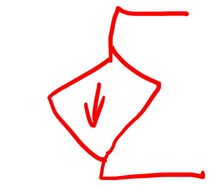
VCCS dependent



Recap

- Dependent sources vs Independent sources
- Circuit analysis for voltage controlled current source (VCCS)
  - Nodal analysis
  - Superposition
  - Thevenin's equivalent circuit
- Non-linear component

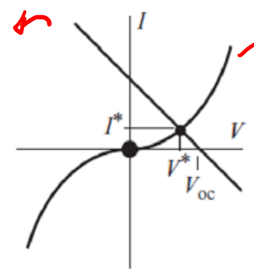


Figure 5.13 The point I, V must lie on both characteristics, and hence at their intersection (I^*, V^*)

Linear

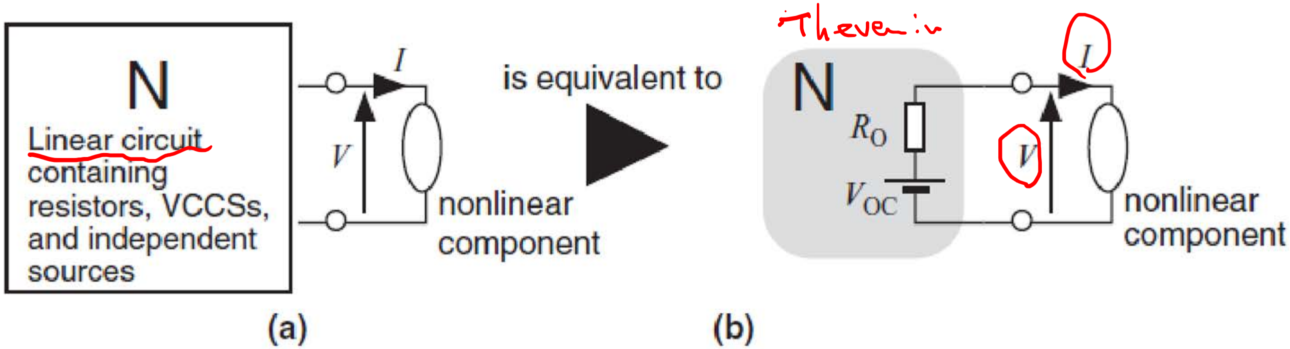


Figure 5.11 (a) A circuit containing one nonlinear component whose voltage and current are of interest; (b) a representation of the linear part of the circuit by a Thevenin model

Quiz 4 Review

The circuit of Fig. 1 contains a Zener diode (as in Fig. 2). A good approximation to its *I-V* relation is shown in Fig.3. The maximum power that can be absorbed by the diode and dissipated as heat is 250 mW.

1. **Calculate the minimum value of *R* that will keep the Zener diode in operation.**
2. **Calculate the power dissipated by the resister *R*.**

