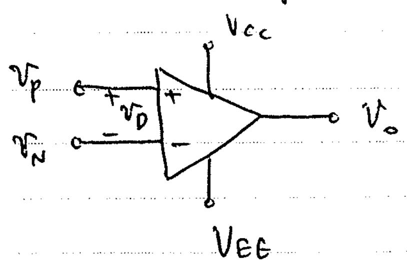
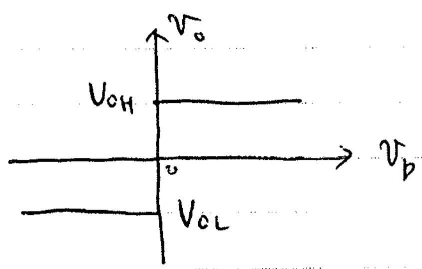
Chapter 9 Nonlinear Circuits

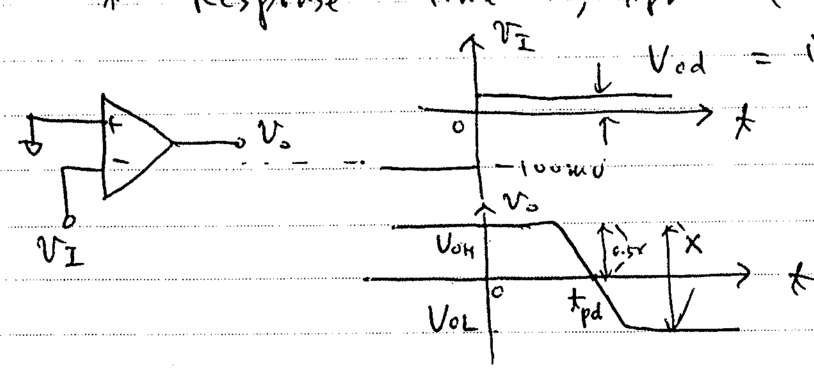
9.1 Voltage Comparators



$$v_O = \begin{cases} V_{OL} & \text{for } v_P < v_N \\ V_{OH} & \text{for } v_P > v_N \end{cases}$$



* Response Time, t_{PD} (= propagation delay)



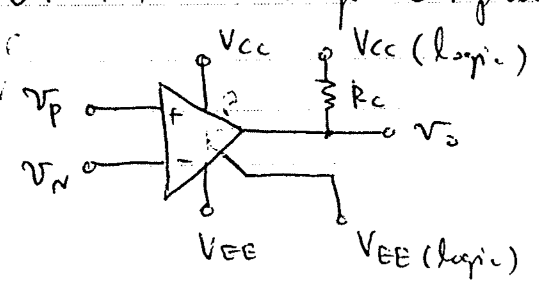
V_{od} = input overdrive

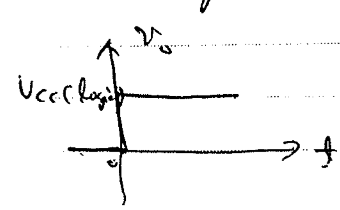
* Threshold Detector : fig 9.3 (p 403)

* LM 311 Voltage comparator : fig 9.5 (p 405)

($v_P > v_N \Rightarrow$? off

$v_P < v_N \Rightarrow$? on)



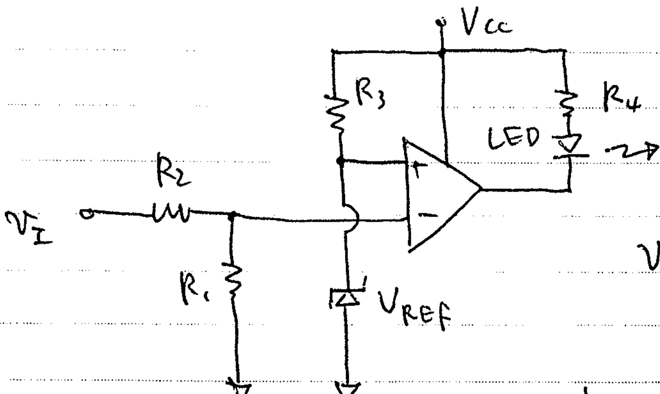


* High-Speed Comparator

- CMP-05 (AD)
- LT1016 (LT)

