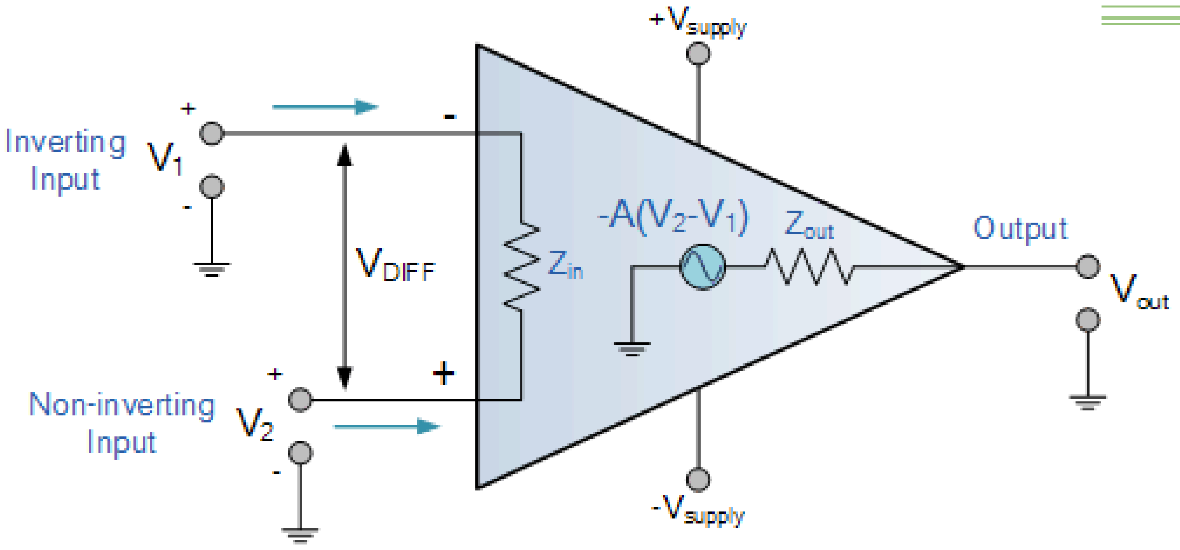
CO2015

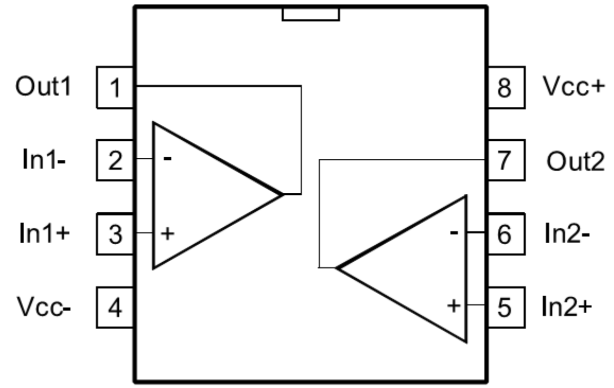
Operational Amplifier (Op-Amp)

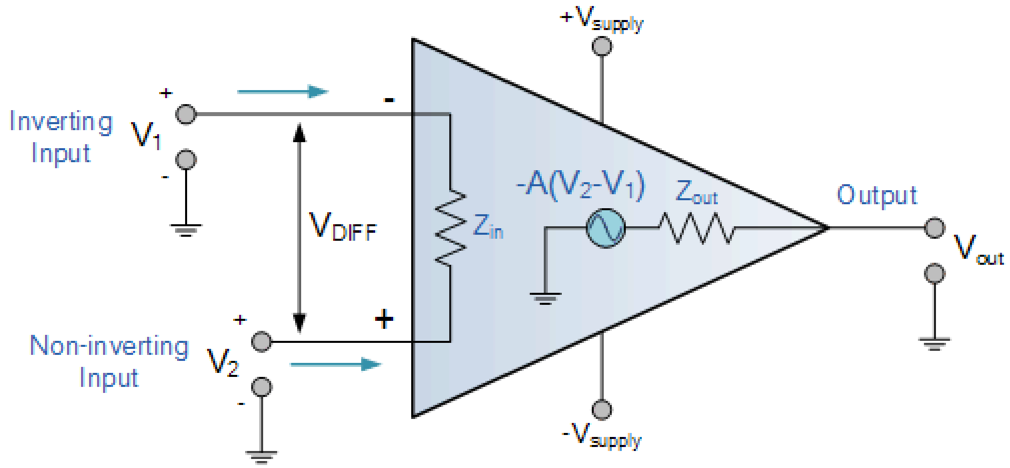


DCE
Dept. of Computer Engineering

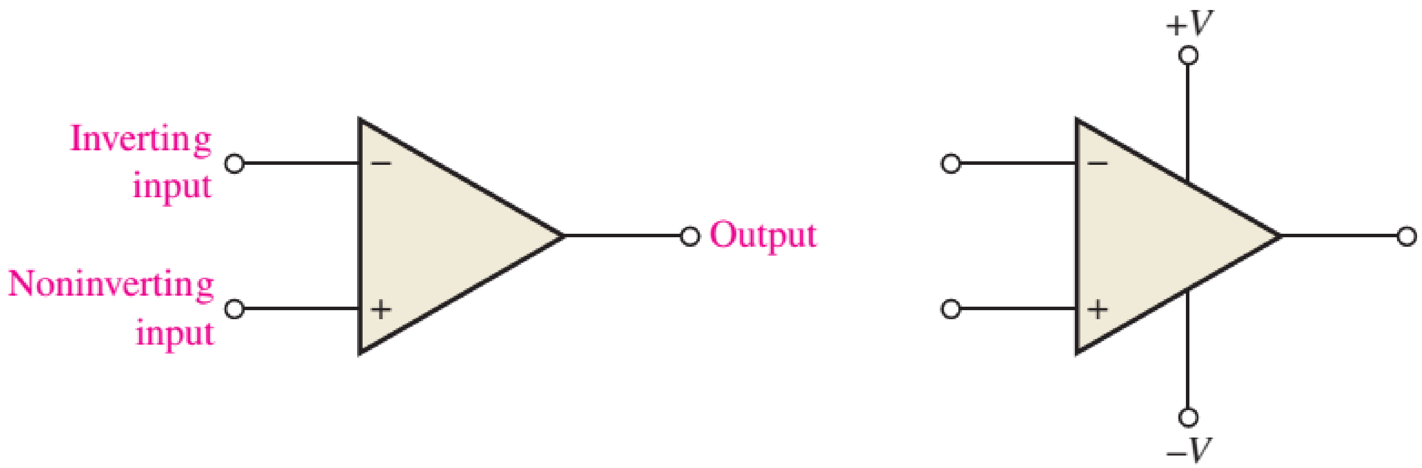
Contents

- Operation
- Feedback Circuit
- Characteristics
- Practical Applications





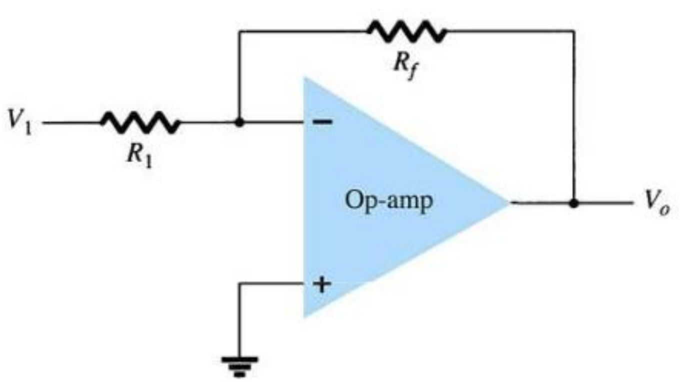
Basic Op-Amp



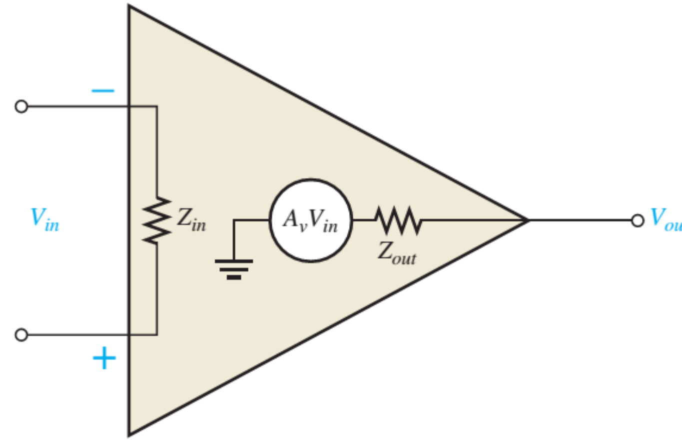
- Op-Amp = **Op**erational **Amp**lifier
- An Op-Amp consist
  - Inverting input
  - Noninverting input
  - Output
- *Two power supply pins* (V+ and V-)

Op-Amp Gain

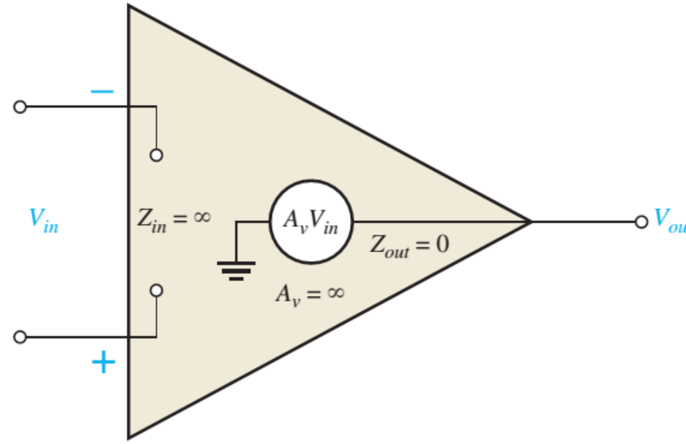
- Op-Amps have a very high gain. They can be connected open-loop or close-loop.
  - Open-loop refers a configuration where there is no feedback from output back to the input. In the open-loop configuration, the gain can exceed 10^5.
  - Closed-loop configuration reduces the gain. In order to control the gain of an op-amp it must have feedback. This feedback is a negative feedback. A negative feedback reduces the gain and improves many characteristics of the op-amp.



Op-Amp Models



- **Practical Model**
  - Z_{in} is very large
  - Z_{out} is small
  - The gain $A_v = \frac{V_{out}}{V_{in}}$ in **open-loop** configuration is very high.

