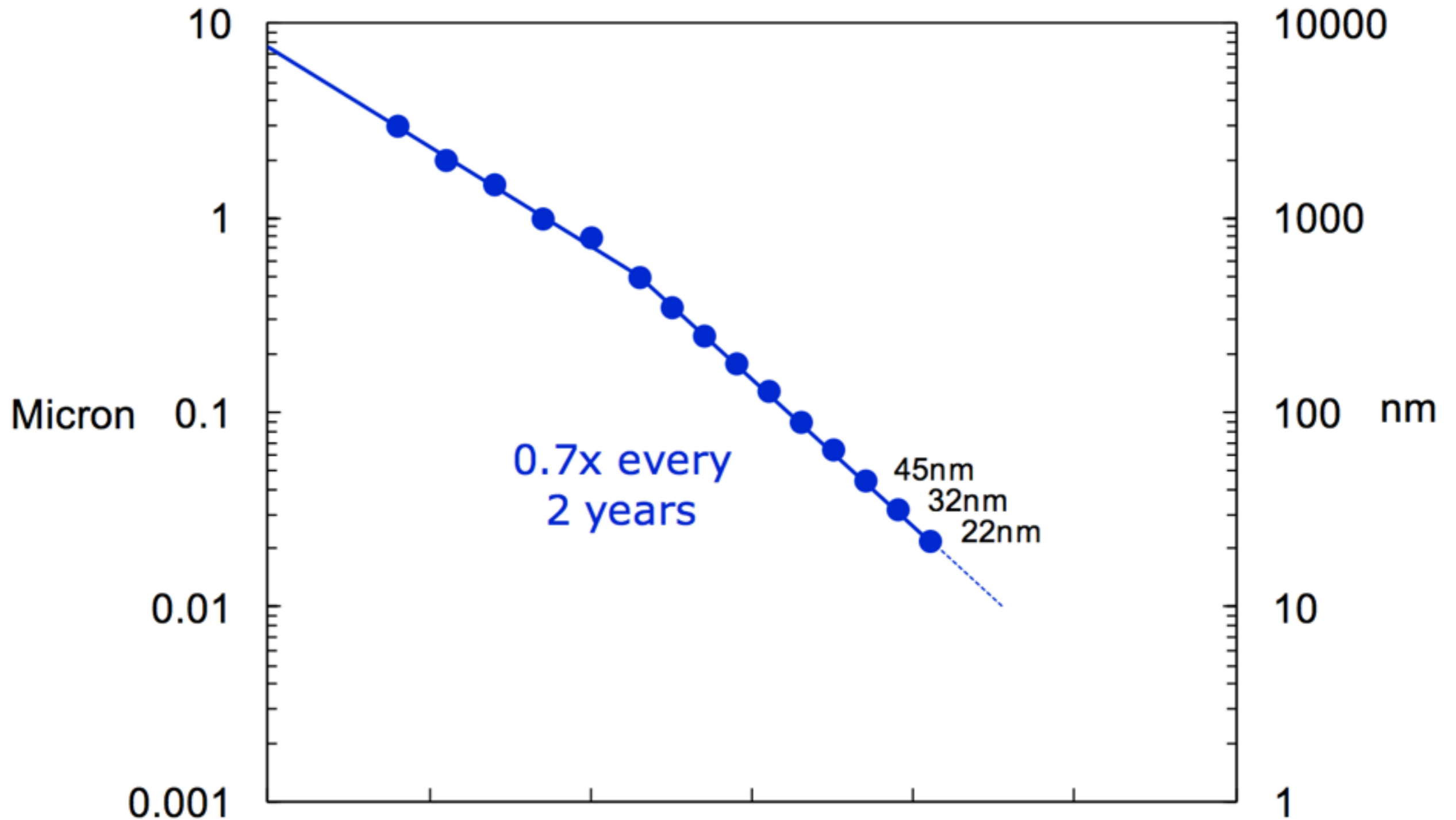


# Analog design with deep sub-micron devices

Scott Fairbanks

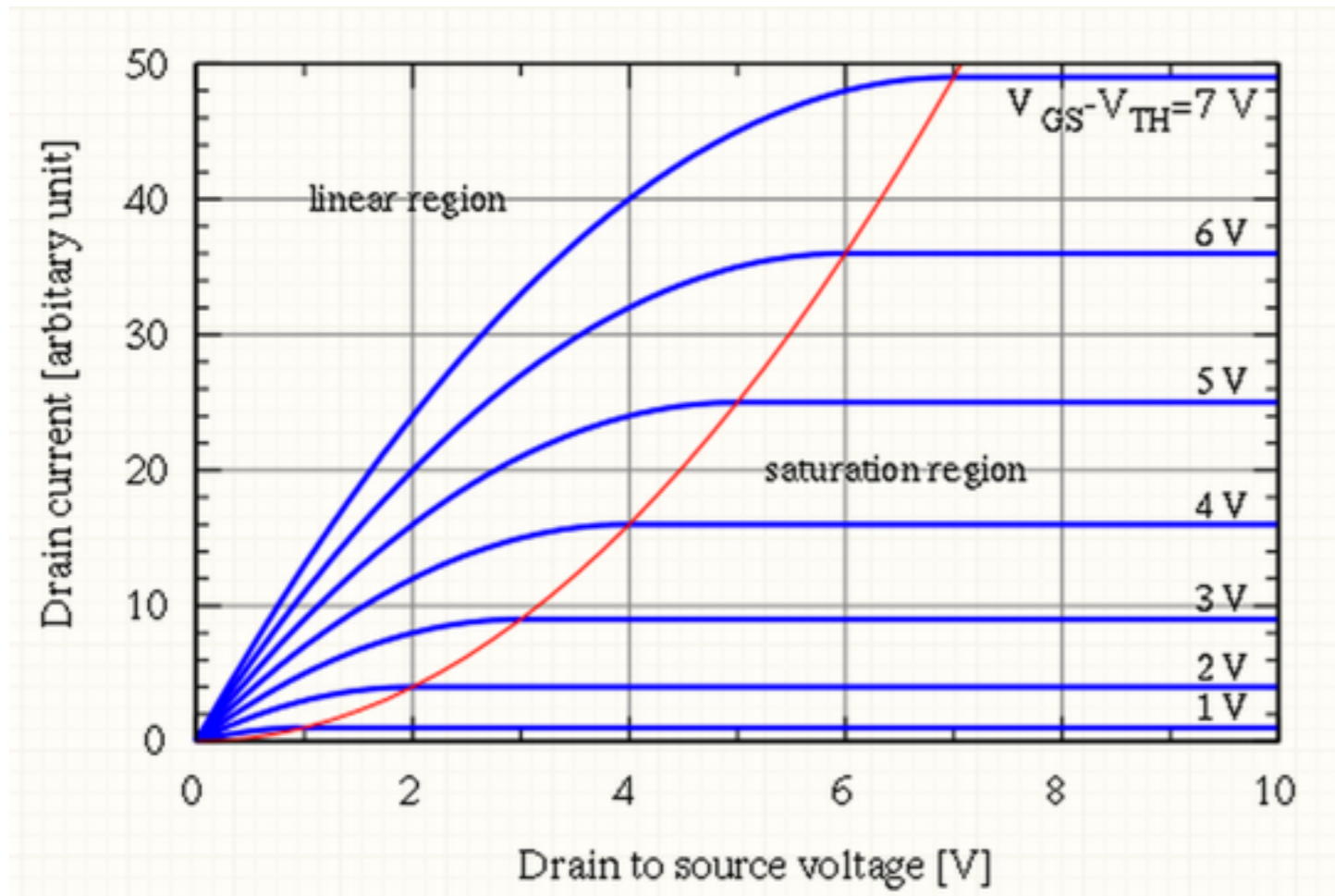
# Moore's law

The density of transistors doubles every 18 months

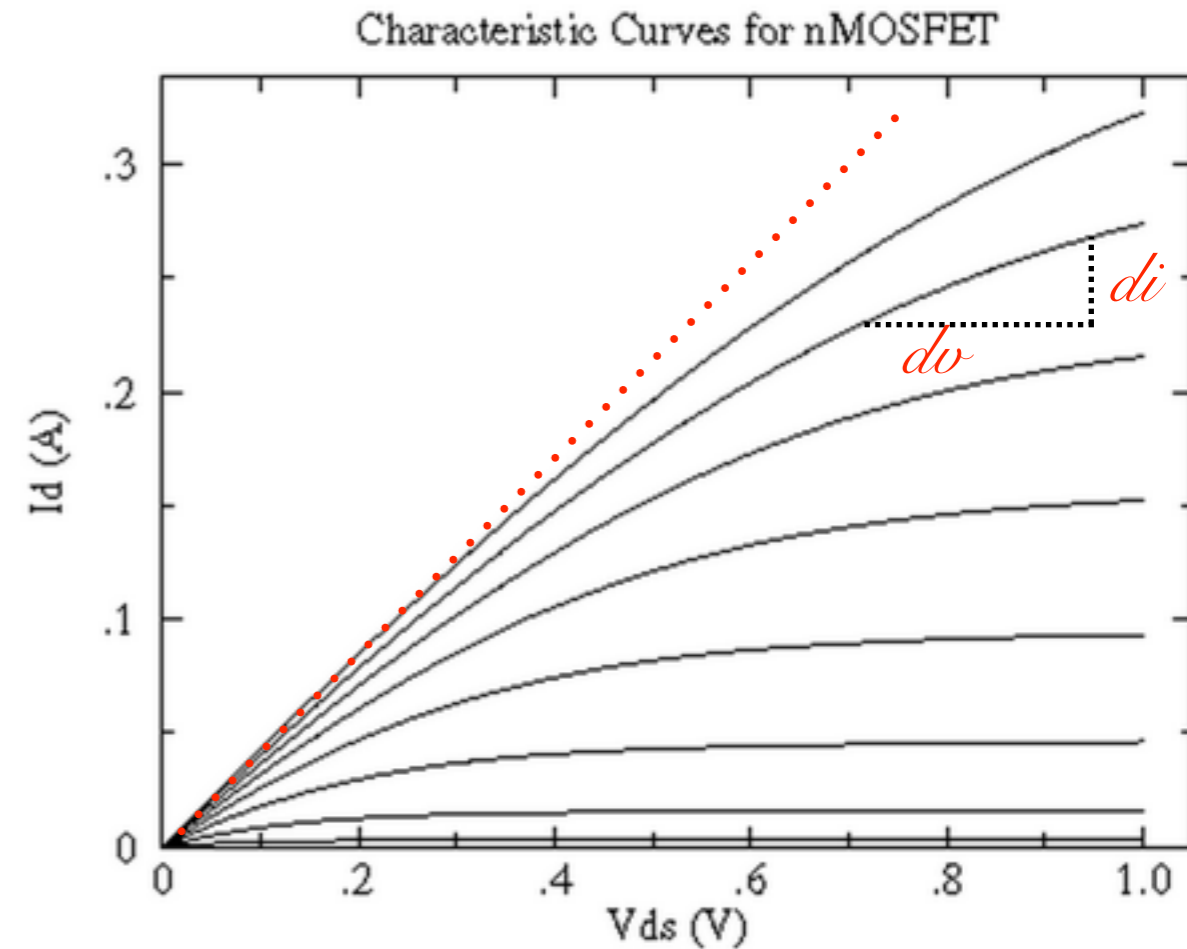


# Compromised Gain

Classic

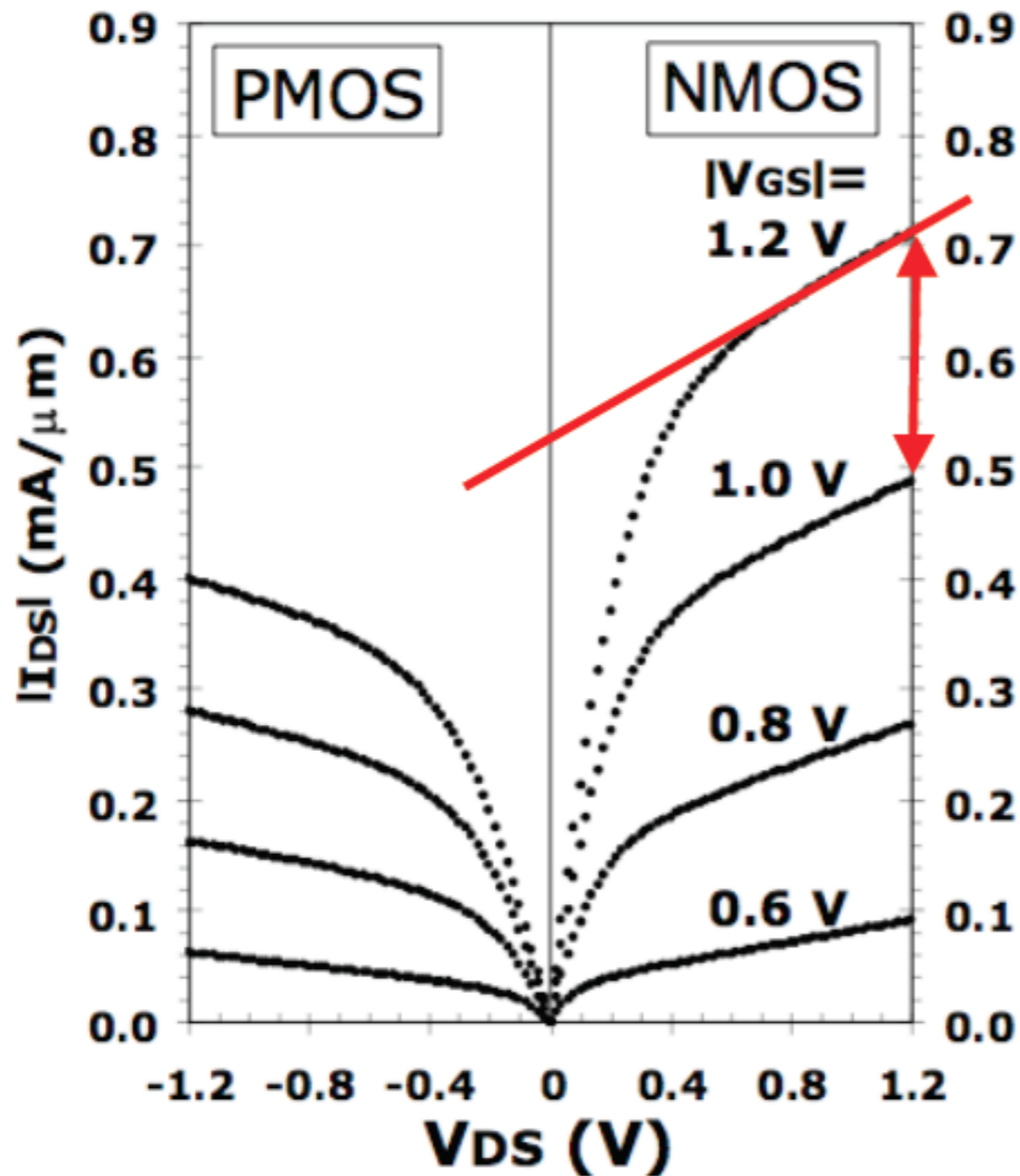


Modern digital



