

date: 2025-02-06

TFE4188 - Lecture 4

Analog frontend and filters

W A W h n y

The behavior of particles is written in the mathematics of quantum mechanics

$$\psi(x, t) = Ae^{j(kx - \omega t)}$$

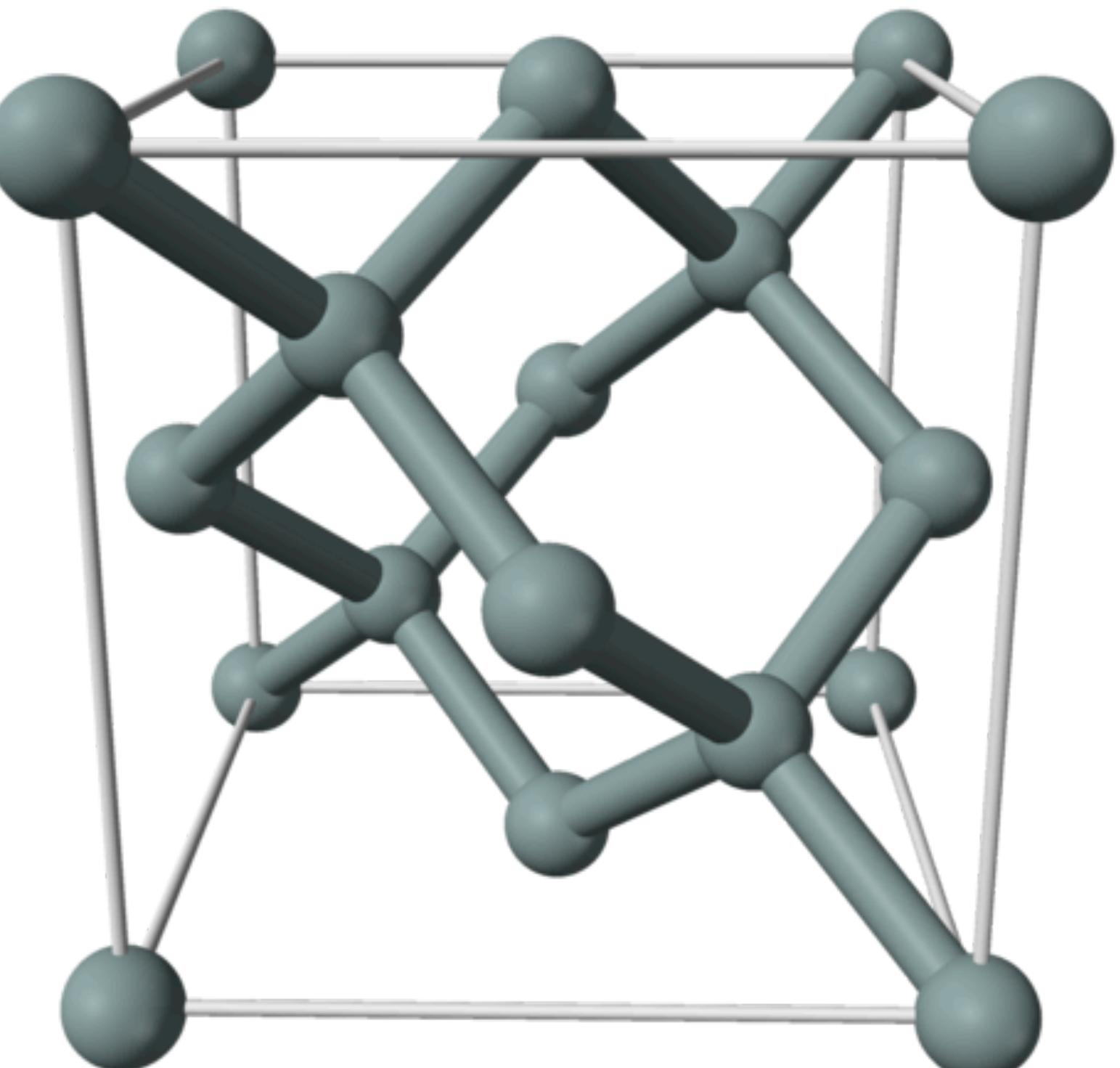
Probability amplitude of a particle

$$\frac{1}{2m} \frac{\hbar}{j^2} \frac{\partial^2}{\partial^2 x} \psi(x, t) + U(x) \psi(x, t) = -\frac{\hbar}{j} \frac{\partial}{\partial t} \psi(x, t)$$

Time evolution of the energy of a particle²

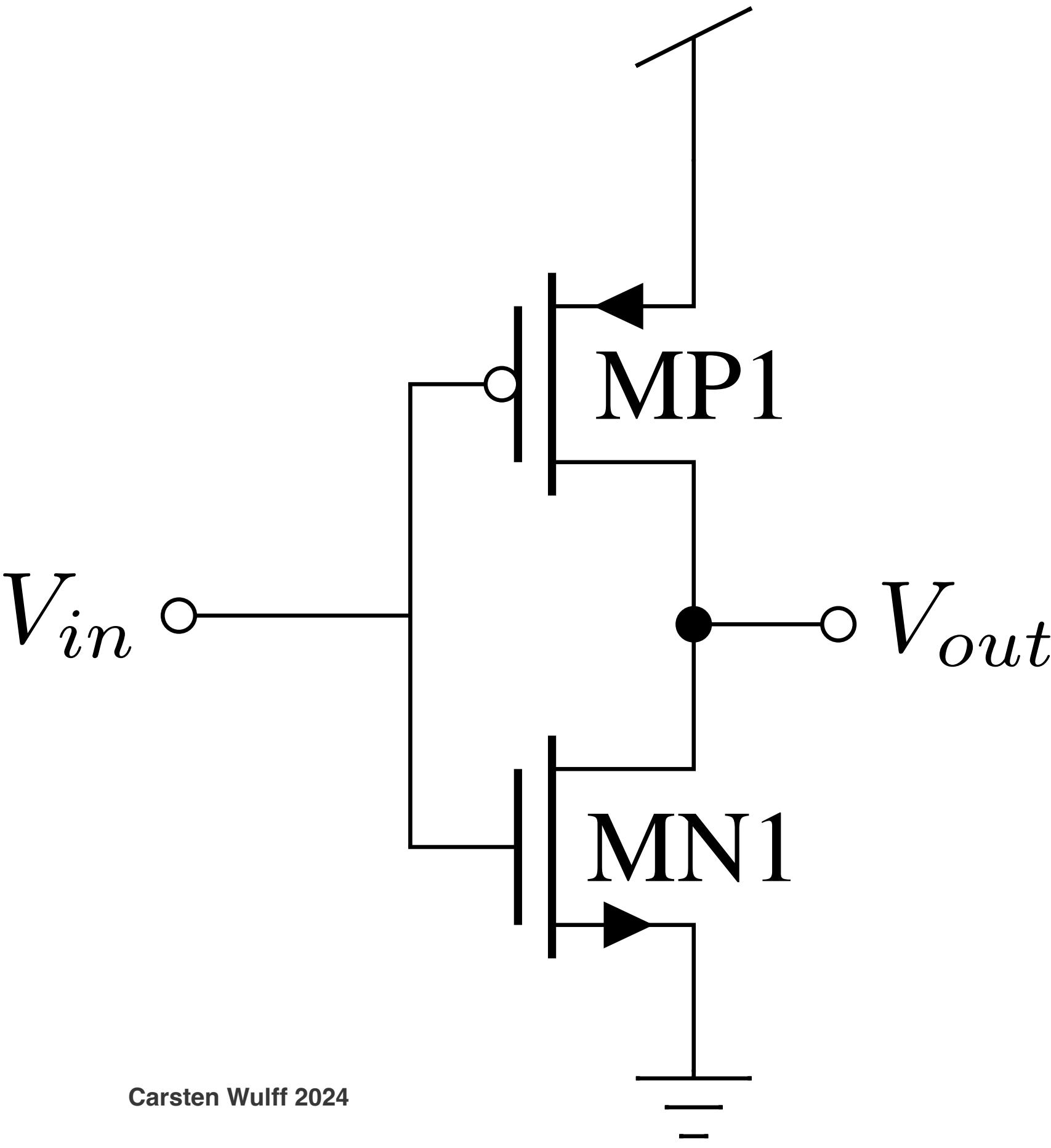
$$\frac{n_n}{n_p} = \frac{e^{(E_p - \mu)/kT} + 1}{e^{(E_n - \mu)/kT} + 1}$$

Relates the average number of fermions in thermal equilibrium to the energy of a single-particle state³



² Schrödinger equation

³ Fermi-Dirac statistics



The world is analog and is written in the mathematics of calculus ¹

$$\oint_{\partial\Omega} \mathbf{E} \cdot d\mathbf{S} = \frac{1}{\epsilon_0} \iiint_V \rho \cdot dV$$

Relates net electric flux to net enclosed electric charge

$$\oint_{\partial\Omega} \mathbf{B} \cdot d\mathbf{S} = 0$$

Relates net magnetic flux to net enclosed magnetic charge

$$\oint_{\partial\Sigma} \mathbf{E} \cdot d\ell = -\frac{d}{dt} \iint_{\Sigma} \mathbf{B} \cdot d\mathbf{S}$$

Relates induced electric field to changing magnetic flux

$$\oint_{\partial\Sigma} \mathbf{B} \cdot d\ell = \mu_0 \left(\iint_{\Sigma} \mathbf{J} \cdot d\mathbf{S} + \epsilon_0 \frac{d}{dt} \iint_{\Sigma} \mathbf{E} \cdot d\mathbf{S} \right)$$

