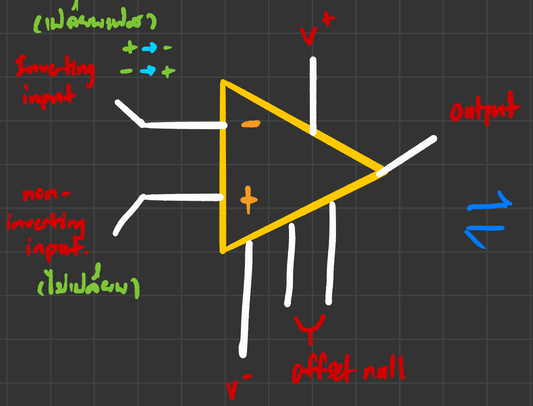
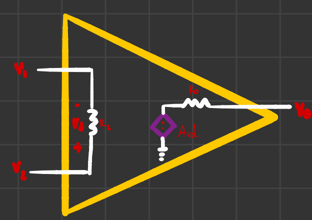
Operational Amplifier. (Op-Amp)

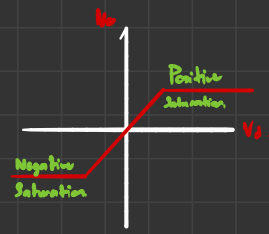
→ behave like "VCVS", use in analog system (active circuit element)



⇄

① [Equivalent Circuit.]





$$\boxed{V_d = V_2 - V_1 \; ; \; V_o = AV_d = A(V_2 - V_1)}$$

└ ค่าอัตราขยาย.

typical range.

② [ideal Op-Amp Laws].

1. Infinite open loop, $A \approx \infty$
2. Infinite input resistance, $R_i \approx \infty$
3. 0 output resistance, $R_o \approx 0$

→ input resistance (R_i) = $\infty\ \Omega$ (ideal)

→ output resistance (R_o) = $0\ \Omega$ (ideal)

$\boxed{i_1 = 0,\ i_2 = 0}$

└ law ①

$\boxed{V_d = V_2 - V_1 = 0 \rightarrow \therefore V_2 = V_1}$

└ law ② and ③.

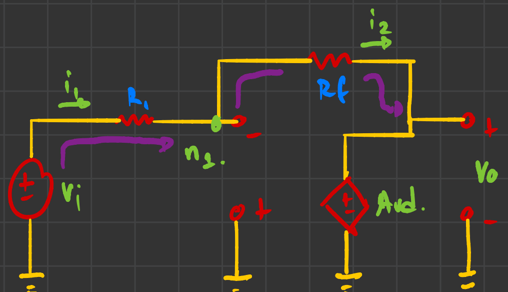
$\boxed{V_d = \frac{V_o}{A}}$

③ [Configuration of Op-Amp].

1. inverting amplifier.

inverting phase

$$\boxed{V_o = -\frac{R_f}{R_1}(V_i)}$$



proof.

$$\frac{V_i - \cancel{V_1}}{R_1} = \frac{\cancel{V_1} - V_o}{R_f}$$

law $V_1 = V_2 = 0$!

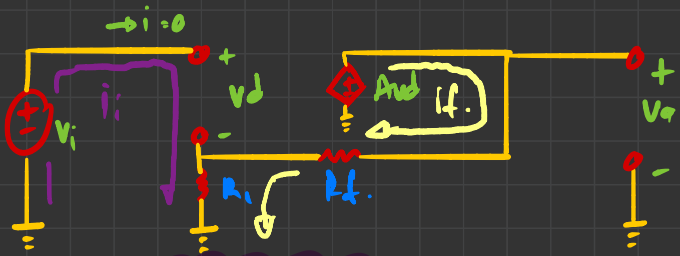
$$; \frac{V_i}{R_1} = \frac{-V_o}{R_f} \quad \therefore V_o = -\frac{R_f}{R_1}(V_i)$$

*

R_1 ต่อกับ ขา - OpAmp.

2. non-inverting amplifier.