$$\begin{aligned} \text{Gain} &= g_m * r_o \\ &= g_m * di/dv \end{aligned}$$

# self-gain for 65 nm digital CMOS



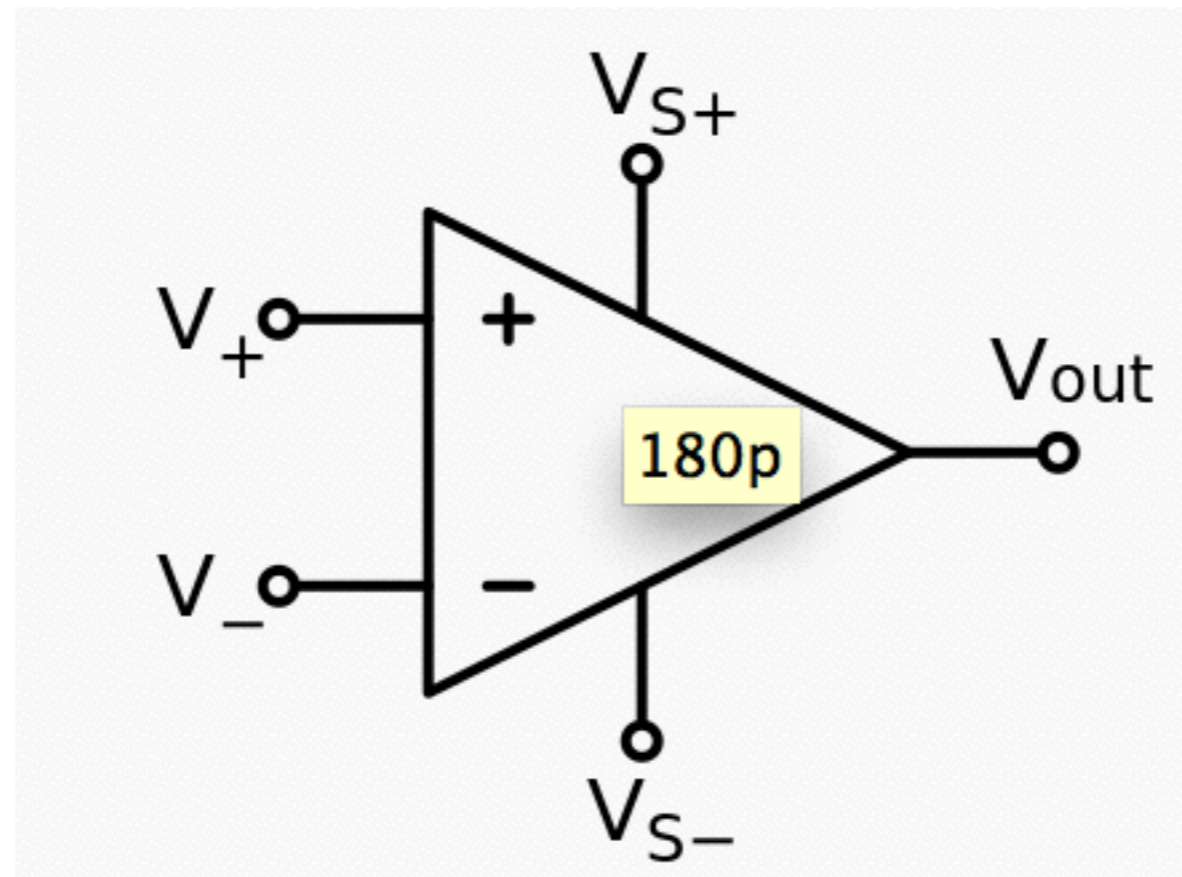
$$g_m \approx \frac{0.2 \text{ mA}/\mu\text{m}}{0.2 \text{ V}} = 1 \text{ mS}/\mu\text{m}$$

$$r_o \approx \frac{1.2 \text{ V}}{0.18 \text{ mA}/\mu\text{m}} \approx 7 \text{ K}\Omega\text{-}\mu\text{m}$$

