LM138/LM338 5-Amp Adjustable Regulators

Check for Samples: LM138, LM338

FEATURES

- **Specified 7A Peak Output Current**
- **Specified 5A Output Current**
- **Adjustable Output Down to 1.2V**
- **Specified Thermal Regulation**
- **Current Limit Constant with Temperature**
- **P⁺ Product Enhancement Tested**
- **Output is Short-Circuit Protected**

APPLICATIONS

- **Adjustable Power Supplies**
- **Constant Current Regulators**
- **Battery Chargers**

DESCRIPTION

The LM138 series of adjustable 3-terminal positive voltage regulators is capable of supplying in excess of 5A over a 1.2V to 32V 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 12A 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 more than 6 inches from the input filter capacitors in which case an input bypass is needed. An output capacitor can be added to improve transient response, while bypassing the adjustment pin will increase the regulator's ripple rejection.

Besides replacing fixed regulators or discrete designs, the LM138 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 output differential is not exceeded, i.e., do not short-circuit output to ground. The part numbers in the LM138 series which have a K suffix are packaged in a standard Steel TO-3 package, while those with a T suffix are packaged in a TO-220 plastic package. The LM138 is rated for −55°C ≤ T_J ≤ +150°C, and the LM338 is rated for 0°C ≤ T_J ≤ +125°C.

Connection Diagram

Connection Diagrams
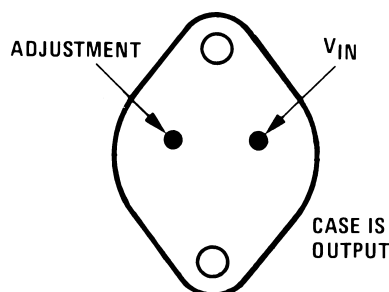
Figure 1. (TO-3) Metal Can Package
Bottom View
See Package Number NDS0002A
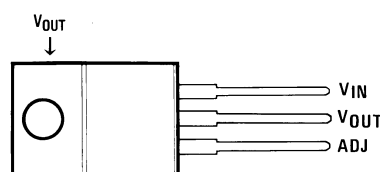
Figure 2. (TO-220) Plastic Package
Front View
See Package Number NDE0003B

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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)(3)]

Power Dissipation	Internally limited
Input/Output Voltage Differential	+40V, −0.3V
Storage Temperature	−65°C to +150°C
Lead Temperature TO-3 Package (Soldering, 10 seconds) TO-220 Package (Soldering, 4 seconds)	 300°C 260°C
ESD Tolerance	TBD

(1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not ensure specific performance limits. For ensured specifications and test conditions, see the Electrical Characteristics.
(2) Refer to RETS138K drawing for military specifications of LM138K.
(3) If Military/Aerospace specified devices are required, please contact the TI Sales Office/ Distributors for availability and specifications.

Operating Temperature Range

LM138	−55°C ≤ T_J ≤ +150°C
LM338	0°C ≤ T_J ≤ +125°C

Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range.** Unless otherwise specified, $V_{IN} − V_{OUT}$ = 5V; and I_{OUT} = 10 mA. [(1)]

Symbol	Parameter	Conditions	LM138			Units
			Min	Typ	Max	
V_{REF}	Reference Voltage	3V ≤ ($V_{IN} − V_{OUT}$) ≤ 35V, 10 mA ≤ I_{OUT} ≤ 5A, P ≤ 50W	**1.19**	**1.24**	**1.29**	V
V_{RLINE}	Line Regulation	3V ≤ ($V_{IN} − V_{OUT}$) ≤ 35V [(2)]		0.005	0.01	%/V
				0.02	**0.04**	%/V
V_{RLOAD}	Load Regulation	10 mA ≤ I_{OUT} ≤ 5A [(2)]		0.1	0.3	%
				0.3	**0.6**	%
	Thermal Regulation	20 ms Pulse		0.002	0.01	%/W
I_{ADJ}	Adjustment Pin Current			**45**	**100**	µA
ΔI_{ADJ}	Adjustment Pin Current Change	10 mA ≤ I_{OUT} ≤ 5A, 3V ≤ ($V_{IN} − V_{OUT}$) ≤ 35V		**0.2**	**5**	µA
$\Delta V_{R/T}$	Temperature Stability	T_{MIN} ≤ T_J ≤ T_{MAX}		**1**		%
I_{LOAD}(Min)	Minimum Load Current	$V_{IN} − V_{OUT}$ = 35V		**3.5**	**5**	mA
I_{CL}	Current Limit	$V_{IN} − V_{OUT}$ ≤ 10V				
		DC	**5**	**8**		A
		0.5 ms Peak	**7**	**12**		A
		$V_{IN} − V_{OUT}$ = 30V		1	1	A
V_N	RMS Output Noise, % of V_{OUT}	10 Hz ≤ f ≤ 10 kHz		0.003		%
$\Delta V_R/\Delta V_{IN}$	Ripple Rejection Ratio	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 0 µF		**60**		dB
		V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 10 µF	**60**	75		dB
	Long-Term Stability	T_J = 125°C, 1000 Hrs		0.3	1	%
θ_{JC}	Thermal Resistance, Junction to Case	NDS Package			1	°C/W

(1) These specifications are applicable for power dissipations up to 50W for the TO-3 (NDS) package and 25W for the TO-220 (NDE) package. Power dissipation is specified at these values up to 15V input-output differential. Above 15V differential, power dissipation will be limited by internal protection circuitry. All limits (i.e., the numbers in the Min. and Max. columns) are specified to TI's AOQL (Average Outgoing Quality Level).
(2) Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.

Product Folder Links: *LM138 LM338*

Electrical Characteristics (continued)

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range.** Unless otherwise specified, $V_{IN} − V_{OUT} = 5V$; and $I_{OUT} = 10$ mA. [1]

Symbol	Parameter	Conditions	LM138			Units
			Min	Typ	Max	
θ_{JA}	Thermal Resistance, Junction to Ambient (No Heat Sink)	NDS Package		35		°C/W

Electrical Characteristics

Symbol	Parameter	Conditions	LM338			Units
			Min	Typ	Max	
V_{REF}	Reference Voltage	$3V ≤ (V_{IN} − V_{OUT}) ≤ 35V$, 10 mA $≤ I_{OUT} ≤ 5A$, $P ≤ 50W$	**1.19**	**1.24**	**1.29**	V
V_{RLINE}	Line Regulation	$3V ≤ (V_{IN} − V_{OUT}) ≤ 35V$ [1]		0.005	0.03	%/V
				0.02	**0.06**	%/V
V_{RLOAD}	Load Regulation	10 mA $≤ I_{OUT} ≤ 5A$ [1]		0.1	0.5	%
				0.3	**1**	%
	Thermal Regulation	20 ms Pulse		0.002	0.02	%/W
I_{ADJ}	Adjustment Pin Current			**45**	**100**	µA
ΔI_{ADJ}	Adjustment Pin Current Change	10 mA $≤ I_{OUT} ≤ 5A$, $3V ≤ (V_{IN} − V_{OUT}) ≤ 35V$		**0.2**	**5**	µA
$\Delta V_{R/T}$	Temperature Stability	$T_{MIN} ≤ T_J ≤ T_{MAX}$		**1**		%
I_{LOAD}(Min)	Minimum Load Current	$V_{IN} − V_{OUT} = 35V$		**3.5**	**10**	mA
I_{CL}	Current Limit	$V_{IN} − V_{OUT} ≤ 10V$				
		DC	**5**	**8**		A
		0.5 ms Peak	**7**	**12**		A
		$V_{IN} − V_{OUT} = 30V$			1	A
V_N	RMS Output Noise, % of V_{OUT}	10 Hz $≤ f ≤ 10$ kHz		0.003		%
$\Delta V_R/\Delta V_{IN}$	Ripple Rejection Ratio	$V_{OUT} = 10V$, f = 120 Hz, $C_{ADJ} = 0$ µF		**60**		dB
		$V_{OUT} = 10V$, f = 120 Hz, $C_{ADJ} = 10$ µF	**60**	**75**		dB
	Long-Term Stability	$T_J = 125°C$, 1000 hrs		0.3	1	%
θ_{JC}	Thermal Resistance	NDS Package			1	°C/W
	Junction to Case	NDE Package			4	°C/W
θ_{JA}	Thermal Resistance, Junction to	NDS Package		35		°C/W
	Ambient (No Heat Sink)	NDE Package		50		°C/W

