

## LM150/LM350A/LM350 3-Amp Adjustable Regulators

### General Description

The LM150 series of adjustable 3-terminal positive voltage regulators is capable of supplying in excess of 3A over a 1.2V to 33V output range. They are exceptionally easy to use and require only 2 external resistors to set the output voltage. Further, both line and load regulation are comparable to discrete designs. Also, the LM150 is packaged in standard transistor packages which are easily mounted and handled.

In addition to higher performance than fixed regulators, the LM150 series offers full overload protection available only in IC's. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal 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 LM150 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., avoid short-circuiting the output.

By connecting a fixed resistor between the adjustment pin and output, the LM150 can be used as a precision current

regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

The part numbers in the LM150 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 LM150 is rated for  $-55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$ , while the LM350A is rated for  $-40^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$ , and the LM350 is rated for  $0^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$ .

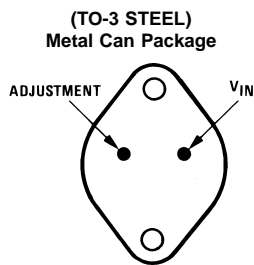
### Features

- Adjustable output down to 1.2V
- Guaranteed 3A output current
- Guaranteed thermal regulation
- Output is short circuit protected
- Current limit constant with temperature
- P+ Product Enhancement tested
- 86 dB ripple rejection
- Guaranteed 1% output voltage tolerance (LM350A)
- Guaranteed max. 0.01%/V line regulation (LM350A)
- Guaranteed max. 0.3% load regulation (LM350A)

### Applications

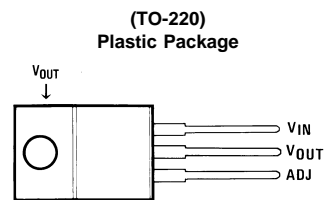
- Adjustable power supplies
- Constant current regulators
- Battery chargers

### Connection Diagrams



Case is Output

**Bottom View**  
Order Number LM150K STEEL  
or LM350K STEEL  
See NS Package Number K02A  
Order Number LM150K/883  
See NS Package Number K02C



**Front View**  
Order Number LM350AT or LM350T  
See NS Package Number T03B

### Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

(Note 4)

|                                   |                    |
|-----------------------------------|--------------------|
| Power Dissipation                 | Internally Limited |
| Input-Output Voltage Differential | +35V               |
| Storage Temperature               | -65°C to +150°C    |

|                                     |  |       |
|-------------------------------------|--|-------|
| Lead Temperature                    |  |       |
| Metal Package (Soldering, 10 sec.)  |  | 300°C |
| Plastic Package (Soldering, 4 sec.) |  | 260°C |
| ESD Tolerance                       |  | TBD   |
| Operating Temperature Range         |  |       |

|        |                                 |
|--------|---------------------------------|
| LM150  | -55°C ≤ T <sub>J</sub> ≤ +150°C |
| LM350A | -40°C ≤ T <sub>J</sub> ≤ +125°C |
| LM350  | 0°C ≤ T <sub>J</sub> ≤ +125°C   |

### Electrical Characteristics

Specifications with standard type face are for T<sub>J</sub> = 25°C, and those with **boldface type** apply over full Operating Temperature Range. Unless otherwise specified, V<sub>IN</sub> - V<sub>OUT</sub> = 5V, and I<sub>OUT</sub> = 10 mA. (Note 2)

| Parameter  | Conditions  | LM150       |             |             | Units |
|--|---|-------------|-------------|-------------|-------|
|  |   | Min         | Typ         | Max         |       |
| Reference Voltage                                      | 3V ≤ (V <sub>IN</sub> - V <sub>OUT</sub> ) ≤ 35V,<br>10 mA ≤ I <sub>OUT</sub> ≤ 3A, P ≤ 30W | <b>1.20</b> | <b>1.25</b> | <b>1.30</b> | V     |
| Line Regulation  | 3V ≤ (V <sub>IN</sub> - V <sub>OUT</sub> ) ≤ 35V (Note 3)                                   |             | 0.005       | 0.01        | %/V   |
|  |   |             | <b>0.02</b> | <b>0.05</b> | %/V   |
| Load Regulation  | 10 mA ≤ I <sub>OUT</sub> ≤ 3A (Note 3)  |             | 0.1         | 0.3         | %     |
|  |   |             | <b>0.3</b>  | <b>1</b>    | %     |
| Thermal Regulation                                     | 20 ms Pulse   |             | 0.002       | 0.01        | %/W   |
| Adjustment Pin Current                                 |   |             | <b>50</b>   | <b>100</b>  | μA    |
| Adjustment Pin Current Change                          | 10 mA ≤ I <sub>OUT</sub> ≤ 3A, 3V ≤ (V <sub>IN</sub> - V <sub>OUT</sub> ) ≤ 35V             |             | <b>0.2</b>  | <b>5</b>    | μA    |
| Temperature Stability                                  | T <sub>MIN</sub> ≤ T <sub>J</sub> ≤ T <sub>MAX</sub>  |             | 1           |             | %     |
| Minimum Load Current                                   | V <sub>IN</sub> - V <sub>OUT</sub> = 35V  |             | <b>3.5</b>  | <b>5</b>    | mA    |
| Current Limit  | V <sub>IN</sub> - V <sub>OUT</sub> ≤ 10V  | <b>3.0</b>  | <b>4.5</b>  |             | A     |
|  | V <sub>IN</sub> - V <sub>OUT</sub> = 30V  | 0.3         | 1           |             | A     |
| RMS Output Noise, % of V <sub>OUT</sub>                | 10 Hz ≤ f ≤ 10 kHz  |             | 0.001       |             | %     |
| Ripple Rejection Ratio                                 | V <sub>OUT</sub> = 10V, f = 120 Hz, C <sub>ADJ</sub> = 0 μF                                 |             | <b>65</b>   |             | dB    |
|  | V <sub>OUT</sub> = 10V, f = 120 Hz, C <sub>ADJ</sub> = 10 μF                                | <b>66</b>   | <b>86</b>   |             | dB    |
| Long-Term Stability                                    | T <sub>J</sub> = 125°C, 1000 hrs  |             | 0.3         | 1           | %     |
| Thermal Resistance, Junction to Case                   | K Package   |             | 1.2         | 1.5         | °C/W  |
| Thermal Resistance, Junction to Ambient (No Heat Sink) | K Package   |             | 35          |             | °C/W  |

