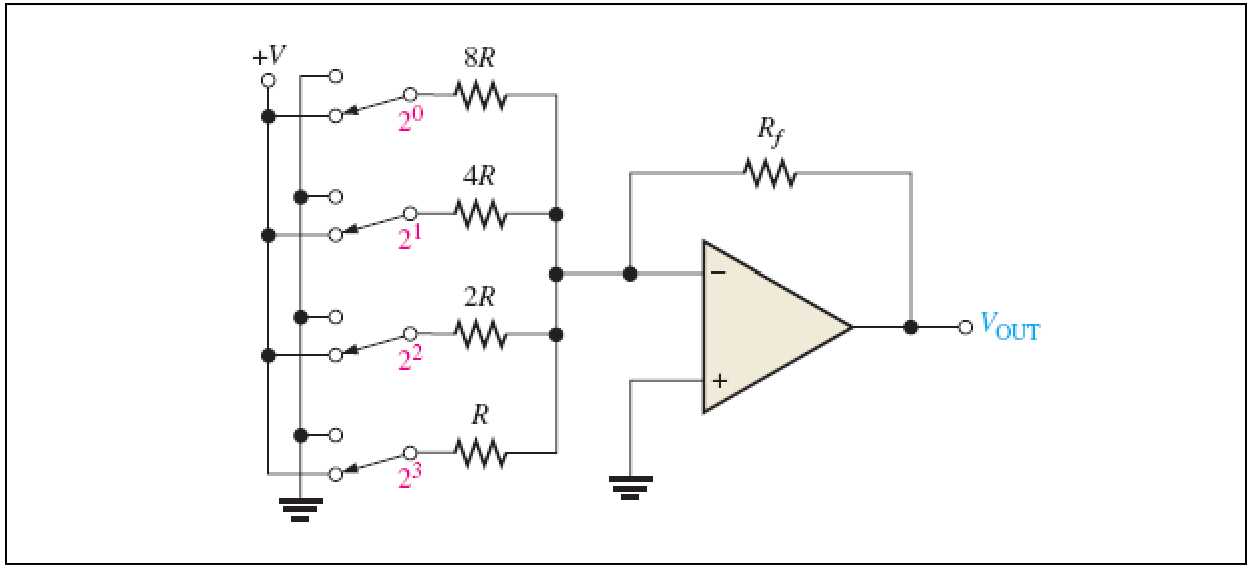
Ch. 13
Basic OP-AMP Circuits

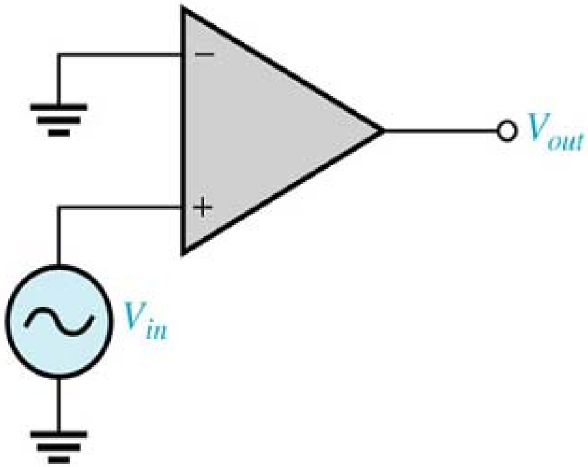


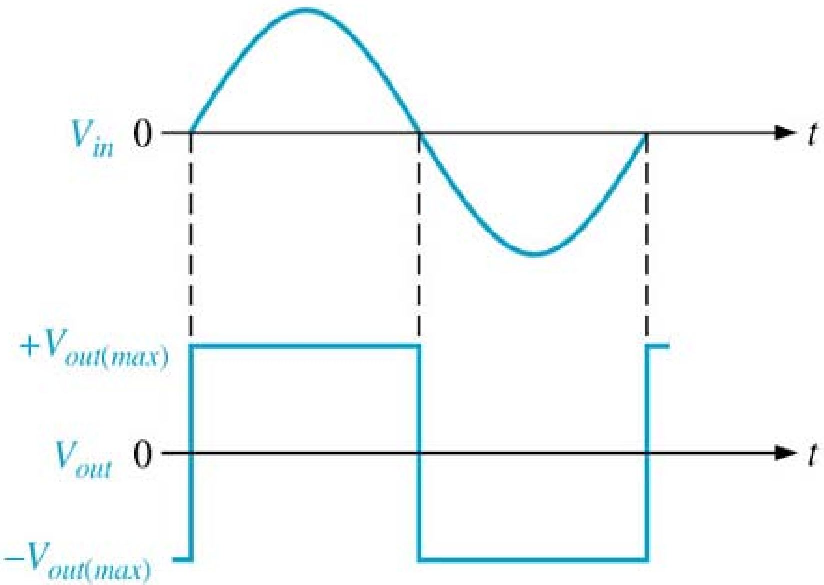
Engineering

국립한경대학교
HANKYONG NATIONAL UNIV.

비교기(Comparator)

- 하나의 전압을 다른 전압 (기준 전압, reference)와 비교하기 위한 비선형 장치
- 영전위 검출



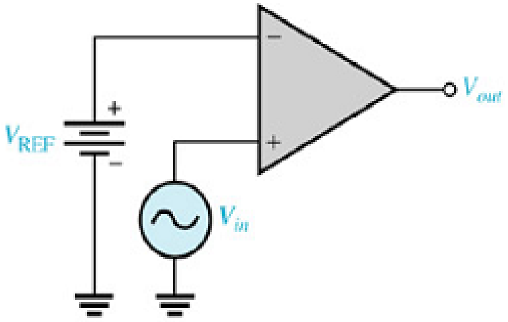


V_{in} > 기준 전압 → $V_{out} = V_{out(max)}$
V_{in} < 기준 전압 → $V_{out} = V_{out(min)}$

