

## Three-terminal 5 A adjustable voltage regulators

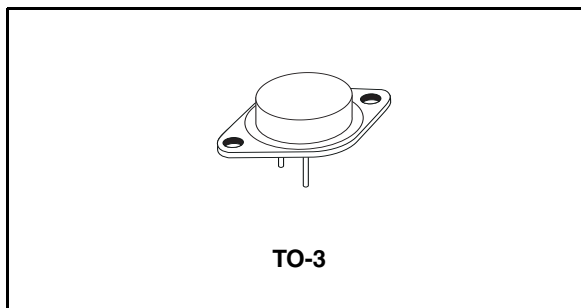
### Features

- Guaranteed 7 A peak output current
- Guaranteed 5 A output current
- Adjustable output down to 1.2 V
- Line regulation typically 0.005 %/V
- Load regulation typically 0.1 %
- Guaranteed thermal regulation
- Current limit constant with temperature
- Standard 3-lead transistor package

### Description

The LM138, LM238, LM338 are adjustable 3-terminal positive voltage regulators capable of supplying in excess of 5 A over a 1.2 V to 32 V output range. They are exceptionally easy to use and require only 2 resistors to set the output voltage. Careful circuit design has resulted in outstanding load and line regulation comparable to many commercial power supplies. The LM138 family is supplied in a standard 3-lead transistor package.

A unique feature of the LM138 family is time-dependent current limiting. The current limit circuitry allows peak currents of up to 12 A to be drawn from the regulator for short periods of time. This allows the LM138 to be used with heavy transient loads and speeds start-up under full-load conditions. Under sustained loading conditions, the current limit decreases to a safe value protecting the regulator. Also included on the chip are thermal overload protection and safe area protection for the power transistor. Overload



protection remains functional even if the adjustment pin is accidentally disconnected.

Normally, no capacitors are needed unless the device is situated far from the input filter capacitors in which case an input bypass is needed. An optional output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejection ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators or discrete designs, the LM238 is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to input differential is not exceeded.

The LM138, LM238, LM338 are packaged in standard steel TO-3 transistor package. The LM138 is rated for operation from - 55 °C to 150 °C, the LM238 from - 25 °C to 150 °C and the LM338 from 0 °C to 125 °C.

**Table 1. Device summary**

Part numbers	Order codes	Temperature range
LM138	LM138K	-55 °C to 150 °C
LM238	LM238K	-25 °C to 150 °C
LM338	LM338K	0 °C to 125 °C

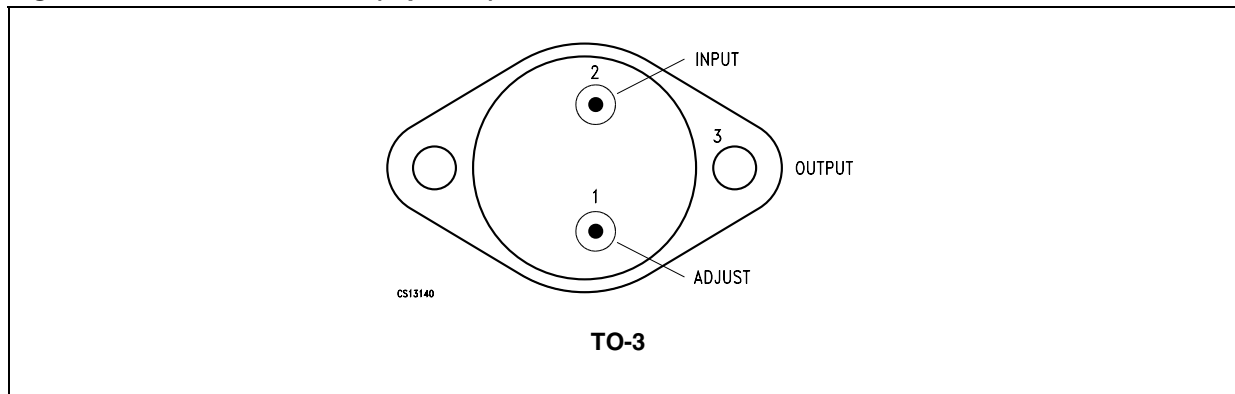
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## 2 Pin configuration

Figure 2. Pin connections (top view)



### 3 Maximum ratings

**Table 2. Absolute maximum ratings**

Symbol	Parameter	Value	Unit
$V_I - V_O$	Input-output voltage differential	35	V
$P_D$	Power dissipation	Internally limited	
$T_{STG}$	Storage temperature range	-65 to 150	°C
$T_{LEAD}$	Lead temperature (Soldering, 10 seconds)	300	°C
$T_{OP}$	Operating junction temperature range	LM138	-55 to 150
		LM238	-25 to 125
		LM338	0 to 125

*Note: Absolute maximum ratings are those values beyond which damage to the device may occur. Functional operation under these condition is not implied.*

**Table 3. Thermal data**

Symbol	Parameter	Value	Unit
$R_{thJC}$	Thermal resistance junction-case	1.4	°C/W
$R_{thJA}$	Thermal resistance junction-ambient	35	°C/W

## 4 Electrical characteristics

**Table 4. Electrical characteristics for LM138/LM238 <sup>(1)</sup>**

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit	
$K_{VI}$	Line regulation <sup>(2)</sup>	$T_A = 25^\circ\text{C}$ , $V_I - V_O = 3$ to $35$ V		0.005	0.01	%/V	
$K_{VO}$	Load regulation <sup>(2)</sup>	$T_A = 25^\circ\text{C}$ $I_O = 10$ mA to $5$ A	$V_O \leq 5$ V		5	15	mV
			$V_O \geq 5$ V		0.1	0.3	%
	Thermal regulation	Pulse = $20$ ms		0.002	0.01	%/W	
$I_{ADJ}$	Adjustment pin current			45	100	$\mu\text{A}$	
$\Delta I_{ADJ}$	Adjustment pin current change	$I_L = 10$ mA to $5$ A, $V_I - V_O = 3$ to $35$ V		0.2	5	$\mu\text{A}$	
$V_{REF}$	Reference voltage	$V_I - V_O = 3$ to $35$ V, $I_O = 10$ mA to $5$ A $P \leq 50$ W	1.19	1.24	1.29	V	
$K_{VI}$	Line regulation <sup>(2)</sup>	$V_I - V_O = 3$ to $35$ V		0.02	0.04	%/V	
$K_{VO}$	Load regulation <sup>(2)</sup>	$I_O = 10$ mA to $5$ A	$V_O \leq 5$ V		20	30	mV
			$V_O \geq 5$ V		0.3	0.6	%
$K_{VT}$	Temperature stability	$T_J = T_{MIN}$ to $T_{MAX}$		1		%	
$I_{O(MIN)}$	Minimum load current	$V_I - V_O \leq 35$ V		3.5	5	mA	
$I_{O(MAX)}$	Current limit	$V_I - V_O \leq 10$ V	DC	5	8	A	
			0.5 ms Peak	7	12		
			$V_I - V_O = 30$ V		1		
$V_{NO}$	RMS output noise (% of $V_O$ )	$T_a = 25^\circ\text{C}$ , $f = 10$ Hz to $10$ kHz			0.003	%	
$R_{VF}$	Ripple rejection ratio	$V_O = 10$ V, $f = 120$ Hz		60		dB	
		$C_{ADJ} = 10$ $\mu\text{F}$	60	75			
$K_{VH}$	Long term stability	$T_A = 125^\circ\text{C}$		0.3	1	%	

- <sup>(1)</sup> ( $T_J = -55$  to  $150$   $^\circ\text{C}$  for LM138,  $T_J = -25$  to  $150$   $^\circ\text{C}$  for LM238,  $V_I - V_O = 5$  V,  $I_O = 2.5$  A. Although power dissipation is internally limited, these specifications apply to power dissipation up to  $50$  W, unless otherwise specified)
- <sup>(2)</sup> Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects are taken into account separately by thermal rejection.

