National Semiconductor

LM138/LM238/LM338
5 Amp Adjustable Power Regulators

General Description

The LM138/LM238/LM338 are adjustable 3-terminal positive voltage regulators 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 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 rejections ratios which are difficult to achieve with standard 3-terminal regulators.

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.

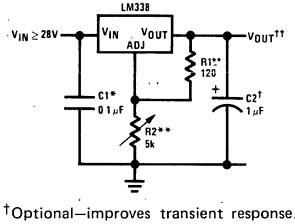
The LM138/LM238/LM338 are packaged in standard steel TO-3 transistor packages. The LM138 is rated for operation from −55°C to +150°C, the LM238 from −25°C to +150°C and the LM338 from 0°C to +125°C.

Features

- Guaranteed 7A peak output current
- Guaranteed 5A output current
- Adjustable output down to 1.2V
- Line regulation typically 0.005%/V
- Load regulation typically 0.1%
- Guaranteed thermal regulation
- Current limit constant with temperature
- **100% electrical burn-in in thermal limit**
- Standard 3-lead transistor package

Typical Applications

1.2V–25V Adjustable Regulator



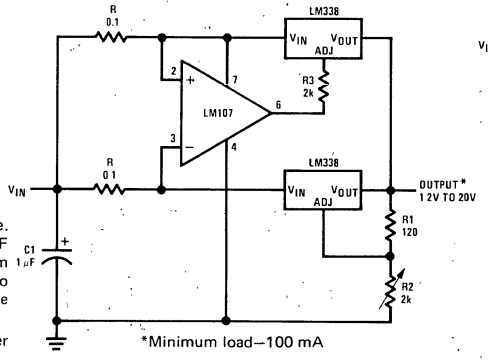
†Optional—improves transient response. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

*Needed if device is far from filter capacitors.

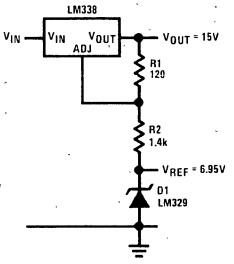
$$^{\dagger\dagger}V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right)$$

**R1 = 240Ω for LM138 and LM238 R1, R2 as an assembly can be ordered from Bourns:
MIL part no. 7105A-AT2-502
COMM part no. 7105A-AT7-502

10A Regulator



Regulator and Voltage Reference



Absolute Maximum Ratings

Power Dissipation	Internally limited
Input–Output Voltage Differential	35V
Operating Junction Temperature Range	
LM138	−55°C to +150°C
LM238	−25°C to +150°C
LM338	0°C to +125°C
Storage Temperature	−65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	300°C

Preconditioning

Burn-In in Thermal Limit — **All Devices 100%**

Electrical Characteristics (Note 1)

PARAMETER	CONDITIONS	LM138/LM238			LM338			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
Line Regulation	$T_A = 25°C$, $3V \le V_{IN} - V_{OUT} \le 35V$, (Note 2)		0.005	0.01		0.005	0.03	%/V
Load Regulation	$T_A = 25°C$, $10\ mA \le I_{OUT} \le 5A$							
	$V_{OUT} \le 5V$, (Note 2)		5	15		5	25	mV
	$V_{OUT} \ge 5V$, (Note 2)		0.1	0.3		0.1	0.5	%
Thermal Regulation	Pulse = 20 ms		0.002	0.01		0.002	0.02	%/W
Adjustment Pin Current			45	100		45	100	μA
Adjustment Pin Current Change	$10\ mA \le I_L \le 5A$		0.2	5		0.2	5	μA
	$3V \le (V_{IN} - V_{OUT}) \le 35V$							
Reference Voltage	$3 \le (V_{IN} - V_{OUT}) \le 35V$, (Note 3)	1.19	1.24	1.29	1.19	1.24	1.29	V
	$10\ mA \le I_{OUT} \le 5A$, $P \le 50W$							
Line Regulation	$3V \le V_{IN} - V_{OUT} \le 35V$, (Note 2)		0.02	0.04		0.02	0.06	%/V
Load Regulation	$10\ mA \le I_{OUT} \le 5A$, (Note 2)							
	$V_{OUT} \le 5V$		20	30		20	50	mV
	$V_{OUT} \ge 5V$		0.3	0.6		0.3	1.0	%
Temperature Stability	$T_{MIN} \le T_j \le T_{MAX}$		1			1		%
Minimum Load Current	$V_{IN} - V_{OUT} = 35V$		3.5	5		3.5	10	mA
Current Limit	$V_{IN} - V_{OUT} \le 10V$							
	DC	5.0	8		5.0	8		A
	0.5 ms Peak	7	12		7	12		A
	$V_{IN} - V_{OUT} = 30V$		1			1		A
RMS Output Noise, % of V_{OUT}	$T_A = 25°C$, $10\ Hz \le f \le 10\ kHz$		0.003			0.003		%
Ripple Rejection Ratio	$V_{OUT} = 10V$, f = 120 Hz		60			60		dB
	$C_{ADJ} = 10\ \mu F$	60	75		60	75		dB
Long Term Stability	$T_A = 125°C$		0.3	1		0.3	1	%
Thermal Resistance, Junction to Case	K Package			1.0			1.0	°C/W

