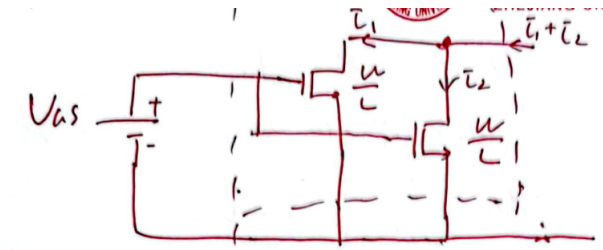


# Large-Signal & Small-Signal Operation

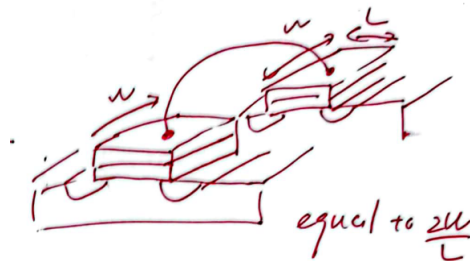
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2023.11.16

## 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.

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

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

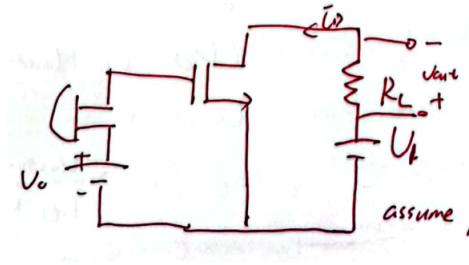
$$g_m = g_{m1} + g_{m2} = \frac{2I_1 + 2I_2}{V_{GS} - V_{TH}} = 2g_{m1} = 2g_{m2}$$

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

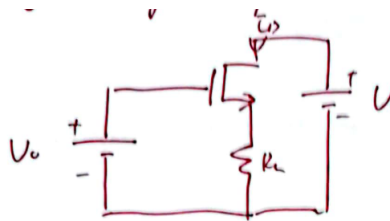
Assume that  $V_D = 0.9V$ ,  $V_{TH} = 0.5V$ ,  $I_D = 1mA$ ,  $R_L = 1k\Omega$ .

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:

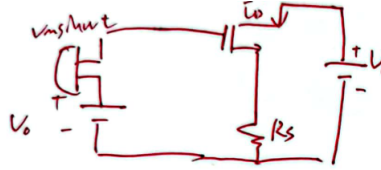
$$I_D = \frac{1}{2} \mu C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2$$

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

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

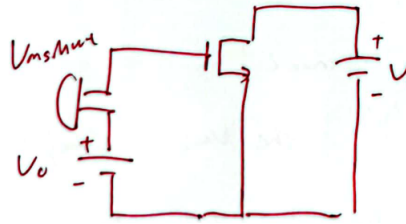


Large-Signal Operation

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:

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

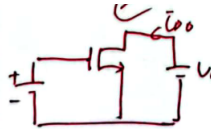
$$I_D = I_{D0} + \frac{2I_{D0}}{V_0 - V_{TH}} V_m \sin \omega t$$

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.

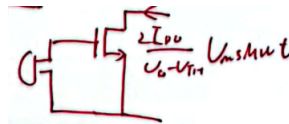
$$g_m = \frac{dI_D}{dV_{GS}}$$

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

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

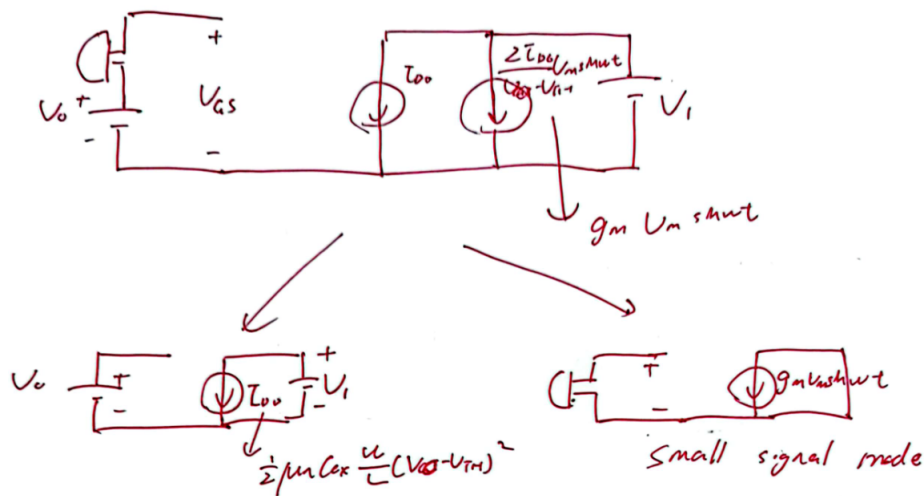


Bias Current



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.

## **Link**

[Razavi Electronics Circuits 1: lectrue 33](#)