R_1 ต่อกับ v1 - op Amp.



$$\boxed{V_a = \left(1+\frac{R_f}{R_1}\right)v_o}$$

proof. at Loop i_1 (KVL) $\quad i_1 = 0$

$$-V_i + V_d + \cancel{i_1}R_1 + i_f R_1 = 0 \rightarrow -V_i + V_d + i_f R_1 \quad \therefore \; i_f = \frac{V_i - V_d}{R_1}$$

at Loop if (KVL) $\quad i_1 = 0$

$$-V_o + i_f R_f + i_f R_1 + \cancel{i_1}R_1 = 0 \rightarrow V_o = i_f(R_f + R_1)$$

เอา if มาแทน. Loop if.

$$\therefore V_o = \left(\frac{V_1 - V_d}{R_1}\right)(R_f + R_1) \qquad V_d = \frac{V_o}{A}.$$

$$; \; V_o = \left(\frac{V_1}{R_1}\right)(R_f + R_1) - \left(\frac{V_d}{R_1}\right)(R_f + R_1)$$

$$; \; V_o = \left(\frac{V_1}{R_1}\right)(R_f + R_1) - \left(\frac{V_o}{A}\right)\frac{(R_f + R_1)}{(R_1)}$$

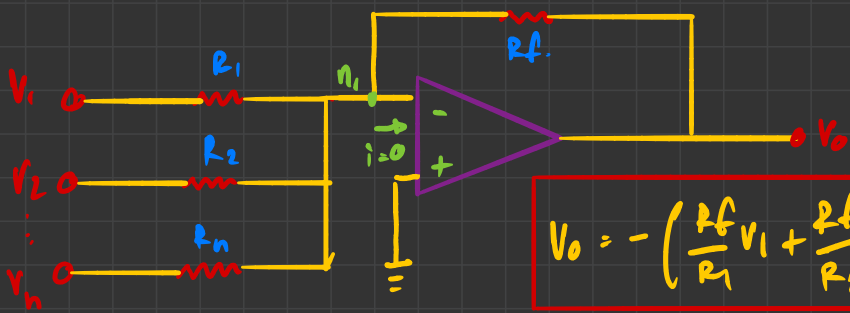
$$; \; V_o + \left(\frac{V_o}{AR_1}\right)(R_f + R_1) = \left(\frac{V_1}{R_1}\right)(R_f + R_1) \qquad \text{(ถ้ามีหลายตัว)}$$

$$\lim_{A \to \infty}$$

$$; \; V_o\left(1 + \cancel{\frac{R_f + R_1}{AR_1}}\right) = V_i\left(\frac{R_f}{R_1} + 1\right)$$

$$\therefore \frac{V_o}{V_i} = \frac{R_f}{R_1} + 1 \qquad \therefore V_o = \left(\frac{R_f}{R_1} + 1\right)V_i \quad \#$$

3. Inverting summing amplifier.



$$\boxed{V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \dots + \frac{R_f}{R_n}V_n\right)}$$

Proof. (KCL) at nodes. - Law $V_1 = V_2 = 0$!

$$\frac{V_1 - \cancel{V_{n_1}}^{0}}{R_1} + \frac{V_2 - \cancel{V_{n_1}}^{0}}{R_2} + \frac{V_n - \cancel{V_{n_1}}^{0}}{R_n} = \frac{\cancel{V_{n_1}}^{0} - V_o}{R_f}$$

$$; \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_n}{R_n} = \frac{-V_o}{R_f} \quad \therefore V_o = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \dots \frac{V_n}{R_n}\right)$$