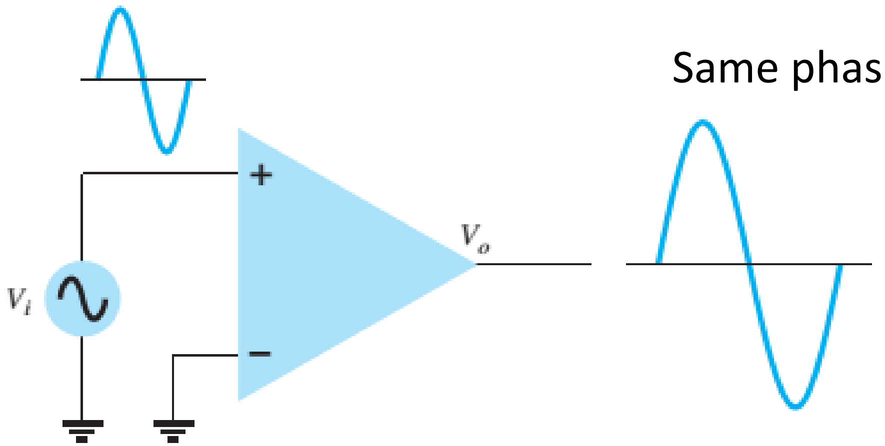


- **Ideal Model** (used for analysis)
  - $Z_{in} = \infty \rightarrow I_{in+} = I_{in-} = 0; V_{in+} = V_{in}$
  - $Z_{out} = 0$
  - The **open-loop gain:** $A_v = \frac{V_{out}}{V_{in}} = \infty$

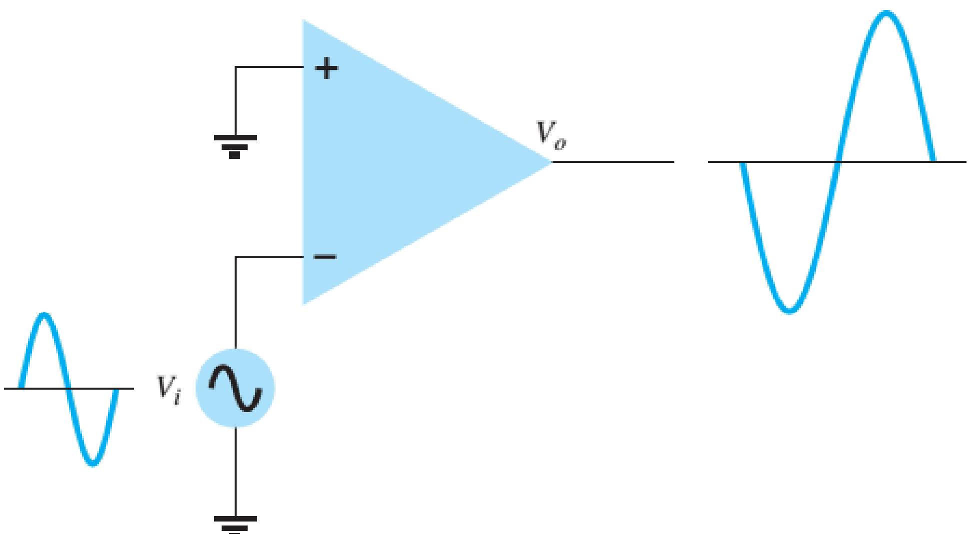
Operation of Op-Amp

- The amplitude of V_{out} is higer than amplitude of V_{in}.

Same phase

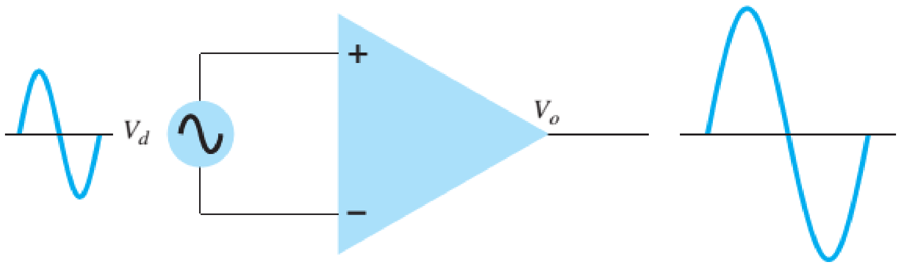


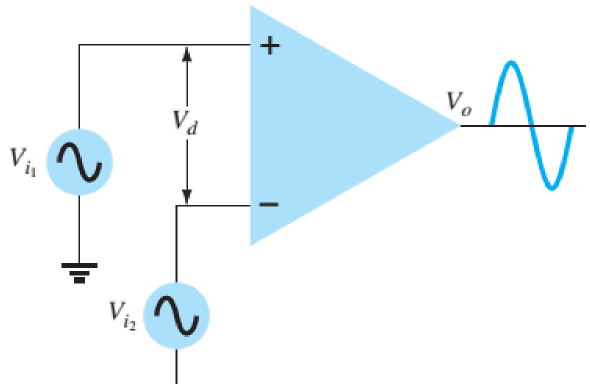
Inversed phase



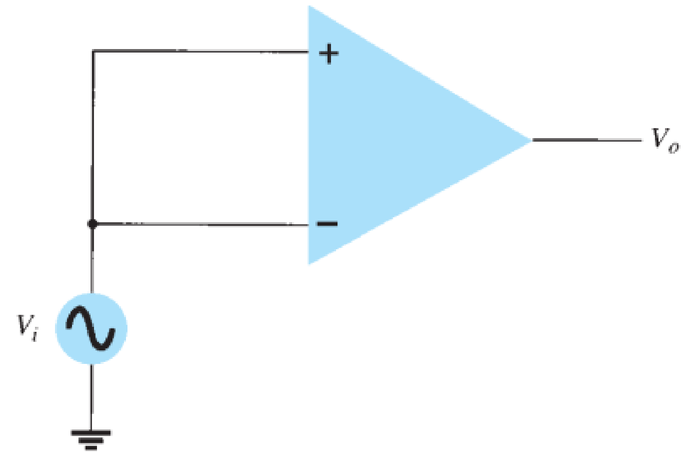
Operation of Op-Amp (cont)

- The <u>differential signal</u> of 2 inputs is amplified.





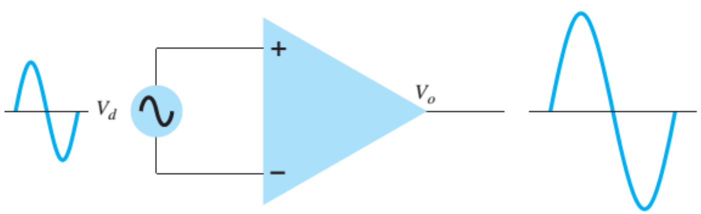
- When 2 inputs use common signal, the output is zero.

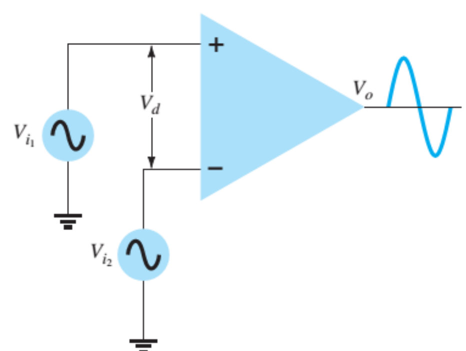


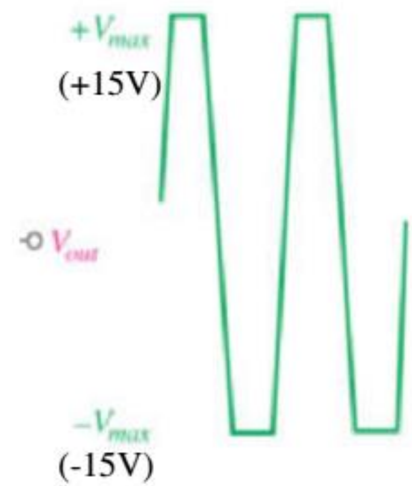
Non Feedback Circuits (Open Loop)

- For the circuits without feedback (i.e. no connection between output and input), the open-loop gain is very large ($>10^5$).

- The output voltage will easily reach the **saturation** and the amplitude will be trimmed.

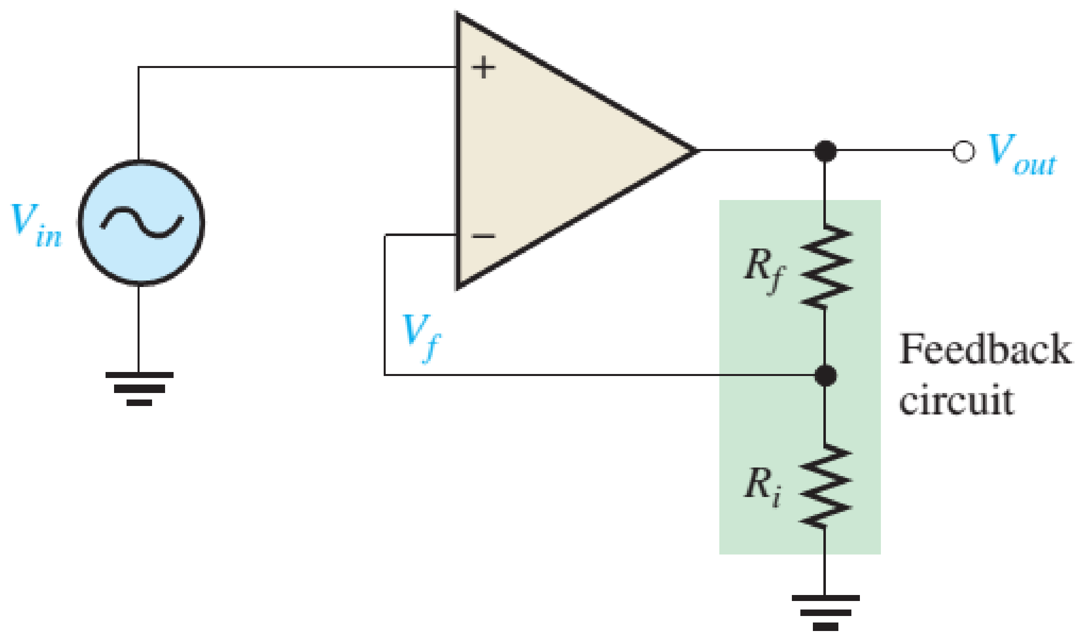




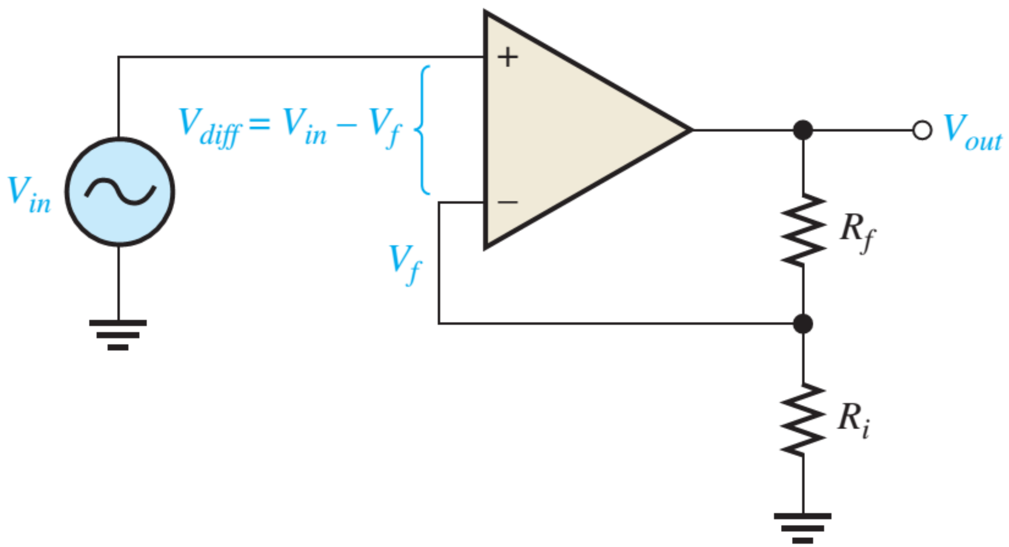


Negative Feedback Circuits (Close Loop)

- In order to control the gain of an op-amp it must have feedback. This feedback is a **negative feedback**. A **negative feedback** reduces the gain and improves many characteristics of the op-amp.