(1) Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.
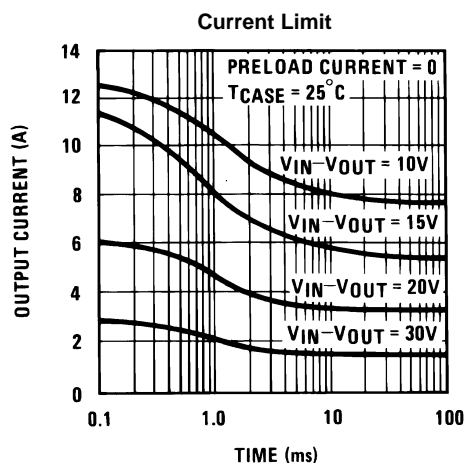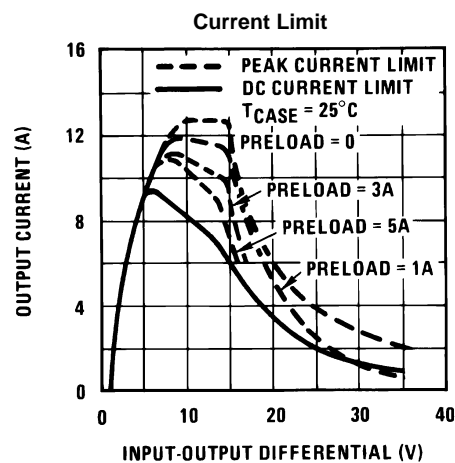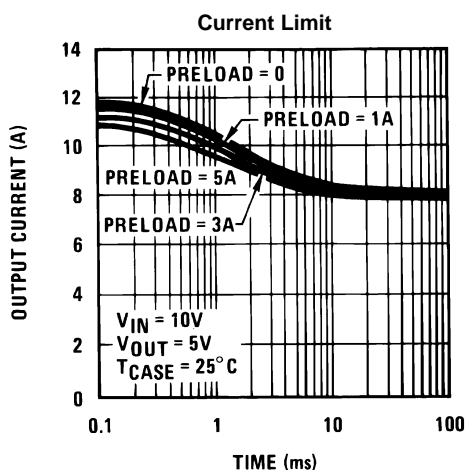
Typical Performance Characteristics

Current Limit

Figure 3.

Current Limit

Figure 4.

Current Limit

Figure 5.

Load Regulation

Figure 6.

Dropout Voltage

Figure .

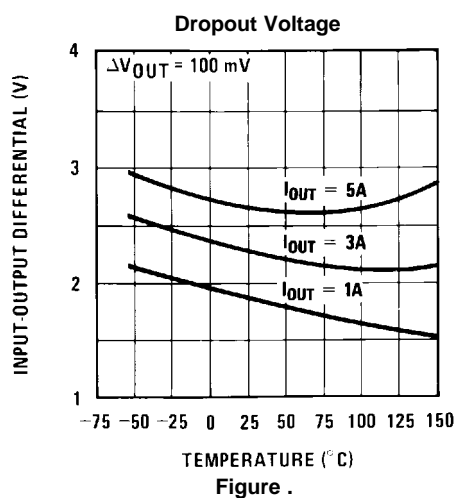**Adjustment Current**

Figure 7.

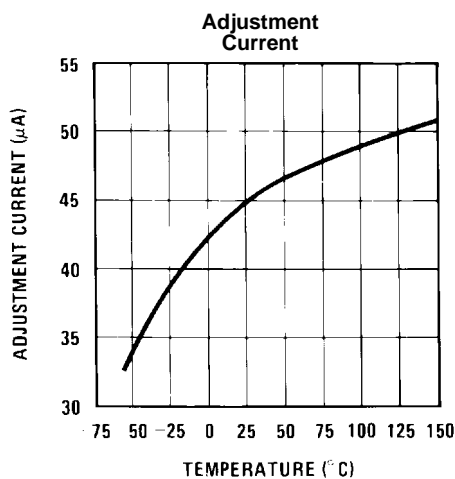Product Folder Links: *LM138 LM338*
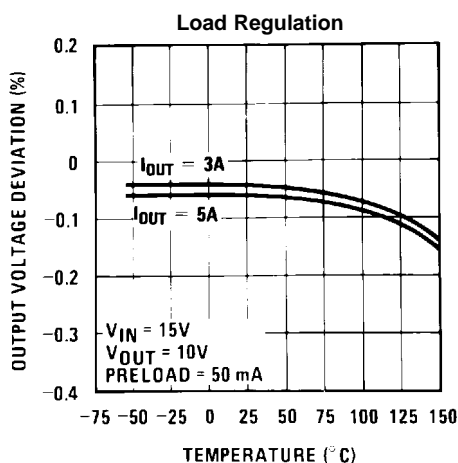
Typical Performance Characteristics (continued)
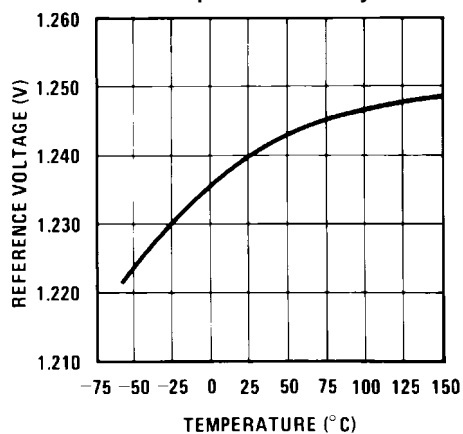
Temperature Stability

Figure 8.