Relates induced magnetic field to changing electric flux and to current

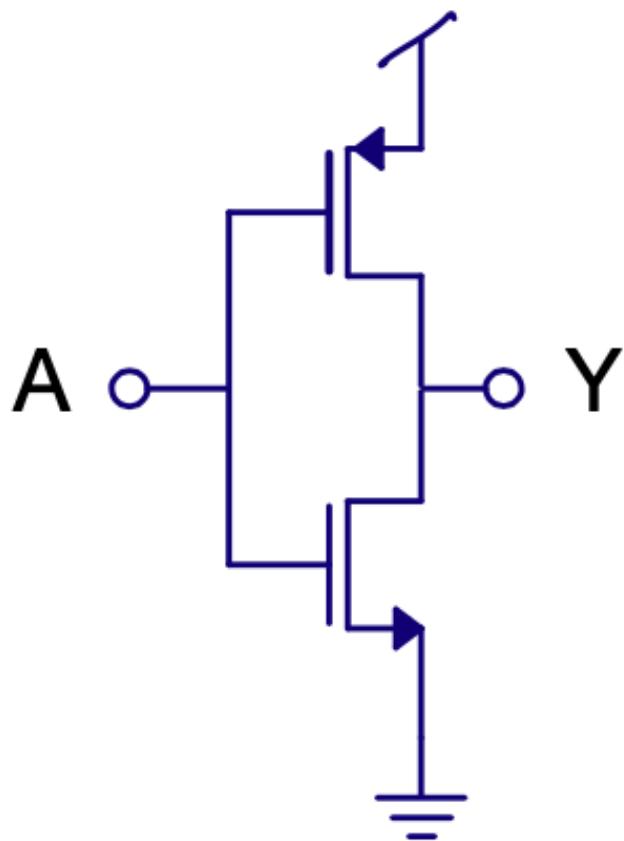
¹ Maxwell's equations

The abstract digital world is written in the mathematics of boolean algebra⁴

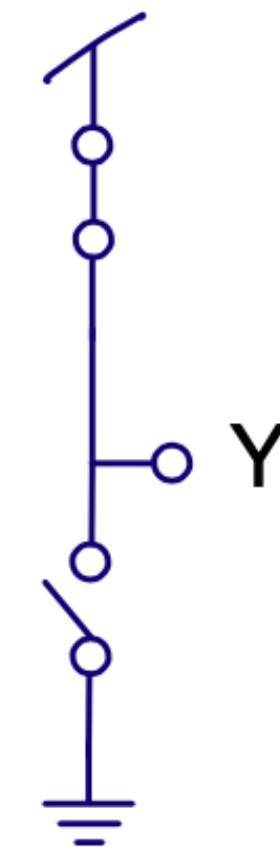
1 = True, 0 = False

A	B	NOT(A AND B)
0	0	1
0	1	1
1	0	1
1	1	0

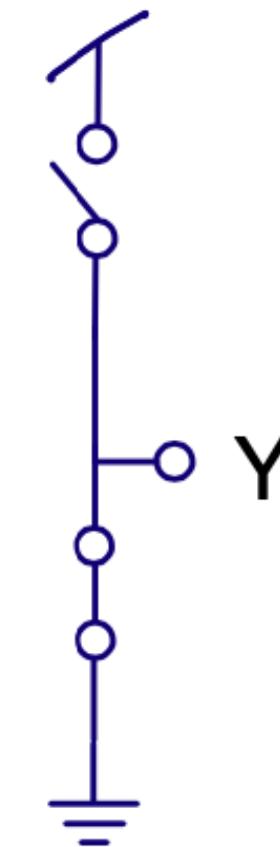
All digital processing can be made with the NOT(A AND B) function!



A=1



A=0



⁴ Boolean algebra

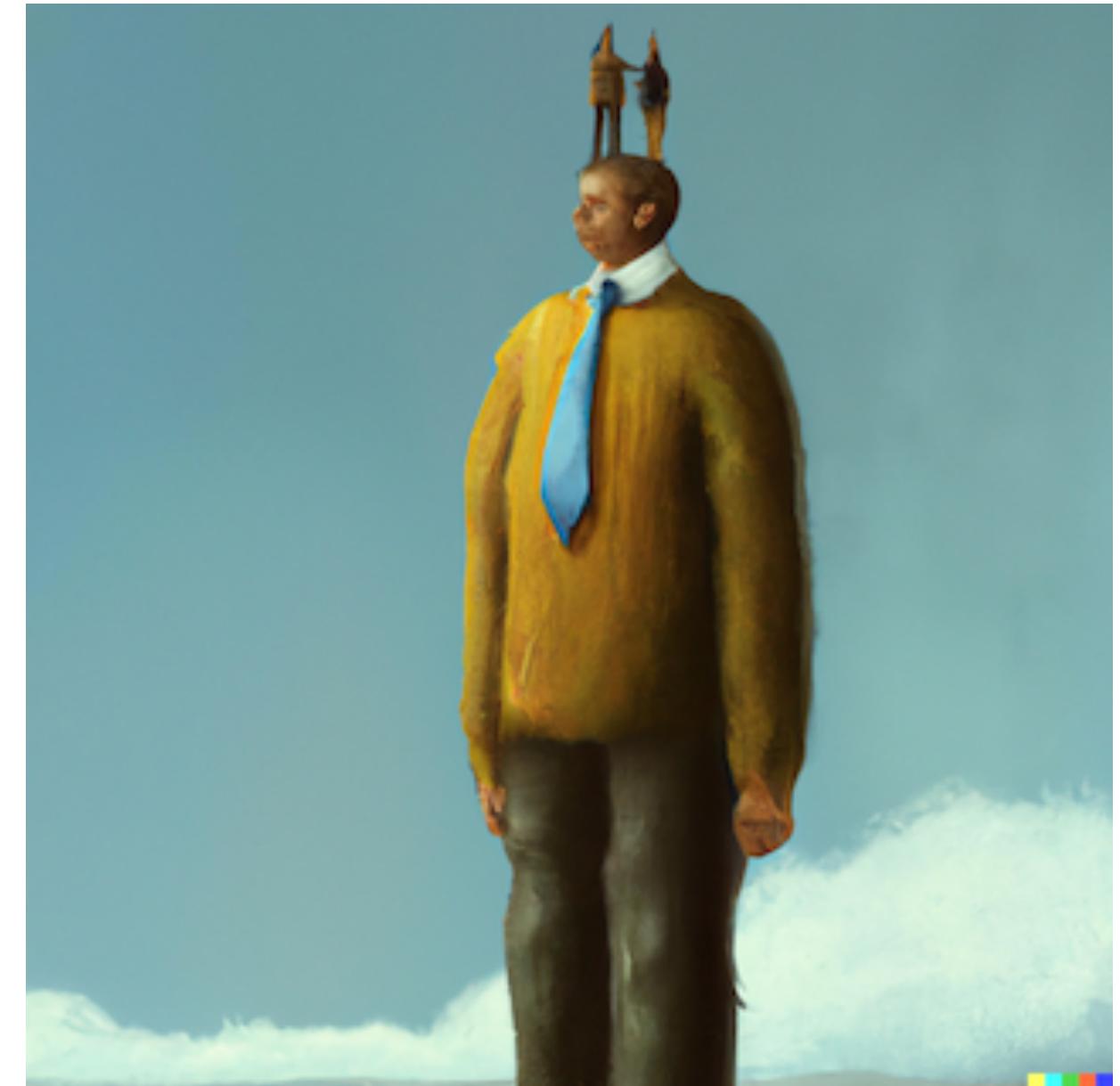
People that make
digital circuits can
easily reuse the
work of others

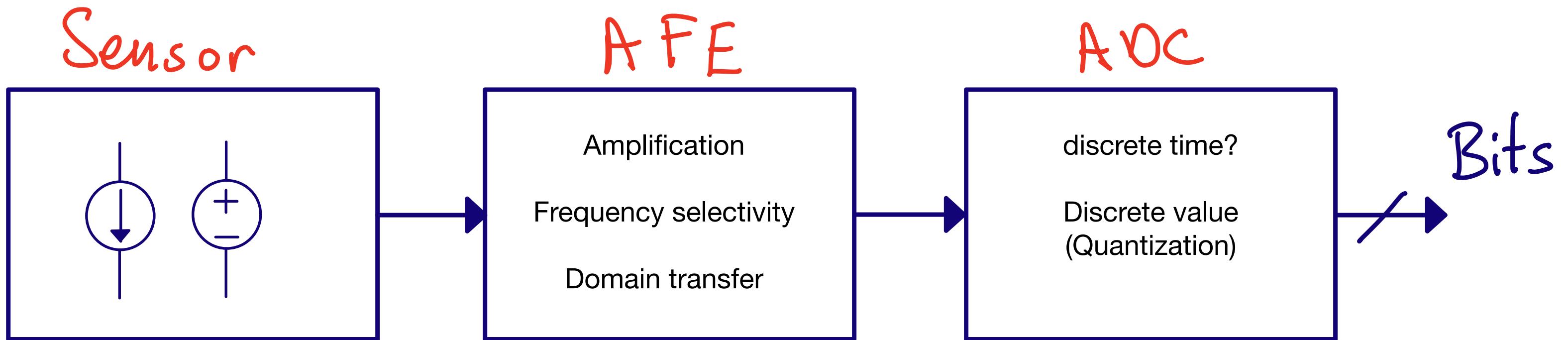




People that make
analog circuits can
learn from others,
but need to deal
with the real world
on their own

Should we do as much as possible in the abstract digital world?





What	Power [dBm]	Voltage [V]
Blocker	-30	7 m
Wanted	-90	7 u
Resolution		Wanted/255 = 28 n

$$\text{ADC resolution} \Rightarrow \ln \frac{7 \text{ mV}}{28 \text{ nV}} / \ln 2 \approx 18 \text{ bits}$$

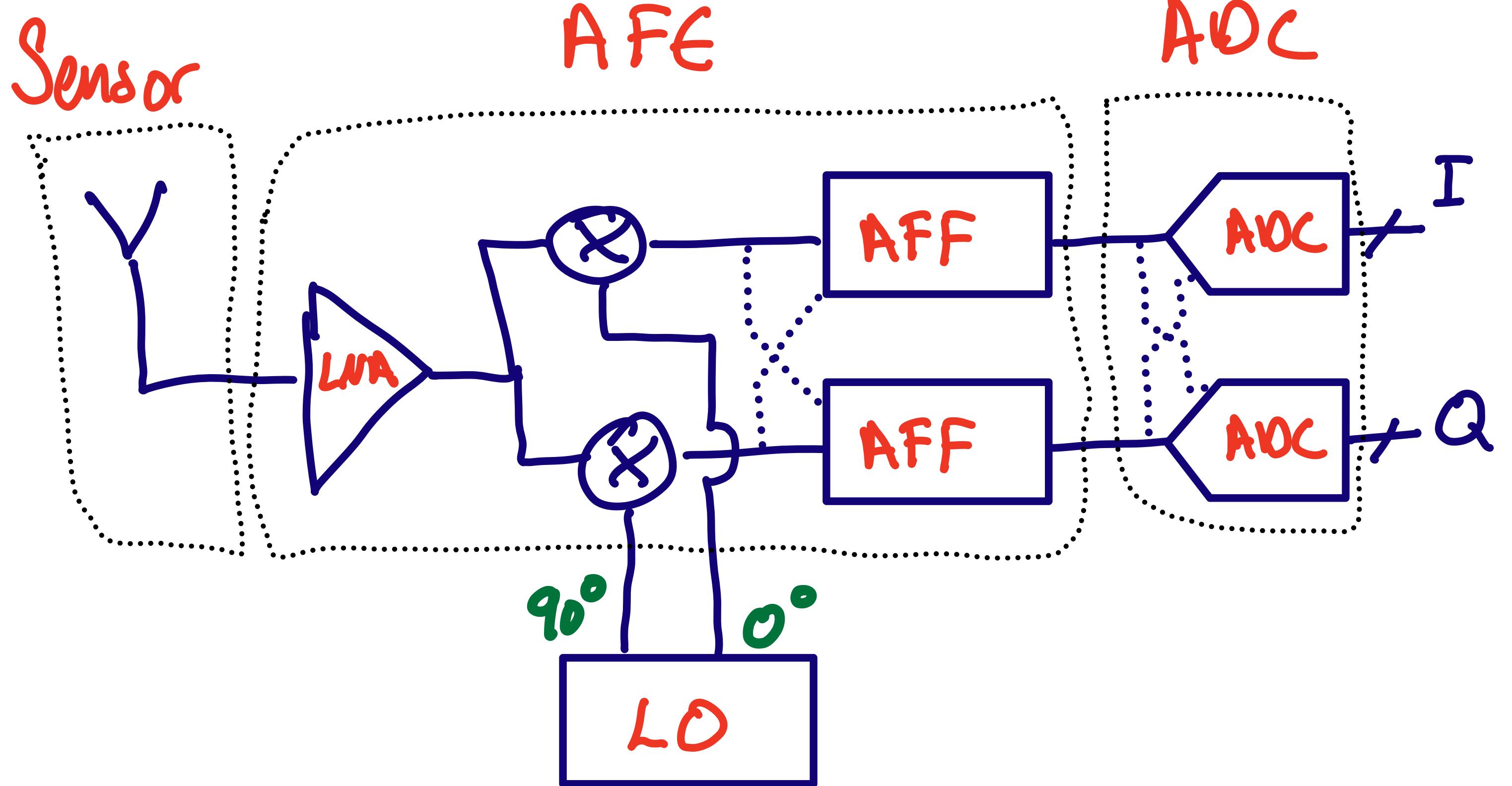
$$FOM = \frac{P}{2^{ENOB} fs}$$

$$P = 1 \text{ fJ/step} \times 2^{18} \times 5\text{GHz} = 1.31 \text{ W}$$

Whoop battery is 205mAh at 3.8 V

$$\text{Hours} = \frac{205 \text{ mAh}}{1.32 \text{ W}/3.8 \text{ V}} = 0.6 \text{ h}$$