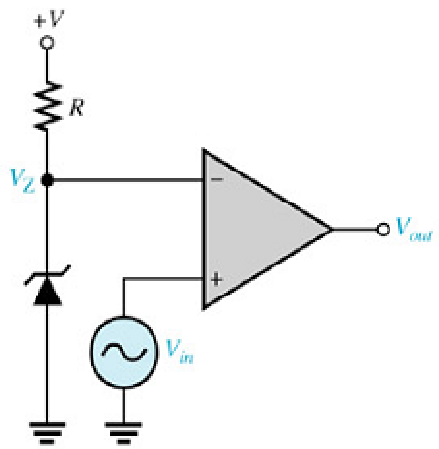
비교기

영이 아닌 전위 검출

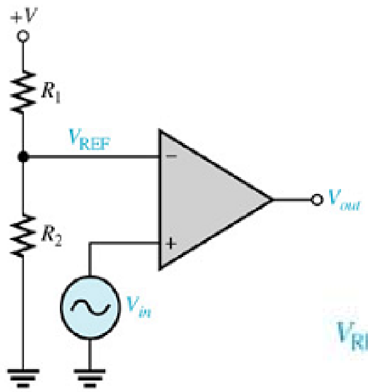
- 기준 배터리

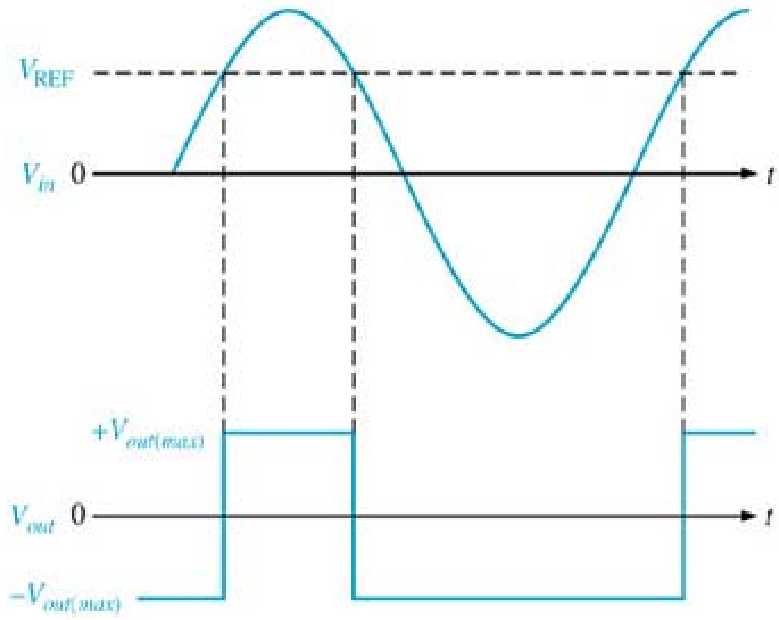


- 기준전압 제너다이오드



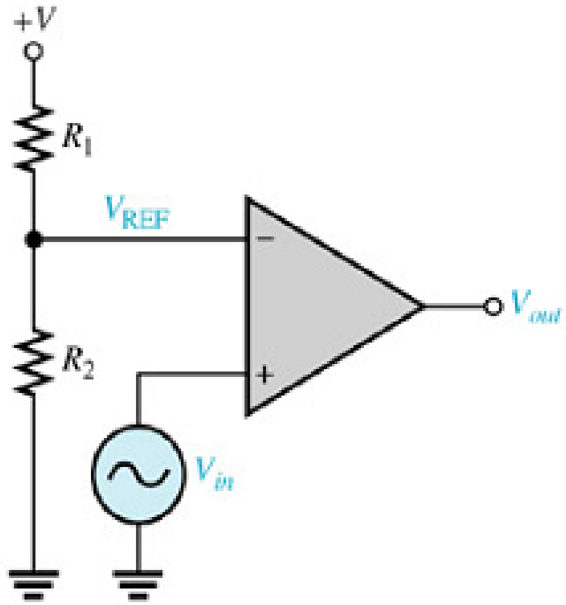
- 기준전압 분배기

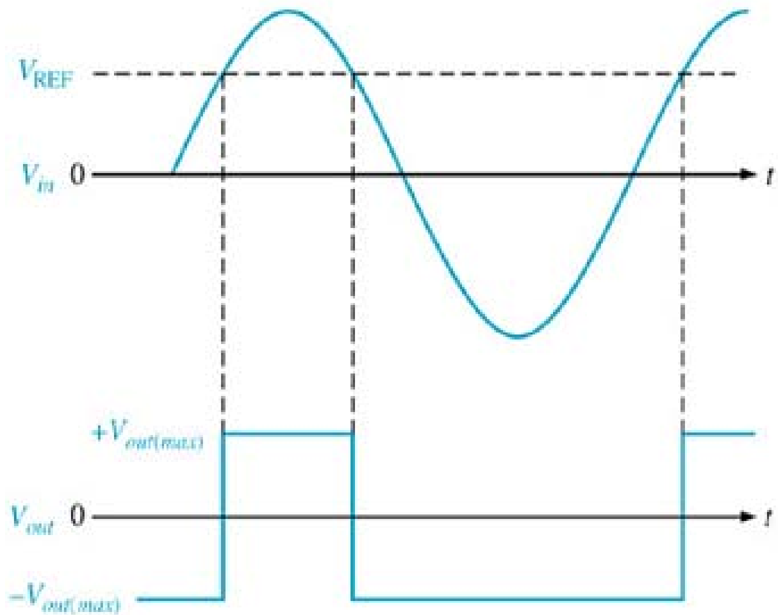




비교기

- 예제 13-1: $V_{out(max)}$ = 12 V, R_1 = 8.2 kΩ, R_2 = 1kΩ

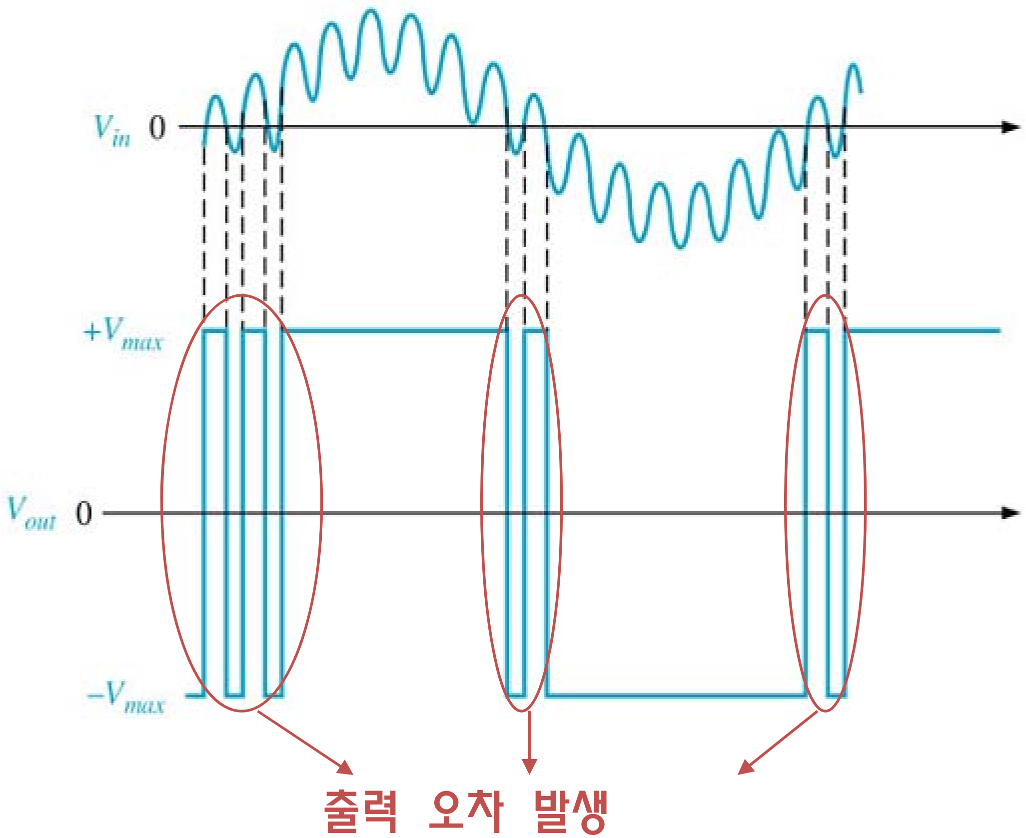


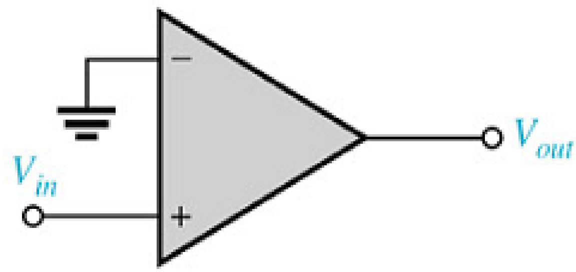


$$V_{REF} = \frac{R_2}{R_1 + R_2} V_{DD} = \frac{1\text{k}}{8.2\text{k} + 1\text{k}}(15) = 1.63\text{V}$$

비교기

- 비교기에서 입력 잡음 영향
  - 입력 잡음 → 출력 에러

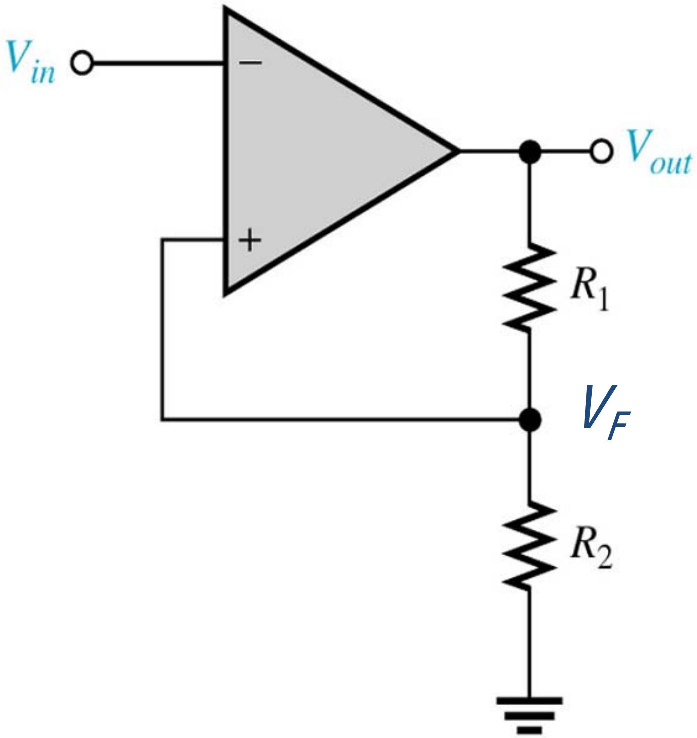




비교기

- 히스테리시스(hysteresis)에 의한 잡음 영향 줄이기
  - 잡음 영향: { (+) → (-) , (-) → (+) } 기준 전압 교차시 발생

→ 히스테리시스 정귀환 이용: 잡음 영향 최소화



1. $V_{out} = + V_{out(max)}$
   → $V_F = V_{UTP}$라 하자

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

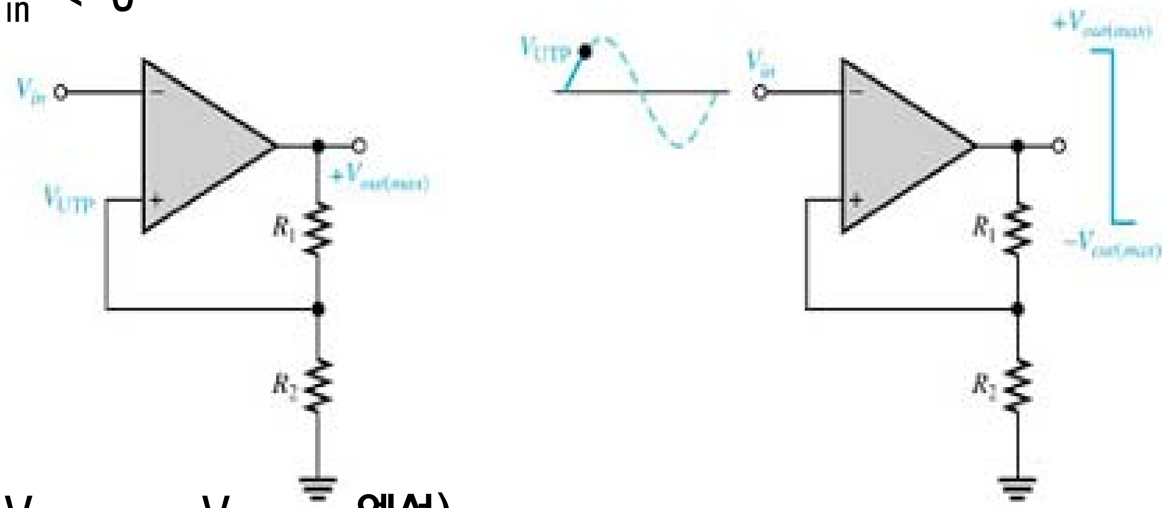
2. $V_{out} = - V_{out(max)}$
   → $V_F = V_{LTP}$라 하자

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

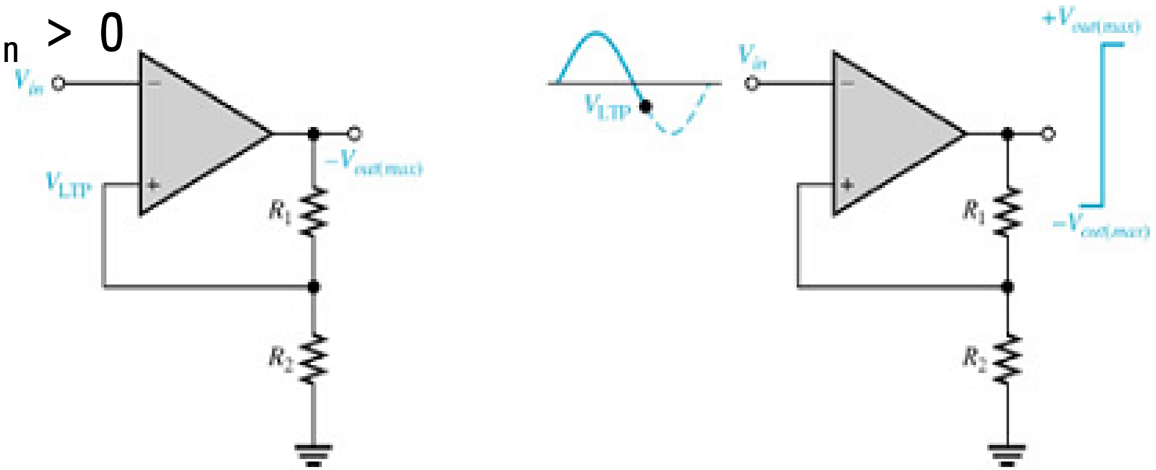
비교기

히스테리시스에 의한 잡음 영향 줄이기

- Case 1) V_{in} > V_{UTP} (단, V_{out} = + $V_{out(max)}$에서)
  - $V_F - V_{in} = V_{UTP} - V_{in} < 0$
  - → V_{out} = - $V_{out(max)}$

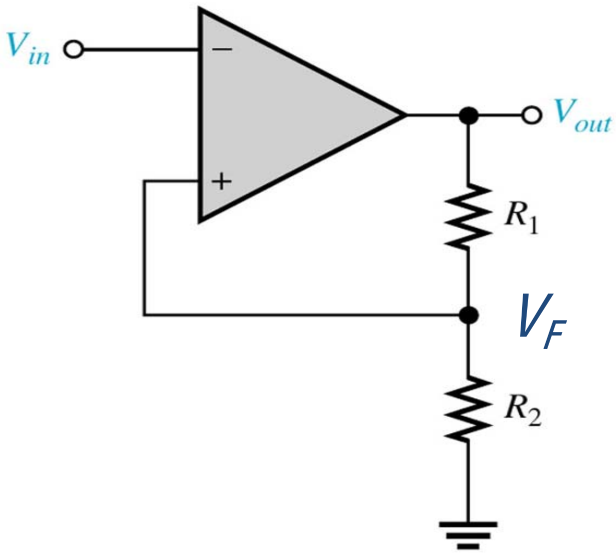


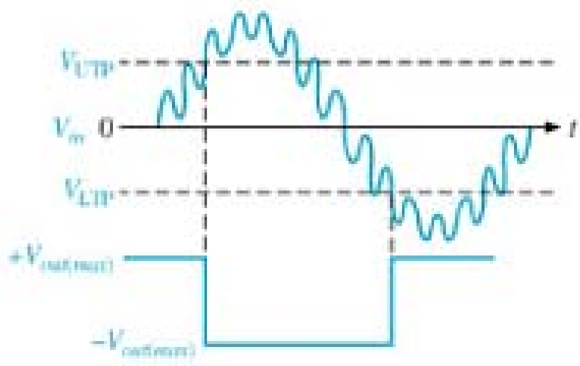
- Case 2) V_{in} < V_{LTP} (단, V_{out} = - $V_{out(max)}$에서)
  - $V_F - V_{in} = V_{LTP} - V_{in} > 0$
  - → V_{out} = + $V_{out(max)}$



비교기

히스테리시스에 의한 잡음 영향 줄이기





→ 잡음 영향이 매우 적음

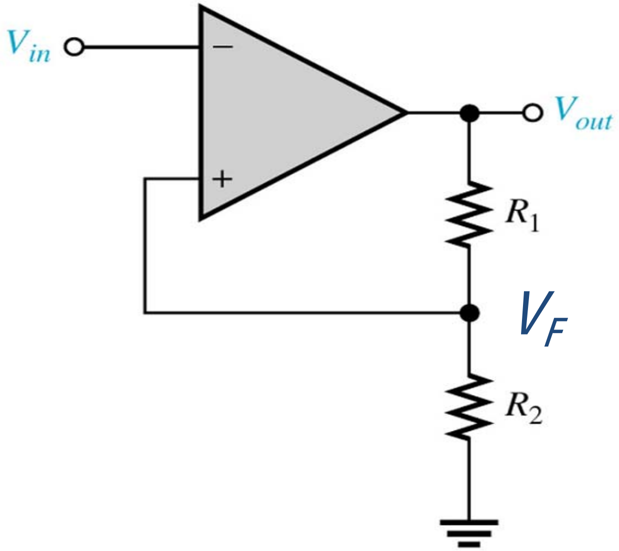
→ 슈마트 트리거 (Schmitt trigger)

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

(히스테리시스 전압)

비교기

- 예제 13-2: $V_{out(max)}$ = 5 V, R_1 = 100 kΩ, R_2 = 100 kΩ → V_{UTP} , V_{LTP}?