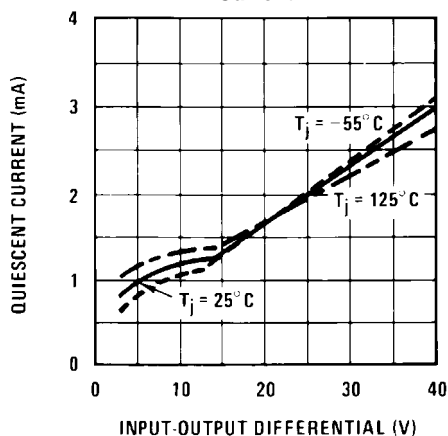**Output Impedance**
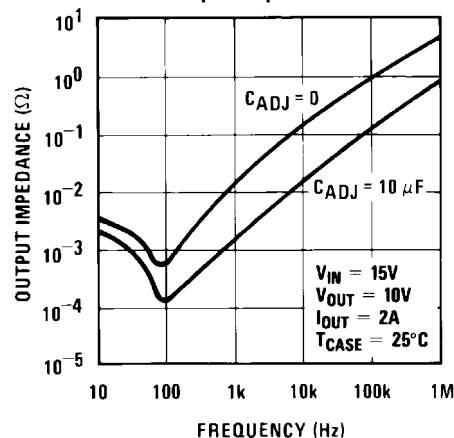
Figure 9.

Minimum Operating Current
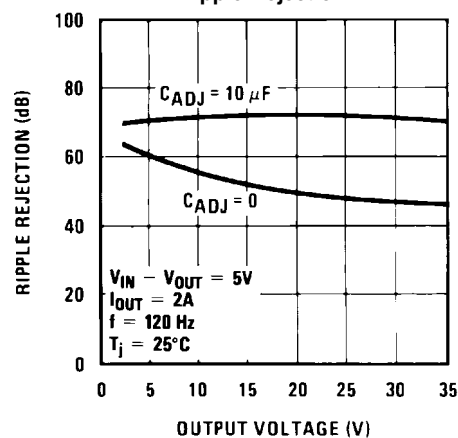

Figure 10.
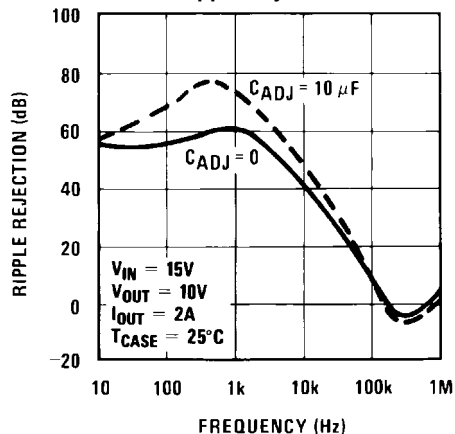
Ripple Rejection

Figure 11.

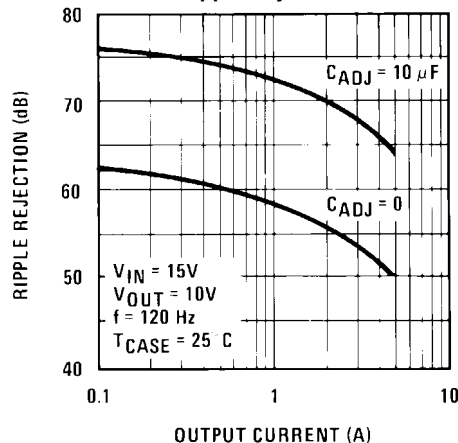**Ripple Rejection**

Figure 12.

Ripple Rejection

Figure 13.

Typical Performance Characteristics (continued)

Line Transient Response

Figure 14.

Load Transient Response

Figure 15.

Product Folder Links: LM138 LM338

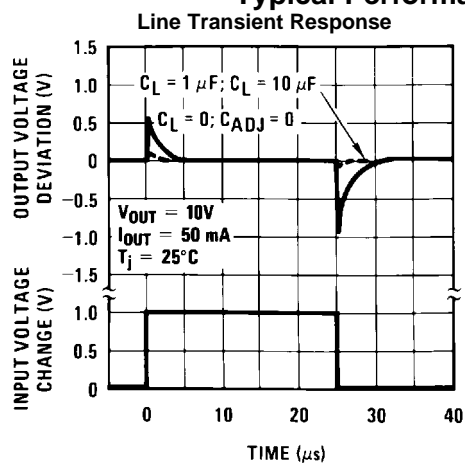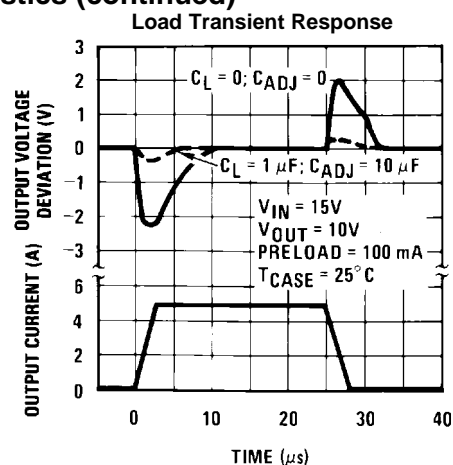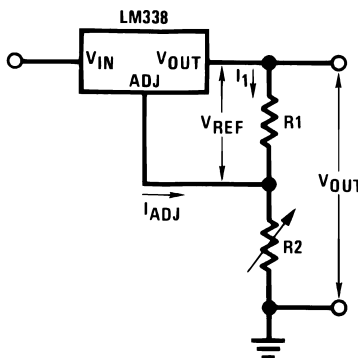## APPLICATION HINTS

In operation, the LM138 develops a nominal 1.25V reference voltage, V_{REF}, between the output and adjustment terminal. The reference voltage is impressed across program resistor R1 and, since the voltage is constant, a constant current I_1 then flows through the output set resistor R2, giving an output voltage of

$$V_{OUT} = V_{REF} \left(1 + \frac{R2}{R1} \right) + I_{ADJ}R2.$$

(1)

Since the 50 µA current from the adjustment terminal represents an error term, the LM138 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.

EXTERNAL CAPACITORS

An input bypass capacitor is recommended. A 0.1 µF disc or 1 µF solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassiing when adjustment or output capacitors are used but the above values will eliminate the possiblity of problems.

The adjustment terminal can be bypassed to ground on the LM138 to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10 µF bypass capacitor 75 dB ripple rejection is obtainable at any output level. Increases over 20 µF 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 µF in aluminum electrolytic to equal 1 µF 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 µF disc may seem to work better than a 0.1 µF disc as a bypass.

Although the LM138 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 µF solid tantalum (or 25 µF aluminum electrolytic) on the output swamps this effect and insures stability.

LOAD REGULATION

The LM138 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 240Ω) should be tied directly to the output of the regulator (case) rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15V regulator with 0.05Ω resistance between the regulator and load will have a load regulation due to line resistance of 0.05Ω × I_L. If the set resistor is connected near the load the effective line resistance will be 0.05Ω (1 + R2/R1) or in this case, 11.5 times worse.

Figure 16 shows the effect of resistance between the regulator and 240Ω set resistor.

