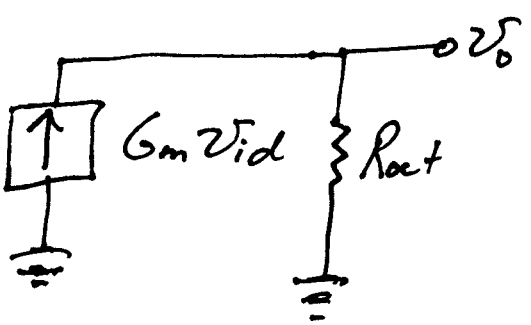
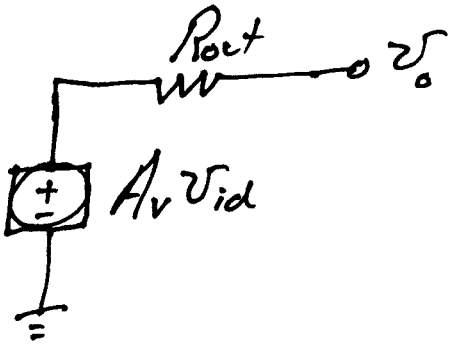
Output Stages

- So far, our designs have high output impedance
  → Generally termed "operational transconductance amplifiers" due to current source output. (OTA)
- To drive resistive loads or large cap loads, need an output stage w/ low output impedance to buffer the load from our key gain stages ⇒ "operational amplifier"
- Equivalent models:



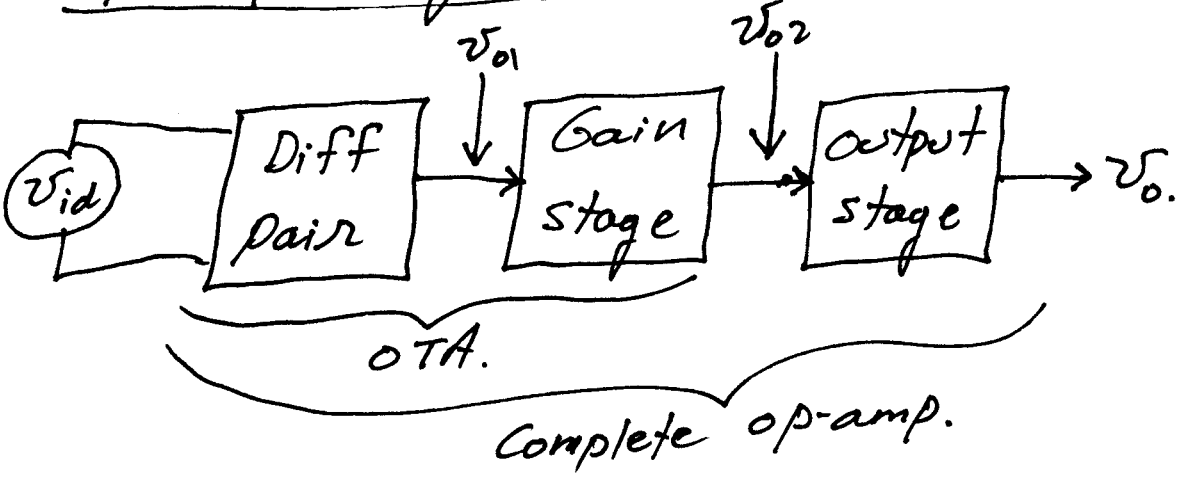
OTA: R_{out} → large



Op-Amp: R_{out} → small

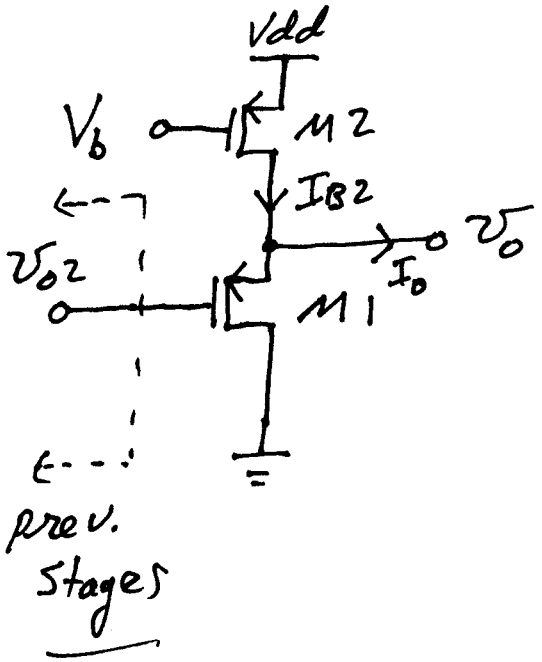
- Next: Add buffer to OTA to realize low output impedance opamp.