Table 5. Electrical characteristics for LM338 (1)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit	
$K_{VI}$	Line regulation (2)	$T_A = 25^\circ\text{C}$ , $V_I - V_O = 3$ to $35$ V		0.005	0.03	%/V	
$K_{VO}$	Load regulation (2)	$T_A = 25^\circ\text{C}$ $I_O = 10$ mA to $5$ A	$V_O \leq 5$ V		5	25	mV
			$V_O \geq 5$ V		0.1	0.5	%
	Thermal regulation	Pulse = $20$ ms		0.002	0.02	%/W	
$I_{ADJ}$	Adjustment pin current			45	100	$\mu\text{A}$	
$\Delta I_{ADJ}$	Adjustment pin current change	$I_L = 10$ mA to $5$ A, $V_I - V_O = 3$ to $35$ V		0.2	5	$\mu\text{A}$	
$V_{REF}$	Reference voltage	$V_I - V_O = 3$ to $35$ V, $I_O = 10$ mA to $5$ A $P \leq 50$ W	1.19	1.24	1.29	V	
$K_{VI}$	Line regulation (2)	$V_I - V_O = 3$ to $35$ V		0.02	0.06	%/V	
$K_{VO}$	Load regulation (2)	$I_O = 10$ mA to $5$ A	$V_O \leq 5$ V		20	50	mV
			$V_O \geq 5$ V		0.3	1	%
$K_{VT}$	Temperature stability	$T_J = T_{MIN}$ to $T_{MAX}$		1		%	
$I_{O(MIN)}$	Minimum load current	$V_I - V_O \leq 35$ V		3.5	10	mA	
$I_{O(MAX)}$	Current limit	$V_I - V_O \leq 10$ V	DC	5	8	A	
			0.5 ms Peak	7	12		
			$V_I - V_O = 30$ V		1		
$V_{NO}$	RMS output noise (% of $V_O$ )	$T_a = 25^\circ\text{C}$ , $f = 10$ Hz to $10$ kHz			0.003	%	
$R_{VF}$	Ripple rejection ratio	$V_O = 10$ V, $f = 120$ Hz		60		dB	
		$C_{ADJ} = 10$ $\mu\text{F}$	60	75			
$K_{VH}$	Long term stability	$T_A = 125^\circ\text{C}$		0.3	1	%	

- ( $T_J = 0$  to  $150^\circ\text{C}$ ,  $V_I - V_O = 5$  V,  $I_O = 2.5$  A. Although power dissipation is internally limited, these specifications apply to power dissipation up to  $50$  W, unless otherwise specified)
- Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects are taken into account separately by thermal rejection.