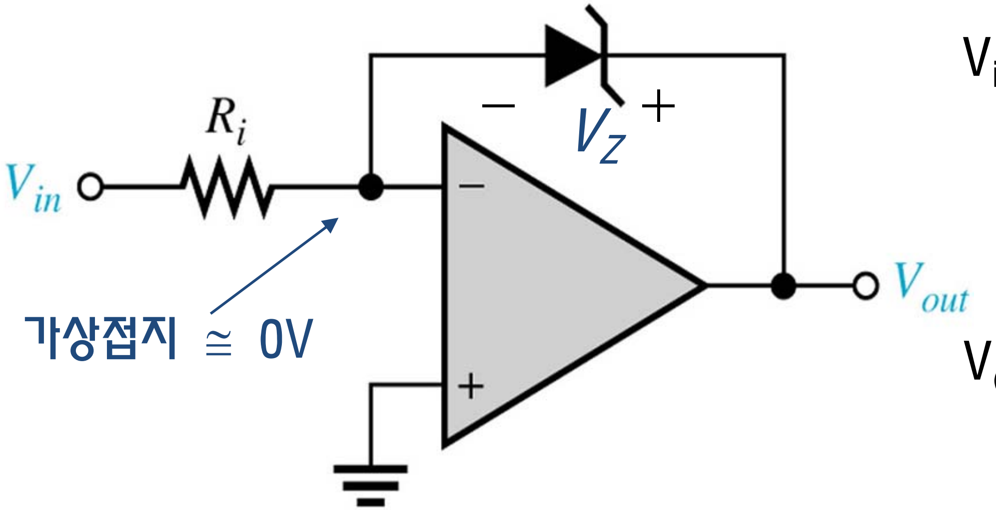


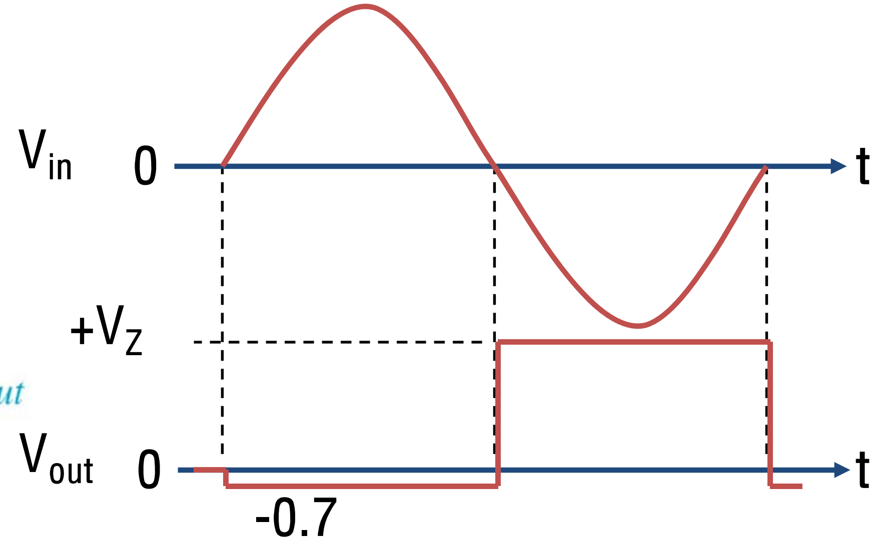
$$V_{UTP} = \frac{R_2}{R_1 + R_2} V_{out(max)} = \frac{100\text{k}}{100\text{k}+100\text{k}}(5) = 2.5\text{V}$$

$$V_{LTP} = \frac{R_2}{R_1 + R_2}\left[-V_{out(max)}\right] = \frac{100\text{k}}{100\text{k}+100\text{k}}(\text{-}5) = -2.5\text{V}$$

비교기

- 출력 제한 (bounding)
  - $V_{out} < V_{out(max)}$ 로 제한하고자 할 때

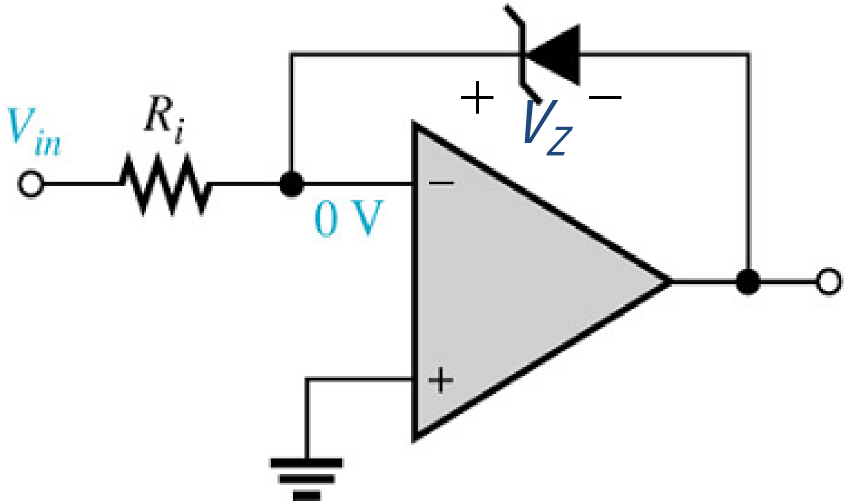


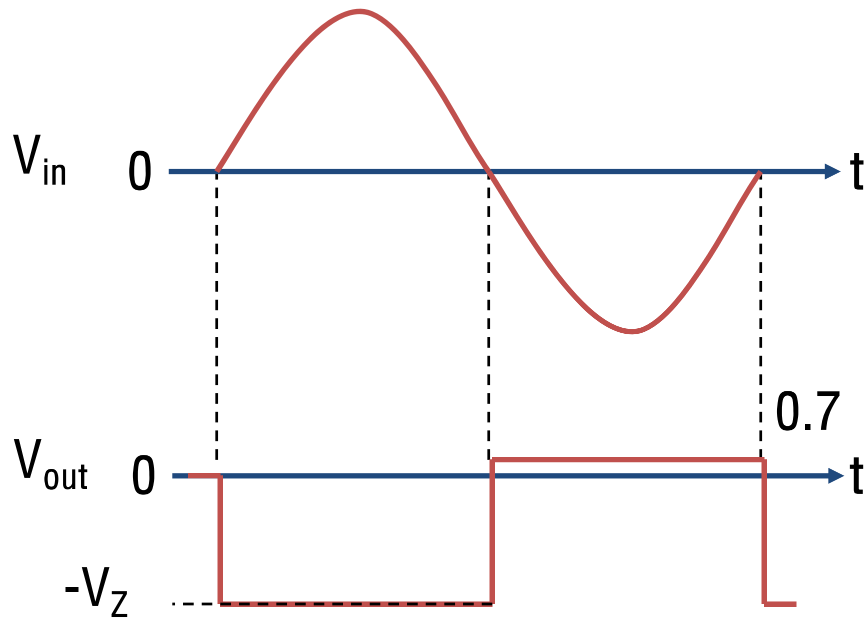


- $V_{out} < -0.7V \rightarrow V_{out} = -0.7V$ (다이오드 전압)
- $-0.7V < V_{out} < V_Z \rightarrow V_{out} = V_{out}$
- $V_{out} > V_Z \rightarrow V_{out} = V_Z$ (제한)