Nordic Inside

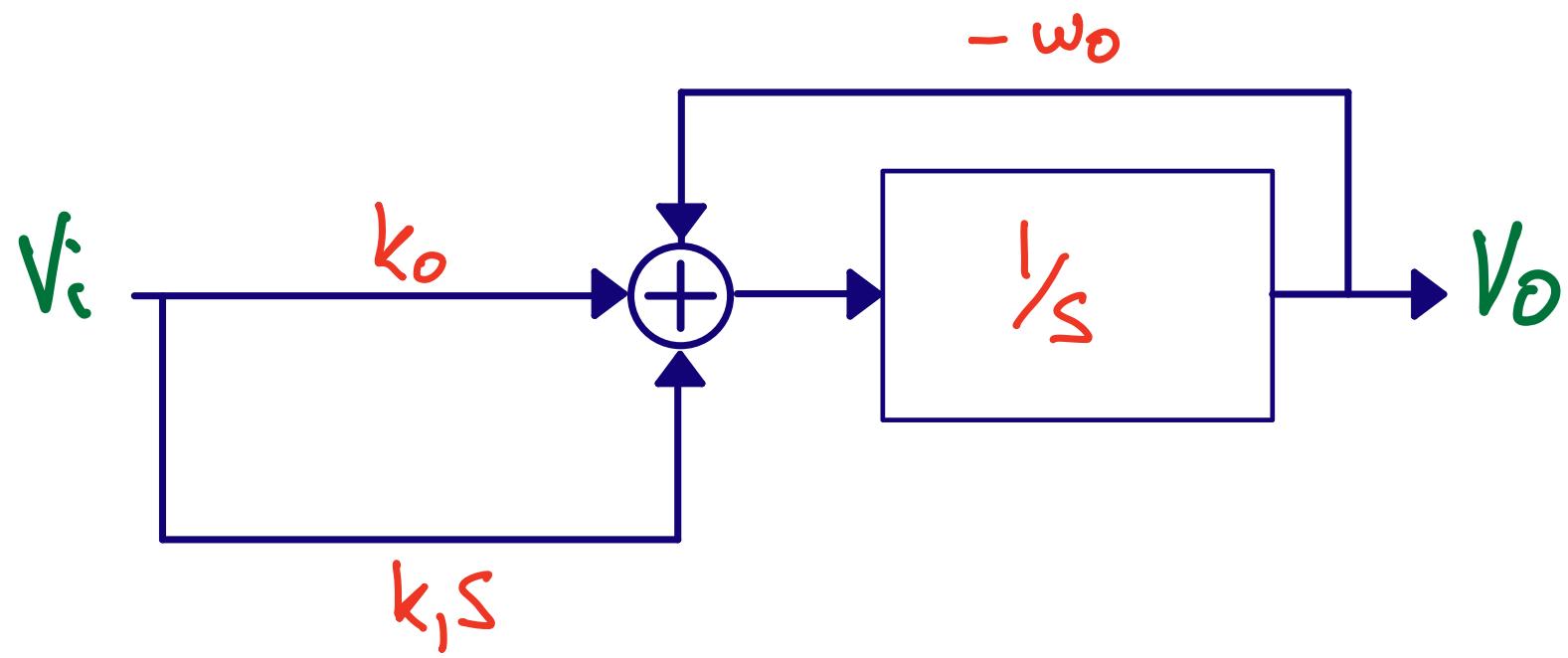


You must know application before you make the AFE!

filters

A combination of 1'st and 2'nd order stages can synthesize any order filter

First order filter



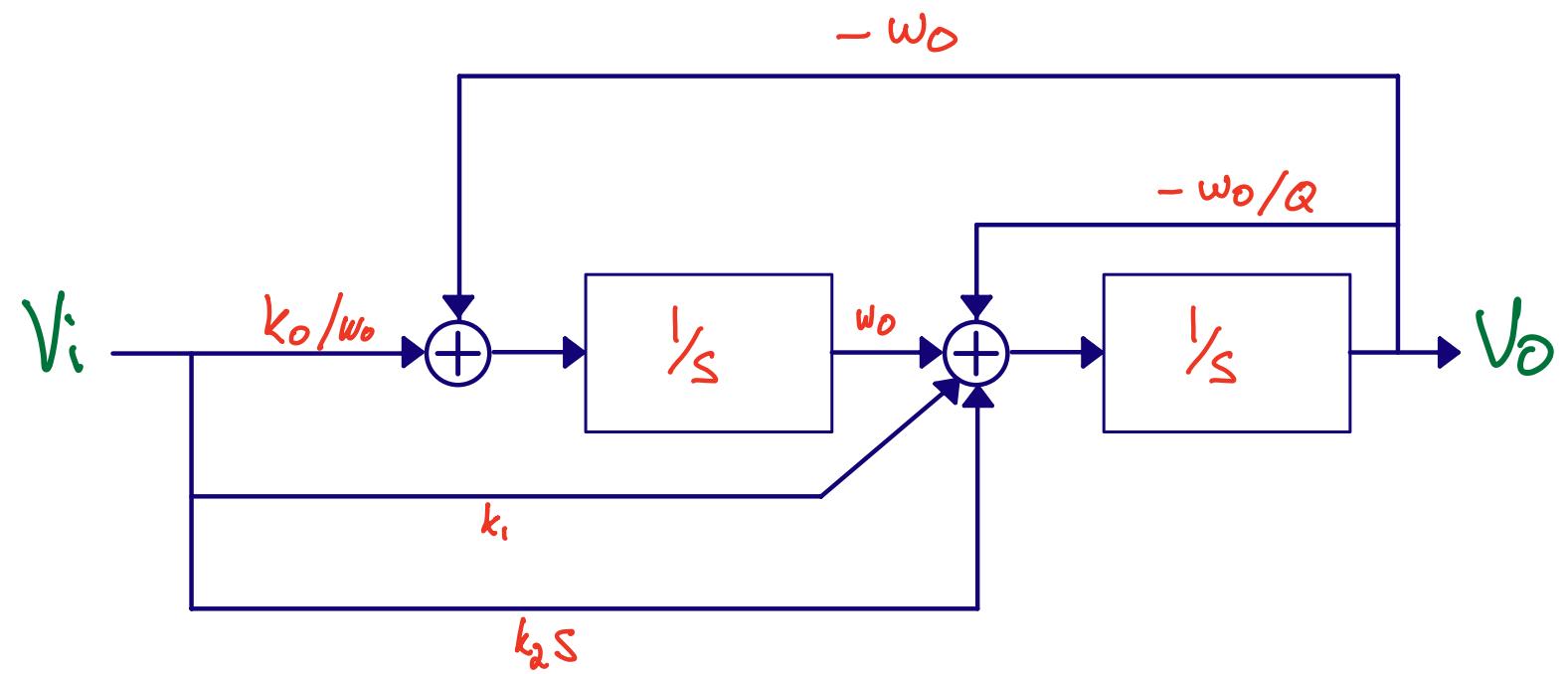
1. any line with a coefficient is a multiplier
2. any box output is a multiplication of the coefficient and the input
3. any sum, well, sum all inputs
4. be aware of gremlins (a sudden -- swap)

$$H(s) = \frac{V_o(s)}{V_i(s)} = \frac{k_1 s + k_0}{s + w_o}$$

Second order filter

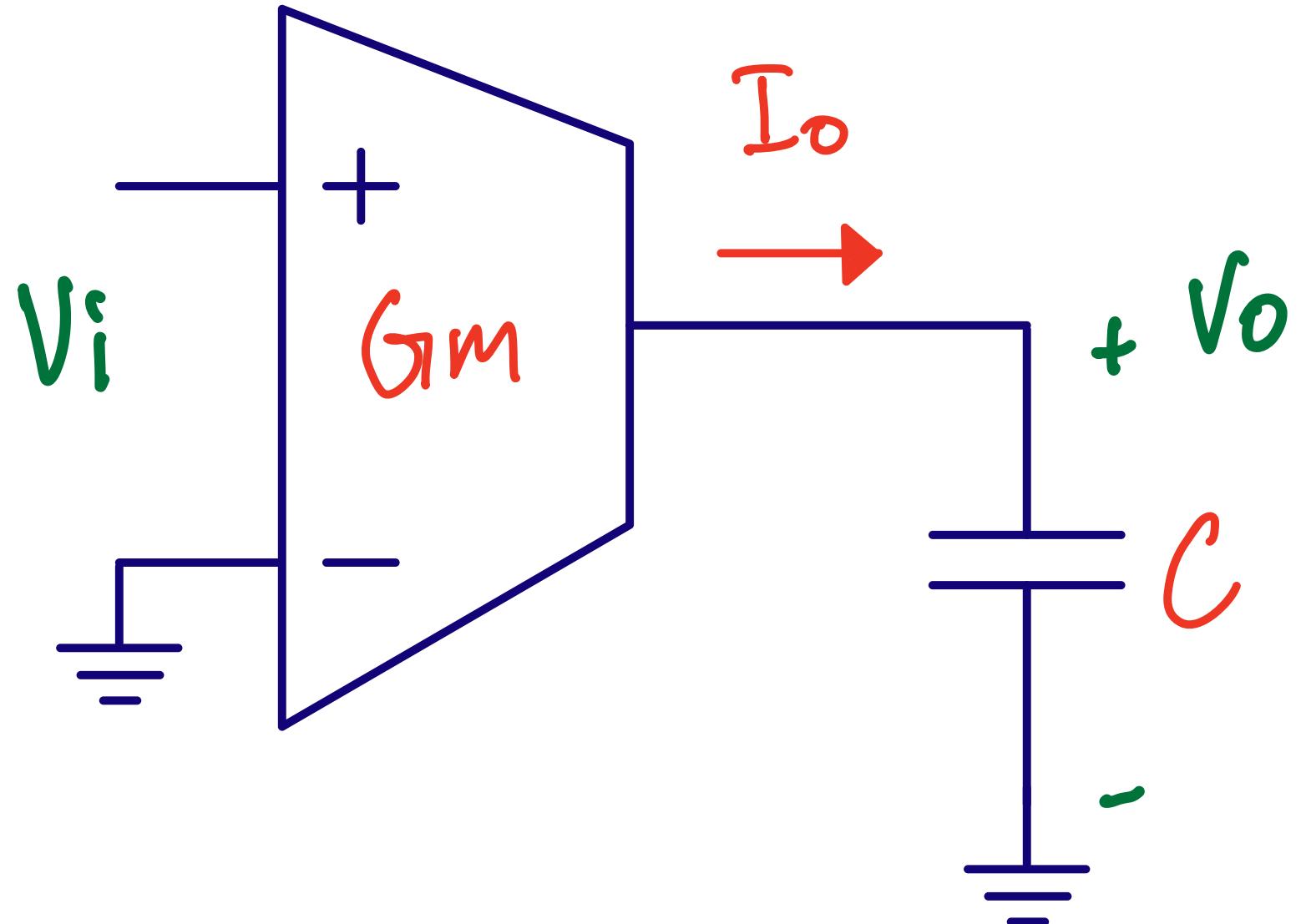
Bi-quadratic is a general purpose second order filter.