9.2 Comparator Applications

* Level Detector (or Threshold Detector)



$$V_N = \frac{R_1}{R_1+R_2} v_I$$

at $v_I = V_T$, $V_N = V_{REF}$

$$\Rightarrow V_T = \left(1+\frac{R_2}{R_1}\right) V_{REF}$$

(i) $v_I < V_T$, LED off
(ii) $v_I > V_T$, LED ON

* On-off Control

Fig 9.12 (p 412) : temp. controller (thermostat)

- LM335 : Temp. sensor
  $V(T) = T/100$, T in kelvin

T↑ → $V_N > V_p$ → Q_o saturate → LM 395 off → Heater off
T↓ → $V_N < V_p$ → Q_o cut off → LM 395 on → Heater ON

$v_I < V_{TL} \rightarrow Q_1$ OFF, Q_2 ON $\rightarrow v_o = 0$
$V_{TL} < v_I < V_{TH} \rightarrow Q_1$ OFF, Q_2 OFF $\rightarrow v_o = V_{CC}$
$v_I > V_{TH} \rightarrow Q_1$ ON, Q_2 OFF $\rightarrow v_o = 0$

- LM395 : high-beta power transistor
- LM329 : 6.9V reference diode

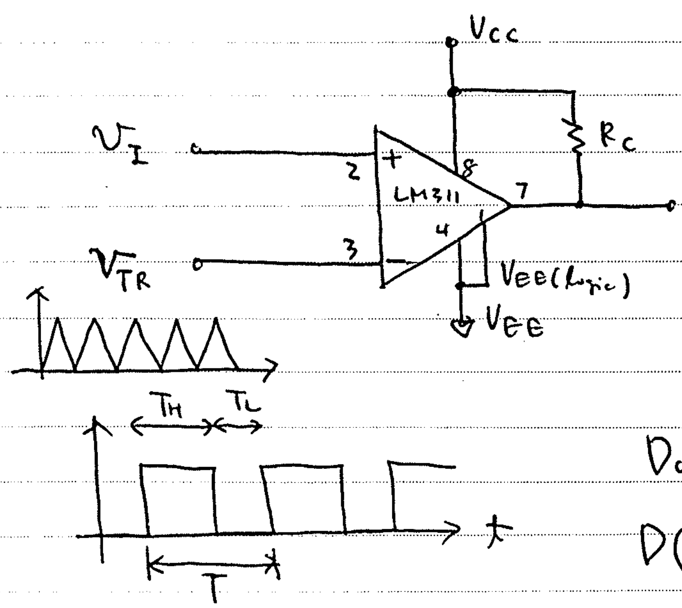
* Window Detectors (Window Comparator)

~~$v_I < V_{TL} \rightarrow Q_1$ ON, Q_2 OFF $\rightarrow v_o = 0$~~
~~$V_{TL} < v_I < V_{TH}$ — Q_1 ON, Q_2 ON~~

- Fig 9.13 (p413)
- Fig 9.14 (p413) : application

* Bar Graph Meters : Fig 9.15 (p415)
Fig 9.16 (p416)

* Pulse Width Modulation (PWM)



: Fig 9.18 (p417)

