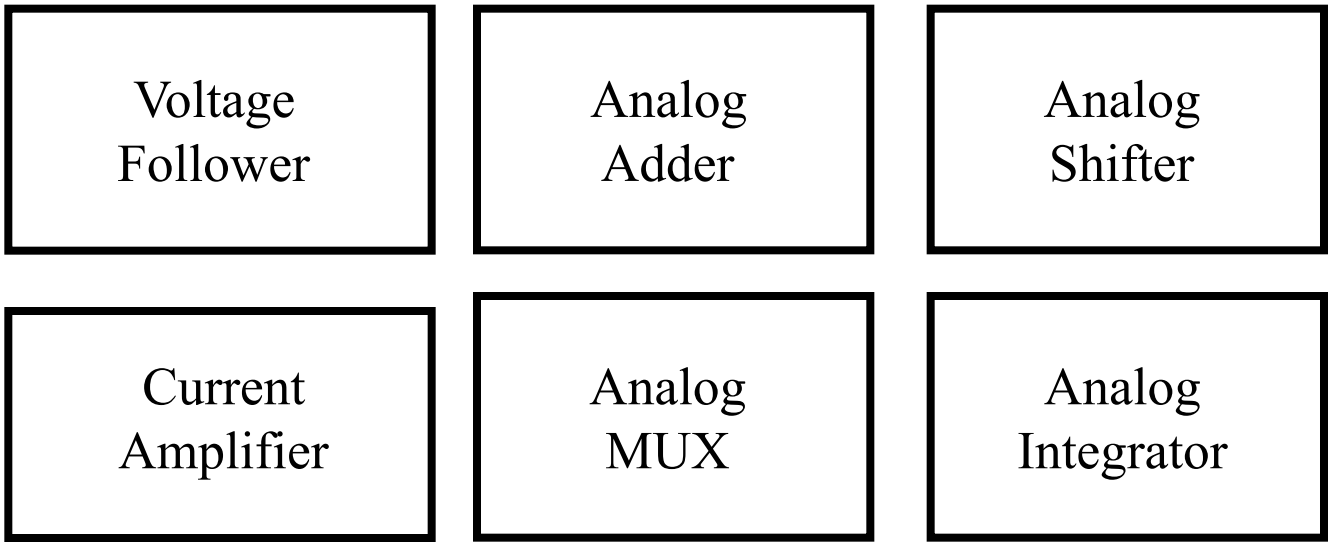
Lecture #10

CMOS Building Blocks: Addendum on Basic Configurations of Operational Amplifiers

Required Building Blocks

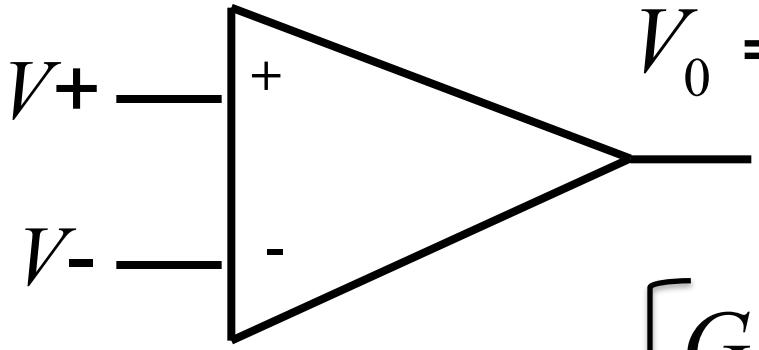


Basic Configurations of Operational Amplifiers

(Book Bio/CMOS: Appendix B)

What's an Op. Amp.?