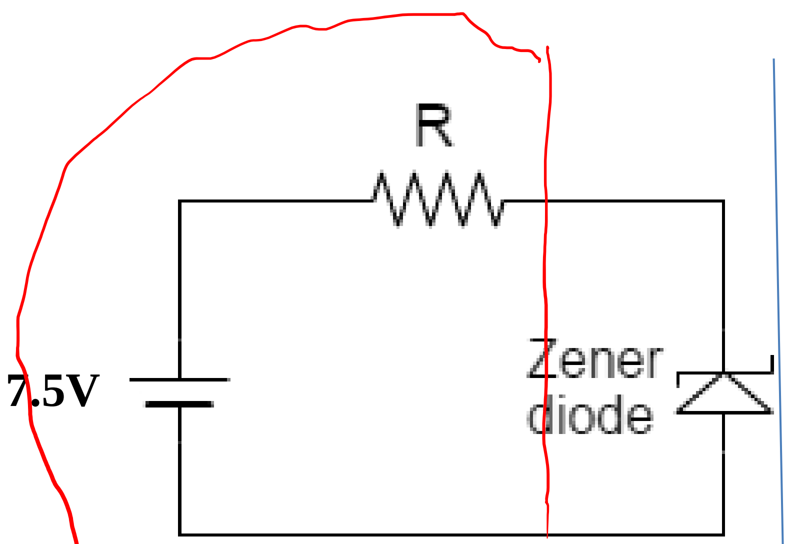


Fig. 1

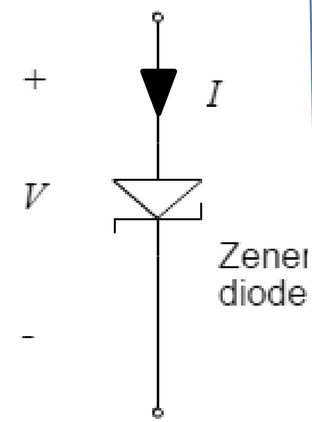


Fig. 2

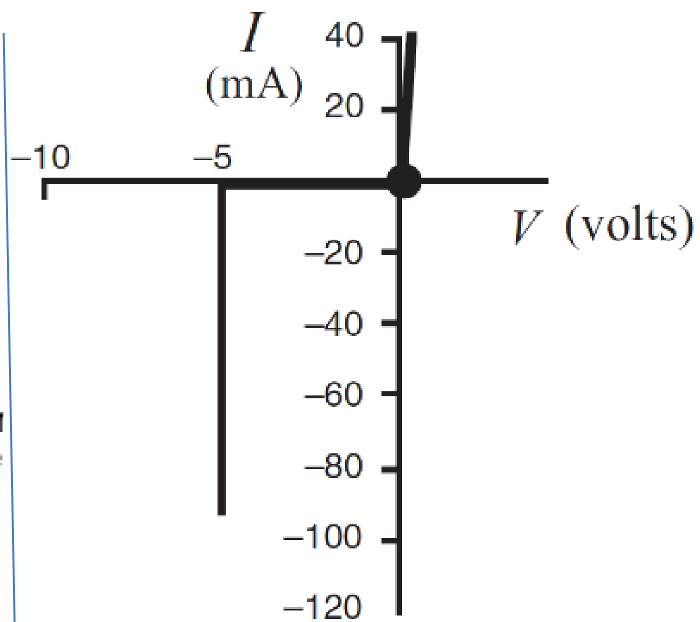


Fig. 3

運算 放大器

Chapter 6

Operational Amplifier

OPAMP

Opamp

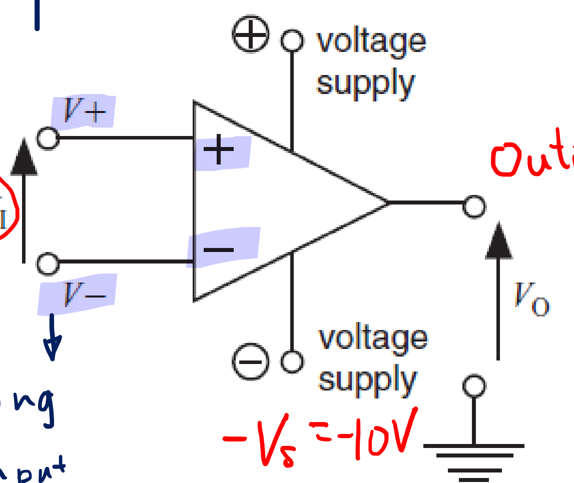
Operational amplifier

Non-inverting Input

Differential Input

$V_I = V_+ - V_-$

$+V_s = 10V$



$-V_s = -10V$

Output

Inverting Input

Gain $\sim 10^5$

$V_O = A\,V_I$

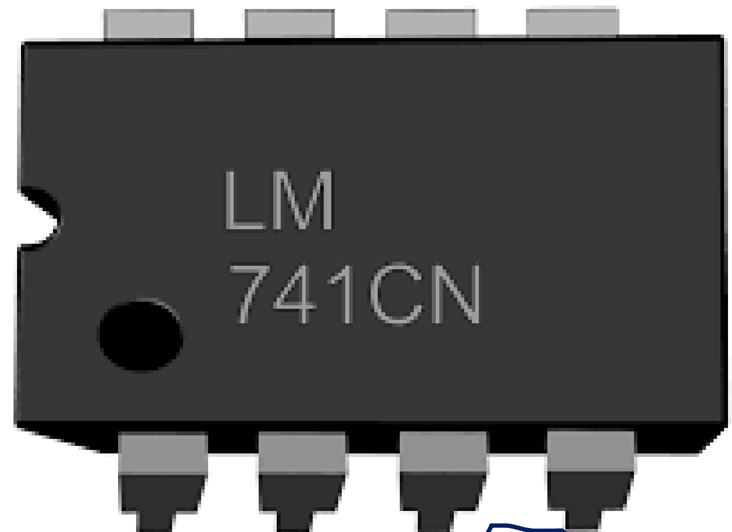
$= A\,(V_+ - V_-)$

Figure 6.1 The voltages associated with an operational amplifier

Operational amplifier

Implemented in Integrated Chip

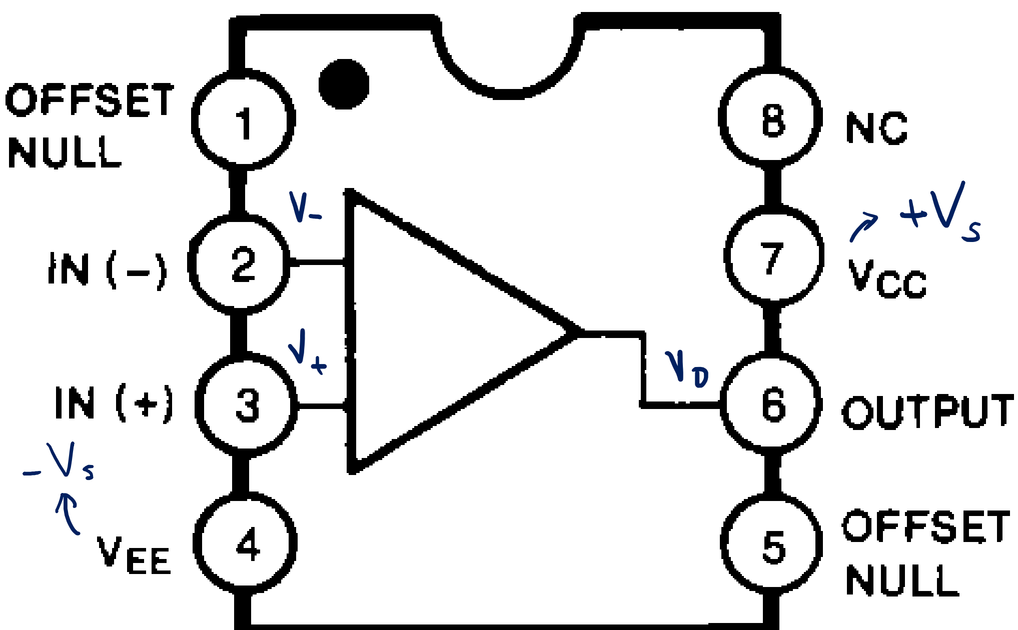
- Transistor
- Capacitor
- Resistor
- Diode



Eight-pin IC, LM741CN

Uses :

- Amplifier
- Active Filter
- Analog Computing

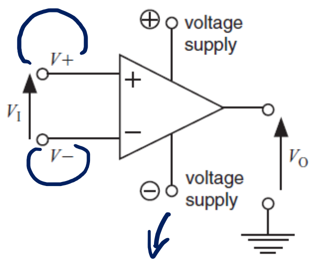


Operational amplifier characteristic

$$V_o = \begin{cases} +V_s & \text{if } V_I > \frac{V_s}{A} \\ AV_I, & \text{if } -\frac{V_s}{A} < V_I < \frac{V_s}{A} \\ -V_s, & \text{if } V_I < -\frac{V_s}{A} \end{cases}$$