### Electrical Characteristics

Specifications with standard type face are for T<sub>J</sub> = 25°C, and those with **boldface type** apply over full Operating Temperature Range. Unless otherwise specified, V<sub>IN</sub> - V<sub>OUT</sub> = 5V, and I<sub>OUT</sub> = 10 mA. (Note 2)

| Parameter                     | Conditions  | LM350A       |              |              | LM350       |             |             | Units |
|-------------------------------|---|--------------|--------------|--------------|-------------|-------------|-------------|-------|
|                               |   | Min          | Typ          | Max          | Min         | Typ         | Max         |       |
| Reference Voltage             | I <sub>OUT</sub> = 10 mA, T <sub>J</sub> = 25°C   | 1.238        | 1.250        | 1.262        |             |             |             | V     |
|                               | 3V ≤ (V <sub>IN</sub> - V <sub>OUT</sub> ) ≤ 35V,<br>10 mA ≤ I <sub>OUT</sub> ≤ 3A, P ≤ 30W | <b>1.225</b> | <b>1.250</b> | <b>1.270</b> | <b>1.20</b> | <b>1.25</b> | <b>1.30</b> | V     |
| Line Regulation               | 3V ≤ (V <sub>IN</sub> - V <sub>OUT</sub> ) ≤ 35V (Note 3)                                   |              | 0.005        | 0.01         |             | 0.005       | 0.03        | %/V   |
|                               |   |              | <b>0.02</b>  | <b>0.05</b>  |             | <b>0.02</b> | <b>0.07</b> | %/V   |
| Load Regulation               | 10 mA ≤ I <sub>OUT</sub> ≤ 3A (Note 3)  |              | 0.1          | 0.3          |             | 0.1         | 0.5         | %     |
|                               |   |              | <b>0.3</b>   | <b>1</b>     |             | <b>0.3</b>  | <b>1.5</b>  | %     |
| Thermal Regulation            | 20 ms Pulse   |              | 0.002        | 0.01         |             | 0.002       | 0.03        | %/W   |
| Adjustment Pin Current        |   |              | <b>50</b>    | <b>100</b>   |             | <b>50</b>   | <b>100</b>  | μA    |
| Adjustment Pin Current Change | 10 mA ≤ I <sub>OUT</sub> ≤ 3A, 3V ≤ (V <sub>IN</sub> - V <sub>OUT</sub> ) ≤ 35V             |              | <b>0.2</b>   | <b>5</b>     |             | <b>0.2</b>  | <b>5</b>    | μA    |

## Electrical Characteristics (Continued)

Specifications with standard type face are for  $T_J = 25^\circ\text{C}$ , and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified,  $V_{IN} - V_{OUT} = 5\text{V}$ , and  $I_{OUT} = 10\text{ mA}$ . (Note 2)

| Parameter  | Conditions   | LM350A     |            |           | LM350      |            |           | Units              |
|--|--|------------|------------|-----------|------------|------------|-----------|--------------------|
|  |  | Min        | Typ        | Max       | Min        | Typ        | Max       |                    |
| Temperature Stability                                  | $T_{MIN} \leq T_J \leq T_{MAX}$  |            | <b>1</b>   |           |            | <b>1</b>   |           | %                  |
| Minimum Load Current                                   | $V_{IN} - V_{OUT} = 35\text{V}$  |            | <b>3.5</b> | <b>10</b> |            | <b>3.5</b> | <b>10</b> | mA                 |
| Current Limit  | $V_{IN} - V_{OUT} \leq 10\text{V}$   | <b>3.0</b> | <b>4.5</b> |           | <b>3.0</b> | <b>4.5</b> |           | A                  |
|  | $V_{IN} - V_{OUT} = 30\text{V}$  | 0.3        | 1          |           | 0.25       | 1          |           | A                  |
| RMS Output Noise, % of $V_{OUT}$                       | $10\text{ Hz} \leq f \leq 10\text{ kHz}$   |            | 0.001      |           |            | 0.001      |           | %                  |
| Ripple Rejection Ratio                                 | $V_{OUT} = 10\text{V}$ , $f = 120\text{ Hz}$ , $C_{ADJ} = 0\text{ }\mu\text{F}$  |            | <b>65</b>  |           |            | <b>65</b>  |           | dB                 |
|  | $V_{OUT} = 10\text{V}$ , $f = 120\text{ Hz}$ , $C_{ADJ} = 10\text{ }\mu\text{F}$ | <b>66</b>  | <b>86</b>  |           | <b>66</b>  | <b>86</b>  |           | dB                 |
| Long-Term Stability                                    | $T_J = 125^\circ\text{C}$ , 1000 hrs   |            | 0.25       | 1         |            | 0.25       | 1         | %                  |
| Thermal Resistance, Junction to Case                   | K Package  |            |            |           |            | 1.2        | 1.5       | $^\circ\text{C/W}$ |
|  | T Package  |            | 3          | 4         |            | 3          | 4         | $^\circ\text{C/W}$ |
| Thermal Resistance, Junction to Ambient (No Heat Sink) | K Package  |            |            |           |            | 35         |           | $^\circ\text{C/W}$ |
|  | T Package  |            | 50         |           |            | 50         |           | $^\circ\text{C/W}$ |

