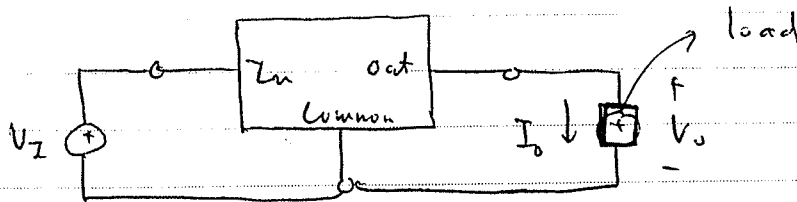


Chapter 11 Voltage References and Regulators



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

Stability : $1 \sim 40 \sim 100 \text{ ppm}/^\circ\text{C}$
 accuracy

11.1 Performance Specifications

* Line and Load Regulation

Line regulation $\equiv \frac{\Delta V_o}{\Delta V_I}$ OR $= \frac{\Delta V_o/V_o}{\Delta V_I} \times 100 (\%)$
 (= input ") $[\text{mV/V}]$ $[\%/V]$
 (= supply ")

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

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

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

* Thermal coefficient

Thermal coeff. of $V_o = TC(V_o) = \frac{\Delta V_o}{\Delta T}$ OR $= \frac{\Delta V_o/V_o}{\Delta T} \times 100$ (%)
 [mv/°C] [%/°C]
 OR $= \frac{\Delta V_o/V_o}{\Delta T} \times 10^6$ [ppm/°C]

* Output noise

* Long-term stability

REF-101 } output noise = 6 μ V_{pp} over 0.1 ~ 10kHz
 stability = 50 ppm/(1000h)

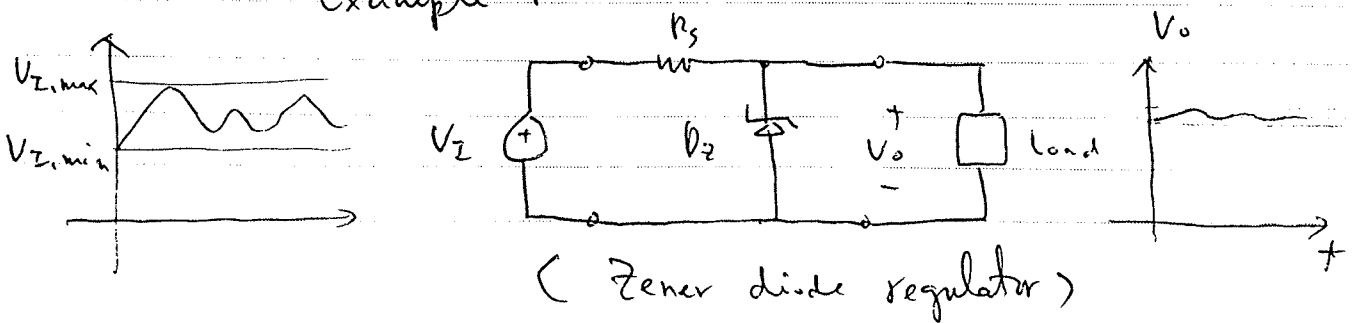
* Dropout voltage

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

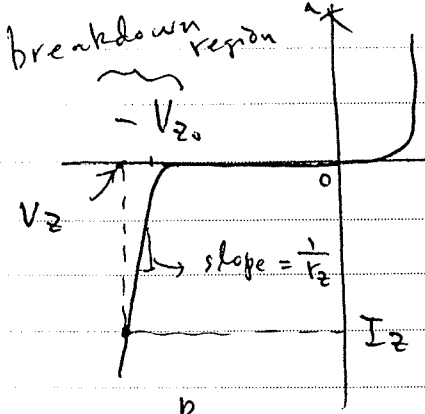
* Start-up circuitry

(prevent the circuit from latching in an undesirable initial state)

* Example 1

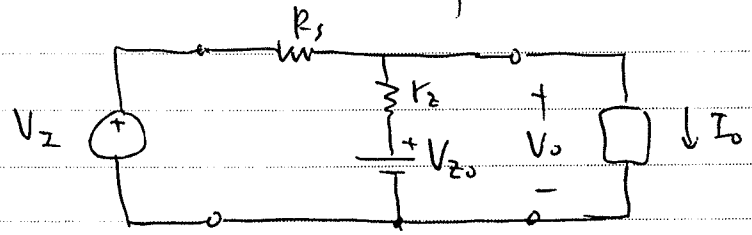


Zener diode $i-v$ characteristic



$$V_z = V_{z0} + r_z I_z$$

$r_z = \text{dynamic resistance}$
($\approx 5 \text{ } \Omega$)