# 5 Typical characteristics

Figure 3. Current limit

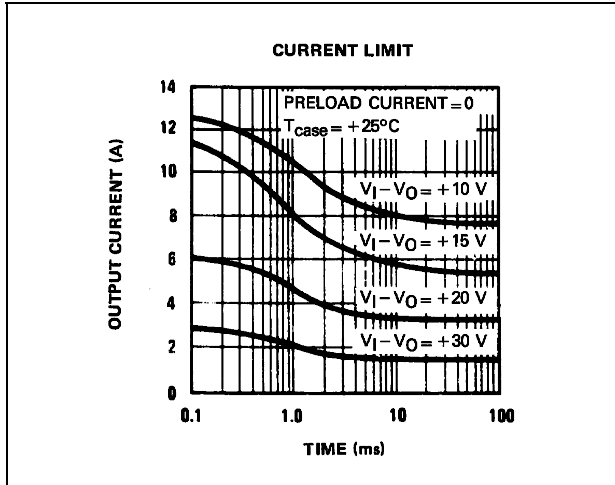


Figure 4. Current limit

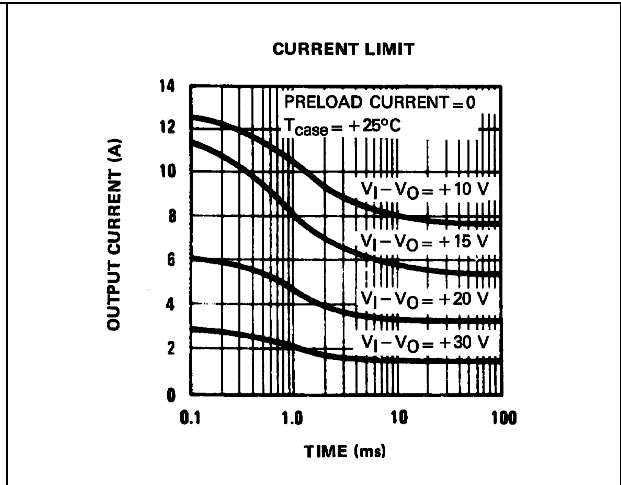


Figure 5. Current limit

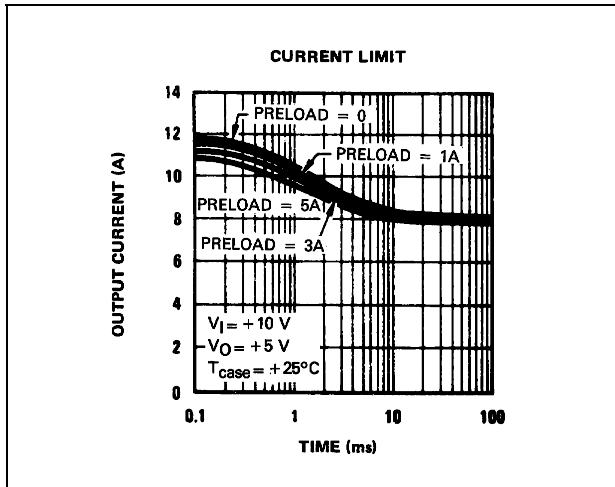


Figure 6. Load regulation

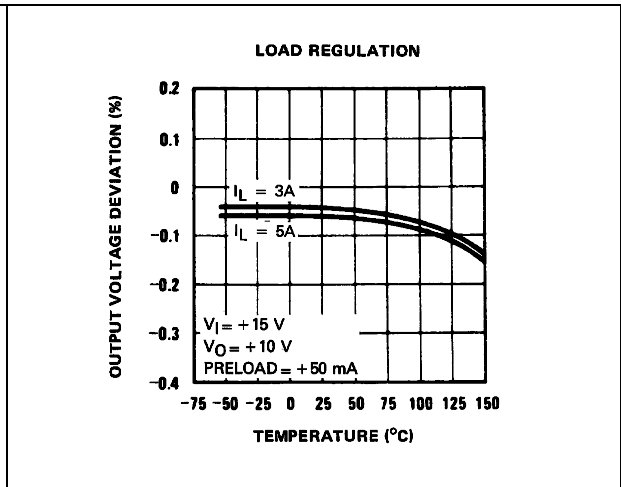




Figure 7. Dropout voltage

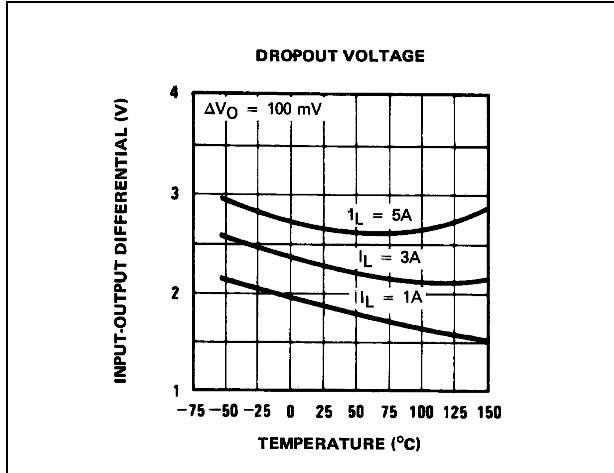


Figure 8. Adjustment current

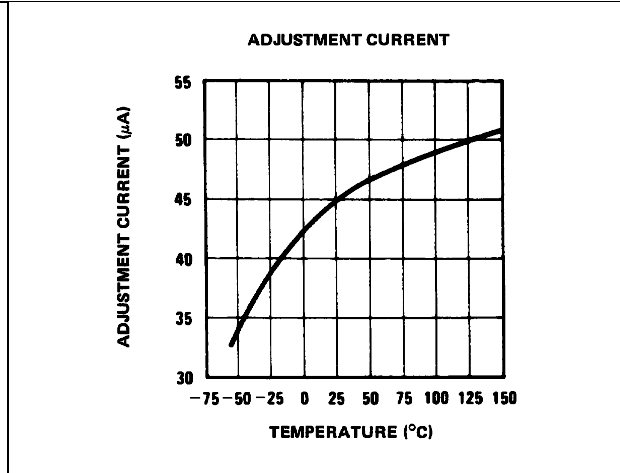


Figure 9. Temperature stability

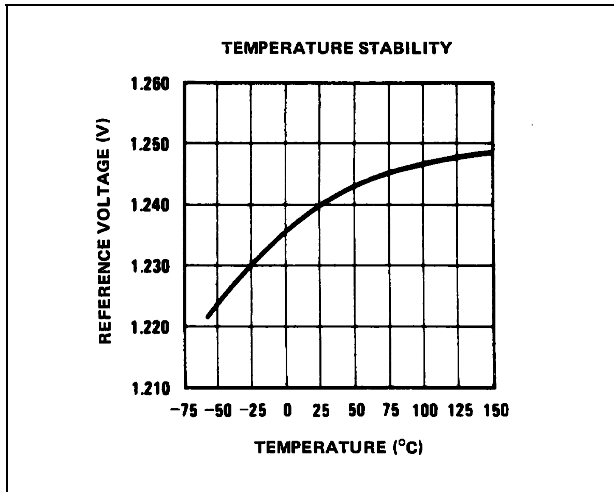


Figure 10. Output impedance

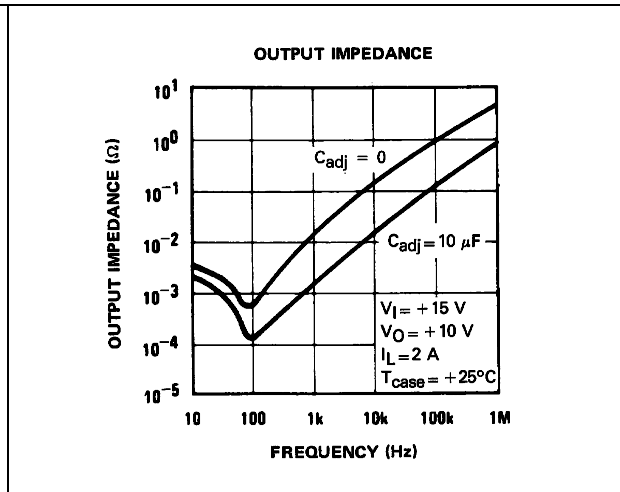


Figure 11. Minimum operating current

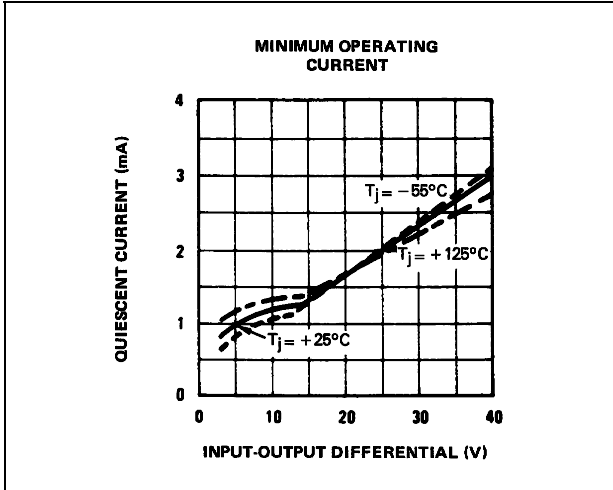


Figure 12. Ripple rejection

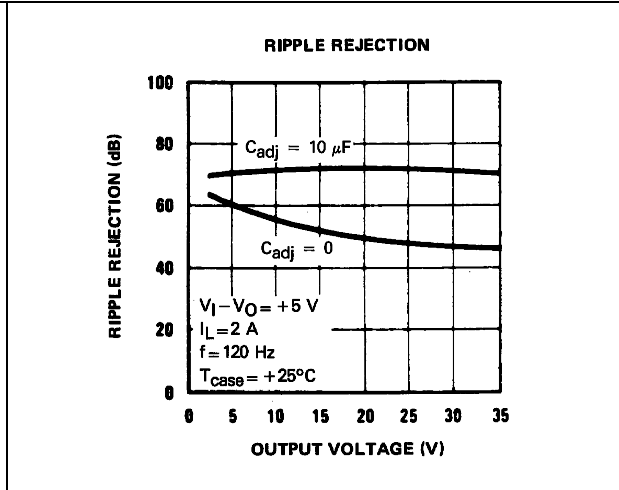


