Electronic Competence Course
Analoque building Blocks

Feedback Systems

Contents

1 General information about stabilisation techniques

To realise a **constant voltage source**, one must ensure a very low internal resistance R_i and keep the original voltage U_0 constant in time. Only in this way is it possible to operate electronic devices optimally. Most electronic devices work with DC voltage, whereby not only the static values but also the dynamic specifications of a voltage source are important.

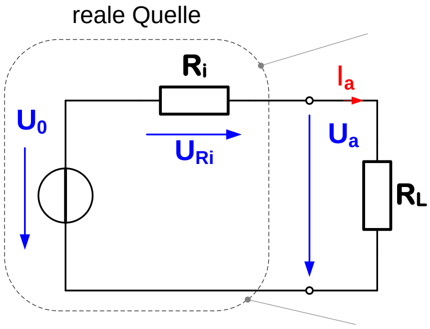
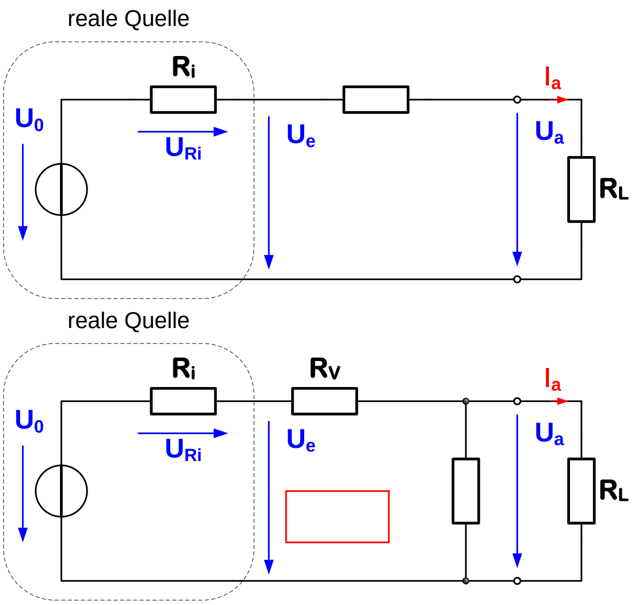


Figure 1: Current source and voltage source are defined by the ratio R_i/R_L.

Examples of such dynamic parameters would be:
- Behaviour during input voltage changes (PSRR)
- Behaviour during load changes (LRR)
- Start Up-behaviour

With the **constant current source** it is important to make the internal resistance of the source as large as possible. Only then will the source always deliver the same current, regardless of the load.
For power sources, not only static but also dynamic parameters are of interest.



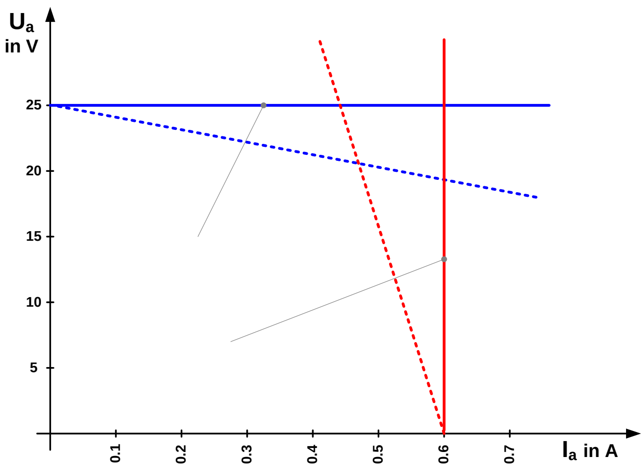


Figure 2: Left: Principle circuits of parallel stabilisation and series stabilisation. Right: Voltage-current characteristics of power sources.

Notice 1: By changing R_S or R_P it is achieved that the voltage U_a or the current I_a remains constant with changes of the load resistance!

Parameters of stabilisation:

- ... Power Supply Rejection Ratio
  response to **noise in input voltage**
- ... differential internal resistance of the source
  response to **change in load resistance**

Power Supply Rejection Ratio in dB and linear scale, measured at nominal load:

$\Delta U_e \ldots$ *change of input voltage*
$\Delta U_a \ldots$ *change of output voltage*

Power Supply Rejection Ratio or Power Supply Ripple Rejection (PSRR) is a measure of a circuit's power supply's rejection expressed as a log ratio of output noise to input noise. PSRR provides a measure of how well a circuit rejects ripple, of various frequencies, injected at its input.

The ripple can be either from the input supply such as a 50Hz/60Hz supply ripple, switching ripple from a DC/DC converter, or ripple due to the sharing of an input supply between different circuit blocks on the board. In the case of LDOs, PSRR is a measure of the regulated output voltage ripple compared to the input voltage ripple over a wide frequency range (10Hz to 1MHz is common) and is expressed in decibels (dB). The PSRR is very critical parameter in many audio and RF applications.

The differential internal resistance r_i of the source results for $U_a = constant$:

$\Delta U_a \ldots$ *change of output voltage*
$\Delta I_a \ldots$ *change of output current*

Notice 2: The larger the PSRR and the smaller the internal resistance r_i, the better the stabilisation works!

2 The Z-diode as parallel voltage stabilisation circuit

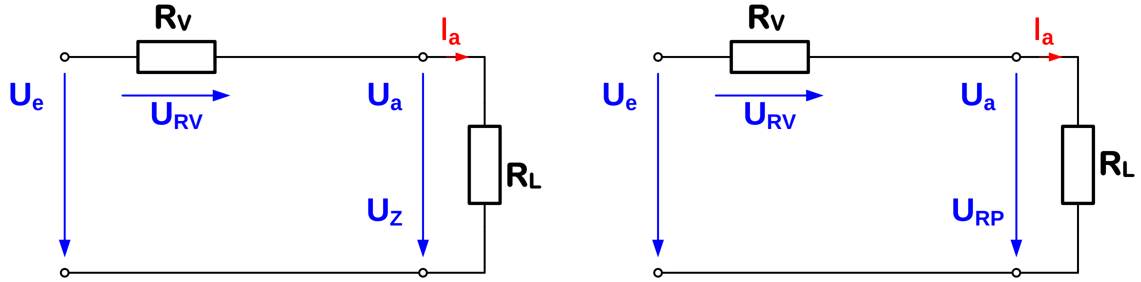


Figure 3: Stabilisation circuit with a Zener diode (left), equivalent stabilisation circuit (right). R_P and the differential internal resistance of the Zener diode r_Z are equivalent.

