Introduction to Electronic Systems

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Part 1: Resistive Circuit Analysis

1. Circuit Variables and Circuit Elements
2. Simple Resistive Circuit Analysis
3. Techniques of Circuit Analysis
4. **Operational Amplifier**

Chapter 4: Operational Amplifier

- Operation Amplifier
- Simple Operational Circuits

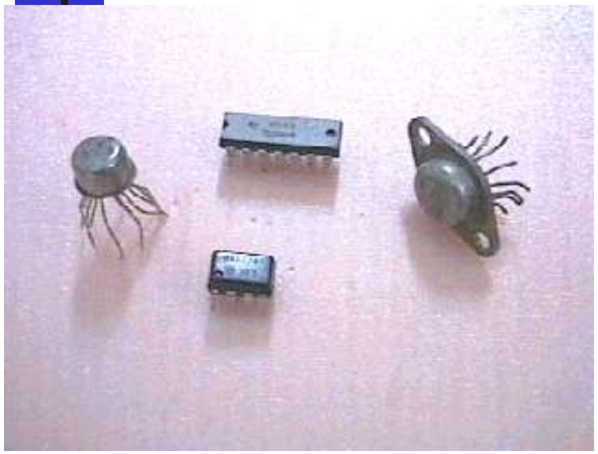
4-1 Operational Amplifier

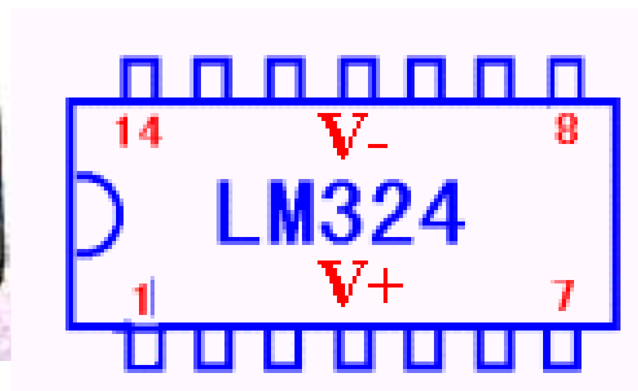
- What is operation amplifier?
- Terminals of operational amplifier
- Ideal operational amplifier

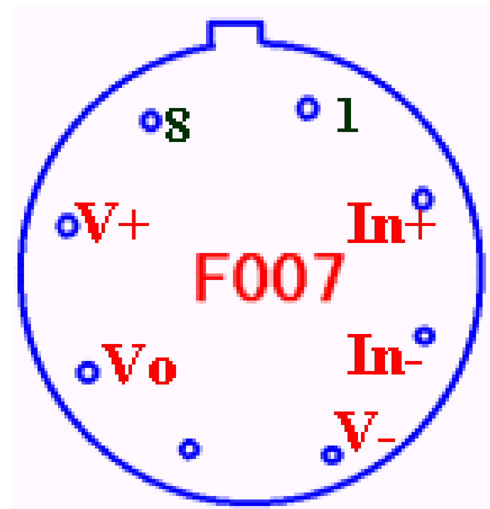
What is op amp?

- Operational amplifier (op amp) is a kind of IC active device with **multi terminals**;
- Combined with external circuit components, op amp can perform useful functions as **scaling, summing, sign changing, subtracting** ……

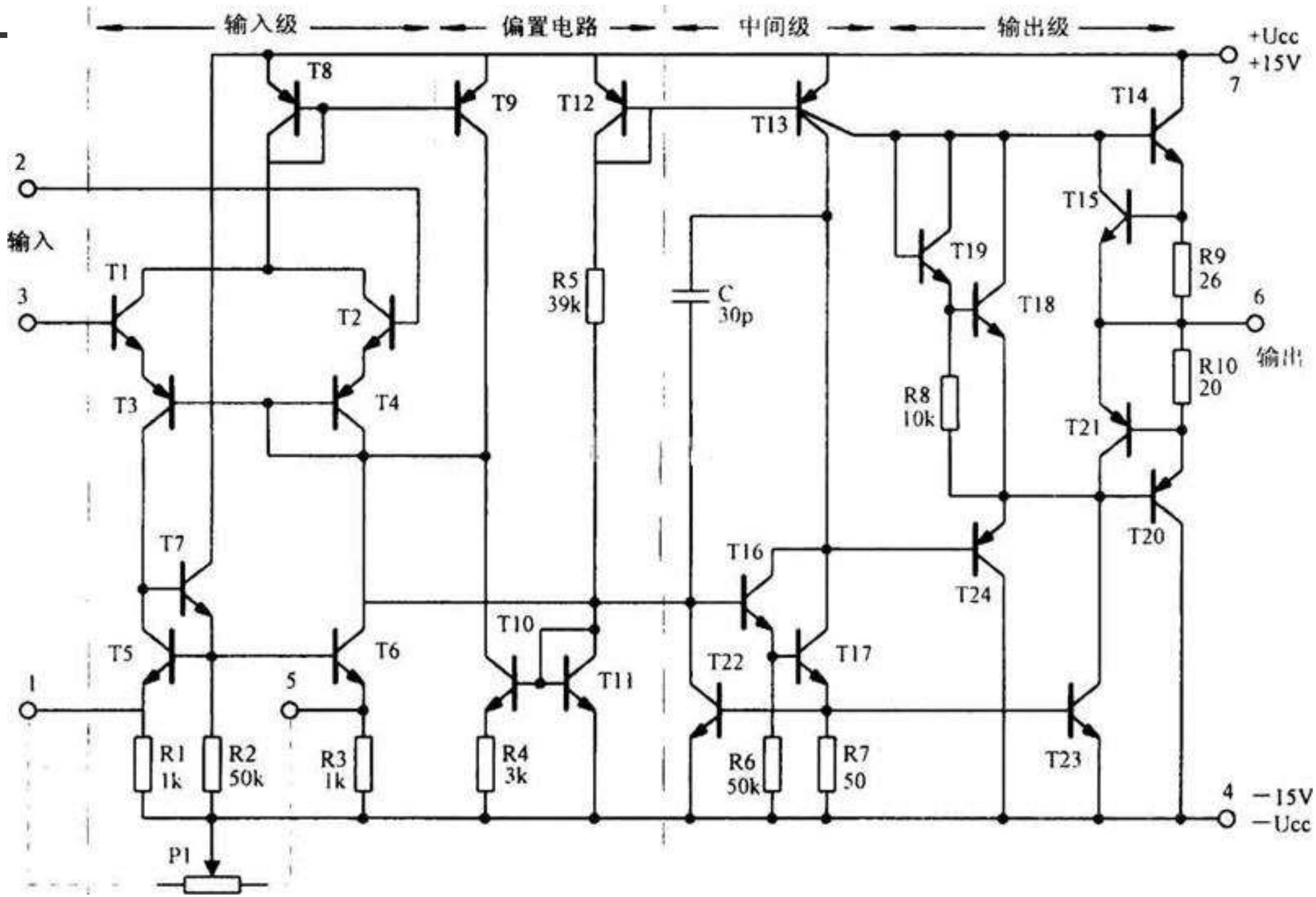
What is op amp?