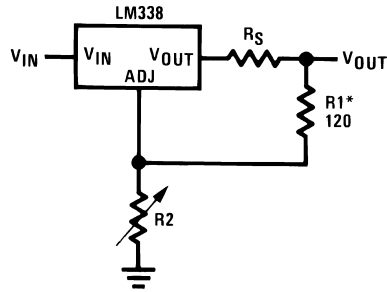
Product Folder Links: *LM138 LM338*

**Figure 16. Regulator with Line Resistance in Output Lead**

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 R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

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 µF capacitors have low enough internal series resistance to deliver 20A 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_{IN}. In the LM138 this discharge path is through a large junction that is able to sustain 25A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 100 µF or less at output of 15V 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 LM138 is a 50Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10 µF capacitance. Figure 17 shows an LM138 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.
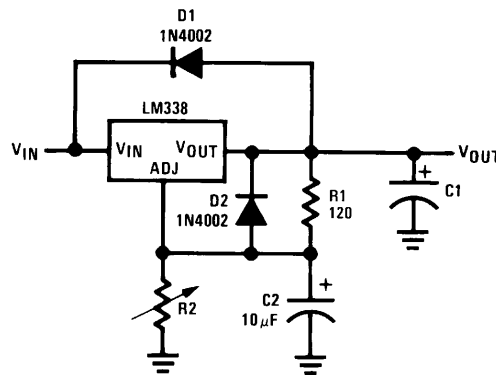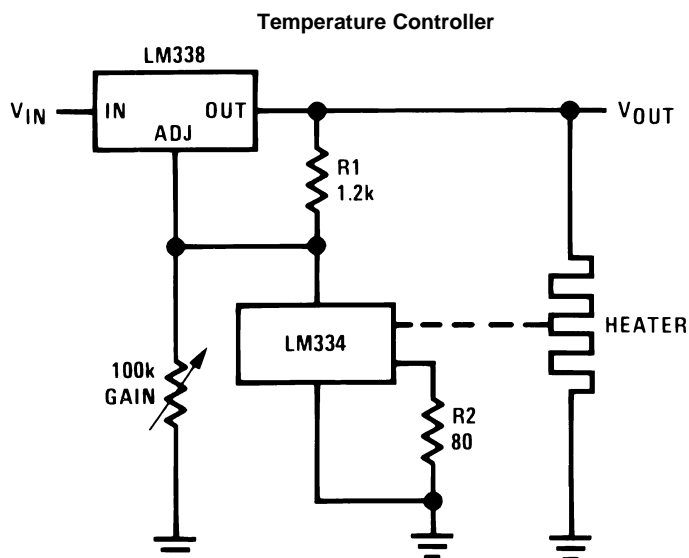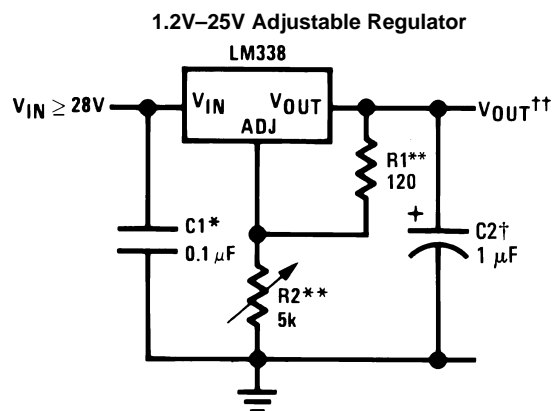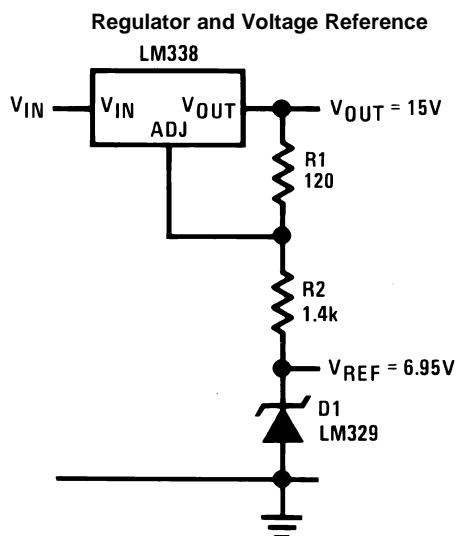

D1 protects against C1
D2 protects against C2

$$V_{OUT} = 1.25V \left(1 + \frac{R2}{R1} \right) + I_{ADJ}R2$$

Figure 17. Regulator with Protection Diodes

Product Folder Links: *LM138 LM338*

Typical Applications

Regulator and Voltage Reference

1.2V–25V Adjustable Regulator

Temperature Controller

Full output current not available at high input-output voltages

†Optional—improves transient response. Output capacitors in the range of 1 µF to 1000 µF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

*Needed if device is more than 6 inches from filter capacitors.
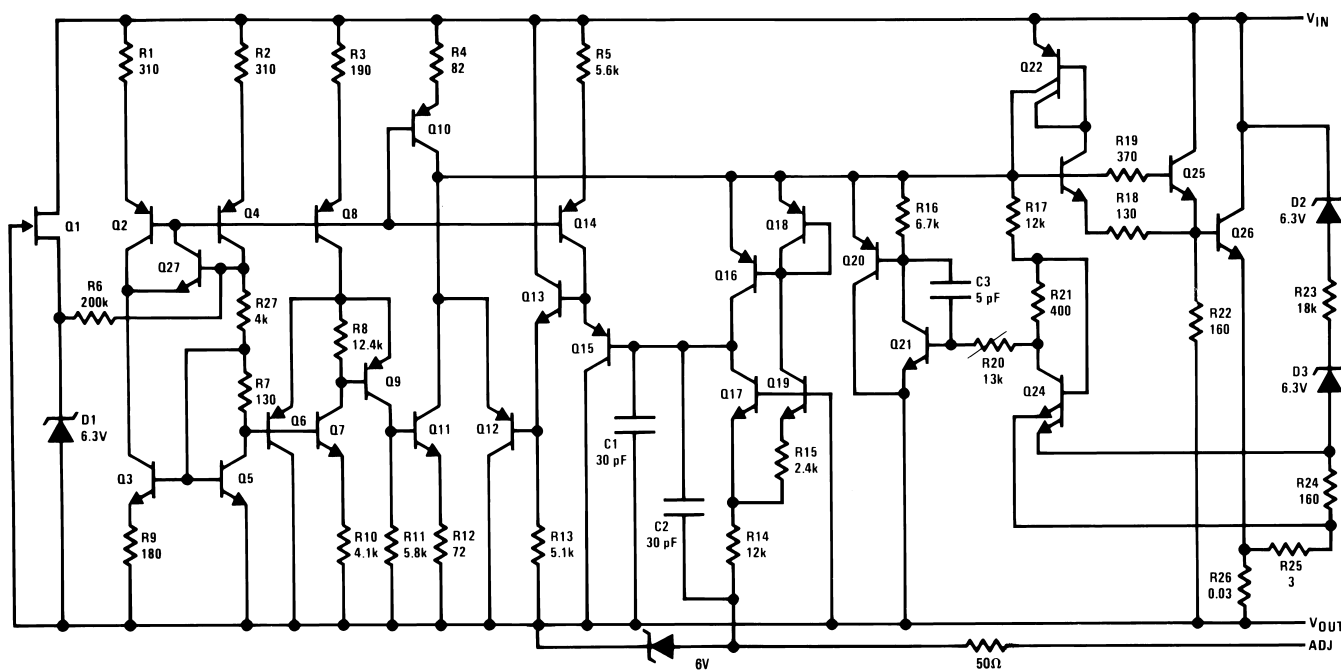
$$\dagger\dagger V_{OUT} = 1.25V \left(1 + \frac{R2}{R1} \right) + I_{ADJ} (R_2)$$

**R1 = 240Ω for LM138. R1, R2 as an assembly can be ordered from Bourns:
MIL part no. 7105A-AT2-502
COMM part no. 7105A-AT7-502