**Note 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 guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

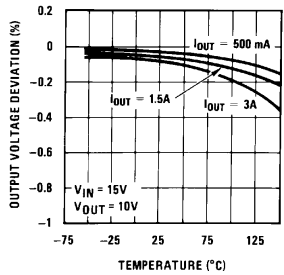
**Note 2:** These specifications are applicable for power dissipations up to 30W for the TO-3 (K) package and 25W for the TO-220 (T) package. Power dissipation is guaranteed at these values up to 15V input-output differential. Above 15V differential, power dissipation will be limited by internal protection circuitry. All limits (i.e., the numbers in the Min. and Max. columns) are guaranteed to National's AOQL (Average Outgoing Quality Level).

**Note 3:** 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.

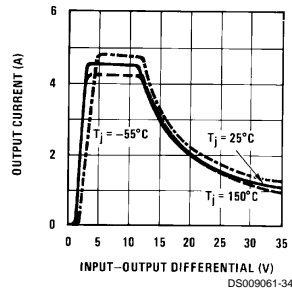
**Note 4:** Refer to RETS150K drawing for military specifications of the LM150K.

## Typical Performance Characteristics

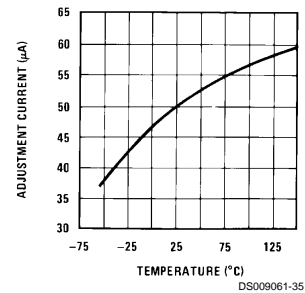
### Load Regulation



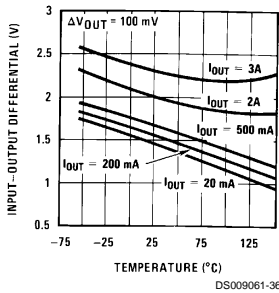
### Current Limit



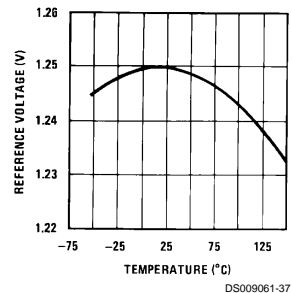
### Adjustment Current



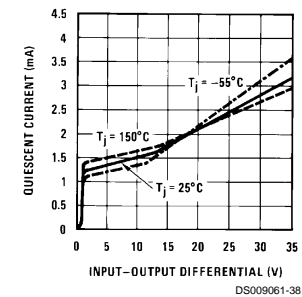
### Dropout Voltage



### Temperature Stability

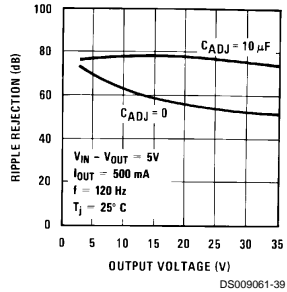


### Minimum Operating Current

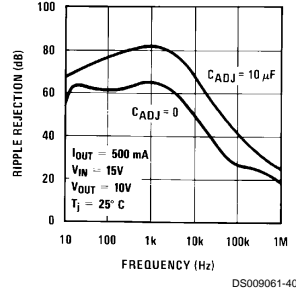


## Typical Performance Characteristics (Continued)

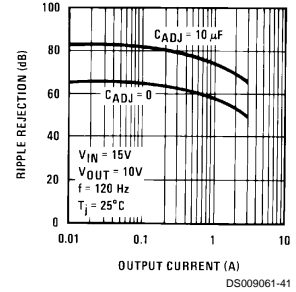
Ripple Rejection



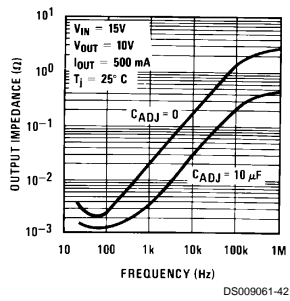
Ripple Rejection



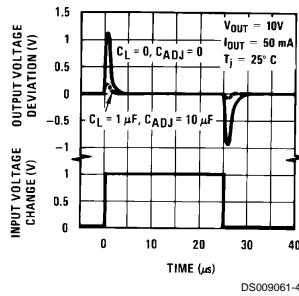
Ripple Rejection



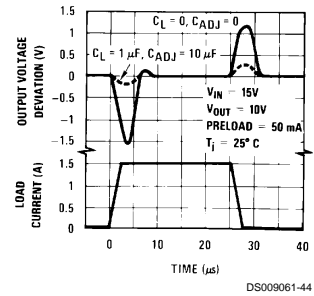
Output Impedance



Line Transient Response



Load Transient Response



## Application Hints

In operation, the LM150 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

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

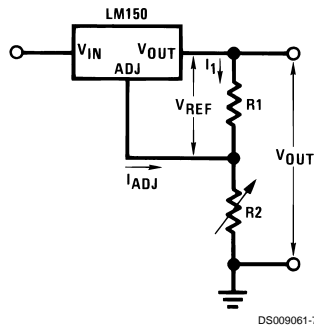


FIGURE 1.