DIFFERENTIAL AMPLIFIER



$$V_0 = G_0(V_+ - V_-)$$

IDEAL CHARACTERISTICS
Op-amp

$$G_0 \to \infty$$

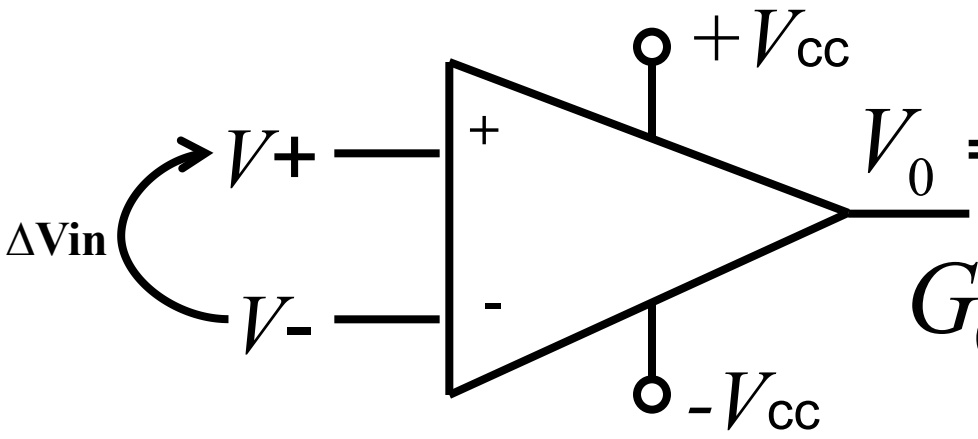
$$R_i \to \infty \quad \to I_i \cong 0$$

$$R_o \cong 0 \quad \to V_o \neq f(R_L)$$

Basic Configurations with Op. Amp.

1. Comparator
2. Inverter Amplifier
3. Non-inverter Amplifier
4. Analog Adder
5. Analog Shifter
6. Analog Integrator/Differentiator

1. Comparator



$$V_0 = G_0(V_+ - V_-)$$

$$G_0 \to \infty$$

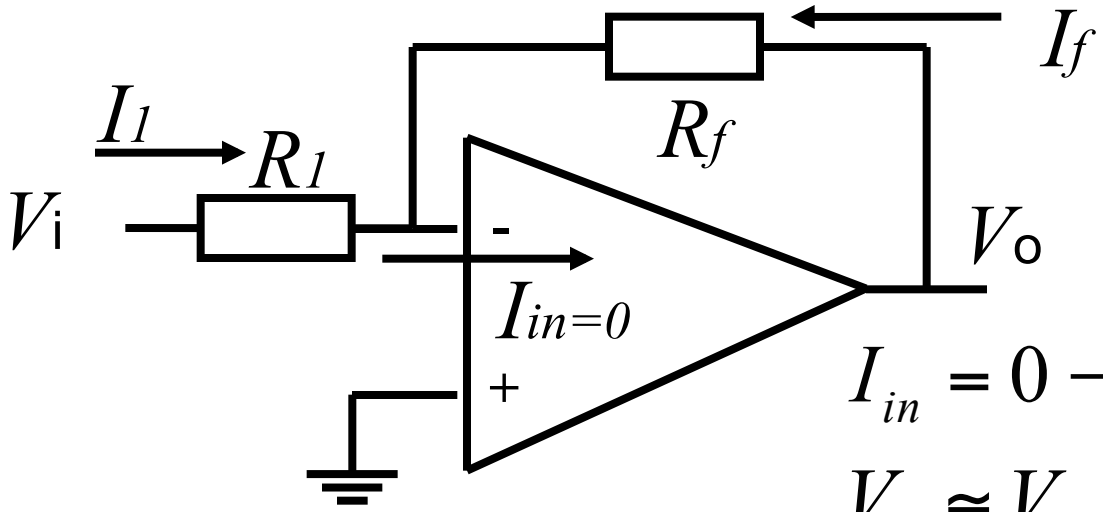
$$if\ V_+ > V_- \to V_0 \to \infty \to V_o = +V_{CC}$$

$$if\ V_+ < V_- \to V_0 \to -\infty \to V_o = -V_{CC}$$

$$if\ V_o \neq \pm V_{cc} \to \Delta V_{in} = V_+ - V_- \equiv \frac{V_o}{G_0} \cong 0$$