2.1 No-load case $R_L = \infty$

The diagram in figure 4 shows the series connection of R_V and the Z-diode in the U-I diagram. The operating point **A** marks the set with the corresponding values U_z and I_z.
If the voltage U_{e1} changes by the amount ΔU_e, the R_V straight line shifts parallel. The new operating point A' is created. As you can see, the output voltage is reduced by $\Delta U_z = \Delta U_a$ which is much smaller than

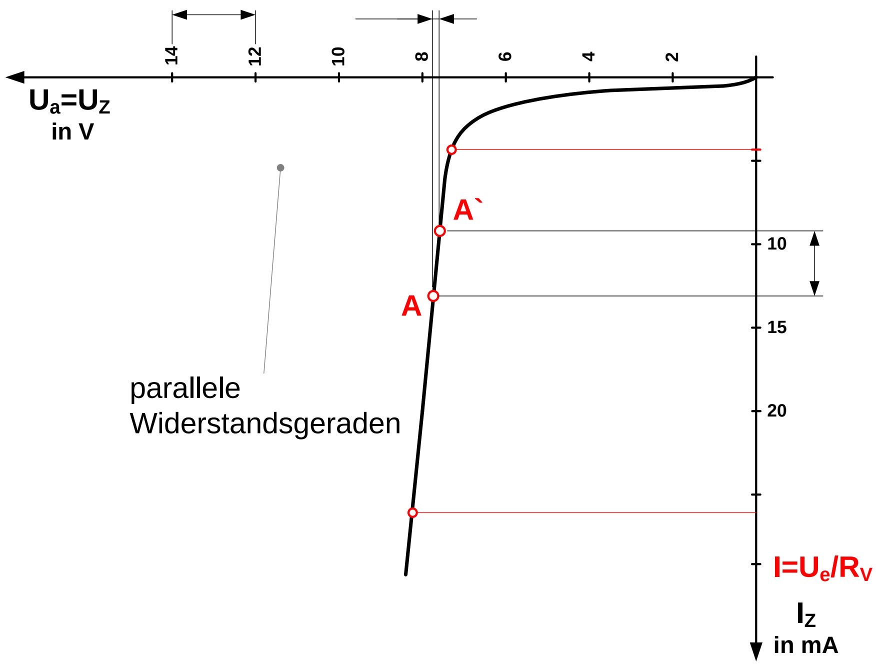


Figure 4: Operating point shift in the circuit.

ΔU_e. The drawn current I_{Zmin} in picture 4 marks the beginning of the straight part of the characteristic curve. The current I_{Zmax} results from the power dissipation hyperbola of the Zener diode.

Notice 3: The steeper the Z-diode characteristic curve, the smaller the change ΔU_a, the more stable the output voltage remains!

The differential resistance r_Z in ohms is:

$\Delta U_Z \ldots$ *change of Zener voltage*
$\Delta I_Z \ldots$ *change in Zener current*

(1) In the input mesh in picture 3 one can form the sum of all voltages of the differences:

(2) Now the factor ΔU_Z can be divided and further transformed. This gives the PSRR:

(3) The linear Power supply rejection ratio can now be written on:

2.2 Load case with R_L

Notice 4: When explaining the stabilisation effect, one assumes that the **total current I is constant**!

Assume that the load changes the output current by ΔI_a. The diode current I_Z now decreases by ΔI_Z = ΔI_a. If the minimum value I_{Zmin} is still maintained, U_Z only changes by a small amount ΔU_Z. → The total current I has remained almost constant!

The circuit behaves like a source with the internal resistance r_i:

$\Delta U_a \ldots$ *change of output voltage*
$\Delta I_a \ldots$ *change in output current*
$r_Z \ldots$ *differential internal resistance of the Zener diode*

The r_Z values are current and type dependent and range between 1Ω and 150Ω. There are "better" and "worse" Zener diodes. Those Z-diodes with the smallest r_Z can be built for Zener voltages around **3 to 8V**.

(1) The total current I is assumed to be constant:

(2) The diode current I_{Zmax} is always highest in no-load operation for $I_L = 0$:

(3) Thus, the power dissipation P_{Vmax} of the Z-diode **at no-load** reaches the maximum value:

If the circuit is loaded, I_Z in Fig. 4 decreases by the load current. It should be noted that I_Z does not fall below the minimum value I_{Zmin}, because then large changes in the output voltage occur → **the stabilisation no longer works!**

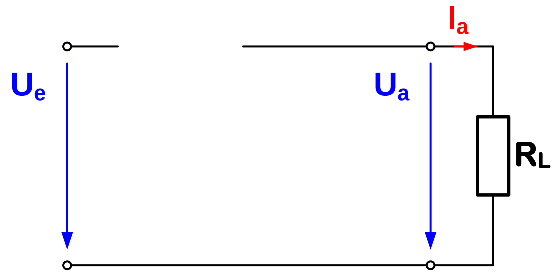
2.3 Design and Calculations

(a)	Input Voltage U_e:	The voltage U_e must always be greater than U_Z, the greater U_e is chosen, the better the stabilisation against fluctuations of U_e → **guideline:** $\mathbf{U_e = 2 \cdot U_Z}$ If the input voltage fluctuates this results in $U_{e\,\mathrm{min}}$ and $U_{e\,\mathrm{max}}$
(b)	Zenercurrent I_Z:	The minimum Zener current I_{Zmin} at the voltage $U_{Z\,\mathrm{min}}$ and the maximum Zener current I_{Zmax} at the voltage $U_{Z\,\mathrm{max}}$ are determined from the data sheet.
(c)	Series resistor R_V:	R_V determines the total current I. This must be dimensioned so, that the minimum current $I_{Z\,\mathrm{min}}$ is not exceeded even under unfavourable conditions. However, R_V cannot become arbitrarily small, because the maximum Zener current $I_{Z\,\mathrm{max}}$ according to the data sheet must not be exceeded.

The range of R_V in ohms can be calculated as follows:

U_e ... *input voltage*
U_Z ... *energy voltage*
I_Z ... *energy current*
I_a ... *load current*

Excercise 1: Z-Diode stabilising circuit!
U_e =15V±1.5V, $R_{L\,\mathrm{min}} = 200\Omega$,
Z-Diode ZD 6.8: I_{Zmin}=10 mA, I_{Zmax}=130 mA
r_Z=1 Ω.



(1.1) Determination of the highest and lowest input voltage U_{emax} and U_{emin}:

(1.2) The output voltage U_a is the nominal Zener voltage:

(1.3) Determination of the maximum load current I_{amax}:

(1.4) Determination of the minimum series resistance R_{Vmin}. The resistance must be at least large enough so that the max. Zener current $I_{Z\max}$ is not exceeded:

(1.5) Determination of the maximum series resistance $R_{V\max}$. The maximum resistance must not fall below the minimum Zener current $I_{Z\min}$:

The resistance R_V may therefore lie between R_V = 74.6Ω and R_V = 152Ω. If R_V is made even smaller, $I_{Z\max}$ can be exceeded, if R_V is made even larger, $I_{Z\min}$ can be undercut!

