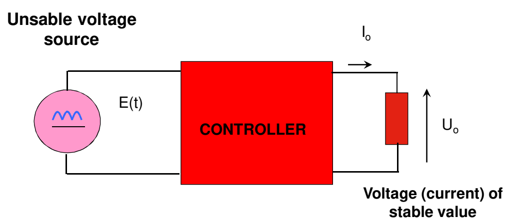
Wroclaw University of Science and Technology

Power supply:
- linear voltage (current) controllers.

Voltage controller



Parameters of voltage controllers (current)

• Input voltage • Range of input voltage • Nominal and maximum output current • Shortage current • Range of ambient temperature • Efficiency	• Output current • Of output voltage • Open voltage • Range of ambient temperature • Efficiency

Basic parameters of linear voltage controllers

Load regulation (dynamic output resistivity)

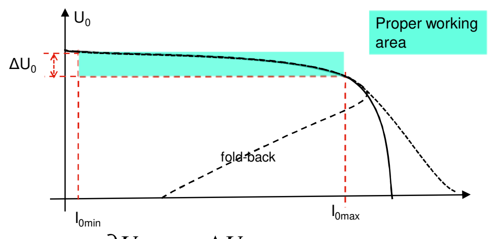
Long-term instability

$$\Delta U_o = \frac{\partial U_o}{\partial E}\Delta E + \frac{\partial U_o}{\partial I_o}\Delta I_o + \frac{\partial U_o}{\partial T}\Delta T + \frac{\partial U_o}{\partial t}\Delta t$$

Line regulation & ripple rejection

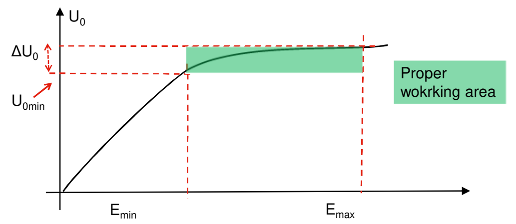
Output voltage temp. coefficient

Load regulation
(output characteristics of the voltage stabilizer)



$$\frac{\partial U_o}{\partial I} \approx \frac{\Delta U_0}{I_{\max} - I_{\min}} \approx R_{output}$$

Line regulation
(transfer characteristics of the voltage stabilizer)



$$E_{\min} - U_{o\min} \approx U_{DROPOUT}$$

$$\frac{\partial U_o}{\partial E} \approx \frac{\Delta U_0}{E_{\max} - E_{\min}}$$

Basic parameters of current controller

Line regulation (dynamic output conductivity)

Long-term intability

$$\Delta I_o = \frac{\partial I_o}{\partial E}\Delta E + \frac{\partial I_o}{\partial U_o}\Delta U_o + \frac{\partial I_o}{\partial T}\Delta T + \frac{\partial I_o}{\partial t}\Delta t$$

Line rgulation & ripple rejetion

Output currrent temp coefficient

Parametric voltage controller

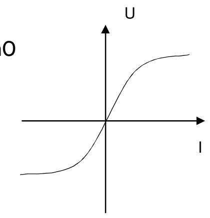
(outpu voltage depends of a „parameter” of the device)

Varistor

metal-oxide varistor (MOV) ZnO

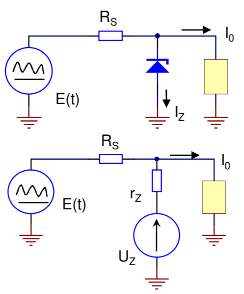
Multi-layer varistor (MLV)

$$U = CI^{0.14 \div 0.5}$$

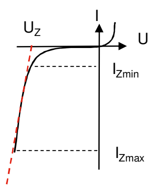


Parametric controller

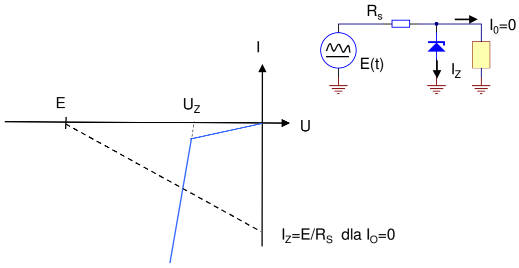
(output voltage depends on a „parameter” of device - no active device)