$+V_s = 15V$

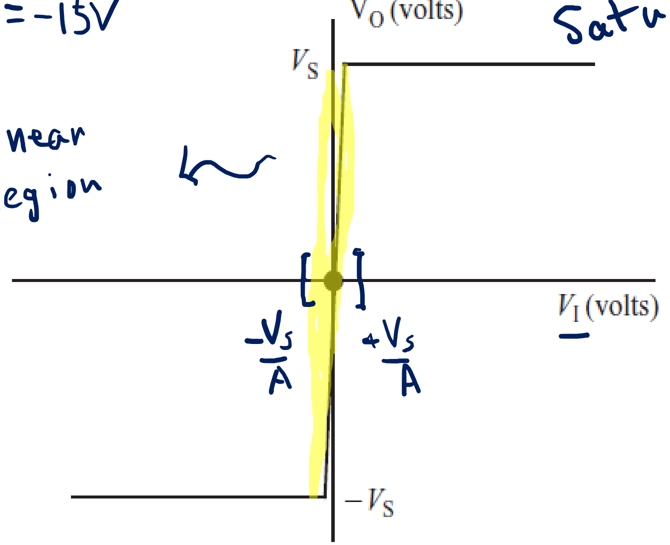
$V_I = V_+ - V_-$



$-V_s = -15V$

Saturation

Linear Region



$V_s \approx 15V$

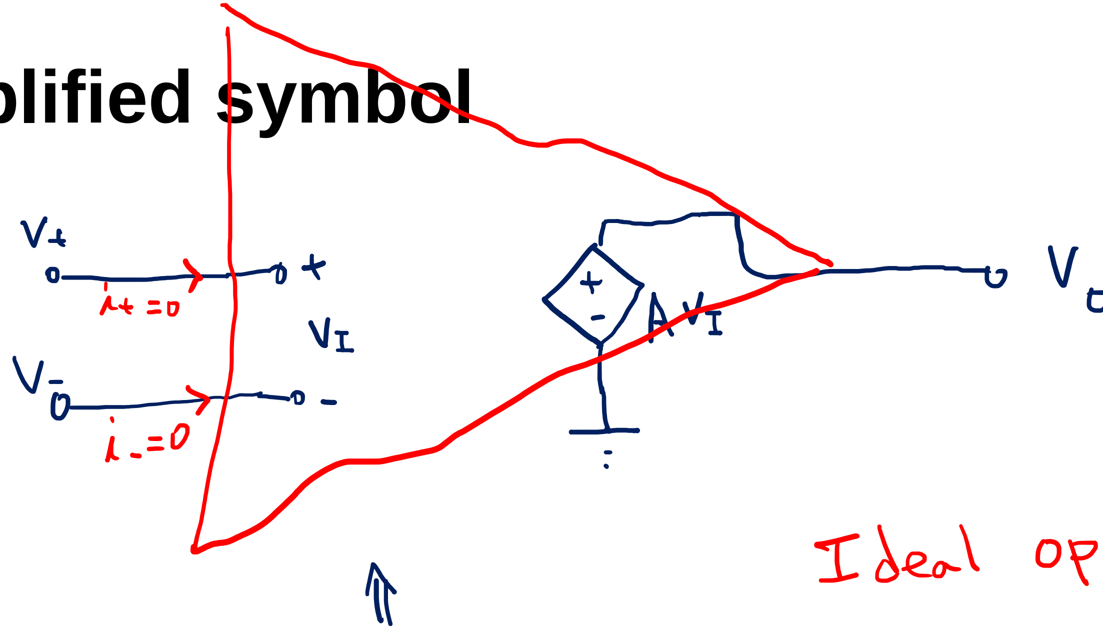
$A \sim 200000$

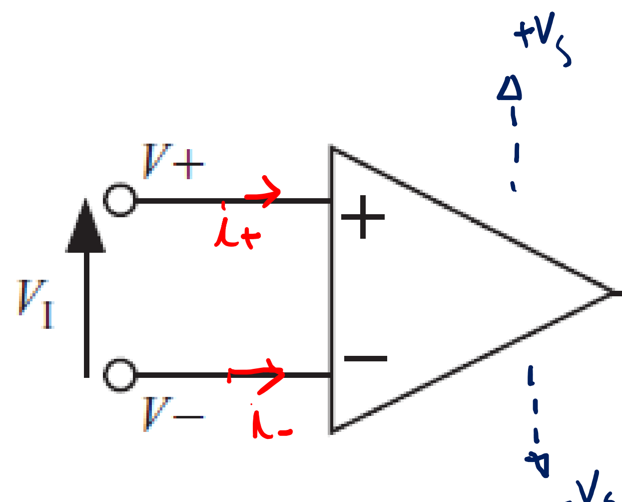
$\frac{V_s}{A} \sim 0.075\ mV$

$\approx 75\ \mu V$

Figure 6.2 The form of the relation between the input V_I and output V_O voltages of an opamp