• Op-Amp Stages:



• Output Stages:

1) Common-Drain (source follower)



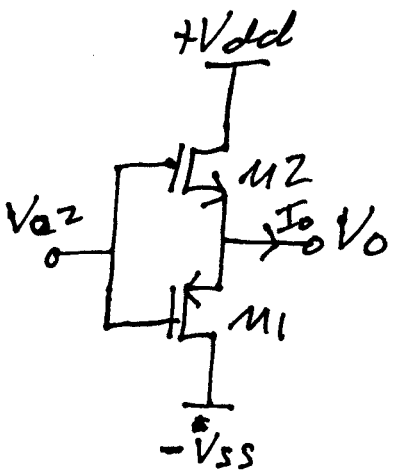
$\frac{v_o}{v_{o2}} \simeq 1$, $R_{out} \simeq 1/g_{m_1}$

- Can source only $I_o^+ = I_{B2}$
- Can sink $I_o^- = I_{D1\text{-}max} - I_{B2}$

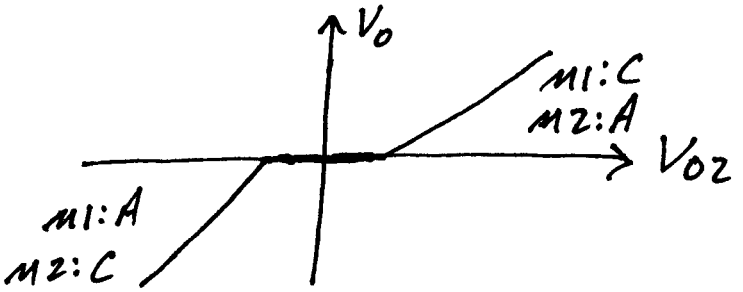
$\Rightarrow$ can be large w/ large $(W/L)_1$

$\Rightarrow$ Class A: - Constant power consumption
- I_o limited by bias I_{B2}
- Highly linear. (all devices active)

2) Two Source Followers:



- Has "cross-over" distortion for V_{o2} near V_o with M_1 & M_2 cut-off:



- @ $I_o = 0 \Rightarrow$ Zero power loss (or quiescent power)

- $(I_o)_{max}$: can be large in both directions by design (large $(W/L)_{1\&2}$).

small-signal

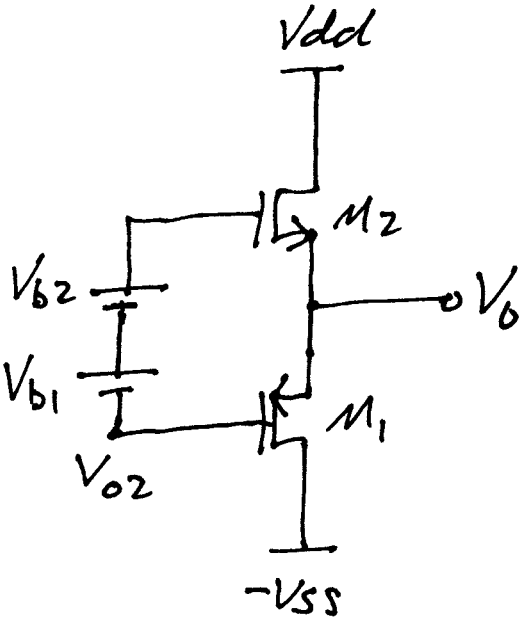
- $\frac{v_o}{v_{o2}} \simeq 1$ } if M_1 or M_2 active; $R_{out} \simeq \frac{1}{g_{m_1}}$ or $\frac{1}{g_{m_2}}$

$\Rightarrow$ Class B: - no quiescent current

- I_o not limited by bias current

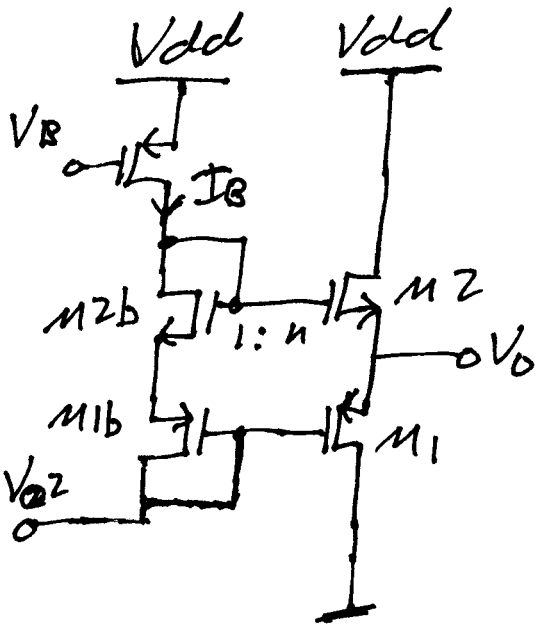
- Cross-over distortion (non-linear)

3) Two source followers w/ biasing:



- use V_{b1} & V_{b2} to "pre-bias" M_1 & M_2 into active region
⇒ reduce or eliminate crossover distortion depending on how much I_Q is allowed.
↖ quiescent current (@ $I_o = 0$)

<u>possible realization</u>



- M1b & M2b bias M1/M2 with $I_{Q1,2} = n \cdot I_B$ so both are active @ $I_o = 0$
- for large I_o^+ ⇒ M2 active, M1 cutoff
For large I_o^- ⇒ reverse.

∴ ⇒ <u>Class A/B</u> : - compromise between distortion & bias current
- I_Q = small (not zero)
- limited distortion
- I_o not limited by bias current.