$$H(s) = \frac{k_2 s^2 + k_1 s + k_0}{s^2 + \frac{\omega_0}{Q} s + \omega_0^2}$$



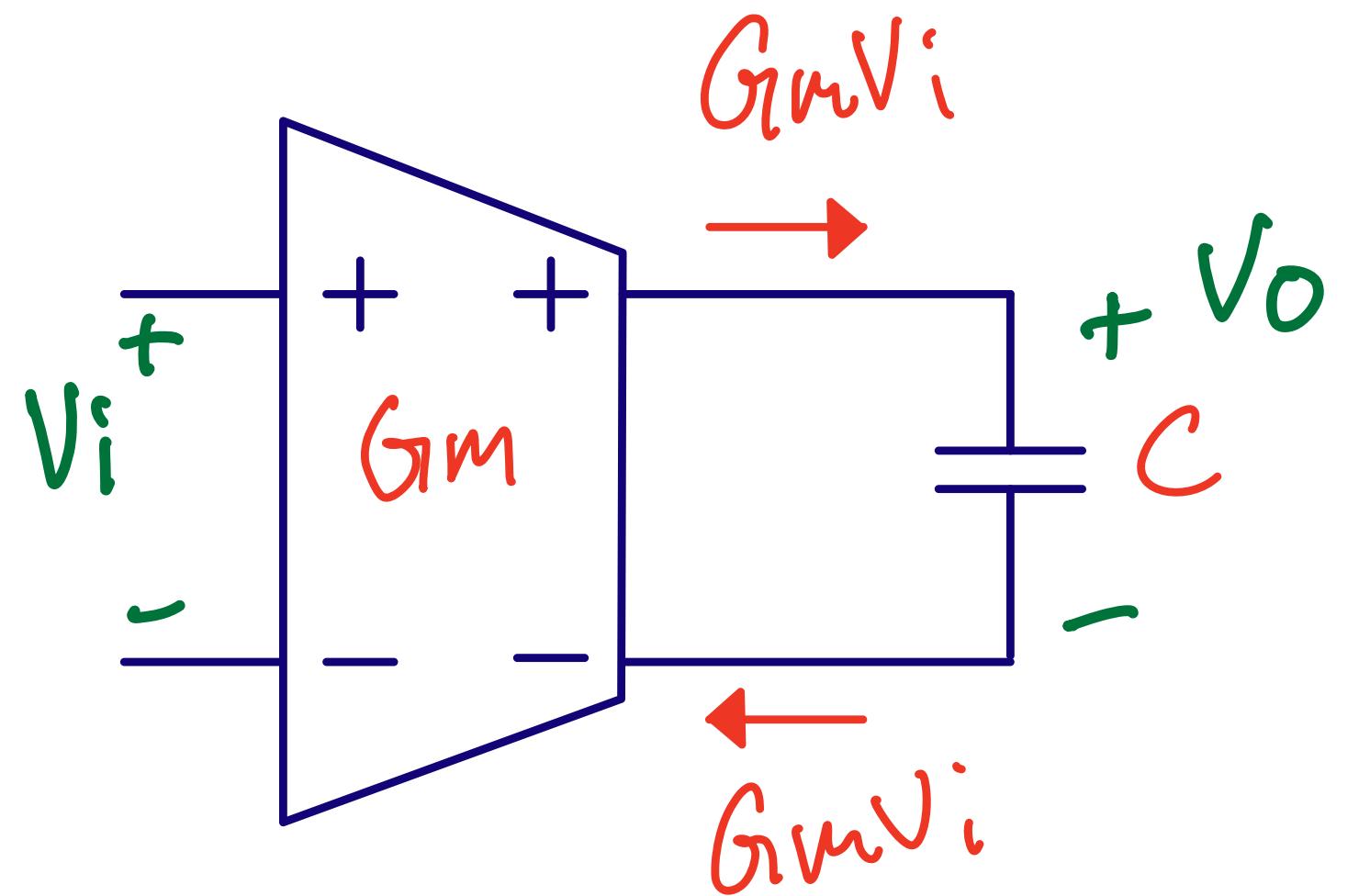
How do we implement the filter sections?

Gram-oc



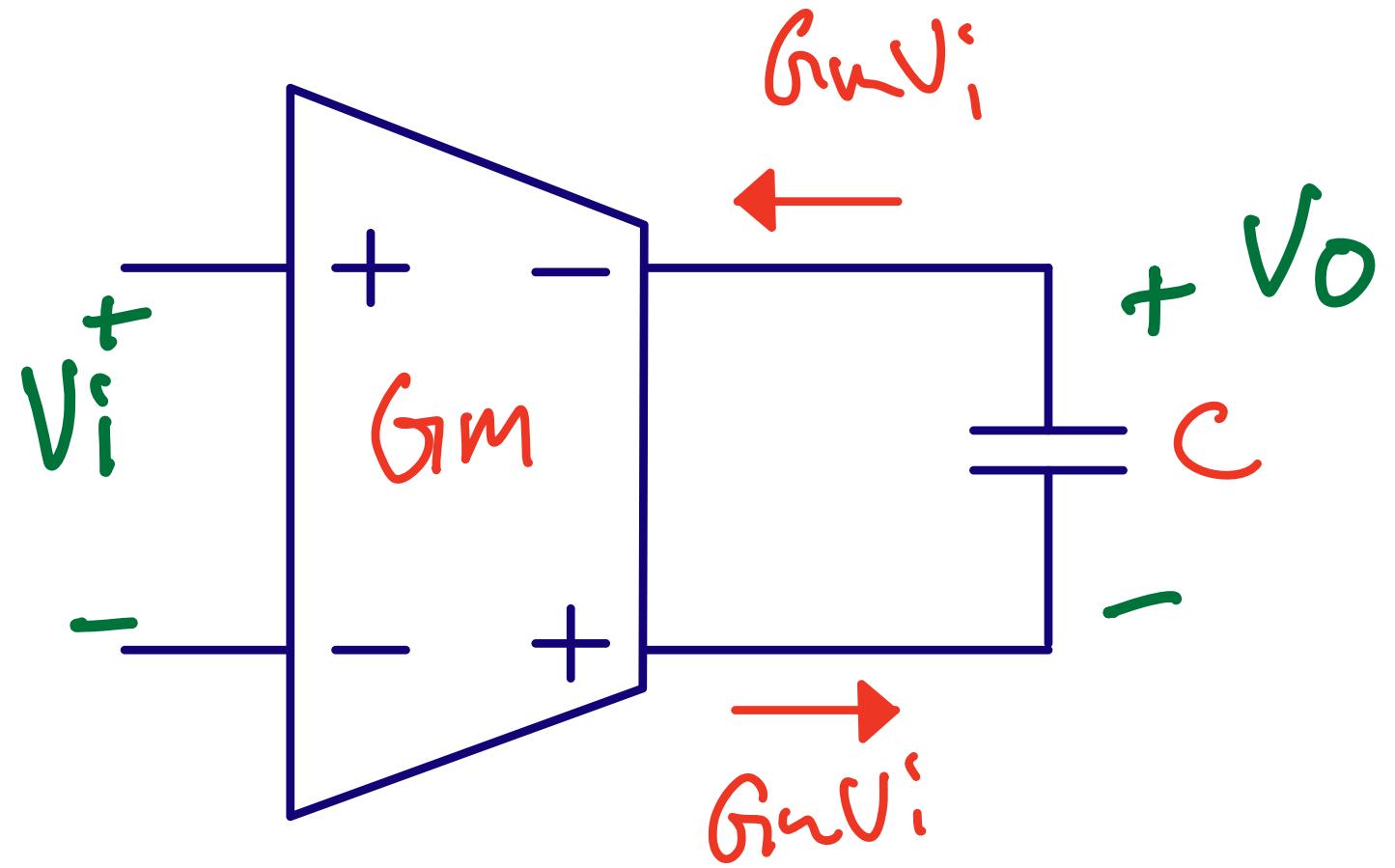
$$V_o = \frac{I_o}{sC} = \frac{\omega_{ti}}{s} V_i$$

