

Golden rules (ideal op amp with feedback)

- No current flows into the inputs
- The output adjusts so both inputs are at the same voltage
- Inverting input of an inverting stage is a virtual ground

Inverting amplifier

Gain $A = -R_f \div R_{in}$

Input impedance $Z_{in} = R_{in}$

Non inverting amplifier

Gain $A = 1 + R_f \div R_g$

Voltage follower $A = 1$ ($R_f = 0$, R_g open)

Summing amplifier

Output $V_{out} = -R_f (V_1/R_1 + V_2/R_2 + V_3/R_3)$

Difference amplifier

Matched $V_{out} = (R_2 \div R_1) \times (V_2 - V_1)$
($R_1 = R_3$, $R_2 = R_4$)

CMRR set by resistor ratio matching

Instrumentation amplifier

3 op amp $G = 1 + 2R \div R_G$

AD620, $G = 1 + 49.4 \text{ k}\Omega \div R_G$

AD8221,
INA129

INA128 $G = 1 + 50 \text{ k}\Omega \div R_G$

INA333 $G = 1 + 100 \text{ k}\Omega \div R_G$

Integrator and differentiator

Integrator $V_{out} = -(1 \div RC) \int V_{in} dt$

Differentiator $V_{out} = -RC \times dV_{in}/dt$

Active low pass $f_c = 1 \div (2\pi R_f C_f)$

Transimpedance (current to voltage)

Output $V_{out} = -I_{in} \times R_f$

Example 4 to 20 mA through 250 Ω gives 1 to 5 V (passive)

Speed limits

Bandwidth $f_{-3dB} = GBW \div \text{noise gain}$

Noise gain $1 + R_f \div R_g$ (both configurations)

Full power bandwidth $f_p = SR \div (2\pi V_{peak})$

Rise time $t_r \approx 0.35 \div f_{-3dB}$

Comparator with hysteresis (Schmitt)

Hysteresis $\Delta V = (R_1 \div R_2) \times \text{width (non inverting)}$
($V_{OH} - V_{OL}$)

Use Stops chattering on slow or noisy signals

Practical tips

- Resistors 1 k Ω to 100 k Ω
- Decouple each supply pin with 100 nF close to the IC
- Use rail to rail output parts on single 3.3 V or 5 V supplies
- Bias current $\times$ feedback resistance = offset; balance with a resistor on the + input