(1.6) Now the $PSRR_{lin}$ can be calculated, for $R_V = 152\Omega$ holds:

(1.7) For the change of U_a with input voltage change U_e for $R_V = 152\Omega$ holds:

With ΔU_e=±1.5 V this would result in a voltage change of ΔU_a = ±9.8 mV at the output!

Disadvantages of the circuit:
If the circuit operates with large load changes, the Z current changes considerably, thus considerable fluctuations of U_Z also occur. The Z diode is particularly heavily loaded during no-load operation and heats up. This results in a temperature-related change of U_a!

> **Notice 5:** The simple Z-diode stabilisation is therefore a parallel stabilisation, and is only used for low power applications!

3 Series stabilisation (linear voltage regulator)

To operate electronic circuits, you usually need a DC voltage that maintains a certain value to within 5 to 10%.

The following problems may occur:

- Mains voltage fluctuations
- Load current fluctuations
- Temperature fluctuations
- Ageing
- Component tolerances

The superimposed ripple voltage should be in the mV range at most. For these reasons, the voltage of a rectifier circuit is not directly suitable as an operating voltage for electronic circuits, but must be stabilised and smoothed by a subsequent voltage regulator.

The most important characteristics of a voltage regulator are:

(a)	It depends on the internal reference voltage.
(b)	This is mainly dependent on the design.
(c)	It is also called "Dropout Voltage".
(d)	Ability to suppress U_e fluctuations.
(e)	Ability to compensate for I_L fluctuations.

3.1 The emitter follower as the simplest version

A simple series regulator is an emitter follower whose base is connected to a reference voltage source. The reference voltage can be obtained from the unstabilised input voltage U_e with the help of a Z-diode. The output voltage is set to the value $U_a = U_{ref} - U_{BE}$. Fluctuations of the input voltage are absorbed by the low differential resistance of the Z-diode.

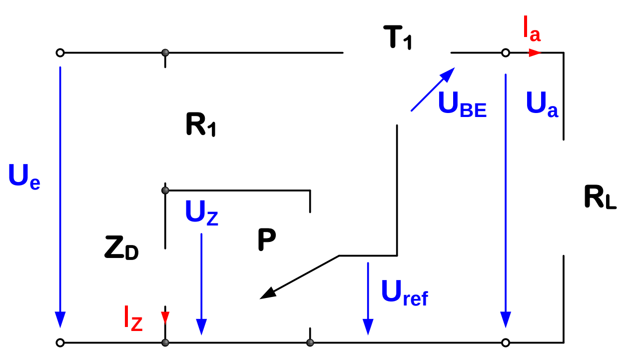
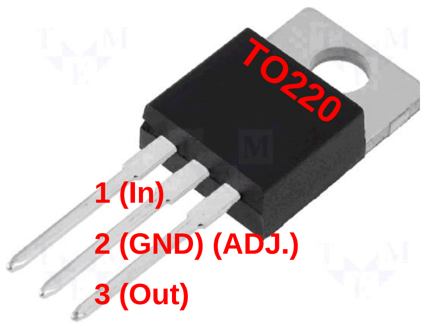


Figure 5: Stabilisation with emitter follower.

If one needs an adjustable output voltage, one can use a part of the Zener voltage U_Z at the potentiometer P.

3.2 Integrated voltage regulator with fixed output voltage

- 3-Terminal Regulators
- Output Current Up to 1.5 A
- Internal Thermal Overload Protection
- High Power Dissipation Capability
- Internal Short-Circuit Current Limiting
- Output Transistor Safe-Area Compensation



In integrated voltage regulators, in addition to a control amplifier (comparator) and a reference source, one finds several other assemblies for protecting the power transistor. A current limiting circuit monitors output current I_a, which is measured with R_3. A thermal protection monitors the temperature and reduces the output current if overheating is imminent.

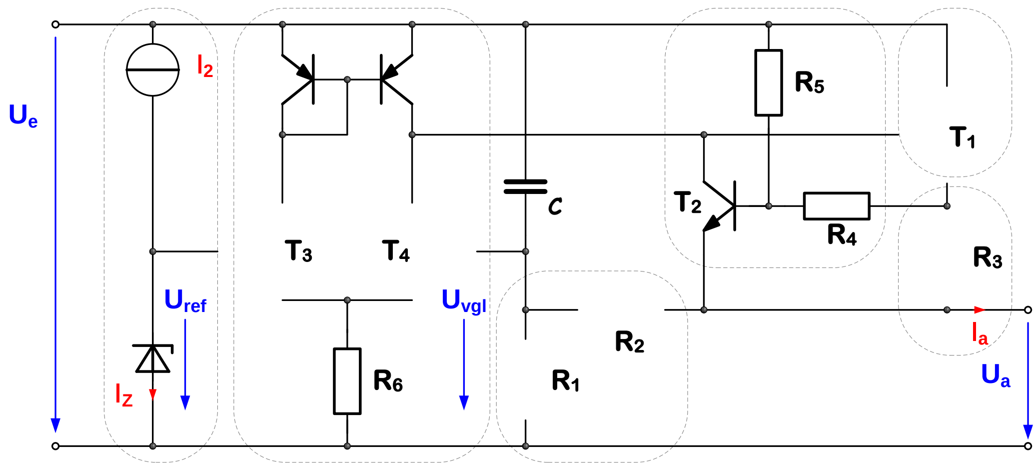


Figure 6: Innere Schaltung eines integrierten Spannungsreglers aus der 78xx-Serie.

The simple differential amplifier T_3, T_4, works together with the Darlington circuit T_1 as a power operational amplifier. The voltage regulator is counter-coupled via the voltage divider R_1 and R_2. The transistor T_2 is used for current limiting. When the voltage drop at R_3 reaches 0.6 V, T_2 becomes conductive and thus reduces the output voltage. This means that the load current is then constant!

Positive Regulators:			**Negative Regulators:**		
	...	5V±0.2V		...	-5V±0.2V
	...	12V±0.5V		...	-12V±0.5V

(1) The voltage drop at R_1 results from the reference voltage:

(2) The current through the resistor R_1 results from Ohm's law:

(3) The same current also flows through the resistor R_2 and causes U_{R_2} there:

(4) According to Kirchhoff, the voltage U_a is composed of the sum of the two voltages U_{R_1} and U_{R_2}:

(5) The following power loss P_V occurs in the output transistor T_1:

External circuit of a fixed voltage regulator μA7808:
U_{ref} is between the non-inverting input (+) of the control amplifier OPV and GND. The output of the OPV controls the emitter follower. The emitter of T_1 generates the output voltage U_a. With R_1 and R_2, a part of the output voltage is counter-coupled from the OPV via the inverting input (-). In the regulated state (after a change of the load current I_L or the input voltage U_e), the differential voltage between the two inputs of the OPV is 0 V again.