F007 op amp

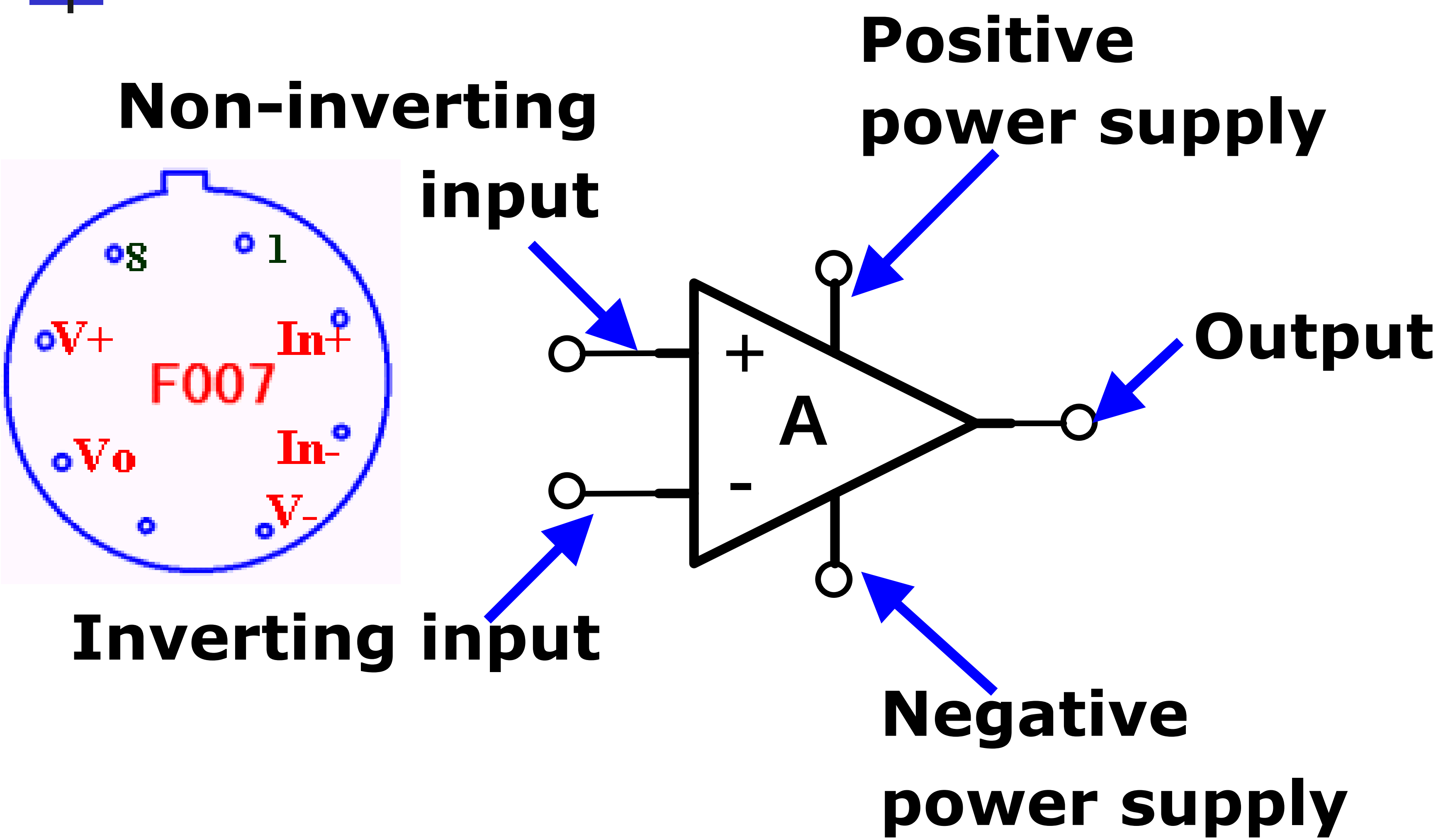


输入级
偏置电路
中间级
输出级
+Ucc
+15V
7
T8
T9
T12
T13
T14
2
输入
3
T1
T2
R5
39k
C
30p
T15
T19
R9
26
6
T18
输出
R10
20
R8
10k
T3
T4
T21
T20
T7
T16
T24
T10
T5
T6
T11
T22
T17
1
5
R1
1k
R2
50k
R3
1k
R4
3k
R6
50k
R7
50
T23
4
−15V
−Ucc
P1