Since the 50  $\mu$ A current from the adjustment terminal represents an error term, the LM150 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  $\mu$ F disc or 1  $\mu$ F 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 LM150 to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10  $\mu$ F bypass capacitor 86 dB ripple rejection is obtainable at any output level. Increases over 10  $\mu$ 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 is solid tantalum. Solid tantalum capacitors have low impedance even at high frequencies. Depending upon capacitor construction, it takes about 25  $\mu$ F in aluminum electrolytic to equal 1  $\mu$ 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  $\mu$ F disc may seem to work better than a 0.1  $\mu$ F disc as a bypass.

Although the LM150 is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values be-

tween 500 pF and 5000 pF. A 1  $\mu$ F solid tantalum (or 25  $\mu$ F aluminum electrolytic) on the output swamps this effect and insures stability.

### LOAD REGULATION

The LM150 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 (case) 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 0.05 $\Omega$  resistance between the regulator and load will have a load regulation due to line resistance of 0.05 $\Omega$   $\times$   $I_{OUT}$ . If the set resistor is connected near the load the effective line resistance will be 0.05 $\Omega$  (1 + R2/R1) or in this case, 11.5 times worse.

Figure 2 shows the effect of resistance between the regulator and 240 $\Omega$  set resistor.

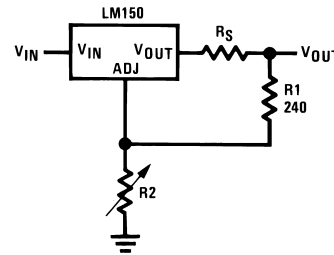


FIGURE 2. Regulator with Line Resistance in Output Lead

With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using two 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

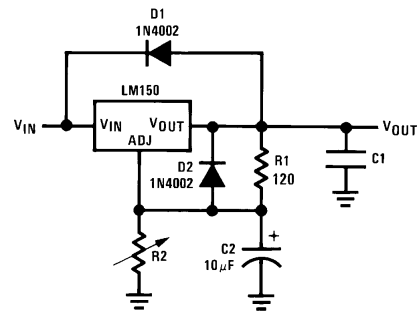
When external capacitors are used with any IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 10  $\mu$ F capacitors have low enough internal series resistance to deliver 20A spikes when shorted. 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 LM150, 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 25  $\mu$ F 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 LM150 is a 50 $\Omega$  resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or

### Application Hints (Continued)

less and 10  $\mu\text{F}$  capacitance. Figure 3 shows an LM150 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.



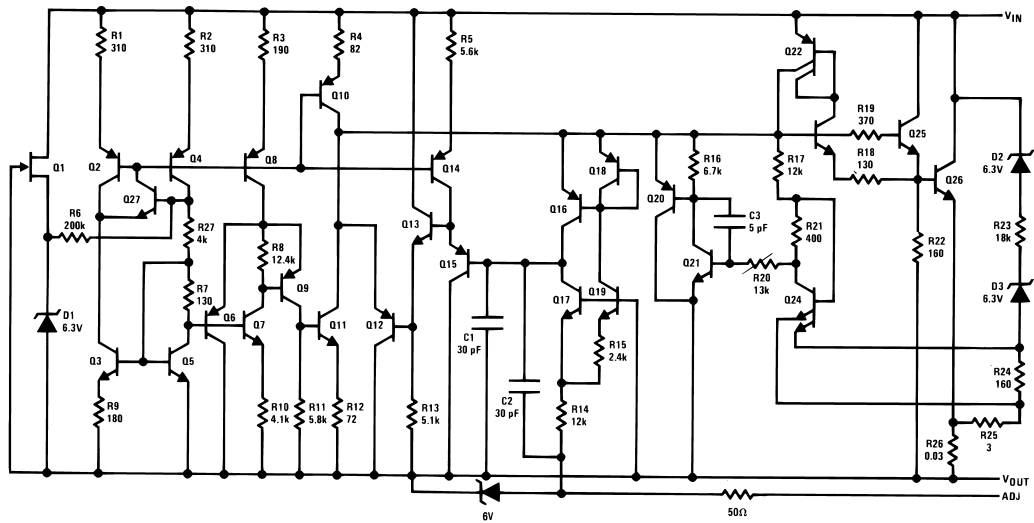
DS009061-9

D1 protects against C1  
D2 protects against C2

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

FIGURE 3. Regulator with Protection Diodes

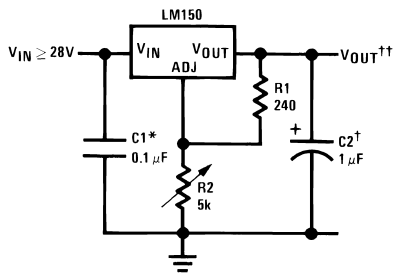
### Schematic Diagram



DS009061-10

## Typical Applications

### 1.2V–25V Adjustable Regulator



DS009061-1

Full output current not available at high input-output voltages.