$$\omega_{ti} = \frac{G_m}{C}$$

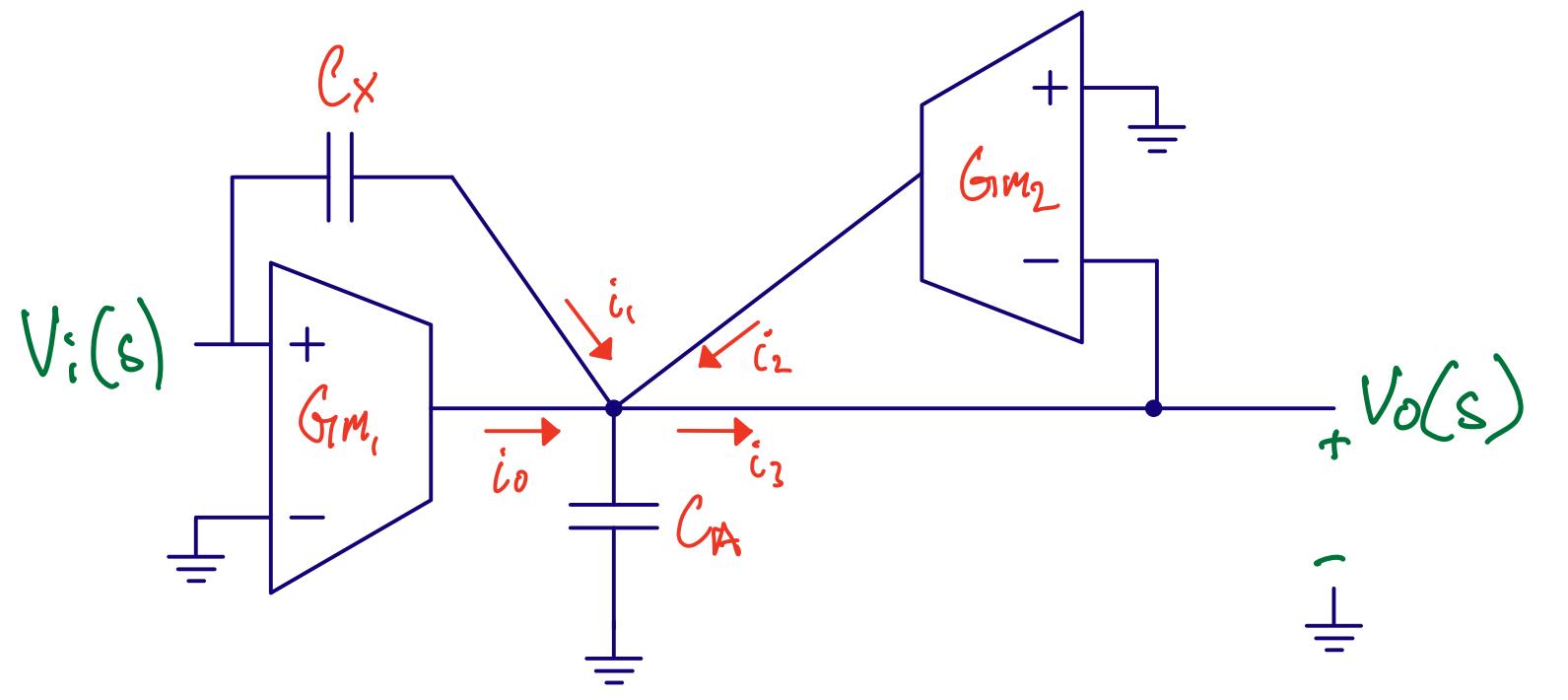


$$sCV_o = G_m V_i$$

$$H(s) = \frac{V_o}{V_i} = \frac{G_m}{sC}$$



$$H(s) = \frac{V_o}{V_i} = -\frac{G_m}{sC}$$



$$i_o =$$

$$i_1 =$$

$$i_L =$$

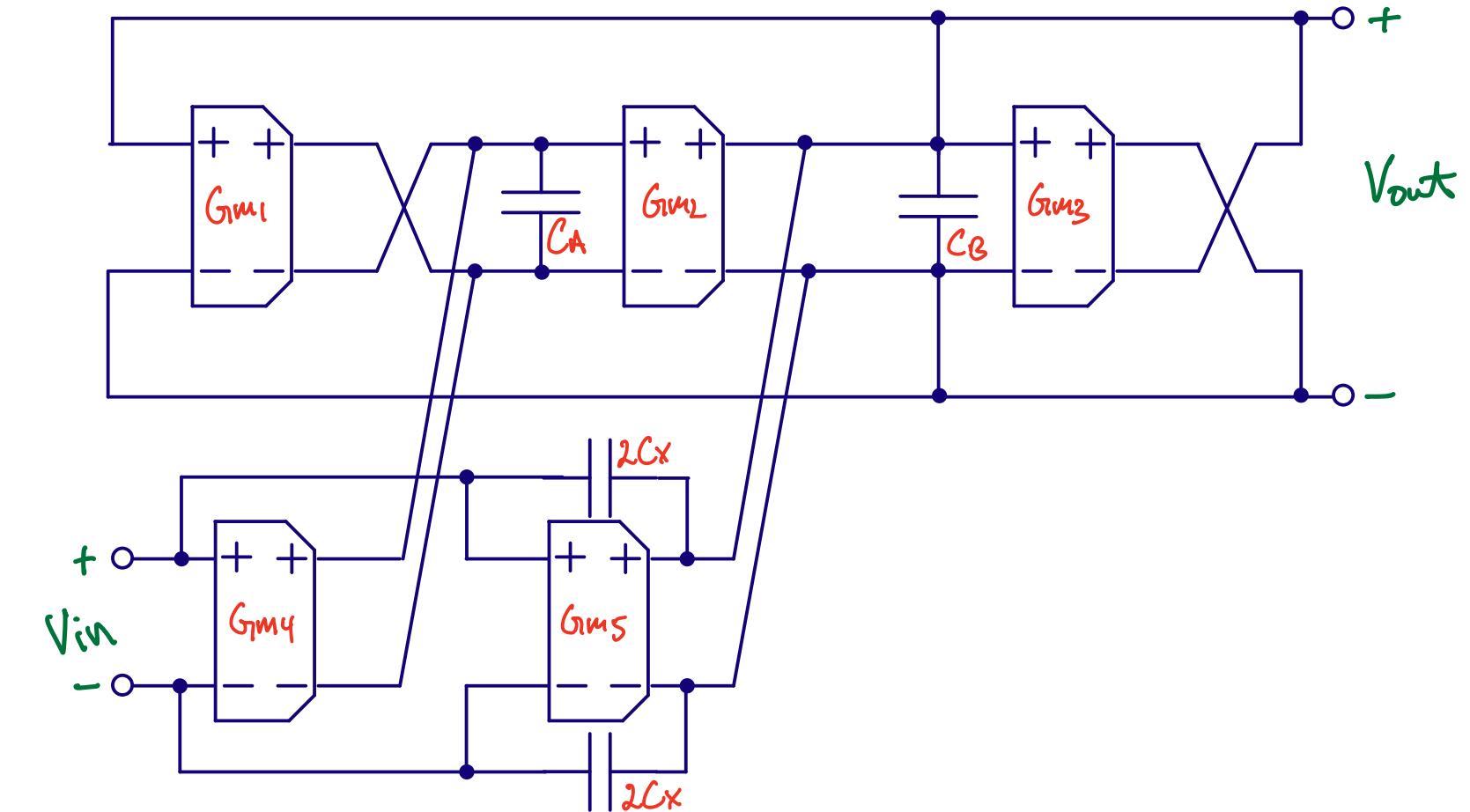
$$i_3 =$$

$$H(s) = \frac{k_1 s + k_0}{s + w_o}$$

$$H(s) = \frac{s \frac{C_x}{C_a+C_x} + \frac{G_{m1}}{C_a+C_x}}{s + \frac{G_{m2}}{C_a+C_x}}$$

$$H(s) = \frac{k_2 s^2 + k_1 s + k_0}{s^2 + \frac{\omega_0}{Q} s + \omega_0^2}$$

$$H(s) = \frac{s^2 \frac{C_X}{C_X+C_B} + s \frac{G_{m5}}{C_X+C_B} + \frac{G_{m2}G_{m4}}{C_A(C_X+C_B)}}{s^2 + s \frac{G_{m2}}{C_X+C_B} + \frac{G_{m1}G_{m2}}{C_A(C_X+C_B)}}$$



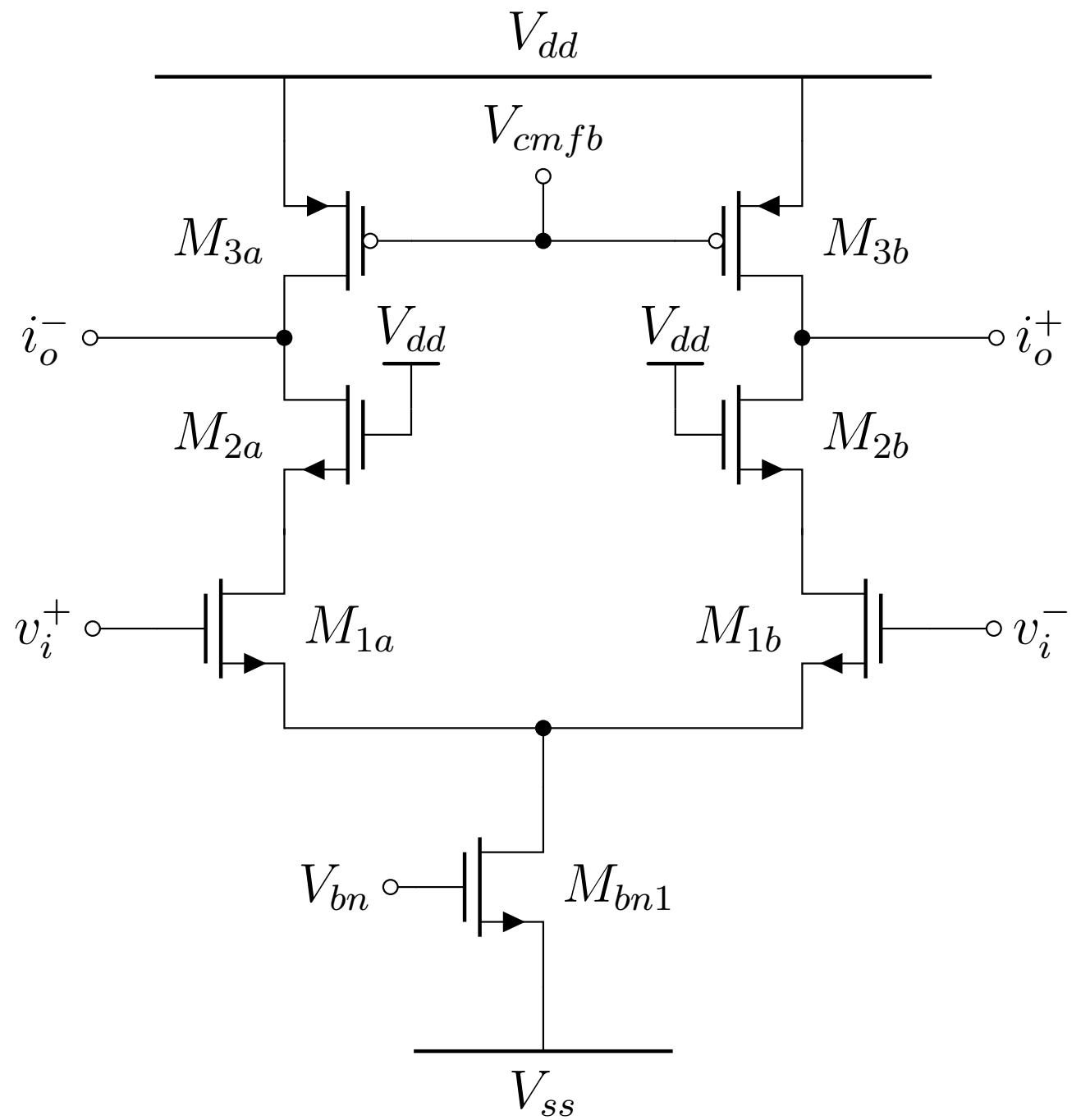
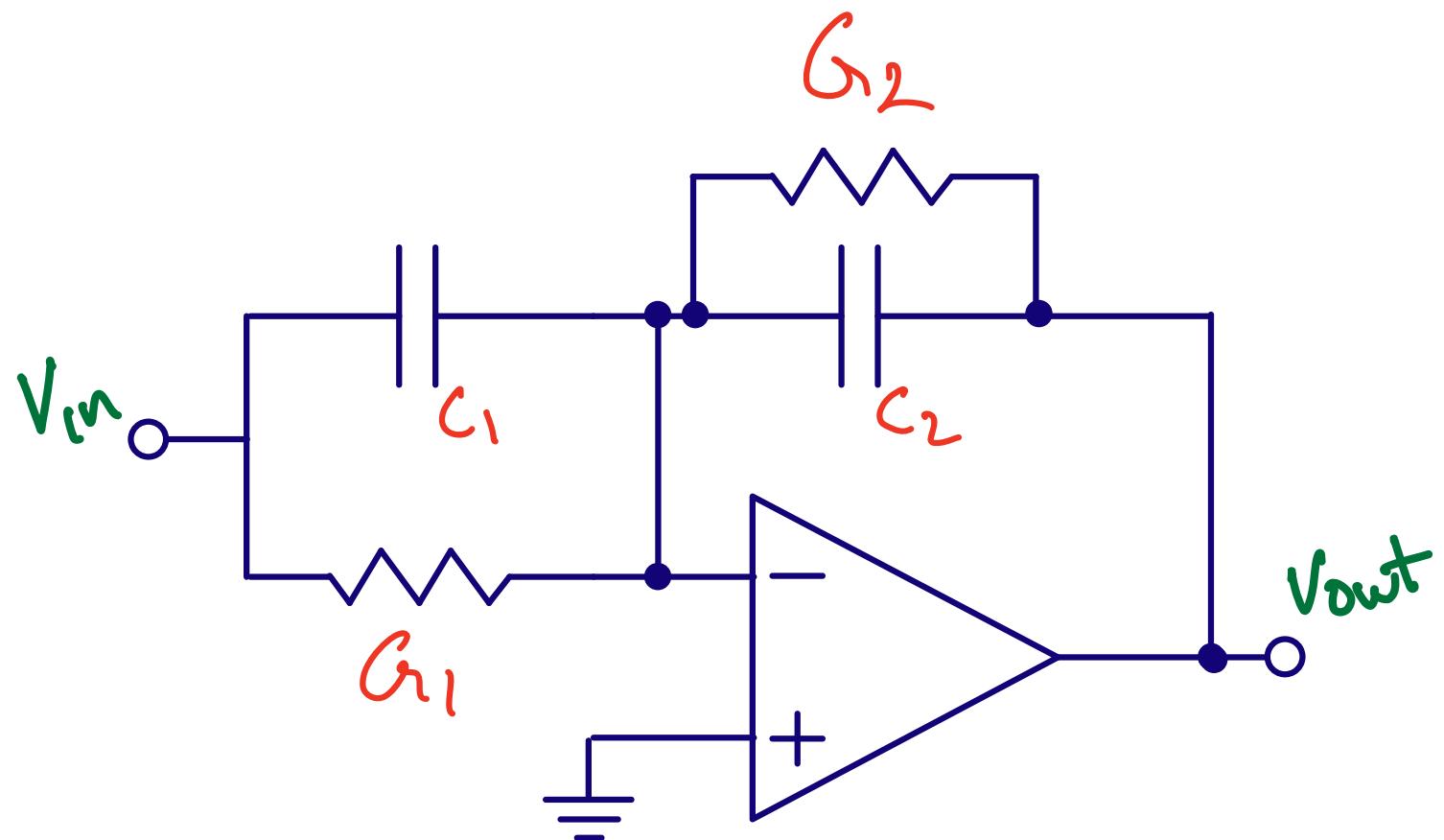