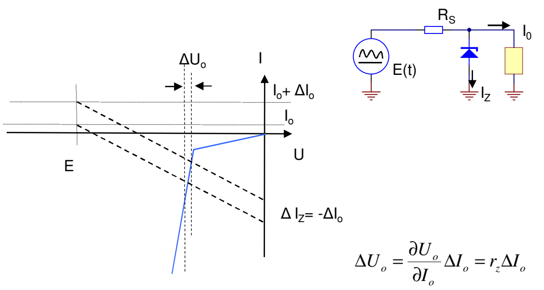
Zener Diode



Zener Diode design

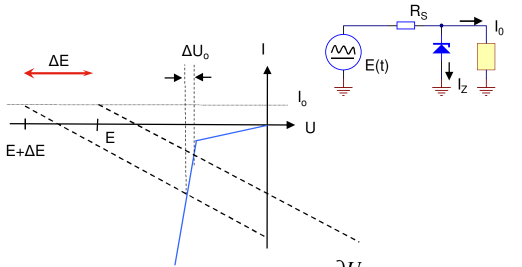


Zener Diode designe load regulation



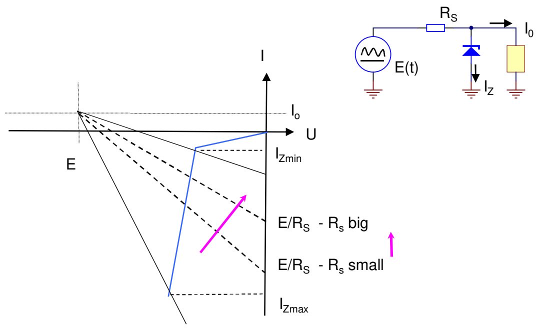
$$\Delta U_o = \frac{\partial U_o}{\partial I_o}\Delta I_o = r_z \Delta I_o$$

Zener Diode designe line regulation

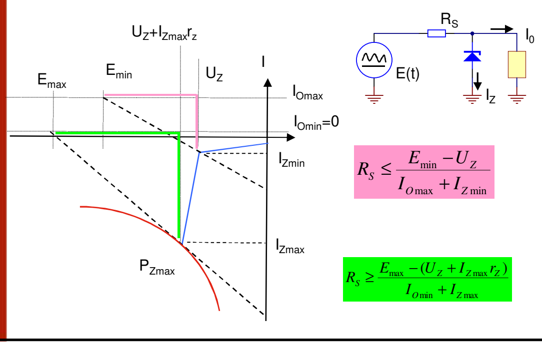


$$\Delta U_o = \frac{\partial U_o}{\partial E}\Delta E = \frac{r_z}{r_z + R_S}\Delta E$$

Zener Diode designe choosing R_S



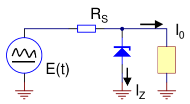
Zener Diode designe choosing R_S



$$R_S \le \frac{E_{min} - U_Z}{I_{Omax} + I_{Zmin}}$$

$$R_S \ge \frac{E_{max} - (U_Z + I_{Zmax} r_Z)}{I_{Omin} + I_{Zmax}}$$

Zener Diode controller advantages and drawbaks



- High input voltage needed E-U_o (R_S is high enough and stabilization is effective)
- High dissipation power P_{strat}= (E-U_o)(I_Z+I_o) +$U_Z I_Z$
- High noises !!!!!!
- Small output current (I_{Zmax} - power dissipation of diode)
- Bad thermal stabilization

Zener diode parameters

$$\Delta U_o = \frac{\partial U_o}{\partial E}\Delta E + \frac{\partial U_o}{\partial I_o}\Delta I_o + \frac{\partial U_o}{\partial T}\Delta T + \frac{\partial U_o}{\partial t}\Delta t$$