Then: $V_- \cong V_+ = 0$

2. Inverter Amplifier

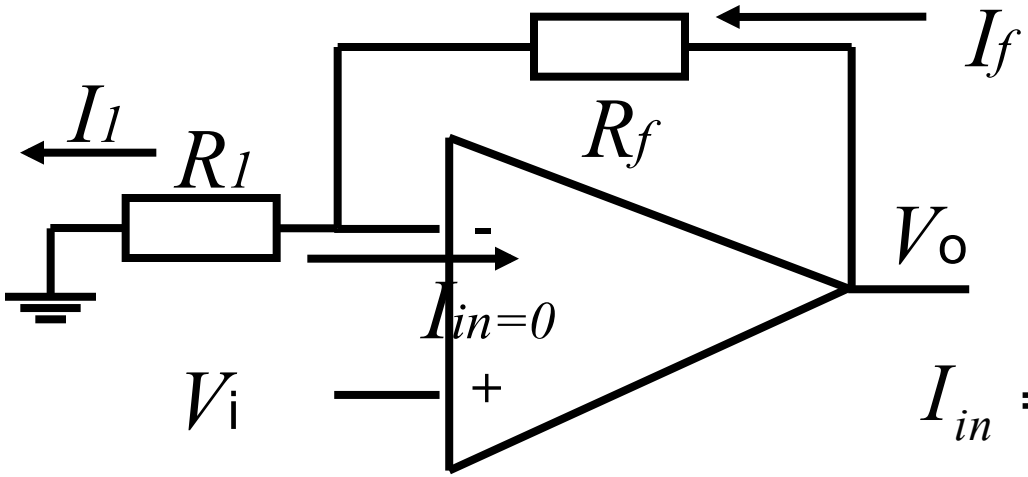


$$I_{in} = 0 \rightarrow \boxed{I_1 = -I_f}$$

$$V_- \cong V_+ = 0$$

$$\frac{V_i}{R_1} = -\frac{V_o}{R_f} \rightarrow V_o = -\frac{R_f}{R_1} V_i \rightarrow G = -\frac{R_f}{R_1}$$

3. Non-Inverter Amplifier

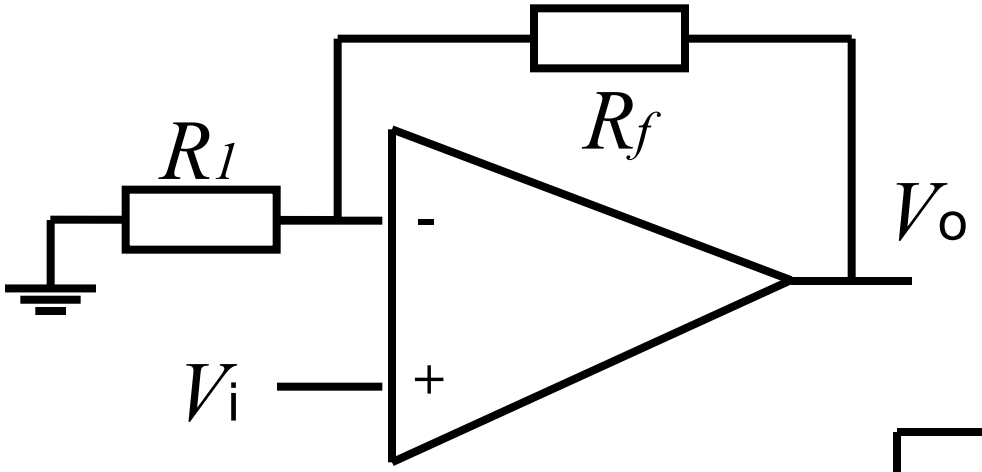


$$I_{in} = 0 \rightarrow I_1 = I_f$$

$$V_- \cong V_+ = V_i$$

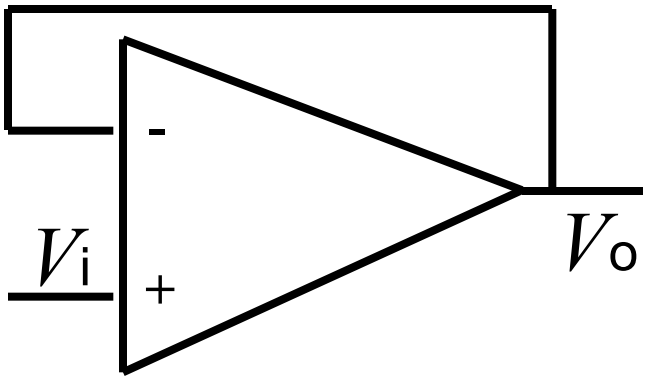
$$\frac{V_i}{R_1} = \frac{V_o - V_i}{R_f} \rightarrow V_o = \frac{R_1 + R_f}{R_1} V_i \quad G = 1 + \quad R_f / R_1$$