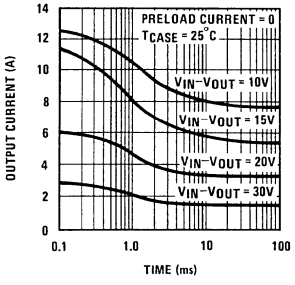
Note 1: Unless otherwise specified, these specifications apply $-55°C \le T_j \le +150°C$ for the LM138, $-25°C \le T_j \le +150°C$ for the LM238 and $0°C \le T_j \le +125°C$ for the LM338, $V_{IN} - V_{OUT} = 5V$ and $I_{OUT} = 2.5A$. Although power dissipation is internally limited, these specifications are applicable for power dissipations up to 50W.

Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects are taken into account separately by thermal regulation.

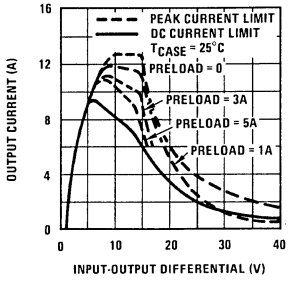
Note 3: Selected devices with tightened tolerance reference voltage available.

Typical Performance Characteristics

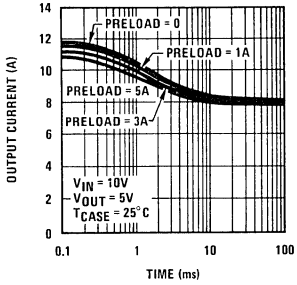
Current Limit



Current Limit

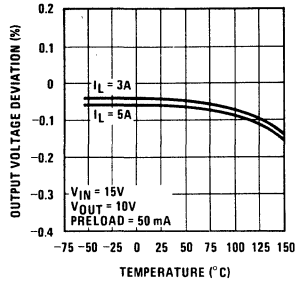


Current Limit

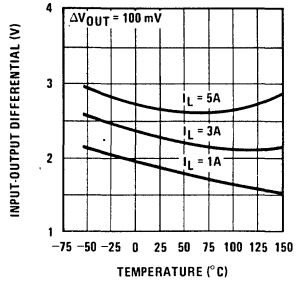


Typical Performance Characteristics (Continued)