Schematic Diagram

Typical Applications

Precision Power Regulator with Low Temperature Coefficient

* Adjust for 3.75 across R1

Product Folder Links: *LM138 LM338*
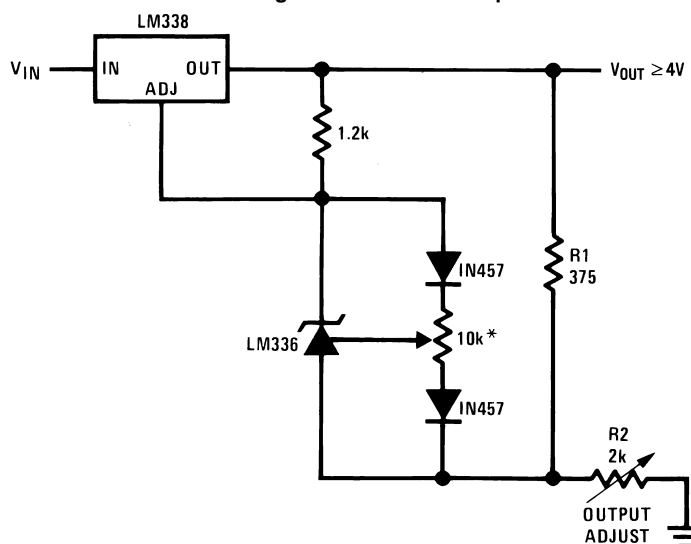
Slow Turn-On 15V Regulator
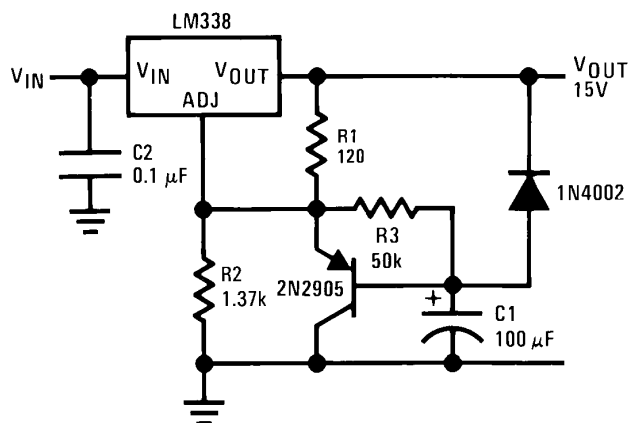
Adjustable Regulator with Improved Ripple Rejection
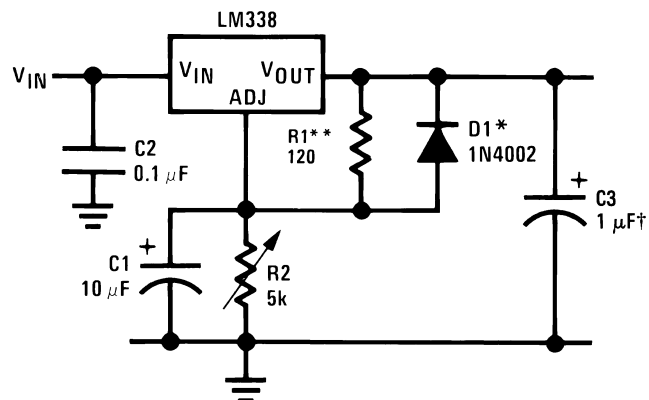
†Solid tantalum
*Discharges C1 if output is shorted to ground
**R1 = 240Ω for LM138

High Stability 10V Regulator
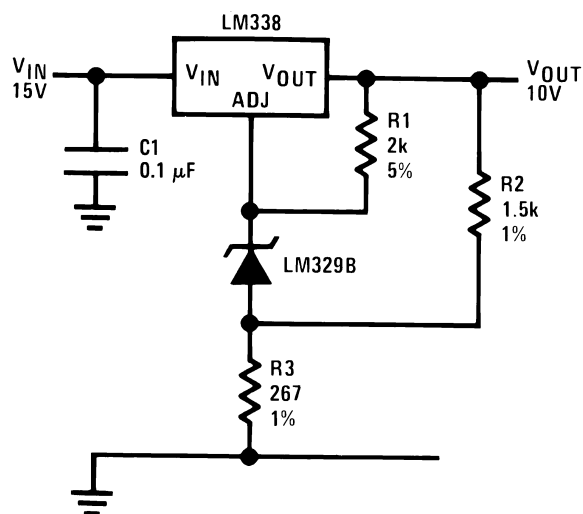
Digitally Selected Outputs
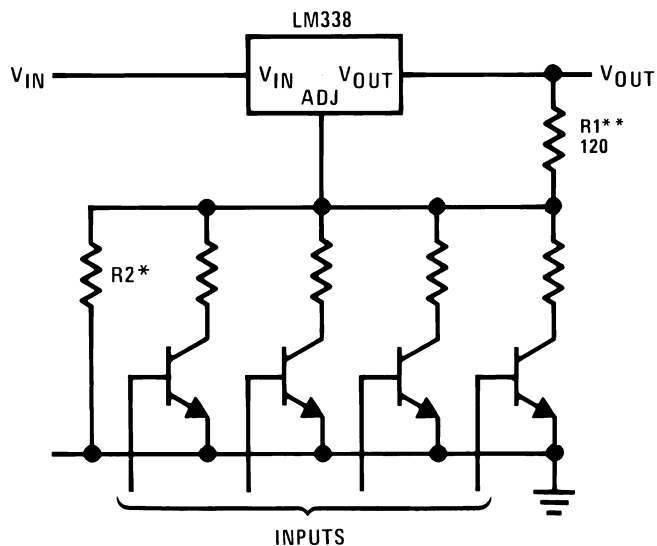
*Sets maximum V_{OUT}
**R1 = 240Ω for LM138

