OPERATIONAL AMPLIFIER

\[ A = \text{huge gain} \]
(in practice it is used to amplify small signals, and for analog computers and analog simulation)

\[ Z_{OA} = \infty \]

\[ I = 0 \Rightarrow I_1 = -I_2 \quad (I = 0, I_2 = 0 \text{ since OA has huge impedance}) \]

Voltage \( V^+ - V^- \) is very small (2 practically on the ground)

1. \( V_{cm} \approx Z_1 I_1 \)
2. \( V_{out} \approx Z_2 I_2 = -Z_2 I_1 \)

\[ I_1 = \frac{V_{cm}}{Z_2} = -\frac{V_{out}}{Z_2} \]

\[ \frac{V_{out}}{V_{cm}} = -\frac{Z_2}{Z_1} \]

**MAIN FORMULA**

\[ \text{CASE 1: } Z_1 = R, \quad Z_2 = \frac{1}{sC} \]

\[ V_{out} = -\frac{1}{sC} V_{cm} \]

**INTEGRATOR**

\[ \text{CASE 2: } Z_1 = \frac{1}{sC}, \quad Z_2 = R \]

\[ V_{out} = -sCR V_{cm} \]

**DIFFERENTIATOR**

\[ V_{cm} = B_1 I_1 + B_2 I_2 + \cdots + B_k I_k = \sum B_i I_i \]

\[ V_{out} = R_0 I_0 \]

\[ \frac{V_{out}}{V_{cm}} = -\frac{R_0}{B_1} \]

\[ I_1 + I_2 + \cdots + I_k \approx -I_0 \]

\[ \frac{V_{in}}{B_1} + \frac{V_{in}}{B_2} + \cdots + \frac{V_{in}}{B_k} = -\frac{V_{out}}{R_0} \]

\[ \Rightarrow V_{out} = -\frac{\sum B_i V_{in}}{B_1} \]
\[ e = r - y \]

\[ \frac{de}{dt} = f(t) + \left( \right) \]

Approximate Derivative \( \frac{s}{\mu s+1} \)

\[ G_{PID}(s) = K_p + \frac{12s}{s} + K_i \frac{s}{\mu s+1} \]

\( \mu = \text{very small} \)

\[ Z_1 = \frac{1}{sC_1} \]

\[ V_{out} = -\frac{Z_2}{Z_1} V_{in} = -\frac{Z_2}{sC_1} \]

\[ V_{in} = -s \eta Z_2 V_{in} \]

\[ C_1 Z_2 = \frac{1}{\mu s+1} \]

\[ Z_2 = \frac{R_1}{R_2} = \frac{R_2}{sC_2} \]

\[ C_2 P_2 \text{ must be small} \]

\[ C_1 P_2 \cdot \frac{1}{sC_2 P_2 + 1} = \frac{1}{\mu s + 1} \]

\[ \Rightarrow C_1 P_2 = 1 \]

\[ C_2 = 1 \text{mF}, \quad P_2 = 1 \mu s \text{2} \]

Actually, \( C_2 = 10 \text{mF} \) can be used.