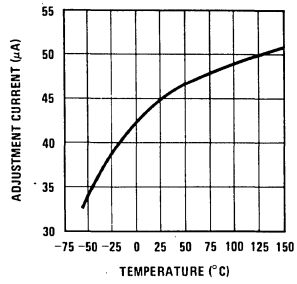
Load Regulation



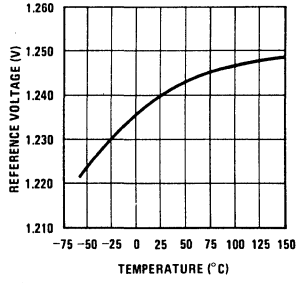
Dropout Voltage



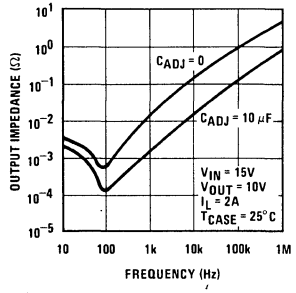
Adjustment Current



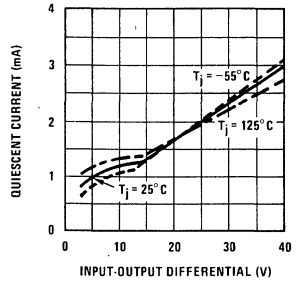
Temperature Stability



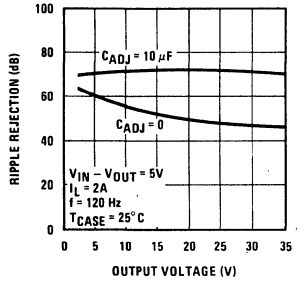
Output Impedance



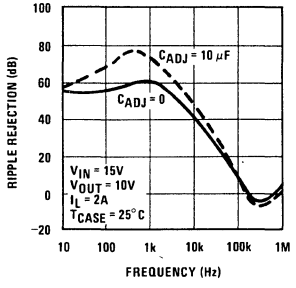
Minimum Operating Current



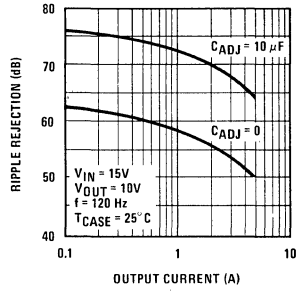
Ripple Rejection



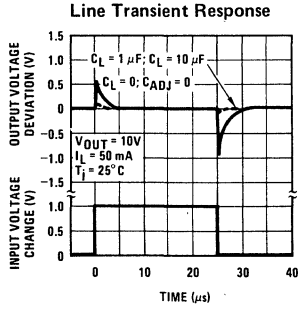
Ripple Rejection



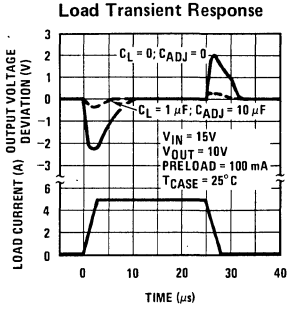
Ripple Rejection



Line Transient Response



Load Transient Response



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

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

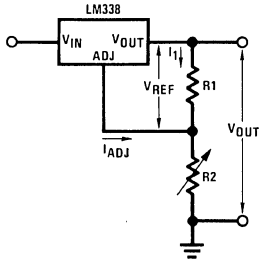


FIGURE 1

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 bypassing when adjustment or output capacitors are used but the above values will eliminate the possibility 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 outout 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 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 x 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 2 shows the effect of resistance between the regulator and 240Ω set resistor.

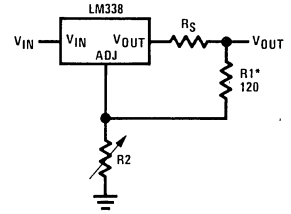


FIGURE 2. Regulator with Line Resistance in Output Lead

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

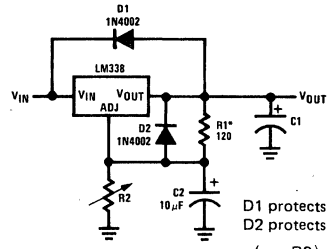
When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 20 μF capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although 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

Application Hints (Continued)

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 3* shows an LM138 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.