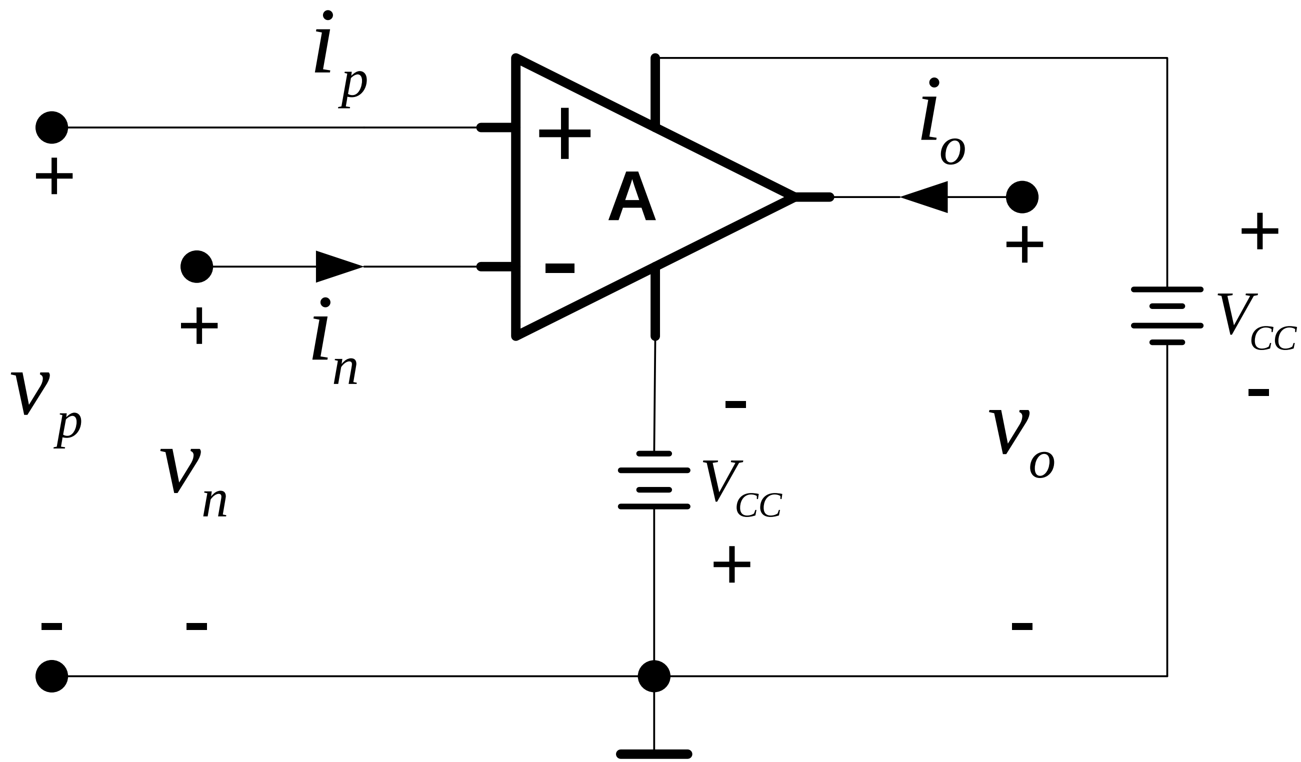
What is op amp?

- op amp has very complex internal circuit structure, but has **simple VCR of terminals**;
- We do not care the internal behavior of op amp, just consider it as a black box;
- We focus on **external terminals behavior** (terminal VCR) of op amps.