Negative Feedback



$$V_f = \left(\frac{R_i}{R_i + R_f}\right)V_{out} \quad B = \frac{R_i}{R_i + R_f}$$

$$V_{out} = A_{ol}(V_{in} - V_f)$$

$$V_{out} = A_{ol}(V_{in} - BV_{out})$$

$$V_{out} + A_{ol}BV_{out} = A_{ol}V_{in}$$

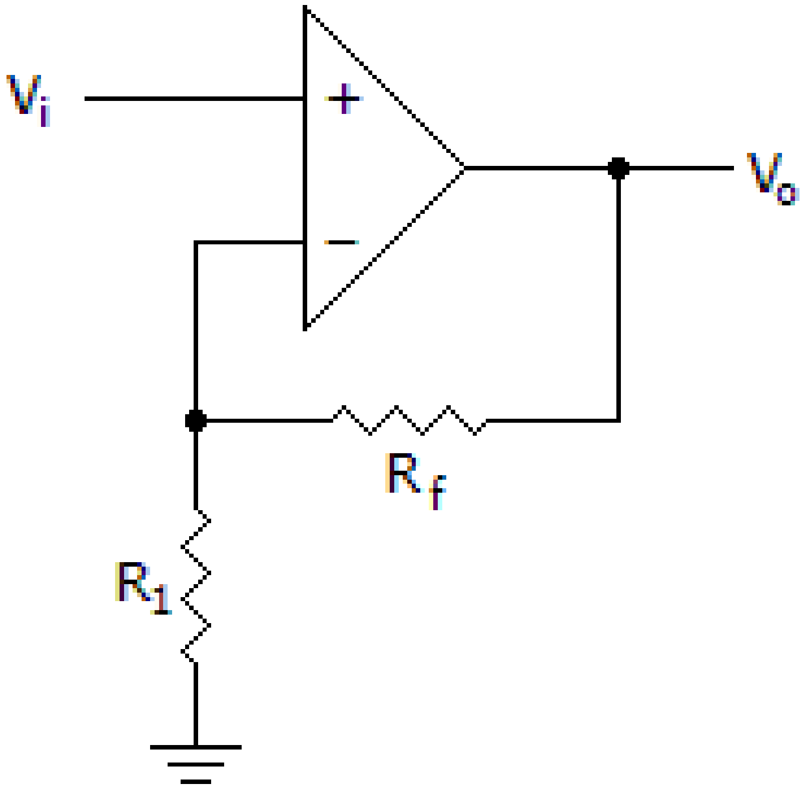
$$\boxed{\frac{V_{out}}{V_{in}} = \frac{A_{ol}}{1 + A_{ol}B}}$$

$$A_{cl(NI)} = \frac{V_{out}}{V_{in}} \cong \frac{1}{B} = \frac{R_i + R_f}{R_i}$$

$$\boxed{A_{cl(NI)} = 1 + \frac{R_f}{R_i}}$$

Exercise

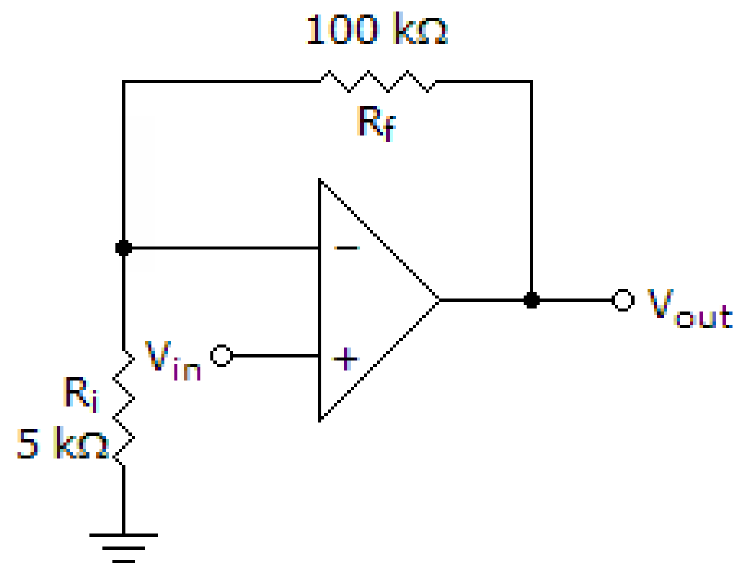
- Calculate the output gain of the circuit if R1 = 100(Ohm) and Rf = 1(KOhm)



Answer

- 11

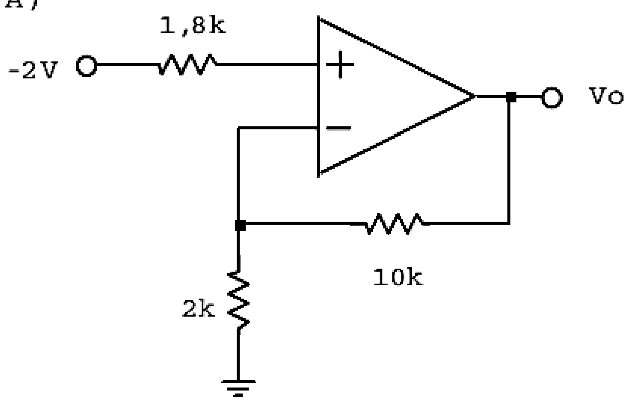
- Refer to the given figure. A dc input signal of –50 mV is applied. You would measure _________ from the inverting input to ground.
  - 50mV
  - 1.05V
  - -1.05V
  - -50mV



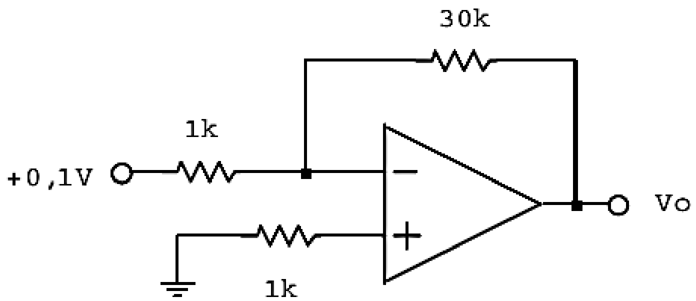
Exercise

- Compute the output voltage in the following circuits using **ideal op-amp**

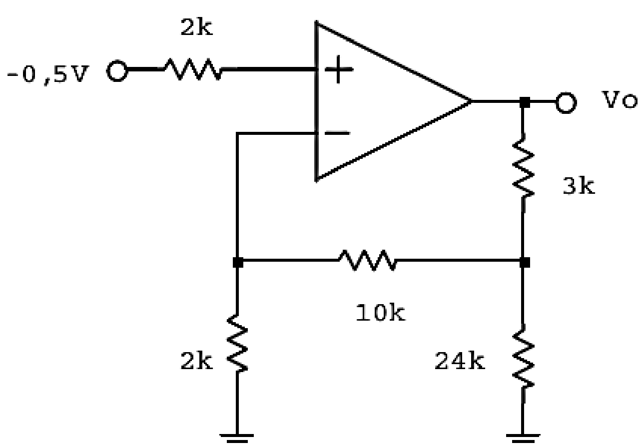
A)



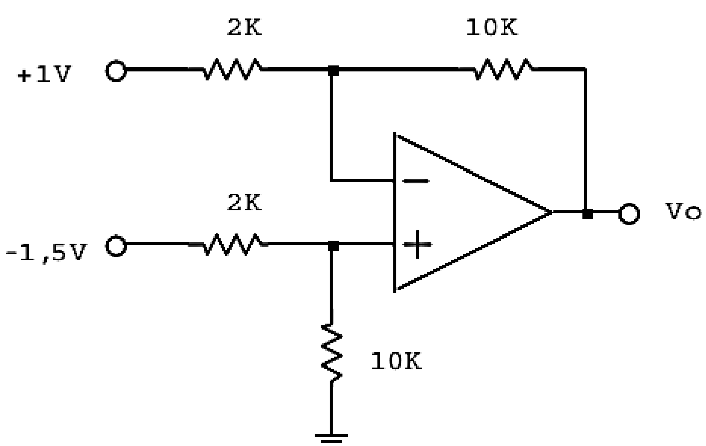
B)



C)

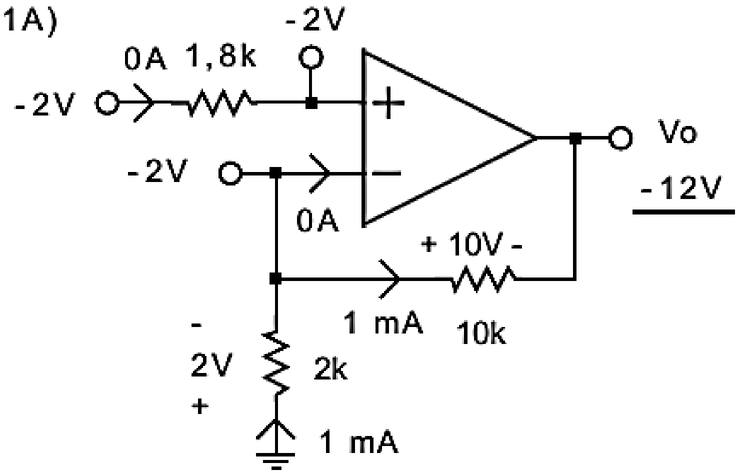


D)