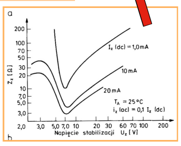
$$\Delta U_o = \frac{r_z}{r_z + R_S}\Delta E + r_z \Delta I_o + (TWU_Z)U_Z\Delta T + \frac{\partial U_Z}{\partial t}\Delta t$$

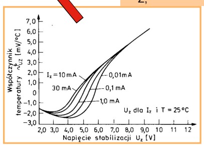
High R_S needed,

So high $E-U_o$

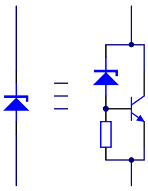
Long term stabilazation

$U_{Z,}=10^{-3}\div10^{-5}$ [1/1000h]





High power Zener diode

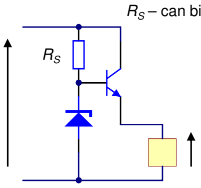


$U_Z' = U_Z + U_{BE}$

Follower (CC) as voltage controller

$$\Delta U_o = \frac{r_z}{r_z + R_S}\Delta E + \frac{r_z}{\beta}\Delta I_o + \left((TWU_Z)U_Z - \frac{\partial U_{BE}}{\partial T}\right)\Delta T + \frac{\partial U_Z}{\partial t}\Delta t$$

R_S – can bi higher

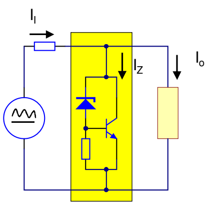


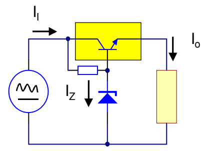
$U_o = U_Z - U_{BE}$

Series vs parallel controller

$$I_I = I_Z + I_O$$

$$I_I \approx I_O$$



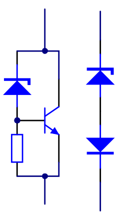


Lower power dissipation

Reference voltage

- Zener Diode
- Compensated Zener Diode
  - Integrated diode
- Band gap („Base-emitter diode thermal compensated")
- Zener diode with in thermostat

Thermal compensated Zener Diode



$(TWU_Z)U_Z \approx 2mV / K$ $for\ U_Z \approx 6 \div 9V$

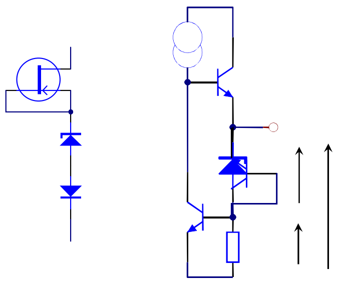
$\frac{\partial U_{BE}}{\partial T} \approx -2mV / K$

$TWU_Z \approx 0$

$U_Z = 6 \div 9V$

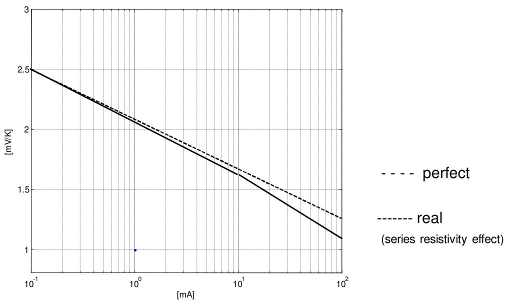
Constant current required as thermal parameters of Zener Diode depends on current

