PHYS 231 Oct. 28, 2024

Last Time:

Op Amp Golden Rules:

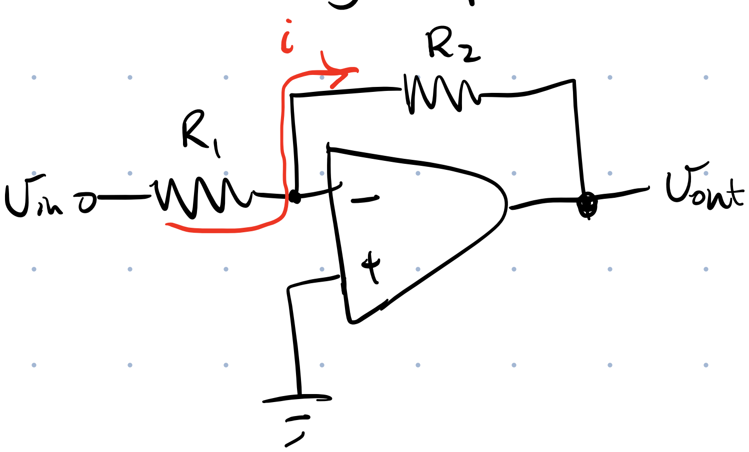
① $i_- = i_+ = 0$

No current into or out of op amp inputs

② When using negative feedback,

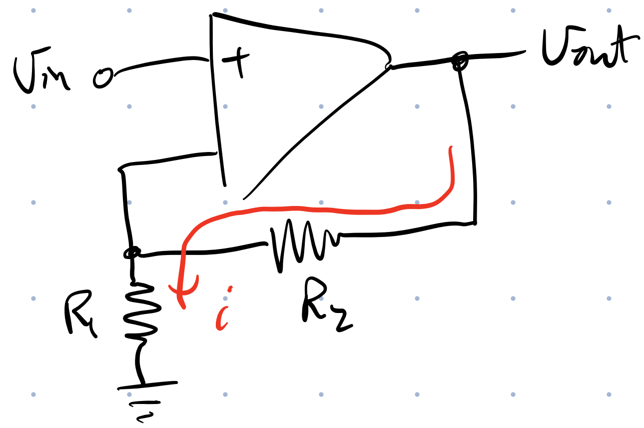
$v_- = v_+$

Inverting amplifier



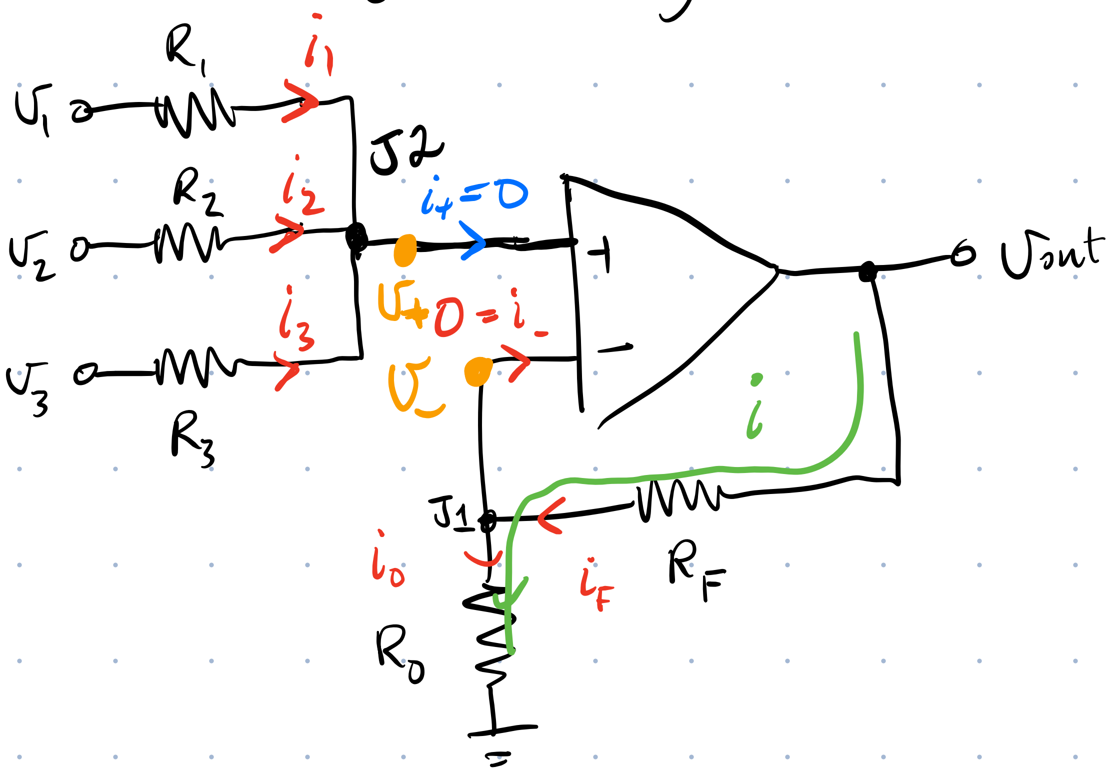
$$v_{out} = -\frac{R_2}{R_1} v_{in}$$

Non-inverting amplifier



$$v_{out} = \left(1 + \frac{R_2}{R_1}\right) v_{in}$$

Today: Summing Circuit



Jcn rule @ J1

$$i_F = i_0 + \cancel{i_-}^{\,0} \Rightarrow i_F = i_0 \equiv i$$

GR #1 $\quad i_- = i_+ = 0$

Track changes in volt. from v_{out} to gnd.

$$v_{out} - iR_F - iR_0 = 0$$

$$\Rightarrow \boxed{i = \frac{v_{out}}{R_F + R_0}}$$

At jcn J2, KJR:

$$i_1 + i_2 + i_3 = \cancel{i_+}^{\,0} = 0$$

$$\boxed{i_1 + i_2 + i_3 = 0}$$

GR#2 requires when using neg. feedback,

$$v_- = v_+$$

Note that voltage at inverting input is equal to

$$v_- = i R_0 = v_{out} \frac{R_0}{R_0 + R_F}$$

$$\boxed{\therefore\ v_+ = v_{out} \frac{R_0}{R_0 + R_F}}$$

Finally, track voltage from v_1 to v_+.

$$v_1 - i_1 R_1 = v_+ \Rightarrow i_1 = \frac{v_1 - v_+}{R_1}$$

Likewise, find $i_2 = \dfrac{V_2 - V_+}{R_2}$

$$i_3 = \frac{V_3 - V_+}{R_3}$$

Require $i_1 + i_2 + i_3 = 0$

$$\left(\frac{V_1}{R_1} - \frac{V_+}{R_1}\right) + \left(\frac{V_2}{R_2} - \frac{V_+}{R_2}\right) + \left(\frac{V_3}{R_3} - \frac{V_+}{R_3}\right) = 0$$

$$\therefore \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right) - V_+\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) = 0$$

$$\therefore V_{out} \frac{R_0}{R_0 + R_F}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) = \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

Solve for V_{out}:

$$V_{out} = \left(1 + \frac{R_F}{R_0}\right)\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)^{-1}\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

Here, V_{out} is a "weighted" sum of the input voltages V_1, V_2 & V_3.

If we choose $R_1 = R_2 = R_3 \equiv R$

then

$$V_{out} = \left(1 + \frac{R_F}{R_0}\right)\underbrace{\left(\frac{1}{R} + \frac{1}{R} + \frac{1}{R}\right)^{-1}}_{\left(\frac{3}{R}\right)^{-1} = \frac{R}{3}} \frac{1}{R}\left(V_1 + V_2 + V_3\right)$$

