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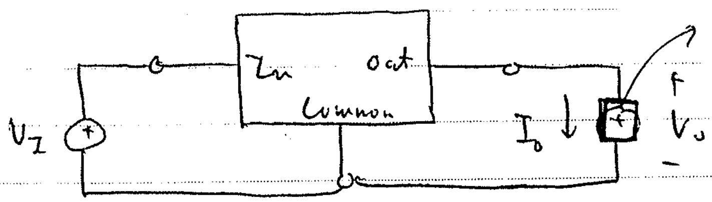
Chapter 11 Voltage References and Regulators



- V_I : unstable input voltage
- V_o : stable output voltage across load.

- stability : 1 ~ 40 ~ 100 ppm/°C
- accuracy

11.1 Performance Specifications

* Line and Load Regulation

Line regulation $= \dfrac{\Delta V_o}{\Delta V_I}$ OR $= \dfrac{\Delta V_o / V_o}{\Delta V_I} \times 100\ (\%)$
(= input ″)
(= supply ″)
[mV/V] [%/V]

Ripple rejection ratio (RRR) $= 20 \log_{10} \dfrac{V_{ri}}{V_{ro}}$

- V_{ri} : input ripple
- V_{ro} : output ripple

Load regulation $= \dfrac{\Delta V_o}{\Delta I_o}$ OR $= \dfrac{\Delta V_o / V_o}{\Delta I_o} \times 100 (\%)$
[mV/mA] [%/mA]

* Thermal coefficient

Thermal coeff. of V_o $= TC(V_o) = \dfrac{\Delta V_o}{\Delta T}$ $[mV/°C]$ OR $= \dfrac{\Delta V_o/V_o}{\Delta T} \times 100$ $[\%/°C]$ (%

OR $= \dfrac{\Delta V_o/V_o}{\Delta T} \times 10^6$ $[ppm/°C]$

* Output noise
* Long-term stability

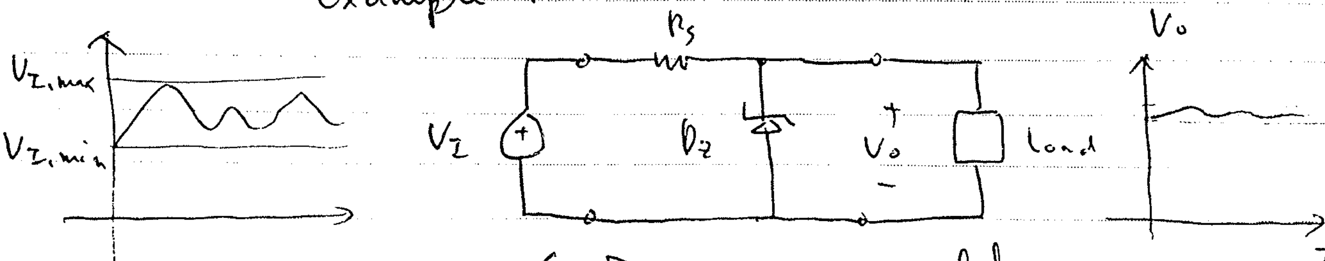
REF101 $\begin{cases} \text{output noise} = 6\,\mu V_{pp} \text{ over } 0.1 \sim 10\,Hz \\ \text{stability} = 50\ ppm/(1000\,h) \end{cases}$

* Dropout voltage

$V_{DO} = |V_I - V_o|_{min}$ for normal operation.

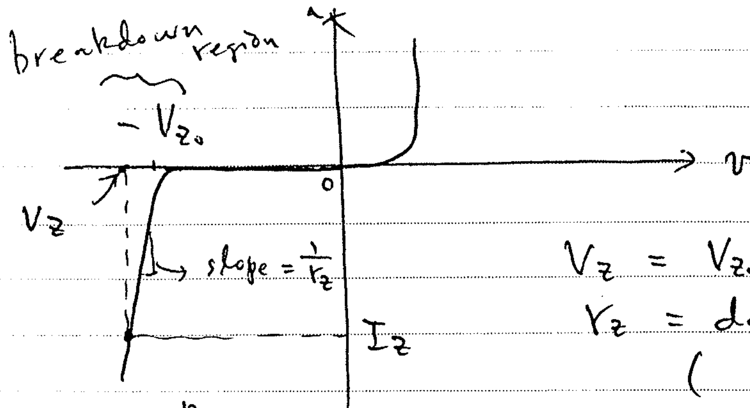
* Start-up circuitry
(prevent the circuit from latching in an undesirable initial state)