Simplified symbol





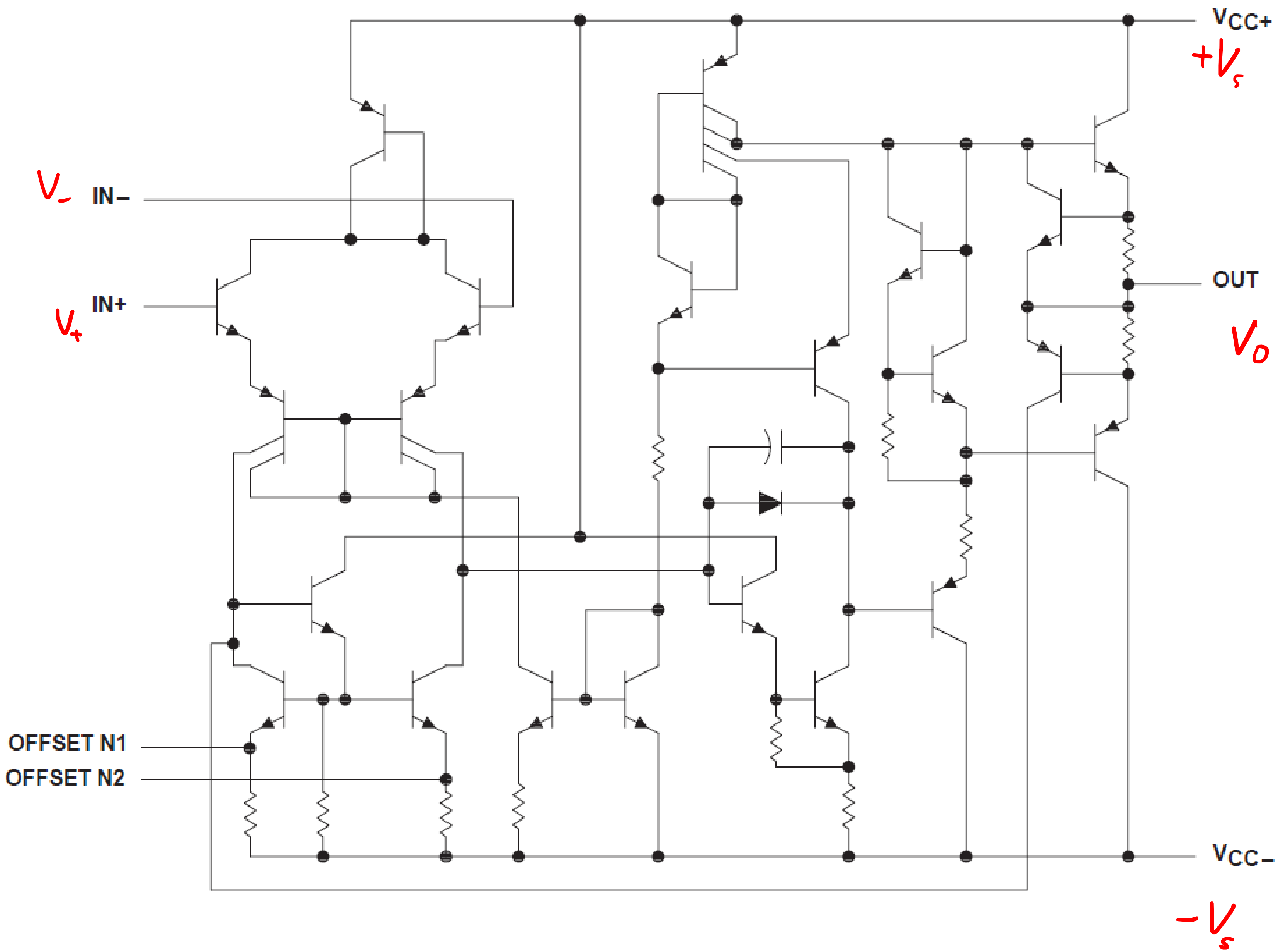
Ideal opamp

$A \to \infty$

$i_+ \simeq 0$

$i_- \simeq 0$

Figure 6.3 The conventional representation of an opamp schematic



http://www.ti.com/product/ua741

TI μA741

Data Sheet

諸元表

Spec

electrical characteristics at specified free-air temperature, $V_{CC\pm} = \pm15$ V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	T_A†	µA741C			µA741I, µA741M			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO}	Input offset voltage	$V_O = 0$	25°C		1	6		1	5	mV
			Full range			7.5			6	
$\Delta V_{IO(adj)}$	Offset voltage adjust range	$V_O = 0$	25°C		±15			±15		mV
I_{IO}	Input offset current	$V_O = 0$	25°C		20	200		20	200	nA
			Full range			300			500	
I_{IB}	Input bias current	$V_O = 0$	25°C		80	500		80	500	nA
			Full range			800			1500	
V_{ICR}	Common-mode input voltage range		25°C	±12	±13		±12	±13		V
			Full range	±12			±12			
V_{OM}	Maximum peak output voltage swing	$R_L = 10$ kΩ	25°C	±12	±14		±12	±14		V
		$R_L \geq 10$ kΩ	Full range	±12			±12			
		$R_L = 2$ kΩ	25°C	±10	±13		±10	±13		
		$R_L \geq 2$ kΩ	Full range	±10			±10			
A_{VD}	Large-signal differential voltage amplification	$R_L \geq 2$ kΩ	25°C	20	200		50	200		V/mV
		$V_O = \pm10$ V	Full range	15			25			
r_i	Input resistance		25°C	0.3	2		0.3	2		MΩ
r_o	Output resistance	$V_O = 0$, See Note 5	25°C		75			75		Ω
C_i	Input capacitance		25°C		1.4			1.4		pF
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICR}$min	25°C	70	90		70	90		dB
			Full range	70			70			
k_{SVS}	Supply voltage sensitivity ($\Delta V_{IO}/\Delta V_{CC}$)	$V_{CC} = \pm9$ V to ±15 V	25°C		30	150		30	150	µV/V
			Full range			150			150	
I_{OS}	Short-circuit output current		25°C		±25	±40		±25	±40	mA
I_{CC}	Supply current	$V_O = 0$, No load	25°C		1.7	2.8		1.7	2.8	mA
			Full range			3.3			3.3	
P_D	Total power dissipation	$V_O = 0$, No load	25°C		50	85		50	85	mW
			Full range			100			100	

Gain

1000 V/V

Comparator circuits

& $V_I = V_+ - V_-$

Ideal opamp $A \to \infty$

$$V_O = \begin{cases} +V_s & \text{if } V_I > 0 \\ -V_s & \text{if } V_I < 0 \end{cases}$$

$\leftarrow V_+ > V_-$

$\leftarrow V_+ < V_-$

$$V_o \begin{cases} +V_s & \text{if } V_I > 0 \\ -V_s & \text{if } V_I < 0 \end{cases}$$

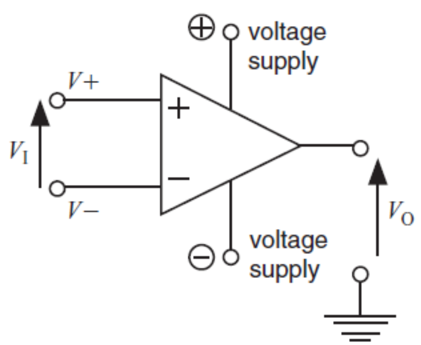


Figure 6.1 The voltages associated with an operational amplifier

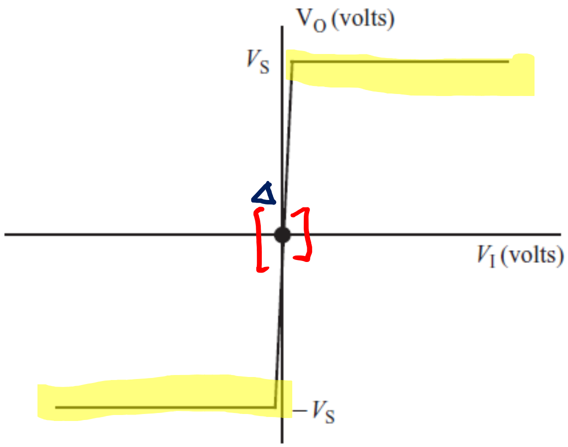
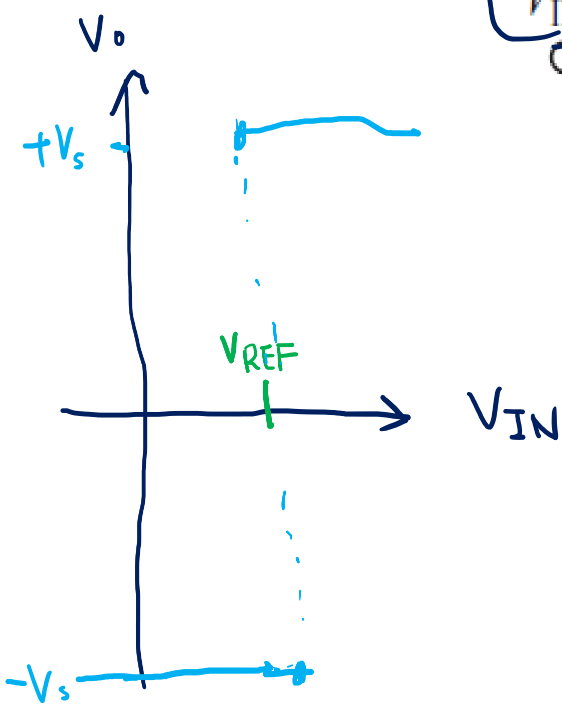
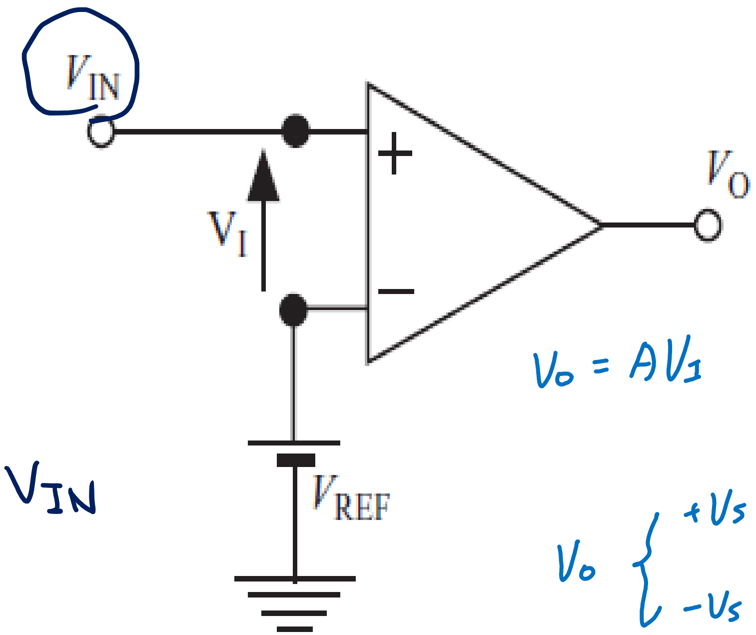


Figure 6.2 The form of the relation between the input V_I and output V_O voltages of an opamp

Comparator

$$V_O = \begin{cases} +V_S & \text{if} \quad V_{IN} > V_{REF} \\ -V_S & \text{if} \quad V_{IN} < V_{REF} \end{cases}$$





$V_O \begin{cases} +V_S \\ -V_S \end{cases}$

$V_O = A V_I$

$V_+ = V_{IN}$

& $V_I = V_+ - V_-$ $\quad V_- = V_{REF}$

$$V_O \begin{cases} +V_S & \text{if } V_I > 0 \quad \therefore V_{IN} > V_{REF} \\ -V_S & \text{if } V_I < 0 \quad \therefore V_{IN} < V_{REF} \end{cases}$$