Dioda Zenera kompensowana termicznie przykład

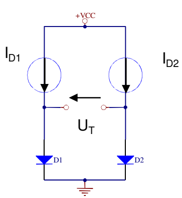


$$U_O = U_Z + U_{BE}$$

$\frac{dU_D}{dT}$ as function of current



Temperture sensor

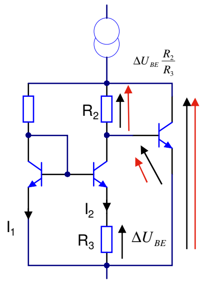


$$I_D = I_S\left(\exp\left(\frac{U_D}{n\varphi_T}\right)-1\right) \qquad \varphi_T = \frac{kT}{e}$$

$$U_T = U_{D2} - U_{D1} = n\varphi_T \ln\left(\frac{I_{D2}}{I_{D1}}\right)$$

$$\frac{dU_T}{dT} = \frac{nk}{e}\ln\left(\frac{I_{D2}}{I_{D1}}\right)$$

band-gap reference



$$\Delta U_{BE} = U_{BE1} - U_{BE2} = n\frac{kT}{e}\ln\left(\frac{I_2}{I_1}\right)$$

$$U_{REF} = \frac{R_2}{R_3}\Delta U_{BE} + U_{BE3}$$

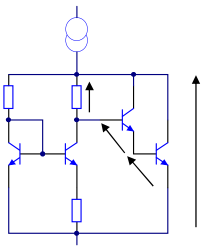
$$\frac{\partial U_{REF}}{\partial T} = \frac{R_2}{R_3}n\frac{k}{e}\ln\left(\frac{I_2}{I_1}\right) + \frac{U_{BE3} - E_{GO} - 3\varphi_T}{T} = 0$$

$$\frac{R_2}{R_3}n\frac{k}{e}\ln\left(\frac{I_2}{I_1}\right) = -\frac{U_{BE3} - E_{GO} - 3\varphi_T}{T}$$

$U_{REF} \approx 1{,}25V$

Or 2,5V

Band-gap 2,5V



$U_{REF} \approx 2{,}5V$

Other brands possible

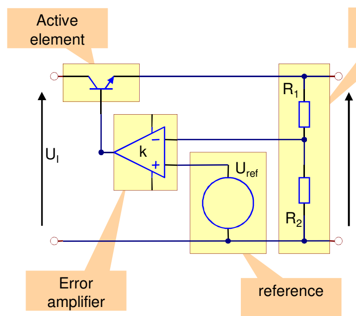
Reference voltage

- Zener Diode
- Compensated Zener Diode
  - Integrated diode
- Band gap („Base-emitter diode thermal s=compensated”)
- Zener diode with in thermostat

Voltage references(examples)

typ	U_{ref} [V]	I_{zas} [mA]	TWU [ppm/K]	Long term stab [ppm/1000h]	$\Delta U_{ref}/\Delta U_{we}$ [%U_{ref}/V]	$\Delta U_{ref}/\Delta I_O$ [%U_{ref}/10mA]	noise [µVpp]
Thermal compensated Zener Diode							
1N821	6,2±5%	7,5	±100	-?			
1N4890	6,2±5%	7,5	±20	100			
Integrated Zener Diode							
µA723	7,15±3%	1,6	50	1000	0,003	0,03	
LM329	6,9±5%	1	30	20	0,1		
REF08G	-10±0,2%	2	10		0,02	0,2	10
Band-gap							
REF05	5±0,3%	1	3	100	0,006	0,05	10
LM385-1.2	1,235±1%	0,01	30	20		0,8	60
LM385-2,5	2,5±1,5%	0,01	30			0,4	120
Zener Diode with termostate							
LM399	6,95±5%	17	0,3	20		0,1	
LTZ1000	7,2±4%	20	0.05	0,3			1,2

Compensated controller

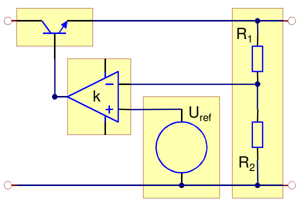


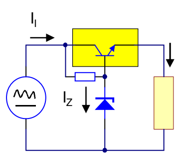
$$U_O = U_{REF}\left(1+\frac{R_1}{R_2}\right)$$

