Chapter 5

Operational Amplifiers

5.1 Introduction

1. Terms
2. Introduction of this chapter

1. terms

Operational Amplifier 运算放大器

inverter 反相器

Voltage follower 电压跟随器

differentiation 微分

integration 积分

integrated circuit package 集成电路封装

The inverting input 倒向输入

The noninverting input 非倒向输入

The closed-loop gain 闭环增益

The open-loop gain 开环增益

saturation 饱和

2. Introduction

(a) The op amp is an electronic unit that behaves like a **voltage-controlled voltage source**.

(b) An op amp can **sum signals**, **amplify a signal**, **integrate it**, or **differentiate it**.

electron tube ⇒ transistor ⇒

integrated operational amplifier

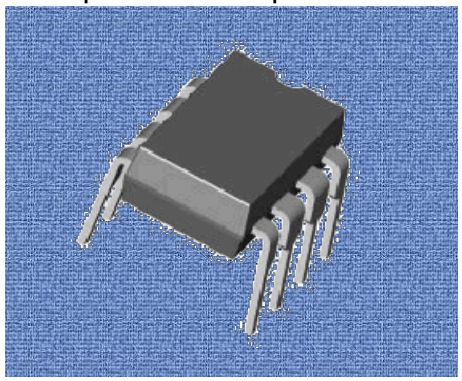
5.2 Operational Amplifiers

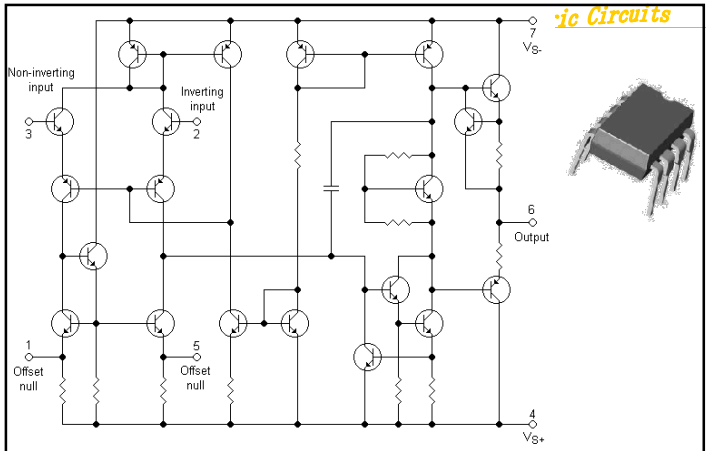
1. Definition and Symbol
2. The equivalent circuit model
3. Active state
4. The input mode
5. Op-amp characteristics

1. Definition and Symbol

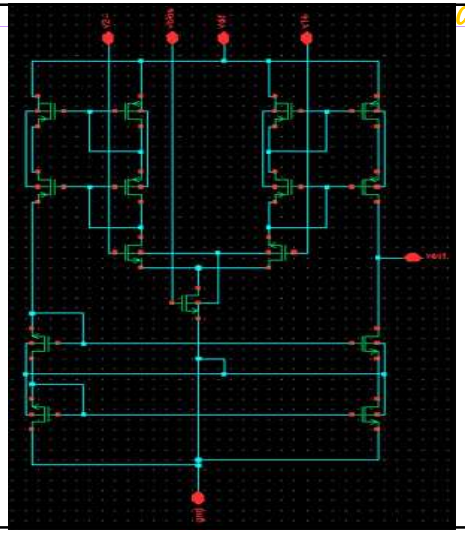
(a) An op amp is **an active circuit element** designed to perform mathematical operations of addition, subtraction, multiplication, division, differer , a gration.