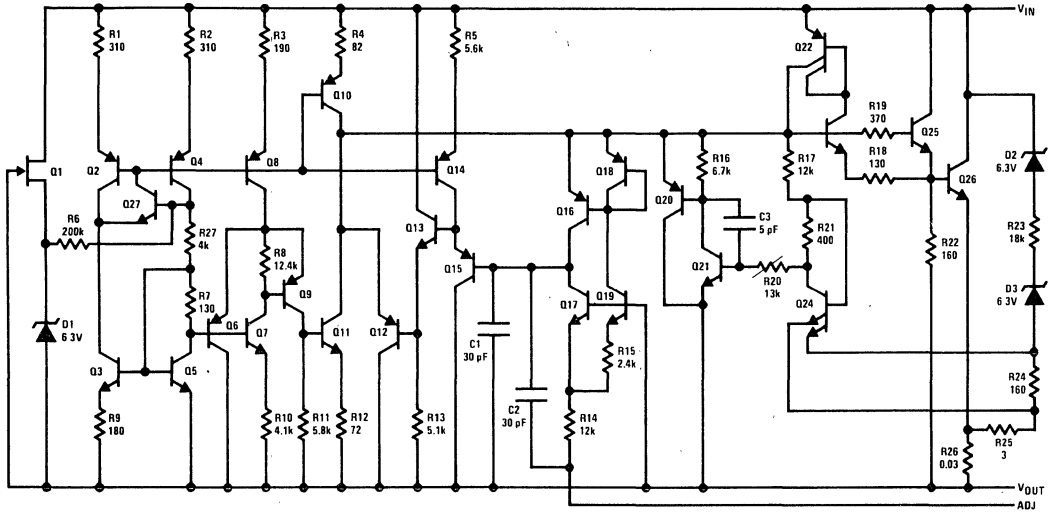


$$V_{OUT} = 1.25V \left(1 + \frac{R2}{R1}\right) + R2I_{ADJ}$$

*R1 = 240Ω for LM138 and LM238

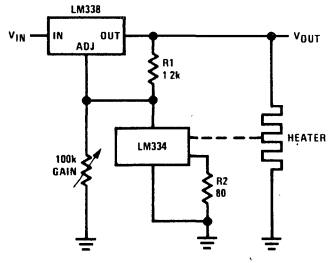
FIGURE 3. Regulator with Protection Diodes

Schematic Diagram

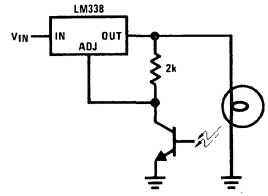


Typical Applications (Continued)

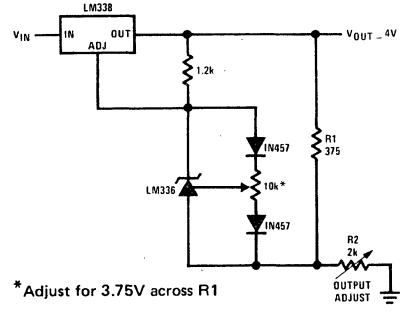
Temperature Controller



Light Controller



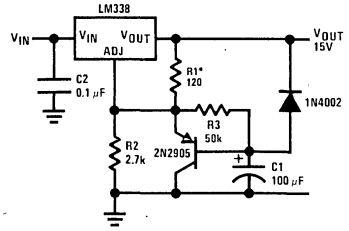
Precision Power Regulator with Low Temperature Coefficient



*Adjust for 3.75V across R1

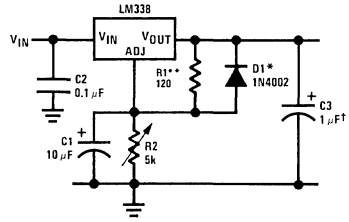
Typical Applications (Continued)

Slow Turn-ON 15V Regulator



*R1 = 240Ω for LM138 and LM238

Adjustable Regulator with Improved Ripple Rejection

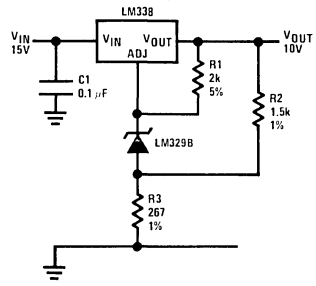


†Solid tantalum

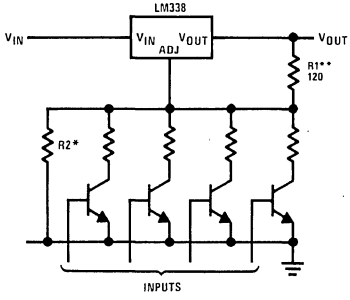
*Discharges C1 if output is shorted to ground