$$\Delta U_O = \Delta U_I \frac{1}{1+k\frac{R_2}{R_1+R_2}} \approx 0$$

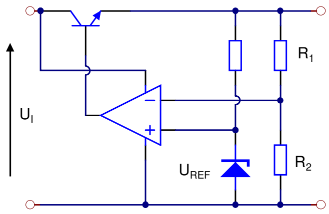
$dla \quad k \to \infty$

Most simple compensatet and series controller



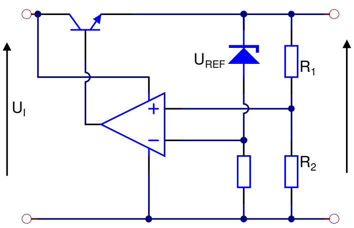


Compensated controller 1



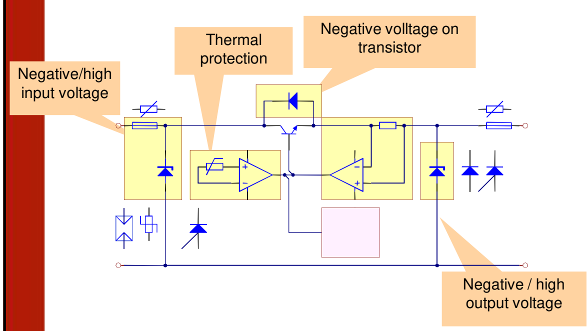
$$U_O = U_{REF}\left(1+\frac{R_1}{R_2}\right)$$

Compensated controller 2



$$U_O = U_{REF}\left(1+\frac{R_2}{R_1}\right)$$

Protection circuits

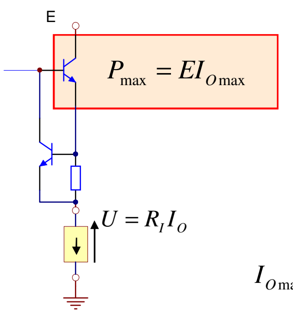


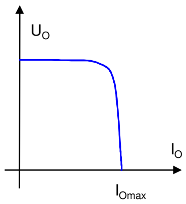
Devices i n protection circuits

Protection devices:

- diode,
- Zener diode,
- transil (uni- bi- directional),
- triac (thyristor),
- arrester,
- Fuse (fast or slow),
- Semiconductor fuse (PTC),
- other……

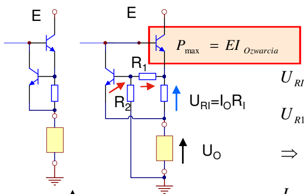
Output current limiter (the simplest ?)

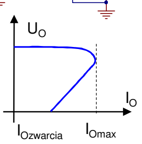




$$I_{O max} = U_{BE} / R_I \approx 0{,}7V / R_I$$

fold-back current limiter





$$U_{RI} = I_{O max} R_I > U_{BE} + U_{R1}$$

$$U_{R1} = \frac{R_1}{R_1 + R_2}\left(U_O + R_I I_{O max}\right)$$

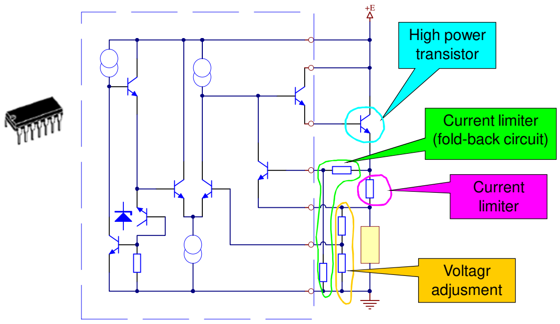
$$\Rightarrow$$

$$I_{O max} = \frac{1}{R_I}\left[\left(1 + \frac{R_1}{R_2}\right)U_{BE} + \frac{R_1}{R_2}U_O\right]$$

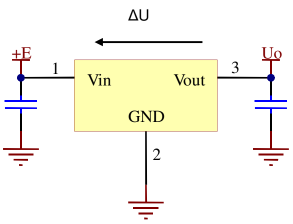
$$gdy \quad U_O = 0$$

$$I_{Ozwarcia} = \frac{1}{R_I}\left[\left(1 + \frac{R_1}{R_2}\right)U_{BE}\right]$$