Terminals of op amp

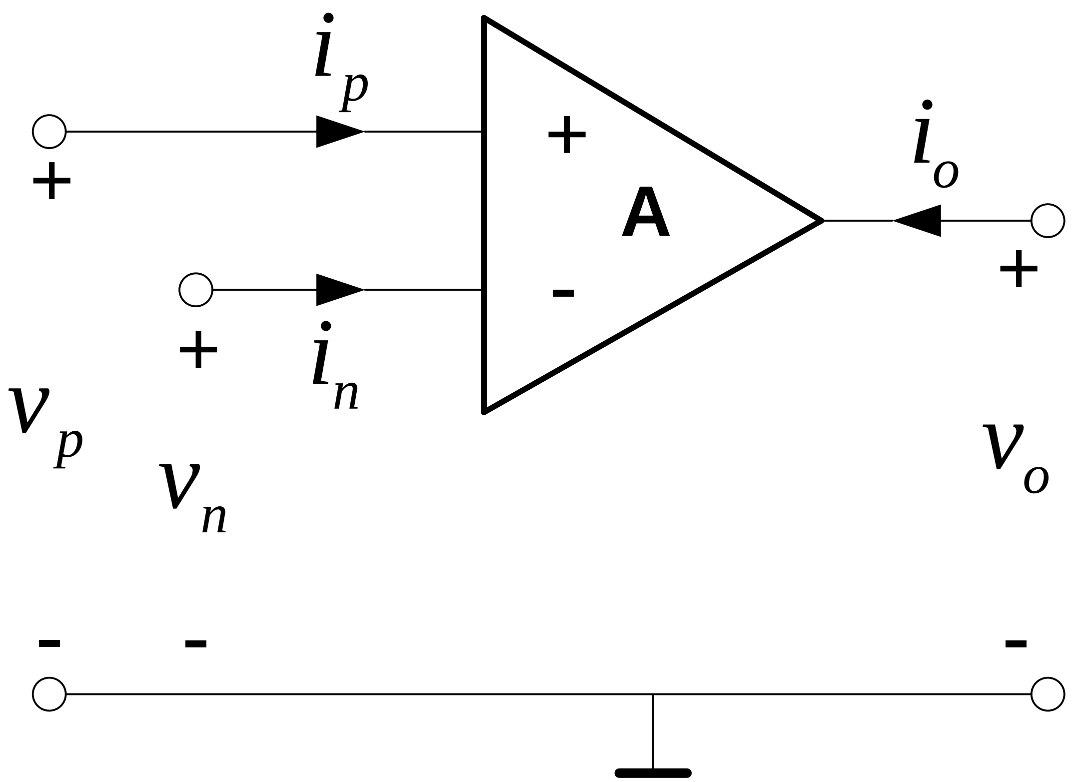


Terminals of op amp



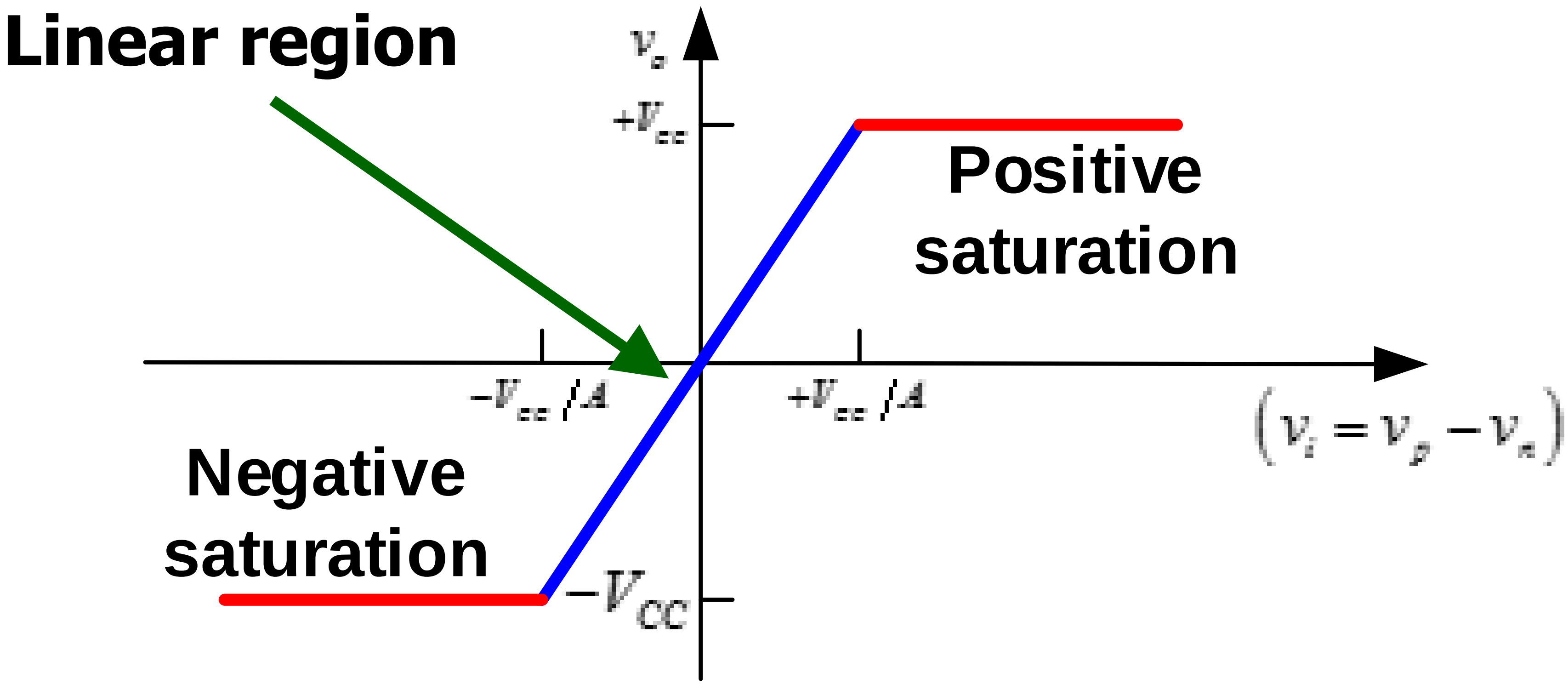
Terminal voltage and current

Simplified Terminals of op amp



op amp symbol more often used

Voltage Transfer Characteristic

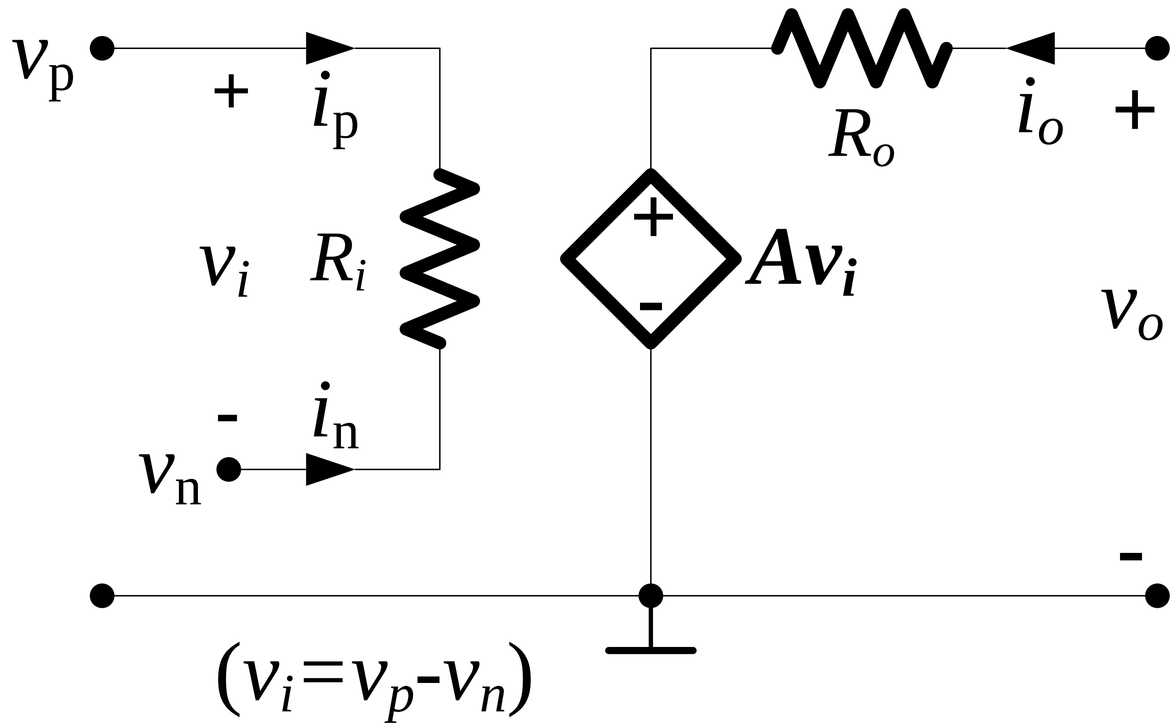


Voltage transfer characteristic:

$$v_o = \begin{cases} -V_{CC} \quad , & Negative \quad saturation \quad region \quad (v_o < -V_{CC}) \\ Av_i \quad , & Linear \quad region \quad (-V_{CC} \le v_o \le +V_{CC}) \\ +V_{CC} \quad , & Positive \quad saturation \quad region \quad (v_o > +V_{CC}) \end{cases}$$

- **Maximum Output Voltage is ±V_{CC}**

Linear Equivalent Circuit Model



- Voltage controlled Voltage source
- A is Open Loop Gain

Ideal Operation Amplifier

- **Ideal op amp has infinite R_i and A:**

$$\begin{cases} A = \infty \\ R_i = \infty \end{cases}$$

For an ideal operation amplifier:

$$v_i = v_p - v_n = \frac{v_o}{A} \to 0 \quad \Rightarrow \quad v_p = v_n$$

$$R_i = \infty \quad \Rightarrow \quad i_p = i_n = 0$$

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Input voltage and current constraints for an ideal operation amplifier:

$$\begin{cases} V_p = V_n \\ i_p = i_n = 0 \end{cases}$$

$\leftarrow$ **Virtual Short**

$\leftarrow$ **Virtual Open**

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4-2 Simple Operational Circuits