$$|A_v(\text{max})| = g_m r_o \approx 7$$

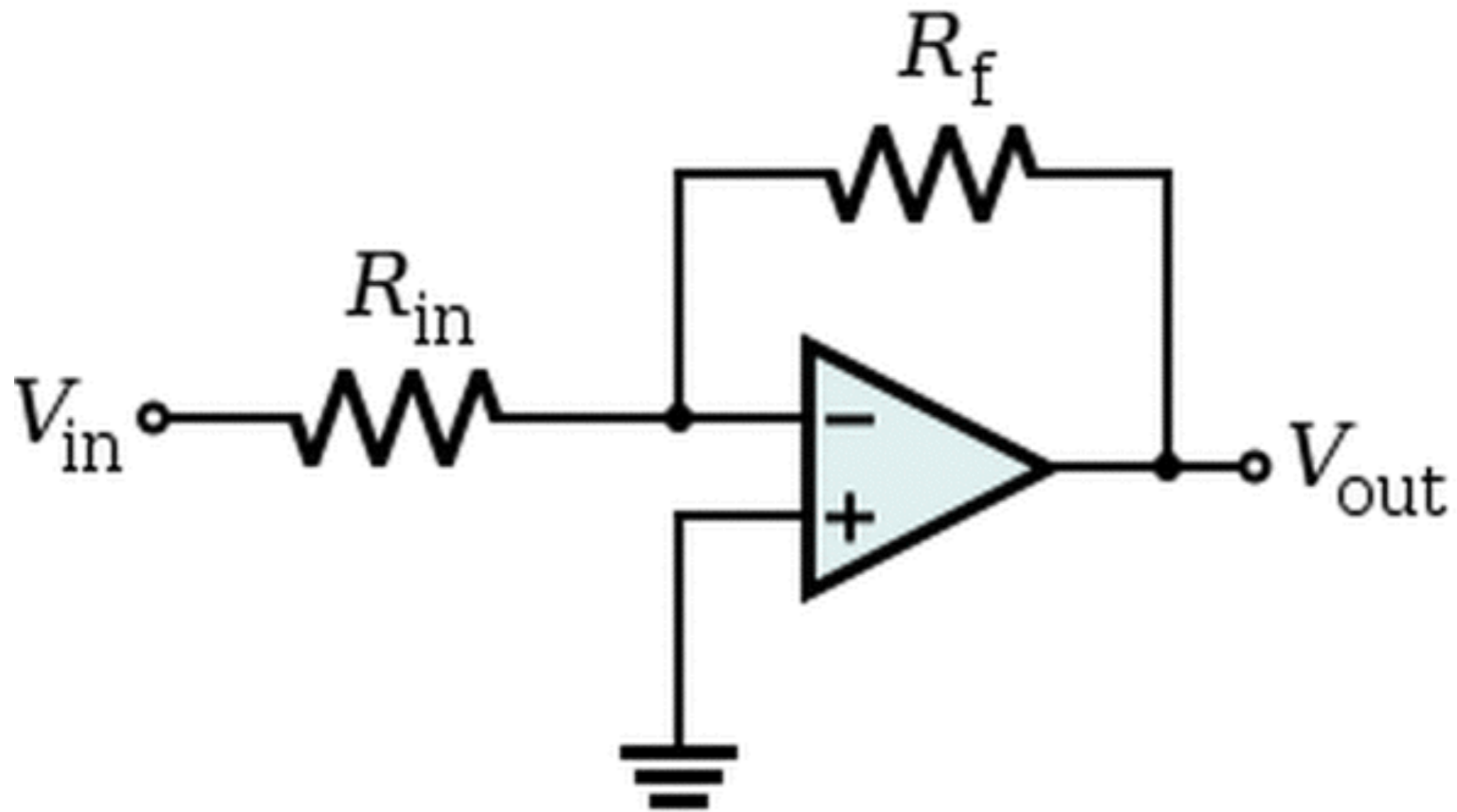
C.-H. Jan. et al., 2005 IEDM

# Operational Amplifier



$$V_{out} = A_{OL} (V_+ - V_-)$$

# Feedback

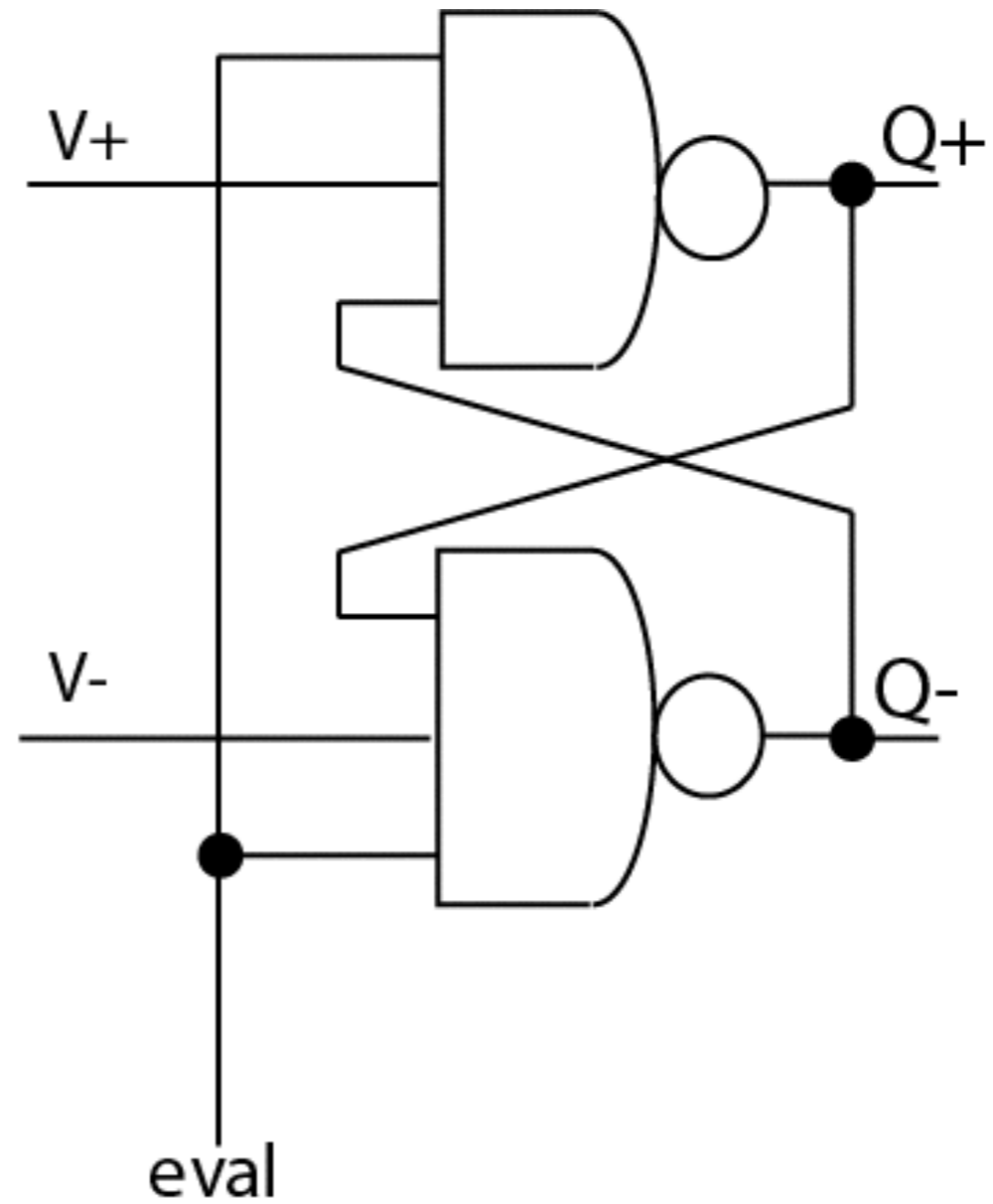
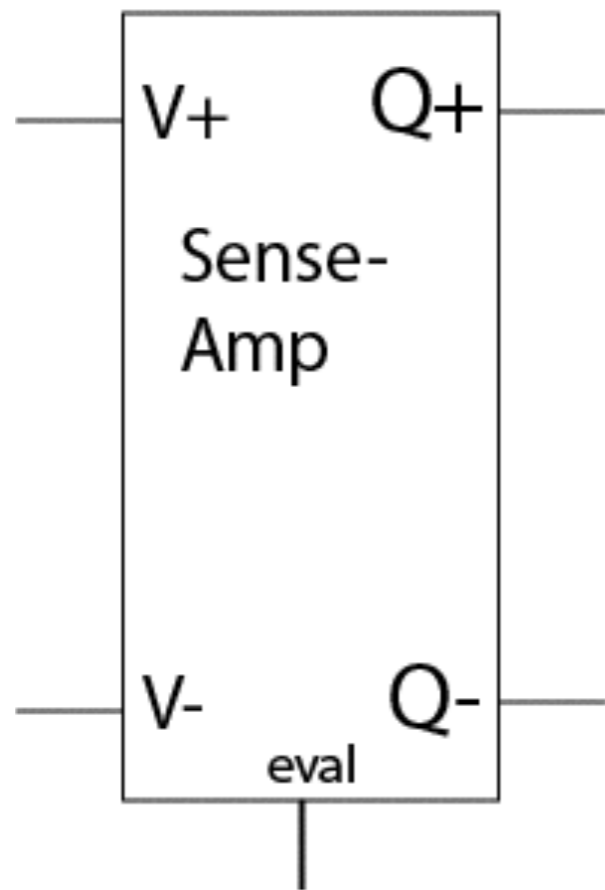


$$V_{out} \approx -V_{in} \frac{R_f}{R_{in}}$$

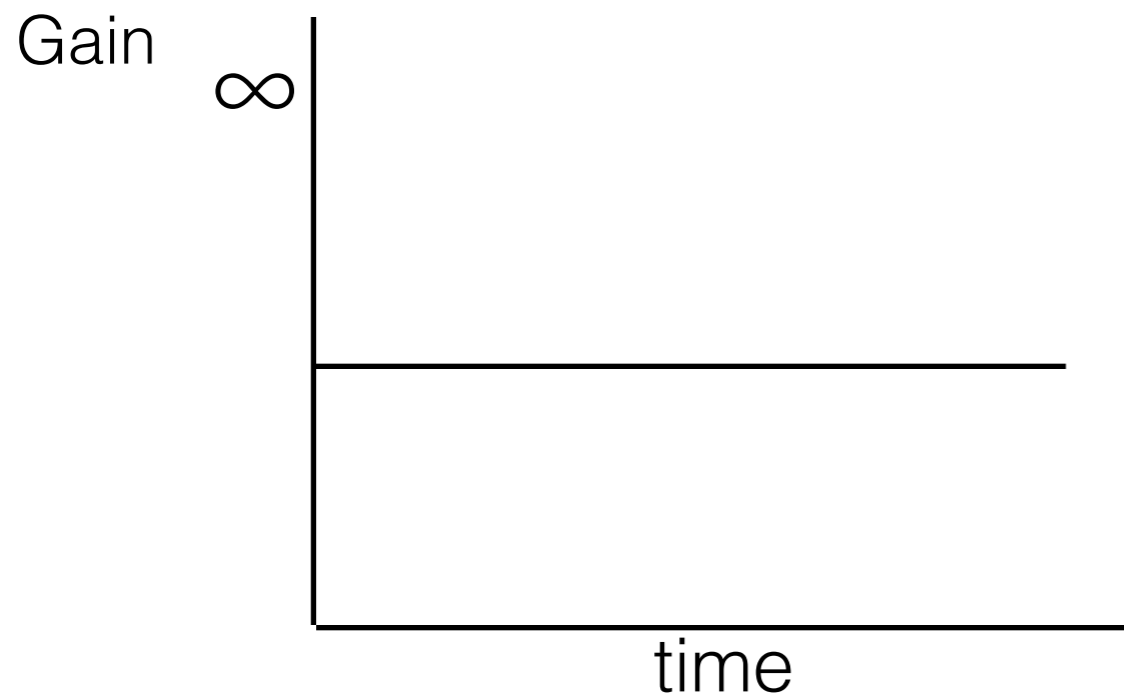
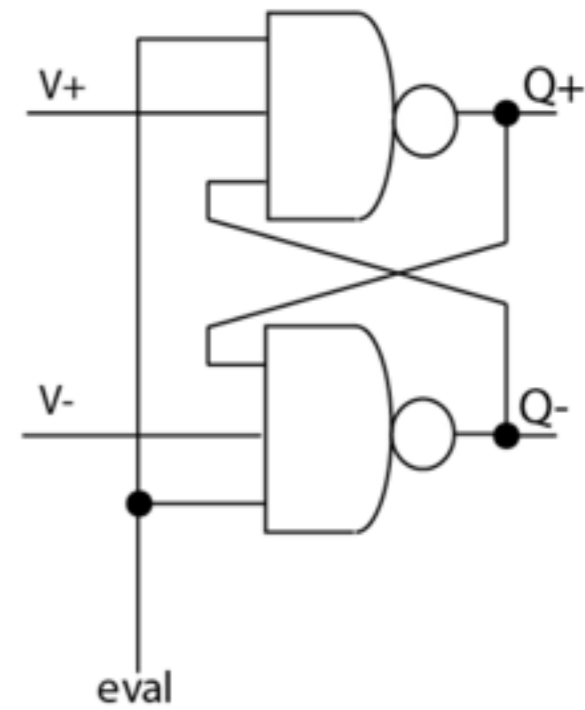
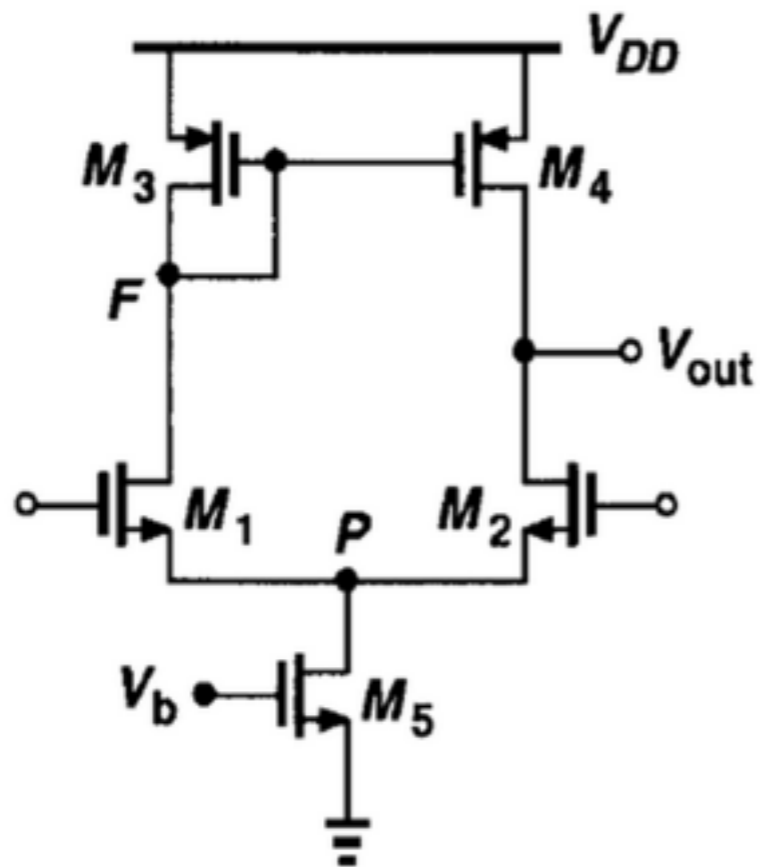
# Deep submicron CMOS devices