Compenasated controller µA723

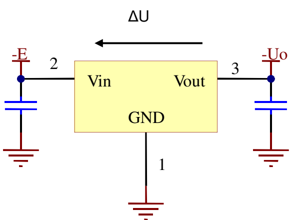


3 pin controllers with predefined voltage - 78xXX



U_O[V]=(XX)
3,3
5
5,2
6
8
8,5
9
12
15
18
24

3 pin controllers with predefined voltage - 79xXX

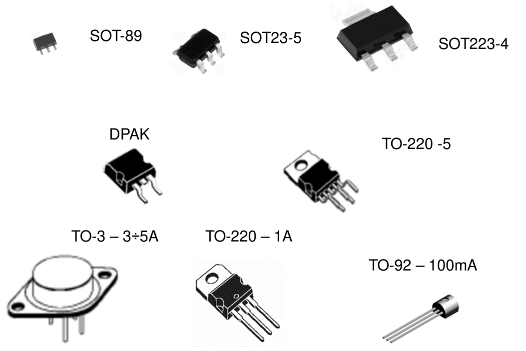


U_O[V]=(XX)
-5
-6
-9
-12
-15
-18
-24

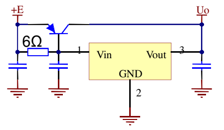
3 pin controllers with predefined voltage - 78xXX

Main fitures:
- Input voltage- 35V(40V)
- Current limiter
  0,1A/1A/3A (TO-92/TO-220/TO-3)
- Drop out voltage ΔU≈2V
- Line / load regulation, thermal prop.
- (not excelent)
- Temperature protection

Integrated circuuits (examples)



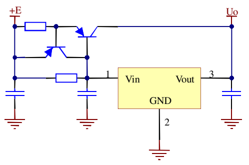
3-pin controllers - extension possibilities



Increased maximum current

-no current limiter

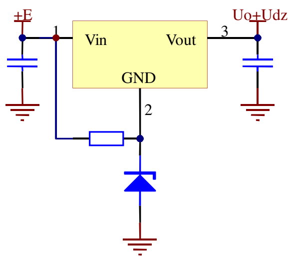
-higher dropout voltage



increased maximum current and current limiter

-higher dropout voltaage

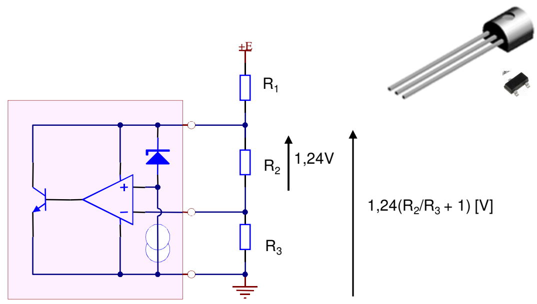
Stabilizatory napięcia stałego - możliwości rozszerzenia zakresu zastosowań



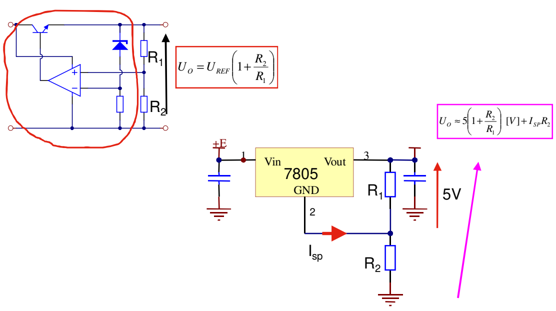
Higher output voltage

-control parameters are like for Zener diode controller

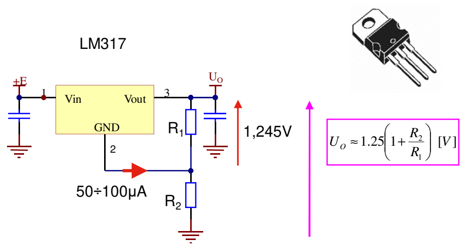
Adjusted reference voltage (parallel controller) LM385-ADJ