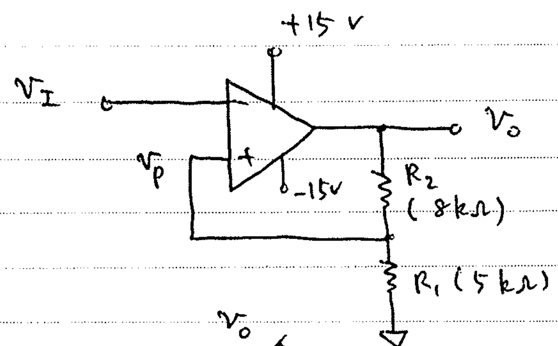
Duty cycle,

$$D(\%) = \frac{T_H}{T_L + T_H} \times 100$$

9.3 Schmitt Triggers

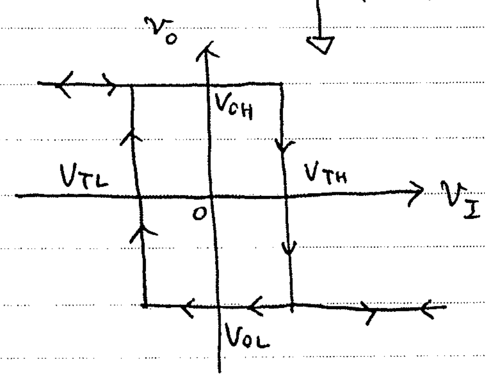
- positive feedback

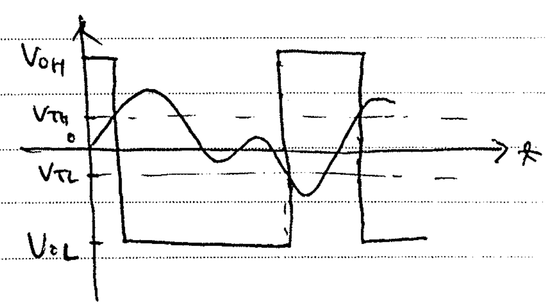
* Inverting Schmitt Trigger



$$V_{TH} = \frac{R_1}{R_1 + R_2} V_{OH}$$

$$V_{TL} = \frac{R_1}{R_1 + R_2} V_{OL}$$

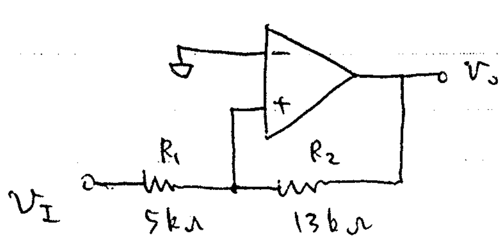


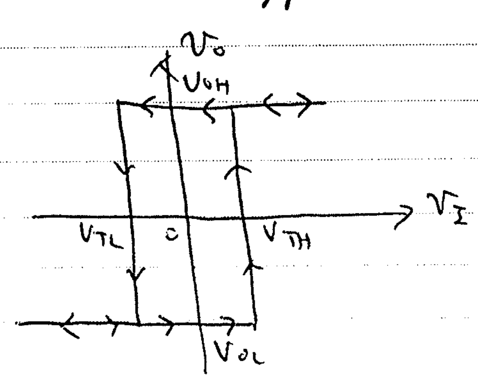


- hysteresis
- hysteresis width $\Delta V_T = V_{TH} - V_{TL}$

$$= \frac{R_1}{R_1 + R_2} (V_{OH} - V_{OL})$$

* Noninverting Schmitt Trigger



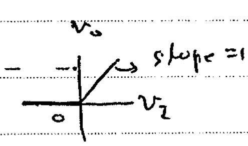


$$
\begin{cases}
V_{TH} = -\dfrac{R_1}{R_2} V_{OL} \\
V_{TL} = -\dfrac{R_1}{R_2} V_{OH} \\
\Delta V_T = \dfrac{R_1}{R_2} (V_{OH} - V_{OL})
\end{cases}
$$

* UTC offsetting in Single Supply Schmitt Trigger
- Fig 9.22 (p 421)
- Fig 9.23 (p 422)

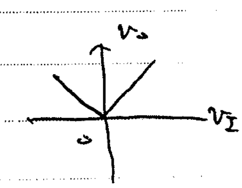
* Hysteresis
- Eliminate comparator chatter (Fig 9.24 & Fig 9.25 in p 423)