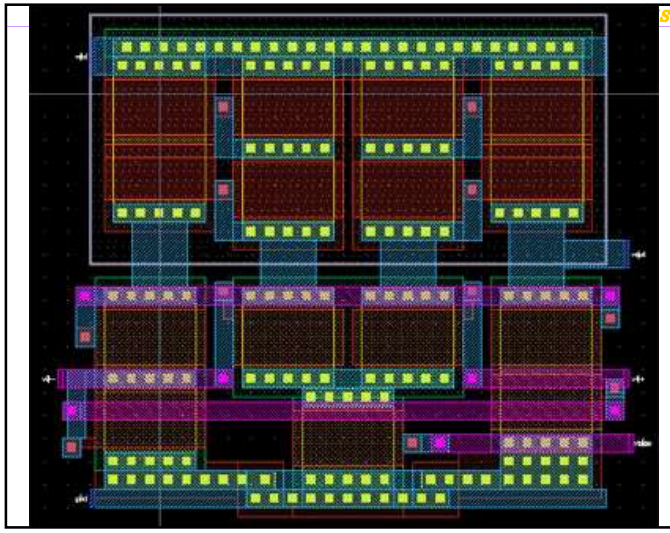
(b) A typical operational amplifier



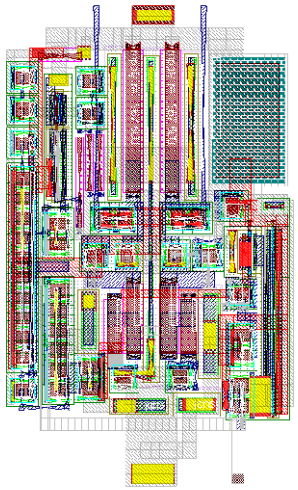


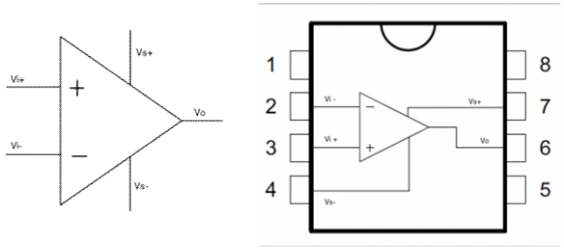
A component level diagram of the common 741 op-amp





opamp_layout





(c)The circuit symbol for the op amp is the triangle in Fig. (a); as shown, the op amp has **two inputs and one output**. The inputs are marked with **minus(-)** and **plus(+)** to specify **inverting and noninverting inputs**, respectively.

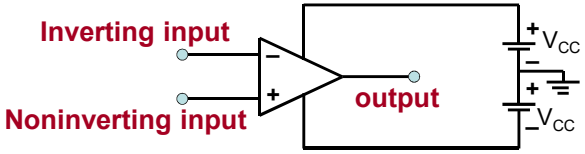


Fig.(a)

2. The equivalent circuit model

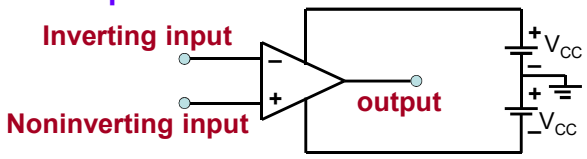
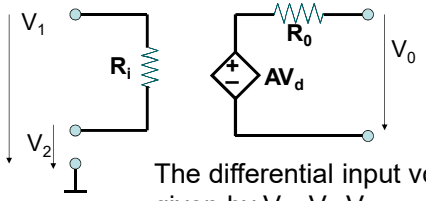


Fig.(a)



The differential input voltage is given by $V_d=V_2-V_1$

3. Active state

(a) Open-loop

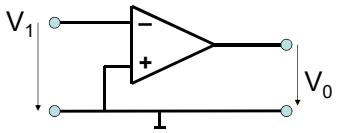
A is called the open-loop voltage gain because it is the gain of the op amp without any external feedback from output to input.

(b) Closed-loop

When there is a feedback path from output to input, the ratio of the output voltage to the input voltage is called the closed-loop gain.

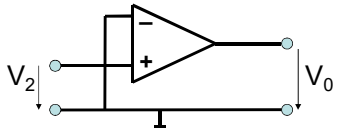
4. The input mode

(a) Inverting input



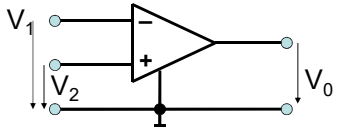
$V_0 = -AV_1$

(b) Noninverting input



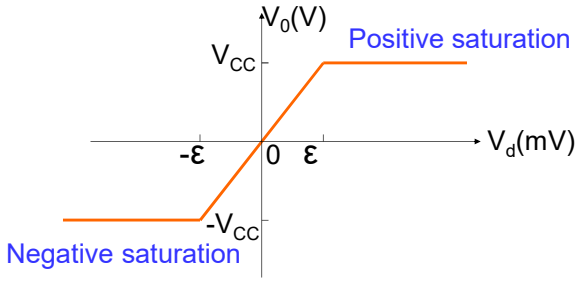
$V_0 = AV_2$

(c) Difference input



$V_0 = A(V_2 - V_1) = AV_d$

5. Op-amp characteristics



5.3 Ideal op amp

1. Definition
2. Two important characteristics
3. Comparison

1.An op amp is ideal if it has the following characteristics:

(a) Infinite open-loop gain, A≈∞.