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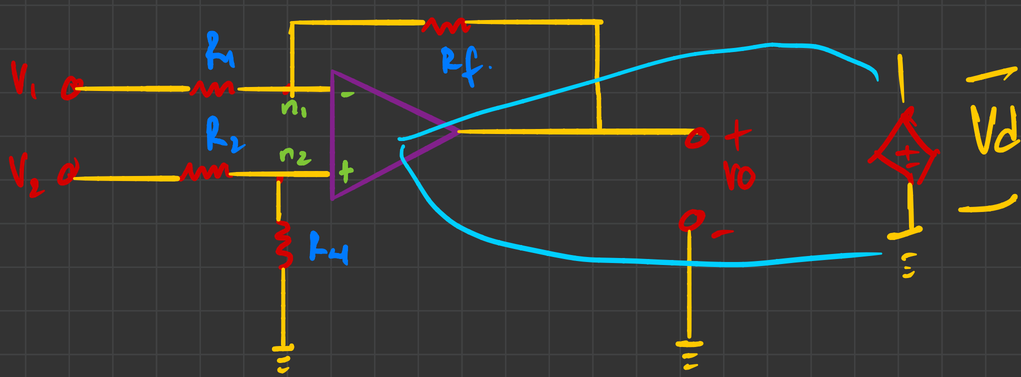
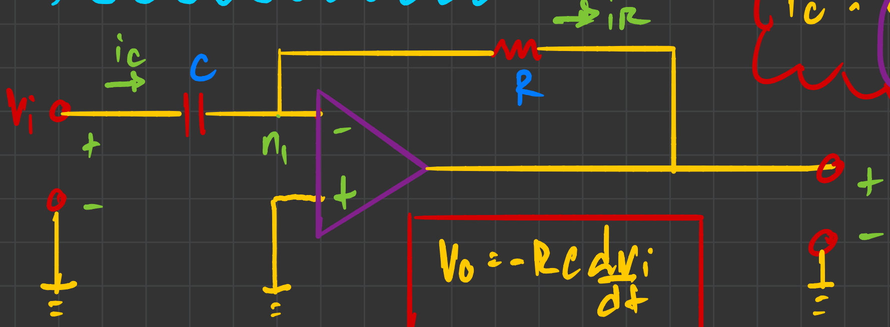
4. Subtracting amplifier.



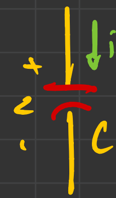
$$\boxed{V_o = V_2 - V_1}$$

5. Differentiator Amplifier



$$\boxed{V_o = -RC\frac{dv_i}{dt}}$$

$i_C = C\frac{dv}{dt}$



∫

proof. KCL at node 1. $\therefore i_C = i_R$.

; $(V_i - \cancel{V_{n_1}}^{0})\, SC = \frac{\cancel{V_{n_1}}^{0} - V_o}{R}$

diff

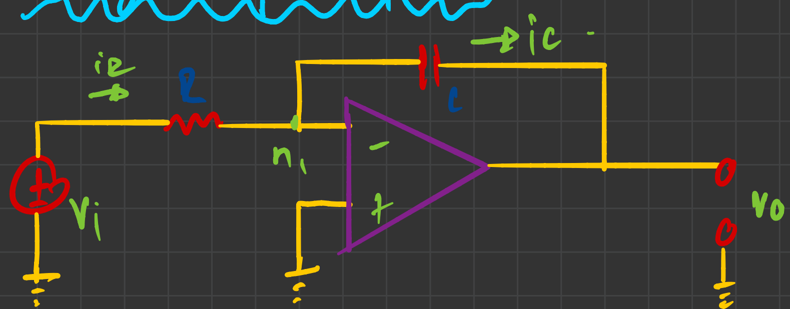
capa ต่ออนุกรม. $\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_n} \ldots$

ถ้าต่อ $R = R_1 + R_2 + R_n \ldots$

∴ ต้องนึกสลับผลคูณ. !

; $V_1 SC = -\frac{V_o}{R} \rightarrow C\frac{dv_i}{dt} = -\frac{V_o}{R}$ $\therefore V_o = -RC\frac{dv_i}{dt}$.

6. Intregrating Amplifier



proof. (KCL) at node 1

$\frac{V_i}{R} = i_C$; $\frac{V_i}{R} = -C\frac{dv_o}{dt}$

$$\boxed{V_o = -\frac{1}{RC}\int V_i dt.}$$

$\therefore V_o = -\frac{1}{RC}\int v_i dt$ #