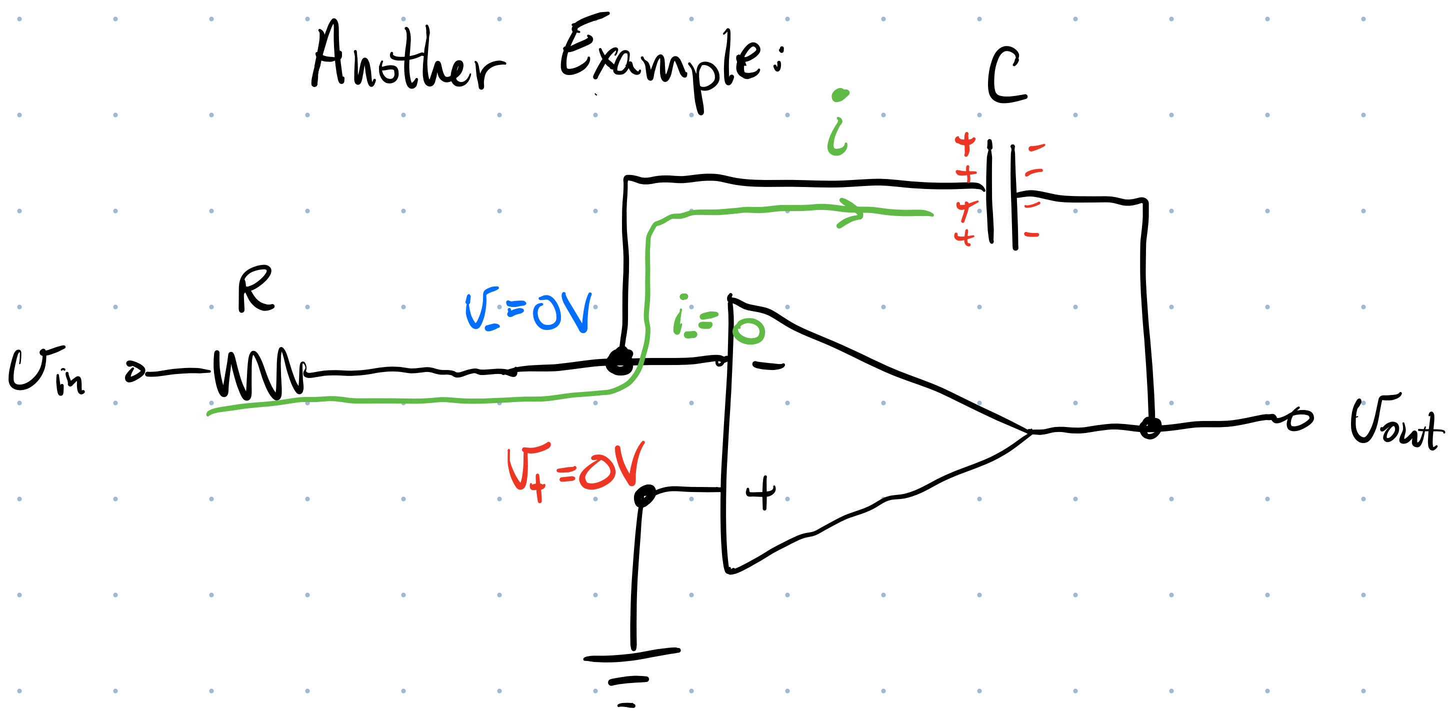
$$\boxed{V_{out} = \frac{1}{3}\left(1 + \frac{R_F}{R_0}\right)\left(V_1 + V_2 + V_3\right)}$$

Now, in this case, V_{out} is proprotional to a "direct" sum of inputs V_1, V_2 & V_3.

If we not select $\frac{R_F}{R_0} = 2$,

then $\boxed{V_{out} = V_1 + V_2 + V_3}$

Another Example:



Track volt. changes from v_{in} to v_-.