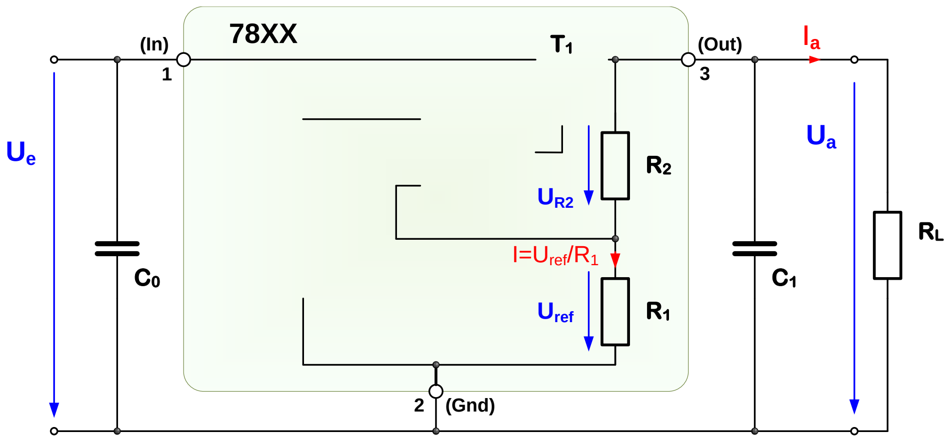


Figure 7: External wiring of an integrated voltage regulator from the 78xx series.

A change in the voltage at U_e or a change in the load current at I_a results in a brief change in U_a. Thus, the voltage at the inverting (-) input of the OPV also changes, divided by R_1 and R_2. This is the negative feedback mechanism that regulates the voltage!

3.3 Integrated controllers with variable output voltage

In addition to fixed voltage regulators, there are also adjustable voltage regulators.

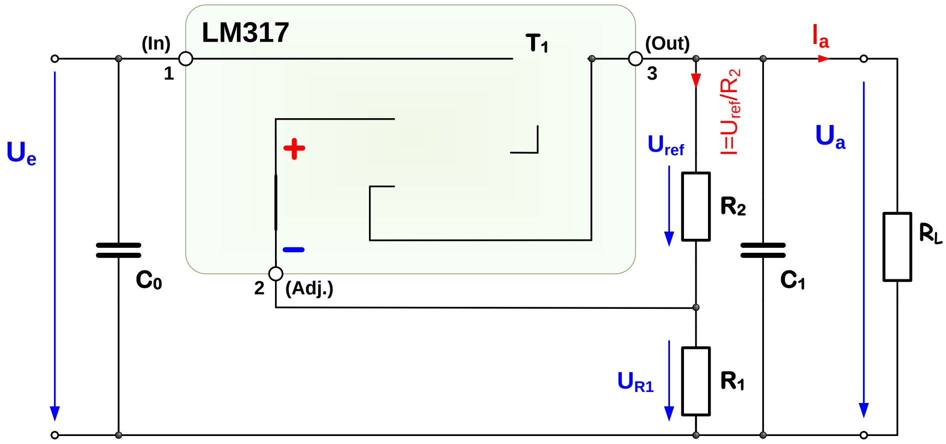


Figure 8: External circuitry of an LM317 integrated voltage regulator.

> **Notice 6:** With the voltage divider R_1, R_2 to be connected, you can set any output voltages between 1.25V and U_e-2.5V!

While in the 78xx voltage regulator family the reference voltage is related to GND, in the LM317 it is related to the output voltage U_a. This trick offers the possibility to determine with only three connections and by means of two resistors which output voltage one wants to have. The controlled state of this type of controller is reached exactly when the voltage between the two inputs of the control amplifier OPV is 0V again. As a result, the voltage across R_2 always corresponds to the reference voltage. Between the inverting input (-) of the OPV and the terminal ***Adj.*** lies Uref, the bandgap reference voltage source with a voltage of 1.25 V. The smallest possible output voltage U_a corresponds to the value of the reference voltage of 1.25 V. This is the case when R_1 has a value of 0 Ohm.

3.4 Precision Voltage Controller Type LM723

The LM723/LM723C is a voltage regulator designed primarily for series regulator applications. By itself, it will supply output currents up to 150 mA, but external transistors can be added to provide any desired load current. The circuit features extremely low standby current drain, and provision is made for either **linear or foldback current limiting**. The LM723/LM723C is also useful in a wide range of other applications such as a shunt regulator, a current regulator or a temperature controller. The LM723C is identical to the LM723 except that the LM723C has its performance guaranteed over a 0° C to +70°C temperature range, instead of -55°C to +125°C.

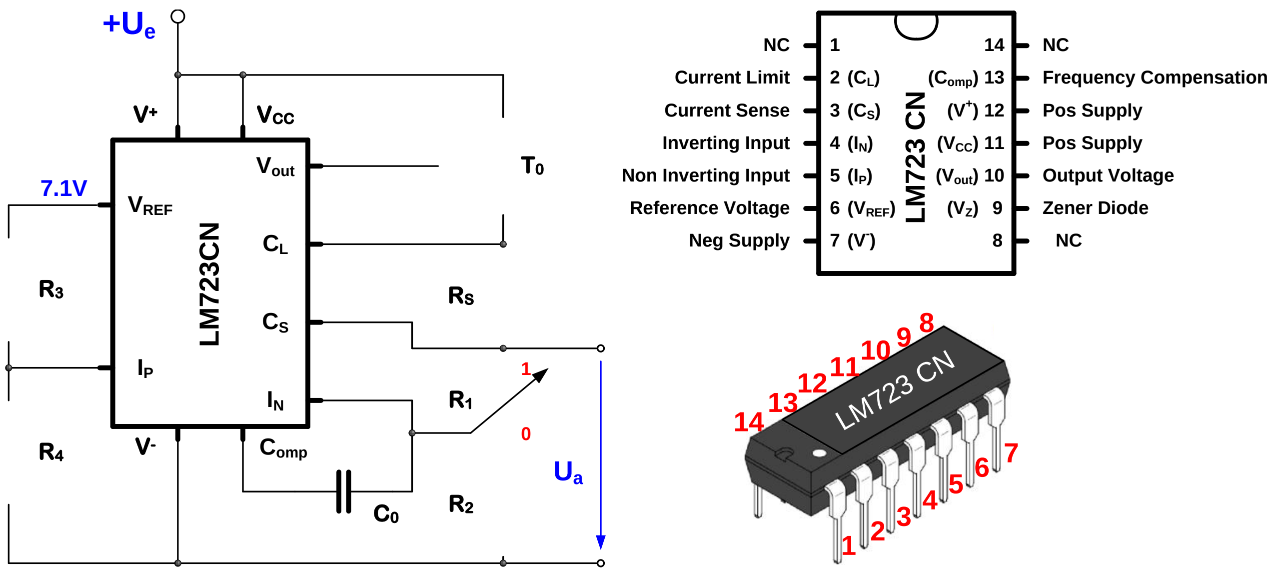


Figure 9: Adjustable Voltage Regulator with LM723.