15A Regulator
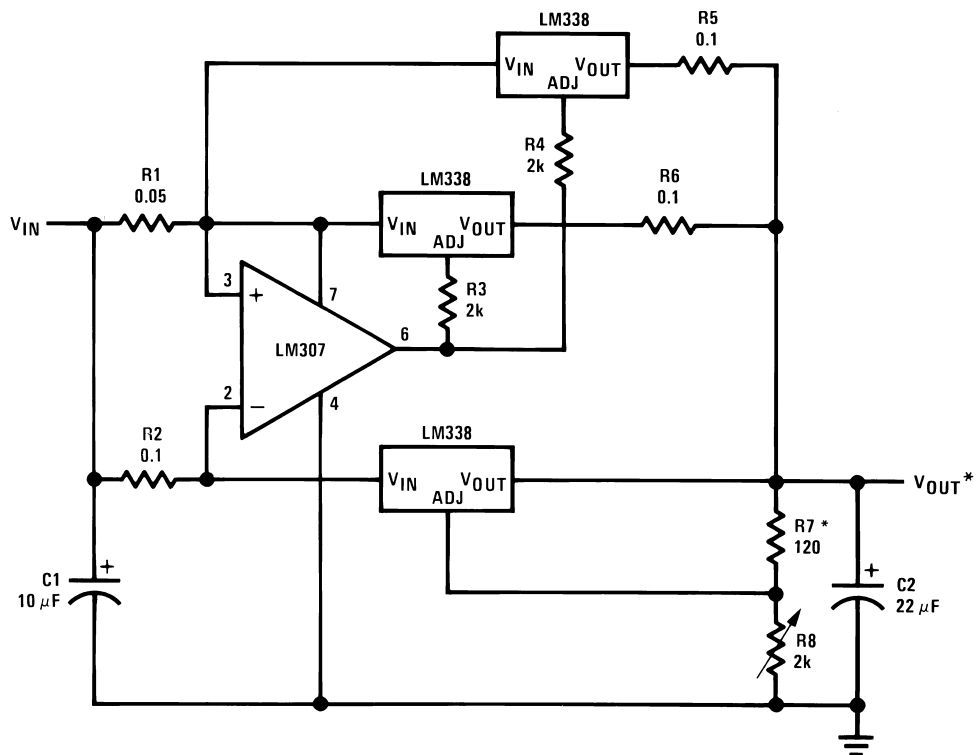
* Minimum load—100 mA

5V Logic Regulator with Electronic Shutdown**

Light Controller

** Minimum output ≈ 1.2V

Product Folder Links: LM138 LM338

0 to 22V Regulator
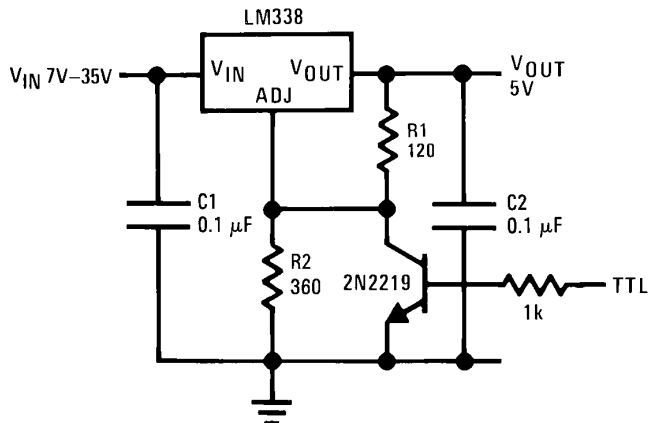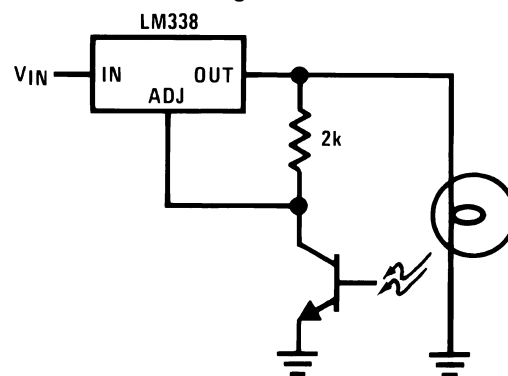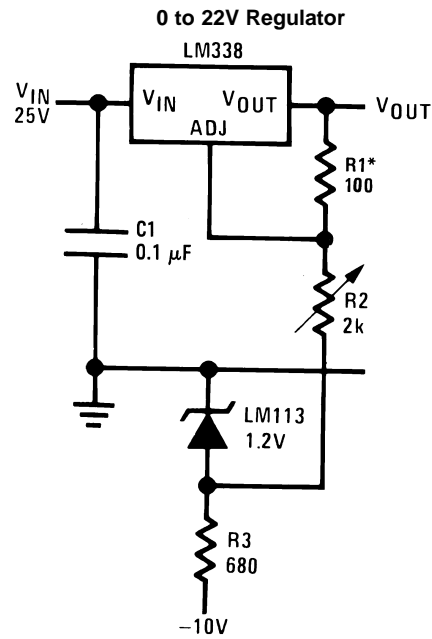
* R1 = 240Ω, R2 = 5k for LM138
Full output current not available at high input-output voltages

12V Battery Charger
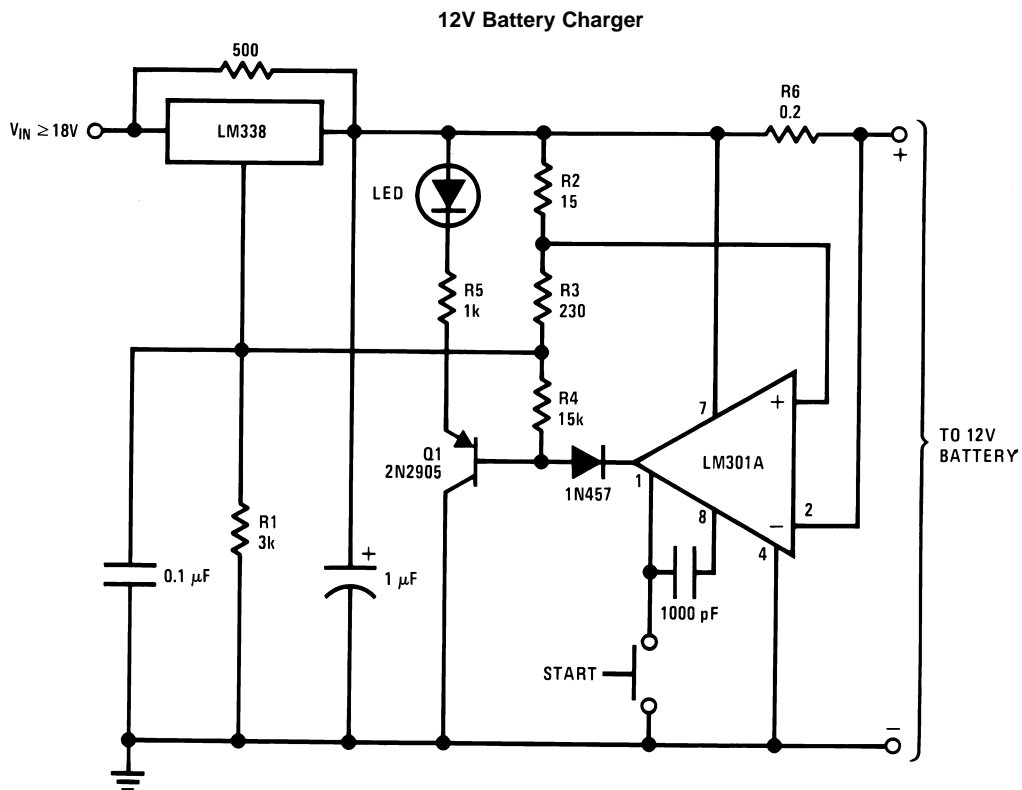
Adjustable Current Regulator
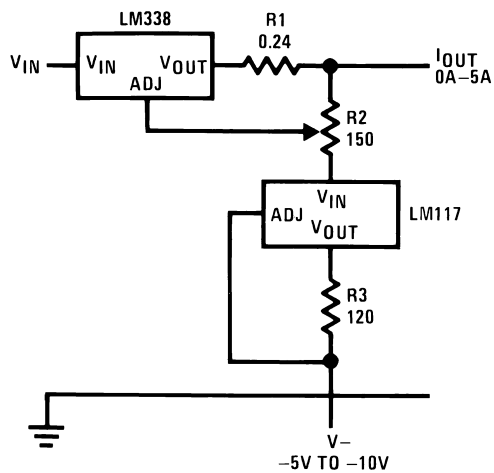
Precision Current Limiter