$$v_{in} - iR = v_- = 0 \Rightarrow \boxed{i = \frac{v_{in}}{R}}$$

Track volt. changes from v_- to v_{out}

$$\cancel{v_-}^{\,0} - v_c = v_{out}$$

$$v_{out} = -v_c$$

$$= -\frac{q}{C}$$

$$= -\frac{1}{C}\int i\,dt$$

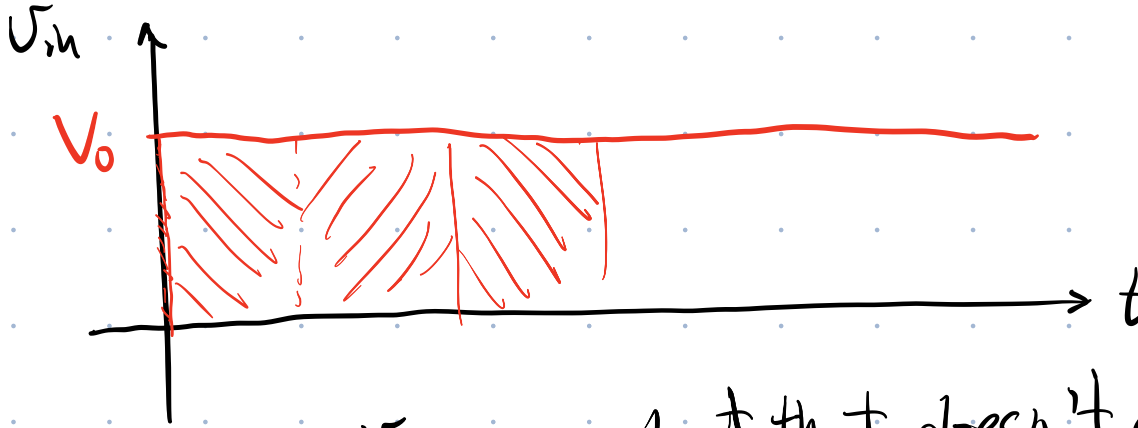
$$C = \frac{q}{v_c}$$

$$\Rightarrow v_c = \frac{q}{C}$$

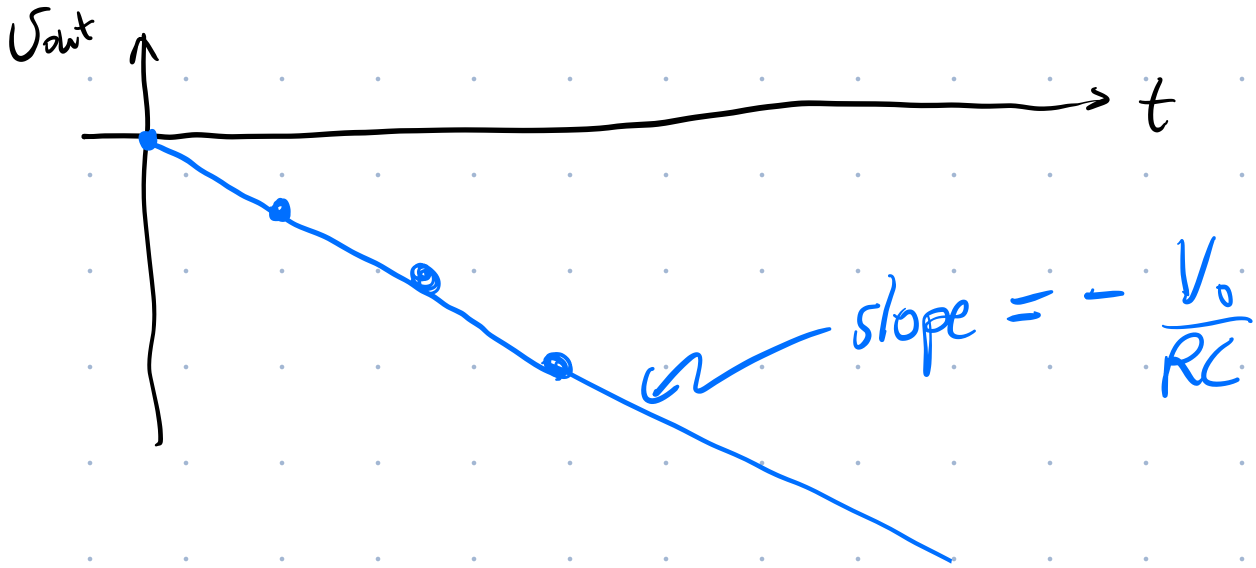
$$i = \frac{dq}{dt} \Rightarrow q = \int i\,dt$$

$$\therefore V_{out} = -\frac{1}{C}\int \frac{V_{in}}{R}\,dt = \boxed{-\frac{1}{RC}\int V_{in}\,dt = V_{out}}$$

Here, V_{out} is prop. to the integral of V_{in}!



