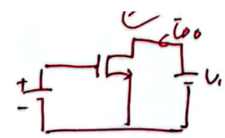
$$I_D = I_{D0} + \frac{2I_{D0}}{V_0 - V_{TH}}V_m sin\omega t$$

We call the former Bias Current, and the latter Signal Current. Obviously the Signal Current is $g_m * V_m sin\omega t$. This fits well with the definition of transconductance, the ability to convert voltage into current.

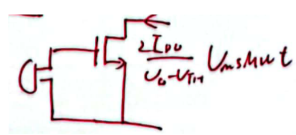
$$g_m = \frac{dI_D}{dV_{GS}}$$

dV_{GS} there is the small $V_m sin\omega t$.

According to this, we can also split this circuit into two parts.

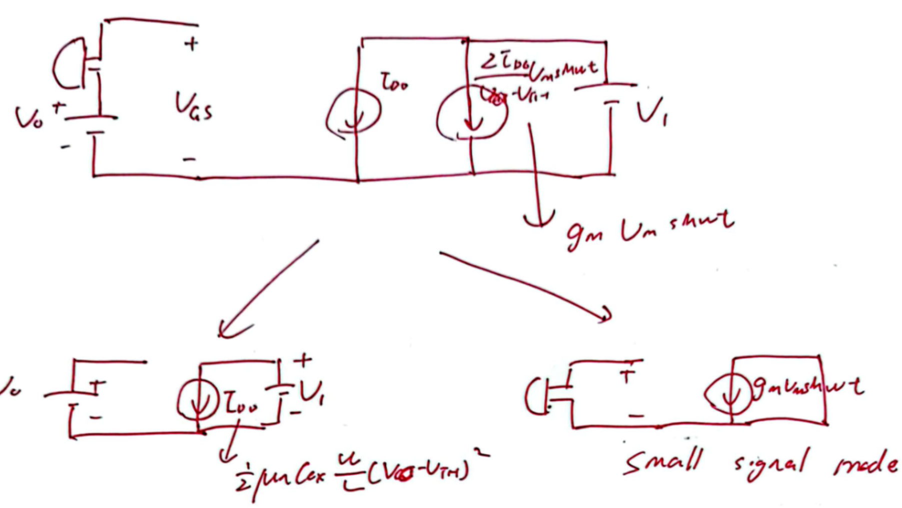


Bias Current



Signal Current

Let's take its simple model.



In this way, we split a model into Large-Signal Model and Small-Signal Model.

Additionally, we can find the Large-Signal Model only has DC component and Small-Signal Model only has AC component.

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