비교기

- 출력 제한 (bounding)
  - $V_{out} < V_{out(max)}$ 로 제한하고자 할 때

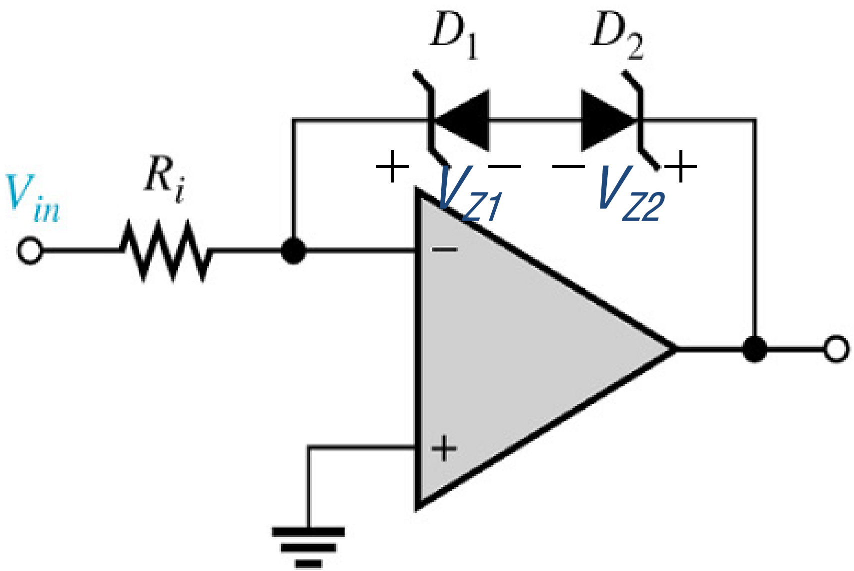


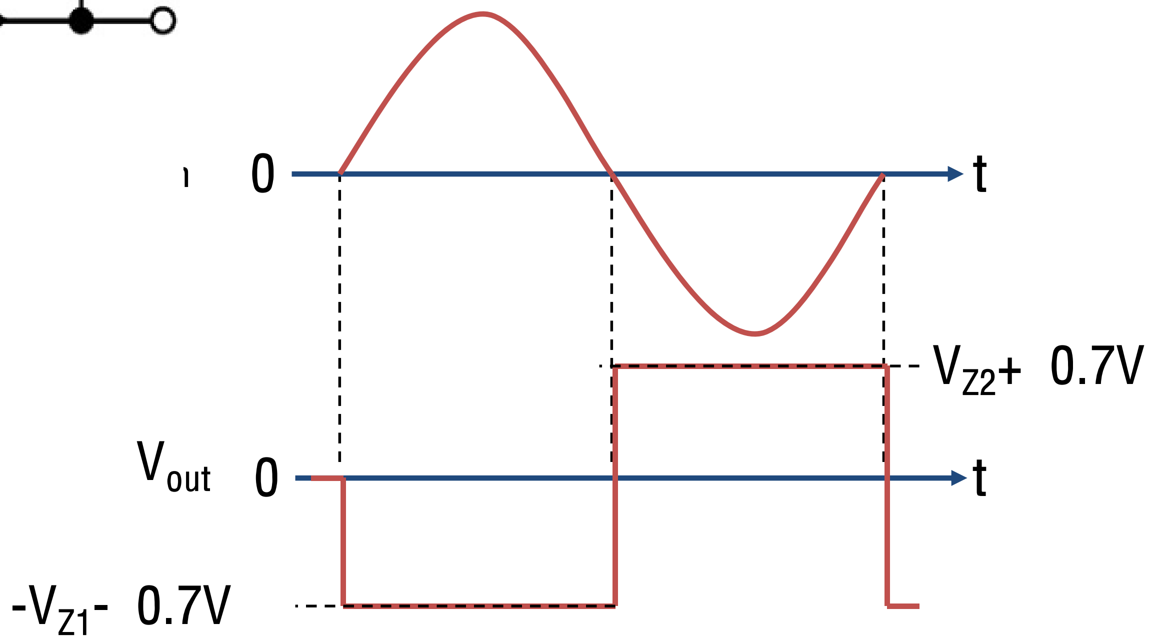


- $V_{out} < -V_Z \rightarrow V_{out} = -V_Z$ (제한)
- $-V_Z < V_{out} < 0.7V \rightarrow V_{out} = V_{out}$
- $V_{out} > 0.7V \rightarrow V_{out} = 0.7V$ (다이오드 전압)

비교기

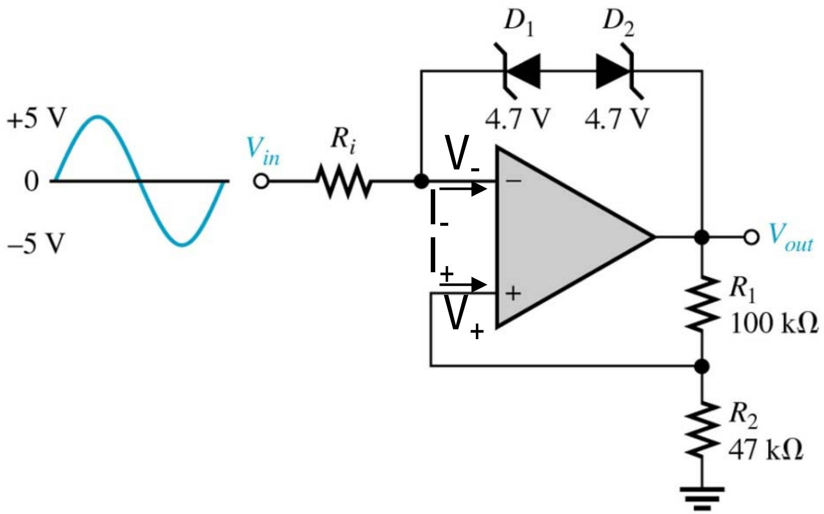
- 출력 제한 (bounding)

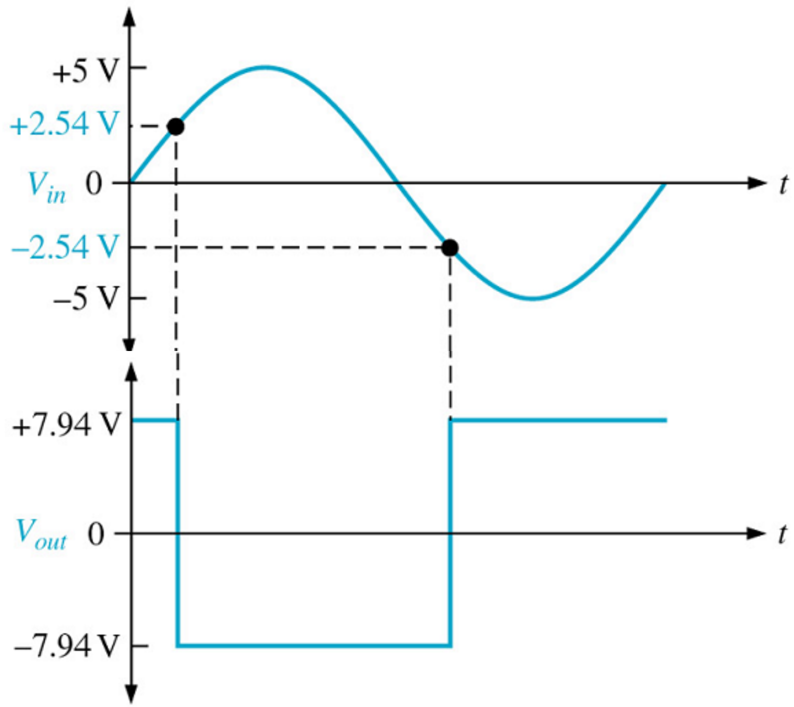




비교기

- 예제 13-3: 히스테리시스 + 제너제한





$I_- \approx I_+ \approx 0$ 이므로 $V_- = V_{out} \pm (4.7 + 0.7) = V_{out} \pm 5.4$

$(V_+ - V_-)$를 무시하면→ $V_+ = V_- = V_{out} \pm 5.4$

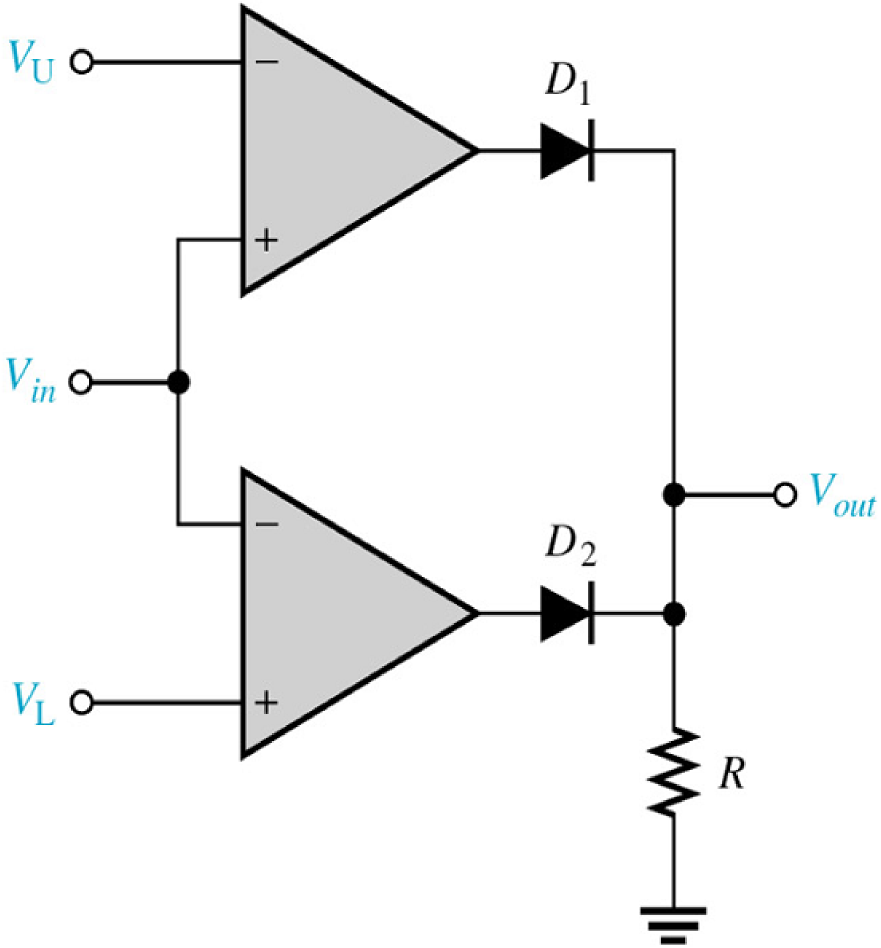
$$I_{R2} = I_{R1} = \frac{V_{R1}}{R_1} = \frac{V_{out} - V_+}{100k} = \frac{V_{out} - V_+}{100k} = \frac{V_{out} - V_-}{100k} = \frac{\pm 5.4}{100k} = \pm 54\mu A$$

$$V_+ = V_{R2} = R_2 I_{R2} = (47k)(\pm 54\mu) = \pm 2.54V$$ → $V_{UTP} = 2.54\ V,\ V_{LTP} = -2.54\ V$

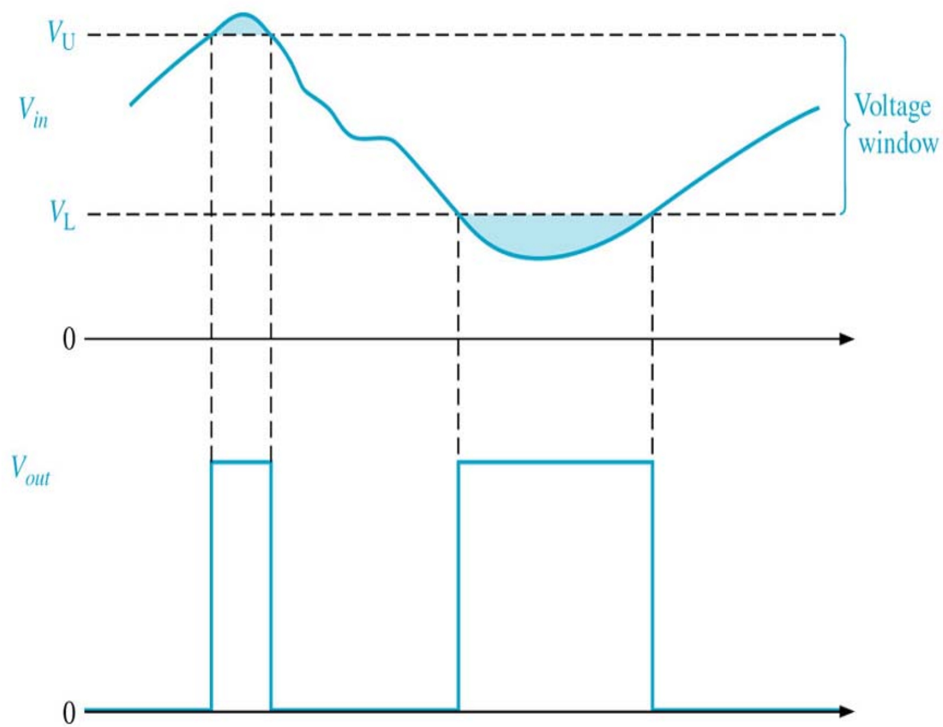
$$V_{out} = V_{R1} + V_{R2} = \pm(5.4 + 2.54) = \pm 7.94V$$