IC - adjustable controllers

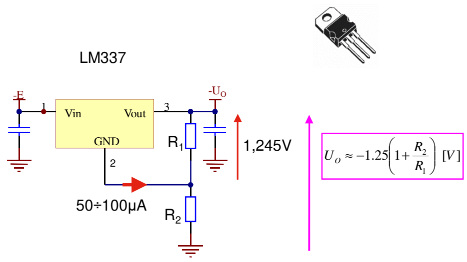


IC LM317 (positive voltage)



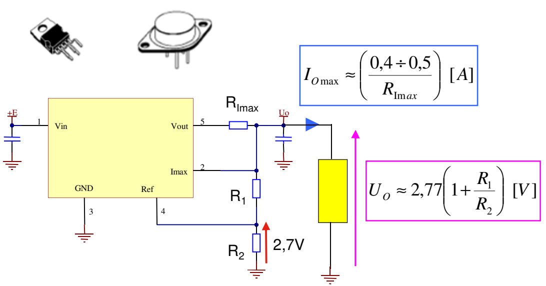
$$U_O \approx 1.25\left(1+\frac{R_2}{R_1}\right)\ [V]$$

IC LM337 (negative voltage)



$$U_O \approx -1.25\left(1+\frac{R_2}{R_1}\right)\ [V]$$

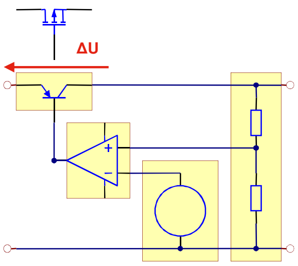
Intrgrated controller with adjustable voltage and maximum current - L200



$$I_{O\max} \approx \left(\frac{0{,}4 \div 0{,}5}{R_{Imax}}\right)\ [A]$$

$$U_O \approx 2{,}77\left(1+\frac{R_1}{R_2}\right)\ [V]$$

Low DropOut (LDO) controllers



In typical controller**ΔU>2V**

In LDO controller

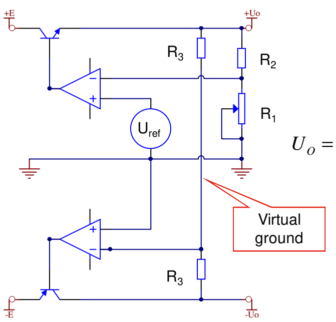
ΔU>0,2÷0,5V

IC controllers

typ	U_{max} [V]	U_O [V]	ΔU_{min} [V]	I_{Omax} [A]	$I_{zasilania}$ [mA]	TWU [ppm/K]	Long term stab [%/1000h]	$\Delta U_O/\Delta U_{we}$ [%U_O/V]	$\Delta U_O/\Delta I_O$ [Ω]
Universal controllers									
µA723	40	2-36	2	0,065a	±100	20	0,001	0,003	0,04
L200	40	2,8-36	2	3,6b	4,3	10	-	0,001	0.002
LM317/337T	40	1,2-37	2	1,5		600	0,3	0.01	0,003
Constant voltage									
LM78L05	35	5±4%	2	0,1	4	300	0,4	0,09	0,01
LM7812	35	12±4%	2	1	4	300	0,4	0,06	0,01
LM7815CT	35	15±4%	2	2	4	300	0,4	0,03	0,01
Negative voltage									
LM7905	-35	-5±4%	2	1	4	300	0,4	0,09	0,01
LDO controllers									
LM2340-05	35	5±4%	0,5	1	4	300	0,4	0,09	0,01

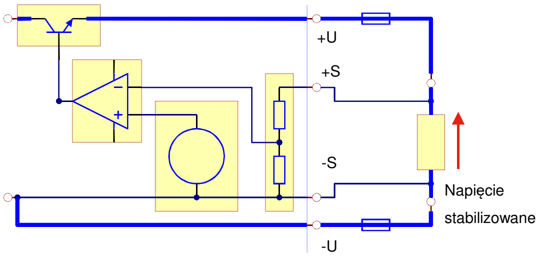
a)- no external transistor and no current limiter

