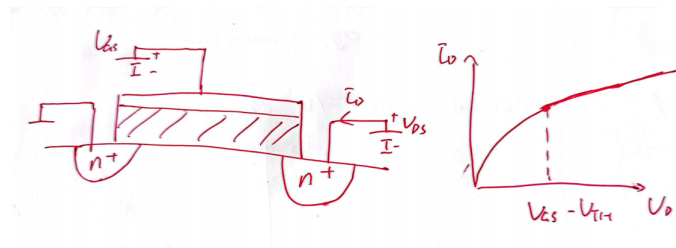


# Biasing, Transconductance

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## Channel-Length Modulation



As  $V_{DS} \uparrow$ , the Channel-Length  $\downarrow$ .

Last day we didn't take this change into consideration. Now let's rederive it. The upper limit of the integral on the left-hand side of the equation changes, leading to the increasing of  $I_D$ .

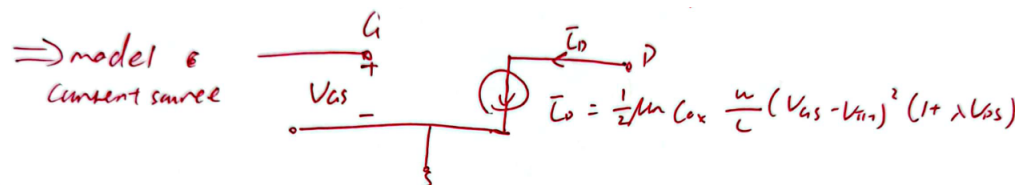
$$\int_0^{L'} I_D dx = \mu_n * W * C_{ox} * \int_0^{V_{GS} - V_{TH}} (V_{GS} - V_{TH} - V(x)) dV$$

Actually, we can simply write down the conclusion with a correlation coefficient  $\lambda$ , showing the relationship between  $V_{DS}$  and  $I_D$  in pinch-off zone.

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

$\lambda$  (unit:  $1/V$ ), is called the **Channel-Length Modulation Coefficient**.

Then we can get a correct current source model.



current source model with  $\lambda$  taken into consideration

# Let's build an amplifier

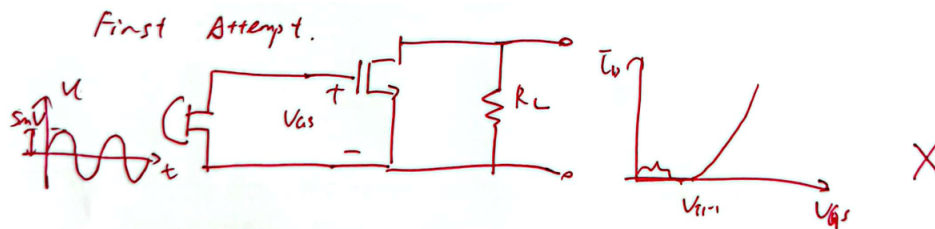
Pay attention that we assume  $\lambda = 0$ .



A simple amplifier model

Assume that we hope to amplify a 5mV sound signal to 5V.

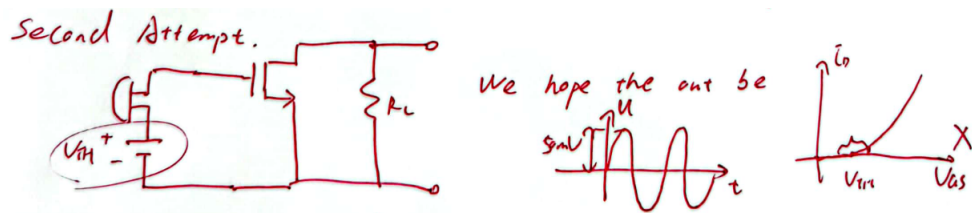
## First Attempt



First attempt

In this case we do not add a bias voltage. The MOSFET turns off.

## Second Attempt



Second attempt

In this case we add a bias voltage, we can calculate the  $I_D$  after amplifying.

Given that  $\mu_n C_{ox} = 100 \mu A/V^2$ ,  $\frac{W}{L} = 10$ ,  $V_{TH} = 0.5V$ .

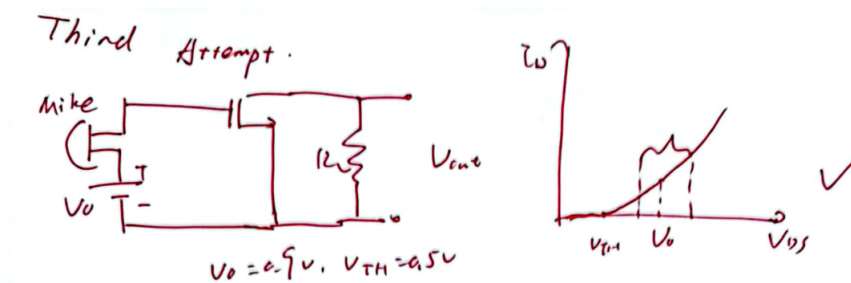
$$I_D = \frac{1}{2} \mu C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2 = 12.5 nA$$

If we want the gain to be equal to 10, we need a resistor:

$$R_L = \frac{50mV}{12.5nA} = 4M\Omega$$

It's too large! Because the operating point is close to  $V_{TH}$ , the gain is too small.