9.4 Precision Rectifiers



- HWR (half-wave rectifier)

$$
v_o = \begin{cases} v_I & \text{for } v_I > 0 \\ 0 & \text{for } v_I \le 0 \end{cases}
$$



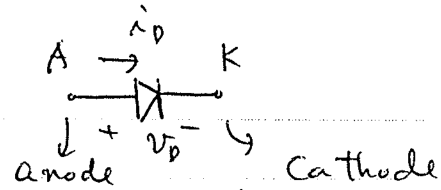
- FWR (full-wave rectifier)

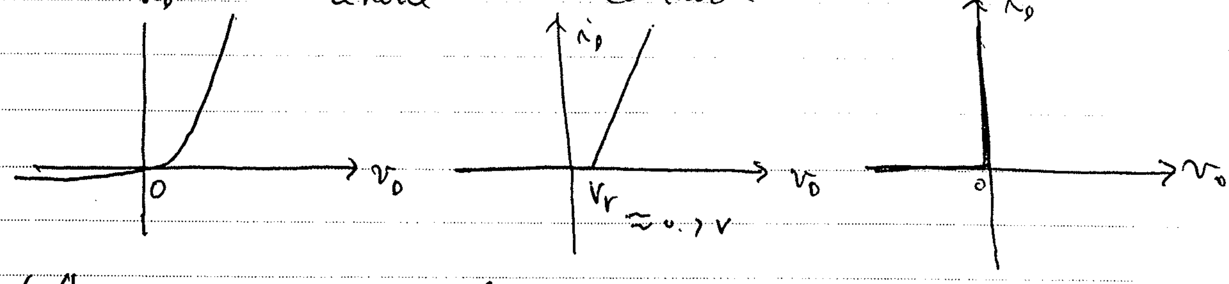
$$
v_o = \begin{cases} v_I & \text{for } v_I > 0 \\ -v_I & \text{for } v_I \le 0 \end{cases}
$$

OR $v_o = |v_I|$

$\Rightarrow$ absolute-value circuit

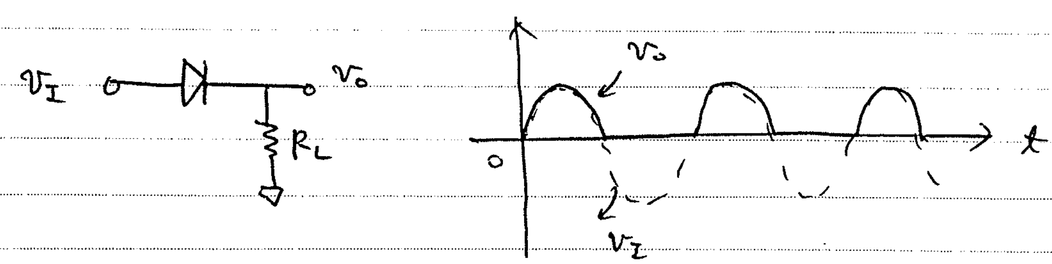
* Diode



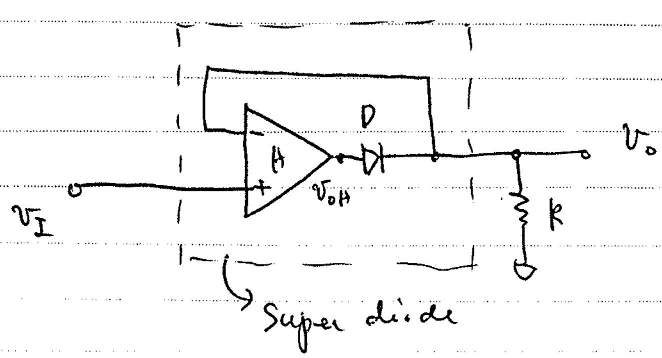


(실제 diode)   (선형 model)   (이상적인 diode)

$$\begin{cases} v_D > V_r & : \text{forward bias, ON} \\ v_D < V_r & : \text{reverse bias, off} \end{cases}$$