4. Voltage Follower



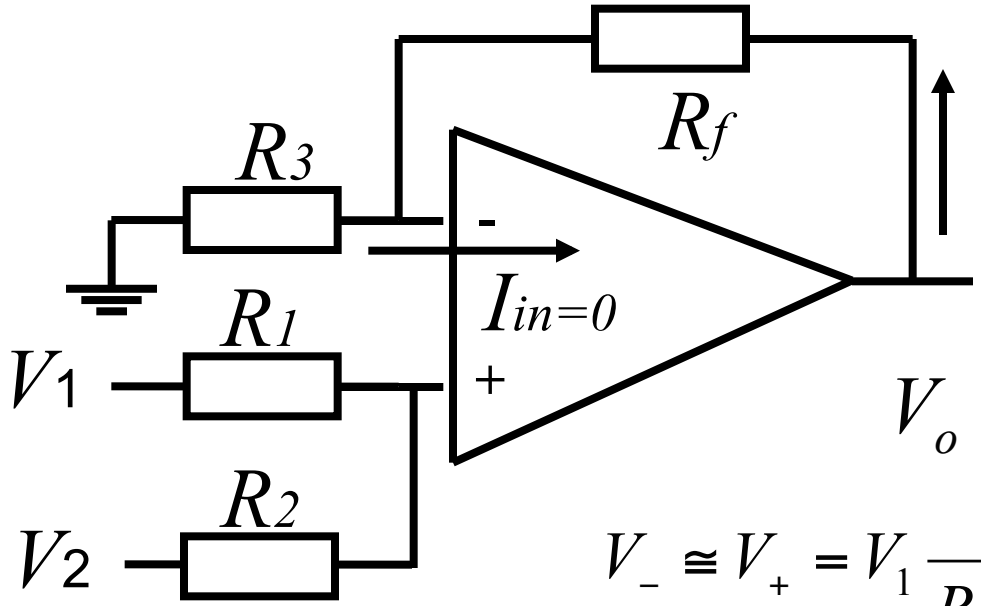
$$R_1 \to \infty$$

$$R_f = 0$$



$$V_o = \frac{R_1 + R_f}{R_1} V_i \to V_o = V_i$$

5. Weighted Analog Adder



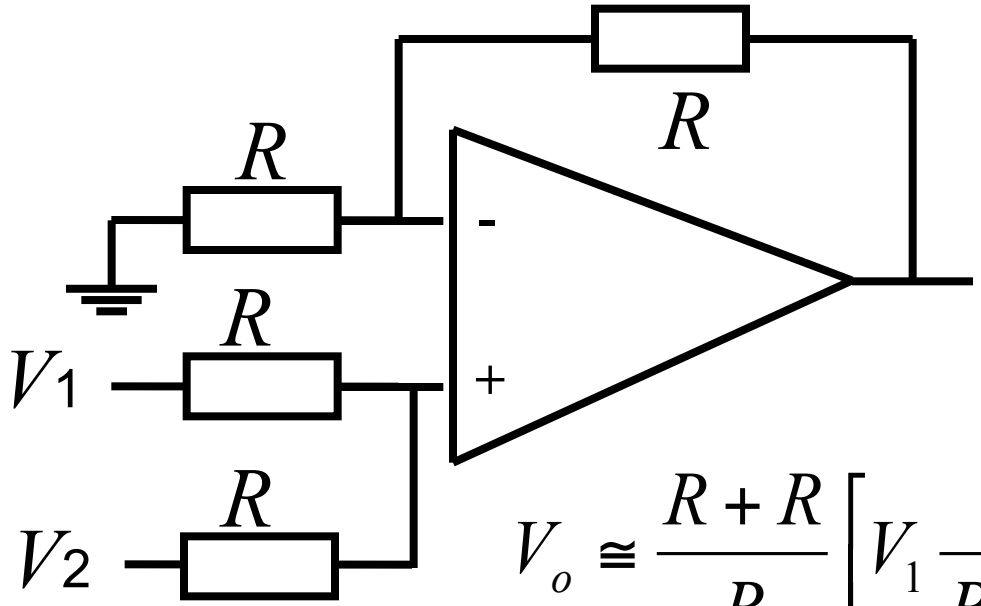
$$I_f = \frac{V_-}{R_3}$$

$$V_o = (R_f + R_3) I_f$$

$$V_- \cong V_+ = V_1 \frac{R_2}{R_1 + R_2} + V_2 \frac{R_1}{R_1 + R_2}$$