Figure 13. Ripple rejection

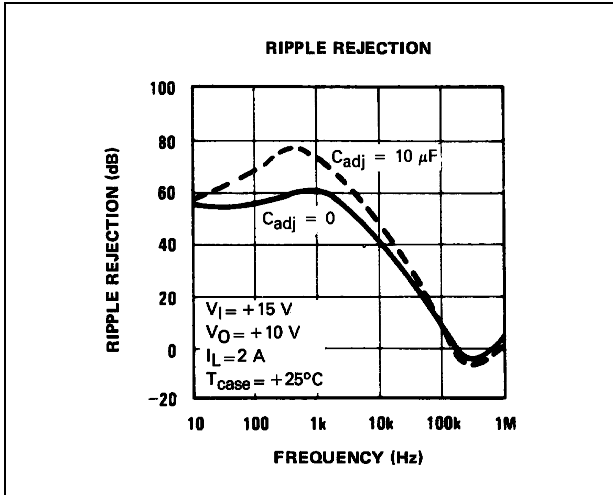


Figure 14. Ripple rejection

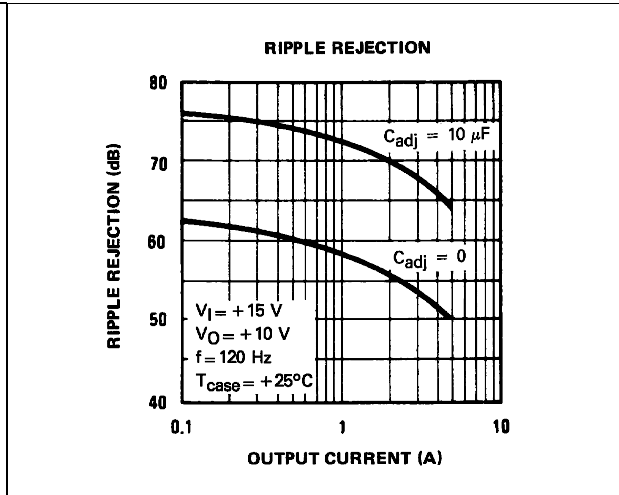


Figure 15. Line transient response

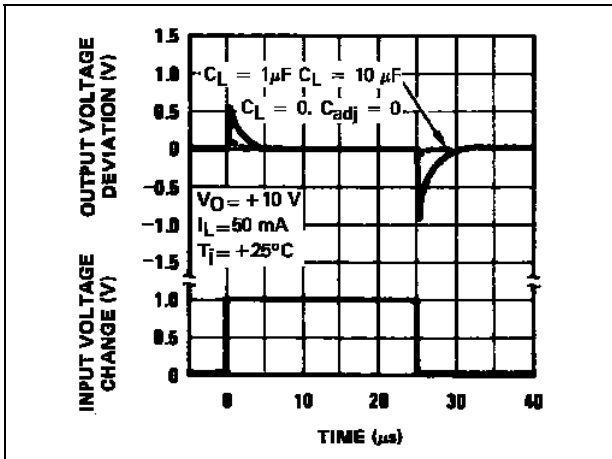
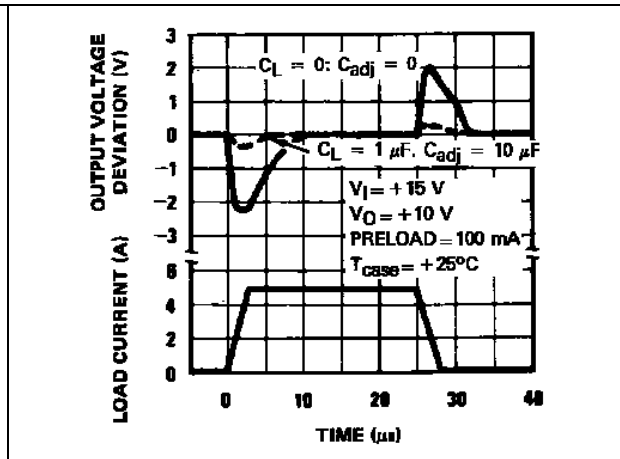
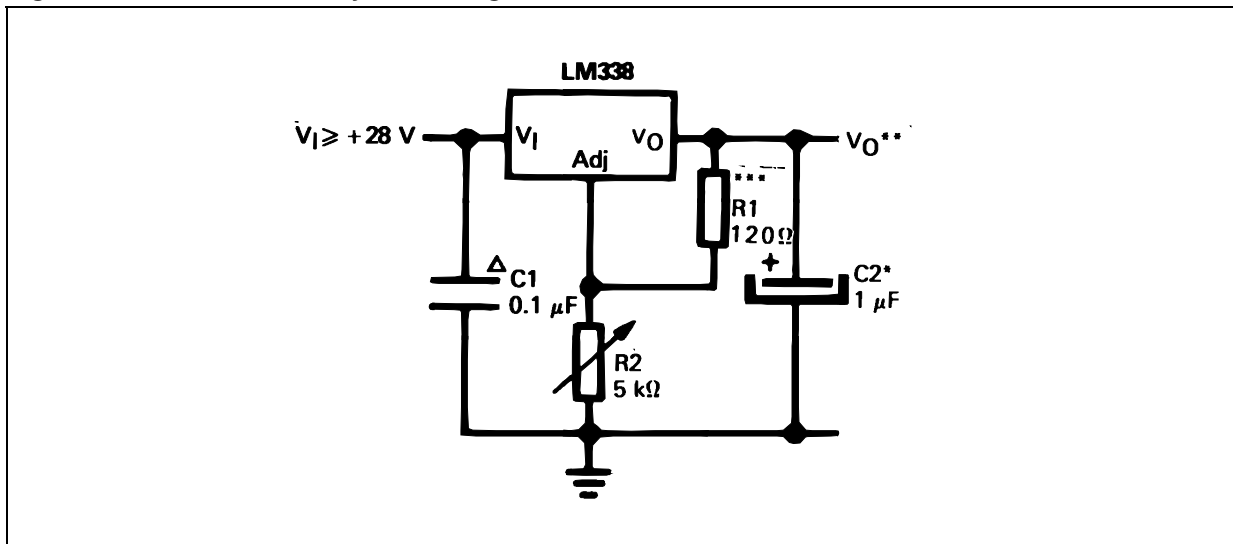


Figure 16. Load transient response



## 6 Typical application

Figure 17. 1.2 V to 25 V adjustable regulator



Needed if device is far from filter capacitors.

\* Optional-improves transient response. Output capacitors in the range of 1mF to 100mF of aluminium or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients

\*\*  $V_O = 1.25 \text{ V} (1 + R_2/R_1)$

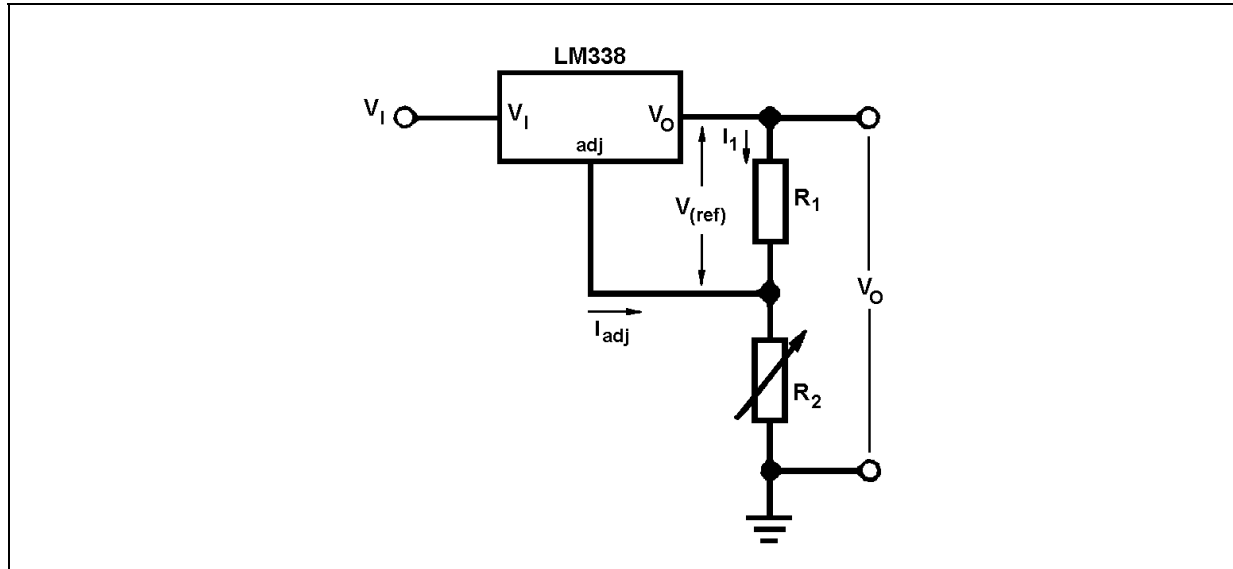
\*\*\*  $R_1 = 240 \text{ } \Omega$  for LM138 and LM238