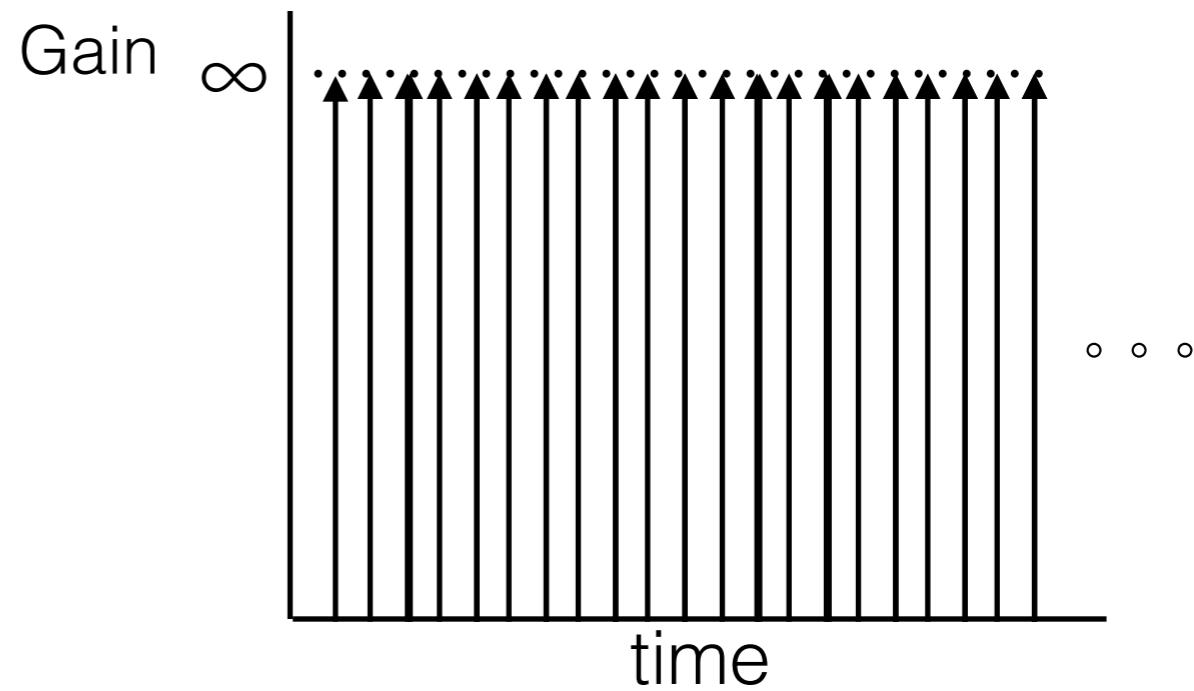
# Sense - amplifier





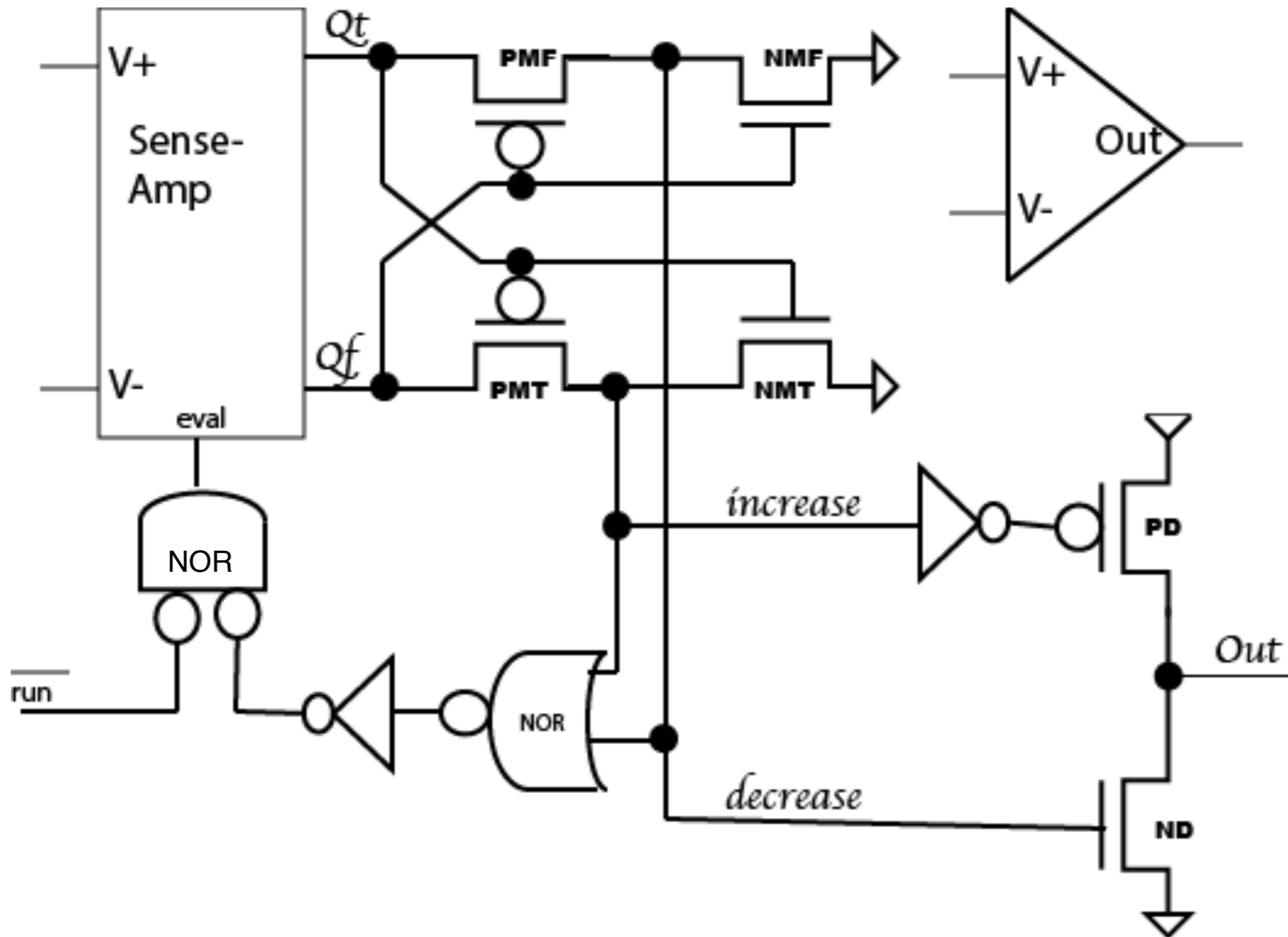


continuous finite gain

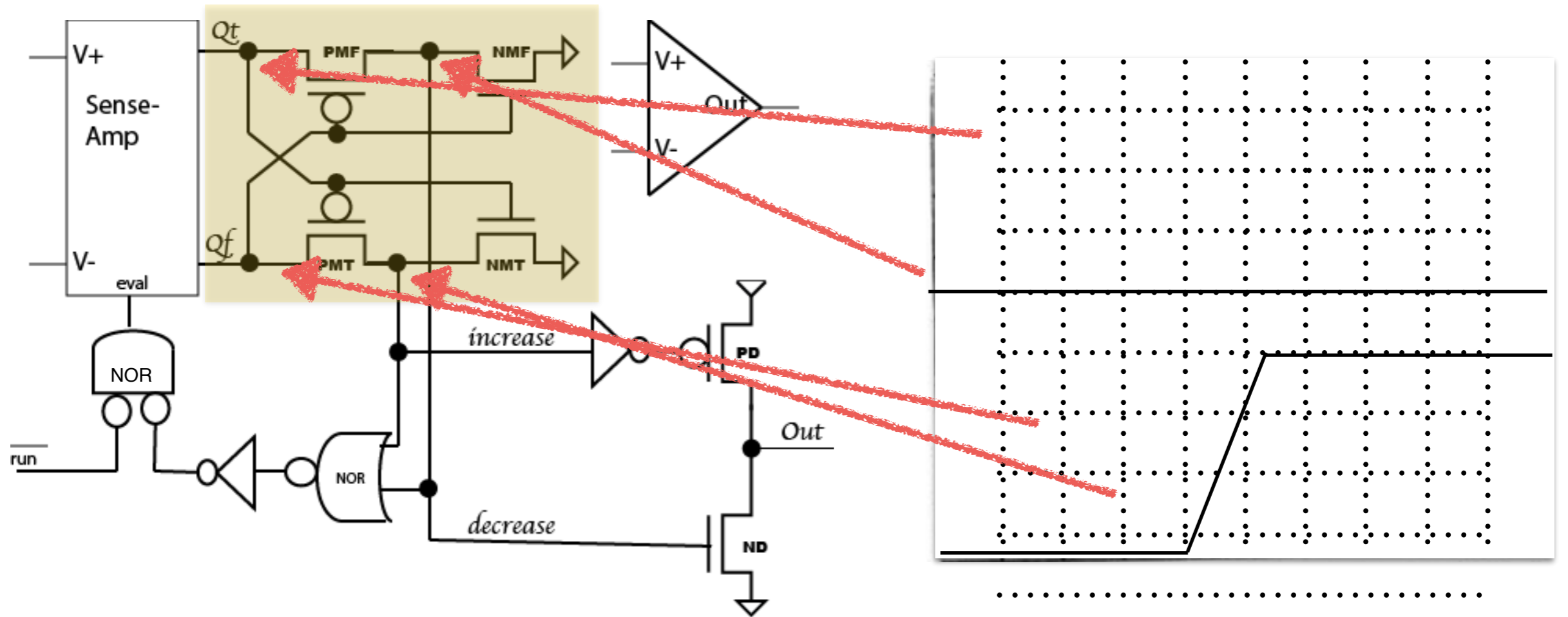


infinite gain at one instance/evaluation