비교기

- 윈도우 비교기



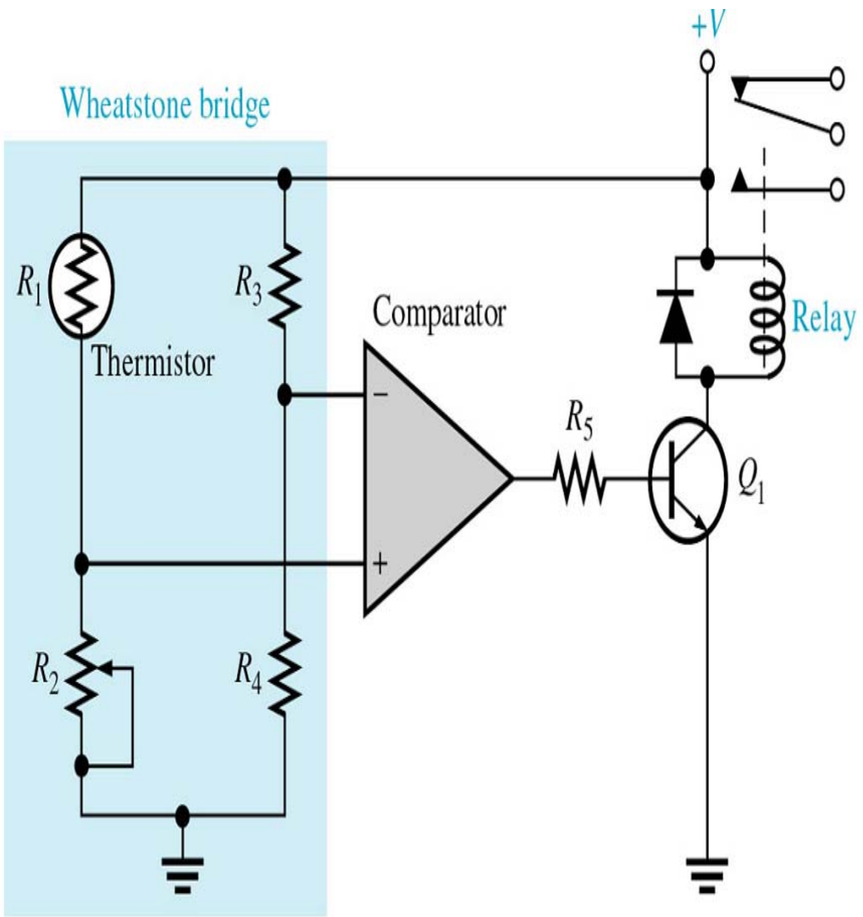
$V_L < V_{in} < V_U \rightarrow V_{out} = 0$



비교기 응용

과열 검출회로(Over-Temperature Sensing Circuit)

휘스톤 브릿지 회로 이용



- Thermistor (R_1): 부성 온도계수
  (온도 ↑ → 저항 ↓)
- 가변저항 (R_2): 임계온도에서 thermistor
  저항과 같은 값
- 상온 (< 임계온도): $R_1 > R_2$
  → V_+ (상온) < V_+ (임계온도)
  → V_+ (상온) < V_- → $V_{out} < 0$
  → Q_1 off
  (단, $R_3 = R_4$ → $V_- = V_+$ (임계온도))
- 온도 ↑ ≈ 임계온도: $R_1 \approx R_2$
  → V_+ (상온) ≈ V_+ (임계온도)
  → V_+ (상온) ≈ V_- → $V_{out} > 0$
  → Q_1 동작 → Relay 동작

비교기

- Analog-to-Digital (A/D) 변환
  - 예) Simultaneous (or flash) A/D 변환 (전압 분배 방식)
    - n자리 → 2진수

      ➔ $2^n - 1$ 개 비교기 필요
    - 만약 3 자리 → $V_7 > V_6 > V_5 > \cdots > V_2 > V_1$
      - 예 V_{in} = 3.7 V, V_{REF} = 8V

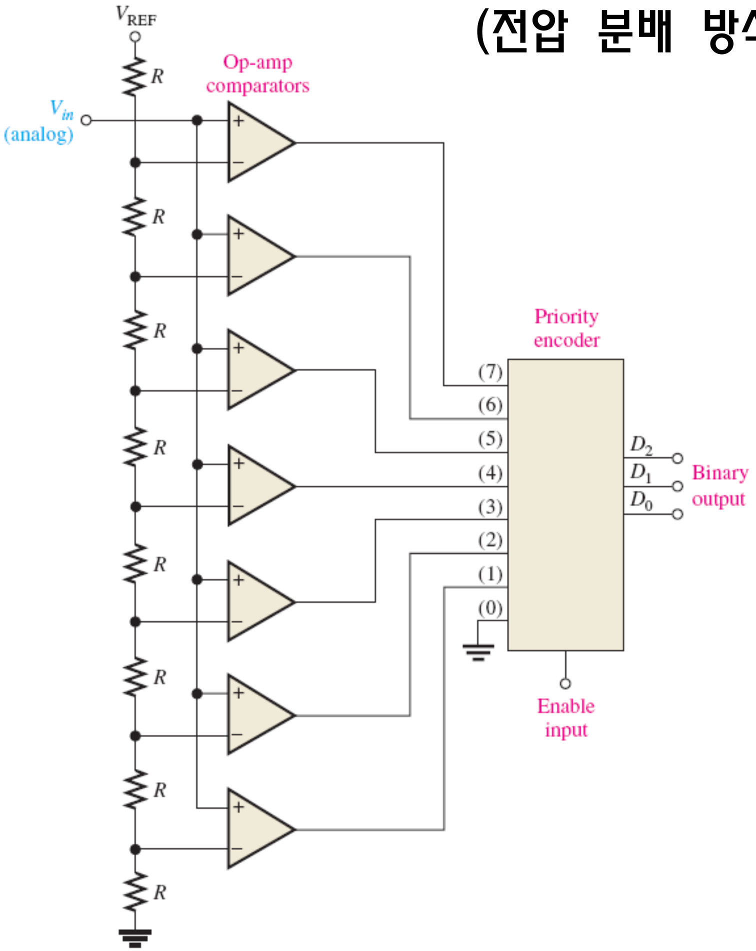
        → V_{in} > V3, V2, V1

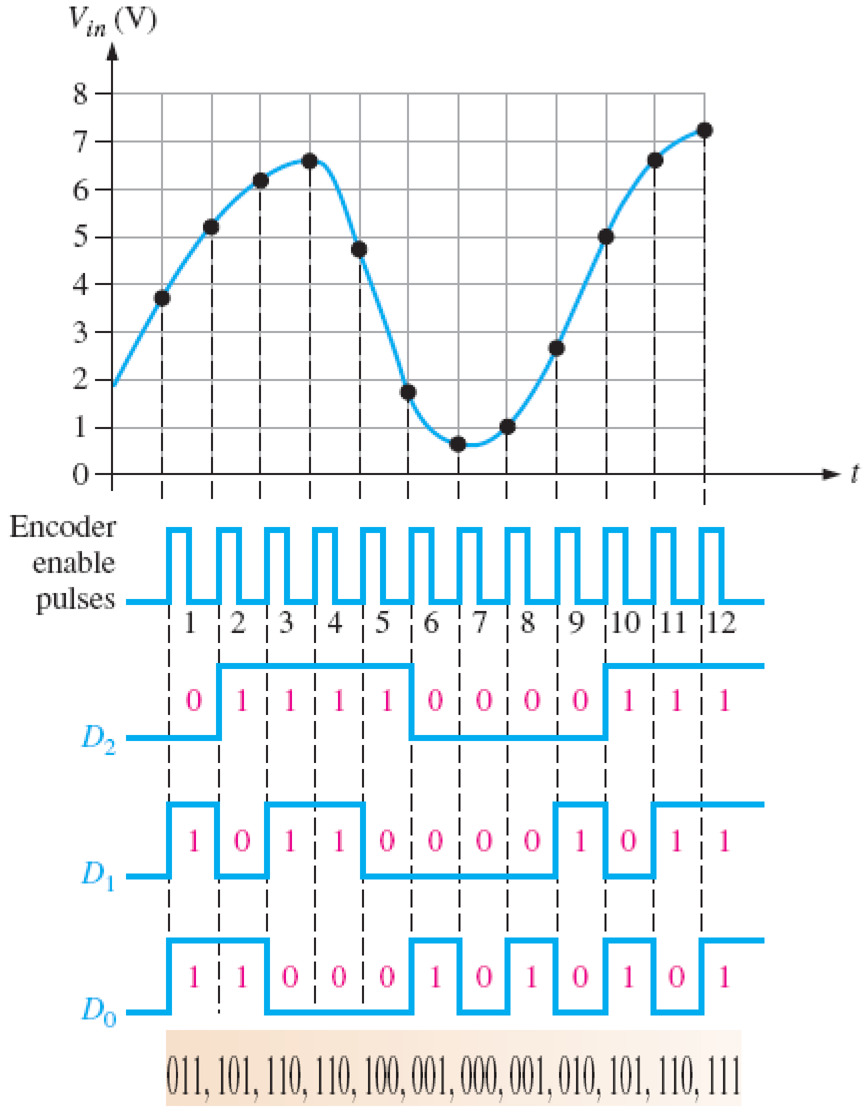
        → (1), (2), (3) : "1" , 나머지: "0"

        → 출력: $D_2D_1D_0$ = 011 → 3

A/D 변환

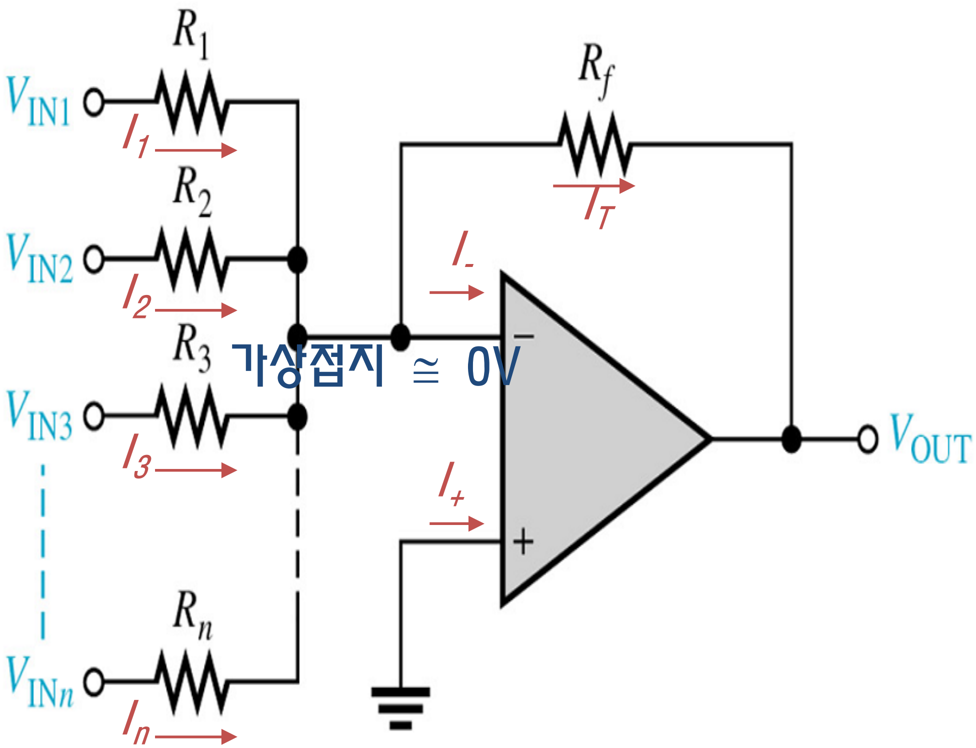
- 예) Simultaneous (or flash) A/D 변환 (전압 분배 방식)





가산기(Summing Amplifier)

- n 입력 가산기



$I_+ = I_- = 0$

$V_+ = V_- = 0$ V (가상접지)