## 7 Application hints

In operation, the LM338 develops a nominal 1.25 V reference voltage,  $V_{(REF)}$ , between the output and adjustment terminal. The reference voltage is impressed across program resistor  $R_1$  and, since the voltage is constant, a constant current  $I_1$  then flows through the output set resistor  $R_2$ , giving an output voltage of

$$V_O = V_{(REF)} (1 + R_2/R_1) + I_{ADJ}R_2$$

Figure 18. Application circuit



Since the 50  $\mu\text{A}$  current from the adjustment terminal represents an error term, the LM338 was designed to minimize  $I_{ADJ}$  and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output will rise.

### 7.1 External capacitors

An input bypass capacitor is recommended. A 0.1  $\mu\text{F}$  disc or 1  $\mu\text{F}$  solid tantalum on the input is suitable input by passing for almost all applications. The device is more sensitive to the absence of input bypassing when adjustment or output capacitors are used by the above values will eliminate the possibility of problems. The adjustment terminal can be bypassed to ground on the LM338 to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10  $\mu\text{F}$  bypass capacitor 75 dB ripple rejection is obtainable at any output level. Increases over 20  $\mu\text{F}$  do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device. In general, the best type of capacitors to use are solid tantalum. Solid tantalum capacitors have low impedance even at high frequencies. Depending upon capacitor construction, it takes about 25  $\mu\text{F}$  in aluminum electrolytic to equal 1  $\mu\text{F}$  solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies, but some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, 0.01  $\mu\text{F}$  disc may seem to work better than a

0.1  $\mu\text{F}$  disc as a bypass. Although the LM338 is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values between 500 pF and 5000 pF. A 1 mF solid tantalum (or 25  $\mu\text{F}$  aluminium electrolytic) on the output swamps this effect and insures stability.

## 7.2 Load regulation

The LM338 is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240  $\Omega$ ) should be tied directly to the output of the regulator rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15 V regulator with 0.05  $\Omega$  resistance between the regulator and load will have a load regulation due to line resistance of 0.05  $\Omega \times I_L$ . If the set resistor is connected near the load the effective line resistance will be 0.05  $\Omega (1 + R_2/R_1)$  or in this case, 11.5 times worse. [Figure 4 on page 8](#) shows the effect of resistance between the regulator and 140  $\Omega$  set resistor. With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using 2 separate leads to the case. The ground of  $R_2$  can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

## 7.3 Protection diodes

When external capacitors are used with any IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 20  $\mu\text{F}$  capacitors have low enough internal series resistance to deliver 20 A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC. When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of  $V_I$ . In the LM338 this discharge path is through a large junction that is able to sustain 25 A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 100  $\mu\text{F}$  or less at output of 15 V or less, there is no need to use diodes. The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when either the input or output is shorted. Internal to the LM338 is a 50  $\Omega$  resistor which limits the peak discharge current. No protection is needed for output voltages of 25 V or less and 10  $\mu\text{F}$  capacitance. [Figure 5 on page 8](#) shows an LM338 with protection diodes included for use with outputs greater than 25 V and high values of output capacitance. An LM338 with protection diodes included for use with outputs greater than 25 V and high values of output capacitance.