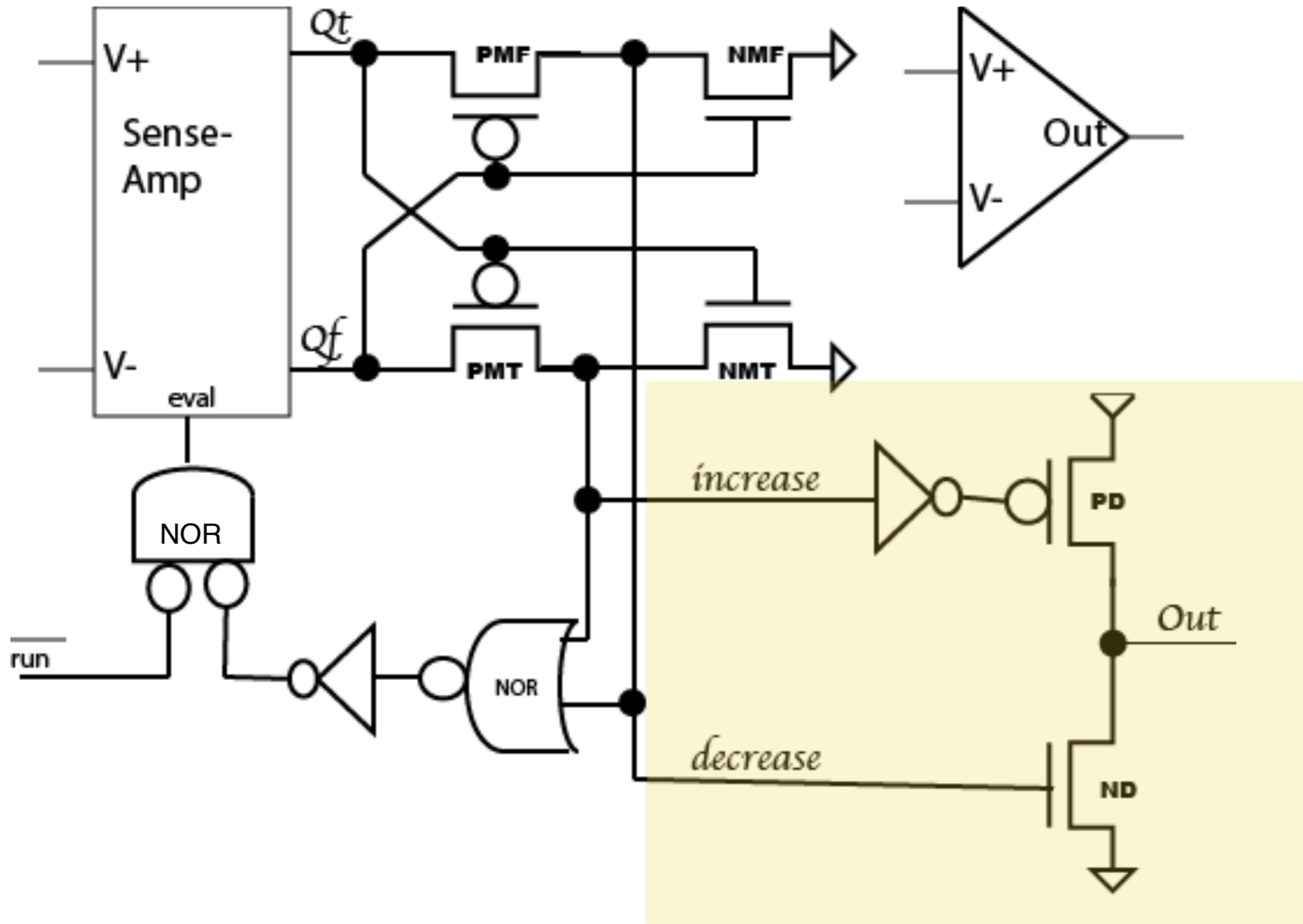
# Digital Operational Amplifier



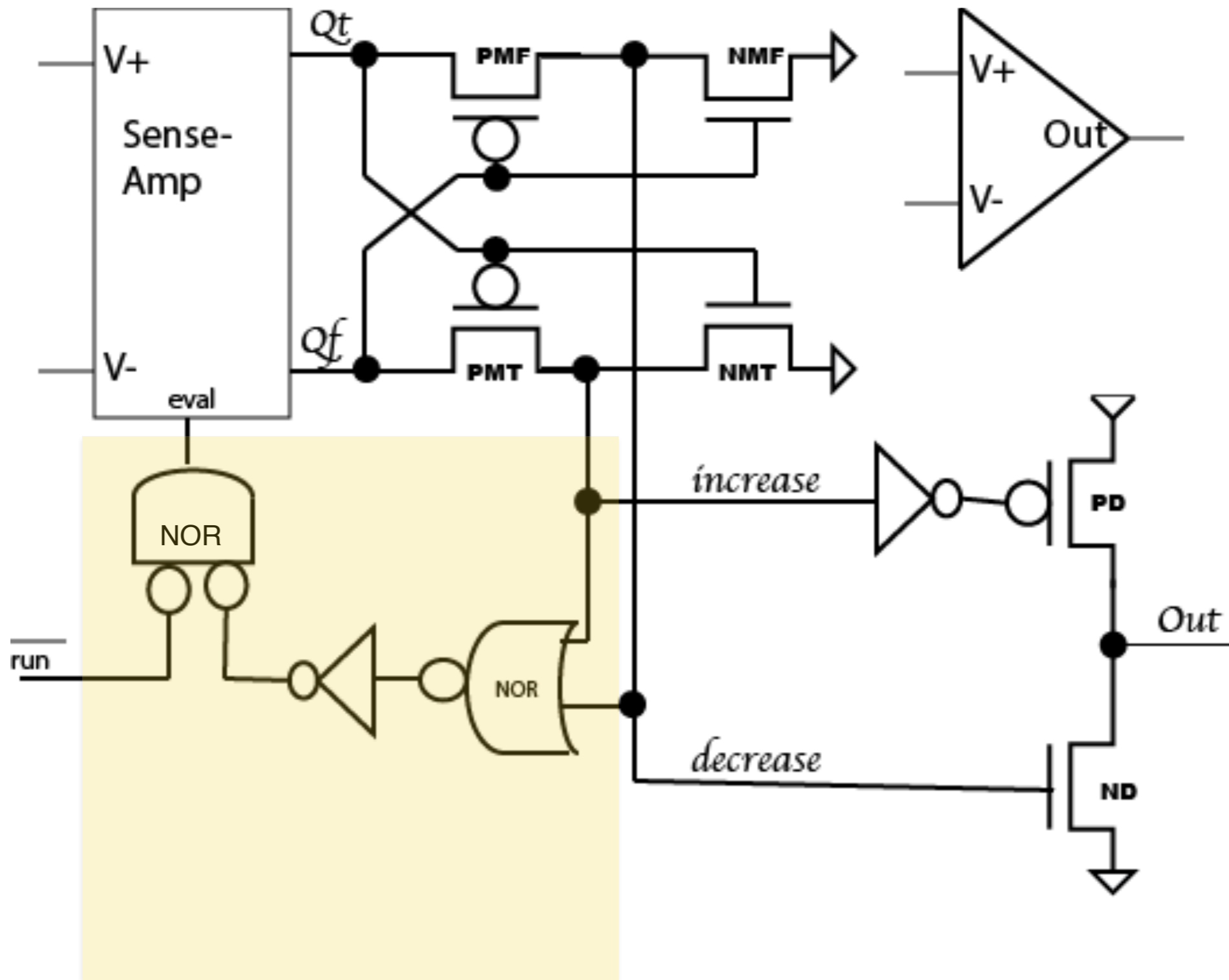
# Metastability resolving circuitry



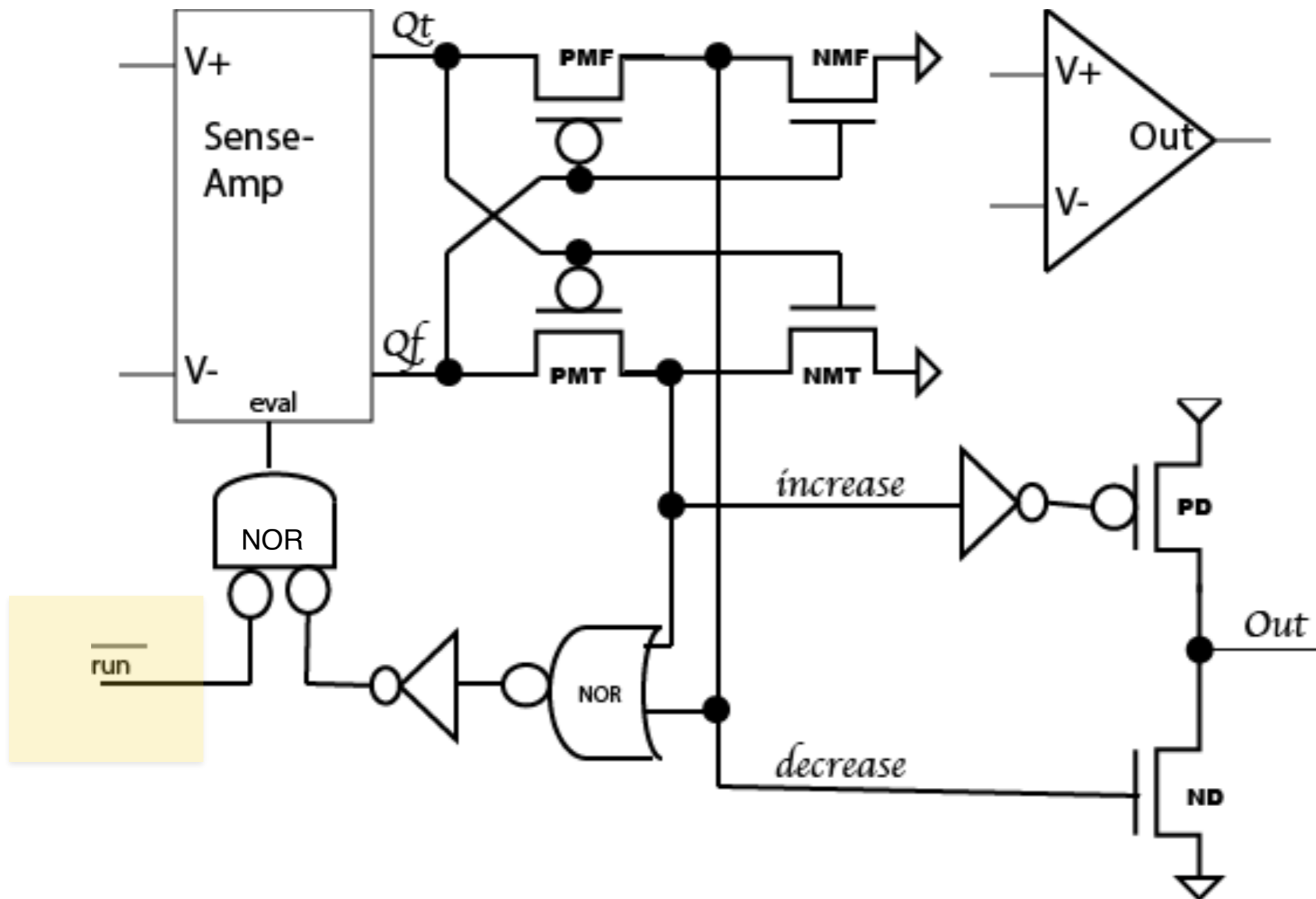