$I_T = I_1 + I_2 + \cdots + I_n$

$V_{out} = -I_T R_f$

$= -(I_1 + I_2 + \cdots + I_n)R_f$

$= -(V_{IN1}/R_1 + \cdots + V_{INn}/R_n)R_f$

if $R_1 = R_2 = \cdots = R_n = R_f$

$\rightarrow V_{out} = -(V_{IN1} + V_{IN2} + \cdots + V_{INn})$

가산기

- 1보다 큰 이득을 갖는 가산기
  - $R_1 = R_2 = \cdots = R_n = R$

$$V_{out} = -\frac{R_f}{R}(V_{in1} + V_{in2} + \ldots + V_{inN})$$

- 평균 증폭기
  - $R_f/R = 1/n$

$$V_{out} = -\frac{V_{in1} + V_{in2} + \ldots + V_{inN}}{n}$$

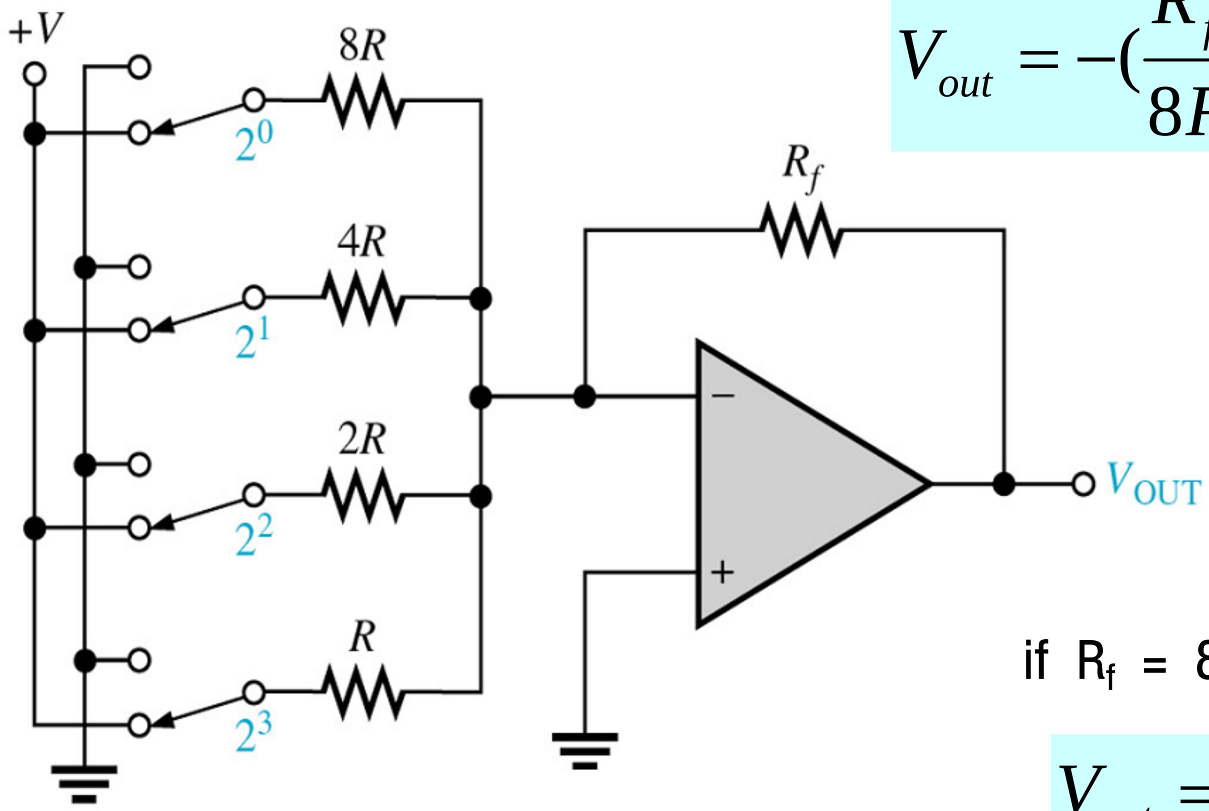
- 스케일링 가산기

$$V_{out} = -(\frac{R_f}{R_1}V_{in1} + \frac{R_f}{R_2}V_{in2} + \ldots + \frac{R_f}{R_n}V_{inN})$$

  - 입력전압 1의 가중치: $R = R_f$
  - 입력전압 2의 가중치: $R = 2R_f$

가산기

스케일링 가산기 응용



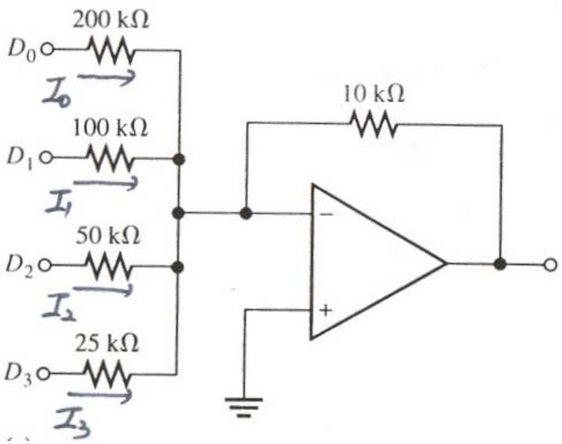
$$V_{out} = -\left(\frac{R_f}{8R} + \frac{R_f}{4R} + \frac{R_f}{2R} + \frac{R_f}{R}\right)V$$

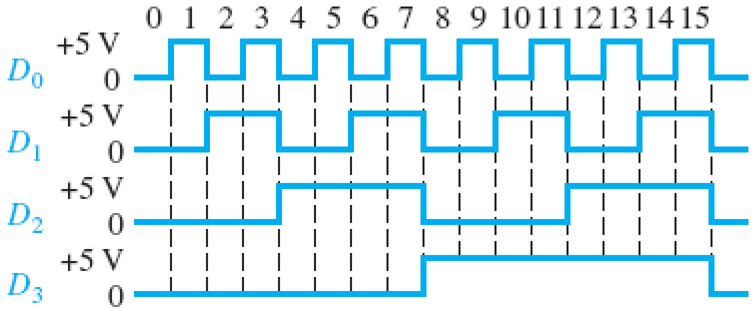
if R_f = 8R

$$V_{out} = -(1+2+4+8)V$$

가산기

스케일링 가산기 응용 - 예제 13-9





I_0 = 5/200k = 0.025mA

I_1 = 5/100k = 0.05mA

I_2 = 5/50k = 0.1mA

I_3 = 5/25k = 0.2mA

$V_{OUT(D0)}$ = $-R_f$ I_0

= -(10k)(0.025m) = -0.25V

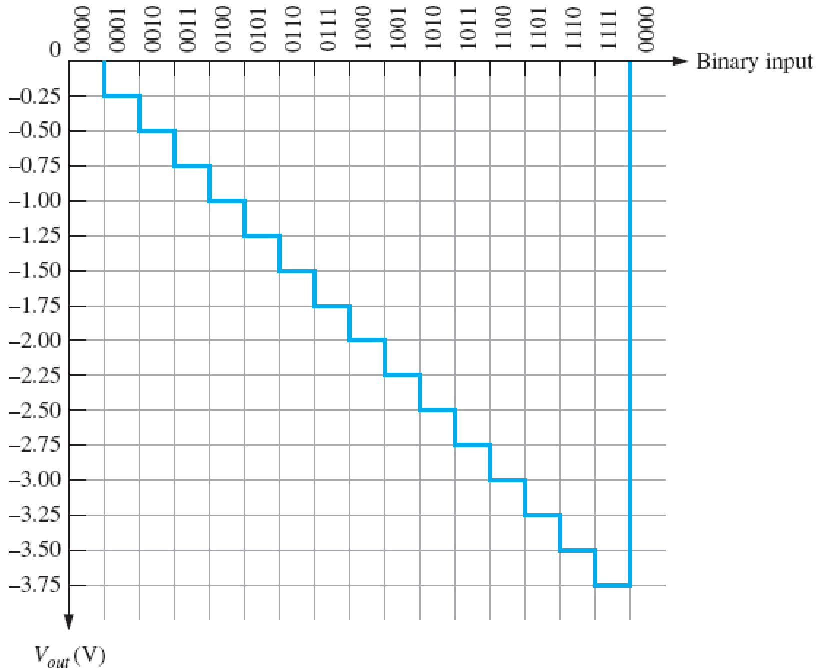
$V_{OUT(D0)}$ = $-R_f$ I_1

= -(10k)(0.05m) = -0.5V

$V_{OUT(D0)}$ = $-R_f$ I_2 = -(10k)(0.1m) = -1V

$V_{OUT(D0)}$ = $-R_f$ I_3 = -(10k)(0.2m) = -2V

예) D_3D_2 D_1D_0 = 0001 =1 → -0.25V



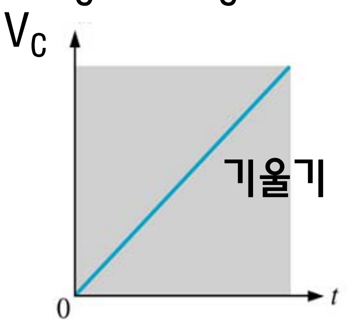
적분기와 미분기

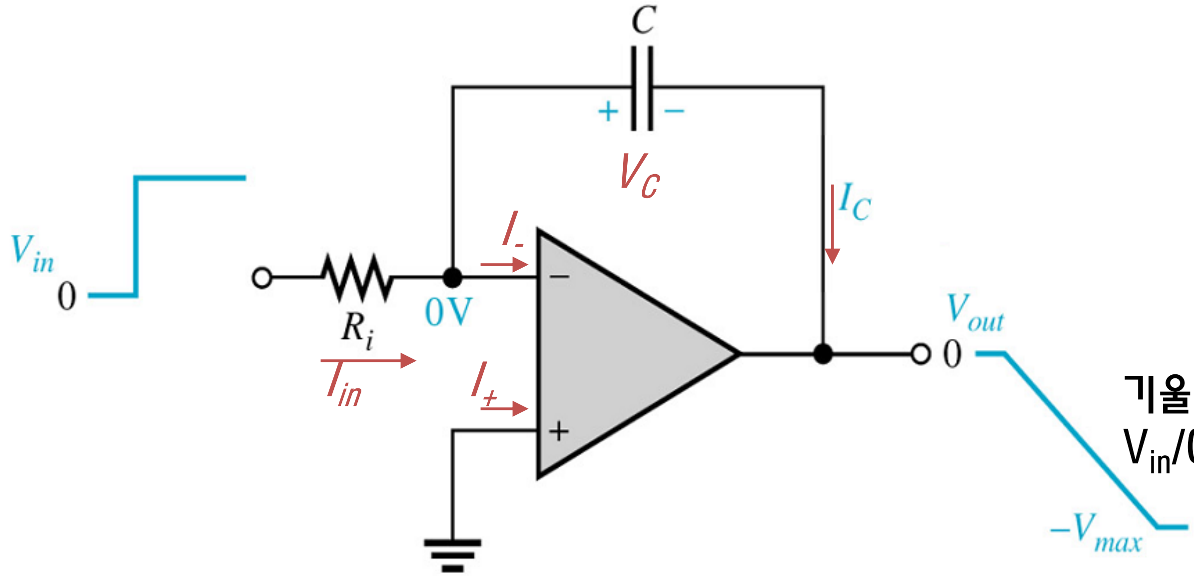
적분기 (Integrator)

- 캐패시터 전하

  $Q = I_C t = CV_C$

  $V_C = (I_C/C)t$





$I_+ = I_- = 0,\ V_+ = V_- = 0\ \mathrm{V}$ (가상접지)