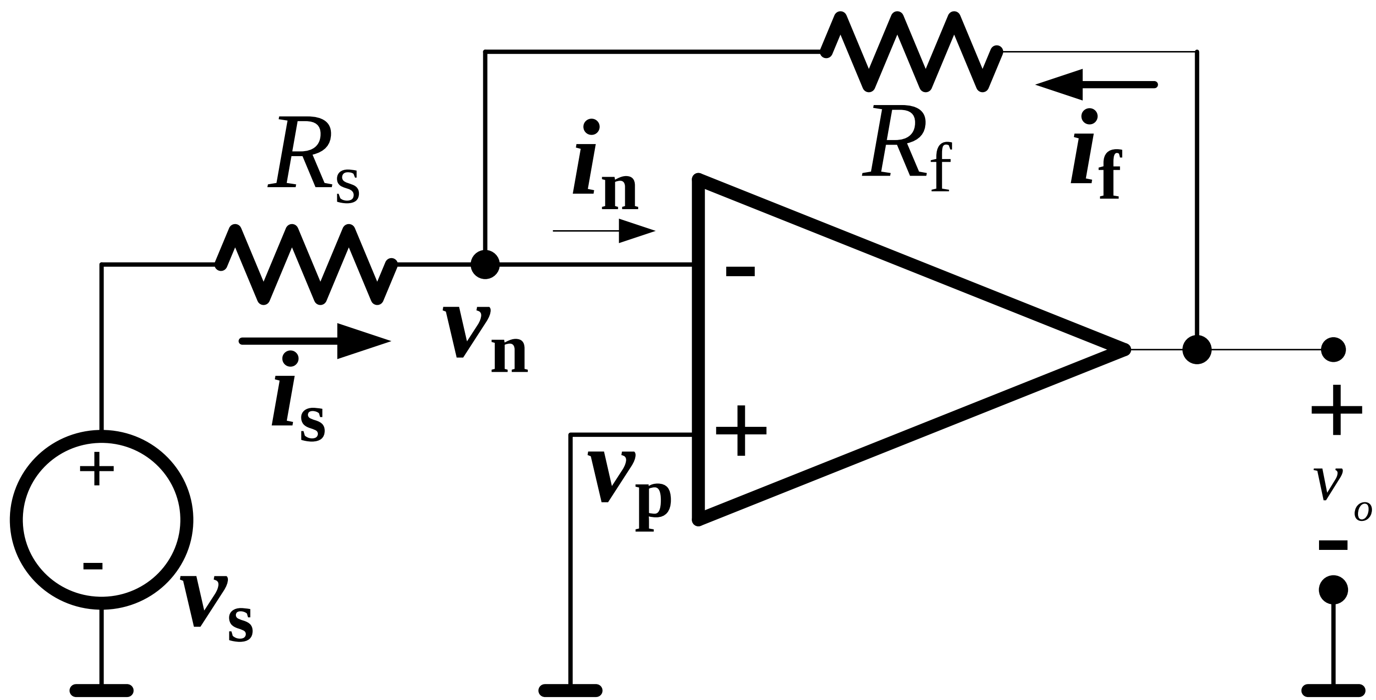
- **Powerful tools in analyzing operational circuits with operation amplifier:**

  1. **Virtual short:** $v_p = v_n$

  2. **Virtual open:** $i_p = i_n = 0$

  3. **KCL**

Inverting Amplifier

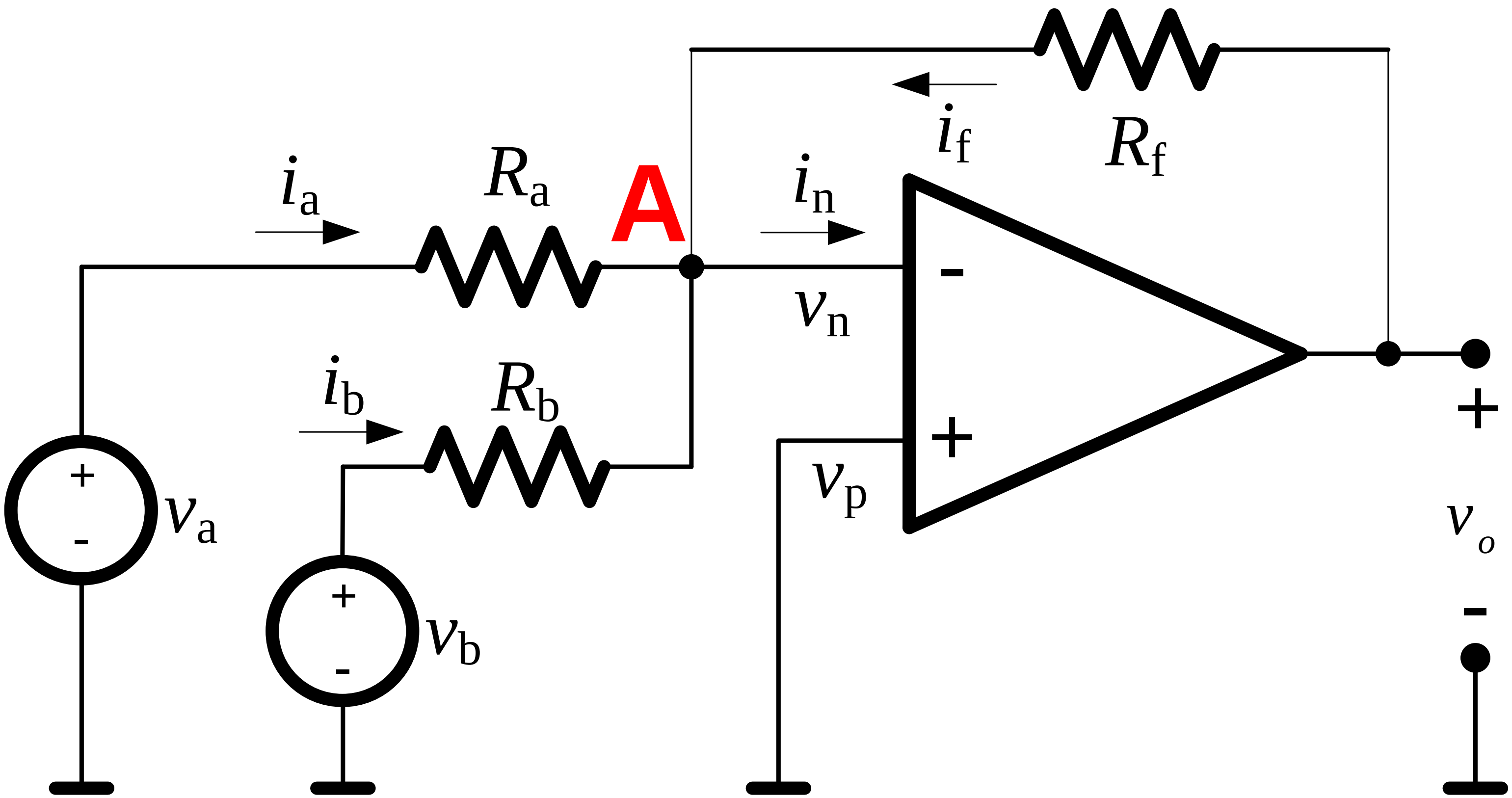


Find the expression of v_o as a function of source voltage v_s.