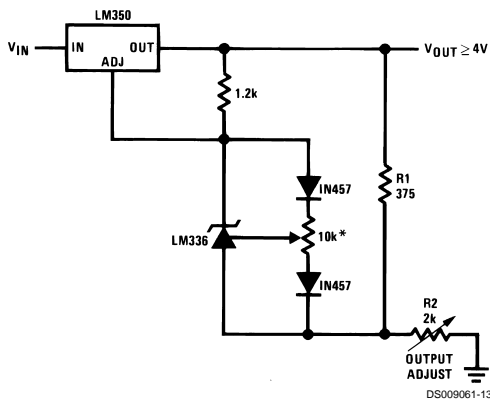
†Optional—improves transient response. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

\*Needed if device is more than 6 inches from filter capacitors.

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

Note: Usually R1 = 240Ω for LM150 and R1 = 120Ω for LM350.

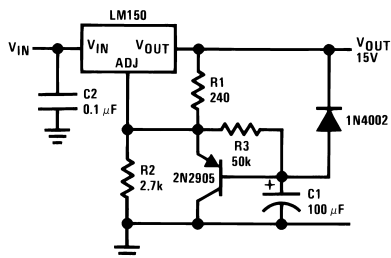
### Precision Power Regulator with Low Temperature Coefficient