(b) Infinite input resistance, R_i≈∞.

(c) Zero output resistance, R_0≈0.

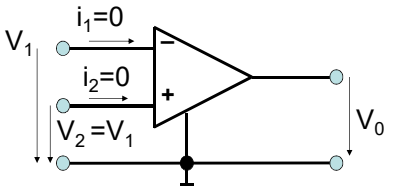


Fig. (d) Ideal op amp model

2.Two important characteristics of the ideal op amp are:

(a) The currents into both input terminals are zero: i_1=0 i_2=0

(b) The voltage across the input terminals is negligibly small: $V_d=V_2-V_1$≈0 or $V_1=V_2$

3. Comparison

	Typical	Ideal
Input Resistance: R_i	10^6- 10^{13} Ω	∞
Output Resistance: R_o	10- 100 Ω	0
Open Loop Voltage Gain	10^5- 10^8	∞

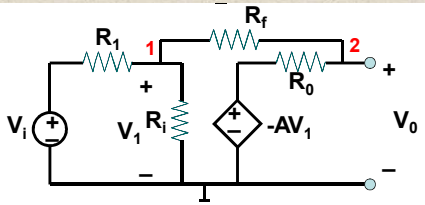
5.4 Inverting Amplifier

-------- The figure and property

Inverting Amplifier

$$\left(\frac{1}{R_1}+\frac{1}{R_i}+\frac{1}{R_f}\right)u_{n1}-\frac{1}{R_f}u_{n2}=\frac{V_i}{R_1}$$

$$-\frac{1}{R_f}u_{n1}+\left(\frac{1}{R_o}+\frac{1}{R_f}\right)u_{n2}=-\frac{AV_1}{R_o}$$



Use nodal analysis, we obtain

$$\left(\frac{1}{R_1}+\frac{1}{R_i}+\frac{1}{R_f}\right)u_{n1}-\frac{1}{R_f}u_{n2}=\frac{V_i}{R_1}$$

$$-\frac{1}{R_f}u_{n1}+\left(\frac{1}{R_o}+\frac{1}{R_f}\right)u_{n2}=-\frac{AV_1}{R_o}$$

$$\because u_{n1}=V_1 \qquad u_{n2}=V_o$$

$$\left(\frac{1}{R_1}+\frac{1}{R_i}+\frac{1}{R_f}\right)V_1-\frac{1}{R_f}V_o=\frac{V_i}{R_1}$$

$$\left(\frac{A}{R_o}-\frac{1}{R_2}\right)V_1+\left(\frac{1}{R_o}+\frac{1}{R_f}\right)V_o=0$$

$$V_o=\frac{-\left(\frac{A}{R_o}-\frac{1}{R_f}\right)\frac{V_i}{R_1}}{\left(\frac{1}{R_o}+\frac{1}{R_f}\right)\left(\frac{1}{R_1}+\frac{1}{R_i}+\frac{1}{R_f}\right)+\frac{1}{R_2}\left(\frac{A}{R_o}-\frac{1}{R_f}\right)}$$

$$\frac{V_o}{V_i}=-\frac{R_f}{R_1}\cdot\frac{1}{1+\dfrac{\left(1+\frac{R_o}{R_f}\right)\left(1+\frac{R_f}{R_1}+\frac{R_f}{R_i}\right)}{A-\frac{R_o}{R_f}}}$$

$\because$ Ideal op amp $\quad R_o\approx 0 \quad R_i\approx\infty \quad A\approx\infty$

$$\therefore \frac{V_o}{V_i} \approx -\frac{R_f}{R_1} \qquad or \qquad V_o \approx -\frac{R_f}{R_1} V_i$$