# Actuate output voltage

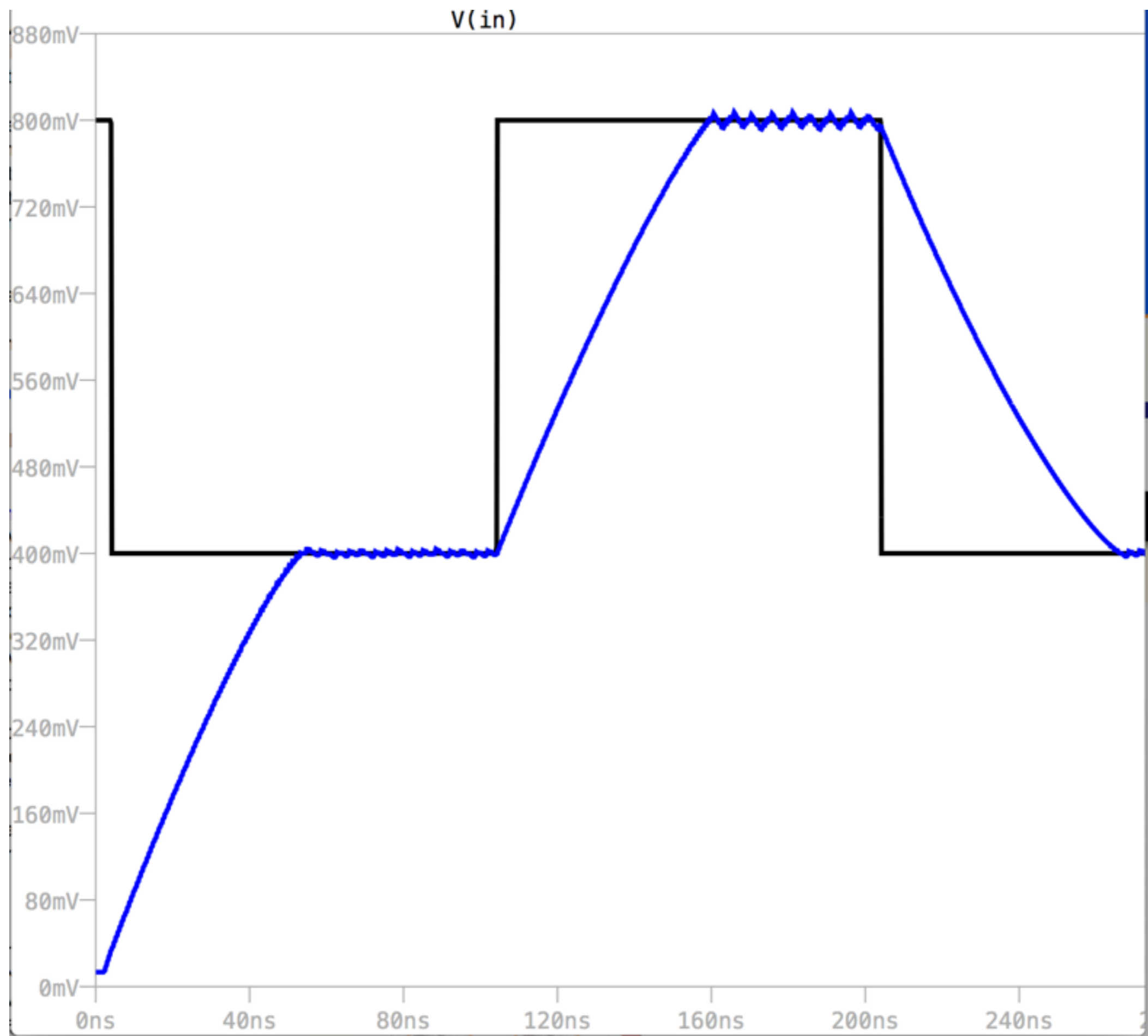


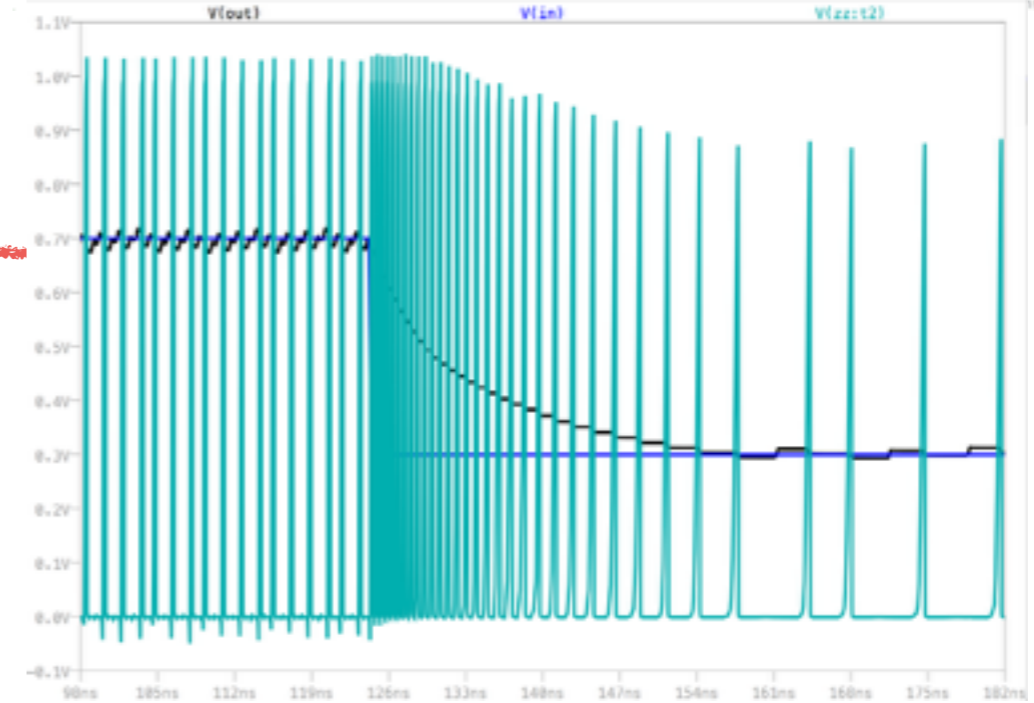
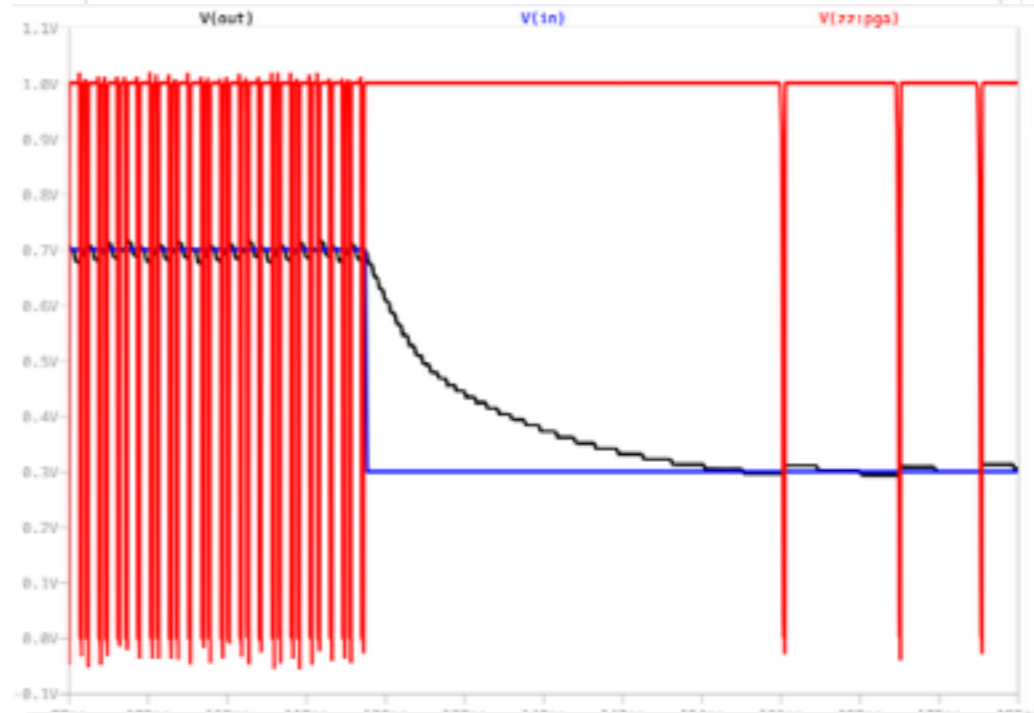
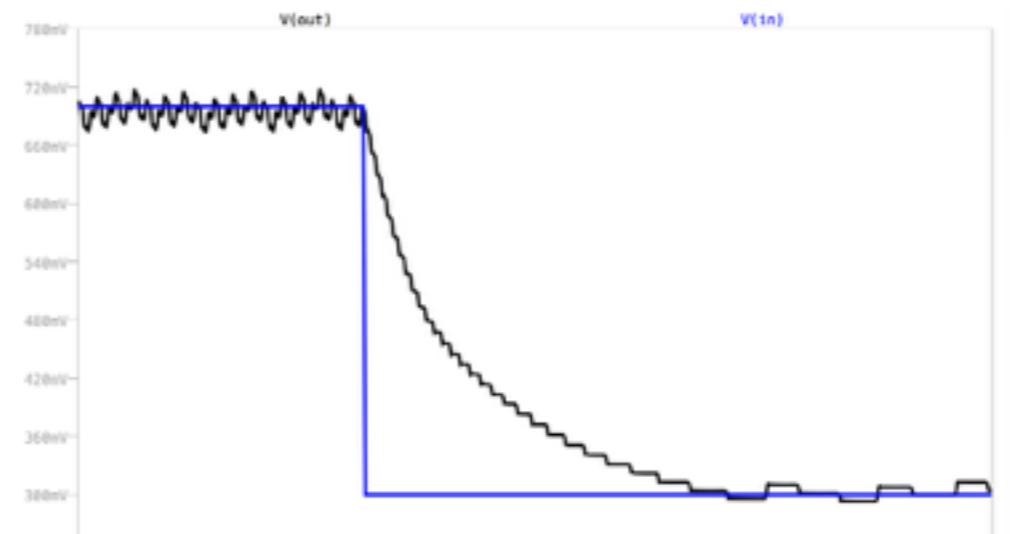
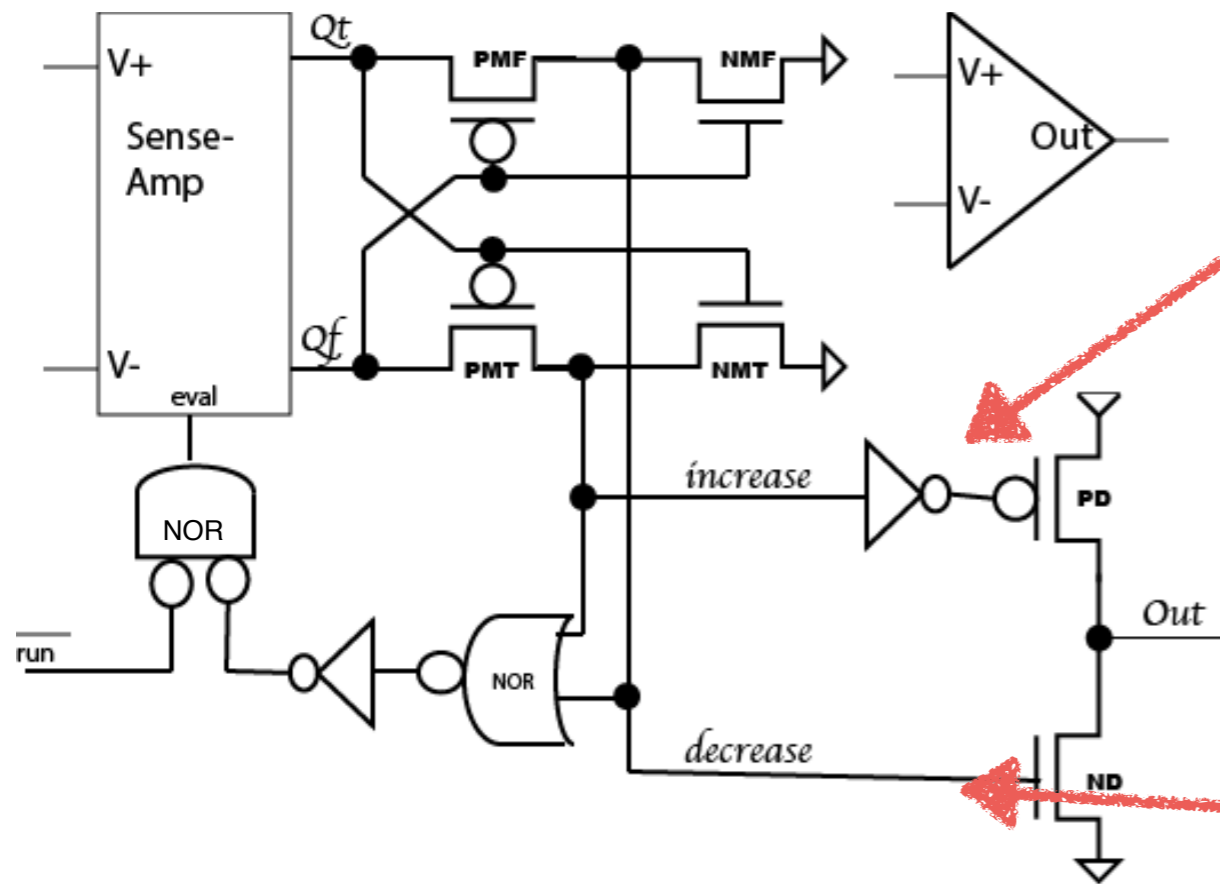
# Reset