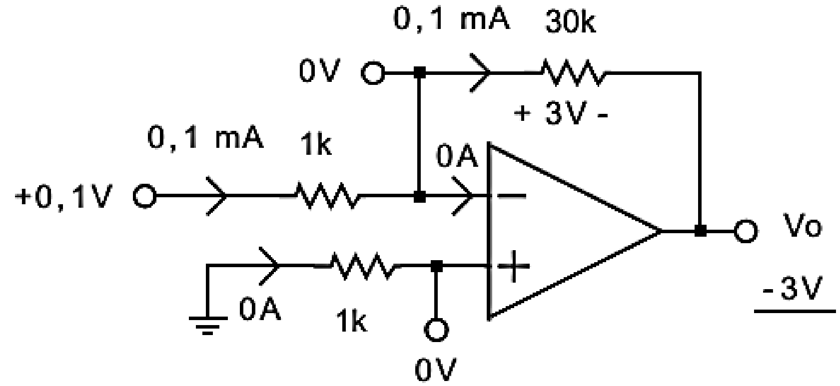


Solution

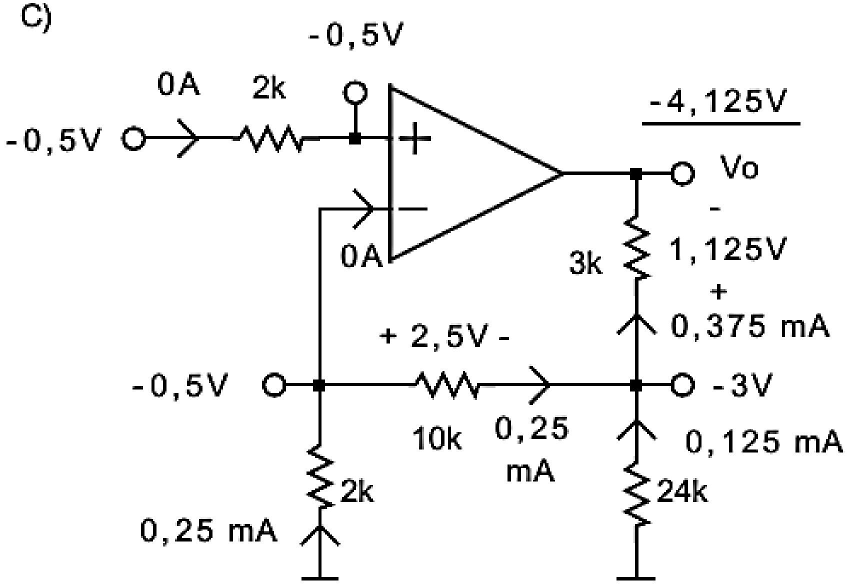
No.1A)



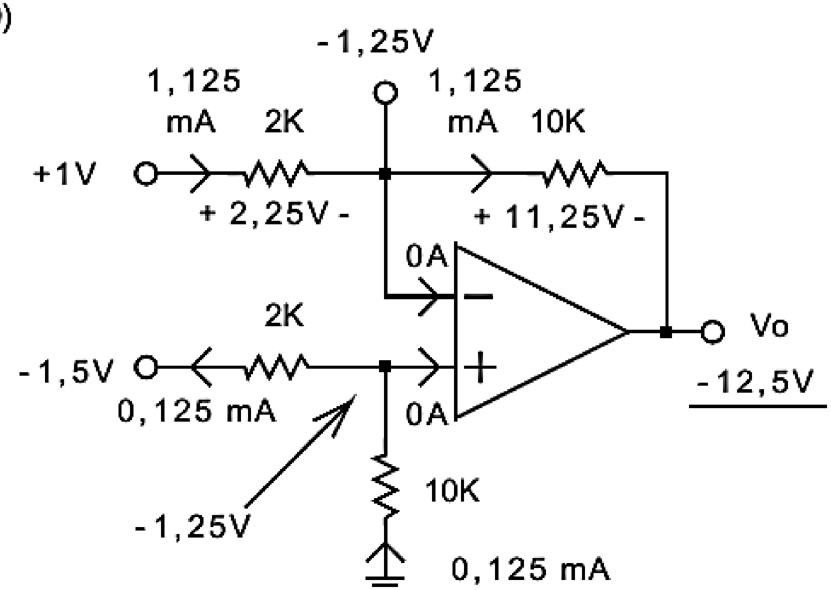
B)



C)



D)

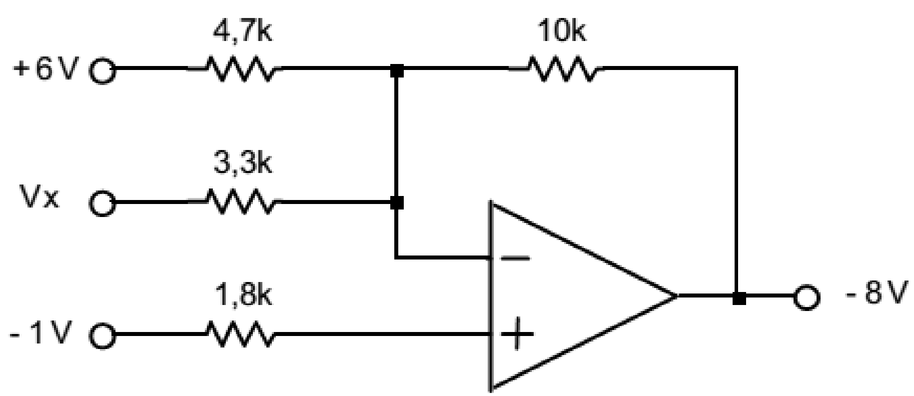


Exercise

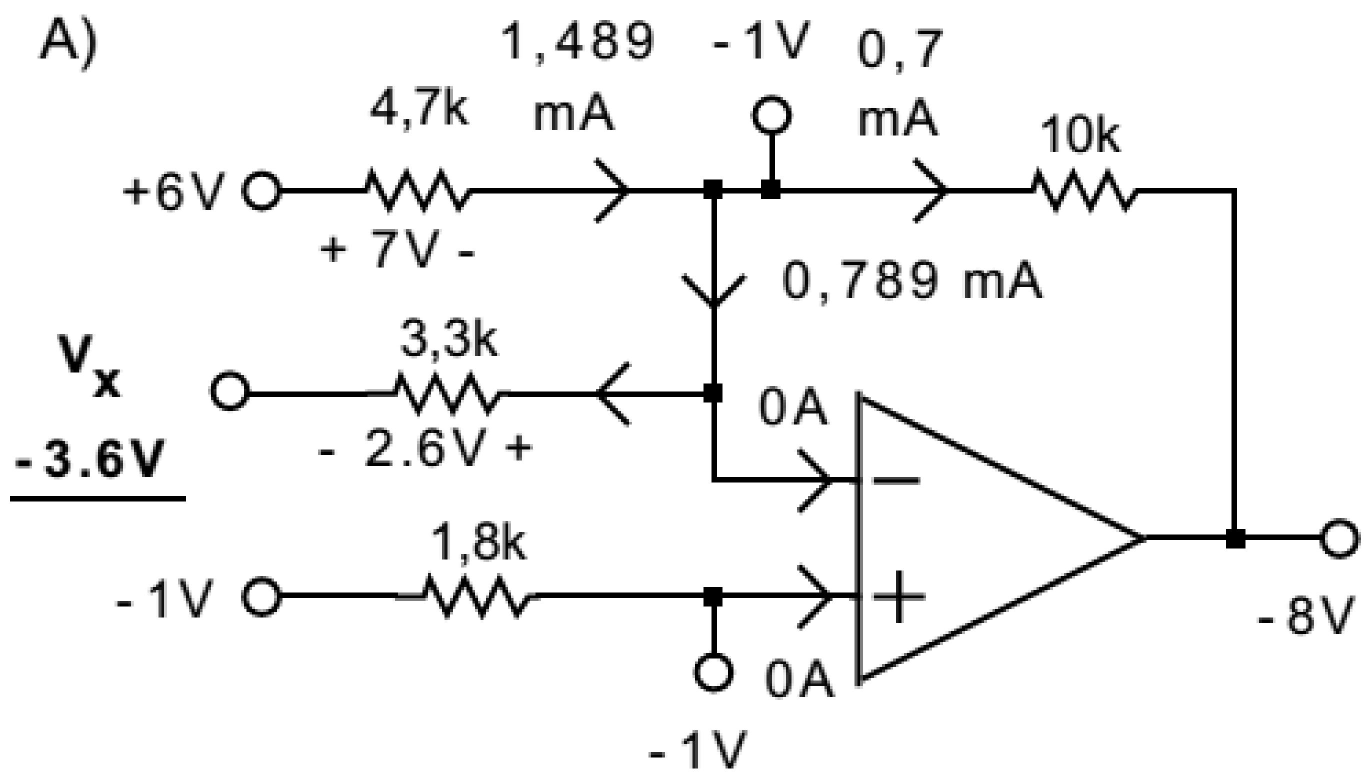
- Characteristics of an Op-Amp is given in the following table. The power supply is ±15V.

Parameter	Minimum	Typical	Maximum
Output Voltage	±12V	±13.5V	
Input Voltage	±11V	±12.5V	
Output current of shorted-circuit	±12mA	±20mA	

- Determine V_X

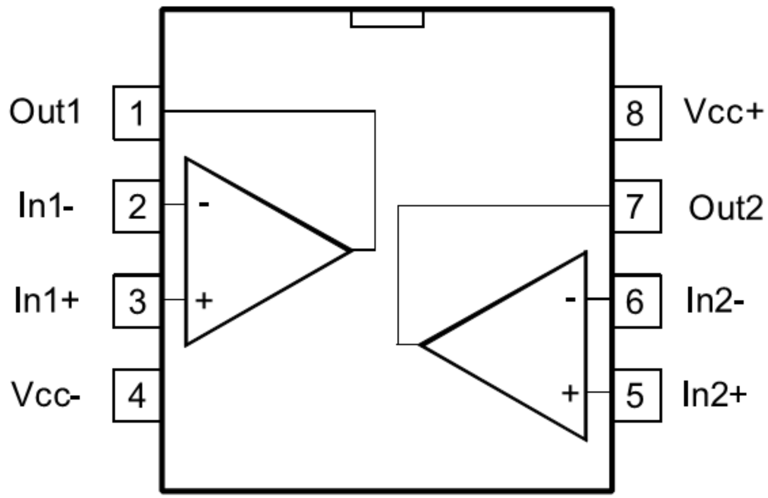


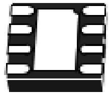
Solution


A)
1,489 mA
-1V
0,7 mA
4,7k
10k
+6V
+ 7V -
0,789 mA
3,3k
V_x
-3.6V
- 2.6V +
0A
1,8k
-1V
0A
-1V
-8V

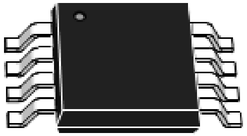
Op-Amp Datasheet

- IC LM358



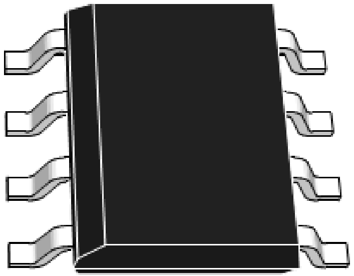


DFN8 2x2



MiniSO8

TSSOP8



SO8

Op-Amp Datasheet (IC LM358)