Figure 6.4 The comparator

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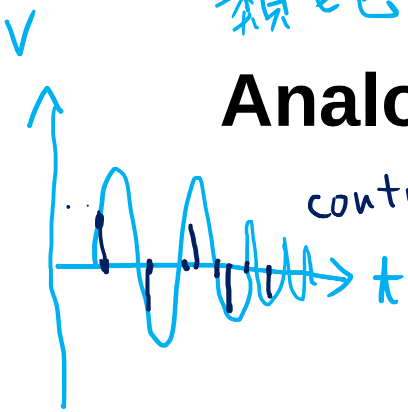
Analog-to-digital (A-D) conversion



continuous discrete

Quantize

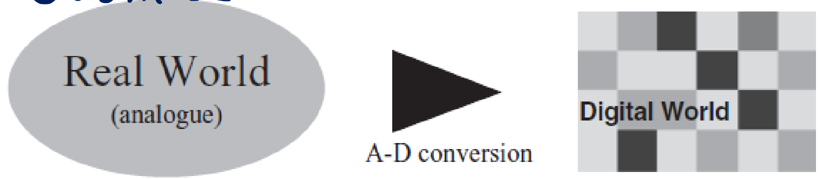
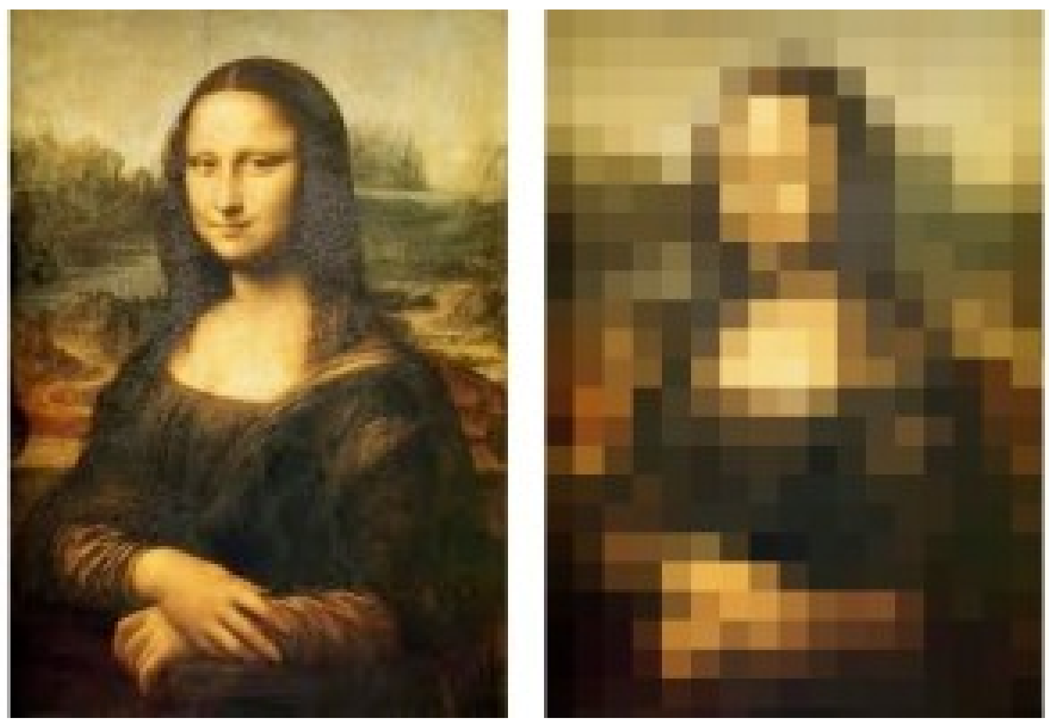
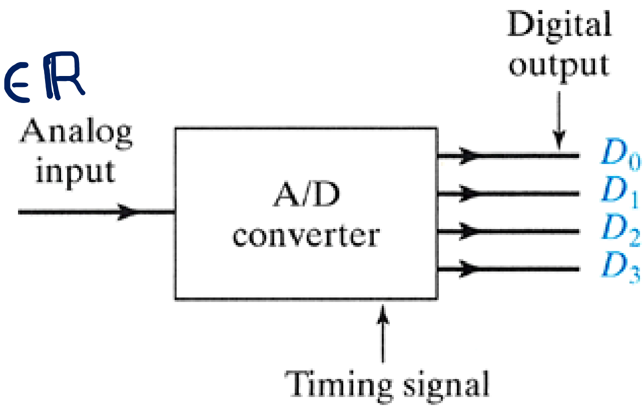


Figure 6.5 It is often convenient for analogue information to be transformed to digital form for easier processing



Analog-to-digital (A-D) conversion

$v(t) \in \mathbb{R}$



0
1
1
0

→ Binary digits

8 Bit → 1 Byte

32 G Bytes

Digital Signal Processing

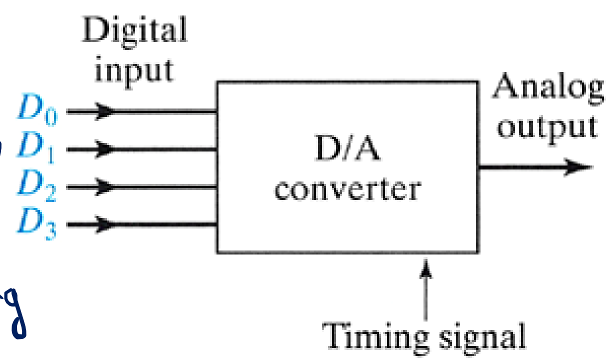
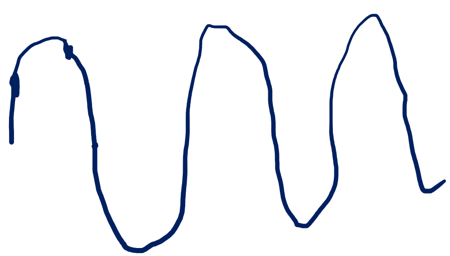


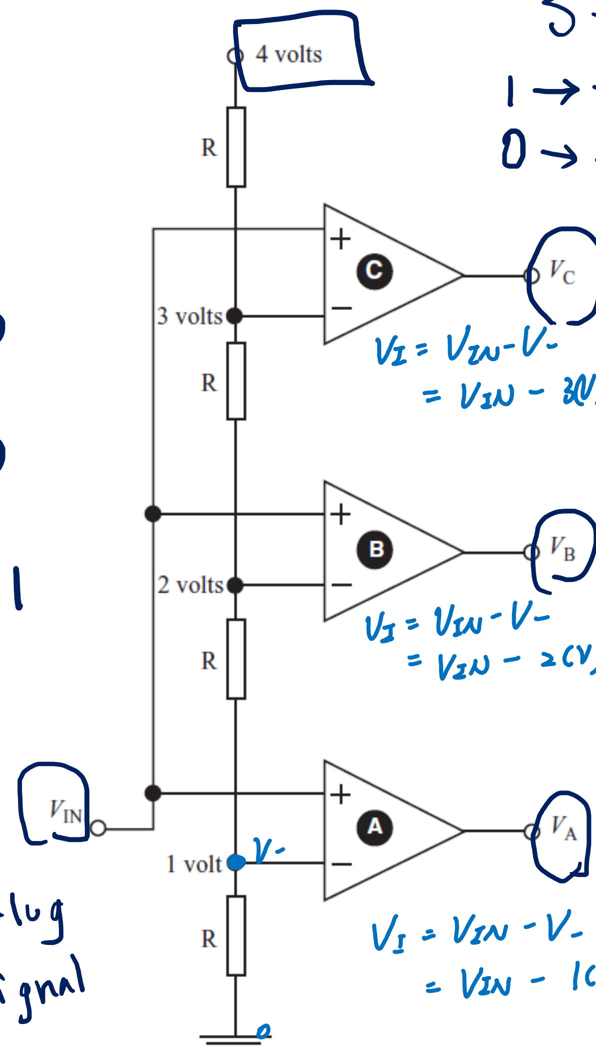
Figure 6.5 It is often convenient for analogue information to be transformed to digital form for easier processing