* Example 1



(Zener diode regulator)

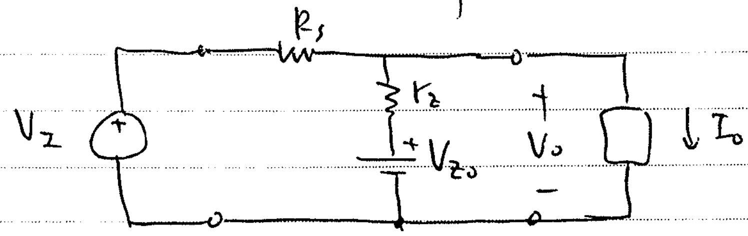
Zener diode $i-v$ characteristic



$$V_Z = V_{Z0} + r_Z I_Z$$

r_Z = dynamic resistance

(수 ~ 5십 Ω)



Zener diode spec은 50% power rating에서 정함

$\Rightarrow$ 6.8 V, 0.5 W, 10 Ω zener의 경우

$$I_Z = \frac{P_Z}{2} \Big/ V_Z = \frac{500/2}{6.8} = 37 \text{ mA}$$

50% power rating이므로

$$V_{Z0} = V_Z - r_Z I_Z = 6.8 - 10 \times 37 \times 10^{-3}$$
$$= 6.43 \text{ V}.$$

Zener diode는 breakdown region에 있어야 함

$\Downarrow$

$$I_Z \geq I_{Z(min)}$$

$\Downarrow$

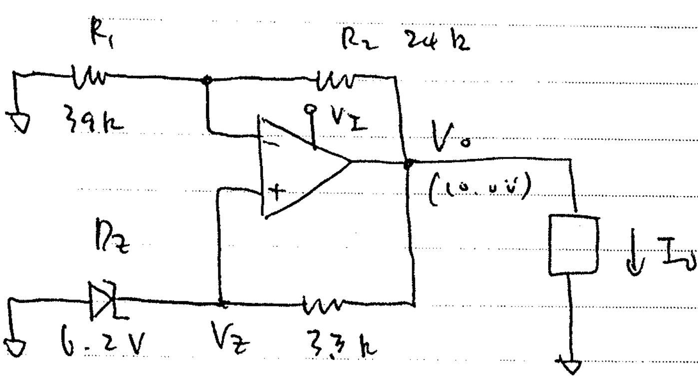
$$R_s \leq \frac{V_{I(min)} - V_{Z0} - r_Z I_{Z(min)}}{I_{Z(min)} + I_{o(max)}}$$

with $\quad I_{Z(min)} \simeq \frac{1}{4} I_{o(max)}$

$$V_o = \frac{r_z}{R_s + r_z} V_I + \frac{R_s}{R_s + r_z} V_{Z_0} - (R_s \,//\, r_z) I_o$$

$$\begin{cases} \text{Line regulation} = \dfrac{r_z}{R_s + r_z} \\ \text{Load regulation} = -(R_s \,//\, r_z) \end{cases}$$

* Example 2



V_I : 12 ~ 36 V

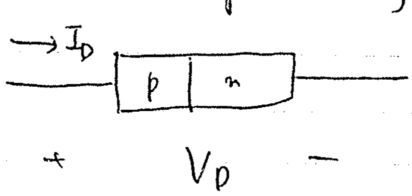
: improved voltage reference circuit (self-regulation)

$$V_o = \left(1 + \frac{R_2}{R_1}\right) V_Z$$

$$\text{Load regulation} \simeq \frac{-z_o}{1 + a\beta}$$

$$\text{Line regulation} = \left(1 + \frac{R_2}{R_1}\right) \times \left(\frac{1}{PSRR} + \frac{0.5}{CMRR}\right)$$

11.2 Voltage References



$$V_D = V_T \ln\left(\frac{I_D}{I_s}\right)$$

V_T : Thermal voltage
I_s : reverse saturation current

$$V_T = kT/q$$

$$\Downarrow$$

$$TC(V_T) = k/q = 0.0862 \text{ mV}/^\circ C$$

$$TC(V_D) = \frac{\partial V_D}{\partial T} = -\left(\frac{V_{G0} - V_D}{T} + \frac{3k}{q}\right)$$

예 : $V_D = 650 \text{mV}$ at $25^\circ C$

$TC(V_D) \simeq -2.1 \text{ mV}/^\circ C$

* Thermally compensated Zener Diode Reference

Fig 11.5 (p511)