$I_{in} = V_{in}/R_i = I_C$

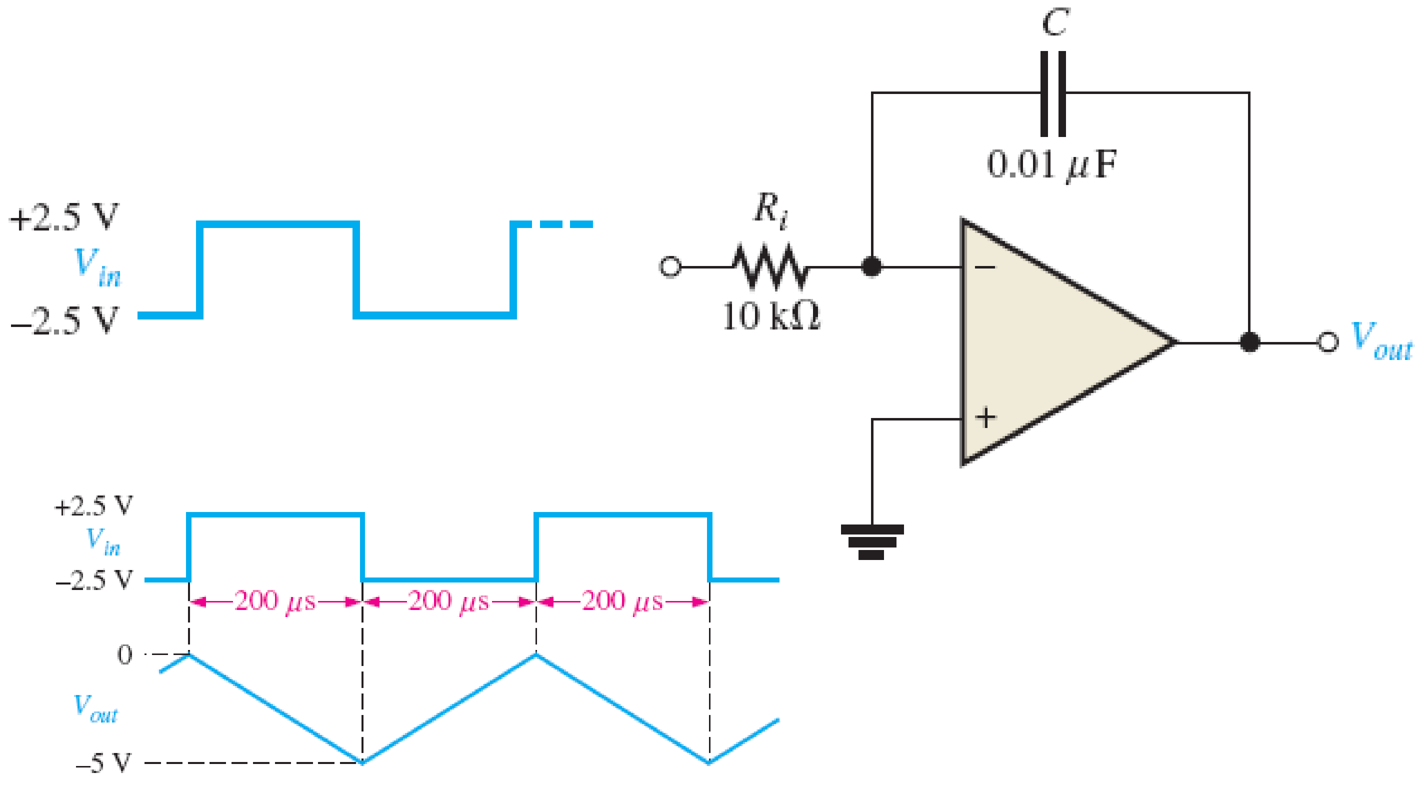
$V_C = (I_C/C)t = (V_{in}/CR_i)t \rightarrow V_{out} = -V_C$

$\rightarrow \Delta V_{out} = -\Delta V_C = (-V_{in}/CR_i)\Delta t$

$$\frac{\Delta V_{out}}{\Delta t} = -\frac{V_{in}}{CR_i} \longrightarrow V_{out} = -\frac{1}{CR_i}\int V_{in}dt$$

적분기와 미분기

예제 13-10

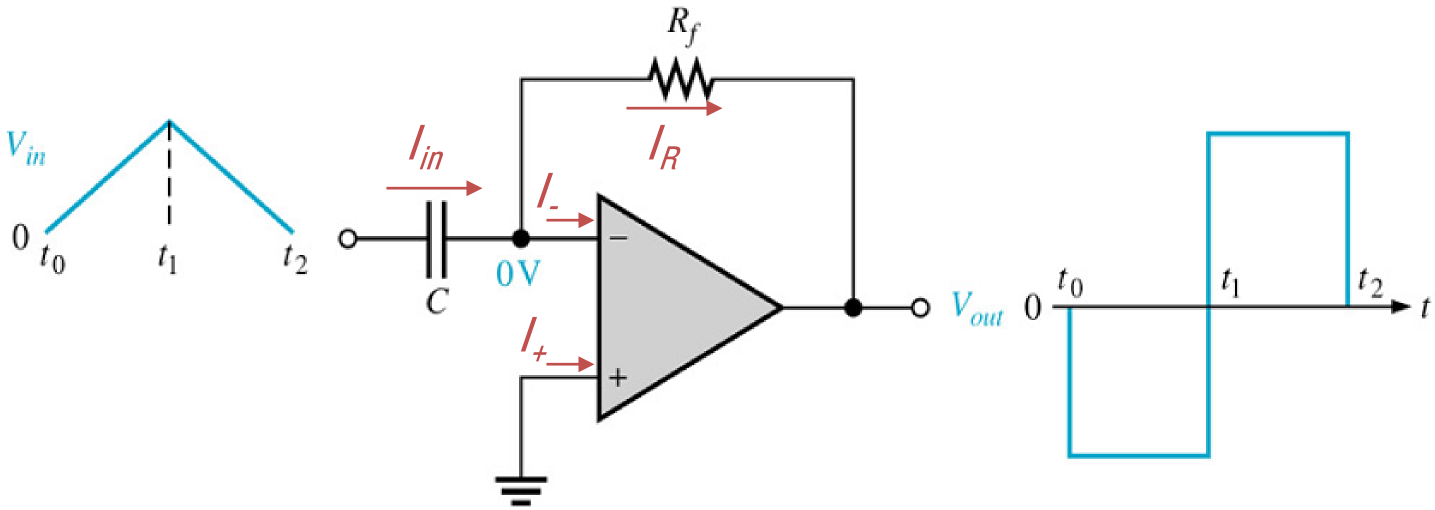


$$\frac{\Delta V_{out}}{\Delta t} = -\frac{V_{in}}{CR_i} = -\frac{2.5}{(0.01\mu)(10\text{k})} = -25\text{kV/s} = \text{-}25\text{mV}/\mu s$$

$$\Delta V_{out} = (25\text{mV}/\mu s)\Delta t = (25\text{mV}/\mu s)(200\mu s) = 5\text{V}$$

적분기와 미분기

미분기 (Differentiator)

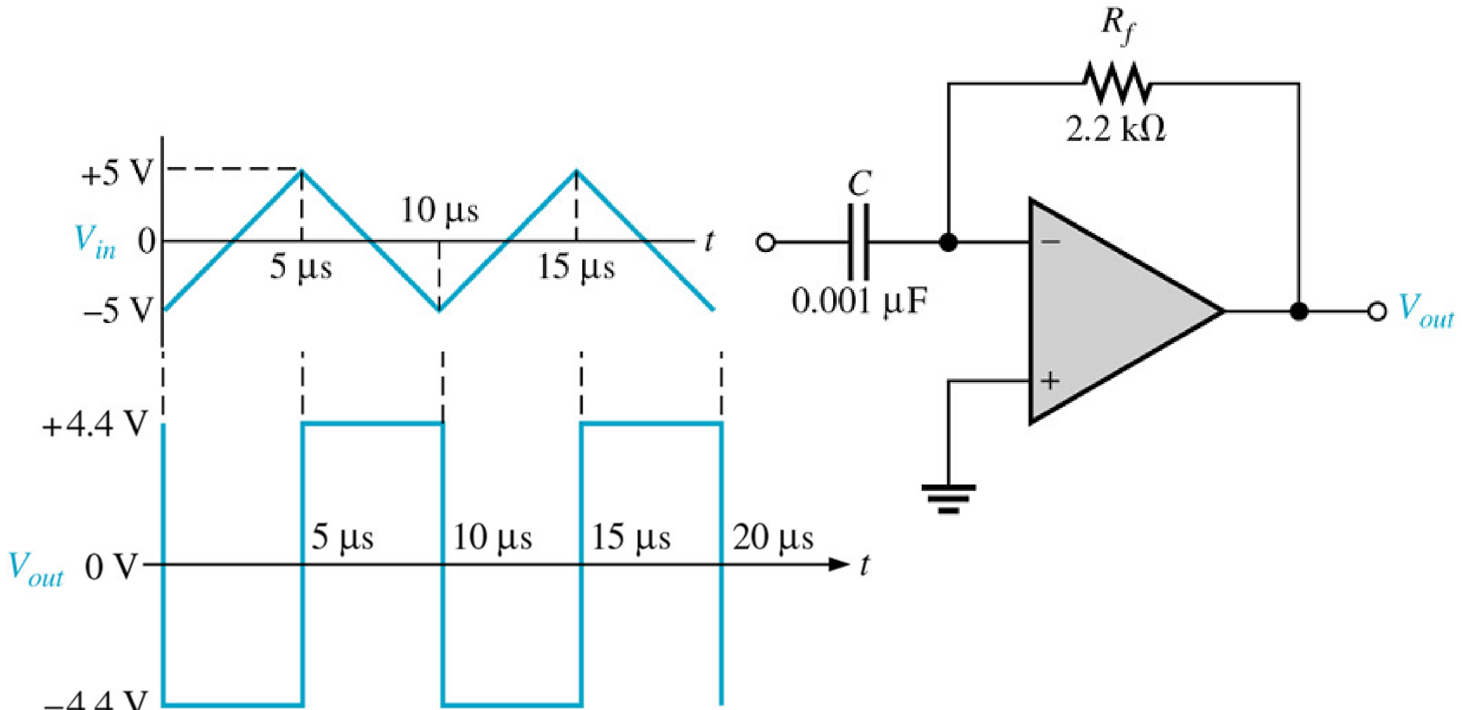


$I_+ = I_- = 0$, $V_+ = V_- = 0$ V (가상접지)
$Q = I_c t = CV_C = CV_{in}$
$V_{in} = (I_{in}/C)t$
$I_{in} = I_R \rightarrow (CV_{in}/t) = -V_{out}/R_f$

$$V_{out} = -CR_f\left(\frac{V_{in}}{t}\right) \longrightarrow V_{out} = -CR_f\frac{dV_{in}}{dt}$$