For the inverting terminal, apply KCL:

$$\left.\begin{array}{l} \dfrac{v_s - v_n}{R_s} + \dfrac{v_o - v_n}{R_f} - i_n = 0 \\ \begin{cases} i_p = i_n = 0 \\ v_p = v_n = v_s \end{cases} \end{array}\right\} v_o = -\frac{R_f}{R_s} v_s$$

Summing Amplifier



Find the expression of v_o.

Summing Amplifier

For node A, apply node-voltage method:

$$\frac{v_a - v_n}{R_a} + \frac{v_b - v_n}{R_b} + \frac{v_o - v_n}{R_f} = i_n$$

$$\begin{cases} i_p = i_n = 0 \\ v_p = v_n = 0 \end{cases}$$

$$\Rightarrow \quad v_o = -\left(\frac{R_f}{R_a} v_a + \frac{R_f}{R_b} v_b\right)$$

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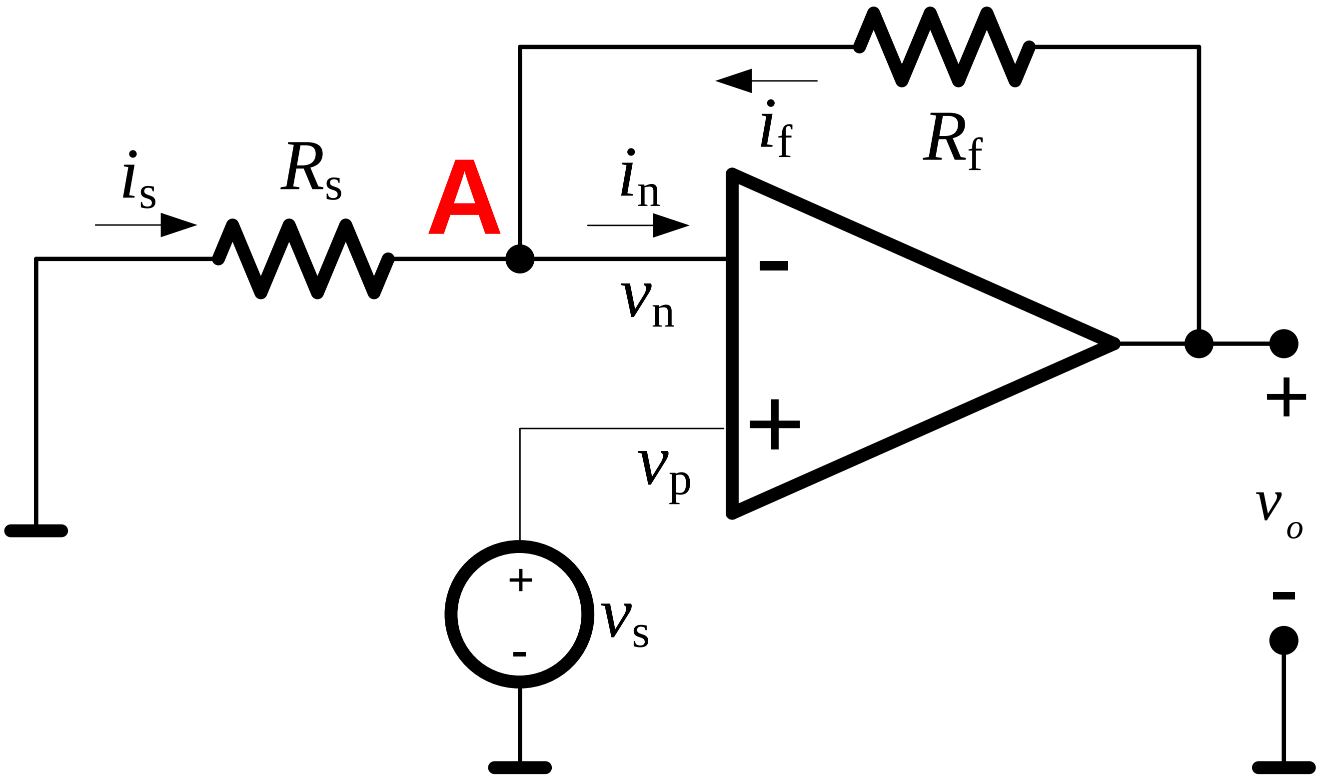
Non-Inverting Amplifier



Find the expression of v_o.

Non-Inverting Amplifier

For node A, apply node-voltage method:

$$\left.\begin{array}{l} \dfrac{0-v_n}{R_s}+\dfrac{v_o-v_n}{R_f}=i_n \\ \begin{cases} i_p=i_n=0 \\ v_p=v_n=v_s \end{cases} \end{array}\right\} v_o=\left(1+\frac{R_f}{R_s}\right)v_s$$