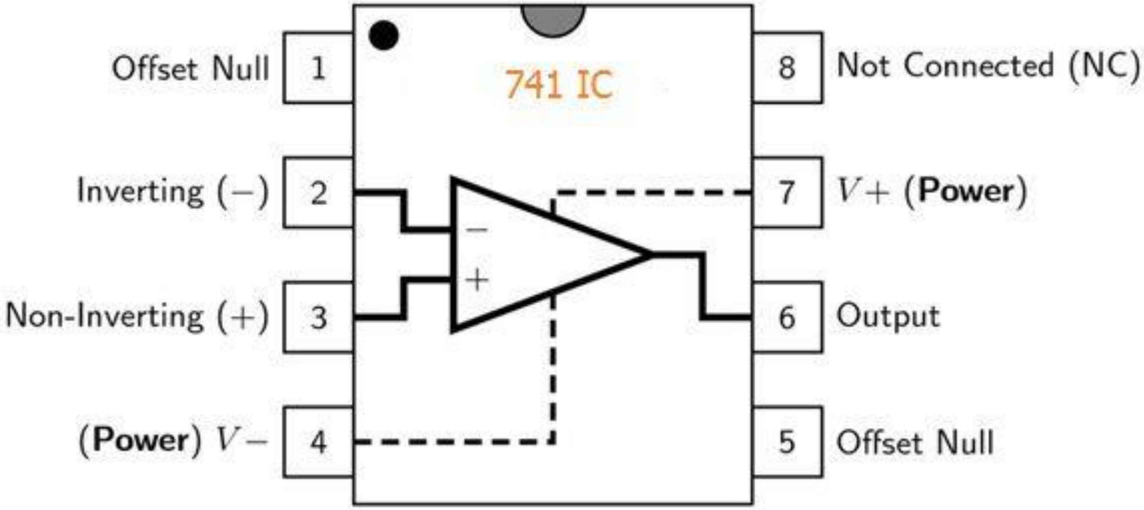
- Maximum power supply: ±22V
- Maximum input voltage: ±15V
- Maximum differential input voltage: ±30V

Absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

	uA741	UNIT
Supply voltage V_{CC+}	22	V
Supply voltage V_{CC-}	−22	V
Differential input voltage	± 30	V
Input voltage any input	± 15	V
Voltage between either offset null terminal (N1/N2) and V_{CC-}	± 0.5	V
Duration of output short-circuit	unlimited	
Continuous total power dissipation at (or below) 25°C free-air temperature	500	mW
Operating free-air temperature range	−40 to 85	°C
Storage temperature range	− 65 to 150	°C
Lead temperature 1,6 mm (1/16 in.) from case for 60 seconds	300	°C
Lead temperature 1,6 mm (1/16 in.) from case for 10 seconds	260	°C

Op-Amp Datasheet

- IC 741



741 Op-Amp IC

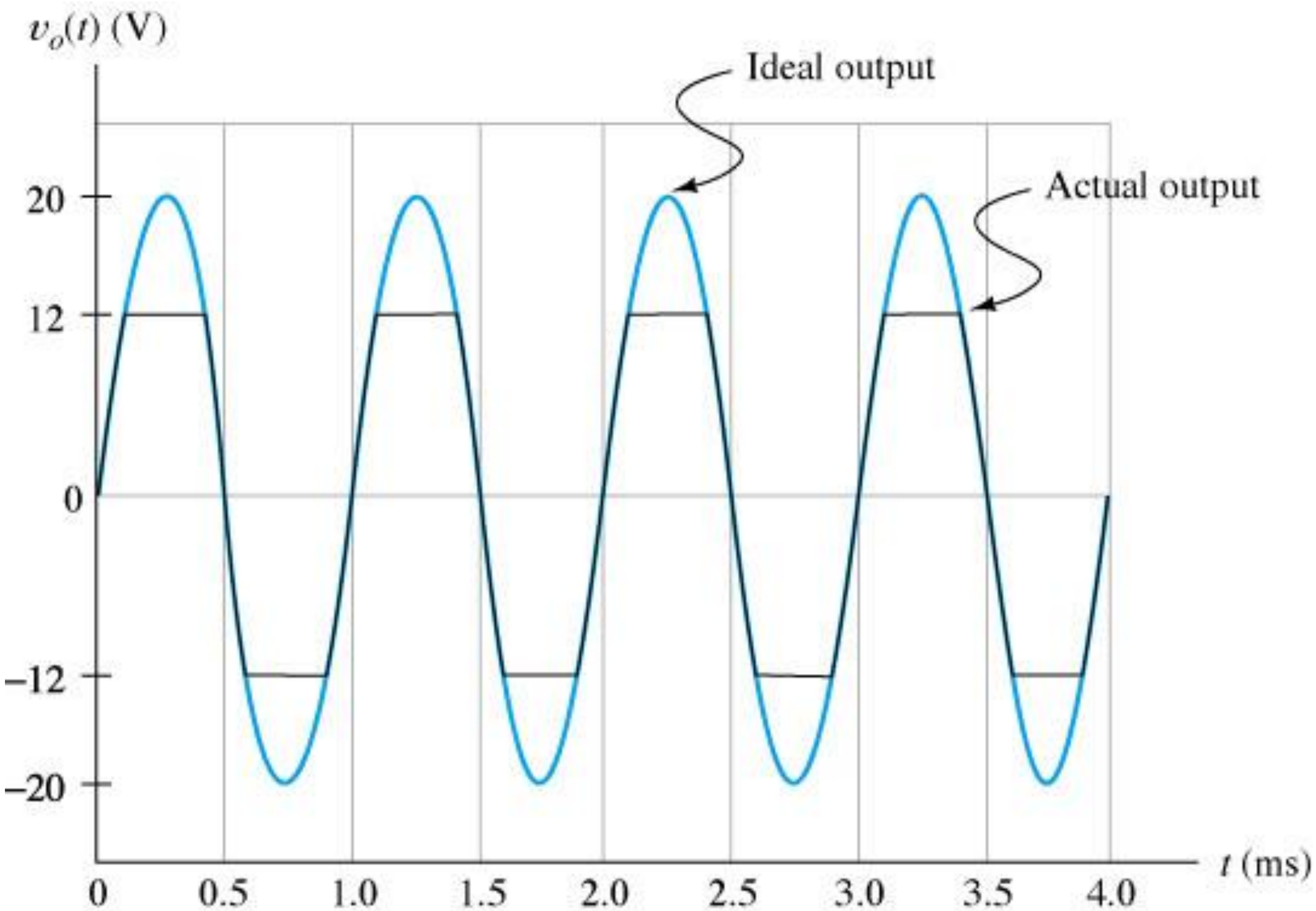
Op-Amp Datasheet (µA741)

µA741 Electrical Characteristics: $V_{CC} = \pm 15$ V, $T_A = 25°C$

Characteristic	Minimum	Typical	Maximum	Unit
V_{IO} Input offset voltage		1	6	mV
I_{IO} Input offset current		20	200	nA
I_{IB} Input bias current		80	500	nA
V_{ICR} Common-mode input voltage range	±12	±13		V
V_{OM} Maximum peak output voltage swing	±12	±14		V
A_{VD} Large-signal differential voltage amplification	20	200		V/mV
r_i Input resistance	0.3	2		MΩ
r_o Output resistance		75		Ω
C_i Input capacitance		1.4		pF
CMRR Common-mode rejection ratio	70	90		dB
I_{CC} Supply current		1.7	2.8	mA
P_D Total power dissipation		50	85	mW

- A_{VD} – Large-signal differential voltage amplification
  - 200V/mV = 200.000
- r_i – input resistance: 2MΩ
- r_o – output resistance: 75Ω

Output Voltage Threshold



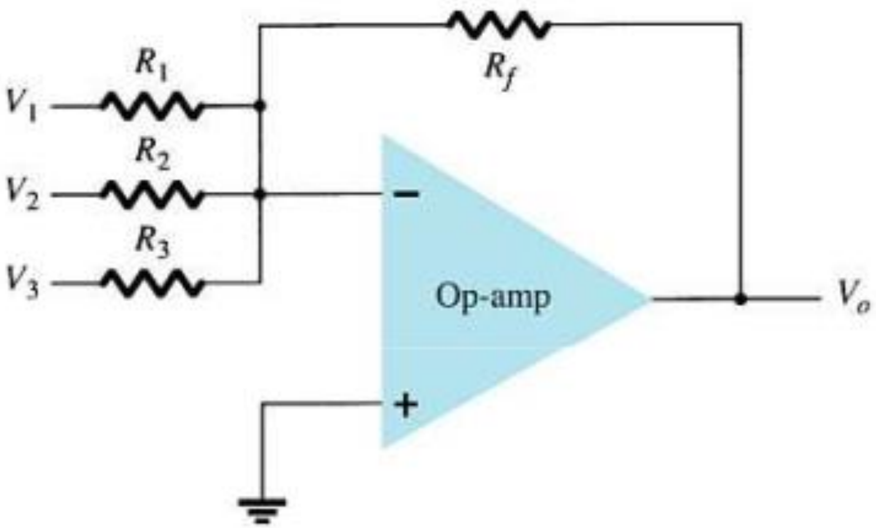
Practical Op-Amp Circuits

- Unity Follower
- Summing Amplifier
- Integrator
- Differentiator
- Comparator

Summing Amplifier

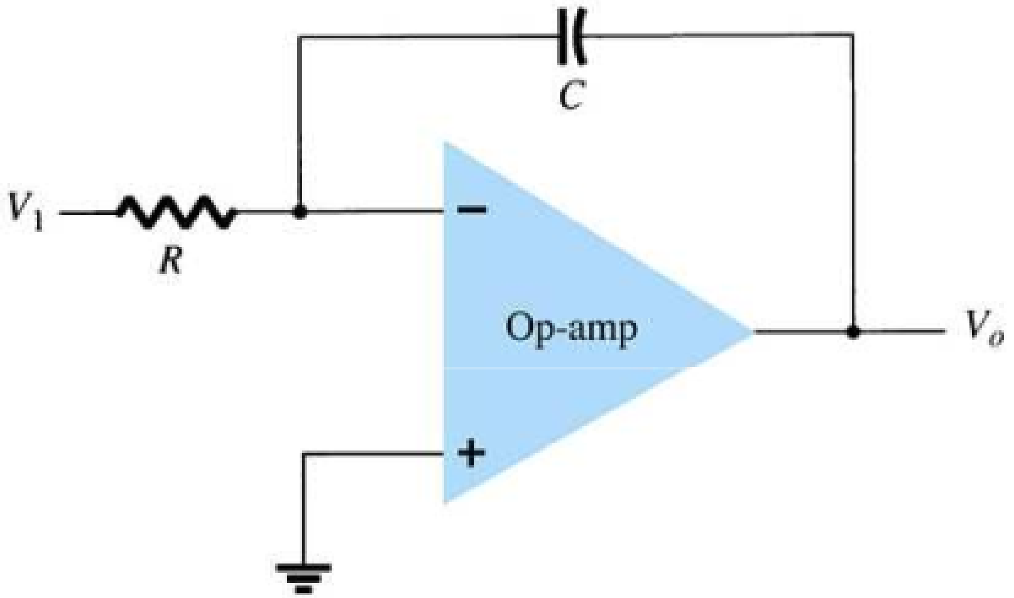
Because the op-amp has a high input impedance, the multiple inputs are treated as separate inputs.

$$V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$



Integrator

The output is the integral of the input. Integration is the operation of summing the area under a waveform or curve over a period of time. This circuit is useful in low-pass filter circuits and sensor conditioning circuits.