# Start/stop







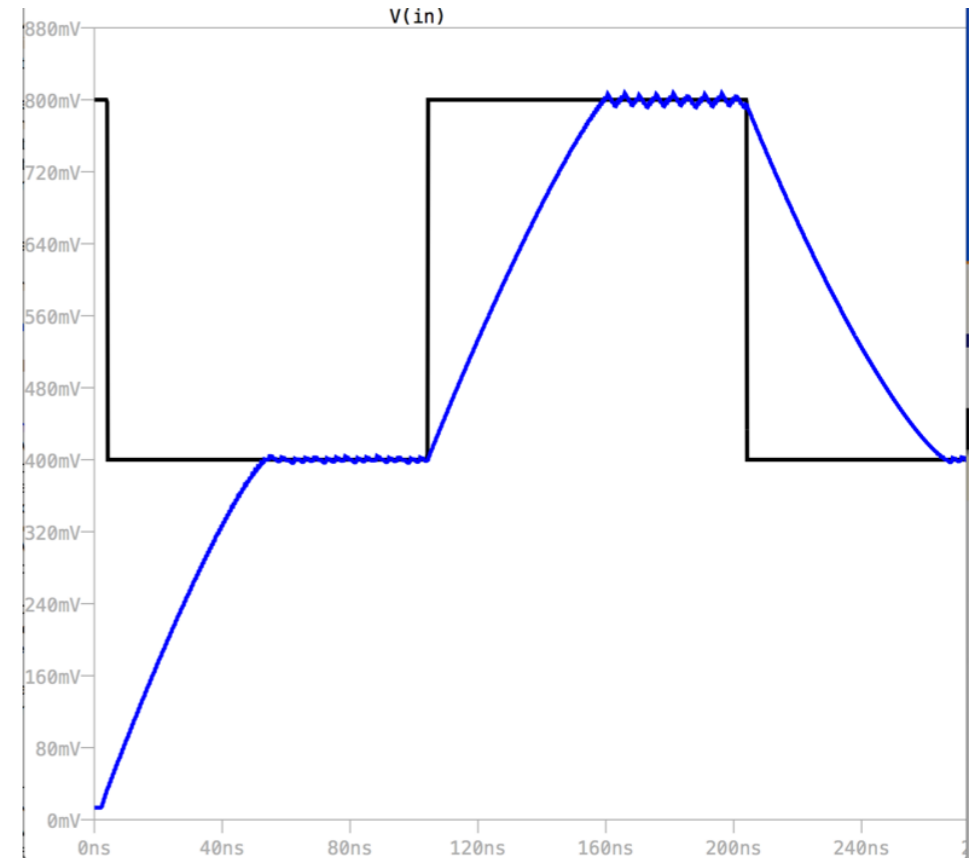


# Advantages

- Robust functionality in the face of unexpected transistor properties or poor sizing.
- rail-to-rail signaling
- no DC currents
- potential very low power operation
- performance scales in the same direction as transistor integration trends

# Weaknesses

- BW scales as  $2^{-n}$
- relatively high output resistance
- distortion especially near rails