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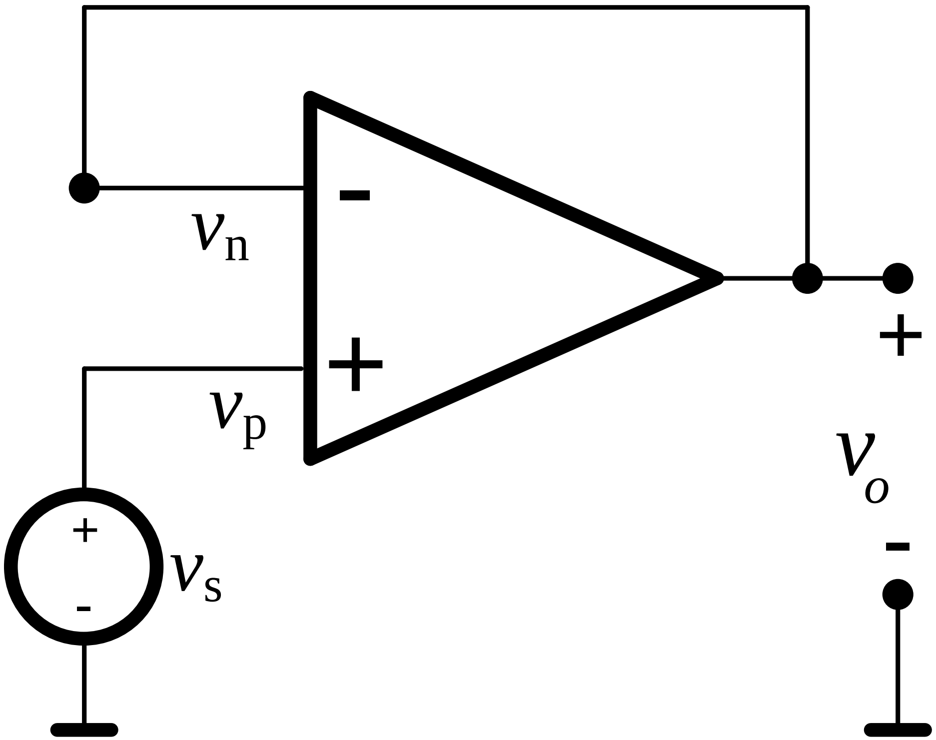
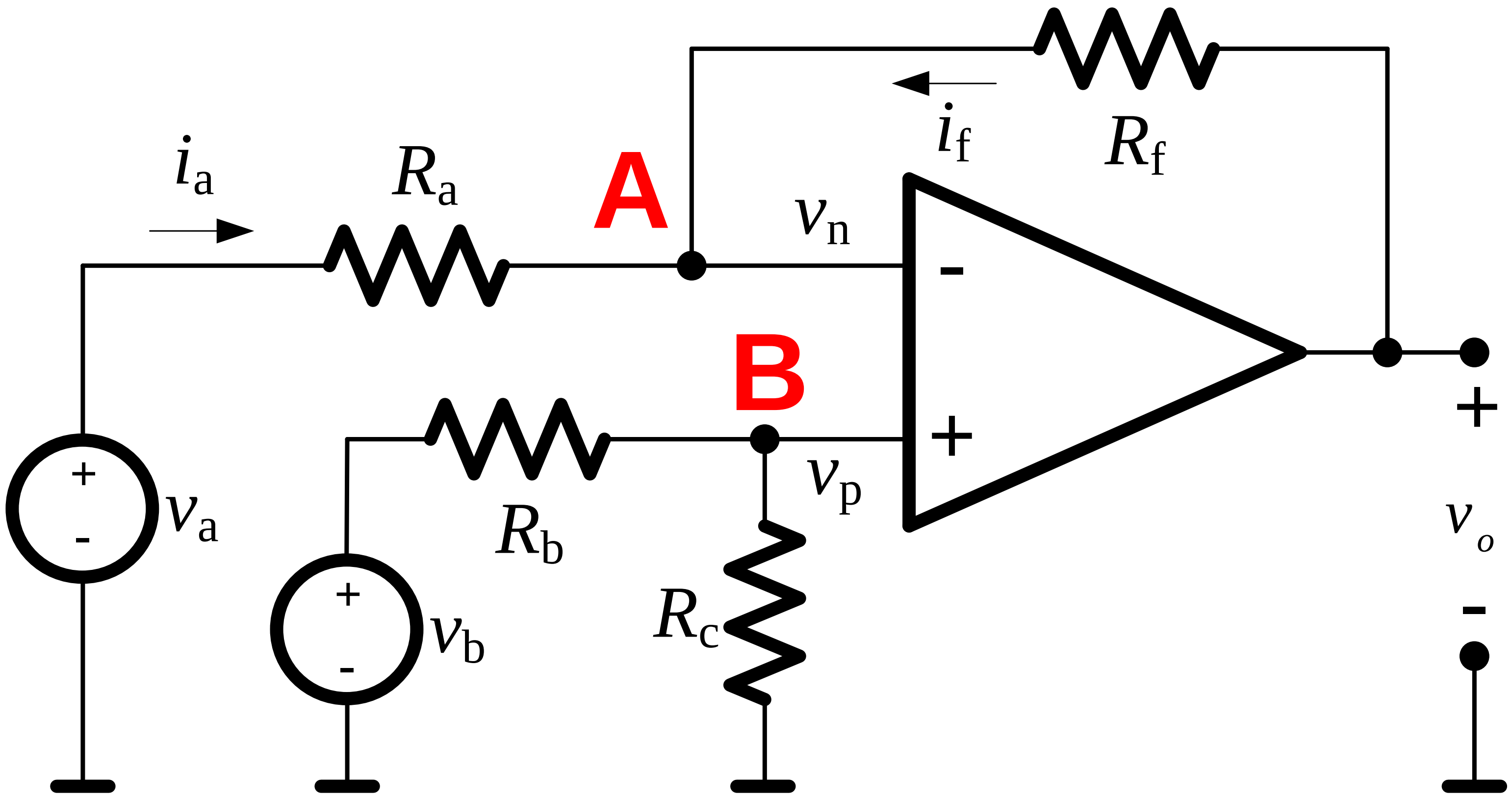
Voltage Follower



$$v_o = v_n = v_p = v_s$$

$$v_o = v_s$$

Difference Amplifier



Find the expression of v_o.