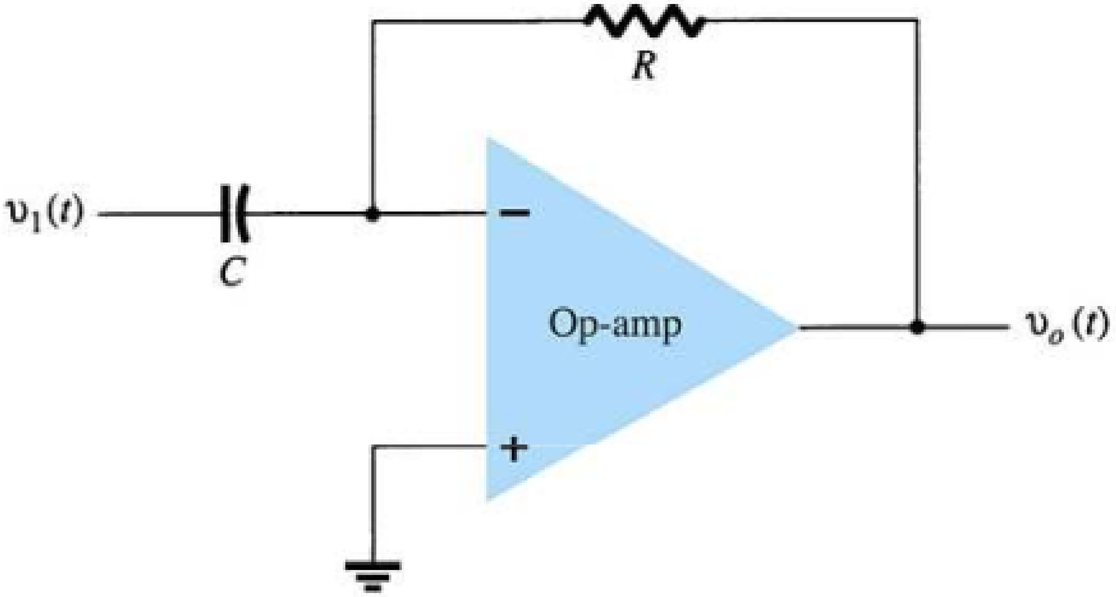


$$v_o(t) = -\frac{1}{RC}\int v_1(t)dt$$

Differentiator

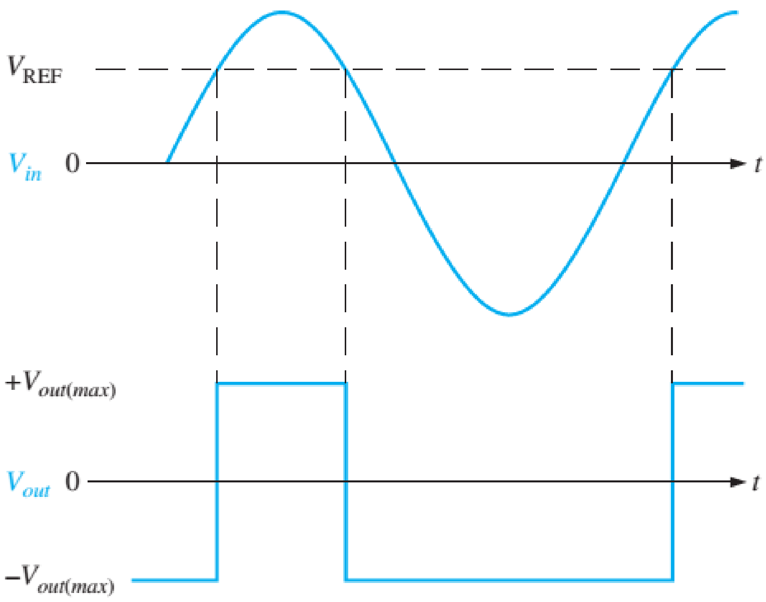
The differentiator takes the derivative of the input. This circuit is useful in high-pass filter circuits.

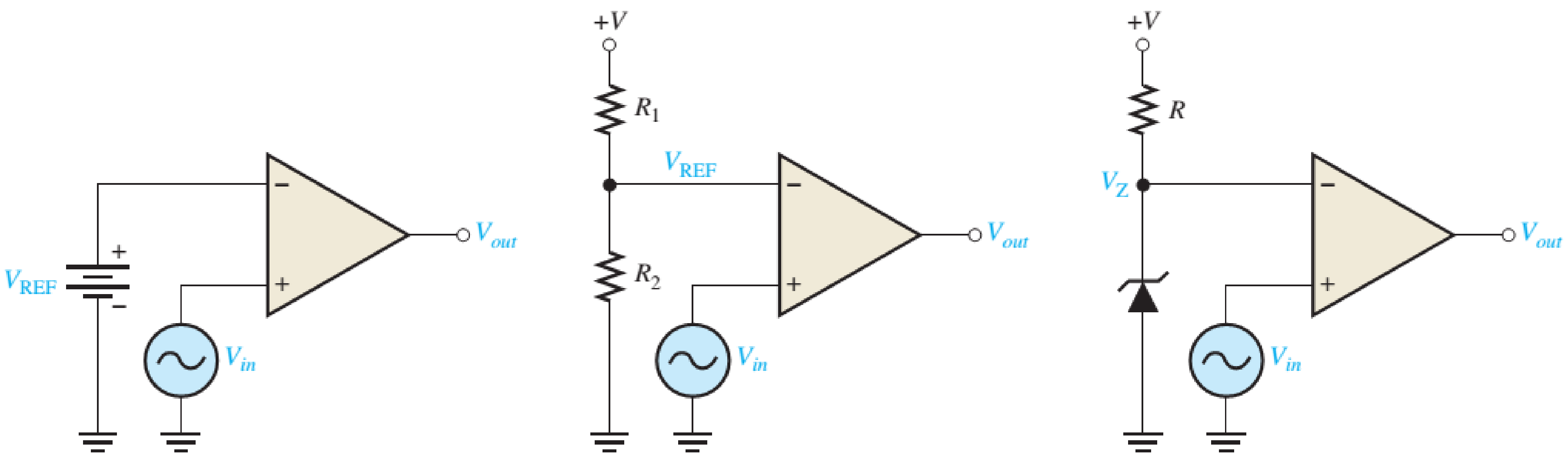
$$v_o(t) = -RC\frac{dv_1(t)}{dt}$$



Comparator

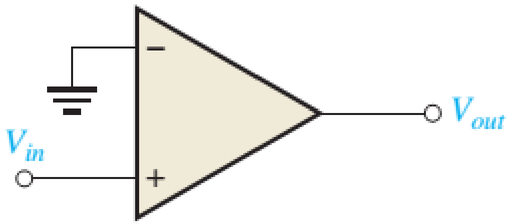
- $V_{out} = +V_{out(max)}$ when V+ > V-
  - $V_{in} > V_{REF}$
- $V_{out} = -V_{out(max)}$ when V+ < V-
  - $V_{in} < V_{REF}$