**R1 = 240Ω for LM138 and LM238

High Stability 10V Regulator



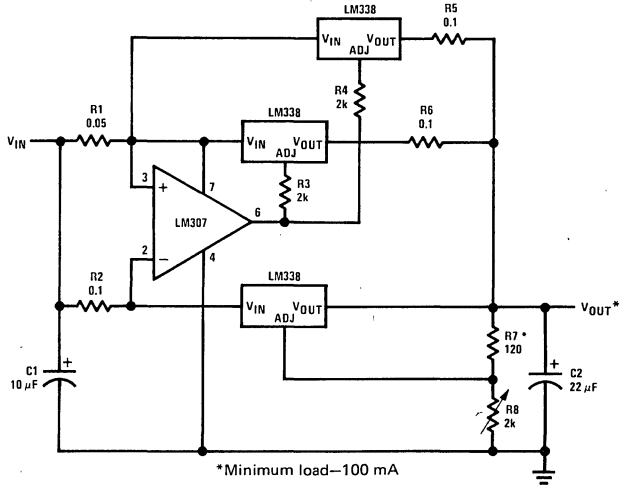
Digitally Selected Outputs



*Sets maximum V_{OUT}

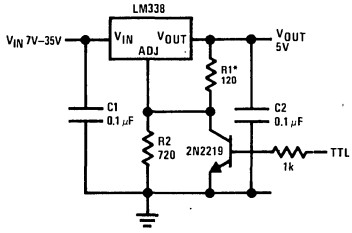
**R1 = 240Ω for LM138 and LM238

15A Regulator



*Minimum load—100 mA

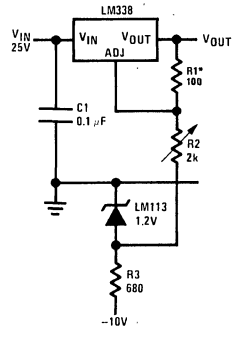
5V Logic Regulator with Electronic Shutdown**



*R1 = 240Ω for LM138 or LM238

**Minimum output ≈ 1.2V

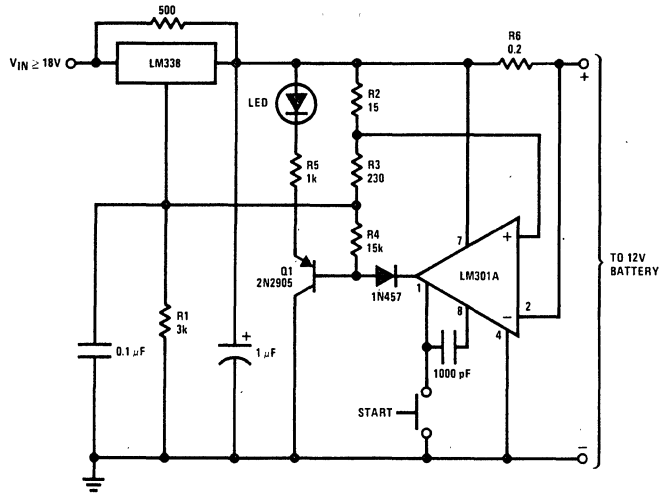
0 to 22V Regulator



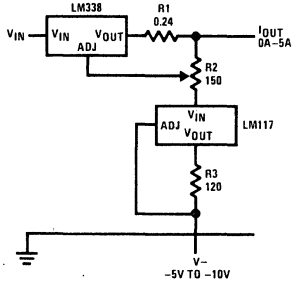
*R1=240Ω, R2 = 5k for LM138 and LM238

Typical Applications (Continued)