$$V_o \cong \frac{R_f + R_3}{R_3} \left[V_1 \frac{R_2}{R_1 + R_2} + V_2 \frac{R_1}{R_1 + R_2} \right]$$

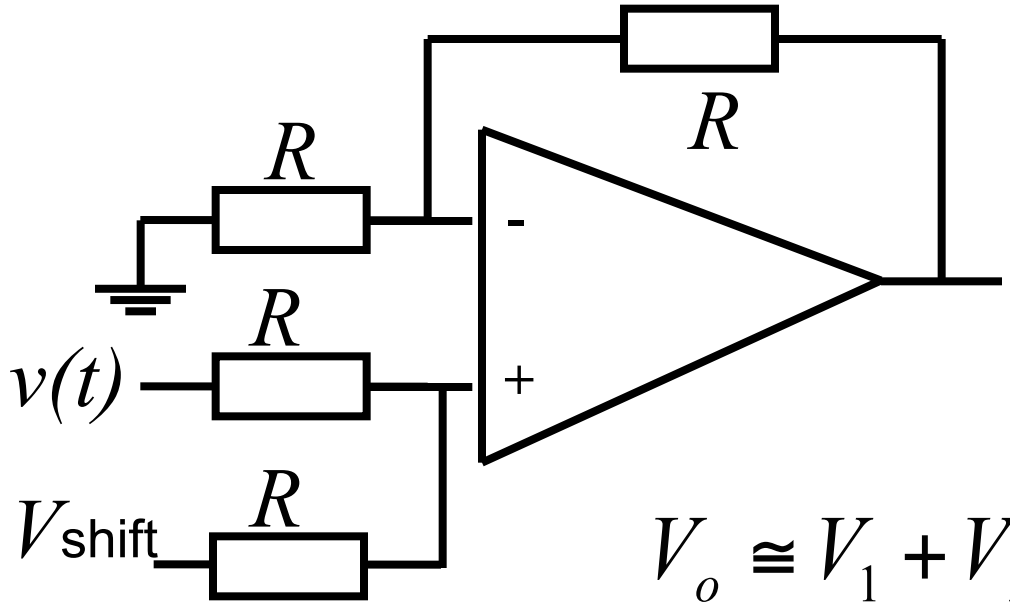
The “pure” Analog Adder



$$V_o \cong \frac{R+R}{R}\left[V_1\frac{R}{R+R}+V_2\frac{R}{R+R}\right]$$

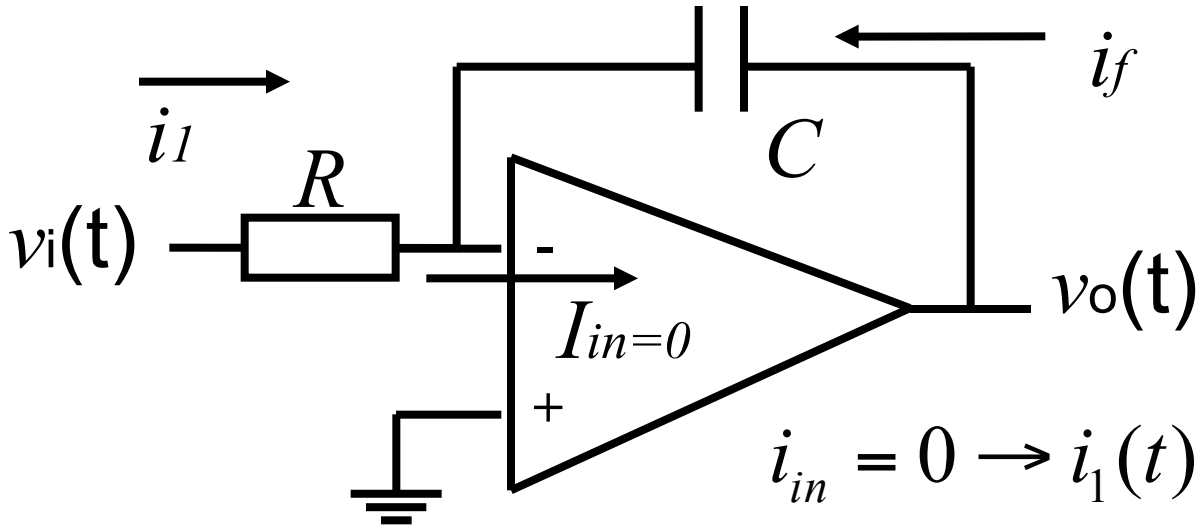
$$V_o \cong 2\left[V_1\frac{1}{2}+V_2\frac{1}{2}\right]=V_1+V_2$$