Calculation of the output voltage: When calculating the output voltage in Fig. 9, it is important that the voltage between points I$_P$ and I$_N$ is **NULL volts** in the regulated case! The potentiometer is in position 0.

(1) U_{R4} is calculated with the voltage divider rule:

(2) Since the control amplifier has a very high amplification, the voltage between the points I$_P$ and I$_N$ is **NULL volts**. The voltage at resistor R_2 is exactly the same as at resistor R_4. The current I_{R2} is then:

(3) The same current also flows through the resistor R_1 and causes the voltage drop U_{R1} there:

(4) U_a results from the sum of the two voltages U_{R_1} and U_{R_2}:

3.4.1 Current Limiter

The LM723 voltage regulator contains an R_S tunable **constant current limitation**. However, the IC also offers the possibility of **foldback current limitation**. This has the advantage that in the event of a short-circuit, the current decreases to such an extent that the thermal load on the power transistor remains very much within limits and thus the heat sink can be dimensioned relatively small.

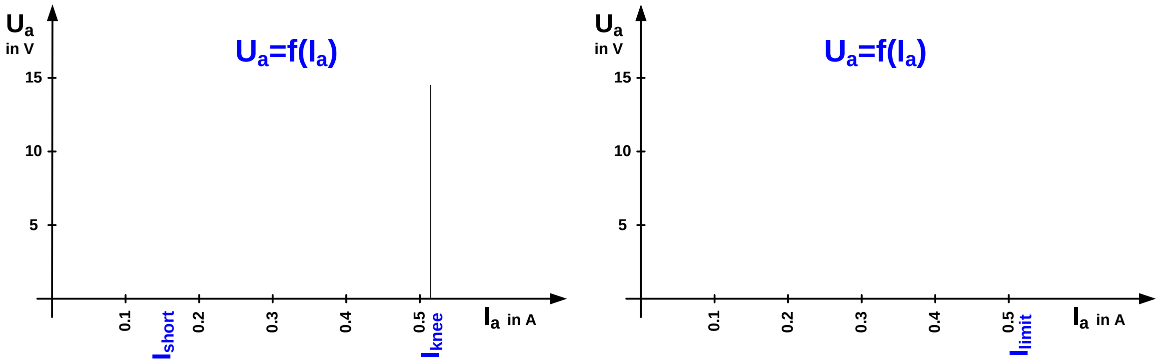


Figure 10: Foldback current limiting (left) and normal Limiting (right), with the LM723.

3.5 Voltage regulator with low voltage loss

The dropout voltage on a linear regulator is about 2.5V!

> **Notice 7:** A high dropout voltage is particularly disturbing when regulating low input voltages!

For most controllers, this results in a power loss of at least 50% of the output power! The dissipation of the resulting heat often leads to problems.

A simple way to keep the voltage drop as small as possible is to use a pnp transistor as the power transistor as shown in 11. The minimum voltage drop at the voltage regulator here is equal to the saturation voltage U_{ECsat} of the power transistor T_1. It can be kept below 0.5V with a correspondingly large base current **below 0.5V**. The transistor T_2 is operated in emitter circuit with current feedback. This ensures the necessary inversion of the signal for driving the PNP power transistor.

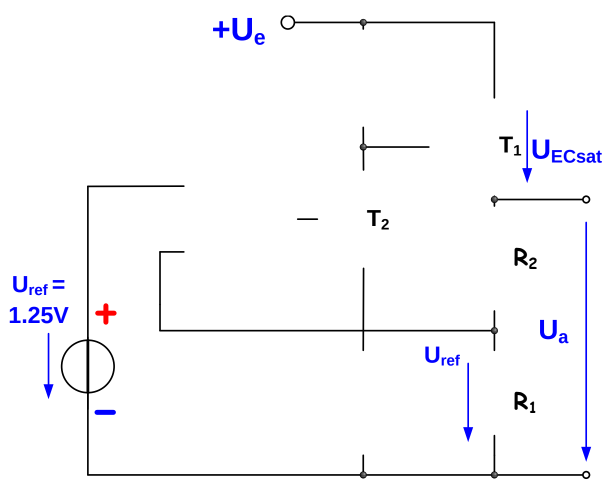


Figure 11: Voltage regulator with low voltage loss (low dropout).

4 Learning objectives check

1. Describe a stabilisation circuit with a Zener diode.
2. State the advantages and disadvantages of stabilisation using a Zener diode.
3. Describe the function of a linear fixed voltage regulator.
4. Describe the function of a linear adjustable voltage regulator.
5. Which methods of current limiting do you know (description of function)?
6. What methods of stabilisation do you know and what is the function.
7. Describe the "low dropout" principle. which wide range of area can the integrated regulator LM723 be used?
8. Explain the functionality of the voltage regulator circuit shown in picture 6.
9. Explain the functionality of the voltage regulator circuit shown in picture 7.
10. Explain the functionality of the voltage regulator circuit shown in picture 8.
11. How to calculate the instantaneous power dissipation of a voltage regulator that is converted into heat.
12. Why do voltages need to be stabilised at all?

Which statement is true about voltage stabilisation using a Zener diode?			
A	The temperature coefficient of the output voltage is always positive.	**D**	$R_{V\,\max}$ results from the minimum required current I_Z at max. load of the circuit.
B	$R_{V\,\min}$ results from the minimum required current I_Z at max. load of the circuit.	**E**	This method is mainly used for small power applications.
C	The steeper a ZD is in the pass-band, the better the stabilisation result.	**F**	The temperature coefficient of the output voltage depends on its level.
	ERGEBNIS:		

LM723/LM723C Voltage Regulator

Check for Samples: LM723, LM723C

FEATURES

- **150 mA Output Current Without External Pass Transistor**
- **Output Currents in Excess of 10A Possible by Adding External Transistors**
- **Input Voltage 40V Max**
- **Output Voltage Adjustable from 2V to 37V**
- **Can be Used as Either a Linear or a Switching Regulator**

DESCRIPTION

The LM723/LM723C is a voltage regulator designed primarily for series regulator applications. By itself, it will supply output currents up to 150 mA; but external transistors can be added to provide any desired load current. The circuit features extremely low standby current drain, and provision is made for either linear or foldback current limiting.