Figure 5.16: Transconductor schematic

Active-RC

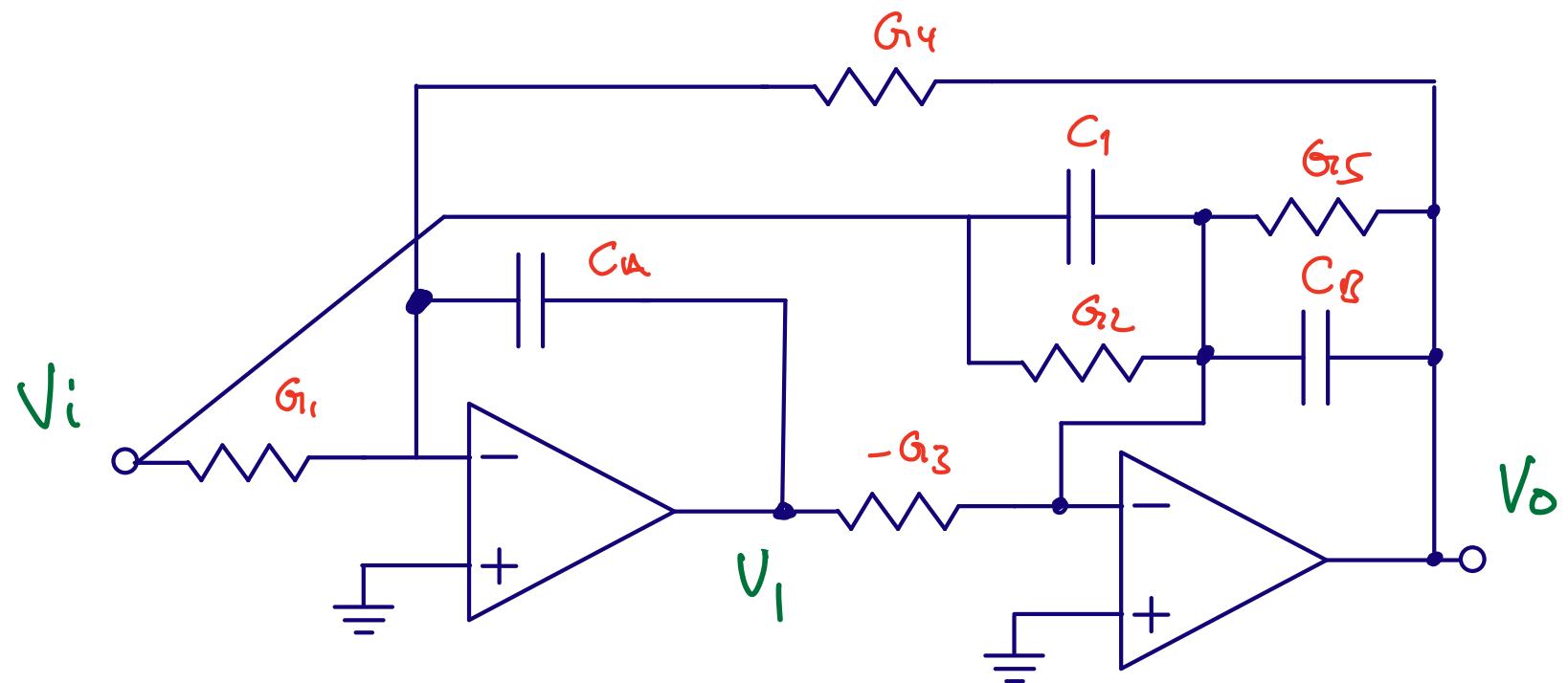
General purpose first order filter



$$H(s) = \frac{k_1 s + k_0}{s + w_o}$$

$$H(s) = -\frac{\frac{C_1}{C_2}s - \frac{G_1}{C_2}}{s + \frac{G_2}{C_2}}$$

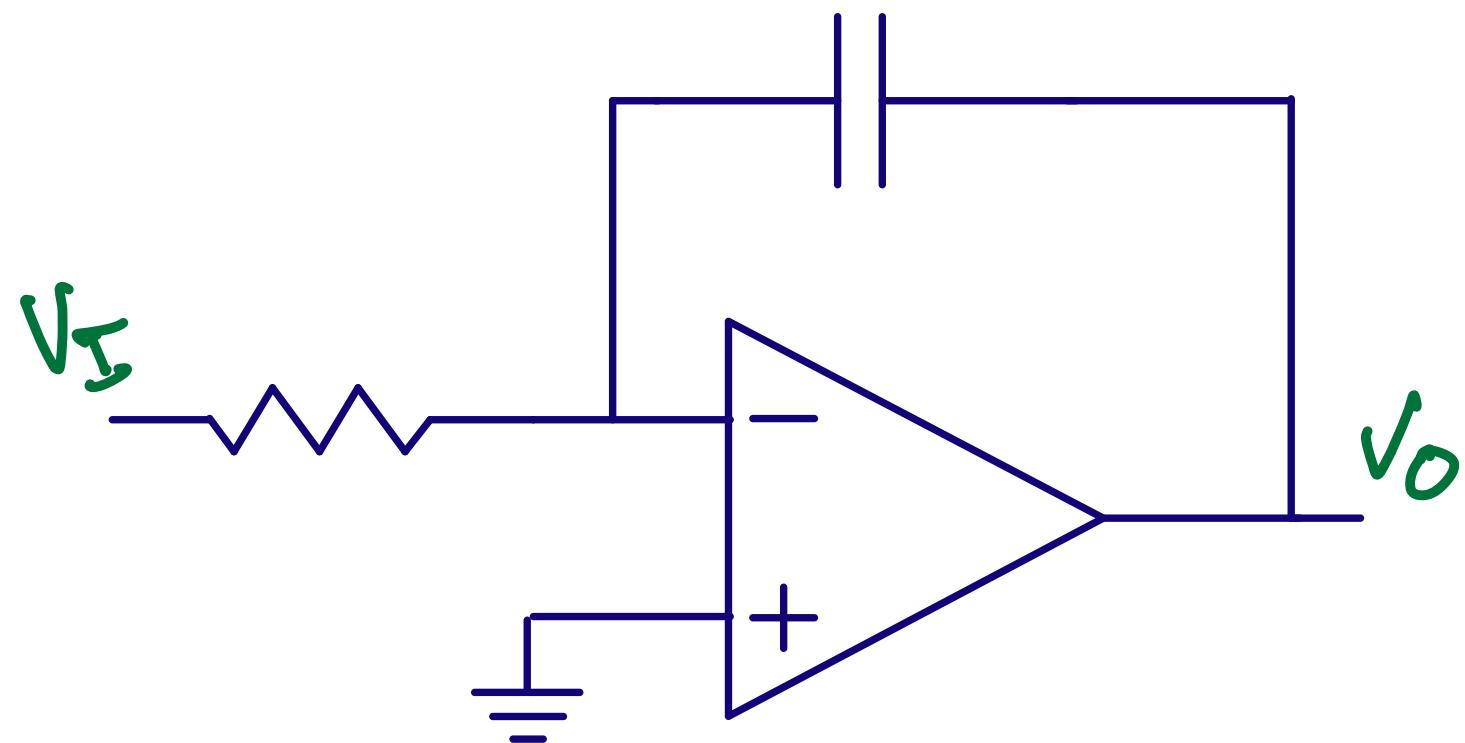
General purpose biquad



$$H(s) = \frac{k_2 s^2 + k_1 s + k_0}{s^2 + \frac{\omega_0}{Q} s + \omega_0^2}$$

$$H(s) = \frac{\left[\frac{C_1}{C_B} s^2 + \frac{G_2}{C_B} s + \left(\frac{G_1 G_3}{C_A C_B} \right) \right]}{\left[s^2 + \frac{G_5}{C_B} s + \frac{G_3 G_4}{C_A C_B} \right]}$$