DS009061-13

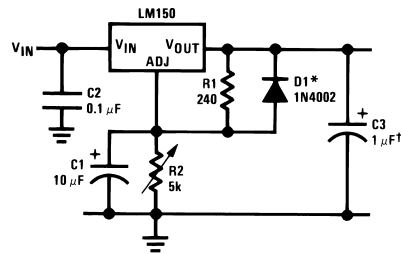
\*Adjust for 3.75V across R1

### Slow Turn-ON 15V Regulator



DS009061-14

### Adjustable Regulator with Improved Ripple Rejection

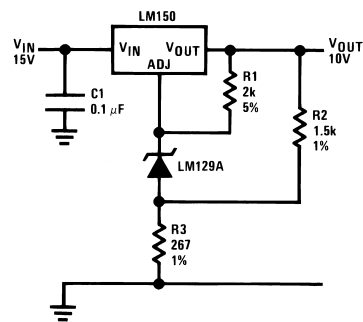


DS009061-15

†Solid tantalum

\*Discharges C1 if output is shorted to ground

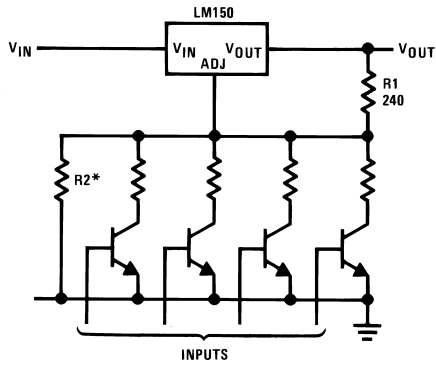
### High Stability 10V Regulator



DS009061-16

## Typical Applications (Continued)

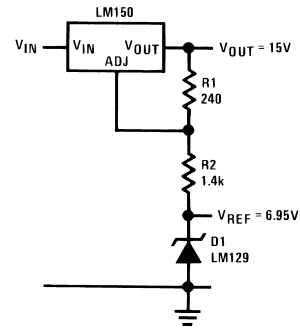
### Digitally Selected Outputs



DS009061-17

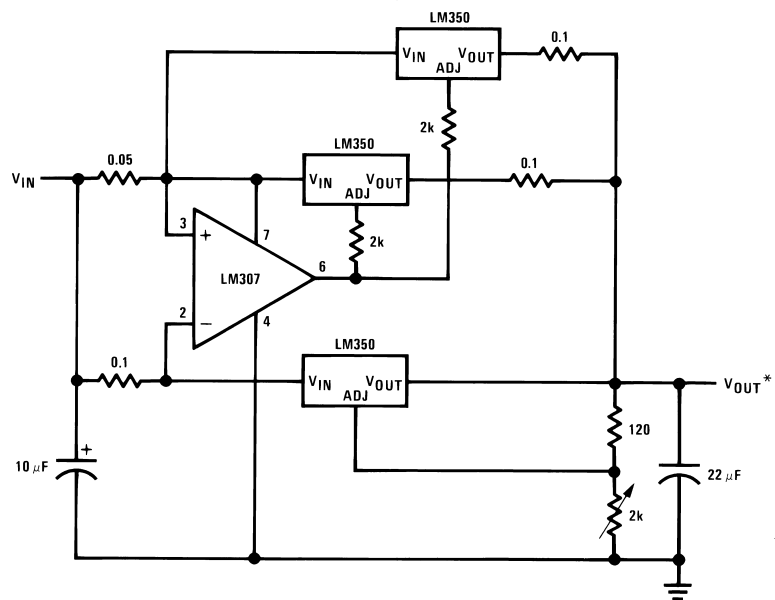
\*Sets maximum  $V_{OUT}$

### Regulator and Voltage Reference



DS009061-3

### 10A Regulator



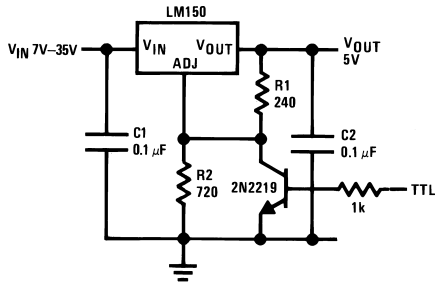
DS009061-18

\*Minimum load current 50 mA



## Typical Applications (Continued)

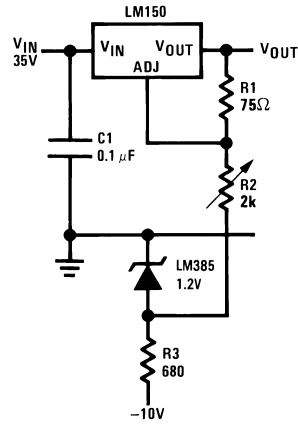
### 5V Logic Regulator with Electronic Shutdown\*



DS009061-19

\*Min output = 1.2V

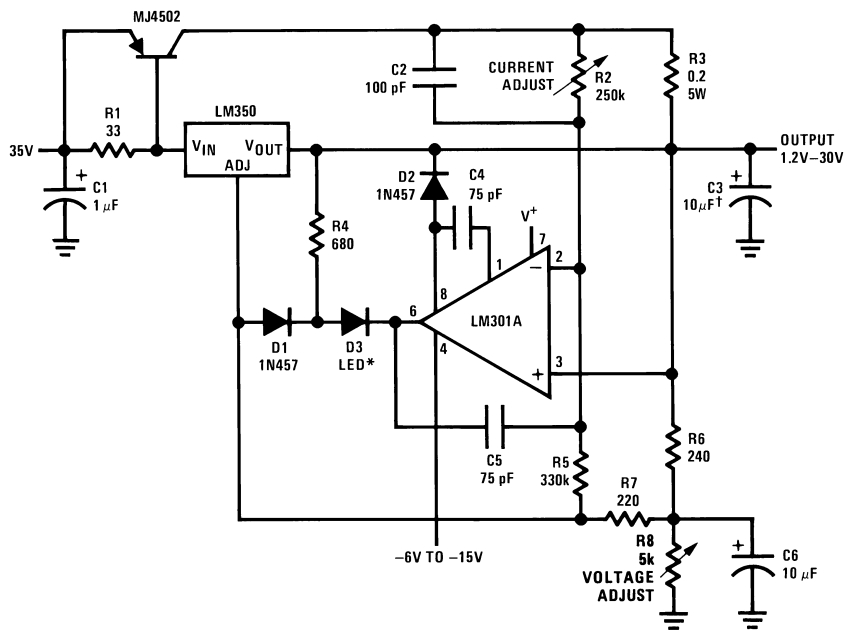
### 0 to 30V Regulator



DS009061-20

Full output current not available at high input-output voltages

### 5A Constant Voltage/Constant Current Regulator



DS009061-21

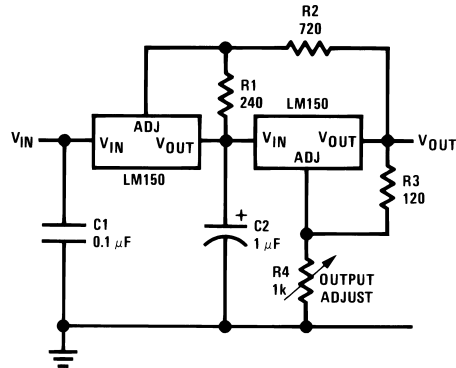
†Solid tantalum

\*Lights in constant current mode



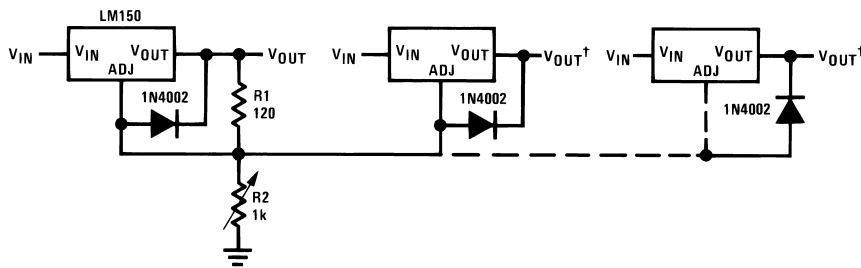
## Typical Applications (Continued)

### Tracking Preregulator



DS009061-27

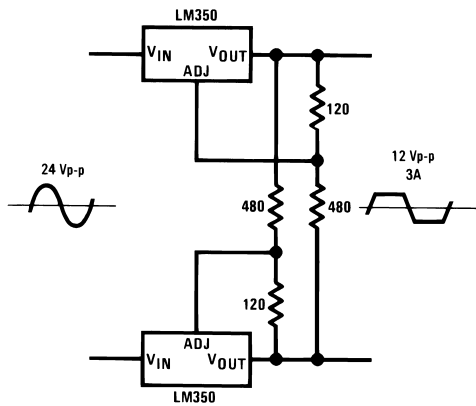
### Adjusting Multiple On-Card Regulators with Single Control\*