Zener diode spec is 50% power rating \Rightarrow

\Rightarrow $6.8 \text{ V}, 0.5 \text{ W}, 10 \text{ } \Omega$ Zener = 1

$$I_z = \frac{P_z}{V_z} = \frac{0.5 \text{ W} / 2}{6.8} = 37 \text{ mA}$$

\hookrightarrow 50% power rating is

$$V_{z0} = V_z - r_z I_z = 6.8 - 10 \times 37 \times 10^{-3}$$

$$= 6.43 \text{ V}$$

Zener diode is breakdown region \Rightarrow $I_z \geq I_z(\text{min})$

$$I_z \geq I_z(\text{min})$$

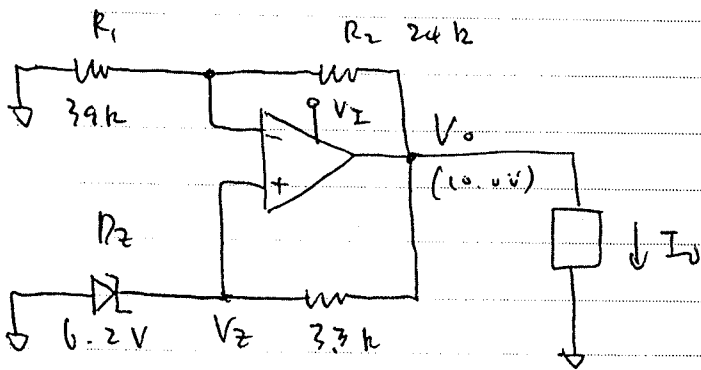
$$R_s \leq \frac{V_I(\text{min}) - V_{z0} - r_z I_z(\text{min})}{I_z(\text{min}) + I_o(\text{max})}$$

with $I_z(\text{min}) \approx \frac{1}{4} I_o(\text{max})$

$$V_o = \frac{r_z}{R_s + r_z} V_I + \frac{R_s}{R_s + r_z} V_{z0} - (R_s \parallel r_z) I_o$$

$$\left\{ \begin{aligned} \text{Line regulation} &= \frac{r_z}{R_s + r_z} \\ \text{Load regulation} &= - (R_s \parallel r_z) \end{aligned} \right.$$

* Example 2



$V_I : 12 \sim 36V$

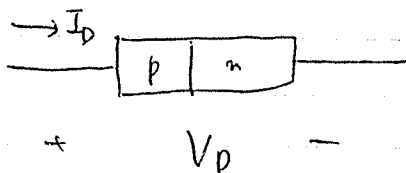
: improved voltage reference circuit (self-regulation)

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

$$\text{Load regulation} \approx \frac{-r_o}{1 + \beta}$$

$$\text{Line regulation} = \left(1 + \frac{R_2}{R_1}\right) \times \left(\frac{1}{\beta SRR} + \frac{0.5}{CRR}\right)$$

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

$$V_T = kT/q$$

↓

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

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

ex: $V_D = 650 \text{ mV}$ at 25°C

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

* Thermally Compensated Zener Diode Reference

Fig 11.5 (p 511)

Fig 11.6 (p 512) REF101 (BB)

Fig 11.8 (p 513) LM329 (NS)

* Bandgap Voltage References

LM385 2.5V micropower ref. diode (NS)

$$\left(\begin{array}{l} TC = 20 \text{ ppm}/^\circ\text{C} \\ r_z = 0.4 \Omega \\ I_z = 20 \mu\text{A} \sim 20 \text{ mA} \end{array} \right.$$

REF-05 5V precision ref. (AD)

$$\left(\begin{array}{l} V_o = 5.00 \text{ V} \pm 30 \text{ mV} \\ TC = 3 \text{ ppm}/^\circ\text{C} \\ \text{Line Reg.} = 0.006\%/\text{V} \\ \text{Load Reg.} = 0.005\%/\text{mA} \\ \text{Output noise} = 10 \mu\text{V}_{\text{pp}} (0.1 \sim 10 \text{ Hz}) \\ \text{Stability} = 65 \text{ ppm}/\text{month} \end{array} \right.$$

* Monolithic Temperature Sensor

→ LM 335 : Fig 11.10 (p 516) , NS
7204223

$$\left\{ \begin{array}{l} T_C(V) = 10 \text{ mV/K} \\ V(25^\circ\text{C}) = (10 \text{ mV/K}) \times (273.2 + 25) \text{ K} \\ \quad = 2.982 \text{ V} \\ \text{accuracy} = \pm 0.5^\circ\text{C} \sim \pm 1^\circ\text{C} \\ I_Z = 0.5 \sim 5 \text{ mA} \\ R_Z \leq 1 \Omega \end{array} \right.$$