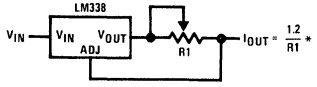
12V Battery Charger



Adjustable Current Regulator

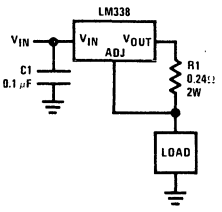


Precision Current Limiter

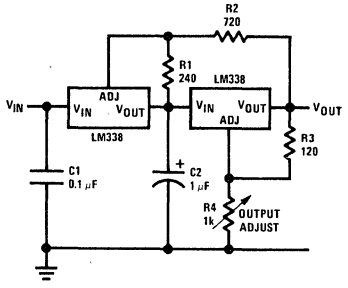


*$0.4 \leq R1 \leq 120\Omega$

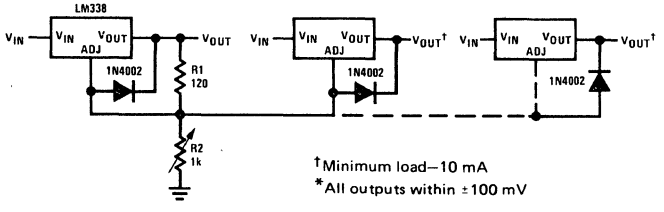
5A Current Regulator



Tracking Preregulator



Adjusting Multiple On-Card Regulators with Single Control*

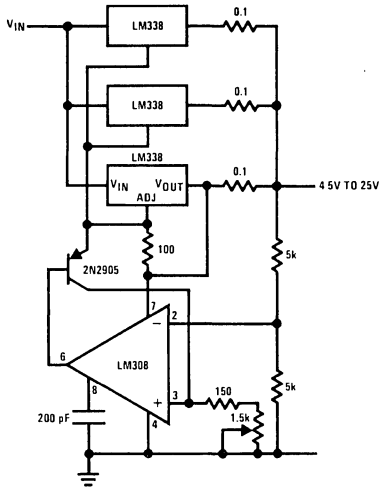


†Minimum load–10 mA

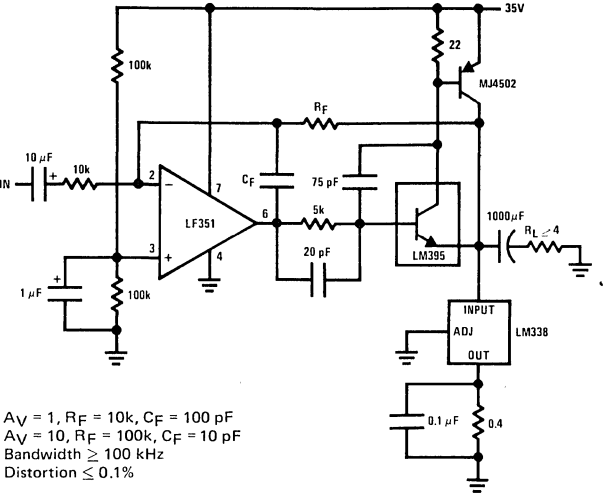
*All outputs within ±100 mV

Typical Applications (Continued)

Adjustable 15A Regulator

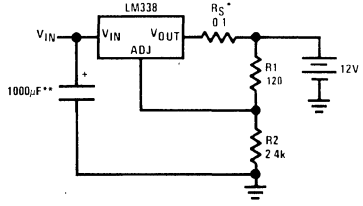


Power Amplifier



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%

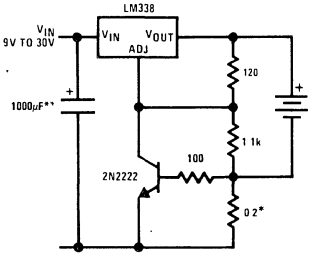
Simple 12V Battery Charger



*R_S—sets output impedance of charger $Z_{OUT} = R_S \left(1 + \frac{R2}{R1}\right)$
Use of R_S allows low charging rates with fully charged battery.

**The 1000 μF is recommended to filter out input transients

Current Limited 6V Charger

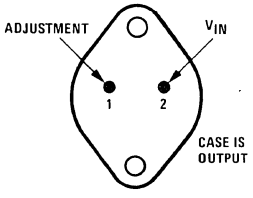


*Sets max charge current to 3A

**The 1000 μF is recommended to filter out input transients

Connection Diagram

Metal Can Package



BOTTOM VIEW

Order Number
LM138K STEEL
LM238K STEEL
LM338K STEEL
See NS Package K02A