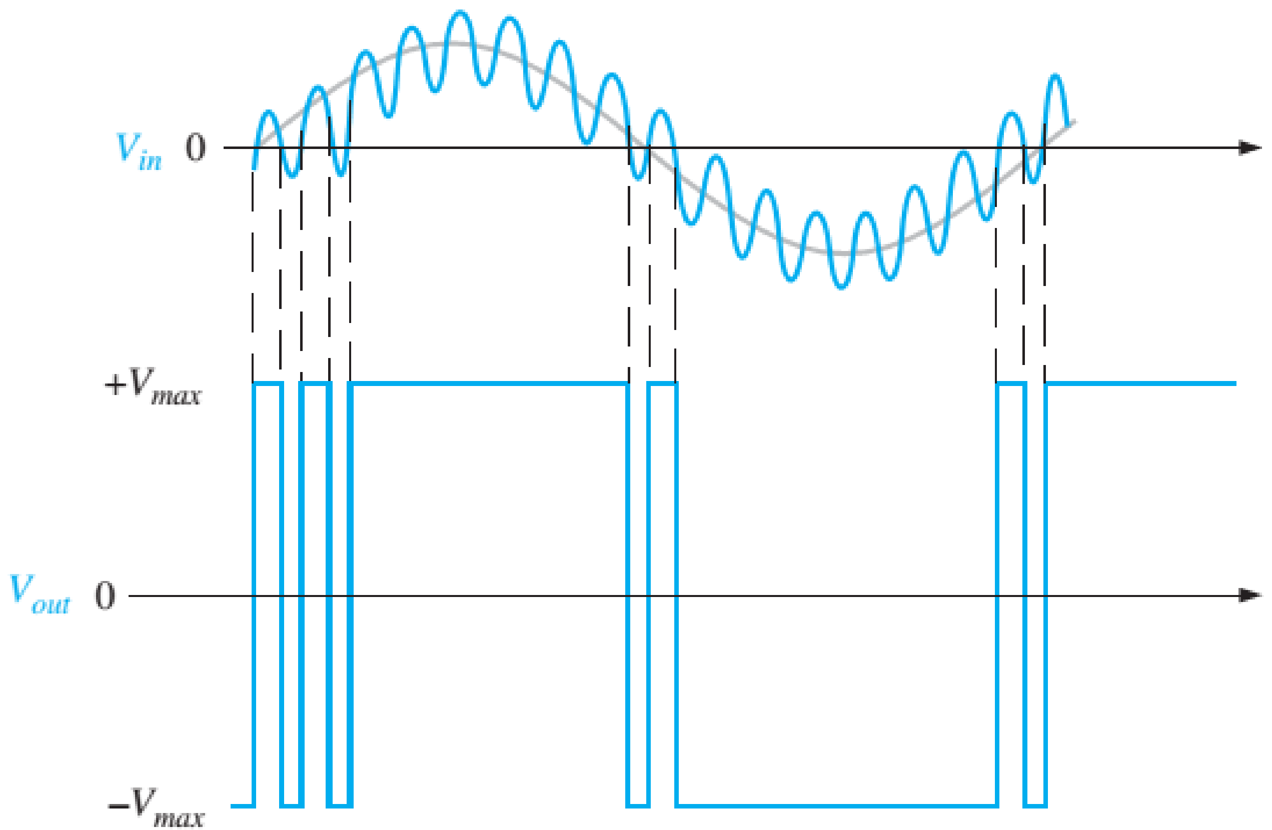




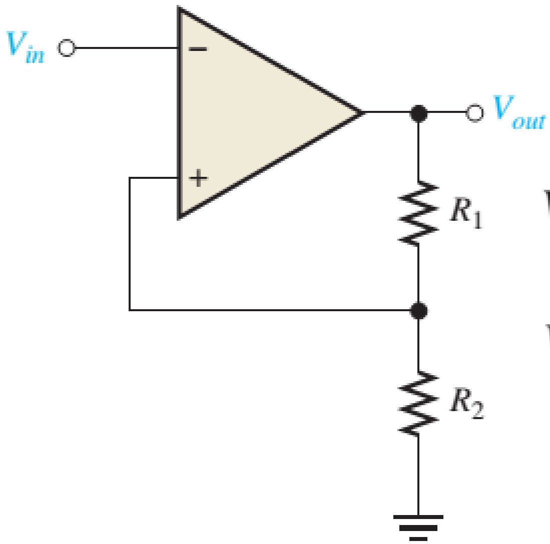
Noisy Comparator

- Unexpected pulses





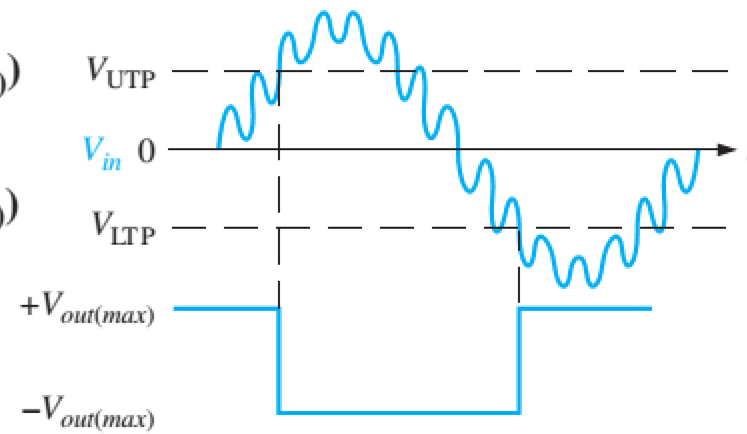
Noiseless Comparator



$$V_{UTP} = \frac{R_2}{R_1 + R_2}(+V_{out(max)})$$

$$V_{LTP} = \frac{R_2}{R_1 + R_2}(-V_{out(max)})$$

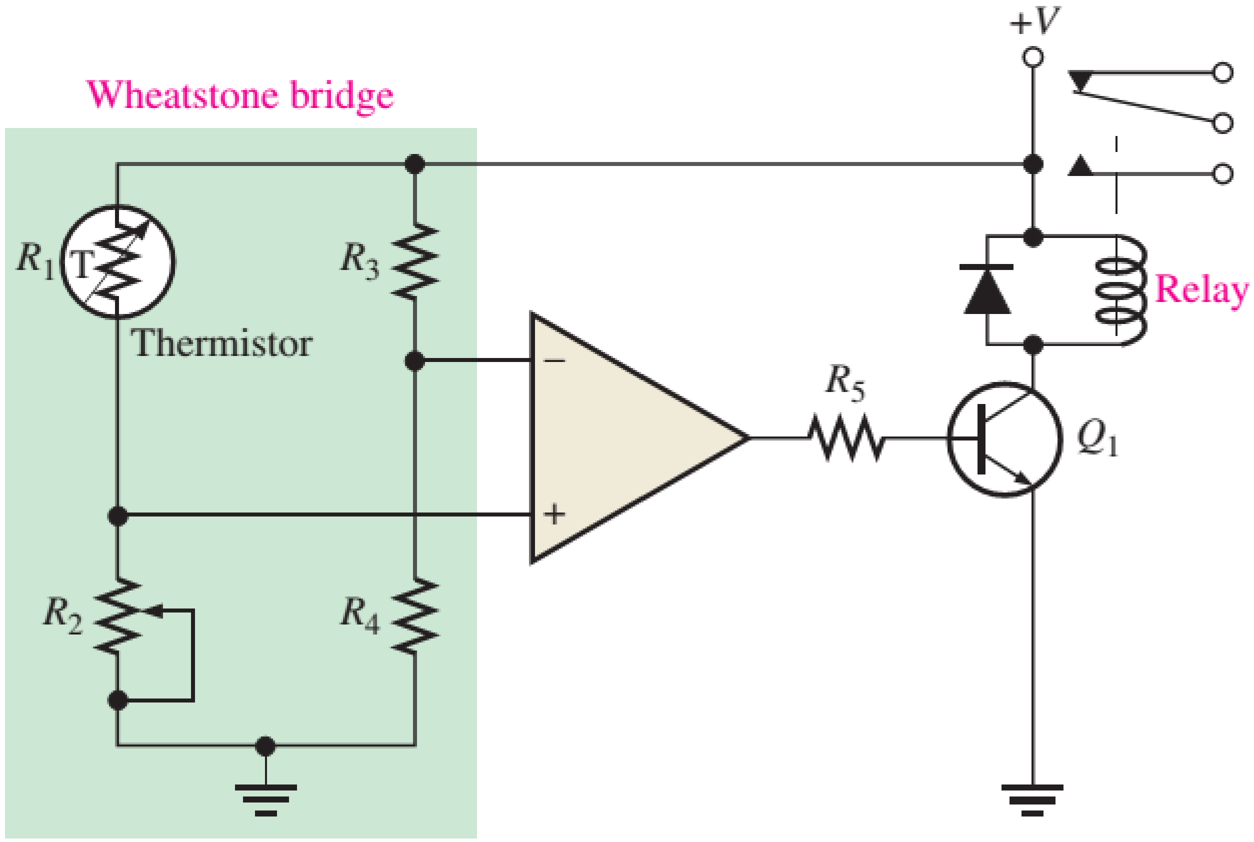
$$V_{HYS} = V_{UTP} - V_{LTP}$$



- Hysteresis
  - $+V_{out(max)} \rightarrow -V_{out(max)}$ if V_{in} is greater than V_{UTP} threshold
  - $-V_{out(max)} \rightarrow +V_{out(max)}$ if V_{in} is smaller than V_{LTP} threshold

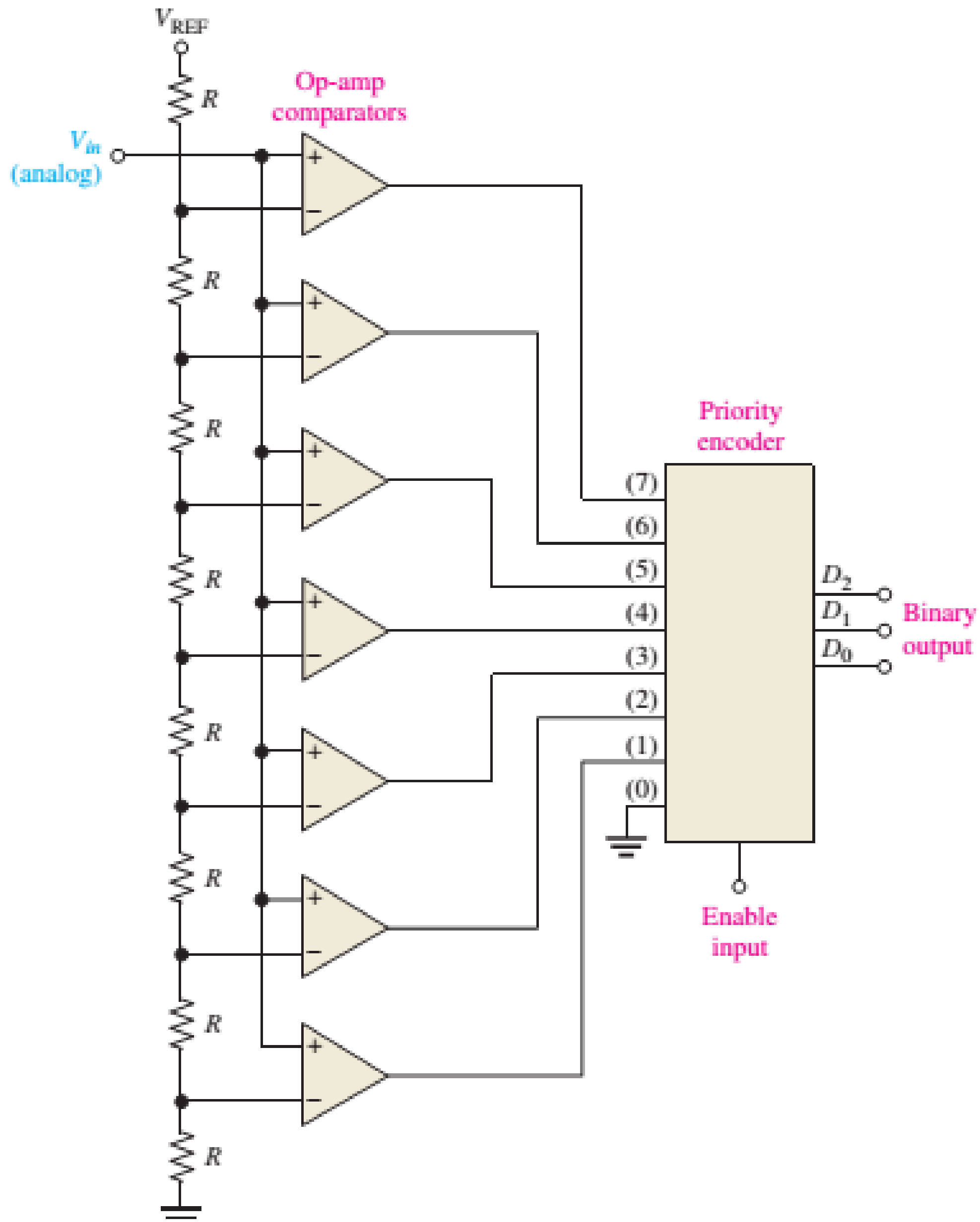
Application (1)