$$I_{OUT} = \frac{V_{REF}}{R1}$$
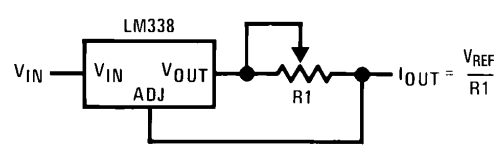
5A Current Regulator
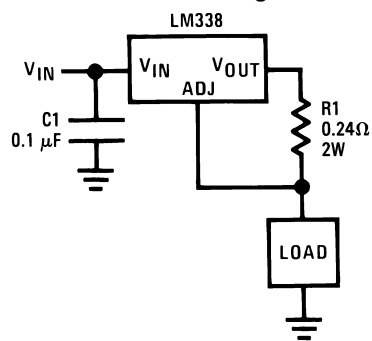
Tracking Preregulator
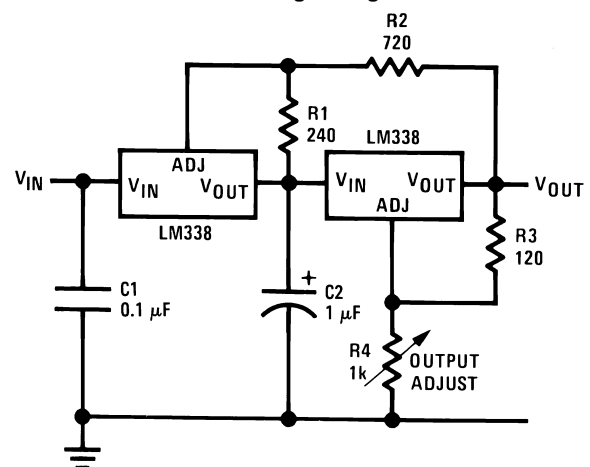
Adjusting Multiple On-Card Regulators with Single Control*
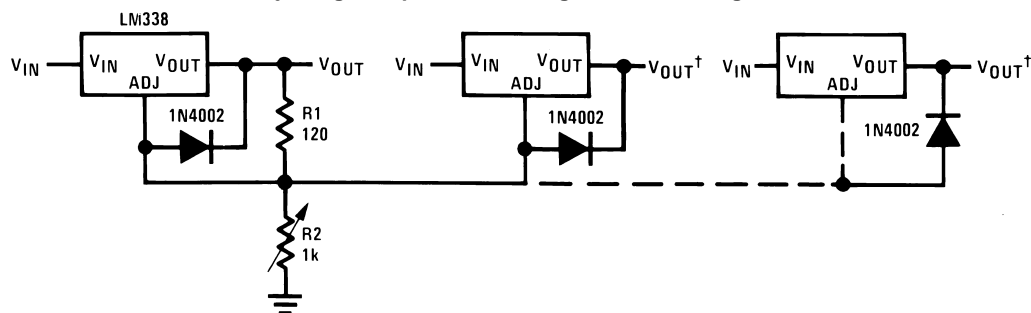
† Minimum load—10 mA
* All outputs within ±100 mV

Product Folder Links: *LM138 LM338*

Power Amplifier
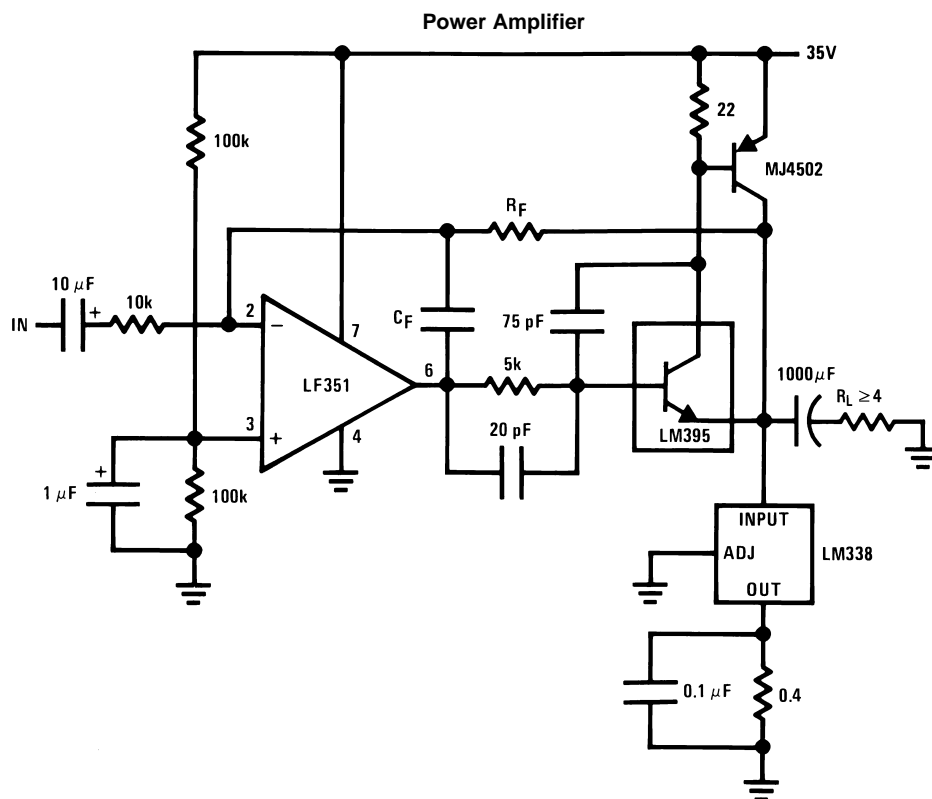
$A_V = 1$, $R_F = 10k$, $C_F = 100$ pF
$A_V = 10$, $R_F = 100k$, $C_F = 10$ pF
Bandwidth ≥ 100 kHz
Distortion ≤ 0.1%

Simple 12V Battery Charger
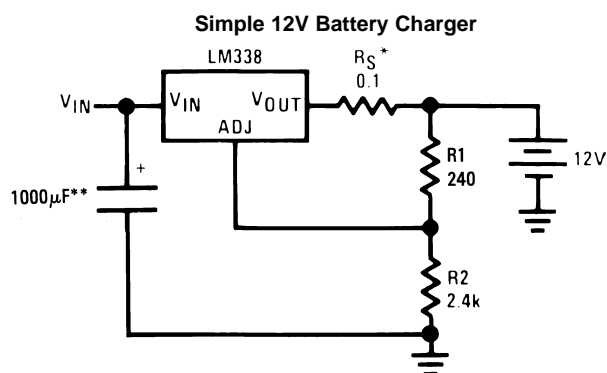
*R_S—sets output impedance of charger $Z_{OUT} = R_S \left(1 + \dfrac{R2}{R1} \right)$

Use of R_S allows low charging rates with fully charged battery.
**The 1000 µF is recommended to filter out input transients