The LM723/LM723C is also useful in a wide range of other applications such as a shunt regulator, a current regulator or a temperature controller.

The LM723C is identical to the LM723 except that the LM723C has its performance ensured over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Connection Diagram

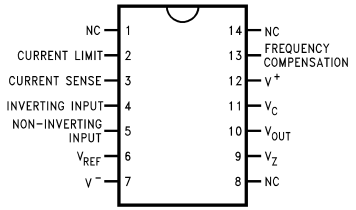
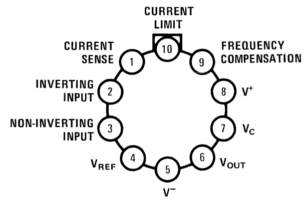


Figure 1. Top View
CDIP Package or PDIP Package
See Package J or NFF0014A



Note: Pin 5 connected to case.

Figure 2. Top View
TO-100
See Package LME

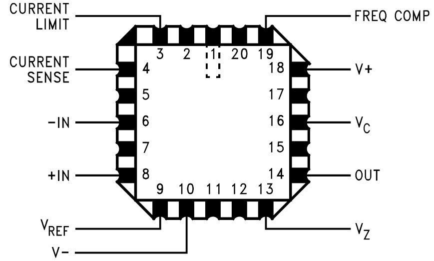
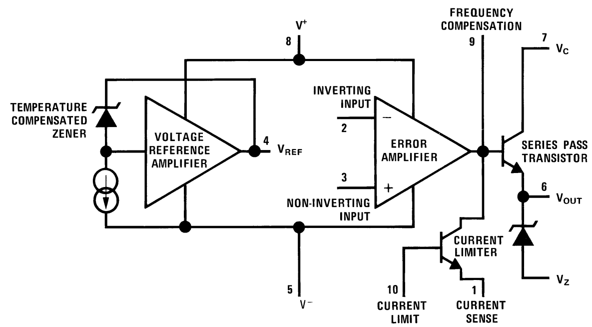


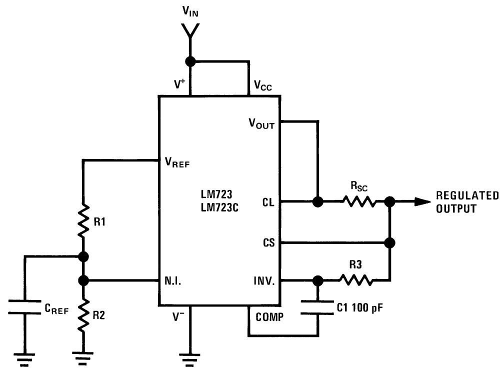
Figure 3. Top View
See Package NAJ0020A

Equivalent Circuit*



*Pin numbers refer to metal can package.

Typical Application



Note: $R3 = \frac{R1\,R2}{R1 + R2}$
for minimum temperature drift.

Typical Performance

Regulated Output Voltage	5V
Line Regulation (ΔV_{IN} = 3V)	0.5mV
Load Regulation (ΔI_L = 50 mA)	1.5mV

Figure 4. Basic Low Voltage Regulator (V_{OUT} = 2 to 7 Volts)

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

ABSOLUTE MAXIMUM RATINGS [1][2]

Pulse Voltage from V^+ to V^- (50 ms)	50V
Continuous Voltage from V^+ to V^-	40V
Input-Output Voltage Differential	40V
Maximum Amplifier Input Voltage (Either Input)	8.5V
Maximum Amplifier Input Voltage (Differential)	5V
Current from V_Z	25 mA
Current from V_{REF}	15 mA
Internal Power Dissipation Metal Can [3]	800 mW
CDIP [3]	900 mW
PDIP [3]	660 mW
Operating Temperature Range	
LM723	−55°C to +150°C
LM723C	0°C to +70°C
Storage Temperature Range Metal Can	−65°C to +150°C
PDIP	−55°C to +150°C
Lead Temperature (Soldering, 4 sec. max.)	
Hermetic Package	300°C
Plastic Package	260°C
ESD Tolerance	1200V
(Human body model, 1.5 kΩ in series with 100 pF)	

(1) "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not ensure specific performance limits.
(2) A military RETS specification is available on request. At the time of printing, the LM723 RETS specification complied with the Min and Max limits in this table. The LM723E, H, and J may also be procured as a Standard Military Drawing.
(3) See derating curves for maximum power rating above 25°C.

ELECTRICAL CHARACTERISTICS [1][2][3][4]

Parameter	Conditions	LM723			LM723C			Units
		Min	Typ	Max	Min	Typ	Max	
Line Regulation	V_{IN} = 12V to V_{IN} = 15V		0.01	0.1		0.01	0.1	% V_{OUT}
	−55°C ≤ T_A ≤ +125°C			0.3				% V_{OUT}
	0°C ≤ T_A ≤ +70°C						0.3	% V_{OUT}
	V_{IN} = 12V to V_{IN} = 40V		0.02	0.2		0.1	0.5	% V_{OUT}
Load Regulation	I_L = 1 mA to I_L = 50 mA		0.03	0.15		0.03	0.2	% V_{OUT}
	−55°C ≤ T_A ≤ +125°C			0.6				% V_{OUT}
	0°C ≤ T_A ≤ +70°C						0.6	% V_{OUT}
Ripple Rejection	f = 50 Hz to 10 kHz, C_{REF} = 0		74			74		dB
	f = 50 Hz to 10 kHz, C_{REF} = 5 μF		86			86		dB

(1) Unless otherwise specified, T_A = 25°C, $V_{IN} = V^+ = V_C$ = 12V, V^- = 0, V_{OUT} = 5V, I_L = 1 mA, R_{SC} = 0, C_1 = 100 pF, C_{REF} = 0 and divider impedance as seen by error amplifier ≤ 10 kΩ connected as shown in Figure 4. Line and load regulation specifications are given for the condition of constant chip temperature. Temperature drifts must be taken into account separately for high dissipation conditions.
(2) A military RETS specification is available on request. At the time of printing, the LM723 RETS specification complied with the Min and Max limits in this table. The LM723E, H, and J may also be procured as a Standard Military Drawing.
(3) Specified by correlation to other tests.
(4) L_1 is 40 turns of No. 20 enameled copper wire wound on Ferroxcube P36/22-3B7 pot core or equivalent with 0.009 in. air gap.