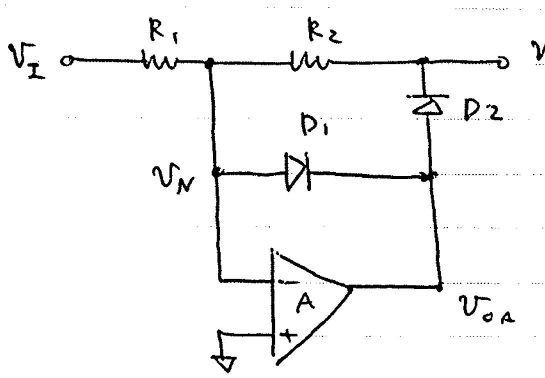
* Half-Wave Rectifier



(i) $v_I > 0 \rightarrow v_{OA} > 0 \rightarrow D$ ON (fig 9.28a)
$\rightarrow v_O = v_I$, $v_{OA} = v_O + V_r$

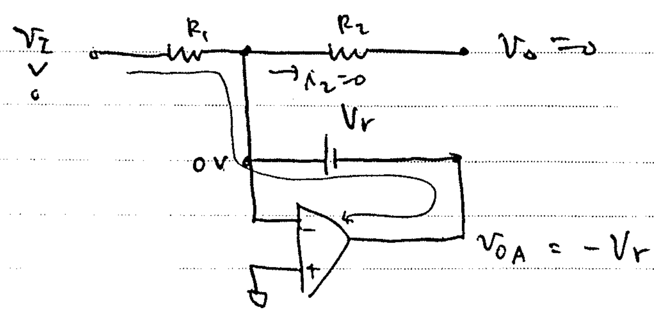
(ii) $v_I < 0 \rightarrow v_{OA} < 0 \rightarrow D$ off (fig 9.28b)
$\rightarrow v_O = 0$, $v_{OA} = V_{OL}$

* Improved HWR

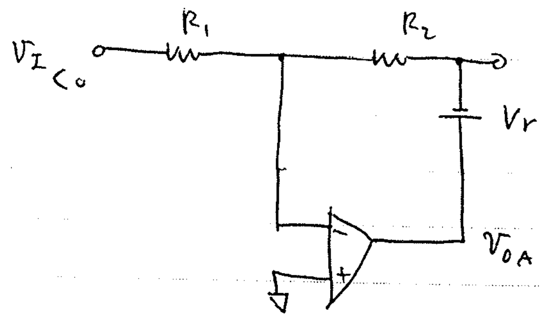


$-V_{D1(on)}$

(i) $v_I > 0 \rightarrow D_1$ ON $\rightarrow v_N = 0$, $v_{OA} = -V_r$
$\rightarrow D_2$ off $\rightarrow v_O = 0$



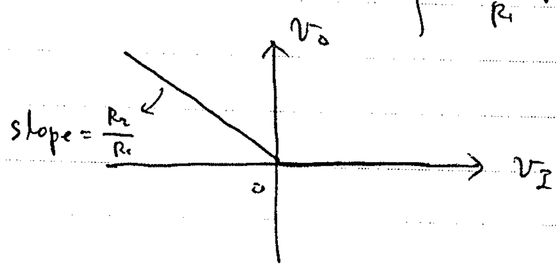
(ii) $v_I < 0 \rightarrow$ ~~D1~~ $v_{OA} > 0 \rightarrow D_2$ ON $\rightarrow v_N = 0$,
D_1 off $\rightarrow \begin{cases} v_O = -\dfrac{R_2}{R_1} v_I \\ v_{OA} = v_O + V_r \end{cases}$