Figure 19. Regulator with line resistance in output lead

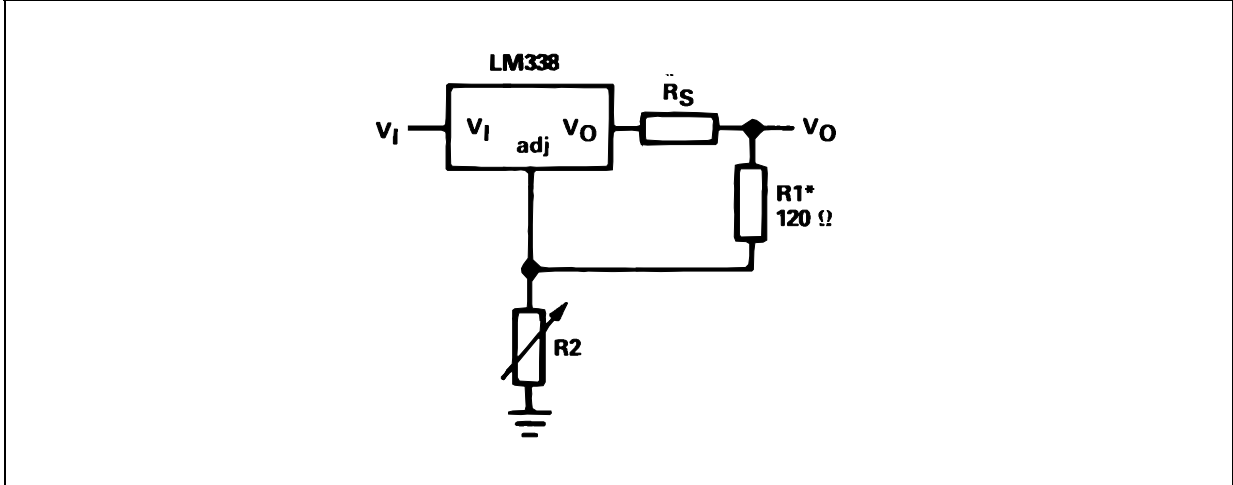


Figure 20. Regulator with protection diodes

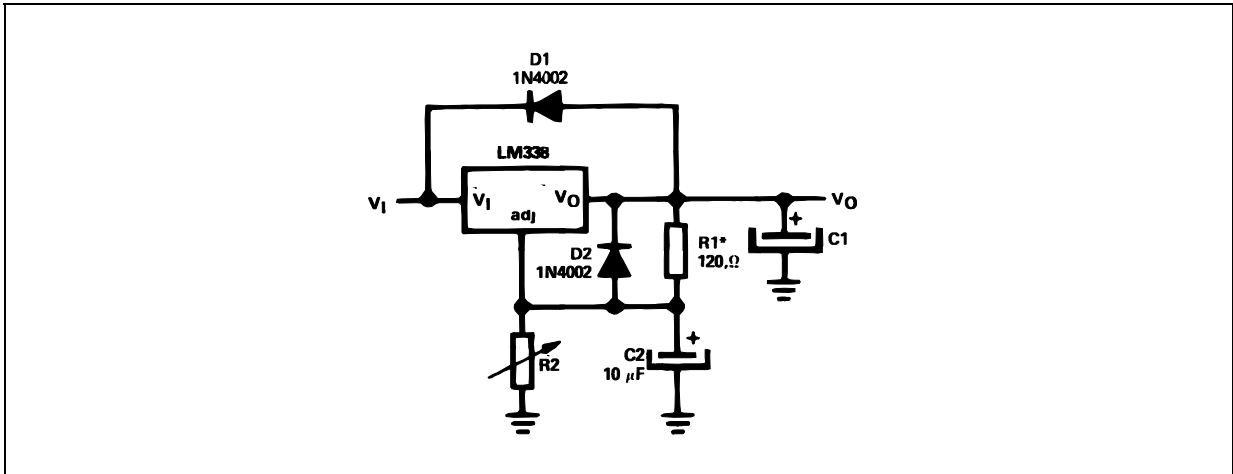
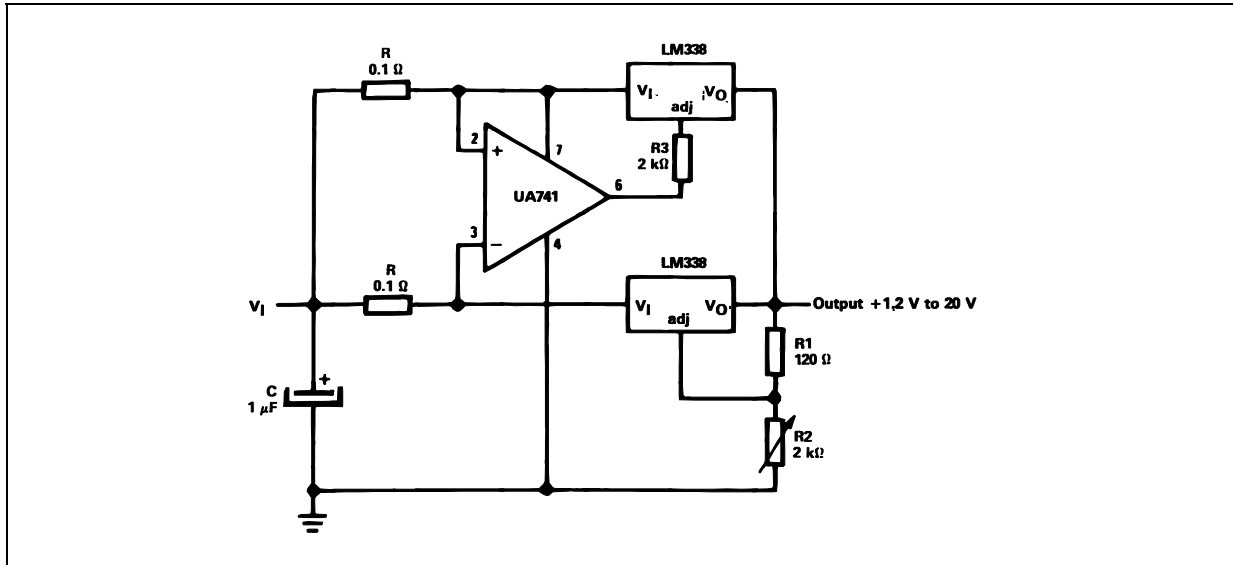
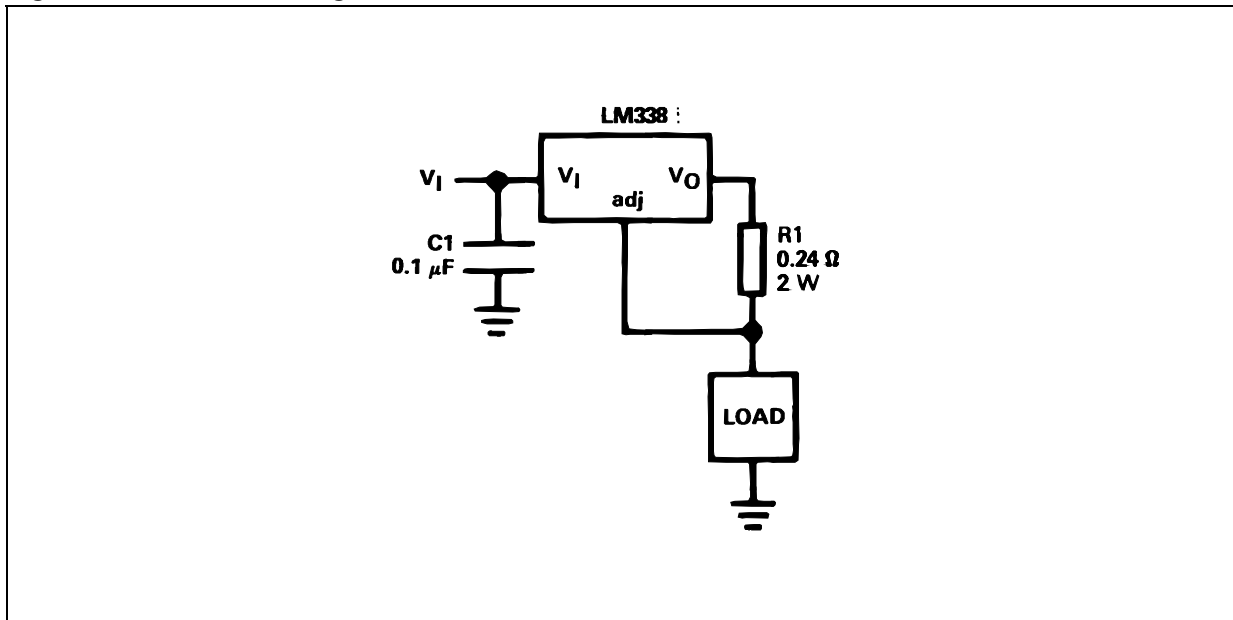


Figure 21. 10 A regulator



\* Minimum load - 100 mA  
 $V_I \geq 10$  V  
 $V_O \geq 3$  V  
 $V_I - V_O \geq 3.5$  V