Analog-to-digital (A-D) conversion

V_{IN}	V_A	V_B	V_C	A	B	C
(0, 1)	$-V_s$	$-V_s$	$-V_s$	0	0	0
(1, 2)	$+V_s$	$-V_s$	$-V_s$	1	0	0
(2, 3)	$+V_s$	$+V_s$	$-V_s$	1	1	0
(3, 4)	$+V_s$	$+V_s$	$+V_s$	1	1	1



Analog Signal



3-bits

$1 \to +V_s$

$0 \to -V_s$

$V_I = V_{IN} - V_-$
$= V_{IN} - 3(V) < 0 \Rightarrow -V_s$
$> 0 \Rightarrow +V_s$

$V_I = V_{IN} - V_-$
$= V_{IN} - 2(V) < 0 \Rightarrow -V_s$
$> 0 \Rightarrow +V_s$

$V_I = V_{IN} - V_-$
$= V_{IN} - 1(V) < 0 \Rightarrow -V_s$
$> 0 \Rightarrow +V_s$

Figure 6.6 A very simple A–D converter based on the use of comparators

Ideal Opamp

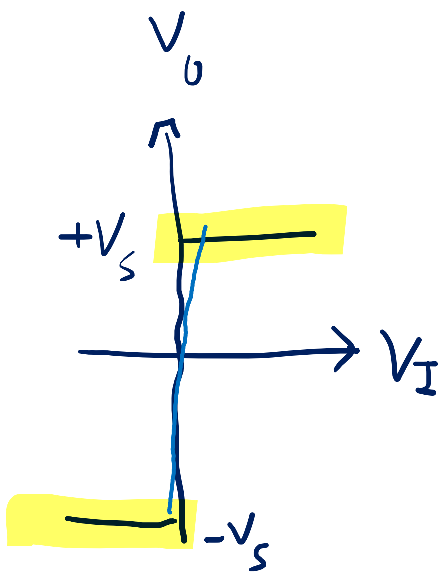
Assumption

Gain $A \to \infty$

Input Current $i_+ = 0$

$i_- = 0$

就視為沒有中間



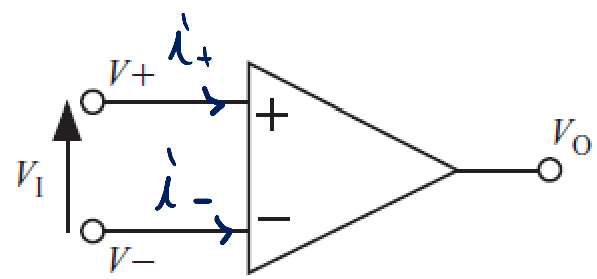
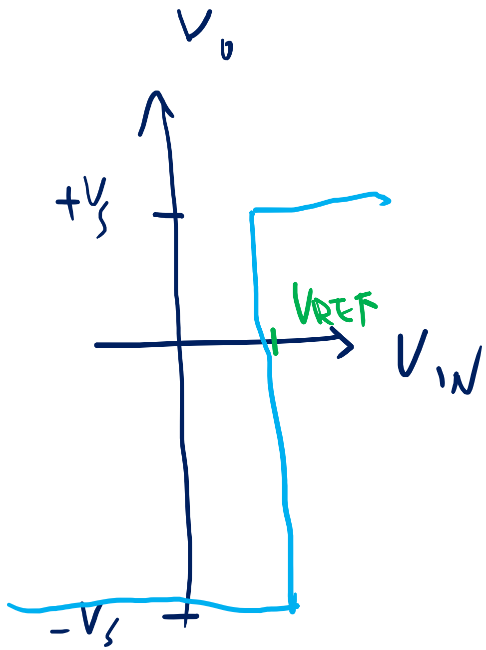
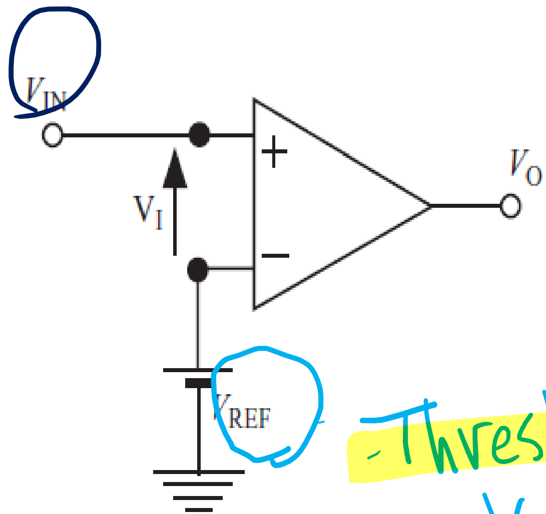


Figure 6.3 The conventional representation of an opamp

Comparator





$= +V_s, \quad V_{IN} > V_{th}$

$-V_s, \quad V_{IN} < V_{th}$

- Threshold

V_{th}

Figure 6.4 The comparator

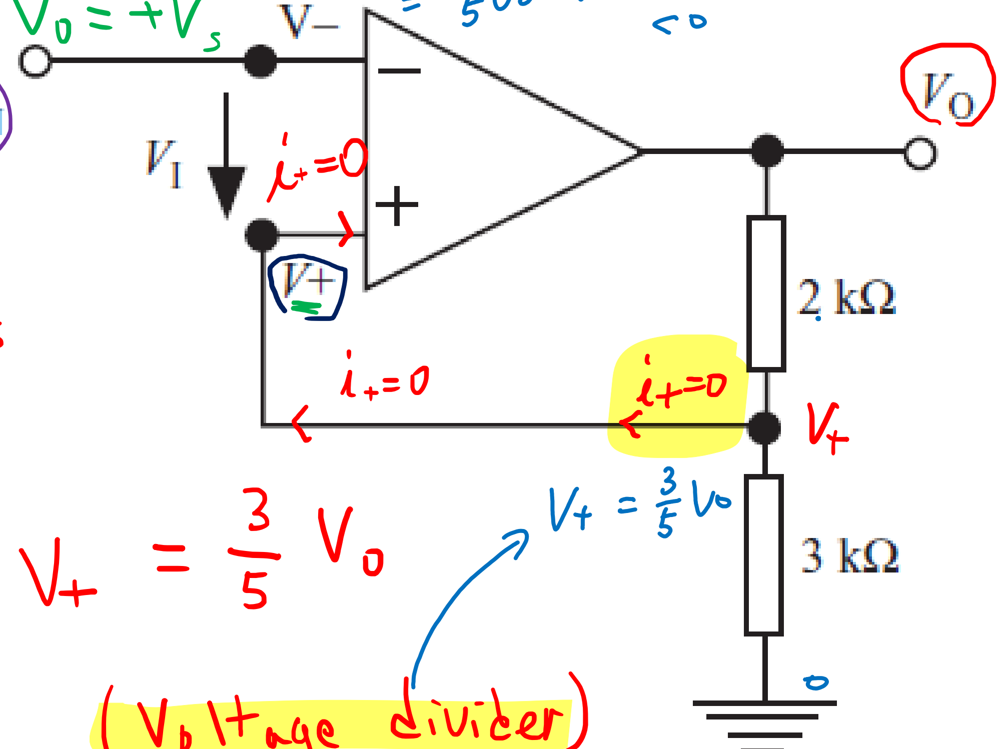
Schmitt trigger

$$V_O \begin{cases} \boxed{+V_S} & \text{if } V_I > 0 \quad \boxed{\tfrac{3}{5}V_o > V_{IN}} \Rightarrow \tfrac{3}{5}V_S > V_{IN} \\ \boxed{-V_S} & \text{if } V_I < 0 \quad \boxed{\tfrac{3}{5}V_o < V_{IN}} \Rightarrow \tfrac{3}{5}(-V_S) < V_{IN} \end{cases}$$