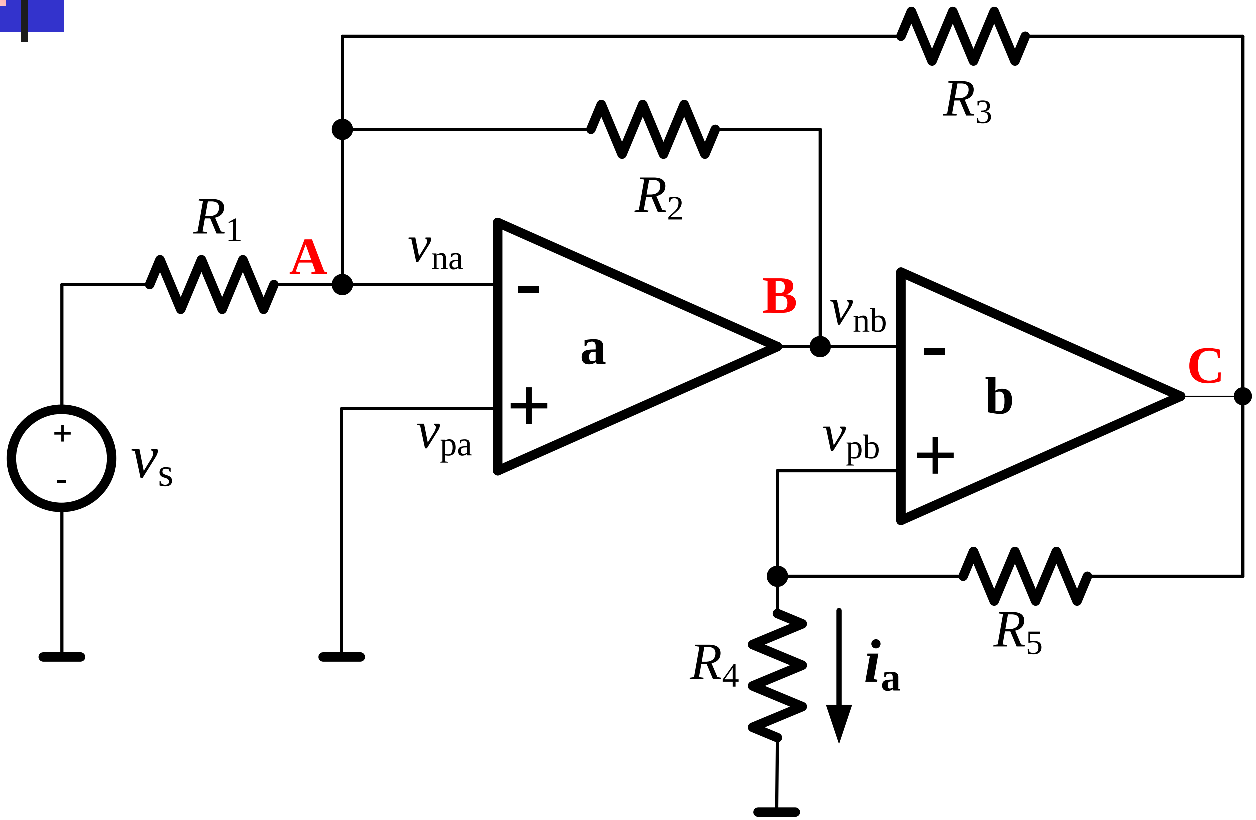
Difference Amplifier

For node A and B, by KCL:

$$\begin{cases} \dfrac{v_o - v_n}{R_f} + \dfrac{v_a - v_n}{R_a} = 0 \\ v_n = v_p = \dfrac{R_c}{R_b + R_c} v_b \end{cases} \Rightarrow v_o = \frac{R_c\left(R_a + R_f\right)}{R_a\left(R_b + R_c\right)} v_b - \frac{R_f}{R_a} v_a$$

$\Rightarrow$ **If** $R_a R_c = R_b R_f$ **,then** $v_o = \dfrac{R_f}{R_a}\left(v_b - v_a\right)$

Example

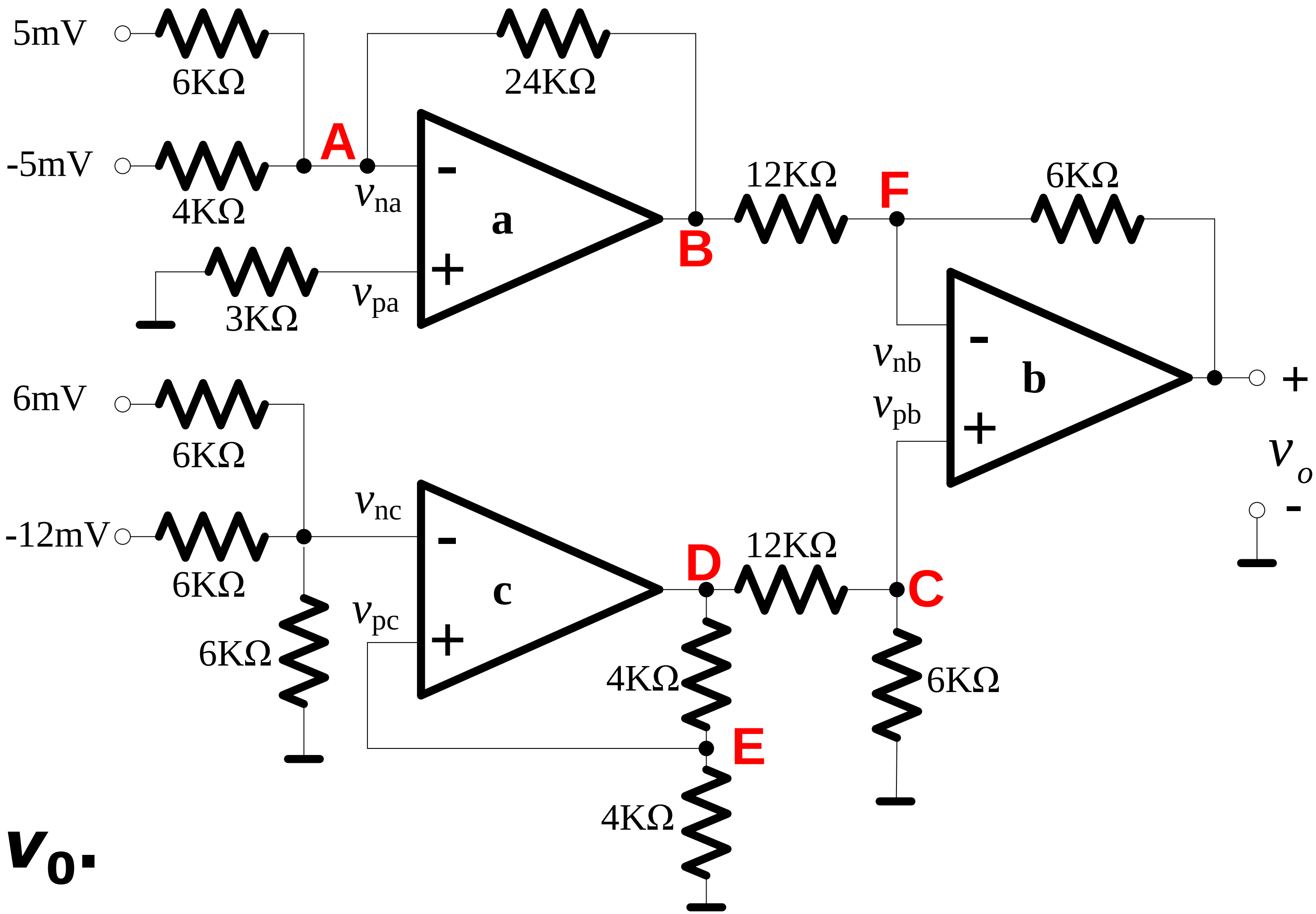


Find the current of i_a.

ANS: $i_a = \dfrac{-R_2R_3}{R_1(R_3R_4 + R_2R_4 + R_2R_5)} v_s$

Example

ANS: v_0=-7mV



Find v_0.

Summary of Chapter 4

- Basic conception of operational amplifier
- Input voltage and current constraints for an ideal op amp: Virtual short and Virtual open
- Analysis of simple circuits with operational amplifiers