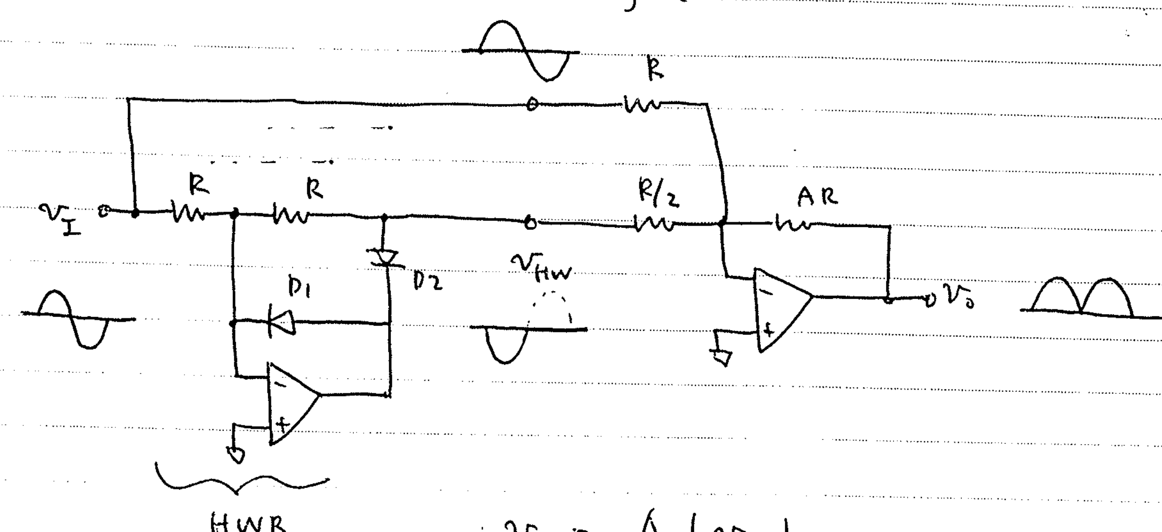
$$v_o = -\frac{R_2}{R_1} v_I$$

$$v_{OA} = v_o + V_r$$

$$\Rightarrow \quad v_o = \begin{cases} 0 & \text{for } v_I > 0 \\ -\frac{R_2}{R_1} v_I & \text{for } v_I < 0 \end{cases}$$



* Full-Wave Rectifier

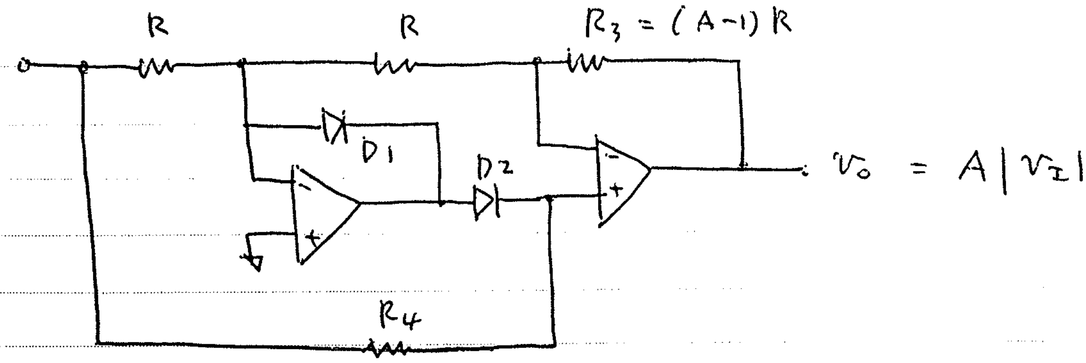


$$v_o = A\,|v_I|$$

$$= -A v_I - 2A v_{HW}$$

$$= -A\left(v_I + 2 v_{HW}\right)$$

예는



* Ac - dc Converter

$$V_{avg} = \frac{1}{T}\int_0^T |v(t)|\,dt$$

정류후 평균치 ↙

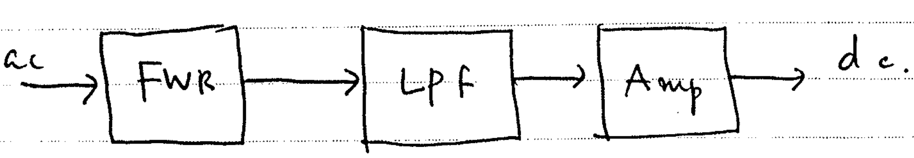
↗ 정현파의 경우

$v(t) = V_m \sin 2\pi f t$ 이면 $V_{avg} = \frac{2V_m}{\pi} = 0.637V_m$

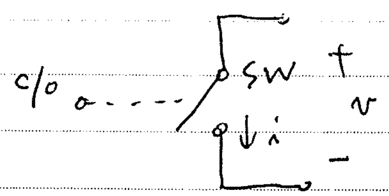
$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)\,dt}$$