5. Analog Shifter



$$V_o \cong V_1 + V_2 = v(t) + V_{Shift}$$

6. Analog Integrator

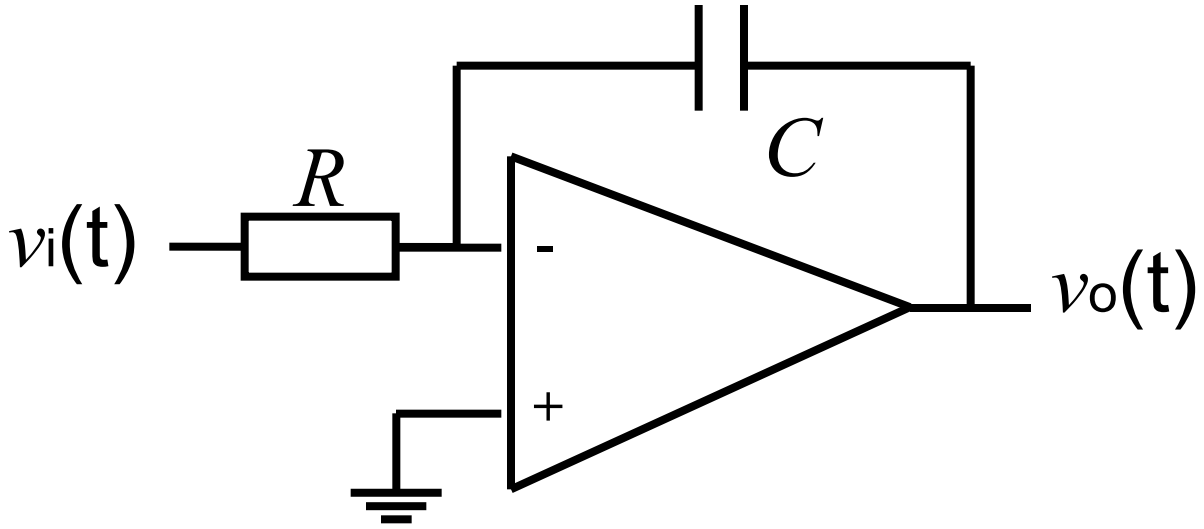


$$i_{in} = 0 \rightarrow i_1(t) = -i_f(t)$$

$$\frac{v_i(t)}{R} = -i_f(t) = -\frac{dq}{dt} = -\frac{Cdv_o(t)}{dt} \rightarrow \frac{dv_o(t)}{dt} = -\frac{1}{RC}v_i(t)$$