Some „tips” „dual tracking regulator”

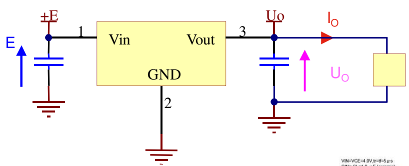


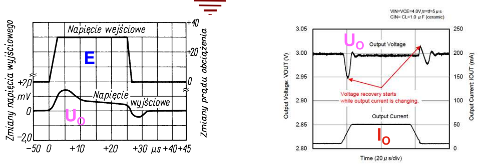
$$U_O = -U_O = U_{REF}\left(1+\frac{R_2}{R_1}\right)$$

External feedback

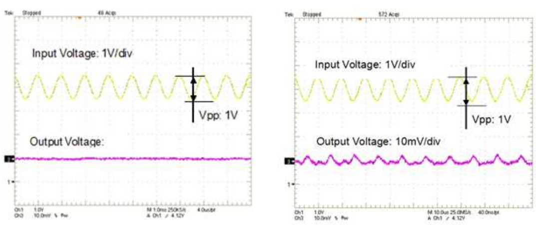


Pulse features of voltage controllers



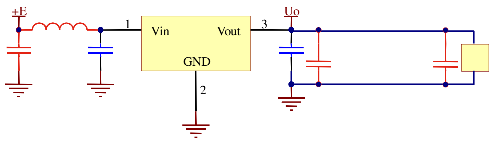


Ripples (1kHz and 100kHz)



https://www.torexsemi.com/technical-support/application-note/basic-knowledge-of-ldo/basic-performance/

Pulse features of voltage controllers



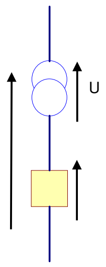
Minimizing the effects of input voltage ripples:

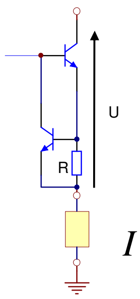
- additional filter (C, L etc .)
- other dumping elements (e.g. transil)
- additional voltage controller

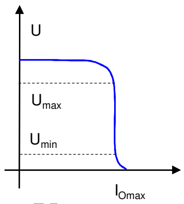
Minimizing the effects of load current jumps:

- reduction of the output impedance by adding capacitors with low impedance for high frequencies
- capacitors in parallel with elements that sink pulsed current

Current controllers

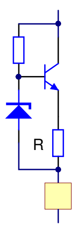






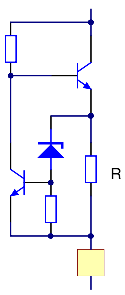
$$I \approx \frac{U_{BE}}{R}$$

Current controllers



$$I = \frac{U_{DZ} - U_{BE}}{R}$$

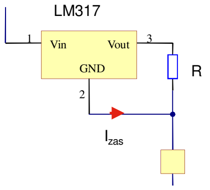
$$U_{\min} = U_{DZ} + U_{Tsat}$$



$$I = \frac{U_{DZ} + U_{BE}}{R}$$

$$U_{\min} = U_{DZ} + U_{BE} + U_{Tsat}$$

Current controllers



$$I \approx \frac{1{,}25V}{R} + I_{zas}$$
$$U_{min} \approx 1{,}25 + 2 = 3{,}25V$$

summary

- Parameters of voltage controllers (line, load regulation – characteristics)
- Parametric controllers with Zener Diodes
- Reference voltage sources
- Idea of compensated controller
- Protection methods in voltage controllers
- Parameters of integrated voltage controllers
- Current controllers

Final test problems

- Idea of series and parallel controller.
- Idea of a simple current limiter (with transistor).
- Idea of „fold-back" current limiter.
- Line and Load regulation curves. What kind of parameters can be read from these graphs ?