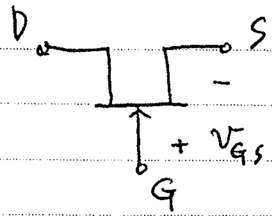
$v(t) = V_m \sin 2\pi f t$ 이면 $V_{rms} = \frac{V_m}{\sqrt{2}} = 0.707V_m$

Fig 9.32 (p 430) : rms calibration.



9.5 Analog Switch

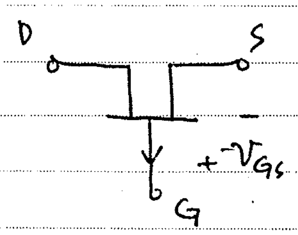




n-channel JFET

$\begin{cases} v_{GS} = 0 \rightarrow D-S \text{ ON} \\ v_{GS} < V_{GS(off)} \rightarrow D-S \text{ off} \end{cases}$

$-4V \le V_{GS(off)} \le -10V$

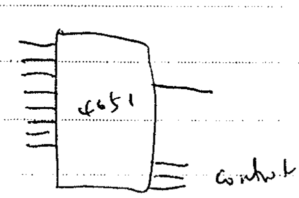


p-channel JFET

$\begin{cases} v_{GS} = 0 \rightarrow D-S \text{ ON} \\ v_{GS} > V_{GS(off)} \rightarrow D-S \text{ off} \end{cases}$

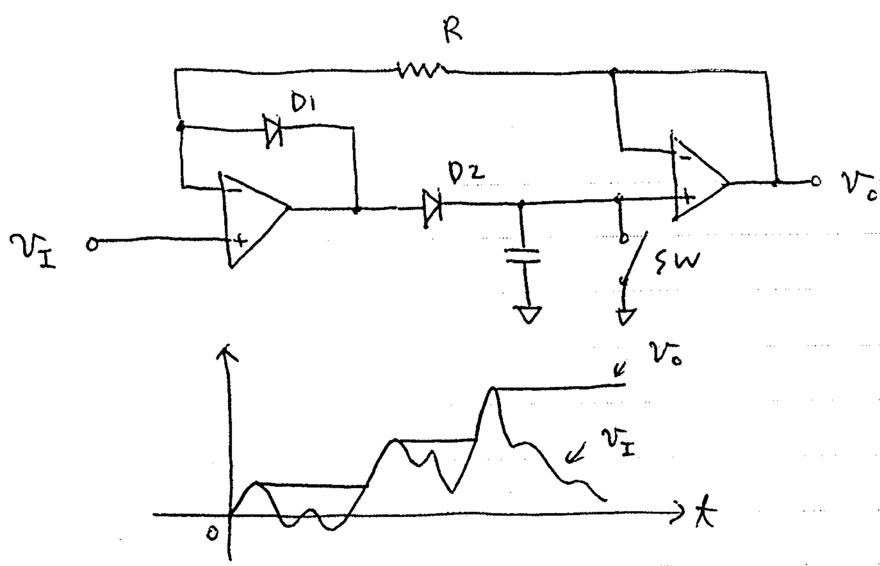
$4V \le V_{GS(off)}$

◎ MOSFET Switch.



◎ CMOS Mux
- 4051
- 4052

9.6 Peak Detector



9.7 Sample-And-Hold Amplifier

Fig 9.44 & Fig 9.45 (p 444)