DS009061-28

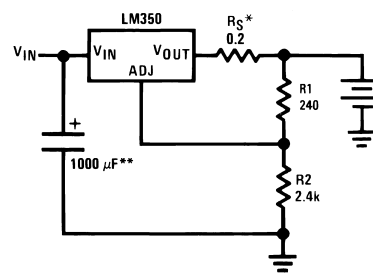
†Minimum load — 10 mA  
\*All outputs within ±100 mV

### AC Voltage Regulator



DS009061-29

### Simple 12V Battery Charger

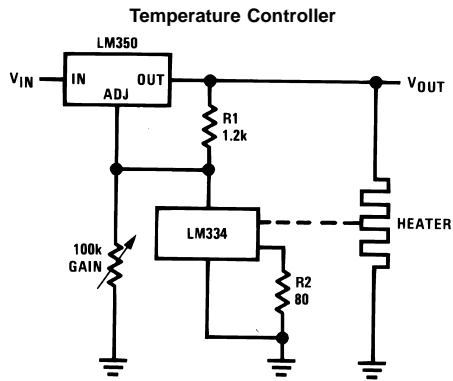


DS009061-30

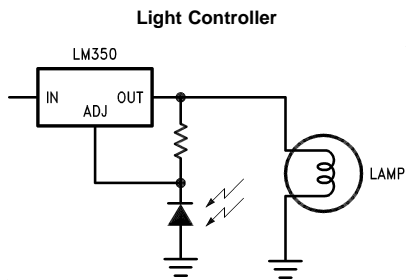
\* $R_S$ —sets output impedance of charger:  $Z_{OUT} = R_S \left( 1 + \frac{R_2}{R_1} \right)$   
DS009061-48

Use of  $R_S$  allows low charging rates with fully charged battery.  
\*\*1000  $\mu$ F is recommended to filter out any input transients

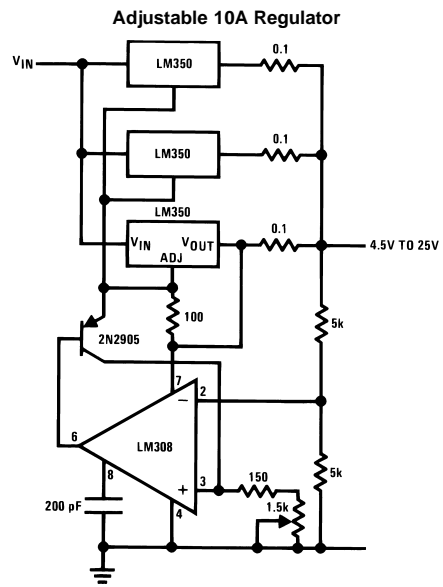
## Typical Applications (Continued)



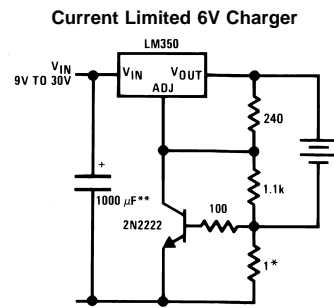
DS009061-11



DS009061-12



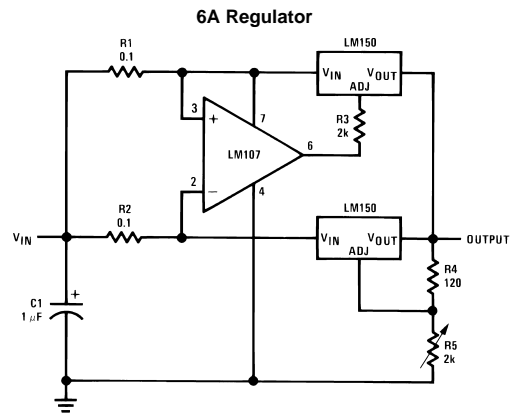
DS009061-31



DS009061-32

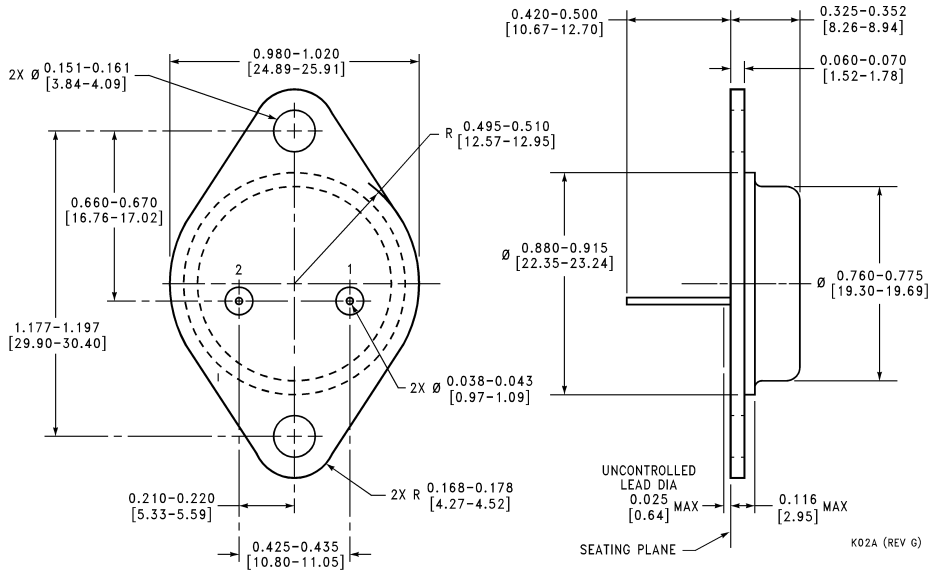
\*Sets peak current (2A for 0.3Ω)

\*\*1000 μF is recommended to filter out any input transients.