## Third Attempt



Third attempt

We add a 0.9V bias to the Gate. This way we get a appropriate gain, a appropriate resistor.

Let's calculate it.

No signal:

$$I_D = \frac{1}{2} \mu C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2 = 80 \mu A$$

Max signal:

$$I_D = \frac{1}{2} \mu C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2 = 82 \mu A$$

The change in  $I_D$  is  $2 \mu A$ , we need a resistance  $\frac{50mV}{2\mu A} = 25k\Omega$ .

## Conclusion

**Need to bias the transistor by creating proper current and terminal voltage (in the absence of signals). So that the device can amplify the signal.**

However,  $V_{DS}$  is not taken into consideration, it must make MOS enter the saturation zone. The model we create just now may not be correct enough. We'll talk about it next day.

Today we only consider the **SATURATION** zone.

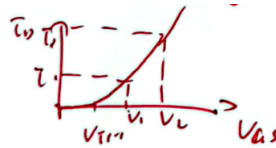
## Observation

A MOS device "converts" a voltage to a current. With this ability we can call it a **Transconductor**.

$$\rightarrow \text{MOS} = V/I \text{ converter} = \text{Trans conductor}$$

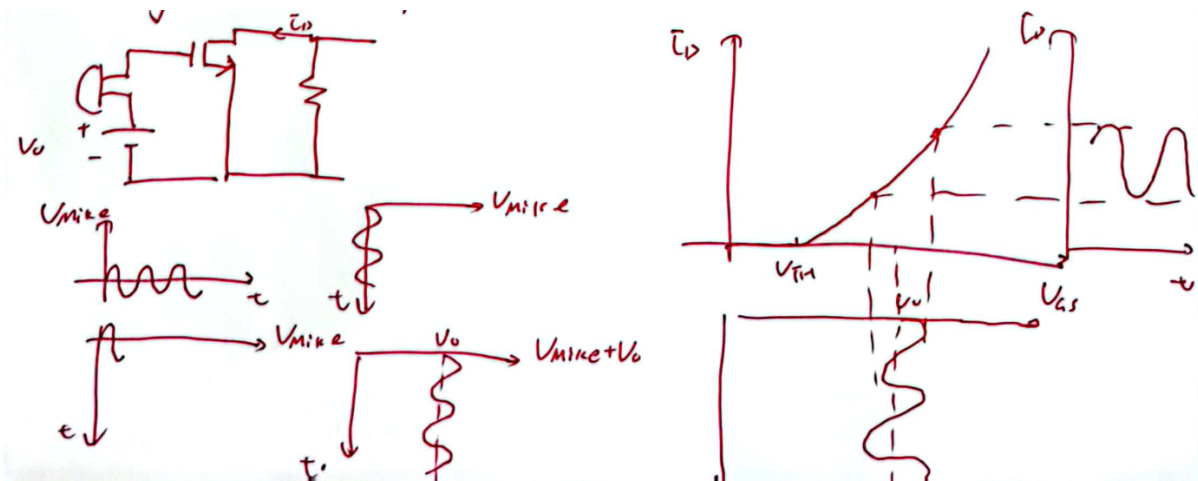
Transconductor

Which operating point is preferred?



Actually, MOS operating in point 2 is stronger than point 1. But it consumes more energy because its drain current is larger.

## Combining Time Response with I/V Characteristics



The relationship between  $I_D$  and time

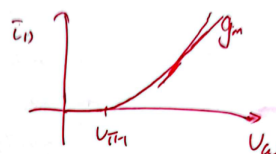
Just rotate the voltage curve 90 degrees.

## Concept of Transconductance

We call the ability to convert a current into a voltage transconductance.

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

unit:  $\frac{1}{\Omega}$ , S, siemens.



It represent on the graph as slope.

From  $I_D = \frac{1}{2}\mu C_{ox} \frac{W}{L}(V_{GS} - V_{TH})^2$ , we can get:

$$g_m = \frac{dI_D}{dV_{GS}} = \mu C_{ox} \frac{W}{L}(V_{GS} - V_{TH})$$

Or:

$$g_m = \frac{2I_D}{V_{GS} - V_{TH}}$$

$$g_m = \sqrt{2I_D \mu C_{ox} \frac{W}{L}}$$

## Link

[Razavi Electronics Circuits 1: lectrue 32](#)