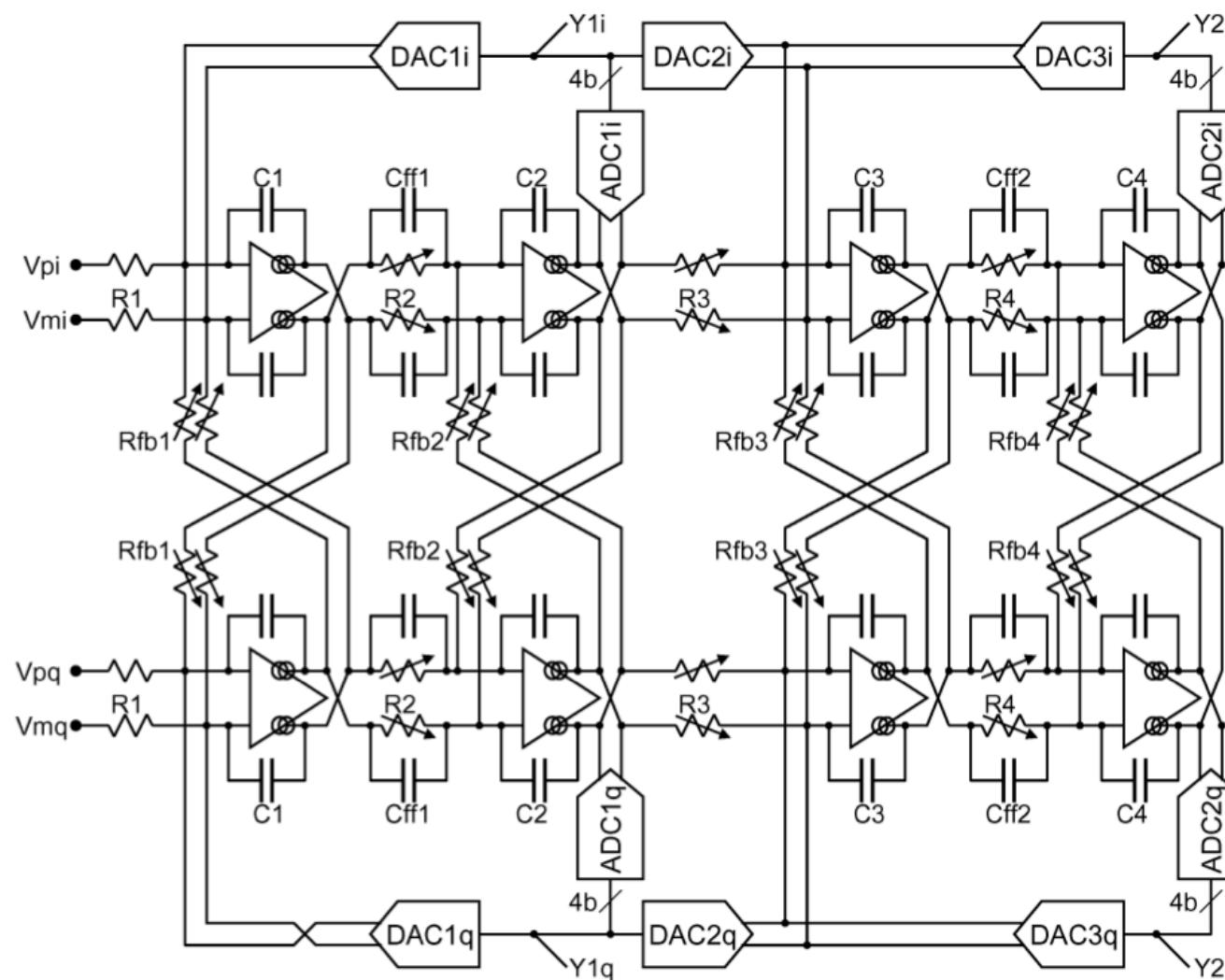
The OTA is not ideal



$$H(s) \approx \frac{A_0}{(1 + sA_o RC)(1 + \frac{s}{\omega_{ta}})}$$

where A_0 is the gain of the amplifier, and ω_{ta} is the unity-gain frequency.

A 56 mW Continuous-Time Quadrature Cascaded Sigma-Delta Modulator With 77 dB DR in a Near Zero-IF 20 MHz Band



sigma-delta modulator design.

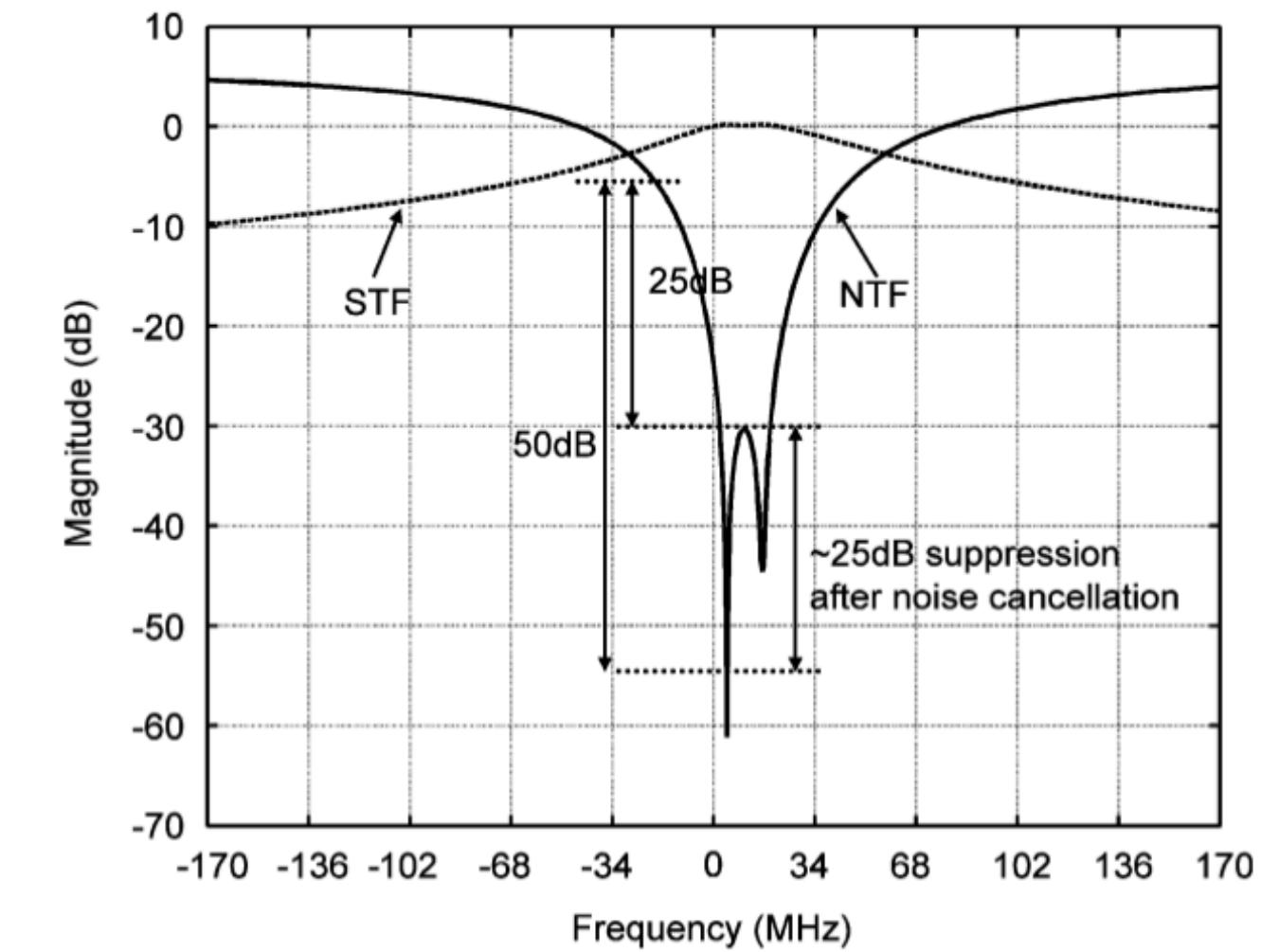
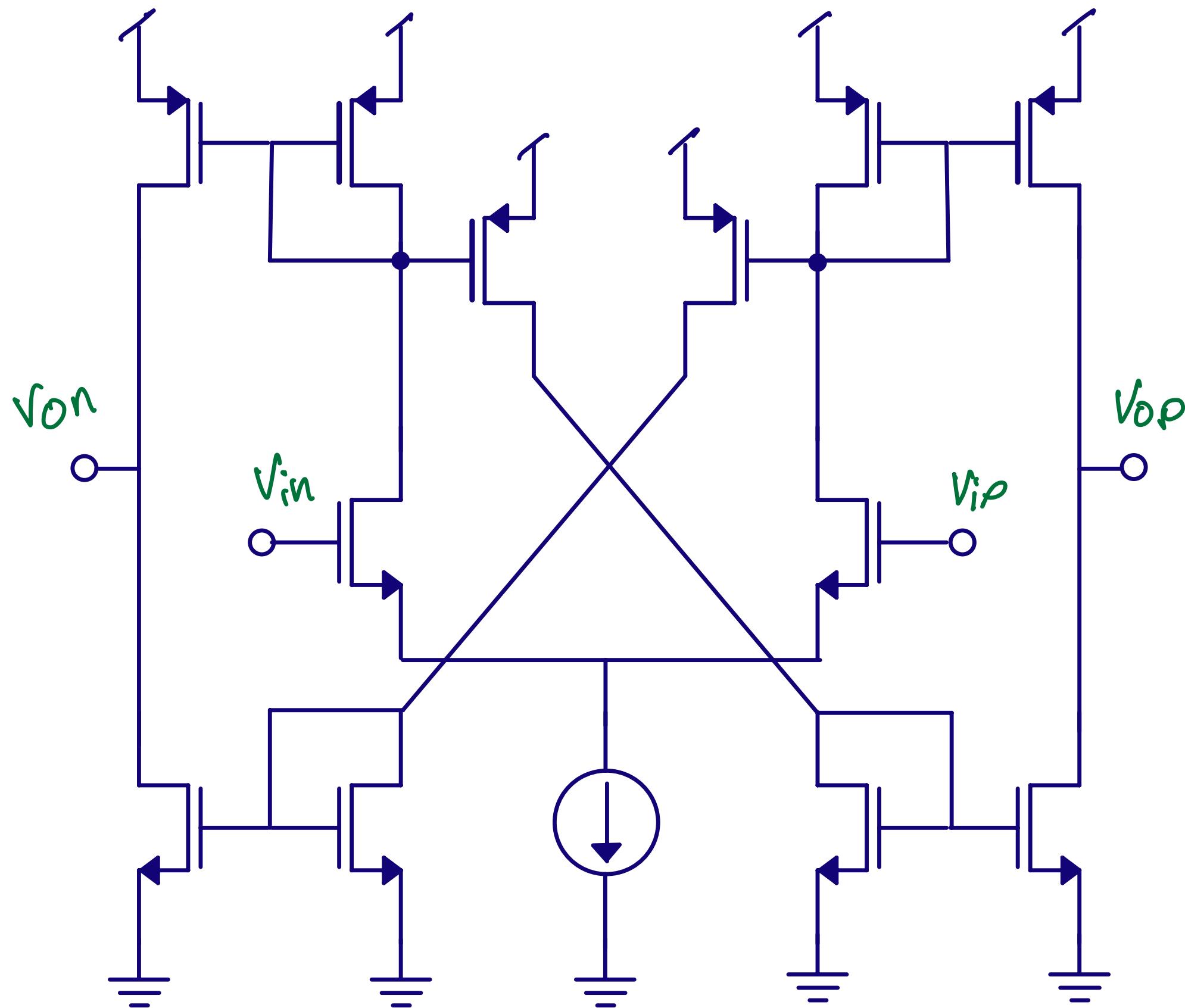
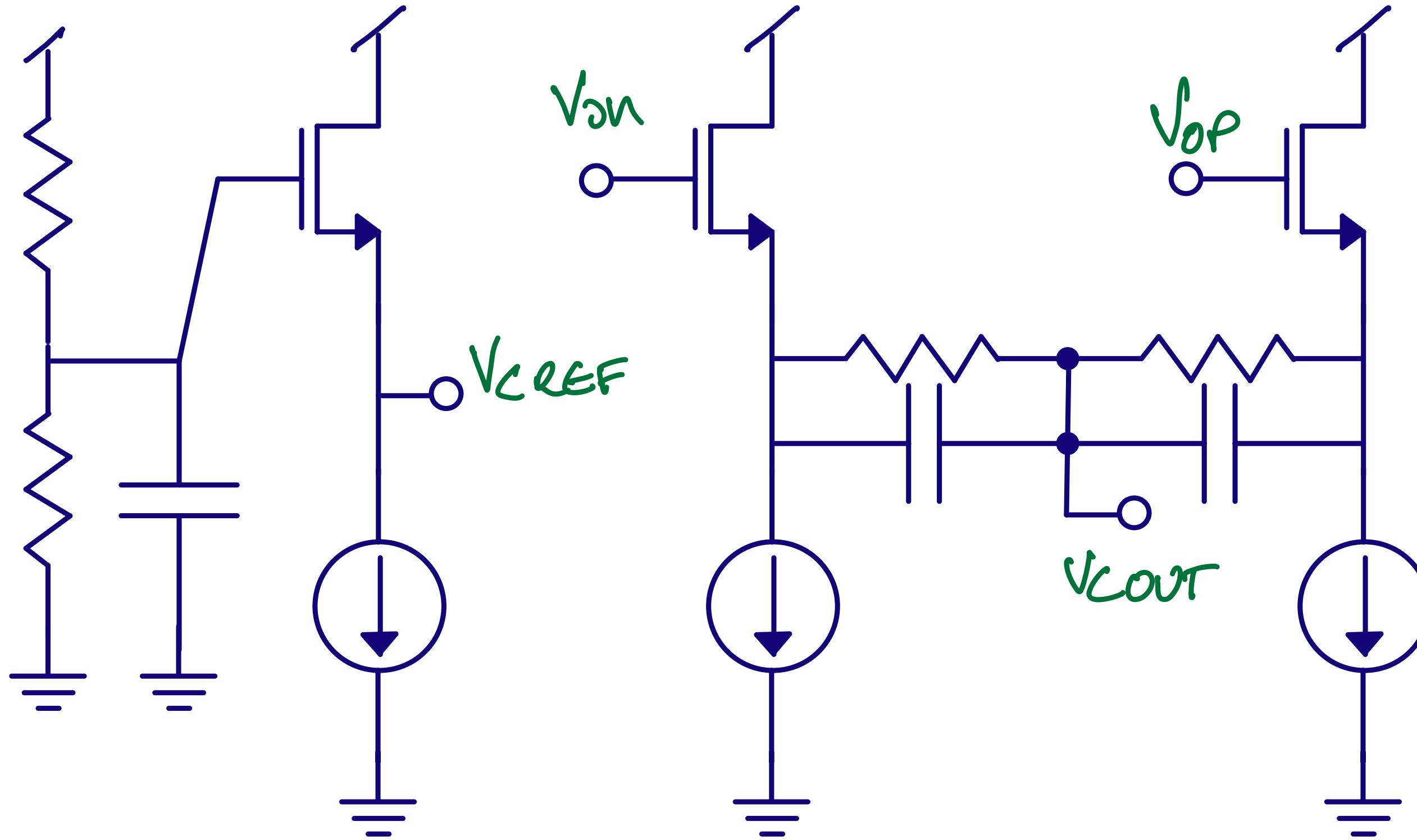
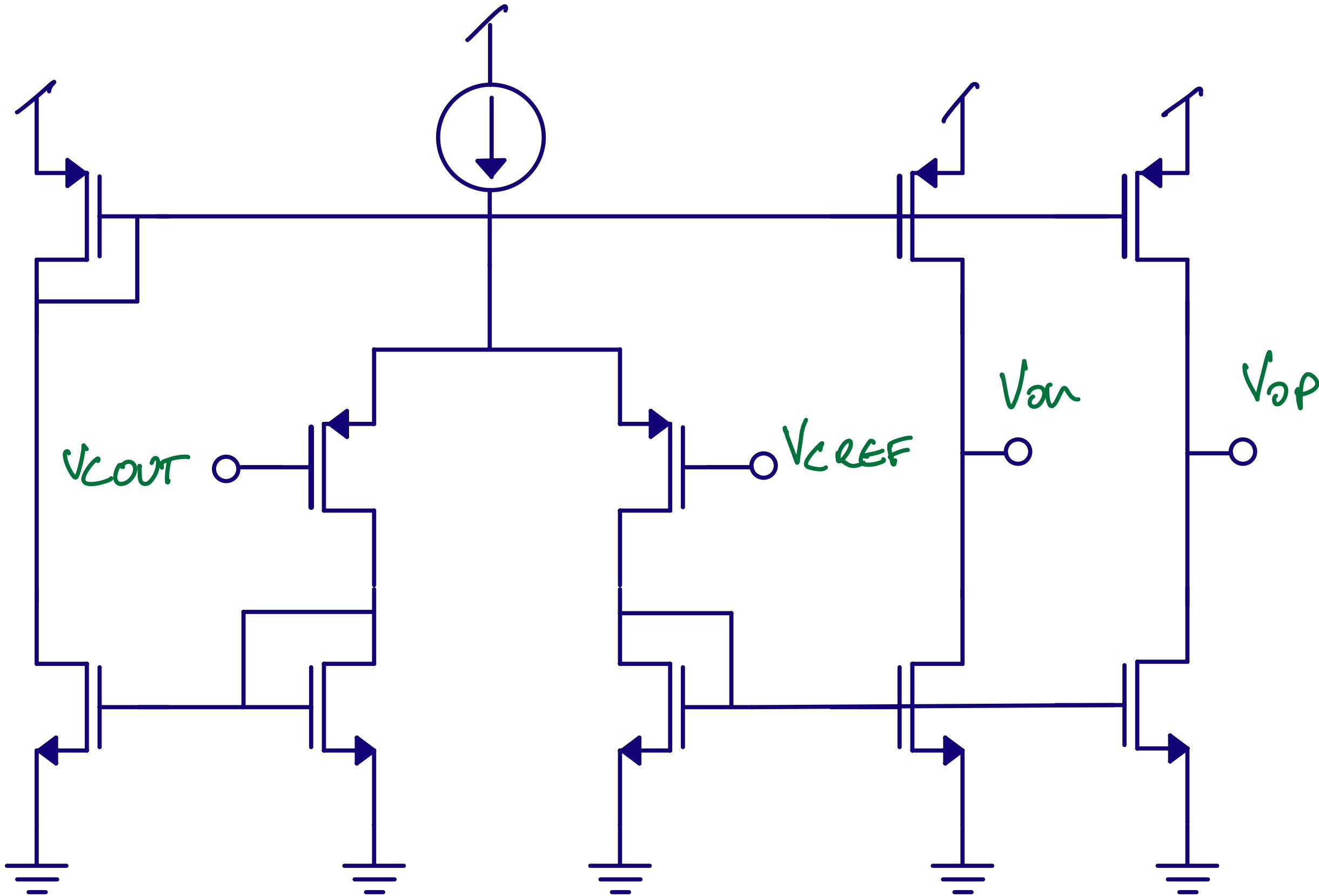