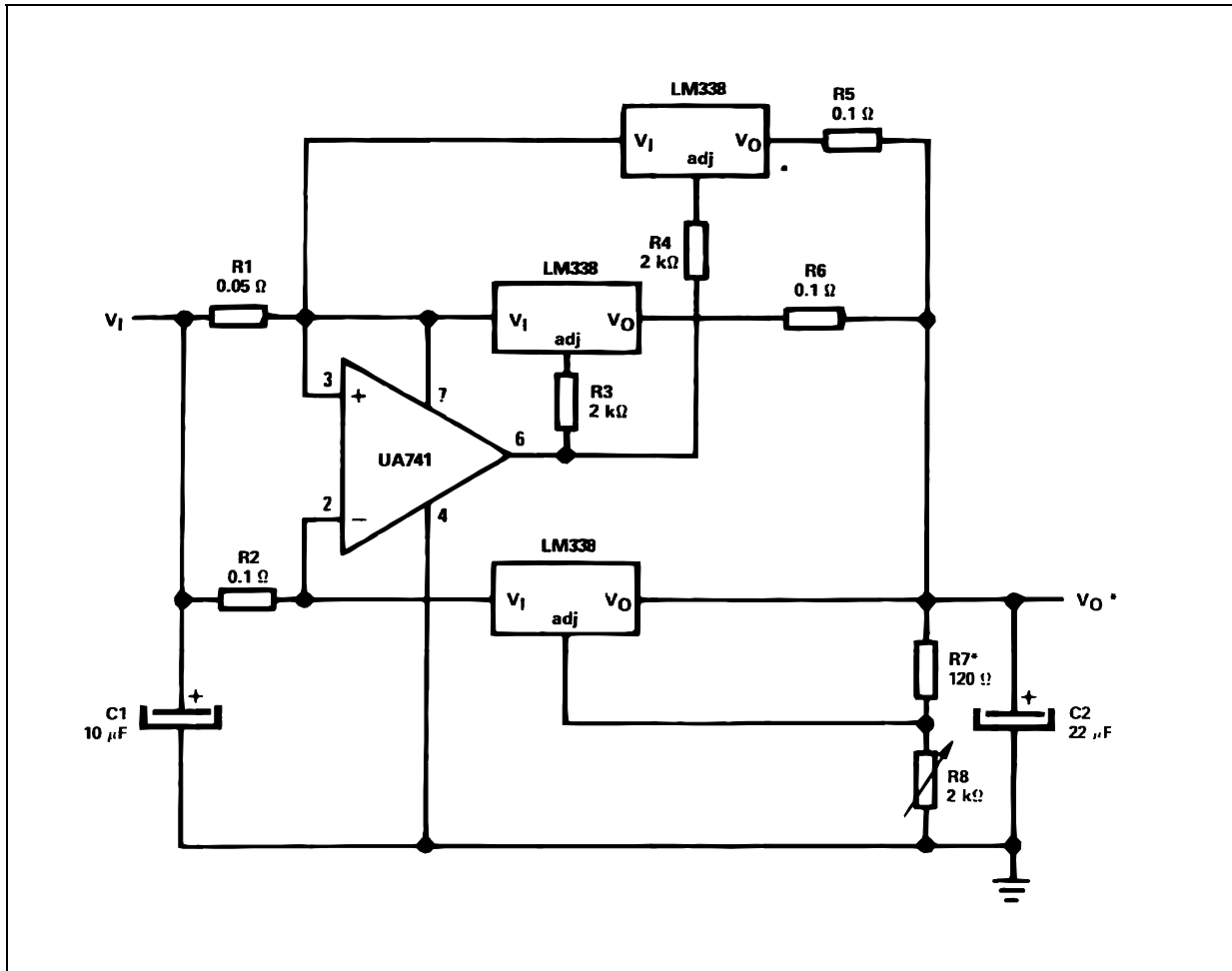
Figure 22. 5 A current regulator



\* Minimum load - 100 mA  
 $V_I \geq 10$  V  
 $V_O \geq 3$  V



Figure 23. 15 A regulator



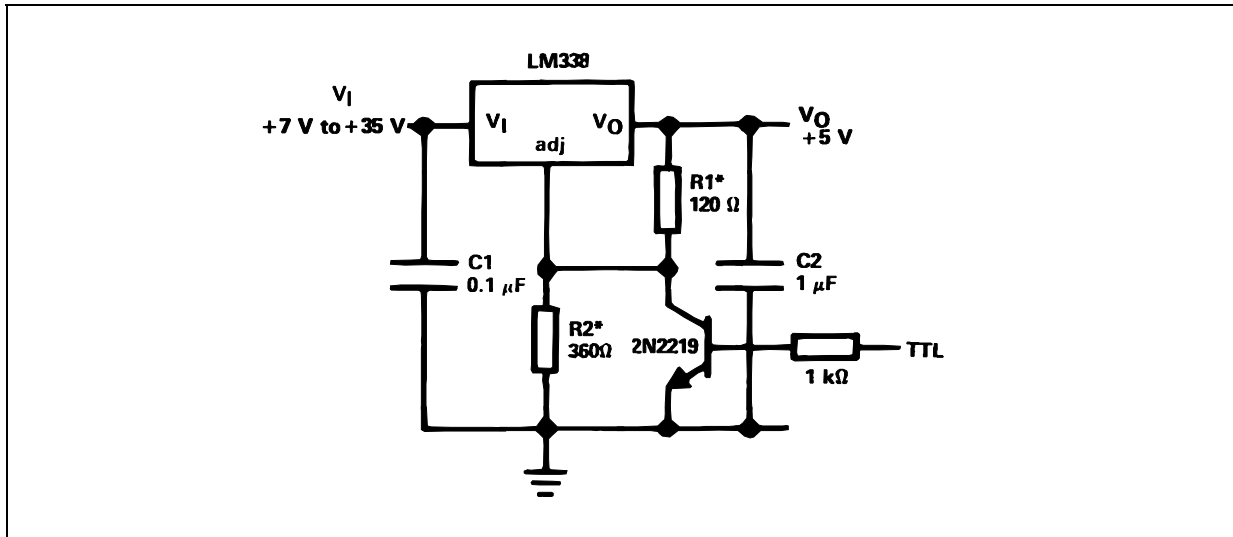
\* Minimum load - 100mA

$V_I \geq 10 \text{ V}$

$V_O \geq 3 \text{ V}$

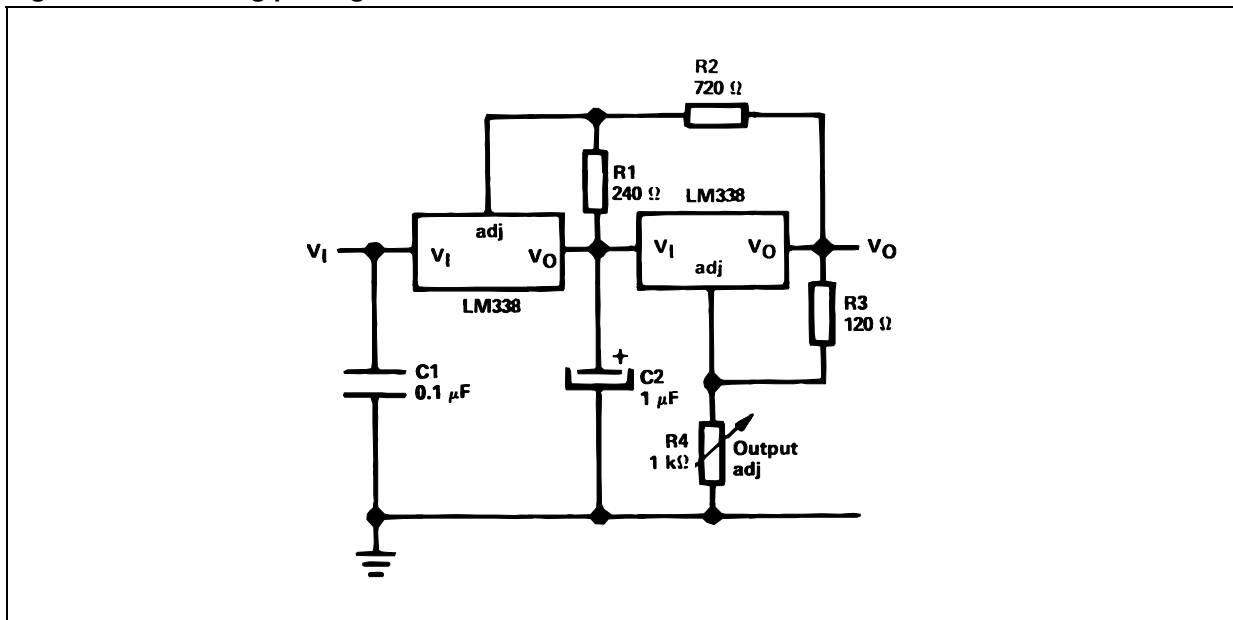
$V_I - V_O \geq 4 \text{ V}$

Figure 24. 5 V logic regulator with electronic shutdown



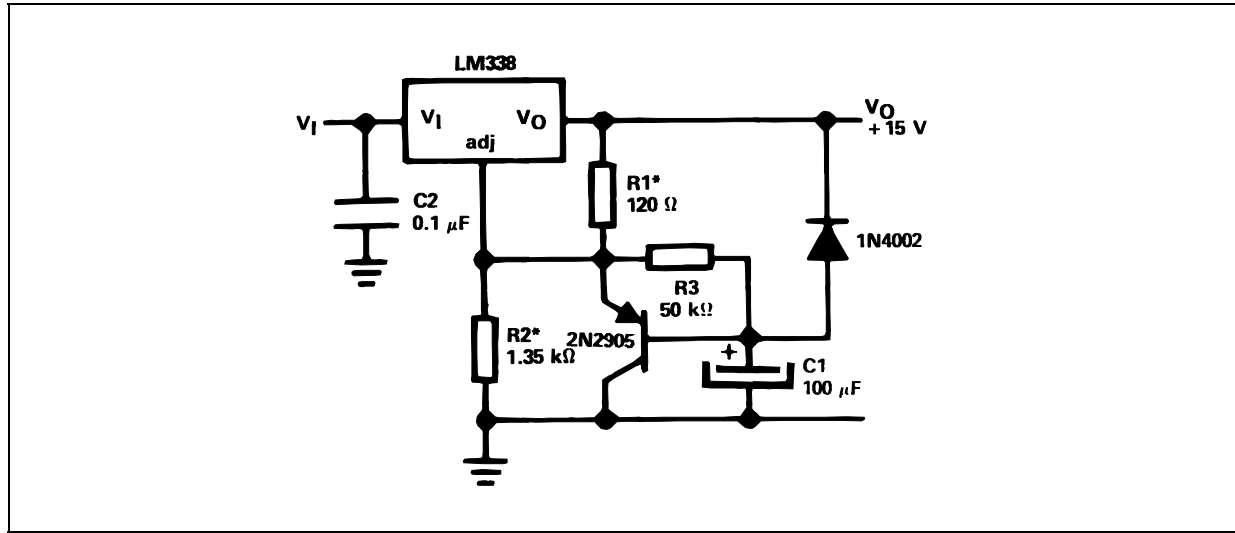
- \*  $R_1 = 240 \Omega$  for LM138 or LM238
- \*  $R_2 = 720 \Omega$  for LM138 or LM238
- \*\* Minimum load - 100 mA

Figure 25. Tracking pre-regulator



- \*  $R_1 = 240 \Omega$  for LM138 or LM238
- \*  $R_2 = 720 \Omega$  for LM138 or LM238
- \*\* Minimum output = 1.2 V

Figure 26. Slow turn-on 15 V regulator



\*  $R_1 = 240 \Omega$  for LM138 or LM238

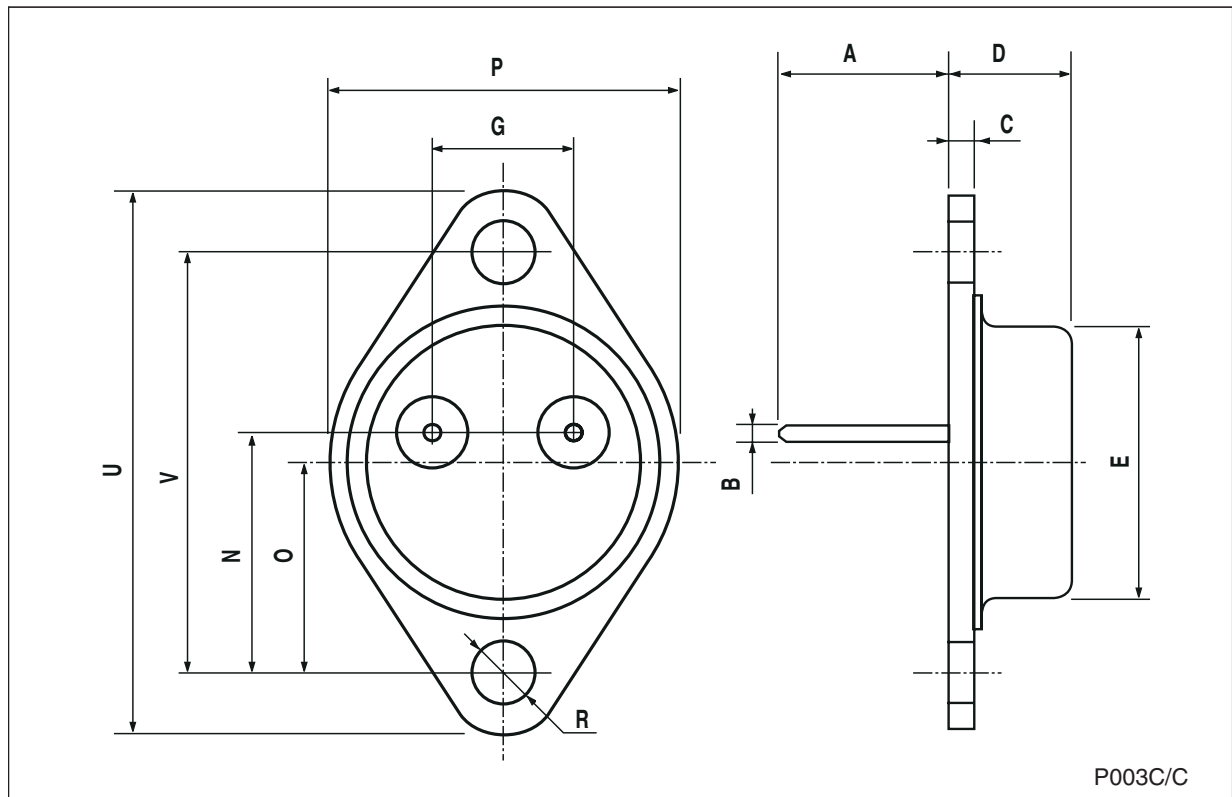
\*  $R_2 = 2.7 \text{ k}\Omega$  for LM138 or LM238

## 8 Package mechanical data

In order to meet environmental requirements, ST offers these devices in ECOPACK<sup>®</sup> packages. These packages have a lead-free second level interconnect. The category of second Level Interconnect is marked on the package and on the inner box label, in compliance with JEDEC Standard JESD97. The maximum ratings related to soldering conditions are also marked on the inner box label. ECOPACK is an ST trademark. ECOPACK specifications are available at: [www.st.com](http://www.st.com).

**TO-3 mechanical data**

Dim.	mm.			inch.		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A		11.85			0.466	
B	0.96	1.05	1.10	0.037	0.041	0.043
C			1.70			0.066
D			8.7			0.342
E			20.0			0.787
G		10.9			0.429	
N		16.9			0.665	
P			26.2			1.031
R	3.88		4.09	0.152		0.161
U			39.5			1.555
V		30.10			1.185	



## 9 Revision history

**Table 6. Document revision history**

Date	Revision	Changes
16-Apr-2003	1	First release.
11-Apr-2008	2	Added: <a href="#">Table 1 on page 1</a> .

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