ELECTRICAL CHARACTERISTICS [1][2][3][4] (continued)

Parameter	Conditions	LM723			LM723C			Units
		Min	Typ	Max	Min	Typ	Max	
Average Temperature Coefficient of Output Voltage [5]	−55°C ≤ T_A ≤ +125°C		0.002	0.015				%/°C
	0°C ≤ T_A ≤ +70°C					0.003	0.015	%/°C
Short Circuit Current Limit	R_{SC} = 10Ω, V_{OUT} = 0		65			65		mA
Reference Voltage		6.95	7.15	7.35	6.80	7.15	7.50	V
Output Noise Voltage	BW = 100 Hz to 10 kHz, C_{REF} = 0		86			86		μVrms
	BW = 100 Hz to 10 kHz, C_{REF} = 5 μF		2.5			2.5		μVrms
Long Term Stability			0.05			0.05		%/1000 hrs
Standby Current Drain	I_L = 0, V_{IN} = 30V		1.7	3.5		1.7	4.0	mA
Input Voltage Range		9.5		40	9.5		40	V
Output Voltage Range		2.0		37	2.0		37	V
Input-Output Voltage Differential		3.0		38	3.0		38	V
θ_{JA}	PDIP					105		°C/W
θ_{JA}	CDIP		150					°C/W
θ_{JA}	H10C Board Mount in Still Air		165			165		°C/W
θ_{JA}	H10C Board Mount in 400 LF/Min Air Flow		66			66		°C/W
θ_{JC}			22			22		°C/W

(5) For metal can applications where V_Z is required, an external 6.2V zener diode should be connected in series with V_{OUT}.

MAXIMUM POWER RATINGS

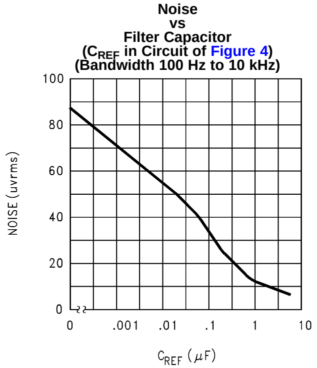


Figure 14.

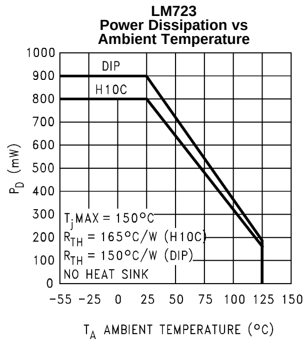


Figure 15.

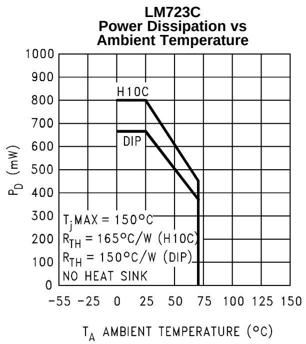


Figure 16.

Table 1. Resistor Values (kΩ) for Standard Output Voltage

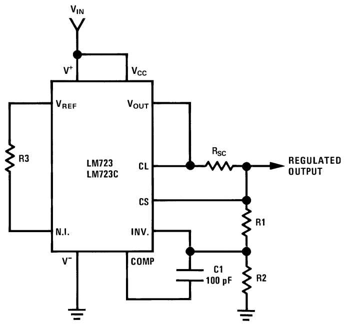
Positive Output Voltage	Applicable Figures	Fixed Output ±5%		Output Adjustable ±10%[1]			Negative Output Voltage	Applicable Figures	Fixed Output ±5%		5% Output Adjustable ±10%		
	See[2]	R1	R2	R1	P1	R2			R1	R2	R1	P1	R2
+3.0	Figure 4, Figure 19, Figure 21, Figure 24, Figure 27 (Figure 19)	4.12	3.01	1.8	0.5	1.2	+100	Figure 22	3.57	102	2.2	10	91
+3.6	Figure 4, Figure 19, Figure 21, Figure 24, Figure 27 (Figure 19)	3.57	3.65	1.5	0.5	1.5	+250	Figure 22	3.57	255	2.2	10	240
+5.0	Figure 4, Figure 19, Figure 21, Figure 24, Figure 27 (Figure 19)	2.15	4.99	0.75	0.5	2.2	−6[3]	Figure 18, (Figure 25)	3.57	2.43	1.2	0.5	0.75
+6.0	Figure 4, Figure 19, Figure 21, Figure 24, Figure 27 (Figure 19)	1.15	6.04	0.5	0.5	2.7	−9	Figure 18, Figure 25	3.48	5.36	1.2	0.5	2.0
+9.0	Figure 17, Figure 19, (Figure 19, Figure 21, Figure 24, Figure 27)	1.87	7.15	0.75	1.0	2.7	−12	Figure 18, Figure 25	3.57	8.45	1.2	0.5	3.3
+12	Figure 17, Figure 19, (Figure 19, Figure 21, Figure 24, Figure 27)	4.87	7.15	2.0	1.0	3.0	−15	Figure 18, Figure 25	3.65	11.5	1.2	0.5	4.3
+15	Figure 17, Figure 19, (Figure 19, Figure 21, Figure 24, Figure 27)	7.87	7.15	3.3	1.0	3.0	−28	Figure 18, Figure 25	3.57	24.3	1.2	0.5	10
+28	Figure 17, Figure 19, (Figure 19, Figure 21, Figure 24, Figure 27)	21.0	7.15	5.6	1.0	2.0	−45	Figure 23	3.57	41.2	2.2	10	33
+45	Figure 22	3.57	48.7	2.2	10	39	−100	Figure 23	3.57	97.6	2.2	10	91
+75	Figure 22	3.57	78.7	2.2	10	68	−250	Figure 23	3.57	249	2.2	10	240

(1) Replace R1/R2 in figures with divider shown in Figure 28.
(2) Figures in parentheses may be used if R1/R2 divider is placed on opposite input of error amp.
(3) V^+ and V_{CC} must be connected to a +3V or greater supply.