Fig. 9. NTF and STF of first stage.

My favorite OTA



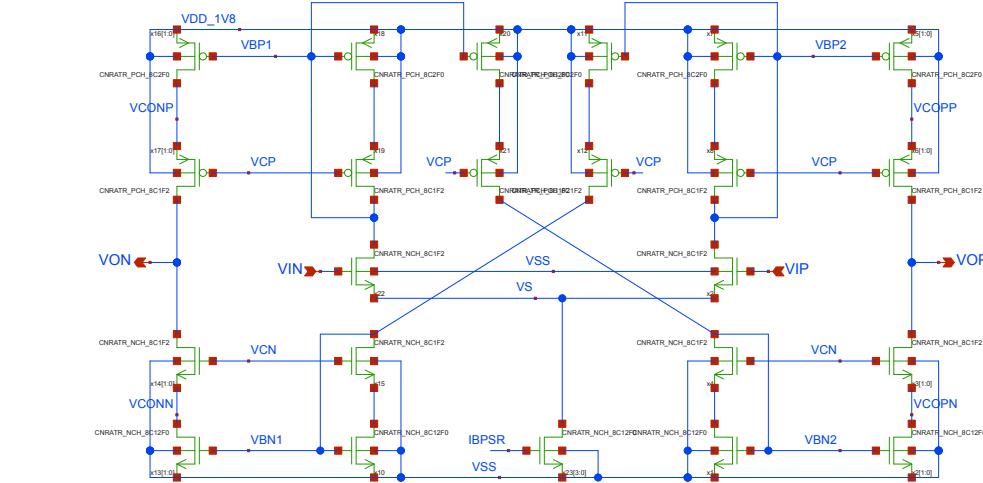
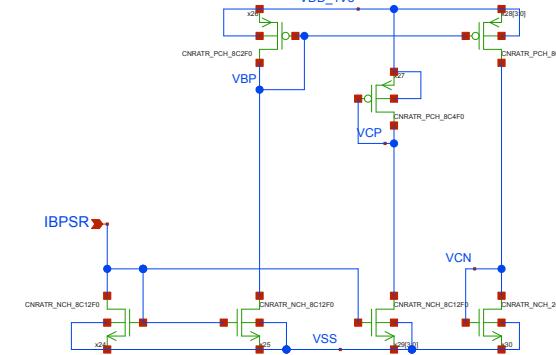




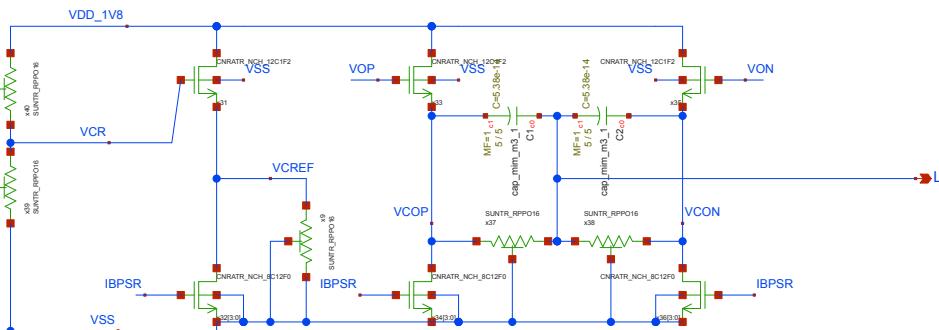
CNR_OTA_SKY130NM

DIFF OTA

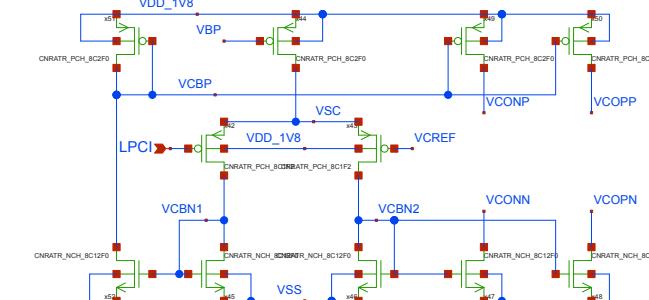
BIAS



VCM



VCM OTA



Designer
Updated

Thanks!