Fig 11.6 (p512) REF 101 (BB)

Fig 11.8 (p513) LM 329 (NS)

* Bandgap Voltage References

LM 385 2.5 V micropower ref. diode (NS)

$TC = 20 \text{ ppm}/^\circ C$

$r_z = 0.4 \Omega$

$I_z = 20 \mu A \sim 20 \text{mA}$

REF-05 5 V precision ref. (AD)

$V_o = 5.00 V \pm 30 \text{mV}$

$TC = 3 \text{ ppm}/^\circ C$

Line Reg. = $0.006 \%/V$

Load reg. = $0.005 \%/\text{mA}$

Output noise = $10 \mu V_{pp}$ (0.1 ~ 10Hz)

Stability = 65 ppm / 1000h

* Monolithic Temperature Sensor

전압출력 → LM335 : fig 11.10 (p516), NS

$$TC(V) = 10\ mV/K$$
$$V(25°C) = (10\ mV/K) \times (273.2 + 25)K = 2.982\ V$$
accuracy = ±0.5°C ~ ±1°C

I_Z = 0.5 ~ 5 mA

$r_Z \leq 1\ \Omega$.

전류출력 → AD590 : fig 11.10 (p516), AD

$$TC(I) = 1\ \mu A/K$$
$$TC(V) = R \times (1\ \mu A/K) = R\ \mu V/K$$
accuracy = ±0.5°C ~ ±0.3°C

V_Z = 4 ~ 30 V

11.3 Voltage Reference Applications

Fig 11.11 (p517) Buffered 10-V reference
Fig 11.12 (p518)
Fig 11.13 (p519) Variable voltage reference
Fig 11.14 (p519) Current source
Fig 11.15
Fig 11.16 (p521) Current boosting
Fig 11.17 (p521) Temp. sensor
Fig 11.18 (p522) Thermocouple

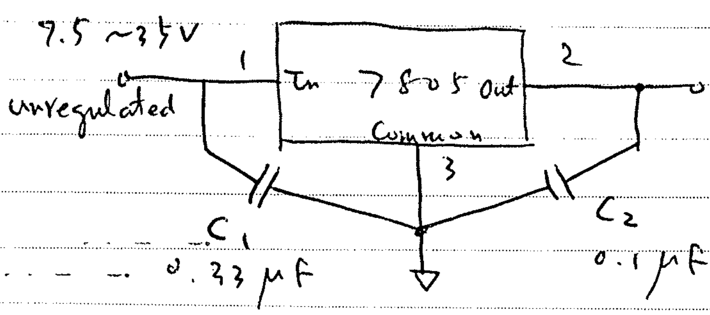
11.4 Linear Regulator

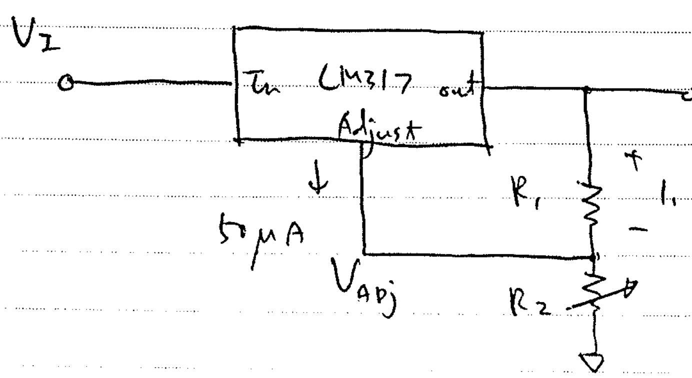
* Monolithic Voltage Regulator

- 78○○ serise : positive regulator
- 79○○ 〃 : negative 〃

(Fig 11.23
(Fig 11.24 : 7805 data sheet.

- LM 317 (NS) : adjustable, positive
- LM 337 (NS) : 〃 , negative.





$$V_o = \left(1+\frac{R_2}{R_1}\right) \times 1.25 + R_2 \times 50(\mu A)$$

V_o : 1.25 ~ 35 V

Fig 11.29 (p572) : power sources

◎ $\eta(\%) = \frac{V_o}{V_I} \times 100$ (efficiency)

PAGE

* Thermal Consideration

{ Use " heatsink" : fig 11.32 (p535)
{ Forced air cooling.

11.6 Switching Regulator

- High effiency by switching operation
- Fig 11.36 (b) : p540

* LT1070 monolithic switching regulator
- Fig. 11.47 , Fig 11.48 (p 555)