7204223

→ AD 590 : Fig 11.10 (p 516) , AD

$$\left\{ \begin{array}{l} T_C(I) = 1 \mu\text{A/K} \\ T_C(V) = R \times (1 \mu\text{A/K}) = R \mu\text{V/K} \\ \text{accuracy} = \pm 0.5^\circ\text{C} \sim \pm 3^\circ\text{C} \\ V_Z = 4 \sim 30 \text{ V} \end{array} \right.$$

11.3 Voltage Reference Applications

Fig 11.11 (p 517) Buffered 1.0-V reference

Fig 11.12 (p 518)

Fig 11.13 (p 519) Variable voltage reference

Fig 11.14 (p 519) Current source

Fig 11.15

Fig 11.16 (p 521) Current boosting

Fig 11.17 (p 521) Temp. sensor

Fig 11.18 (p 522) Thermocouple

11.4 Linear Regulator

* Monolithic Voltage Regulator

$\left\{ \begin{array}{l} 7800 \text{ Series} : \text{positive regulator} \\ 7900 \text{ " } : \text{negative "} \end{array} \right.$

(Fig 11.23

(Fig 11.24 : 7805 data sheet.

$\left\{ \begin{array}{l} LM 317 (NS) : \text{adjustable, positive} \\ LM 337 (NS) : \text{" , negative} \end{array} \right.$

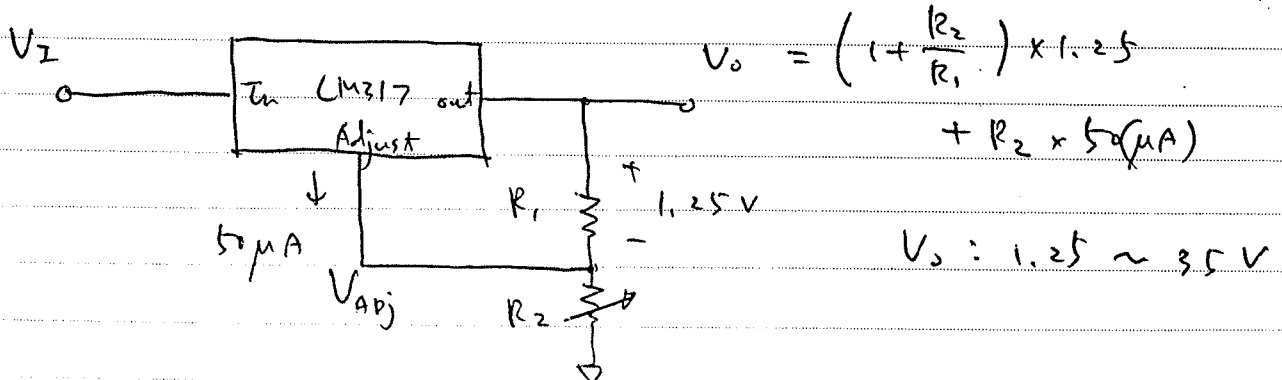
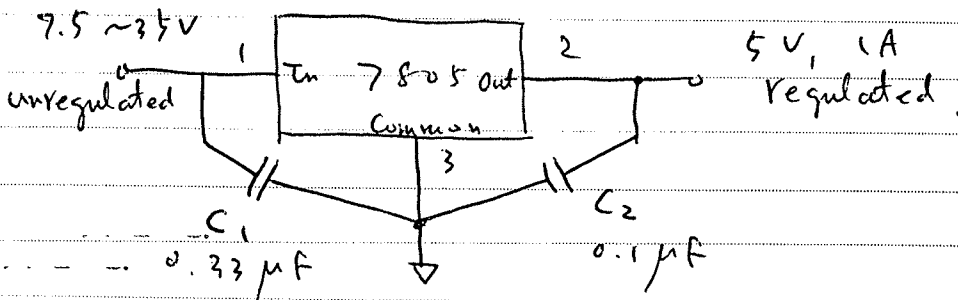


Fig 11.29 (p572)

: power sources

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

* Thermal Consideration

} Use " heatsink " : fig 11.32 (p 535)
} Forced air cooling.

11.6 Switching Regulator

- High efficiency by switching operation
- Fig 11.36 (b) : p 540

* LT 1070 Monolithic Switching Regulator
- Fig. 11.47, Fig 11.48 (p 535)