적분기와 미분기

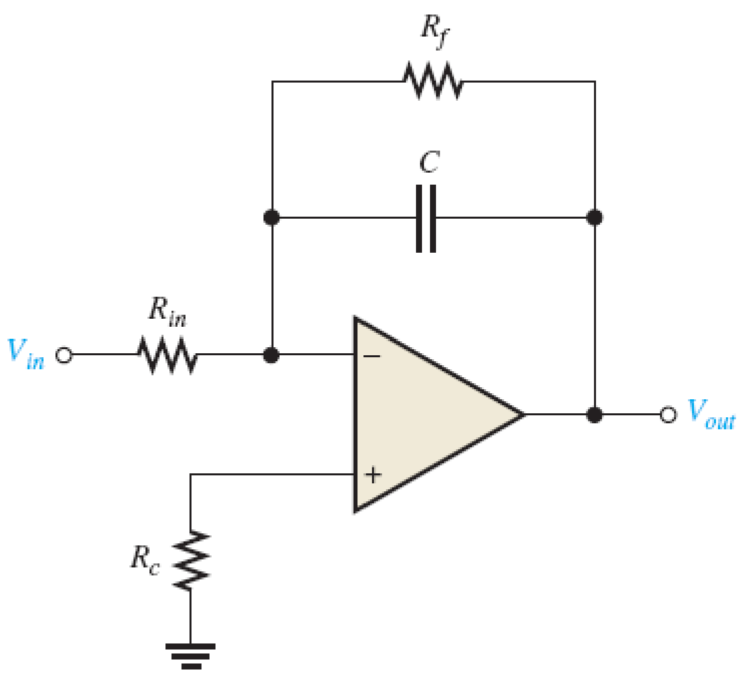
예제 13-11



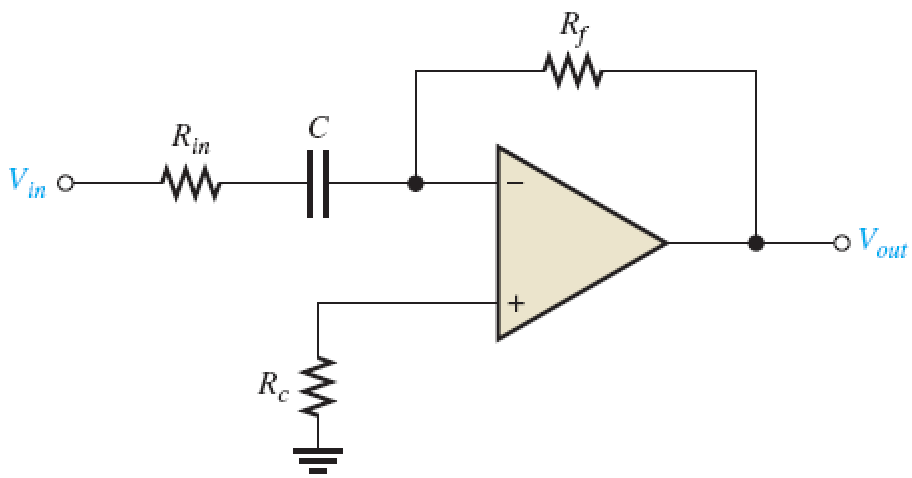
$$V_{out} = -CR_f\left(\frac{V_{in}}{t}\right) = -(0.001\mu)(2.2\text{k})\left[\frac{+5-(-5)}{5\mu}\right] = -4.4\text{V}$$

적분기와 미분기

The Practical Integrator



The Practical Differentiator



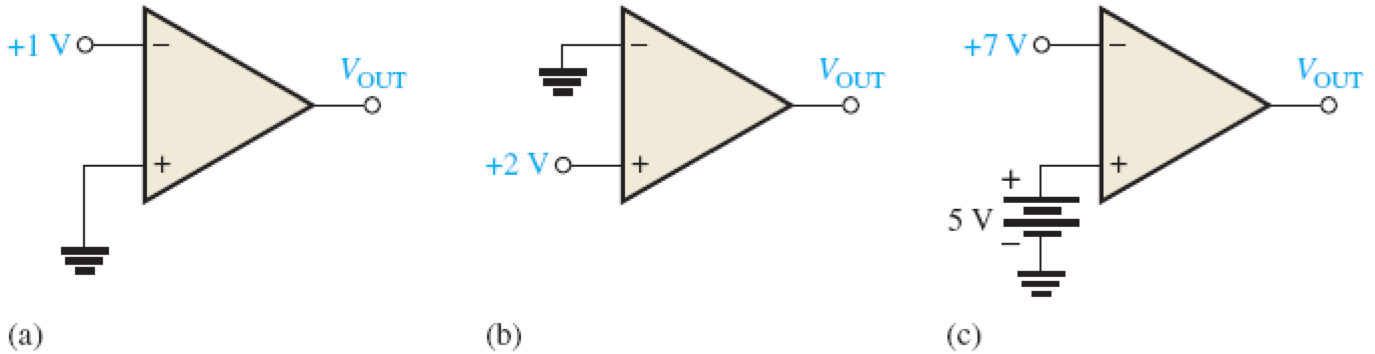
Homework

All Examples

Selected Problems(P.711-717):

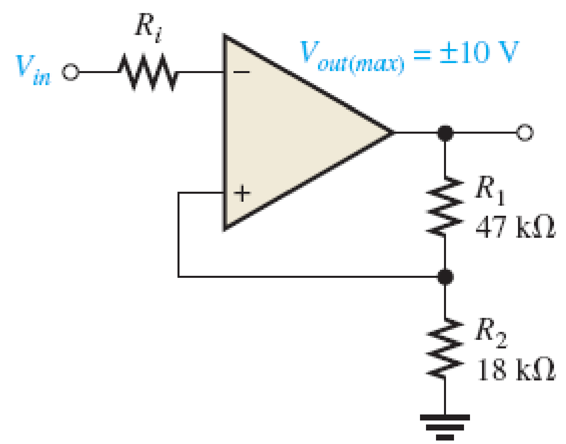
2,3,4,8,10,11,14,16,19

2. Determine the output level (maximum positive or maximum negative) for each comparator in Figure 13–60.



▲ FIGURE 13–60

▶ FIGURE 13–61



3. Calculate the V_{UTP} and V_{LTP} in Figure 13–61. $V_{out(max)} = \pm 10$ V.

4. What is the hysteresis voltage in Figure 13–61?

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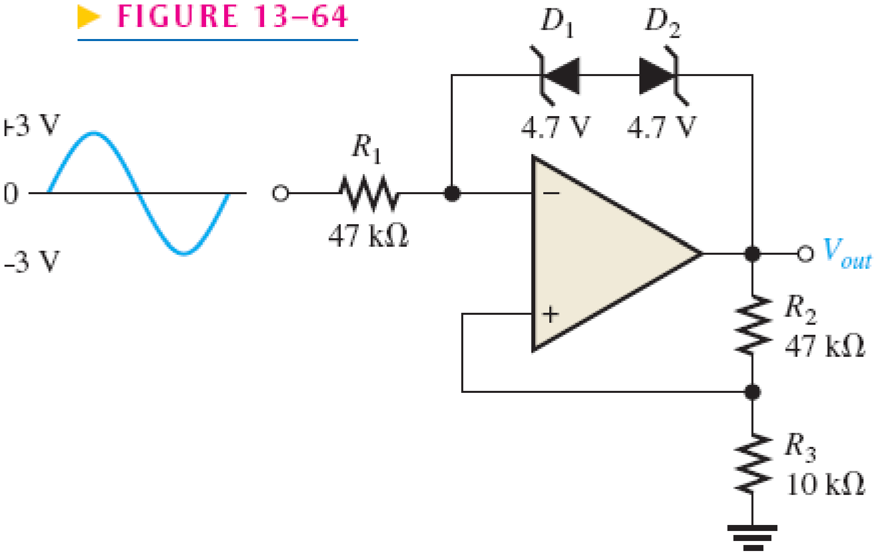
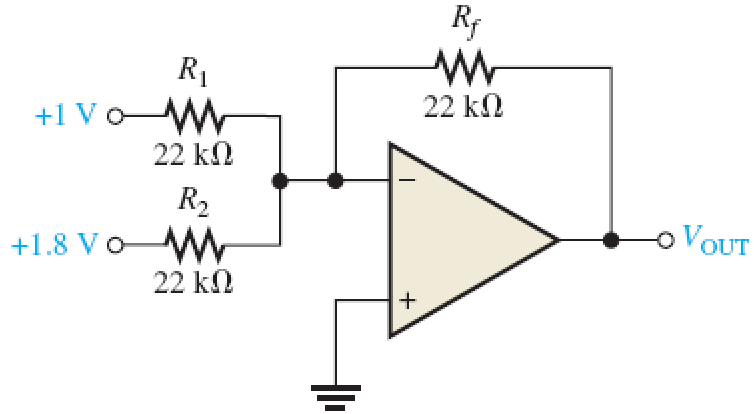
8. Determine the output voltage waveform in Figure 13–64.

▶ FIGURE 13–64



▶ FIGURE 13–66



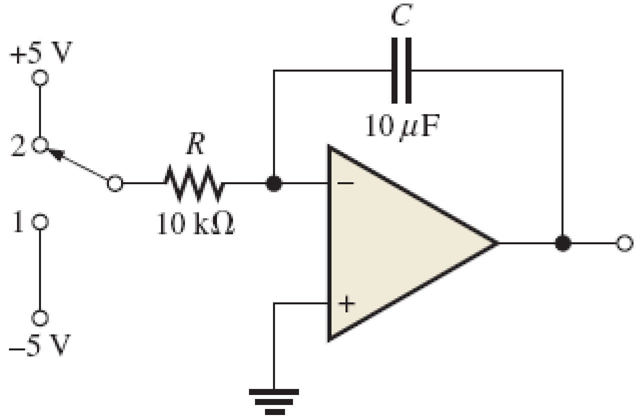
10. Refer to Figure 13–66. Determine the following:

(a) V_{R1} and V_{R2} (b) Current through R_f (c) V_{OUT}

11. Find the value of R_f necessary to produce an output that is five times the sum of the inputs in Figure 13–66.

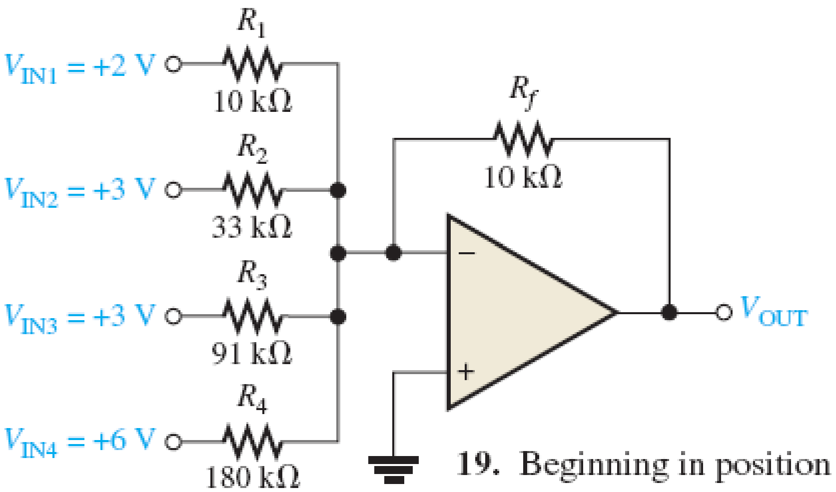
14. Determine the values of the input resistors required in a six-input scaling adder so that the lowest weighted input is 1 and each successive input has a weight twice the previous one. Use $R_f = 100\ \text{k}\Omega$.

▲ FIGURE 13–70



(b)

▶ FIGURE 13–67



19. Beginning in position 1 in Figure 13–70(b), the switch is thrown into position 2 and held there for 10 ms, then back to position 1 for 10 ms, and so forth. Sketch the resulting output waveform if its initial value is 0 V. The saturated output levels of the op-amp are ±12 V.

16. A triangular waveform is applied to the input of the circuit in Figure 13–69 as shown. Determine what the output should be and sketch its waveform in relation to the input.

▶ FIGURE 13–69