$$V_I = V_+ - V_- = V_+ - V_{IN}$$

$$V_I = V_+ - V_-$$
$$= V_+ - V_{IN}$$
$$= \tfrac{3}{5}V_o - V_{IN} \;\; {>0 \atop <0}$$

$$\left[\begin{array}{l} V_{IN} > V_+ \Rightarrow V_I < 0 \Rightarrow V_0 = -V_S \\ V_{IN} < V_+ \Rightarrow V_I > 0 \Rightarrow V_0 = +V_S \end{array} \right.$$



either

$$V_{IN} < V_+ \rightarrow V_+ = +\tfrac{3}{5}V_s \quad (V_0 = +V_s)$$

or

$$V_{IN} > V_+ \rightarrow V_+ = -\tfrac{3}{5}V_s \quad (V_0 = -V_s)$$

$$V_+ = \frac{3}{5}V_0$$

(Voltage divider)

Figure 6.7 The Schmitt trigger

Schmitt trigger

$$V_o \begin{cases} \boxed{+V_s} & \text{if } V_I > 0 \quad \boxed{\frac{3}{5}V_o > V_{IN}} \Rightarrow \frac{3}{5}V_s > V_{IN} \quad 6V > V_{IN} \\ \boxed{-V_s} & \text{if } V_I < 0 \quad \boxed{\frac{3}{5}V_o < V_{IN}} \Rightarrow \frac{3}{5}(-V_s) < V_{IN} \quad -6V < V_{IN} \end{cases}$$

$$\begin{aligned} V_I &= V_+ - V_- \\ &= V_+ - V_{IN} \\ &= \frac{3}{5}V_o - V_{IN} \begin{matrix} > 0 \\ < 0 \end{matrix} \end{aligned}$$

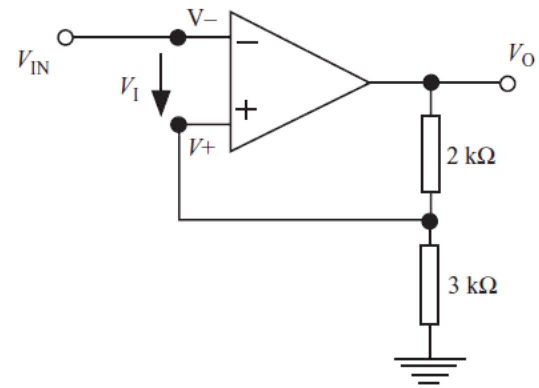


Figure 6.7 The Schmitt trigger

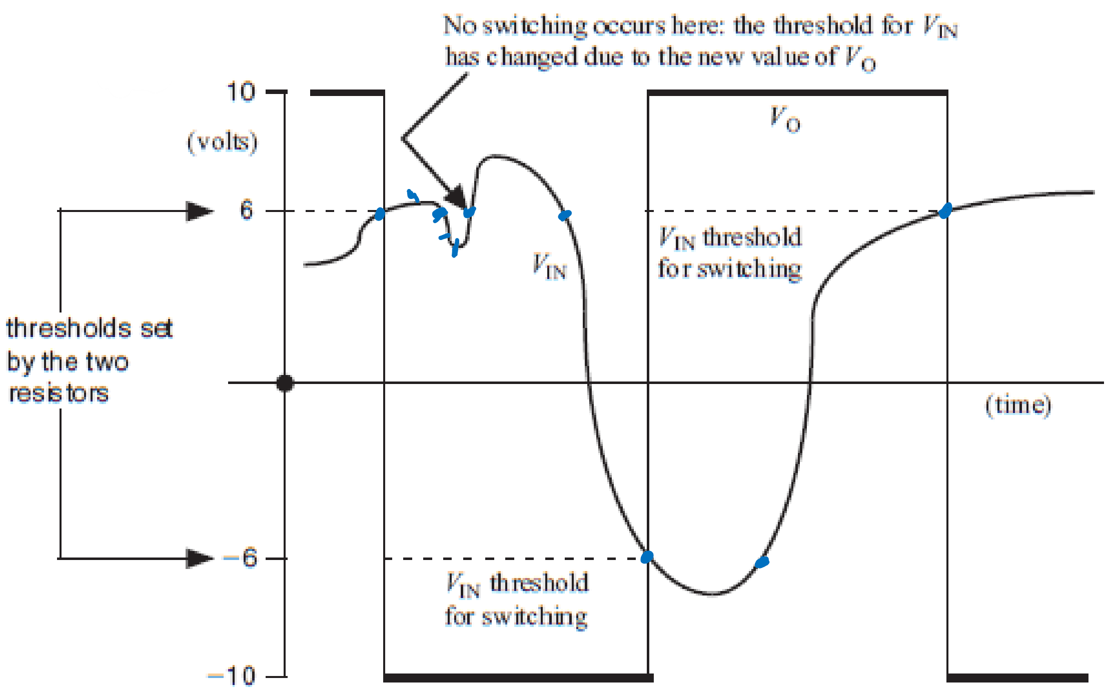
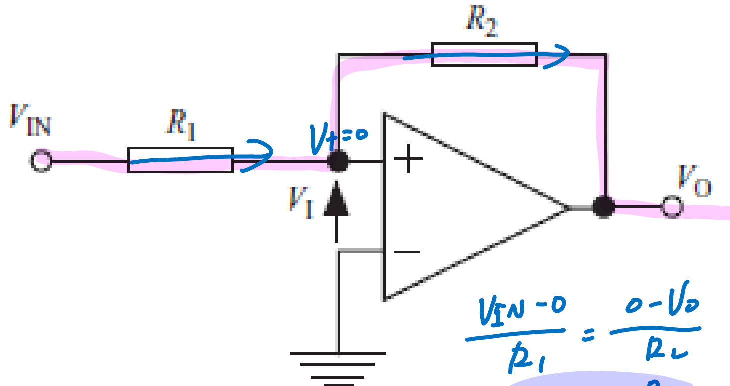


Figure 6.10 The behaviour of the Schmitt trigger for an arbitrary input voltage waveform. Take particular note of the fact that the threshold for V_{IN} changes when the output voltage changes

Another trigger circuit

$V_o \begin{cases} +V_s, & \text{if } V_I > 0 \\ -V_s & \text{if } V_I < 0 \end{cases}$

$V_I = V_+ - \cancel{V_-}^{\,0}$



$$\frac{V_{IN}-0}{R_1} = \frac{0-V_o}{R_2}$$

$$V_{IN} = -\frac{R_1}{R_2} V_o$$

Figure 6.11 Another trigger circuit whose output state can be controlled by an input voltage