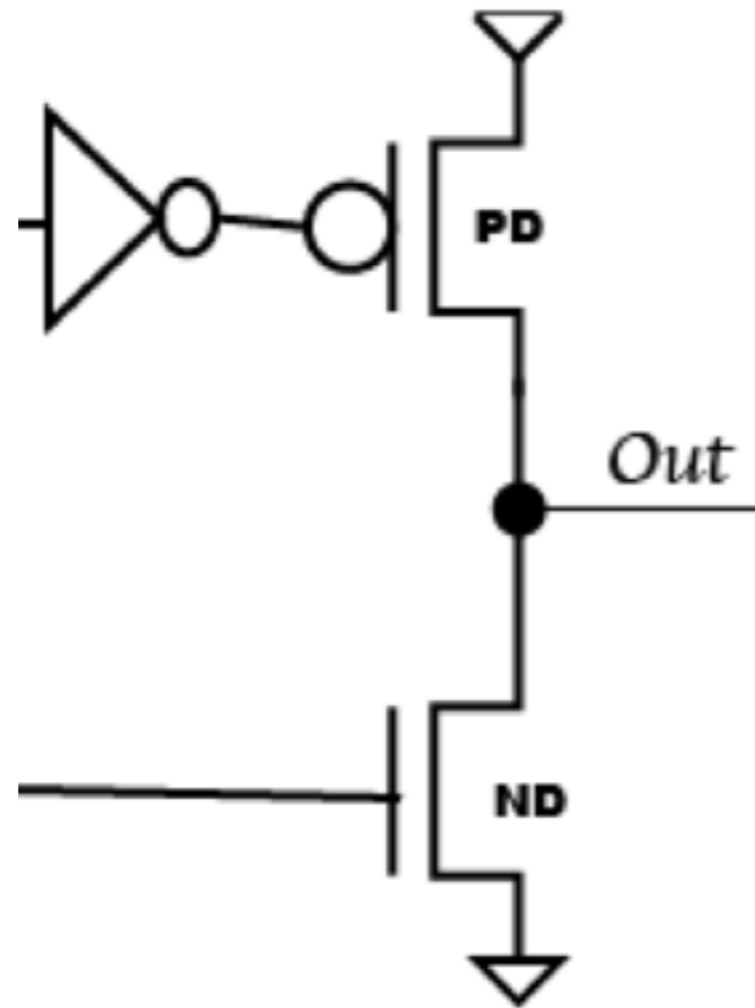
# Bandwidth

$$BW \propto \frac{1}{(t_{\text{eval}})^* (2^{\text{bits}+1})}$$

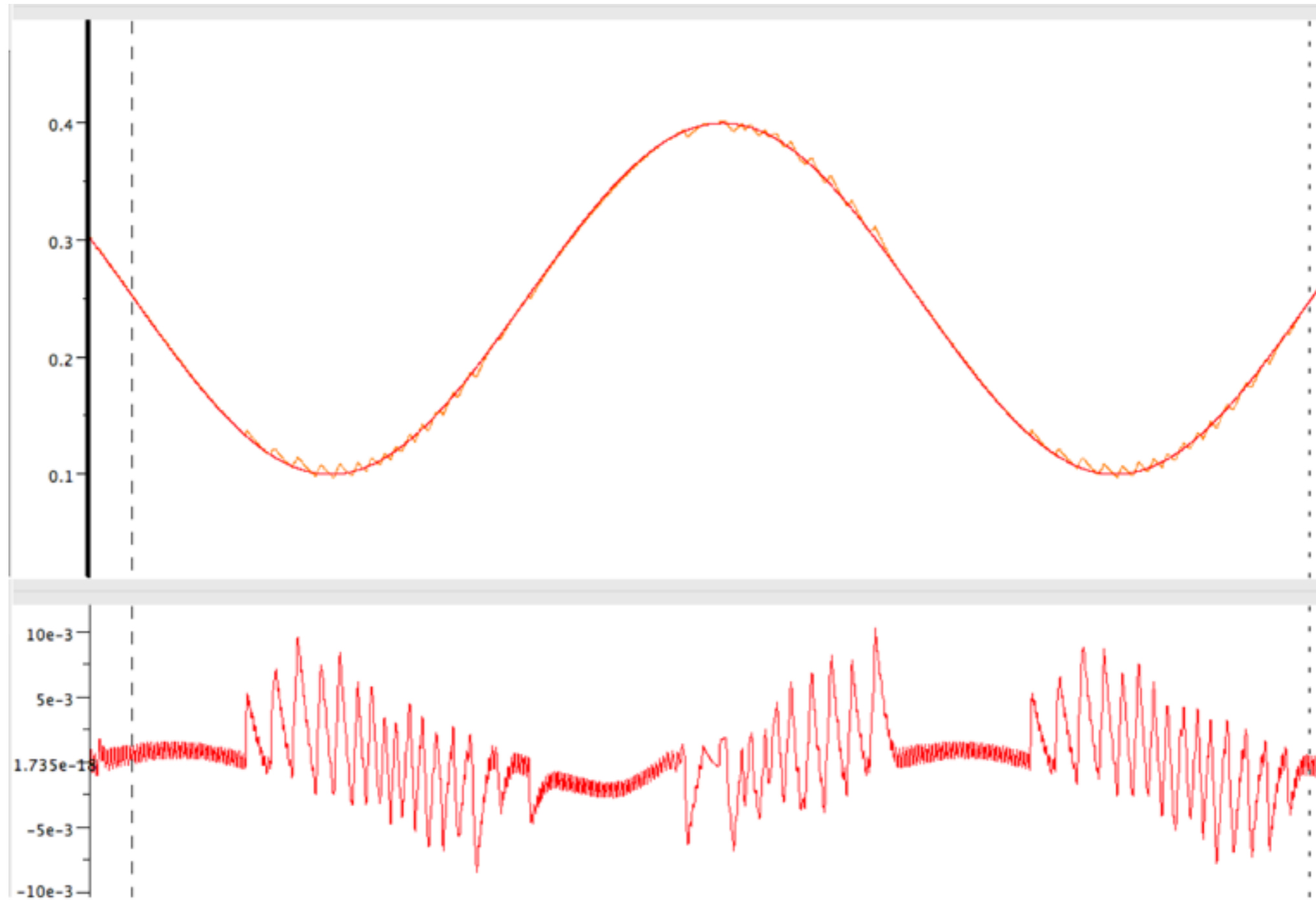
Conventional amplifier:

$$\text{Gain} * BW = \text{Constant}$$

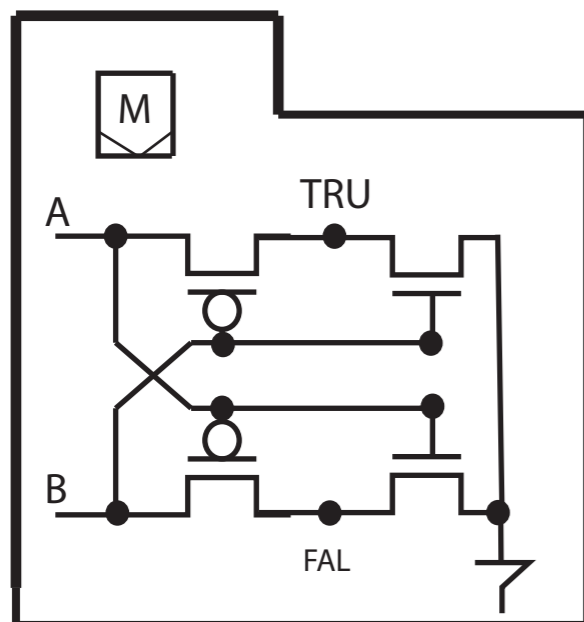
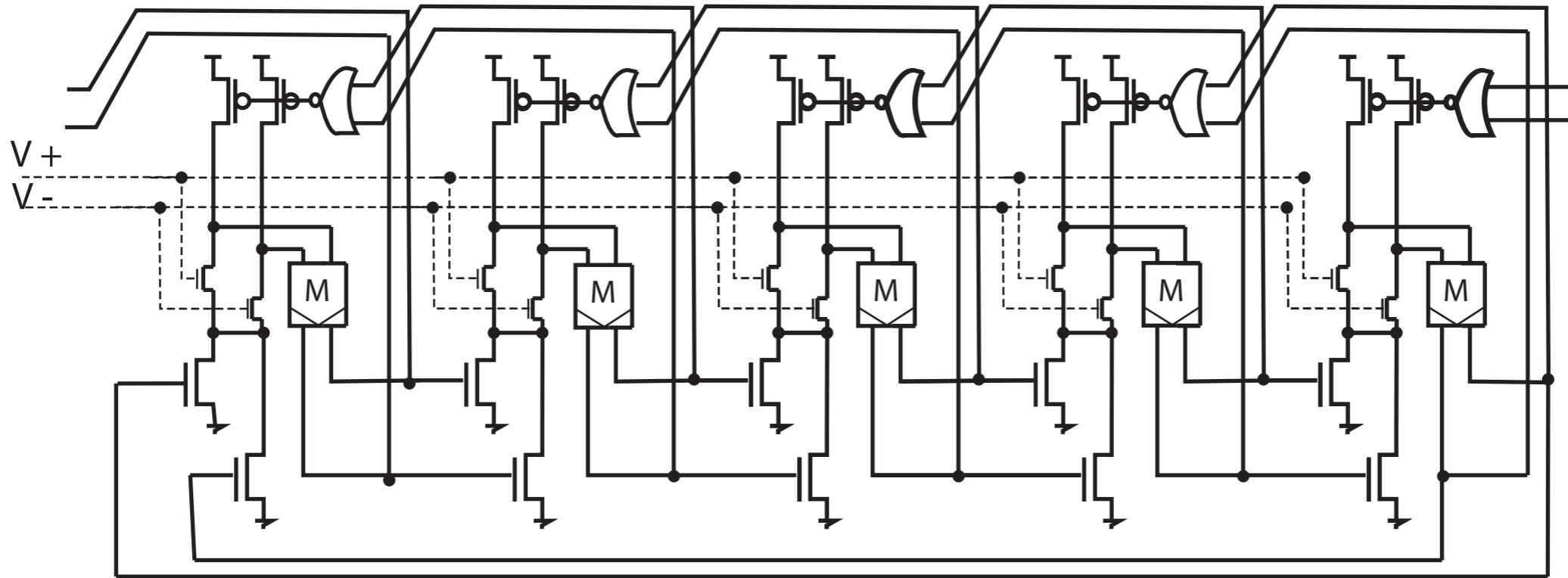
# High output resistance



# Distortion



# Embellishments



New evaluation every 2 gate delays

transistor matching issues

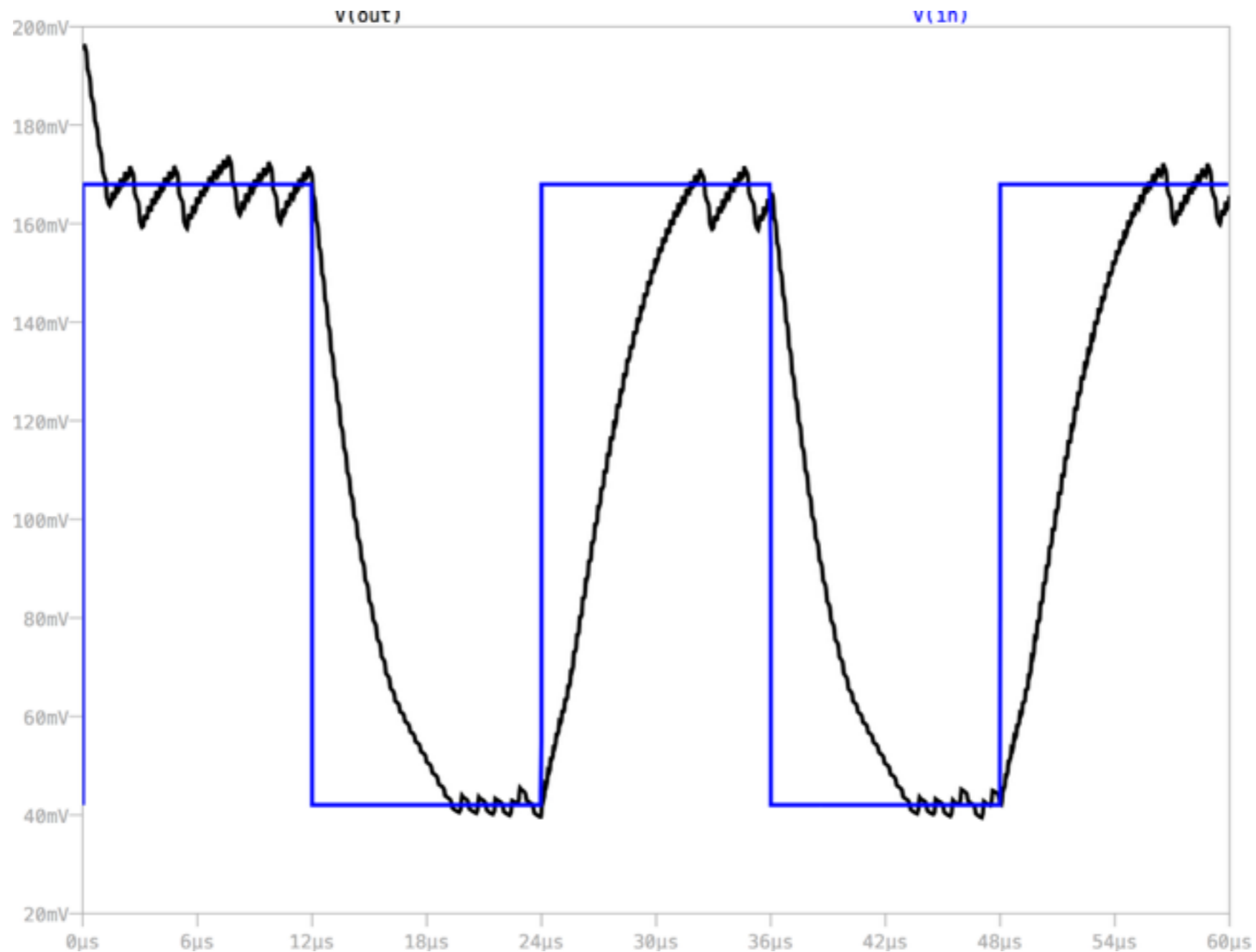
# Application: Analog datapath

Area of 64 bit microprocessors  
largely determined by wire routing.

With a 1V supply, four bits of resolution (62.5mV / level)  
easily achievable with this amplifier.

Upper limit of 16x area reduction.

# Applications: ultra-low power





# Switched Capacitor amplifier