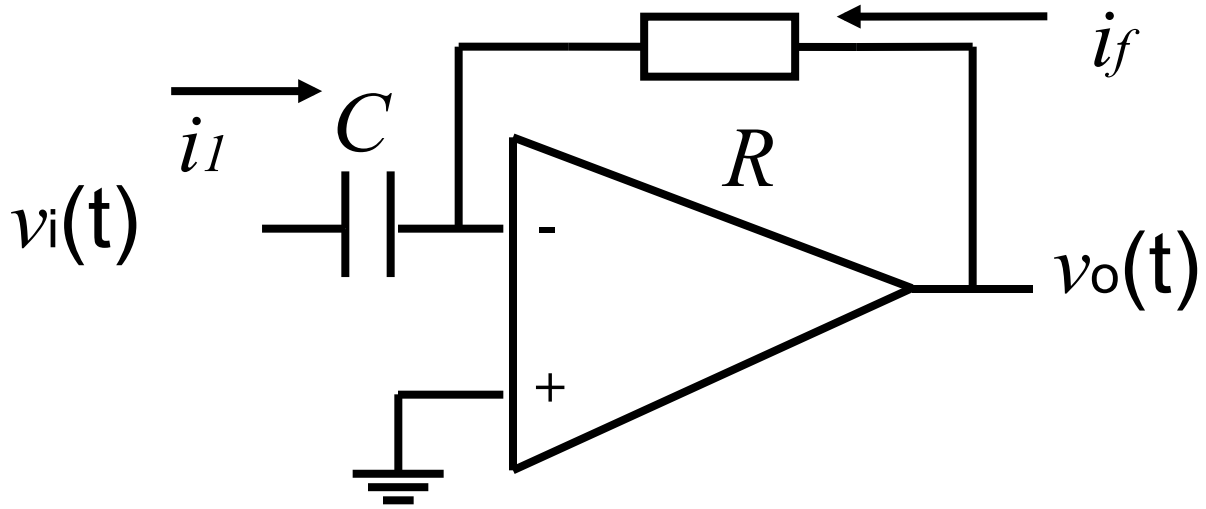
$q=Cv_0(t)$

6. Analog Integrator



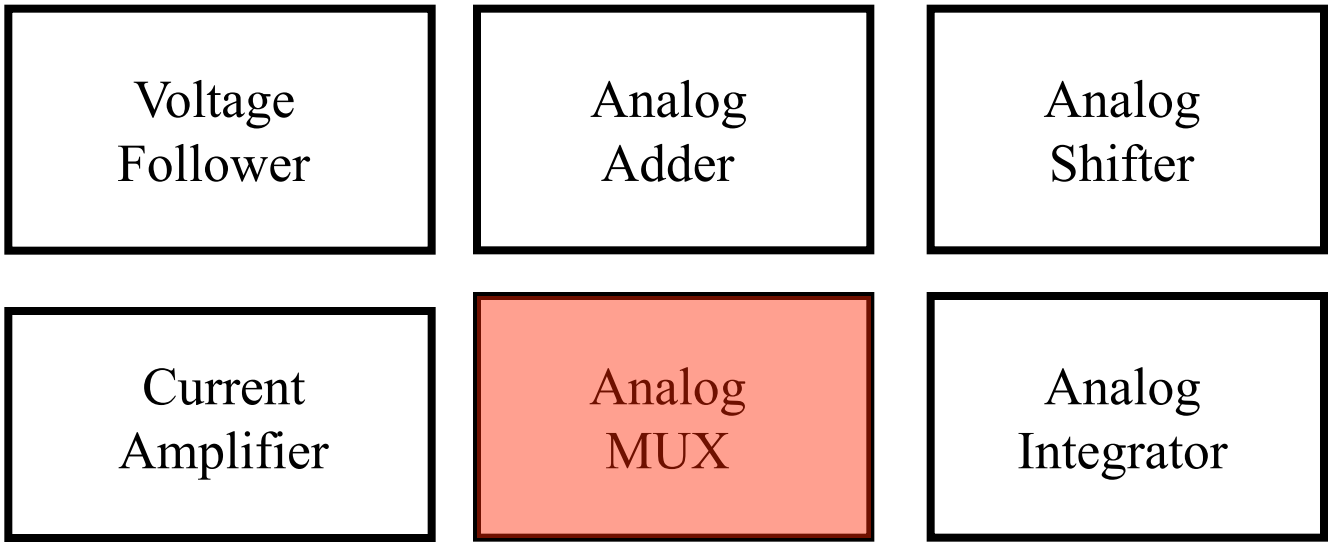
$$\frac{dv_o(t)}{dt} = -\frac{1}{RC}v_i(t) \rightarrow v_o(t) = -\frac{1}{RC}\int_0^t v_i(\tau)d\tau$$