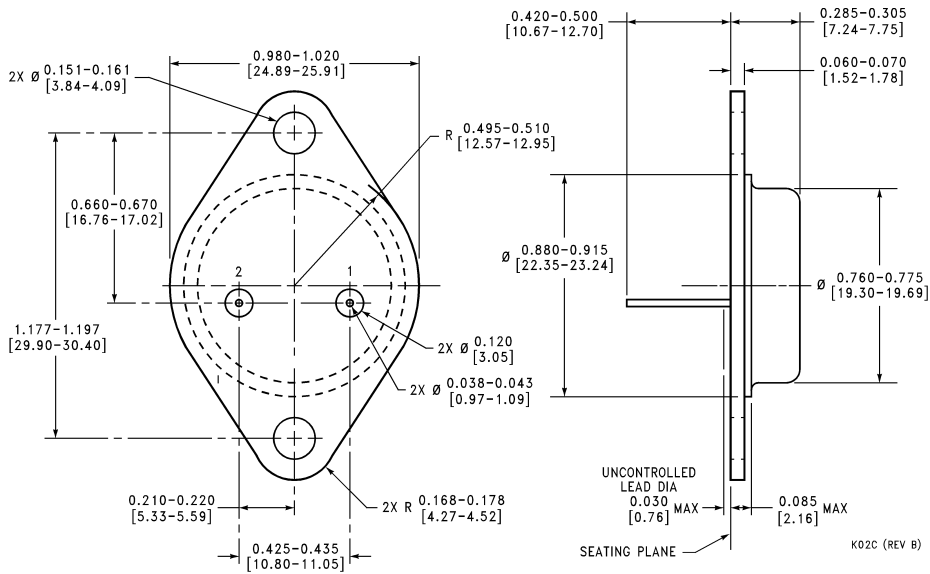


DS009061-2

**Physical Dimensions** inches (millimeters) unless otherwise noted

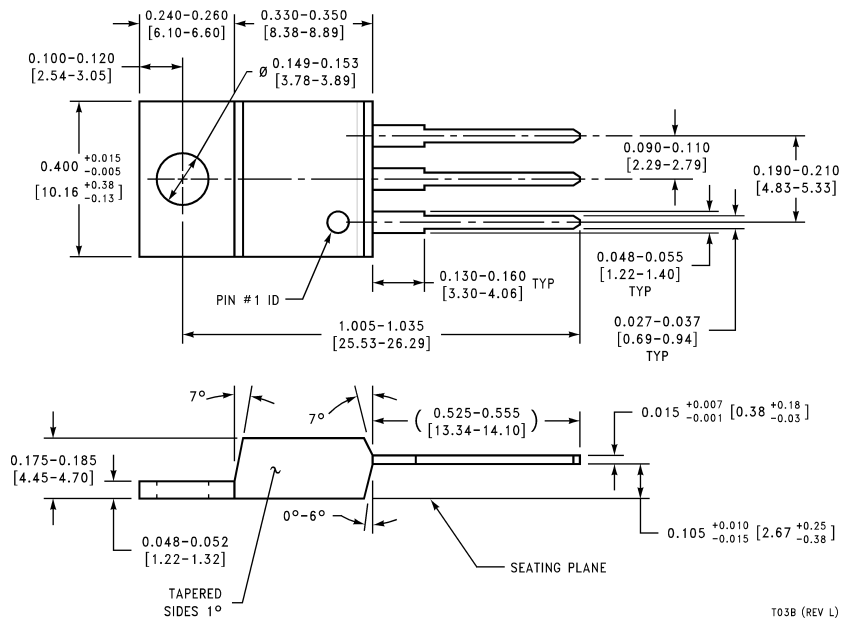


**2 Lead TO-3 Metal Can Package (K)**  
**Order Number LM150K STEEL or LM350K STEEL**  
**NS Package Number K02A**



**2 Lead TO-3 Metal Can Package (K)**  
**Mil-Aero Product**  
**Order Number LM150K/883**  
**NS Package Number K02C**

**Physical Dimensions** inches (millimeters) unless otherwise noted (Continued)



**3 Lead Molded TO-220 (T)**  
**Order Number LM350AT or LM350T**  
**NS Package Number T03B**

**LIFE SUPPORT POLICY**

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.



**National Semiconductor Corporation**  
 Americas  
 Tel: 1-800-272-9959  
 Fax: 1-800-737-7018  
 Email: support@nsc.com

**National Semiconductor Europe**  
 Fax: +49 (0) 1 80-530 85 86  
 Email: europe.support@nsc.com  
 Deutsch Tel: +49 (0) 1 80-530 85 85  
 English Tel: +49 (0) 1 80-532 78 32  
 Français Tel: +49 (0) 1 80-532 93 58  
 Italiano Tel: +49 (0) 1 80-534 16 80

**National Semiconductor Asia Pacific Customer Response Group**  
 Tel: 65-2544466  
 Fax: 65-2504466  
 Email: sea.support@nsc.com

**National Semiconductor Japan Ltd.**  
 Tel: 81-3-5639-7560  
 Fax: 81-3-5639-7507

www.national.com