If $V_o = -10V$

threshold $V_{IN} = +10\frac{R_1}{R_2}$

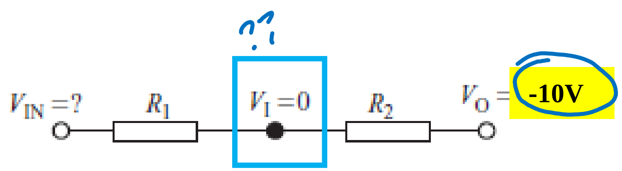


Figure 6.12 Circuit relevant to the calculation of the value of V_{IN} needed to cause the output voltage of the circuit of Figure 6.11 to change from +10 to −10 V

LAB 1. Schmitt trigger simulation

1. Build a Schmitt trigger on the simulator online.
2. For the opamp, set 'Max Output' to 10 and 'Min Output' to -10.
3. Add an 'AC Voltage Source (1-terminal)' as V_{IN}, and set Waveform as 'Triangle'.
4. Add an 'Analog Output' as V_{O}.
5. Change R_1, R_2, and Max Voltage V_{IN} according to your student ID (details in the next slide).
6. Show input and output waveforms.
7. Save the work by 'Export as Text', and submit the text file to 'Moodle'.

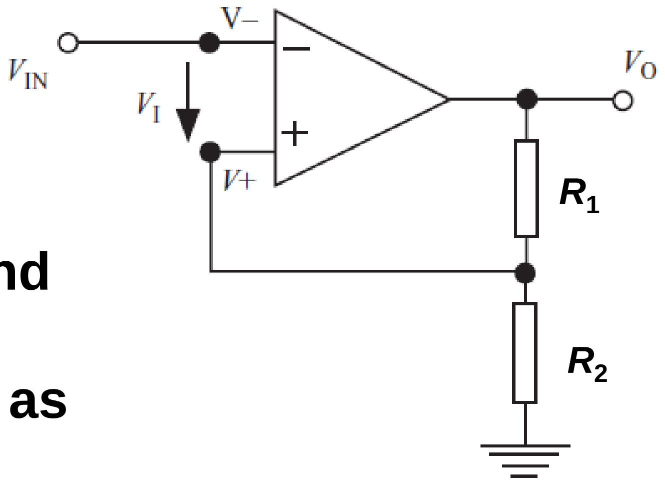


Figure 6.7 The Schmitt trigger

Simulator Link 1

Simulator Link 2

LAB 1. Schmitt trigger simulation (cont.)

Setting of parameters:

Suppose your student ID is

E(NN) 0 (BBB) (CC)

For AC Voltage Source V_{IN}

- **If NN=14, set Max Voltage=7.5**
- **If NN=34, set Max Voltage=8**
- **If NN=44, set Max Voltage=8.5**
- **If NN=54, set Max Voltage=9**
- **If NN=64, set Max Voltage=9.5**
- **If NN=84, set Max Voltage=10**

Set resistors

R1= B.BB K

R2= 2.CC K

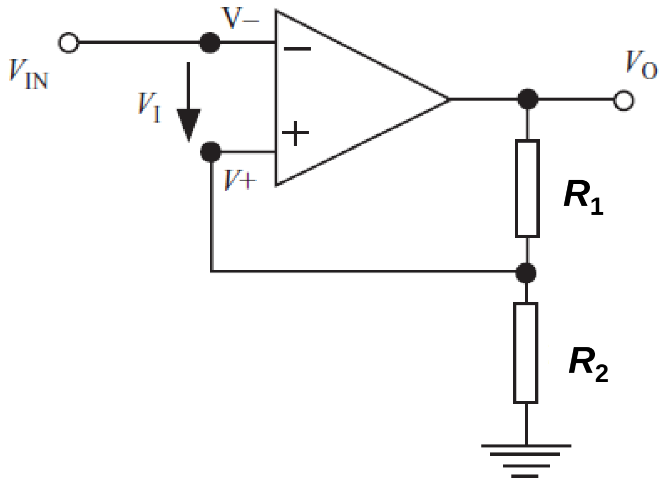


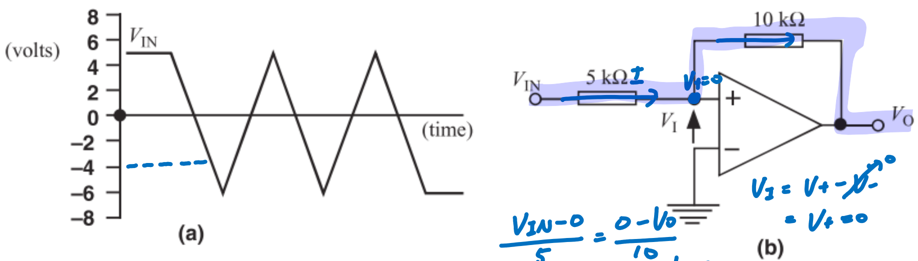
Figure 6.7 The Schmitt trigger

Example: ID E34048154
NN=34, Max Voltage=8
R1=4.81 K
R2=2.54 K

Example 6.2

A voltage V_{IN} having the triangular waveform (but with nonzero average value) shown in Figure 6.13(a) is applied to the input of the circuit shown in Figure 6.13(b). Find the resulting waveform of the voltage V_O. The output voltage V_O of the opamp limits at ±8 V.

$$V_o \begin{cases} +V_s\ (+8V) & \text{If } V_I > 0 \\ -V_s\ (-8V) & \text{If } V_I < 0 \end{cases}$$



$V_I = V_+ - \cancel{V_-}^{\,0} = V_+ = 0$

$\dfrac{V_{IN} - 0}{5} = \dfrac{0 - V_o}{10}$

$\therefore V_{IN} = -\frac{1}{2} V_s$

Figure 6.13 The waveform (a) of the input applied to the trigger circuit (b)

$V_s = +8V \Rightarrow V_{IN} = -4(V)$

$V_s = -8V \Rightarrow V_{IN} = 4(V)$

The subcircuit shown in Figure 6.14 controls the threshold values of V_{IN}. With V_O at 8 v it is easily seen that for V_I to be zero the value of V_{IN} must be −4 V. Similarly, when V_O is at −8 V, V_{IN} would have to rise above +4 V in order to make V_I, and hence V_O, positive. The resulting waveform of V_O is shown in Figure 6.15, with the threshold values of V_{IN} shown as dashed lines.

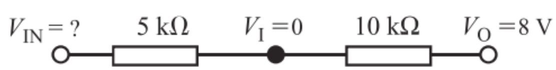
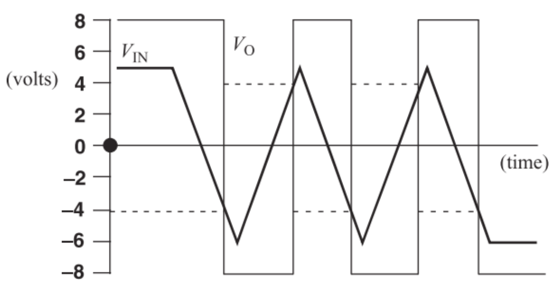


Figure 6.14 Model allowing calculation of the threshold voltages for the circuit of Figure 6.13(a)



$V_o = +8V \Rightarrow V_{IN} = -4V$

$V_o = -8V \Rightarrow V_{IN} = 4V$

Figure 6.15 The waveform of the output voltage of the trigger circuit of Figure 6.13(a)