6. Inverting Differentiator



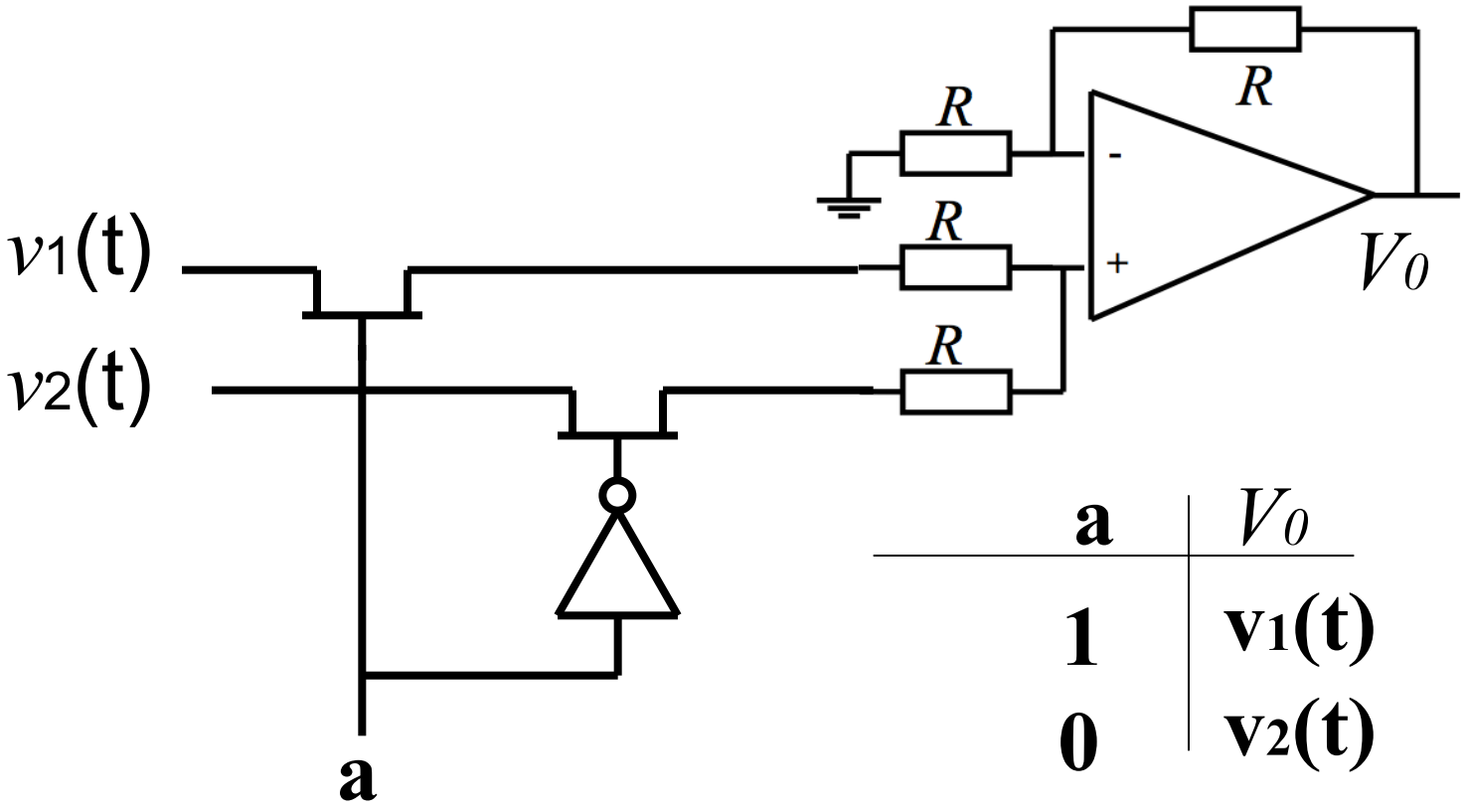
$$\left.\begin{aligned} i_1 &= dq/dt \\ i_f &= v_0 / R \end{aligned}\right\} \quad i_1 = -i_f \quad \rightarrow d[C\ v_i\ ]/dt = -\ v_0\ /R\ \rightarrow\ v_0\ = -RC\ dv_i/dt$$

Required Building Blocks



CMOS Operational Amplifiers (OpAmp)

An Analog MUX



a	V_0
1	v1(t)
0	v2(t)