V_{in} is a constant that doesn't change with time.



We will use an integrator circuit w/ a const. input voltage as part of your final PHYS 231 project.

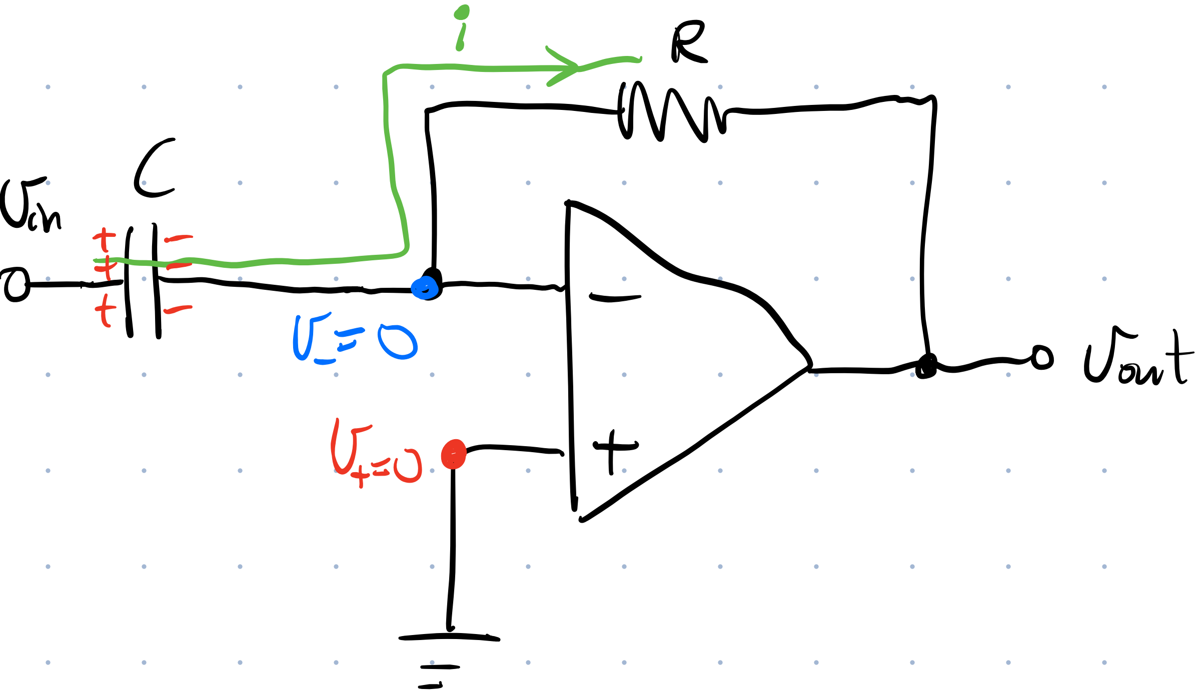
$$v_{out} = -\frac{1}{RC}\int_0^t v_{in}\,dt$$

if $v_{in} = V_0$ (const)

$$v_{out} = -\frac{1}{RC}\int_0^t V_0\,dt = -\frac{V_0}{RC}\int_0^t dt$$

$$= -\frac{V_0}{RC}\,t$$

Change position of R & C.



From V_{in} to V_-

$$V_{in} - V_c = V_- = 0$$

$$\therefore V_{in} = V_c = \frac{q}{C}$$

Take the derivative of V_{in} w.r.t. time.

$$\frac{dV_{in}}{dt} = +\frac{1}{C}\frac{dq}{dt} = \frac{i}{C}$$

solve for i: $\boxed{i = C\frac{dV_{in}}{dt}}$

From v_- to v_{out}

$$\cancel{v_-} - iR = v_{out}$$ ($v_- \to 0$)

$$\therefore v_{out} = -iR$$

$$\therefore v_{out} = -RC\frac{dv_{in}}{dt}$$

$$v_{out} \propto \frac{dv_{in}}{dt}$$