- Protection Circuit using Op-Amp Comparator

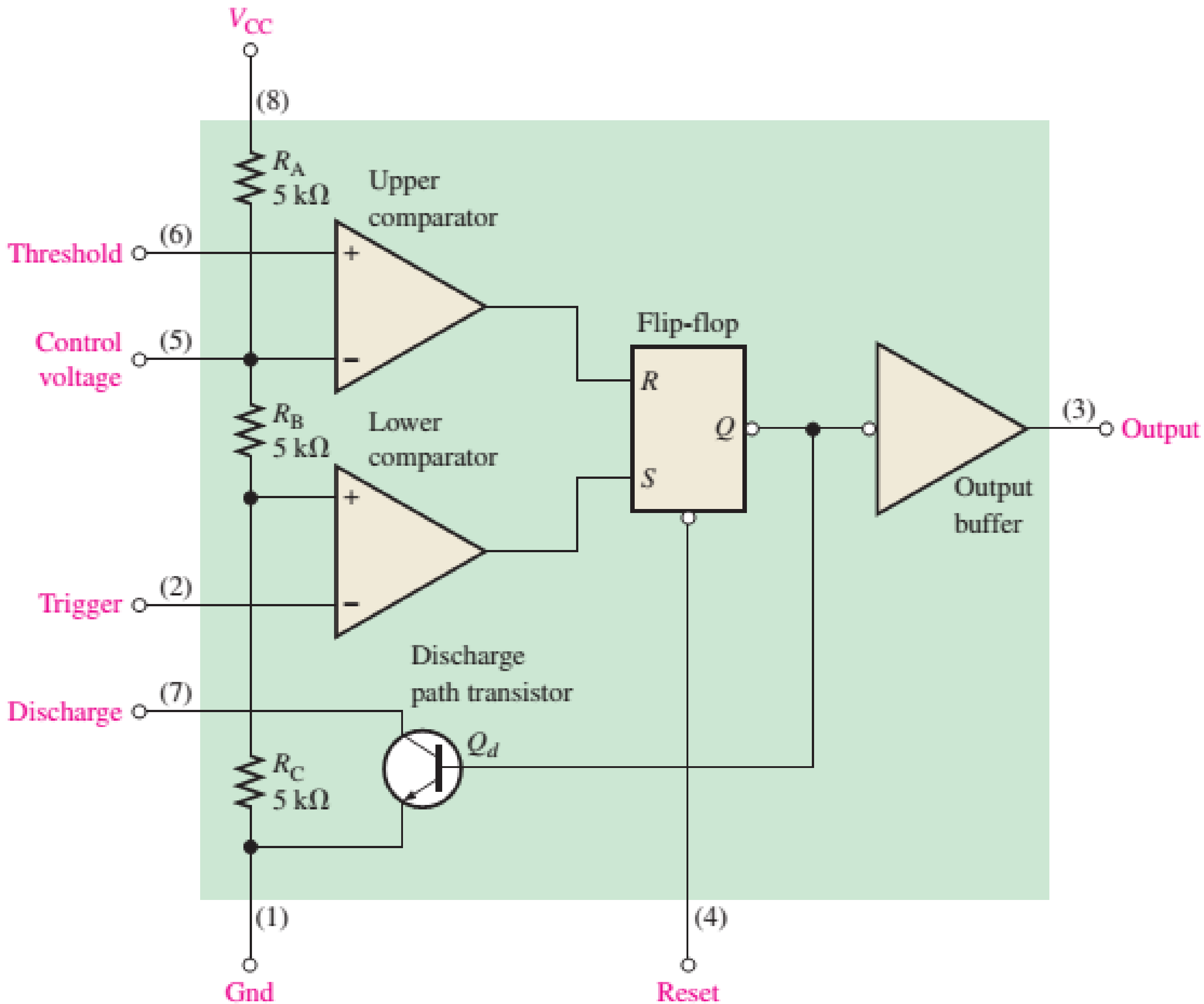


Application (2)

- Analog to Digital Conversion



IC 555


V_{CC}
(8)
R_A
5 kΩ
Upper
comparator
Threshold
(6)
Control
voltage
(5)
R_B
5 kΩ
Lower
comparator
Flip-flop
R
Q
S
Output buffer
(3)
Output
Trigger
(2)
Discharge
path transistor
Discharge
(7)
Q_d
R_C
5 kΩ
(1)
Gnd
(4)
Reset

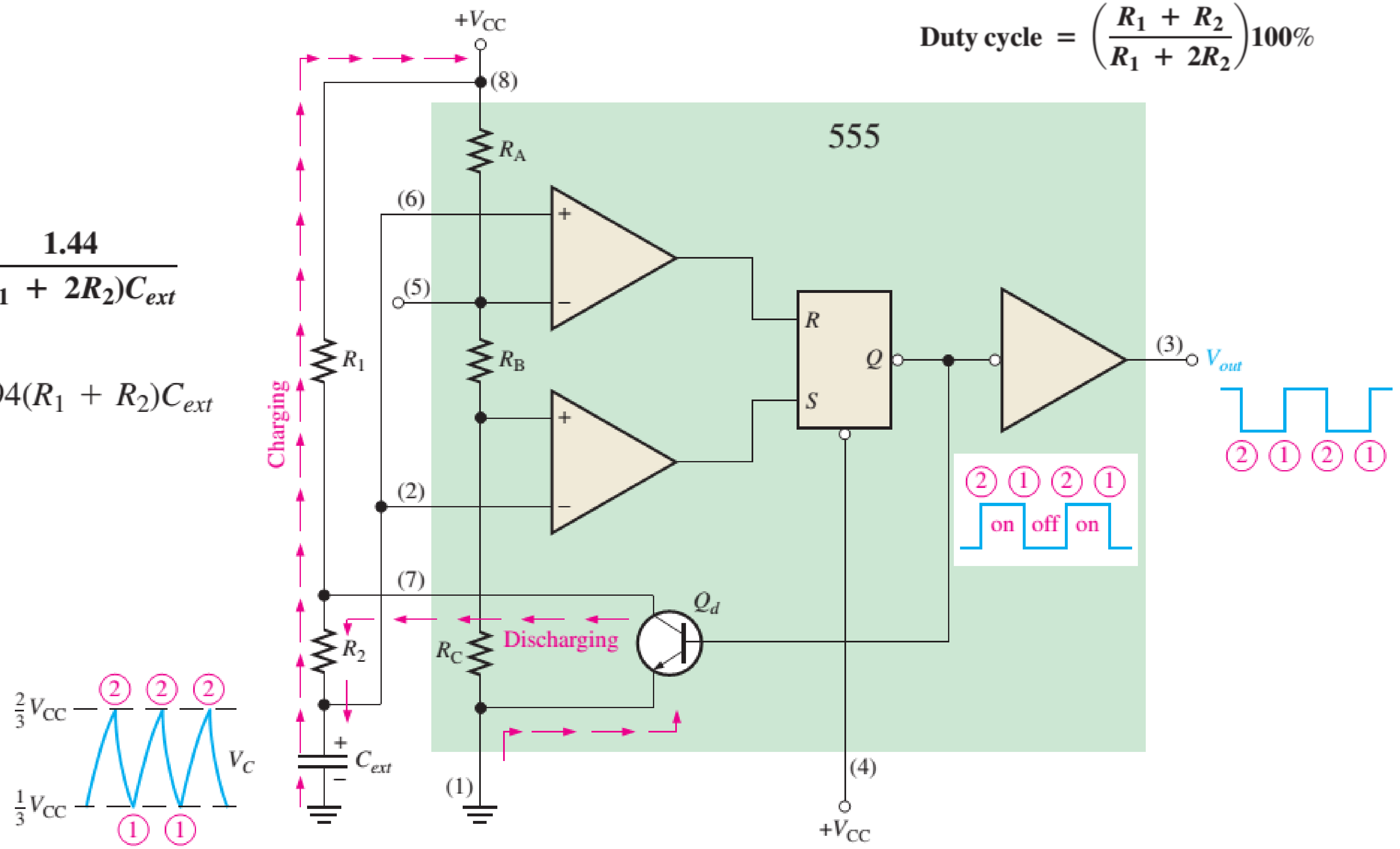
IC555 – Clock Pulse Generator

$$\text{Duty cycle} = \left(\frac{t_H}{T}\right)100\% = \left(\frac{t_H}{t_H + t_L}\right)100\%$$

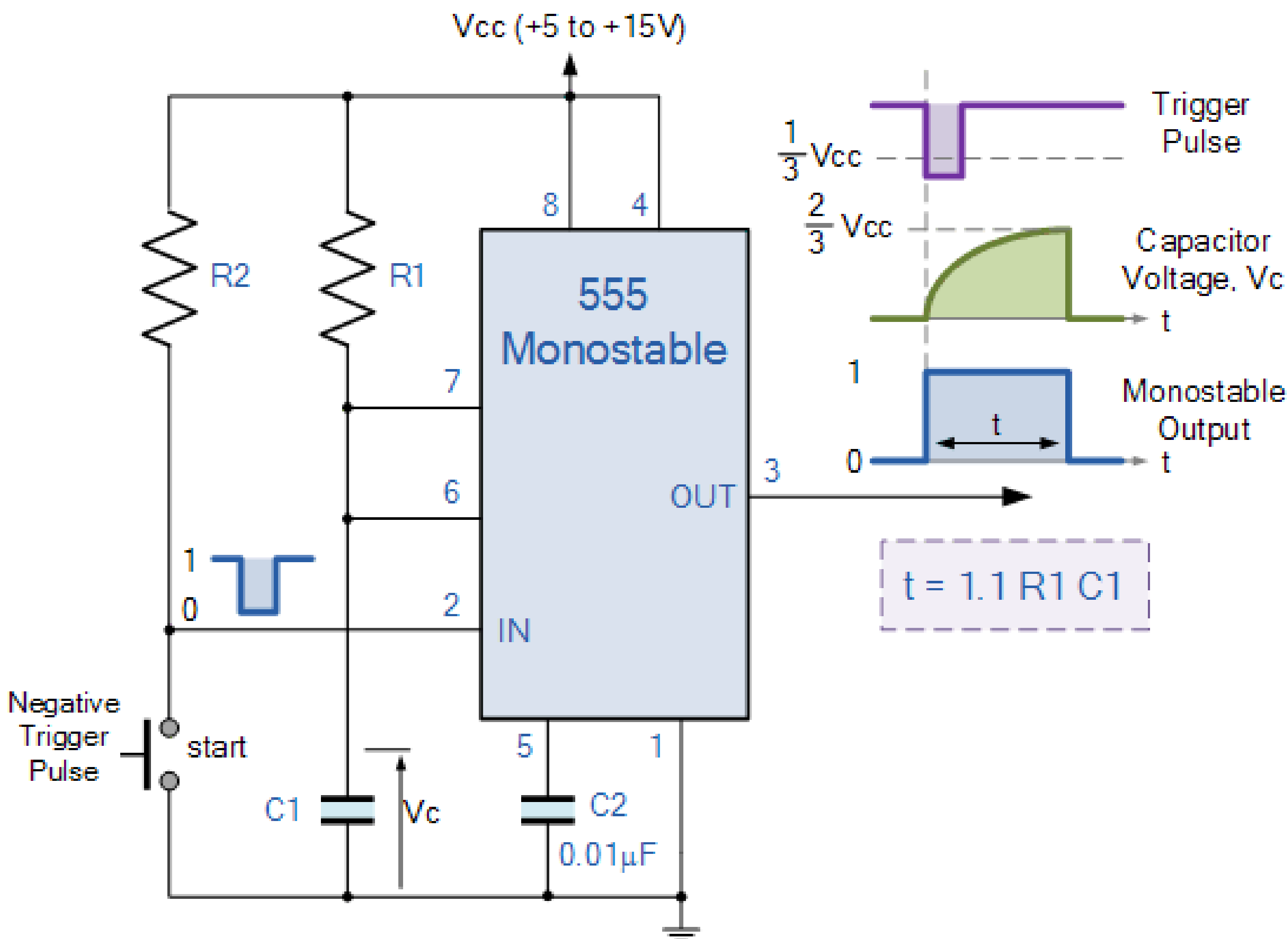
$$\textbf{Duty cycle} = \left(\frac{R_1 + R_2}{R_1 + 2R_2}\right)100\%$$

$$f_r = \frac{1.44}{(R_1 + 2R_2)C_{ext}}$$

$$t_H = 0.694(R_1 + R_2)C_{ext}$$



IC555 – Delay Circuit



- Calculate the input voltage if the final output is 10.08 V
  - ***0.168V***