Table 2. Formulae for Intermediate Output Voltages

Outputs from +2 to +7 volts	Outputs from +4 to +250 volts	Current Limiting
(Figure 4 Figure 19 Figure 20 Figure 21 Figure 24 Figure 27) $V_{OUT} = \left(V_{REF} \times \frac{R2}{R1 + R2}\right)$	(Figure 22) $V_{OUT} = \left(\frac{V_{REF}}{2} \times \frac{R2 - R1}{R1}\right)$; R3 = R4	$I_{LIMIT} = \frac{V_{SENSE}}{R_{SC}}$
Outputs from +7 to +37 volts	**Outputs from −6 to −250 volts**	**Foldback Current Limiting**
(Figure 17 Figure 19 Figure 20 Figure 21 Figure 24 Figure 27) $V_{OUT} = \left(V_{REF} \times \frac{R1 + R2}{R2}\right)$	(Figure 18 Figure 23 Figure 25) $V_{OUT} = \left(\frac{V_{REF}}{2} \times \frac{R1 + R2}{R1}\right)$; R3 = R4	$I_{KNEE} = \left(\frac{V_{OUT}\,R3}{R_{SC}\,R4} + \frac{V_{SENSE}\,(R3 + R4)}{R_{SC}\,R4}\right)$ $I_{SHORT\ CKT} = \left(\frac{V_{SENSE}}{R_{SC}} \times \frac{R3 + R4}{R4}\right)$

TYPICAL APPLICATIONS

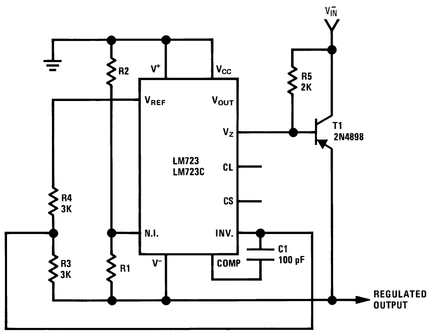


Note: $R3 = \frac{R1\,R2}{R1 + R2}$
for minimum temperature drift.
R3 may be eliminated for minimum component count.

Typical Performance

Regulated Output Voltage	15V
Line Regulation (ΔV_{IN} = 3V)	1.5 mV
Load Regulation (ΔI_L = 50 mA)	4.5 mV

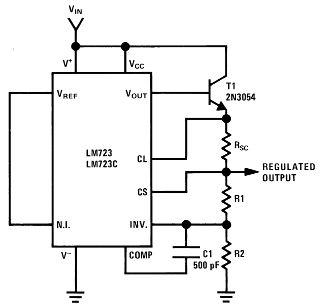
Figure 17. Basic High Voltage Regulator (V_{OUT} = 7 to 37 Volts)



Typical Performance

Regulated Output Voltage	−15V
Line Regulation (ΔV_{IN} = 3V)	1 mV
Load Regulation (ΔI_L = 100 mA)	2 mV

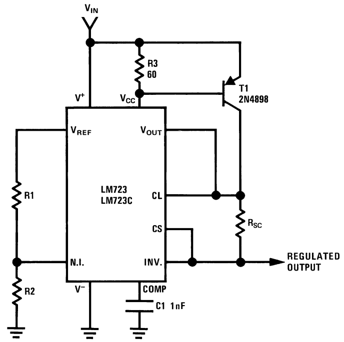
Figure 18. Negative Voltage Regulator



Typical Performance

Regulated Output Voltage	+15V
Line Regulation (ΔV_{IN} = 3V)	1.5 mV
Load Regulation (ΔI_L = 1A)	15 mV

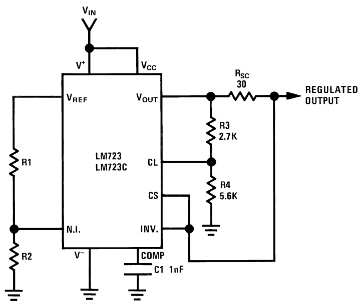
Figure 19. Positive Voltage Regulator (External NPN Pass Transistor)



Typical Performance

Regulated Output Voltage	+5V
Line Regulation (ΔV_{IN} = 3V)	0.5 mV
Load Regulation (ΔI_L = 1A)	5 mV

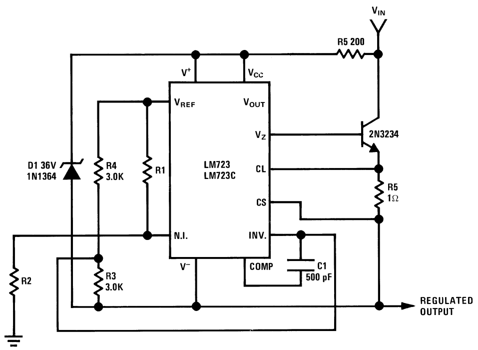
Figure 20. Positive Voltage Regulator (External PNP Pass Transistor)



Typical Performance

Regulated Output Voltage	+5V
Line Regulation (ΔV_{IN} = 3V)	0.5 mV
Load Regulation (ΔI_L = 10 mA)	1 mV
Short Circuit Current	20 mA

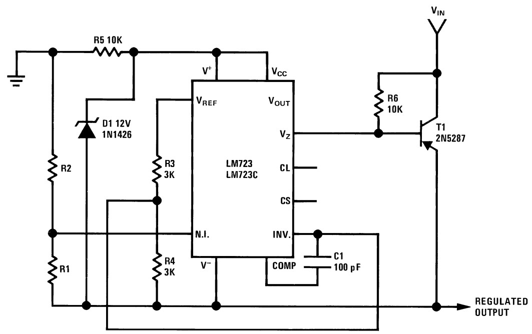
Figure 21. Foldback Current Limiting



Typical Performance

Regulated Output Voltage	+50V
Line Regulation (ΔV_{IN} = 20V)	15 mV
Load Regulation (ΔI_L = 50 mA)	20 mV

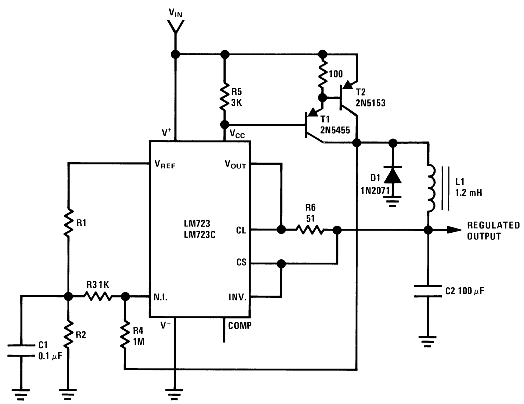
Figure 22. Positive Floating Regulator



Typical Performance

Regulated Output Voltage	−100V
Line Regulation (ΔV_{IN} = 20V)	30 mV
Load Regulation (ΔI_L = 100 mA)	20 mV

Figure 23. Negative Floating Regulator



Typical Performance

Regulated Output Voltage	+5V
Line Regulation (ΔV_{IN} = 30V)	10 mV
Load Regulation (ΔI_L = 2A)	80 mV

Figure 24. Positive Switching Regulator