Adjustable 15A Regulator

Current Limited 6V Charger
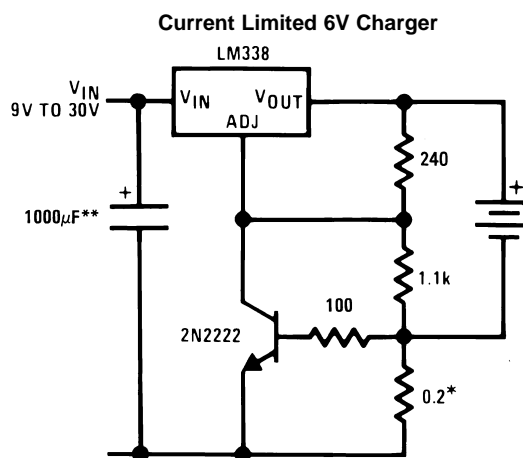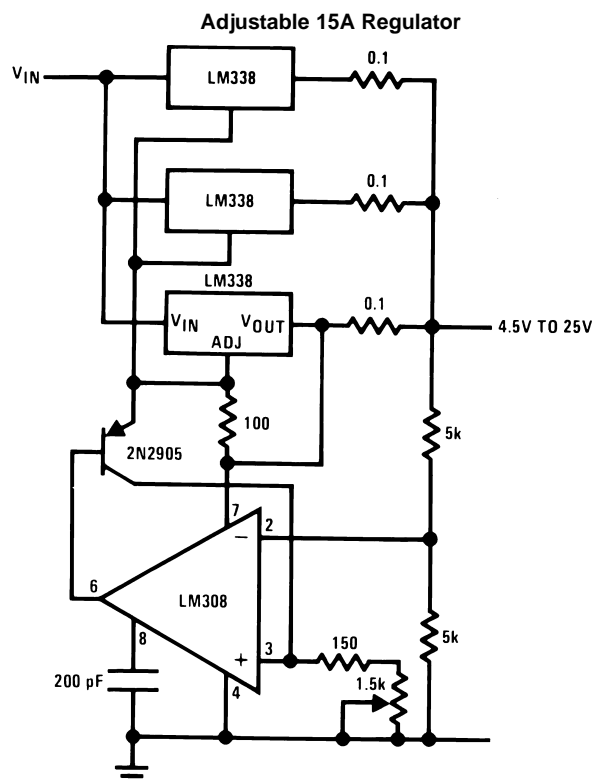
* Set max charge current to 3A
** THE 1000 µF is recommended to filter out input transients.

Product Folder Links: LM138 LM338

10A Regulator
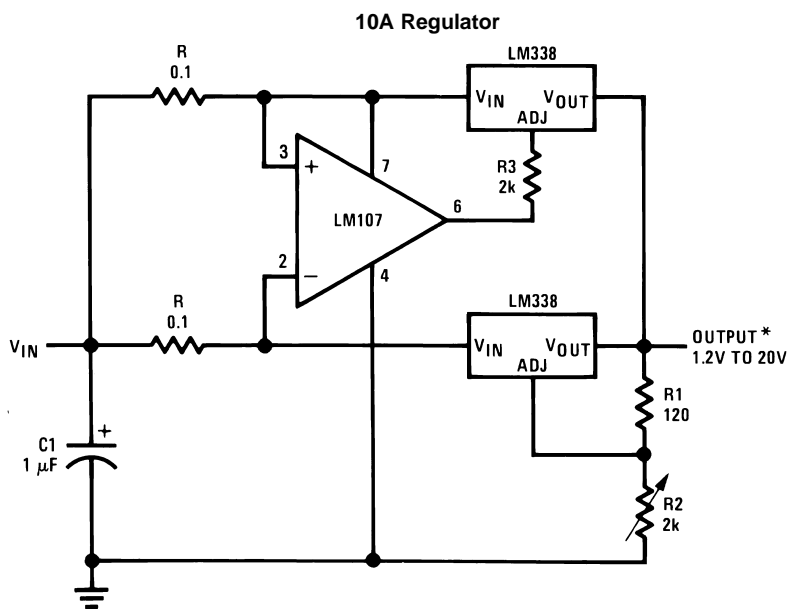
* Minimum load—100 mA

REVISION HISTORY

Changes from Revision A (April 2013) to Revision B   **Page**

• Changed layout of National Data Sheet to TI format 17

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM138K STEEL	ACTIVE	TO-3	NDS	2	50	TBD	Call TI	Call TI	-55 to 125	LM138K STEELP+	Samples
LM138K STEEL/NOPB	ACTIVE	TO-3	NDS	2	50	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	-55 to 125	LM138K STEELP+	Samples
LM338K STEEL	ACTIVE	TO-3	NDS	2	50	TBD	Call TI	Call TI	0 to 125	LM338K STEELP+	Samples
LM338K STEEL/NOPB	ACTIVE	TO-3	NDS	2	50	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	0 to 125	LM338K STEELP+	Samples
LM338T	NRND	TO-220	NDE	3	45	TBD	Call TI	Call TI	0 to 125	LM338T P+	
LM338T/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	0 to 125	LM338T P+	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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NDS0002A

2X Ø $\begin{array}{c}0.151-0.161\\ [3.84-4.09]\end{array}$

$\begin{array}{c}0.980-1.020\\ [24.89-25.91]\end{array}$

R $\begin{array}{c}0.495-0.510\\ [12.57-12.95]\end{array}$

$\begin{array}{c}0.660-0.670\\ [16.76-17.02]\end{array}$

2

1

$\begin{array}{c}1.177-1.197\\ [29.90-30.40]\end{array}$

2X Ø $\begin{array}{c}0.038-0.043\\ [0.97-1.09]\end{array}$

$\begin{array}{c}0.210-0.220\\ [5.33-5.59]\end{array}$

2X R $\begin{array}{c}0.168-0.178\\ [4.27-4.52]\end{array}$

$\begin{array}{c}0.425-0.435\\ [10.80-11.05]\end{array}$

$\begin{array}{c}0.420-0.500\\ [10.67-12.70]\end{array}$

$\begin{array}{c}0.325-0.352\\ [8.26-8.94]\end{array}$

$\begin{array}{c}0.060-0.070\\ [1.52-1.78]\end{array}$

Ø $\begin{array}{c}0.880-0.915\\ [22.35-23.24]\end{array}$

Ø $\begin{array}{c}0.760-0.775\\ [19.30-19.69]\end{array}$

UNCONTROLLED
LEAD DIA
$\begin{array}{c}0.025\\ [0.64]\end{array}$ MAX

$\begin{array}{c}0.116\\ [2.95]\end{array}$ MAX

SEATING PLANE

K02A (REV G)

NDE0003B

0.240-0.260
[6.10-6.60]

0.330-0.350
[8.38-8.89]

0.100-0.120
[2.54-3.05]

Ø 0.149-0.153
[3.78-3.89]

0.400 $^{+0.015}_{-0.005}$
[10.16 $^{+0.38}_{-0.13}$]

0.090-0.110
[2.29-2.79]

0.190-0.210
[4.83-5.33]

PIN #1 ID

0.130-0.160 TYP
[3.30-4.06]

0.048-0.055
[1.22-1.40]
TYP

0.027-0.037
[0.69-0.94]
TYP

1.005-1.035
[25.53-26.29]

7°

7°

(0.525-0.555)
[13.34-14.10]

0.015 $^{+0.007}_{-0.001}$ [0.38 $^{+0.18}_{-0.03}$]

0.175-0.185
[4.45-4.70]

0°-6°

0.048-0.052
[1.22-1.32]

TAPERED
SIDES 1°

SEATING PLANE

0.105 $^{+0.010}_{-0.015}$ [2.67 $^{+0.25}_{-0.38}$]

T03B (REV L)

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